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Recent trends of high-latitude vegetation activity assessed and explained by contrasting modelling approaches with earth observation data

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Satellite observations of Normalized Difference Vegetation Index (NDVI) showed increasing trends in the arctic tundra and the boreal forests since the 1980s. This greening is related to an increase in photosynthetic activity and is driven by increasing temperatures and a prolongation of the growing season. However, NDVI experienced a decrease in large regions of the boreal forests since the mid-1990s. This browning is related to fire disturbances, temperature-induced summer drought and potentially to insect infestations and diseases.

Terrestrial biosphere models (TBM) can be used to assess the impacts of these changes in vegetation productivity on the carbon and water cycles and on the climate system. In general, these models provide descriptions of ecosystem processes and states that are forced by and feedback to the climate system such as photosynthesis and transpiration, ecosystem respiration, soil carbon and water stocks and vegetation composition. The evaluation of TBMs against observations is a necessary step to assess their suitability to simulate such processes and dynamics. The increasing availability of long-term observations of vegetation activity enables us to evaluate the model ability to diagnose these vegetation greening and browning trends in arctic and boreal regions.

The first aim of this study is to evaluate trends in vegetation activity in high-latitude regions as simulated by TBMs against observed trends in vegetation activity. The second aim is to identify potential drivers of these observed and simulated trends to evaluate the ability of models to reproduce the observed functional relations between climatic and environmental drivers and the vegetation trends.

The trends in vegetation activity were estimated for a set of satellite-based remote sensing products: NDVI from AVHRR (Advanced Very High Resolution Radiometer) and MODIS (Moderate Resolution Imaging Spectrometer), as well as FAPAR observations (Fraction of Observed Photosynthetically Active Radiation) from SeaWiFS (Sea-viewing Wide Field-of-view Sensor) and MERIS (Medium Resolution Imaging Spectrometer). Photosynthetic activity was diagnosed through gross primary production (GPP) estimates from three different approaches: a data-driven upscaling algorithm based on a model-tree ensemble (MTE) and global-distributed eddy-covariance site measurements of carbon fluxes (FLUXNET); a land surface scheme of an earth system model (JSBACH, Jena Scheme for Biosphere-Atmosphere Coupling in Hamburg); and a dynamic global vegetation model (LPJ, Lund-Potsdam-Jena DGVM).

Trends in GPP from the different approaches were compared against remotely sensed trends in vegetation activity. The comparison was based on time series decomposition methods and a break point analysis to assess trends and trend changes in the observed and modelled variables. We used regression analysis to identify drivers of these trends, considering as explanatory variables temperature, precipitation, radiation and drought indicators as well as remotely sensed land cover and burned areas.

Our results show that global ecosystem models are able to reproduce the observed temperature-driven greening in the 80's. In the 90's, the data-driven GPP model (MTE-FLUXNET) simulates a slight decline of photosynthetic activity in the boreal forest, which is due to the fact that it is forced with FAPAR observations. However, during this decade, the two process-oriented models (JSBACH and LPJ) show still an increase in photosynthetic activity instead of the observed browning in the boreal region. These results highlight the limitations of process models in diagnosing vegetation dynamics at decadal scales in the boreal regions, which can be related to inappropriate representations of fire activity, drought effects and insect disturbances. Overall, our analyses show that integrating remotely sensed fields on vegetation activity and empirically inferred global flux fields contributes to a critical appraisal of model performance and identification of needs for improvement in modelling structures.