



Diversity II – Preliminary Dryland Products

Booklet for Test Site 15 Caatinga, Brazil



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European Space Agency

Project requirement definition; user interface; EO data provision; project control



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Introduction

With the Diversity II project (<http://www.diversity2.info/>) ESA aims at contributing with EO based methods to the strategic goals of the Convention on Biological Diversity (CBD), especially the supportive goal E: Enhance implementation through participatory planning, knowledge management and capacity building. Besides the CBD and other interested parties, also the UN Convention to Combat Desertification (UNCCD) is a major relevant and interested stakeholder and participating in the User Requirement compilations. The specific aim of this project is to set up an EO-based monitoring scheme for assessment of status, changes and trends of biodiversity and ecosystem NPP (Net Primary Production) in global drylands using moderate resolution EO data. The project is based on Envisat MERIS data and comprises a period of analysis from 2002-2012. Figure 1 gives an overview of the dry land sites which have been selected in the Diversity II project.

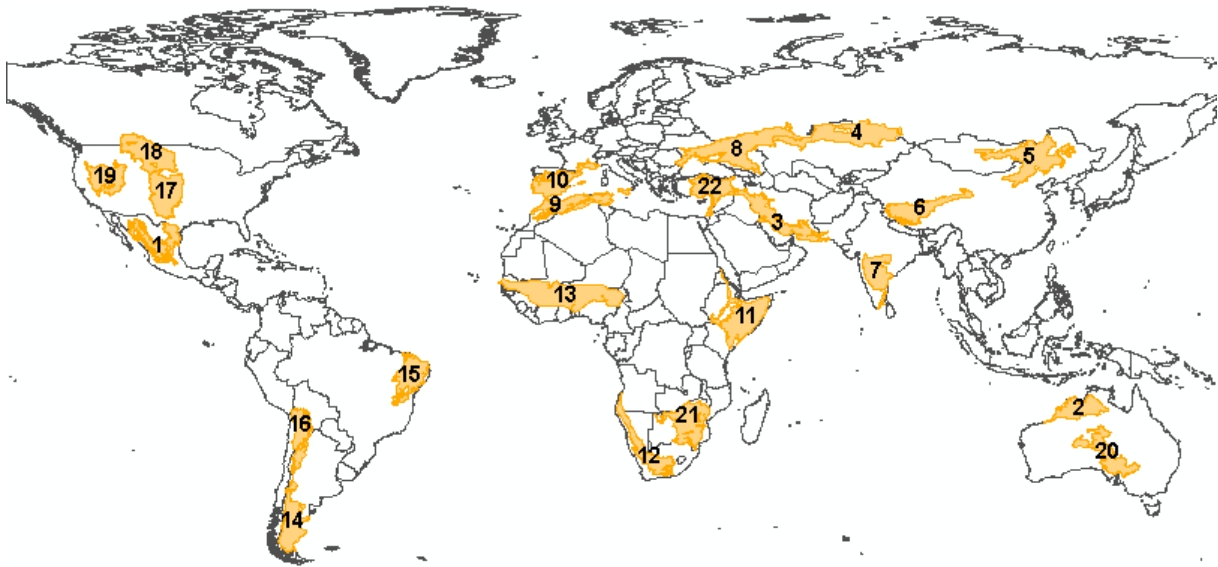


Figure 1: Distribution of global Diversity II dry land sites

Scope of the Preliminary Booklet

This booklet presents NPP proxy and Rain Use Efficiency (RUE) status, change and trend maps for study site 10, Southern Europe along with some basic background information. The booklet is in a preliminary stage and may be changed upon user request to include further or different results of the analyses. The booklets can be downloaded on <http://www.diversity2.info/testsites/ppd/>.

However, the focus of the booklet is on the most significant and important results of the studies, while complete documentations of methods, techniques and all results will be subject of the project reports. The presented maps can be downloaded via FTP (see page 10 for FTP access).

Up to now, only so-called “Level one” products are shown, i.e. descriptive maps of status and trends of NPP proxies and RUE. They will be supplemented with level-two products, which are currently under development and aim to present the results in more abstract and synthesised ways.

The booklet serves not only to present methods and results in a compact way to users, but also to elicit user feedback. At the end of the booklet (page 32), a short questionnaire is included, aiming at structuring the feedback along some general lines. However, for convenience we recommend to use the on-line questionnaire on <http://www.diversity2.info/testsites/ppd/uq/>.

Overview of Test Site

The map in Figure 2 presents an overview of the study site 15 in the eastern part of Brazil. The map on the left-hand side shows the GlobCover v. 2.3 2009 data, which were derived (<http://due.esrin.esa.int/globcover/>) based on ENVISAT MERIS FR (300m) reflectance data. The GlobCover map shows a rather densely vegetated test site mainly characterized by mosaic croplands and vegetation and closed to open shrubland. The eastern and southern parts of the test site are dominated by mosaic vegetation.

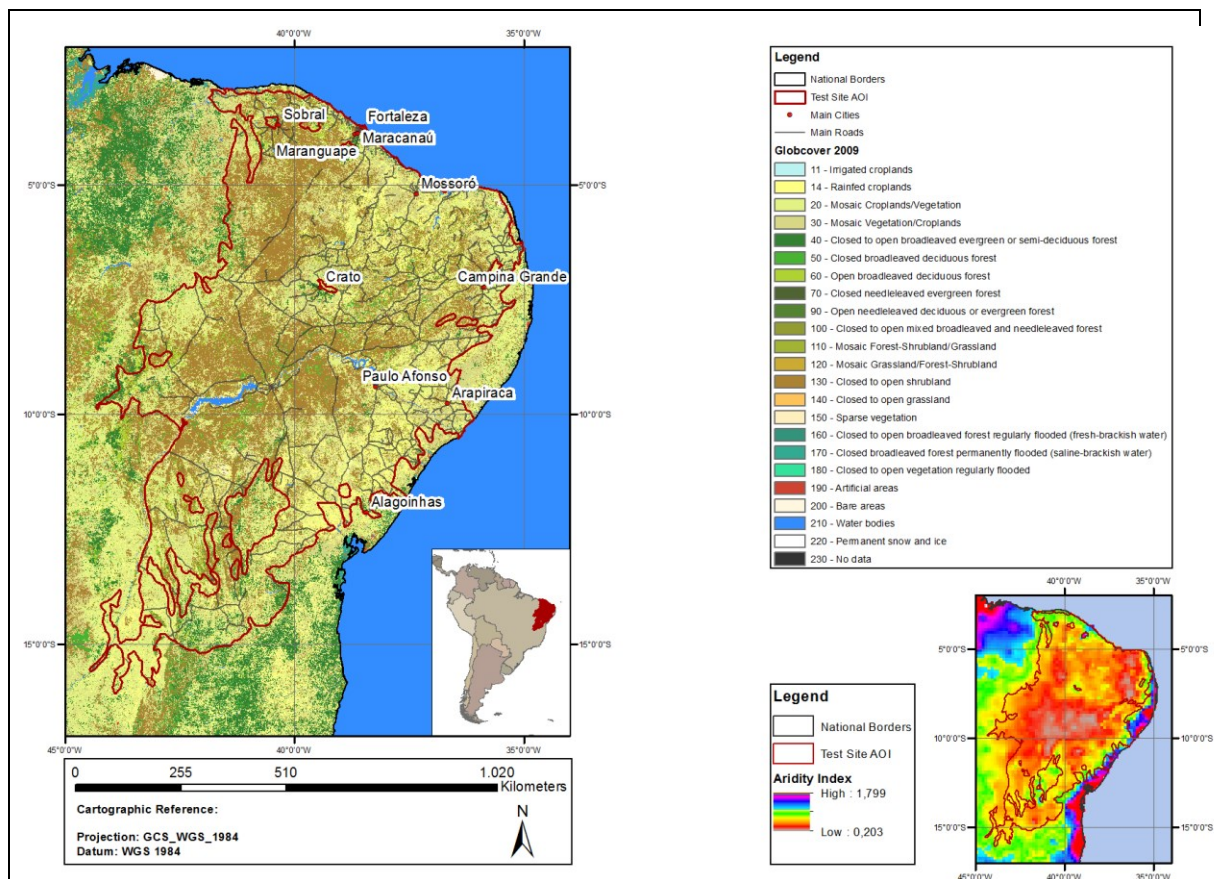


Figure 2: Overview of test site 15, Caatinga, showing land cover from the GlobCover 2009 data set on the left-hand side and an aridity index map on the right-hand side derived from the CGIAR-CSI global aridity data base

Towards the central and northern parts a shift towards shrubland in land cover can be observed. This pattern is clearly following the aridity index derived from the CGIAR-CSI global aridity data base (Zomer et. al, 2007, Zomer et. al, 2008) which is depicted on the right-hand side of Figure 2. The CGIAR-CSI global aridity index is computed as ratio of mean annual precipitation and mean annual potential evapotranspiration. Note that declining values indicate increasing aridity. As such, greater aridity is followed by an increased dominance of shrubland in test site 15. The Brazilian test site comprises aridity values between 0,2 – 1,8 with the majority ranging between 0,2 and 0,5 (following the CGIAR-CSI classification scheme this corresponds to arid conditions).

Figure 3 shows a two climographs of Northern and Southern Caatinga, respectively. Both climographs exhibit a similar seasonal behavior, but also represent the more humid conditions in the South, compared to the North.

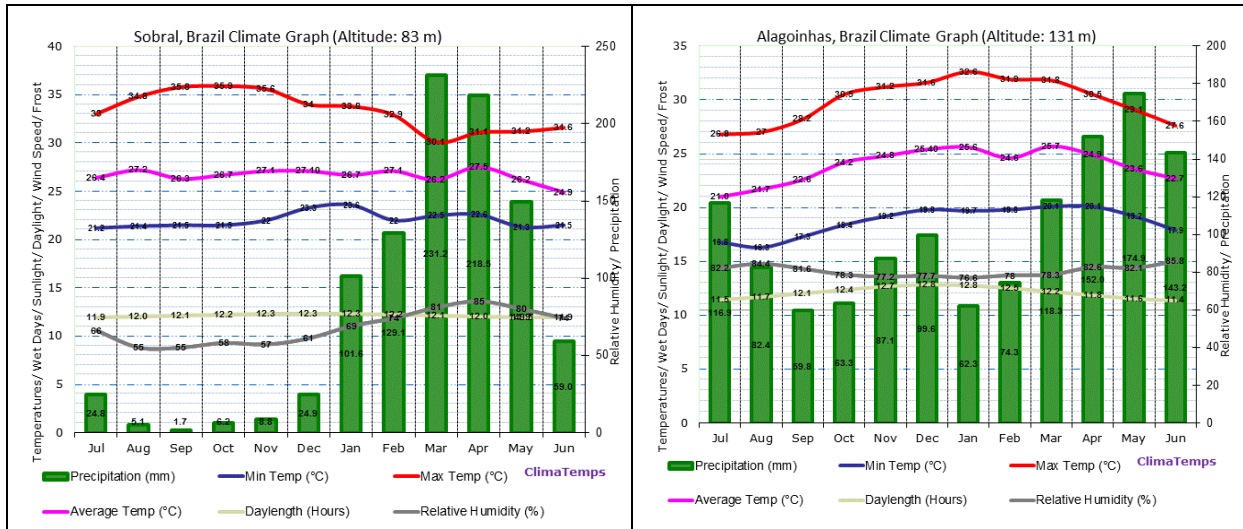


Figure 3: Climographs of Sobral (Northern Caatinga, Brasil) and Alagoinhas (Southern Caatinga, Brasil), sources: <http://www.sobral.climatemps.com/graph.php>, <http://www.alagoinhas.climatemps.com/graph.php>

Vegetation and Biophysical Time Series

The seasonal behaviour of the vegetation greenness and important water related parameters are shown in Figure 5. Figure 4 presents the locations of the time series data in all diagrams derived for test site 15, of which time series for location 21 and 24 are presented in Figure 5.

As NPP proxy the NOAA AVHRR GIMMS NDVI (http://gcmd.nasa.gov/records/GCMD_GLCF_GIMMS.html) were used, along with the corresponding rainfall (http://disc.sci.gsfc.nasa.gov/precipitation/documentation/TRMM_README/TRMM_3B42_readme.shtml), CCI soil moisture (<http://www.esa-soilmoisture-cci.org/>) and MODIS evapotranspiration (http://modis.gsfc.nasa.gov/data/dataproduct/dataproducts.php?MOD_NUMBER=16) time series data. All these global data sets can be downloaded from the internet free of charge.

The two diagrams shown give an impression of both the spatial and the temporal variability of rainfall and subsequently of soil moisture and vegetation. MODIS evapotranspiration follows this seasonal pattern at both locations.

