NORTH STATE - ENABLING INTELLIGENT GMES SERVICES FOR CARBON AND WATER BALANCE MODELING OF NORTHERN FOREST ECOSYSTEMS

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ABSTRACT

The North State project of the Framework Program 7 of the European Union will demonstrate how innovative methods applied to the new Sentinel data streams can be combined with models to monitor carbon and water fluxes for pan-boreal Europe.

The project will provide a paradigm for the development of products for future Copernicus services that will be applicable far beyond its specific application to the boreal zone. The North State has sites for intensive study in Finland, Iceland and Russia. Additionally, the fluxes will be modelled over a pan-boreal – pan-arctic region reaching from Iceland to the Ural Mountains. The project (grant agreement 606962) started in October 2013 and will last three years.

1. INTRODUCTION

One of the greatest sources of uncertainty in climate predictions is the feedback between climate and changes in land surface processes (IPCC 2007), with northern high latitudes being particularly important because of the vast store of carbon in northern forests and peat lands (Pan *et al.* 2011). Such feedbacks include the following key land processes:

1. Modifications in the spatial and seasonal patterns of vegetation, snow and albedo alter the associated radiative and biogeochemical balances and have major land surface and atmospheric feedbacks.

2. Disturbances, particularly fire, are linked to climate through large-scale atmospheric circulation patterns, and contribute to the inter-annual variations in atmospheric carbon dioxide in the Northern Hemisphere.

A further key factor of change, with associated consequences for greenhouse gas (GHG) emissions, is increased Russian forest activity, with significantly more clear-felling. Russian forest resources information is largely outdated and the development trend of forest biomass is poorly known.

Knowledge on the carbon and water balances, how they change under climate warming and the effects on GHG fluxes is crucial to understanding these feedbacks. Current estimates of flux rates, based on national forest inventories, are highly uncertain and lack spatial resolution. There is therefore an urgent need to develop a system to monitor high latitude changes and to assess their consequences.

The objective of North State is to develop innovative data fusion methods that exploit the new generation of multi-source data from Sentinels and other satellites in an intelligent, self-learning framework that interfaces state-of-the-art carbon and water flux models with a view monitoring of these fluxes over boreal Europe with the aim of reducing their current large uncertainties. This will provide a paradigm for the development of products for future Copernicus services.

2. MATERIALS AND METHODS

North State has four sites for intensive studies (*Figure 1*). Additionally, the model input variables will be estimated and models applied over European boreal and sub-arctic region from Ural Mountains to Iceland.

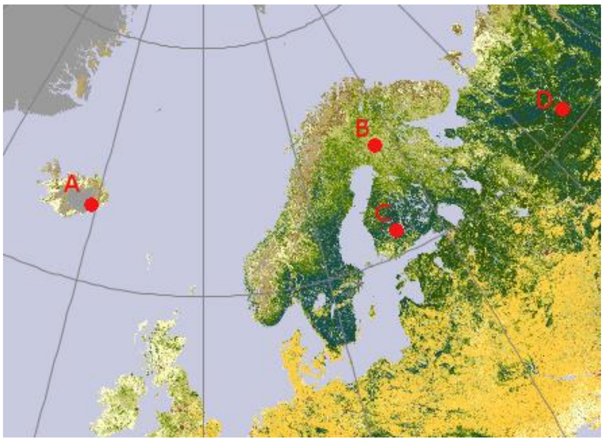

Figure 1. The four study sites in the North State. The boreal forest is depicted in green. (A: Hallormsstadur, Iceland; B: Sodankylä, Finland; C: Hyytiälä, Finland; D: Pechora-Ilych nature reserve, Komi republic, Russia) Image source: NASA.

North State will move beyond the state-of-the-art by amalgamating the carbon and water balance models with the new EO data streams, to allow continual monitoring of the carbon stocks and fluxes and water status of the boreal forest. This will also significantly improve the climate, soil, land cover, and phenology inputs to Dynamic Global Vegetation Models (DGVM) (Quegan *et al.* 2011) for future climate change predictions. The key challenges to accomplish this include:

(1) retrieving relevant information from the EO data at appropriate spatial scale,

(2) adequate calibration of models for all relevant regions and species, and

(3) scaling up to appropriate regions with estimates of uncertainty.

We also aim to combine the advantages of the forest-specific models (Mäkelä *et al.* 2008) with the wider scale and better representation of dynamics in the DGVM's.

