The carbon cycle parameters in the dark-coniferous forests of southern taiga

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Forest ecosystems represent major carbon sink, however "sink's strength" greatly varies among different forest biomes (Молчанов, 1990; Уткин, 1995). Boreal forests are the second largest forest biome and act as a greater C sink than it supposed to be for the rainforests. Due to severe climatic conditions and slow biological processes, boreal ecosystems are storage of several hundred petagrams of carbon in soils and detritus (Post et al., 1982, Meentemeyer et al., 1985, Hobbie et al., 2000, Заварзин, 1999; Добровольский и др., 1999 и др.). Vast peat stores and strong energy feedbacks to high latitude climate under the present environments emphasize an important role of boreal forest ecosystems in the global climate system and sustainable development (Кобак, 1988; Budiko, Groisman, 1991; Соммерс, 1997; Абаимов и др., 1997 и др.).

The ecosystems of Siberia play an important role in maintaining a structural balance between carbon and nutrients as they have a great capability for self-regulation and to reach a steady state under the present environments. Siberian forests take 1/5 part of global forested area, form 60% of northern hemisphere sink and NPP of Siberian ecosystems is about 20 % of global one, as well. The necessary for studying of boreal ecosystems of Siberia is defined by absence of information about carbon storage and fluxes as well as processes responsible for these functions. More over, currently it is not clear how these ecosystems will function and be changed under regional climate changes that are expected as a consequence of global warming.

From the standpoint of aforesaid, several international scientific projects aimed to contribute on the complex studying of Siberian forest ecosystems and estimating their role in global carbon balance have been started. Scientifically, projects are lead by a consortium of core institutions, consisting of the V.N. Sukachev Institute of Forest, Krasnoyarsk, Siberian Federal University, Krasnoyarsk, Karpov Institute of Physical Chemistry, Moscow, A.M. Obukhov Institute of Atmospheric Physics, Moscow, Russia and Max-Planck-Institute for Biogeochemistry, Jena, Max-Planck-Institute for Chemistry, Mainz, Institute for Tropospheric research, Leipzig, Germany.

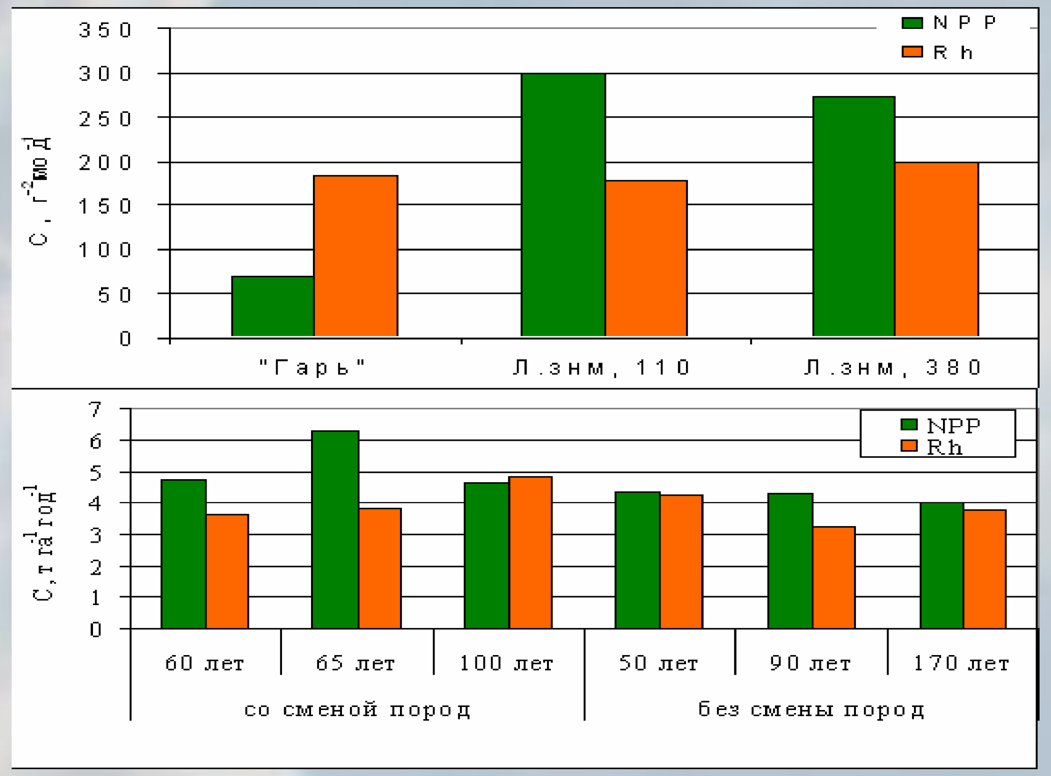

Fig.1 Carbon fluxes intensity across different forest successions, C, t ha^{-1} y^{-1}