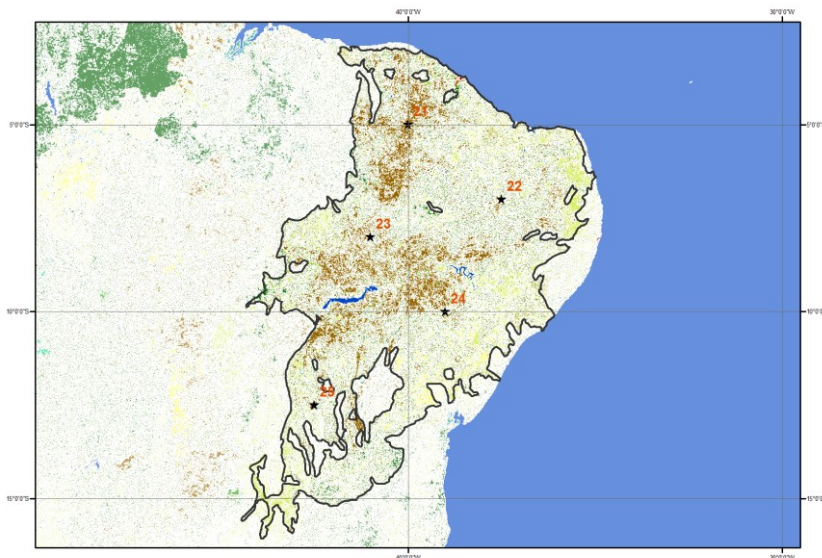


Figure 4: Locations of derived time series diagrams

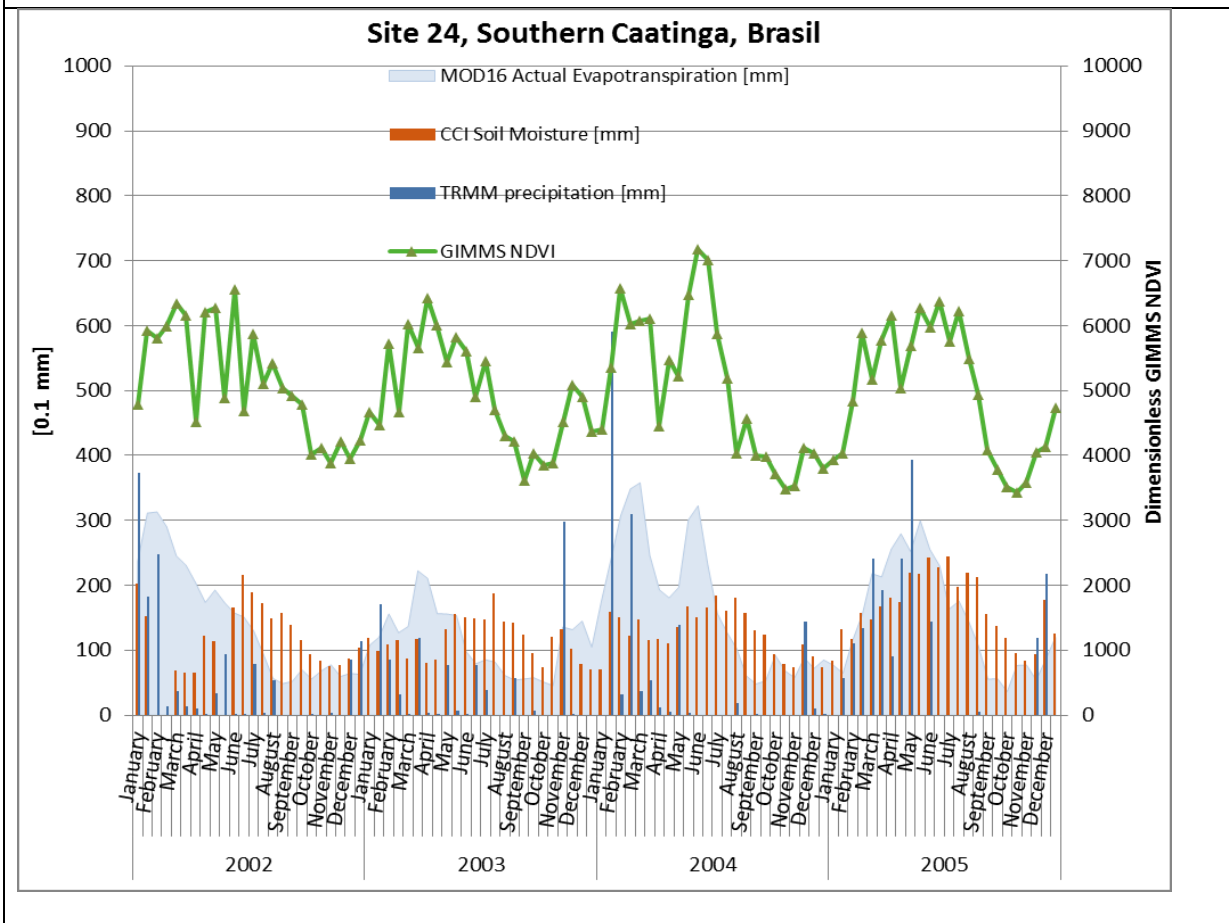
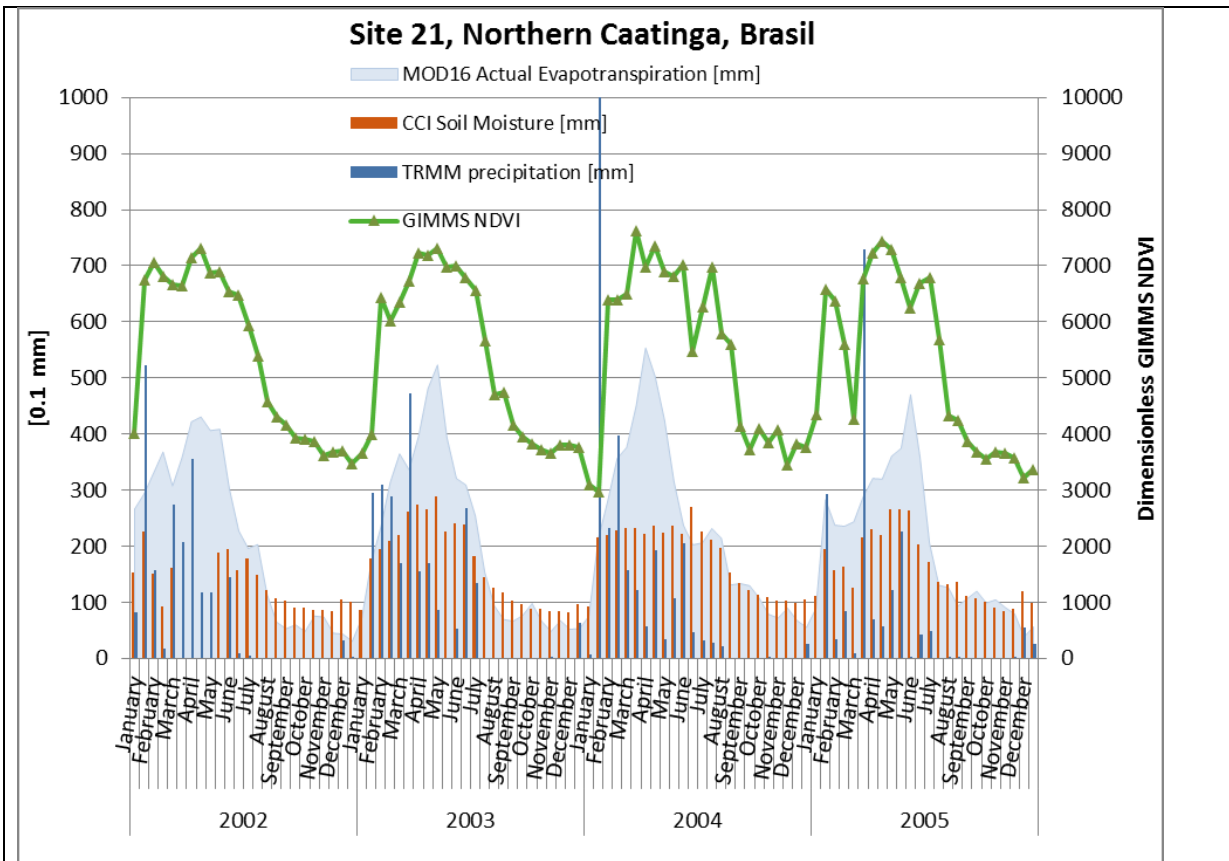


Figure 5: Time series diagrams for locations 21 and 24 in Figure 4

Underlying Data of the Generated Indicators

Based on ENVISAT MERIS FR (Full Resolution) data with a ground resolution of 300m, all NPP proxies presented here and the indicators derived therefrom originate from the fraction of absorbed photosynthetically active radiation (fAPAR) computed according to Gobron et al. 1999. The fAPAR values are compiled on a bi-weekly basis, resulting in time series data with 24 values per calendar year. In addition, TRMM 3b42 rainfall data were used to relate the productivity data to precipitation.

Generation of NPP-Proxies

In a first step, phenological descriptors and periods are derived individually for each year, as shown in Figure 6. The diagram in Figure 6 shows the temporal course of the NPP proxy data (here NOAA GIMMS NDVI) during a 3-years periods and the subdivision into different seasonal periods. The vegetation year includes the full yearly vegetation cycle starting at the end of the preceding dry season and ending at the end of the following dry season – or in case of several green seasons during a year – at or before the begin of the (statistically) dominant green season. The vegetation year length of a given year varies with possible shifts of the green season start time.

The **vegetation year** can be subdivided into different periods, limited by defined starting and ending points in time. The **growing season** includes ascending (green segment of the curve) and descending parts (brown part) and starts once a selected greenness threshold is surpassed on the way from the start of the vegetation year to the green peak. The brown part of the curve demarcates the **senescence period**, which ends again once a defined lower fAPAR threshold is passed. The thresholds depend on the ranges between the fAPAR minima before and after the green peak, respectively, and the peak fAPAR value. Here, 10 percent of these ranges added to the respective minima define the thresholds. The ochre part of the vegetation curve constitutes the “**dry season**”.

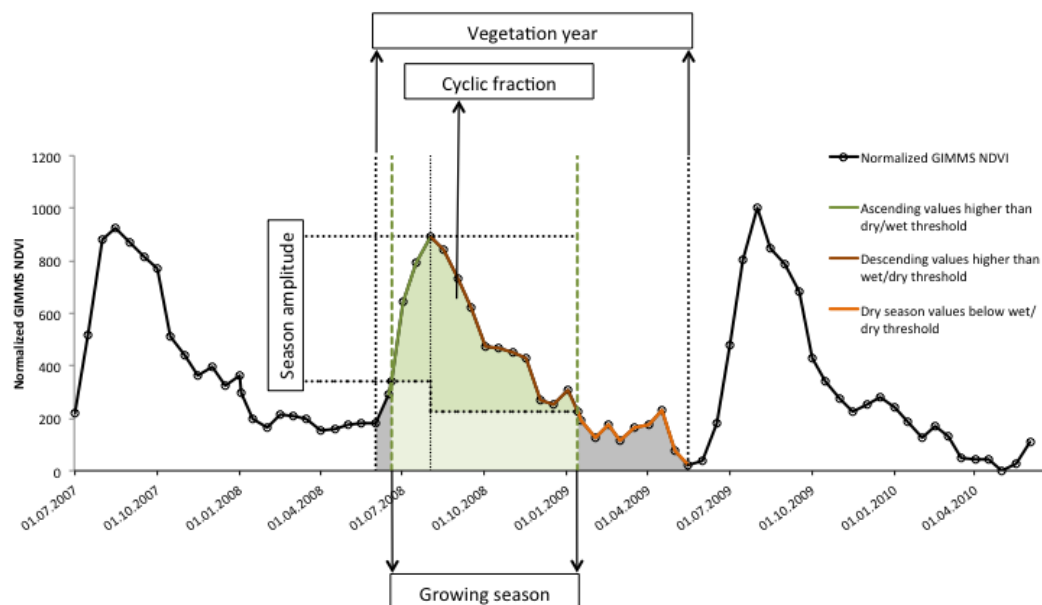


Figure 6: Scheme of the extracted phenological descriptors and periods . Note: the actual NPP proxies are derived based on MERIS fAPAR

For the above described phenological periods, the MERIS fAPAR values have been temporally integrated to either sum or average values, or in case of the season amplitude (figure 4), the

difference between the fAPAR at the start of the growing season and the peak fAPAR is taken. The results are called “**NPP proxies**”, and constitute yearly (one value per vegetation year) values. The indicator maps presented in this preliminary version of the booklet are based on the following NPP proxies:

- **Average vegetation year fAPAR:** Mean value of all fAPAR values within one full vegetation cycle, constituting a proxy for the annual NPP.
- **Cyclic fraction fAPAR:** The cyclic fraction of the vegetation comprises summed fAPAR values of the green peak(s) during a vegetation year, subtracting the non-cyclic base levels. The cyclic fraction fAPAR can be interpreted as the amount of NPP that is directly related to the annual cycle of the climatic vegetation growth factors, especially rainfall.
- **Average dry season fAPAR:** For the dry season the low fAPAR values after the green peak are taken, defined by a 10% amplitude threshold. The dry season greenness values reflect the portion of plants that remain green after senescence of the annual vegetation or grow new green leaves during the dry period. High dry season levels indicate the presence of shrubs, bushes and trees.

From Proxies to Indicators

By analyzing the annual NPP proxies and rainfall through time, a set of indicators for vegetation/ecosystem condition and change is derived. The indicators shown so far can be divided into status and trend type. Given the MERIS data period from June 2002 to March 2012 and the globally varying vegetation cycles, NPP proxy and Rain Use Efficiency indicators for a total of eight vegetation years could be extracted, starting in 2003/(2002) and ending in 2011/(2012).

Hence, the status and trend indicators cover worldwide eight vegetation years. Status indicators for this period include 8-year averages and the coefficients of variation. In addition, the 8-year period was subdivided into two epochs covering four vegetation years each. The corresponding epochal status maps and epochal difference maps are not shown in this booklet.

For the trend indicators, absolute and relative trends are shown. They were derived with the non parametric Theil Sen trend slope estimator (Theil 1950, Sen 1968) and limited with the Mann Kendall significance test (Kendall 1962) to trends with a probability greater than 0.95.

All indicator maps show distinct ranges of the original continuous values, using the same class intervals and colour scheme worldwide.

Maps of Indicators

The following section contains maps for the entire test site and surrounding regions for each indicator product. The first two maps of each item depict status and variability maps while the third and fourth map show absolute and relative trends maps, respectively. An exception is the rainfall maps, where instead of the relative trend the difference between the two epochs (2002 – 2006 and 2007 – 2011, respectively) is shown. The maps are described with short product specifications.

