PBSsatellite 1.0: User's Guide

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Abstract

This report describes the first version of PBSsatellite, software designed to simplify the extraction and statistical analysis of gridded satellite data. This software extends the R Project for Statistical Computing, and it uses PBSmapping, an existing R package, to aid in spatial analysis and the production of plots. The tools found in this package provide users with the functionality necessary to work with data from a variety of sources. Additionally, users are able to write their own data interpretation algorithms and provide them as arguments to some analysis functions within this package.

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Contents

1 Introduction

When the development of the package PBSsatellite began in 2015, the existing R packages related to satellite data typically focused on importing, rather than analyzing, data. With these libraries, users were largely responsible for writing their own analysis functions. This package was created to address the analysis need. It provides a frontend to the existing import tools, and it provides additional functions for satellite data analysis. In some cases, it complements PBSmapping, an existing R package that offers tools for spatial analysis and the plotting of both linear and polygonal data.

This chapter explores two fundamental aspects of PBSsatellite: (a) the use of the NetCDF file format and the reasons for its adoption and (b) the data sources that were used in the development of the package's data structures.

Chapter 2 explains the package's primary data structure (`ncdfData`). Most of the package's functions for the extraction and manipulation of data require objects of this structure. Additionally, this chapter explains the `TimeSeries` data structure in further detail. This latter structure simplifies the visualization of satellite data trends and the creation of plots.

Chapter 3 demonstrates complex applications of PBSsatellite's features. The first example shows the creation of a time series plot that compares, over time, sea surface temperatures for the Northern and Southern Hemispheres. The second harnesses the power of PBS Mapping to create and subsequently use a complex polygon for selecting and plotting satellite data covering the BC coast. The final example guides a user through the conversion from an incompatible file format (HDF) to a NetCDF file that can be imported into PBSsatellite.

This report concludes with Ch. 4, which documents the functions found in PBSsatellite. This function documentation is also available within R's help system.

1.1 NetCDF dependency

Three formats are widely used for exchanging and storing meteorological data: (a) Extensible Markup Language (XML), (b) Network Common Data Format (NetCDF), and (c) Hierarchical Data Format (HDF) [1]. XML is substantially more verbose than the other two formats, and this verbosity leads to unnecessarily large files. With this being the case, XML was not seriously considered as the primary format for PBSsatellite. The two remaining formats, NetCDF and HDF, received further consideration.

We selected NetCDF over HDF primarily due to the availability and quality of R packages for importing these files. At the time of writing, the Comprehensive R Archive Network (CRAN) did not host any packages explicitly for importing HDF4 files. The hosted package rgdal[1] provides bindings for the Geospatial Data Abstraction Library, which can import HDF4 files when appropriately configured. Unfortunately, the available Mac OS X and (reportedly) Windows versions are built *without* support for HDF4. In contrast, three available NetCDF packages were hosted on CRAN: ncdf, ncdf4, and RNetCDF.[2] Therefore, we selected NetCDF over HDF for PBSsatellite.

After focusing on NetCDF, we aimed to build upon the best of the three available NetCDF packages. The best package would maximize NetCDF compatibility while minimizing additional system requirements (see Table 1.1).

Table 1.1: NetCDF Packages

Package	Advantages	Disadvantages
ncdf	• minimal requirements	• supports only NetCDF version 3
ncdf4	• supports NetCDF versions 3 & 4 • supports offsetting into data files	• requires library netcdf ($\geq$ 4.1)
RNetCDF	• none	• supports only NetCDF version 3 • requires library netcdf ($\geq$ 3.6), udunits ($\geq$ 1.11.7), or udunits2 ($\geq$ 2.1.22)

It was important to make PBSsatellite compatible with as many data sets as possible. Given the information in Table 1.1, we chose ncdf4. While ncdf4 adds one external dependency,[3] it provides support for both NetCDF version 3 and 4 and the ability to offset into NetCDF data files. When users are interested in only a subset of data within a large data set, the offset functionality can effectively skip irrelevant data to reach desired data, making processing significantly faster.

1.2 Data sources

Before designing the `ncdfData` object (Section 2.1), eight data sets were obtained and inspected. Five of these data sets were from the National Oceanic and Atmospheric Administration (NOAA), one was from the Joint Institute for the Study of the Atmosphere and Ocean (JISAO), one was from the U.S. Joint Global Ocean Flux Study (USJGOFS), and the last was from the Climate Research Unit (CRU) at the University of East Anglia. These data sets were analyzed for consistencies, particularly in data location and attribute naming.

[1] rgdal is available from `https://cran.r-project.org/web/packages/rgdal/index.html`.

[2] ncdf is no longer available on CRAN, ncdf4 is available from `https://cran.r-project.org/web/packages/ncdf4/index.html`, and RNetCDF is available from `https://cran.r-project.org/web/packages/RNetCDF/index.html`. Additional packages suitable for importing NetCDF files appear to now be available, too.

[3] This external library, netcdf, is available for Mac OS X, Linux, and Windows from a variety of sources.

Table 1.2: The NetCDF data sources initially selected prior to designing the `ncdfData` object. A data location of "error" indicates that the R ncdf4 library could not open the file, and such files were not used in the design stage.

Source	**Data Type**	**Data Location**
NOAA	Bedrock	error
NOAA	Sea Surface Temperature (Kelvin)	1
NOAA	Sea Surface Temperature (Celsius)	1
NOAA	Sea Surface Temperature	error
NOAA	Sea Surface Temperature (Kelvin)	1
JISAO	Chlorophyll Concentrations	1
USJGOFS	Chlorophyll Concentrations	2
CRU	Sea Surface Temperature (Kelvin)	1

Where data sets consistently named their attributes in a particular way, this naming convention became the default for `ncdfData` attribute acquisition. For example, most NetCDF data sets use the names "lat" and "lon" to store attributes of latitude and longitude coordinate sequences, respectively. Whenever possible, PBSsatellite locates such fundamental attributes automatically. When a NetCDF data file does not follow the expected naming conventions, the user must provide attribute names to the import functions to ensure that PBSsatellite locates the correct attributes.

The data variable ("Data Location", Table 1.2) most commonly appeared as the first variable. Some data sets, however, used a different location, e.g., the USJGOFS data set used the second data variable. For this reason, the first variable is the default when creating an `ncdfData` object, but it can be overridden when necessary using the `dataVariable` argument of the `read.ncdfData` function. For example, the user could pass `dataVariable=2` to `read.ncdfData` when loading the USJGOFS data set.

The sort order used for the X and Y coordinates was also common between several data sources. Most of the data sets had increasing X (longitude) and decreasing Y (latitude) coordinates. While it is possible to reorder these coordinates after creation, the operation can be time consuming. For that reason, we adopted the most frequently encountered order: increasing X and decreasing Y. When a NetCDF file does not follow this convention, `read.ncdfData` detects the situation and reorganizes the X and Y coordinates accordingly so that the resulting object is always consistent in its ordering.

The time units within NetCDF files varied. For example, some files strictly used seconds since an epoch, whereas others used minutes or hours since an epoch. The format of this time attribute also varied greatly between data sets, e.g., "seconds since 1981-01-01 00:00:00" or "hours since 1997-1-1 1:0:0". When creating an `ncdfData` object, the import routine performs a date conversion on these time attributes to create consistent timestamps. The creation of consistent timestamps simplifies subsequent data extraction and comparison operations. For example, prior to date conversion, a sheet of data with the epoch "seconds since 1981-01-01 00:00:00" could have erroneously received a date of "1". After introducing date conversion, however, it correctly receives the date "1981-01-01 00:00:0**1**".

NetCDF data sets frequently have missing data (see Section 2.1.2), and the value used to represent them varies between data sets, e.g., one data set might use -32767 and another might use -99. The ncdf4 package's function `nc_open`, which is used by PBSsatellite to read NetCDF files, automatically detects the NetCDF's missing value attribute and replaces all occurrences of the specified value with `NA`. Given this ncdf4 functionality, missing data consistently appears as `NA` within `ncdfData` objects.

Other inconsistencies included the temperature units in sea surface temperature data sets. As stated in Chapter 2, `ncdfData` objects contain an attribute that stores the `ncdfData`'s data units. In most cases, the attributes in `ncdfData` objects are detected upon import without input from the user. In cases where an attribute is not located or an incorrect value is selected, the user can manually change the unit's variable when creating the `ncdfData` object (the same applies with the data type variable).

2 Data structures

PBSsatellite works with gridded satellite data in the NetCDF format and provides users with tools for manipulating, extracting, and analyzing information in a user-friendly manner. Given the variety of and variability within NetCDF files, this package introduces a new data type, `ncdfData`, to make the representation of data consistent within PBSsatellite. In addition to this new type, the `extractTimeSeries` function produces a well-defined data frame intended for statistical analyses. The sections that follow describe both of these data structures.

2.1 `ncdfData` data structure

The `ncdfData` data structure is the primary type used by the functions in PBSsatellite. The structure is a list of named objects (*slices*), where each slice represents satellite data from a point in time and is named with the date. More specifically, a slice is a list of matrices, where each matrix is known as a *layer*. One of these layers, the data layer, is mandatory, and it contains the gridded satellite data from a point in time. This layer is always the first in the slice, i.e., the first element in the list of layers. In some situations, a slice has additional layers such as the missing and/or error layer. These additional layers are created by the `scaleRegion` function, which is used to change the resolution of an `ncdfData` object.

2.1.1 Attributes

In addition to the R objects (lists and matrices) that must appear in an `ncdfData` object, these objects must also have a set of attributes (Table 2.1). This section describes each attribute.

An `ncdfData` object consists of at least one slice, and the conventional attribute `names` provides each slice's name as a character vector. The slice names are timestamps: a slice's data (one or more matrices) is associated with a moment in time. Naming slices in this way allows for easy data extraction for both exact dates and date ranges. Slices are always stored in chronological order, i.e., the first slice in an `ncdfData` object is the oldest.

The `dataType` attribute descibes the data being stored, e.g., "Long Term Mean of Sea Surface Temperature". Its value is often retrieved automatically when importing NetCDF data, but the

Table 2.1: Required attributes for an `ncdfData` object.

