Detecting changes in essential ecosystem and biodiversity properties- towards a Biosphere Atmosphere Change Index: BACI

DeliverableD4.2 Global products of FLUXNET derived ecosystem functional properties at annual time scale with quantified uncertainties

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Introduction

Ecosystem Functional Properties (EFPs) are downstream products obtained starting from half hourly up-scaled carbon and energy fluxes and ancillary meteorological drivers. The EEP variables describe the capability of plant ecosystems to optimize available environmental resources (e.g. Light or Water Use Efficiency), physiological properties of vegetation (e.g. the maximum photosynthesis capacity), or relationships between photosynthesis and meteorological forces (e.g. with precipitation) and for this reason they can represent the "functionalities" of an ecosystem. Tracking their change in time and space is a key information in a project like BACI because in addition to the normal evolution of and ecosystem they can be an indicator of disturbances (in particular in the short and medium time frame) or of a slow and constant status change (in the long term) for example in response to climate change..

In this deliverable five different EFPs have been produced starting from the first version of the upscaled halfhourly fluxes that will be consolidated in Deliverable 4.4:

1) Maximum of the gross primary production (GPPmax);
2) Light Use Efficiency;
3) Water Use Efficiency;
4) Precipitation Use Efficiency;
5) Bowen ratio.

EFPs have been produced at global level and for the period 2001-2014 (except GPPmax that is available for the years 2001-2010). In the following section a brief description of each EFP is provided while in the last section the uncertainty of the products is presented.

Description of the EFPs

Maximum of the gross primary production

__Definition:__ Maximum gross primary production (GPPmax) is an indicator of the maximum photosynthesis daily rate of an ecosystems.

__Unit of measurement:__ gC m^{-2} day^{-1}.

__Method:__ GPPmax has been estimated as the 90th percentile of daily GPP over the year. The decision to take the 90th percentile respect to the maximum value has been taken in order to avoid the possible effect of outliers. In particular, half hourly up-scaled GPP has been aggregated at daily time scale pixel y pixel and then for each year the 90th percentile calculated and reported.

__Scientific relevance:__ GPPmax varies among ecosystems and it is also function of climate, vegetation density and plant composition (for example it is in general higher for ecosystems having high percentage of C4 plants, and in particular for the C4 cropland). It is independent respect to the total annual GPP and for this reason it is an additional important parameter. In fact, the total annual GPP is a combination of assimilation rate and length of the growing season. For example, the highest GPPmax values are not in the tropics (where the annual GPP is maximum, see below for details), instead in sites where the optimal environmental conditions (climate and vegetation) for the photosynthesis occur at one point in the growing season.

__Spatial pattern:__ GPPmax (Figure 1) shows an hot spots in North America (around 42°N, 90°W, Figure 1), and a smaller hot spot in the middle east of Asia (around 42°N, 135°E). Land cover is dominated in both the areas by cropland. The climate is hot with dry winter in the North America hot spot, cold with dry summer in the one located in middle east Asia. High values of GPPmax were also found in the Tropics and in European continent. In figure 2 the trend of the GPPmax values in the reference period (2001-2010) are presented (only for significant trend with $p<0.05$) and as it is possible to note the two hotspot in GPPmax don't show trends.

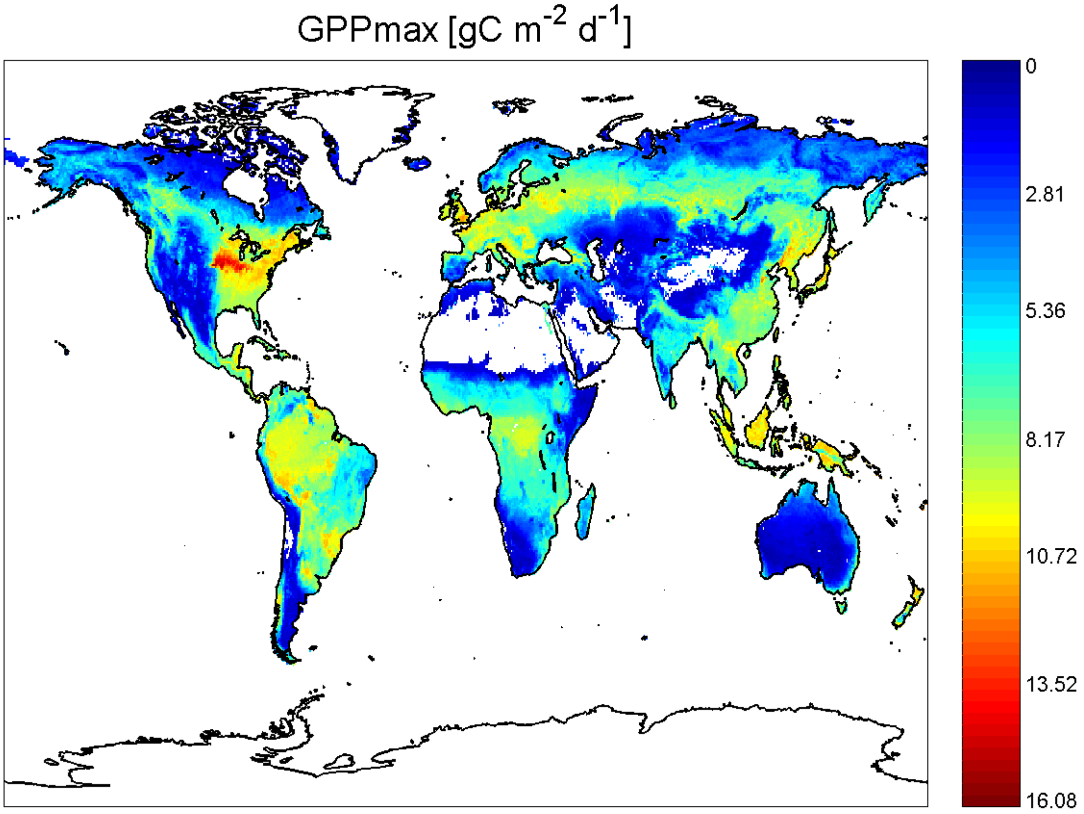

Figure 1: map of mean annual GPPmax. The average GPPmax was calculated for the period 2001-2010.

