BACI

Newsletter

Detecting Changes in Essential Ecosystem and Biodiversity Properties: Towards a Biosphere Atmosphere Change Index

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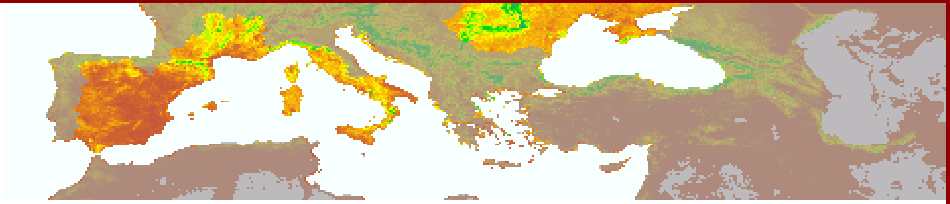
http://baci-h2020.eu



Dear friends and colleagues:

Welcome to the third issue of the BACI newsletter! With this semi-annual summary we want to keep you informed about the work progress, the most important successes, upcoming events and activities in this EU project. We also would like to congratulate our BACI colleagues on a series of excellent publications. We hope that the summary of this work will provide starting points for biodiversity scientists and ecologists, experts in land system science, experts in co-design and co-production of knowledge, land managers and practitioners. We hope you find this overview interesting. More information about the project as a whole can be found on the last three pages. If you have any questions, suggestions, feedback or comments you would like to address to the consortium or to the project coordination, please e-mail us.

Thank you for joining us!

Miguel Mahecha

BACI group picture from the 2017 progress meeting

This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 640176.

Unexpectedly large impact of forest management and grazing on global vegetation biomass

Plants hold the largest amount of carbon of live on Earth. Changes in vegetation carbon stocks - due to sequestration or release of carbon from biomass - can impose large consequences on the concentration of CO2 in the atmosphere, and consequently on climate. This renders vegetation one of the key components of global carbon cycle.

In this work, the authors estimate the amount of carbon that has been lost from terrestrial vegetation as a result of land land use, through the conversion of ecosystems (change from one type to another) as well as through management, i.e. changes that occur within a land use type. In order to quantify these effects, they compiled and compared global maps of actual biomass stocks and potential biomass stocks that would exist without human interference.

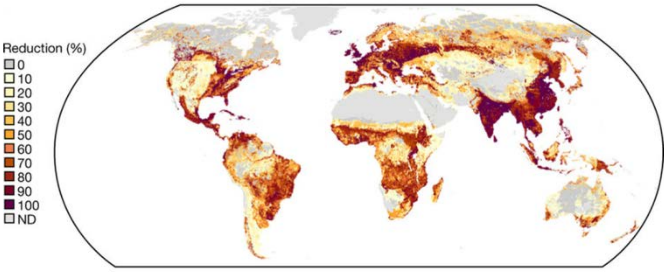
Seven global maps of actual biomass stocks, based on current state-of-the art datasets from remote sensing and inventories, were computed, including aboveground as well as belowground living biomass compartments. For the potential biomass stocks, six maps were reconstructed, using information from ecological literature as well as remote sensing information. These potential biomass stock maps represent the biomass stocks that would prevail in vegetation if in the absence of human disturbances but with current climate. They thus represent the current full absorption potential for carbon in biomass, and a comparison with the actual biomass stocks allows isolating the land-use impact on biomass stocks.

Globally, a mean of 450 petagram of carbon (PgC) is estimated for the current prevalent vegetation. On the other hand, the mean of the six maps of potential biomass stocks, results in 916 PgC.

The difference of the two estimates suggests a reduction of carbon that could be potentially stored in terrestrial biomass by ca. 50% due to land use. The difference in biomass between potential and actual stocks in general follows the global agricultural patterns. However, the difference is also considerably high in regions dominated by forest and natural grassland use.

"In fact land cover change and land management contribute almost equally to the overall difference between potential and actual biomass stocks."

An analysis of the dataset revealed that the effect of land management, i.e. of forest management and of livestock grazing of natural grasslands and savannahs, is with 42-47% of the total reduction almost as large as the effect of land cover conversions (53-58%), such as the deforestation for agriculture.



The figure above shows the spatial pattern of land-use-induced biomass stock differences expressed as the average of 42 estimates resulted from the different pairing of the 7 actual and 6 potential biomass stock (in percentage of potential biomass stock).

The authors call for prudent and cautious approach in land-based mitigation strategies in the light of the trade-offs between maintaining or increasing biomass productivity and supply on the maintenance or even enhancement of biomass stocks.

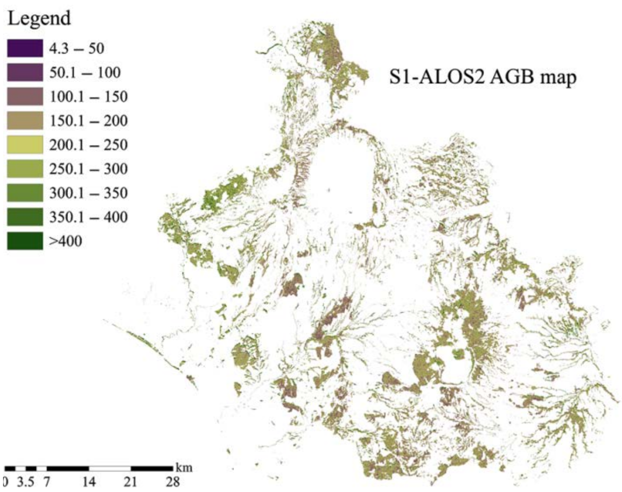
Original publication

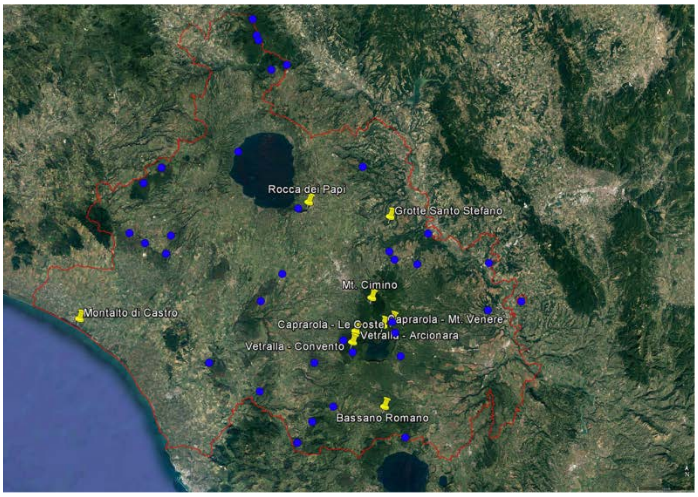
Erb, K.-H., Kastner, T., Plutzar, C., Bais, A. L. S., Carvalhais, N., Fetzel, T., Gingrich, S., Haberl, H., Lauk, C., Niedertscheider, M., Pongratz, J., Thurner, M., Luyssaert, S. (2018). Unexpectedly large impact of forest management and grazing on global vegetation biomass. Nature, 553(7686), 73-76. doi:10.1038/nature25138.

