The CoastWatch Utilities User's Guide

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Contributions by:
Peter Hollemans, Terrenus Earth Sciences
Xiaoming Liu, SP Systems, Inc.

U.S. DEPARTMENT OF COMMERCE
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NATIONAL ENVIRONMENTAL SATELLITE, DATA, AND INFORMATION SERVICE
COASTWATCH PROGRAM

Errata

Parts of this guide have not kept pace with the software development. Specific inaccuracies herein include the following and will be remedied in a future version of this guide:

- The chapter on CDAT is outdated and contains diagrams for versions 3.8.0 and earlier. The new layout of CDAT version 4.0.0 is different, though some panels are similar and have similar functionality.

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Developed by: CoastWatch / OceanWatch
Center for Satellite Applications and Research
https://coastwatch.noaa.gov

Obtaining a Copy

To download a copy of the CoastWatch Utilities, visit:

https://coastwatch.noaa.gov

and search for "utilities" in the search box. The website also contains general information on CoastWatch products and services.

Providing Feedback

Email questions, comments, suggestions, and bug reports to the CoastWatch help desk at coastwatch.info@noaa.gov. In order to receive help, you should include the following information:

1. The version and operating system of the software, for example *cwutils-3.3.2 on Windows 10*.
2. The type of data file and where you obtained the file, for example *CoastWatch .hdf files obtained from the CoastWatch web site*. If the data origin is unknown, include some example data filenames.
3. If sending a bug report or asking for clarification, a description of how to reproduce your result:
    - For a command-line tool, a transcript of the terminal session during which the question or problem arose. You can cut and paste the contents of the terminal session including the command used and its output directly into the email.
    - For a graphical interface tool, a list of steps to reproduce the problem. For example, *Open data file xxx, click this button, then that button*.

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Typographic Conventions

In this guide, we use the following conventions for the font and color of text. References within the document are in the standard font, but are red to emphasize that they are active links, for example a reference to a section: "see chapter 3 for information on the CoastWatch Data Analaysis Tool". External references are a `typewriter` font in magenta, such as a web site address: "`https://duckduckgo.com` is a great search engine". Terminal commands, terminal output, file names, and verbatim character strings are in a `typewriter` font. Java class names are in *italics*. Replacement parameters in command line programs are in CAPITALS.

Acknowledgments

We would like to acknowledge the following for support in creating the CoastWatch Utilities software (in no particular order):

- John Sapper of NOAA/NESDIS for initial funding and requirements.
- The CoastWatch Central Operations group and other NOAA/NESDIS researchers for continued funding support and new requirements.
- The CoastWatch node managers, operations managers, and CLASS archive staff who were invaluable in providing feedback.
- CoastWatch data users who have provided critical review of the software, bug reports, and new ideas for functionality.
- The open source software community for providing high quality code libraries upon which the utilities are built.

Chapter 1

Introduction

The main goal of the CoastWatch Utilities software is to aid data users in working with NOAA/NESDIS CoastWatch satellite data. CoastWatch data is distributed as individual files in a scientific data format that is not recognized by standard image viewers, and the CoastWatch Utilities are useful for manipulating data and creating images from CoastWatch data for both recreational and scientific applications. CoastWatch data files contain:

1. Global file attributes that describe the date/time and location of the earth data in the file, as well as any relevant data processing details.
2. Earth data as a set of two-dimensional numerical arrays, each with a unique name. These *variables* hold the actual scientific data and accompanying attributes, such as scaling factor and units, that describe how to use the data values.

The CoastWatch Utilities allow users to selectively access and extract this information in a number of ways.

1.1 A Brief History

The CoastWatch Utilities have been evolving since 1998. The original software was capable of working with CoastWatch IMGMAP format data files, the standard data distribution format (limited to NOAA AVHRR data) for CoastWatch satellite data until 2003. The current utilities are capable of reading HDF, NetCDF 3, NetCDF 4, and NOAA 1b. Following is a sketch of the software evolution:

- Version 1: 1997. The first version created CoastWatch IMGMAP files from TeraScan Data Format (TDF), a proprietary format from SeaSpace Corporation. It was never publicly released.
- Version 2: 1998-2000. The second version was released to the CoastWatch data user community and worked with CoastWatch IMGMAP (CWF) files only. Users could convert CWF files to other formats, create GIF images, perform land and cloud masking, create data composites, and other related tasks.
- Version 3: 2001-present. The third version was designed to have a more flexible data handling capability, with support for the new CoastWatch HDF and NetCDF formats. The CoastWatch Data Analysis

Tool (CDAT) was integrated into the package. Additional capabilities were added for NOAA 1b, level 2 swath style data, automatic navigational correction, ESRI shapefiles, and other improvements.

1.2 Installation Notes

1.2.1 System Requirements

Operating system The CoastWatch Utilities are currently available for Windows, Mac, and Linux.

Disk space A minimum of 400 Mb is required for the installed software. We recommended at least 1 Gb of space in total to allow for downloading and manipulating satellite datasets. More disk space may be required for larger datasets.

Memory A minimum of 4 Gb is recommended. More memory may be required depending on the number of concurrent processes running on the computer.

1.2.2 Downloading

To download a copy of the CoastWatch Utilities, visit:

`https://coastwatch.noaa.gov`

and click *Data Tools* and then *CoastWatch Utilities* or search for "utilities" in the search box. Download the package appropriate for your operating system. To install, read one of the following sections depending on your system.

1.2.3 Installing on Windows

If upgrading to a new version, there is no need to uninstall the previous version – the new installation setup program will handle the details. To install the new version, simply double-click the downloaded installation package. The setup program will install the software in a user-specified directory, and add entries to the Windows *Start Menu*. The User's Guide (this document) is also added to the *Start Menu*.

If you use the command line tools you may want to add the installed executable directory to the path for easier command line execution. This is done automatically starting with version 3.8.1 – you can test this by opening a new *Command Prompt* window and typing:

```
cwinfo --version
```

If you get an error message, then the path wasn't set correctly and you may need to do it manually as shown below.

If installing a previous CoastWatch Utilities version, on Windows 10 go the the Windows *Start Menu* and click the *Settings* gear icon. In the search box type "environment" and select *Edit environment variables for your account*. Under *User variables* edit the *Path* variable and add a new entry, for example `C:\Program Files\CoastWatch Utilities\bin`. Other Windows versions have a similar procedure for adding a path.

1.2.4 Installing on Unix

macOS

The macOS installation package is a disk image (DMG) file that contains support for Intel-based Macs only. Download the DMG file, double-click to mount it, and then double-click the *CoastWatch Utilities Installer* icon. When upgrading, the installer will automatically uninstall an old version if it exists.

If you use the command line tools you may want to add the installed executable and man page directories to your paths for easier command line execution. In a *Terminal* session, type the following to verify which shell you're running:

```
echo $SHELL
```

If the output of the command is `/bin/bash`, your account uses the Bash shell, and you can add the following lines to the `~/.bash_profile` file:

```
export PATH=${PATH}:"/Applications/CoastWatch Utilities/bin"
export MANPATH=${MANPATH}:"/Applications/CoastWatch Utilities/doc/man"
```

If the output is `/bin/zsh` (newer macOS versions), then your account uses the Z shell, and you can add the lines above to the `~/.zshrc`. In either case, open a new *Terminal* window for the changes to take effect.

Linux

The Linux version installs from a tar archive, extracted as follows:

```
tar -zxf cwutils-3_x_x-linux-x86_64.tar.gz
```

You may also want to add the installed executable and man page directories to your environment variables for easier command line execution, for example under CSH and TCSH in the `~/.cshrc` file:

```
setenv PATH ${PATH}:$HOME/cwutils/bin
setenv MANPATH ${MANPATH}:$HOME/cwutils/doc/man
```

or under BASH in the `~/.bashrc` file:

```
export PATH=${PATH}:$HOME/cwutils/bin
export MANPATH=${MANPATH}:$HOME/cwutils/doc/man
```

Note that some Linux users with display scaling turned on in the Linux display settings have reported issues with running CDAT and the CoastWatch Master Tool – the application windows, icons, and some fonts appear small and unreadable. If this happens, try adding this option when running CDAT:

```
-J-Dsun.java2d.uiScale=2.0
```

To use this option every time you run CDAT without having to explicitly add it to the command line, add this line to your startup resources:

```
export INSTALL4J_ADD_VM_PARAMS=-Dsun.java2d.uiScale=2.0
```

1.3 Using the Software

The CoastWatch Utilities are made up of various individual tools. Graphical tools allow you to point and click, working with data interactively; the graphical tools have a built-in help system with brief details on each key feature. To complement these, there are also command line tools that allow you to process data using a text-only command prompt or scripting language. Call any command line tool with the **--help** option to get a short synopsis of parameters. See the manual pages of Appendix A for a complete discussion on the command line parameters for both graphical and command line tools.

Functionally, the CoastWatch Utilities are designed to meet the data processing and rendering needs of many different types of data users. The individual tools have been developed from both in-house requirements and data user suggestions. The functionality of the tools may be divided into several categories based on data processing task:

Information and Statistics File contents, statistics computations on variables (for example min, max, mean, standard deviation), direct access to raw file and variable attributes.

Data Processing Data format conversions, compositing, generic variable math, data sampling.

Graphics and Visualization Interactive visualization/analysis, batch image rendering, ancillary graphics creation such as data coverage maps, grids, coastlines, landmasks.

Registration and Navigation Resampling of data from one projection to another, interactive generation of map projections, manual and automatic navigational correction, computation of solar and earth location angles.

1.4 Third Party Software

There are a number of other software packages than can be used to read data from CoastWatch HDF and NetCDF data files. They are *generic* in the sense that they can read the numerical and text data, but they generally cannot interpret the metadata conventions used by CoastWatch. They are well suited to advanced users who want to have more detail on the HDF or NetCDF data file contents. You can refer to the CoastWatch HDF metadata specification of Appendix B when using third party software.

The HDF Group is the main source of information on the HDF format specification and software libraries. You can download tools for working with HDF from the main web site:

`http://www.hdfgroup.org`

Many of the tools are command line, but HDFView is a useful graphical tool. Note that since NetCDF 4 is implemented using HDF, NetCDF 4 files can also be viewed in HDFView. For NetCDF-specific software, visit the Unidata site:

`http://www.unidata.ucar.edu/software/netcdf`

A number of data analysis programming languages have also been linked to the HDF and NetCDF libraries including IDL, Matlab, and Python.

Chapter 2

Common Tasks

The first step in using the CoastWatch Utilities is to discover which tool to use for the task at hand. To help with this search, this section categorizes the tools by the most common tasks that data users perform. Use this section as a guide to the functionality of the tools, while referring to the manual pages of Appendix A for complete details on each tool's behaviour and command line options. You can also use the cwtools command to list all the tools in the package.

2.1 Information and Statistics

The cwinfo tool lists data file contents, including various global file attributes and the full set of earth data variables in the file. This tool is mainly useful because its output is human readable, as opposed to a raw data dump from a generic HDF tool. It also allows you to display latitude and longitude data for the data corners and center point. The --**verbose** option shows the process of identifying the file format, useful for file format debugging or when you suspect a file is corrupt.

The cwstats tool calculates statistics for each earth data variable in the file: count, valid, minimum, maximum, mean, standard deviation. This is good for assessing the data quality and checking to see that the data values fall into the expected range. Use --**sample**=0.01 to sample only 1% of the data as this saves a large amount of I/O and computation time. The *count* is the total number of data values (rows $\times$ columns), while the *valid* value is the number of data values that were not just fill values. CoastWatch satellite data does not always cover the full region of the file, since the satellite view may have clipped the edge of the region during overpass. In these cases, fill values are written for the missing data and the fill values are skipping during statistics computations. Fill values are also used to signify that data has been masked out for quality purposes (see the cwmath tool for an example of masking and section 2.2 for details on how masking can be used).

The hdatt tool is only useful for CoastWatch HDF files[1], and performs low-level reading and writing of HDF attribute data. You can use it to change an attribute value without rewriting the file, or to append an attribute value to the file. The hdatt manual page gives many good examples of when it may be required to modify or create attributes.

[1]The hdatt tool works with any HDF 4 file using the SDS interface, but is primarily intended for CoastWatch HDF files, as opposed to any other non-HDF file format supported by the utilities.

2.2 Data Processing

The cwimport tool converts data into CoastWatch HDF format. Note that it is *not necessary* to convert all data into CoastWatch HDF before working with the data using the CoastWatch Utilities. In many cases, you can perform the same operations on the data in its native format, especially when the operation only reads information and performs no file modification. This is due to the design of the CoastWatch Utilities, which contains a software layer (called the *Earth Data Reader* or *EDR* layer) separating the tools from the physical input file format. The cwexport tool complements cwimport – it converts data into various simple text or binary formats. The cwexport tool benefits from the EDR layer as well, and as such can export data from CoastWatch HDF, NetCDF, NOAA 1b, and others.

During satellite data processing, it is often necessary to compare data from the satellite sensor to data from in-situ measurements. The cwsample tool performs this function by taking as input a geographic latitude/longitude point or set of points and printing out the data values found at those points in the file.

Another common task in data processing is to combine data from one or more variables using a mathematical equation, or to combine data from multiple files in a data composite. The cwmath tool takes a math expression of the form $y = f(a, b, c, ...)$ where $a, b, c...$ are earth data variables in the file, and loops over each pixel in the file to compute f. The cwcomposite tool combines data from one earth data variable across multiple files by computing the mean, median, minimum, maximum, or latest value. You can use the cwmath and cwcomposite tools in tandem to create composite data for a given earth variable; for example to create a weekly composite of sea-surface temperature (SST), mask out all cloud contaminated SST from each file using the cwmath *mask* function, and follow by running cwcomposite on all the masked SST files to compute the mean or median.

Certain data processing tasks are beyond the capabilities of the CoastWatch Utilities command line tools. In such a case, the recommendation is to:

1. Access and process data using the Java Language API outlined in chapter 4, either by writing Java code or by using a script written in BeanShell (`http://beanshell.org`) with the cwscript tool.

2. Use native C code with the HDF or NetCDF libraries (see section 1.4).

3. Use a higher level programming language like IDL, Matlab, or Python which have HDF and NetCDF access libraries available.

The advantage of using the Java API provided by the CoastWatch Utilities is that metadata and file I/O operations are already implemented and generally transparent to the programmer.

2.3 Graphics and Visualization

The main interactive tool for displaying CoastWatch data files is the CoastWatch Data Analysis Tool (CDAT). The complexity of CDAT is such that it deserves its own section – see chapter 3 for a complete discussion of CDAT and its features. CDAT is mainly useful for creating unique plots of CoastWatch data, performing data surveys, and drawing annotations on top of the data image. In contrast, the command line tools discussed in this section are designed for the automated creation of plots and graphics from CoastWatch data from a scripting language such as Unix shell, Perl, or Windows batch files.

The cwrender tool creates images from earth data variables, using either a palette or three channel composite mode. Many rendering options are available including coast line, land mask, grid line, topographic, and ESRI shapefile overlays, custom region enlargement, and units conversion. Output formats supported include PNG, JPEG, GIF, GeoTIFF, and PDF.

The cwcoverage tool creates graphics for documentation or web pages that show the physical area that a data file or group of files covers on the earth. The output shows an orthographic map projection with the boundary of each data file traced onto the earth and labeled. Along similar lines, the cwgraphics tool creates land, coast, and grid graphics for the region covered by a data file. The output of cwgraphics is inserted into the data file as an 8-bit data variable for later use by cwrender or alternatively to be exported via cwexport for use in custom rendering or masking routines.

2.4 Registration and Navigation

Earth data from two data files is said to be *in register* if every corresponding pair of pixels has the same earth location. We use the term *registration* to refer to the process of resampling data to a *master* projection. Data that has first been registered to a master can be intercompared or combined with other data registered to the same master. Standard CoastWatch map-projected data files that have been registered to the same master projection can be intercompared or combined on a pixel by pixel basis.

You can create your own master projections and CoastWatch map-projected data files using the cwmaster and cwregister2 tools. The cwmaster tool is an interactive tool for designing master map projections. The tool enables you to create CoastWatch HDF masters that use one of the various map projections supported by the General Cartographic Transformation Package (GCTP)[2], such as Mercator, Polar Stereographic, Orthographic, and many others. Once a master is created you can used it in the cwregister2 tool to resample data to the new master projection.

When earth image data is captured from a satellite and processed, there are cases in which inaccuracies in satellite position and attitude (roll, pitch, and yaw) cause coastlines to appear *shifted* with respect to the image data. We say that such data requires a *navigation correction*. Ideally the navigation correction should be applied to the satellite data while in the sensor projection before any registration to a map projection master. In reality data users often only have access to the final map-projected products. However since these map-projected products generally cover a small geographic area, acceptable navigation corrections can often be achieved by applying an offset to the image data of a few pixels in the rows direction and a few pixels in the columns direction. You can use the cwnavigate and cwautonav tools to apply navigation corrections to CoastWatch data files. The cwnavigate tool applies a manual correction, normally derived from your own observation of the data or from some preexisting database of corrections. The cwautonav tool attempts to derive and apply a correction automatically from the image data in the file.

A final tool related to registration/navigation is cwangles which computes explicit latitude, longitude, and solar angles based on metadata in the CoastWatch data file. Some data users appreciate having latitude and longitude values at each pixel rather than simply GCTP map projection parameters or swath polynomial coefficients. Such earth location data is useful when exporting CoastWatch data for use in other software packages. Note that text output from the cwexport tool (see section 2.2) can also include the latitude and longitude of each pixel without having to run cwangles.

[2]See Appendix B for a discussion of CoastWatch HDF metadata which relies on GCTP for map projection parameters.

Chapter 3

The CoastWatch Data Analysis Tool

This section contains out of date diagrams from version 3.8.0. Many parts of the software are similar enough that these descriptions can still be useful. This section will be updated in a future verion of this guide.

3.1 Getting to know CDAT

The CoastWatch Data Analysis Tool (CDAT) displays 2D geographic data as a color image. CDAT converts numerical data such as sea surface temperature to a color map. You can change the way data values are converted to colors by selecting one of the various different color palettes and by changing the data enhancement range. CDAT can draw coastlines, borders, latitude/longitude grid lines, and other graphics on top of the color image. You can analyze the data and compute statistics by surveying at a single point, along a line, or within a polygon. CDAT has features for analyzing and correcting errors in the geographic position of the data. Finally, CDAT can export geographic data to a variety of image and data formats.

Figure 3.1 shows the main components of the CDAT window:

Menu bar – Access to file operations, tools, and the help system. The help system contains a short version of this chapter, so that if you want to quickly look up a topic, you can usually scan the help system and find it. The tools contain a preferences window that sets the default color palette, enhancement range, and units for geographic data.

Tool bar – Data file operations and view navigation. You can use the data file buttons to open and close files, and export data. More than one data file can be open at once, similar to tabs in a web browser. The view buttons allow you to zoom in and out and move the view center.

File tabs – Displays the currently open data file names, and allows you to select the desired file. To close a file, select its tab and click the *Close* button. You can flip back and forth between tabs to compare data from different files.

Control tabs – Access to the data view control panels.

Data view controls – The control panels are used to change various aspects of the data view: enhancement range, color palette, and graphics overlays. You can also use the controls to perform data surveys, turn on color composite mode, and correct the geographic position (navigation correction).

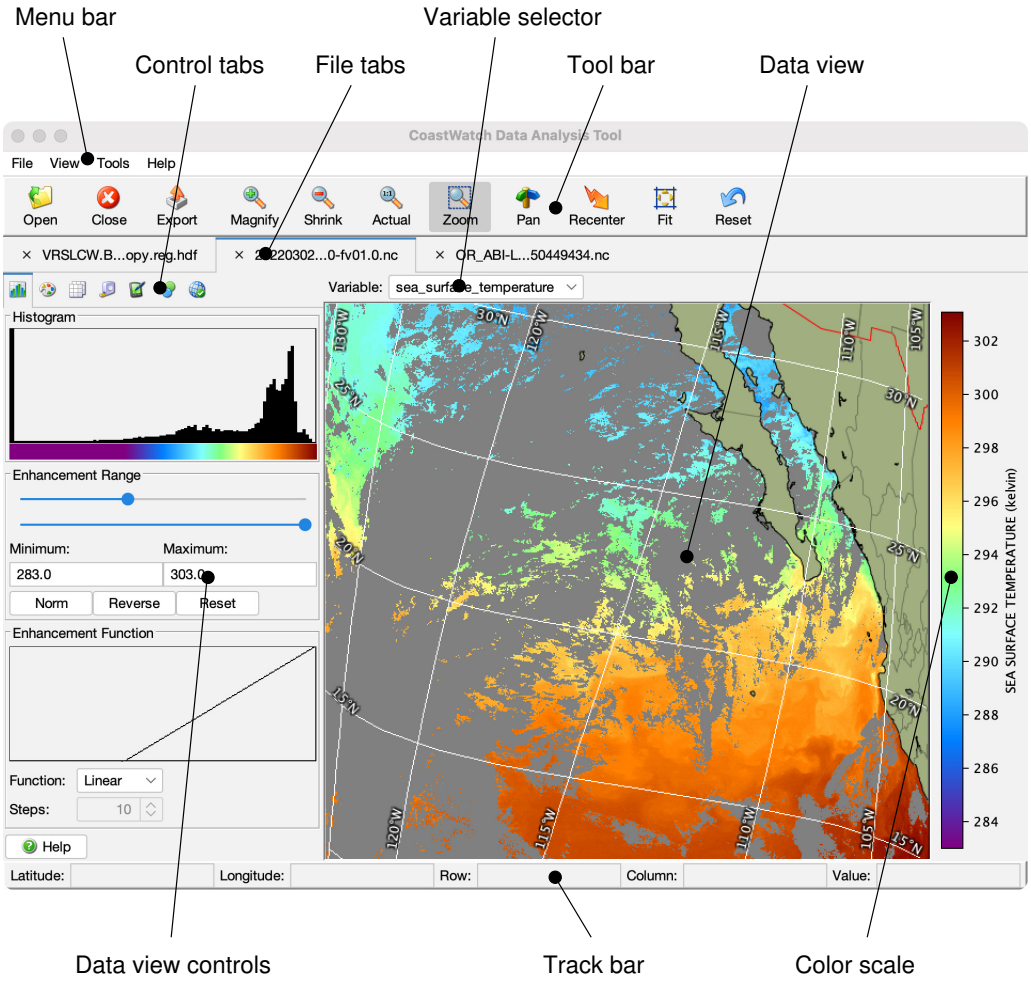


Figure 3.1: Components of the CDAT window

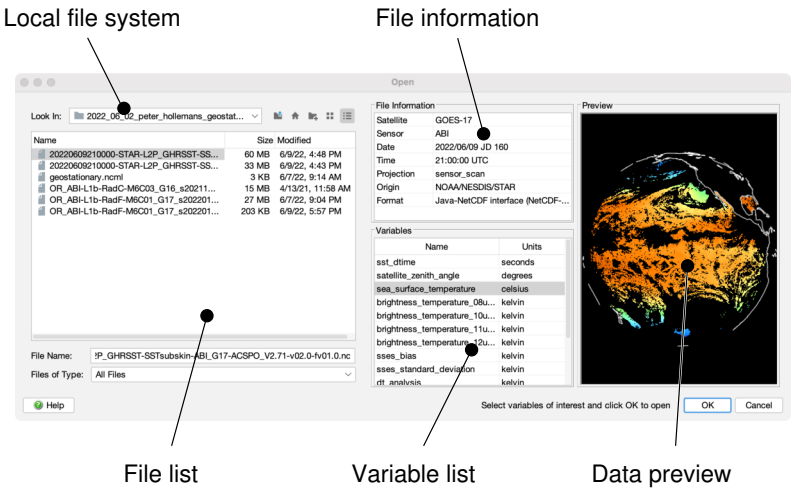


Figure 3.2: File *Open* window. Windows, Unix, and Mac will show slightly different local file choosers (left hand panel). This example shows the Unix file chooser.

Variable selector – Displays the currently selected variable from the data file. You can show a new variable by selecting its name from the drop-down list button.

Data view – The main area showing the current geographic data file. The data view can show one of several variables from a data file, for example sea surface temperature, albedo, thermal channel data, etc.

Track bar – Tracks mouse movement and shows the pointer location in latitude/longitude and image row/column coordinates, as well as the data variable value.

Color scale – Shows the relationship between color and data value. The variable name and units are also shown. The data values in the track bar are given in the units indicated by the color scale.

3.2 Loading data files

Click the *Open* button to open a data file, and a new *Open* window will appear for selecting the file and variables to load (see Figure 3.2). Note that CDAT was originally designed to read CoastWatch HDF, CoastWatch IMGMAP (no longer supported), and NOAA 1b AVHRR data files, but also reads other formats as described in Appendix C. Selecting the file name triggers the file information and variable list to change.

Generally data files contain more than one *variable*, for example sea surface temperature (SST) data files from the AVHRR sensor contain SST, cloud mask, visible and thermal channel data, and satellite viewing angles. Each *variable* holds a complete 2D geographic image, and CDAT can load any combination of variables from a data file. Once a data file is selected, you can preview the various variables be selecting the variable name in the list. To load a set of variables into CDAT, use a combination of Shift-click and Ctrl-click (or ⌘-click on Mac) and click OK. There will be a short delay as CDAT loads and analyzes the

data in preparation for display. Once loaded you can change the variable displayed using the variable selector above the data view.

When a data file is first opened, all variables are displayed according to a set of default user preferences for the color palette, data enhancement range, and units based on the variable name. For example CDAT installs with preferences that indicate the variable *sst* should have the *HSL256* palette and an enhancement range of -60 to 45 Celsius. If a variable name is unknown, CDAT falls back on a grayscale palette and a range that matches the minimum and maximum data values found in the data. To change these preferences for any variable or to add new variable names to CDAT, see section 3.11 on user preferences.

3.3 Navigating in CDAT

CDAT displays 2D geographic data in the same way as a map, with north in the *up* direction. You can use the tool bar buttons in combination with the mouse to zoom in and out on the data view and move around within the view. Following is a list of all the actions you can perform while navigating in CDAT:

Zoom in – There are three ways to zoom in: (i) click the *Zoom* button to enter zoom mode and drag on the view to draw a rectangle to magnify, (ii) click the *Magnify* button to magnify the view $\times 2$, or (iii) click the *Actual* button to make data pixels the same size as screen pixels.

Zoom out – To zoom out, click the *Shrink* button to shrink the view $\times 2$.

Move around – There are two ways to move around within the view: (i) click the *Pan* button to enter pan mode and drag on the view to move it, or (ii) click the *Recenter* button to enter recentering mode and click the view to recenter on the mouse cursor.

Reset – There are two ways to reset the view, depending on the desired effect: (i) click the *Reset* button to completely reset the view so that all data is displayed, or (ii) click the *Fit* button to fit as much data as possible into the view area so that the view is completely filled (some edges of the data may be cropped off).

3.4 Changing data image colors

The CoastWatch Data Analysis Tool creates a color image from 2D geographic data by converting data values to colors using a color palette, enhancement range, and enhancement function. The control tabs hold two sets of controls that are used to change the way data values are converted to colors: the *Color Enhancement* tab and the *Color Palette* tab (see Figure 3.3). Figure 3.4 shows the two step process: (i) normalization of data values using an enhancement function, and (ii) conversion of normalized values to colors. Typically a linear enhancement function is used so that the minimum and maximum range values map to 0 and 1 respectively, and all data values in the range are scaled linearly between 0 and 1. In contrast, a log function scales data values by powers of ten, for example if the range is $[0.01..100]$, 0.1 scales to 0.25, 1 scales to 0.5, and 10 scales to 0.75.

The *Color Enhancement* tab has a number of controls to change the enhancement range and function. Use the sliders to change the range visually, or enter numbers into the minimum/maximum text fields and press Enter. The data histogram is a visual guide that shows where most of the data values lie – move the sliders to above and below the major histogram peaks to see the data with the best possible color contrast.

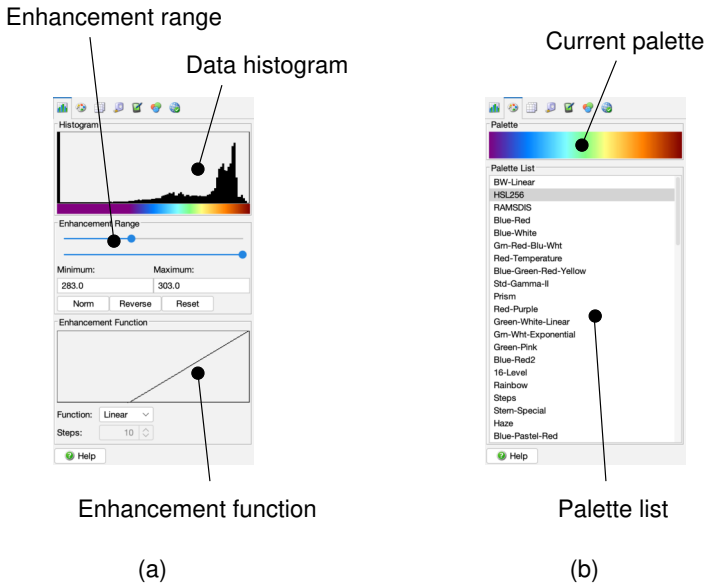


Figure 3.3: Color conversion tabs. (a) Controls for the enhancement function and range. (b) Controls for palette selection.

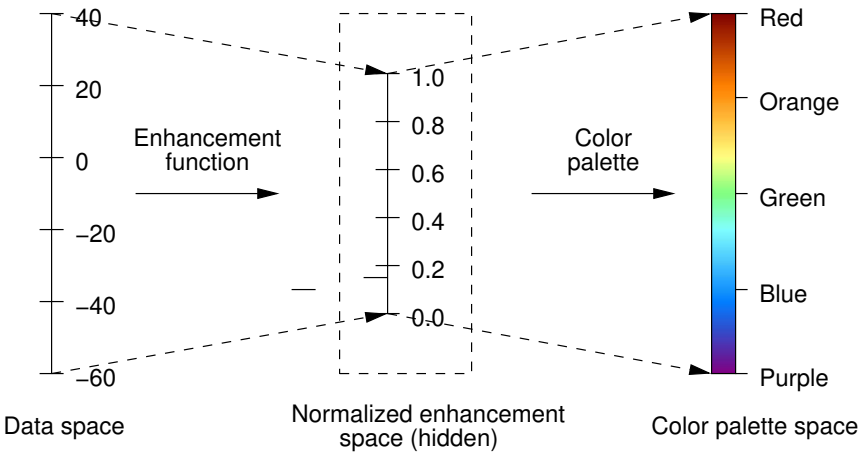


Figure 3.4: Color enhancement process. Two steps are performed, first the enhancement function is applied, and then the color palette.

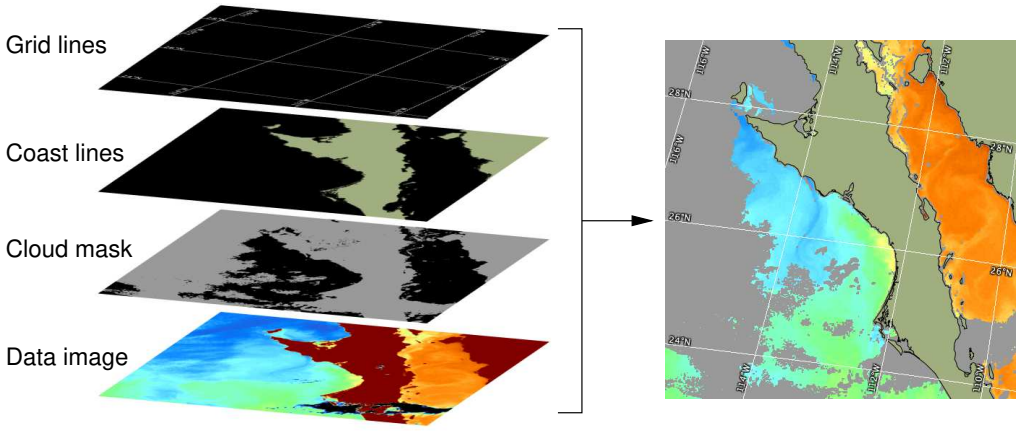


Figure 3.5: Overlay graphics drawing order.

To simplify setting the range, the *Normalize* button changes the range to bracket the data mean with a 1.5 standard deviation unit window, the *Reverse* button swaps the minimum and maximum range values, and the *Reset* button sets the range back to its full extents. The enhancement function can be: (i) *Linear*, (ii) *Log10* for log base 10 as described above, (iii) *Step* for a linear function with discrete steps, or (iv) *Gamma* for brightness data (0% - 100%) that needs a correction for computer displays.

The *Color Palette* tab shows the current color palette and list of available palettes. CDAT comes installed with a number of palettes but users can also add their own palettes in an XML text format as described in section 3.11.

3.5 Displaying coastlines, grids, and more

The CoastWatch Data Analysis Tool uses graphics *overlays* to show reference lines like latitude and longitude, coastlines, political borders, bathymetry, and topography, as well as mask data such as cloud masks. Overlays are arranged in *layers* like overhead projector slides – most of each layer is transparent except where the graphics occur and graphics from an upper layer are drawn on top of graphics from a lower layer as shown in Figure 3.5. Overlays can be added and removed, turned on and off, their layering order rearranged, and their properties modified such as color, font style, and line style. The *Overlay Layers* tab holds the overlay controls as shown in Figure 3.6.

3.5.1 Types of overlays

Several different types of overlays can be added to the data view. In general, any overlay can have a custom color and transparency, and line overlays can have custom line style, font, and drop shadow settings.

Grid – Grid lines of two different types:

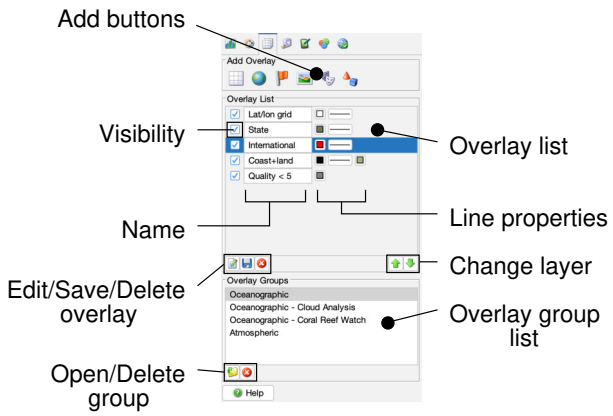


Figure 3.6: *Overlay Layers* tab

- *Lat/Lon* – Latitude and longitude lines. The default is to render labeled lines at regular increments based on the zoom factor, but you can customize the line increment value and labels.
- *Data reference* – Row and column lines that follow the image data. The default is to render labeled lines at regular increments based on the zoom factor, but you can set the line placement and customize the labeling.

Coast – Land/water boundaries including oceans, lakes, islands in lakes, and ponds in islands derived from the Global Self-consistent Hierarchical High-resolution Shorelines (GSHHS) data set: http://www.ngdc.noaa.gov/mgg/shorelines/gshhs.html. The resolution of the lines drawn depends on the zoom factor of the data view and ranges from 25 km (crude resolution) to 0.2 km (high resolution). Land polygons can be drawn by specifying a fill color.

Political – International and state border lines derived from CIA WDB-II data. As with coastline data, the resolution of the lines changes with the data view zoom. Only international borders are shown by default – you can add state borders manually.

Topography – Topographic and bathymetric lines contoured in real-time from ETOPO5 elevation data: https://www.ngdc.noaa.gov/mgg/global/etopo5.HTML. Only the 200 m and 2000 m bathymetric contours are shown by default. The topography levels can be modified to include any set of topographic or bathymetric contours.

Mask – One of three different types of masks:

- *Bitmask* – A single-color mask that uses a bitwise AND operation. A bitmask uses data values from a variable and performs a bitwise AND with each data value and an integer mask value to determine which pixels in the data view should be masked. If the results of the AND operation are non-zero, the pixel if masked otherwise is is left unmasked. Suppose that an integer data variable named "cloud" contains a value of 0 when no clouds are present, or a value of 1 when clouds are detected at a pixel. Then a bitmask with an integer mask value of 1 will cover all cloud pixels with the mask color. More complex masking can also be achieved – for example, suppose a variable named "graphics" has the fourth bit set when land is present at the pixel.

Then a bitmask with an integer mask value of 8 will select out all graphics pixels with the fourth bit set in order to mask only land pixels.

- *Multilayer* – A multiple-color mask that combines a set of single-color bitmasks. A multilayer mask uses data values from a variable and colors each bit set to 1 in the data value with a different color. The idea is that if none or only a few of the bits in each data value are set, the mask will let the data show through in most locations and mask it with a bit-identifying color in others. This is useful when working with data analysis output such as cloud masking where each bit in an integer data value represents the output from a different cloud mask test. A multilayer mask can handle up to 32 different colors, one color for each bit in a 32-bit integer data value.
- *Expression mask* – A single-color mask that uses a boolean expression. An expression mask evaluates a boolean expression and masks any pixels for which the expression is true. Expression masks are slower to compute than bitmasks or multilayer masks, but are much more flexible because almost any mathematical combination of data variable values can be used. For example, an expression mask with the mask expression of "sst < 5" will mask out all SST temperature data values less than 5 degrees. Any mathematical operator or constant supported by the cwmath tool can be used in the expression, as long as the variables referenced in the expression were imported when the data file was loaded.

Shape – Shape data lines stored in either ESRI shapefile format or simple text files with lists of lat/lon values. Shape overlays are limited in a number of ways: (i) only line and polygon shape data is rendered (no point data), (ii) shape overlays cannot be saved as part of an overlay group, and (iii) rendering may be slow for large and complex shapefiles.

3.5.2 The *Overlay List*

Overlays are added by clicking one of the buttons from the *Add Overlay* area of the *Overlay Layers* tab. When an overlay is first added to the data view, it's given a default set of properties (line style, line color, fill color, etc.) and appears in the *Overlay List* area. You can change any of the basic overlay properties by just clicking the property in the list, or change some of the more complex and overlay-specific properties by selecting the overlay and clicking the *Edit Properties* button (double-clicking the overlay also brings up the full property editor).

Since overlays are layered like overhead projector slides, their order can be changed using the *Move Up* and *Move Down* buttons. They can be set temporarily invisible with the *Visibility* check box, or deleted altogether using *Delete*.

3.5.3 Overlay groups

The *Overlay Groups* area of the tab lets you save and restore a set of overlays that you frequently use. Overlay groups are useful for when you've created a complex set of overlays, arranged them into the correct order, changed their properties, and want to use them again for another data file. A default set of overlay groups are provided when CDAT is installed (see Figure 3.7):

Atmospheric – Latitude/longitude grid lines, coast, and state/international borders for use on atmospheric data with a grayscale palette.

Oceanographic – Latitude/longitude grid lines, coast with filled land polygons, state and international borders for use on oceanographic data with a color palette.

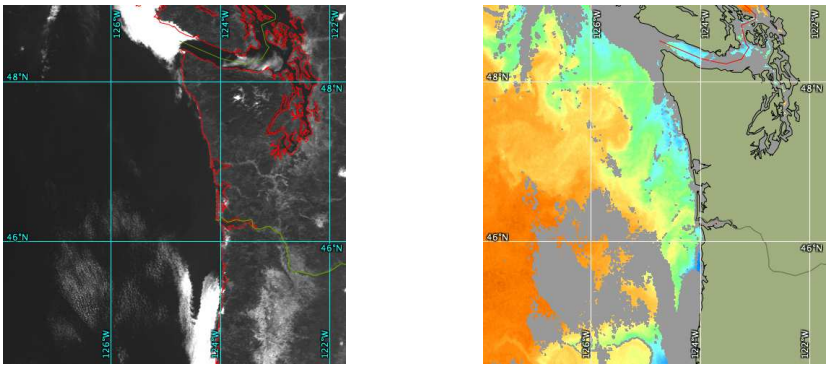


Figure 3.7: Examples of default overlay groups. The grayscale image shows the *Atmospheric* overlay group, while the color image shows *Oceanographic - Cloud Analysis*.

Oceanographic - Cloud Analysis – The same overlays as Oceanographic, with extra cloud analysis overlays for NOAA NESDIS SST product users.

Oceanographic - Coral Reef Watch – Special overlays customized for use with Coral Reef Watch data (see the Coral Reef Watch page at `http://coralreefwatch.noaa.gov` for data and other details).

To use one of the default groups, select it in the list and click the *Open Group* button. The overlays are loaded into the overlay list on top of any existing overlays. To create a new overlay group, select a set of overlays from the *Overlay List* using Shift-click and Ctrl-click (⌘-click on Mac), then click the *Save Group* button. You can create a new overlay group by typing in a new name, or replace an existing overlay group. To remove an unwanted overlay group, select it and click *Delete Group*.

Another useful feature of overlay groups is that once created, they can be used for command line data rendering by specifying the **--group** option in the cwrender tool. Overlay groups are saved in a special directory on a per-user basis along with other user preferences as described in section 3.11.

3.6 Measuring distances and data statistics

CDAT can be used perform several different types of surveys of the current variable in the data view. The *Data Surveys* tab (Figure 3.8) allows you to manage a list of surveys and create new ones by selecting areas of the data view. Each data survey performed results in a set of data statistics, survey dimensions such as endpoints and distances, and a line or histogram plot.

3.6.1 Types of surveys

To perform a survey, select one of the *Survey Mode* buttons and click on the data view as follows:

Point (single click)
A single point survey with only the point position and data value reported but no statistics or plot. A

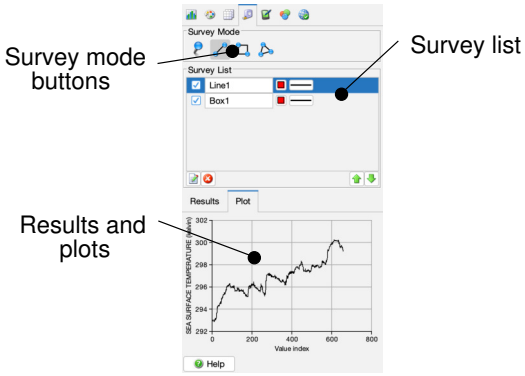


Figure 3.8: *Data Surveys* tab

point survey is a good way to mark a certain position and easily be able to recall its data value, such as for an ocean buoy. Point surveys are marked with a small cross.

Line (click/drag)
A straight line survey with the line endpoint positions, distance in kilometers, statistics, and an X-Y plot of the data values along the line. A line survey simulates an airplane or ship track of the data values, and is useful for gradient and front analysis.

Box (click/drag)
A rectangular box survey, with the box corner point positions, statistics, and a histogram plot of the data within the box. A box survey is useful for a clustering analysis to show groups of similar data values in an area as peaks in the histogram.

Polygon (click corners / double-click last corner)
A polygon survey with statistics and a histogram plot of the data within the polygon. Polygon surveys are similar to box surveys, but can help when the area has an irregular shape.

3.6.2 The *Survey List* and results

When you perform a data survey, a new entry is added to the *Survey List* area that shows the survey name and line properties. By default surveys are marked by thick red lines but the line color and style can easily be changed to more easily see the difference between similar surveys. Surveys can be temporarily hidden and shown again by clicking the *Visibility* check box, or deleted using *Delete*. The *Survey List* area is very similar in usage to the *Overlay List* area in the *Overlay Layers* tab (see subsection 3.5.2).

Selecting an entry in the survey list changes the *Results* and *Plot* tabs to display the results of the survey. For line surveys all data values along the line are sampled and the statistics reported. For box and polygon surveys, CDAT attempts to speed up statistics computations by only sampling 1% of the data values although this may not always be possible for smaller areas. The statistics reported are as follows:

Sample – For box and polygon surveys only, the number of data values sampled as a percentage of the total number of data values in the survey area.

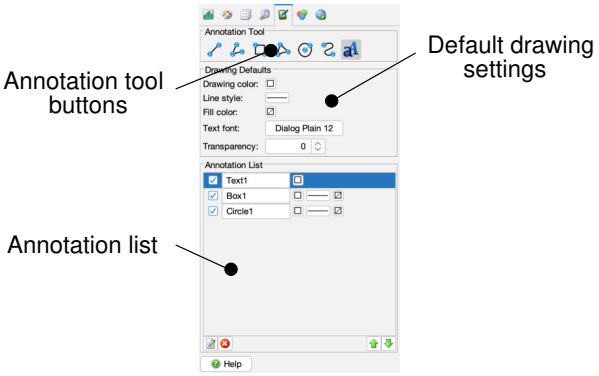


Figure 3.9: *Annotations* tab

Count – The total number of data values sampled.

Valid – The total number of data values encountered that were not marked as missing. Missing data values are skipped by the statistics computations. In many cases data values are marked as missing prior to being written to the data file for data quality reasons.

Min – The minimum valid data value sampled.

Max – The maximum valid data value sampled.

Mean – The mean of all valid data values sampled.

Stdev – The standard deviation from the mean of all valid data values sampled.

Line survey plots show the data value as a function of the pixel distance along the line. Box and polygon survey plots show a normalized histogram bin count as a function of the data value.

3.7 Drawing lines, shapes, and text

The CoastWatch Data Analysis Tool can be used to draw lines, boxes, circles, curves, and text on the data view. When the data view is exported to an image file, the annotations are drawn as well; annotations are an easy way to create example images for presentations that highlight features of interest in the data. The *Annotations* tab (Figure 3.9) allows you to pick the annotation mode and manage a list of annotations on the data view.

