USE OF REMOTELY SENSED SNOW COVER AND SOIL STATE INFORMATION FOR CARBON BALANCE MAPPING: CASE STUDIES AT THE SODANKYLÄ-PALLAS SATELLITE CAL-VAL SITE, NORTHERN FINLAND

Jouni Pulliainen[1], Tuomas Laurila[1], Anna Kontu[1], Ali Nadir-Arslan[1], Olli-Pekka Mattila[2], Matias Takala[1], Tuula Aalto[1], Juha Lemmetyinen[1], Tiina Markkanen[1], Jarkko Koskinen[1] and Kari Luojus[1]

[1]Finnish Meteorological Institute (FMI)
[2]Finnish Environment Institute (SYKE)

1. INTRODUCTION

Carbon sinks and sources will act as critical feedbacks to warming, but they are poorly understood, both at present and as they respond to future climates. This is a key problem in predicting the impact of climate change, given the power of the feedbacks. Measurements in high latitudes are very sparse. Consequently, the magnitude, spatial patterns, and likely future behavior of carbon sinks and sources in the North are poorly known. A key issue in northern latitudes is the impact of the seasonal snow cover and other cryospheric processes. These phenomena are directly linked to carbon cycle. For example, changes in seasonal snow cover lead to changes in $CO2$ balance, as snow cover directly affects biological respiration (carbon sources) and in the total biomass (magnitude of carbon sinks). Moreover, the timing of snow melt is an important factor affecting the magnitude $CH4$ net fluxes from wetlands on top of permafrost regions.

The evolution of polar orbiting satellite systems has enabled the mapping of snow and soil information at full spatial and high temporal coverage for high latitudes. However, information is needed on how to relate these observations to the modeling and assessment of carbon cycle. In practice, detailed *in situ* reference measurements for selected locations are required for the algorithm development, validation and calibration. Without reference data on all environmental parameters affecting the space-borne observations, the development of the retrieval of relevant geophysical information from satellite systems is typically difficult or impossible.

This study investigates the feasibility of microwave remote sensing sensors to retrieve information relevant to carbon balance mapping. Additionally, it is shown how this information is related to carbon balance at the high latitudes. This is demonstrated for the Sodankylä-Pallas site, northern Finland, by comparing satellite and tower-based remote sensing data and retrievals with *in situ* observations on carbon fluxes and soil/snow characteristics. The relevant parameters here include snow water equivalent (SWE), soil freezing/thawing and soil moisture.

2. STUDY AREA AND DATA SET

The Sodankylä-Pallas site is located in northern Finland north of the Arctic Circle and it is a good representative of boreal and sub-arctic Eurasian environment in a transition zone from marine to continental climate (a transition from marine to continental in the west to east direction). The site provides in situ monitoring and high spatial resolution land cover data sets that are not available for other regions north of the latitude of 60°. A special feature of the site is that it is the westernmost part of the Eurasian taiga belt that reaches close to the Pacific Ocean in its easternmost extent.

The data sets available for the Sodankylä-Pallas region include the weather and atmospheric parameter monitoring data from the Finnish Meteorological Institute (FMI), land cover characteristics and hydrological monitoring and modelling data from the Finnish Environment Institute (SYKE), and selected data sets form other Finnish research institutes and universities. Intensive stations equipped with a large variety of atmospheric sampling, profiling and automatic surface parameter measurement systems are located near the town of Sodankylä, and at/in the vicinity of Pallas Mountain 100 km north-west from Sodankylä. Continuous $CO2$ and methane flux measurements are available for several forest and bog sites at the both regions, see Fig.

1 for the flux measurement mast at the Sodankylä (pine forest at the location of snow and soil remeote sensing reference measurements).