Above-ground biomass prediction by Sentinel-1 multitemporal data in central Italy with integration of ALOS2 and Sentinel-2 data

Vaglio Laurin et al., have used Sentinel 1 multitemporal data in tandem with ALOS2 and Sentinel2 data, to predict above ground forest biomass (biomass hereafter) in the Viterbo (Italy) province at very high spatial resolution and with limited saturation effects.

As mentioned in the previous paper information on biomass is very important in global carbon accounting in respect to global scenario of climate change. Information on biomass is very important to understand the climate change effects on forests. Remote sensing can be sued to retrieve biomass over large areas, allowing to spatially extrapolate biomass measures taken in field visits. Many different earth observation data are available: this research stresses the importance of radar (SAR) Sentinel 1 data, not affected by cloud cover issues and freely available in dense time series. The figure on the right represents the Viterbo province area: surveyed forests are indicated by yellow marks, provincial boundary in red, national forest samples by blue dots; on the background Landsat 8 real color image from Google Earth. The figure on the left shows the estimated biomass map using Sentinel 1 (S1) plus ALOS2 SAR data.





Specifically, authors show that time series of S1 alone explains biomass variability only moderately in the study area. The integration of S1 with ALOS2 SAR improves the estimates, as the latter has longer wavelength and thus more capability to penetrate the forest than S1. Also the integration of Sentinel2 (S2) produced an improvement of estimates, possibly thanks to the ability of optical data to discriminate among forest types. The addition of S2 to S1 possibly produced overestimation of biomass, with results obtained by S1+ALOS2 being more conservative. However, estimation based on the S1-ALOS2 required additional information of deciduous or evergreen species presence, while the model using S1-S2 did not. This represents an advantage when detailed information on forest type is not available. **The authors promote the usefulness of S1 data for analyzing the spatial distribution of biomass in fragmented landscapes of moderate biomass density.**

Original publication

Vagio Laurin, G., Balling, J., Corona, P., Mattioli, W., Papale, D., Puletti, N., Rizzo, M., Truckenbrodt, J., Urban, M. (2018). Above-ground biomass prediction by Sentinel-1 multitemporal data in central Italy with integration of ALOS2 and Sentinel-2 data. Journal of Applied Remote Sensing, 12(1): 016008. doi:10.1117/1.JRS.12.016008.

Improving near-real time deforestation monitoring in tropical dry forests by combining dense Sentinel-1 time series with Landsat and ALOS-2 PALSAR-2

Combining observations from different optical and synthetic aperture radar (SAR) satellites can improve near real time deforestation monitoring in dry tropical regions. Solely optical monitoring systems in these regions have limited data availability due to persistent cloud cover.

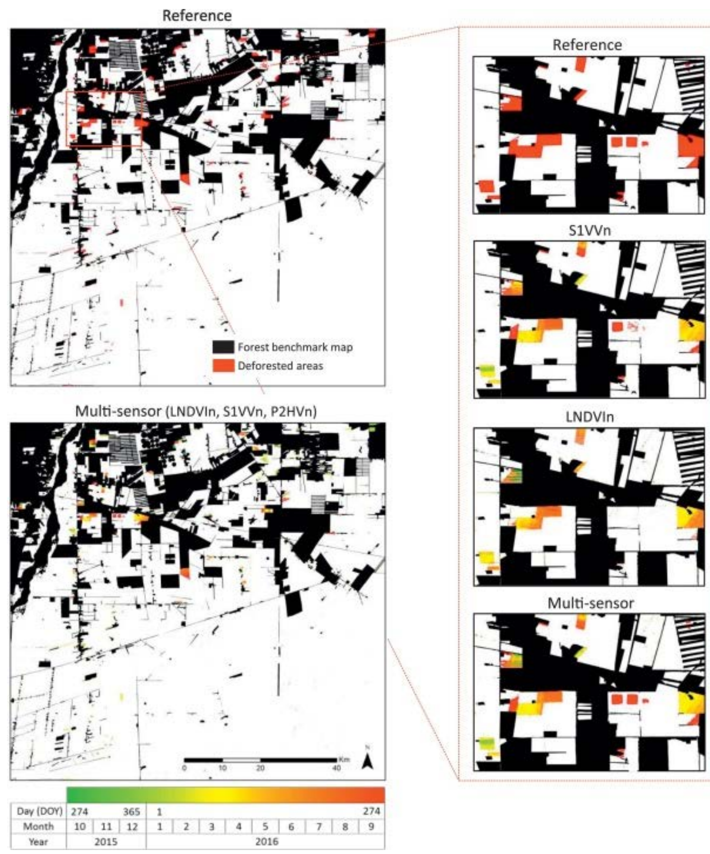
Benefiting from the recent launch of Sentinel-1 satellites (SAR type), the authors demonstrate multi-sensor near real-time deforestation detection in tropical dry forests, by combining Sentinel-1 C-band SAR time series with ALSO-2 PALSAR-2 L-band SAR, and Landsat-7/ETM+ and 8/OLI.

The study site is a dry tropical forest located in the province of Santa Cruz in Bolivia. Logging activities in the last decade resulted in large deforested patches. To detect deforestation in near-real time, first spatial normalization was used to reduce the dry forest seasonality in the optical and SAR time series. Then the data was combined within a probabilistic approach.