3.7.1 Types of annotations

To add an annotation to the data view, click one of the *Annotation Tool* buttons and add it to the data view as follows:

Line (click/drag)
Draws a line in the current color and style.

Polyline (click endpoints / double-click last point)
Draws a series of connected line segments in the current color and style.

Box (click/drag)
Draws a rectangular box in the current color and style, and fills with the fill color.

Polygon (click corners / double-click last corner)
Draws an irregular polygon in the current color and style, and fills with the fill color.

Circle (click/drag)
Draws a circle from the center to radius point in the current color and style, and fills with the fill color.

Curve (click control points / double-click last point)
Uses a set of polyline control points to draw a Bezier curve in the current color and style.

Text (click and enter text)
Places the specified text in the current font and color. The text font size is relative to the screen, and so remains constant if the data view zoom factor is modified. The text anchor point moves with the view.

3.7.2 The *Annotation List*

When creating an annotation, a new entry is added to the *Annotation List* according to the current *Drawing Defaults* settings. Similar to overlays and surveys, annotation layers can be hidden/shown, deleted, rearranged, and edited (see subsection 3.5.2).

3.8 Using composite image mode

CDAT normally displays 2D geographic data as a color image by mapping the data values of a variable to colors using a color palette. Rather than using a palette, an alternative way of deriving the color values at each pixel is to treat data values from different variables as components of a color. CDAT uses the RGB color model (see http://en.wikipedia.org/wiki/RGB) to combine data from three different variables to form the pixel colors. The process of converting data values to color components is similar to that shown in Figure 3.4 but rather than converting the normalized value to a palette color in the second step, the normalized value is used as the intensity of red, green, or blue in the pixel color.

The *Color Composite* tab (Figure 3.10) contains controls for choosing the variables to use as components, and for turning on/off color composite mode. To create a color composite:

1. Choose three variables from those imported when the data file was opened. Set the variables as the *Red*, *Green*, and *Blue* components in the *Color Composite* tab. The best choice of variables depends on the data – satellite data channels of different wavelengths work well as long as the three channels are reasonably independent.

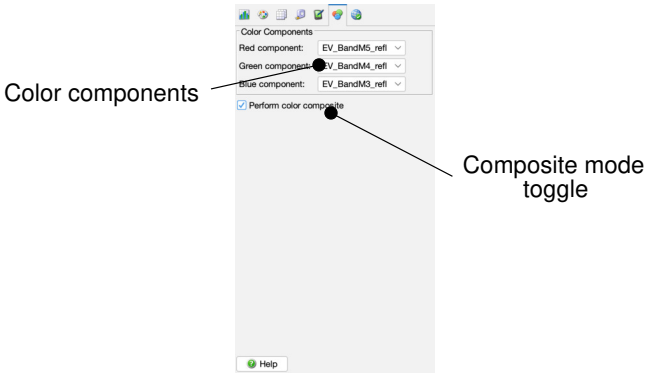


Figure 3.10: *Color Composite* tab

2. Use the variable selector (see Figure 3.1) to view each variable and set up the enhancement function in the *Color Enhancement* tab. The easiest way to set up the enhancement function is to use a grayscale palette to visually judge the scene contrast and click *Normalize* which centers the enhancement function around the mean. Then use the range sliders to fine tune the enhancement. In the case when the variable(s) represents reflecance data in the range of 0 to 1, or albedo data in the range 0 to 100, it's best to use a *Gamma* enhancement function.

3. Click the *Perform color composite* check box in the *Color Composite* tab to turn composite mode on. While in composite mode you can continue to select variables and change their enhancement functions to obtain the best mixture of color components.

Figure 3.11 shows examples of RGB color composite images created using NOAA AVHRR data and Chinese FY-1D MVISR data.

3.9 Correcting geographic location problems

The CoastWatch Data Analysis Tool was written in part for NOAA/NESDIS researchers to use in evaluating the quality of satellite data products. One of the quality measures is computed satellite angle data (*navigation* data) including latitude, longitude, solar zenith, satellite zenith, and relative azimuth angles. Of particular interest are latitude and longitude because uncertainty in those angles determines the positional accuracy of the data. For example if the latitude and longitude of a pixel have an uncertainty of 0.01° then the pixel has a positional accuracy of $\sim$1 km. Small uncertainties such as these can exist when a satellite's true orientation and position are not known exactly. In this case the image data in CDAT may not line up correctly with coastline overlays. The image may appear to be shifted, rotated, or sheared in comparison to the coastlines. Navigation errors are not as prevalent if the data file has been produced recently, but are not uncommon in older data files or in experimental satellite data products.

There are two tools in CDAT designed for working with navigation data errors: the *Navigation Correction* tab and the *Navigation Analysis* panel. Navigation correction writes a set of correction parameters to a data file so that subsequent data access using the CoastWatch Utilities takes into account the correction.

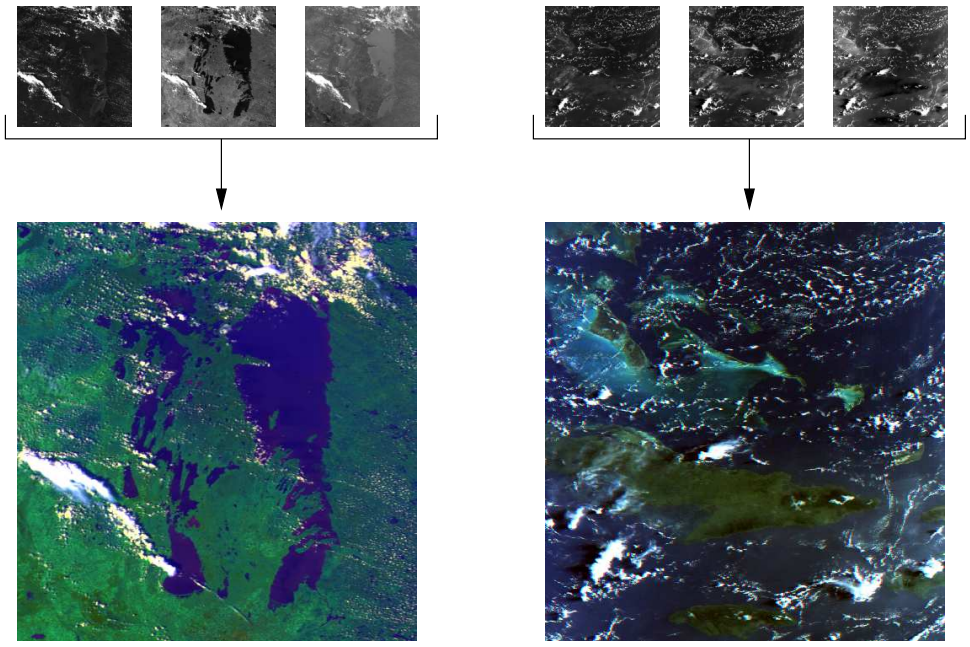


Figure 3.11: RGB composite examples. (a) NOAA-18 AVHRR false color composite using channels 1/2/4. (b) FY-1D MVISR true color composite using channels 1/9/7.

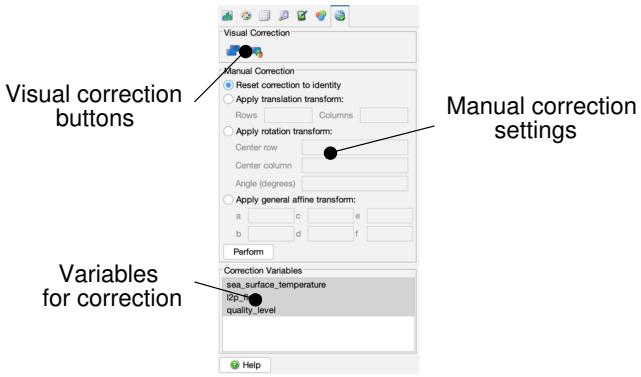


Figure 3.12: *Navigation Correction* tab

Navigation analysis allows you to examine the navigation accuracy of various points in the data file and save point position, variable data, and navigation offsets for later analysis.

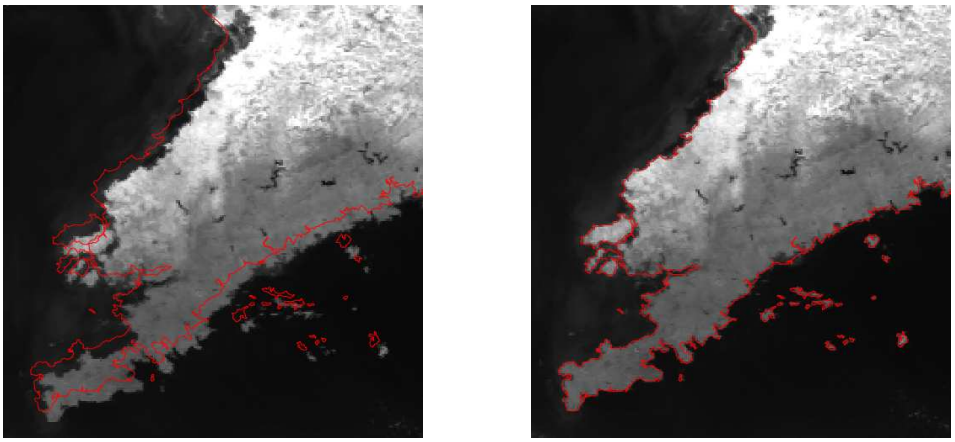
3.9.1 Navigation correction

The *Navigation Correction* tab (see Figure 3.12) is used to write correction parameters to a data file so that the data view image lines up correctly with actual geographic features such as coastlines. Only data files in CoastWatch HDF (.hdf) format can be corrected. Also, only satellite sensor and sensor-derived variables in a data file should be corrected – not latitude/longitude data, graphics, or viewing angle data. You must select which specific variables to correct using the *Correction Variables* list (default is all variables imported when the file was opened). Navigation corrections will only be applied to the selected variables in the list. Examples of data variables that may require correction include AVHRR channel data, SST and cloud. Figure 3.13 shows an example of an uncorrected and corrected albedo image.

You can perform a navigation correction in one of two ways:

Visually – Click one of the *Visual Correction* buttons, either *Translation* or *Rotation*. *Translation* mode corrects the navigation by shifting the entire image in the row and column directions – click and drag anywhere on the data view to shift the origin. *Rotation* mode corrects the navigation by rotating around the center of the data view – click on an edge of the view and drag to rotate.

Manually – Select the type of transformation, fill in the parameters, and click *Perform* to correct the navigation. The *translation transform* is similar to the visual translation mode – it shifts the data origin by some number of rows and columns. The *rotation transform* is more general than the visual rotation mode because the rotation center point row and column can be specified rather than having to use the data view center. The *general affine transform* is the most general of all (it has no visual mode counterpart) because it can be used to correct for translation, rotation, skew, and scaling problems. The affine transform is applied to the row and column coordinates of each data view pixel to translate



(a) (b)

Figure 3.13: Navigation correction example. (a) Visible channel albedo image before navigation correction. (b) Image after translation correction.

the "desired" row and column coordinates (R', C') to the "actual" coordinates (R, C) in the data file:

$$\begin{bmatrix} R' \\ C' \\ 1 \end{bmatrix} = \begin{bmatrix} a & c & e \\ b & d & f \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} R \\ C \\ 1 \end{bmatrix}.$$

To completely remove the navigation correction on a variable, click *Reset correction to identity* and then *Perform*. More information about how navigation corrections are stored in CoastWatch HDF data files can be found in Appendix B. Command line tools for performing navigation correction from a script rather than interactively are described in section 2.4, and in more detail in the cwnavigate and cwautonav manual pages.

3.9.2 Navigation analysis

The *Navigation Analysis* panel shown in Figure 3.14 is accessed from the *Tools* menu and enables researchers to gather statistics on navigation errors for a series of points in a data file. You can compare the known coastline geography from GSHHS coastline data to the data view image coastline to check for navigation errors. The panel shows a list of navigation points and allows you to add new points to the list, adjust the navigation offset for each point, and save the points to a data file.

There are two modes for adding new navigation points to the list, both of which work by clicking on the data view in the main CDAT window to select the point location. *Manual* mode adds a point to the list and lets the user adjust the navigation offset manually. *Automatic* mode adds a point to the list and additionally runs the image data in the box surrounding the point through an automatic navigation algorithm that attempts to: (i) classify the image data into land and water based on histogram splitting, and (ii) compute an optimal offset for the navigation box by finding the offset with maximum correlation between classified image data and pre-computed land mask data. The automatic navigation algorithm can

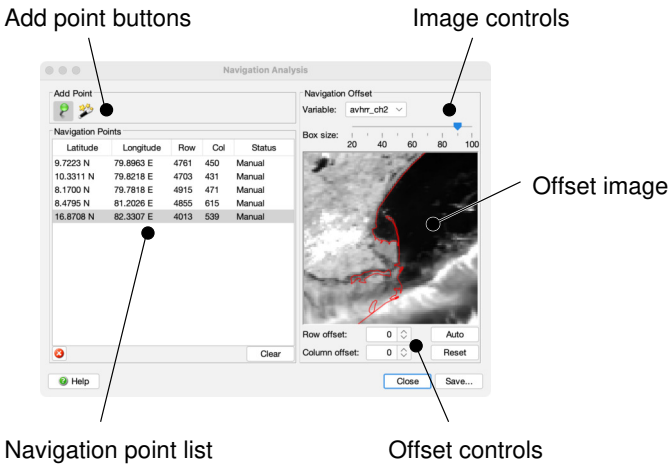


Figure 3.14: *Navigation Analysis* panel

sometimes fail to find a significant correlation at any offset in which case the *Status* column indicates *Auto failed* otherwise it indicates *Auto OK*.

Once a series of points are added to the list, the navigation offset of each point can be adjusted. Even if the automatic navigation algorithm was successful, it may be necessary to manually adjust the offsets – the algorithm is only capable of returning integer-valued offsets and some cases may require fractional offsets for the best coastline fit. To adjust the offset of a point, select the point in the list and click/drag on the offset image or use the row and column offset adjustment controls. You can change the variable shown in the offset image and the navigation box size to better see the contrast between land and water. The *Variable* and *Box size* controls also determine what data is used for automatic navigation when adding new points. Click *Auto* to re-try the automatic navigation algorithm after changing the variable or box size, or *Reset* to set the offset back to zero. Navigation points are removed from the list by clicking *Delete*, or the point list cleared entirely by clicking *Clear*.

After adding navigation points to the list and adjusting their offsets if needed, the point locations (latitude, longitude, row, column), navigation offset (row and column), variable data values, and other metadata can be saved to a text file. There are two output formats: XML (structured markup language) and CSV (comma separated value). The XML format writes out each point using XML tags and attributes and is useful for web browser display and XML readers. The CSV format writes each point as a line of comma separated values, ready for input to a spreadsheet or plotting program. Examples of each format can be found in Appendix D.

To save navigation points, click *Save...* and choose:

- Points to save (default is all points)
- Variable data values (default is no variable data)
- Output format (default is XML)
- File name and location

Regardless of the output format, the following data is saved for each point:

Earth location – The latitude (-90..90) and longitude (-180..180) of the point in degrees.

Data location – The row and column of the point in the data file, referenced from (0,0).

North direction – The direction of north for the point as a unit vector with row and column components. This is useful for recovering satellite projection information at the point.

Navigation offset – The navigation offset of the point in the row and column directions.

Comment – The value of the status column indicating *Manual*, *Auto OK*, or *Auto failed*.

Variable values – A data value for each variable selected in the save dialog.

3.10 Exporting images and data

CDAT can export either the main data view (a color image with color scale and information legends) or the data file values and metadata (character, integer, floating point values). How the exported data is to be used determines the format – *color image formats* such as PNG and JPEG are commonly used for creating graphics for the web, printable materials, or presentation slides for meetings while *numerical data formats* such as HDF, NetCDF, and ArcGIS are used for getting data into other analysis or GIS software packages.

To export the current data view to a color image, click the  *Export* button and select one of the image formats: PNG (the default), GIF, JPEG, GeoTIFF, or PDF. Each format has certain characteristics:

PNG – A non-lossy compressed image format supported by most web browsers and image manipulation software. PNG has similar data compression characteristics to GIF and additionally supports 24-bit color images.

GIF – A non-lossy compressed format also supported by most web browsers and image manipulation software. The GIF files produced use LZW compression. Images stored in GIF format are run through a color quantization algorithm to reduce the color map to 256 colors or less. Although file sizes are generally smaller than PNG, image quality may be compromised by the reduced color map.

JPEG – A lossy compressed format that should be used with caution for images with sharp color lines such as those found in text and annotation graphics. The JPEG format generally achieves higher compression than PNG or GIF resulting in smaller image file sizes.

GeoTIFF – A flexible image format with support for earth location metadata. Many popular GIS packages handle GeoTIFF images and allow the user to combine a GeoTIFF base map image with other sources of raster and vector data. The GeoTIFF images generated are non-lossy uncompressed image data (unless a compression is specified in the options), and can be much larger than the corresponding PNG, GIF, or JPEG. In general the GeoTIFFs generated are 24-bit colour images, but when no overlays are used or the image color option is set, a special 8-bit paletted image file is generated and comments describing the data value scaling equation are inserting into the image description tags. Note that the cwexport command line tool also creates GeoTIFF files that contain 32-bit IEEE floating-point data values rather than color pixels.

PDF – A standard document format for high quality publishing developed by Adobe Systems and used for output to a printer via such tools as the Adobe Acrobat Reader. In general, PDF files are slightly larger than the equivalent PNG but retain highly accurate vector graphics components such as lines and fonts.

To export data from the current data file to a numerical data format, click the *Export* button and select one of the data formats: CoastWatch HDF, NetCDF 3, NetCDF 4, binary raster, text file, or ArcGIS binary grid. Numerical data formats can hold data from one or more of the data file variables (with the exception of ArcGIS grids which only hold one variable), and either the full data file geographic extents or only the subset of the data shown in the data view. Each data format has certain characteristics:

CoastWatch HDF – Hierarchical Data Format (HDF) version 4 with CoastWatch metadata. HDF is a scientific data format used by CoastWatch and others to distribute satellite data. Information and access software may be found at https://www.hdfgroup.org. A description of the current CoastWatch HDF metadata standards is given in Appendix B.

NetCDF 3/4 – Network Common Data Format with CF 1.4 metadata. See the document "Encoding CoastWatch Satellite Data in NetCDF using the CF Metadata Conventions", Peter Hollemans, February 2010, included with the CoastWatch Utilities installation for more details. Access software can be found at https://www.unidata.ucar.edu/software/netcdf.

Binary raster – A simple stream of binary data values – either 8-bit unsigned bytes, 16-bit signed integers, or 32-bit IEEE floating point values. Data values may optionally be scaled to integers using the equation integer = value/factor + offset. Each data variable may be prepended with a 72-bit dimension header: 8-bit dimension count (always 2) with 32-bit row count, 32-bit column count.

Text file – An ASCII text file with latitude, longitude, and data value printed – one data value per line. Each data variable may be prepended with a 1-line dimension header: dimension count (always 2), row count, column count.

ArcGIS binary grid – A stream of 32-bit IEEE floating point values, ready for input to ESRI's ArcGIS as a binary grid file. A header file may also be created to specify the earth location and other parameters.

3.11 User Preferences

3.11.1 General preferences

CDAT has an application-wide set of general user preferences that you can access by clicking *Preferences* from the *Tools* menu (see Figure 3.15). The general preferences include:

Memory limits – The maximum heap size (the total memory used by the Java VM for dynamic memory allocation) and the tile cache size (the amount of that heap used for storing data in memory prior to display). These can only be specified at VM startup time, so changes to these values must be followed by a restart of CDAT. In some cases you may receive an error message while reading a file that starts with `java.lang.OutOfMemoryError: Java heap space`. In such a case, increase the heap size and cache size, restart CDAT, and repeat as needed until the error message no longer appears. This error occurs as a result of reading certain data files with larger data caching requirements.

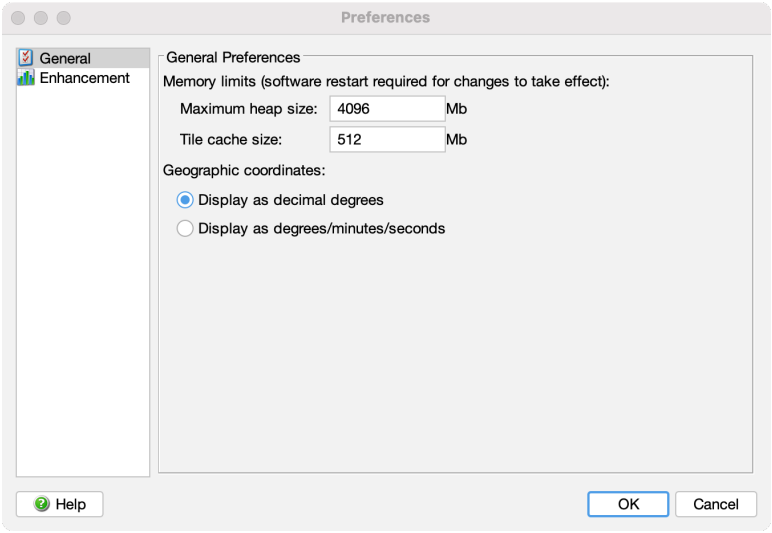


Figure 3.15: *General* section in the *Preferences* panel

Geographic coordinates – The preferred format for geographic coordinates in various CDAT windows, including the main window where the geographic coordinates are displayed at the location of the mouse cursor.

3.11.2 Setting color palette, enhancement, and units

When a data file is opened and variables are selected, CDAT shows the initial data view for each variable using a color palette, enhancement range, and units determined from the user preferences (see section 3.2 on loading data). Rather than having to customize all these items each time a data file is opened, you can set up preferences for each variable name. CDAT comes with a set of built-in preferences for a number of common variable names. To edit these preferences or add new variables, click *Preferences* from the *Tools* menu, then click *Enhancement* for the enhancement preferences (see Figure 3.16). To modify the settings for a certain variable, click the variable name in the *Variable* list or type in a new variable name and click *Add* to add it to the list (some default preferences will be assigned to it that need to be modified). Once a variable is selected, you can change various settings:

Palette – Choose one of the palettes from the list. New palettes can be added to the list using an XML palette format, see subsection 3.11.3.

Units – Keep the same units as in the data file or choose different units to display the variable data values. CDAT normally uses the units that the data file was originally written with. For example if a sea surface temperature data variable was written with Celsius units, then CDAT uses Celsius for all numerical value readings: the data view track bar, the *Color Enhancement* tab sliders and text fields, the *Data Surveys* tab statistics and plots, and any other location that a numerical value is displayed. But if the units are set to "Display in units of fahrenheit", then all numerical readings are shown in Fahrenheit instead. If you select different data units, remember to also modify the *Minimum* and

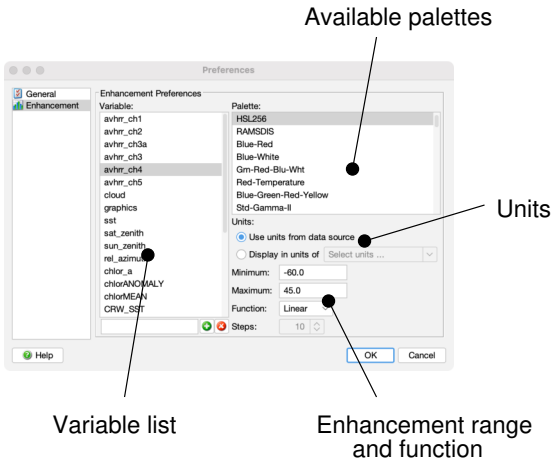


Figure 3.16: *Enhancement* section in the *Preferences* panel

Maximum text fields to match those units. A number of common units are provided in the drop-down units box. If your preferred units are not shown, you can also type in the units. Most common units are supported, and base units can be combined with spaces, slashes, and exponentiation. For example, wind or ocean current speed in kilometers per hour could be written a number of ways: "km/h", "km hr^ -1", "kilometers / hour", or "kilometers per hour". For other possible unit names, see the conventions used by the Unidata UDUNITS package and its supported units file.

Enhancement function – Select the color scale minimum and maximum values and the type of function: *Linear*, *Step*, or *Log10*. See section 3.4 for a description of the *Color Enhancement* tab where these preferences are used.

After modifying any of the preferences, click *OK* the save them or *Cancel* to discard all the changes. Note that enhancement preferences only take effect the next time a data file is opened and variables loaded.

3.11.3 Resources directory

CDAT stores preferences for each user on the system individually. Depending on the operating system, preferences are stored in a resources directory under your home directory:

Windows 2K/XP/2003 – `\Documents and Settings\[User name]\Application Data\CoastWatch`

Windows Vista/7/10 – `\Users\[User name]\AppData\Roaming\CoastWatch`

Mac OS X – `~/Library/Application Support/CoastWatch`

Unix – `~/.coastwatch`

Preferences are normally modified using the CDAT *Preferences* panel but can also be modified by editing the XML files in the resources directory. On some operating systems it may be necessary to show hidden

directories to reveal the resources directory. **Only attempt to modify the resources manually if you are familiar with editing XML files and have made a backup of any files first.** In the case of some resource file problem indicated by an error when launching CDAT, you can delete the resources directory, restart CDAT, and the resources directory will be recreated and populated with the default preferences.

The resources directory contains various files and subdirectories as follows:

`prefs.xml` – Main preferences file with general and enhancement preferences.

`overlays/` – Directory for storing overlay groups from the *Overlay Layers* tab. Each overlay group is stored as a separate file with a `.jso` extension for "Java Serialized Object", a binary format used for saving/restoring a Java object's state. Overlay groups can be copied between computers, even between different operating systems, although some incompatibilities in overlays may exist between different CoastWatch Utilities versions.

`palettes/` – Directory for storing extra user-supplied palettes. Any files with a `.xml` extension will be considered to be palette files and read into CDAT for use in the *Color Palette* tab and *Preferences* panel. Palette files must have the format described in section D.3 for color palettes.

Some users have asked "How can I modify an existing color palette and use that in CDAT?" To do this, you can extract it from the `lib/java/cwutils.jar` file in the CoastWatch Utilities installation directory using the Java jar command in a command line session, for example:

```
jar xf <path to CW utils>/lib/java/cwutils.jar noaa/coastwatch/render/HSL256.xml
```

which will extract the HSL256 palette XML file to a `noaa` subdirectory (do this command in some scratch working directory, not in the `lib/` directory). Then modify the palette file RGB color triplets, rename the file, change the `<palette name="...">` inside the file to match, and copy the new XML file into the `palettes/` directory. After restarting CDAT the new palette should appear in the *Color Palette* tab.

3.12 Connections with command line tools

The CoastWatch Data Analysis Tool can be used on conjunction with the CoastWatch Utilities command line tools (described in chapter 2 and Appendix A) in a number of ways:

Visualization – CDAT can be used to set up a plot's characteristics for use with the cwrender tool. You can manually transfer settings from CDAT to the rendering command line:

- Variable being displayed → **--enhance**
- Enhancement min/max text fields and function → **--range**, **--function**
- Selected color palette → **--palette**
- Overlay layers → **--coast**, **--grid**, **--political**, **--bath**, **--group** and others
- Units preferences → **--units**
- Region shown in data view → **--magnify**
- Color composite variables → **--composite**

Note that custom palettes and overlay groups stored in the user's resource directory (subsection 3.11.3) can also be used by cwrender.

Statistics – To perform a similar box data survey from a script as was performed using the *Data Surveys* tab *Box* mode (section 3.6), you can either (i) hover the mouse cursor over the center of the box and note the latitude and longitude value to use in the **--region** option to the cwstats tool, or (ii) note the box corner row and column values from the survey results for the **--limit** option.

Sampling – To perform a similar point data survey from the command line as was performed using the *Data Surveys* tab *Point* mode, you can note the latitude and longitude values in the point survey results and use them for the **--sample** option in the cwsample tool. Multiple variables in a data file can be sampled at once using cwsample, rather than CDAT which only surveys the displayed variable.

Navigation – After using the *Navigation Analysis* panel (subsection 3.9.2) to determine the best navigation correction for the data file, you can apply/reset the navigation correction using the cwnavigate tool. If you save a number of navigation points that would likely be good for future navigation efforts, their latitude/longitude coordinates could be used as input to the cwautonav tool.

Export – The CDAT *Export* button (section 3.10) has almost the same functionality as the cwrender and cwexport tools combined. The *Format* box in the CDAT *Export* window has the same color image formats as the **--format** option in cwrender, and the same numerical data formats as **--format** in cwexport. CDAT export options map to the command line as follows:

- Color image options → **--nolegends**, **--tiffcomp**, **--worldfile**, **--noantialias**, **--imagecolors** in cwrender
- Numerical data options → **--header**, **--match**, **--missing**, **--scale**, **--range**, **--byteorder**, **--size**, **--nocoords**, **--reverse** in cwexport

File information – The file information shown by clicking *Tools — File Information* in CDAT is the same as that reported by the cwinfo tool. The file information window in CDAT also has a raw metadata search and display that shows the same metadata values as the hdatt tool or the NetCDF software ncdump program.

Data formats – The same data formats read by CDAT can be read by most of the command line tools. See Appendix C for more details on data format compatibility between tools.

Chapter 4

Programmer's API

4.1 How to use the API

Developers may want to use some of the same code used by the CoastWatch Utilities to read and write data, render images, or perform some variation on the existing functionality. Since the CoastWatch Utilities are written almost entirely in Java (conforming to the Java 11 language spec), the Java Application Programming Interface (API) documentation is available in standard Javadoc-generated HTML web page format, included with the CoastWatch Utilities distribution package as the compressed `doc/api.zip` file in the installation directory. Users of the graphical installers on Windows, Mac, and Linux have to manually check off the "Source code and API docs" when the package is installed in order to get the API zip file (you also get the full source code `src.zip` file whose Java code files serve as examples of using the API). Unzipping the API file creates a new directory with an `index.html` file to use as the starting point for all API documentation. The Javadoc is fairly verbose and can be used as a reference for all Java classes in the software, along with this chapter which provides a high-level overview of the main classes.

In order to effectively develop your own Java code that uses the CoastWatch API and link it to the CoastWatch libraries, you should be familiar with using the Java compiler, JAR files, how to navigate through Javadoc pages, and possibly be familiar with automated code compiling tools such as Apache Ant. There are a number of directories and files in the installation that are of use to developers:

`lib/java/` – Contains the main `cwutils.jar` file of CoastWatch Utilities code.

`lib/java/depend/` – Contains the Java JAR dependencies that supply such functionality as:

- User interface styling
- Shapefiles
- GIF, PDF, and GeoTIFF encoding
- XML parsing
- Command line option parsing
- Mathematical expressions
- Plotting symbols

- Matrices
- HDF and NetCDF file formats
- Terrenus HRPT interfaces for NOAA1b instrument data

`lib/native/` – Native libraries for various operating systems. C language code has been compiled to native binary libraries and linked to Java via JNI in cases where no Java libraries existed.

To use the API, you *must* have the `cwutils.jar` file in your Java class path to compile and run custom code, for example on Unix:

```
javac -classpath ~/cwutils/lib/java/cwutils.jar MyCode.java
java -classpath  .:~/cwutils/lib/java/cwutils.jar MyCode
```

Depending on what CoastWatch classes are used in the `MyCode.java` code, other JAR files as listed above may also need to be in the Java class path, and as well native library directories may need to be in the dynamic link path. For example using a Unix bash shell under Mac OS X, this code fragment sets up the environment for compiling and running with the CoastWatch Utilities:

```
cwutils_root="/Applications/CoastWatch Utilities 3.2.2"
CLASSPATH=".:$cwutils_root/lib/java/cwutils.jar"
for fname in "$cwutils_root"/lib/java/depend/* ; do
  CLASSPATH=${CLASSPATH}:"$fname"
done
export CLASSPATH
export DYLD_LIBRARY_PATH="$cwutils_root"/lib/native/macosx_x86_64
```

If you prefer to use a GUI development environment such as Eclipse or JBuilder, then the GUI will have settings to store the class and native library paths for the current project. CoastWatch Utilities development is currently performed using Ant for the build/test cycle and ej-technologies install4j product (see www.ej-technologies.com) for building multi-platform installation packages and launching the various Java programs.

The rest of this chapter is dedicated to describing the main packages available in the API as follows:

noaa.coastwatch.io – I/O classes for satellite and other geographic data formats.

noaa.coastwatch.render – Utility classes for transforming geographic data into images.

noaa.coastwatch.gui – Graphical classes for custom user interface components.

noaa.coastwatch.util – General utility classes for working with geographic data arrays and performing numerical operations.

noaa.coastwatch.tools – Main program classes for all GUI and command line tools.

4.2 Data I/O

The *noaa.coastwatch.io* package contains a number of classes for performing I/O with satellite and geographic data formats. The superclasses and static method classes for most of the functionality are as follows:

EarthDataReader
: Reads various formats of geographic data. The data reader classes read global information about the data file such as the date and time of the data, what sensor or model it came from, what organization gathered/processed the data, and how to transform data array coordinates into geographic locations on the earth. The reader classes also report back on a list of n-dimensional "variables" that hold numerical data. The *CWFReader*, *HDFReader*, *NOAA1bReader*, and *OpendapReader* are all examples of *EarthDataReader* classes.

EarthDataWriter
: Writes various formats of geographic data. Just as the data reader classes read global information and variables, the data writers construct from some global information and set of variables, and then write out the numerical data to a specific format. The *BinaryWriter*, *HDFWriter*, and *TextWriter* are all examples of *EarthDataWriter* classes.

EarthImageWriter
: Writes various color image formats of geographic data. Unlike the data writer classes, the *EarthImageWriter* (i) has no subclasses and (ii) only writes color pixel data to an output file rather than numerical data. Image formats include PNG, JPEG, GeoTIFF, GIF, and PDF. The *EarthImageWriter* makes use of *GeoTIFFWriter*, *GIFWriter*, and *WorldFileWriter* to perform parts of its job.

CachedGrid
: Reads 2D numerical data using a least-recently-used caching strategy. Data format specific subclasses of *CachedGrid* form the basis of most of the high-performance I/O operation in the CoastWatch Utilities. *CWFCachedGrid*, *HDFCachedGrid*, and *NOAA1bCachedGrid* are all subclasses. The *OpendapGrid* class is not part of the *CachedGrid* hierarchy but performs some similar operations for OPeNDAP data sources.

EarthDataReaderFactory
: Perhaps one of the most useful classes, the reader factory has one static method, *create()*, that takes a data file name, automatically identifies the file format, and returns an *EarthDataReader* object. The reader factory has a special property: it can be extended to read data formats that are not supported by the standard CoastWatch Utilities distribution. To add your own data format support to CDAT and the CoastWatch Utilities command line tools, simply subclass *EarthDataReader*, place the compiled code into a JAR file in the `lib/` directory, and add the name of your subclass to the `extensions/reader.properties` file. Most tools in the package use *EarthDataReaderFactory.create()* for data reading, so your custom data format will be easy to incorporate into most tool operations. In case of problems with automatic file identification, use the cwinfo tool with **-v** option to print verbose messages during the file identification process.

4.3 Data rendering

The *noaa.coastwatch.render* package is the heart of all rendering operations: converting 2D numerical geographic data arrays to a color image (palettes, enhancement functions), drawing line, symbol, and text overlays, and drawing legends (logos, icons, text, color scales) The main classes are as follows:

EarthDataView
: Renders 2D geographic data to a color image. The data view classes take numerical data and convert it to colors using various schemes: *ColorEnhancement* uses a color palette and enhancement function

where as *ColorComposite* uses three enhancement functions, one each for the red, green and blue components of the output color.

EarthDataOverlay
: Renders line, mask, symbol, and text overlays for an *EarthDataView* object. There are more than a dozen concrete overlay classes for all different purposes: *MaskOverlay*, *TextOverlay*, *CoastOverlay*, *TopographyOverlay*, *LatLonOverlay*, and so on. Each overlay class draws graphics to the view by implementing the *render()* method and in some cases uses only the data view properties and other cases uses supplementary data such as coastline segment data or topographic elevation data.

Legend
: Renders legends for plots with information such as color scaling, date and time of the data, geographic location and projection. The two classes of legends are *DataColorScale* and *EarthPlotInfo*, mainly to accompany the output from an *EarthDataView*.

Feature
: Stores the geometry of some geographic feature, along with a set of attributes attached to the feature. The concrete feature classes are *PointFeature*, *LineFeature*, and *PolygonFeature* to handle those major feature types.

FeatureSource
: Reads or creates a set of features from some geographic data source. There are many concrete feature sources for various data including *BinnedGSHHSReader* for reading GSHHS coastline polygon data, *ContourGenerator* for generating contour line features from numerical data, and inner classes of *ESRIShapefileReader* for extracting features from ESRI shapefile format files.

PointFeatureSymbol
: Draws symbol graphics, mainly for use with an *EarthDataView* in the context of a *PointFeatureOverlay*. The *ArrowSymbol* and *WindBarbSymbol* are examples of concrete symbol classes for drawing vector wind and current fields.

EnhancementFunction
: Specifies the functional form for mapping data values to a normalized range of $[0..1]$ for use with a *Palette* in a *ColorEnhancement*. *LinearEnhancement*, *StepEnhancement*, and *LogEnhancement* are all types of functions. The *EnhancementFunctionFactory* is useful for creating enhancement functions from a text specification and range.

Palette
: Holds a set of colors for use in a *ColorEnhancement*. The *PaletteFactory* is useful for obtaining one of many predefined palettes, mostly derived from IDL but also some special-purpose CoastWatch palettes.

4.4 Graphical user interface components

The *noaa.coastwatch.gui* package is the largest and most complex package in the CoastWatch Utilities, and provides all the GUI components for the CoastWatch Data Analysis Tool, and the CoastWatch Master Tool (cwmaster) using Java Swing for platform-dependent look and feel. There are far too many classes to describe here, but the following are some of the more general and re-usable classes:

HTMLPanel
: Displays an HTML web page and allows for hyperlinks and page navigation (forward, back, top, etc). The panel is the basis of the *Help and Support* menus in the graphical tools.

EarthDataViewController
: Displays the contents of a *noaa.coastwatch.io.EarthDataReader* object in a panel and provides various other control panels for users to control the data view. The controller is the basis for each tab in CDAT.

MapProjectionChooser
: Lets you choose the specifications of a GCTP-style map projection. This panel is used in the CoastWatch Master Tool.

EarthDataChooser
: A panel and dialog for choosing *noaa.coastwatch.io.EarthDataReader* objects using either network or local file access and showing a variable preview image.

LightTable
: A general purpose drawing class that displays rubber band style graphics on top of another component for use in interactive drawing input. This class is responsible for the rubber banding in CDAT during a zoom operation, or while drawing annotations and surveys.

PaletteChooser
: Presents a list of *noaa.coastwatch.render.Palette* objects and lets you select one of them, showing a preview of the selected palette.

FullScreenWindow
: Displays a component in a full screen window with a toolbar. This class is used in CDAT for displaying the data view in full screen mode.

4.5 General utility classes

The *noaa.coastwatch.util* package provides a number of general utility classes for working with geographic data:

EarthLocation
: Holds a latitude and longitude value and allows for intelligently incrementing the values, formatting them to standard string representations, shifting datums, and computing the physical distance to other locations.

DataLocation
: Holds an n-dimensional index for use in addressing a value in an *DataVariable*.

EarthTransform
: Converts *DataLocation* objects to and from *EarthLocation* objects in order to tie data to a physical geographic space. *MapProjection*, *SwathProjection*, and *SensorScanProjection* are all examples of transforms.

Function
: Maps a set of variables to a function value such that $y = f(x_1, x_2, x_3, ...)$. *LagrangeInterpolator*, *BivariateEstimator*, and *noaa.coastwatch.render.EnhancementFunction* are examples of concrete *Function* classes.

DataVariable
: Holds an n-dimensional array of data and allows for get/set of values, units conversion, value formatting, and statistics. The variable has two concrete classes with specialized methods for their rank: *Line* for 1D data, and *Grid* for 2D data.

EarthDataInfo
: Holds information about a geographic dataset including the data source, the date and duration of data recording (possible more than one), and the *EarthTransform* object.

LandMask
: Consults a land mask database to return true or false for the query: "Is there land at location (lat,lon)?".

Statistics
: Computes statistics for a set of data values including the minimum, maximum, mean, standard deviation, median, and average deviation. This class is used for all statistics computations in the CoastWatch Utilities.

GridResampler
: Computes a resampling of 2D *Grid* data from one *EarthTransform* to another. There are two algorithms for resampling used by the concrete *InverseGridResampler* and *MixedGridResampler* classes.

4.6 Main programs

The main program classes in the *noaa.coastwatch.tools* package include all the command line tools, graphical tools, and some supporting classes for preferences and user resources. The main programs' source code are a reference for using the top-level API classes. See Appendix A for the full manual pages for all main programs, and chapter 2 for a category-based guide to using the programs.

Appendix A

Manual Pages

A.1 Tool Help

A.1.1 cwtools

Name

cwtools - lists all tools in the CoastWatch Utilities.

A.2 Information and Statistics

A.2.1 cwinfo

Name

cwinfo - prints earth data file information.

Synopsis

cwinfo [OPTIONS] input

Options:

-h, --help
-t, --transform
-c, --coord
-e, --edge
-l, --locFormat=TYPE
-v, --verbose
--version

Description

The information utility dumps earth data information in a display-friendly format. The global earth information is printed such as satellite name, sensor, date, and earth transform information. The name of each variable is printed along with its data type, dimensions, scaling factor, and so on. For more detailed printing of generic HDF file contents, use the HDF hdp command.

When the **--transform** option is used, various additional earth transform information is printed. Let nc and nr be the x and y coordinate dimensions respectively, and mc=(nc-1)/2, mr=(nr-1)/2 be the midpoint coordinates. Note that indexing is zero-based and coordinates refer to the pixel center. Then the following information is computed:

- Pixel width at (mc,mr)
- Pixel height at (mc,mr)
- Total width from (0,mr) to (nc-1,mr)
- Total height from (mc,0) to (mc,nr-1)
- Center lat/lon at (mc,mr)
- Upper-left lat/lon at (0,0)
- Upper-right lat/lon at (nc-1,0)

- Lower-left lat/lon at (0,nr-1)
- Lower-right lat/lon at (nc-1,nr-1)

When the --**coord** option is used, Common Data Model coordinate systems are printed if available. Generally this style of coordinate system information is only available for files read by the NetCDF Java library.

Parameters

Main parameters:

input The input data file name.

Options:

-h, --help Prints a brief help message.

-t, --transform Specifies that additional earth transform information should also be printed. The default is to show only global and variable information.

-c, --coord Specifies that Common Data Model coordinate system information should also be printed. The default is to show only global and variable information.

-e, --edge Specifies that transform information should print the coordinates of the extreme edges of the corner pixels. The default is to print the coordinates of the center of corner pixels.

-l, --locFormat=TYPE Specifies the format style for geographic coordinates printed by the --**transform** option. Valid values are:

- D - Integer degrees, eg: '124 W'.
- DD - 2-digit degrees, eg: '124.36 W'.
- DDDD - 4-digit degrees, eg: '124.3600 W'.
- DDMM - Degrees, minutes, eg: '124 21.60 W'.
- DDMMSS - Degrees, minutes, seconds, eg: '124 21 36.00 W'.
- RAW - Decimal degrees up to the full 64-bit precision, eg: '-124.36003592404', in the range [-90,90] for latitude and [-180,180] for longitude.

The default is 'DDDD'.

-v, --verbose Turns verbose mode on. The current status of automatic file identification is printed. This output is useful when trying to understand why a certain file is not being recognized by this and other tools. The default is to run quietly.

--**version** Prints the software version.

Exit status

0 on success, $>$ 0 on failure. Possible causes of errors:

- Invalid command line option
- Invalid input file name
- Unsupported input file format

Examples

The following shows an information dump of a CoastWatch HDF file:

```
phollema$ cwinfo --transform 2019_320_0511_m01_wj.hdf

Contents of file 2019_320_0511_m01_wj.hdf

Global information:
  Satellite:           metop-1
  Sensor:              avhrr
  Date:                2019/11/16 JD 320
  Time:                05:11:42 UTC
  Scene time:          night
  Projection type:     mapped
  Transform ident:     noaa.coastwatch.util.trans.MercatorProjection
  Map projection:      Mercator
  Map affine:          0 -1470 1470 0 -13397799.15 3887086.51
  Spheroid:            WGS 84
  Origin:              USDOC/NOAA/NESDIS CoastWatch
  Format:              CoastWatch HDF version 3.4
  Reader ident:        noaa.coastwatch.io.CWHDFReader

Variable information:
  Variable       Type    Dimensions  Units          Scale     Offset
  avhrr_ch3      short   1024x1024   celsius        0.01      0
  avhrr_ch4      short   1024x1024   celsius        0.01      0
  avhrr_ch5      short   1024x1024   celsius        0.01      0
  cloud          ubyte   1024x1024   -              1         0
  graphics       ubyte   1024x1024   -              1         0
  sat_zenith     short   1024x1024   degrees        0.01      0
  sst            short   1024x1024   celsius        0.01      0

Earth location information:
  Pixel width:                   1.3054 km
  Pixel height:                  1.3123 km
  Total width:                   1334.7650 km
  Total height:                  1340.7132 km
```

```
Center:                         27.2500 N, 113.6000 W
Upper-left (pixel center):      33.1139 N, 120.3545 W
Upper-right (pixel center):     33.1139 N, 106.8455 W
Lower-left (pixel center):      21.0565 N, 120.3545 W
Lower-right (pixel center):     21.0565 N, 106.8455 W
```

A.2.2 cwstats

Name

cwstats - calculates earth data file statistics.