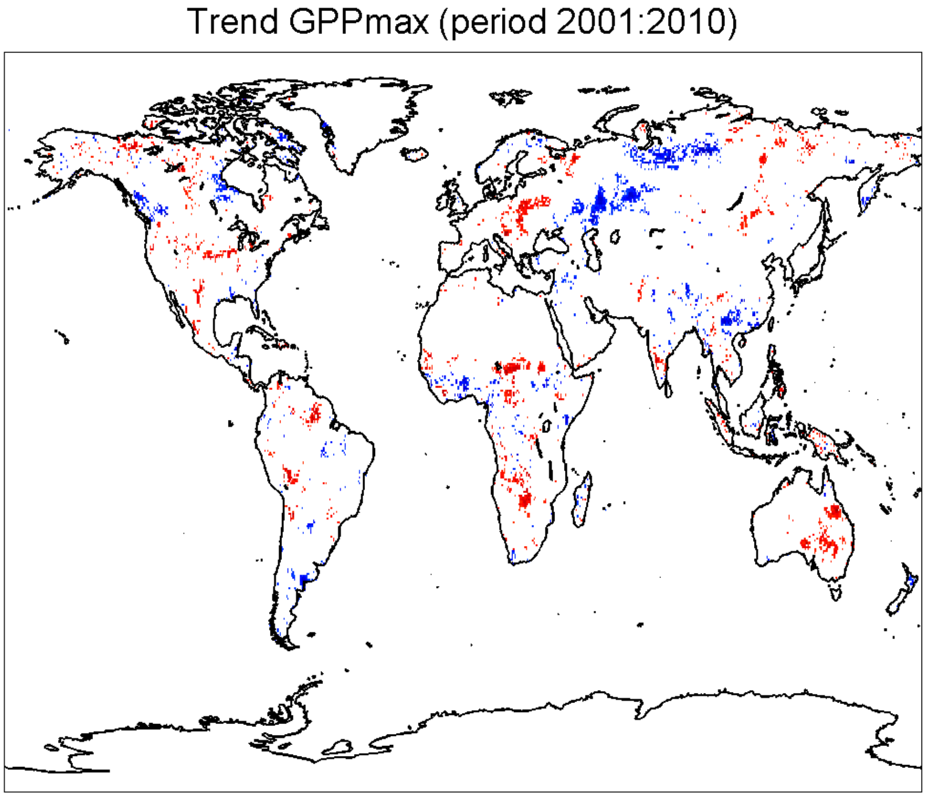

Figure 2: map of the trend of GPPmax in the period 2001-2010. Only pixel where the trend is significant are reported ($p<0.05$). Red are positive trends, blue are negative trends.

Light use efficiency

__Definition:__ Light use efficiency (LUE) states the capacity with which vegetation converts the incoming light to fixed carbon (Gitelson et al., 2015).

__Unit of measurement:__ g C MJ^{-1}.

__Method:__ LUE has been estimated as the ratio between the mean annual values of daily GPP and incoming solar radiation.

__Scientific importance:__ LUE has been derived by the work of Monteith (1972) and Monteith et al., (1977) and it is largely used in the ecosystem scale photosynthesis models. It varies with the ecosystem types, vegetation health, seasonality and environmental constraining factors. In ecosystem characterized by seasonality, LUE varies during the vegetative season: it is maximum when leaves are well developed and at the minimum during the senescence period.

Spatial pattern: Spatial pattern of LUE (Figure 3) largely mirror the one of the mean annual GPP (Jung et al., 2011). The highest values have been found in the tropics where there is the maximum vegetation density and environmental conditions are optimal for the photosynthesis during the whole year. Lower (but close to the median) values have been found in the temperate climate, where the green vegetation density and photosynthesis change seasonally (e.g. in Europe). Conversely minimum values occur in the subtropical climate where seasonal dry condition occurs, or in cold ecosystems. In terms of dynamic in time, it is interesting to notice that there are areas where the trend is significant (both negative and positive) confirming that it is probably a change happening in the ecosystem status.

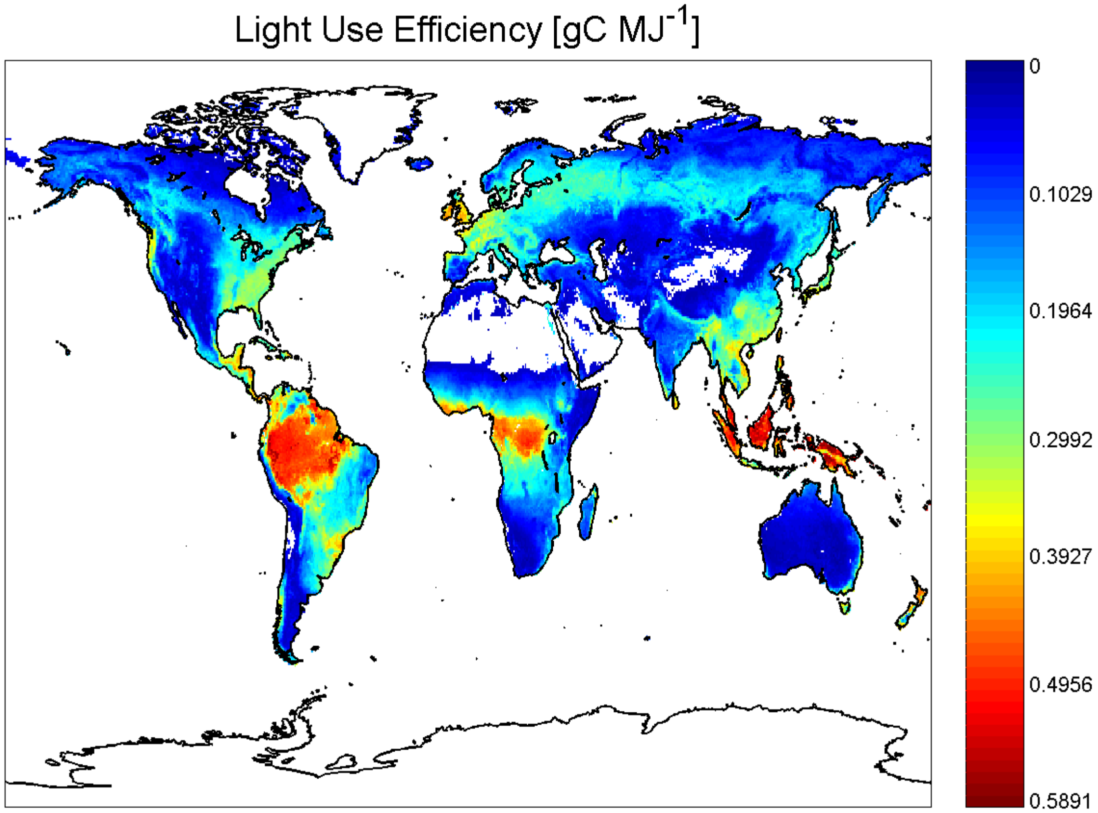

Figure 3: map of mean annual LUE. Data for map was calculated from the period 2000-2013.