They show due to high observation availability, Sentinel-1 was able to detect the deforestations more timely compared to Landsat and ALOS-2 PALSAR-2. Here how the near real-time deforestation detection is associated with a trade-off between the confidence in detection and temporal accuracy is quantified.

The trade-off influences the choice on how to use the data for different applications such as fast alerting with high temporal accuracy but lower confidence vs. accurate detection at lower temporal detail.

The authors quantified how the near real-time deforestation detection is associated with a trade-off between the confidence in detection and the temporal accuracy. They showed that the trade-off affects the choice on how to use the near-real time data for different applications such as fast alerting with high temporal accuracy but lower confidence versus accurate detection at lower temporal detail.



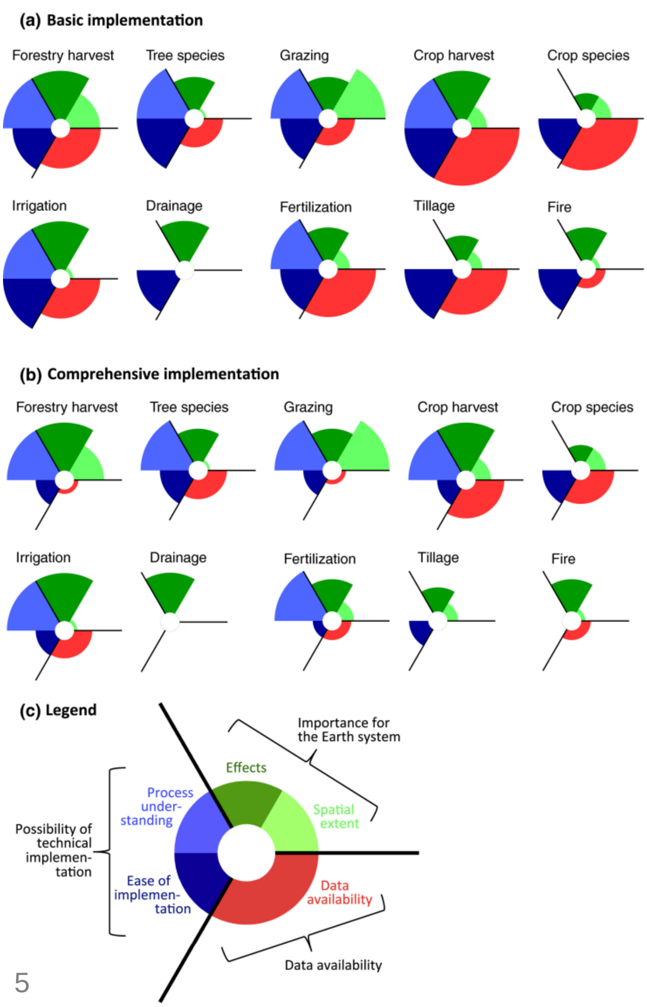
Original publication

Reiche, J., Hamunyela, E., Verbesselt, J., Hoekman, D., Herold, M. (2018). Improving near-real time deforestation monitoring in tropical dry forests by combining dense Sentinel-1 time series with Landsat and ALOS-2 PALSAR-2. Remote Sensing of Environment, 204, 147-161. doi:10.1016/j.rse.2017.10.034.

Models meet data: Challenges and opportunities in implementing land management in Earth system models

As shown by Erb and colleagues (see page 5), land management is as important as land cover change for reduction of potential biomass. The inclusion of land management practices in earth system models (ESM) can facilitate these models to be used in studying mitigation and adaptation strategies under climate change. Pongratz et al., carried out a survey among modeling groups and evaluate models with implementation of land-cover change only to more sophisticated model approaches with integration of land management changes.

They consider 10 different land management practices; forestry harvest, tree species selection, grazing and mowing harvest, crop harvest, crop species selection, irrigation, wetland drainage, fertilization, tillage, and fire.



The implementation of the 10 management practices in models are evaluated by three different criteria; “(1) the importance of a land management practice for the Earth system as indicated by spatial extent and strength of biogeochemical and biogeophysical effects, (2) the possibility of technical implementation as indicated by the process understanding and ease of implementation, and (3) data availability.”

Starting from a typical land surface component of an ESM that can represent lan-cover changes, two levels of comprehensiveness are considered. A “basic” implementation that aimed at including the most obvious effects of a management practice (e.g., biomass removal for forest harvest) and a “comprehensive” one accounting for more details on how the practice is done (e.g., harvesting of differently aged forest and influencing canopy structure).

Comparing the two approaches and the different criteria, **they show that the most straight forward approach to extend ESMs in modeling land management effects is the basic implementation of crop and forestry harvest and fertilization. In addition, it becomes clear that data availability is a limiting factor for many of the land management practices to be comprehensively implemented.** The results indicate a need for more process understanding of crop species selection and tillage.

Current ESMs structure are to a part adequate in capturing main effects of land management. Although, for the models to capture both biogeophysical and biogeochemical effects comprehensively, major extensions are needed.

Original publication

Pongratz, J., Dolman, H., Don, A., Erb, K.-H., Fuchs, R., Herold, M., Jones, C., Luyssaert, S., Kuemmerle, T., Meyfroidt, P., Naudts, K. (2018). Models meet data: Challenges and opportunities in implementing land management in Earth system models. Global Change Biology, 24(4), 1470-1487. doi:10.1111/gcb.13988..

Recent enhanced high-summer North Atlantic Jet variability emerges from three-century context

Climatic extreme events such as drought episodes or flooding in Europe have recently been related to anomalously northern or southern positions of the North Atlantic Jetstream (NAJ). The jet is essentially a meandering band of strong westerly winds in the upper troposphere that separates cold polar air masses from warm subtropical air masses. Accordingly, an anomalously northern NAJ position promotes heatwaves, droughts, and wildfires in southeastern Europe, whereas an extremely southern position can lead to heavy precipitation and flooding in northwestern Europe. These links have been established for the instrumental period, but it remains unclear, how extreme recent events were in a long-term context and if they are becoming stronger in the course of anthropogenic climate change.