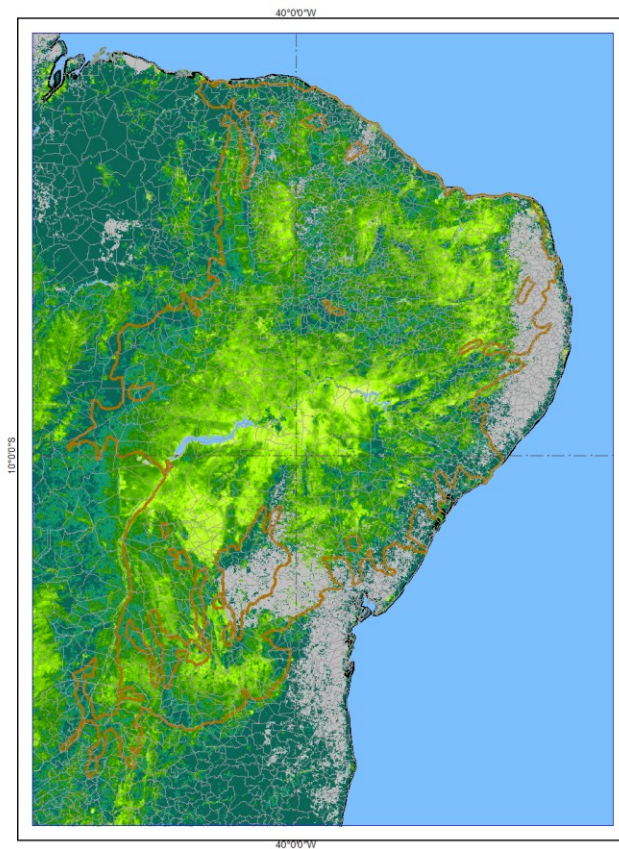
They can be downloaded from:

Domain: <ftp.brockmann-consult.de>

Username: diversity-pub

Password: dl&iw-usr

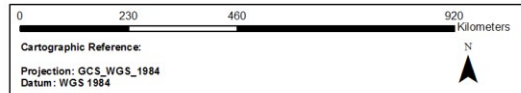
Average Vegetation Year Greenness



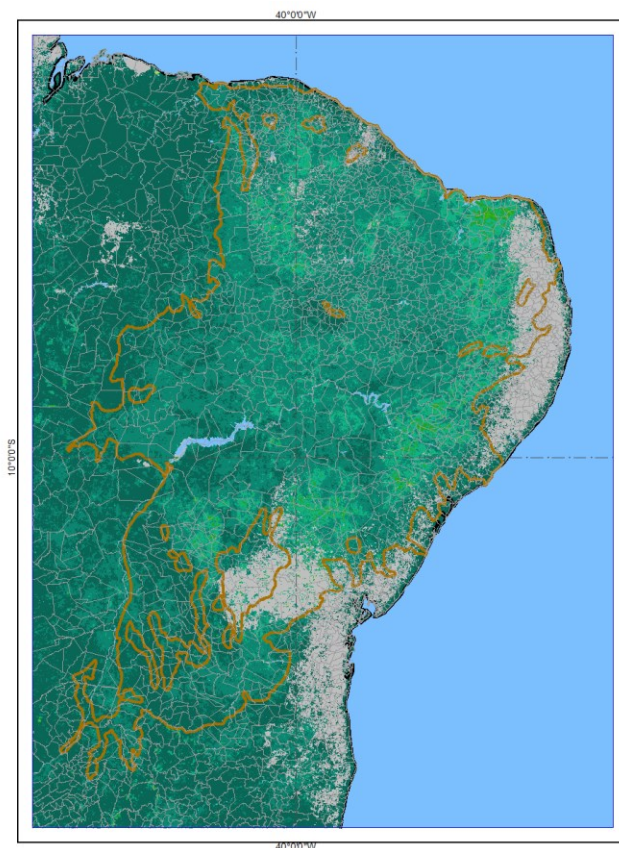
Description:

Status of ENVISAT MERIS fAPAR average vegetation year greenness, calculated as mean value for the period 2002-2011 in test site Caatinga. One vegetation year comprises one full phenological cycle of the vegetation.

Legend



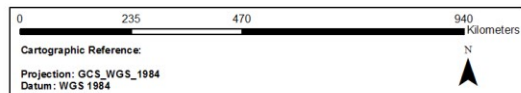
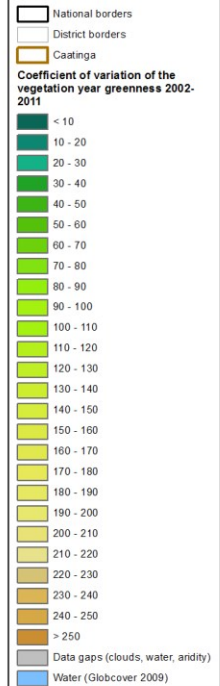
Vegetation Year Variability



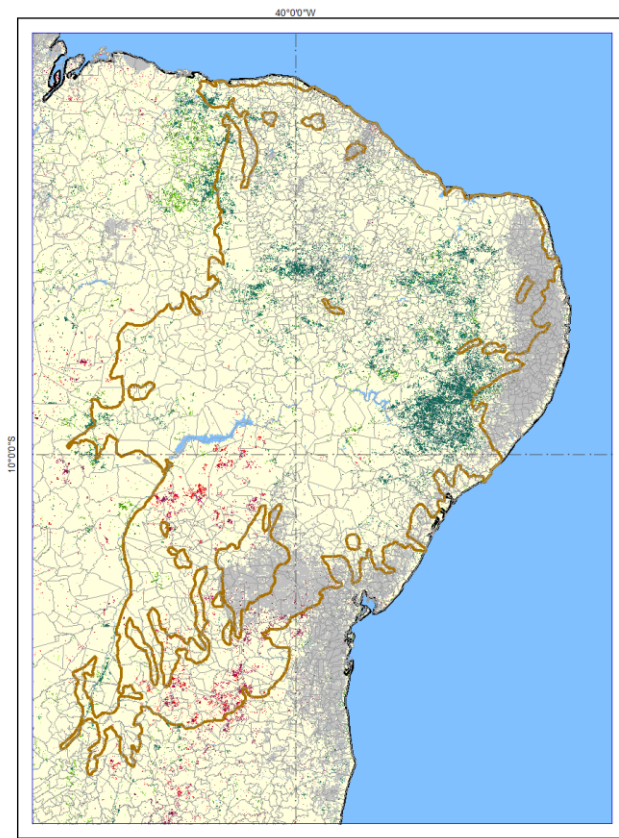
Description:

Variability of ENVISAT MERIS fAPAR vegetation year greenness expressed by the coefficient of variation for the period 2002-2011 in test site Caatinga. One vegetation year comprises one full phenologic cycle of the vegetation.

Legend



Vegetation Year Greenness Trend (abs.)



Description:

Slopes of absolute trends of ENVISAT MERIS fAPAR vegetation year averages in test site Caatinga throughout the period 2002-2011. One vegetation year comprises one full phenological cycle of the vegetation and hence constitutes a proxy for the overall annual NPP. The vegetation year is defined to start at the onset of vegetation greening following first rainfalls and last until the end of the dry season. The actual start of each vegetation year is individually determined for each year.

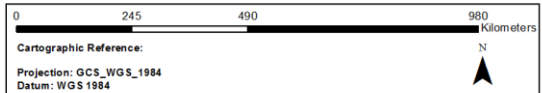
Trends are calculated using the median trend estimator after Theil (1950) and Sen (1968). Only significant trends ($p < 0.05$) are depicted based on the trend test on significance according to Mann (1945) and Kendall (1975).

Trend values indicate average change per year. Original fAPAR values reach from 0 to 1 and have been stretched from 0 to 1000.

Data gaps in the time series resulting from cloud cover, a too pronounced aridity or water bodies have been masked out.

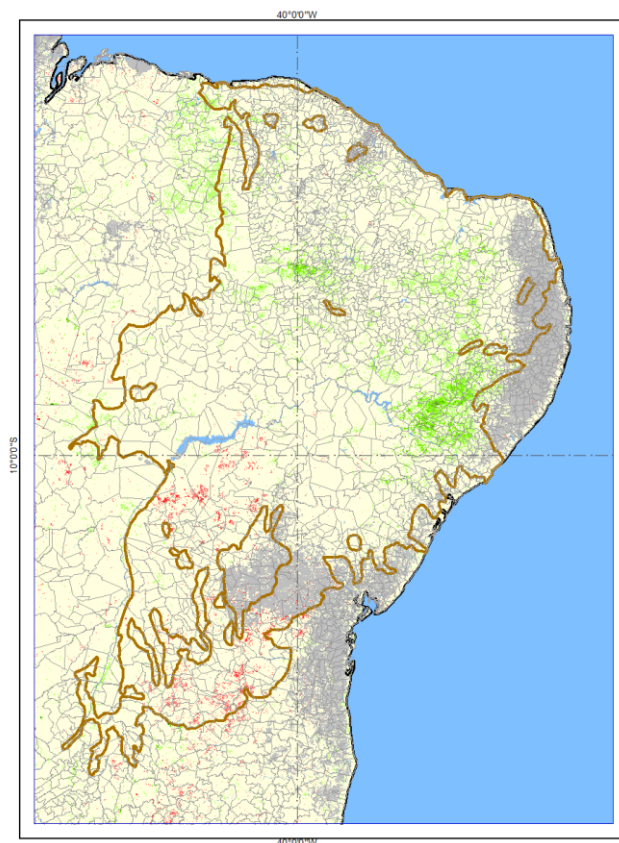
Legend

- National borders
- District borders
- Caatinga
- Absolute trend slopes of vegetation year average greenness 2002 – 2011**
- yearly decrease > 15
- yearly decrease 12 - 15
- yearly decrease 9 - 12
- yearly decrease 6 - 9
- yearly decrease 3 - 6
- yearly decrease 1 - 3
- yearly increase 1 - 3
- yearly increase 3 - 6
- yearly increase 6 - 9
- yearly increase 9 - 12
- yearly increase 12 - 15
- yearly increase > 15
- Insignificant or trend < 1
- Data gaps (clouds, water, aridity)
- Water (Globcover 2009)



Cartographic Reference:
Projection: GCS_WGS_1984
Datum: WGS 1984

Vegetation Year Greenness Trend (rel.)



Description:

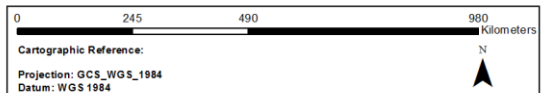
Relative yearly changes of ENVISAT MERIS fAPAR vegetation year averages in test site Caatinga throughout the period 2002-2011. One vegetation year comprises one full phenological cycle of the vegetation and hence constitutes a proxy for the overall annual NPP. The vegetation year is defined to start at the onset of vegetation greening following first rainfalls and last until the end of the dry season. The actual start of each vegetation year is individually determined for each year.

Trends are calculated using the median trend estimator after Theil (1950) and Sen (1968). Only significant trends ($p < 0.05$) are depicted based on the trend test on significance according to Mann (1945) and Kendall (1975).

Data gaps in the time series resulting from cloud cover, a too pronounced aridity or water bodies have been masked out from the analysis.

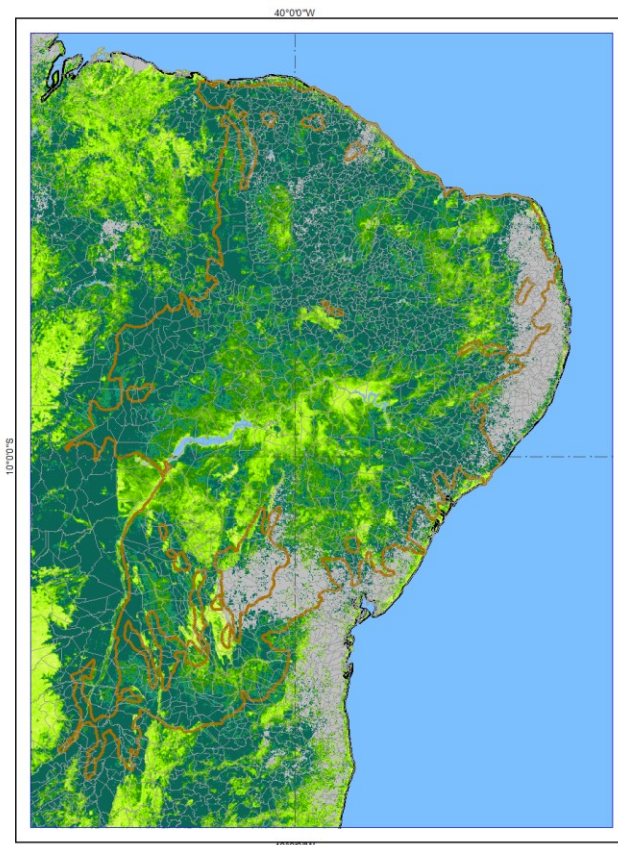
Legend

- National borders
- District borders
- Caatinga
- Relative trend of vegetation year average greenness 2002 – 2011**
- yearly decrease > 15%
- yearly decrease 10 - 15%
- yearly decrease 5 - 10%
- yearly decrease < 5%
- yearly increase < 10%
- yearly increase 10 - 20%
- yearly increase 20 - 30%
- yearly increase 30 - 40%
- yearly increase 40 - 50%
- yearly increase 50 - 60%
- yearly increase 60 - 80%
- yearly increase > 80%
- Insignificant or abs. trend < 0.5
- Data gaps (clouds, water, aridity)
- Water (Globcover 2009)



Cartographic Reference:
Projection: GCS_WGS_1984
Datum: WGS 1984

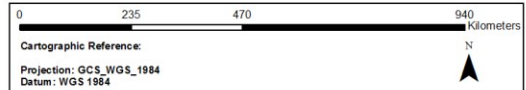
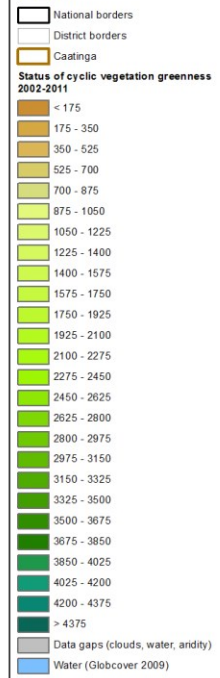
Cyclic Vegetation Greenness



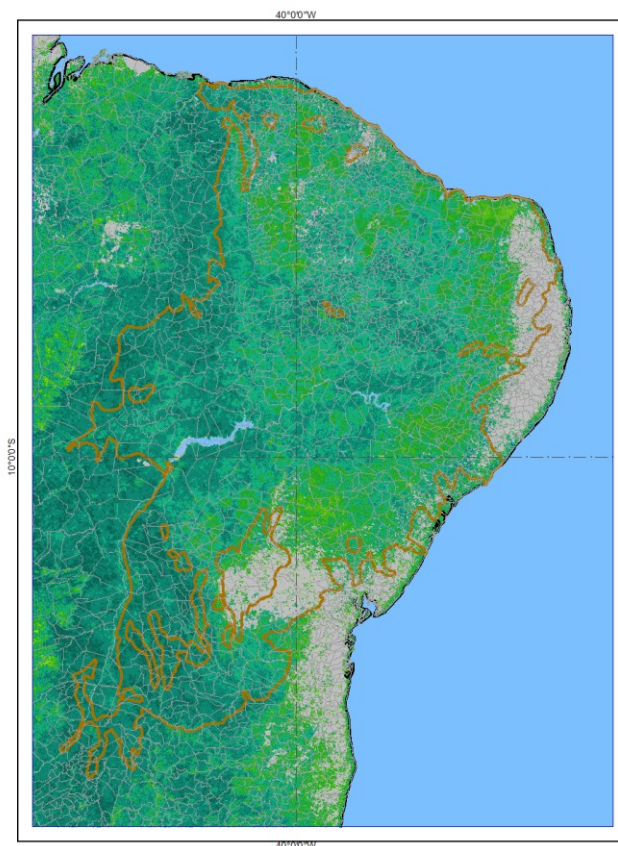
Description:

Status of ENVISAT MERIS fAPAR cyclic vegetation greenness calculated as mean value for the period 2002-2011 in test site Caatinga. The cyclic fraction of the vegetation comprises summed fAPAR values of the green peak(s) during a vegetation year, subtracting the non-cyclic base levels.

