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Changes in vegetation activity and land-surface phenology related to climatologies

Rogier de Jong[1,*], Irene Garonna[1], Alexander Damm[1] and Michael E. Schaepman[1]

The biosphere plays a large role in the global carbon cycle and as such in the climate system. The other way around, climatologies constrain vegetation growth. This feedback mechanism expresses itself in the phenology of the land surface (LSP) and is a crucial but uncertain component in Earth system models. An important deficiency is the decomposition of the natural and the anthropogenic signals in this land-atmosphere carbon cycle[1].

We studied the changes in yearly vegetation activity and LSP metrics, and linked these to changes in potential climatological growth constraints (temperature, precipitation, radiation), both at global scale and in more detail for Switzerland. With this, we aim at improved attribution of detected biospheric changes to underlying drivers, both climatological and from other origin.

Methods

Data
GIMMS version 2g (1981-2008)
CRU ts 3.10
MOD13A2 (1km)
MeteoSwiss climate grids

Preprocessing
Climate data has been used from the respective data sources without further corrections. Negative outliers in the GIMMS data (e.g. due to persistent cloudiness) have been filtered using harmonic analysis[3]. For the MODIS data, observations flagged as clouds have been removed and the resulting gaps were filled using a structural model in combination with a Kalman filter.

Trend analysis
Changes in both vegetation activity and climatologies were quantified using a seasonal-trend model of the form:

$$y_t = \alpha_1 + \alpha_2 t + \sum_{j=1}^{k} \gamma_j \sin\left(\frac{2\pi j t}{f} + \delta_j\right) + \varepsilon_t$$

The slope of the linear term represents the magnitude of change[3].

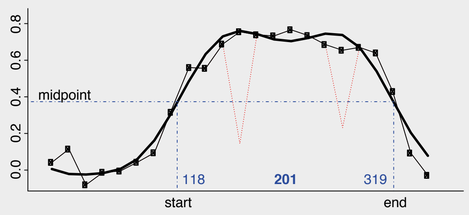
Relationships with climatologies
Statistical relationships with potential drivers were established using a mixed-effects model[4]. The fixed effects (climate association) was modeled using a regression approach and the other structured effects using a Gaussian random field. Backfitting assured an optimal model fit.

$$Y(s) = k(s) + h(s) + Z(s)$$

deterministic trend *fixed effects* — spatial field *random effects*

$$= d\mathbf{X}(s)'\beta + \sum_{i=1}^{n} \lambda_i(s)(Y_i - d\mathbf{X}(s)'\beta) + Z(s)$$

Land-surface phenology
Vegetation-index data were preprocessed as described and LSP metrics were subsequently extracted using the midpoint method (figure below)[2]. Changes were quantified using a linear model. Complex seasonal patterns, including multiple growing seasons per year and cycles straddling the year end, were flagged. The reliability of the LSP metrics was estimated based on these flags and on the coefficient of variation. Locations with low reliability were masked.