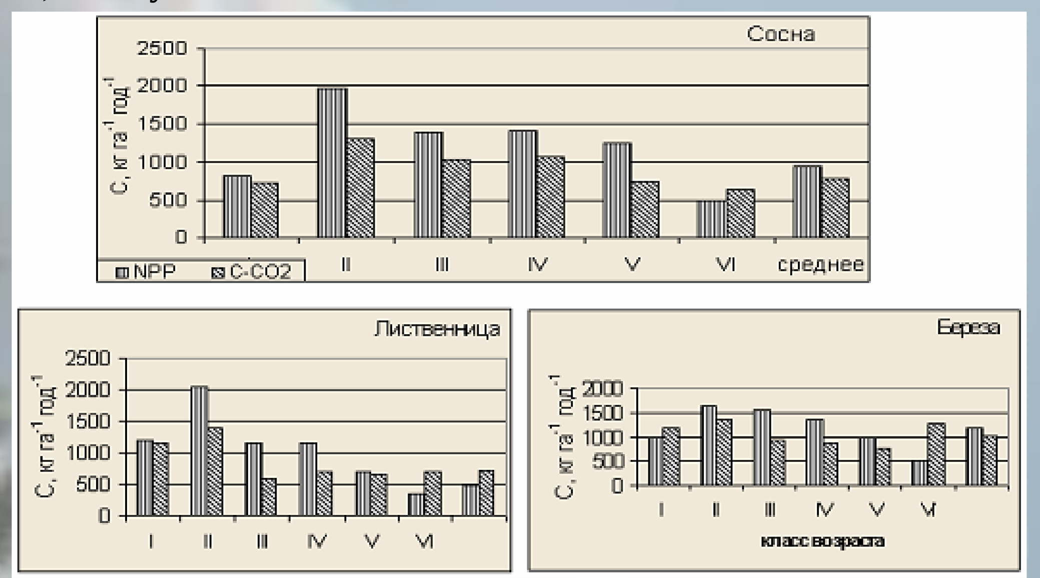

Fig.2 NPP and C-CO_2 in pine, larch and birch forest stands, C, kg ha^{-1} y^{-1}

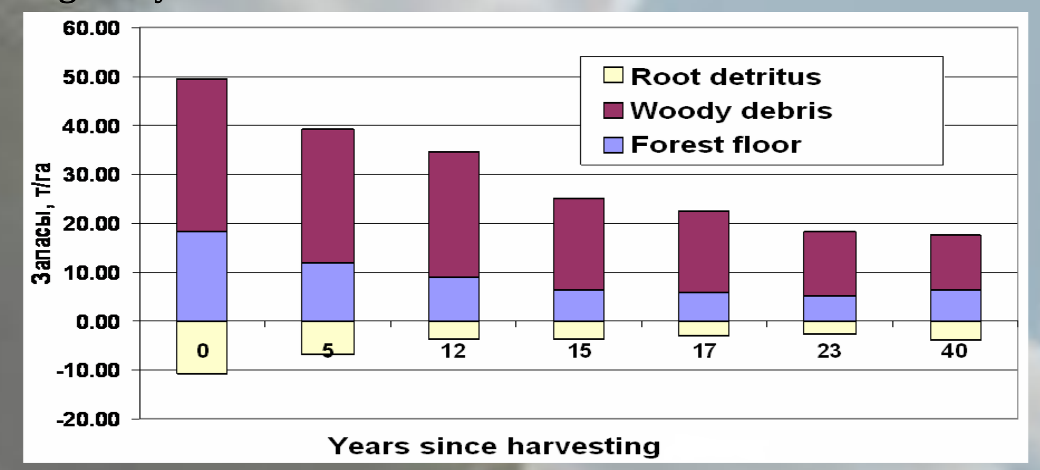

Fig.3 Soil organic matter dynamic after forest harvest, t ha^{-1}

To realize aims of continuous studying,
generally accepted complementary approaches are used:

1. Measurements *in situ*

Field measurements, based on a balance estimating of carbon stores and fluxes, which demands a direct assessing of C content in each of the compounds of carbon balance in forest ecosystems. For current purpose, some study areas covered ecosystem mosaic in the Northern, Central and Southern Siberian taiga have been inventoried. (Ведрова и др., 2002; Климченко, 2007; Прокушкин, 2006; Кошурникова, 2007; Иванова, 2006; Мухортова, 2002 и др.).