Legend



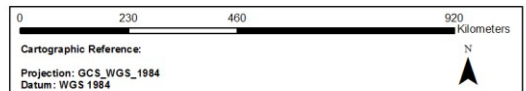
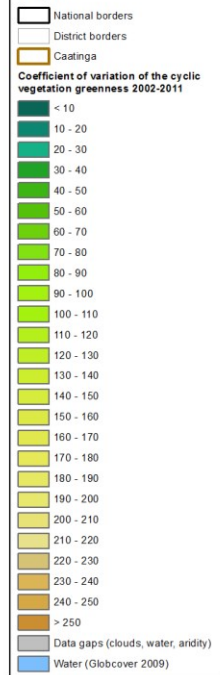
Cyclic Vegetation Variability



Description:

Variability of ENVISAT MERIS fAPAR cyclic vegetation greenness expressed by the coefficient of variation for the period 2002-2011 in test site Caatinga. The cyclic fraction of the vegetation comprises summed fAPAR values of the green peak(s) during a vegetation year, subtracting the non-cyclic base levels.

Legend



Cyclic Vegetation Greenness Trend (abs.)



Description:

Slopes of absolute trends of ENVISAT MERIS fAPAR vegetation year averages in test site Caatinga throughout the period 2002-2011. One vegetation year comprises one full phenological cycle of the vegetation and hence constitutes a proxy for the overall annual NPP. The vegetation year is defined to start at the onset of vegetation greening following first rainfalls and last until the end of the dry season. The actual start of each vegetation year is individually determined for each year.

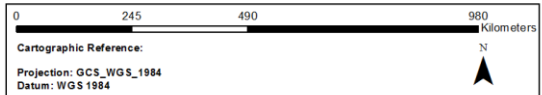
Trends are calculated using the median trend estimator after Theil (1950) and Sen (1968). Only significant trends ($p < 0.05$) are depicted based on the trend test on significance according to Mann (1945) and Kendall (1975).

Trend values indicate average change per year. Original fAPAR values reach from 0 to 1 and have been stretched from 0 to 1000.

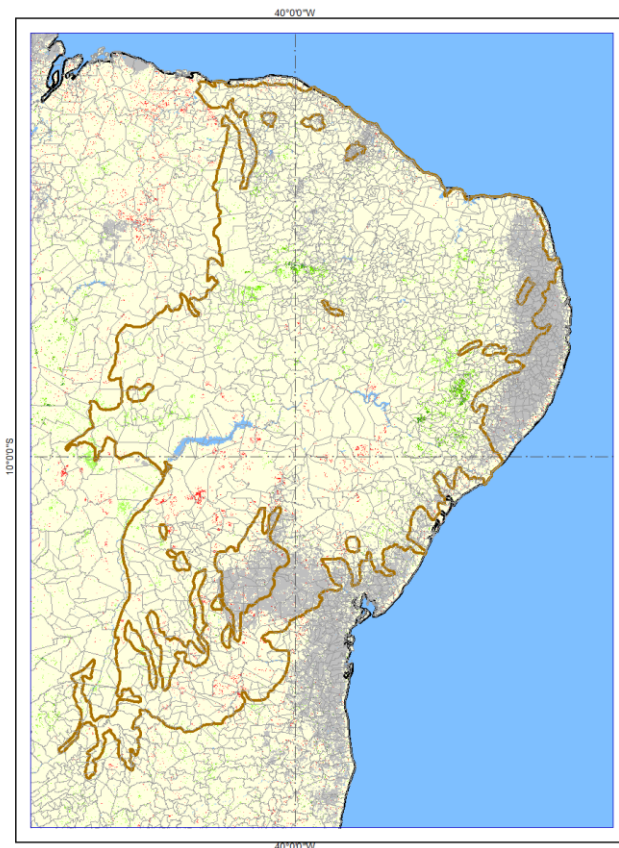
Data gaps in the time series resulting from cloud cover, a too pronounced aridity or water bodies have been masked out.

Legend

- National borders
- District borders
- Caatinga
- Absolute trend slopes of vegetation year average greenness 2002 - 2011**
 - yearly decrease > 15
 - yearly decrease 12 - 15
 - yearly decrease 9 - 12
 - yearly decrease 6 - 9
 - yearly decrease 3 - 6
 - yearly decrease 1 - 3
 - yearly increase 1 - 3
 - yearly increase 3 - 6
 - yearly increase 6 - 9
 - yearly increase 9 - 12
 - yearly increase 12 - 15
 - yearly increase > 15
 - Insignificant or trend < 1
 - Data gaps (clouds, water, aridity)
 - Water (Globcover 2009)



Cyclic Vegetation Greenness Trend (rel.)



Description:

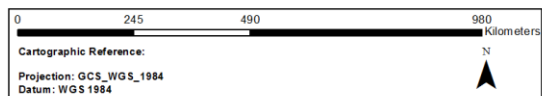
Relative yearly changes of ENVISAT MERIS fAPAR "cyclic fraction" values in test site Caatinga throughout the period 2002-2011. The cyclic fraction of the vegetation comprises summed fAPAR values of the green peak(s) during a vegetation year, subtracting the non-cyclic base levels. The cyclic fraction fAPAR can be interpreted as the amount of NPP being directly related to the annual cycle of the climatic vegetation growth factors, especially rainfall.

Trends are calculated using the median trend estimator after Theil (1950) and Sen (1968). Only significant trends ($p < 0.05$) are depicted based on the trend test on significance according to Mann (1945) and Kendall (1975).

Data gaps in the time series resulting from cloud cover, a too pronounced aridity or water bodies have been masked out from the analysis.

Legend

- National borders
- District borders
- Caatinga
- Relative trend of cyclic vegetation greenness 2002 - 2011**
 - yearly decrease > 15%
 - yearly decrease 10 - 15%
 - yearly decrease 5 - 10%
 - yearly decrease < 5%
 - yearly increase < 10%
 - yearly increase 10 - 20%
 - yearly increase 20 - 30%
 - yearly increase 30 - 40%
 - yearly increase 40 - 50%
 - yearly increase 50 - 60%
 - yearly increase 60 - 80%
 - yearly increase > 80%
 - Insignificant or abs. trend < 10
 - Data gaps (clouds, water, aridity)
 - Water (Globcover 2009)



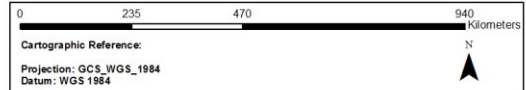
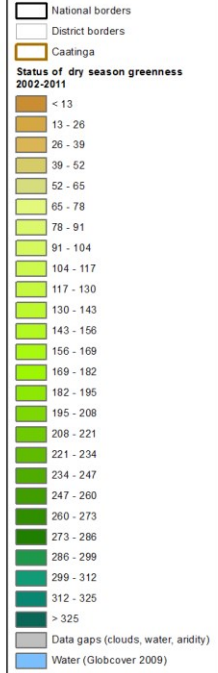
Dry Season Greenness



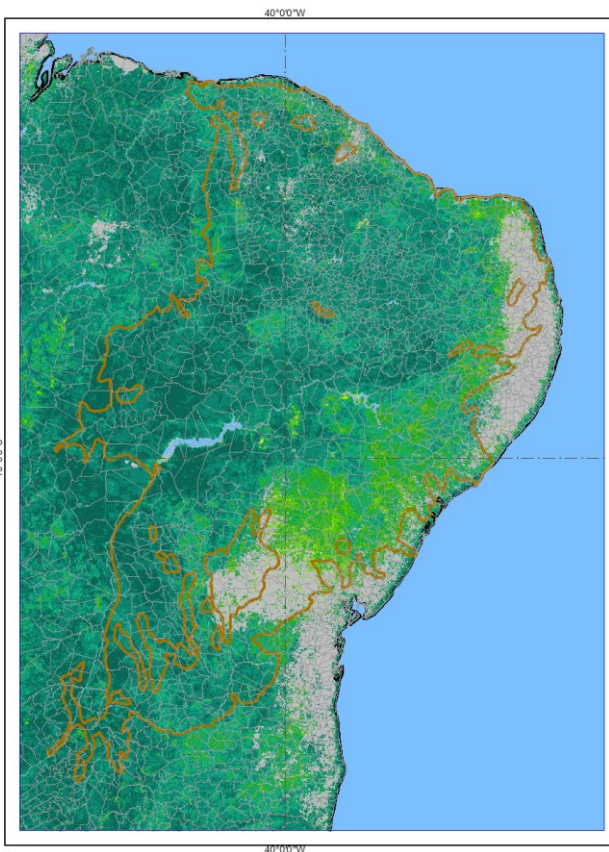
Description:

Status of ENVISAT MERIS fAPAR dry season greenness calculated as mean value for the period 2002-2011 in test site Caatinga. The dry season greenness values reflect the portion of plants that remain green after senescence of the annual vegetation or grow new green leaves during the dry period.

Legend



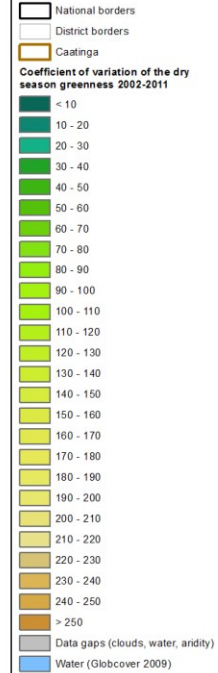
Dry Season Variability



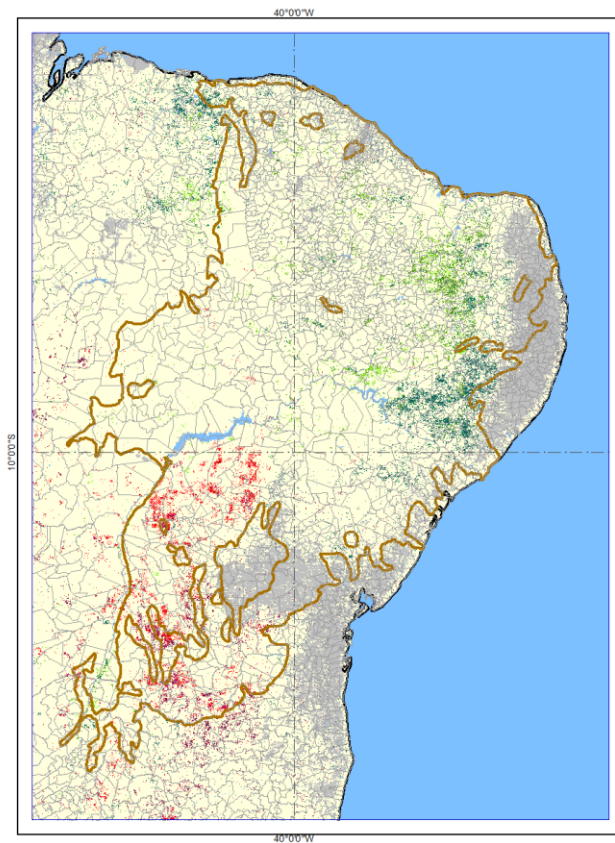
Description:

Variability of ENVISAT MERIS fAPAR dry season greenness expressed by the coefficient of variation for the period 2002-2011 in test site Caatinga. The dry season greenness values reflect the portion of plants that remain green after senescence of the annual vegetation or grow new green leaves during the dry period.

Legend



Dry Season Greenness Trend (abs.)



Description:

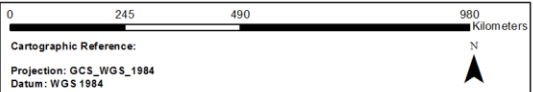
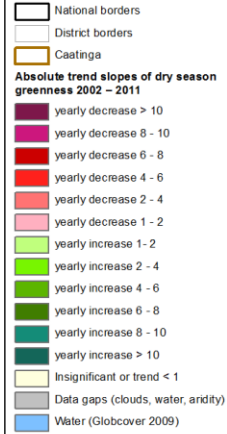
Slopes of absolute trends of ENVISAT MERIS fAPAR dry season averages in test site Caatinga throughout the period 2002-2011. For the dry season the low fAPAR values after the green peak are taken, defined by a 10% amplitude threshold. The dry season greenness values reflect the portion of plants that remain green after senescence of the annual vegetation or grow new green leaves during the dry period.

Trends are calculated using the median trend estimator after Theil (1950) and Sen (1968). Only significant trends ($p < 0.05$) are depicted based on the trend test on significance according to Mann (1945) and Kendall (1975).

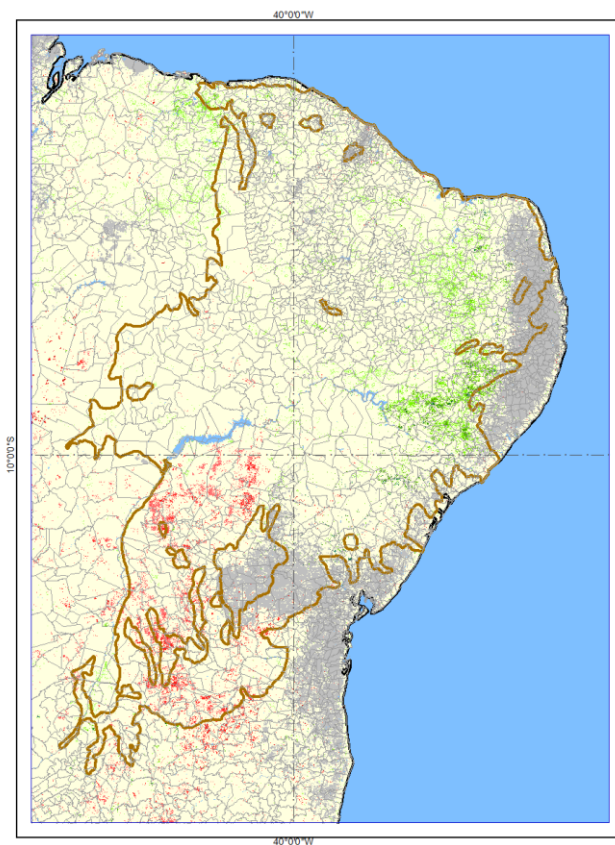
Trend values indicate average change per year. Original fAPAR values reach from 0 to 1 and have been stretched from 0 to 1000.

Data gaps in the time series resulting from cloud cover, a too pronounced aridity or water bodies have been masked out from the analysis.

