

Preface to the special issue on Monitoring and Modelling of Carbon-Balance-, Water- and Snow-Related Phenomena at Northern Latitudes

Tuula Aalto^{1)*}, Mikko Peltoniemi²⁾, Mika Aurela¹⁾, Kristin Böttcher³⁾, Yao Gao¹⁾, Sanna Härkönen⁴⁾, Pekka Härmä³⁾, Juho Kilkki¹⁾, Pasi Kolari⁵⁾, Tuomas Laurila¹⁾, Aleksi Lehtonen²⁾, Terhikki Manninen¹⁾, Tiina Markkanen¹⁾, Olli-Pekka Mattila³⁾, Sari Metsämäki³⁾, Petteri Muukkonen²⁾, Annikki Mäkelä⁶⁾, Jouni Pulliainen¹⁾, Jouni Susiluoto¹⁾, Matias Takala¹⁾, Tea Thum¹⁾, Boris Ľupek²⁾, Markus Törmä³⁾ and Ali Nadir Arslan¹⁾

¹⁾ Finnish Meteorological Institute, P.O. Box 503, FI-00101 Helsinki, Finland (*corresponding author's e-mail: tuula.aalto@fmi.fi)

²⁾ Natural Resources Institute Finland, P.O. Box 18, FI-01301 Vantaa, Finland

³⁾ Finnish Environment Institute, P.O. Box 140, FI-00251 Helsinki, Finland

⁴⁾ Natural Resources Institute Finland, P.O. Box 68, FI-80101 Joensuu, Finland

⁵⁾ Department of Physics, P.O. Box 64, FI-00014 University of Helsinki, Finland

⁶⁾ Department of Forest Sciences, P.O. Box 27, FI-00014 University of Helsinki, Finland

The carbon balance of northern terrestrial ecosystems is particularly sensitive to climatic changes in autumn and spring (Goulden *et al.* 1998, Piao *et al.* 2008, Luus *et al.* 2013). During recent decades, a greening trend has been observed in Eurasia (Zhou *et al.* 2001, Bogaert *et al.* 2002), characterized by a longer growing season and greater photosynthetic activity, thus enhancing carbon sequestration and extending the period of net carbon uptake. However, the relationship between inter-annual temperature variability and northern vegetation productivity might be weakening (Piao *et al.* 2014), possibly due to saturating temperature responses of vegetation in summer, and complex feedbacks from expansion of more southerly species. The strength of the relationship varies according to continent and region (Bi *et al.* 2013). In temperate ecosystems, the weakening of the relationship coincides with an increase in drought. There is evidence that the increasing water stress created by more frequent regional droughts play a significant role also in boreal ecosystems, increasing the tree mortality in boreal forests

(Peng *et al.* 2011). In addition to the definitive but often relatively limited area mortality effect, droughts may temporarily reduce gross primary productivity (GPP) and increase respiration thus reducing net carbon storages over a large region. The drought sensitivity of trees differs according to species, forest heterogeneity, soil characteristics and topography (e.g. Lloyd & Fastie 2002, Kljun *et al.* 2007). Some field studies have shown that deciduous broadleaved species are more sensitive than evergreen coniferous species (Welp *et al.* 2007) though spruce dominated forests were also found vulnerable (Beck & Goetz 2011). Mixed stands may be more drought-sensitive than pure stands (Grossiord *et al.* 2014). However, globally many forest species operate with narrow hydraulic safety margins for xylem water transport and show convergence in their vulnerability to drought (Choat *et al.* 2012).

Snow cover has an effect on carbon balance via regulating the soil thermal conditions (Gouttevin *et al.* 2012), and melting of snow can be used as a proxy for the start of vegetation period in boreal forests (Böttcher *et al.* 2014).

Springtime onset of CO₂ uptake from micrometeorological flux and phenological observations the onset of shoot elongation in pine trees were compared by Böttcher *et al.* (2014) with changes in NDWI, NDVI and Fractional Snow Cover (FSC) indices from MODIS. Calendar day when growing season begins as indicated by a decrease in FSC, showed best correspondence with multi-year *in situ* observations of coniferous evergreen forests springtime onset of CO₂ uptake, indicating the potential of snow cover observations in vegetation seasonality studies. Properties of snow cover, when differentiated for forested and non-forested areas, have a significant effect on soil physical state and soil carbon cycling according to land surface modelling experiments (Gouttevin *et al.* 2012). In comparison with treeless tundra, the lower thermal conductivity and density and thus higher insulation by snow in northern forested areas induces higher soil temperatures, which may persist during summer. These thermal changes have implications for the modelled soil carbon stocks through complex interplay of carbon balance with soil water and nutrient status. The nitrogen limitation is loosened by higher all-year soil temperatures at the southern permafrost margins enhancing productivity of trees, while increased surface water stress acts on opposite direction. Furthermore, the thermal changes accelerate the respiration rates and increase the area exposed to microbial decomposition via reducing permafrost extent and deepening the active layers. These effects combine to produce lower soil carbon stocks in the pan-Arctic terrestrial area in comparison with those simulated using uniform snow properties for forested and non-forested areas.