Following results have been found out during long-term observations:

In Central Siberian green moss pine forests, underwoods represent the strongest C sink whereas processes of carbon balance in old pine forests are in equilibrium. As for a lichen pine forests, underwoods act as a weak C sink, but ripening and old forests are changed into a source of CO_2 to the atmosphere (Трефилова, 2005).

In derivative forests of Central Siberian southern dark taiga, phytodetritus plays a key role in forming of CO_2 flux to the atmosphere. None of the studied ecosystems is a source of C-CO_2 to the atmosphere. In most cases, carbon assimilating is greater (60 - 65-y-old birch forests, 50-y-old fir forests) or is balanced with mineralization processes (fig.1)(Кошурникова, 2007).

Forest fires and cuttings change ecological functions and assimilating potential of forest ecosystems and so play an important role in a carbon cycle, especially in boreal region where reforestation processes take many decades. Only living phytomass and woody litter losses have been taken into consideration during estimating of C-CO_2 fire emissions to the atmosphere. Crown fire destroys needles, leaves, litter and 20% of bark, whereas only litter and 10% of bark are burned in case of a ground fire. Using some calculations it has been estimated that in a territory of southern boreal region, C-CO_2 emissions to the atmosphere because of the fires in pine, larch and birch forests are about 21.8 th t ha y^{-1}. Inputs of burned phytomass and litter in forming of C-CO_2 emissions to the atmosphere are equal: 11 and 10.8 th t ha y^{-1}, correspondingly. Annual C-CO_2 fire emissions are only 0.2% compared to total losses of C during native destruction processes (fig.2)(Ведрова, 2005).

Chronosequence of harvested Central Siberian pine forest stands represents stages of ecosystem development and gives a unique possibility for studying the developing ecosystem in terms of carbon cycle's features and parameters to estimate their role in global carbon balance. It has been found a strong difference in the amount of soil organic matter in stands of different ages (fig.3). Decreasing in soil organic matter stores is about 60% 20-25 years after cutting. This pattern is in accordance with a Covington's ecosystem paradigm and could be resulting from two primary factors: accelerated decomposition after harvest and changes in litter inputs over time.

2. Tower measurements of CO_2 concentrations and other greenhouse gases at 250-300 m above the earth's surface

For this purpose the International observatory ZOTTO consisting of a 300m tall tower, has been built in Central Siberia (near 60N, 90E) about 20km west of the Yenisei river.

These measurements probe a relatively homogeneous part of the atmosphere (the mixed layer). Mixed-layer observations combine the benefits of sensing surface flux processes integrated over a very large area and of avoiding the "noise" caused by the diurnal changes in photosynthetic rates close to the earth's surface. In vegetated areas the amplitude of diurnal carbon signals next to the ground can be very large, reaching up to 300 ppm. The signals of the large respiration fluxes are amplified by the suppressed near-ground mixing during the night, which traps and concentrates respired carbon within a shallow layer. In winter time average CO_2 concentrations are about 394.5 ± 3.4 ppm (fig.5).

In addition to the benefits of taking measurements at very large height, tall tower permits measurements of vertical concentrations and flux profiles of trace substances and meteorological variables. These observations also permit analysis of mixing within the surface layer and the processes responsible for mass exchange between the surface and mixed layer, as well as more local ecosystem-atmosphere exchange processes.

ZOTTO is part of a larger network of monitoring stations in northern Eurasia, which were established as part of the EU-Projects EUROSIBERIAN CARBONFLUX and Terrestrial Carbon Observing System – Siberia (TCOS-Siberia).