Legend



Dry Season Greenness Trend (rel.)



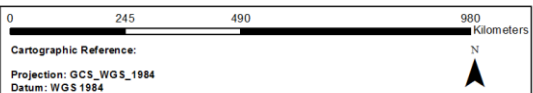
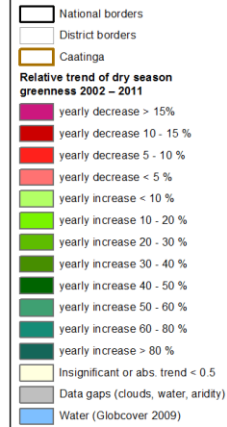
Description:

Relative yearly changes of ENVISAT MERIS fAPAR dry season averages in test site Caatinga throughout the period 2002-2011. For the dry season the low fAPAR values after the green peak are taken, defined by a 10% amplitude threshold. The dry season greenness values reflect the portion of plants that remain green after senescence of the annual vegetation or grow new green leaves during the dry period.

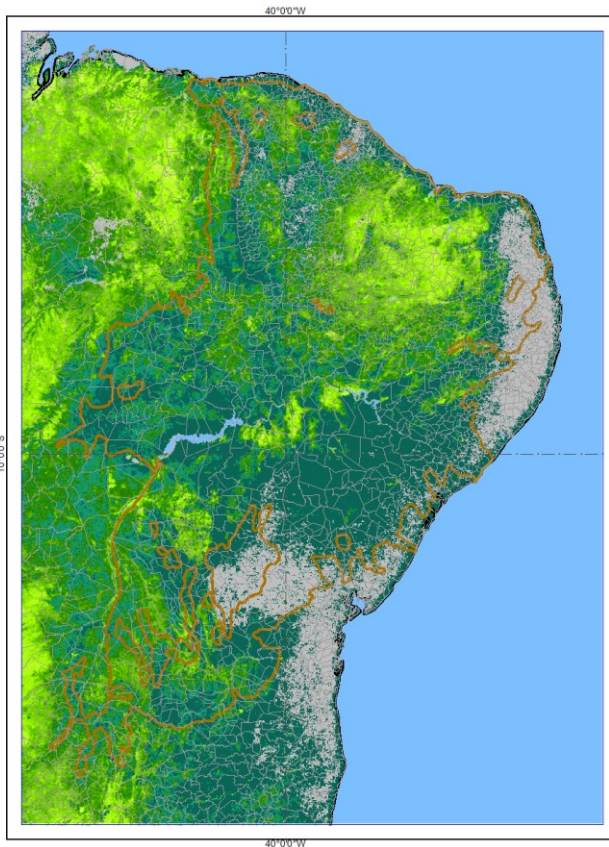
Trends are calculated using the median trend estimator after Theil (1950) and Sen (1968). Only significant trends ($p < 0.05$) are depicted based on the trend test on significance according to Mann (1945) and Kendall (1975).

Data gaps in the time series resulting from cloud cover, a too pronounced aridity or water bodies have been masked out from the analysis.

Legend

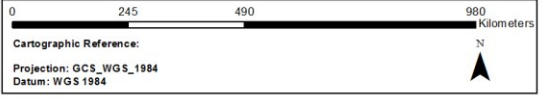
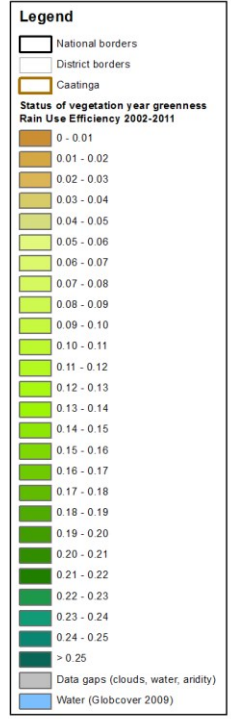


Average Vegetation Year Rain Use Efficiency Status



Description:

Status of ENVISAT MERIS fAPAR vegetation year greenness Rain Use Efficiency for the period 2002-2011 in test site Caatinga is calculated based on ENVISAT MERIS fAPAR values (averaged over the vegetation years) divided by the average rainfall (TRMM 3b42 precipitation) of the vegetation years, which are backwards lagged by two months. TRMM 3b42 precipitation estimates are resampled to technically match the MERIS fAPAR spatial resolution, knowing that their actual spatial resolution of 0.25° does not (!) match the fAPAR data.

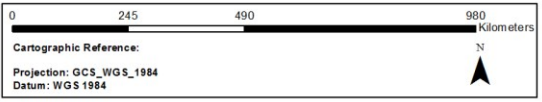
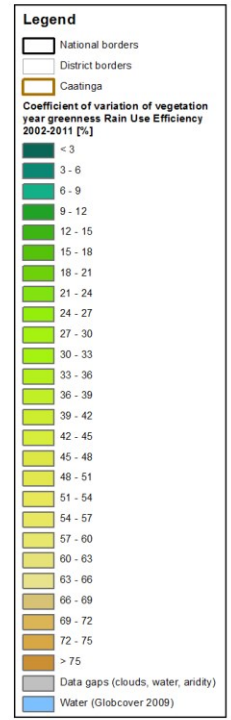


Vegetation Year Rain Use Efficiency Variability

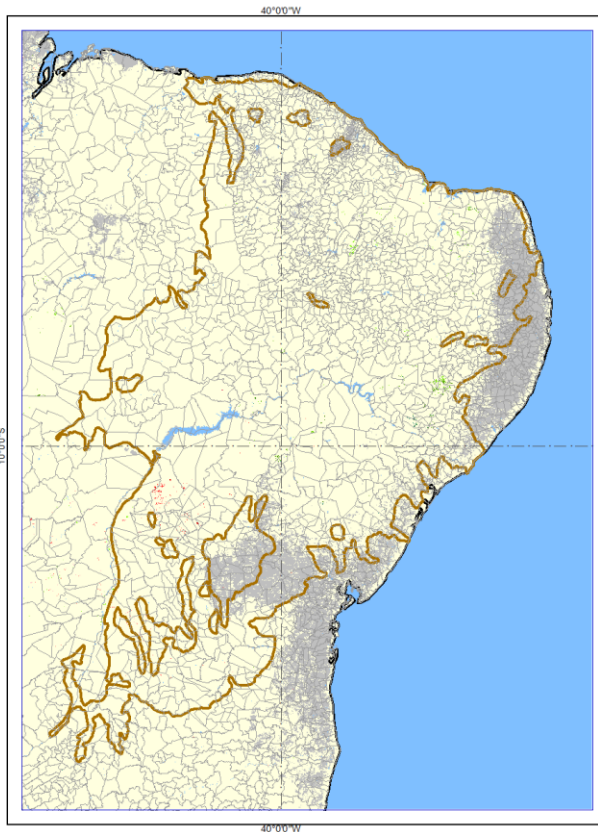


Description:

Variability of vegetation year greenness Rain Use Efficiency expressed by the coefficient of variation for the period 2002-2011 in test site Caatinga.



Vegetation Year Rain Use Efficiency Trend (abs.)



Description:

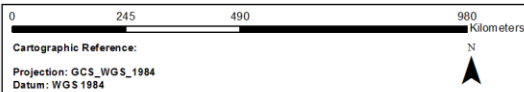
Slopes of absolute trends of vegetation year average greenness Rain Use Efficiency (RUE) in test site Caatinga throughout the period 2002-2011. Vegetation year average greenness RUE calculation is based on ENVISAT MERIS fAPAR values (averaged over one vegetation year) divided by rainfall data (TRMM 3b42 precipitation). TRMM 3b42 precipitation estimates are bilinearly resampled to technically match the MERIS fAPAR spatial resolution, knowing that their actual spatial resolution of 0.25° does not (!) match the fAPAR data.

Trends are calculated using the median trend estimator after Theil (1950) and Sen (1968). Only significant trends (p 0.05) are depicted based on the trend test on significance according to Mann (1945) and Kendall (1975).

Trend values indicate average change per year. Original fAPAR values reach from 0 to 1 and have been stretched from 0 to 1000. Data gaps in the time series resulting from cloud cover, a too pronounced aridity or water bodies have been masked out from the analysis.

Legend

- National borders
 - District borders
 - Caatinga
- Absolute trend slopes of vegetation year average greenness Rain Use Efficiency 2002-2011**
- yearly decrease > 0.05
 - yearly decrease 0.04 - 0.05
 - yearly decrease 0.03 - 0.04
 - yearly decrease 0.02 - 0.03
 - yearly decrease 0.01 - 0.02
 - yearly decrease 0.001 - 0.01
 - yearly increase 0.01 - 0.02
 - yearly increase 0.02 - 0.03
 - yearly increase 0.03 - 0.04
 - yearly increase 0.04 - 0.05
 - yearly increase > 0.05
 - Insignificant or trend < 0.001
 - Data gaps (clouds, water, aridity)
 - Water (Globcover 2009)



Vegetation Year Rain Use Efficiency Trend (rel.)



Description:

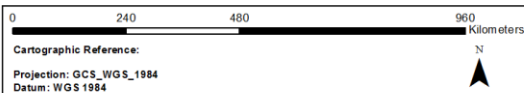
Relative yearly changes of vegetation year average greenness Rain Use Efficiency (RUE) in test site Caatinga throughout the period 2002-2011. Vegetation year average greenness RUE calculation is based on ENVISAT MERIS fAPAR values (averaged over one vegetation year) divided by rainfall data (TRMM 3b42 precipitation). TRMM 3b42 precipitation estimates are bilinearly resampled to technically match the MERIS fAPAR spatial resolution, knowing that their actual spatial resolution of 0.25° does not (!) match the fAPAR data.

Trends are calculated using the median trend estimator after Theil (1950) and Sen (1968). Only significant trends (p 0.05) are depicted based on the trend test on significance according to Mann (1945) and Kendall (1975).

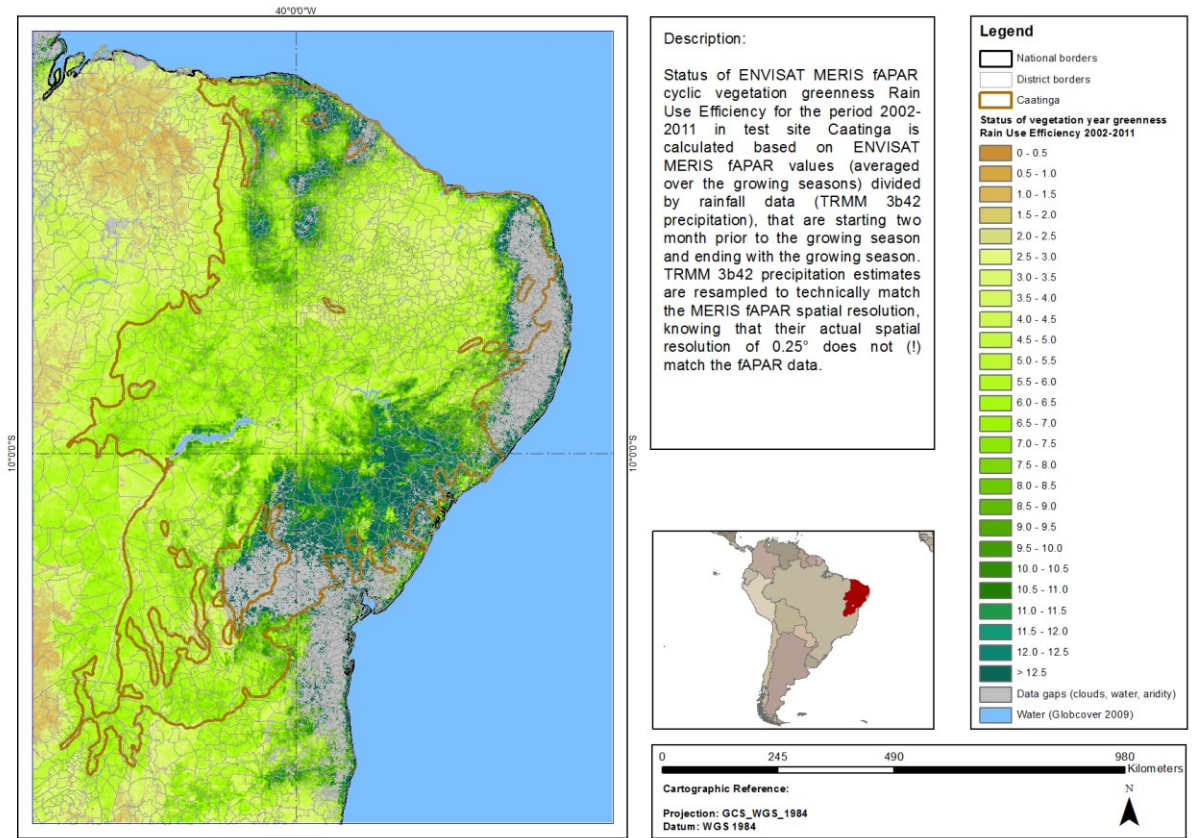
Trend values indicate average change per year. Original fAPAR values reach from 0 to 1 and have been stretched from 0 to 1000. Data gaps in the time series resulting from cloud cover, a too pronounced aridity or water bodies have been masked out from the analysis.