Accurate regional carbon balances can only be attained through realistic representation of land cover with sufficient resolution to capture its heterogeneity. Micrometeorological carbon flux measurements can be up-scaled using sophisticated empirical algorithms together with land-cover information retrieved from space borne and surface observations (Jung *et al.* 2011, Bontemps *et al.* 2012). In connection, regional uncoupled land surface models are needed in order to efficiently develop the underlying process descriptions and scaling approaches, and to make future projections (McGuire *et al.* 2009). It is essential to collate the land cover for regional studies

from high resolution maps which contain up-to-date information about the vegetation types. For example, changes in the proportions of evergreen and deciduous forest in the model domain affect the simulated length of growing season and annual carbon balances (Törmä *et al.* 2015). In addition, the up-to-date land-cover maps provide tools to study the changes in land cover and are a precondition to realistic land-use-change projections. Realistic land-cover description is also essential for top-down inverse modelling of carbon balances when trying to disentangle different emission categories. There the prior flux estimate given by a land surface model is re-assessed by using atmospheric concentration measurements as a constraint for the surface fluxes. However, the concentration observation network is relatively sparse, limiting the resolution and accuracy of surface fluxes solved. The land use of Europe, for example, is so heterogeneous that 1° × 1° resolution is not fine enough to obtain the carbon balances in desirable accuracy (Peters *et al.* 2010). In order to be assimilated in models, data from the concentration measurement network have to be consistent, i.e. measurements need to be at the same scale and confluent principles should be used in evaluating the representativeness of the signal (Masarie *et al.* 2011).

In this special issue, carbon- and water-related phenomena in northern ecosystems and atmosphere are considered from measurement and modelling points of view, combining remote sensing observations, land-cover data, *in situ* observations of atmospheric concentrations, ecosystem fluxes, vegetation biomass, forest health and land-atmosphere system modelling. Land cover and its resolution in models were studied in connection with carbon balance and climate. High landscape heterogeneity implies high resolution land-cover mapping. Härkönen *et al.* (2015) studied leaf area index (LAI) for forested areas of Finland. LAI is used in vegetation carbon and water flux estimations and is a key variable in many land surface models and studies of land use change. A high-resolution (30 m) LAI map prepared based on NFI data and Landsat 5 TM satellite product (Landsat-NFI LAI) was compared with a moderate-resolution (500 m) LAI map produced based on reduced simple ratio derived from remotely sensed MODIS reflectances (MODIS-

RSR LAI). Regional averages of the two different LAI products were at the same level, but several geographical and land-use related differences between them were detected. The difference was largest in the lake district of Finland and in northern Finland, and it increased with decreasing share of forests and increasing share of deciduous trees. As MODIS-RSR LAI does not take into account the sub-pixel variation in land use, the Landsat-NFI LAI was considered to produce more reliable estimates.

Using global land-cover maps that are not fully validated for regional scale may induce bias in regional carbon balance estimations. Törmä *et al.* (2015) prepared land-cover type distributions for Finland for use in regional modelling of climate and carbon balances. The land-cover type distributions were prepared according to different revised land-cover data sets and recoded in 18 km resolution according to the Global Land Cover Characteristics (GLCC-GEC) nomenclature for ecosystem classes, thus enabling a comparison of three distributions of plant functional types in Finland; original GLCC-GEC, GlobCover and the Finnish HR CLC (high resolution national CLC database). The results show that in comparison with the Finnish HR CLC classification, the original GLCC-GEC does not represent the Finnish landscape particularly well. For example, wetlands are missing and there are errors in the land-cover type distributions, e.g. narrow conifers (e.g. larch) that are translated into coniferous deciduous and deciduous broadleaf trees, are erroneously placed in central and southern Finland. Furthermore, the values of certain land surface parameters which are assigned to land-cover types, namely forest ratio and leaf area index, were typically found to be too large for Finland. However, the total proportion of coniferous evergreen species was close to the Finnish HR CLC. GlobCover overestimated the proportions of forests and sparsely-vegetated areas, whereas in particular agricultural areas and shrubs were heavily underestimated. Problems in plant functional type distributions are clearly visible in the seasonal partitioning of GPP, as shown by modelling the temporal evolution of GPP with JSBACH, the land surface component of the Earth System Model developed by Max Planck Institute for Meteorology (MPI-ESM). Törmä *et al.* (2015) found on aver-

age higher spring GPP in the GLCC-GEC and Finnish HR CLC than in GlobCover, which can be attributed to higher proportion of coniferous evergreen species in those land-cover type distributions.