This study combined two summer temperature-sensitive tree-ring records from the British Isles and the northeastern Mediterranean to reconstruct interannual variability in the latitudinal position of the August NAJ back to 1725 CE. **This reconstruction served as a multi-century benchmark for the occurrence and persistence of recent anomalies and showed an unprecedented increase in NAJ variance since the 1960s. This increase corresponds to enhanced late-twentieth century jet variability that has also been observed in the Central and North Pacific Basin. This combined evidence points to an overall wavier Jetstream in the late 20th century that provides a pathway for Arctic warming to influence mid-latitude weather. As this increase in NAJ variability is unprecedented over the past ~300 years, it appears likely that the latitudinal Jetstream position is affected by climate warming.**

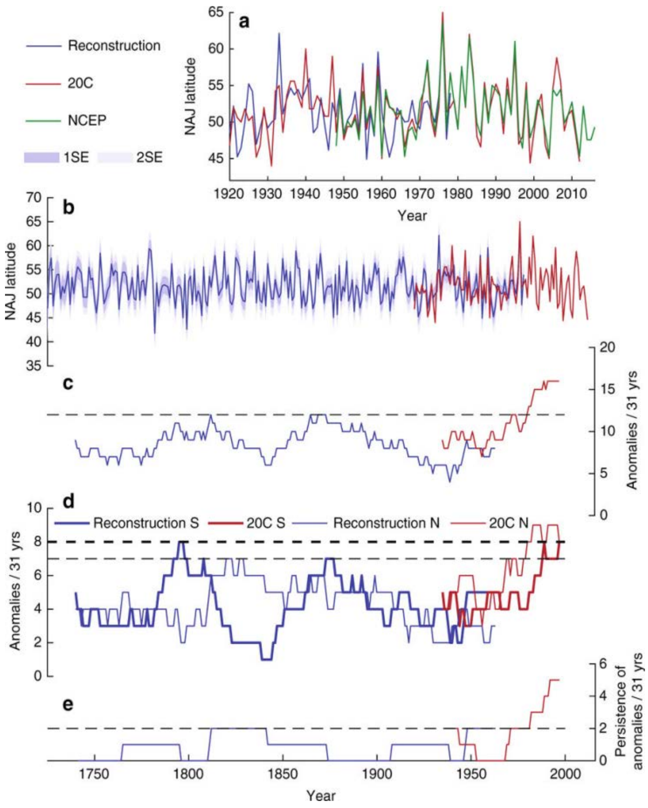


Figure- “The full NAJ reconstruction (1725–1978) including combined error estimations is plotted in b. Running 31-year window number of NAJ anomalies (c), number of northern (N) and southern (S) NAJ anomalies (d), and persistence of anomalies (e) are plotted on the central year of the window for reconstructed (blue) and 20C Reanalysis (red) NAJ time series. Anomalies are defined as years when NAJ >1 stdev, with standard deviation calculated based on a merged time series of reconstructed (1725–1919) and 20C Reanalysis (1920–1978) NAJ values.”

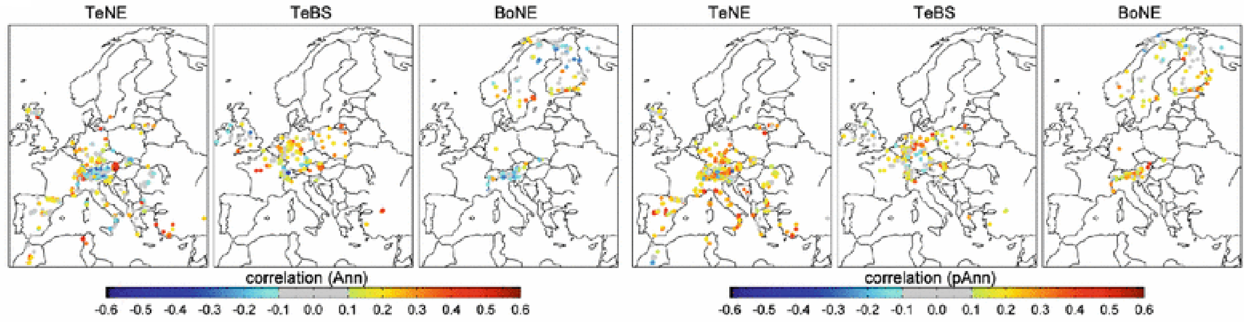
Original publication

Trouet, V., Babst, F., Meko, M. (2018). Recent enhanced high-summer North Atlantic Jet variability emerges from three-century context. Nature Communications, 9: 180. doi:10.1038/s41467-017-02699-3.

Converging climate sensitivities of European forests between observed radial tree growth and vegetation models

Forests are an important component of the terrestrial carbon cycle because they bind and store large amounts of carbon in their woody biomass for decades to centuries. How forests respond to changing climatic conditions will thus critically determine their future potential to mitigate anthropogenic CO2 emissions. The primary tool used to predict terrestrial (and forest) carbon cycling at large spatial scales are dynamic global vegetation models (DGVMs). Problematically, these models are not designed to simulate tree growth explicitly, but treat wood production as a fraction of photosynthesis. Hence, it is important to evaluate the extent to which DGVMs are able to reproduce the climate sensitivity of forest growth and thereby identify structural deficits that can be amended in future DGVM development.

This study compared the simulated climate sensitivity of net primary productivity (NPP) from two DGVMs – ORCHIDEE-FM and LPJ-wsl – with the observed climate sensitivity from about 1000 tree-ring sites across Europe. The two models were able to reproduce the broad biogeographic patterns in climate response, i.e. a positive temperature response of forests at high altitudes and latitudes and a negative response in central European lowlands and the Mediterranean region. However, the climate sensitivity and particularly the drought response of DGVMs were enhanced compared to the tree-ring observations. The authors related this oversensitivity to **a lack of biological processes (e.g. the storage and remobilization of non-structural carbohydrates) in the models that lead to a less instantaneous climate response of growth compared to that of photosynthesis. Including carbohydrate storage pools in future DGVMs will thus be key to improve the ability of these models to simulate forest growth and its climate sensitivity accurately.**



Spatial distributions of correlation coefficients between TRW and ORC-FM-1A simulated NPP in Ann and pAnn.

Original publication

Zhang, Z., Babst, F., Bellassen, V., Frank, D., Launois, T., Tan, K., Ciais, P., Poulter, B. (2018). Converging climate sensitivities of European forests between observed radial tree growth and vegetation models. Ecosystems, 21(3), 410-425. doi:10.1007/s10021-017-0157-5.