Legend

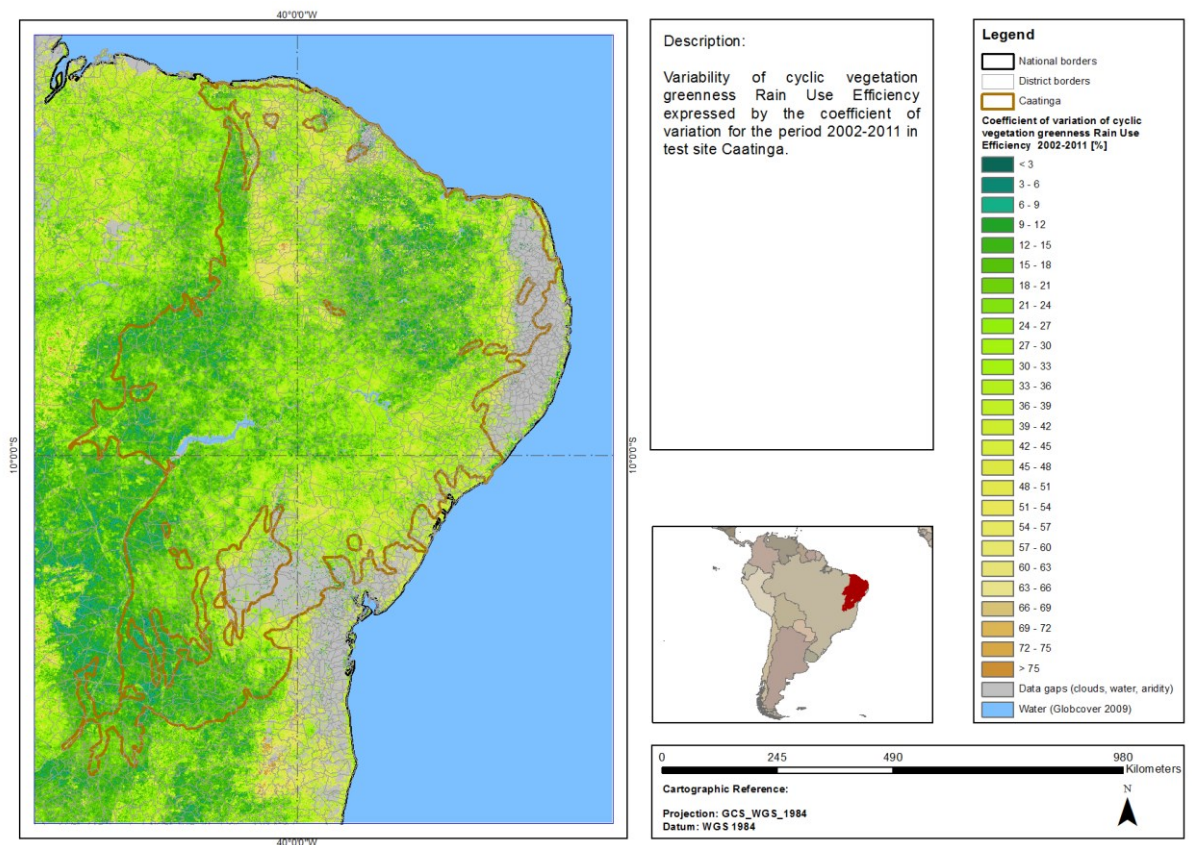
- National borders
 - District borders
 - Caatinga
- Relative trend of vegetation year average greenness Rain Use Efficiency 2002-2011**
- yearly decrease > 15%
 - yearly decrease 10 - 15%
 - yearly decrease 5 - 10%
 - yearly increase < 5%
 - yearly increase < 10%
 - yearly increase 10 - 20%
 - yearly increase 20 - 30%
 - yearly increase 30 - 40%
 - yearly increase 40 - 50%
 - yearly increase 50 - 60%
 - yearly increase 60 - 80%
 - yearly increase > 80%
 - Insignificant or abs. trend < 0.05
 - Data gaps (clouds, water, aridity)
 - Water (Globcover 2009)



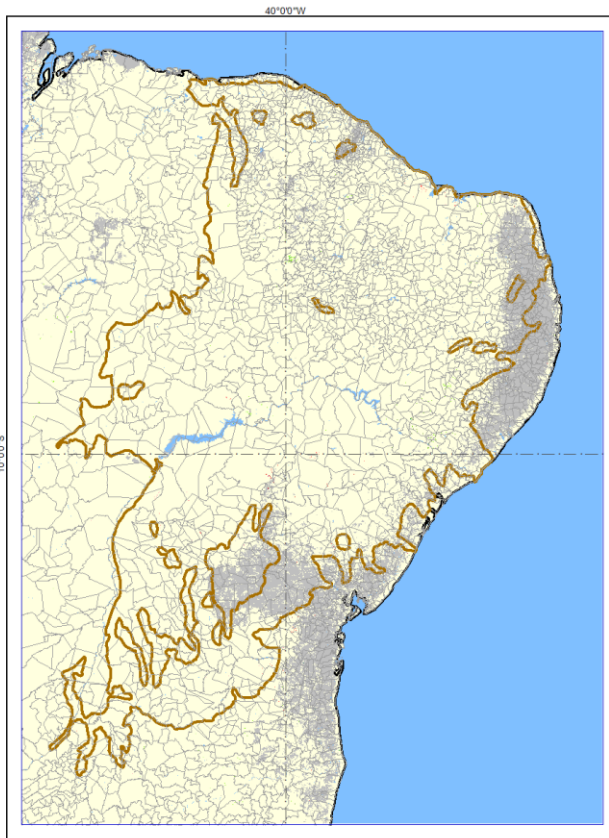
Cyclic Vegetation Rain Use Efficiency Status



Cyclic Vegetation Rain Use Efficiency Variability



Cyclic Vegetation Rain Use Efficiency Trend (abs.)



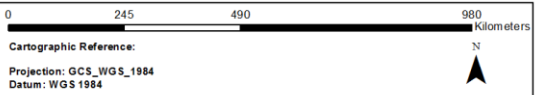
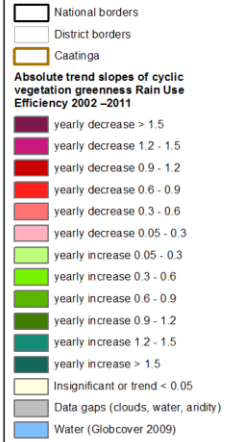
Description:

Slopes of absolute trends of cyclic vegetation greenness Rain Use Efficiency (RUE) in test site Caatinga throughout the period 2002-2011. Cyclic vegetation greenness RUE calculation is based on ENVISAT MERIS fAPAR values (of the green peak – "cyclic fraction") divided by rainfall data (TRMM 3b42 precipitation). TRMM 3b42 precipitation estimates are bilinearly resampled to technically match the MERIS fAPAR spatial resolution, knowing that their actual spatial resolution of 0.25° does not (!) match the fAPAR data.

Trends are calculated using the median trend estimator after Theil (1950) and Sen (1968). Only significant trends (p 0.05) are depicted based on the trend test on significance according to Mann (1945) and Kendall (1975).

Trend values indicate average change per year. Original fAPAR values reach from 0 to 1 and have been stretched from 0 to 1000. Data gaps in the time series resulting from cloud cover, a too pronounced aridity or water bodies have been masked out from the analysis.

Legend



Cyclic Vegetation Rain Use Efficiency Trend (rel.)



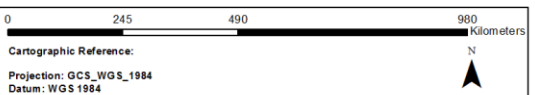
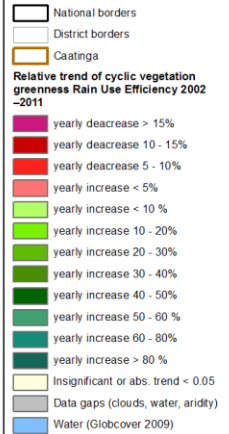
Description:

Relative yearly changes of cyclic vegetation greenness Rain Use Efficiency (RUE) in test site Caatinga throughout the period 2002-2011. Cyclic vegetation greenness RUE calculation is based on ENVISAT MERIS fAPAR values (of the green peak – "cyclic fraction") divided by rainfall data (TRMM 3b42 precipitation). TRMM 3b42 precipitation estimates are bilinearly resampled to technically match the MERIS fAPAR spatial resolution, knowing that their actual spatial resolution of 0.25° does not (!) match the fAPAR data.

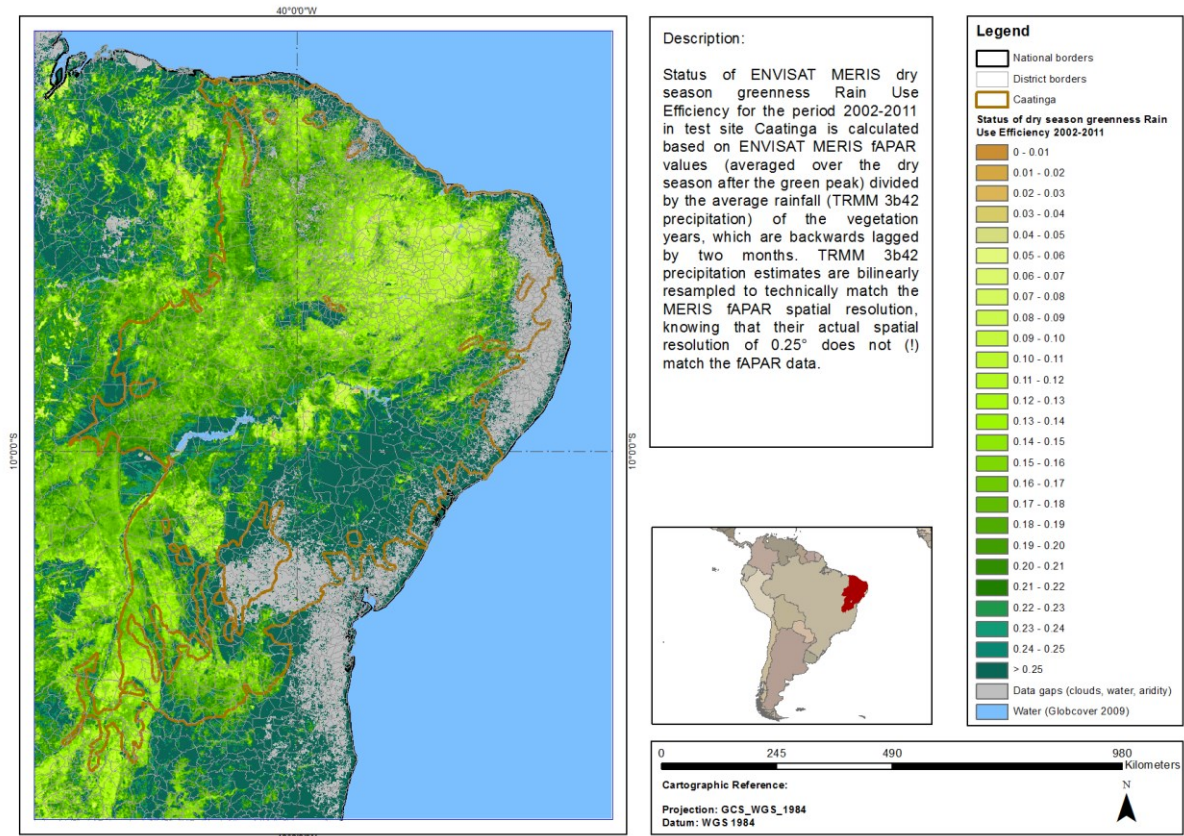
Trends are calculated using the median trend estimator after Theil (1950) and Sen (1968). Only significant trends (p 0.05) are depicted based on the trend test on significance according to Mann (1945) and Kendall (1975).

Trend values indicate average change per year. Original fAPAR values reach from 0 to 1 and have been stretched from 0 to 1000. Data gaps in the time series resulting from cloud cover, a too pronounced aridity or water bodies have been masked out from the analysis.

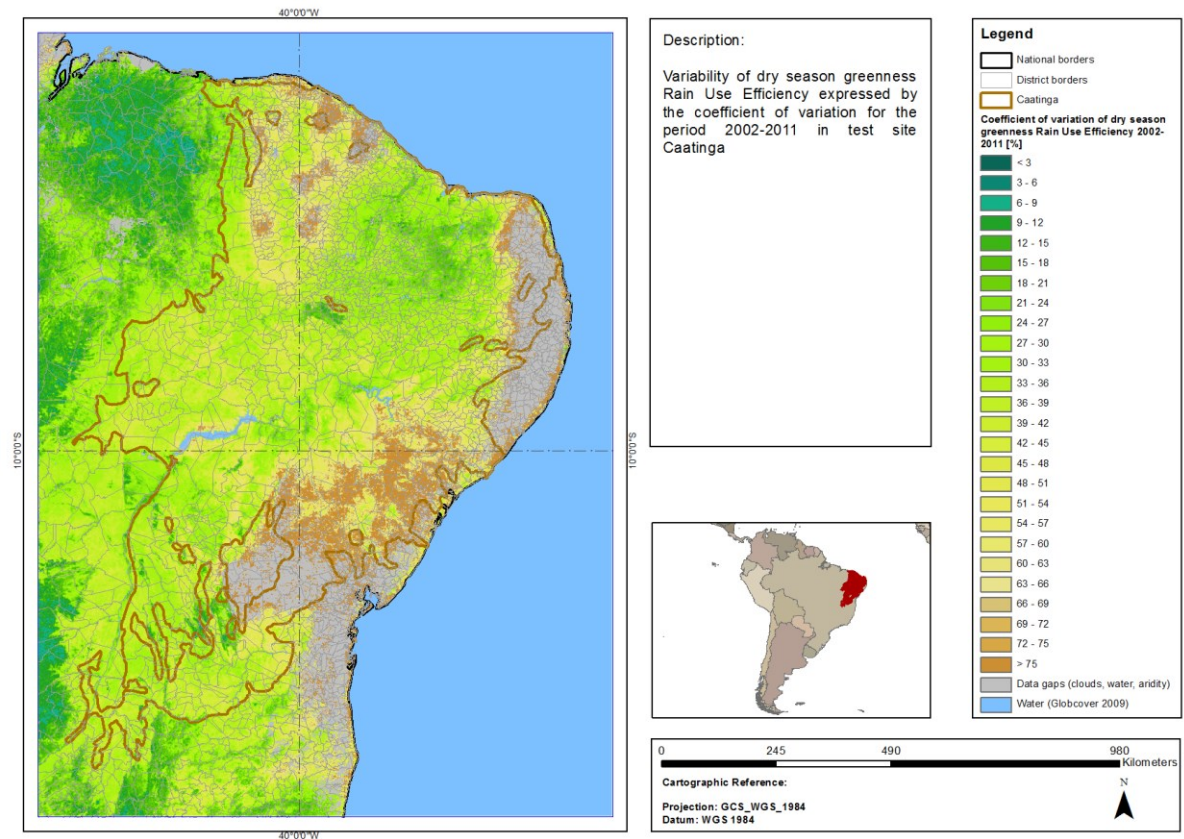
Legend



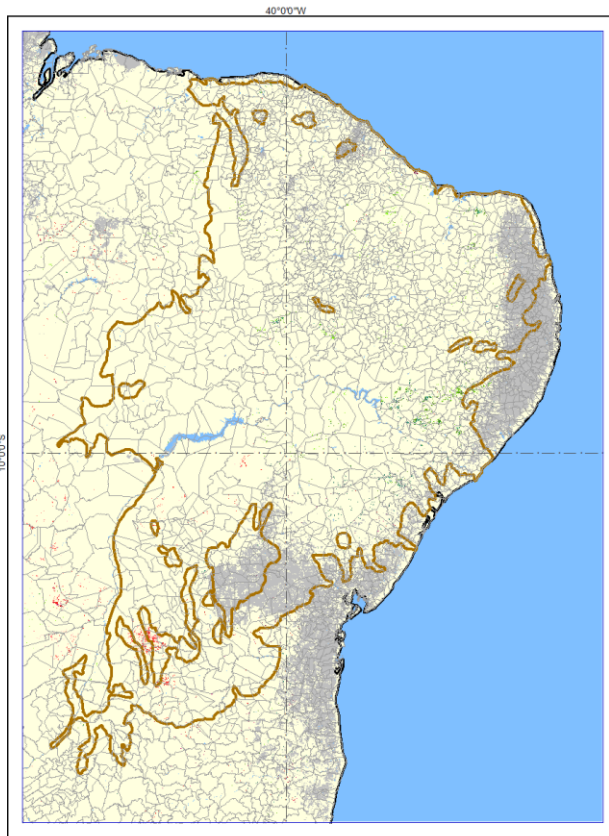
Dry Season Rain Use Efficiency Status



Dry Season Rain Use Efficiency Variability



Dry Season Rain Use Efficiency Trend (abs.)