Synopsis

cwstats [OPTIONS] input

Options:

-h, --help
-i, --region=LAT/LON/RADIUS
-l, --limit=STARTROW/STARTCOL/ENDROW/ENDCOL
-m, --match=PATTERN
-p, --polygon=FILE
-s, --stride=N
-S, --sample=FACTOR
--version

Description

The statistics utility calculates a number of statistics for each variable in an earth data file:

- Count - the count of total data values sampled
- Valid - the number of valid (not missing) data values
- Min - the minimum data value
- Max - the maximum data value
- Mean - the average data value
- Stdev - the standard deviation from the mean
- Median - the median data value

To speed up the statistics calculations, a subset of the data values in each variable may be specified using either the **--stride** or **--sample** options, and one of the **--limit**, **--region**, or **--polygon** options. The **--match** option may also be used to limit the statistics calculations to a subset of the variables.

Parameters

Main parameters:

input The input data file name.

Options:

-h, --help Prints a brief help message.

-i, --region=LAT/LON/RADIUS The sampling region for each two-dimensional variable. The region is specified by the center latitude and longitude in degrees, and the radius from the center in kilometers. Only data within the rectangle specified by the center and radius is sampled. By default, all data is sampled. Only one of the **--region**, **--limit**, or **--polygon** options may be specified.

-l, --limit=STARTROW/ENDROW/STARTCOL/ENDCOL The sampling limits for each two-dimensional variable in image coordinates. Only data between the limits is sampled. By default, all data is sampled. Only one of the **--region**, **--limit**, or **--polygon** options may be specified.

-m, --match=PATTERN The variable name matching pattern. If specified, the pattern is used as a regular expression to match variable names. Only variables matching the pattern are included in the calculations. By default, no pattern matching is performed and all variables are included.

-p, --polygon=FILE The file name containing a list of polygon vertex points to use for constraining the statistics calculation. The file must be an ASCII text file containing vertex points as latitude / longitude pairs, one pair per line, with values separated by spaces or tabs. The points are specified in terms of earth location latitude and longitude in the range [-90..90] and [-180..180] with a datum matching that of the input file. Only data inside the polygon is sampled. By default, all data is sampled. Only one of the **--region**, **--limit**, or **--polygon** options may be specified.

-s, --stride=N The sampling frequency for each variable dimension. The default is to sample all data values (stride = 1).

-S, --sample=FACTOR The sampling factor for each variable. The sampling factor is a value in the range [0..1] that specifies the number of data values sampled as a fraction of the total number of data values. Optionally, the sample value can be specified in percent, eg: 50%. To sample 1 percent of all data values, the sample factor would be specified as 0.01 or 1%. The default is to sample all data values (factor = 1).

--version Prints the software version.

Exit status

0 on success, > 0 on failure. Possible causes of errors:

- Invalid command line option
- Invalid input file name
- Unsupported input file format
- Error reading input data values

Examples

The following shows a statistics calculation on a CoastWatch HDF file from the Great Lakes:

```
phollema$ cwstats 2002_197_1719_n16_gr.hdf

Variable        Count     Valid     Min       Max       Mean        Stdev
avhrr_ch1       1048576   483728    3.49      74.36     13.059646   11.371605
avhrr_ch2       1048576   483728    1.97      71.35     18.520041   9.844144
avhrr_ch3a      1048576   483728    0.53      52.84     14.664213   8.88201
avhrr_ch4       1048576   483728    -44.8     31.55     11.052207   13.683309
avhrr_ch5       1048576   483728    -45.48    27.05     7.978351    13.185983
sst             1048576   483728    -44.51    51.43     20.166333   16.714169
cloud           1048576   1048576   0         127       23.24175    37.179013
sat_zenith      1048576   483728    0.36      0.7       0.466376    0.077153
sun_zenith      1048576   483728    0.87      0.95      0.907019    0.022209
rel_azimuth     1048576   483728    -0.58     -0.33     -0.465731   0.058149
graphics        1048576   1048576   0         14        6.84576     2.931459
```

A.2.3 hdatt

Name

hdatt - reads or writes HDF file attributes.

Synopsis

hdatt [OPTIONS] input

Options:

-h, --help
-n, --name=STRING
-t, --type=TYPE
-l, --value=STRING1[/STRING2/...]
-V, --variable=STRING
--version

Description

The attribute tool reads or writes HDF file attributes using the HDF Scientific Data Sets (SDS) interface. The two modes work as follows:

Read mode In read mode, the tool can read from either the global attribute set (the default), or the attribute set specific to a variable (when then --**variable** option is specified). It can read either all attribute values in the set (the default), or just a single attribute value (when the --**name** option is specified).

Write mode Write mode is specified by the use of the --**value** option, which provides a value for a named attribute. In write mode, the user is required to supply an attribute name and value, and optionally a type. If no type is specified, the type defaults to 'string' (see the --**type** option below for the meanings of various type names). Attributes may be written to the global attribute set (the default), or to specific variables in the data file using the --**variable** option.

Note: The attribute tool is currently limited to reading and writing only the signed HDF data types. In read mode, unsigned HDF attribute data are read correctly, but the value displayed as if it were signed.

Parameters

Main parameters:

input The input data file name.

Options:

-n, --name=STRING The name of the attribute to read or write.

-t, --type=TYPE The attribute data type (write mode only). The valid types and their HDF equivalents are as follows:

Type name	HDF type
string	DFNT_CHAR8
byte	DFNT_INT8
short	DFNT_INT16
int	DFNT_INT32
long	DFNT_INT64
float	DFNT_FLOAT32
double	DFNT_FLOAT64

-l, --value=STRING1[/STRING2/...] The value(s) for the named attribute. If specified, this places the tool into write mode, and **--name** must specify an attribute name. If an attribute already exists, its value is overwritten with the new value. If an attribute with the name does not exist, it is created and the new value assigned to it. By default if this option is not used, the tool is in read mode.

-V, --variable=STRING The variable to read or write the attribute data. By default, the attribute is read from or written to the global attribute set.

--version Prints the software version.

Exit status

0 on success, $>$ 0 on failure. Possible causes of errors:

- Invalid command line option
- Invalid input or output file names
- Invalid variable name
- Invalid attribute name in read mode
- Invalid attribute type in write mode
- Value does not convert to the specified attribute data type

Examples

As an example of read mode, the following command reads and prints all the global attribute data from a CoastWatch HDF file:

```
phollema$ hdatt 2005_095_1522_n17_er.hdf

satellite = noaa-17
```

```
sensor = avhrr
origin = USDOC/NOAA/NESDIS CoastWatch
cwhdf_version = 3.2
pass_type = day
pass_date = 12878
start_time = 55371.0
projection_type = mapped
projection = Mercator
gctp_sys = 5
gctp_zone = 0
gctp_parm = 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
gctp_datum = 12
et_affine = 0.0 -1470.0 1470.0 0.0 -8804259.100925786 5723777.271647277
rows = 1401
cols = 1302
polygon_latitude = 45.83810150571052 45.83810150571052 45.83810150571052
  45.83810150571052 45.83810150571052 42.51315402540104 38.99999999998719
  35.30179546333813 31.424886223357582 31.424886223357582 31.424886223357582
  31.424886223357582 31.424886223357582 35.30179546333813 38.99999999998719
  42.51315402540104 45.83810150571052
polygon_longitude = -79.09000515710031 -74.79500257855015 -70.5 -66.20499742144985
  -61.90999484289969 -61.90999484289969 -61.90999484289969 -61.90999484289969
  -61.90999484289969 -66.20499742144985 -70.5 -74.79500257855015 -79.09000515710031
  -79.09000515710031 -79.09000515710031 -79.09000515710031 -79.09000515710031
history = cwimport product.tshdf product.hdf
```

To dump only a single attribute:

```
phollema$ hdatt --name satellite 2005_095_1522_n17_er.hdf

noaa-17
```

or a single attribute from a specific variable:

```
phollema$ hdatt --name units --variable avhrr_ch3a 2005_095_1522_n17_er.hdf

albedo*100%
```

As an example of write mode, suppose that we wanted to save the date when the file was originally downloaded from the server:

```
phollema$ hdatt --name download_date --value "Mon Apr 11 18:20:15 PDT 2005"
  2005_095_1522_n17_er.hdf
```

Now suppose we wanted to assign an integer quality value of 65% to the file based on some test that was performed on the file data:

```
phollema$ hdatt --name quality_value --value 65 --type int 2005_095_1522_n17_er.hdf
```

Finally, suppose that we wanted to change the units and scaling factor / offset of a variable, originally in degrees Celsius and scaled by 0.01, to degrees Fahrenheit:

```
phollema$ hdatt --name units --value "deg F" --variable sst 2005_095_1522_n17_er.hdf
phollema$ hdatt --name scale_factor --value 0.018 --type double --variable sst
  2005_095_1522_n17_er.hdf
phollema$ hdatt --name add_offset --value -1777.777777 --type double --variable sst
  2005_095_1522_n17_er.hdf
```

A.3 Data Processing

A.3.1 cwimport

Name

cwimport - translates earth data into CoastWatch HDF.

Synopsis

cwimport [OPTIONS] input1 [input2 ...] output

Options:

-c, --copy
-g, --nogroup
-h, --help
-m, --match=PATTERN
-v, --verbose
--version

Description

The import tool translates earth data into CoastWatch HDF format. Multiple input files may be specified, but must have matching earth transforms and dates. The utility loops over all input files and creates a single CoastWatch HDF output file. The utility does not handle multiple variables with the same name – if a variable in an input file is encountered with the same name as an existing variable from a previous input file, the new variable is skipped. Options are available to alter verbosity and variable name matching.

Parameters

Main parameters:

input1 [input2 ...] The input data file name(s). At least one input file is required. If multiple files are specified, they must have matching dates and earth transforms. The currently supported input formats are CoastWatch HDF, NetCDF 3/4 with CF metadata, TeraScan HDF, and NOAA 1b format GAC/LAC/HRPT AVHRR.

output The output data file name.

Options:

-c, --copy Turns on copy mode. In copy mode, variables from the input files are copied into an existing output file. The default is to create a new output file and populate it with data. Copy mode is

especially useful for copying variables from one CoastWatch HDF file to another.

-g, --nogroup Turns on removal of the group path in variable names. If variable names contain a leading group path ending with '/', the group path is removed.

-h, --help Prints a brief help message.

-m, --match=PATTERN The variable name matching pattern. If specified, the pattern is used as a regular expression to match variable names. Only variables matching the pattern will be imported. By default, no pattern matching is performed and all variables are imported.

-v, --verbose Turns verbose mode on. The current status of data conversion is printed periodically. The default is to run quietly.

--version Prints the software version.

Exit status

0 on success, $>$ 0 on failure. Possible causes of errors:

- Invalid command line option
- Invalid input or output file names
- Unsupported input file format
- Input file dates or earth transforms do not match

Examples

The following shows the import of a NetCDF file to CoastWatch HDF with verbose mode on:

```
phollema$ cwimport --verbose --match analysed_sst
  20220621-GHRSST-Blended-v02.0-fv01.0.nc 2022_06_21_night_sst.hdf
[INFO] Reading input 20220621-GHRSST-Blended-v02.0-fv01.0.nc
[INFO] Creating output 2022_06_21_night_sst.hdf
[INFO] Reading file [1/1], 20220621-GHRSST-Blended-v02.0-fv01.0.nc
[INFO] Writing analysed_sst
```

A.3.2 cwexport

Name

cwexport - translates earth data into external file formats.

Synopsis

cwexport [OPTIONS] input output

General options:

-f, --format=TYPE
-h, --help
-H, --header
-m, --match=PATTERN
-M, --missing=VALUE
-v, --verbose
--version

Binary raster options:

-c, --scale=FACTOR/OFFSET
-o, --byteorder=ORDER
-r, --range=MIN/MAX
-s, --size=TYPE

ASCII text options:

-d, --dec=DECIMALS
-D, --delimit=STRING
-n, --nocoords
-R, --reverse

NetCDF options:

-S, --dcs
-C, --cw

GeoTIFF options:

-T, --tiffcomp=TYPE
-F, --tiffsize=TYPE

Description

The export tool translates earth data into external formats as described below. In all cases, 2D data sets are exported in row major order starting from row 0. For example, if the earth data values form the 2D array:

```
 0  1  2  3
 4  5  6  7
 8  9 10 11
12 13 14 15
```

then values are output in the order:

```
0 1 2 3 4 5 6 7 ...
```

In the general case, multiple variables may be exported to the same data file. The use of the **--match** option may be used to select a specific variable or subset of variables.

Binary raster:

The output is a stream of binary data values – either 8-bit unsigned bytes, 16-bit signed integers, or 32-bit IEEE floating point values. For 8- and 16-bit output, data values may be scaled to integers (essentially a packing scheme to reduce the output file size) using a minimum and maximum or by using a scaling factor and offset. For minimum/maximum scaling, integer data is calculated from data values using the equation:

```
integer = type_min + type_range*((value - min) / (max - min))
```

where `type_min` is 0 for 8-bit and -32768 for 16-bit, and `type_range` is 255 for 8-bit and 65535 for 16-bit. For scaling factor and offset, the following equation is used:

```
integer = value/factor + offset
```

In both cases, the results are rounded to the nearest integer and out of range values are assigned the missing value.

ASCII text:

The output is an ASCII text file with latitude, longitude, and data value printed – one data value per line.

ArcGIS binary grid:

The output is a stream of 32-bit IEEE floating point values, ready for input to ArcGIS applications as a binary grid file. A header file may also be created to specify the earth location and other parameters. In the case of the ArcGIS format, only one variable is allowed per binary grid file. If an attempt to export multiple variables is made, only the first variable is actually written.

NetCDF:

The output is either a NetCDF 3 or 4 dataset with CF 1.4 convention metadata. The formatting follows as much as possible the recommendations and examples in the document "Encoding CoastWatch Satellite Data in NetCDF using the CF Metadata Conventions", Peter Hollemans, February 2010. In some cases, the source data for some attributes may not be available, in which case the output NetCDF may need to be modified and extended.

GeoTIFF:

The output is an 8-bit unsigned integer, 16-bit unsigned integer, or 32-bit IEEE floating pointing data TIFF file with GeoTIFF georeference tags. The number of samples per pixel in the TIFF image matches the number of variables exported. The resulting image file is not suitable for display as a regular TIFF image, but rather is meant for import into a GIS package.

Parameters

Main parameters:

input The input data file name.

output The output data file name. Unless the **--format** option is used, the output file extension indicates the desired output format:

- filename.raw = binary
- filename.txt = text
- filename.flt = ArcGIS
- filename.nc = NetCDF 3
- filename.nc4 = NetCDF 4
- filename.tif = GeoTIFF

General options:

-f, --format=TYPE The output format. The current formats are 'bin' for binary raster, 'text' for ASCII text, 'arc' for ArcGIS binary grid, 'netcdf' for NetCDF 3, 'netcdf4' for NetCDF 4, 'geotiff' for GeoTIFF, or 'auto' to detect the format from the output file name. The default is 'auto'.

-h, --help Prints a brief help message.

-H, --header Specifies that a header should be written as well as the output data. The method of writing the header is different depending on the output format:

- Binary: The header consists of one byte specifying the number of dimensions followed by a series of 32-bit signed integers specifying the dimension lengths. The header is written on a per-variable basis, before each block of variable values in the output file.
- Text: The header is one line consisting of an integer specifying the number of dimensions followed by a series of integers specifying the dimension lengths. The header is written on a per-variable basis before each set of variable values in the output file.
- ArcGIS: The header is a separate file used by ArcGIS applications to determine the dimensions of the data, the geographic position and resolution, and other parameters. The header file name is created by replacing any '.' followed by an extension in the output file name with '.hdr'
- NetCDF, GeoTIFF: Not applicable, all metadata in NetCDF and GeoTIFF is written into the dataset itself.

By default no header is written.

-m, --match=PATTERN The variable name matching pattern. If specified, the pattern is used as a regular expression to match variable names. Only variables matching the pattern will be exported. By default, no pattern matching is performed and all variables are exported.

-M, --missing=VALUE The output value for missing or out of range data. The default missing value is different depending on the output format:

- Binary: The default is 0 for 8-bit unsigned bytes, -32768 for 16-bit signed integers, and the IEEE NaN value for floating point.
- Text: The default is to print 'NaN' for missing values.
- ArcGIS: The missing value is fixed at -3.4e38 and the **--missing** option is ignored.
- NetCDF: Not applicable, the missing values for variable data are copied from the input data source.
- GeoTIFF: The default is to write (i) zeros for integer data types, or (ii) 32-float IEEE NaN values with bit pattern 0x7fc00000 for 32-bit float data in the TIFF image data.

-v, --verbose Turns verbose mode on. The current status of data conversion is printed periodically. The default is to run quietly.

--version Prints the software version.

Binary raster options:

-c, --scale=FACTOR/OFFSET The data scale factor and offset for integer packing. Data values are scaled to integers using the factor and offset (see the equation in the **Description** section above, under **Binary raster**). The default factor is 1 and offset is 0.

-o, --byteorder=ORDER The output byte order. Valid choices are 'host' for the host byte order, 'msb' for most significant byte first, or 'lsb' for least significant byte first. The default is the host byte order.

-r, --range=MIN/MAX The data scaling range for integer packing. Data values are mapped to integers using the minimum and maximum values (see the equation in the **Description** section above, under **Binary raster**). There is no default range.

-s, --size=TYPE The binary value size. Valid choices are 'byte' for 8-bit unsigned bytes, 'short' for 16-bit signed integers, or 'float' for 32-bit IEEE floating point values. The default is 32-bit floats.

ASCII text options:

-d, --dec=DECIMALS The number of decimal places for printed geographic coordinate values. The default is 6 decimals.

-D, --delimit=STRING The value delimiter string. By default, values are separated with a single space character.

-n, --nocoords Turns geographic coordinate printing off. By default, each line has the form 'latitude longitude value' but with no coordinates, each line simply contains the data value.

-R, --reverse Specifies that coordinates should be printed in reverse order, 'longitude latitude'. The default is 'latitude longitude'.

NetCDF options:

-S, --dcs Turns on writing of ocean color Data Content Standard metadata. The default is to write only CF-1.4 metadata. DCS metadata is written as a set of global NetCDF attributes with the namespace prefix 'dcs'. Only the minimal set of 15 required attributes are written. Since the NetCDF file will generally contain more than one variable, the required DCS attributes observedProperty and observedPropertyAlgorithm are set to 'Unknown' and must be modified manually.

-C, --cw Turns on writing of CoastWatch HDF-style metadata. The default is to write only CF-1.4 metadata. CoastWatch metadata is written as a set of global- and variable-level NetCDF attributes with the namespace prefix 'cw'. Only a very small subset of the original CoastWatch HDF metadata is written, those attributes that have no CF-1.4 equivalent.

GeoTIFF options:

-T, --tiffcomp=TYPE The TIFF compression algorithm. The valid types are 'none' for no compression, and 'deflate' or 'lzw' for ZIP style compression. The default is to use deflate compression.

-F, --tiffsize=TYPE The TIFF data value size. The valid types are 'byte' for 8-bit unsigned integers, 'ushort' for 16-bit unsigned integers, or 'float' for 32-bit IEEE floating point values. The default is to write 32-bit floats.

Exit status

0 on success, $>$ 0 on failure. Possible causes of errors:

- Invalid command line option

- Invalid input or output file names
- Invalid variable name
- Unrecognized format, size, or byte order

Examples

The following shows the export of AVHRR channel 1 data from a CoastWatch HDF file with to a binary 32-bit IEEE floating point value format, host byte order, no header, in verbose mode:

```
phollema$ cwexport -v --match 'avhrr_ch1' 2019_250_2241_n19_mr.hdf
  2019_250_2241_n19_mr_ch1.raw

[INFO] Creating output 2019_250_2241_n19_mr_ch1.raw
[INFO] Writing avhrr_ch1
```

The example below shows the export of AVHRR channels 1, 2, and 4 to the same output file from a CoastWatch HDF file using 8-bit unsigned byte format, no header, in verbose mode. Range scaling is used to scale all values between -30 and 30 prior to conversion to byte values in the range 0 to 255. Note that some values may fall outside the range and be clipped, especially albedo values which can range up to 100. The clipped values are assigned the default missing value, which for byte data is 0.

```
phollema$ cwexport -v --match 'avhrr_ch[124]' --size byte --range -30/30
  2019_250_2241_n19_mr.hdf 2019_250_2241_n19_mr_ch124.raw

[INFO] Creating output 2019_250_2241_n19_mr_ch124.raw
[INFO] Writing avhrr_ch1
[INFO] Writing avhrr_ch2
[INFO] Writing avhrr_ch4
```

The next example shows the export of AVHRR channel 4 data to an ASCII text file from a CoastWatch HDF file in verbose mode. The geographic coordinates are printed in the order (longitude, latitude), and delimited with a comma character. Any missing values are denoted with the value -999. A one line dimension header is prepended to the dataset.

```
phollema$ cwexport -v --match 'avhrr_ch4' --format text --reverse
  --delimit ',' --missing -999 --header 2019_250_2241_n19_mr.hdf
  2019_250_2241_n19_mr_ch4.txt

[INFO] Creating output 2019_250_2241_n19_mr_ch4.txt
[INFO] Writing avhrr_ch4
```

The first few lines of the output file are as follows:

```
2,1101,1401
-98.243664,31.051575,31.48
-98.230459,31.051575,31.59
-98.217254,31.051575,31.59
-98.204049,31.051575,31.59
-98.190843,31.051575,32.03
-98.177638,31.051575,32.03
-98.164433,31.051575,32.47
-98.151228,31.051575,32.25
-98.138022,31.051575,32.58
```

The example below shows the export of AVHRR channel 2 data to an ArcGIS binary grid file from a CoastWatch HDF file in verbose mode. The binary grid data is written to a '.flt' file and the header data to a '.hdr' file.

```
phollema$ cwexport -v --format arc --match 'avhrr_ch2' --header
  2019_250_2241_n19_mr.hdf 2019_250_2241_n19_mr_ch4.flt

[INFO] Creating output 2019_250_2241_n19_mr_ch4.flt
[INFO] Writing avhrr_ch2
```

The header data is written to **2019_250_2241_n19_mr_ch4.hdr** as follows:

```
nrows 1101
ncols 1401
xllcorner -1.0937169680601347E7
yllcorner 1999676.93911416
cellsize 1470.0
nodata_value -3.4E38
byteorder MSBFIRST
nbits 32
```

A final example shows the export of SST and cloud data to a NetCDF dataset:

```
phollema$ cwexport -v --match '(sst|cloud)' 2010_040_1636_m02_wj.hdf
  2010_040_1636_m02_wj.nc

[INFO] Creating output 2010_040_1636_m02_wj.nc
[INFO] Writing cloud
[INFO] Writing sst
```

Running the NetCDF software `ncdump -h` command shows the file contents:

```
netcdf 2010_040_1636_m02_wj {
```

```
dimensions:
  time = 1 ;
  level = 1 ;
  row = 1024 ;
  column = 1024 ;
variables:
  int coord_ref ;
    coord_ref:grid_mapping_name = "mercator" ;
    coord_ref:longitude_of_projection_origin = 0. ;
    coord_ref:standard_parallel = 0. ;
    coord_ref:false_easting = 0. ;
    coord_ref:false_northing = 0. ;
    coord_ref:semi_major_axis = 6378137. ;
    coord_ref:inverse_flattening = 298.257223653 ;
    coord_ref:longitude_of_prime_meridian = 0. ;
  double x(column) ;
    x:standard_name = "projection_x_coordinate" ;
    x:units = "m" ;
  double y(row) ;
    y:standard_name = "projection_y_coordinate" ;
    y:units = "m" ;
  double lat(row, column) ;
    lat:standard_name = "latitude" ;
    lat:units = "degrees_north" ;
  double lon(row, column) ;
    lon:standard_name = "longitude" ;
    lon:units = "degrees_east" ;
  double time(time) ;
    time:standard_name = "time" ;
    time:units = "seconds since 1970-01-01 00:00:00 UTC" ;
  double level(level) ;
    level:standard_name = "height" ;
    level:units = "m" ;
    level:positive = "up" ;
  byte cloud(time, level, row, column) ;
    cloud:missing = 0b ;
    cloud:valid_range = 0, 255 ;
    cloud:coordinates = "lat lon" ;
    cloud:cell_methods = "area: mean" ;
    cloud:grid_mapping = "coord_ref" ;
  short sst(time, level, row, column) ;
    sst:scale_factor = 0.01 ;
    sst:add_offset = -0. ;
    sst:missing = -32768s ;
    sst:units = "celsius" ;
    sst:coordinates = "lat lon" ;
    sst:cell_methods = "area: mean" ;
    sst:grid_mapping = "coord_ref" ;
```

```
      sst:source = "nonlinear_split_window linear_triple_window_modified" ;

  // global attributes:
    :Conventions = "CF-1.4" ;
    :source = "METOP2_AVHRR " ;
    :institution = "USDOC/NOAA/NESDIS CoastWatch" ;
    :history = "[2010-03-13 09:46:43 IST cwf-3.2.4-pre-build169 phollema] cwexport
      -v --match (sst|cloud) 2010_040_1636_m02_wj.hdf 2010_040_1636_m02_wj.nc" ;
  }
```

A.3.3 cwsample

Name

cwsample - extracts data values at specified earth locations.

Synopsis

cwsample [OPTIONS] input output

Sampling type options:

-s, --sample=LATITUDE/LONGITUDE
-S, --samples=FILE

General options:

-d, --dec=DECIMALS
-D, --delimit=STRING
-h, --help
-H, --header
-i, --imagecoords
-m, --match=PATTERN
-M, --missing=VALUE
-n, --nocoords
-R, --reverse
-t, --statsvar=NAME
-V, --variable=NAME1[/NAME2/...]
-w, --window=N
--version

Description

The sampling tool extracts data values at specified Earth locations from 2D data variables. A sample point may be specified on the command line using geographic coordinates, or multiple sample points may be specified using a data file. A number of 2D data variables may be sampled simultaneously. The sampled values are printed as ASCII text to the output file, one line per sample point. Various options are available to modify the output decimals places, delimiters, and so on.

Parameters

Main parameters:

input The input data file name.

output The output text file name. If the output file name is '-', output is sent to standard output (normally the terminal). In this case, the end of the options must be indicated with a lone '--' (see the examples) or the '-' output file name will be interpreted as an option.

Sampling type options:

-s, --sample=LATITUDE/LONGITUDE The sample point for a single sampling operation. The point is specified in terms of earth location latitude and longitude in the range [-90..90] and [-180..180] with a datum matching that of the input file.

-S, --samples=FILE The file name containing a list of sample points for performing multiple sampling operations. The file must be an ASCII text file containing sample points as latitude / longitude pairs, one pair per line, with values separated by spaces or tabs. The points are specified in terms of earth location latitude and longitude in the range [-90..90] and [-180..180] with a datum matching that of the input file.

General options:

-d, --dec=DECIMALS The number of decimal places for printed geographic coordinate values. The default is 6 decimals.

-D, --delimit=STRING The value delimiter string. By default, values are separated with a single space character.

-h, --help Prints a brief help message.

-H, --header Specifies that a one line header should be written. The header is written before any data and consists of the output column names. By default no header is written.

-i, --imagecoords Specifies that image coordinates (row and column) should be printed for each output line. The default is to print only geographic coordinates.

-m, --match=PATTERN The variable name matching pattern. If specified, the pattern is used as a regular expression to match variable names. Only variables matching the pattern will be sampled. By default, no pattern matching is performed and all variables are sampled unless the **--variable** option is used. Note that either **--variable** or **--match** may be specified, but not both.

-M, --missing=VALUE The output value for missing or out of range data. The default is to print 'NaN' for missing values.

-n, --nocoords Turns geographic coordinate printing off. By default, each output line has the form 'latitude longitude value(s)' but with no coordinates, each line simply contains the data value(s).

-R, --reverse Specifies that coordinates should be printed in reverse order, 'longitude latitude'. The default is 'latitude longitude'.

-t, --statsvar=NAME The variable name to compute statistics. If specified, the named variable is used to compute statistics using the values within an NxN window surrounding each sample point. The statistics are reported on each output line as:

- Count - the count of total data values sampled
- Valid - the number of valid (not missing) data values
- Min - the minimum data value
- Max - the maximum data value
- Mean - the average data value
- Stdev - the standard deviation from the mean
- Median - the median data value

See also the --**window** option to set the window size. The default is not to compute statistics and only report the variable sample values at the sample points.

-V, --variable=NAME1[/NAME2/...] The variable names to sample. If specified, the variable sample values are printed in columns in exactly the same order as they are listed. This option is different from the --**match** option because it (i) specifies the column order, where as --**match** orders the columns as the variables are encountered in the file, and (ii) does not support pattern matching; all variable names must be specified exactly. Without this option or the --**match** option, all variables are sampled. Note that either --**variable** or --**match** may be specified, but not both.

-w, --window=N The window size in pixels for computing statistics. The default is to use a 3x3 window. Only odd values are allowed: 3, 5, 7, etc. This option is only relevant when the --**statsvar** option is also specified.

--**version** Prints the software version.

Exit status

0 on success, $>$ 0 on failure. Possible causes of errors:

- Invalid command line option
- Invalid input or output file names
- Invalid sample coordinates file format

Examples

In the example below, a sample points file named `sample_locs.txt` was set up to follow the 93 W longitude line at regular 0.2 degree intervals as follows:

```
28 -93
28.2 -93
28.4 -93
28.6 -93
```

```
28.8 -93
29 -93
29.2 -93
29.4 -93
29.6 -93
29.8 -93
30 -93
```

and a Gulf of Mexico data file sampled for SST and cloud data along this line with output to the terminal screen:

```
phollema$ cwsample --header --match '(sst|cloud)' --samples sample_locs.txt
  -- 2002_325_1546_n17_mr.hdf -

latitude longitude sst cloud
28 -93 25.24 0
28.2 -93 25.24 0
28.4 -93 24.78 0
28.6 -93 23.84 0
28.8 -93 22.72 0
29 -93 21.37 0
29.2 -93 20.06 0
29.4 -93 19.29 0
29.6 -93 18.16 0
29.8 -93 17.57 6
30 -93 17.48 22
```

Another example shows the sampling of one SST value as in the case of comparison with a single buoy measurement with output to the terminal screen:

```
phollema$ cwsample --header --match sst --sample 28.8/-93 -- 2002_325_1546_n17_mr.hdf -

latitude longitude sst
28.8 -93 22.72
```

A.3.4 cwmath

Name

cwmath - combines earth data using a mathematical expression.

Synopsis

cwmath [OPTIONS] input
cwmath [OPTIONS] input1 [input2 ...] output

Options:

-c, --scale=FACTOR/OFFSET | none
-e, --expr=EXPRESSION
-h, --help
-k, --skip-missing
-l, --longname=STRING
-m, --missing=VALUE
-p, --parser=TYPE
-s, --size=TYPE
--serial
--threads=MAX
-t, --template=VARIABLE
-f, --full-template
-u, --units=STRING
-v, --verbose
--version

Description

The math tool combines earth data using a mathematical expression. The expression takes the form:

```
variable = formula
```

where the variable is the output variable to create and the formula is a mathematical combination of input variables. The formula may contain a number of standard operators, for example addition and subtraction, as well as functions such as sine and cosine and numerical and symbolic constants. The formula syntax can follow one of two standards specified by the **--parser** option: the legacy syntax as originally supported by the math tool, or Java syntax that takes advantage of the full java.lang.Math function library and in some cases allows for simpler expressions. See the Java API documentation for a full list of java.lang.Math functions. A comparison of the most common language features is as follows:

Language Feature	Legacy Parser Syntax	Java Parser Syntax
Unary plus	+x	Unsupported
Unary minus	-x	-x
Addition	x + y	x + y
Subtraction	x - y	x - y
Multiplication	x * y	x * y
Division	x / y	x / y
Modulus	x % y or mod (x, y)	x % y
Exponentiation	x ^ y	pow (x, y)
Bitwise AND	and (x, y)	x & y
Bitwise OR	or (x, y)	x | y
Bitwise XOR	xor (x, y)	x ^ y
Bitwise NOT	not (x)	~x
Less than	x < y	x < y
Greater than	x > y	x > y
Less than or equal to	x <= y	x <= y
Greater than or equal to	x >= y	x >= y
Not equal to	x != y	x != y
Equal to	x == y	x == y
Boolean conjunction	x && y	x && y
Boolean disjunction	x || y	x || y
Boolean negation	!x	!x
Sine	sin (x)	sin (x)
Cosine	cos (x)	cos (x)
Tangent	tan (x)	tan (x)
Arcsine	asin (x)	asin (x)
Arccosine	acos (x)	acos (x)
Arctangent	atan (x)	atan (x)
Hyperbolic sine	sinh (x)	sinh (x)
Hyperbolic cosine	cosh (x)	cosh (x)
Hyperbolic tangent	tanh (x)	tanh (x)
Inverse hyperbolic sine	asinh (x)	asinh (x)
Inverse hyperbolic cosine	acosh (x)	acosh (x)
Inverse hyperbolic tangent	atanh (x)	atanh (x)
Natural log	ln (x)	log (x)
Base 10 log	log (x)	log10 (x)
Polar coordinate angle	angle (y, x)	atan2 (y, x)
Absolute value	abs (x)	abs (x)
Random value [0..1]	rand()	random()
Square root	sqrt (x)	sqrt (x)
Sum of values	sum (x1, x2, ...)	sum (x1, x2, ...)
Conditional operator	select (condition, x, y)	(condition ? x : y)
Hexadecimal constant	hex ("0xffff")	0xffff
Data value masking	mask (x, flag, bitmask)	((flag & bitmask) == 0 ? x : NaN)
Value of e (2.71828...)	e	E
Value Pi (3.14159...)	pi	PI
Not-a-Number as 64-bit	nan	NaN
Test for Not-a-Number	Unsupported	isNaN (x)
Haversine distance (km)	Unsupported	dist (lat1, lon1, lat2, lon2)

Note that in legacy parser expressions, boolean result values from operators (==, !=, >, <, >=, <=, &&, ||, !) evaluated to either 1.0 (true) or 0.0 (false). As a result, legacy parser expressions could treat boolean values as numbers in arithmatic expressions such as addition, subtraction, etc. This is not the case with the Java parser, and even when emulating the legacy parser, arithmatic operations on boolean values generate a parsing error. The only solution for this is to modify the expression. For example:

```
result = (var1 != 0) + (var2 != 0)
```

should be modified to:

```
result = (var1 != 0 ? 1 : 0) + (var2 != 0 ? 1 : 0)
```

and the new Java parser used (see the --**parser** option below).

Parameters

Main parameters:

input The single input and output data file. In the case that a single input file is specified and no output file, data is read from and written to the same file. The new variable created by the expression must not already exist in the input file.

input1 [input2...] The input data file name(s). If multiple input files are specified, variables on the right hand side of the expression (or used in the --**template** option) must be prefixed by the string 'file<N>_' where <N> is replaced with the index of the input file which contains the variable and input file indexing starts at 1. For example, to reference the variable 'avhrr_ch4' in the second input file, use 'file2_avhrr_ch4' in the expression.

output The output data file name. If specified and the file does not already exist, it will be created using metadata from the first input file. If it does exist, it will be opened and checked for a compatible earth transform and the new variable data will be added to the file. The new variable created by the expression must not already exist in the output file. The output file can be one of the input files if needed.

Options:

-c, --scale=FACTOR/OFFSET | none The output variable scale and offset. The scaling is effectively a packing scheme to reduce data file size by scaling floating-point values to integers using the equation:

```
integer = value/factor + offset
```

The default is '0.01/0'. If 'none' is specified, the expression result is considered to be an integer and stored directly in the output value. This option is ignored for floating-point storage types, namely if --**size** is 'float' or 'double' or if the template variable type is floating-point.

-e, --expr=EXPRESSION The mathematical expression. See above for the expression syntax and supported operators and functions. If no expression is specified, the user will be prompted to enter an expression at the keyboard. The latter method is recommended for operating systems such as Microsoft Windows in which the command line shell can mangle some expression characters such as the equals sign.

-h, --help Prints a brief help message.

-k, --skip-missing Turns on skip missing mode. When on, the computation skips any locations where one or more variable values are set to the missing value. This is an optimization for when the expression does not contain any tests for NaN values, and data values flagged as missing would lead to in an invalid computation result.

-l, --longname=STRING The output variable long name. The long name is a verbose string to describe the variable in common terms. For example, the variable named 'sst' might have the long name 'sea surface temperature'. The default is to use the output variable name as the long name.

-m, --missing=VALUE The missing output value. The missing value is used to mark output locations in the variable where there is no valid value, either because the computation of the expression failed, or no value was ever or should ever be written to the location (possibly, it falls outside some geographic domain). By default, the missing value is type-dependent and is set to the minimum representable value for integer types. For floating point types, this option is ignored and the missing value is set to the NaN value or inherited from the template variable.

-p, --parser=TYPE The expression parser type. Valid choices are 'java' or 'emulated':

- **Java (DEFAULT)** - The Java expression parser accepts expressions written in the Java Language Specification, with access to the full java.lang.Math class static methods, in addition to the constants E, PI, NaN, and the functions isNaN(x), asinh(x), acosh(x), atanh(x), and sum(x1,x2,...). The Java parser compiles expressions to Java byte code and runs the code natively for high speed expression evaluation. The Java parser is more strict with type checking than the legacy or emulated legacy parsers. For example, operands of the bitwise operators must be an integer type (or cast to an integer type) in order to pass the parsing phase without a type error.
- **Legacy emulated** - The emulated expression parser emulates the legacy parser (the original parser used in the math tool) by internally converting the legacy expression syntax, operators, functions, and constants to Java Language Specification. The converted expression is then parsed and evaluated by the high speed Java expression parser.

-s, --size=TYPE The output variable type. Valid choices include integer data in both signed and unsigned types, and floating-point data as follows:

- 8-bit byte: 'byte' or 'ubyte'
- 16-bit short integer: 'short' or 'ushort'
- 32-bit integer: 'int' or 'uint'
- 64-bit long integer: 'long' or 'ulong'
- 32-bit floating-point: 'float'
- 64-bit floating-point: 'double'

Integer output types can be used to represent floating-point values by specifying the --**scale** option. The default variable type is 'short', and with the default scaling factor of 0.01, floating-point values are packed into 16-bit signed integers with a range of [-327.68 ... 327.67] and two decimals of accuracy.

--**serial** Turns on serial processing mode. By default the program will use multiple processors in parallel to process chunks of data.

--**threads=MAX** Specifies the maximum number of threads for parallel processing. By default the program will automatically detect the maximum number of threads possible.

-**t,** --**template=VARIABLE** The output template variable. When a template is used, the output variable size, scaling, units, long name, and missing value are all determined from the template variable. Any of these properties set from the command line using --**size**, --**scale**, --**units**, --**longname** or --**missing** override the corresponding template property. There is no template variable by default, rather the math routine outputs 16-bit scaled integer values. See the --**size** and --**scale** options for details.

-**f,** --**full-template** Turns on full template attribute mode. All attributes from the template variable (except for those overridden at the command line) are copied to the output variable. By default only the minimal set of attributes is written.

-**u,** --**units=STRING** The output variable units. For example if the output variable data is based on temperature in Celsius, the variable units might be 'celsius'. There is no default units value.

-**v,** --**verbose** Turns verbose mode on. The current status of computation is printed periodically. The default is to run quietly.

--**version** Prints the software version.

Exit status

0 on success, $>$ 0 on failure. Possible causes of errors:

- Invalid command line option
- Invalid input or output file names
- Unsupported input file format
- Invalid mathematical expression
- Output variable already exists in input file
- Invalid scale or size specified
- Unsupported variable rank detected
- Invalid expression variable name

Examples

The following shows the correction of AVHRR channel 2 data for solar zenith angle. The output variable is named 'avhrr_ch2_corr' and is written to the input file:

```
phollema$ cwmath -v --units percent --longname "AVHRR channel 2 corrected"
  --expr "avhrr_ch2_corr = avhrr_ch2 / cos (toRadians (sun_zenith))"
  2019_250_2241_n19_mr.hdf

[INFO] Opening input/output 2019_250_2241_n19_mr.hdf
[INFO] Creating avhrr_ch2_corr variable
[INFO] Total grid size is 1101x1401
[INFO] Found 8 processor(s) to use
[INFO] Processing 9 data chunks of size 512x512
```

Another example below shows the computation of Normalized Difference Vegetation Index (NDVI):

```
phollema$ cwmath -v --longname "Normalized Difference Vegetation Index"
  --expr "ndvi = (avhrr_ch2 - avhrr_ch1)/(avhrr_ch2 + avhrr_ch1)"
  2019_015_2121_n19_er.hdf

[INFO] Opening input/output 2019_015_2121_n19_er.hdf
[INFO] Creating ndvi variable
[INFO] Total grid size is 1401x1302
[INFO] Found 8 processor(s) to use
[INFO] Processing 9 data chunks of size 512x512
```

To show how to mark certain data values in a variable as invalid, the example below masks the 'sst' variable using data from the 'cloud' variable:

```
phollema$ cwmath -v --template sst
  --expr 'sst_masked = ((cloud & 0x6f) == 0 ? sst : NaN)'
  2019_015_2121_n19_er.hdf

[INFO] Opening input/output 2019_015_2121_n19_er.hdf
[INFO] Creating sst_masked variable
[INFO] Total grid size is 1401x1302
[INFO] Found 8 processor(s) to use
[INFO] Processing 9 data chunks of size 512x512
```

We use a hexadecimal value to set which bits from the 8-bit cloud mask to use for masking. In this case the value '0x6f' tests the cloud mask bits 1, 2, 3, 4, 6, and 7 – to use all cloud mask bits, the value would be '0xff'. The output value 'NaN' is a special number that marks the SST as invalid where the cloud mask has detected cloud (ie: at least one of the cloud mask bits specified in the mask is set to 1). The conditional

operator is also used: (condition ? x : y) means 'if condition is true, the value of x, otherwise the value of y'.

A final example below shows how the tool may be used to compute complex formulas using a Unix Bourne shell script. The example computes the theoretical AVHRR channel 3b albedo at night for NOAA-17 using actual channel 3b temperatures and channel 3b emission temperatures estimated from channel 4 and 5:

```
#!/bin/sh

input=$1
T3E_A=6.82947
T3E_B=0.97232
T3E_C=1.66366
ZERO_C=273.15
t3="(avhrr_ch3 + $ZERO_C)"
t4="(avhrr_ch4 + $ZERO_C)"
t5="(avhrr_ch5 + $ZERO_C)"
t3e="($T3E_A + $T3E_B*$t4 + $T3E_C*($t4 - $t5))"
planck_c1=1.1910427e-5
planck_c2=1.4387752
w3=2669.3554
c3b_a=1.702380
c3b_b=0.997378
rad3="(($planck_c1*pow ($w3, 3)) / (pow (E, ($planck_c2*$w3)/($c3b_a + $c3b_b*$t3)) - 1.0))"
rad3e="(($planck_c1*pow ($w3, 3)) / (pow (E, ($planck_c2*$w3)/($c3b_a + $c3b_b*$t3e)) - 1.0))"
alb3="(100*(1 - $rad3/$rad3e))"
cwmath -v --longname "AVHRR channel 3 albedo" --units "percent" \
  --expr "avhrr_ch3_albedo=$alb3" $input
```

A.3.5 cwcomposite

Name

cwcomposite - combines a time series of earth data.

Synopsis

cwcomposite [OPTIONS] input [input2 ...] output
cwcomposite [OPTIONS] --inputs=FILE output

Options:

-c, --coherent=VARIABLE1[/VARIABLE2[...]]
-h, --help
-k, --keephistory
-m, --match=PATTERN
-M, --method=TYPE
-o, --optimal=VARIABLE/TYPE
-p, --pedantic
-S, --savemap
--serial
--threads=MAX
-t, --collapsetime
-v, --verbose
-V, --valid=COUNT
--version

Description

The composite tool combines a time series of earth data. Data variables are combined on a pixel-by-pixel basis using one of several statistical or temporal methods: mean, geometric mean, median, minimum, maximum, explicit or latest. The input files must have matching earth transforms but may have different dates. The composite tool may be used, for example, to combine a number of sea-surface-temperature datasets into one in order to obtain a mean SST for a certain region and help eliminate cloud. Another use is to combine datasets from different regions that are registered to the same earth transform to create a mosaic. The output dataset is constructed using metadata from each input dataset so that it properly reflects the different input dataset dates and other metadata.

Parameters

Main parameters:

input [input2 ...] The input data file names. At least one input file is required, unless the --**inputs** option is used. If multiple files are specified, they must have matching earth transforms.

--**inputs=FILE** The file name containing a list of input data files. The file must be an ASCII text file containing input file names, one per line. If multiple files are listed, they must have matching earth transforms. If the inputs file name is '-', input is read from standard input.

output The output data file name.