Acknowledgements
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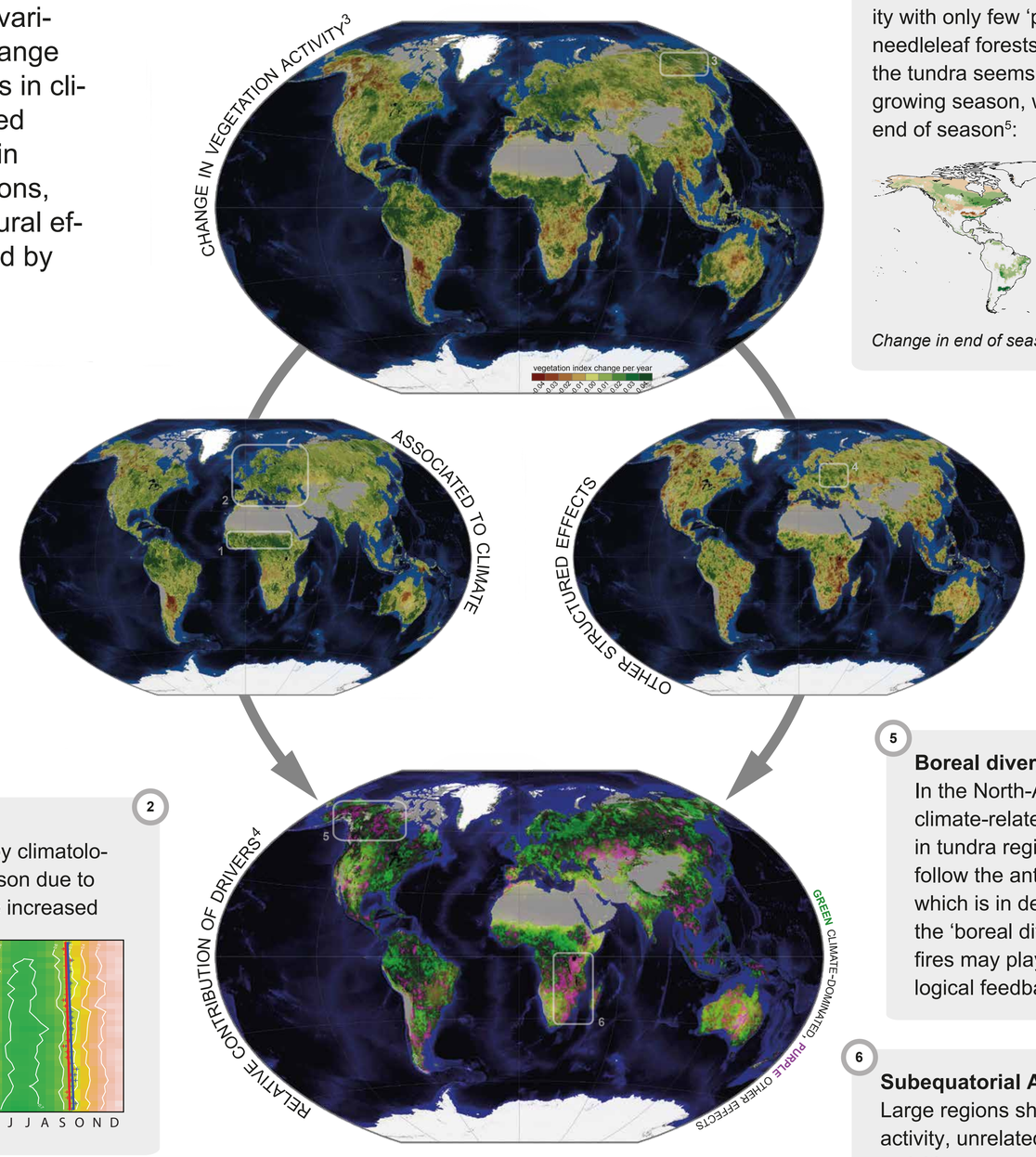
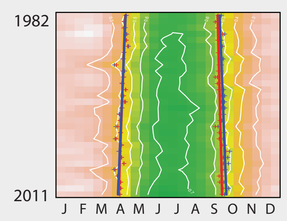
Global patterns since the 1980s

Little over 50% of the spatial variance in vegetation-activity change could be attributed to changes in climatologies. The nonassociated model component may contain large- scale human interventions, feedback mechanisms or natural effects, which were not captured by the climatologies.



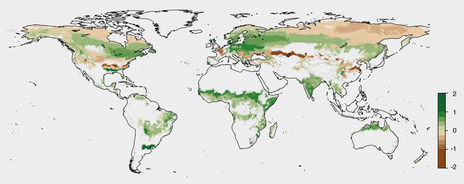
1 Sahelian and Sudanian zones (SSZ)
Greening of the Sahel has been demonstrated and debated, illustrating that the system of drivers in this area is complex. To a large extent, greening seems associated to climate variability, although 'purple hotspots' remain.

2 Europe
Greening patterns largely captured by climatologies, lengthening of the growing season due to temperature increase seems to drive increased vegetation activity[2]:



Changes in vegetation activity (background color scale) and in start/end of season. Blue and red lines represent two different methods for extracting LSP metrics.

3 Asian (sub)arctic
Climate-related increases in vegetation activity with only few 'purple spots' in deciduous needleleaf forests. Interestingly, greening in the tundra seems to coincide with a shorter growing season, which is driven by an earlier end of season[5]:



Change in end of season (days/year)

4 Eastern Europe
Not all greening can be associated to climate. Land conversions, e.g. abandonment of agricultural areas, have likely boosted vegetation activity.