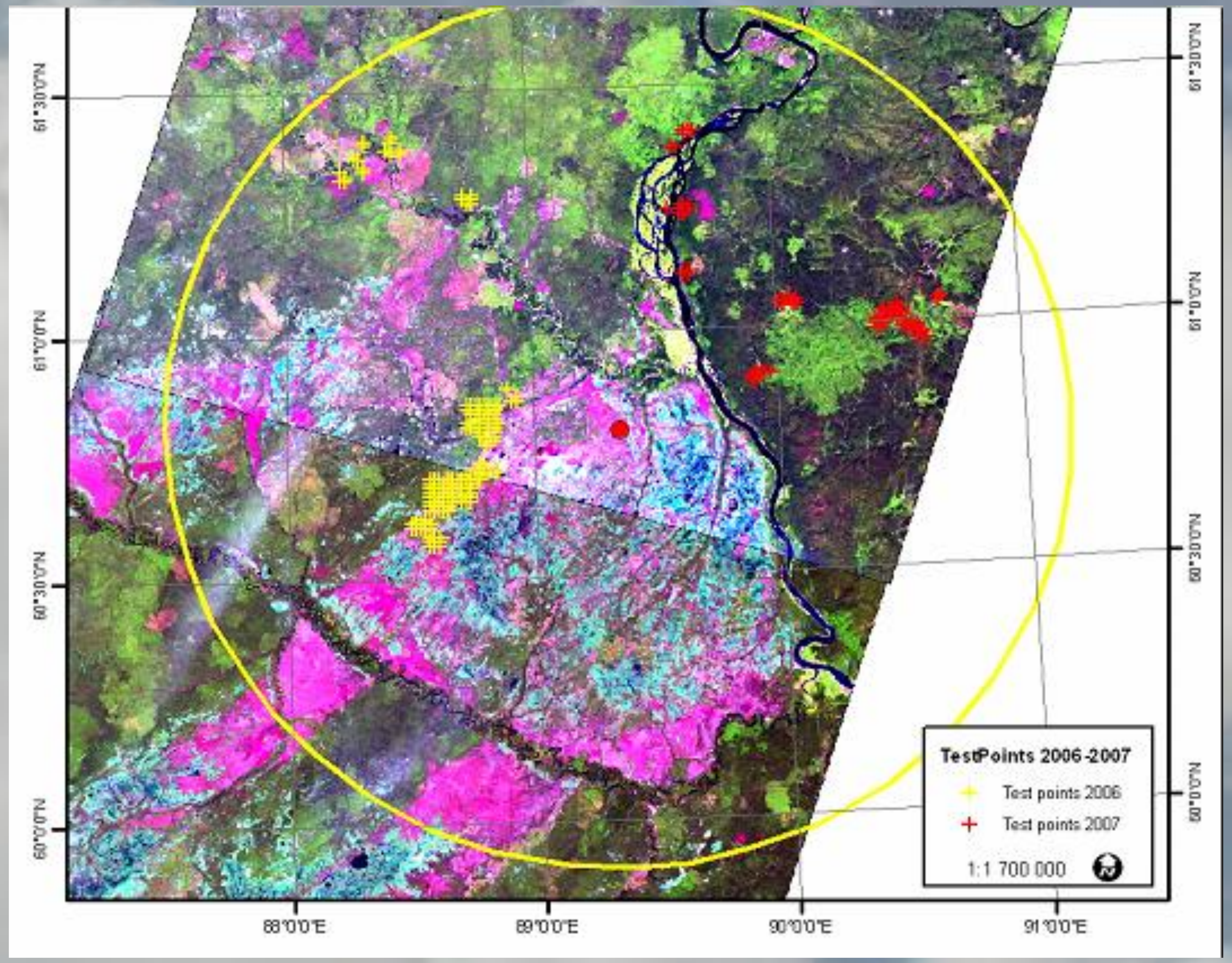

Fig.4 Test points covered area in the tall tower footprint (inventoried in 2006-2007)

3. Data integrating and mathematical modeling

Obtained characteristics of carbon signals together with the heterogeneity of the land biosphere and accurate estimating of all the carbon cycle's parameters *in situ* allow an interpretation of near ground measurements on continents in a regional to global context.

The combining of data on surface fluxes of greenhouse gases, on vertical profiles of these parameters up to the boundary layer with data on composition and parameters of ecosystems and their dynamic.

The using of state-of-the-art methods of validation of images from satellites LANDSAT and MODIS allows permanent monitoring of the footprint of tall tower, and verification of images by ground inventorying of ecosystems gives us additional tools for using and accruing of remote sensing.

These integrated ground and atmospheric studies serve as background for calculating of meteorological and biogeochemical parts of model of carbon balance at continental scale.

Future directions:

To continue measurements of ecosystem parameters and their dynamics *in situ* and develop an updated data base containing the mosaic and main parameters of different ecosystem types

To make parameterized model of main ecosystem types in the tall tower footprint

To continue complex atmospheric measurements at ZOTTO observatory

To combine the data on surface fluxes of greenhouse gases, on vertical profiles of these parameters up to the boundary layer with data on composition and parameters of ecosystems and their dynamic