During the winter of 2009-2010 extensive satellite CAL-VAL campaigns are conducted in Sodankylä releted to the remote sensing of snow cover. They include the NoSREx campaign aiming to the development of the CoReH$_2$O satellite of the European Space Agency (ESA) for the mapping of SWE using an X/Ku-band SAR. The tower-based remote sensing reference systems include an X/Ku-band scatterometer (SnowScat), 8-channel microwave radiometer (SodRad) and the Elbara-II L-band radiometer (a reference instrument of the ESA SMOS satellite). Fig. 2 depicts the Sodankylä site for the tower-based snow measurements at an opening of forest on a mineral soil site. Detailed observation time-series on physical snow pack profile characteristics are available since 2006, and they are accompanied with longer time series of automatic snow and soil observations (including soil moisture profiles and soil and snow pack temperature profiles).

Figure 1. Micro-meteorological tower experiment at Sodankylä (left) and Pallas (right). The 48-m mast at Sodankylä is installed into a Scots pine forests on sandy soil measuring eddy-covariance fluxes of CO_2, latent and sensible heat and momentum, radiation components, and gradients of the CO_2 concentration, temperature and wind. Soil, vegetation and snow parameters are also monitored in the forest region around the tower. Analogious measurements are carried out for the spruce forest site.

Figure 2. Snow and soil remote sensing reference site at Sodankylä. Left: Instrumentation including the X-Ku-band SnowScat scatterometer (foreground), L-band Elbara-II radiometer and X-, K-, Ka- and W-band SodRad radiometer (back). Right: Overview.

In addition to the use of tower-based microwave radar and radiometer data, space-borne observed time-series from microwave radiometer data (AMSR-E, SSM/I and SMOS) and microwave radar (QuikScat) are applied. As well, satellite data products are employed, for example snowmelt information based on SSMI/I and AMSR-E [1].

3. METHODOLOGY AND RESULTS

This study investigates the following issues: (a) the relation between remote sensing data and CO2/CH4 fluxes and annual carbon balance, (b) the corresponding relation for satellite data products and (c) effect of different parameters to carbon fluxes and annual balance. The overall goal is to find out whether the satellite observations with microwave sensors (radars and radiometers) are able to provide useful information for the mapping of spatial differences in carbon fluxes. Both the tower based radiometer and radar observations and corresponding satellite data time-series [2] for the Sodankylä-Pallas region are applied together with concurrent *in situ* measurements.

Figure 3 depicts a typical behaviour of net carbon flux for a spruce forest site at the Pallas. These data are compared with brightness temperature and backscattering coefficient time-series. As well, satellite data products, such as the snow clearance date estimate shown in Fig. 4, are applied for the analysis. In order to estimate how well satellite data and products correspond to snow and soil moisture/frost characteristics, observation time-series for parameters, such as SWE (Fig. 5) are applied.

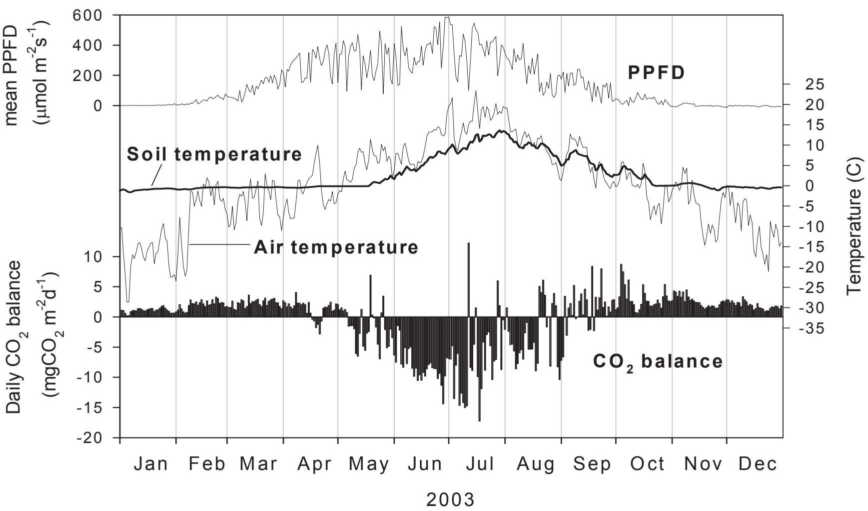

Figure 3. Carbon net fluxes at the Pallas spruce site, an example for the year 2003. In spring, the start of carbon net uptake is related to the rise of temperature and to the snow clearance. During winter and autumn, the net carbon release is due to respiration that is affected by the thickness of snow cover and soil freezing. These data show e.g. that at the high latitude forests, the warming of autumn period causes an increase to carbon flux into the atmosphere [3].