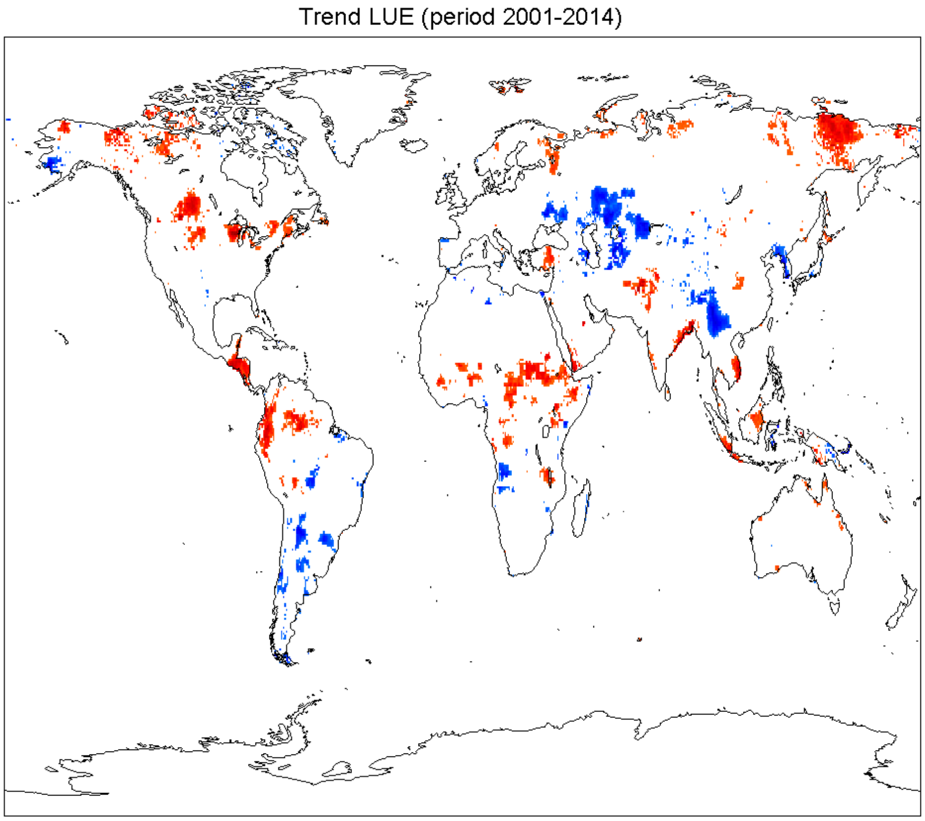

Figure 4: map of the trend of LUE in the period 2000-2013. Only pixel where the trend is significant are reported ($p<0.05$). Red are positive trends, blue are negative trends.

Water Use Efficiency

__Definition:__ Water Use Efficiency (WUE) states the capability of an ecosystem to convert each unit of water loss (by evapotraspiration) in gross primary production (Beer et al., 2009).

__Unit of measurement:__ gC mm^{-1}.

__Method:__ WUE has been estimated as the ratio between the mean annual values of daily GPP and the mean annual value of evapotraspiration. Both variables were up scaled from eddy covariance measurements by machine learning techniques.

__Scientific importance:__ At leaf level photosynthetic rate is directly related to the water loss as transpiration trough stomata (Cowan and Farquhar, 1977). The increasing of stomata conductance increase the carbon uptake but conversely the water lost by transpiration. As reflection, GPP at the ecosystem scale generally increase with the increasing of evapostrapiration. WUE (at ecosystem scale) states the capability of green ecosystem to optimize the water resource moved from soil to atmosphere through plant canopies for the photosynthesis. WUE varies as function of soil water availability and environmental conditions constraining water demand (e.g. high vapour pressure deficit).

Spatial pattern: Spatial pattern of WUE (Figure 5) largely mirrored the ones of LUE, with highest values in the tropical zones but with high WUE also in European country, central Eurasia, in the east of North America, and in general in the subtropical not arid climate. Lower values have been found in the cold and dry climate. Interestingly the temporal pattern of WUE is instead different from RUE in many areas, showing different hotspots (Figure 6)

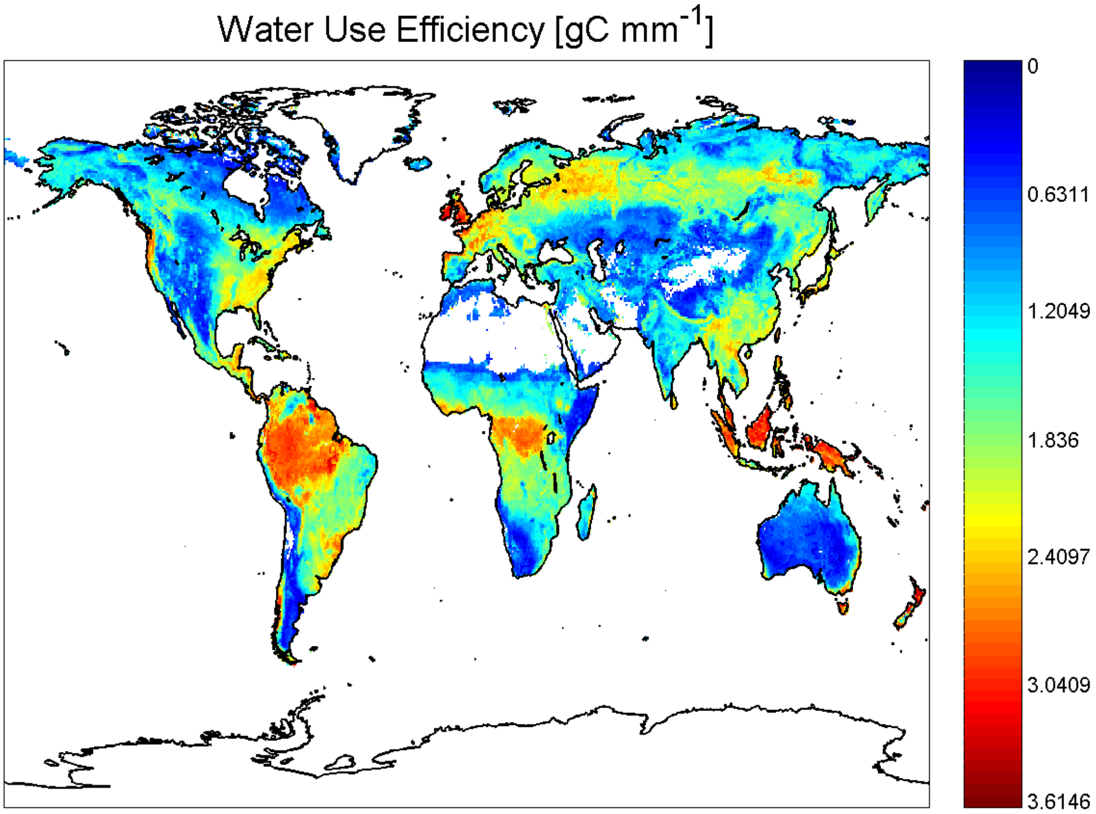

Figure 5: map of mean annual WUE. Data for map was calculated from the period 2000-2013.

