Package ‘sta’

October 14, 2022

Version 0.1.7

Date 2022-05-29

Title Seasonal Trend Analysis for Time Series Imagery in R

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Description Efficiently estimate shape parameters of periodic time series imagery with which a statistical seasonal trend analysis (STA) is subsequently performed. STA output can be exported in conventional raster formats. Methods to visualize STA output are also implemented as well as the calculation of additional basic statistics. STA is based on (R. Eastman, F. Sangermano, B. Ghimire, H. Zhu, H. Chen, N. Neeti, Y. Cai, E. Machado and S. Crema, 2009) <doi:10.1080/01431160902755338>.

LazyData true

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Encoding UTF-8

Depends raster (>= 2.9-5), R (>= 3.5.0), geoTS (>= 0.1.1), foreach (>= 1.4.4), parallel (>= 3.6.1)

Suggests sp (>= 1.2-0), grDevices

Imports trend (>= 1.1.1), doParallel (>= 1.0.14), mapview (>= 2.7.0), RColorBrewer (>= 1.1-2)

NeedsCompilation no

RoxygenNote 7.2.0

Repository CRAN

Date/Publication 2022-05-30 02:30:02 UTC

R topics documented:

`sta-package` *Statistical Trend Analysis (STA) for Time Series of Satellite Imagery*

Description

STA applies the Mann-Kendall test for trend to the so-called *shape parameters* of periodic time series. STA estimates shape parameters via harmonic regression. STA can handle `numeric` time series and `RasterStack` of satellite images.

Details

Shape parameters is the term used in vegetation monitoring to refer to the amplitudes and phase angles resulting from fitting a harmonic regression model to time series of vegetation indices derived from satellite images. Regardless of its origin, STA can be applied to any periodic time series which makes this package potentially useful to other disciplines such as hydrology, climatology and econometrics.

With `sta` (the main function of this package) it is possible to perform the Mann-Kendall test for trend on time series of the three most commonly used shape parameters: *mean*, *annual* and *semi-annual*. These parameters are the estimated amplitude coefficients of the aforementioned harmonic regresion model. This function allows parallel processing to handle large satellite time series imagery.

STA includes the following graphical methods:

- `plot.staNumeric`: generic plot displaying `sta`'s output for numeric time series.
- `plot.staMatrix`: maps of `mapview-class` displaying `sta`'s output for `RasterStack`.

STA include the following datasets:

- `marismas`: numeric vector containing 10-day Composite NDMI values from 2000 to 2018.
- `ndmi`: `RasterStack` containing 612 spatial subsets of 10-day Composite NDMI images acquired from 2001 to 2017.

Author(s)

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References

Eastman, R., Sangermano, F., Ghimire, B., Zhu, H., Chen, H., Neeti, N., Cai, Y., Machado, E., Crema, S. (2009). *Seasonal trend analysis of image time series*, International Journal of Remote Sensing **30(10)**, 2721–2726.

getMaster — *Get a* RasterLayer *with no missing values from a* Raster* *object*

Description

The term *master* refers to a raster layer whose extent and coordinate reference system are used as a reference to rasterize further objects, e.g. matrices. To rasterize, *master* must be free of missing values.

Usage

```
getMaster(x)
```

Arguments

x	Raster* object

Value

RasterLayer

See Also

matrixToRaster

marismas — *10-day Composite NDMI Time Series*

Description

A numeric vector of length 684 containing 10-day composite values of the Normalized Difference Moisture Index (NDMI) from 2000 to 2018. NDMI = (NIR-MIR)/(NIR+MIR) where NIR and MIR are the Near Infrared and Mid-Infrared bands of the MCD43A4 MODIS product, respectively. This numeric vector was taken from a RasterStack covering the Natural Protected Area *Reserva de la Biosfera Marismas Nacionales* at Nayarit, Mexico.

Usage

```
data(marismas)
```

Format

An object of class "numeric".

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ndmi *10-day Composite NDMI RasterStack*

Description

A RasterStack containing 612 layers of the Normalized Difference Moisture Index (NDMI) from 2001 to 2017. NDMI = (NIR-MIR)/(NIR+MIR) where NIR and MIR are the Near Infrared and Mid-Infrared bands of the MCD43A4 MODIS product, respectively. This RasterStack is a spatial subset of a larger RasterStack covering the Natural Protected Area *Reserva de la Biosfera Marismas Nacionales* at Nayarit, Mexico.

ndmi.tif

A "RasterStack" object with 36 rows, 55 columns, 1980 cells and 612 layers.