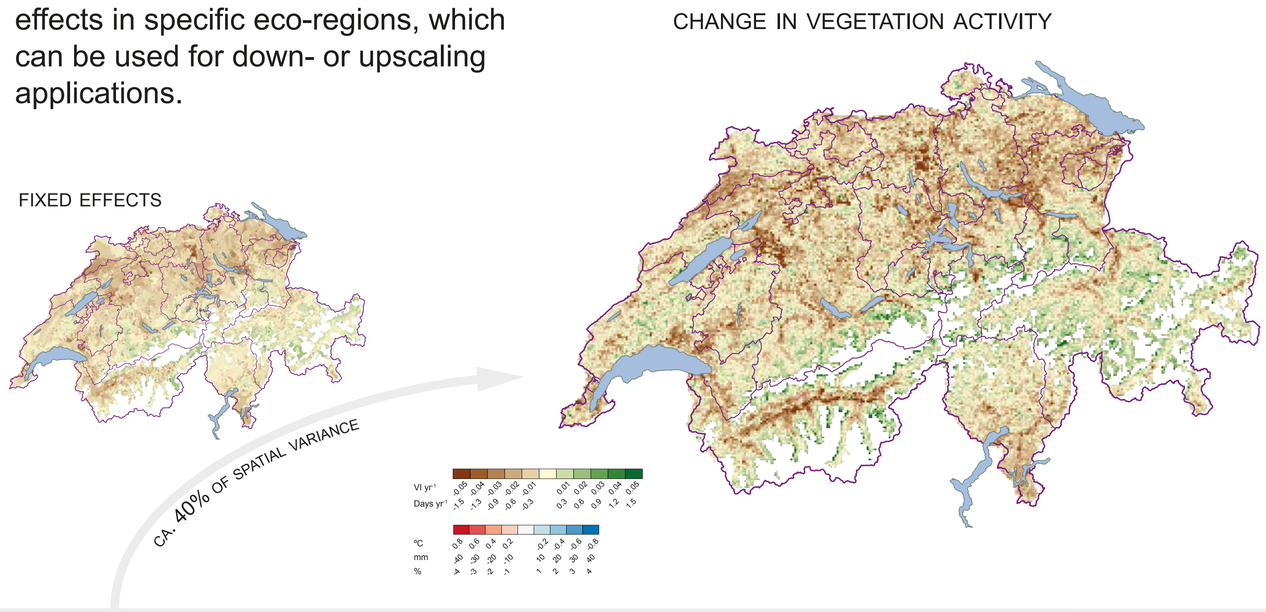
5 Boreal divergence
In the North-American (sub)arctic, climate-related greening is conspicuous in tundra regions. Boreal forests do not follow the anticipated greening pattern, which is in dendroclimatology known as the 'boreal divergence issue'. Forest fires may play a role, as well as hydrological feedbacks.

6 Subequatorial Africa
Large regions show decreases in vegetation activity, unrelated to climatologies. Human activities seem to have enforced the degradation of vegetation systems.

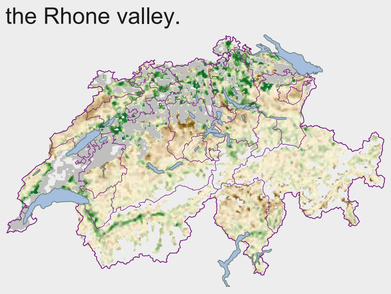
Trends in Switzerland since 2000

The Swiss Earth Observation Network (SEON) quantifies functioning of ecosystems and studies links between Earth spheres using field and airborne experiments. Trends in vegetation activity allow attribution of change effects in specific eco-regions, which can be used for down- or upscaling applications.

Jura and Midlands
Most regions showed a slight decrease in vegetation activity with various 'browning hotspots'. Around 40% of the spatial variance in these trends can be statistically attributed to climatologies but these relationships are not straight forward and do not explain most of the hotspots.

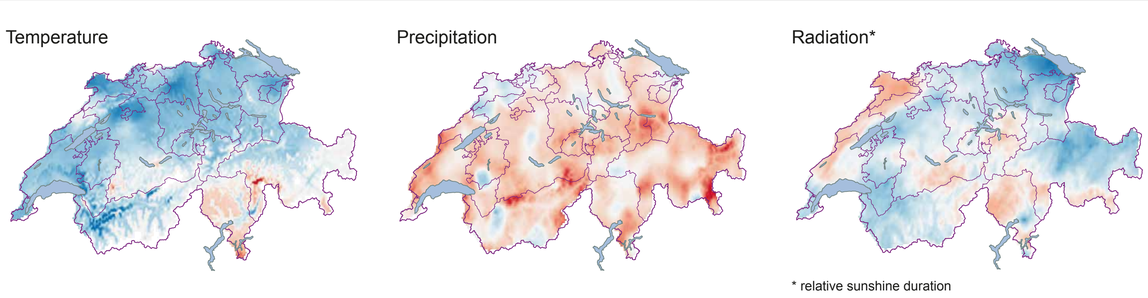


Length of growing season
In many regions, the reduction in vegetation activity seems not to concide with a shorter growing season. On the contrary, the GSL seems to have increased in parts of the midlands and in the Rhone valley.



Change in growing-season length (days/year)

The Alps and the valleys
Slight greening trends were observed in mountainous regions without strong links to climatologies or LSP. Snow cover may play a role. Most valleys, including the Rhone and Rhine, show browning trends. The role of agricultural practices needs to be investigated.



* relative sunshine duration

Trends in climatologies
The last decade shows a slight cooling and drying trend, which may partly explain the reduction in vegetation activity. However, this relationship should be interpreted with care: changes over a 14-year period may not represent actual climate change but may be influenced by anomalous years.

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[1] University of Zurich (UZH), Remote Sensing Laboratories (RSL) • Swiss Earth Observatory Network (SEON) • UZH Reserach Priority Program on Global Change and Biodiversity (URPP GCB) • * contact: rogier.dejong@geo.uzh.ch