Description:

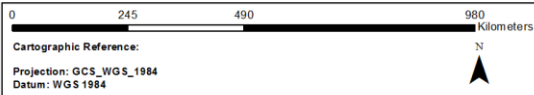
Slopes of absolute trends of dry season greenness Rain Use Efficiency (RUE) in test site Caatinga throughout the period 2002-2011. Dry season greenness RUE calculation is based on ENVISAT MERIS fAPAR values (averaged over the dry season after the green peak) divided by rainfall data (TRMM 3b42 precipitation). TRMM 3b42 precipitation estimates are bilinearly resampled to technically match the MERIS fAPAR spatial resolution, knowing that their actual spatial resolution of 0.25° does not (!) match the fAPAR data.

Trends are calculated using the median trend estimator after Theil (1950) and Sen (1968). Only significant trends ($p < 0.05$) are depicted based on the trend test on significance according to Mann (1945) and Kendall (1975).

Trend values indicate average change per year. Original fAPAR values reach from 0 to 1 and have been stretched from 0 to 1000. Data gaps in the time series resulting from cloud cover, a too pronounced aridity or water bodies have been masked out from the analysis.

Legend

- National borders
- District borders
- Caatinga
- Absolute trend slopes of dry season greenness Rain Use Efficiency 2002-2011**
- yearly decrease > 0.025
- yearly decrease 0.02 - 0.025
- yearly decrease 0.015 - 0.02
- yearly decrease 0.01 - 0.015
- yearly decrease 0.005 - 0.01
- yearly decrease 0.001 - 0.005
- yearly increase 0.001 - 0.005
- yearly increase 0.005 - 0.01
- yearly increase 0.01 - 0.015
- yearly increase 0.015 - 0.02
- yearly increase 0.02 - 0.025
- yearly increase > 0.025
- insignificant or trend < 0.001
- Data gaps (clouds, water, aridity)
- Water (Globcover 2009)



Dry Season Rain Use Efficiency Trend (rel.)



Description:

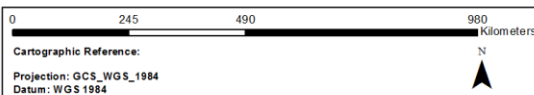
Relative yearly dry season vegetation greenness Rain Use Efficiency (RUE) in test site Caatinga throughout the period 2002-2011. Dry season vegetation greenness RUE calculation is based on ENVISAT MERIS fAPAR values (averaged over the dry season after the green peak) divided by rainfall data (TRMM 3b42 precipitation). TRMM 3b42 precipitation estimates are bilinearly resampled to technically match the MERIS fAPAR spatial resolution, knowing that their actual spatial resolution of 0.25° does not (!) match the fAPAR data.

Trends are calculated using the median trend estimator after Theil (1950) and Sen (1968). Only significant trends ($p < 0.05$) are depicted based on the trend test on significance according to Mann (1945) and Kendall (1975).

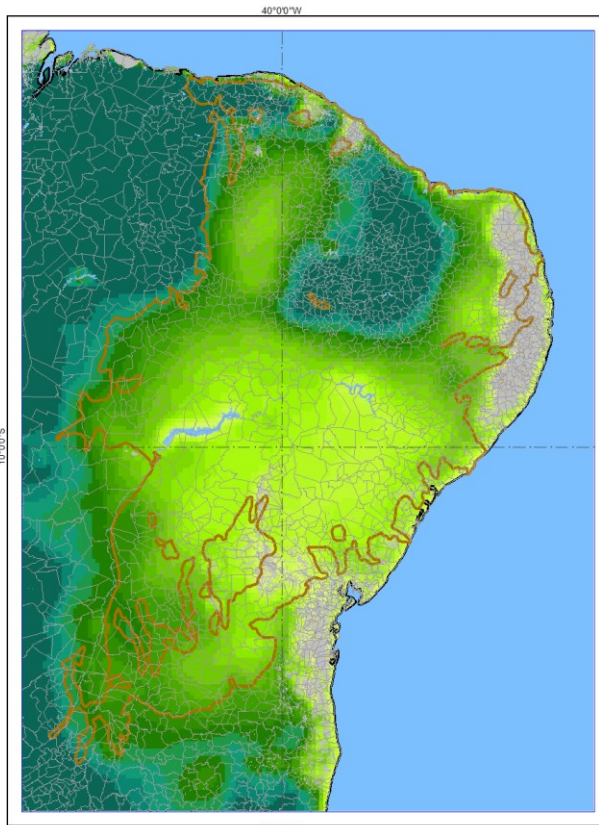
Trend values indicate average change per year. Original fAPAR values reach from 0 to 1 and have been stretched from 0 to 1000. Data gaps in the time series resulting from cloud cover, a too pronounced aridity or water bodies have been masked out from the analysis.

Legend

- National borders
- District borders
- Caatinga
- Relative trend of dry season greenness Rain Use Efficiency 2002-2011**
- yearly decrease > 15%
- yearly decrease 10 - 15%
- yearly decrease 5 - 10%
- yearly increase < 5%
- yearly increase < 10%
- yearly increase 10 - 20%
- yearly increase 20 - 30%
- yearly increase 30 - 40%
- yearly increase 40 - 50%
- yearly increase 50 - 60%
- yearly increase 60 - 80%
- yearly increase > 80%
- insignificant or abs. trend < 0.05
- Data gaps (clouds, water, aridity)
- Water (Globcover 2009)

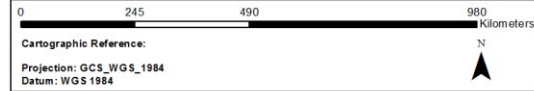
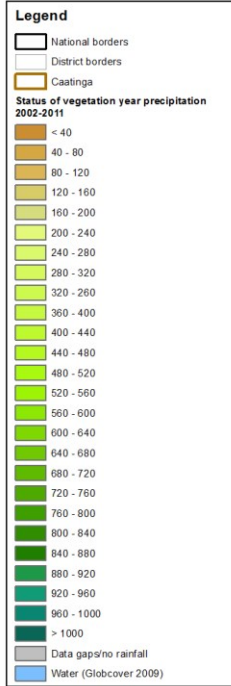


Vegetation Year Precipitation Status

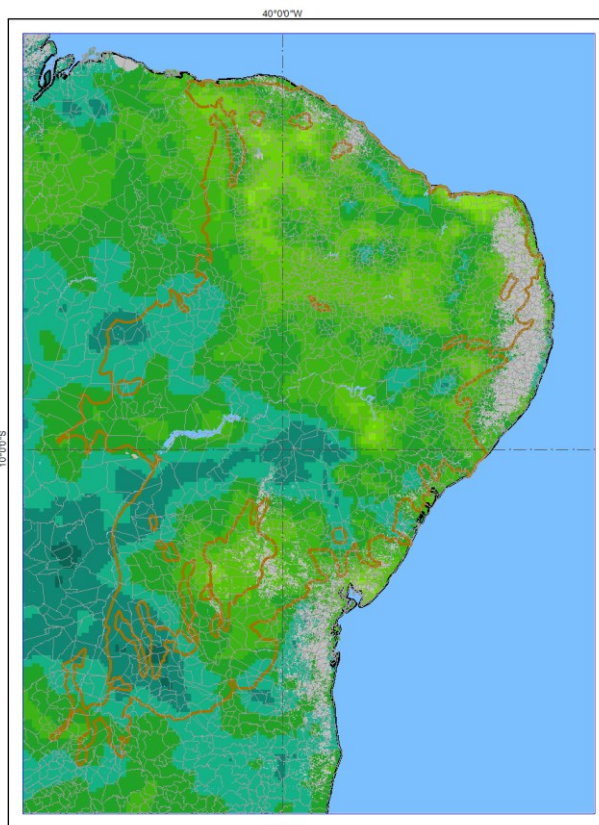


Description:

Status of TRMM 3b42 precipitation estimates summed over vegetation years calculated as mean value for the period 2002-2011 in test site Caatinga. Yearly aggregation periods are derived from the corresponding vegetation year with a temporal backward shift of two months. Thus, each precipitation vegetation year starts and ends two months earlier than the corresponding vegetation year.

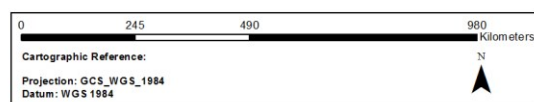
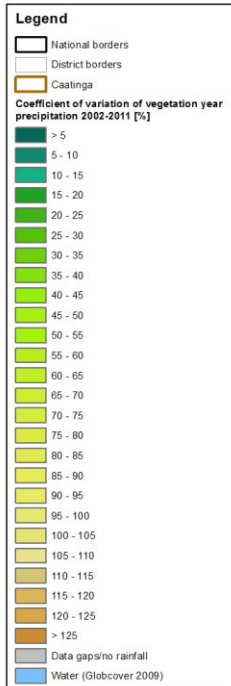


Vegetation Year Precipitation Variability

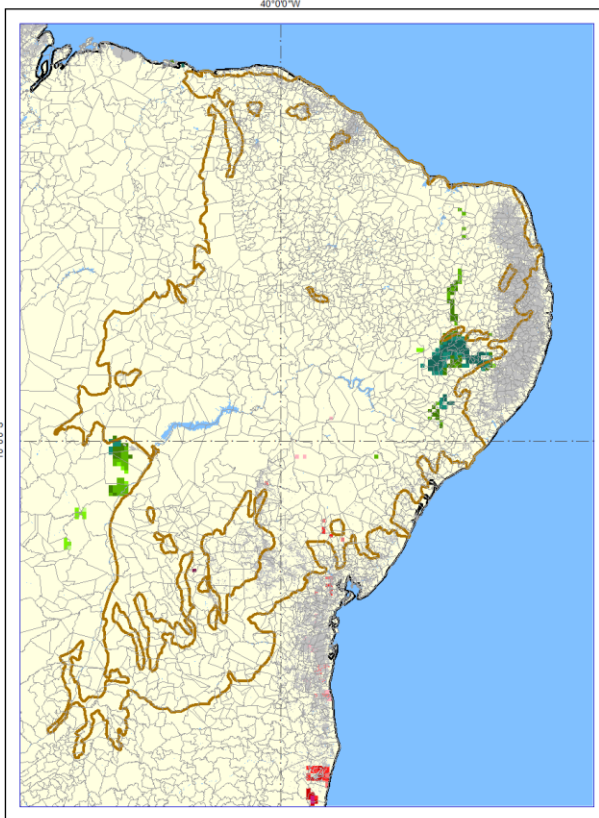


Description:

Variability of TRMM 3b42 precipitation estimates summed over vegetation years expressed by the coefficient of variation for the period 2002-2011 in test site Caatinga. Yearly aggregation periods are derived from the corresponding vegetation year with a temporal backward shift of two months. Thus, each precipitation vegetation year starts and ends two months earlier than the corresponding vegetation year.



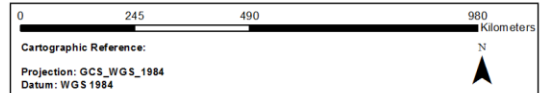
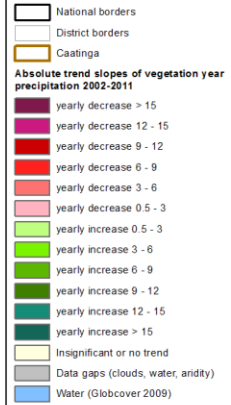
Vegetation Year Precipitation Trend (abs.)



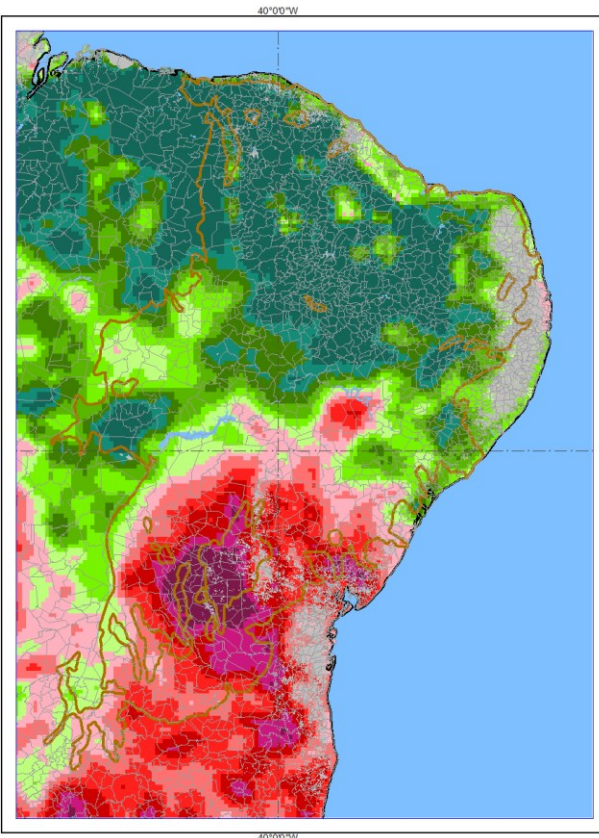
Description:

Slopes of absolute trends of TRMM 3b42 precipitation estimates summed over vegetation years in test site Caatinga throughout the period 2002-2011. Yearly aggregation periods are derived from the corresponding vegetation year with a subsequent temporal backward shift of two months. Thus, each precipitation vegetation year starts and ends two months earlier than the corresponding vegetation year.