Options:

-**c,** --**coherent=VARIABLE1[/VARIABLE2[...]]** Turns on coherent mode (can only be used with --**method latest**, --**method explicit**, or --**method optimal**). In coherent mode, the output values for all variables at a given pixel location are guaranteed to originate from the same input file. The specified variable list is used to prioritize variables to check for a valid latest/last value. If there are no valid values for the first variable at a given location, then the next variable is checked and so on until the latest/last valid value is found. This mode is useful for when data variables and their respective quality flags should be kept together during a composite operation. Without this option, the 'latest' and 'explicit' composite methods may select the latest/last valid data value from one input file, and the latest/last valid quality flag from another input file for a given location.

-**h,** --**help** Prints a brief help message.

-**k,** --**keephistory** Turns keep history mode on. In keep history mode, the processing commands used to create each input file are combined together, along with the composite command. The combined history of all processing commands from all input files can be very large and in many cases overflows the maximum length for history metadata in the output file, so by default only the composite command is written to the output file history.

-**m,** --**match=PATTERN** The variable name matching pattern. If specified, the pattern is used as a regular expression to match variable names. Only variables matching the pattern will be present in the output. By default, no pattern matching is performed and all variables are combined.

-**M,** --**method=TYPE** The composite method. Valid methods are:

- mean - Computes the arithmetic mean or average value (sum of values over n)
- geomean - Computes the geometric mean (nth root of product of values)
- median - Finds the median value (middle value of n values)
- min - Finds the minimum value
- max - Finds the maximum value
- latest - Finds the most recent valid value (latest in time according to the data time stamp)
- explicit - Finds the last valid value in the set of input files, according to the explicit order given on the command line. This would yield the same results as the 'latest' method if the files were listed in chronological order on the command line.

- optimal - Finds the best pixel from the set of input files based on the minimum or maximum of an optimization variable. See the --**optimal** option for more details. This method turns on coherent mode as specified by the --**coherent** option.

The default is to compute the mean value.

-**o, --optimal=VARIABLE/TYPE** The optimization variable and type to use for optimal compositing (see --**method optimal** above). The valid types are 'min', 'minabs', 'max', and 'maxabs'. Optimal compositing is done by searching for the input file whose data value is either minimum (min), maximum (max), minimum absolute value (minabs), or maximum absolute value (maxabs). The output values for all variables at a given pixel location are then guaranteed to originate from this same input file. By default, the input files are searched for a satellite zenith angle variable and optimized by selecting the minimum absolute satellite zenith angle value, which corresponds to the minimum atmospheric path length and maximum sensor resolution.

-**p, --pedantic** Turns pedantic mode on. In pedantic mode, metadata from each input file is combined exactly such that composite attributes in the output file may contain repeated values. When pedantic mode is off, composite attributes are collapsed so that only unique values appear. By default, pedantic mode is off.

-**S, --savemap** Saves the source index mapping to the output file in coherent mode. The variable 'source_index' is written as a 16-bit signed integer, and for each destination pixel in the output, represents the 0-based index of the input file used to copy variable values into the output file. An attribute is written to the mapping variable specifying, in index order, the names of the input files used. See the --**coherent** option above for details on coherent mode.

--**serial** Turns on serial processing mode. By default the program will use multiple processors in parallel to process chunks of data.

--**threads=MAX** Specifies the maximum number of threads for parallel processing. By default the program will automatically detect the maximum number of threads possible.

-**t, --collapsetime** Specifies that the time metadata in the output file should be simplified and collapsed into a single period with start date/time, and end date/time. By default the output file contains the full time period metadata with the time periods from all of the input files preserved.

-**v, --verbose** Turns verbose mode on. The current status of data combination is printed periodically. The default is to run quietly.

-**V, --valid=COUNT** The minimum number of valid values required to form an aggregate function. By default, only one value per pixel is required. If the actual number of valid values is below this threshold, the output value is set to invalid.

--**version** Prints the software version.

Exit status

0 on success, $>$ 0 on failure. Possible causes of errors:

- Invalid command line option

- Invalid input or output file names
- Unsupported input file format
- Input file earth transforms do not match
- No matching variables found
- Unsupported composite method

Examples

The following shows the combination of 24 hours of Himawari-8 NetCDF SST data files into one median composite file, using a maximum heap size of 8 Gb and at least 5 valid pixels per median calculation:

```
phollema$ cwcomposite -J-Xmx8g -v --method median --valid=5
  --match sea_surface_temperature 2019*.nc composite.hdf
[INFO] Checking input file information
[INFO] Checking input file [1/24] 20190410000000-AHI_H08.nc
[INFO] Adding sea_surface_temperature to composite output variables
[INFO] Checking input file [2/24] 20190410010000-AHI_H08.nc
[INFO] Checking input file [3/24] 20190410020000-AHI_H08.nc
[INFO] Checking input file [4/24] 20190410030000-AHI_H08.nc
[INFO] Checking input file [5/24] 20190410040000-AHI_H08.nc
[INFO] Checking input file [6/24] 20190410050000-AHI_H08.nc
[INFO] Checking input file [7/24] 20190410060000-AHI_H08.nc
[INFO] Checking input file [8/24] 20190410070000-AHI_H08.nc
[INFO] Checking input file [9/24] 20190410080000-AHI_H08.nc
[INFO] Checking input file [10/24] 20190410090000-AHI_H08.nc
[INFO] Checking input file [11/24] 20190410100000-AHI_H08.nc
[INFO] Checking input file [12/24] 20190410110000-AHI_H08.nc
[INFO] Checking input file [13/24] 20190410120000-AHI_H08.nc
[INFO] Checking input file [14/24] 20190410130000-AHI_H08.nc
[INFO] Checking input file [15/24] 20190410140000-AHI_H08.nc
[INFO] Checking input file [16/24] 20190410150000-AHI_H08.nc
[INFO] Checking input file [17/24] 20190410160000-AHI_H08.nc
[INFO] Checking input file [18/24] 20190410170000-AHI_H08.nc
[INFO] Checking input file [19/24] 20190410180000-AHI_H08.nc
[INFO] Checking input file [20/24] 20190410190000-AHI_H08.nc
[INFO] Checking input file [21/24] 20190410200000-AHI_H08.nc
[INFO] Checking input file [22/24] 20190410210000-AHI_H08.nc
[INFO] Checking input file [23/24] 20190410220000-AHI_H08.nc
[INFO] Checking input file [24/24] 20190410230000-AHI_H08.nc
[INFO] Creating output file composite.hdf
[INFO] Total grid size is 5500x5500
[INFO] Found 8 processor(s) to use
[INFO] Creating sea_surface_temperature variable with chunk size 1834x1834
```

A.3.6 cwscript

Name

cwscript - runs a shell script written in BeanShell.

Synopsis

cwscript [OPTIONS] input [ARGUMENTS]

Options:

-h, --help
-c, --console
--version

Description

The script tool runs a shell script written in the BeanShell language, which is a simplified variant of Java. All of the CoastWatch API is available to the code using import statments. The arguments passed on the command line of the tool are available in the shell script by accessing the `String[] args` array starting with `args[0]` as the first argument.

Parameters

Main parameters:

input The input shell script file.

Options:

-h, --help Prints a brief help message.

-c, --console Shows an interactive console for running scripts, ignoring any script input.

--version Prints the software version.

Exit status

0 on success, $>$ 0 on failure. Possible causes of errors:

- Invalid command line option
- Invalid input file name
- Error encountered running the shell script

Examples

The following script prints the start time of a data file:

```
import noaa.coastwatch.io.EarthDataReaderFactory;

reader = EarthDataReaderFactory.create (args[0]);
print (reader.getInfo().getStartDate());
```

A sample run on a CoastWatch HDF file:

```
phollema$ cwscript start_time.bsh 2018_217_0309_n18_wj.hdf
Sat Aug 04 20:09:27 PDT 2018
```

Another example script prints out the latitude and longitude values along the satellite subpoint of a data file:

```
import noaa.coastwatch.io.EarthDataReaderFactory;
import noaa.coastwatch.util.DataLocation;

input = args[0];
reader = EarthDataReaderFactory.create (input);
lat = reader.getVariable ("latitude");
lon = reader.getVariable ("longitude");
dims = lat.getDimensions();

rows = dims[0];
cols = dims[1];
print (rows);
print (cols);

for (int i = 0; i < rows; i++) {
  loc = new DataLocation (i, cols/2);
  print (lat.getValue (loc) + " " + lon.getValue (loc));
} // for
```

The output from running on a NOAA 1b format Metop-2 FRAC file:

```
phollema$ cwscript sat_subpoint.bsh NSS.FRAC.M2.D10206.S1053.E1235.B1953132.SV
4733
2048
66.71659851074219 -1.3313000202178955
66.7074966430664 -1.341499924659729
66.69829559326172 -1.351599931716919
66.68930053710938 -1.3616999387741089
```

```
66.68009948730469 -1.3717999458312988
66.6709976196289 -1.3819999694824219
66.66189575195312 -1.3919999599456787
...
```

The example script below shows how to use the new *noaa.coastwatch.util.chunk* API to retrieve chunks of data from a data variable in any file:

```
import noaa.coastwatch.io.EarthDataReader;
import noaa.coastwatch.io.EarthDataReaderFactory;
import noaa.coastwatch.util.chunk.DataChunk;
import noaa.coastwatch.util.chunk.ChunkPosition;
import noaa.coastwatch.util.chunk.GridChunkProducer;

reader = EarthDataReaderFactory.create (args[0]);
lat = reader.getVariable ("latitude");
producer = new GridChunkProducer (lat);
pos = new ChunkPosition (2);
pos.start[0] = 0;
pos.start[1] = 0;
pos.length[0] = pos.length[1] = 16;
chunk = producer.getChunk (pos);

print (chunk);
```

Running this script on a CoastWatch HDF format VIIRS granule produces:

```
phollema$ cwscript chunk_type.bsh VXSRCW.B2018205.180733.hdf
noaa.coastwatch.util.chunk.FloatChunk@edf4efb
```

Graphics windows can also be created from a script, using the **cwgscript** launcher which properly sets up a graphics environment. The following script run with **cwgscript** displays a view of a variable in an input file:

```
import java.awt.Color;
import javax.swing.JFrame;

import noaa.coastwatch.gui.EarthDataViewFactory;
import noaa.coastwatch.gui.EarthDataViewPanel;
import noaa.coastwatch.gui.GUIServices;
import noaa.coastwatch.gui.WindowMonitor;
import noaa.coastwatch.io.EarthDataReader;
import noaa.coastwatch.io.EarthDataReaderFactory;
import noaa.coastwatch.render.CoastOverlay;
import noaa.coastwatch.render.LatLonOverlay;
```

```
file = args[0];
var = args[1];

// Set up the view
reader = EarthDataReaderFactory.create (file);
view = EarthDataViewFactory.getInstance().create (reader, var);
view.addOverlay (new CoastOverlay (Color.WHITE));
view.addOverlay (new LatLonOverlay (Color.WHITE));
view.resizeHeight (600);

// Create a panel
panel = new EarthDataViewPanel (view);
panel.setPreferredSize (view.getSize (null));

// Create a graphics frame to show
frame = new JFrame (file);
frame.setContentPane (panel);
frame.addWindowListener (new WindowMonitor());
frame.pack();

// Show the frame onscreen
GUIServices.showFrame (frame);
```

A sample call on a NetCDF file to display SST data is as follows:

```
phollema$ cwgscript view.bsh ncdcOisst2Agg_7a1d_a943_b8c6.nc sst
```

A.3.7 cwtccorrect

Name

cwtccorrect - corrects top-of-atmosphere true color reflectance data.

Synopsis

cwtccorrect [OPTIONS] input [output]

General options:

-h, --help
-b, --bands=RED/GREEN/BLUE
-e, --esun=RED/GREEN/BLUE
-n, --nameext=TEXT
-p, --props=FILE
-s, --sensor=NAME
--threads=MAX
-v, --verbose
--version

Angle options:

-l, --latitude=VARIABLE
-L, --longitude=VARIABLE
-u, --sunzen=VARIABLE
-U, --sunazi=VARIABLE
-a, --satzen=VARIABLE
-A, --satazi=VARIABLE
-r, --relazi=VARIABLE

Description

The true color correction tool corrects top-of-atmosphere true color reflectance data. The correction accounts for molecular (Rayleigh) scattering and gaseous absorption (water vapor, ozone) but performs no aerosol correction (dust, ash, smoke, sulfate). No real-time input or ancillary data is required. The algorithm used was originally written by Jacques Descloitres for use with the MODIS Rapid Response Project, NASA/GSFC/SSAI.

The input file can be in either level 2 or level 3 projection, and must at a minimum contain:

- Red, green, and blue color band data. By default these are found by looking for common variable names for a given sensor used in CoastWatch product files, or can be specified directly using the

--**bands** option. Band data can either be in radiance units or reflectance units. If in radiance units, the data is first normalized to reflectance using a known solar irradiance value for the sensor band and solar zenith angle data.

- Latitude and longitude geolocation data, and zenith and azimuth angles for both sun and satellite. By default the correct variables containing the angle data are detected from a combination of the variable names and the long name (if any) specified in the metadata. Note that if relative azimuth angle data is found, it will be used instead of the individual solar and satellite azimuth angles.

The result of the operation is to write a new set of band reflectance variables into the input file, or into a new output file, by appending '_refl' to the band variable names. The corrected surface reflectance is an approximation only, but is well suited for providing near real time true color imagery.

Parameters

Main parameters:

input The input data file name.

output The output data file name. If specified and the file does not already exist, it will be created using metadata from the input file. If it does exist, it will be opened and checked for a compatible earth transform and the new corrected reflectance data will be added to the file. The new variables must not already exist in the output file.

General options:

-h, --help Prints a brief help message.

-b, --bands=RED/GREEN/BLUE The names of the band variables to use for each of red, green, and blue wavelengths. By default when the sensor is known, the band names are automatically determined. Use this option to overrride the default band names, or in case the sensor is unknown.

-e, --esun=RED/GREEN/BLUE Specifies the values of the solar irradiance (the esun constant) for each of the red, green, and blue wavelengths in mW/cm2/um. This is only needed when the data is in radiance units rather than reflectance units. By default when the sensor is known, the solar irradiance values are automatically determined. Use this option to overrride the default solar irradiance values, or in case the sensor is unknown.

-n, --nameext=TEXT The text to use to extend the band variable names when creating the new corrected reflectance variables. By default '_refl' is used to extend the band variable names.

-p, --props=FILE The path for a custom properties file giving the names of supported sensors and their bands and solar irradiance values. By default the `true_color.properties` file in the installation directory `data/noaa/coastwatch/tools` is used. The format of the properties file is a set of key/value pairs. For example to add the new *Zork Visible Spectrum Imager* aboard the satellite *Frobozz-5* to the list of allowed sensors, you can create a new properties file as follows:

```
sensors = fbz5_zvsi
```

```
fbz5_zvsi.keywords = frobozz-5 fbz-5 zvsi
fbz5_zvsi.red.band = Band_3
fbz5_zvsi.green.band = Band_2
fbz5_zvsi.blue.band = Band_1
fbz5_zvsi.red.esun = 150.072
fbz5_zvsi.green.esun = 181.820
fbz5_zvsi.blue.esun = 195.128
```

Then supply the new properties file path to the --**props** option. This helps to reduce the command line parameters needed to correct data for an unsupported sensor. Alternatively, you can also add the content above to the default `true_color.properties` file and the new sensor will be automatically detecting using the keywords.

-s, --sensor=NAME The name of the sensor to use. This is normally determined automatically from the metadata, but if the automatic test fails, use this option. The currently supported sensors are 'n20_viirs', 'npp_viirs', 's2a_msi', 's2b_msi', 's3a_olci', and 's3b_olci'. The sensor name is used to determine the solar irradiance values and the band names for known sensors, and is not needed if both the --**bands** and --**esun** options are set.

--threads=MAX Specifies the maximum number of threads for parallel processing. By default the program will automatically detect the maximum number of threads possible. To process data in serial, use a max value of 1.

-v, --verbose Turns verbose mode on. The current status of data conversion is printed periodically. The default is to run quietly.

--version Prints the software version.

Angle options:

-l, --latitude=VARIABLE The latitude angle variable name, by default determined from metadata.

-L, --longitude=VARIABLE The longitude angle variable name, by default determined from metadata.

-u, --sunzen=VARIABLE The solar zenith angle variable name, by default determined from metadata.

-U, --sunazi=VARIABLE The solar azimuth angle variable name, by default determined from metadata.

-a, --satzen=VARIABLE The satellite zenith angle variable name, by default determined from metadata.

-A, --satazi=VARIABLE The satellite azimuth angle variable name, by default determined from metadata.

-r, --relazi=VARIABLE The relative azimuth angle variable name, by default determined from metadata. Note that relative azimuth is only needed if either the satellite azimuth or solar azimuth are not available.

Exit status

0 on success, $>$ 0 on failure. Possible causes of errors:

- Invalid command line option
- Invalid input or output file names
- Unsupported input file format
- Input / output file dates or earth transforms do not match
- Sensor not supported
- Angle data could not be automatically detected

Examples

The following shows the true color correction of level 2 NOAA-20 VIIRS data with verbose mode on:

```
phollema$ cwtccorrect -v VRSLCW.C2023001.102322.hdf
  VRSLCW.C2023001.102322.corr.hdf
[INFO] Opening input VRSLCW.C2023001.102322.hdf
[INFO] Creating output VRSLCW.C2023001.102322.corr.hdf
[INFO] Found supported sensors: [n20_viirs, npp_viirs, s2a_msi, s2b_msi, s3a_olci, s3b_olci]
[INFO] Detected sensor 'n20_viirs'
[INFO] Computing reflectance for red band 'EV_BandM5'
[INFO] Using Earth-Sun distance factor 1.0169916, solar irradiance 151.096 mW/cm^2/um
[INFO] Using variable 'sun_zenith' in reflectance computation
[INFO] Total grid size is 768x3200
[INFO] Using 12 parallel threads for processing
[INFO] Processing 27 data chunks of size 362x362
[INFO] Computing reflectance for green band 'EV_BandM4'
[INFO] Using Earth-Sun distance factor 1.0169916, solar irradiance 182.753 mW/cm^2/um
[INFO] Total grid size is 768x3200
[INFO] Using 12 parallel threads for processing
[INFO] Processing 27 data chunks of size 362x362
[INFO] Computing reflectance for blue band 'EV_BandM3'
[INFO] Using Earth-Sun distance factor 1.0169916, solar irradiance 197.808 mW/cm^2/um
[INFO] Total grid size is 768x3200
[INFO] Using 12 parallel threads for processing
[INFO] Processing 27 data chunks of size 362x362
[INFO] Using variable 'latitude' for latitude angle data
[INFO] Using variable 'longitude' for longitude angle data
[INFO] Using variable 'sun_zenith' for solar zenith angle data
[INFO] Using variable 'sun_azimuth' for solar azimuth angle data
[INFO] Using variable 'sat_zenith' for satellite zenith angle data
[INFO] Using variable 'sat_azimuth' for satellite azimuth angle data
[INFO] Computing atmospheric correction for true color bands
```

```
[INFO] Total grid size is 768x3200
[INFO] Using 12 parallel threads for processing
[INFO] Processing 27 data chunks of size 362x362

phollema$ cwinfo VRSLCW.C2023001.102322.corr.hdf
Contents of VRSLCW.C2023001.102322.corr.hdf

Global information:
  Satellite:           NOAA-20
  Sensor:              VIIRS
  Date:                2023/01/01 JD 001
  Start time:          10:23:22 UTC
  End time:            10:24:46 UTC
  Projection type:     swath
  Transform ident:     noaa.coastwatch.util.trans.SwathProjection
  Origin:              NOAA/NESDIS/STAR/SOCD
  Format:              CoastWatch HDF version 3.4
  Reader ident:        noaa.coastwatch.io.CWHDFReader

Variable information:
  Variable         Type    Dimensions   Units     Scale   Offset
  latitude         float   768x3200     degrees   -       -
  longitude        float   768x3200     degrees   -       -
  EV_BandM5_refl   float   768x3200     1         -       -
  EV_BandM4_refl   float   768x3200     1         -       -
  EV_BandM3_refl   float   768x3200     1         -       -
```

A.4 Graphics and Visualization

A.4.1 cwanimate

Name

cwanimate - creates earth data animations.

Synopsis

cwanimate [OPTIONS] input [input2 ...] [output]

Options:

-a, --axis NAME/INDEX | NAME/START/END[/STEP]
-c, --colormap PALETTE/MIN/MAX[/FUNCTION]
-C, --credit TEXT
-h, --help
-H, --height PIXELS
-l, --list-vars
-L, --logo NAME | FILE
-q, --query-var VARIABLE
-r, --rate FPS
-t, --title TEXT
-u, --units UNITS
-V, --variable VARIABLE
-v, --verbose
--version
-W, --width PIXELS
-z, --zoom LATITUDE/LONGITUDE[/SCALE]

Description

The animate tool creates a movie out of multiple frames of earth data. You can specify either a single file or URL to a THREDDS / DODS / ERDDAP server or multiple files on the local file system as input. The data is scaled using a color map and output with standard annotations to an output MP4 file. The defaut is to search for a time axis in the input for animation, but other axes can also be used. Before animating, you can query the input for variables and axes:

```
$ cwanimate --list-vars input.nc4
$ cwanimate --query-var sst input.nc4
```

The output MP4 file contains metadata including the software version used and the command line parameters,

so that you can create new animations based on existing ones. Use the exiftool on Linux or Mac to query the output file metadata.

Parameters

Main parameters:

input [input2 ...] Either (i) a single input dataset specified as a local file name or URL containing a set of 2D data grids with additional time, level, or some other axis, or (ii) a list of input datasets each containing a single timestep of 2D data grids.

[output] The output movie file name.

Options:

-a, --axis NAME/INDEX | NAME/START/END[/STEP] The axis name and index/range for animation. Only one axis can be specified with a range and optional step value to animate, and all other axes with a single index value. If an axis name is not specfied, the zero index is assumed for that axis.

-c, --colormap PALETTE/MIN/MAX[/FUNCTION] The color map assignment for the data, consisting of the palette name (see cwrender), minimum data value, maximum data value, and optionally a function type: 'linear' (default), 'log', 'stepN', or 'gamma'.

-C, --credit TEXT The data credit text, default is the origin/institution metadata value.

-h, --help Prints a brief help message.

-H, --height PIXELS The height of the output in pixels, default is 720.

-l, --list-vars Lists the variables in the input data that are available to animate.

-L, --logo NAME | FILE The logo on the plot, default is the NOAA logo. The logo can either be a name like in cwrender, or a custom PNG, GIF, or JPEG file.

-q, --query-var VARIABLE Performs a query of the specified variable in the input data and prints out the axis information.

-r, --rate FPS The frame rate of the output in frames per second, default is 15.

-t, --title TEXT The title text, default is the variable long name metadata value.

-u, --units UNITS The units for the color map, default is to read from the input file.

-V, --variable VARIABLE The variable data to animate.

-v, --verbose Turns verbose mode on. The current status of creating the data animation is printed periodically. The default is to run quietly.

--version Prints the software version.

-W, --width PIXELS The width of the output in pixels, default is 1280.

-z, --zoom LATITUDE/LONGITUDE[/SCALE] Zooms and recenters the view on a new latitude and longitude point. The optional zoom scale is either a screen:data pixel factor (eg: 0.5, 1, 2), a screen pixel size in kilometres (eg: '5km'), or a GIS map zoom level (eg: 'L5'). The default zoom scale is 1:1 screen:data pixels.

Exit status

0 on success, $>$ 0 on failure. Possible causes of errors:

- Invalid command line option
- Invalid input or output file names
- Unsupported input file format
- Input file earth transforms do not match
- Variable name not found
- No variable specified to animate
- Axis name not found

Examples

- Create a chlorophyll-a animation centered on the Gulf of Mexico from a time series of NetCDF files:

```
$ cwanimate -v --zoom 24.7/-87.7/L5 --variable chlor_a
--colormap NCCOS-chla/0.01/64/log dineof/*.nc output_dineof_chlor_a_gom.mp4
```

- Similar to above, but for monthly Hawaii data over a three year period and from a THREDDS server:

```
$ cwanimate -v --zoom 20.6/-156.9/L7 --axis time/0/36 --variable chlor_a
--colormap Turbo/0.01/1/log
https://oceanwatch.pifsc.noaa.gov/thredds/dodsC/noaa_snpp_chla/monthly
output_chlor_a_hawaii.mp4
```

- Create a sea surface temperature animation centered on the Gulf of Mexico from a NetCDF 4 file containing multiple time steps downloaded from a THREDDS server using the NetCDF Subset Service:

```
$ cwanimate -v --title "SST Analysis Gulf of Mexico" --zoom 24.7/-87.7/L6
--variable sst_analysis_night_only --colormap Turbo/8/35
CW_BLENDED_NIGHT_SST_cwblendednightsst.nc4 output_sst_gom.mp4
```

A.4.2 cdat

Name

cdat - performs interactive earth data analysis.

Synopsis

cdat [OPTIONS] [input]

Options:

-h, --help
-g, --geometry=WxH
--version

Description

The CoastWatch Data Analysis Tool (CDAT) allows users to view, survey, and save earth datasets. Detailed help on the usage of CDAT is available from within the utility using the menu bar under *Help* | *Help and Support*.

Parameters

Main parameters:

input The optional input data file name. If specified, the data file is opened immediately after CDAT starts.

Options:

-h, --help Prints a brief help message.

-g, --geometry=WxH The window geometry width and height in pixels. The default is 960x720.

--version Prints the software version.

Exit status

0 on success, $>$ 0 on failure. Possible causes of errors:

- Invalid command line option
- Invalid input file name

Examples

The following shows the use of CDAT to view data from a CoastWatch HDF file:

```
phollema$ cdat 2002_319_2144_n16_wl_c2.hdf
```

A.4.3 cwrender

Name

cwrender - performs earth data visualization.

Synopsis

cwrender [OPTIONS] input output

Rendering type options:

-c, --composite=RED/GREEN/BLUE
-e, --enhance=VARIABLE1[/VARIABLE2]

General options:

-h, --help
-v, --verbose
--version
--split=EXPRESSION

Output content and format options:

-a, --noantialias
-D, --date=STARTDATE[/ENDDATE]
--font=FAMILY[/STYLE[/SIZE]]
--fontlist
-f, --format=TYPE
--hybridmask=EXPRESSION
-i, --indexed
-I, --imagecolors=NUMBER
-l, --nolegends
--noinfo
-m, --magnify=LATITUDE/LONGITUDE/FACTOR
-o, --logo=NAME
--logolist
-s, --size=PIXELS | full | WIDTH/HEIGHT
-T, --tiffcomp=TYPE
-W, --worldfile=FILE

Plot overlay options:

-A, --bath=COLOR[/LEVEL1/LEVEL2/...]
-b, --bitmask=VARIABLE/MASK/COLOR
-C, --coast=COLOR[/FILL]
-d, --cloud=COLOR
-g, --grid=COLOR
-H, --shape=FILE/COLOR[/FILL]
-L, --land=COLOR
-p, --political=COLOR
-S, --nostates
-t, --topo=COLOR[/LEVEL1/LEVEL2/...]
-u, --group=GROUP
-w, --water=COLOR
-X, --exprmask=EXPRESSION/COLOR
--watermark=TEXT[/COLOR[/SIZE[/ANGLE]]]
--watermarkshadow

Color enhancement options:

-E, --enhancevector=STYLE/SYMBOL[/SIZE]
-F, --function=TYPE
-k, --background=COLOR
-M, --missing=COLOR
-P, --palette=NAME
--palettefile=FILE
--palettecolors=COLOR1[/COLOR2[/COLOR3...]]
--palettelist
--paletteimage=FILE
-r, --range=MIN/MAX
--scalewidth=PIXELS
--ticklabels=LABEL1[/LABEL2[/LABEL3/...]]
-U, --units=UNITS
--varname=TEXT

Color composite options:

-B, --bluerange=MIN/MAX
-G, --greenrange=MIN/MAX
-R, --redrange=MIN/MAX
-x, --redfunction=TYPE
-y, --greenfunction=TYPE
-z, --bluefunction=TYPE
--compositehint=HINT

Description

Overview

The render tool performs earth data visualization by converting 2D datasets in the input file to color images. The data values are converted from scientific units to a color using either an enhancement function and color palette or by performing a color composite of three data variables – one for each of the red, green, and blue color components. The resulting earth data plot may have legends displaying the color scale, data origin, date, time, and projection information as well as data overlays showing latitude/longitude grid lines, coast lines, political boundaries, masks, and shapes.

As of version 3.7.1, a hybrid rendering mode is possible that combines both color composite and color enhancement. The color enhancement is rendered on top of the color composite and by default any missing data pixels in the enhancement are transparent and allow the composite pixels to show through. See the --**enhance**, --**composite**, and --**hybridmask** options below for more details.

Overlay colors

Overlay colors may be specified using simple color names such as 'red', 'gray', 'cyan', 'blue', and 'green'. Overlays may be made to appear slightly transparent (allowing the color behind to show through) by following the color name with a colon ':' and a transparency value in percent, for example 'red:50' would make the overlay red with a 50% transparency. Transparency values range from 0 (completely opaque) to 100 (completely transparent).

Colors may also be specified using explicit hexadecimal notation for red/green/blue color components and optional alpha component as follows:

```
0xAARRGGBB
  ^ ^ ^ ^
  | | | ----- Blue              \
  | | ------- Green             |---- Range: 00 -> ff
  | --------- Red               |
  ----------- Alpha (optional)  /
```

Note that the prepended '0x' denotes a hexadecimal constant, and must be used even though it is not part of the color component values. As an example, the simple color names above may be specified as hexadecimal values:

```
0xff0000    red
0x555555    gray
0x00ffff    cyan
0x0000ff    blue
0x00ff00    green
0x80ff0000  red, 50% transparent
```

Rendering order

The data view itself (not including the legends) is rendered in such a way that overlays may overlap each other. For example, latitude/longitude grid lines may fall on top of land polygons because the grid overlay is rendered after the coastline overlay. Knowing the order in which the data and overlays are rendered may answer some questions if the data view doesn't look the way the user expects. The data view is rendered in the following order:

1. Before any overlay or data, the data view is filled with a background color (normally white) for vector plots or a missing color (normally black) for color enhancement or color composite plots.
2. Color vectors or image pixels are rendered to the data view. The background or missing color will show though where no vectors or pixels were rendered.
3. Data overlays are rendered to the view in the following order (see the description of each option below):
    - Cloud mask (--**cloud**)
    - Bit masks (--**bitmask**), possibly more than one
    - Expression masks (--**exprmask**), possibly more than one
    - Water mask (--**water**)
    - Bathymetric contours (--**bath**)
    - Land mask (--**land**)
    - Coastline and filled land polygons (--**coast**)
    - Political lines (--**political**)
    - Topography contours (--**topo**)
    - Shape files (--**shape**), possibly more than one
    - Latitude/longitude grid lines (--**grid**)
    - Overlay groups (--**group**)
    - Markers (--**marker**)

Parameters

Main parameters:

input The input data file name.

output The output image file name. Unless the --**format** option is used, the file extension indicates the desired output format: '.png', '.jpg', '.tif', or '.pdf'.

Rendering type options:

-c, --composite=RED/GREEN/BLUE Specifies color composite mode using the named variables. The data variable values are converted to colors using an individual enhancement function for each variable. The data values are scaled to the range [0..255] and used as the red, green, and blue components of each pixel's color. Either this option or --**enhance** must be specified, or both options for hybrid mode rendering (see the --**hybridmask** option below).

-e, --enhance=VARIABLE1[/VARIABLE2] Specifies color enhancement mode using the named variable(s). The data variable values are converted to colors using an enhancement function and color palette. Either this option or --**composite** must be specified, or both options for hybrid mode rendering (see the --**hybridmask** option below). If one variable name is specified, the plot shows color-enhanced image data. If two variable names are specified, the plot shows color-enhanced vectors whose direction is derived using the two variables as vector components. See the --**enhancevector** and --**background** options for settings that are specific to vector plots.

General options:

-h, --help Prints a brief help message.

-v, --verbose Turns verbose mode on. The current status of data rendering is printed periodically. The default is to run quietly.

--**version** Prints the software version.

--**split=EXPRESSION** The command line parameter splitting expression. By default, parameters on the command line are specified using a slash '/' character between multiple arguments, for example --**coast white/brown**. But in some cases, for example when a variable name includes a slash, another character should be used to parse the command line parameters. A common alternative to the slash is a comma ',' character, for example --**coast white,brown**.

Output content and format options:

-a, --noantialias Turns off line and font antialiasing. By default, the edges of lines and fonts are smoothed using shades of the drawing color. It may be necessary to turn off antialiasing if the smoothing is interfering with the readability of annotation graphics, such as in the case of very small fonts. This option only effects raster image output formats such as PNG, GIF and JPEG.

-D, --date=STARTDATE[/ENDDATE] Specifies that the plot legend should be rendered with the given date(s). By default the date is automatically detected from the input file metadata. In some cases the metadata is incorrect or the date and time information is not available. In these cases, the data start and end date can be manually specified by this option, in ISO date/time format 'yyyy-mm-ddThh:mm:ssZ'. For example, Dec 19, 2013 at 11 pm UTC would be specified as '2013-12-19T23:00:00Z'. If the data has no known end date, the end date value may be omitted.

--**font=FAMILY[/STYLE[/SIZE]]** The legend and overlay text font with optional style and size. The default is 'Dialog/plain/9'. The font family names available differ based on the fonts installed on a given system. The family names 'Dialog', 'DialogInput', 'Monospaced', 'Serif', and 'SansSerif' are always available and map to certain system fonts at runtime. For a full listing of fonts families available on the system, use the --**fontlist** option. Valid styles are 'plain', 'bold', 'italic', and 'bold-italic'. For example to use an Arial font available on some systems, bold style, of 12 point size, specify 'Arial/bold/12'. To use a sans serif font with default style and size, specify 'SansSerif'.

--**fontlist** Lists the font family names available on the system.

-f, --format=TYPE The output format. The current formats are 'png' for Portable Network Graphics, 'gif' for Graphics Interchange Format, 'jpg' for Joint Picture Experts Group, 'tif' for Tagged Image File

Format with geolocation tags (GeoTIFF), 'pdf' for Portable Document Format, or 'auto' to detect the format from the output file name. The default is 'auto'. The correct choice of output format is governed by the desired use of the rendered image as follows:

- **PNG** is a non-lossy compressed image format supported by most web browsers and image manipulation software. It has similar data compression characteristics to GIF and additionally supports 24-bit color images.
- **GIF** is a non-lossy compressed format also supported by most web browsers and image manipulation software. The GIF files produced use LZW compression. Images stored in GIF format are run through a color quantization algorithm to reduce the color map to 256 colors or less. Although file sizes are generally smaller than PNG, image quality may be compromised by the reduced color map.
- **JPEG** is a lossy compressed format that should be used with caution for images with sharp color lines such as those found in text and annotation graphics. The JPEG format generally achieves higher compression than PNG or GIF resulting in smaller image file sizes.
- **GeoTIFF** is a flexible image format with support for earth location metadata. Many popular GIS packages handle GeoTIFF images and allow the user to combine a GeoTIFF base map image with other sources of raster and vector data. The GeoTIFF images generated are non-lossy image data compressed with the deflate algorithm (unless no compression or a different compression scheme is specified using --**tiffcomp**), and can be larger than the corresponding PNG, GIF, or JPEG. Since GeoTIFF images are generally destined for import into a GIS system, the use of this format turns on the --**nolegends** option. In general the GeoTIFFs generated are 24-bit colour images, but when no overlays are specified or the --**indexed** or --**imagecolors** options are used, a special 8-bit paletted image file is generated and comments describing the data value scaling are inserting into the image description tags (unless JPEG compression is used).
- **PDF** is a standard for high quality publishing developed by Adobe Systems and is used for output to a printer via such tools as the Adobe Acrobat Reader. In general PDF files are slightly larger than the equivalent PNG but retain highly accurate vector graphics components such as lines and fonts.

--**hybridmask=EXPRESSION** Specifies the mask expression used to determine the transparent pixels in the color enhancement layer during hybrid mode rendering. The mask expression is a boolean expression that evaluates to true where the color enhancement pixels should be transparent, and false where they should be opaque. By default the color enhancement pixels are tested for missing values, and the missing data pixels are set to transparent. The syntax for the expression is identical to the right-hand-side of a **cwmath** Java expression (see the **cwmath** tool manual page).

-**i,** --**indexed** Short for --**imagecolors 256**. See the --**imagecolors** option below.

-**I,** --**imagecolors=NUMBER** The number of colors to use for the index color model of the data image, up to 256. Normally the data image uses an unlimited number of colors because this achieves the best visual rendering quality. But in some cases it may be desirable to make the output file smaller by limiting the number of colors to <=256 values and using a index color model so that each data pixel can be represented as 8-bit bytes. This option can only be used with PNG, GIF, GeoTIFF, and PDF output formats, and only with color enhancements, not color composites. While in index color mode, antialiasing is turned off.

-**l,** --**nolegends** Turns the plot legends off. By default, the Earth data view is shown in a frame on the left and to the right color scale and plot information legends are drawn. With no legends, the Earth data is simply rendered by itself with no frame, borders, or legends.

--**noinfo** Turns the plot information legend off. By default, the plot information legend is drawn to the right of the color scale. With no plot information legend, only the color scale is drawn if applicable. See the --**nolegends** option above which removes all legends.

-**m,** --**magnify=LATITUDE/LONGITUDE/FACTOR** The magnification center and factor. The data view is set to the specified center and pixel magnification factor. The center position is specified in terms of Earth location latitude and longitude in the range [-90..90] and [-180..180] and the magnification factor (greater than zero) is a decimal value, the image to data pixel ratio. A factor of 1 shows data at its native resolution, where as factors > 1 zoom in and factors < 1 zoom out. By default, the data view shows the entire data field with an optimal magnification factor to fit the desired view size (see --**size**).

-**o,** --**logo=NAME** The logo used for plot legends. The list of predefined logo names can be listed using the --**logolist** option. The user can also specify a custom logo file name, which can be any PNG, GIF, or JPEG file. The default is the official NOAA logo.

--**logolist** Lists the logo names available on the system.

-**s,** --**size=PIXELS** | **full** | **WIDTH/HEIGHT** The Earth data view size in pixels. The data view is normally accompanied by a set of legends unless the --**nolegends** option is used. By default, the view size is 512 pixels, plus the size of any legends. If 'full' is specified rather than a size in pixels, the view size is set to match the actual full extent of the data, ie: full resolution. If the --**magnify** option is used, the size of the magnified region may optionally be specified by width and height, otherwise the region is a square.

-**T,** --**tiffcomp=TYPE** The TIFF compression algorithm. The valid types are 'none' for no compression, 'deflate' or 'lzw' for ZIP style compression, 'pack' for RLE style PackBits compression, and 'jpeg' for JPEG compression (JPEG is experimental/beta). By default, deflate compression is used. This option is only used with GeoTIFF output.

-**W,** --**worldfile=FILE** The name of the world file to write. A world file is an ASCII text file used for georeferencing images that contains the following lines:

- Line 1: x-dimension of a pixel in map units
- Line 2: rotation parameter
- Line 3: rotation parameter
- Line 4: NEGATIVE of y-dimension of a pixel in map units
- Line 5: x-coordinate of center of upper left pixel
- Line 6: y-coordinate of center of upper left pixel

World files may be written for any GIF, PNG, or JPEG image. The use of this option turns on the --**nolegends** option. The convention used in GIS is to name the world file similarly to the image file, but with a different extension. GDAL expects world files with a ".wld" extension, where as ESRI applications expect ".pgw" for PNG, ".gfw" for GIF, and ".jgw" for JPEG. Users should name their world files accordingly.

Plot overlay options:

-A, --bath=COLOR[/LEVEL1/LEVEL2/...] The bathymetric contour color and levels. The color is specified by name or hexadecimal value (see above). Bathymetric contours are generated for the specified integer levels in meters. If no levels are specified, contours are drawn at 200 m and 2000 m. The default is not to render bathymetric contours.

-b, --bitmask=VARIABLE/MASK/COLOR Specifies that a mask should be rendered on top of the data image whose pixels are obtained by a bitwise AND with the mask value. The named variable is used to mask the Earth data with the specified color and mask. The color is a name or hexadecimal value (see above). The mask is a 32-bit integer hexadecimal value specifying the mask bits. The bitmask is formed by bitwise ANDing the data value and mask value. If the result of the operation is non zero, the pixel is colored with the bitmask color. This option is useful for overlaying graphics on the data image when the graphics are stored as an integer valued variable in the data set. Such variables include cloud and land mask graphics. Multiple values of the --**bitmask** option may be given, in which case the masks are applied in the order that they are specified.

-C, --coast=COLOR[/FILL] The coast line color and optional fill color. The colors are specified by name or hexadecimal value (see above). The default is not to render coast lines.

-d, --cloud=COLOR The cloud mask color. The color is specified by name or hexadecimal value (see above). Cloud masking requires that a 'cloud' variable exists in the input file. The default is not to render a cloud mask.

-g, --grid=COLOR The latitude/longitude grid line color. The color is specified by name or hexadecimal value (see above). The default is not to render grid lines.

-H, --shape=FILE/COLOR[/FILL] The name and drawing/fill colors for a user-supplied shape file. The colors are specified by name or hexadecimal value (see above). The file formats currently supported are ESRI shapefile format (line and polygon data, no point data), and simple text files with lists of lat/lon values (the same format as described for the --**polygon** option in the **cwstats** tool). The fill color is optional and is used to fill polygons if any are found in the file. Multiple values of the --**shape** option may be given, in which case the shape overlays are rendered in the order that they are specified.

-L, --land=COLOR The land mask color. The color is specified by name or hexadecimal value (see above). Land masking requires that a 'graphics' variable exists in the input file with a land mask at bit 3 where bit numbering starts at 0 for the least significant bit. The default is not to render a land mask. For an alternative to the --**land** option, try using the --**coast** option with a fill color.

--marker=LAT/LON/COLOR[/FILL[/SYMBOL[/TEXT]]] The specifications for a symbol used to mark a location. The marker position is specified in terms of earth location latitude and longitude in the range [-90..90] and [-180..180]. The color is specified by name or hexadecimal value (see above). Optional parameters may be specified by appending the fill color (default is no fill), symbol (default is a circle), and text label (default is no label). The symbol may be one of 'cross', 'x', 'square', 'circle', 'triup', 'tridown', or 'diamond'.

-p --political=COLOR The political boundaries color. The color is specified by name or hexadecimal value (see above). The default is not to render political boundaries.

-S, --nostates Turns off state boundary rendering. The default when --**political** is specified is to render international and state boundaries. With this option is specified, only international boundaries are rendered.

-t, --topo=COLOR[/LEVEL1/LEVEL2/...] The topographic contour color and levels. The color is specified by name or hexadecimal value (see above). Topographic contours are generated for the specified integer levels in meters. If no levels are specified, contours are drawn at 200 m, 500 m, 1000 m, 2000 m, and 3000 m. The default is not to render topographic contours.

-u, --group=GROUP The overlay group name to render. Overlay groups are a concept from the CoastWatch Data Analysis Tool (CDAT). CDAT users can save a set of preferred overlays as a group and then restore those overlays when viewing a new data file. The same group names saved from CDAT are available to be rendered here. This is an extremely useful option that allows users to design a set of overlays graphically and adjust the various overlay properties beyond what can be achieved using the command line options for cwrender. If specified, this option will cause all overlays in the group to be drawn on top of any other overlays specified by command line options.

-w, --water=COLOR The water mask color. The color is specified by name or hexadecimal value (see above). Water masking is performed similarly to land masking (see the **--land** option), but the sense of the land mask is inverted. The default is not to render a water mask.

-X, --exprmask=EXPRESSION/COLOR Specifies that a mask should be rendered on top of the data image whose pixels are obtained by evaluating the expression. The color is specified by name or hexadecimal value (see above). An expression mask is a special type of multipurpose mask similar to a bitmask (see the **--bitmask** option above) but which allows the user to specify a mathematical expression to determine the mask. If the result of the expression is true (in the case of a boolean result) or non-zero (in the case of a numerical result), the data image is masked at the given location with the given color. Multiple values of the **--exprmask** option may be given, in which case the masks are applied in the order that they are specified. The syntax for the expression is identical to the right-hand-side of a **cwmath** legacy mode expression (see the **cwmath** tool manual page).

--watermark=TEXT[/COLOR[/SIZE[/ANGLE]]] Specifies the text for a watermark that is placed in the center of the image plot to denote special status such as experimental or restricted, or some other property of the data. The default watermark text is white, 50% opacity, 50 point font, and 0 degrees rotation. Optional parameters may be specified by appending the watermark color (name or hexadecimal value as described above), the point size, and baseline angle (0 is horizontal, 90 is vertical). For example, --watermark=EXPERIMENTAL/white/36/20 adds the text EXPERIMENTAL in solid white, 36 point font, at a 20 degree baseline rotation.

--watermarkshadow Draws a drop shadow behind the watermark to increase visibility. By default the watermark is drawn plain with no drop shadow.