Attribute	Description
`names`	Vector of timestamps, one per slice
`dataType`	Description of the data set
`dataUnits`	Units of the data set
`x`	Vector of longitude coordinates
`y`	Vector of latitude coordinates
`class`	name of the data structure (`ncdfData`)

user can override the description if desired.

The `dataUnits` attribute refers to the actual units for the object's data component, e.g., "degC" or "Kelvin". As with `dataType`, it is often retrieved automatically and can be overridden. Within an `ncdfData` object, the units are consistent, i.e., the `dataUnits` attribute applies to every slice within the object.

The `x` attribute provides a numeric vector of longitude values (in degrees) for the X axis of the data in each slice. This sequence is always stored in ascending order, i.e., longitude values increase from left to right on a map. Note that internally, this attribute actually names the *rows* of a slice matrix rather than the columns. Storing the data in this manner allows for the familiar ordering of X and Y when indexing a matrix, i.e., `[X, Y]`.

The `y` attribute provides a numeric vector of latitude values (in degrees) for the Y axis of the data in each slice. This sequence is always stored in descending order, i.e., latitude values decrease from top to bottom on a map. Note that internally, this attribute actually names the *columns* of a slice matrix rather than the rows for the reason discussed earlier.

Given the sort order of the values in the `x` and `y` attributes, the top-left corner of a map is the origin. For example, if a variable `s` contains a matrix of data, the point `s[1, 1]` is located in the top-left corner of a plotted map.

In addition to the above attributes, an `ncdfData` object must have the class `ncdfData`. Where PBSsatellite functions expect `ncdfData` objects, they may verify the existance of this class.

2.1.2 Structure details

As introduced in Sect. 2.1, an `ncdfData` object often contains multiple time slices. A single slice can be retrieved by either name or index, e.g., the syntax `sst$"2001-02-01"` and `sst[[1]]` both retrieve the first (and oldest) slice from the `sst` data set.[1] Each slice must always have a layer (`data`) containing the satellite data, and it may contain additional layers such as the missing and/or error layer. The `scaleRegion` function can create these two additional layers when it scales down an `ncdfData` object. The missing layer (`miss`) contains the percentage of missing values encountered when scaling down a region. Similarly, the error layer (`error`) contains the percentage of error when scaling down a region. It is important to note that these

[1] The `sst` data set comes with PBSsatellite, and it can be loaded with the command `data(sst)`.

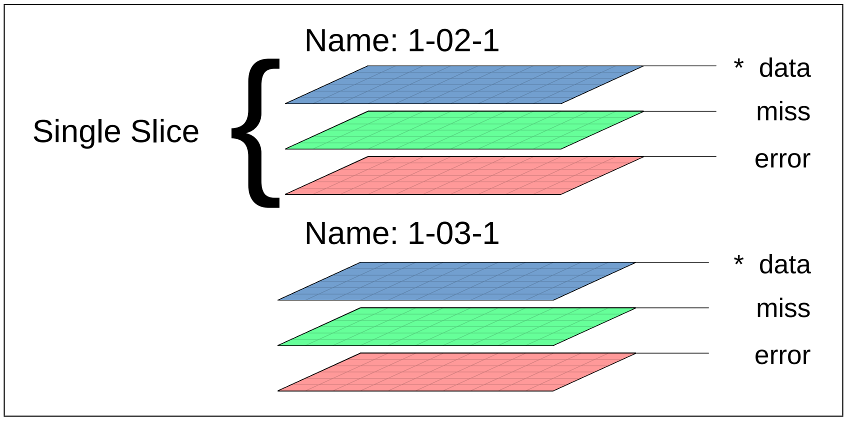


Figure 2.1: `ncdfData` Layers. (* = Required Layer)

additional layers must have the same dimensions as the data layer, i.e., they must contain point-for-point as much data (Fig. 2.1).

Each layer in an `ncdfData` object is stored as a matrix. For slices with multiple layers, individual layers can be retrieved using list notation in the same way that slices can be retrieved.

In certain data sets such as the ones that pertain to SST (Sea Surface Temperature), it is common to have missing data values, e.g., data points on land or points obstructed by cloud cover. In an `ncdfData` object, a `NA` value is used to represent missing data.

Using matrices to store geographic data can be problematic as matrices are inherently rectangular and areas of interest may be non-rectangular. A non-rectangular region can be represented within rectangular matrices by assigning the value `NaN` (Not a Number) to points outside the region of interest.

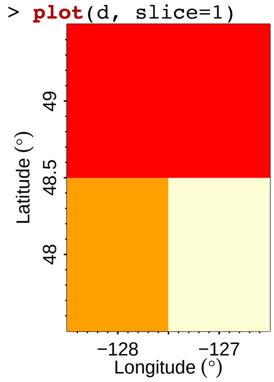
In order to save processing time and space for such an `ncdfData` object, functions will always produce the lowest dimension matrices (considering all layers) that can store all of the object's data (values not encoded as `NaN`). In other words, any rows or columns in an `ncdfData` object that contain `NaN` values exclusively will be removed, as these regions are no longer of importance due to clipping. For an example, see Figs. 2.2 and 2.3.

The code below shows creating, printing, and plotting a trivial `ncdfData` object.

```
d <- list()
d$`2017-06-16` <- list()
d$`2017-06-16`$data <-
  matrix(c(1, 1, 2, 3),
         nrow=2,
         byrow=FALSE)
attr(d, "x") <- c(-128, -127)
attr(d, "y") <- c(49, 48)
attr(d, "dataType") <- "Sample"
attr(d, "dataUnits") <- "none"
attr(d, "class") <- "ncdfData"
```

```
> print(d)
NCDF data
  Data type:  Sample
  Data units: none
Slices:
  Count: 1
  First: 2017-06-16
  Last:  2017-06-16
Slice data:
  X: -128.000 to -127.000 by  1.000
  Y:   48.000 to   49.000 by  1.000
> print(d$`2017-06-16`$data)
     [,1] [,2]
[1,]    1    2
[2,]    1    3
```

```
> plot(d, slice=1)
```



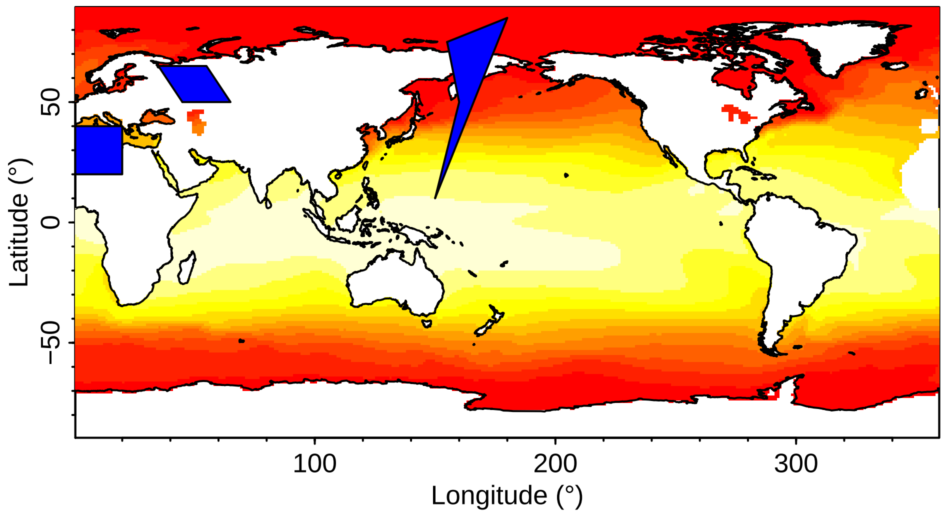


Figure 2.2: Three arbitrary polygons (blue) and the polygons from PBSmapping's `worldLL` data set (white) plotted on unclipped `ncdfData`.

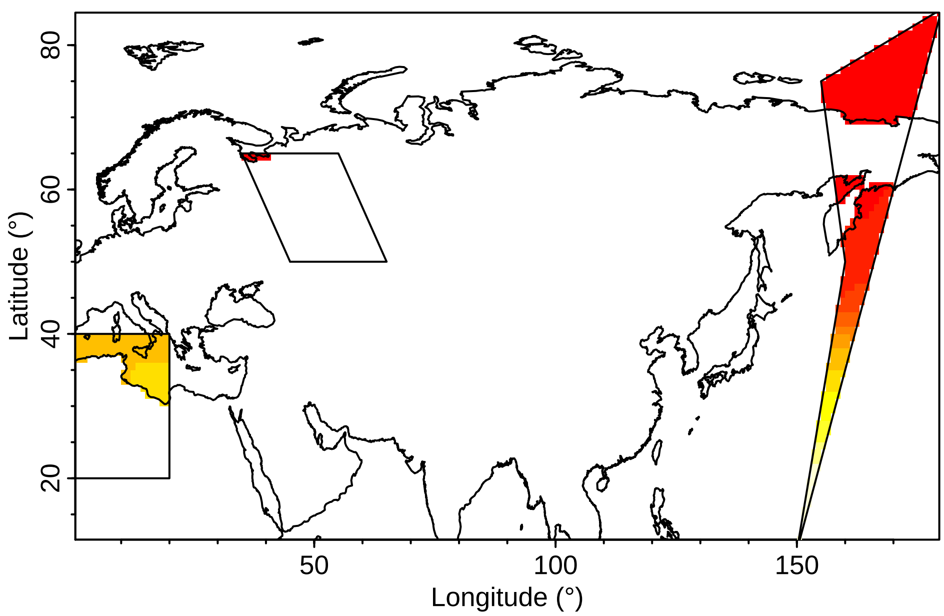


Figure 2.3: The result of clipping `ncdfData` using the polygons in Fig. 2.2. In the resulting `ncdfData` object, `NaN` values represent clipped areas outside of the three polygons and `NA` values represent areas inside the polygons that have a missing data component.

2.2 TimeSeries data structure

A TimeSeries is a list of data frames that contains an analytical summary of an ncdfData's slices over time. A TimeSeries object can be created using the function extractTimeSeries. The extractTimeSeries function will accept standard R summary functions such as **mean**, **sum**, and **sd** (standard deviation). In addition to standard R functions the extractTimeSeries function will accept user defined summary functions. User defined summary functions provides users with the ability to incorporate their own research and summary techniques into the extractTimeSeries function, which allows for unique data analysis. All of the summary functions provided with the functions argument will be used when creating the TimeSeries.