Impacts of droughts and extreme-temperature events on gross primary production and ecosystem respiration

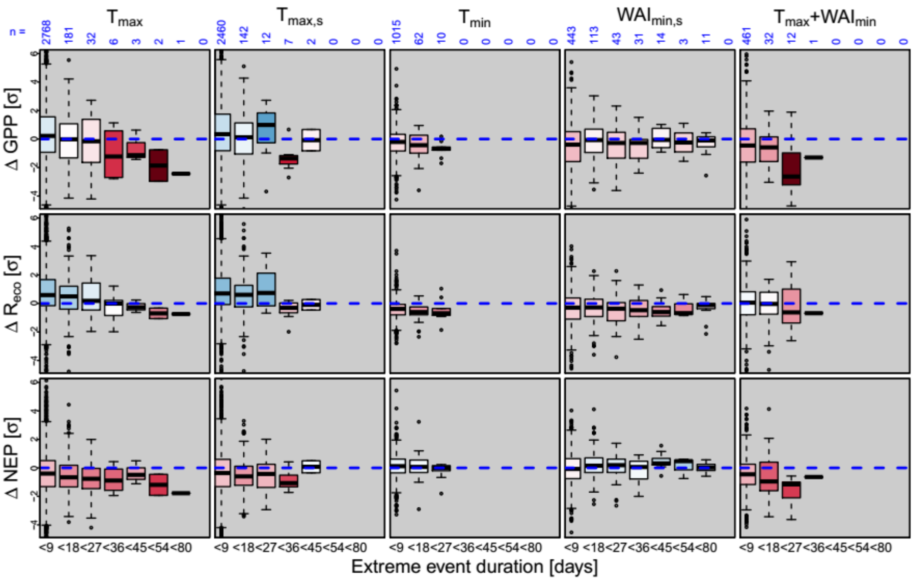
Extreme climatic conditions like drought are important features of the earth's climate variability. Climate extremes influence on ecosystem functioning and also ecosystem-atmosphere feedbacks. It is expected that extreme events will increase in their intensity and frequency in the future. Thus, understanding the impacts of extreme events on ecosystem processes and functions are highly valuable and timely.

von Buttlar and colleagues studied the impacts of extreme event on ecosystem processes, i.e. on photosynthesis (GPP), respiration (Reco), and the resulting net ecosystem production (NEP). The innovation was to systematically assess 70 FLUXNET sites covering different vegetation types and climate zones globally.

The study shows a few general tendencies. For instance:

- **Short-term heat extremes increased Reco more strongly than it reduced GPP. This results in moderate reduction of NPP.**
- **Both GPP and Reco decrease only slightly by drought extremes in absence of heat extremes. So sometimes we have even no significant change in NEP.**
- **When drought and heat extremes coincide they led to the strongest reduction in GPP but offset each other when it comes to Reco.**

However, **a key finding of this study is that duration of the extreme is most important factor**; "for heat stress during droughts, the magnitude of impacts systematically increased with duration, whereas under heat stress without drought, the response of Reco over time turned from an initial increase to a downregulation after about 2 weeks."



Original publication

von Buttlar, J., Zscheischler, J., Rammig, A., Sippel, S., Reichstein, M., Knohl, A., Jung, M., Menzer, O., Arain, M. A., Buchmann, N., Cescatti, A., Gianelle, D., Kieley, G., Law, B. E., Magliulo, V., Margolis, H., McCaughey, H., Merbold, L., Migliavacca, M., Montagnani, L., Oechel, W., Pavelka, M., Peichl, M., Rambal, S., Raschi, A., Scott, R. L., Vaccari, F. P., van Gorsel, E., Varlagin, A., Wohlfahrt, G., Mahecha, M. D. (2018). Impacts of droughts and extreme-temperature events on gross primary production and ecosystem respiration: a systematic assessment across ecosystems and climate zones. Biogeosciences, 15(5), 1293-1318. doi:10.5194/bg-15-1293-2018.

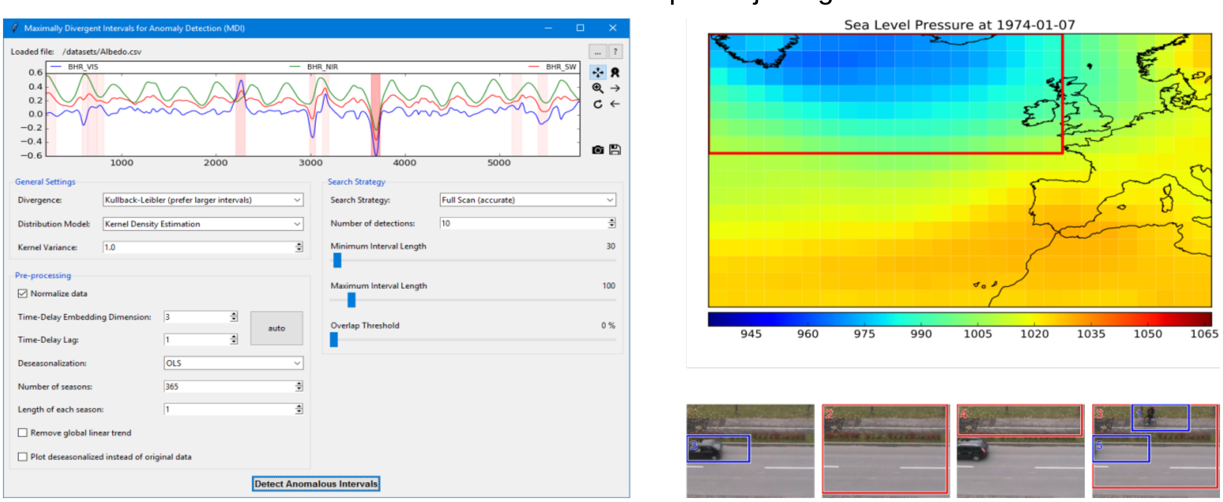
Detecting Regions of Maximal Divergence for Spatio-Temporal Anomaly Detection

The detection of anomalies – events deviating from normal behavior – is of interest in many applications. It is not only used to identify outliers in data for preprocessing cleanup steps, but also in fields where the anomaly itself is of interest, e.g., fraud detection such as credit card fraud, fault detection in industrial processes, anomaly detection in healthcare like in monitoring patient condition, or environmental extremes. “Automated methods for anomaly detection are especially crucial nowadays, where huge amounts of data are available that cannot be analyzed by humans.”