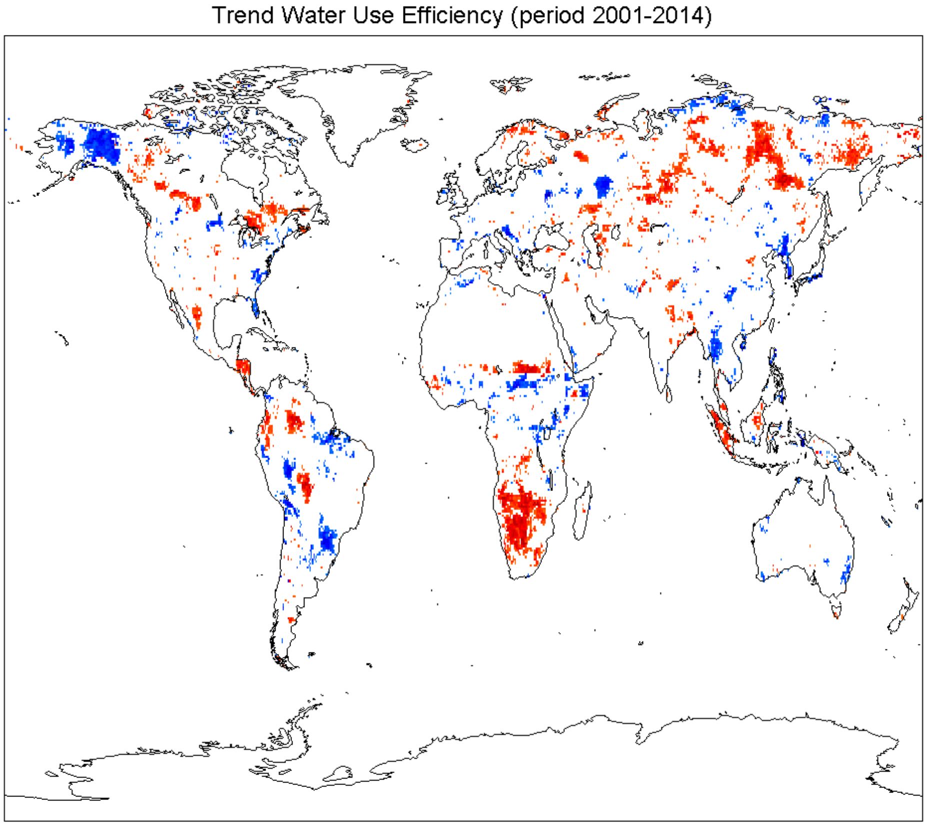

Figure 6: map of the trend of WUE in the period 2000-2013. Only pixel where the trend is significant are reported ($p<0.05$). Red are positive trends, blue are negative trends.

Precipitation Use Efficiency

Definition: Precipitation Use Efficiency (PUE) states the ratio between gross photosynthesis production and mean annual precipitation (Huxman et al., 2004).

Unit of measurement: gC mm^{-1}.

Method: PUE has been defined as the ratio between the mean annual values of daily GPP and the mean annual value of precipitation.

Scientific importance: PUE is a useful index to explain the relationships between ecosystem carbon and water cycle (Hu et al., 2010, Bai et al., 2008). This index is related to plant physiological characteristics and physical water loss processes. In fact water input by precipitation are not totally available for plant ecosystems because precipitation can be largely lost. High vegetation density increase the fraction of precipitation captured by canopies and then lost by evaporation. A fraction of water precipitation reaching the soil can be lost by runoff. Runoff is affected by site morphology, and change by slope and also by soil type and porosity and green vegetation type and density. Climate change can modify both vegetation and precipitation event (e.g. reducing the frequency and increasing the intensity, or modifying distribution over the season) hence the relationships between carbon and water cycle over land ecosystems.

Spatial pattern: Spatial pattern of PUE (Figure 7) and their trend (Figure 8) are largely different respect to the WUE. The highest values have been found in the northern hemisphere in particular in the north of America, in central Europe and in the boreal zones. High value of PUE have been also found in the boundary zone surrounding the arid regions where the precipitation are low. Tropics didn't show high value probably because large part of precipitation is captured by the dense canopies and then evaporated in the atmosphere. Low values have been also found in the mountainous regions where water runoff increases due to slope.