Legend



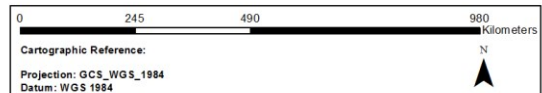
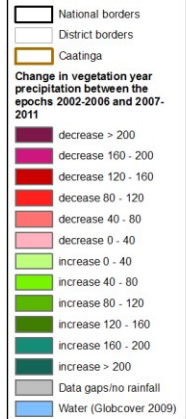
Vegetation Year Precipitation Change



Description:

Change in TRMM 3b42 precipitation estimates summed over vegetation years between the two epochs 2002-2006 and 2007-2011 in test site Caatinga. The calculation of per-epoch precipitation is based on epoch median values. Yearly aggregation periods are derived from the corresponding vegetation year with a temporal backward shift of two months. Thus, each precipitation year starts and ends two months earlier than the corresponding vegetation year.

Legend



Generic Interpretation of the Maps with regard to Degradation and Potential Loss of Biodiversity

The maps that are so far shown in the booklet include phenologically differentiated NPP proxy (Net Primary Production) and RUE (Rain Use Efficiency) status and trend maps, as well as rainfall status, trend – and change maps.

Overall the status maps describe the amount and variability (coefficient of variation) of greenness (NPP proxy) in the differentiated phenological seasons, as well greenness in relation to the amount of rainfall (RUE).

While vegetation productivity obvious follows the rainfall gradients at the large scale (not considering temperature and radiation differences), the smaller scale differentiations exhibit the presence of further influences on vegetation growth at more local scales. These local and regional factors are especially land use, soil properties and topography and include also the protection status of areas. For instance many linear features with (mostly) higher NPP proxy and RUE values than their surroundings can be related to river valleys (often with only seasonal or ephemeral surface water).

Consequently, the spatial distribution of RUE varies not only with rainfall, but depends on the constellation of all these factors at various scales. Hence RUE status (average condition) values, even if stratified according to aridity, cannot directly be interpreted in terms of existing soil degradation or exposure to degradation or richness/poverty of biodiversity without knowledge about growth factors other than rainfall, and about bio-geographical properties.

Biomes with rich floristic biodiversity can be expected to exhibit higher NPP response to rainfall throughout the year as diverse plant communities may be characterised by a high phenological variability with optimised water exploitation. However, it is not known whether, where and to which degree this theory translates into measurable spatial differences of RUE. Here an assessment of the results by local experts and the usage of reference maps and information will help interpret the results. An example with an extended area of extraordinary high average RUE conditions is the Succulent Karoo biome in South Africa (*"The Succulent Karoo is notable for the world's richest flora of succulent plants, and harbours about one-third of the world's approximately 10,000 succulent species"* http://en.wikipedia.org/wiki/Succulent_Karoo).

The differentiation of the NPP and RUE indicators into phenological periods helps diagnose the seasonal behaviour of the vegetation and thus provides clues about the presence and dominance of evergreen perennial vegetation versus annual vegetation (e.g. annual grasses, crops). Accordingly, changes and trends of the phenological vegetation behaviour can be used as indicators for developments such as land use change and land cover change. For instance the worldwide observed phenomenon of bush encroachment (woody encroachment, woody thickening) in drylands (Ratajczak et al. 2011) will lead to a shift of vegetation phenology, where especially an increase of dry season greenness, possibly, but not necessarily combined with a decrease of the cyclic greenness can be expected.

Bush encroachment in drylands is often perceived as negative development, where the bushes lead to range land degradation by reducing grass cover and impeding the access of cattle to the remaining grass. Also impoverishment of biodiversity was frequently found as an effect of bush encroachment (Ratajczak et al. 2011). The greening trends especially in the dry season are indeed a widespread phenomenon in the derived NPP proxy maps (p. 16), possibly pointing to continued bush encroachment or enhanced growth and greening of existing bushes, partly related to rainfall increases. Dry season greening may also be caused by the plantation of (especially evergreen) woody plants and forests. In case of greening trends related to commercial forest plantations, the trends can also be interpreted as a biodiversity loss.

The “classical” degradation measure is exhibited by decreasing RUE trends, i.e. the decrease of NPP proxies in relation to rainfall, theoretically indicating the decreasing ability of the vegetation to exploit available water. In the test sites so far studied, RUE decreases are rarely observed for the cyclic vegetation of the growing season (p. 20). This means, the cyclic vegetation response to rainfall is not widespread diminished and degradation of soils leading to reduced usability of rainfall for vegetation growth seems to be hardly found in the test sites so far. Where it is found it seems to co-occur with regional rainfall increases, and may be interpreted as lacking ability of the vegetation to respond to apparently improved hydrologic growing conditions. Extended areas in South and East Portugal are an example for wide spread RUE decreases of the cyclic vegetation related to rainfall increase without cyclic vegetation decrease. However, increased rainfall quantities may also come with higher rainfall intensities and may have also negative effects (increased runoff, more erosive power), and can be assumed to be not generally positively correlated with vegetation productivity.

RUE decreases are more frequently found when looking at the vegetation of the entire vegetation year (p. 17), and are also often related to rainfall increases, and not to greenness decreases. RUE decreases are not only indicating potential degradation developments (progressing degradation triggered e.g. by land over-utilisation), but may be as well related to land cover/use changes, such as the conversion of rangeland into cropland, deforestation (less important in dry lands), etc. Especially processes such as urbanisation or mining will lead to extreme NPP proxy and RUE decreases. Decreases of only the dry season RUE (p. 22) may in particular be related to conversion of rangeland into rainfed cropland, assuming a lower primary productivity of the cropland during the dry season. Also the clearing of shrubs, bushland and savannah vegetation may lead especially to dry season RUE decreases.

To summarize the observable NPP proxy and RUE trends cannot be directly interpreted as degradation or biomass losses, or, in case of positive trends, as land improvements. There are always multiple possible underlying causes and developments, hence in situ knowledge and information is indispensable for the interpretation of these developments, as well as for the average conditions expressed in the status maps. Especially the frequently found greening trends in the dry season, at first glance positive trends, may even be primarily related to adverse processes such as bush encroachment. However, caution is also necessary in this respect, as likewise range land improvement and tree planting activities may lead to diverse positive trends.

Finally it must be stated that the observation period is rather short, with several consequences for this study. The variability of rainfalls and subsequently vegetation greenness from year to year is so significant in drylands that it certainly hides trends, which in such a short period may be rare and not very pronounced. Trends must pass a high statistical significance threshold to be recognised as significant trends. There may be more relevant changes going on than the trend maps with only the highly significant trends can show, especially as many change events cannot be expected to exhibit gradual indicator developments. Also the rainfall trend maps (p. 24) show hardly any significant trends, while the rainfall change map between the two epochs shows large positive and negative change regions with partly big epochal rainfall differences.

On the other hand, the epochal change maps (differences between the means or median values of epochs, part of the overall products) are strongly influenced by variability and do certainly not only reflect “true” changes in the sense of concrete changes (e.g. land use change) or persisting developments (trends). Therefore these maps (that - except for rainfall - are not shown in the booklet) must be used with care.

Outlook

The phenologically differentiated analysis of NPP proxies and RUE so far performed will allow for a combination of the single results into integrated second order products. Their intention is to provide more evaluative assessments of the possible recent developments than the individual indicators. For instance, the occurrence of dry season greening in the absence of positive cyclic vegetation trends or in combination with negative cyclic vegetation trends may be derived as a an indicator for bush encroachment, either in the past and/or ongoing, where theoretically also the trend of the ratio of dry season to vegetation year greenness may support the diagnosis of increases of woody vegetation at the expense of grasses. The generation and/or interpretation of second order products may also be supported by means of land cover data.

Further on, CCI soil moisture (<http://www.esa-soilmoisture-cci.org/>) data, where available without greater data gaps, will be used as an additional and alternative measure for available water, and “Soil Moisture Use Efficiency” (SMUE) products analogue to RUE products will be derived thereof. Theoretically, soil moisture is the better suited water parameter for this purpose, as it almost directly constitutes the available water for plants, whereas rainfall only partly penetrates into the soil. The comparison of the SMUE with the RUE products will be of high interest.

Selected second order indicators will be added to these booklets, while the first order indicator maps may be reduced to keep the booklets focused on the most significant results. The results will be interpreted in terms of so-called “Biodiversity Stories”, which will verbally highlight the most prominent and significant developments found in the data.

Description of Biodiversity of Test Site 15 Caatinga

The Caatinga is the only endemic biome of Brazil and one of the world’s 37 major wilderness areas, comprising a mosaic of scrub vegetation and dry forest (Leal et al. 2005). Located in the semi-arid Northeast, it occupies an area of around 800,000 km² that represents over 10% of the Brazilian territory, extending across eight federal states: Piauí, Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, Sergipe, Bahia, and northern Minas Gerais (MMA 2007; Camardelli et al. 2012). The Caatinga is mainly settled on a flattened depression of sandstone and crystalline rock, broken by isolated plateaus, and mountain massifs that can reach elevations of over 2000 m above sea level (Leal et al. 2005; Santos et al. 2011; WWF 2013a). The region is submitted to a hot and dry climate, with averages of annual temperature between 24-26°C, annual rainfall ranging from 240 to 1500 mm and high evapotranspiration rates of over 1400 mm (Sampaio 1995; Prado 2003; Auler et al. 2004; WWF 2013a). The climate is seasonal with a well-defined rainy season during the Summer/Autumn, followed by 6 to 11 dry months (larger number in the more central areas) (Auler et al. 2004; Leal et al. 2005). Additionally, interannual variability in rainfall is considerably high, resulting in periodic severe droughts (Leal et al. 2005).

For long the Caatinga has been perceived as holding very few species, but despite the harsh climate, the region harbours a great degree of biological diversity. Substantial biotic interchange has always occurred between the Caatinga and other major Neotropical biomes that border the region, such as the Amazon forest to the northwest, and the Cerrado and Atlantic forest to the west and southwest (WWF 2013a). Adding to this is the Caatinga’s own heterogeneous landscape, which has allowed for example the existence of “moist forest islands” of both Amazon and/or Atlantic forest affinity, with great levels of endemism, in higher elevation topographic features such as plateaus and mountain ranges (Camardelli et al. 2012).

Besides the relict moist forests, the Caatinga is predominantly characterized by steppe savannah and dry forest type habitats, with intermittent river systems (Auler et al. 2004; Leal et al. 2005). The vegetation is made up mainly of xerophytic, woody, thorny, and deciduous physiognomies, which lie

dormant and leafless throughout most of the year (Auler et al. 2004; Leal et al. 2005). Inventories and assessments have recorded up to 1200 species of vascular plants, of which around 30% are only found in the region (Leal et al. 2005; WWF 2013a).

In terms of animal taxa, the numbers yielded by the Caatinga are also considerable, with at least 240 fish species, 175 amphibians and reptiles, 520 birds (across 62 families) and 156 mammals (of which 44.7% are bats) (Oliveira et al. 2003; Santos et al. 2011; Albuquerque et al. 2012; Sá-Neto & Marinho-Filho 2013). Invertebrates are still poorly studied, however there are no reasons to believe that their numbers and diversity will be low (Araújo et al. 2005), and for example 187 bee species have been reported in the region (Santos et al. 2011). Overall levels of endemism are not as high as for plants, but still, values range from about 7% for mammals, 3 to 9 % for birds, 12% for amphibians and reptiles, and 57% for fishes (Leal et al. 2005; Santos et al. 2011; Albuquerque et al. 2012). All of these current biodiversity scores are equal or higher when compared to other semi-arid biomes around the globe, and numbers can increase even further if we take into account that by 2004/2005 41% of the region had never been surveyed and 80% had been only poorly explored (Leal et al. 2005; Santos et al. 2011). Overall, sample size and sampling efforts are relatively small and scattered, which has made many researchers adhere to information networks such as TROPIC-DRY to better maintain contact with other works and to compare results to other dry forest regions worldwide (Albuquerque et al. 2012).

Endemic species of the Caatinga are highly threatened. The more serious cases come from bird species: the Spix's macaw (*Cyanopsitta spixii*) has become extinct in the wild and it is maintained through captive breeding programs; the Lear's macaw (*Anodorhynchus leari*) is reduced to a population of around 1000 individuals, separated into only two colonies (Leal et al. 2005). Another example comes from the Brazilian three-banded armadillo (*Tolypeutes tricinctus*), which was also thought to be extinct but was recently rediscovered in remnants of relict forest (Leal et al. 2005).

The major threat for the conservation of the Caatinga and its wildlife are, without a doubt, the destruction and transformation of habitat for intensive land uses. Over 25 million people live in the Caatinga, most of them poor, and around 50% of the region has been already either completely converted, or altered in a significant way, due to the establishment of unsustainable agriculture and livestock practices (including exotic species), extraction of wood for fuel, uncontrolled fires, modification of river regimes and water flows, and construction of cities and roads (Leal et al. 2005; Alves et al. 2009; WWF 2013a). The intensive land use is responsible for severe environmental damage, with 15% of the region now under the risk of desertification, and remaining natural habitats being highly fragmented and degraded (Santos & Tabarelli 2002; Leal et al. 2005). Another major concern for the sustainability of the Caatinga's biota is intense hunting and persecution. This includes both: illegal hunting and sale of endangered wildlife; and subsistence hunting by the local people, for which various animals are important resources of food but also of medicinal remedies and ornamental pieces, as well as some species being killed for being considered threats (mainly snakes), while others are kept and enjoyed as pets (birds mostly) (Alves et al. 2009; Barbosa et al. 2011; Albuquerque et al. 2012).

In the face of all these sizable threats and increasing human pressures, the Caatinga has the fewest and smallest protected areas of any major Brazilian biome, with only 11 reserves that cover less than one per cent of the region (Leal et al. 2005). More recently in 2007, the Brazilian Ministry of the Environment (MMA) defined priority conservation areas across the entire country, and a study in 2012 showed that the majority of areas of endemism for amphibians overlapped with the priority areas set by the MMA in the Caatinga biome (Camardelli et al. 2012). Despite the current state of knowledge and conservation practice in the Caatinga, there is a clear effort from various government, state and local agencies, as well as NGO's, to try turn the tide, and a good example comes from the Parque Nacional da Serra da Capivara, one of the most visited and best managed National Parks that insures the conservation of a key set of species as well as an important archaeological site (Leal et al. 2005; Santos et al. 2011; Albuquerque et al. 2012; WWF 2013a).

Additionally, four AZEs sites are located within the Caatinga (AZE 2013), and the north-eastern part is considered an Important Bird Area (BirdLife International 2013i).

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1. How do you judge the overall relevance and quality of the presented products?

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3. What further products (level one) would be interesting to you to have?

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