Geophysical Research Abstracts
Vol. 17, EGU2015-15471, 2015
EGU General Assembly 2015

Identifying controls on vegetation greenness phenology through model-data integration

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Satellite observations demonstrate significant trends in vegetation phenology since the 1980s like an earlier start of the growing season or a wide-spread greening of northern ecosystems. Nevertheless, identifying the environmental controls for these trends and for inter-annual variability is challenging. Firstly, quantifications of land surface phenology and greenness dynamics are impaired by differences between satellite datasets and phenology detection methods. Secondly, dynamic global vegetation models (DGVM) that can be used to diagnose controls still reveal structural limitations and contrasting sensitivities to environmental drivers. Combining DGVMs with observational data sets can potentially help to revise current modelling approaches and thus to enhance the understanding of processes that control seasonal to long-term vegetation greenness dynamics. Here we implemented a new phenology model based on the growing season index (GSI) approach within the LPJmL (Lund Potsdam Jena managed lands) DGVM and integrated several observational data sets to improve the ability of the model in reproducing seasonal to long-term greenness dynamics. Specifically, we optimized model parameters against decadal satellite time series of the fraction of absorbed photosynthetic active radiation (FAPAR), albedo and gross primary production using a genetic optimization algorithm. We assessed the model performance by considering observational uncertainties from three satellite datasets of vegetation greenness and ten statistical phenology detection methods. LPJmL with new phenology and optimized parameters better reproduces seasonality, inter-annual variability and trends of vegetation greenness. We quantified the effects of temperature, incoming short-wave radiation, water availability, fire, permafrost, land use/land cover change, and CO_2 fertilization on average patterns, inter-annual variability and trends of the start of growing season and peak greenness. Start of growing season inter-annual variability and trends are in addition to cold temperature controlled by incoming radiation and water availability in temperate and boreal forests. For peak greenness, inter-annual variability and trends are dominantly controlled by water availability and land use and land cover change (LULCC) in all regions. In permafrost-underlain boreal forests and the arctic tundra, the seasonal freezing and thawing of the upper soil layer contributes strongly to inter-annual variability and trends in start-of-growing season and peak greenness trends. Our findings emphasize that in addition to cold temperature, water availability is globally a co-dominant control for trends in land surface phenology and greenness.