If a polygons argument is provided to the extractTimeSeries function, this will create subregions in each ncdfData slice. Data are then extracted from each of these subregions and processed individually by all of the specified summary functions. If a polygons argument is not provided the whole ncdfData is considered one large subregion and the entire object will be individually analyzed by the supplied summary functions.

A TimeSeries object contains a list of data frames. Each data frame contains a summary for a single slice of an ncdfData object. TimeSeries objects may have different data frames as each polygon adds an additional row and each summary function creates and additional column; therefore, within a single TimeSeries, all data frames are uniform. Each data frame row is identified by a PID (polygon identifier) to represent the subregion that data belongs to. If a polygons argument is provided, each polygon is given a number of 1 to n polygons in the order in which the polygons were passed in (Fig. 2.4).

Slices from the original ncdfData object may be omitted from the TimeSeries object using extractTimeSeries's tlim (time limit) argument. When the user provides a tlim argument, only the slices that fall within the provided tlim will be used to create the TimeSeries object. The xlim and ylim arguments allow the user to limit the range of x and y coordinates that will be used in the TimeSeries. Just like the tlim argument only the coordinates that fall within the ranges of xlim and ylim will be used to create the TimeSeries. When using the xlim and ylim arguments, it is possible to clip out polygons. In the case where a polygon has been clipped, the data frame will have a missing PID for the polygon that has been removed (Figs. 2.4(no clipped polygons) and 2.5(clipped polygons)).

```r
## load sample ncdfData object
data(sst)

## create a PolySet with two polygons
polys <- data.frame(
    PID=c(rep(1, 4), rep(2, 4)),
    POS=c(1:4, 1:4),
    X=c(155, 160, 150, 180,  0, 20, 20,  0),
    Y=c( 75,  50,  10,  85, 20, 20, 40, 40))
polys <- as.PolySet(
    polys, projection="LL")

## create a time series object that
## contains a summary for each of the
## two polygons
ts <- extractTimeSeries(sst, polygons=polys)
```

(a) The code to create a `TimeSeries` object. The function `extractTimeSeries` uses `sum`, `mean`, and `sd` by default.

```
$`2001-02-01`
  PID     sum      mean        sd
1   1 1190.98  2.802306 7.5412064
2   2 1729.63 15.040261 0.8559354

$`2001-03-01`
  PID     sum      mean        sd
1   1 1152.40  2.711529 7.4471030
2   2 1733.61 15.074869 0.7494353

$`2001-04-01`
  PID     sum      mean       sd
1   1 1254.69  2.952212 7.716375
2   2 1825.51 15.874000 0.721301

$`2001-05-01`
  PID     sum      mean        sd
1   1 1535.88  3.613835 8.1701254
2   2 2082.60 18.109565 0.5885894
```

(b) The resulting `TimeSeries` object created by the sample code in (a).

Figure 2.4: Sample code to create a `TimeSeries` object and the resulting object.

```r
## load ncdfData object
data(sst)

## create a PolySet with three polygons
polys <- data.frame(
    PID=c(rep(1, 4), rep(2, 4), rep(3, 4)),
    POS=c(1:4, 1:4, 1:4),
    X=c(155, 160, 150, 180,   0,  20,  20,
          0,  45,  75,  65,  35),
    Y=c( 75,  50,  10,  85,  20,  20,  40,
         40, 80, 90, 75, 65))
polys <- as.PolySet(polys, projection="LL")

## create a time series object that contains
## one summary for each polygon that is not
## clipped by the xlim/ylim argument
ts <- extractTimeSeries(sst, polygons=polys,
    xlim=c(0, 100), ylim=c(35, 60))
```

(a) Code that creates a `TimeSeries` object. The function `extractTimeSeries` accounts for both PolySet's polygons and the `xlim` and `ylim` arguments.

```
$`2001-02-01`
  PID     sum     mean        sd
1   2 1196.96 14.59707 0.4590395

$`2001-03-01`
  PID     sum     mean        sd
1   2 1203.55 14.67744 0.3992889

$`2001-04-01`
  PID     sum     mean        sd
1   2 1269.96 15.48732 0.3930226

$`2001-05-01`
  PID     sum     mean        sd
1   2 1459.84 17.80293 0.3553732
```

(b) The resulting `TimeSeries` object created by the sample code in (a). Notice that the X/Y limits caused the first and third polygons to be clipped.

Figure 2.5: Sample code to create a `TimeSeries` object that combines a PolySet with `xlim` and `ylim` arguments. Note that a polygon (PID 1) is missing in the resulting `TimeSeries` due to a clipping operation specified by the `xlim` and `ylim` arguments.

3 Usage patterns

This chapter describes some common usage patterns and aims to further explain the package's functionality. PBSsatellite's functionality greatly simplifies the otherwise complex operations.

The first example describes how to create a time series plot from imported satellite data to visualize changes over time. The second describes how to leverage a related package, PBSmapping, to create a complex polygon of British Columbia's coastline. After creating this polygon, it is possible to extract, from an `ncdfData` object, the data points that overlap with the ocean. Following the extraction, this resulting `ncdfData` object could be processed as in the first example to create a time series plot for the coastal region. Finally, the last example describes how to convert a sequence of files from version 4 of the Hierarchical Data Format (HDF) to NetCDF. Following the conversion, PBSsatellite can import the data into R.

3.1 Creating time series plots

When studying satellite data, the ability to quickly visualize trends for a specific geographic region can improve the efficiency of data analysis. In PBSsatellite, the `extractTimeSeries` function returns a `TimeSeries` object. This object has a straightforward structure (Section 2.2), and using the PBSsatellite function `listToDF`, can be converted into a data frame and easily plotted using built-in R functions.

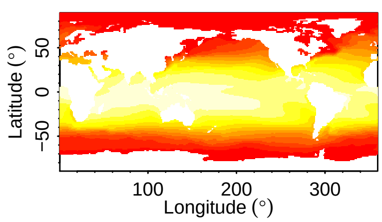
Consider the first slice of the sea-surface temperature data set (`sst`) included with the PBSsatellite package (Fig. 3.1a). Suppose that the user wants to extract time series data for each hemisphere and plot the mean sea surface temperature for each hemisphere. The PBSmapping commands

```
> g <- makeGrid(x=c(0, 360), y=c(-90, 0, 90), addSID=FALSE)
> print(g)
  PID POS   X   Y
1   1   1   0 -90
2   1   2 360 -90
3   1   3 360   0
4   1   4   0   0
5   2   1   0   0
6   2   2 360   0
7   2   3 360  90
8   2   4   0  90
```

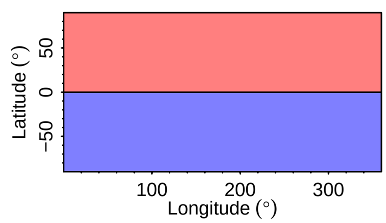
create a PolySet with one polygon for each hemisphere (Fig. 3.1b). Superimposing the two polygons (Fig. 3.1b) over the sea-surface temperatures (Fig. 3.1a) with the commands

```
> plot(sst, slice=1)
> addPolys(g, col=adjustcolor(c("blue", "red"), alpha.f=0.5))
```

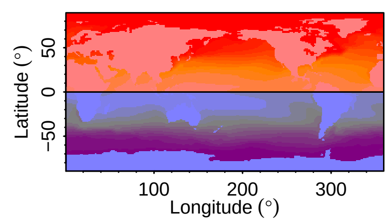
produces Fig. 3.1c and clearly shows the relationship between the polygons and the data set.



(a) The `sst` data set bundled with PBSsatellite.



(b) The PolySet generated by `makeGrid`.



(c) The PolySet representing the two hemispheres superimposed on the `sst` data set.

Figure 3.1: Input data used in this example.

Given this input data, the PBSsatellite function `extractTimeSeries` can extract summary data for each polygon from each slice of the `sst` object. The command

```
> extractTimeSeries(sst)
```

will generate Fig. 3.2a. Although such a `TimeSeries` object follows rather directly from the input data, it is not especially amenable to plotting and further analysis. The PBSsatellite function `listToDF` simplifies further processing by using the list element names to collapse the data frames into a single data frame while generating a new column for the names (Fig. 3.2b).

Given the data frame from `listToDF`, built-in R functions can generate a time series plot (Fig. 3.3). This figure provides code for the complete process that includes creating one polygon for each hemisphere, creating a `TimeSeries` object, and plotting the collapsed time series object.

```
$`2001-02-01`
  PID      sum     mean       sd
1   1 357483.4 15.46141 10.73330
2   2 246355.0 11.67670 11.95005

$`2001-03-01`
  PID      sum     mean       sd
1   1 355020.1 15.35488 10.92622
2   2 247695.1 11.74022 12.07278

$`2001-04-01`
  PID      sum     mean       sd
1   1 342895.3 14.83047 11.02855
2   2 255777.8 12.12332 12.28897

$`2001-05-01`
  PID      sum     mean       sd
1   1 325321.3 14.07038 10.92656
2   2 271396.7 12.86362 12.42489
```

(a) Sample list produced by `extractTimeSeries`.

```
       names PID      sum     mean       sd
1 2001-02-01   1 357483.4 15.46141 10.73330
2 2001-02-01   2 246355.0 11.67670 11.95005
3 2001-03-01   1 355020.1 15.35488 10.92622
4 2001-03-01   2 247695.1 11.74022 12.07278
5 2001-04-01   1 342895.3 14.83047 11.02855
6 2001-04-01   2 255777.8 12.12332 12.28897
7 2001-05-01   1 325321.3 14.07038 10.92656
8 2001-05-01   2 271396.7 12.86362 12.42489
```