Color enhancement options:

-E, --enhancevector=STYLE/SYMBOL[/SIZE] The color-enhanced vector specifications. This option is only used if two variable names are passed to the **--enhance** option. The vector style may be either 'uvcomp' or 'magdir'; the default is 'uvcomp'. In uvcomp mode, the variables that are passed to the **--enhance** option are taken to be the U (x-direction) and V (y-direction) components of the vector. In magdir mode, the first variable is taken to be the vector magnitude, and the second to be the vector direction in degrees clockwise from north. The vector symbol may be either 'arrow' to draw arrows in the direction of the vector, or 'barb' to draw WMO wind barbs; the default is 'arrow'. If wind barbs are used, the feathered end of the barb points in the direction that the wind is coming from (unless metadata attached to the direction variable is used to alter that convention). WMO wind barbs are drawn differently depending on the wind speed units, m/s or knots:

- Solid pennant: 25 m/s or 50 knots
- Full barb: 5 m/s or 10 knots
- Half barb: 2.5 m/s or 5 knots
- X symbol: missing wind speed
- No symbol: missing wind direction

Lastly, the size of the vector symbols in pixels may be specified; the default size is 10.

-F, --function=TYPE The color enhancement function. Data values are mapped to the range [0..255] by the enhancement function and range, and then to colors using the color palette. The valid enhancement function types are 'linear', 'boolean', 'stepN', 'log', 'gamma', 'linear-reverse', 'stepN-reverse','log-reverse', and 'gamma-reverse' where N is the number of steps in the function, for example 'step10'. The 'boolean' function is a shorthand way of specifying 'step2' as the function, and '0/1' as the range, useful for data with only 0 and 1 as data values. The reverse functions are equivalent to the non-reversed functions but map data values to the range [255..0] rather then [0..255]. By default, the enhancement function is 'linear'. A log enhancement may be necessary when the data value range does not scale well with a linear enhancement such as with chlorophyll concentration derived from ocean color data. A gamma enhancement may be needed when the data values represent a brightness from 0% to 100% and compensates for the gamma correction in computer displays.

-k, --background=COLOR The color for the background of vector plots. The color is specified by name or hexadecimal value (see above). The default background color is white.

-M, --missing=COLOR The color for missing or out of range data values. The color is specified by name or hexadecimal value (see above). The default missing color is black.

-P, --palette=NAME The color palette for converting data values to colors. The current list of color palette names can be listed using the **--palettelist** option. The palettes have been derived from a number of sources including SeaSpace Terascan, Interactive Data Language (IDL) v5.4, and the Python matplotlib cmocean package, and have similar names. By default the grayscale 'BW-Linear' palette is used.

--palettefile=FILE The file of color palette XML data for converting data values to colors. The format of the XML file is described in the User's Guide. By default, the 'BW-Linear' palette is used.

--palettecolors=COLOR1[/COLOR2[/COLOR3...]] The palette colors for converting data values to colors. Up to 256 colors may be specified by name or hexadecimal value (see above). By default, the 'BW-Linear' palette is used.

--palettelist Lists the palette names available on the system, including any palettes in the user's resource directory.

--paletteimage=FILE Renders an image of the palette names and color bars available on the system, including any palettes in the user's resource directory. The file name can end in '.png', '.jpg', '.tif', or '.bmp'.

-r, --range=MIN/MAX The color enhancement range. Data values are mapped to colors using the minimum and maximum values and an enhancement function. By default, the enhancement range is derived from the data value mean and standard deviation to form an optimal enhancement window of 1.5 standard deviation units around the mean.

--**scalewidth=PIXELS** The data color scale width. By default the data color scale is 90 pixels wide which includes the color bar, tick marks, value labels, and the variable name and units. This default accommodates most scales, but if a scale requires a wider size, it will grow to fit. In some cases this results in data plots with different data ranges being different widths overall, which may be undesirable. In these cases the scale width can be set explicitly to a larger value.

--**ticklabels=LABEL1[/LABEL2[/LABEL3/...]]** The numeric tick mark labels to use for the data color scale. By default the tick mark labels are generated automatically. For example:
--ticklabels=1.0/1.1/1.2/1.3/1.4/1.5
would put tick marks and labels at evenly spaced locations on the color scale from 1.0 to 1.5.

-**U,** --**units=UNITS** The range and color scale units for the enhancement variable(s). By default, the user must specify the values for the --**range** option in the standard units indicated in the data. If the user prefers a different set of units to be used, they may be specified here. Many common units are accepted (and various forms of those units), for example 'kelvin', 'celsius' and 'fahrenheit' for temperature data, 'knots', 'meters per second' or 'm/s' for wind speed, and 'mg per m^-3' or 'kg/m-3' for concentration. For other possible unit names, see the conventions used by the Unidata UDUNITS package and its supported units file.

--**varname=TEXT** The variable name to show in the color scale legend. By default the name of the variable is used, or in the case of a vector plot either the magnitude variable or U/V components.

Color composite options:

-**B,** --**bluerange=MIN/MAX** The blue component enhancement range, see --**redrange**.

-**G,** --**greenrange=MIN/MAX** The green component enhancement range, see --**redrange**.

-**R,** --**redrange=MIN/MAX** The red component enhancement range. Data values are mapped to the range [0..255] using the minimum and maximum values and an enhancement function. By default, the enhancement range is derived from the data value mean and standard deviation to form an optimal enhancement window of 1.5 standard deviation units around the mean.

-**x,** --**redfunction=TYPE** The red component enhancement function. Data values are mapped to the range [0..255] by the enhancement function and range, and then the pixel color is created by compositing the red, green, and blue mapped values into one 32-bit integer color value. See the --**function** option for valid function types. By default, the red, green, and blue enhancements are linear.

-**y,** --**greenfunction=TYPE** The green component enhancement function, see --**redfunction**.

-**z,** --**bluefunction=TYPE** The blue component enhancement function, see --**redfunction**.

--**compositehint=HINT** Performs the color composite using a hint for setting the composite functions and ranges, ignoring any other composite settings. The hints available are:

- 'true_color' – Creates a true color image from red/green/blue variables that have been corrected for atmosphere so that all variables contain reflectance data with a range [0..1].
- 'true_color_vivid' – Similar to true color above, but produces slightly higher contrast true color images.

- 'true_color_uncorr' – Similar to true color above, but handles data that has not been corrected for atmosphere and contains albedo or radiance data. The components are analyzed to determine approximate dark pixel correction and maximum brightness values.
- 'avhrr_day' – AVHRR daytime false color using channels 1, 2, and 4.
- 'avhrr_night' – AVHRR nighttime false color using channels 3, 4, and 5.

Exit status

0 on success, $>$ 0 on failure. Possible causes of errors:

- Invalid command line option
- Invalid input or output file names
- Invalid variable name
- Unrecognized format
- Unrecognized color name
- Invalid palette name
- Invalid magnification center

Examples

As an example of color enhancement, the following command shows the rendering of AVHRR channel 2 data from a CoastWatch HDF file to a PNG image, with coast and grid lines in red and the default linear black to white palette. We allow the routine to calculate data statistics on channel 2 for an optimal enhancement range:

```
phollema$ cwrender --verbose --enhance avhrr_ch2 --coast red --grid red
  2002_288_1435_n17_er.hdf 2002_288_1435_n17_er_ch2.png

[INFO] Reading input 2002_288_1435_n17_er.hdf
[INFO] Normalizing color enhancement
[INFO] Preparing data image
[INFO] Rendering overlay noaa.coastwatch.render.CoastOverlay
[INFO] Rendering overlay noaa.coastwatch.render.LatLonOverlay
[INFO] Writing output 2002_288_1435_n17_er_ch2.png
```

For a color composite of the same file, the following command shows the rendering of AVHRR channels 1, 2, and 4 to a PNG image. Again, we allow the routine to calculate statistics for optimal enhancement ranges. Note that the final enhancement function is reversed in order to map warm AVHRR channel 4 values to dark and cold values to bright:

```
phollema$ cwrender --verbose --composite avhrr_ch1/avhrr_ch2/avhrr_ch4
  --bluefunction reverse-linear --coast black --grid gray
  2002_288_1435_n17_er.hdf 2002_288_1435_n17_er_ch124.png

[INFO] Reading input 2002_288_1435_n17_er.hdf
[INFO] Normalizing red enhancement
[INFO] Normalizing green enhancement
[INFO] Normalizing blue enhancement
[INFO] Preparing data image
[INFO] Rendering overlay noaa.coastwatch.render.CoastOverlay
[INFO] Rendering overlay noaa.coastwatch.render.LatLonOverlay
[INFO] Writing output 2002_288_1435_n17_er_ch124.png
```

A further example below shows the rendering of AVHRR derived sea-surface-temperature data from the same file with a cloud mask applied. The color enhancement uses a blue to red color palette and an explicit range from 5 to 20 degrees Celsius:

```
phollema$ cwrender --verbose --enhance sst --coast white --grid white
  --palette HSL256 --range 5/20 --cloud gray 2002_288_1435_n17_er.hdf
  2002_288_1435_n17_er_sst.png

[INFO] Reading input 2002_288_1435_n17_er.hdf
[INFO] Preparing data image
[INFO] Rendering overlay noaa.coastwatch.render.BitmaskOverlay
[INFO] Rendering overlay noaa.coastwatch.render.CoastOverlay
[INFO] Rendering overlay noaa.coastwatch.render.LatLonOverlay
[INFO] Writing output 2002_288_1435_n17_er_sst.png
```

An example usage of the --**magnify** option is shown below to create a plot of cloud masked sea-surface-temperature data off Nova Scotia:

```
phollema$ cwrender --verbose --enhance sst --coast white --grid white
  --palette HSL256 --range 5/20 --cloud gray --magnify 43/-66/1
  2002_288_1435_n17_er.hdf 2002_288_1435_n17_er_sst_mag.png

[INFO] Reading input 2002_288_1435_n17_er.hdf
[INFO] Preparing data image
[INFO] Rendering overlay noaa.coastwatch.render.BitmaskOverlay
[INFO] Rendering overlay noaa.coastwatch.render.CoastOverlay
[INFO] Rendering overlay noaa.coastwatch.render.LatLonOverlay
[INFO] Writing output 2002_288_1435_n17_er_sst_mag.png
```

For an example of true color rendering, the next example shows the use of the --**compositehint** option for rendering top of atmopshere OLCI radiance data to a JPEG image:

```
phollema$ cwrender --verbose --nolegends --size 1024
  --composite EV_BandOa07/EV_BandOa06/EV_BandOa04
  --compositehint true_color_uncorr
  --coast white OLCMCW.I2021048.135053.hdf OLCMCW.I2021048.135053.true.jpg

[INFO] Reading input OLCMCW.I2021048.135053.hdf
[INFO] Set red component range to [0.8290487916208804, 28.153357705221403]
[INFO] Set green component range to [1.4429238677024843, 30.664745965510583]
[INFO] Set blue component range to [2.5182327458634974, 35.567549666418145]
[INFO] Preparing data image
[INFO] Rendering overlay noaa.coastwatch.render.CoastOverlay
[INFO] Writing output OLCMCW.I2021048.135053.true.jpg
```

The following shows a unique example of true color rendering from an existing color GeoTIFF file into a PNG with legends. The GDAL and NetCDF Operators (NCO) software are also needed to accomplish this:

```
phollema$ gdal_translate n20_viirs_20201031_175619.tif
  n20_viirs_20201031_175619.nc
phollema$ ncatted -a sensor,GLOBAL,c,c,VIIRS n20_viirs_20201031_175619.nc
phollema$ ncatted -a platform_ID,GLOBAL,c,c,N20 n20_viirs_20201031_175619.nc
phollema$ ncatted -a institution,GLOBAL,c,c,"NOAA CoastWatch"
  n20_viirs_20201031_175619.nc
phollema$ ncatted -a time_coverage_start,GLOBAL,c,c,2020-10-31T17:56:19Z
  n20_viirs_20201031_175619.nc
phollema$ ncatted -a time_coverage_end,GLOBAL,c,c,2020-10-31T17:56:19Z
  n20_viirs_20201031_175619.nc
phollema$ cwrender --verbose --size 700 --coast white --grid white
  --composite Band1/Band2/Band3 --redrange 0/255 --greenrange 0/255
  --bluerange 0/255 n20_viirs_20201031_175619.nc n20_viirs_20201031_175619.png

[INFO] Reading input n20_viirs_20201031_175619.nc
[INFO] Preparing data image
[INFO] Rendering overlay noaa.coastwatch.render.CoastOverlay
[INFO] Rendering overlay noaa.coastwatch.render.LatLonOverlay
[INFO] Writing output n20_viirs_20201031_175619.png
```

This next example shows how to render ocean current vector data by supplying two variables to the --**enhance** option. Rendering vector data is best done by using the --**magnify** option as well. This call renders data off the east coast of Japan using color vectors on a black background:

```
phollema$ cwrender --verbose --enhance ugos/vgos --range 0/2 --palette Blue-Red
  --function step10 --coast black/gray40 --grid white --background black
  --magnify 35/143/10 --size 800/700 example_altim_surface_curr_feb_2023.nc
  example_altim_surface_curr_feb_vector.png

[INFO] Reading input example_altim_surface_curr_feb_2023.nc
```

```
[INFO] Preparing data image noaa.coastwatch.render.ColorPointEnhancement
[INFO] Rendering overlay noaa.coastwatch.render.PointFeatureOverlay
[INFO] Rendering overlay noaa.coastwatch.render.CoastOverlay
[INFO] Rendering overlay noaa.coastwatch.render.LatLonOverlay
[INFO] Writing output example_altim_surface_curr_feb_vector.png
```

Known Bugs

When using the --**coast** option with a fill color and output is to a PDF file, lakes may contain a thin stripe of land in some places. In this case, use the --**land** for land filling instead.

When using the --**coast** option with a fill color, map projection discontinuities or swath projection edges may not be filled correctly.

A.4.4 cwcoverage

Name

cwcoverage - creates an earth data coverage map.

Synopsis

cwcoverage [OPTIONS] input1 [input2 ...] output
cwcoverage [OPTIONS] output

General options:

-h, --help
-v, --verbose
--version

Output content and format options:

-a, --noantialias
-b, --background=COLOR
-c, --center=LATITUDE/LONGITUDE
-f, --foreground=COLOR
-s, --size=PIXELS

Dataset boundary options:

-H, --highlight=PATTERN
-l, --labels=LABEL1/LABEL2/...
-m, --map=OUTPUT
-x, --box=COLOR

Ground station options:

-C, --stationcolor=COLOR
-e, --elevation=DEGREES
-E, --height=KILOMETERS
-L, --stationlabels=LABEL1/LABEL2/...
-S, --stations=LAT1/LON1/LAT2/LON2/...

Description

The coverage tool creates an earth data coverage map by accessing a number of user-specified earth data sets and tracing the boundaries onto an orthographic map projection. The map is output as a PNG graphics file. Approximate satellite ground station coverage boundaries may also be added to the map.

Parameters

Main parameters:

input1 [input2 ...] The input data files name(s). If none are specified, the output PNG image contains only map graphics and possibly ground station circles (see the --**stations** option).

output The output PNG file name.

General options:

-h, --help Prints a brief help message.

-v, --verbose Turns verbose mode on. The current status of data rendering is printed periodically. The default is to run quietly.

--**version** Prints the software version.

Output content and format options:

-a, --noantialias Turns off line antialiasing. By default, the edges of lines are smoothed using shades of the drawing color. The use of this option can significantly reduce the size of the output file, while sacrificing visual quality.

-b, --background=COLOR The map background color. The color is specified by name or hexadecimal value. The default is black.

-c, --center=LATITUDE/LONGITUDE The map center location. By default, the center location is determined from the data sets.

-f, --foreground=COLOR The map foreground color. The color is specified by name or hexadecimal value. The default is a gray of 63% RGB intensity.

-s, --size=PIXELS The coverage map size in pixels. By default, the map size is 512 pixels.

Dataset boundary options:

-H, --highlight=PATTERN The highlighted input file matching pattern. By default, all input files are highlighted with the box boundary fill and color. With this option, only input files whose names match the pattern are highlighted. The remaining non-matching input file boundaries are drawn using the foreground color.

-l, --labels=LABEL1/LABEL2/... The labels for each input file. Labels are drawn at the center point of each dataset boundary. By default, no labels are drawn.

-m, --map=OUTPUT The output file for HTML image map output. The output file contains an HTML fragment with an image map and area polygons for each input file, similar to the following:

```
<map name="coverage_map">
  <area shape="poly" id="region_0" coords="111,64,170,63,179,132,108,134,111,64" />
  <area shape="poly" id="region_1" coords="75,106,132,109,133,179,66,174,75,106" />
  <area shape="poly" id="region_2" coords="121,124,183,121,192,188,119,191,121,124" />
</map>
```

The map may be used in an HTML document in conjunction with the output PNG coverage image to provide users with a clickable interface for area of interest selection.

-x, --box=COLOR The box boundary and fill color. The color is specified by name or hexadecimal value. The default is a color close to cyan.

Ground station options:

-C, --stationcolor=COLOR The ground station circle color. This option is only used in conjunction with the --**stations** option. By default, the box color is used (see the --**box** option).

-e, --elevation=DEGREES The minimum elevation of the ground station antenna above the horizon in degrees. This option is only used in conjunction with the --**stations** option. By default, the antenna elevation is set to 5 degrees, which approximates a NOAA HRPT tracking station with a 1.7 m diameter dish.

-E, --height=KILOMETERS The orbital height of the theoretical satellite above the earth surface in kilometers. This option is only used in conjunction with the --**stations** option. By default, the satellite orbital height is set to 846.5 km which approximates a NOAA polar orbiter.

-L, --stationlabels=LABEL1/LABEL2/... The ground station labels. This option is only used in conjunction with the --**stations** option. When specified, each ground station location is labelled with its corresponding label. By default, no labels are drawn.

-S, --stations=LAT1/LON1/LAT2/LON2/... A list of ground station locations. For each ground station, a circle is drawn on the Earth, centered at the ground station. The circle shows the approximate area that a theoretical satellite can view from orbit while in sight of the station, ie: the ground station's real-time coverage area. See the --**height** and --**elevation** options to control the orbital parameters of the theoretical satellite. Note that the swath width of the satellite sensor is not taken into account in drawing the circle, so the area should be used as a conservative estimate of satellite coverage.

Exit status

0 on success, $>$ 0 on failure. Possible causes of errors:

- Invalid command line option

- Unrecognized color name
- Invalid map center or station location
- Mismatch between label and file or station count

Examples

As an example, the following command shows the creation of a coverage plot of the ER and SR CoastWatch regions covering the US East coast:

```
phollema$ cwcoverage -v --labels ER/SR 2004_155_1147_n15_er.hdf
  2004_155_1147_n15_sr.hdf east_coast.png

cwcoverage: Reading input 2004_155_1147_n15_er.hdf
cwcoverage: Reading input 2004_155_1147_n15_sr.hdf
cwcoverage: Writing east_coast.png
```

A.4.5 cwgraphics

Name

cwgraphics - creates earth data annotation graphics.

Synopsis

cwgraphics [OPTIONS] input
cwgraphics [OPTIONS] input output

Options:

-c, --coast=PLANE
-g, --grid=PLANE
-h, --help
-l, --land=PLANE
-p, --political=PLANE
-v, --verbose
-V, --variable=NAME
--version

Description

The graphics tool creates earth data annotation graphics in the form of a byte-valued variable. Each output byte in the new variable contains 8 bits, one for each of 8 possible graphics planes numbered 1 to 8 from the least significant bit to the most significant bit. The graphics planes are independent of one another and encode a bitmask for graphical data annotation, where a bit value of 0 is interpreted as 'off' and a bit value of 1 as 'on'. In this way, 8 separate binary bitmasks may be encoded into one byte value. For example a pixel with graphics planes 2, 3, and 4 on is encoded as:

```
Binary value  = 00001110
Decimal value = 14
```

Following the standard convention for graphics planes in CoastWatch product files, the default behaviour places latitude/longitude grid graphics in plane 2, coastline graphics in plane 3, and land mask graphics in plane 4. Coastlines are derived from GSHHS coastline data, and land polygons are filled GSHHS polygons (see the GSHHS website). The default output variable name is 'graphics'. These defaults may be changed using command line options to alter the planes used for each type of annotation, to exclude or add some types of annotation, and to change the output variable name.

Once the graphics planes are created, they may be used as overlay graphics for rendered earth data images. The graphics byte data may be exported using the cwexport tool for use in other software packages, or may be used in the cwrender tool with the **--bitmask** option.

Parameters

Main parameters:

input The input data file name.

output The output file name. If the output file name is not specified, the input file name is used and the new variable must not already exist in the input file.

Options:

-c, --coast=PLANE The coastline graphics plane. The default is plane 3. If the plane value is 0, no coast graphics are rendered.

-g, --grid=PLANE The grid line graphics plane. The default is plane 2. If the plane value is 0, no grid graphics are rendered.

-h, --help Prints a brief help message.

-l, --land=PLANE The land mask graphics plane. The default is plane 4. If the plane value is 0, no land graphics are rendered.

-p, --political=PLANE The political line graphics plane. There is no default plane for political lines, as they are normally excluded from rendering.

-v, --verbose Turns verbose mode on. The current status of data rendering is printed periodically. The default is to run quietly.

-V, --variable=NAME The output variable name. The default name is 'graphics'.

--version Prints the software version.

Exit status

0 on success, $>$ 0 on failure. Possible causes of errors:

- Invalid command line option
- Invalid input or output file names
- Unsupported input file format
- Output variable already exists in input file

Examples

The following shows the creation of a standard set of graphics planes using cwgraphics. The file being acted upon is a CoastWatch HDF file created using the graphical cwmaster tool:

```
phollema$ cwgraphics -v bc_coast.hdf

[INFO] Reading input bc_coast.hdf
[INFO] Creating graphics variable
[INFO] Rendering overlay at plane 2
[INFO] Rendering overlay at plane 3
[INFO] Rendering overlay at plane 4
```

Another example below shows the alteration of the default options. Only coastline and political line graphics are rendered to plane 1, and the output variable is named 'geography':

```
phollema$ cwgraphics -v --land 0 --grid 0 --coast 1 --political 1
  --variable geography bc_coast.hdf

[INFO] Reading input bc_coast.hdf
[INFO] Creating geography variable
[INFO] Rendering overlay at plane 1
[INFO] Rendering overlay at plane 1
[INFO] Rendering overlay at plane 1
```

A.5 Registration and Navigation

A.5.1 cwmaster

Name

cwmaster - creates map projection master datasets.

Synopsis

cwmaster [OPTIONS] [input]

Options:

-h, --help
--version

Description

The master utility creates map projection master data sets using a graphical user interface. A master projection specifies the translation between grid row and column coordinates and Earth latitude and longitude coordinates. A number of common map projections are available such as Mercator, Transverse Mercator, Polar Stereographic, Orthographic, Lambert Conformal Conic, and so on. Detailed help on the usage of cwmaster is available from within the utility using the menu bar under *Help* | *Help and Support*.

Parameters

Main parameters:

input The optional input data file name. If specified, the data file is opened and used as the initial map projection master.

Options:

-h, --help Prints a brief help message.

--version Prints the software version.

Exit status

0 on success, $>$ 0 on failure. Possible causes of errors:

- Invalid command line option

- Invalid input file name
- Unsupported input file format
- Input file does not contain a map projection

Examples

The following shows the use of cwmaster to load master parameters from a CoastWatch HDF file:

```
phollema$ cwmaster 2021_232_1630_120_gr.hdf
```

A.5.2 cwregister

Name

cwregister - resamples gridded earth data to a master projection.

Synopsis

cwregister [OPTIONS] master input output

Options:

-f, --srcfilter=TYPE
-h, --help
-m, --match=PATTERN
-M, --method=TYPE
-O, --overwrite=TYPE
-p, --polysize=KILOMETERS
-r, --rectsize=WIDTH/HEIGHT
-s, --srcexpr=EXPRESSION
-v, --verbose
--version

Description

THIS TOOL HAS BEEN DEPRECATED AND REPLACED WITH CWREGISTER2. IT ONLY EXISTS TO HELP WITH BACKWARDS COMPATIBILITY. USERS SHOULD TRANSITION TO CWREGISTER2 FOR BETTER TIME PERFORMANCE AND ACCURACY.

The register tool resamples gridded earth data to a master projection. A master projection specifies the translation between grid row and column coordinates and earth latitude and longitude coordinates. The master projection file is any valid earth data file from which a set of row and column dimensions and earth transform parameters may be extracted. This includes standard CoastWatch product files as well as master files created using the **cwmaster** tool.

Parameters

Main parameters:

master The master projection file name. Note that the master file is not altered in any way. It is simply accessed in order to determine grid and earth transform parameters.

input The input data file name.

output The output data file name.

Options:

-h, --help Prints a brief help message.

-f, --srcfilter=TYPE Specifies a filter used to determine whether source pixels at a given location should be used in registration. The only filter type currently supported is 'viirs', which filters out pixels from the VIIRS sensor that have been omitted due to bow-tie overlap. By default all valid source pixels are used in registration. See also the --**srcexpr** option to filter using an expression.

-m, --match=PATTERN The variable name matching pattern. If specified, the pattern is used as a regular expression to match variable names. Only variables in the input file matching the pattern will be registered. By default, no pattern matching is performed and all variables are registered.

-M, --method=TYPE The registration resampling method. Valid methods are 'inverse', 'mixed', and 'direct':

- **Inverse** - This method divides the destination grid into a series of rectangles of physical size no larger than that specified by the --**polysize** option (100 km by default), and computes polynomial coefficients for approximating the coordinate transform within each rectangle. Each polynomial approximation computes a source coordinate in the source grid for each destination coordinate in the destination grid rectangle. This is the default method of registration and is recommended when the source earth location data is smooth and continuous such as with AVHRR LAC swath data.
- **Mixed** - This method divides the source grid into rectangles of a size specified by the --**rectsize** option (50x50 pixels by default), and computes polynomial coefficients on each rectangle that are used to approximate a source coordinate in the source grid rectangle for each destination coordinate in the corresponding destination grid rectangle. The method follows up with a single pixel interpolation to fill in pixels that fell between destination rectangles bounds. This method is recommended when the source earth location data is discontinuous at regular intervals, such as with MODIS swath data. In this case, the --**rectsize** option must be used to specify rectangles that are compatible with the discontinuity. For example if the source earth location data is discontinuous at 16 pixel intervals along the row direction, then the rectangle size should be set to 16x16.
- **Direct** - This method is the simplest and performs a direct lookup of the source coordinate in the source grid for each destination coordinate in the destination grid. This method is available mainly as a comparison for testing the accuracy and speed of the other methods, since it is expected to run more slowly but have the highest accuracy. Note that the direct method cannot currently be used if the source grid contains discontinuous earth location data (such as MODIS swath data).

-O, --overwrite=TYPE ADVANCED USERS ONLY. Sets the overwrite policy for 'mixed' mode resampling: either 'always' (the default), 'never', or 'closer'. If during resampling, more than one source pixel maps to a single destination pixel, this option is used to determine if the new value should overwrite the old value. By default, the new value always overwrites the destination pixel (the 'always' mode). If 'never' is specified, the first written value is never overwritten. If 'closer' is specified, the destination pixel is only overwritten if the source pixel is closer in physical location to the destination than any previous source pixel.

-p, --polysize=KILOMETERS The polynomial approximation rectangle size in kilometers. This option is only used by the inverse resampling method (see the --**method** option). The inverse resampling

method employs a polynomial approximation to speed up the calculation of data locations. The polynomial rectangle size determines the maximum allowed size of the resampling rectangles in the destination. The default polynomial size is 100 km, which introduces an error of less than 0.15 km for AVHRR LAC data.

-**r, --rectsize=WIDTH/HEIGHT** The polynomial approximation rectangle size in pixels. This option is only used by the mixed resampling method (see the --**method** option). The mixed resampling method employs a polynomial approximation to speed up the calculation of data locations. The polynomial rectangle size determines the exact dimensions of the resampling rectangles in the source. The default polynomial rectangle size is 50/50, which introduces only a small error for AVHRR LAC data.

-**s, --srcexpr=EXPRESSION** Specifies that an expression should be used to determine if pixels from the source should be used in registration. If the result of the expression is true (in the case of a boolean result) or non-zero (in the case of a numerical result), the source pixel at the given location is used, otherwise it is ignored. The syntax for the expression is identical to the right-hand-side of a **cwmath** expression (see the **cwmath** tool manual page). By default all valid source pixels are used in registration.

-**v, --verbose** Turns verbose mode on. The current status of data conversion is printed periodically. The default is to run quietly.

--**version** Prints the software version.

Exit status

0 on success, $>$ 0 on failure. Possible causes of errors:

- Invalid command line option
- Invalid master, input or output file names
- Unsupported master or input file format

Examples

The following shows the registration of NOAA-17 AVHRR channel 2 swath data to a southern California master:

```
phollema$ cwregister -v --match avhrr_ch2 ws_master.hdf 2002_318_1826_n17_mo.hdf
  2002_318_1826_n17_ws.hdf

[INFO] Reading master ws_master.hdf
[INFO] Reading input 2002_318_1826_n17_mo.hdf
[INFO] Creating output 2002_318_1826_n17_ws.hdf
[INFO] Adding avhrr_ch2 to resampled grids
[INFO] Found 1 grid(s) for resampling
[INFO] Resampling 4788x2048 to 1024x1024
[INFO] Creating location estimators
[INFO] Computing row 0
```

```
[INFO] Computing row 100
[INFO] Computing row 200
[INFO] Computing row 300
[INFO] Computing row 400
[INFO] Computing row 500
[INFO] Computing row 600
[INFO] Computing row 700
[INFO] Computing row 800
[INFO] Computing row 900
[INFO] Computing row 1000
[INFO] Closing files
```

A.5.3 cwregister2

Name

cwregister2 - resamples gridded earth data to a master projection using a revised set of high accuracy algorithms.

Synopsis

cwregister2 [OPTIONS] input output

Options:

-h, --help
-c, --clobber
-d, --diagnostic
-D, --diagnostic-long
-g, --nogroup
-M, --master=FILE
-m, --match=PATTERN
-p, --proj=SYSTEM
-r, --resolution=SIZE
-S, --savemap
-H, --sensorhint=HINT
--serial
--threads=MAX
-t, --tiledims=ROWS/COLS
-u, --usemap=FILE[/ROW_VAR/COL_VAR]
-v, --verbose
--version

Description

The new registration tool resamples gridded earth data to a master projection using a revised set of high accuracy algorithms. The new tool replaces the old **cwregister** tool in order to simplify and streamline registration. Specifically, the new tool improves registration by:

1. Selecting the most appropriate resampling algorithm automatically rather than making the user choose
2. Automatically creating an optimal master projection for the input file
3. Performing diagnostics on the accuracy of the resampling algorithm
4. Handling terrain-corrected data with sensor-specific algorithms
5. Performing registration on 2D tiles of data in parallel

Parameters

Main parameters:

input The input data file name.

output The output data file name.

Options:

-h, --help Prints a brief help message.

-c, --clobber Turns on clobber mode, in which the output file is overwritten even if it already exists. The default is to check if an output file exists and not overwrite it if so.

-d, --diagnostic Turns on diagnostic mode, in which the output file resampling accuracy is checked and compared to the optimal resampling. The default is to run without diagnostics because diagnostic mode is much slower. The diagnostics calculated are:

- Distance - distance in kilometers from the destination pixel center to the corresponding source pixel center.
- Distance error - the value of **(dist - opt)** where **dist** is the distance in kilometers between the destination pixel and mapped source pixel (see above) and **opt** is the distance in kilometers between the destination pixel and optimal source pixel. The optimal source pixel is the source pixel whose center has the minimum physical distance from the destination pixel center out of all pixels in the input file. Thus the value of **(dist - opt)** is always positive since **dist** $>=$ **opt**.
- Normalized performance metric - normalized value calculated as **1 - (dist - opt)/(dist + opt)** where **dist** and **opt** are defined above. The normalized metric has a range of [0..1] where 0 is the least optimal resampling and 1 is the most optimal.
- % of suboptimal destination pixels. A suboptimal destination pixel is one where the source pixel mapped to it wasn't the optimal source pixel.

Diagnostic mode also turns on verbose mode.

-D, --diagnostic-long Turns on long form diagnostic mode. In addition to the diagnostics mentioned above, each suboptimal remapping is printed: destination coordinates, source coordinates, optimal source coordinates, and distance error.

-g, --nogroup Turns on removal of the group path in variable names. If variable names contain a leading group path ending with '/', the group path is removed.

-M, --master=FILE The master projection file name. The master file is not modified, only accessed for earth transform parameters. By default an optimal output projection is determined automatically from the input file if no master file is specified.

-m, --match=PATTERN The variable name matching pattern. The pattern is a regular expression that determines which variables to register, otherwise all variables are registered.

-p, --proj=SYSTEM The projection system to use for a master. This can be:

- geo - Geographic

- ortho - Orthographic
- mercator - Mercator
- polar - Polar Stereographic
- tm - Transverse Mercator
- utm - Universal Transverse Mercator

An optimal destination master is created using the specified projection system, and is set up with its center location, resolution, and extents matching the input file. If no projection system is specified and no master file is provided, the default is UTM.

-r, --resolution=SIZE Specifies the pixel resolution for the optimal destination master. The pixel resolution is specified in degrees for a geographic projection or kilometers for all other projections. By default the resolution is automatically determined from the center location of the input file unless a master file is specified (see --**master** above).

-S, --savemap Saves the row and column mapping to the output file. These can be used in a later registration run with --**usemap** to speed up the registration for input files that always have the same source coordinates. The variables 'source_row' and 'source_col' are added to the output file, and specify for each destination pixel, which source row and column they were mapped from.

-H, --sensorhint=HINT Provides a hint for the sensor for non-invertible transform types to help with the resampling. The default is to automatically detect if sensor-specific handling is needed from the input file. The hints available are 'viirs_mband_edr' and 'viirs_iband_edr', which are not detected automatically.

--serial Turns on serial processing mode. By default the program will use multiple processors in parallel to process chunks of data.

--threads=MAX Specifies the maximum number of threads for parallel processing. By default the program will automatically detect the maximum number of threads possible.

-t, --tiledims=ROWS/COLS Specifies the 2D tile size to use in the output file. This is the size the HDF chunks will be written as. The default is 512 by 512 tiles for all variables.

-u, --usemap=FILE[/ROW_VAR/COL_VAR] Uses the file to load previously saved row and column mapping variables. The names of the variables are optional, and default to 'source_row' and 'source_col'. The data can be from a previous run of **cwregister2**, or can be user-generated from some other method -- if so the variables should be saved as **int32** type.

-v, --verbose Runs in verbose mode, printing the current status of data registration rather than running silently.

--version Prints the software version.

Exit status

0 on success, $>$ 0 on failure. Possible causes of errors:

- Invalid command line option

- Invalid master, input or output file names
- Unsupported master or input file format
- Output file already exists
- Invalid tile dimensions
- No variables found for registration
- Projection system specified is unsupported
- Error during registration computation

Examples

The following shows the registration of a VIIRS level 2 granule to an optimal Mercator projection wih diagnostic output:

```
phollema$ cwregister2 --diagnostic --proj mercator --clobber
  VRSLCW.B2018157.213433.hdf VRSLCW.B2018157.213433.mercator.hdf
[INFO] Opening input file VRSLCW.B2018157.213433.hdf
[INFO] Creating optimal destination transform
[INFO] Creating output file VRSLCW.B2018157.213433.mercator.hdf
[INFO] Creating output variable latitude
[INFO] Creating output variable longitude
[INFO] Creating output variable rel_azimuth
[INFO] Creating output variable sat_zenith
[INFO] Creating output variable sun_zenith
[INFO] Creating output variable EV_BandM8
[INFO] Creating output variable EV_BandM6
[INFO] Creating output variable EV_BandM11
[INFO] Creating output variable EV_BandM1
[INFO] Creating output variable EV_BandM5
[INFO] Creating output variable EV_BandM2
[INFO] Creating output variable EV_BandM10
[INFO] Creating output variable EV_BandM4
[INFO] Creating output variable EV_BandM3
[INFO] Creating output variable EV_BandM7
[INFO] Creating output variable edgemask
[INFO] Initializing resampling map factory
[INFO] Source has size 768x3200
[INFO] Destination has size 1378x4032
[INFO] Found 8 processor(s) to use
[INFO] Processing 384 chunks of size 512x512
[INFO] Performing diagnostic
[INFO] Diagnostic summary statistics
  Distance (km)       min = 0.002940, max = 1.265793, avg = 0.376542
  Distance error (km) min = 0.000000, max = 0.001918, avg = 0.000000
```

```
  Norm perf metric    min = 0.998856, max = 1.000000, avg = 1.000000
[INFO] Found 22 suboptimal of 28851 samples (0.08%)
[INFO] Closing files
```

A.5.4 cwnavigate

Name

cwnavigate - adds navigation corrections to earth data.

Synopsis

cwnavigate [OPTIONS] input

Correction options:

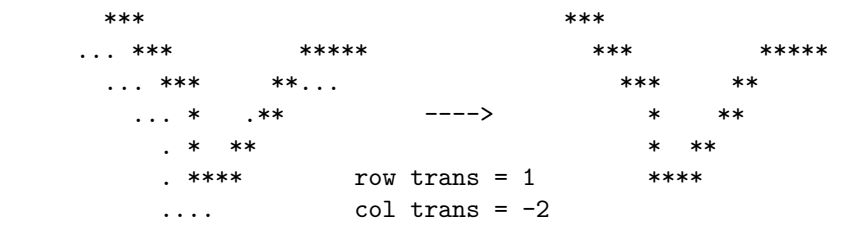
-t, --trans=ROWS/COLS
-r, --rotate=ANGLE
-a, --affine=A/B/C/D/E/F
-R, --reset

General options:

-h, --help
-m, --match=PATTERN
-v, --verbose
--version

Description

The navigation tool adds navigation corrections to 2D variables in an earth data file by setting navigation transform parameters. The most basic navigation transform consists of additive translation in the row and column data coordinates. As an example of translation, the following diagram shows coastlines in the earth image data as a '.' (period) symbol and coastlines derived from a GIS database as a '*' (star). Translation has been used to correct the position of the image data:



A more generic navigation transform consists of a translation combined with a rotation or shear. To represent generic navigation transforms, an affine transform matrix is used to convert "desired" data coordinates to "actual" data coordinates as follows:

```
|row'|   |a  c  e|  |row|
|    |   |       |  |   |
|col'| = |b  d  f|  |col|
|    |   |       |  |   |
| 1  |   |0  0  1|  | 1 |
```

where [a..f] are the affine transform matrix coefficients and (row',col') is the actual data coordinates at which the desired data value for (row,col) may be found.

To apply a navigation transform to a 2D variable, the existing navigation transform is read and the new transform is applied to it using matrix multiplication to create a combined transform. As an example, suppose that T1 is the initial navigation transform. The application of an additional transform T2 results in a new transform that is equivalent to:

```
T2 (T1 (row, col))
```

A navigation transform can be applied to a subset of 2D variables, or all variables in the file. Note that satellite channel data or channel-derived variables should be corrected with navigation but GIS-derived variables such as coastline and lat/lon grid graphics should not be corrected. Setting the navigation transform simply establishes a mapping between desired and actual data coordinates – it does not change the gridded data values themselves. Once a navigation transform has been set, other CoastWatch tools in this package will take the transform into account when reading the data.

Parameters

Main parameters:

input The input data file name. The navigation corrections are applied to the input file in-situ. For CoastWatch HDF files, the corrections are applied to individual variables. No other file formats are supported.

Correction options:

-t, --trans=ROWS/COLS The translation transform to apply. The actual row and column coordinates are calculated by adding the specified row and column translation to the desired coordinates.

-r, --rotate=ANGLE The rotation transform to apply. The actual row and column coordinates are calculated by rotating the desired row and column coordinates about the data center by the specified angle in degrees. Positive angles rotate counter-clockwise while negative angles rotate clockwise.

-a, --affine=A/B/C/D/E/F The explicit affine transform to apply. The coefficients are used to form the affine transform matrix (see the Description section above) which is applied to the existing transform using matrix multiplication.

-R, --reset Specifies that the existing navigation transform should be reset to the identity. Under the identity transform, no navigation correction is performed.

General options:

-h, --help Prints a brief help message.

-m, --match=PATTERN The variable name matching pattern. If specified, the pattern is used as a regular expression to match variable names. Only variables matching the pattern will be navigated. By default, no pattern matching is performed and all variables are navigated.

-v, --verbose Turns verbose mode on. The status of navigation correction is printed periodically. The default is to run quietly.

--version Prints the software version.

Exit status

0 on success, $>$ 0 on failure. Possible causes of errors:

- Invalid command line option
- Invalid input file name
- Unsupported input file format
- Unsupported navigation correction

Examples

The following example shows the navigation correction of a NOAA-15 CoastWatch HDF data file from the Gulf of Mexico:

```
phollema$ cwnavigate --trans -3/3 -v --match '(avhrr.*|cloud|sst)'
  2002_328_1326_n15_ml.hdf

cwnavigate: Reading input 2002_328_1326_n15_ml.hdf
cwnavigate: Applying navigation correction to avhrr_ch1
cwnavigate: Applying navigation correction to avhrr_ch2
cwnavigate: Applying navigation correction to avhrr_ch4
cwnavigate: Applying navigation correction to cloud
cwnavigate: Applying navigation correction to sst
```

Another example below shows the navigation correction of a NOAA-15 CoastWatch HDF data file from the US east coast:

```
phollema$ cwnavigate --trans -2/1 -v 2002_326_1330_n15_er_c2.hdf

cwnavigate: Reading input 2002_326_1330_n15_er_c2.hdf
cwnavigate: Applying navigation correction
```

A.5.5 cwautonav

Name

cwautonav - automatically determines a navigation correction based on earth image data.

Synopsis

cwautonav [OPTIONS] locations-file variable input

Options:

-c, --correlation=FACTOR
-f, --fraction=FRACTION
-h, --help
-H, --height=PIXELS
-m, --match=PATTERN
-M, --minboxes=N
-s, --search=LEVEL
-S, --separation=DISTANCE
-t, --test
-v, --verbose
-w, --width=PIXELS
--version

Description

The autonavigation tool automatically determines a navigation correction based on earth image data. The algorithm is as follows:

- **Step 1** - The user supplies a number of boxes of coastal data to use for navigation. The boxes are specified by the latitude and longitude of each box center in a text file separate from the earth data file. The box dimensions are controlled by command line options.
- **Step 2** - Each box is run through an offset estimation algorithm. The algorithm first attempts to separate the pixels within a given box into two classes: land and water. If the classes are sufficiently separable, an image correlation is run by "shifting" the image data around to find the maximum correlation between land/water classes and a precomputed land mask database.
- **Step 3** - All navigation boxes with successful offset estimates are used to compute the mean offset for the entire input file. All user-specified variables in the input file are then corrected with the mean offset.

Note that because of the autonavigation algorithm design, there are a number of **limitations:**

- **Coastline features** - The algorithm relies partly on the user being able to specify navigation boxes containing "wiggly" coastline features such as peninsulas and bays. A flat coastline can cause the algorithm to generate inaccurate offset estimates.
- **Distinct classes** - Image data in the navigation boxes must be separable into distinct land and water classes. If the image data contains cloud, or if the land and water pixels do not differ significantly (too similar in visible or thermal radiance), then the class separation step will fail for some boxes.
- **Large areas** - The mean offset generated from the set of successful offset estimates in Step 3 may not model the actual navigation correction for data files that cover a large physical area. If the offsets differ significantly for navigation boxes at a great distance from each other, then the user should treat a number of subsets of the data file separately.
- **Rotation or scaling** - An offset correction cannot model the actual navigation correction if the data requires a rotation or scale correction.

Note that satellite channel data or channel-derived variables should be corrected with navigation but GIS-derived variables such as coastline and lat/lon grid graphics should not be corrected. Applying a navigation correction simply establishes a mapping between desired and actual data coordinates – it does not change the gridded data values themselves. Once a data file has been autonavigated successfully, other CoastWatch tools in this package will take the correction into account when reading the data.

See the **cwnavigate** tool in this package for details on how to set a navigation correction manually, or to reset the existing navigation.

Parameters

Main parameters:

locations-file The file name containing a list of navigation box centers. The file must be a text file containing center points as latitude / longitude pairs, one line per pair, with values separated by spaces or tabs. The points are specified in terms of Earth location latitude and longitude in the range [-90..90] and [-180..180].

variable The variable name to use for image data.

input The input data file name. The navigation corrections are applied to the input file in-situ. For CoastWatch HDF files, the corrections are applied to individual variables. No other file formats are supported.

Options:

-c, --correlation=FACTOR The minimum allowed image versus land mask correlation factor in the range [0..1]. If the image data matches the precomputed land mask to within the specified correlation factor, the navigation is considered to be successful. The default correlation factor is 0.95. Caution should be used in lowering this value, as it has a significant impact on the quality of navigation results.

-f, --fraction=FRACTION The minimum allowed class fraction in the range [0..1]. The class fraction is the count of land or water pixels from the class separation stage, divided by the total number of

pixels in the navigation box. If the fraction of either land or water pixels is too low, the image data is rejected. The default minimum fraction is 0.05.

-h, --help Prints a brief help message.

-H, --height=PIXELS The navigation box height. By default, each navigation box is 100 pixels in height.

-m, --match=PATTERN The variable name matching pattern. If specified, the pattern is used as a regular expression to match variable names. Only variables matching the pattern will have the navigation correction applied. By default, no pattern matching is performed and all variables are navigated.