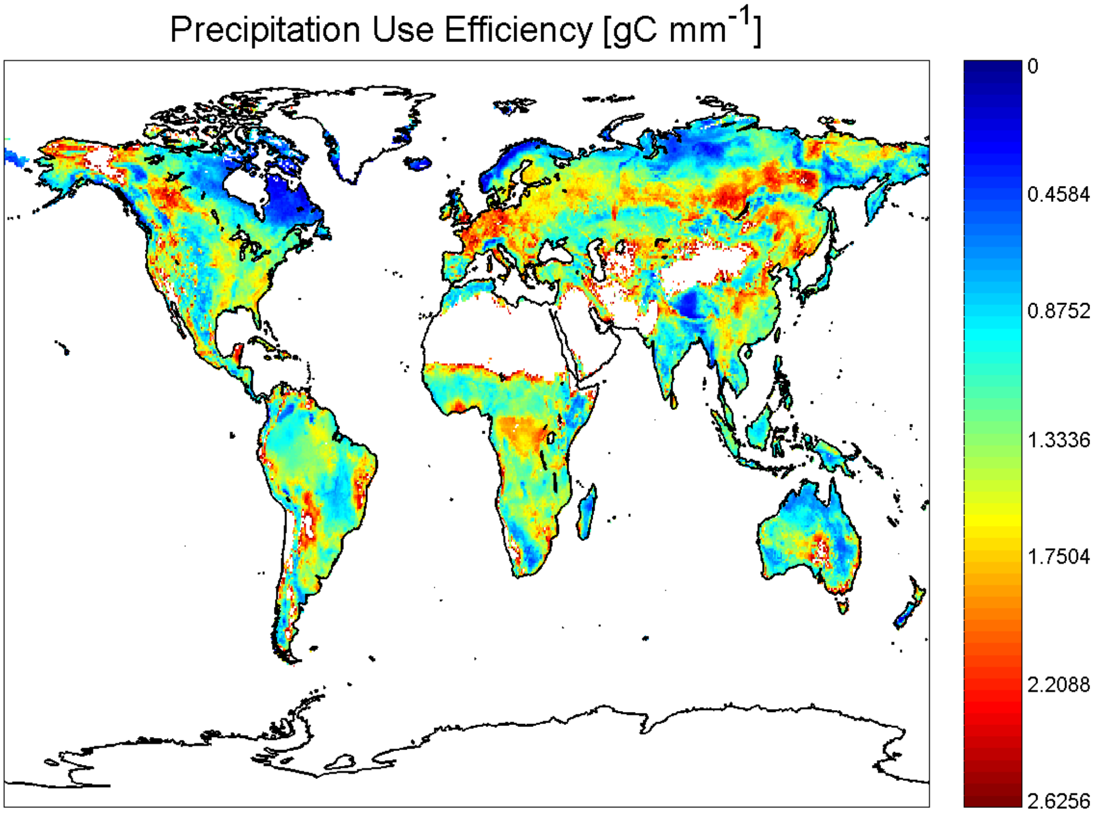

Figure 7: map of mean annual PUE. Data for map was calculated from the period 2000-2013.

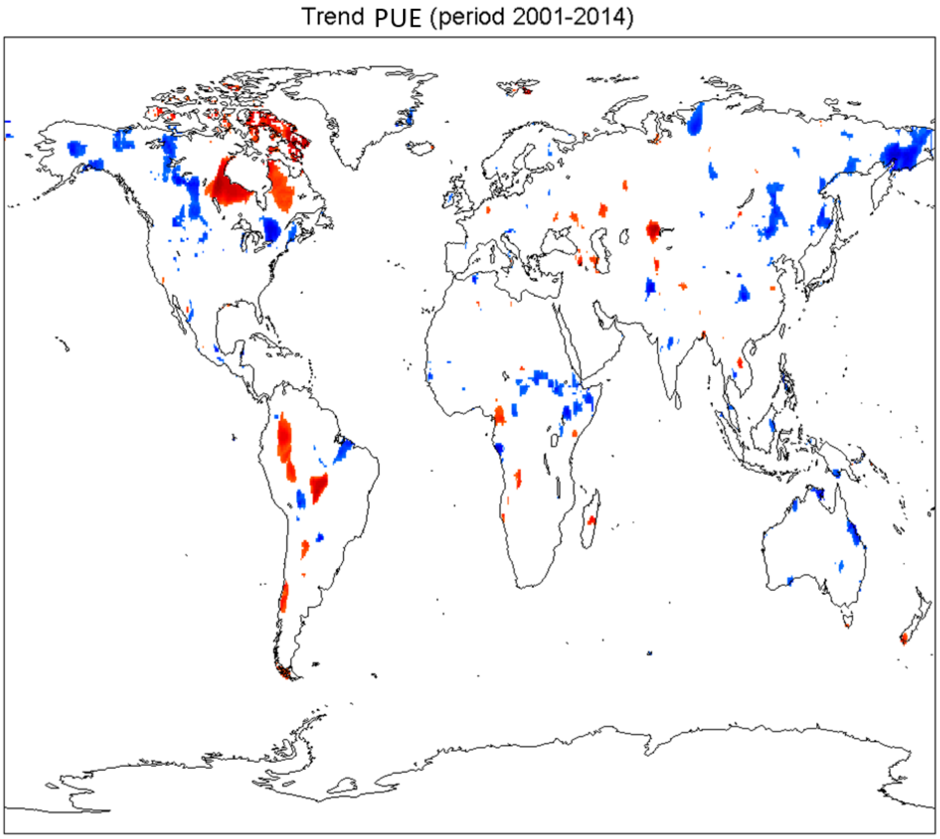

Figure 8: map of the trend of PUE in the period 2000-2013. Only pixel where the trend is significant are reported ($p<0.05$). Red are positive trends, blue are negative trends.

Bowen ratio

Definition: Bowen ratio is defined as the ratio between fluxes of sensible heat and latent heat of evapotranspiration.

Unit of measurement: adimensional.

Method: the Bowen ration has been calculated as the ration between mean annual values of sensible heat and latent heat.

Scientific importance: Energy provided at the ground surface by net radiation are partitioned in soil heat flux, sensible and latent heat of evapotraspiration. Soil heat flux is considered negligible respect to the other two in terms of magnitude and for this reason only the last two are contidered. Sensible heat produce warming of ground surface while latent heat of evapotraspiration move liquid water from soil to the atmosphere and it is involved in photosynthesis processes. The Bowen ratio is important because describe the partitioning of net radiation in sensible and latent heat of evapotraspiration. The mean annual value of Bowen ratio change spatially as consequence of vegetation type and water availability. However, Bowen ratio can change also seasonally as changing in vegetation cover or season (dry or wet). An increase over the years could be related to warming of the ecosystems or to a reduction of evapotraspiration (or water resource).

Spatial pattern: Bowen ratio exhibits high value in the arid regions in which vegetation cover is generally reduced (Figure 9). Some regions having high Bowen ration overlap with the ones having high PUE (e.g. the boundary regions close to deserts). The highest productive ecosystems, characterized by high values of LUE, WUE and GPPmax, conversely exhibited low value of Bowen ratio.