Barz et al. introduce an unsupervised algorithm for detecting anomalous regions in multivariate spatial and temporal time series. The algorithm can identify anomalous region in large amounts of data, including video and text data. In contrast to current techniques that can detect isolated anomalous data points, they propose “Maximally Divergent Intervals” (MDI).

This framework can be used to automatically identify coherent anomalous spatial regions and time intervals characterized by a high Kullback-Leibler divergence compared with all other data given. Barz, the first author of the publication: “In this regard, we define an unbiased Kullback-Leibler divergence that allows for ranking regions of different size and show how to enable the algorithm to run on large-scale data sets in reasonable time using an interval proposal technique.”

The authors show example application of the method using real data from various field, such as climate analysis, video surveillance, and text forensics. They demonstrate the wide applicability of the method for detecting events of interest in different data types.
The method is also implemented in C++ and is provided in “libmaxdiv” library. More information can be found here: https://cvjena.github.io/libmaxdiv/



Graphical User Interface for the MDI algorithm (left) and two example applications for detecting anomalous events in climate data (top right) and videos (bottom right).

Original publication

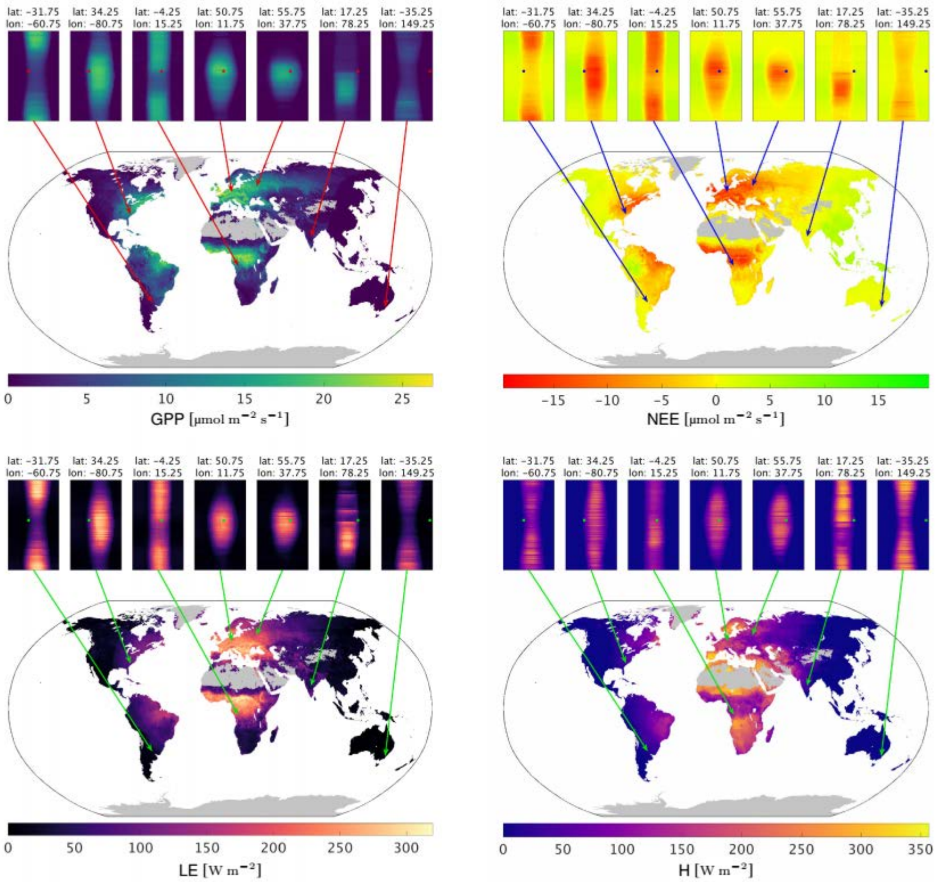
B. Barz, E. Rodner, Y. Guanche Garcia, J. Denzler."Detecting Regions of Maximal Divergence for Spatio-Temporal Anomaly Detection.“ IEEE Transactions on Pattern Analysis and Machine Intelligence, 2018. DOI: 10.1109/TPAMI.2018.2823766.

Upscaled diurnal cycles of land-atmosphere fluxes: a new global half-hourly data product

Fluxes of carbon and energy are used to characterize the interaction between the biosphere and atmosphere. These fluxes are measured at individual flux sites where eddy covariance towers are installed. To analyze the global pattern of these fluxes, one has to upscale fluxes. Previously this was done on time scales of monthly or daily. However, Bodesheim and colleagues have accomplished to provide **global maps continuous half-hourly fluxes of net ecosystem exchange, gross primary production, latent heat and sensible heat**.

The authors used measured flux data from the towers in large scale regression models. The model results were compared using extensive cross-validation experiments using different sets of predictor variables. Finally, the best approach was selected to calculate the global half-hourly flux products based on remote sensing and meteorological predictor variables.

The global half-hourly data products are available online.



The global maps show estimated values for half-hourly GPP (top left), NEE (top right), LE (bottom left), and H (bottom right) on June 14th, 2014 at 1:00 pm UTC. In addition, fingerprints for selected grid cells are used to visualize half-hourly values for each day of the year.

Original publication

Bodesheim, P., Jung, M., Gans, F., Mahecha, M. D., and Reichstein, M. (2018). Upscaled diurnal cycles of land-atmosphere fluxes: a new global half-hourly data product. Earth Syst. Sci. Data Discuss., https://doi.org/10.5194/essd-2017-130, in review

News and upcomming events

BACI holds a session at the 10th international Conference on Ecological Informatics

On the 24th-28th of September 2018, BACI will host a session at the ICEI in Jena. The session “Quantifying the functions in terrestrial ecosystems: from concepts to data driven methods” aims to discuss latest developments in observing ecosystem functions using diverse data streams or analytic frame works, from the site level to the global scale. *More information on the conference is provided in this link: website*.