-M, --minboxes=N The minimum number of successful navigation boxes needed to apply the navigation correction. The default is 2.

-s, --search=LEVEL The search level starting from 0. This option should only be used if the magnitude of the navigation correction is likely to be half or more the size of the navigation box, as it can significantly increase the algorithm running time. In these cases, the offset estimation can often fail because the image data is so far off the correct geographic features that the class separation and image correlation steps are meaningless. When this option is specified, an area of (n+1)^2 times the size of the navigation box is searched, where n is the search level. By default, only image data within the navigation box is used (n = 0).

-S, --separation=DISTANCE The minimum allowed class separation distance in standard deviation units. Typical values are in the range [1..4]. The greater the distance, the more distinct the land and water classes are. The default distance is 2.5.

-t, --test Turns on test mode. All operations that compute the navigation correction are performed, but no actual correction is applied to the input file. By default, test mode is off and the input file is modified if a correction can be computed.

-v, --verbose Turns verbose mode on. Details on offset estimation and navigation correction are printed. The default is to run with minimal messages.

-w, --width=PIXELS The navigation box width. By default, each navigation box is 100 pixels in width.

--version Prints the software version.

Exit status

0 on success, $>$ 0 on failure. Possible causes of errors:

- Invalid command line option
- Invalid input file name
- Unsupported input file format

Examples

The following example shows an automatic correction of an East Coast HDF file containing AVHHR channel 2 data. A total of 3 navigation boxes are specified in a text file, and the size of each box set to 60 by 60 pixels. The output shows that 2 of the 3 boxes were successful and a final navigation correction of (rows, cols) = (-3, 1) was applied to the file.

```
phollema$ cwautonav -v --width 60 --height 60 navbox.txt
  avhrr_ch2 2004_064_1601_n17_er.hdf

[INFO] Reading input 2004_064_1601_n17_er.hdf
[INFO] Testing box at 37.0503 N, 76.2111 W
[INFO] Land/water class separation distance = 2.33
[INFO] Insufficient separation
[INFO] Box failed
[INFO] Testing box at 44.2783 N, 66.1377 W
[INFO] Land/water class separation distance = 3.436
[INFO] Image correlation = 0.965 at offset = (-3, 1)
[INFO] Box offset = (-3, 1)
[INFO] Testing box at 45.1985 N, 65.9262 W
[INFO] Land/water class separation distance = 3.814
[INFO] Image correlation = 0.987 at offset = (-3, 1)
[INFO] Box offset = (-3, 1)
[INFO] Mean offset = (-3, 1)
[INFO] Applying navigation correction
```

The next example below shows the import and automatic correction of multiple CWF files from the Gulf of Mexico. The AVHRR channel 1, channel 2, SST, and cloud mask variables are first imported to an HDF file. The automatic correction then runs using only data from AVHRR channel 2 which provides high contrast between land and water during the day. The final correction is applied to all variables in the input file. This combination of import and autonavigation is a convenient way of correcting a set of CoastWatch HDF data files all at once, using just data from AVHRR channel 2.

```
phollema$ cwimport -v --match '(avhrr.*|sst|cloud)' 2004_313_1921_n16_mr*.hdf
  2004_313_1921_n16_mr.hdf

[INFO] Reading input 2004_313_1921_n16_mr_c1.hdf
[INFO] Creating output 2004_313_1921_n16_mr.hdf
[INFO] Converting file [1/4], 2004_313_1921_n16_mr_c1.hdf
[INFO] Writing avhrr_ch1
[INFO] Converting file [2/4], 2004_313_1921_n16_mr_c2.hdf
[INFO] Writing avhrr_ch2
[INFO] Converting file [3/4], 2004_313_1921_n16_mr_cm.hdf
[INFO] Writing cloud
[INFO] Converting file [4/4], 2004_313_1921_n16_mr_d7.hdf
[INFO] Writing sst
```

```
phollema$ cwautonav -v --width 60 --height 60 navbox2.txt avhrr_ch2 2004_313_1921_n16_mr.hdf

[INFO] Reading input 2004_313_1921_n16_mr.hdf
[INFO] Testing box at 26.7734 N, 82.1731 W
[INFO] Land/water class separation distance = 3.239
[INFO] Image correlation = 0.945 at offset = (-2, 1)
[INFO] Insufficient correlation
[INFO] Box failed
[INFO] Testing box at 29.1666 N, 83.0324 W
[INFO] Land/water class separation distance = 3.54
[INFO] Image correlation = 0.985 at offset = (-2, 1)
[INFO] Box offset = (-2, 1)
[INFO] Testing box at 29.9141 N, 84.3543 W
[INFO] Land/water class separation distance = 4.514
[INFO] Image correlation = 0.976 at offset = (-2, 0)
[INFO] Box offset = (-2, 0)
[INFO] Testing box at 30.3258 N, 88.1352 W
[INFO] Land/water class separation distance = 3.006
[INFO] Image correlation = 0.954 at offset = (-3, 0)
[INFO] Box offset = (-3, 0)
[INFO] Testing box at 27.8423 N, 82.5433 W
[INFO] Land/water class separation distance = 3.59
[INFO] Image correlation = 0.953 at offset = (-2, 1)
[INFO] Box offset = (-2, 1)
[INFO] Mean offset = (-2.25, 0.5)
[INFO] Applying navigation correction
```

Another example below shows the correction of a Hawaii AVHRR HDF file using many 15 by 15 pixel navigation boxes distributed throughout the islands. AVHRR channel 2 data is used to compute the optimal offset, and the final correction is applied only to AVHRR sensor bands and derived variables.

```
phollema$ cwautonav -v --match '(avhrr.*|sst|cloud)' --width 15 --height 15
  navbox3.txt avhrr_ch2 2005_042_0051_n16_hr.hdf

[INFO] Reading input 2005_042_0051_n16_hr.hdf
[INFO] Testing box at 21.7885 N, 160.2259 W
[INFO] Land/water class separation distance = 1.537
[INFO] Insufficient separation
[INFO] Box failed
[INFO] Testing box at 21.9856 N, 160.0938 W
[INFO] Land/water class separation distance = 1.395
[INFO] Insufficient separation
[INFO] Box failed
[INFO] Testing box at 21.6033 N, 158.2847 W
[INFO] Land/water class separation distance = 1.562
[INFO] Insufficient separation
[INFO] Box failed
```

```
[INFO] Testing box at 21.7144 N, 157.9678 W
[INFO] Land/water class separation distance = 1.982
[INFO] Insufficient separation
[INFO] Box failed
[INFO] Testing box at 21.0961 N, 157.3207 W
[INFO] Land/water class separation distance = 1.517
[INFO] Insufficient separation
[INFO] Box failed
[INFO] Testing box at 21.2448 N, 157.2547 W
[INFO] Land/water class separation distance = 2.252
[INFO] Insufficient separation
[INFO] Box failed
[INFO] Testing box at 21.2076 N, 156.9774 W
[INFO] Land/water class separation distance = 3.236
[INFO] Image correlation = 0.973 at offset = (-2, 0)
[INFO] Box offset = (-2, 0)
[INFO] Testing box at 21.1581 N, 156.7001 W
[INFO] Land/water class separation distance = 2.293
[INFO] Insufficient separation
[INFO] Box failed
[INFO] Testing box at 20.9225 N, 157.0698 W
[INFO] Land/water class separation distance = 1.448
[INFO] Insufficient separation
[INFO] Box failed
[INFO] Testing box at 20.7115 N, 156.9642 W
[INFO] Land/water class separation distance = 1.506
[INFO] Insufficient separation
[INFO] Box failed
[INFO] Testing box at 21.3067 N, 158.1130 W
[INFO] Land/water class separation distance = 1.601
[INFO] Insufficient separation
[INFO] Box failed
[INFO] Testing box at 21.3067 N, 157.6508 W
[INFO] Land/water class separation distance = 1.593
[INFO] Insufficient separation
[INFO] Box failed
[INFO] Testing box at 20.5374 N, 156.7001 W
[INFO] Land/water class separation distance = 5.142
[INFO] Image correlation = 0.978 at offset = (-2, 0)
[INFO] Box offset = (-2, 0)
[INFO] Testing box at 20.5499 N, 156.5680 W
[INFO] Land/water class separation distance = 2.834
[INFO] Image correlation = 0.947 at offset = (-2, -1)
[INFO] Insufficient correlation
[INFO] Box failed
[INFO] Testing box at 20.5996 N, 156.4360 W
[INFO] Land/water class separation distance = 2.285
[INFO] Insufficient separation
```

```
[INFO] Box failed
[INFO] Testing box at 20.8108 N, 156.5152 W
[INFO] Land/water class separation distance = 2.092
[INFO] Insufficient separation
[INFO] Box failed
[INFO] Testing box at 20.9349 N, 156.4756 W
[INFO] Land/water class separation distance = 3.629
[INFO] Image correlation = 0.969 at offset = (-2, -1)
[INFO] Box offset = (-2, -1)
[INFO] Testing box at 20.8357 N, 156.1190 W
[INFO] Land/water class separation distance = 2.46
[INFO] Insufficient separation
[INFO] Box failed
[INFO] Testing box at 20.2635 N, 155.8813 W
[INFO] Land/water class separation distance = 2.522
[INFO] Image correlation = 0.964 at offset = (-2, 0)
[INFO] Box offset = (-2, 0)
[INFO] Testing box at 19.5140 N, 154.7985 W
[INFO] Land/water class separation distance = 1.64
[INFO] Insufficient separation
[INFO] Box failed
[INFO] Testing box at 19.7392 N, 155.0230 W
[INFO] Land/water class separation distance = 1.833
[INFO] Insufficient separation
[INFO] Box failed
[INFO] Testing box at 19.7267 N, 155.1022 W
[INFO] Land/water class separation distance = 1.688
[INFO] Insufficient separation
[INFO] Box failed
[INFO] Testing box at 18.9119 N, 155.6965 W
[INFO] Land/water class separation distance = 1.378
[INFO] Insufficient separation
[INFO] Box failed
[INFO] Testing box at 19.8642 N, 155.9342 W
[INFO] Land/water class separation distance = 1.583
[INFO] Insufficient separation
[INFO] Box failed
[INFO] Testing box at 19.0375 N, 155.8813 W
[INFO] Land/water class separation distance = 1.638
[INFO] Insufficient separation
[INFO] Box failed
[INFO] Testing box at 22.0349 N, 159.7901 W
[INFO] Land/water class separation distance = 1.919
[INFO] Insufficient separation
[INFO] Box failed
[INFO] Testing box at 22.1826 N, 159.3279 W
[INFO] Land/water class separation distance = 1.496
[INFO] Insufficient separation
```

```
[INFO] Box failed
[INFO] Mean offset = (-2, -0.25)
[INFO] Applying navigation correction
```

A.5.6 cwangles

Name

cwangles - computes earth location and solar angles.

Synopsis

cwangles [OPTIONS] input

Options:

-f, --float
-d, --double
-h, --help
-l, --location
-s, --scale=FACTOR/OFFSET
-u, --units=TYPE
-v, --verbose
-z, --sunzenith
--version

Description

The angles tool computes earth location and solar angles for an earth data file. Angles may be computed as scaled integer or floating point values, and in radians, degrees, or cosine. The earth location values computed refer to the center of each pixel.

Parameters

Main parameters:

input The input data file name.

Options:

-f, --float Specifies that data should be stored as 32-bit floating point values with no scaling. The default is to store as 16-bit signed integers with a scaling factor of 0.01.

-d, --double Specifies that data should be stored as 64-bit floating point values with no scaling. The default is to store as 16-bit signed integers with a scaling factor of 0.01.

-h, --help Prints a brief help message.

-l, --location Specifies that earth location latitude and longitude data should be computed.

-s, --scale=FACTOR/OFFSET The data scale factor and offset. Data values are scaled to integers using the factor and offset under the equation:

```
integer = value/factor + offset
```

The default factor is 0.01 and offset is 0. This option is ignored if --**float** or --**double** is used.

-v, --verbose Turns verbose mode on. The current status of data computation is printed periodically. The default is to run quietly.

-u, --units=TYPE The units type. Valid units are 'deg' for degrees, 'rad' for radians, or 'cos' for cosine of the angle. The default is to compute angles in degrees.

-z, --sunzenith Specifies that solar zenith angle data should be computed.

--**version** Prints the software version.

Exit status

0 on success, $>$ 0 on failure. Possible causes of errors:

- Invalid command line option
- Invalid input file name
- No angle computations specified

Examples

The following shows the computation of latitude and longitude data for a CoastWatch HDF product file:

```
phollema$ cwangles --float --location Master.hdf

[INFO] Reading input Master.hdf
[INFO] Creating latitude variable
[INFO] Creating longitude variable
[INFO] Calculating angles
[INFO] Computing row 0
[INFO] Computing row 100
[INFO] Computing row 200
[INFO] Computing row 300
[INFO] Computing row 400
[INFO] Computing row 500
```

Another example below shows the computation of solar zenith angle, stored as the cosine and scaled to integer data by 0.0001:

```
phollema$ cwangles -v --sunzenith --units cos --scale 0.0001/0 test_angles.hdf

[INFO] Reading input test_angles.hdf
[INFO] Creating sun_zenith variable
[INFO] Calculating angles
[INFO] Computing row 0
[INFO] Computing row 100
[INFO] Computing row 200
[INFO] Computing row 300
[INFO] Computing row 400
[INFO] Computing row 500
[INFO] Computing row 600
[INFO] Computing row 700
[INFO] Computing row 800
[INFO] Computing row 900
[INFO] Computing row 1000
[INFO] Computing row 1100
[INFO] Computing row 1200
```

A.6 Hidden command line options

There are a number of useful options for the command line tools that are not documented in the tool manual pages themselves. This is because they can be used with all tools or some large subset of tools, and they alter some subtle feature of a tool's internal behaviour for which there is a reasonable default setting. However, some users may want to tune or optimize these defaults. All of the options are specified using a somewhat odd syntax with a leading `-J` to protect them from being passed to the tool command line processing engine – instead they're intercepted and passed to the Java VM to become part of the Java environment in which the tool runs. The options are as follows:

`-J-XmxSIZEm` The maximum Java heap size where SIZE is replaced by a size in megabytes, for example `-J-Xmx1024m` would specify a gigabyte. The heap is where Java allocates memory dynamically as new objects are created on-the-fly. A larger heap may be required if an out of memory error is thrown when running a tool. The tools all have slightly different default values for the maximum heap size, as required by their function. For example, cwrender has a default heap size that is larger than cwinfo.

`-J-Dcw.cache.size=SIZE` The maximum cache size for storing tiles of 2D data read from data files, currently only implemented for NetCDF files. The SIZE is replaced by a size in megabytes, with a default value of 512 Mb. For example `-J-Dcw.cache.size=1024` specifies a cache size of 1024 Mb. A larger cache size may be needed for some files when the files are written with monolithic compression, ie: the entire data variable is compressed and written as one chunk which expands to a size larger than 512 Mb in memory. We generally discourage data providers from using monolithic data variables because they require decompression of an entire variable even if only one value or a small section is being accessed, which greatly increases the time for interactive display and analysis or automated data processing.

`-J-Dcw.compress.mode=true|false` The compression mode flag for writing CoastWatch HDF data files, by default true. When true, HDF4 data files are created or modified so that each variable is compressed into square chunks. In some cases this may be undesirable if processing speed is important, for example if the file is being written from cwmath as an intermediate step in a longer computation, and the file will be deleted afterwards. When false, HDF4 data files are written without chunking or compression. This increases the speed at which files can be written and subsequently read from.

`-J-Dcw.chunk.size=SIZE` The chunk size used for writing CoastWatch HDF data files, by default 512 kb. The SIZE is replaced by a size in kilobytes, so for example `-J-Dcw.chunk.size=1024` writes data in 1 Mb chunks. Note that this is different from the chunk dimensions. If the chunk size is 512 kb, then 16-bit integer data is written in chunks of dimensions 512×512 because 2 bytes per value × 512 × 512 = 524288 bytes = 512 kb. This is no coincidence, since CoastWatch HDF with AVHRR data originally contained mostly 16-bit scaled integer data and 512×512 was a convenient chunk size for fast reading and display. Using 512 kb chunks means that 8-bit byte data is written in 724×724 chunks, 32-bit float data is written in 362×362 chunks, and so on.

Appendix B

CoastWatch HDF Metadata Specification

B.1 Overview

CoastWatch HDF format may be used to store almost any scientific data that has an associated set of earth locations, including satellite data and output from numerical models. The term *metadata* refers to information describing data. HDF stores metadata as a set of attribute name and value pairs. For example, if a dataset is derived from a satellite called NOAA-16, it is useful to store the attribute name `satellite` and value `noaa-16` along with the data to denote its origin. Along these lines, the CoastWatch metadata standards have been written to help developers write software to read and write data and its associated metadata in a consistent fashion. This document describes the standard and can be used as a reference guide to the HDF attribute names and values in CoastWatch HDF files. A number of overall conventions are used for storing data:

1. Multiple 2D data grids are stored in one HDF file using the HDF Scientific Data Sets (SDS) model. A standard CoastWatch HDF file contains data for one region only.

2. A standard set of global attributes is encoded with the data, describing the date and time, earth locations, data source or satellite/ sensor, and so on from which the data originated.

3. A standard set of variable attributes is encoded with each variable, describing the variable units, scaling factor, and so on as well as any other important information.

As the requirements for the CoastWatch HDF format evolve, new metadata specifications are added, thus new metadata *versions* support features that older versions do not. An effort is made with each new metadata version to maintain compatibility with older versions:

Version 2.4 The original metadata version supported by the CW utilities version 2.3 and 2.4 and CDAT 0.6 and 0.7. CoastWatch HDF was originally designed to store projection-mapped satellite data only, and had a very limited set of metadata.

Version 3.1 Support was added for multiple metadata versions, unmapped swath data, per-variable navigation transforms, and the interpretation of the `et_affine` attribute was changed.

Version 3.2 Support was added for non-satellite derived data, composite datasets from multiple time ranges, raster pixel types, region codes and names, temporal extents, vector direction variables, polygon outlines, and various other features.

Version 3.3 Support was added for satellite sensor scan projection type.

Version 3.4 Units strings were standardized to use Unidata UDUNITS style. Vector direction variables now have a convention attribute.

B.2 Global Metadata

The following table lists the standard set of global attributes for CoastWatch HDF:

Attribute name	HDF type	Description	Since version
`cwhdf_version`†	CHAR8	The metadata version. The version is written as a string attribute but should be interpreted as a fractional number, for example 2.3 or 3.1. If absent, version 2.4 is assumed.	3.1
`satellite`‡	CHAR8	If data is from a satellite, the satellite name, for example `noaa-16`, `goes-8`, `orbview-2`.	2.4
	CHAR8	If the data is a composite, multiple values are newline-separated.	3.2
`sensor`‡	CHAR8	If data is from a satellite, the satellite sensor name, for example `avhrr`, `seawifs`.	2.4
	CHAR8	If the data is a composite, multiple values are newline-separated.	3.2
`data_source`‡	CHAR8	If data is not from a satellite, the data source, for example the instrument used to collect the data or the model used to generate the data. If the data is a composite, multiple values are newline-separated.	3.2
`composite`	CHAR8	The composite flag, `true` if the data is derived from multiple datasets, or `false` if not. If true, then the `pass_date`, `start_time`, and `temporal_extent` attributes may contain arrays of values, and the `satellite`, `sensor`, `data_source`, `orbit_type`, `pass_type`, and `origin` attributes may have multiple newline-separated values. If absent, it is assumed that the data is not a composite.	3.2

Attribute name	HDF type	Description	Since version
pass_date†	INT32	The date of data recording in days since January 1, 1970.	2.4
	INT32[ ]	If the data is a composite, the dates of data recording in days since January 1, 1970. Date and time data must be stored in sorted order from least recent to most recent.	3.2
start_time†	FLOAT64	The start time of the data recording in seconds since 00:00:00 UTC.	2.4
	FLOAT64[ ]	If the data is a composite, the start times of data recording in seconds since 00:00:00 UTC.	3.2
temporal_extent	FLOAT64[ ]	The time duration in seconds between the start of data recording and the end of data recording. Multiple values may be present if the data is a composite. If absent, it is assumed that each data recording is instantaneous.	3.2
pass_type	CHAR8	The satellite pass temporal type: `day`, `night`, `day/night`. If the data has been registered to a different spatial grid than the original data capture, this attribute indicates the original source temporal type.	2.4
	CHAR8	If the data is a composite, multiple values are newline-separated.	3.2
orbit_type	CHAR8	If the data is from an orbiting satellite that crosses the equator in a northward or southward direction, the orbit type as `ascending` or `descending` respectively. If the data is a composite, multiple values are newline-separated.	3.2
origin†	CHAR8	The original data source as an agency or organization name, for example `USDOC/NOAA/NESDIS CoastWatch`.	2.4
	CHAR8	If the data is a composite, multiple values are newline-separated.	3.2
history†	CHAR8	A newline-separated list of utilities and command line parameters used to create the file and perform processing.	2.4

†This attribute is required. Other attributes are optional.
‡Either `satellite` and `sensor`, or `data_source` are required, but not both.

B.3 Earth Location Metadata

In addition to the standard global attributes listed above, a number of earth location attributes are also present. Prior to version 3.1, only mapped data was supported. For mapped data, all map projection calculations are performed using the General Cartographic Transformation Package (GCTP) from the USGS National Mapping Division. A number of global attributes are dedicated to storing GCTP related parameters. For documentation on the allowed values of GCTP parameters, see section B.6. The table below lists the

standard set of global attributes for earth location metadata:

Attribute name	HDF type	Description	Since version
`projection_type` †	CHAR8	The projection type: `mapped`, `swath`, or `sensor_scan`. Mapped data is formatted to a well-known map projection and accompanied by GCTP map projection parameters. Swath data is data that is not in a standard map projection, but is accompanied by earth location data for each pixel (see section B.5 on swath data). Sensor scan data is similar to swath in that it cannot be described by a set of map projection parameters, but it can be described by a set of sensor-specific parameters and does not require earth locations to be stored for each pixel.	3.1
`projection`‡	CHAR8	For mapped data, a descriptive projection name, for example `mercator`, `geographic`, `polar stereographic`.	2.4
`gctp_sys`‡	INT32	For mapped data, the GCTP projection system code.	2.4
`gctp_zone`‡	INT32	For mapped data, the GCTP zone for UTM projections.	2.4
`gctp_parm`‡	FLOAT64[ ]	For mapped data, the GCTP projection parameters (15).	2.4
`gctp_datum`‡	INT32	For mapped data, the GCTP spheroid code.	2.4
`et_affine`‡	FLOAT64[ ]	For mapped data, the map affine transform (6).	2.4
`sensor_code`*	INT32	For sensor scan data, the sensor code. The only code currently available is 0, which indicates a geostationary satellite.	3.3
`sensor_parm`*	FLOAT64[ ]	For sensor scan data, the sensor parameters. For a geostationary satellite (`sensor_code=0`): 1. Subpoint latitude in degrees (geocentric). 2. Subpoint longitude in degrees. 3. Distance of satellite from center of Earth in kilometers. 4. Scan step angle in row direction in radians. 5. Scan step angle in column direction in radians.	3.3
`rows`†	INT32	The number of rows of data.	2.4
`cols`†	INT32	The number of columns of data.	2.4
`polygon_latitude`	FLOAT64[ ]	Latitude components of the bounding polygon with initial element repeated.	3.2
`polygon_longitude`	FLOAT64[ ]	Longitude components of the bounding polygon with initial element repeated.	3.2

Attribute name	HDF type	Description	Since version
raster_type	CHAR8	One of RasterPixelIsArea or RasterPixelIsPoint to capture the same distinction as the GeoTIFF global attribute GTRasterTypeGeoKey. If pixels represent point data, then extra SDS variables latitude and longitude in the dataset localize the point within the pixel area which otherwise defaults to the pixel center. If absent, pixels are assumed to represent area data.	3.2
region_code	CHAR8	The data processing region code as a short abbreviation.	3.2
region_name	CHAR8	The data processing region name in full.	3.2
station_code	CHAR8	The data capture ground station as a short abbreviation.	3.2
station_name	CHAR8	The data capture ground station name in full.	3.2

†This attribute is required. Other attributes are optional.
‡Required for mapped data only.
*Required for sensor scan data only.

B.3.1 Version 2 Affine

The et_affine attribute is used by CoastWatch software to translate between map (x,y) coordinates in meters and image (row,col) coordinates. GCTP is used to translate between (lat,lon) in degrees and map (x,y) in meters. With this two-step process, the translation between image (row,col) and earth location (lat,lon) is very flexible and can be expressed partly as a linear coordinate transform. The six affine transform parameters are used in a matrix equation as follows. Let $a..f$ be the et_affine attribute array values $0..5$, (X, Y) be map coordinate easting and northing in meters, and (R, C) be 1-relative row and column image coordinates, then:

$$\begin{bmatrix} X \\ Y \\ 1 \end{bmatrix} = \begin{bmatrix} a & b & e \\ c & d & f \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} C \\ R \\ 1 \end{bmatrix}$$

or alternatively:

$$\begin{aligned} X &= aC + bR + e \\ Y &= cC + dR + f \end{aligned}$$

The inverse operation may be performed by inverting the affine transform:

$$\begin{aligned} \alpha &= ad - bc \\ a' &= d/\alpha \\ b' &= -b/\alpha \\ c' &= -c/\alpha \\ d' &= a/\alpha \\ e' &= -(a'e + b'f) \\ f' &= -(c'e + d'f) \end{aligned}$$

$$\begin{bmatrix} C \\ R \\ 1 \end{bmatrix} = \begin{bmatrix} a' & b' & e' \\ c' & d' & f' \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ 1 \end{bmatrix}$$

or alternatively:

$$\begin{aligned} C &= a'X + b'Y + e' \\ R &= c'X + d'Y + f' \end{aligned}$$

B.3.2 Version 3 Affine

The conventions of the `et_affine` attribute are slightly different in version 3 metadata. The affine transform is stored and used (in matrix form) as:

$$\begin{bmatrix} X \\ Y \\ 1 \end{bmatrix} = \begin{bmatrix} a & c & e \\ b & d & f \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} R \\ C \\ 1 \end{bmatrix}$$

or alternatively:

$$\begin{aligned} X &= aR + cC + e \\ Y &= bR + dC + f \end{aligned}$$

where (R, C) are 0-relative, **not** 1-relative image coordinates. Deriving the inverse transform is similarly changed.

B.4 Variable Metadata

The following table shows the standard set of variable attributes for CoastWatch HDF. Some attribute groups are created by HDF SD convenience functions in order to make data more readable and usable by generic HDF viewing programs. A <*var*> in the *HDF Type* indicates that the attribute type is the same as the variable data type.

Attribute name	HDF type	Description	Since version
long_name†	CHAR8	*Written by SDsetdatastrs.* A descriptive variable name, for example AVHRR channel 4, sea surface temperature.	2.4
units†	CHAR8	*Written by SDsetdatastrs.* A descriptive units name in the conventions used by the Unidata UDUNITS package and its supported units file. Many common units are acceptable (and various forms of those units), for example kelvin, celsius and fahrenheit for temperature data, knots, meters per second or m/s for windspeed, mg per m^-3 or kg/m-3 for concentration, percent or % for reflectance, and degrees or radians for angles.	2.4, updated in 3.4
format†	CHAR8	*Written by SDsetdatastrs.* A FORTRAN-77 style format string, for example F7.2.	2.4
coordsys†	CHAR8	*Written by SDsetdatastrs.* A descriptive coordinate system name, the same as the global projection attribute.	2.4
_FillValue	<*var*>	*Written by SDsetfillvalue.* The value used to fill in for missing or unwritten data.	2.4
scale_factor‡	FLOAT64	*Written by SDsetcal.* The calibration scale factor.	2.4
scale_factor_err‡	FLOAT64	*Written by SDsetcal.* The calibration scale error.	2.4
add_offset‡	FLOAT64	*Written by SDsetcal.* The calibration offset.	2.4
add_offset_err‡	FLOAT64	*Written by SDsetcal.* The calibration offset error.	2.4
calibrated_nt‡	INT32	*Written by SDsetcal.* The HDF data type code for uncalibrated data.	2.4
C_format†	CHAR8	A C style format string, for example %7.2f.	2.4
missing_value	<*var*>	The value used to fill in for missing or unwritten data; same as _FillValue.	2.4
fraction_digits†	INT32	The number of significant digits after the decimal place for calibrated or floating-point variable data. This is an alternative to the C or FORTRAN notation for value formatting and is independent of the programming language.	3.1
nav_affine	FLOAT64[ ]	The navigation correction affine transform. If absent, an identity transform is assumed.	3.1
direction_variable	CHAR8	The name of the associated SDS variable for vector direction. Any variable with this attribute is assumed to be the magnitude component of a vector field, for which the named variable is the direction component. The direction component is encoded as degrees clockwise from north.	3.2

Attribute name	HDF type	Description	Since version
direction_convention	CHAR8	When this SDS variable is the direction component of a vector, the convention for the direction is either DirectionIsTo or DirectionIsFrom to indicate that the direction indicates where the vectors are pointing to, or pointing from. For example, wind direction is normally quoted as where the wind is coming from, where as ocean currents are quoted as where the current is moving towards. This attribute is only required for direction component SDS variables (see the direction_variable attribute).	3.4
quality_flag	CHAR8	The name of the associated SDS variable that contains quality flag information.	3.2
quality_mask	INT64	The value to use as a mask in a bitwise AND operation to isolate the quality bits in the SDS variable named by the quality_flag attribute.	3.2
flag_bits	CHAR8	The newline-separated list of flag descriptions for each bit from least significant to most significant. This is generally only required if this SDS variable contains quality flag information for another SDS variable. Any unused bits are denoted by Unused.	3.2

† This attribute is required. Other attributes are optional.
‡ Required for calibrated data only.

B.4.1 Calibration Values

The calibration attributes are used to read and write variable data as follows:

$$\begin{aligned} float &= \texttt{scale\_factor}(int - \texttt{add\_offset}) \quad (\text{on read}) \\ int &= float/\texttt{scale\_factor} + \texttt{add\_offset} \quad (\text{on write}) \end{aligned}$$

where $float$ and int are the floating-point and integer values respectively. See the HDF User's Guide for more details on data calibration. If no calibration data is found, the data is assumed to be already calibrated.

B.4.2 Navigation Correction

The navigation correction transform has 6 coefficients, similar to the global et_affine attribute, and is used (in matrix form) as:

$$\begin{bmatrix} R' \\ C' \\ 1 \end{bmatrix} = \begin{bmatrix} a & c & e \\ b & d & f \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} R \\ C \\ 1 \end{bmatrix}$$

where$a..f$ are the nav_affine matrix coefficients in order and (R', C') are the actual image coordinates at which the desired data value for (R, C) may be found.

B.5 Swath Earth Location Encoding

There are currently two methods for specifying earth location data for CoastWatch HDF swath files:

1. **Explicit encoding:** Two standard 2D HDF SDS variables named `latitude` and `longitude` are written to the file. Each variable must be accompanied with appropriate metadata as outlined above. The latitude and longitude data must not have any values set to the missing or fill value, or problems may occur in performing earth coordinate transformations.
2. **Polynomial encoding:** A number of 1D HDF SDS variables named *swath_struct*, *swath_bounds*, *swath_lat*, and *swath_lon* are used to define data structures for use in a polynomial approximation algorithm that supports an efficient and accurate estimation of latitude and longitude values for the swath data.

The polynomial encoding option is described in this section. The polynomial approximation scheme is given, along with details on the required HDF variables.

The easiest approach to swath earth location encoding is to simply record latitude and longitude values for every data value in the swath. For a typical AVHRR swath size of 2048×5000, this can add about 80 Mb of extra data to a file using 32-bit floating point values. To convert a data (row,col) coordinate to geographic (lat,lon) coordinate, an application simply reads the (lat,lon) data at the specified coordinate from the file. This method requires either a large amount of file I/O or a large amount of memory, depending on how much of the earth location data is read at once. It also does not lend itself to an efficient reverse lookup algorithm for converting an arbitrary (lat,lon) back to (row,col).

In order to support swath data in CoastWatch HDF files but avoid the overhead of storing the earth locations, a polynomial approximation scheme is used. The approximation scheme also lends itself to an efficient reverse lookup algorithm. The approximation divides the data into a number of rectangular partitions of varying size in rows and columns but bounded physical size in kilometres. For a typical AVHRR swath whose resolution is lowest at the left and right edge of the image data, the rectangular partitioning may look something like Figure B.1.

The approximation derives a set of bivariate polynomials on each partition for latitude and longitude estimation. To convert a (row,col) coordinate to (lat,lon), the partitions are first searched for the one containing the data coordinate. Using the polynomials for that partition, latitude and longitude are calculated for the data coordinate using the polynomial coefficients. By bounding the physical size of each partition, it is possible to bound the error in latitude and longitude estimation. For a typical AVHRR pass, it has been found that a 100 km maximum partition size yields a maximum error of approximately 50 m in earth location.

The polynomial approximation scheme used is as follows. For each partition, nine latitude and longitude values are sampled in a 3×3 grid pattern as shown in Figure B.2. The (row,col) coordinates and (lat,lon) data values are used to derive two independent sets of 9 polynomial coefficients, one set for latitude and one set for longitude. These coefficients, denoted $a_0..a_8$ and $b_0..b_8$ can be used to recover the latitude and longitude values using the formulae:

$$\begin{aligned} lat(x,y) &= a_0 + a_1x + a_2x^2 + a_3y + a_4xy + a_5x^2y + a_6y^2 + a_7xy^2 + a8x^2y^2 \\ lon(x,y) &= b_0 + b_1x + b_2x^2 + b_3y + b_4xy + b_5x^2y + b_6y^2 + b_7xy^2 + b_8x^2y^2 \end{aligned}$$

where x is the image row and y is the image column. Note that the polynomial approximation also acts to interpolate (lat,lon) coordinates between integer data coordinates, since there are no requirements on x and

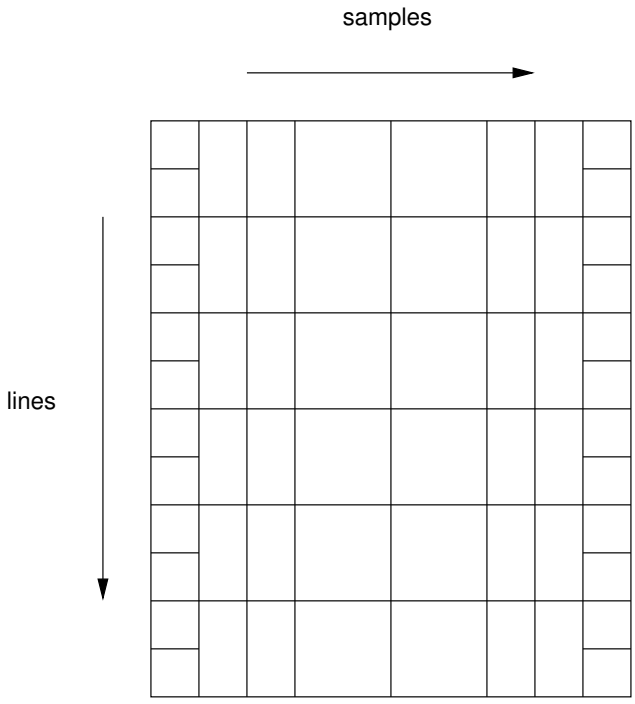


Figure B.1: A partitioning of AVHRR swath data. Each partition has a bounded physical size in the lines and samples directions.

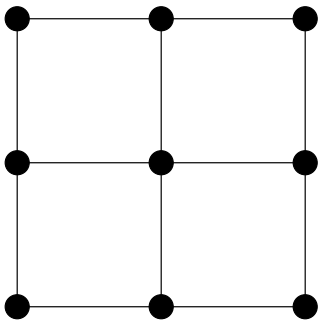


Figure B.2: Sampling pattern for polynomial approximation. Each • symbol is a sampling point for latitude and longitude.

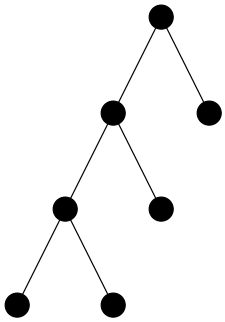


Figure B.3: Binary tree encoding example. The tree is encoded under a preorder traversal by the binary string 000111.

y to be integers in the above equations. This is important for the accuracy of the reverse-lookup algorithm described later.

Since each partition is associated with its own set of coefficients, a simple algorithm to search for the appropriate partition for a data (row,col) coordinate is to loop through all partitions, checking the row and column bounds on each partition until one containing the desired (row,col) coordinate is found. If there are n partitions, then the loop will perform $O(n)$ (where $O()$ denotes an *order of* upper bound relationship) partition bound checks. In order to avoid this, a binary tree is used to arrange the partitions in a hierarchical structure. The set of partitions with polynomial coefficients form the leaves of the tree. The relationship between parent and child nodes is such that each child is a binary sub-partition of the parent. In this way, a search through n partitions is replaced by a search down the binary tree through $O(\log n)$ partitions until a leaf is encountered. For encoding purposes, a binary tree structure may be encoded uniquely using a preorder traversal of its nodes. A 0 is used to encode a left child, and a 1 for a right child (the root is not recorded because we assume that the preorder traversal starts at the root). Figure B.3 shows the binary tree for the encoding 000111. A more complex example in Figure B.4 show the binary tree for the encoding 000111001101.

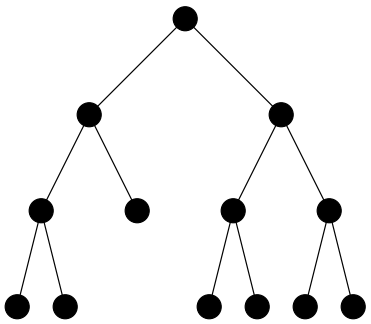


Figure B.4: A more complex binary tree encoding example. The tree is encoded under a preorder traversal by the binary string 000111001101.

For a complete encoding of the swath including the polynomial coefficients for each leaf partition, all partition boundaries, and the binary tree structure, the following HDF variables are used:

Variable name	HDF type	Description
`swath_struct`	INT8	A preorder encoding of the binary tree. The encoding bits are zero-padded at the end to the nearest byte.
`swath_bounds`	FLOAT64	Upper-left and lower-right (row,col) bounds for each partition. All partition bounds are recorded, including all leaf and non-leaf partitions in the tree.
`swath_lat`	FLOAT64	Latitude polynomial coefficients for each leaf partition. There are 9 coefficients stored for each partition.
`swath_lon`	FLOAT64	Longitude polynomial coefficients for each leaf partition. There are 9 coefficients stored for each partition.

This encoding may be used to re-create the tree structure and populate the tree with partition bound and polynomial information. For a typical AVHRR pass which might require 80 Mb of data if all (lat,lon) coordinates were pre-computed, this encoding only requires about 500 kb using a maximum partition size of 100 km.

Finally, the reverse-lookup algorithm to convert (lat,lon) coordinates back to (row,col) is as follows. Define the following symbols:

Let T be a tolerance distance in kilometers.
Let $\overrightarrow{C}_g^{in}$ be the input geographic (lat,lon) coordinate.
Let $\overrightarrow{C}_d^{out}$ be the output data (row,col) coordinate.
Let $D_{\overrightarrow{C}_g}(\overrightarrow{C}_d)$ be a function that computes the physical distance in kilometers between geographic coordinate $\overrightarrow{C}_g$ and data coordinate $\overrightarrow{C}_d$.
Let N_r and N_c be the total number of rows and columns.
Let $\overrightarrow{\nabla}_d$ be the gradient operator in data coordinates, $\overrightarrow{\nabla}_d = (\frac{\partial}{\partial r}, \frac{\partial}{\partial c})$.

Now, initialize $\overrightarrow{C}_d^{out}$ and iterate until the tolerance is satisfied:

$\overrightarrow{C}_d^{out} = (N_r/2, N_c/2)$
$d = D_{\overrightarrow{C}_g^{in}}(\overrightarrow{C}_d^{out})$
while $d > T$ {
  $\overrightarrow{u} = \overrightarrow{\nabla}_d D_{\overrightarrow{C}_g}(\overrightarrow{C}_d)$
  $\hat{u} = \overrightarrow{u}/|\overrightarrow{u}|$
  $\overrightarrow{C}_d^{out} = \overrightarrow{C}_d^{out} - d\hat{u}$
  $d = D_{\overrightarrow{C}_g^{in}}(\overrightarrow{C}_d^{out})$
}

This algorithm is particularly well suited to be used with a polynomial approximation scheme for (lat,lon) because it can provide sub-pixel accuracy in the (row,col) coordinate. For example as part of a data resampling algorithm, once a fractional data coordinate is obtained for a given (lat,lon), nearest neighbour or bilinear interpolation may then be used to provide a smooth data resampling.

