TERRESTRIAL ECOSYSTEMS FULL CARBON ACCOUNT FOR RUSSIA: A REANALYSIS

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ABSTRACT
This paper presents major results of the terrestrial ecosystems full carbon account (FCA) for Russia based on the IIASA semi-empirical landscape-ecosystem approach following the major requirements of a verified FCA. The country's ecosystems served in 2005 as a net carbon (C) sink (Net Biome Production of the vegetated land is estimated at 31 ± 11 g C m^{-2} yr^{-1}, CI=0.9), albeit some large regions and land classes are estimated as a net C source. This assessment is considered as an initial step to a verified full greenhouse gas account.

INTRODUCTION
Data on the impacts of Russia's terrestrial ecosystems on the global carbon cycle during the last decades are inconsistent – from a net sink of almost 1.0 Pg C yr^{-1} to a source of about 0.05 Pg C yr^{-1} - with large, but unknown uncertainties. The philosophy behind this assessment is that proper understanding of the role that terrestrial ecosystems play in functioning of the Earth System, as well as future attempts of adaptation to, and mitigation of, negative consequences of climate change, should be based on a *verified terrestrial ecosystems full greenhouse gas account* (FGGA), of which a full carbon account (FCA) serves as an information and methodological nuclei. A verified FCA means that (1) assessing all fluxes of major carbon contained greenhouse gases (CO_2, CH_4, BVOC, some others), aerosols, and lateral carbon fluxes in the hydrosphere and lithosphere includes all ecosystems and all processes spatially explicitly and continuously over time; (2) uncertainties are assessed in a comprehensive and transparent way and they do not exceed a preliminary settled threshold; and (3) the methodology used should present guidance on what is the optimal way to manage the uncertainties. The FCA is an alternative to a partial carbon accounting scheme (limited by *the "managed biosphere"*) introduced into international practice by the Kyoto protocol and ensuing decisions of COP. The latter contradicts the eventual goal of the UNFCCC and generates many political and economic problems in the post Kyoto negotiation process.

METHODS AND DATA
The FCA is a complicated stochastic dynamic underspecified (fuzzy) system that cannot be directly verified in any practical implementations. Considered individually, the four major approaches used in the FCA (i.e., bottom-up inventories of C pools and fluxes; direct measurements of C exchange with the atmosphere by eddy covariance; dynamic vegetation models; and top-down inverse modeling) are not able to estimate structural uncertainties, and the reported uncertainties present in essence only "within model" assessments. We used systems aggregation of all available information sources, different approaches and models of different types as a cornerstone of the methodology. The "semi-empirical" landscape-ecosystem approach (LEA) is used for designing the problem and as the background of the account; while three other major carbon accounting approaches are used for harmonization and multiple constraints of intermediate and final results and their uncertainties (Shividenko et al., 2009). The LEA is based on a relevant combination of pool-based and flux-based approaches. Sets of different empirical models are used for assessing many-year averages of major components of the FCA and corrections of the latter for climatic indicators of individual years. This presentation basically considers the results of the FCA obtained by the LEA as a first step of the FGGA.

An Integrated Land Information System for Russia (resolution 1km) served as an information background of the LEA. Hybrid land cover classification (overall ~ 300 land classes combined in six

aggregated groups – agricultural land, forest, wetland, natural grassland and shrubland, and unproductive land) was done based on harmonization of multi-sensor remote sensing products (GLC-2000, MODIS VCF, AVHRR, LANDSAT TM, others), available on-ground data (e.g., State Land Account, State Forest Account), and other appropriate data sets (map of forest enterprises, soil map, vegetation map etc.). The harmonization and parameterization have been done for each 1 km pixel by a special optimization algorithm using a system of decision rules with priorities settled according to levels of reliability of information sources used and based on an integrated suitability index (Schepaschenko et al., 2009). Evaluation of the land cover dataset by classes was provided based on the level of confidence in the assignment of different information sources. The confidence was satisfactory: two classes of higher confidence comprised 70% of the total area and only 2% revealed substantial contradictions in primary sources. Details of parameterization depends on land class and its contribution to the FCA (e.g., about 40 indicators were used for forests: dominant species, age, site index, growing stock, live biomass by components, coarse woody debris by components, disturbances, soil characteristics, etc.).

RESULTS

The results are represented by geo-referenced major indicators of all components of the FCA by land class (estimates of carbon pools, Net Primary Production, Heterotrophic Respiration, Net Ecosystem Production, emissions caused by disturbances (fire, insect outbreaks, harvest and consumption of plant products, anthropogenic impacts), fluxes to the lithosphere and hydrosphere) and, finally, by Net Biome Production) by land classes. The total area of the country comprises 1709.84 x 10^6 ha, of which vegetative land covers 1571.4 x 10^6 ha (91.9%). Non-vegetative land includes unproductive land and interim water. The overall pool of organic C of terrestrial ecosystems of Russia accounts for 381 Pg C: 324 Pg in soil (14.2 Pg in on-ground organic layer and 309.8 Pg in 1m top layer); 42.0 Pg in live biomass (82.1% in forests); 14.6 Pg in dead vegetation (coarse woody debris and dead roots). Major fluxes by aggregated land classes are presented in Table 1. HR comprises 75% of NPP, consumption of plant products and disturbances 12.5% and lateral fluxes 2.5%.

Table 1. Major carbon fluxes, g C m^{-2} yr^{-1}, by aggregated land classes

Indicators	Aggregated land classes						
	AL	Forest	OW	DF	Wetland	G & Sh	Total
Area, x10^6 ha	218.9	794.7	82.6	27.5	146.9	300.8	1571.4
NPP	540	297	227	346	268	266	319
HR	405	208	154	382	202	230	240
Disturbance + Consumption	122	29	46	36	17	18	40
Lateral fluxes	11	7	6	8	12	7	8
NBP	2	53	21	-80	37	11	31

Overall, terrestrial ecosystems of Russia in 2005 (a “normal” year by climatic conditions and moderate natural disturbances) served as a net sink of 487 Tg C yr^{-1} (31g C m^{-2} yr^{-1}), or ~10% of NPP. However, arable land served as a C source (-40 g C m^{-2} yr^{-1}). Substantial areas on permafrost were also estimated as a source, mostly close to a neutral state. Uncertainties of major fluxes (“within approach” estimate, CI 0.9) are estimated at the level of 7-12%, with NBP about 30%.

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