Near-surface temperature, precipitation and surface energy fluxes are also subjects of change when land cover is modified. Gao *et al.* (2015) compared a high-resolution land-cover map, CORINE Land Cover (CLC), with the GLCC-GEC, which is used as a standard land-cover map in the regional climate model REMO. Present-day climate simulations over northern Europe were performed by using REMO with both CLC and GLCC-GEC. Surface albedo was the dominating factor during snow cover period, and evapotranspiration (ET) during growing season, for the differences in near-surface temperature between the CLC and GLCC-GEC. Simulated near-surface air temperatures, diurnal temperature range and precipitation were compared with observational data. The regional mean precipitation was slightly closer to observations when using the CLC. However, previously known biases from simulated climate variables to observations were only marginally reduced when using the updated land cover. These biases arise from climate model physics descriptions and improvements are expected to be achieved by further model developments.

Peltoniemi *et al.* (2015b) applied materials of Gao *et al.* (2015), Härkönen *et al.* (2015) and Törmä *et al.* (2015) in model development. GPP of Finnish forests was estimated using two models, JSBACH, and a new model PRELES (Peltoniemi *et al.* (2015a) that was intended for concurrent GPP and ET estimation of boreal forests. The parameters of PRELES were optimized for two boreal pine-forest sites, Hyytiälä and Sodankylä. The model calibrated for Hyytiälä slightly overestimated GPP and ET in Sodankylä, but responses were similar and its performance levelled with the model calibrated for Sodankylä in a dry year. The model parameterized for Hyytiälä estimated GPP in Sodankylä nearly as well as the model parameterized for Sodankylä. The result suggests that similar parametrisations related to GPP and its temperature response can be used for boreal pine sites located in southern boreal and northern boreal zones. The two models, JSBACH and PRELES, utilize different

data sources. JSBACH draws forest data from the CLC maps and general plant functional type descriptions while PRELES utilizes forest information derived from forest inventory (Härkönen *et al.* 2015). In Peltoniemi *et al.* (2015b), the predictions of JSBACH and PRELES were compared with remotely-sensed GPP from MODIS and the national forest greenhouse gas inventory. When aggregated to the national level, the JSBACH and PRELES results agreed well, but predicted lower GPP than MODIS. This can be only partially explained by inadequate presentation of understory vegetation in the models (*see also* Härkönen *et al.* 2015). JSBACH predicted equally high seasonal GPP rates for both deciduous and evergreen trees while the growing season of deciduous trees started later, resulting in a moderately lower annual GPP. In PRELES, the seasonal patterns were similar for both deciduous and coniferous trees because seasonality model of deciduous species was not yet implemented (Linkosalo *et al.* 2008). Temporal trends in annual GPP were also parallel among the models, and convergent with the national forest greenhouse gas inventory. Spatial differences in GPP originated from the fine resolution differences in the model LAI input and its latitudinal gradient, and from the differences in the soil data applied in the models and the model sensitivities to soil water. PRELES indicated stronger response of GPP to drought during the warm and dry period in summer 2006, which can be due to greater moisture sensitivity of PRELES or merely indicate differences in soil properties information used by the models.

Variations in soil moisture may alter the carbon balance of boreal forest stands, but it is difficult to obtain experimental information about soil conditions at broad spatial scales that are needed for these estimations. For example, some sites with thin soil layer are more vulnerable for decreased soil moisture than others, which causes decrease in GPP and growth, and may provoke stress symptoms much before tree mortality occurs. Muukkonen *et al.* (2015) studied the drought induced stress symptoms of trees by combining forest health observation data in Finland with GIS data describing growing conditions, soil properties and soil water predictions in order to map the most vulnerable risk areas. The summer of 2006 was extremely dry and the soil

water index of August was only about 25% of the 30-year-long average. The dry period caused significant increase in visible drought damage symptoms at the forest health-observation sites. The climatic conditions and soil properties determined the risk of drought damage and its spatial variation. The variables best describing the drought risk were the proportion of bare rock areas, topographic wetness index, soil water indices and latitude.