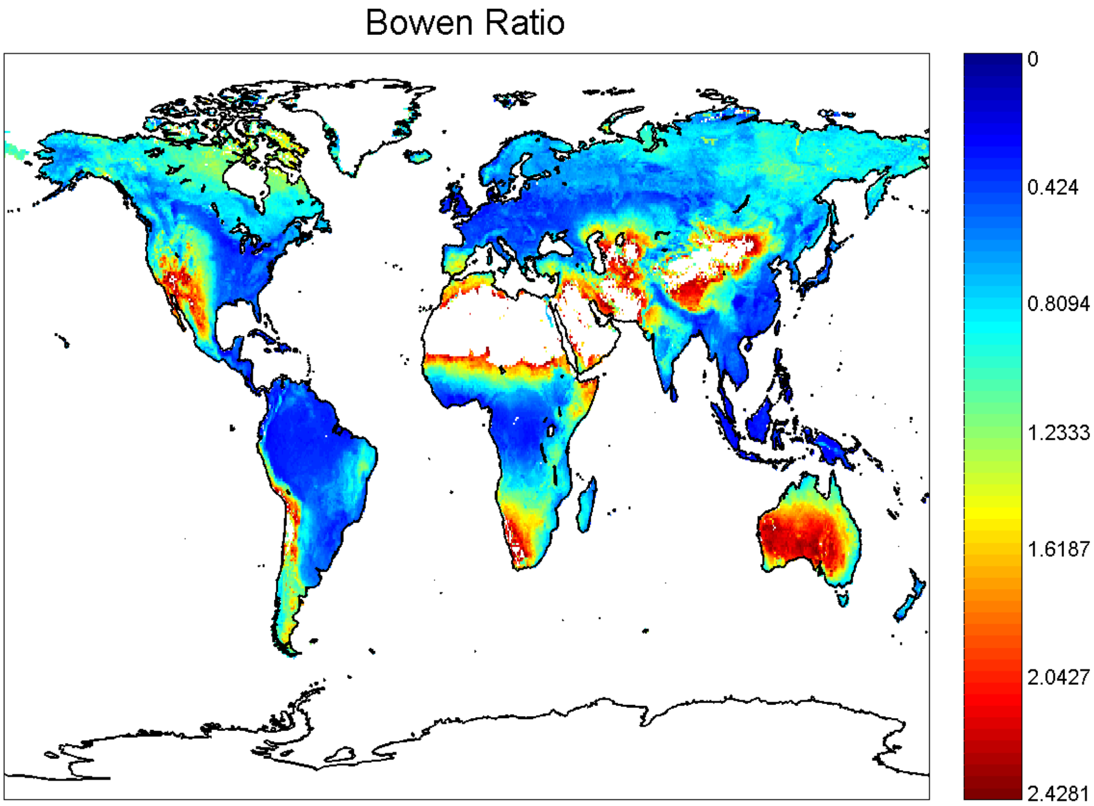

Figure 9: map of mean annual Bowen Ratio. Data for map was calculated from the period 2000-2013.

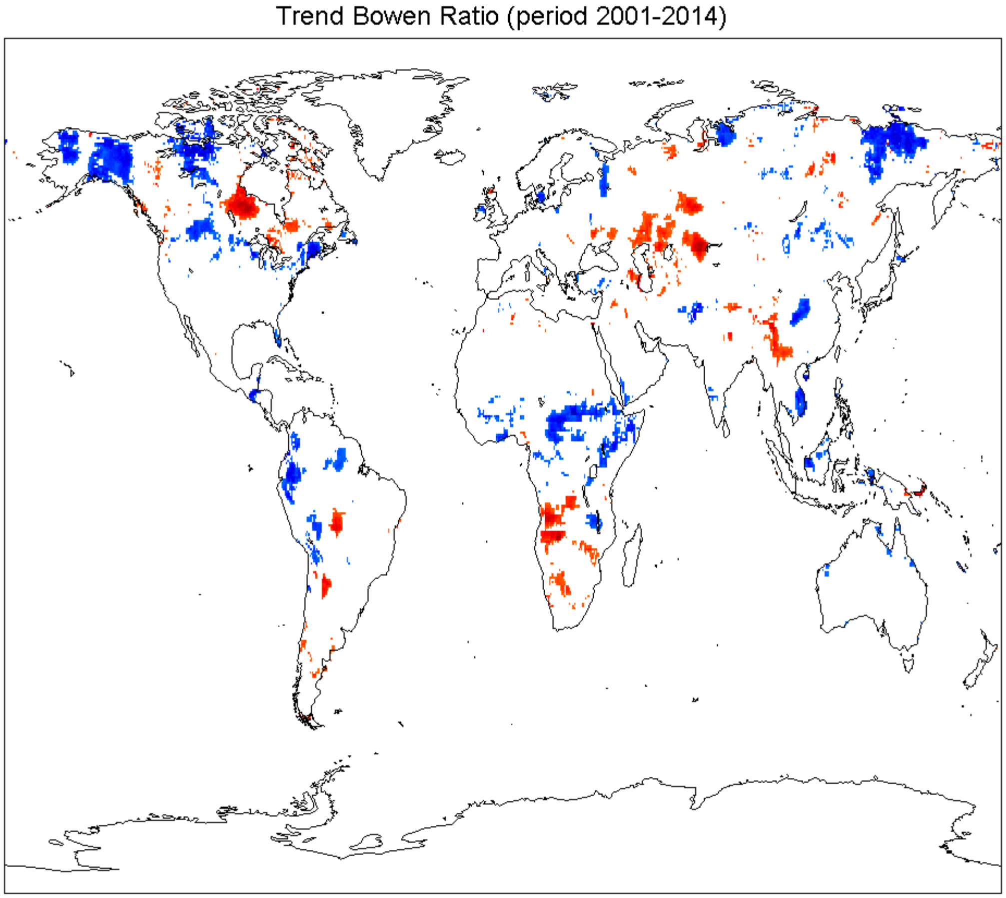

Figure 10: map of the trend of Bowen ratio in the period 2000-2013. Only pixel where the trend is significant are reported ($p<0.05$). Red are positive trends, blue are negative trends.

Uncertainty of the products (EFPs)

Uncertainty has been accounted at site level by a leave-one-site-out cross-validation strategy. This means that for each FLUXNET tower, fluxes and EFP have been predicted using a Random Forest regression model parameterized from observations of all the other FLUXNET towers. The following index have been used to evaluate uncertainties and the agreement between modelled and measured values:

a) Pearson linear correlation coefficient (ρ), estimated as the ratio between the covariance between the modelled and observed values and the product of their standard deviation (range between -1 and +1);

b) Model Efficiency (MEF) estimated following Nash, 1970. Range between –inf and 1;

c) Ratio of variance (ROV) that is the ratio among the variance of prediction and the one of observations (range 0 to Inf).
d) Median absolute deviation (MAD), estimated as the median of the absolute value of residuals, in which residuals are the differences between predictions and observations. This measurement accounts both the systematic an random uncertainties but the sensitivity to data outliers is reduced (range 0 to Inf).
e) Root mean square error (RMSE) estimated as the root square of the mean value of squared residuals. This measurement accounts both the systematic an random uncertainties but it is more sensitive to data if compared with MAD (range 0 to Inf).
f) Bias, calculated as the mean value of residuals. This error account only for the systematic differences (range –Inf to Inf).