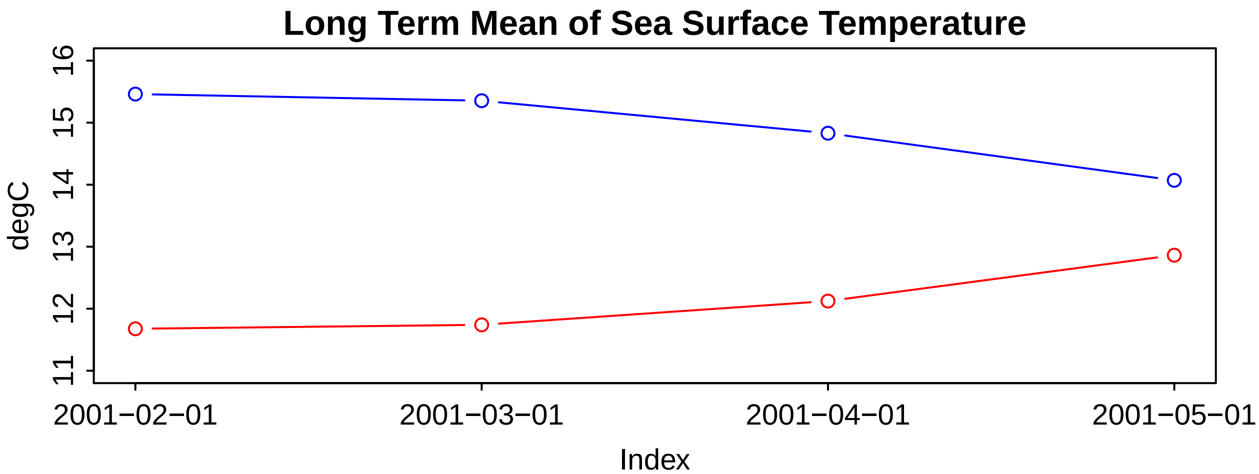
(b) Sample data frame returned from `listToDF` when given the list in (a).

Figure 3.2: Conversion from a list produced by `extractTimeSeries` to a data frame using the function `listToDF`.

3.2 Working with coastlines

Satellite data sets often include points spanning the entire globe, and in many cases, these readings include both land and water. On the other hand, analysis may focus on a specific geographic area, e.g., only measurements for the water within a region. This section provides an example of selecting a region of interest (a coastline) and excluding land measurements from the `ncdfData` object.

In this scenario, a user wants to perform sea-surface temperature analysis on the coastal region of British Columbia (BC). Consider the sea-surface temperature data set (`sst`) included with PBSsatellite, which was previously used in Sec. 3.1 (Fig. 3.1a). The PBSmapping commands



(a) A time series plot showing the mean sea surface temperature for data within the southern (blue) and northern (red) hemispheres.

```r
## load ncdfData object
data(sst)

## create a PolySet with a polygon
## for each hemisphere
polys <- makeGrid(
    x=c(0, 360), y=c(-90, 0, 90),
    addSID=FALSE, projection="LL")

## create a time series object
tsList <- extractTimeSeries(
    sst, polygons=polys)

## convert the time series object into
## a data frame
tsDF <- listToDF(tsList)

## set up some plot parameters
par(mgp=c(1.7, 0.4, 0),
    mar=c(2.7, 2.7, 1.5, 1.5),
    tck=c(-0.02), cex=0.9)

## plot mean for the southern hemisphere
## first (without x axis)
plot(tsDF[tsDF$PID == 1, "mean"],
     type='b', xaxt='n', col='blue',
     ylim=c(11, 16),
     ylab=attributes(sst)$dataUnits)
lines(tsDF[tsDF$PID == 2, "mean"],
      type='b', col='red')

## create appropriate x-axis labels and
## add a title
axis(1,
     at=1:nrow(tsDF[tsDF$PID == 1, ]),
     lab=as.Date(names(tsList)))
title(main=attributes(sst)$dataType)
```

(b) The code used to generate the time series plot shown in (a).

Figure 3.3: Time series plot.

```
> bcCoast <- data.frame(PID=c(rep(1, 7)), POS=c(1:7),
>                       X=c(223, 226, 235, 238, 238, 226, 223),
>                       Y=c( 58,  53,  48,  48,  50,  60, 59.5))
> bcCoast <- as.PolySet(bcCoast, projection="LL")
> print(bcCoast)
  PID POS   X    Y
1   1   1 223 58.0
2   1   2 226 53.0
3   1   3 235 48.0
4   1   4 238 48.0
5   1   5 238 50.0
6   1   6 226 60.0
7   1   7 223 59.5
```

create a `PolySet` containing a polygon with seven vertices that overlies both land and sea within the BC coastal region (Fig. 3.4a). PBSmapping includes the `joinPolys` function, which can join one or more PolySets using a logical operation, and this function can be used to subtract the BC coastline and its islands from the seven-vertex polygon to exclude land readings. The following PBSmapping commands

```
> data(worldLLhigh)
> bcComplex <- joinPolys(bcCoast, worldLLhigh, operation="DIFF")
```

perform the subtraction and produce the polygon shown in Fig. 3.4b.

The PBSsatellite commands

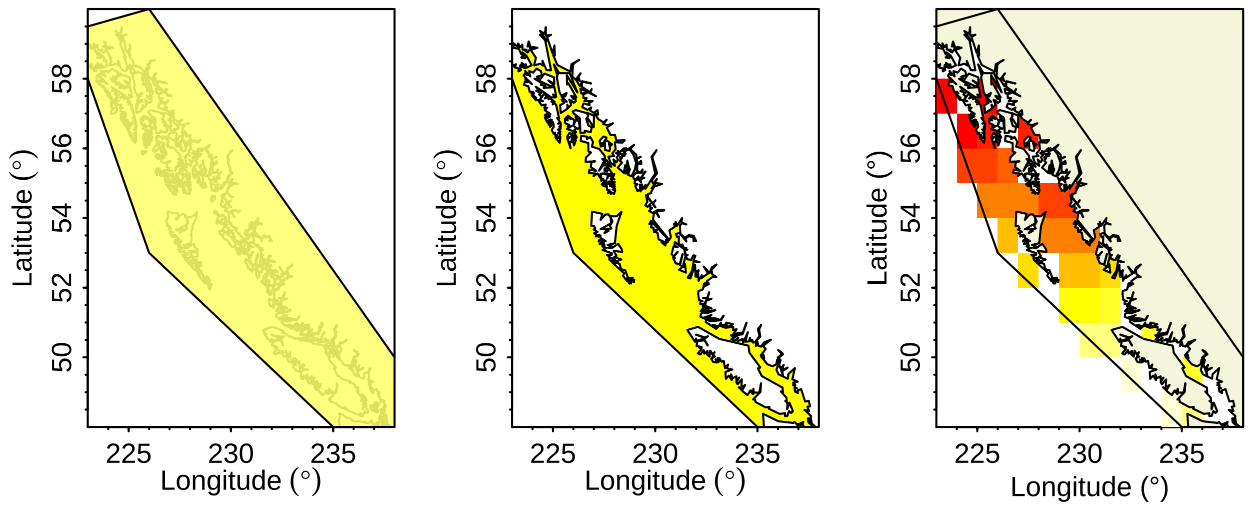
```
> data(sst)
> sstBcCoast <- clipRegion(sst, polygons=bcComplex)
```

clip data from the existing data set (`sst`). The resulting data set contains sea-surface temperature readings for the coloured portions of Fig. 3.4c. Note that regions without colour have no numerical value.

3.3 HDF to NetCDF to `ncdfData` conversion

As stated in section 1.1 HDF file formats are lacking sufficient R libraries, for these reasons PBSsatellite is currently working with NetCDF files. On of the goals with PBSsatellite was to create a platform for satellite analysis that expands beyond the boundaries of a singular data format such as NetCDF. The more data sets that are compatible with this package the more powerful it will become, the quality of satellite analysis strongly depends on the quality and variety of satellite data available. For these reasons providing users with the ability to convert data sets into a supported file format is fundamental.

HDF files are known to provide high resolution data and they also offer a large variety of data, this made the HDF to `ncdfData` conversion an obvious choice for this usage pattern. Because NetCDF is currently the only supported file format for PBSsatellite we took a conversion approach to make HDF files compatible. By converting HDF to NetCDF files we are able to accommodate HDF data files without adding more library dependencies to the package. These



(a) Arbitrary polygon used in this example.

(b) Polygonal result of subtracting (a) from the BC coast (`worldLLhigh`) with PBSmapping's `joinPolys` function.

(c) Sea surface temperature (SST) data clipped using the polygon in (b).

Figure 3.4: The steps in isolating the sea surface temperatures (SSTs) within an arbitrary polygon.

converted NetCDF files can then be transformed into `ncdfData` objects.

3.3.1 Conversion software

Here are two software packages that are necessary to complete the the HDF to `ncdfData` conversion.

Software designed by NCAR Command Language (NCL) provides NetCDF conversion functionality for multiple satellite files at once, including HDF to NetCDF conversation. This software also provides functionality for other file types to be converted to NetCDF.

A strong benefit of this software is that it provides version for Windows, Mac, and Linux systems with user friendly step by step installation instructions and examples. The software installation instructions can be found at `https://www.ncl.ucar.edu/Download/`. Navigate halfway down the page to a section labelled "Download source code or the appropriate binaries for your system."

The second software package that aids in the HDF to `ncdfData` conversion is developed by the NetCDF Operators (NCO) and provides NetCDF merging functionality. NCO additionally provides a variety of additional tools such as ones for renaming and creating dimensions which are fundamental for this conversion process.

As well as NCL, NCO also provides software versions for Windows, Mac, and Linux systems. Users can download NCO and access installation instructions here `http://nco.sourceforge.net/` find the section "Get NCO Binary Executables" which will walk you through a step by step installation process.

3.3.2 Problems with converted NetCDF files

Here is the list of problems that we will solve in our conversion process. The solutions to the following problems are documented in section 3.3.3.

HDF files contain information for one date at a time: This means if we converted these NetCDF files to `ncdfData` objects they only contain a single slice which creates limitations. Previous NetCDF files we used used contained data over a time period, the data for these dates were merged together and stored in an array. For example, the data component of a NetCDF file could access different slices in time with the following operation: data[, , 1] (first slice) or data[, , 2] (second slice). With the current conversion this data this component is lacking and will need to be created, this will be done by merging the new NetCDF files together.

Merged NetCDF files contain the following inconsistencies with when compared to native NetCDF files.