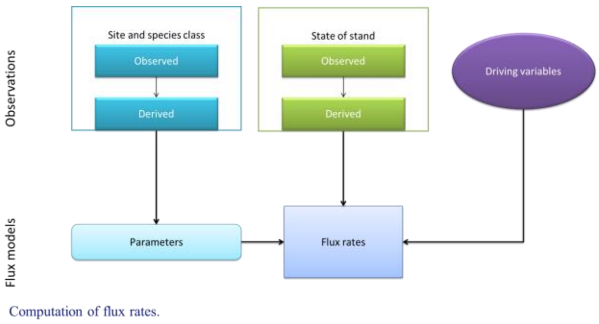

Figure 2.Three types of data required for estimating carbon and water fluxes at grid cell scale.

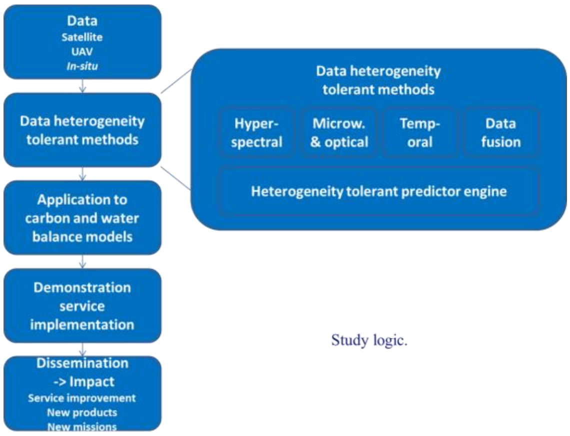

Figure 3. Study logic of North State.

The key EO data can be grouped into three classes that are related essentially to land cover, driving variables and dynamics (*Figure 2*). These classes need to be available at the scale appropriate to each type of model (stand scale for forest models, aggregated to grid-cell scale for DGVMs). In some cases, EO data may be a secondary source of information, e.g. weather variables, but for others, such as LAI, logging events or fire, it is critical.

In combination with the EO and auxiliary data, the land and forest models available to North State will allow us to estimate the net carbon balance (and its component fluxes) and the water fluxes for each grid cell. Data from selected European flux towers will be used to test these estimates. EO-based predictions will also be tested against those made with ground-based data (Härkönen *et al., 2*011).

The principal input satellite data are from the Sentinels of the Copernicus program. Airborne and space-borne hyper-spectral data will be utilized to investigate in particular the marginal utility of hyper-spectral sensors compared to the super-spectral sensor of Sentinel-2. Landsat and Envisat ASAR data will be used before Sentinel data becomes available.

In-situ data from Finland will be obtained from Metsähallitus that manages the government-owned forests in Finland. Field sample plots of the national forest inventory will be used as well. From Icelandic and Komi sites field sample plot *in-situ* data are available.

The core remote sensing part of North State is development of the Heterogeneity tolerant predictor engine. This means developing automated data fusion and object-based approaches that combine data from multiple satellite and *in-situ* sources in order to measure and interpret land processes and change. The predictions will be interfaced to state-of-the-art carbon and water models, with special emphasis on exploiting new developments in forest models (*Figure 3*). New image analysis methods are built on the foundation of existing approaches including neural networks, statistical methods and the Probability method (Benediktsson *et al.* 1990, Häme *et al.* 2001).

The most important variables to be estimated are:

- Fraction of Absorbed Photosynthetically Active Radiation (fAPAR)
- Leaf area index (LAI)
- Forest area
- Plant functional type (or tree species)
- Tree height
- Snow cover
- Phenology; start and end of growing season:
- Logging events
- Biomass (or growing stock volume)
- Peatland extent

Also such variables that are used as outputs of the carbon and water flux models are estimated from EO data. The rationale of the introduction of the EO based variables in the modelling comes from the need to calibrate the models and assess their accuracy. Many of these variables will also be applicable for other purposes including relevant FP7, Horizon 2020, and Climate Change Initiative (CCI) of ESA projects. For some of the variables, such as the fAPAR (Baret *et al.* 2013) and snow extent (Metsämäki *et al.* 2012), third party sources will be utilized.

3. CONCLUSIONS

Together with the EO based variable estimates and the carbon and water balance models, North State will enable continual monitoring of the carbon stocks and fluxes and water status of the boreal forest. This will also significantly improve the climate, soil, land cover, and phenology inputs to dynamic global vegetation models for future climate change predictions.

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