European Geosciences Union General Assembly 2018

Relevant BACI contributions to the EGU General Assembly 8 – 13 April 2018, Vienna, Austria:

- Information extraction from satellite observations using data-driven methods. M. Mahecha et *al., More info here*
- Assessing the impact of land use on the carbon state of global vegetation. K.H. Erb et *al., More info here*
- On the controlling factors of inter-annual variability of ecosystem photosynthetic capacity in forest ecosystems at global scale. T.Musavi et *al., More info here*

AIT2018 IX CONFERENCE ITALIAN SOCIETY OF REMOTE SENSING Firenze 4-6 July 2018
Associazione Italiana di Telerilevamento

AIT2018 - The IX Conference of the Italian Society of Remote Sensing

The 9th AIT conference will be held on the 4th to 6th of July 2018 in Florence, Italy. The conference will be on remote sensing technologies for supporting sustainable development and natural resource management. BACI will present “Remote sensing of ecosystem properties” by G. Vaglio Laurin. *More information on the conference can be found on the events website*.

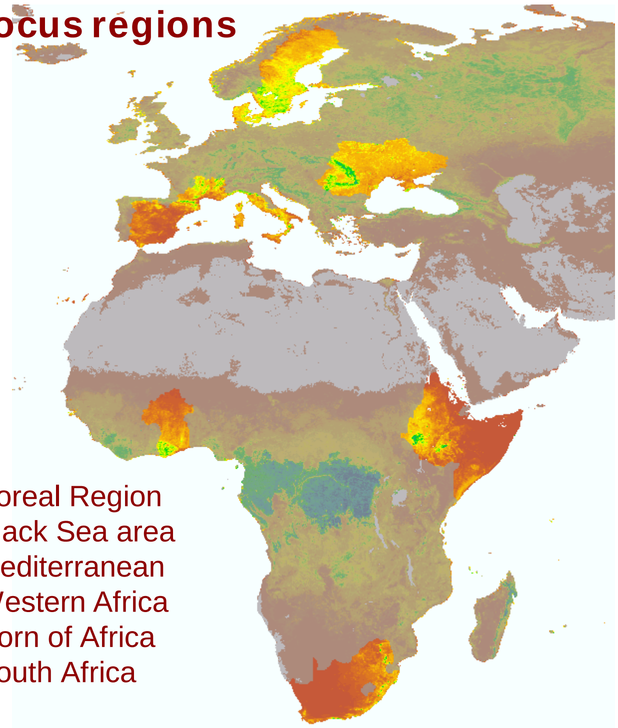
International Geoscience and Remote Sensing Symposium
July 22-27, 2018
Valencia, Spain

This year BACI presents various projects in different topics in this conference. These will be presented by Markus Reichstein (info.), Gaia Vaglio Laurin (more info. here & here), Christian Requena-Mesa (info.). *You could find more information about the event here: website* .

BACI in a nutshell

Space data offer multiple opportunities for monitoring ecosystems and their transformations, e.g., in response to human interventions or climate extremes. Today, these data are available in unprecedented spatial, spectral, and temporal resolutions. This development is complemented with the increasing availability of a wide range of ground data on diverse aspects of ecosystem functioning and ecosystem structure, and other parameters relevant to fully describe the functional biogeography of ecosystems. In this broad context, the BACI project aims to tap into the yet-to-be realized potential of existing and scheduled space-borne Earth observation (EOs) in conjunction with ground data to derive new “Essential Ecosystem Variables” and detect changes in ecosystem functioning. The specific objective is to derive novel downstream data products by integrating Earth observations and in-situ data with machine learning methods. A second component of BACI consists of building a system that automatically detects critical transitions in ecosystems and attributes these to transitions and the societal system.

Focus regions

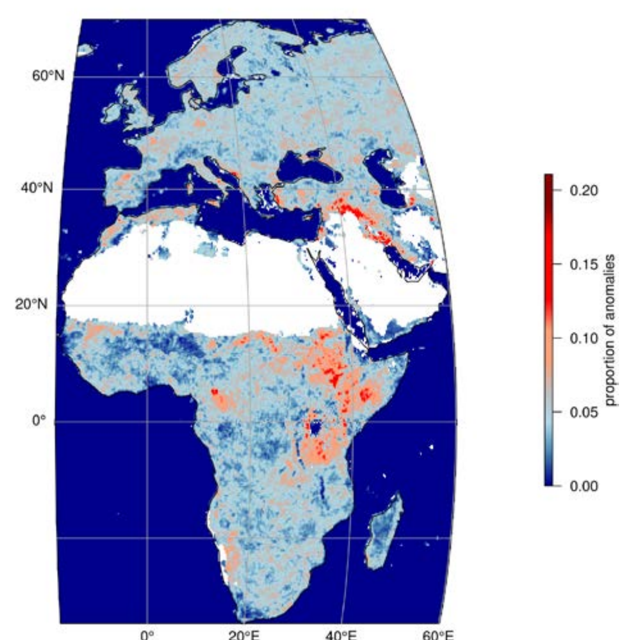


- Boreal Region
- Black Sea area
- Mediterranean
- Western Africa
- Horn of Africa
- South Africa

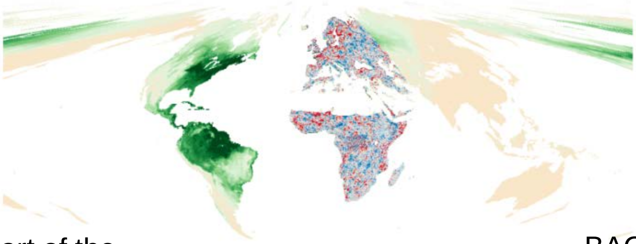
One of the goals is identifying hotspots of change within selected key regions in Europe and Africa, all of which are undergoing different societal-ecological transformations that might itself be attributable to environmental change.

Overarching goals

- To **trace transient/abrupt changes** in biodiversity and ecosystem states.
- To **co-interpret the index** of change based on state-of-the-art machine learning.
- To **attribute hotspots of change** to climate drivers, bio-physical variation of the land-surface, and socio-ecological transformations.
- To **develop a biodiversity early warning system** that combines observations of ecosystem change with an assessment of biodiversity vulnerability.