Time attributes are incorrectly formatted: The time unit attribute in these converted files is spread over multiple parameters such as a day, hour, minute, seconds. Where as the time attribute in native NetCDF files is formatted in a single time units attribute such as "days since 2006-01-01 00:00:00."

Time dimension is absent: With a correct time attribute a dimension must be specified. This dimension holds a 1:1 ratio per sheet in the NetCDF file, or for each file we have merged together i.e, if we have merged 3 hdf files together this array will be of size 3. It is mandatory to know when slice in an `ncdfData` object has occurred, without a time dimension time series analysis is not possible.

Latitude and Longitude coordinate sequences are absent: The new NetCDF files do not contain proper X and Y sequence components see figure 3.5 for more information on these sequences. Without these components it is not possible to create an `ncdfData` object because points of data are lacking locations in geographic space.

```
$names
[1] "1-02-01" "1-03-01" "1-04-01" "1-05-01"

$dataType
[1] "Long Term Mean of Sea Surface Temperature"

$dataUnits
[1] "degC"

$x
  [1]   0.5   1.5   2.5   3.5   ...    359.5

$y
  [1]  89.5  88.5  87.5  86.5   ...    -89.5

$class
[1] "ncdfData"
```

Figure 3.5: The attributes of a sample `ncdfData` object within R.

Missing value attribute is not properly formatted: The missing value argument, while it is included in the in the new NetCDF file it is not named properly. On import the ncdf4 library automatically detects the missing value argument and converts them all occurrences of these values to NA. In order for plots and data analysis to be accurate it is essential to properly format the missing values.

With the additional software package NCO we can successfully fix all of the above issues and are able to make the newly created NetCDF files fully functional with our package. This whole process is possible without adding extra R software or library dependencies.

3.3.3 HDF to NetCDF to `ncdfData` conversion process

This section provides a step-by-step description of how HDF data can be imported into PBSsatellite. The process involves converting the HDF files into NetCDF files, which are subsequently merged and used to create an `ncdfData` object.

This conversion is described in four parts. Parts one to three use the operating system's command line with the required software mentioned in section 3.3.1.[1] Part four uses R and completes the conversion by creating an `ncdfData` object.

At the start of the process, assume that three HDF files exist in a directory with the following filenames: `20150702.hdf`, `20150706.hdf`, and `20150709.hdf`.[2] These three related HDF files hold data separated by three days each, with the first file having the date July 2, 2015. It is important that all of the HDF files are from the same data source as attempts to merge files with varying resolutions and/or units will likely fail. If the file names did not contain necessary information for the conversion, e.g., dates or units, the command `ncl_filedump` can be used to gather more information about the file, e.g., Fig. 3.6.

Part 1: Convert HDF files to NetCDF

The program `ncl_convert2nc` performs the HDF to NetCDF conversion. Further documentation and examples can be found at https://www.ncl.ucar.edu/Document/Tools/ncl_convert2nc.shtml.

The following command

```
$ ncl_convert2nc *.hdf -c 'Comment: Converted 3 HDF version 4 files to NetCDF
```

will convert all of the files with the `hdf` file extension within the current directory, and it will produce NetCDF files within the same directory. The `-c` argument will create a comment within the new NetCDF files. In our example, the preceding command will convert `20150702.hdf`, `20150706.hdf`, and `20150709.hdf` to produce `20150702.nc`, `20150706.nc`, and `20150709.nc`, respectively.

[1] We tested these commands on both an Ubuntu Linux and a Mac OS X machine. The commands may need to be adapted for a Windows machine.

[2] These files were downloaded from http://data.nodc.noaa.gov/crw/tsps50km/sst/2015/. The original filenames, e.g., `sst.night.field.50km.n19.20150702.hdf`, have been abbreviated for clarity.

```
$ ncl_filedump 20150702.hdf
 Copyright (C) 1995-2015 - All Rights Reserved
 University Corporation for Atmospheric Research
 NCAR Command Language Version 6.3.0
 The use of this software is governed by a License Agreement.
 See http://www.ncl.ucar.edu/ for more details.

Variable: f
Type: file
filename:       20150702
path:       20150702.hdf
   file global attributes:
      crwhdf_version : 1.0
      cwhdf_version : 3.4
      ...
      start_time : 14400
      start_time_unit : seconds since 00:00:00 UTC
      begin_date : 2015-06-29
      begin_time : 04:00:00 UTC
      stop_date : 2015-07-02
      stop_time : 04:00:00 UTC
      ...
```

Figure 3.6: Abbreviated output from the command `ncl_filedump` showing the date and time of collection.

Part 2: Merge New NetCDF Files

After converting individual HDF files to the NetCDF format, the individual NetCDF files must be merged into a single NetCDF file containing an array of slices (Section 3.3.2). To simplify the commands in Part 3, we recommend that you create the output file in a different directory than the input files, e.g., a subdirectory named `out`. The following command

```
$ ncecat 20150702.nc 20150706.nc 20150709.nc out/20150702-20150709.nc
```

will merge all of the files with the file extension `nc` within the current directory, and it will produce the output file `20150702-20150709.nc` within a directory named `out`. In the preceding command, the input filenames were listed explicitly to ensure that they appeared in the correct order. Depending on the filenames, you may be able to use a shortcut. If the following command

```
$ echo *.nc
20150702.nc 20150706.nc 20150709.nc
```

lists the files in the correct order, then the `ncecat` command line can safely be abbreviated to

```
$ ncecat *.nc 20150702-20150709.nc
```

Part 3: Add Missing Attributes

At this stage, we have a single NetCDF file (`20150702-20150709.nc`) that contains the data of all the source NetCDF files. Before we can import this file into an R-based `ncdfData` object, we must add some fundamental dimensions to it:

- an integer `time` dimension for units since an epoch,
- a `lon` dimension for longitude values in the grid,
- a `lat` dimension for latitude values in the grid, and
- an integer `missing_value` attribute that specifies the value used for missing data.

The integer `time` dimension will provide a timestamp for each slice within the merged file. We recommend that you use `ncl_filedump` to manually find the appropriate attributes by inspecting one of the input NetCDF files, e.g.,

```
$ ncl_filedump 20150702.nc
      ...
      pass_date_unit : days since 1 January 1970
      pass_date : 16615
      ...
```

In the sample above, the string `pass_date_unit` describes the epoch and `pass_date` provides an appropriate integer for the `time` dimension. At this time, note the string used for the epoch; you will not need it until Part 4. To extract all of the integer timestamps, use the following command

```
$ TIMES=($(ls *.nc | xargs -n1 ncl_filedump | grep "pass_date :" | egrep -o '
```

and determine whether the command succeeded by listing the times with the command

```
$ echo $TIMES[@]
```

In our example, the command produces the output `16615 16618 16622`.

Given that the variable `TIMES` now contains the timestamps, we can add them to the merged NetCDF file with the following command

```
$ ncap2 -Oh -s "defdim(\"time\", ${#TIMES[@]}); \
              time[time]={$(IFS=,; echo "${TIMES[*]}")};" \
   out/20150702-20150709.nc out/20150702-20150709.nc
```

In the preceding command, `defdim(\"time\", ${#TIMES[@]});` defines a new dimension named `time` with a fixed size equal to the number of times in the variable names `TIMES`. The fixed size should also correspond to the number of files that were merged together. The argument `out/20150702-20150709.nc` appears twice on the command line: the first occurrence refers to the input file and the second the output file. In this particular case, the command will overwrite the file `out/20150702-20150709.nc` with a new file containing the time dimension.

The next step in this part involves involves adding the longitude (`lon`) and latitude (`lat`) dimensions to the NetCDF file. We recommend that you use `ncl_filedump` to manually determine the distance between points in the newly created NetCDF file `out/20150702-20150709.nc`.

```
$ ncl_filedump out/20150702-20150709.nc
      ...
      easternmost_longitude : 179.75
      westernmost_longitude : 179.75
      northernmost_latitude : 85.25
      southernmost_latitude : -80.25
      spatial_description : The rows of the data array are
```

```
      oriented in west-east direction and columns in north-south
      direction.  Each element (pixel) is 0.5 by 0.5 degree in
      size. The first element (0,0) is at the northwest corner of
      the coverage area.  The southernmost_latitude,
      northernmost_latitude, westernmost_longitude, and
      easternmost_longitude attributes give the locations of the
      outer edges of the boundary pixels.
    ...
    spatial_resolution_row :  0.5
    spatial_resolution_column :  0.5
    ...
    latitude = 331
    longitude = 720
```

Note that the attribute names vary between NetCDF files. For example, we have observed `Longitude_Step` and `Latitude_Step` in place of `spatial_resolution_column` and `spatial_resolution_row`, respectively. Look for attributes that describe the data layout, too, e.g., the preceding `spatial_description` attribute.

In the output above, note that `westernmost_longitude` and `easternmost_longitude` contain an error. Given that these boundaries represent the outer edges of boundary pixels (`spatial_description`), the western-most pixel center would be -179.5 and the eastern-most pixel center would be 179.5. The sequence -179.5, -179.0, -169.5, …, 179.5 contains 719 points, one less than the expected 720. To determine the correct range of longitude points, we revisited the data source web site: http://coralreefwatch.noaa.gov/satellite/metadata/crw_sst_50km_xml_2003_format_20110103.txt. This page describes

> Each grid is 0.5 degree latitude by 0.5 degree longitude in size, centered at latitudes of from 80.0S northward to 85.0N and at longitudes of from 180W eastward to 179.5E.

The following commands will create and display the size of longitude and latitude dimensions.

```
$ LON=($(seq -180 0.5 179.5))
$ echo ${#LON[@]}
720
$ LAT=($(seq 85 -0.5 -80))
$ echo ${#LAT[@]}
331
```

Once these values are correct, the commands

```
$ ncap2 -Oh -s "defdim(\"lon\", ${#LON[@]}); \
                lon[lon]={$(IFS=,; echo "${LON[*]}")};" \
    out/20150702-20150709.nc out/20150702-20150709.nc
$ ncap2 -Oh -s "defdim(\"lat\", ${#LAT[@]}); \
                lat[lat]={$(IFS=,; echo "${LAT[*]}")};" \
    out/20150702-20150709.nc out/20150702-20150709.nc
```

will create the dimensions in the NetCDF file.