Data used for cross validation are coming from more than 200 eddy covariance sites, and related to the years between 1991-2007. In this analysis the EFPs values have been computed only if more than 100 daily values were available at the site. Results are shown in table 1. Scatter plot are also shown in Appendix A.

Table 1: agreement and uncertainty index estimated by the cross validation at site level of the following EFPs

EFPs	R	MEF	ROV	MAD	RMSE	BIAS	N° of points (sites x years)
GPPmax	0.7661	0.3617	0.3308	2.1352	3.7638	-0.0485	843
LUE	0.8426	0.6186	0.4841	0.0577	0.1133	-0.0485	420
WUE	0.7522	0.3517	0.2651	0.6972	1.5221	-0.7508	310
PUE	0.8911	0.7899	0.7499	0.4830	3.0645	-0.3947	420
Bowen Ratio	0.7551	0.5565	0.3377	0.2032	0.5911	-0.1199	539

Correlation between modelled and measured data are good (range or R: 0.75-0.89) while the MEF and ROV are comparatively lower in some of the EFPs (GPPmax, WUE and Bowen Ratio). The uncertainty of products are low and the relative median absolute deviation ranging between the 20-26% of the median value of the EFPs (absolute value of error metrics are not directly comparable because the different magnitude of EFPs). Products have also a relatively low bias;

in fact the fraction of mean square error due to the systematic error, estimated following Gupta et al., (2009) is lower than 24%.

Appendix A: Scatter plot of EFPs site level cross-validation.

Scatter plot showing comparison between observed and modelled EFPs are show at follow. In particular, GPPmax, LUE, WUE, PUE and Bowen Ration are show in figures A1-A5