B.6 GCTP Appendices

```
Function Description
********************

gctp - Initializes projection transformation parameters and performs
transformations.

SYNTAX

  FUNCTION gctp (incoor, insys, inzone, inparm, inunit, indatum, ipr,
  efile, jpr, pfile, outcoor, outsys, outzone, outparm, outunit,
  outdatum, fn27, fn83, iflg)

  double incoor[2];
  long *insys;
  long *inzone;
  double inparm[15];
  long *inunit;
  long *indatum;
  long *ipr;
  char efile[];
  long *jpr;
  char pfile[];
  double outcoor[2];
  long *outsys;
```

```
  long *outzone;
  double outparm[15];
  long *outunit;
  long *outdatum;
  char fn27[];
  char fn83[];
  long *iflg;

PARAMETERS

* incoor (input, double, length(2))

  Array of two input coordinates (X-Y, Longitude-Latitude,
  Northing-Easting, etc) to be translated. The nature of the
  coordinates is defined by insys, inzone, and inunit. The east-west
  dimension (X, Longitude, Easting) is first followed by the
  north-south (Y, latitude, Northing).

* insys (input, long)

  Defines the input projection system. Valid codes are:
  = 0: GEO (Geographic)
  = 1: UTM (Universal Transverse Mercator)
  = 2: SPCS (State Plane Coordinates)
  = 3: ALBERS (Albers Conical Equal Area)
  = 4: LAMCC (Lambert Conformal Conic)
  = 5: MERCAT (Mercator)
  = 6: PS (Polar Stereographic)
  = 7: POLYC (Polyconic)
  = 8: EQUIDC (Equidistant Conic)
  = 9: TM (Transverse Mercator)
  = 10: STEREO (Stereographic)
  = 11: LAMAZ (Lambert Azimuthal Equal Area)
  = 12: AZMEQD (Azimuthal Equidistant)
  = 13: GNOMON (Gnomonic)
  = 14: ORTHO (Orthographic)
  = 15: GVNSP (General Vertical Near-Side Perspective)
  = 16: SNSOID (Sinusoidal)
  = 17: EQRECT (Equirectangular)
  = 18: MILLER (Miller Cylindrical)
  = 19: VGRINT (Van der Grinten)
  = 20: HOM (Hotine Oblique Mercator--HOM)
  = 21: ROBIN (Robinson)
  = 22: SOM (Space Oblique Mercator--SOM)
  = 23: ALASKA (Modified Stereographic Conformal--Alaska)
  = 24: GOOD (Interrupted Goode Homolosine)
  = 25: MOLL (Mollweide)
  = 26: IMOLL (Interrupted Mollweide)
```

```
  = 27: HAMMER (Hammer)
  = 28: WAGIV (Wagner IV)
  = 29: WAGVII (Wagner VII)
  = 30: OBLEQA (Oblated Equal Area)

* inzone (input, long)

  Input zone for UTM and State Plane projection systems. The UTM
  Coordinate System (insys = 1) and State Plane Coordinate System
  (insys = 2) use zone codes instead of specific projection parameters
  (See Appendix B--UTM and Appendix C--State Plane). For Southern
  Hemisphere UTM, use a negative zone code. Inzone will be ignored for
  all other projections.

* inparm (input, double, length(15))

  Array of fifteen projection parameters. These parameters are
  required to define each map projection.  (See Appendix A)

* inunit (input, long)

  Unit code for input coordinates. Valid unit codes are:
  = 0: radians
  = 1: U.S. feet
  = 2: meters
  = 3: seconds of arc
  = 4: degrees of arc
  = 5: International feet
  = 6: Table supplying the unit code, which is legislated
       for the State zone selected

* indatum (input, long)

  Input spheroid code. This identifies the semi-major axis and
  eccentricity that is to be used in the transformation process. If a
  negative spheroid code is entered, inparm elements 1 and 2 are to be
  used (See Appendix A). Supported spheroids include:
  = 0: Clarke 1866 (default)
  = 1: Clarke 1880
  = 2: Bessel
  = 3: International 1967
  = 4: International 1909
  = 5: WGS 72
  = 6: Everest
  = 7: WGS 66
  = 8: GRS 1980
  = 9: Airy
  = 10: Modified Everest
```

```
  = 11: Modified Airy
  = 12: WGS 84
  = 13: Southeast Asia
  = 14: Australian National
  = 15: Krassovsky
  = 16: Hough
  = 17: Mercury 1960
  = 18: Modified Mercury 1968
  = 19: Sphere of Radius 6370997 meters

  Note: State Plane projection (insys = 2) only supports Clarke 1866
  (indatum = 0) and GRS 1980 (indatum = 8) spheroids corresponding to
  datums NAD27 and NAD83 respectively (See Appendix B).

* ipr (input, long)

  Error message print flag. If ipr is zero, error messages will be
  printed to the terminal. If ipr is one, error messages will be
  printed to efile. If ipr is two, error messages will be printed to
  both the terminal and efile. If ipr is something else, error
  messages will not be printed.

* efile (input, character, length(*))

  The file which will contain the output error messages. efile need
  not be opened at this time.

* jpr (input, long)

  Projection parameter print flag. If jpr is zero, projection
  parameters will be printed to the terminal. If jpr is one,
  projection parameters will be printed to pfile. If jpr is two,
  projection parameters will be printed to both the terminal and
  pfile. If jpr is something else, the projection parameters will not
  be printed. As specified by jpr, Projection parameters are printed
  each time the input projection parameters (insys, inzone, inparm,
  inunit, indatum, outsys, outzone, outparm, outunit, and outdatum)
  change.

* pfile (input, character, length(*))

  The file which will contain the output projection parameter
  messages. pfile need not be opened at this time.

* outcoor (output, double, length(2))

  Array of two transformed coordinates. See incoor for an explanation.
```

```
* outsys (input, long)

  Defines the output projection system. See insys.

* outzone (input, long)

  Output zone for UTM and State Plane projection systems. The UTM
  Coordinate System (outsys = 1) and State Plane Coordinate System
  (outsys = 2) use zone codes instead of specific projection
  parameters (See Appendix B--UTM and Appendix C--State Plane). For
  Southern Hemisphere UTM, use a negative zone code. Outzone will be
  ignored for all other projections.

* outparm (input, double, length(15))

  Array of fifteen projection parameters. These parameters are
  required to define each map projection.  (See Appendix A)

* outunit (input, long)

  Unit code for output coordinates. See inunit.

* outdatum (input, long)

  Output spheroid code. See indatum.

* fn27 (input, character, length(*))

  Name of the file which contains the NAD 1927 State Plane zone
  parameters.

* fn83 (input, character, length(*))

  Name of the file which contains the NAD 1983 State Plane zone
  parameters.

* iflg (output, long)

  Error flag after transformation. The error number returned will
  correspond to the specific error.

DESCRIPTION

  This routine initializes the proper projection parameters when
  initialization is required. The proper informational and error
  message handling is initialized. Then, the incoor coordinates are
  converted from the insys map projection to the outsys map projection
  and are returned in outcoor.
```

```
RETURN VALUE

  gctp() has no return value.


Projection Transformation Package Projection Parameters
*******************************************************
```

Code & Projection Id	Array Element							
	1	2	3	4	5	6	7	8
0 Geographic								
1 U T M	Lon/Z	Lat/Z						
2 State Plane								
3 Albers Equal Area	SMajor	SMinor	STDPR1	STDPR2	CentMer	OriginLat	FE	FN
4 Lambert Conformal C	SMajor	SMinor	STDPR1	STDPR2	CentMer	OriginLat	FE	FN
5 Mercator	SMajor	SMinor			CentMer	TrueScale	FE	FN
6 Polar Stereographic	SMajor	SMinor			LongPol	TrueScale	FE	FN
7 Polyconic	SMajor	SMinor			CentMer	OriginLat	FE	FN
8 Equid. Conic A	SMajor	SMinor	STDPAR		CentMer	OriginLat	FE	FN
Equid. Conic B	SMajor	SMinor	STDPR1	STDPR2	CentMer	OriginLat	FE	FN
9 Transverse Mercator	SMajor	SMinor	Factor		CentMer	OriginLat	FE	FN
10 Stereographic	Sphere				CentLon	CenterLat	FE	FN
11 Lambert Azimuthal	Sphere				CentLon	CenterLat	FE	FN
12 Azimuthal	Sphere				CentLon	CenterLat	FE	FN
13 Gnomonic	Sphere				CentLon	CenterLat	FE	FN
14 Orthographic	Sphere				CentLon	CenterLat	FE	FN
15 Gen. Vert. Near Per	Sphere		Height		CentLon	CenterLat	FE	FN
16 Sinusoidal	Sphere				CentMer		FE	FN
17 Equirectangular	Sphere				CentMer	TrueScale	FE	FN
18 Miller Cylindrical	Sphere				CentMer		FE	FN
19 Van der Grinten	Sphere				CentMer	OriginLat	FE	FN
20 Hotin Oblique Merc A	SMajor	SMinor	Factor			OriginLat	FE	FN
Hotin Oblique Merc B	SMajor	SMinor	Factor	AziAng	AzmthPt	OriginLat	FE	FN
21 Robinson	Sphere				CentMer		FE	FN
22 Space Oblique Merc A	SMajor	SMinor		IncAng	AscLong		FE	FN
Space Oblique Merc B	SMajor	SMinor	Satnum	Path			FE	FN
23 Alaska Conformal	SMajor	SMinor					FE	FN
24 Interrupted Goode	Sphere							
25 Mollweide	Sphere				CentMer		FE	FN
26 Interrupt Mollweide	Sphere							
27 Hammer	Sphere				CentMer		FE	FN
28 Wagner IV	Sphere				CentMer		FE	FN
29 Wagner VII	Sphere				CentMer		FE	FN
30 Oblated Equal Area	Sphere		Shapem	Shapen	CentLon	CenterLat	FE	FN

Array elements 9-15 Continued on page 2

Projection Transformation Package Projection Parameters elements 9-15
continued from page 1:

Code & Projection Id	Array Element 9	10	11	12	13
0 Geographic					
1 U T M					
2 State Plane					
3 Albers Equal Area					
4 Lambert Conformal C					
5 Mercator					
6 Polar Stereographic					
7 Polyconic					
8 Equid. Conic A	zero				
Equid. Conic B	one				
9 Transverse Mercator					
10 Stereographic					
11 Lambert Azimuthal					
12 Azimuthal					
13 Gnomonic					
14 Orthographic					
15 Gen. Vert. Near Per					
16 Sinusoidal					
17 Equirectangular					
18 Miller Cylindrical					
19 Van der Grinten					
20 Hotin Oblique Merc A	Long1	Lat1	Long2	Lat2	zero
Hotin Oblique Merc B					one
21 Robinson					
22 Space Oblique Merc A	PSRev	LRat	PFlag		zero
Space Oblique Merc B					one
23 Alaska Conformal					
24 Interrupted Goode					
25 Mollweide					
26 Interrupt Mollweide					
27 Hammer					
28 Wagner IV					
29 Wagner VII					

```
   30 Oblated Equal Area   |Angle|    |     |    |    |
   ---------------------------------------------------
```

where

Lon/Z	Longitude of any point in the UTM zone or zero. If zero, a zone code must be specified.
Lat/Z	Latitude of any point in the UTM zone or zero. If zero, a zone code must be specified.
SMajor	Semi-major axis of ellipsoid. If zero, Clarke 1866 in meters is assumed.
SMinor	Eccentricity squared of the ellipsoid if less than zero, if zero, a spherical form is assumed, or if greater than zero, the semi-minor axis of ellipsoid.
Sphere	Radius of reference sphere. If zero, 6370997 meters is used.
STDPAR	Latitude of the standard parallel
STDPR1	Latitude of the first standard parallel
STDPR2	Latitude of the second standard parallel
CentMer	Longitude of the central meridian
OriginLat	Latitude of the projection origin
FE	False easting in the same units as the semi-major axis
FN	False northing in the same units as the semi-major axis
TrueScale	Latitude of true scale
LongPol	Longitude down below pole of map
Factor	Scale factor at central meridian (Transverse Mercator) or center of projection (Hotine Oblique Mercator)
CentLon	Longitude of center of projection
CenterLat	Latitude of center of projection
Height	Height of perspective point
Long1	Longitude of first point on center line (Hotine Oblique Mercator, format A)
Long2	Longitude of second point on center line (Hotine Oblique Mercator, format A)
Lat1	Latitude of first point on center line (Hotine Oblique Mercator, format A)
Lat2	Latitude of second point on center line (Hotine Oblique Mercator, format A)
AziAng	Azimuth angle east of north of center line (Hotine Oblique Mercator, format B)
AzmthPt	Longitude of point on central meridian where azimuth occurs (Hotine Oblique Mercator, format B)
IncAng	Inclination of orbit at ascending node, counter-clockwise from equator (SOM, format A)
AscLong	Longitude of ascending orbit at equator (SOM, format A)
PSRev	Period of satellite revolution in minutes (SOM, format A)
LRat	Landsat ratio to compensate for confusion at northern end of orbit (SOM, format A -- use 0.5201613)
PFlag	End of path flag for Landsat: 0 = start of path,

```
                1 = end of path (SOM, format A)
      Satnum    Landsat Satellite Number (SOM, format B)
      Path      Landsat Path Number (Use WRS-1 for Landsat 1, 2 and 3 and
                WRS-2 for Landsat 4, 5 and 6.)  (SOM, format B)
      Shapem    Oblated Equal Area oval shape parameter m
      Shapen    Oblated Equal Area oval shape parameter n
      Angle     Oblated Equal Area oval rotation angle

                                  NOTES

   Array elements 14 and 15 are set to zero
   All array elements with blank fields are set to zero
   All angles (latitudes, longitudes, azimuths, etc.) are entered in packed
        degrees/ minutes/ seconds (DDDMMMSSS.SS) format



   The following notes apply to the Space Oblique Mercator A projection.

      A portion of Landsat rows 1 and 2 may also be seen as parts of rows
   246 or 247.  To place these locations at rows 246 or 247, set the end of
   path flag (parameter 11) to 1--end of path.  This flag defaults to zero.

      When Landsat-1,2,3 orbits are being used, use the following values
   for the specified parameters:

      Parameter 4   099005031.2
      Parameter 5   128.87 degrees - (360/251 * path number) in packed
      DMS format
      Parameter 9   103.2669323
      Parameter 10  0.5201613

      When Landsat-4,5 orbits are being used, use the following values
   for the specified parameters:

      Parameter 4   098012000.0
      Parameter 5   129.30 degrees - (360/233 * path number) in packed
      DMS format
      Parameter 9   98.884119
      Parameter 10  0.5201613


UTM Zone Codes
**************

The Universal Transverse Mercator (UTM) Coordinate System uses zone codes
instead of specific projection parameters.  The table that follows lists
```

UTM zone codes as used by GCTPc Projection Transformation Package.

Zone	C.M.	Range	Zone	C.M.	Range
01	177W	180W-174W	31	003E	000E-006E
02	171W	174W-168W	32	009E	006E-012E
03	165W	168W-162W	33	015E	012E-018E
04	159W	162W-156W	34	021E	018E-024E
05	153W	156W-150W	35	027E	024E-030E
06	147W	150W-144W	36	033E	030E-036E
07	141W	144W-138W	37	039E	036E-042E
08	135W	138W-132W	38	045E	042E-048E
09	129W	132W-126W	39	051E	048E-054E
10	123W	126W-120W	40	057E	054E-060E
11	117W	120W-114W	41	063E	060E-066E
12	111W	114W-108W	42	069E	066E-072E
13	105W	108W-102W	43	075E	072E-078E
14	099W	102W-096W	44	081E	078E-084E
15	093W	096W-090W	45	087E	084E-090E
16	087W	090W-084W	46	093E	090E-096E
17	081W	084W-078W	47	099E	096E-102E
18	075W	078W-072W	48	105E	102E-108E
19	069W	072W-066W	49	111E	108E-114E
20	063W	066W-060W	50	117E	114E-120E
21	057W	060W-054W	51	123E	120E-126E
22	051W	054W-048W	52	129E	126E-132E
23	045W	048W-042W	53	135E	132E-138E
24	039W	042W-036W	54	141E	138E-144E
25	033W	036W-030W	55	147E	144E-150E
26	027W	030W-024W	56	153E	150E-156E
27	021W	024W-018W	57	159E	156E-162E
28	015W	018W-012W	58	165E	162E-168E
29	009W	012W-006W	59	171E	168E-174E
30	003W	006W-000E	60	177E	174E-180W

Obtained from Software Documentation for GCTP General Cartographic Transformation Package: National Mapping Program Technical Instructions, U.S. Geological Survey, National Mapping Division, Oct 1990,

Note: The following source contains UTM zones plotted on a world map:

Snyder, John P. Map Projections--A Working Manual: U.S. Geological Survey Professional Paper 1395 (Supersedes USGS Bulletin 1532), United States Government Printing Office, Washington D.C. 1987. p. 42.

State Plane Zone Codes
****

State Plane Coordinate System uses zone codes instead of specific projection parameters. The table that follows lists State Plane zone codes as used by the GCTPc Projection Transformation Package.

Jurisdiction Zone name or number	Zone Code	Zone Code
Alabama		
East	0101	0101
West	0102	0102
Alaska		
01 through 10	5001	5001
thru	5010	5010
Arizona		
East	0201	0201
Central	0202	0202
West	0203	0203
Arkansas		
North	0301	0301
South	0302	0302
California		
01 through 07	0401	0401
thru	0407	0406
Colorado		
North	0501	0501
Central	0502	0502
South	0503	0503
Connecticut	0600	0600
Delaware	0700	0700
District of Columbia	1900	1900
Florida		
East	0901	0901
West	0902	0902
North	0903	0903
Georgia		
East	1001	1001
West	1002	1002
Hawaii		
01 through 05	5101	5101
thru	5105	5105
Idaho		
East	1101	1101
Central	1102	1102

West	1103	1103
Illinois		
East	1201	1201
West	1202	1202
Indiana		
East	1301	1301
West	1302	1302
Iowa		
North	1401	1401
South	1402	1402
Kansas		
North	1501	1501
South	1502	1502
Kentucky		
North	1601	1601
South	1602	1602
Louisiana		
North	1701	1701
South	1702	1702
Offshore	1703	1703
Maine		
East	1801	1801
West	1802	1802
Maryland	1900	1900
Massachusetts		
Mainland	2001	2001
Island	2002	2002
Michigan		
East(TM)	2101	----
Central(TM)	2102	----
West(TM)	2103	----
North(Lam)	2111	2111
Central(Lam)	2112	2112
South(Lam)	2113	2113
Minnesota		
North	2201	2201
Central	2202	2202
South	2203	2203
Mississippi		
East	2301	2301
West	2302	2302
Missouri		
East	2401	2401
Central	2402	2402
West	2403	2403
Montana	----	2500
North	2501	----
Central	2502	----

South	2503	----
Nebraska	----	2600
North	2601	----
South	2602	----
Nevada		
East	2701	2701
Central	2702	2702
West	2703	2703
New Hampshire	2800	2800
New Jersey	2900	2900
New Mexico		
East	3001	3001
Central	3002	3002
West	3003	3003
New York		
East	3101	3101
Central	3102	3102
West	3103	3103
Long Island	3104	3104
North Carolina	3200	3200
North Dakota		
North	3301	3301
South	3302	3302
Ohio		
North	3401	3401
South	3402	3402
Oklahoma		
North	3501	3501
South	3502	3502
Oregon		
North	3601	3601
South	3602	3602
Pennsylvania		
North	3701	3701
South	3702	3702
Rhode Island	3800	3800
South Carolina	----	3900
North	3901	----
South	3902	----
South Dakota		
North	4001	4001
South	4002	4002
Tennessee	4100	4100
Texas		
North	4201	4201
North Central	4202	4202
Central	4203	4203
South Central	4204	4204

South	4205	4205
Utah		
North	4301	4301
Central	4302	4302
South	4303	4303
Vermont	4400	4400
Virginia		
North	4501	4501
South	4502	4502
Washington		
North	4601	4601
South	4602	4602
West Virginia		
North	4701	4701
South	4702	4702
Wisconsin		
North	4801	4801
Central	4802	4802
South	4803	4803
Wyoming		
East	4901	4901
East Central	4902	4902
West Central	4903	4903
West	4904	4904
Puerto Rico	5201	5200
Virgin Islands	----	5200
St. John, St. Thomas	5201	----
St. Croix	5202	----
American Samoa	5300	----
Guam	5400	----

Obtained from Software Documentation for GCTP General Cartographic Transformation Package: National Mapping Program Technical Instructions, U.S. Geological Survey, National Mapping Division, Oct 1990,

Note: Equations for State Plane zones are given in:

> Clarie, Charles N, State Plane Coordinates by Automatic Data Processing, U.S. Department of Commerce, Environmental Science Services Administration, Coast and Geodetic Survey, United States Government Printing Office, Publication 62-4, 1973.

Appendix C

Data Format Compatibility

Many of the tools automatically detect the input file format and perform the same operation for a number of different formats, for example viewing of HDF 4 and NOAA 1b files. The following table shows the file format compatibility of the various tools:

TOOL	INPUT	OUTPUT
cdat	HDF 4, NetCDF 3/4, NOAA 1b	HDF 4, NetCDF 3/4, Binary, Text, ArcGIS, PNG, GIF, JPEG, PDF, GeoTIFF
cwangles	HDF 4, NetCDF 3	–
cwautonav	HDF 4, NetCDF 3	–
cwcomposite	HDF 4, NetCDF 3/4	HDF 4
cwcoverage	HDF 4, NetCDF 3/4, NOAA 1b	PNG
cwexport	HDF 4, NetCDF 3/4, NOAA 1b	Binary, Text, ArcGIS, NetCDF 3/4
cwgraphics	HDF 4, NetCDF 3/4, NOAA 1b	HDF 4
cwimport	HDF 4, NetCDF 3/4, NOAA 1b	HDF 4
cwinfo	HDF 4, NetCDF 3/4, NOAA 1b	–
cwmaster	HDF 4, NetCDF 3/4	HDF 4
cwmath	HDF 4, NetCDF 3/4, NOAA 1b	HDF 4
cwnavigate	HDF 4, NetCDF 3	–
cwregister	HDF 4, NetCDF 3/4, NOAA 1b	HDF 4
cwrender	HDF 4, NetCDF 3/4, NOAA 1b	PNG, GIF, JPEG, PDF, GeoTIFF
cwsample	HDF 4, NetCDF 3/4, NOAA 1b	Text
cwstats	HDF 4, NetCDF 3/4, NOAA 1b	–

Note that the metadata and/or versions supported by the physical file formats are as follows:

PHYSICAL FORMAT	METADATA / VERSION
HDF 4	CoastWatch 3.4, TeraScan (only `rectangular`, `polarstereo`, `mercator`, `emercator`, and `sensor scan` projections), ACSPO
NetCDF 3	CoastWatch 3.4, CF 1.4
NetCDF 4	CoastWatch 3.4, CF 1.4, ACSPO
NOAA 1b	AVHRR, AMSU-A, AMSU-B, HIRS 4, and MHS sensors AVHRR LAC or GAC in 8/10/16-bit sensor word sizes File format versions 1 through 5, with or without archive header
ArcGIS	32-bit IEEE float binary grid with accompanying header file
GeoTIFF	TIFF spec 6.0, GeoTIFF spec 1.8.2 Uncompressed, Deflate/LZW (ZIP-style), and PackBits compression 8-bit or 24-bit colour, 32-bit IEEE floating point data Map projections supported: Alaska Conformal Albers Conical Equal Area Azimuthal Equidistant Equirectangular Gnomonic Lambert Azimuthal Equal Area Lambert Conformal Conic Mercator Miller Cylindrical Orthographic Polar Stereographic Polyconic Robinson Sinusoidal Stereographic Transverse Mercator Universal Transverse Mercator Van der Grinten
GIF	Version 89a with LZW compression and optional world file
JPEG	JFIF standard 1.02 with optional world file
PDF	Version 1.4 with LZW image compression
PNG	8-bit, 24-bit with LZW compression and optional world file

Appendix D

Miscellaneous Formats

D.1 Navigation analysis XML output

```
<?xml version="1.0"?>

<pointList
  xmlns="http://coastwatch.noaa.gov"
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xsi:schemaLocation="http://coastwatch.noaa.gov http://coastwatch.noaa.gov/xml/pointlist.xsd">

  <dataset
    name="2006_340_0942_n18_ws.hdf"
    format="CoastWatch HDF version 3.4"/>

  <point>
    <earthLoc lat="34.442345084532306" lon="-120.5162100165965"/>
    <dataLoc row="702.0" col="586.0"/>
    <northDir row="-1.0" col="0.0"/>
    <navOffset row="0.0" col="0.0"/>
    <comment value="Manual"/>
    <varValue name="avhrr_ch3" value="13.34" units="celsius"/>
    <varValue name="avhrr_ch4" value="13.75" units="celsius"/>
    <varValue name="avhrr_ch5" value="13.19" units="celsius"/>
    <varValue name="sat_zenith" value="27.41" units="degrees"/>
  </point>

  <point>
    <earthLoc lat="33.71715205953104" lon="-118.35055152964117"/>
    <dataLoc row="768.0" col="750.0"/>
    <northDir row="-1.0" col="0.0"/>
    <navOffset row="0.0" col="0.0"/>
    <comment value="Manual"/>
```

```
    <varValue name="avhrr_ch3" value="13.66" units="celsius"/>
    <varValue name="avhrr_ch4" value="13.38" units="celsius"/>
    <varValue name="avhrr_ch5" value="13.32" units="celsius"/>
    <varValue name="sat_zenith" value="12.86" units="degrees"/>
  </point>

  <point>
    <earthLoc lat="37.96232720746668" lon="-122.93276796240643"/>
    <dataLoc row="373.0" col="403.0"/>
    <northDir row="-1.0" col="0.0"/>
    <navOffset row="0.0" col="0.0"/>
    <comment value="Auto failed"/>
    <varValue name="avhrr_ch3" value="10.77" units="celsius"/>
    <varValue name="avhrr_ch4" value="11.06" units="celsius"/>
    <varValue name="avhrr_ch5" value="10.36" units="celsius"/>
    <varValue name="sat_zenith" value="43" units="degrees"/>
  </point>

  <point>
    <earthLoc lat="32.67355292893255" lon="-117.21490134745726"/>
    <dataLoc row="862.0" col="836.0"/>
    <northDir row="-1.0" col="0.0"/>
    <navOffset row="0.0" col="0.0"/>
    <comment value="Auto OK"/>
    <varValue name="avhrr_ch3" value="13.97" units="celsius"/>
    <varValue name="avhrr_ch4" value="14.11" units="celsius"/>
    <varValue name="avhrr_ch5" value="13.7" units="celsius"/>
    <varValue name="sat_zenith" value="3.22" units="degrees"/>
  </point>

  <point>
    <earthLoc lat="33.992583436357236" lon="-119.92197445615143"/>
    <dataLoc row="743.0" col="631.0"/>
    <northDir row="-1.0" col="0.0"/>
    <navOffset row="0.0" col="0.0"/>
    <comment value="Auto failed"/>
    <varValue name="avhrr_ch3" value="12.17" units="celsius"/>
    <varValue name="avhrr_ch4" value="12.4" units="celsius"/>
    <varValue name="avhrr_ch5" value="11.91" units="celsius"/>
    <varValue name="sat_zenith" value="23.27" units="degrees"/>
  </point>

</pointList>
```

D.2 Navigation analysis CSV output

Note that long lines are wrapped and continuation lines indented. In the actual output, each point is on a single line.

```
"LAT","LON","ROW","COL","ROW_NORTH","COL_NORTH","ROW_OFFSET","COL_OFFSET",
  "COMMENT","AVHRR_CH3","AVHRR_CH4","AVHRR_CH5","SAT_ZENITH"
34.442345084532306,-120.5162100165965,702.0,586.0,-1.0,0.0,0.0,0.0,
  "Manual",13.34,13.75,13.19,27.41
33.71715205953104,-118.35055152964117,768.0,750.0,-1.0,0.0,0.0,0.0,
  "Manual",13.66,13.38,13.32,12.86
37.96232720746668,-122.93276796240643,373.0,403.0,-1.0,0.0,0.0,0.0,
  "Auto failed",10.77,11.06,10.36,43
32.67355292893255,-117.21490134745726,862.0,836.0,-1.0,0.0,0.0,0.0,
  "Auto OK",13.97,14.11,13.7,3.22
33.992583436357236,-119.92197445615143,743.0,631.0,-1.0,0.0,0.0,0.0,
  "Auto failed",12.17,12.4,11.91,23.27
```

D.3 Color palette XML format

```
<?xml version="1.0" encoding="ISO-8859-1"?>
<!DOCTYPE palette SYSTEM "http://coastwatch.noaa.gov/xml/palette.dtd">

<palette name="HSL256" length="256">
  <color r="128" g="0" b="127" />
  <color r="125" g="3" b="130" />
  <color r="123" g="5" b="132" />
  <color r="120" g="8" b="135" />
  <color r="118" g="10" b="137" />

(... lines omitted ...)

  <color r="140" g="12" b="0" />
  <color r="137" g="10" b="0" />
  <color r="135" g="7" b="0" />
  <color r="132" g="5" b="0" />
  <color r="130" g="2" b="0" />
  <color r="128" g="0" b="0" />
</palette>
```

Appendix E

AVHRR SST Product FAQ

This list of frequently asked questions is designed to answer some of the more in-depth user questions received about AVHRR sea surface temperature products. The NOAA CLASS archive (http://www.class.noaa.gov) holds a long series of CoastWatch AVHRR SST products from 1990 to the present. The data is available in close to its original AVHRR LAC pixel resolution (1.1 km) in various projections depending on region including Mercator and polar stereographic. CoastWatch IMGMAP (.cwf) products (no longer supported by this software) are available prior to November 10, 2003 as a set of high/medium/low resolution regions with various AVHRR channels, SST, cloud, and sensor angle data split into separate files for a given AVHRR pass. CoastWatch HDF (.hdf) products are available from November 10, 2003 to the present as high resolution regions with all AVHRR channel data, derived data, and angles in one file for a given AVHRR pass. The questions and answers below deal with both CWF and HDF files.

E.1 Data formats and archiving

What are all the various categories of CoastWatch data files on CLASS?

There are many CoastWatch products on CLASS to search through – following is a guide to the categories:

CW_SWATH
: CoastWatch HDF capture station swath files produced starting November 10, 2003 to the present. The swath files contain data in the original AVHRR sensor scan projection before registration to a Mercator or polar stereographic map. Swath files are equivalent to NOAA 1b HRPT data but with SST and cloud data computed, and AVHRR channels calibrated.

CW_REGION
: CoastWatch HDF regional node files produced starting November 10, 2003 to the present. Each HDF region file contains data from the swath files registered to a map projection.

CWALA, CWCAR, CWGRL, CWGOM, CWHAW, CWNOE, CWSOE, CWWEC
: CWF files produced before November 10, 2003 for the Alaska, Caribbean, Great Lakes, Gulf of Mexico, Hawaii, Northeast, Southeast, and West Coast regions.

Why do I get all sorts of error messages when I run cwinfo with the -v option?

The **-v** option for the cwinfo tool tells it to print the status of file identification. The code steps through a number of file formats before it finds the one that works, prints the file information, and then exits with a zero status code (zero indicates nothing went wrong). Leave off the **-v** option if you only want to see normal output and no error messages. The tool prints the file identification tests as Java code *exceptions* just as a convenience so that programmers can check the line numbers in the code for where the identification failed, which is good for debugging, but not intended for the average user.

When I run the CoastWatch tools on some files from CLASS, I get error messages. Is there something wrong with the files?

We have had reports of data files obtained from the CLASS archive that are truncated or corrupt in some way. Users report that CoastWatch tools crash, report error messages, or simply don't recognize the file format. In some cases you can re-download the file and try accessing it again, because the error occurred during transmission from CLASS to your local machine. CLASS can provided a digital signature file in order to check that the downloaded file was not corrupted during transmission (see the options in the CLASS shopping cart). In other cases, the files are corrupt in the archive itself, and should be reported to CLASS as being invalid.

Not all the HDF files I access contain an SST or cloud variable. Why is that?

Some NOAA-12 data files covering Hawaii do not have SST and cloud computed because of a special arrangement with Hawaii data users who wanted AVHRR channel data when no NOAA-12 operational SST equation was available. There are also some NOAA-15 data files covering various US regions that do not have SST and cloud due to a processing system bug that was corrected by reprocessing the data (although some files were missed by the reprocessing). In general, all AVHRR SST products should contain SST and cloud data. If they don't, report the data file to CLASS.

Why does the graphics variable in some CWF files not have any data in it?

Some full regional panel CWF data files such as the ER region for the East Coast do not contain any graphics data. This is due to a problem with the processing system for those files. There is a *placeholder* for graphics data in CWF files which in some cases contains graphics for the smaller 512×512 CWF files, but in some larger region CWF files it contains all zeroes.

An easy way to create the missing graphics is to import a CWF SST file into HDF with cwimport (make sure to use `--match sst` so that the graphics aren't imported as well) and run the cwgraphics tool on it to create and insert coast/land/grid graphics into the HDF file.

E.2 SST computation

Can I use the AVHRR SST products for front analysis?

CoastWatch AVHRR SST data can be used for SST front detection and is useful for small areas due to its relatively high spatial resolution. See the follow paper for one such front detection algorithm:

> Ullman, D.S., and P.C. Cornillon, 2000: Evaluation of Front Detection Methods for Satellite-Derived SST Data Using In Situ Observations. *J. Atmos. Oceanic Technol.*, 17, 1667-1675.

Why are there so many SST algorithms for the CWF data files on CLASS?

The different SST algorithms listed under "Datatype" on CLASS go hand-in-hand with the file naming convention – each SST algorithm used has a different code as the last two characters before the `.cwf` extension. To search for any available SST, select all of the possible SST products. Generally only one SST product will have been produced for a given satellite pass, but various algorithms have been used over the time period of the CWF file production so they all appear in the Datatype check boxes.

The naming of the SST algorithms may be confusing for new users. "MCSST" stands for multi-channel but really *any* SST algorithm used by CoastWatch uses multiple channels to compute the SST. Sometimes SST is called "moisture corrected" because that's how *all* of the SST algorithms work – they generally use channel 4 and correct it for moisture in the atmosphere using thermal channel difference terms ($ch_4 - ch_5$, $ch_3 - ch_5$, $ch_3 - ch_4$), either in a linear combination or non-linear combination. The most accurate algorithm and coefficients to run at a given time is determined by NESDIS researchers who call it the "operational algorithm" which changes from satellite to satellite and time period to time period.

The results of an SST data search on CLASS should return a single SST product file per satellite pass whose data is SST – only advanced users comparing AVHRR channel data to SST results should be concerned with which algorithm was used, or those who need to provide such details with a publication.

As an added note, CoastWatch HDF files are not searchable by SST algorithm because only one SST algorithm is available per region: the most accurate one according to comparison with buoy measurements. HDF products contain SST in the `sst` HDF variable, and the SST algorithm used is documented by the `sst_equation` attribute attached to the variable. Some older HDF files may be missing this attribute due to a bug in the processing software.

What happens when the solar terminator passes close to the center of a scene, which SST algorithm is used?

NOAA series polar orbiting satellites (for example NOAA-14, NOAA-15, NOAA-16 and so on) are launched into a sun synchronous polar orbit which results in the satellite passing over low and mid latitude regions at roughly the same time every day (as opposed to polar regions where it passes over every 100 minutes). That time is initially set up to be once for daytime (sunlight hours) and once for nighttime (complete darkness). Some satellites such as NOAA-15 have slipped over time and pass over a region when the region is partially lit and partially dark because the sun has set and the satellite is viewing the solar terminator. In these cases, the SST algorithm used is switched between a daytime algorithm and a nighttime algorithm depending on the sun angle at each pixel. For CoastWatch data, either in CWF or HDF format, the algorithm is switched when the solar zenith angle is 85°. For $sz \leq 85°$, the pixel undergoes a daytime SST algorithm, and for

$sz > 85°$ a nighttime SST algorithm. Note that the cloud masking algorithm (mentioned below) uses a different threshold: 80° rather than 85°.

Why can I see a discontinuity in the SST values in some mixed day/night scenes?

See the question above. When the SST algorithm switches in the middle of a mixed day/night scene, the SST values computed often show a slight discontinuity at the threshold because the different algorithms use different coefficients and possibly use different thermal AVHRR channels. The discontinuity is more pronounced in cloudy data, data that should be masked anyway.

E.3 Cloud masking

What cloud mask tests were used for day and night scenes?

The cloud mask tests are different for day and night as follows:

Daytime

Bit 1: Reflective Gross Cloud Test
Bit 2: Reflectance Uniformity Test
Bit 3: Reflectance Ratio Cloud Test
Bit 4: Channel 3 Albedo Test
Bit 5: Thermal Uniformity Test
Bit 6: Four Minus Five Test
Bit 7: Thermal Gross Cloud Test

Nighttime

Bit 1: Thermal Gross Cloud Test
Bit 2: Thermal Uniformity Test
Bit 3: Uniform Low Stratus Test
Bit 4: Four Minus Five Test
Bit 5: Cirrus Test
Bit 6: Channel 3B Albedo Test (CLAVR-x, HDF only)
Bit 7: Channel 3B Albedo Uniformity Test (CLAVR-x, HDF only)

where bit 1 is the least significant bit, and bit 8 is the most significant. The CWF data files use only CLAVR-1 cloud mask tests as described in:

> Stowe, L.L., P.A. Davis, and E.P. McClain, 1999: Scientific Basis and Initial Evaluation of the CLAVR-1 Global Clear/Cloud Classification Algorithm for the Advanced Very High Resolution Radiometer. *J. Atmos. Oceanic Technol.*, 16, 656-681.

The HDF files use mainly CLAVR-1 tests but also two CLAVR-x tests at night, described in:

> Jelenak, A. and A.K. Heidinger: Validation of CLAVR-x cloud detection over ocean using AVHRR GAC sea surface temperature. Proceedings of SPIE – Volume 5658 Applications with Weather Satellites II, W. Paul Menzel, Toshiki Iwasaki, Editors, January 2005, pp. 292-298.

and have modified versions of the RGCT, RUT, and RRCT during the day that take advantage of CLAVR-x style thresholds rather than static thresholds for these tests.

What happens with the cloud mask when a scene contains the solar terminator?

For data users interested in SST masking, the intended use for the cloud mask data is that regardless of scene time (day, night, or mixed day/night), the cloud mask should be treated as zero = clear, non-zero = cloudy. If a scene contains the solar terminator then the set of cloud mask tests is switched at a solar zenith angle of 80°, but the zero/non-zero rule still applies. If you need more information about exactly which tests were used at each pixel, you can use the solar zenith angle data for the pixel. For $sz \leq 80°$, the pixel has daytime cloud mask tests, and for $sz > 80°$ it has nighttime tests (although see the answer to the next question below about cloud test bit mixing).

The CWF and HDF files have the same behaviour with respect to cloud mask test switching. The HDF files always contain the solar zenith angle data for day or mixed day/night scenes, but are missing the solar zenith angle for night scenes to decrease the file size, and because solar zenith angle data is largely useless at night. CWF SST and cloud mask data files may in some cases be accompanied by corresponding solar zenith angle files (datatype ZA on CLASS) but not always as their production was based on the data requirements at the time. In most cases the scene time of CWF files and hence which set of cloud mask tests were used can be determined from the scene time output line from the cwinfo tool.

Why can I see a discontinuity in the cloud mask data in some mixed day/night scenes?

See the question above for a partial explanation. A different set of cloud mask tests are used for day pixels versus night pixels, so the cloud mask data pixels have different bits set depending on which side of the discontinuity they lie. There is no one-to-one correspondence between day and night cloud tests.

In addition to a cloud mask data discontinuity at the solar zenith, in some cases the change from day to night tests is not "clean", rather there are some pixels on the day side of the $sz = 80°$ line that appear to have bits set the same as the night side of the line and vice-versa. There are two issues that contribute to this:

1. The solar zenith angles are rounded to the nearest 1/100th of a degree when written to an HDF file (or either 1/100th or 1/128th for a CWF file depending on the compression used) so a few pixels with values of, for example, 80.003° will be rounded down to 80° even though they underwent processing with the nighttime cloud tests.

2. The cloud tests in some cases use neighborhood functions. The uniformity tests use a 2×2 box of data pixels to the right and below a given pixel in the array to check for a condition being true, and the result of the uniformity test flags all pixels in the 2×2 box with the test results, regardless of whether all those pixels are day or night. Both day and night have uniformity tests, so the results of uniformity tests at the day/night boundary are mixed. The mixing is generally acceptable because the results are intended to be used for SST masking, not cloud type evaluation and the mixing only occurs in cloudy conditions, not clear SST conditions.

E.4 Navigation correction

What does navigation correction actually do, rewrite all the data in the file?

No, it only adds metadata to the file header to advise the CoastWatch Utilities software of how to read the data. Think of navigation correction like this. The file metadata says "this file starts at a certain latitude/longitude and has a certain number of rows, columns, and pixel size". That metadata sets the physical area for the file and cannot be changed by the navigation correction. Performing a navigation correction on the file sets up extra metadata in the header that says "for this variable (for example SST), when the user requests the pixel data at (0,0), give them the data from (0+x,0+y)" where x and y are the navigation correction offsets.

Have the CoastWatch products on CLASS been autonavigated to correct the coastlines, and if so how accurate is the navigation?

The CW_REGION and CW_SWATH files have been autonavigated, but the older CWF files listed under other regional node categories have not. The autonavigation is accurate to ± 1 pixel when it runs successfully, which is about 90% of the time. If navigation accuracy is a major concern, products should be checked by hand and corrected if needed. Starting in 2007, both swath and mapped HDF products contain two extra global HDF attributes to indicate the success/failure of the autonavigation algorithm: `autonav_performed` which indicates `true` or `false`, and `autonav_quality` which is an integer attribute written when the autonavigation is successful to give an indication of the quality of the navigation as low (0), medium (1), or high (2).

Was the cwautonav tool used for autonavigating the 2003 and later HDF files?

No, the CoastWatch data processing system for AVHRR uses the SeaSpace TeraScan software for autonavigation, which employs a similar algorithm to cwautonav. The cwautonav tool was added to the CoastWatch software in 2004, mainly to aid users in working with the older CWF data files.

Is the autonavigation performed by the CoastWatch AVHRR processing system more accurate than cwautonav?

Yes, the best spatial accuracy is achieved by correcting navigation problems during HDF file production rather than using cwautonav after production. The source of most navigation errors with NOAA satellites is an inaccuracy in the on-board clock and an uncertainty in the roll of the satellite. Those errors translate respectively to a shift in the scan line direction and sample direction when viewing the image data in its original sensor scan geometry. The AVHRR processing system makes the correction while in sensor scan geometry, and then registers the data to a map projection. Once in a map projection, you cannot correct the navigation perfectly using a simple x and y shift, except in small areas. Generally CoastWatch regional data files cover only small areas of about 500-1000 km in radius, so correcting with an x and y shift works well enough in most cases.

How can I perform autonavigation of the pre-2003 CWF files?

The best way to perform navigation of CWF files is to import multiple CWF files to an HDF file with cwimport, then run the cwautonav tool on the new HDF file. That way, you only have to run the navigation once and the results are applied to all the variables in the HDF file selected for navigation (see the question below about variables that should be navigated). Use the cwautonav command line tool with the default options. The key to successful autonavigation is to choose many navigation boxes with feature-rich coastline segments (rather than a flat coastline with no curves). Use AVHRR visible channel 2 for navigation when possible, as channel 2 data provides the most contrast between land and water. At night, you can fall back on AVHRR channel 4, channel 3, or SST since SST is very similar to channel 4.

After manually navigating a CoastWatch data file in CDAT, how can I access the navigation offsets?

For CWF files that have been manually navigated, there is no way to extract the navigation metadata directly from the file using the most recent version (3.x) of the CoastWatch Utilities. You *can* use version 2.3 of the package, by running the cwfatt tool (see the user's guide in that version) and ask it to print the `horizontal_shift` and `vertical_shift` attributes. You can then apply them to other CWF files from the same date/time using the cwfnav tool (also in the version 2.3 package) as shown by example in the user's guide. Be careful about mixing version 2 (cwfnav) and version 3 (cwnavigate) command-line navigation tools – they use different conventions for the navigation offset. A positive translation offset in the version 2 tool is a negative translation offset in the version 3 tool and vice-versa. However once the offsets are set (using either the old or new tools), CDAT will know how to interpret them correctly. Note that navigating a CWF file and then converting to HDF to get the navigation metadata won't work – when the import to HDF is done, the navigation is taken into account by shifting the image data, so the HDF file will not contain the navigation metadata.

For HDF files that have been manually navigated, you can extract the navigation metadata using the hdatt tool by asking for the `nav_affine` attribute for a specific variable since HDF files stored navigation metadata individually for each variable. See Appendix B for a description of HDF navigation metadata. An alternative to hdatt is the hdp command in the HDF Group software.

Why do the HDF files contain floating-point navigation corrections, but CWF files only contain integer corrections?

The floating-point values in the HDF files are a feature of the new file format. CWF files can only contain integer-valued translation offsets, where as HDF files can contain float-valued affine transform coefficients which are much more flexible and can represent rotation, scale, shear, and translation transformations. The CoastWatch Utilities software uses whatever offsets it can find in the file and converts them internally to floats. When writing navigation corrections to CWF files, the translation offsets are rounded to integers and an error occurs if the affine transform represents anything but a simple translation.

Should navigation corrections in CDAT, cwautonav, and cwnavigate be applied to all variables in an HDF file?

No, only certain variables should have navigation corrections applied, namely those from the AVHRR sensor and sensor data derived variables. Graphics, solar zenith, satellite zenith, and relative azimuth angles

should *not* be corrected. AVHRR channel data, SST, and cloud *should* be corrected. If you're using the command line tools, you can use the following option to match only the sensor type data: `--match "avhrr_ch.*|sst|cloud"`.

Are there any other autonavigation algorithms that I can use for CoastWatch data?

Randy Ferguson et. al. (NOAA, National Centers for Coastal Ocean Science, Center for Coastal Fisheries and Habitat Research) have written a research paper on their experience with automatic registration of daytime CoastWatch SST data:

Ferguson. R.L., C. Krouse, M. Patterson, and J.A. Hare. Automated Thematic Registration of NOAA, CoastWatch, and AVHRR Images. *Photogrammetric Engineering & Remote Sensing*. Vol. 72, No. 6, June 2006, pp. 677-685.

E.5 Map projections

What is the spheroid used for the CWF data files?

The answer is complicated. Running the cwinfo tool on a CWF file reveals that the files use a WGS-72 spheroid which has a semi-major axis of 6378135 m and inverse flattening of 298.26. The reality is that the CWF files were registered to a Mercator or polar stereographic map projection using a sphere of radius 6371200 m, but the NOAA 1b file (the source of the AVHRR data) used a WGS-72 spheroid for the geographic coordinates with geodetic latitudes but the geodetic latitudes were not converted (datum shifted) to geocentric when the data was registered. If the data is regarded as having a spherical earth model when imported into a GIS system, the coastlines at all points in the image are completely wrong in the north-south direction. However assuming WGS-72, you'll find that if you match the center points of the CWF files based on coastlines, the image data will match the coastlines reasonably well except at the corners and edges where a 1-2 pixel error occurs.

Are the land mask and other graphics the same for all data files?

No. All the HDF files for a given region (for example the ER region) have the same land mask and graphics in each file because they all cover the same physical area. However, when the switch from CWF files to HDF files occurred in 2003, the map projections were upgraded to use a true WGS-84 spheroid rather than the mixed spheroid model as discussed above. Thus, CWF files all have a slightly different land mask and graphics data compared to their corresponding HDF files, because they represent a slightly different physical area. This means that pixel (0,0) in a CWF file is not at the same latitude/longitude as pixel (0,0) in the corresponding HDF file.

Which CWF file regions correspond most closely to the new HDF file regions?

The rough correspondence is as follows (note that some HDF regions have no corresponding CWF region):

HDF region	CWF node and region
Alaska North	CWALA Northern Alaska
Alaska Sitka	CWALA Vancouver
Alaska South	CWALA Southern Alaska
Alaska West	CWALA Western Alaska
Caribbean East	CWCAR East Caribbean Synoptic
Caribbean West	CWCAR West Caribbean Synoptic
East Coast Bermuda	none
East Coast North	CWNOE Full Regional Panel
East Coast South	CWSOE Full Regional Panel
Great Barrier Reef	none
Great Lakes	CWGRL Full Regional Panel
Great Salt Lake	none
Gulf of Mexico	CWGOM Full Regional Panel
Hawaii	CWHAW Synoptic
West Coast Acapulco	none
West Coast Baja	CWWEC Baja Mexico Synoptic
West Coast North	CWWEC Northwest
West Coast South	CWWEC Southwest

When converting the Alaska HDF products to an ArcGIS binary grid, why do I end up with the data looking like it's on the wrong side of the earth?

The CoastWatch HDF files and ArcGIS use different conventions for specifying the rotation angle of the central meridian. For the Alaska products, use the following projection string:

```
PROJCS['WGS_1984_Stereographic_North_Pole',
  GEOGCS['GCS_WGS_1984',
    DATUM['D_WGS_1984',SPHEROID['WGS_1984',6378137.0,298.257223563]],
    PRIMEM['Greenwich',0.0],
    UNIT['Degree',0.0174532925199433]
  ],
  PROJECTION['Stereographic_North_Pole'],
  PARAMETER['False_Easting',<insert value>],
  PARAMETER['False_Northing',<insert value>],
  PARAMETER['Central_Meridian',<insert value>],
  PARAMETER['Standard_Parallel_1',60.0],
  UNIT['Meter',1.0]
]
```

and insert values for the central meridian, false easting, and false northing. The central meridian can be determined from the center point longitude reported by running `cwinfo -t`, and the false easting and northing can be computed from the `.hdr` file values for `xllcorner` and `yllcorner` as follows:

$$\begin{bmatrix} false\ east \\ false\ north \end{bmatrix} = \begin{bmatrix} 1-\cos t & -\sin t \\ \sin t & 1-\cos t \end{bmatrix} \begin{bmatrix} xllcorner \\ yllcorner \end{bmatrix}$$

where t is the central meridian angle.