The studies so far dealt with seasonal changes in the ambient environment, land-cover information and GPP estimation. For the purposes of NEE estimation, one needs to present the cycling of carbon in different soil pools correctly, and thus e.g. precise litter input estimates for soil carbon models. Litter inputs are typically estimated using regionally averaged and species-specific biomass turnover rates which are lacking the spatial precision. By utilising extensive long term measurements of needle age (cohorts) or intensive measurements of foliar litterfall, Āupek *et al.* (2015) produced spatially more precise needle-cohort based turnover rates (NT), compared them with litterfall-biomass based turnover rates (LT), and also with NT values used in soil carbon model of the Finnish greenhouse gas inventory. The turnover rates originated from Scots pine and Norway spruce stands (NT and LT), and silver- and downy-birch stands (LT). The NT results generally agreed better with LT, if NT did not account for resorption of nutrients and carbohydrates. For evergreen stands, the new regionally-averaged NT values were greater than turnover rates used in the greenhouse gas inventory model in Finland. For deciduous stands, the new averaged LT values were close to the turnover rate currently used for the entire Finland. In due time these results will likely be adopted to greenhouse gas inventories and ecosystem models.

Finally, the reflections of surface sources and sinks in the tropospheric CO₂ concentrations were studied by Aalto *et al.* (2015) and Kilkki *et al.* (2015). The natural and anthropogenic influences in the concentration signal were studied as well as the background concentration in the atmospheric boundary layer. Aalto *et al.* (2015) used two models describing the transport of air masses, FLEXTRA and SILAM, in estimating the influence regions (IR) for the observed CO₂

concentration at Pallas (northern Finland). The models produced similar synoptic features and associated observations of background CO₂ concentration with marine IR and elevated CO₂ concentration with continental IR, but there were also differences which affected the interpretation of observations. The background, i.e. marine boundary layer (MBL) signal selected from Pallas observations by the models, compared well to the NOAA MBL reference compiled from a network of global background observations. Aalto *et al.* (2015) also used anthropogenic emission tracers, i.e. observed carbon monoxide concentration and fossil fuel CO₂ concentration simulations by TM5 model, to study the human impact in Pallas air masses. The anthropogenic influence at Pallas was extractable from the background. It was more pronounced in winter than in summer, and it had a large inter-annual variation. Kilkki *et al.* (2015) examined four new ground-based atmospheric monitoring stations in Finland (Sodankylä, Puijo, Kumpula and Utö) for local and large-scale signals in carbon dioxide concentration, and the results were compared with the corresponding values obtained from Pallas and NOAA MBL reference time series. Different filtering methods using local weather and air composition measurements were applied to the observations. Periods of a well-mixed boundary layer and relatively pollutant-free air were close to the Pallas time series, particularly in the winter. Mean winter-time mole fractions were higher than the MBL signal at all stations, emphasizing the need to use information of air mass history if MBL signal is to be extracted. However, all stations, with the possible exception of the urban site Kumpula in Helsinki, showed potential for observing a large-scale CO₂ signal valid for regional modelling studies. Through atmospheric inversion modelling, the observations can be used to validate the ground based carbon balance estimates (e.g. inventories).

These articles provide a valuable insight into boreal region carbon balances and their interplay with climate, and provide material for future modelling and experimental studies, gathered via efforts of the interdisciplinary research team. In future, a significant body of work by the team will be conducted to study seasonality of the boreal ecosystems in more detail using diverse observational and modelling methods. We will also study indicators of climate change, such as

snow cover, albedo, soil moisture, evapotranspiration, carbon dioxide and methane balances, and make projections to future decades. Within the on-going EU Life+ project 'MONIMET' we will further participate in estimations of the impact of climate change on ecosystems and their vulnerability assessment.

Acknowledgements: We would like to acknowledge the LIFE+ financial instrument of the European Union: LIFE07 ENV/FIN/000133SNOWCARBO and LIFE09 ENV/FI/000571 CLIMFORISK. Further, we acknowledge Finnish Academy project CARB-BAL, Helsinki University Centre for Environment (HENVI) project 'Optimizing forest management and conservation to account for multiple interactions with the climate' and EU Infrastructure ICOS 'Integrated Carbon Observation System' (ICOS 271878, ICOS-Finland 281255 and ICOS-ERIC 281250 funded by Academy of Finland).

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