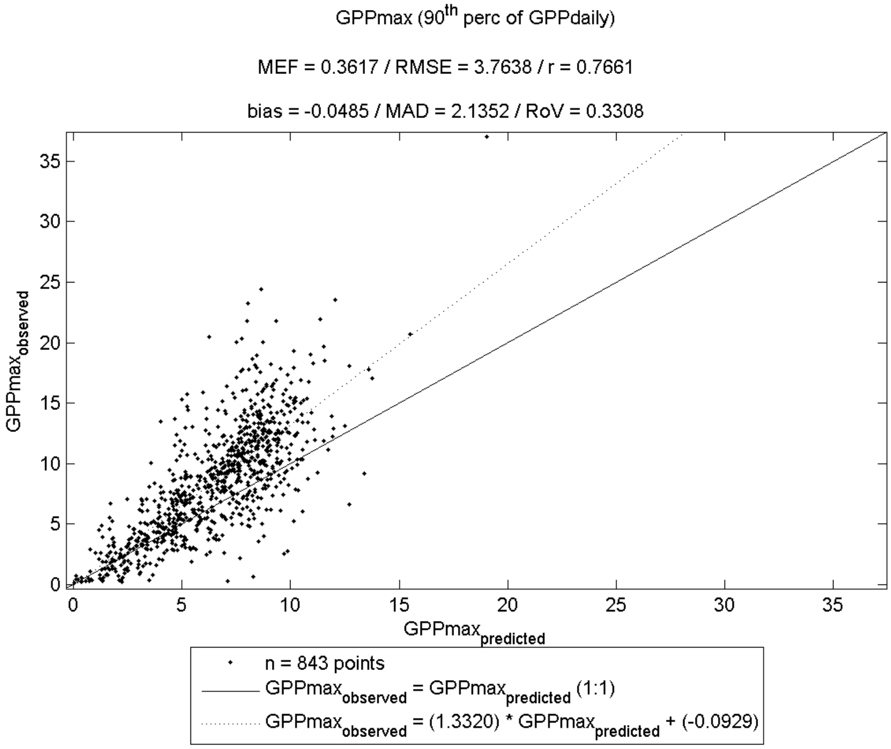

Figure A1: scatter plot showing the cross-validation results for GPPmax

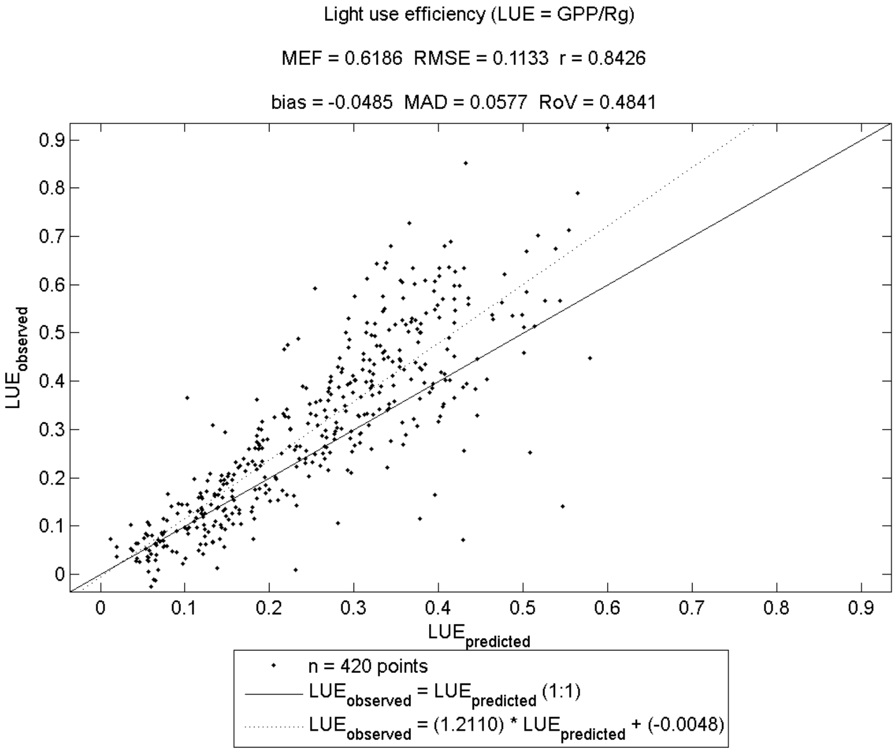

Figure A2: scatter plot showing the cross-validation results for LUE

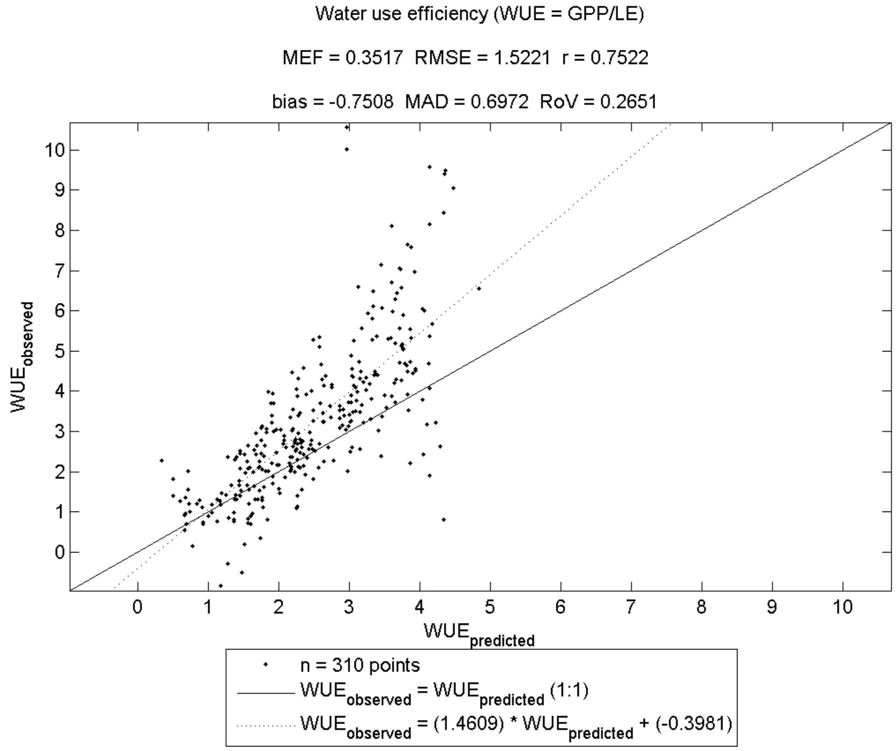

Figure A3: scatter plot showing the cross-validation results for WUE

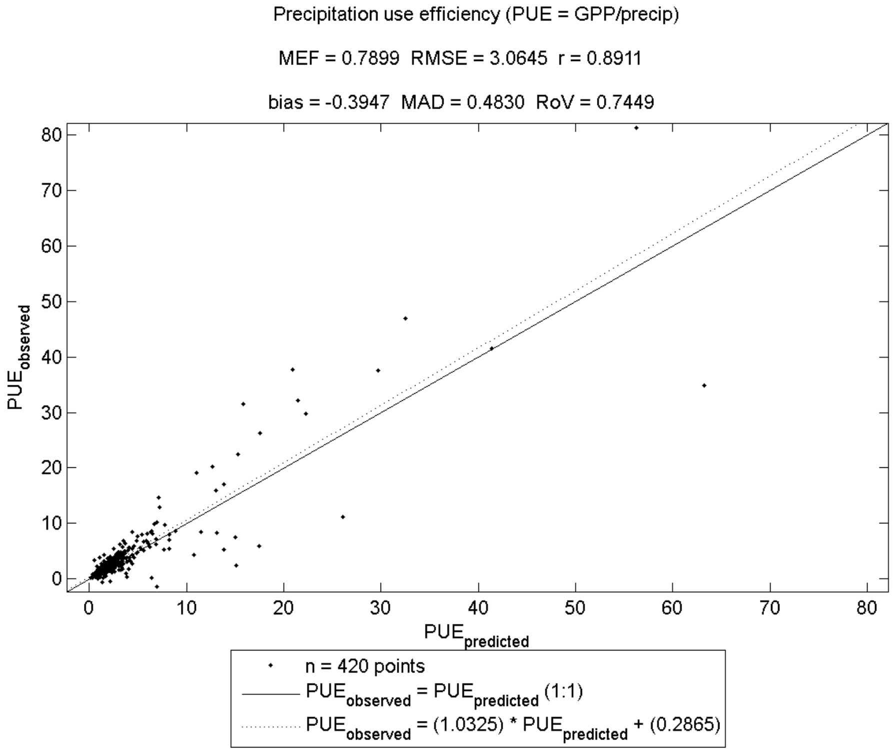

Figure A4: scatter plot showing the cross-validation results for PUE

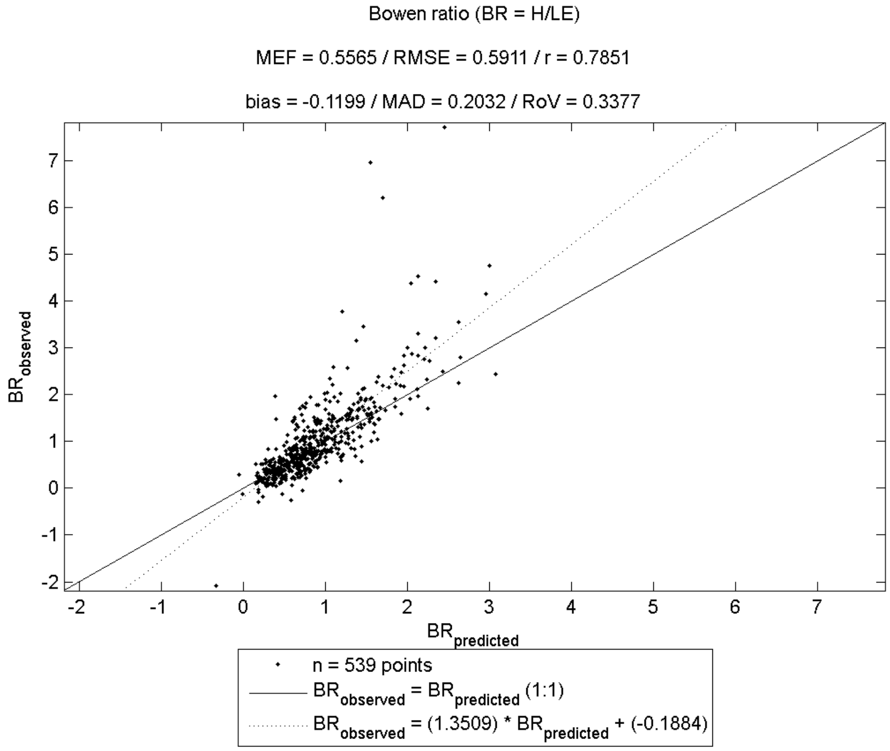

Figure A5: scatter plot showing the cross-validation results for BR

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