Appendix F

Acronyms

API Application Programming Interface

AVHRR Advanced Very High Resolution Radiometer

CDAT CoastWatch Data Analysis Tool

CLASS Comprehensive Large Array-data Stewardship System

CWF CoastWatch Format

DMG Disk Image

ESRI Environmental Systems Research Institute

FAQ Frequently Asked Question(s)

FY Feng Yun

GAC Global Area Coverage

GCTP General Cartographic Transformations Package

GeoTIFF Geographic Tagged Image File Format

GIF Graphics Interchange Format

GIS Geographic Information System

GMT Greenwich Mean Time *or* Generic Mapping Tools

GSHHS Global Self-consistent, Hierarchical, High-resolution Shorelines

GUI Graphical User Interface

HDF Hierarchical Data Format

HRPT High Resolution Picture Transmission

IDL Interactive Data Language

IMGMAP Image Map

JPEG Joint Picture Experts Group

JRE Java Runtime Environment

JNI Java Native Interface

LAC Local Area Coverage

MVISR Multichannel Visible and Infrared Scan Radiometer

NAD North American Datum

NCSA National Center for Supercomputing Applications

NDVI Normalized Difference Vegetation Index

NESDIS National Environmental Satellite, Data, and Information Service

NetCDF Network Common Data Form

NOAA National Oceanic and Atmospheric Administration

OPeNDAP Open-source Project for a Network Data Access Protocol

PDF Portable Document Format

PNG Portable Network Graphics

RGB Red/Green/Blue

SAA Satellite Active Archive (now part of CLASS)

SDS Scientific Data Set

SST Sea Surface Temperature

TDF TeraScan Data Format

THG The HDF Group

UTC Coordinated Universal Time

UTM Universal Transverse Mercator

WGS World Geodetic System

XML Extensible Markup Language

Appendix G

History of Changes

Version 4.0.1 – Dec 2024

Updates

- The --optimal option in cwcomposite now supports two new function types for selecting the optimization variable data value: minabs and maxabs for the minimum and maximum absolute value respectively.
- ACSPO geostationary data format reading is updated to handle the metadata conventions in version 2.90 files.
- A new --console option to cwgscript starts a BeanShell script console for interactive testing of script snippets.
- The new tool *cwanimate* creates animations of data from either local files or datasets on ERDDAP, THREDDS, and OPeNDAP servers.

Bug fixes

- The hybrid CoastWatch / CF metadata NetCDF data format reader no longer incorrectly promotes integer data variables to double-precision floating-point data.

Version 4.0.0 – May 2024

Updates

- A new --tiffsize option was added to cwexport to write GeoTIFF files of either 8-bit integer, 16-bit integer, or 32-bit IEEE float data. Previously only 32-bit float data was supported.

- New levels of verbose debugging messages from command line tools can be displayed using the -J-Dcw.debug=fine and -J-Dcw.debug=finer options. The log message format can also be made longer by setting the -J-Dcw.log.format=long options.
- Network data access for files that start with HTTPS is now supported by command line tools. Network data is typically accessed on a THREDDS server via OPeNDAP. Previously only HTTP was supported.
- The data color scale in CDAT and output from cwrender now more intelligently handles long tick label values.
- Installation of the command line tools under Windows now sets the user's PATH variable automatically.
- A new --noinfo option was added to cwrender to turn off the plot legend in output images. There is also a new similar option when exporting data from CDAT.
- CDAT users can now restore the original overlay groups if an overlay group is accidentally deleted. Users can also display the user resource directory so that setup files are easier to access.
- CDAT users can now specify a custom logo file for exported data.
- CDAT users can now set the full enhancement range even after opening the data file. Previously, a user needed to close the file, adjust the preferences, and open the file again. The enhancement range, palette, and function can also now be saved directly from the enhancement slider area.
- The CDAT overlay group load/save functionality is now more user friendly.
- The cwcomposite tool has new --optimal and --savemap options that control which data values are prioritized in the output file. This allows the user to use data variables such as satellite zenith angle to prioritize the output data.
- The CDAT file chooser has been rewritten to be more compact, user friendly, and reliable.
- CDAT now has new functionality to save a set of favourite palettes, and a new palette named Turbo.
- The CDAT color composite functionality is now more user friendly.
- A new functionality for showing the memory usage for command line tools can be turned on using the -J-Dcw.memory.monitor=true option.
- The CDAT enhancement sliders are now smoother and more accurate and update the number of decimal places in the text boxes based on the slider minimum and maximum range. Previously the minimum slider increment was an integer.
- Added a new behaviour to cwcomposite and cwmath to dynamically scale the number of parallel threads used to fit within the maximum heap space available. This greatly simplifies command line operations when processing many data files of unknown chunks sizes and data types.
- The cwsample tool now has new options --statsvar and --window used to compute and print statistics for a window surrounding each sample point.
- The CDAT user interface has been rearranged to work more like a modern map viewer and updated for overall ease of use.

Bug fixes

- Reading and writing NetCDF files with null attribute values in the metadata were causing errors. Null values attributes are now detected and handled.
- Launching CDAT on the Mac now properly handles double-clicking a file in the Mac Finder. Previously CDAT would launch but not open the file.
- When reading NetCDF files, temporal metadata was being truncated in some cases. Now reading uses the full temporal metadata accuracy.
- CDAT full screen mode was broken on some versions of MacOS – starting full screen mode caused the screen to go blank with no way to exit the mode. Full screen mode now works again on all operating systems.
- When adjusting the view enhancement sliders in CDAT with composite mode turned on, some variable enhancement ranges reverted back to their previous values when composite mode was switched off. This has been fixed and works correctly.

Version 3.8.0 – May 2023

Updates

- A new file format of latitude/longitude location lists was added for use in cwrender and CDAT, where only ESRI shapefiles were previously supported.
- Initial beta support for ESRI point shapefiles was added to CDAT.
- A new --marker option was added to cwrender to label user-specified locations with a point symbol and text label.
- The cwrender tool --size option now accepts a number of rows and columns for the output image size.
- A new command line tool named *cwtools* was created to list all the tools and their functions.
- The cwimport tool now has a --nogroup option to eliminate the group structure if found in imported data files. It has also been modified to better preserve earth location data in imported level 2 swath files.
- A new command line tool named *cwtccorrect* was created to help with visualizing top-of-atmosphere true color data from VIIRS, MSI, OLCI, and user-defined sensors. The correction accounts for molecular (Rayleigh) scattering and gaseous absorption (water vapor, ozone).
- The cwstats tool --factor option now accepts values in %.
- The cwrender, cwexport, and CDAT tools have all been updated to default to writing GeoTIFF data using the deflate compression algorithm.
- CDAT has been updated to ignore any group name prefix when searching for range and palette preferences by variable name. This helps with visualizing data variables that can occur both in a hierarchical group structured file or a file with no groups.
- CDAT and cwrender have been updated to optionally use ETOPO1 data for rendering contours.

Bug fixes

- In the CDAT trackbar, data value display was hard to read when the data value had many digits. This has been updated so that data values are always left-justified.
- Reading NetCDF files with zero length string attributes was throwing an exception in CDAT when showing the raw file attribute information. Zero length string attributes are now being detected and handled.
- Earth context diagrams were being drawn on output from cwrender and CDAT even for global dataset views. This has been corrected so that context diagrams are only shown when the area is above some threshold value.
- An obscure error was being thrown when attempting to write 64-bit integer data to HDF 4 files. This has been fixed to report that HDF 4 files cannot contain 64-bit integer data (though HDF 5 files can).
- Incorrect data was being written by cwcomposite in some cases when input data files contained data variables with matching names but different missing values. This has been corrected.
- Incorrect data was being written by the cwmath expression parser in some cases when input data files contained integer data variables with missing values and unity scaling (scale factor of 1 with offset of 0). This has been corrected.
- The cwstats tool and CDAT had an issue with detecting when some data variables contained both NaN values and Infinity values in IEEE floating-point data. This has been corrected so that both are detected and flagged as invalid.

Version 3.7.1 – July 2022

Updates

- The user interface in CDAT was updated to better handle display scaling on Windows and Linux. This involved updating the user interface toolkit which now has a more uniform look across different platforms.
- The Java VM was updated to 17.0.2 on all platforms (Linux, Windows, and Mac) for bug fixes and security patches.
- The Java code documentation was updated for the latest Java virtual machine Javadoc tool.
- The User's Guide and in-application help was updated to reflect the latest software updates.
- The CDAT file chooser was reorganized for easier data file selection. Now when opening a file, long variable names and units have more room for display.
- The CDAT file information window was enhanced to show more complete file contents. It also includes a new tab with the ability to search for text in metadata names and values.
- The cwcomposite, cwmath, and cwregister2 tools have new command line options --threads and --serial to control the amount of multithreading used for data processing.

- The render tool has a new hybrid rendering mode to combine color enhancements with composite color images. For hybrid mode rendering, the --composite and --enhance options are no longer mutually exclusive, and a new --hybridmask option specifies transparent pixel areas.
- A new standardized NOAA logo is now included as the default for plot legends. The new logo uses the official NOAA colors.
- Various command line tools were updated for better info/verbose logging and for clearer and shorter error messages.
- The cwdownload and cwstatus tools were deprecated and removed. These tools have been replaced with various methods of downloading data from the CoastWatch node websites such as THREDDS, ERDDAP, HTTP, FTP, etc.

Bug fixes

- When clicking the Help buttons in CDAT, help windows sometimes appeared behind their parent window. This has been fixed so that help windows always appear correctly in front.
- When reading HDF files in cwcomposite, unchunked variable data was not being read and composited correctly. This has been fixed so that now all HDF variable data both chunked or unchunked is read correctly.

Version 3.7.0 – September 2021

Updates

- New GeoTIFF compression types were added to the CDAT save options panel.
- The pass_type attribute in CoastWatch HDF data files is no longer updated to match the temporal and spatial coverage of newly created files. The attribute was causing confusion when registering level 2 files that covered a small area of a larger master region. The CoastWatch HDF metadata specification was similarly updated.
- File reading was improved for NetCDF files with CoastWatch HDF and CF compliant metadata for variables of various ranks.
- More complete support for gamma enhancement in GeoTIFF images was added for writing the equation used for scaling data values to indexed colour map values.
- The cwcomposite tool was modified to discard the history attribute in its input files and write only its own history attribute. The history attribute combined from multiple inputs was overflowing the allowed metadata limits. The --keephistory option was added to override the new behaviour.
- Error handling was improved when parsing user colour palette XML files read by CDAT and the cwrender tool.

Version 3.6.1 – March 2021

Updates

- GeoTIFFs written by CDAT, cwrender, and cwexport now conform to the cloud-optimized GeoTIFF recommendations.
- GeoTIFFs created by cwrender and cwxeport now have extra compression options available: LZW and JPEG.
- The cwmath, cwcomposite, and cwregister2 tools have been updated to handle floating-point data variables with scaling factors.
- NetCDF NcML datasets are now supported to help with data file aggregation and metadata modification.
- The cwrender tool now has a --compositehint option to help with automatically setting function types and ranges for rendering color composites.
- Plot legends from cwrender and CDAT now contain more information about grid mapped projections from NetCDF files.

Bug fixes

- There was an error produced in cwrender when rendering files that had already been closed by the Java garbage collector. This has been corrected and the error no longer occurs.
- HDF 4 files were being written with signed missing_value attributes even when the variable data was unsigned. This has been corrected so that the missing_value and variable types match.
- Some data files containing geographic projections that span both the prime meridian and anti-meridian were not being recognized – this is now fixed.

Version 3.6.0 – August 2020

Updates

- CDAT now remembers the last directory that it was in when a file was opened.
- CDAT now has increased memory defaults to help with reading certain NetCDF datasets.
- The cwregister2 tool now has a --sensorhint option to help with processing data from sensors that cannot be detected automatically.
- The cwrender tool now has added documentation on how wind barbs are rendered depending on the wind speed units.
- The cwmath documentation now shows examples of how to use the new Java expression parsing syntax.

- The cwregister2 tool now accounts for the full pixel size at the edges of source datasets. Previously there were small gaps when assembling multiple successive granules from some sensors.
- The cwregister2 tool now has a --nogroup option to remove the leading group path name when source variables are contained in a group.

Bug fixes

- There was an issue reading NetCDF files with scaled variables that are missing the add_offset attribute value.
- The cwregister2 tool had issues with automatically determining the resolution of some sensor data with repeated locations such as OLCI.
- The export of NetCDF-3 files from cwexport and CDAT wrote incorrect lat/lon data for some cylindrical projections.

Version 3.5.1 – November 2019

Updates

- The Mac and Linux installation sections in the user's guide have new notes on using the command line program man pages.
- The cwdownload tool has a new fallback behaviour to ignore an invalid SSL certificate when downloading over an SSL connection.
- The command line tools have a new warning message when an out of memory error occurs with advice on how to re-run the command with a higher memory setting.
- The cwexport tool now exports data to 32-bit floating point GeoTIFF images to help with importing scientific data into GIS systems.
- The cwcomposite tool has a new --collapsetime option that helps preserve time metadata when creating long time series composites.
- The cwrender tool has a new --paletteimage option that creates an image of all available color palettes and their names to help users choose a palette.
- The cwsample tool now produces an error when the file being processed does not have a compatible data projection for sampling. Previously versions ran but produced incorrect results for some swath projection files.
- The NetCDF 3 and 4 output from CDAT and cwexport has some changes in how the coordinate metadata is written to help CF-compliant readers recognize the projection.
- The cwmath tool has been updated to use the Java expression parser syntax by default rather than the legacy syntax.
- The cwrender tool has a new --varname option that overrides the variable name in the color bar legend with a custom label.

Bug fixes

- CDAT and cwrender had an issue when overwriting existing output images with a smaller size image – garbage data was being left at the end of the file.
- GeoTIFF writing from cwrender or CDAT was broken under the previous release since migrating to OpenJDK 11. This has been fixed.
- The HDF 4 library has a write limitation of 65535 bytes for attributes. This was causing an error when compositing long time series. The error has been fixed by truncating any attribute that exceeds this length with a warning, and also an option added to cwcomposite (see above).
- Some Sentinal-1A data was being rendered in a mirrored orientation. This has been fixed.
- CDAT and cwrender had issues when rendering land polygons near the edges of some projections. This has been corrected for geographic, swath, orthographic, and GVNSP projections.
- The cwgraphics tool had an issue with rendering graphics correctly for projections requiring an orientation flip for display.
- CDAT and cwexport were writing incorrect missing value metadata to NetCDF 3 variables. This has been corrected and now matches the NetCDF 4 output. The issue affected statistics and display of data from the exported NetCDF 3 files.

Version 3.5.0 – April 2019

Updates

- The Java VMs on all supported platforms have been upgraded to Java 11 using Oracle OpenJDK 11.0.1, and source code migrated accordingly.
- The NOAA 1b format AVHRR reading has been updated to handle Metop-3 files.
- Some of the command line and GUI tools have started to be migrated to use a more flexible and standardized event logging system. The migration will be complete in the next version.
- A new tool called cwregister2 is now available to perform fast multithreaded registration with special handling for terrain-corrected data.
- Various code modules are being migrated and refactored towards being able to run some of the command line tools from CDAT, based on user requests.
- The cwcomposite tool has been completely re-written to perform fast multithreaded composition.

Bug fixes

- The composite tool exited with an error when attempting to combine NetCDF datasets with cylindrical map projections that were not equally spaced, and geostationary satellite projections. These have been fixed and it now runs correctly.

Version 3.4.1 – October 2018

Updates

Graphical tools

- CDAT now computes point data overlay statistics in a background thread for a faster user experience.
- CDAT has new oceanographic palettes derived from the Python matplotlib cmocean package.
- The CDAT color enhancement functions have a new option "Gamma" for displaying visible band satellite data. The gamma function accounts for computer display gamma correction when showing visible data scaled between 0% and 100% intensity values.
- The visual appearance of coastlines plotted on images in CDAT and cwrender has been improved in some cases by adding a new higher resolution coastline database, and adjusting the algorithm that selects the coastline detail level to use for the scene being displayed.

Command line tools

- The cwdownload and cwstatus tools now support SSL network connections via the HTTPS protocol.
- A new tool *cwscript* is available for running scripts in BeanShell (`http://beanshell.org`) that can make calls to the CoastWatch Utilities API. An extra launcher *cwgscript* is also available to run scripts that create GUI windows. The cwscript manual page gives several examples of scripts.
- The cwregister tool has been improved and now runs up to 1.9x faster.
- The cwrender tool has a new enhancement type 'gamma' for use with visible band satellite data.
- The cwrender tool has a new --palettelist option that prints a list of valid palette names that can be specified for color enhancement.

Bug fixes

- The CDAT window had an issue preserving the view contents after resizing – it now works more like Google Earth.
- CDAT point data overlay display now correctly saves overlay changes when the point data chooser dialog window is closed.
- The automatic documentation generation system was re-written to correct various user's guide and manual page formatting issues.
- The cwrender tool no longer creates a 'palette' directory in the user resources if the directory is not found. This was causing issues on some systems.
- GOES-style geostationary projection is now computed correctly. Previously only Meteosat/Himawari scanners were supported.

- CDAT on Windows now correctly detects when a user double-clicks a file in the Windows file explorer, and opens the file in the currently running CDAT instance, rather than creating a new CDAT window.
- CDAT on Linux uses a new GUI theme as a workaround for a tab bar issue. When many file tabs were opened, the tab bar became unusable.

Version 3.4.0 – March 2018

Updates

Graphical tools

- CDAT has a new menu item *Open Recent* under the *File* menu, with a list of recently opened files for quick access.
- CDAT has new items in the *View* menu for controlling the data view, copying the view zoom between tabs, and showing/hiding the top toolbar and left-side control tabs.
- Tabs in CDAT now have a little x close button built into the tab.
- The documentation for CDAT now has a section on setting memory limits in the user preferences.

Command line tools

- The cwmath tool has been largely re-written to improve performance. The tool now processes 2D chunks of data rather than individual rows, and uses a new Java Language math expression syntax. An emulation parser mode supports legacy expressions. New options can be used to fully take advantage of the performance increase and specify a greater variety of output variable types without having to use a template variable: --scale none, --skip-missing, --missing, --parser, and --size int/uint/long/ulong/double.
- The cwrender tool now has a --font option to set the legend and overlay font and a --fontlist option to list system-specific fonts available.
- The user's guide now has a section on hidden command line options for the command line tools (after the tool manual pages), to be used for performance tuning.

Bug fixes

- CDAT full screen mode now works correctly on multi-monitor setups.
- Reading of time axis metadata is now more complete for NetCDF 4 files.
- The cwgraphics tool now correctly omits the scale factor and offset for the graphics byte variable it creates. Scale and offset are reserved for packed data only.
- The cwregister tool now distinguishes between a file not found error and a format error for the master file.

- Detection of link errors with the native HDF library code is now more user-friendly.
- The bundled Java VM version has been updated to 1.8.0_162.

Version 3.3.2 – October 2017

Updates

Graphical tools

- CDAT optionally checks on startup if software update is available.
- CDAT now displays iQuam SST quality monitoring point data files and computes the statistics between image and point data attributes. Use by adding a shape overlay to an image and selecting an iQuam SST data file.

File formats and I/O

- GeoTIFF, JPEG, GIF, PNG, and PDF rendered files have extra metadata tags that describe the software version and options used.
- New support for NetCDF 4 files in level 2 swath projection and non-geographic dimensions.
- NetCDF 4 files now have better support for grid mapped projections in the CF metadata.
- HDF is now updated to the HDF Java 3.2.1 version.
- Data file opening now correctly reports an out of memory issue if it occurs while identifying the file type.
- GeoTIFF output now supports UTM projection data.

Command line tools

- Manual page for cwsample now correctly shows how to output to the terminal.
- Manual page for cwcomposite clarifies use of --method option.
- The cwregister tool has two new options --srcfilter and --srcexpr to limit pixels used from the source data in registration.
- The cwrender tool now has a --date option to override the plot legend date in cases where the file metadata is incorrect or unavailable.
- The cwstats tool now has a --polygon option that computes statistics within a polygon boundary.
- The cwrender tool has a new --scalewidth option to explicitly set the width of the color scale legend. This is useful so that a series of plots match in overall width.

Bug fixes

- Long text lines in plot legends are now wrapped.
- NetCDF 4 file writing now properly includes missing value attribute for variable data.
- NetCDF 4 float and double types now read with full precision formatting.
- NetCDF 4 files with 4D and 5D variables are read more reliably.
- GRIB files with variables names containing double underscores now read correctly.
- The cwregister tool performance is now greatly improved in some cases where source and destination data is chunked.
- Topographic and other lines are now drawn more reliably on plots in geographic projection.
- NetCDF 4 data is now correctly displayed in the case where a cylindrical projection is used with irregularly spaced latitude and longitude axes.
- The color scale legend in PDF output plots has an improved appearance in onscreen PDF readers.
- Open NetCDF files that are no longer needed are now properly closed.
- GeoTIFF ModelTransformationTag values have been updated to correct a 0.5 pixel error.

Version 3.3.1 – January 2016

Updates

Graphical tools

- Added ability in CDAT to save/recall window size since the last time the application was run. Also added menu options to set window to various predefined sizes or a custom size.
- Added preference options in CDAT to allow the user to specify the maximum Java Virtual Machine heap size for dynamic memory allocation, and a cache size for data tiles read from HDF and NetCDF files. This allows CDAT to better read files with large compressed data chunks, and users who need to have many files open at once to better manage their memory requirements.
- Bitmask overlays in CDAT now handle up to 32-bit integer mask values. This is much better for cloud mask testing than the original maximum value of 255.
- Updated latitude/longitude line labelling algorithm to handle full-disk projections such as orthographic and near-size perspective. The new algorithm places line labels in the center of the image rather than at the edges.
- Added an experimental scripting console to CDAT that allows users to run their own custom code within CDAT using Java language syntax. All the APIs documented in the CoastWatch Utilities are available.

File formats and I/O

- Added NetCDF 4 file saving from cwexport and CDAT. NetCDF 4 files are written with CF-1.4 metadata, and compressed in chunks. This is an alternative to NetCDF 3 files which do not support compression.
- Improvements for reading ACSPO NetCDF and HDF format files, both polar orbiting and geostationary data.
- Added end of data capture to time period read from NOAA 1b format files. Previously only start of data capture was read.
- Added support for reading data that is written from south to north and west to east. Some data providers prefer this order, and data appeared upside-down in CDAT and other tools.

Command line tools

- Added Unix man pages for all tools.
- Added identification of file reading module used to recognize a file format to the output of cwinfo. Also improved output spacing when encountering long variable names.
- Improved the output of registration in cwregister when time-sequential swaths are being registered to the same master and then combined with cwcomposite. Previously, single-pixel gaps existed between time-sequential swaths.

Bug fixes

- Fixed issues with memory leaking when closing some file formats. This was resulting in an "out of heap space" error message.
- Many internal documentation and unit testing updates.
- Fixed Java VM splash screen in graphical tools to reliably indicate loading delays.
- Fixed issue with Java VM crashing due to multiple threads accessing native HDF 4 and 5 libraries.
- Fixed error when performing a point survey.
- Fixed startup issue on some Windows machines when attempting to read user preferences file.
- Fixed numerical issues in registration when the source file contains data on either side of the -180/+180 longitude boundary.

Version 3.3.0 – October 2013

Updates

Graphical tools

- Added support for loading and saving of *profiles* in CDAT – groups of enhancements and overlays.

File formats and I/O

- Updated file handling for Mac OS X 10.5+ operating system.
- Removed read support for the CoastWatch IMGMAP file format.
- Updated ACSPO HDF 4 reading for new VIIRS sensor and non-chunked compressed data files.
- Added ability to read ACSPO NetCDF 4 data files.
- Added NetCDF 3 with CF-1.4 metadata as an export data format in cwexport with (optional CW and DCS metadata).
- Added read support in all tools for data files in NetCDF 4 with CF-1.4 variable and CW metadata.
- Updated to use the new Java HDF 2.9 interface with native 32- and 64-bit HDF 4 and 5 libraries.
- Added read support in all tools for data files in NetCDF 4 with L2P metadata.
- Added support for memory caching when reading NetCDF 4 data files.

Command line tools

- Added a print option to cwinfo for Common Data Model coordinate system information (if available).
- Added extra options to cwrender for: (i) rendering with custom color palettes specified by a file or directly on the command line, (ii) adding watermark text to the image, and (iii) manually specifying the data scale tick marks.
- Converted all GCTP coordinate transform code to Java to run on 64-bit Java VMs for all tools.

Bug fixes

- Fixed the error message "no parent window" when opening data files.
- Fixed problem with reliably closing HDF 4 files.
- Corrected direction error in vector symbols (winds, currents, etc).
- Fixed non-functional State Plane Coordinate System support.

Version 3.2.3 – March 2009

Updates

- Added support for NOAA 1b KLMN data files with AMSU-A, AMSU-B, and MHS sensor data.

- Added informational "Reading file information" message when opening large files in CDAT.
- Updated to use the netCDF Java library 2.2.22 for improved GRIB 2 file support.
- Improved expression parsing in cwmath to allow for symbol characters in variable names, such as minus signs.
- Added geometric mean composite and explicit command line ordering options in cwcomposite tool.
- Added 64-bit IEEE floating point output option in cwangles tool.
- Created tool to automatically test command line tools and options (work in progress).

Bug fixes

- Corrected problem with reading CoastWatch HDF swath geolocation data. This was causing an error when displaying or working with CoastWatch HDF swath projection data files.
- Regenerated HDF land mask files for use with autonavigation. The cwautonav tool was failing when encountering navigation points with latitude $>$ 45 degrees.
- Fixed problem with ACSPO HDF file buoy data variables being read and displayed in CDAT.
- Fixed problem with full orbit FRAC data files from Metop. Opening a full orbit file was resulting in a very long wait and CDAT becoming unresponsive.
- Fixed out of memory problems with opening and closing many large files in CDAT.
- Fixed unsupported file format error when reading TOVS data files with no archive header.
- Corrected ACSPO file I/O routines to read both orbit and granule metadata conventions.
- Corrected overflow error in cwdownload byte count for large file transfers.

Version 3.2.2 – November 2007

Updates

Graphical tools

- Improved visibility of shape drawing in CDAT during zoom and annotation operations.
- Added full screen data view mode in CDAT.
- Added navigation analysis panel in CDAT.
- Added data reference grid overlays for drawing lines at regular image row and column spacings.
- Added a warning dialog in CDAT when navigation correction is about to modify a data file.
- Improved file open/save functionality in the CoastWatch Master Tool (cwmaster).

File formats and I/O

- Added support for reading NOAA/NESDIS AVHRR Clear-Sky Processor for Oceans (ACSPO) HDF data files.
- Modified ArcGIS binary grid header writer to include "nbits" value.
- Added support for reading NOAA 1b High Resolution Infrared Radiation Sounder (HIRS) data from NOAA KLMNN' satellites.
- Modified CoastWatch HDF writing to handle writing explicit lat/lon values for earth location data.
- Modified netCDF file reading to handle data with greater than two dimensions as a set of 2D arrays.
- Added "scan_time" variable to NOAA 1b file variables.
- Modified NOAA 1b file reading to read only the largest contiguous run of valid scan lines.
- Added support for reading erroneous NOAA-15 data files from CLASS that indicate the wrong file version in the header.
- Added checks for spheroid compatibility in GCTP map projections.

Command line tools

- Added step sequential color palette for East Coast Node chlorophyll data.
- Added version printing option "--version" to all command line tools.
- Added the "--copy" option to cwimport so that entire variables can be copied from one file to another.
- Added median value computation results to the output of the cwstats command.

Bug fixes

- Fixed problem with overlay groups not updating between CDAT tabs.
- Fixed problem with directory refresh on file open in CDAT.
- Fixed problems with box surveys in CDAT that were not correctly surveying very small boxes of pixels.
- Fixed some problems with earth location reverse lookup in full orbit swath datasets.

Version 3.2.1 – November 2006

Updates

- Updated GUI code for better Mac OS X integration.
- Added help buttons in some areas of CDAT to aid users in getting context-specific help.

- Added color scale legend beside data view in CDAT in response to user suggestions.
- Added warning message in CDAT before applying navigation to make sure user understands that the data file is being modified.
- Changed "Save As" in CDAT to "Export" to avoid confusion. The data file should be thought of as read-only and the save formats as export formats.
- Changed the order of operations for exporting data in CDAT to simplify the number of steps users need to perform.
- Added continuous enhancement updates in CDAT for visual appeal.
- Updated icons for data view controls in CDAT.
- Added drag-and-drop support in CDAT for opening data files.
- Updated all dialog box buttons in CDAT to more closely match platform defaults.
- Factored code for earth transforms to allow for both native C and Java map projection implementations in the future.
- Added support in CDAT and cwrender for expression masking.
- Added support in CDAT for preferred units.
- Added support in CDAT and cwrender for saving image files with indexed 8-bit palettes.
- Added support in CDAT and cwrender for saving world files.
- Changed splash screen to not display by default for GUI tools. This was causing users to think that startup was abnormally slow.
- Added support in NOAA 1b reading code for version 4 and 5 file formats, 8-bit and 16-bit sensor word sizes, MetOp data files, and files with missing scan lines.
- Added support for user file formats via the extensions/ directory.
- Added TIFF file compression in CDAT and cwrender.
- Added code for the Earth Data Access Client (EDAC) for for use by the CoastWatch East Coast Node (ECN).
- Added support in TeraScan HDF I/O code for importing a user-specified set of attributes.
- Updated GSHHS reading code to handle binned political line data, and replaced databases in TeraScan vector format with new HDF binned data from GMT. This speeds up the access and rendering of state and international lines considerably.
- Enhanced color scale in cwrender and CDAT to correctly show log scale ticks above the highest power of ten on the scale. This helps with chlorophyll plotting when users scale between non-power-of-ten minimum and maximum.
- Added CDAT and cwrender palettes for Coral Reef Watch data.

- Added the --coherent option to cwcomposite based on CoastWatch central processing request. See the manual page for details.
- Updated look and content of application help files for CDAT, cwmaster, and cwstatus to be easier to read and navigate.
- Added ubyte/ushort types, and xor/not functions to cwmath.
- Added the --overwrite option to cwregister based on CoastWatch central processing request. See the manual page for details.
- Added the ability in cwrender to accept multiple --shape and --bitmask options. This makes rendering much more flexible.
- Added the --variable option to cwsample. It was confusing to users to have only --match and not be able to depend on the ordering of columns in the output text file.
- Added the --region option to cwstats that takes a center point and radius for sampling.
- Modified the base directory for user preferences to be operating system specific. The base directory was causing problems because different operating systems expect software to place customization directories in different locations. See the help files in CDAT for the new locations.
- Standardized on coastwatch.info@noaa.gov as the destination for all support emails.

Bug fixes

- Fixed error with log enhancement normalization by disabling the Normalize button for log enhancements.
- Fixed status dialog problem in CDAT when loading variables with long names from files with short names.
- Fixed color, stroke, and font swatch rendering in CDAT for Mac OS X.
- Fixed problem with writing ArcGIS files from CDAT and cwexport. Header file accuracy was being impacted by writing to only two decimal places.
- Fixed problem when reading OPeNDAP files with 2D data of odd dimensions.
- Fixed error with retrieving chunks lengths while reading netCDF files, since netCDF has no chunking or compression support.
- Fixed null line color errors in CDAT overlays.
- Fixed problem with rendering text shadows for black grid lines in CDAT and cwrender.
- Fixed problem with lat/lon separator characters in cwautonav. Now the documentation and implementation match.
- Fixed cwdownload to delete partial files when a transfer error occurs.
- Fixed the lack of equation description in log-enhanced GeoTIFF output from cwrender and CDAT.
- Fixed error when working with geographic projection data that crosses the date line.

Version 3.2.0 – October 2005

Updates

- Added RasterPixelIsPoint style earth location code for wind data.
- Improved speed of NOAA 1b reading by caching scan lines rather than tiles, as this reflects the actual file organization.
- Added support for OPeNDAP-accessible datasets with CoastWatch HDF metadata.
- Updated to perform datum shifting between Earth transforms of different datums.
- Changed "datum" terminology to "spheroid" in various locations.
- Added support for abstract GIS features to help in ESRI shapefile processing.
- Added spectrum and wind palettes for cwrender and CDAT.
- Added --limits option in cwstats.
- Added check for incompatible overlay group files in CDAT.
- Added support in cwrender for overlay group rendering, world files, vector data rendering, and units conversion.
- Updated CDAT to have a special interface for opening OPeNDAP connections and datasets, moved file information to a full size window, and added 1:1 toolbar button.
- Added various detailed control options in cwautonav.
- Added hdatt tool for direct manipulation of HDF attribute information.

Bug fixes

- Corrected NOAA 1b longitude interpolation in polar regions.
- Modified to ignore coordinate variables in HDF files (for compliance with CF metadata conventions).
- Relaxed NOAA 1b format description check for varying descriptions in CLASS data files.
- Fixed unreliable convergence problem in swath earth location reverse lookup algorithm.
- Fixed dropouts between rectangles in mixed resampling method for cwregister.
- Fixed earth context element in output from cwrender to not draw coverage polygon when area is larger than orthographic projection area.
- Fixed problem with minimized window icons in graphical tools.
- Modified cwmaster so that map projections that support only sphere Earth models cannot be saved with an ellipsoid model.
- Modified the default locale for number formatting and printing to English/US to resolve problems with inconsistent parsing of numbers formatted in other countries.

Version 3.1.9 – April 2005

Updates

- Updated NOAA 1b AVHRR reading for version 3 format.
- Added support in metadata and CW HDF reading/writing for sensor scan geometry geostationary satellite data.
- Added LZW compressed GIF output for CDAT and cwrender.
- Added mixed resampling method to cwregister for handling discontinuities in the source data, such as in MODIS sensor data.
- Added cwautonav tool for estimating navigational corrections using image data.
- Added transparent overlay color rendering in CDAT and cwrender, specifically for overlaying user-specified polygon data without obscuring the background image.
- Modified graphical tools to output error messages that would normally go to the terminal to a dialog. Now users will be able to see "uncaught" exceptions and decide to ignore them or file a bug report.
- Added standard palettes specific to chlorophyll data.
- Added basic ESRI shapefile rendering support in CDAT and cwrender.
- Reformatted all tool manual pages and usage notes for clarity, as well as adding the equivalent one-letter options for all word-length options.
- Added general settings section in CDAT user preferences, initially for lat/lon format preferences.
- Modified all tools to clean up partially written data files after unexpected errors have occurred.
- Modified cwexport and cwrender to detect the desired file format based on the output file extension.
- Added --nostates (don't plot state border, just international borders) and --logo (plot a user-specified logo) options to cwrender.
- Added --imagecoords (print image row and column coordinates) to cwsample.
- Added log scale enhancements to CDAT.
- Updated graphical tool icons, menus, help pages, and Unix look-and-feel.
- Modified drop shadow rendering in CDAT and cwrender for better text readability.
- Added --projection option to cwdownload to allow the user to download only mapped or swath data files.

Bug fixes

- Fixed overflow problem when writing HDF attribute data beyond 65535 values long.
- Fixed registration problem with navigationally corrected data.
- Fixed inappropriate missing value problem in ESRI ArcGIS grid and raw float output.
- Fixed "almost equals" problem with map projection parameter comparisons.
- Fixed background fill problem in CDAT data view when performing navigation.
- Fixed CDAT image saving bug; data view changed or became unusable after saving.
- Fixed problem with CDAT leaving files open even when user has closed file.
- Fixed PDF page size problem.

Version 3.1.8 – November 2004

Updates

- Extended data caching in I/O routines to handle arbitrary size data arrays. Previously, some utilities would memory-thrash when faced with a large column count.
- Renamed various SatelliteXXX classes to EarthXXX to mirror more generality in metadata.
- Updated I/O for new metadata specifications, including multiple time periods and composite attributes.
- Modified the default metadata version to 3.2. Now by default, new files created with the utilities are no longer compatible with the older CDAT version 0.7a and earlier.
- Updated coastline data files to GSHHS v1.3 and corrected known polygon fill problems on the US East Coast, Africa, and South America.
- Updated ETOPO5 topography database and corrected problems with contours fills producing strange bullseye artifacts.
- Added a --timeout option to cwdownload to allow the user to select a network timeout value.
- Added a --transform option to cwinfo to print earth transform information.
- Modified the behaviour of cwcomposite to append dataset metadata together rather than simply use the last file's global metadata (time, satellite, etc). The --pedantic option was also added to allow exact tracking of source dataset metadata.
- Added a --inputs option to cwcomposite to allow the user to specify a list of files in a text file rather than on the command line.
- Recompiled the HDF library for Linux to allow up to 256 open files. This allows the cwcomposite to handle more than 31 input datasets which was the previous limit.
- Modified cwmath to allow multiple input files, and output to an existing file that is not an input file.

- Updated to new install4j installation package wizard to fix various bugs and allow the user to select components during a graphical installation.
- Added various option to cwcoverage tool for plotting ground station coverage circles.

Bug fixes

- Fixed stall problem in cwdownload when data server is unavailable or not responding within a certain timeout period.
- Fixed spelling problems with GCTP sinusoidal projection.
- Fixed swath reverse-lookup problems for non-AVHRR data.
- Fixed registration problems with partially swath-covered partitions in the output dataset.
- Fixed bitmask overlay navigation problem in CDAT.
- Fixed font problems in overlay group loading in CDAT on MacOS X.
- Fixed small polygons bug in CDAT coastline overlay.
- Fixed legend bounding rectangle line style problems in output from CDAT and cwrender.
- Fixed bitmask overlay rendering problems in CDAT on MacOS X.
- Fixed step color scale problems in image file output from CDAT.
- Fixed printing problems in cwinfo and cwstats.
- Fixed CDAT data view size change when many files are opened.
- Fixed CDAT data view so that if multiple file tabs are open and the user switches tabs, the data view does not continue to render to the wrong tab.
- Fixed CDAT problem with allowing multiple overlay property control dialogs.
- Fixed CDAT problem with contour level deletion causing a stall.
- Fixed stall problems in CDAT related to delayed rendering.
- Fixed stall problems in cwstatus when server is not responding.

Version 3.1.5 – September 2003

- Extended GeoTIFF output in cwrender to generate a paletted file when no overlays are used, and such that the ImageDescription TIFF tag contains a mapping equation from palette index to data value.
- Corrected cwimport so that the "pass_type" attribute is correctly written when the metadata version is < 3.
- Corrected the text output from cwexport to write "NaN" for invalid values.

- Corrected a 0.5 pixel offset problem in image overlay rendering.
- Added land polygon filling algorithms for cwmaster (by default) and cwrender (by using --coast).
- Added --operator option in cwstatus for verbose operator messages.
- Added bitwise or/and functions in cwmath.
- Added new "cwgraphics" tool to generate standard CoastWatch graphics overlays.
- Modified cwdownload to more gracefully handle connection errors and network timeouts.

Version 3.1.6 – December 2003

- Fixed space in resource path problem in Windows.
- Added support for AIX and IRIX.
- Added a resize bar for cwstatus between the online data list and data coverage / data preview panels.
- Added the cwcoverage tool for showing region coverage plots (need to add ground station coverage circle feature).

Version 3.1.7 – June 2004

- Updated TeraScan HDF import for equirectangular projections and spheroid detection.
- Changed EarthVectorReader to EarthVectorSource.
- Moved file path creation to IOServices.
- Created ContourGenerator and TopographyOverlay classes and added contouring to cwrender.
- Changed command line tools to split multi-parameter options on regular expression, including ',' and '/'.
- Added splash screen for cwmaster and cwstatus.
- Added support in CWHDFReader for explicit lat/lon data rather than polynomial coefficients.
- Changed use of Vector in many classes to ArrayList for better performance.
- Added support for unsigned HDF and CWF variable data.
- Modified data color scale in cwrender for better log scale behaviour.
- Modified cwmaster and cwstatus batch files to run with the Windows look and feel.
- Fixed automatic center calculation problem in cwcoverage.
- Fixed rounding problem in EarthDataViewPanel.TrackBar.
- Added build file for ant.

- Now using the Java install4j wizard to create installation packages.
- Re-coded and extended the CoastWatch Data Analysis Tool to work with the Java API. In addition to its 0.7a version, CDAT now has annotation and navigation capabilities, online help, GeoTIFF output, topography overlays, generic bitmask overlays, overlay groups, support for swath files, and more. CDAT is now an integrated part of the package.
- Modified the cwstatus menus to allow users to connect to a different server.
- Removed the cwrender preview option – it was causing problems with headless operations.
- Updated online documentation in cwstatus and cwmaster.
- Replaced palette and RGB database files with XML versions.
- Added the --template option to cwmath so that users may use an existing variable as a template for the new variable rather than having to specify all of its properties.
- Added an update agent to graphical tools that informs the user if a software update is available.

Version 3.1.4 – May 2003

- Added two new tools: cwmath and cwcomposite.
- Added MacOS X support in the dynamic JNI libraries and wrapper script.
- Fixed dateline crossing navigation problems in NOAA 1b readers – still needs refinement for near-polar areas.
- Added basic GSHHS polygon rendering code to BinnedGSHHSReader – still needs refinement for bin boundaries and polygons broken by projection distortion.
- Added support for rendering progress to EarthDataView in preparation for CDAT operations.
- Added GLERL palettes "GLERL-Archive" and "GLERL-30-Degrees" palettes to the rendering tool and "NDVI" palette.
- Added "--age" option to download tool for specifying the desired maximum age of the data in hours.
- Added file chooser filters for ".hdf" and ".cwf" files in the cwmaster tool for easier use.
- Added 3D logos to rendering output.

Version 3.1.3 – March 2003

- Added new tool for server status monitoring.
- Optimized download and status tools for database usage and updated command line options.
- Added GeoTIFF output for mapped projection data to cwrender.
- Added NOAA 1b GAC/LAC AVHRR input.

- Fixed various bugs and made performance improvements.
- Updated Unix startup script for headless operations.

Version 3.1.2 – December 2002

- Optimized coordinate translation code, rendering now runs 20% faster.
- Modified rendering normalization for viewable data only.
- Added grid overlay label drop shadows for better label legibility.
- Removed miter problems in shape drawings and coast lines.
- Added gridded dataset tile read/write caching for improved memory performance.
- Added NDVI palette.
- Corrected bitmask rendering for PDF files.
- Added registration tool for mapping between projections.
- Added generic bitmask rendering.
- Added navigation, master, sampling tools.
- Modified download tool command line parameters for regular expression matching.
- Added angle calculation tool.
- Improved coastline selection and rendering performance using binned GMT HDF dataset.

Version 3.1.1 – October 2002

- Added rendering.
- Compiled shared libraries for Windows and Solaris.

Version 3.1.0 – July 2002

- Implemented in Java using Java native interface to CWF and GCTP code.
- Now uses HDF4 via the HDF JNI calls.
- Now supports swath data.

Version 2.4 – June 2001 (internal release)

- Changed Makefile to include cwproj.c in libcwf.a
- Created cwflmaskdb routine
- cwproj.c: Modified for linear lat/lon header errors
- Fixed hdfinfo and cwftohdf usage messages
- cwf.c: Added orbit_type "both" and channel_number "sst_multi"
- cwftohdf.c: Added orbit_type "both" and channel_number "sst_multi"
- cwf.c: Added flat file support, reading only
- Moved cwftohdf to cwftocwhdf
- Moved hdfinfo to cwhdfinfo
- Fixed CWclone bug in hcwf library
- Added Julian day printing to cwhdfinfo

Version 2.3 – October 1999

- cwfcomp.c:
  Added -b option to allow badval specification
  Changed output file date to match last file
- cwf.c:
  Added f to various float constants
  Added test for near-zero IR values
  Simplified round function
  Fixed bug in cw_compress for files with cols < 512
  Added calibration guess for older WCRN files
- cwfnav.c:
  Fixed usage message
- cwftogif.c cwftohdf.c cwftonc.c cwftoraw.c cwfval.c cwproj.c:
  Simplified round function
- cwproj.c:
  Added corrections for WCRN's linear files
- cwftogif.c:
  Modified graphics plane layering, reformatted and commented
  Added ramsdis color palette for CH4 IR
- cwftohdf.c: Completely rewritten

- Created new HDF information routine: hdfinfo
- Created new land masking routine, cwflmask
- Updated Makefile for new HDF and netCDF releases

Version 2.2 – January 1999

- cwf.c:
  Fixed file close bug in decompression routine
  Added more NOAA satellite codes (NOAA-15, -16, -17)
- Created composite program, cwfcomp
- cwftoarc.c:
  Corrected lower-left pixel position and cell size
  Added binary output option
  Added polar projection conversion
  Added projection specifications note
- cwftogif.c:
  Changed IR default min
  Changed brightness temperature legend
- cwproj.c:
  Modified polar projection calculation for Alaska file bugs

Version 2 – September 1998 (first public release)

Version 1 – October 1997 (internal release)

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