In the last step of this part, an attribute named `missing_value` may need to be added to the NetCDF file. The utility `ncl_filedump` can help identify an appropriate value for this attribute:

```
$ ncl_filedump out/20150702-20150709.nc
        ...
        missing_value :         -7777
        ...
        _FillValue :        -7777
        ...
```

Note that the missing value attribute may appear under other names, too, e.g., `Fill`. In this particular case, the value -7777 is a placeholder for missing values in the data matrix.

After identifying the value for the missing attribute, the following command can be used to set the attribute:

```
$ ncatted -O -a missing_value,,c,i,"-7777" out/20150702-20150709.nc
```

Even if a correctly-named attribute exists, the preceding call to `ncatted` can be used without causing any harm. It is important to use the name `missing_value` because the R library `ncdf4` will look such an attribute when converting missing values to `NA`.

Part 4: Create ncdfData object

The preceding parts have produced a NetCDF file, e.g., `out/20150702-20150709.nc` that can be imported into R. For this part, use the PBSsatellite package within R.

The following command will create an `ncdfData` object and complete the conversation from HDF to `ncdfData`:

```
> ncdfData <- read.ncdfData("out/20150702-20150709.nc",
                            Ux="degrees", Uy="degrees",
                            Utime="days since 1970-01-01",
                            dataUnits="x100 Celsius",
                            dataType="SST")
```

Note that the units for both the X and Y dimension are specified using the argument `Uy` and `Uy`, respectively. The `Utime` argument uses the epoch noted earlier in subsection 3.3.3. In order for the library to correctly interpret the string, the date `days since 1 January 1970` must be rewritten as `days since 1970-01-01`. In some cases, the R package `ncdf4` cannot detect data units; for this reason, specify `dataUnits` and `dataType` to ensure the `ncdfData` object has the correct information. The `dataUnits` argument specifies the units for each point of data in the data set, and the `dataType` effectively specifies the title for the data set.

The output from the command-line program `ncl_filedump` can provide hints for how to set these various arguments. For more information about `ncdfData` attributes, see section 2.1.

4

PBSsatellite functions

PBSsatellite *Plotting and Statistical Analysis of Satellite Data*

Description

This software creates a standardize object of NetCDF data know as ncdfData. The ncdfData object allows for multiple NetCDF files to become compatible, regardless of differences in length, attributes, data type, and version.

The ncdfData object allows users to manipulate satellite data for their own usage such as scaling, region clipping, and removing erroneous data values. PBSsatellite also provides easy access to satellite data such as extracting data of interested based on dates and date ranges. Users have the ability to run summary functions on ncdfData which allows for statistical analysis of specific regions of data over time. Users also have the ability to create their own summary functions for more specific staistical analysis.

Author(s)

Nicholas Lefebvre and Nicholas Boers

See Also

PBSmapping

`assessMissingData` *Assessment of Missing Data*

Description

Create an assessment of missing data in each `ncdfData` slice.

Usage

```
assessMissingData(ncdfData, tlim=NULL, xlim=NULL, ylim=NULL,
      polygons=NULL, include.lowest=TRUE)
```

Arguments

`ncdfData`	`ncdfData` used for missing data assessment (required).
`tlim`	start date and end date of assessment. If `tlim=NULL`, then assess all slices.
`xlim`	range of X-coordinates.
`ylim`	range of Y-coordinates.
`polygons`	complex region to apply assessment.
`include.lowest`	see `clipRegion`.

Details

It is common with satellite data for data sets to have missing values. This function is useful to indicate to the user whether a given data set is relatively complete or incomplete. It is also common for satellites to have a bad reading for a given duration, e.g., a week, thus the function is applied to every slice. The user can determine which slices are complete enough for their use.

Value

Numeric vector containing a percentage of missing data for each slice in `ncdfData`.

Author(s)

Nicholas Lefebvre

See Also

extractSlices, clipRegion.

Examples

```
local(envir=.PBSsatEnv,expr={
  ## load ncdfData object
  data(sst)
  ## get missing data assessment
  md <- assessMissingData(sst)
  print(md)

  ## user a polygon for missing data assessment
  ## create 2 polygons
  polys <- data.frame(PID=c(rep(1, 4), rep(2, 4)), POS=c(1:4, 1:4),
                      X=c(155, 160, 150, 180, 0, 20, 20, 0),
                      Y=c(75, 50, 10, 85, 20, 20, 40, 40))
  md <- assessMissingData(sst, polygons=polys)
  print(md)
})
```

clipRegion	*Clip an existing ncdfData object*

Description

Clip the region of a `ncdfData` object. Clipping is applied to all slices in `ncdfData` for the specified region.

Usage

```
clipRegion(ncdfData, xlim=NULL, ylim=NULL, polygons=NULL, include.lowest=TRUE)
```

Arguments

`ncdfData` `ncdfData` from which to clip region (required).

`xlim` range of X-coordinates for data slice(s).

`ylim` range of Y-coordinates for data slice(s).

`polygons` data slice(s) dimensions will be created to match one or more `polygon` dimensions.

`include.lowest` ignored unless user specifies `xlim/ylim`: if `TRUE`, includes points that fall on `min(xlim)` and/or `min(ylim)` but not points that fall on `max(xlim)` and/or `max(ylim)`. If `FALSE`, it does the opposite, includes points that fall on `max(xlim)` and/or `max(ylim)` but not points that fall on `min(xlim)` and/or `min(ylim)`. If `NULL`, includes all boundary points.

Details

In most cases data sets contain information spanning the whole world; therefore, it is useful for the user to be able select a region that better suits their needs. The user will be able to select a geographical area by specifying `xlim` and/or `ylim` arguments, e.g., Northeast Pacific. For more complex selection a user is able to select a geographical area based on a `polygon`, e.g., Georgia Strait.

Clipping will be applied to every `ncdfData` slice.

In situations where `xlim` and/or `ylim` as well as a polygon are provided, `xlim` and `ylim` clipping with be clipped first from `ncdfData`, the `polygon` clipping will be applied to the result.

Value

The `clipRegion` method returns a new `ncdfData` object containing geographically modified slices from an existing `ncdfData`.

Author(s)

Nicholas Lefebvre

See Also

`extractSlices`.

Examples

```
local(envir=.PBSsatEnv,expr={
  ## load ncdfData object
  data(sst)
  ## load worldLL polygons for displaying
  data(worldLL)

  ## clip region based on xlim and ylim
  ncdfDataClip <-clipRegion(sst, xlim=c(190, 320), ylim=c(5, 80),
                                                 include.lowest=NULL)
  ## print newly clipped ncdfData object
  print(ncdfDataClip)

  ## plot ncdfData object
  plot(ncdfDataClip, slice=1)
  addPolys(worldLL, col="beige")

  ## clip region based on xlim, ylim, and polygons
  ## create 2 polygons
  polys <- data.frame(PID=c(rep(1, 4), rep(2, 4)), POS=c(1:4, 1:4),
                      X=c(155, 160, 150, 180, 0, 20, 20, 0),
                      Y=c(75, 50, 10, 85, 20, 20, 40, 40))

  ncdfDataClip <-clipRegion(sst, xlim=c(.5, 300), ylim=c(-50, 90),
  polygons=polys, include.lowest=NULL)

  ## print newly clipped ncdfData object
  print(ncdfDataClip)

  ## plot ncdfData object
  plot(ncdfDataClip, slice=1)

  ## add some polygons to show the clipped region
  addPolys(polys, border="blue", lwd=2)
  addPolys(worldLL, border="gray")
```

```
})
```

`convert.ncdfData` *Convert ASCII Data to NetCDF*

Description

Convert satellite ASCII data to a netCDF file, specifically a ncdf4 binary file.

Usage

```
convert.ncdfData(filename, zfld, nc.filename="converted.nc", summary.func=sum,
   offset=c(0,0), mv=-99, dataType="Chlorophyll", dataUnits="mg/m3")
```

Arguments

`filename`	Name of the ASCII source file (comma-delimied, CSV-like) containing satellite gridded data.
`zfld`	String vector of fields in the source file that contain satellite measurements (e.g., ”Chl”).
`nc.filename`	Name of the NetCDF binary file that user wants to create.
`summary.func`	Summary function (e.g., `sum`) to aggregate multiple measurements at unique combinations of (lon, lat, time).
`offset`	Coordinate (x,y) offset to adjust ASCII (X,Y) grid coordinates in case the latter is defined by some vertex other than the top left one.
`mv`	Missing value indicator, usually -99 in PBSsatellite.
`dataType`	String representing type of data in the file (e.g., ”SST”, ”Chl”).
`dataUnits`	String representing units of dataType (e.g., ”Celsius”, ”mg m^3”).

Details

Users sometimes prefer storing satellite data in cumbersome ASCII files. This function attempts to convert such files to a more effienct ncdf4 binary format. The function imprts the ASCII file and locates the appropriate three dimesnions (lon, lat, date) to create 3-D arrays of z-value data. These data are then passed to the PBSsatellite function `create.ncdfData`, which creates an ncdf4 binary file.

Value

An ncdf4 file (e.g., "converted_chla.nc") is created in the user's working directory. No object is returned to the user's working environment.

Note

This function uses the `fread` function from the R package data.table to facilitate loading very large ASCII files.

Author(s)

Rowan Haigh, Research Biologist,
Pacific Biological Station, Fisheries and Oceans Canada, Nanaimo BC

See Also

`create.ncdfData`, `read.ncdfData`, `plot.ncdfData` `create.ncdfData` *Create an ncdf4 File*

Description

Create a netCDF (ncdf4) file from data.