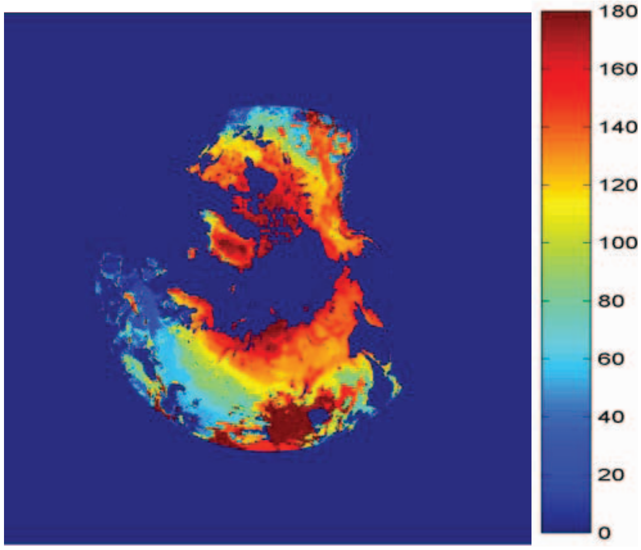

Figure 4. Example of global scale snow map relevant for the carbon balance: The day of snow clearance for the year 2008 as derived from AMSR-E radiometer data (day from the beginning of the year). Outside the regions of seasonal snow cover or for glaciers the illustrated map does not provide realistic values.

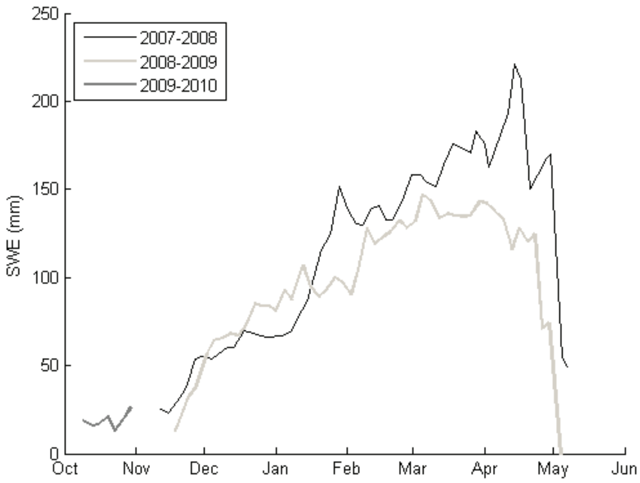

Figure 5. Behavior of SWE at Sodankylä since the winter of 2007.

REFERENCES

[1] M. Takala, J. Pulliainen, S. Metsämäki and J. Koskinen, "Detection of snow melt using spaceborne microwave radiometer data in Eurasia from 1979-2007", *IEEE Transactions on Geoscience and Remote Sensing*, 47, pp. 2996-3007, 2009.

[2] A. Kontu and J. Pulliainen, "Simulation of spaceborne microwave radiometer measurements of snow cover using in situ data and brightness temperature modelling", *IEEE Transactions on Geoscience and Remote Sensing*, in press.

[3] S. Piao, P. Ciais, P.Friedlingstein, P. Peylin, M. Reichstein, S. Luyssaert, H. Margolis, J. Fang, A. Barr, A. Chen, A. Grelle, D.Y. Hollinger, T. Laurila, A. Lindroth, A.D. Richardson and T. Vesala, "Net carbon dioxide losses of northern ecosystems in response to autumn warming", *Nature*, 451, pp. 49-52, 2008.