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plot.staMatrix *Plot method for* sta *function*

Description

This function displays some maps of mapview-class

Usage

```
## S3 method for class 'staMatrix'
plot(x, significance = NULL, master, ...)
```

Arguments

x	an object of class "staMatrix"
significance	numeric indicating significance of each shape parameter trend
master	RasterLayer used to transfer STA output to raster layers.
...	additional plot parameters

See Also

sta, getMaster, matrixToRaster

plot.staNumeric — *Plot method for* `sta` *function*

Description

This function returns a plot

Usage

```
## S3 method for class 'staNumeric'
plot(x, significance = NULL, ...)
```

Arguments

`x`	an object of class "staNumeric"
`significance`	numeric indicating significance of each shape parameter trend
`...`	additional plot parameters

See Also

`sta`

sta — *Statistical Seasonal Trend Analysis for numeric vector or* `RasterStack`

Description

Statistical Seasonal Trend Analysis for numeric vector or `RasterStack`

Usage

```
sta(
  data,
  freq,
  numFreq = 4,
  delta = 0,
  startYear = 2000,
  endYear = 2018,
  intraAnnualPeriod = c("wetSeason", "drySeason"),
  interAnnualPeriod,
  adhocPeriod = NULL,
  significance = NULL,
  save = FALSE,
  dirToSaveSTA = NULL,
  numCores = 20
)
```

Arguments

`data`	numeric vector, matrix or RasterStack object
`freq`	integer with the number of observations per period. See `Details`
`numFreq`	integer with the number of frequencies to employ in harmonic regression fitting. See `haRmonics`
`delta`	numeric (positive) controlling regularization and prevent non-invertible hat matrix in harmonic regression model. See `haRmonics`
`startYear`	numeric, time series initial year
`endYear`	numeric, time series last year
`intraAnnualPeriod`	character indicating seasons (wet or dry) to be considered for additional statistical analysis. See `Details`
`interAnnualPeriod`	numeric vector indicating the number of years to be considered in STA. For instance, 1:5, indicates that the first five years will be utilized for STA. Similarly, c(2,6,10) indicates that the second, sixth and tenth years will be utilized for STA. See `Details`
`adhocPeriod`	numeric vector with the specific observations to be considered in additional statistical analysis. See `Details`
`significance`	numeric in the interval (0,1) to assess statistical significance of trend analysis. `NULL` by default.
`save`	logical, should STA output be saved, default is `FALSE`
`dirToSaveSTA`	character with full path name used to save `sta` progress report. When `save = TRUE`, `sta`'s output is saved on this path.
`numCores`	integer given the number of cores to use; pertinent when `data` is a RasterStack or a `matrix`

Details

When the input is a `matrix`, its first two columns must correspond to geographic coordinates. For instance, the matrix resulting from applying `rasterToPoints` to a `RasterStack` has this format.

`freq` must be either 12 (monthly observations), 23 (Landsat annual scale) or 36 (10-day composite) as this version implements STA for time series with these frequencies.

This version sets `intraAnnualPeriod` to either the `wetSeason` or the `drySeason` of Mexico. Empirical evidence suggests that while wet season runs from May to October, dry season runs from November to April. Should a desired STA require specific months/days, these must be provided through `adhocPeriod`.

When `interAnnualPeriod` is not specified and `class(data)=numeric`, `interAnnualPeriod = 1:(length(data)/freq)`; when `class(data)` is either `RasterStack` or `matrix`, `interAnnualPeriod = 1:((ncol(data)-2)/freq)`.

Since `adhocPeriod` defines an inter annual period "ad-hoc", the specific days of this ad-hoc season must be known in advance and consequently, the specific time-points (with respect to the time series under consideration) must be provided in a numeric vector.

When save=T, a valid dirToSaveSTA must be provided, that is, this folder should have been created previously. In this case, sta's output is saved on dirToSaveSTA. This version saves arrays of STA of the mean, annual and semi-annual parameters (along with their corresponding basic statistics) in the file sta_matrix_output.RData inside dirToSaveSTA. Also, in the same directory, the file sta_progress.txt records the progress of the STA process.

save=T, dirToSaveSTA, numCores and master are required when data is either a RasterStack or a matrix. The aforementioned basic statistics are: mean and standard deviation of the time series of annual maximum and minimum as well as the global minima and maxima.

Value

When class(data) is a numeric, an object of class "staNumeric" containing:

data numeric vector

freq integer with the number of observations per period

startYear numeric, time series initial year

endYear numeric, time series last year

intraAnnualPeriod
character indicating seasons (wet or dry)

interAnnualPeriod
numeric vector indicating the number of years considered in STA

ts time series object; data in ts format

fit numeric vector with output of haRmonics

sta a list containing the following elements:

- mean a list of 12 elements with STA output for shape parameter *mean*
- annual a list of 12 elements with STA output for shape parameter *annual*
- semiannual a list of 12 elements with STA output for shape parameter *semiannual*

significance numeric in the interval (0,1) or NULL when default used

When class(data) is a RasterStack or a matrix, an object of class "staMatrix" containing:

freq integer with the number of observations per period

daysUsedFit integer vector indicating the indices used to fit harmonic regression. see haRmonics

intervalsUsedBasicStats
numeric vector indicating the indices used on calculation of basic statistics

sta a list containg the following elements:

- mean a matrix of 4 columns with STA output for shape parameter *mean*. First two columns provide geolocation of analyzed pixels, third and fourth columns show p-value and slope estimate of STA, respectively
- mean_basicStats a matrix of 10 columns with basic statistics for shape parameter *mean*. First two columns provide geolocation of analyzed pixels, from third to tenth columns show mean, standard deviation, global minimum, and maximum of minimum values, as well as mean, standard deviation, global minimum, and maximum of maximum values, respectively

- `annual` a matrix of 4 columns with STA output for shape parameter *annual*. First two columns provide geolocation of analyzed pixels, third and fourth columns show p-value and slope estimate of STA, respectively
- `annual_basicStats` a matrix of 10 columns with basic statistics for shape parameter *annual*. First two columns provide geolocation of analyzed pixels, from third to tenth columns show mean, standard deviation, global minimum, and maximum of minimum values, as well as mean, standard deviation, global minimum, and maximum of maximum values, respectively
- `semiannual` a matrix of 4 columns with STA output for shape parameter *semiannual*. First two columns provide geolocation of analyzed pixels, third and fourth columns show p-value and slope estimate of STA, respectively
- `semiannual_basicStats` a matrix of 10 columns with basic statistics for shape parameter *semiannual*. First two columns provide geolocation of analyzed pixels, from third to tenth columns show mean, standard deviation, global minimum, and maximum of minimum values, as well as mean, standard deviation, global minimum, and maximum of maximum values, respectively

Note

STA is based on the following ideas. Let y_t denote the value of a periodic time series at time-point t. It is well-known that this type of observations can be modeled as:

$$y_t = a_0 + a_1 cos((2\pi t)/L - \phi_1) + ... + a_K cos((2\pi K t)/L - \phi_K) + \varepsilon_t, t = 1, \ldots, L.$$

This model is known as harmonic regression. L denotes the number of observations per period, K is the number of harmonics included in the fit, a_i's and ϕ_i's are called amplitude coefficients and phase angles, respectively. K can be known empirically. Amplitudes and phase angle can be obtained as the solution of a least-squares problem.

In vegetation monitoring, amplitudes and phase angles are known as *shape parameters*. In particular, a_0, a_1 and a_2 are called *mean* and *annual* and *semiannual* amplitudes, respectively. Applying the harmonic regression model to observations over P periods of length L each, results in estimates of shape parameters for each period. Thus, focusing only on amplitudes, `sta` yields time series of mean, annual and semiannual parameters. A subsequent Mann-Kendall test for trend is performed on each of these series.

References

Eastman, R., Sangermano, F., Ghimine, B., Zhu, H., Chen, H., Neeti, N., Cai, Y., Machado E., Crema, S. (2009). *Seasonal trend analysis of image time series*, International Journal of Remote Sensing, **30(10)**, 2721–2726.

Examples

```
sta_marismas <- sta(data=marismas, freq=36)
str(sta_marismas)
plot(sta_marismas)
plot(sta_marismas, significance=0.09)

# Use of interAnnualPeriod
sta_21016 <- sta(data = marismas, freq = 36, interAnnualPeriod = c(2, 10, 16))
plot(sta_21016)
```

```
# Use of intraAnnualPeriod
sta_drySeason_218 <- sta(data = marismas, freq = 36,
                     interAnnualPeriod = 2:18, intraAnnualPeriod = "drySeason")
plot(sta_drySeason_218)

# Use of adhocPeriod and significance
adhoc <- list()
beginPeriod <- (1:17) * 36
endPeriod <- 2:18 * 36
adhoc$partial <- c( sapply(1:length(beginPeriod),
                 function(s) c(beginPeriod[s]+1, endPeriod[s]) ) )
adhoc$full <- c( sapply(1:length(beginPeriod),
              function(s) (beginPeriod[s]+1):endPeriod[s]) )
sta_adhoc_218 <- sta(data = marismas, freq = 36, interAnnualPeriod = 2:18,
                startYear = 2000, endYear = 2018, adhocPeriod = adhoc, significance=0.05)
plot(sta_adhoc_218)

# Use of ndmi RasterStack

ndmi_path = system.file("extdata", "ndmi.tif", package = "sta")
ndmiSTACK <- stack(ndmi_path)
dir.create(path=paste0(system.file("extdata", package="sta"), "/output_ndmi"),
          showWarnings=FALSE)
outputDIR = paste0(system.file("extdata", package="sta"), "/output_ndmi")

sta_ndmi_21016 <- sta(data = ndmiSTACK, freq = 36,
                  numFreq = 4, delta = 0.2, intraAnnualPeriod = "wetSeason",
                  startYear = 2000, endYear = 2018, interAnnualPeriod = c(2,10,16),
                  save = TRUE, numCores = 2L, dirToSaveSTA = outputDIR)
```

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