Usage

```
create.ncdfData(filename, xvals, yvals, tvals, tmess="days since 1900-01-01", zl
   mv=-99, dataType="Chlorophyll", dataUnits="mg/m3", longname=filename)
```

Arguments

`filename`	Name of ncdf4 file to create
`xvals`	Discrete values of X (longitude) that define the spatial grid
`yvals`	Discrete values of Y (latitude) that define the spatial grid
`tvals`	Discrete values of time (dates "YYYY-MM-DD") to define temporal slices.
`tmess`	Time message or descriptor – most versatile = "days since YYYY-MM-DD", where specified date is the first in the series.
`zlist`	List of z-value 3-D arrays, where each array dimension is defined by (lon, lat, date).
`mv`	Missing value indicator, usually -99 in PBSsatellite.
`dataType`	String representing type of data in the file (e.g., "SST", "Chl").
`dataUnits`	String representing units of dataType (e.g., "Celsius", "mg m^3").
`longname`	Long name descriptor – e.g., "Some chlorophyll data I downloaded from NOAA"

Details

This function creates netCDF files in ncdf4 format, which loads into R incredibly quickly.

Value

An ncdf4 file (e.g., "some_chla.nc") is created in the user's working directory. No object is returned to the user's working environment.

Note

See posting by by user3710546 (Mar 11 ’15 at 10:48) at:
http://stackoverflow.com/questions/28949971/writing-data-to-a-netcdf-file-with-r

Author(s)

Rowan Haigh, Research Biologist,
Pacific Biological Station, Fisheries and Oceans Canada, Nanaimo BC

See Also

read.ncdfData, print.ncdfData, plot.ncdfData

extractSlices	*Extract ncdfData slice(s)*

Description

Extract slices from a `ncdfData` object.

Usage

```
extractSlices(ncdfData, slices=NULL, dates=NULL, tlim=NULL)
```

Arguments

`ncdfData`	`ncdfData` from which to extract slices (required).
`slices`	numeric vector containing the slices to extract from `ncdfData`.
`dates`	vector of date strings containing specific dates of slices used to extract slices from `ncdfData`.
`tlim`	vector of date strings (length 2) used to extract slices from `ncdfData` based on a time range.

Details

User must specify one of the three arguments `slices`, `dates`, or `tlim`. A new `ncdfData` object will be created containing the slices that the user has indicated using one of the three extraction methods.

Value

A `ncdfData` object containing slices provided by the extraction method.

Author(s)

Nicholas Lefebvre

See Also

`assessMissingData`, `clipRegion`.

Examples

```
local(envir=.PBSsatEnv,expr={
  ## load ncdfData object
  data(sst)

  ## extract slices based on date strings
  ## create dates object
  dates <- c("2001-03-01", "2001-05-01")
  newNcdfData <- extractSlices(sst, dates=dates)
  print(newNcdfData)

  ## extract slices based date range/tlim
  ## create tlim object
  tlim <- c("2001-02-04", "2001-07-02")
  newNcdfData <- extractSlices(sst, tlim=tlim)
  print(newNcdfData)

  ## extract slices based on slices
  newNcdfData <- extractSlices(sst, slices=c(2,3))
  print(newNcdfData)
})
```

`extractTimeSeries` *Extract ncdfData Time Series*

Description

Create a time series of `ncdfData` based on a given location, using specified functions.

Usage

```
extractTimeSeries (ncdfData, xlim=NULL, ylim=NULL,
                              polygons=NULL, functions=c("sum", "mean", "sd"),
                              na.rm=TRUE, tlim=NULL, combine=1, by=NULL,
                              include.lowest=TRUE)
```

Arguments

`ncdfData`	`ncdfData` to extract time series from (required).
`xlim`	range of X-coordinates.
`ylim`	range of Y-coordinates.
`polygons`	complex range of coordinates from which to extract time series. If more than one polygon time series is created for each polygon and will be specified by a PID.
`functions`	vector of function strings, where each function accepts a numeric vector and produce a single numeric value.
`na.rm`	Boolean or Boolean vector that indicates whether NA's should be omitted; if a vector, should match one-to-one with the functions.
`tlim`	start date and end date of when to begin and end a time series.
`combine`	integer number of slices to be combined into each call to each function in `functions`, e.g., given `ncdfData` with 6 slices, a `combine` value of 2 will produce time series statistics for three times, where each of its times considers the data from two source slices.
`by`	integer number indicating whether the function should skip slices, e.g., produce time series statistics for every second slice in `ncdfData`.
`include.lowest`	see `clipRegion`.

Details

In the case of xlim/ylim, the resulting time series data does not include a subregion identifier. In the case of polygons (one or more), the resulting data set contains a subregion identifier equal to the corresponding PID from polygons.

For each slice in the data set, the function will determine which points fall within the region(s) of interest. It will pass these points (as a vector) into each of the listed functions.

If a combine value is provided that is not a factor of length(ncdfData) (# of slices), slices will be removed from the tail of the ncdfData object in order to accommodate the combine value.

Value

A list of date named data frames. The data frames contain a PID for each polygon that exists inside of xlim and ylim. If xlim and/or ylim=NULL functions will take the full span of ncdfData. Each polygon contains a row in the data frame and will have columns for every function in functions.

If polygons=NULL there will be only one PID for the entire xlim/ylim of ncdfData.

Author(s)

Nicholas Lefebvre

See Also

clipRegion, EventData.

Examples

```
local(envir=.PBSsatEnv,expr={
  ## load ncdfData object
  data(sst)

  ## create a time series based on full map
  ts <- extractTimeSeries(sst)
  print(ts)

  ## create a time series based on 2 polygons
  ## create polygons
  polys <- data.frame(PID=c(rep(1, 4), rep(2, 4)), POS=c(1:4, 1:4),
                      X=c(155, 160, 150, 180, 0, 20, 20, 0),
                      Y=c(75, 50, 10, 85, 20, 20, 40, 40))
  ts <- extractTimeSeries(sst, polygons=polys)
  print(ts)
```

```
})
```

Description

Convert a Lists such as a TimeSeries returned from `extractTimeSeries` into a singular data frame.

Usage

```
listToDF(lst, newColumnName="names")
```

Arguments

`lst` `list` to be converted to a data frame.

`newColumnName`
name of the new column in the data frame.

Details

Converts a list to a data frame. A list contains a name for each list element. The list names are extracted from the list and are stored in a column named by the `newColumnName` argument. This simplifies a list by having both the list names and the list elements data component in a single row contained in a data frame.

Value

A data frame containing a lists names as part of the data frame located in the column named `newColumnName`.

Author(s)

Nicholas Boers

See Also

`data.frame`, `extractTimeSeries`.

Examples

```
local(envir=.PBSsatEnv,expr={
  ## load ncdfData object
  data(sst)

  ## create a time series based on 2 polygons
  ## create polygons
  polys <- data.frame(PID=c(rep(1, 4), rep(2, 4)), POS=c(1:4, 1:4),
                      X=c(155, 160, 150, 180, 0, 20, 20, 0),
                      Y=c(75, 50, 10, 85, 20, 20, 40, 40))
  ts <- extractTimeSeries(sst, polygons=polys)

  ## turn TimeSeries list into a DataFrame
  tsDF <- listToDF(ts)
  print(tsDF)
})
```

`ncdfData`	*NcdfData Object*

Description

PBS Satellite data object that contains satellite data for varying data types and spatial resolutions.

Details

A `ncdfData` object contains at least once slice. A slice contains a date name and at least one layer known as the data layer. The data layer contains the data information for gridded satellite data in a matrix format. The `ncdfData` objects contain attributes for data type (title of data), vectors of x and y coordinates, slice names, and data units. Slices can optionally hold additional layers of information that contain point for point the same data span as the the data layer. Additional layers are created with functions such as `scaleRegion` that gives the user the option to include a missing layer and error layer when scaling down.

A clipped `ncdfData` object with a polygon creates a complex region. In order to store a matrix style of representation of this complex region, slices layers use NaN as a place holder for data that has been clipped for the existing `ncdfData` object. Data that is missing from the original data set and has not been clipped is represented as NA.

Value

A `ncdfData` object

Author(s)

Nicholas Lefebvre and Nicholas Boers

See Also

`read.ncdfData`, `scaleRegion`, `clipRegion`.

Description

Plot an ncdfData time slice.

Usage

```
## S3 method for class 'ncdfData'
plot(x, slice, layer = "data", xlim = NULL,
     ylim = NULL, style = c("image", "contour"),
     projection = "LL", tck = -0.014,
     tckMinor = 0.5 * tck, ...)
```

Arguments

`x`	`ncdfData` object, location of `slice` to be plotted (required).
`slice`	time slice to plot; if `NULL` then first `slice` is selected
`layer`	layer name to plot.
`xlim`	range of X-coordinates to plot.
`ylim`	range of Y-coordinates to plot.
`style`	method for plotting the Z-value – either `"image"` or `"contour"`.
`projection`	desired projection when `PolySet` lacks a `projection` attribute; one of `"LL"`, `"UTM"`, or a numeric value. If Boolean, specifies whether to check `polys` for a `projection` attribute.
`tck`	numeric vector (length 1 or 2) describing the length of tick marks as a fraction of the smallest dimension. If `tckLab = TRUE`, these tick marks will be automatically labelled. If given a two-element vector, the first element describes the tick marks on the x-axis and the second element describes those on the y-axis.
`tckMinor`	numeric vector (length 1 or 2) describing the length of tick marks as a fraction of the smallest dimension. These tick marks can not be automatically labelled. If given a two-element vector, the first element describes the tick marks on the x-axis and the second element describes those on the y-axis.
`...`	additional arguments sent to `style` function.

Details

Plots a `ncdfData` `layer`. If no `slice` is given assumes the first `slice`. If no layer is given assumes the `"data"` layer of `ncdfData` object.

The user can select a region to plot based on `xlim` and/or `ylim` arguments.

The user can select different plotting styles to plot `ncdfData` such as `"image"`, or `"contour"`.

Author(s)

Nicholas Boers

See Also

`read.ncdfData`, `ncdfData`, `plotMap`, `addPolys`.

Examples

```
local(envir=.PBSsatEnv,expr={
  ## load ncdfData object
  data(sst)
  ## load worldLL polygons from PBSmapping
  data(worldLL)

  ## plot map using image functionality on the first slice
  plot(sst, slice=1, style="image")
  addPolys(worldLL)

  ## plot map using contour functionality on the first slice
  plot(sst, slice=1, style="contour")
  addPolys(worldLL)
})
```

`print.ncdfData` *Print ncdfData Object*

Description

Pring ncdfData object.

Usage

```
 ## S3 method for class 'ncdfData'
print(x, ...)
```

Arguments

`x`	`ncdfData` object to be printed (required).
`...`	additional printing arguments.