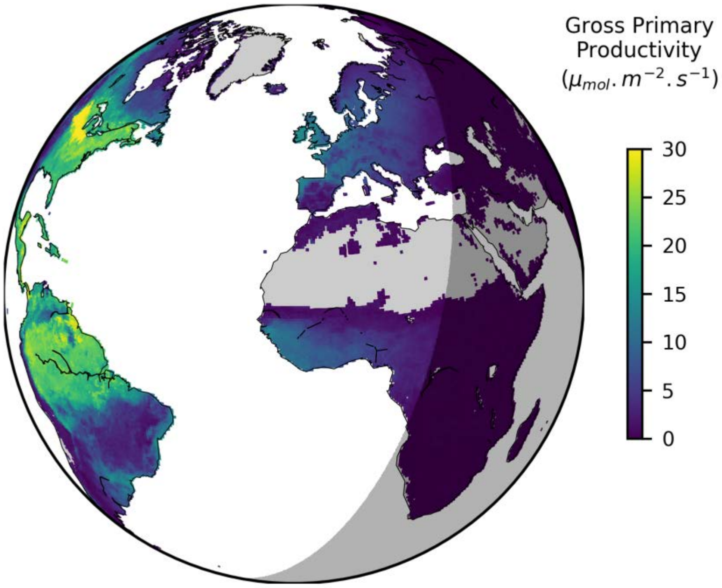
Decoding multiple data streams to a general index of change



Encoding local information towards upscaled "Essential Ecosystem Variables"

The most exploratory part of the BACI project is developing a novelty index of change to detect (in near real-time) abrupt changes relevant to "Essential Ecosystem Variables" (EEVs). We want to find transitions relevant to the functioning of terrestrial ecosystems, biosphere-atmosphere exchanges of matter and energy, and biodiversity related properties. The index is based on modern machine learning tools and will also detect major extreme events in our data streams.

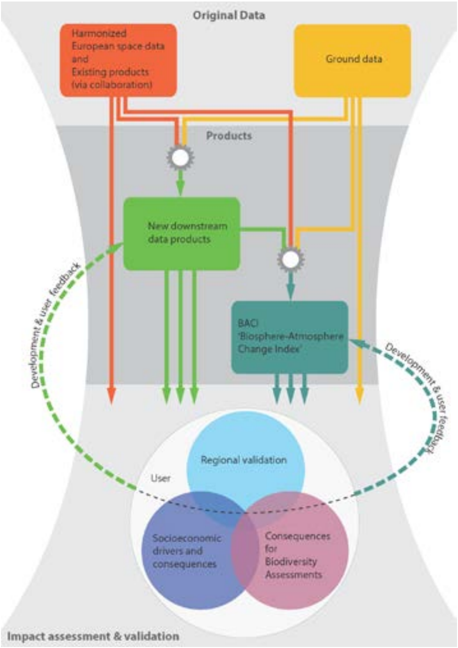
BACI focusses on deriving "Essential Ecosystem Variables" (EEVs). These are variables essential to the monitoring of the fundamental feedbacks in the Earth System. Of particular interest to BACI are interactions between the biosphere and atmosphere. Specific objectives include integrating Earth observations and in-situ data with machine learning methods to resolve the diurnal patterns of gross primary production, latent heat fluxes, or the spatial prediction of tree ring variability.



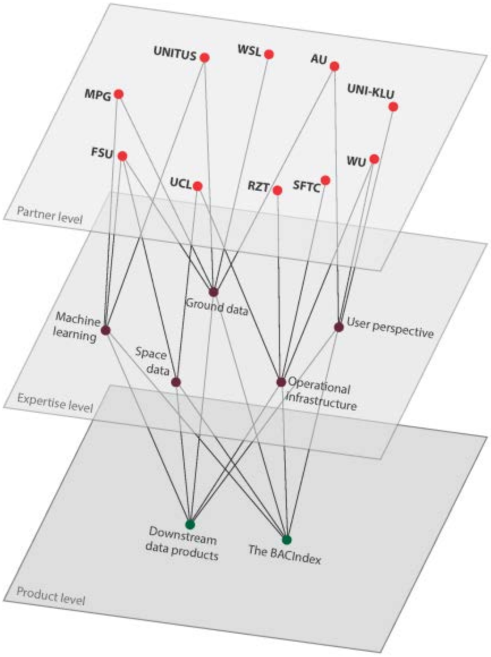
GPP globe map: The total uptake of CO_2 via photosynthesis ("Gross Primary Production, GPP") can only be observed from eddy covariance towers. However, using modern machine learning methods and high-resolution ancillary data (e.g. from satellites or meteorology), we were able to estimate GPP at half-hourly intervals at the global scale. In this figure, we see how the day-night transition in GPP occurs.

Approach

The BACI project is a cascading workflow separated into seven work packages. The integration of ground and space observations leads to a series of new downstream products (light green) that can be either directly interpreted by the user community, or ingested to a statistical system that translate these variables to a general index of change (BACIndex). The novel data products will be evaluated against independent data. We selected regional study areas (Focus regions), as well as fast track sites for which regional evaluations are foreseen.
Partners and tasks covering various aspects of land-use of change, regional attributions, socio-ecological transformations, and biodiversity monitoring aspects are key elements of the project and constantly seeking the interaction with a broader user community.



Partners and expertise



The consortium is a composite of experts in the field of terrestrial remote sensing ecosystem and biodiversity ground observations of different types, machine learning big data processing, and applications of innovative methods in biogeochemistry, terrestrial ecosystem modelling, biodiversity monitoring and modelling, and socio-ecological change assessments.

The BACI consortium is formed by 10 institutions from 7 European Countries:

- **MPG**: Max Planck Institute for Biogeochemistry representing the Max Planck Society, Jena Germany.
- **UNITUS**: Università degli Studi della Tuscia, Italy.
- **WSL**: Eidgenoessische Forschungsanstalt, Switzerland.
- **FSU**: Friedrich-Schiller-Universität Jena, Germany.
- **WU**: Wageningen University, The Netherlands.
- **UCL**: University College London, UK.
- **UNI-KLU**: Alpen-Adria Universität Klagenfurt-Vienna-Graz, Austria.
- **AU**: Aarhus University, Denmark.
- **RZT:** Rezatec Limited, UK.
- **STFC**: Science and Technology Facilities Council, UK.