Details

Prints a `ncdfData` object.

Author(s)

Nicholas Boers

See Also

`read.ncdfData`, `ncdfData`, `print`.

Examples

```
local(envir=.PBSsatEnv,expr={
  ## load ncdfData object
  data(sst)

  ## print ncdfData object
  print(sst)
})
```

read.ncdfData	*Create new ncdfData object*

Description

Create and return a `ncdfData` object. When possible, auto detect names from file and inform the user. User has the ability to override any inconsistencies between NetCDF attribute names and the given `ncdfData` object attribute values.

Usage

```
read.ncdfData(filename, dataVariable=1, convertMissingValues=FALSE,
        dataType=NULL, dataUnits=NULL, xlim=NULL, ylim=NULL, tlim=NULL,
        x=NULL, y=NULL, time=NULL, Ux=NULL, Uy=NULL, Utime=NULL)
```

Arguments

`filename` path/filename of the NetCDF file to be read (required).

`dataVariable`
location of data variable within the NetCDF file `(default=1`).

`convertMissingValues`
if `true` convert missing values "NA" back to native form (`default=FALSE`).

`dataType` string representing type of data in the file (e.g., "SST", "Chl").

`dataUnits` string representing units of dataType (e.g., "Celsius", "mg m^3").

`tlim` range of time (slices) to import. If `tlim=NULL` then import all slices.

`xlim` range of X-coordinates for data slice(s).

`ylim` range of Y-coordinates for data slice(s).

`x` name of x variable. If `xlim=NULL`, then `x="lon"`.

`y` name of y variable. If `ylim=NULL`, then `y="lat"`.

`time` name of time variable. If `time=NULL` then `time="time"`.

`Ux` units of x variable.

`Uy` units of y variable.

`Utime` units of time variable.

Details

Creates a ncdfData object that can be used with other PBSsatellite functions. Where possible, this function attempts to read names from the data file, but it allows the user to override names to account for the inconsistencies between different NetCDF files. The function read.ncdfData makes it possible for a variety of different NetCDF formats with varying data types to become compatible.

Value

The read.ncdfData method creates and returns a ncdfData object containing attributes and data slices from a NetCDF file.

Author(s)

Nicholas Lefebvre

See Also

clipRegion, extractSlices.

Examples

```
local(envir=.PBSsatEnv,expr={
  ## read in the whole NetCDF file containing the full region
  path <- system.file("sst.ltm.1971-2000.nc", package="PBSsatellite")
  ncdfData <- read.ncdfData(filename=path)
  print(ncdfData)

  ## clipping the NetCDF file by dates
  ## create a tlim argument of date strings
  dates <- c("1-02-01","1-05-01")
  ncdfData <- read.ncdfData(filename=path, tlim=dates)
  print(ncdfData)

  ## clipping the NetCDF file by dates and region
  ncdfData <- read.ncdfData(filename=path, tlim=dates, xlim=c(20, 80),
    ylim=c(-80, 10))
  print(ncdfData)
})
```

`removeAnomalousValues` *Remove Anomalous Values from a ncdfData Object*

Description

Remove specified anomalies from every `ncdfData` slice.

Usage

```
removeAnomalousValues(ncdfData, zlim)
```

Arguments

`ncdfData`	`ncdfData` from which to remove anomalies (required).
`zlim`	numeric vector containing a range of acceptable values in `ncdfData` slices. All values that do not fall in the range of `zlim` are removed from the data set and will be replaced with `ncdfData` objects missing value (required). NA can be used to omit part of a range in zlim.

Details

It is common with satellite data for data sets to contain values that are anomalous. This can happen due to a variety of environmental reasons. A `zlim` argument is required that contains a numeric vector containing a range of values that are considered valid.

Value

returns a new `ncdfData` object containing slices with removed anomalous values.

Author(s)

Nicholas Lefebvre

See Also

`assessMissingData`.

Examples

```
local(envir=.PBSsatEnv,expr={
  ## load ncdfData object
  data(sst)

  ## remove values less than -2 and greater than 25
  newNcdfData <- removeAnomalousValues(sst, zlim=c(-2, 25))

  ## remove values greater than 25
  newNcdfData <- removeAnomalousValues(sst, zlim=c(NA, 25))
})
```

Description

Scale ncdfData slices to a new resolution based on a scale factor.

Usage

```
scaleRegion(ncdfData, scaleFactor, fun="drop", placement="topleft",
      includeErrorMatrix=FALSE, includeMissMatrix=FALSE,
      remainder="crop", na.rm=TRUE)
```

Arguments

`ncdfData` — `ncdfData` which will be scaled by `scaleFactor` (required).

`scaleFactor` — positive or negative integer describing the scale factor. A positive integer will scale up a `ncdfData` object a negative integer will scale down a `ncdfData` object. All integers must be a power of two. A positive integer increases the number of data points to 1*`scaleFactor` in each axis for a total increase of 1*`scaleFactor^2`. A negative integer reduces the number of data points to 1/`scaleFactor` in each axis for a total reduction of 1 /`scaleFactor^2` (required).

`fun` — string of a function to used to scale down: `"mean"`, `"min"`, `"max"`, `"drop"`. When scaling up `"repeat"` is always used.

`placement` — string indicating placement for the computed data point: `"topleft"`, `"centre"`.

`includeErrorMatrix` — logical indicates whether an error matrix should paired with each data matrix in the resulting `ncdfData` object.

`includeMissMatrix` — logical indicates whether a missing matrix should be paired with each data matrix in the resulting `ncdfData` object.

`remainder` — string if `"crop"`: if `len(x)` of `ncdfData` and/or `len(y)` of `ncdfData` is not a factor of `scaleFactor` crop will remove rows and/or columns from `ncdfData` slices in order to make `len(x)` and/or `len(y)` a factor of `ncdfData`. If `"fill"`: rows and/or columns of NA values will be added on to `ncdfData` slices to make `len(x)` and/or `len(y)` a factor of `scaleFactor`.

`na.rm` — logical indicates if vector values should omit NA values before call to `fun`.

Details

It is common for satellite data to be in different resolutions. e.g., SST (1/4 degree) or Chl (1/8 degree) It is much easier to compare different data sets that are in a standardized resolution.

This function creates a new `ncdfData` object with slices converted to a new resolution. For this initial version, the new resolution must be an integer scaleFactor of the original resolution. The user must specify a `scaleFactor`. When computing new data points, the user may choose to have the computed data point placed at the `"topleft"` point's position or in the `"centre"` of the scaled points (scaling down only).

A negative `scaleFactor` argument can take a `fun` to perform the scaling operation. Drop is also an option that `scaleRegion` provides. `fun="drop"`: drop points that do not fall on the points of the new scaled down region.

A positive `scaleFactor` argument will only use the `"repeat"` method for version one. `fun="repeat"`: is the default and only function available for scaling up, repeat will repeat a points data 1 * `scaleFactor`^2 times in order to properly increase the scale of `ncdfData` slices.

Value

A `ncdfData` object containing slices with a newly scaled region. If the user has specified `includeErrorMatrix=TRUE` and/or `includeMissMatrix=TRUE` the slices in the `ncdfData` object will now have an additional two layers (error and/or missing). These layers are of the same resolution (point for point) as the slices. These additional layers will have a percent error and a percentage of missing values with every corresponding point in a given slice.

If `placement="topleft"` `x` and `y` attributes will be increased (+ `scaleFactor`) or reduced (- `scaleFactor`).

If `placement="centre"` `x` and `y` attributes will be increased (+ `scaleFactor`) or reduced (- `scaleFactor`) and `x` and `y` attributes will be shifted towards the centre of the point.

Author(s)

Nicholas Lefebvre

See Also

`read.ncdfData`.

Examples

```
local(envir=.PBSsatEnv,expr={
```

```
  ## load ncdfData object
  data(sst)

  ## scale down ncdfData slices by a factor of 2, using mean
  sd <- scaleRegion(sst, scaleFactor=-2, fun="mean", remainder="fill")
  print(sd)

  ## scale down ncdfData slices by a factor of 2, using drop, place result
  ## in the centre of the clip region
  sd2 <- scaleRegion(sst, scaleFactor=-2, fun="drop", remainder="drop",
  placement="centre")
  print(sd2)

  ## scaling up ncdfData slices by a factor of 4
  sd3 <- scaleRegion(sst, scaleFactor=4, fun="repeat")
  print(sd3)
})
```

Description

This is a `ncdfData` object used in the PBSsatellite examples. It contains a data set of long term means of sea surface temperature for several months of 2001. This data set has grid spacing of 1.0 degree latitude and 1.0 degree longitude.

Format

`ncdfData`

Note

Names attribute on this ncdfData object were renamed from 01-MM-DD to 2001-MM-DD for easier understanding in example code.

Source

NOAA_OI_SST_V2 data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/.

References

Reynolds, R.W., N.A. Rayner, T.M. Smith, D.C. Stokes, and W. Wang, 2002: An improved in situ and satellite SST analysis for climate. J. Climate, 15, 1609-1625.

Description

Create `EventData` object from a `ncdfData` slice.

Usage

```
to.EventData(ncdfData, slice)
```

Arguments

`ncdfData`	`ncdfData` where `slice` is located. (required).
`slice`	date string or integer of `slice` location.

Details

Converts a `ncdfData` `slice` to `EventData`. `EventData` makes `ncdfData` compatible with `PBSmapping` functionality. `EventData` is used to find which data points are in a polygon and which points fall outside a polygon, known as the points in polygon problem.

Value

`EventData` with `ncdfData` `slice` information.

Author(s)

Nicholas Lefebvre

See Also

`extractTimeSeries`, `assessMissingData`, `clipRegion`, `PBSmapping`, `findPolys`.

Examples

```
local(envir=.PBSsatEnv,expr={
  ## load ncdfData object
  data(sst)

  ## convert slice to ncdfData
  ed <- to.EventData(sst, slice=1)
  dim(ed); head(ed)
})
```

References

[1] World Meteorological Organization. *Satellite Data Formats and Standards*. http://www.wmo.int/pages/prog/sat/formatsandstandards_en.php. last accessed July 9, 2015.