Systems Methodology of the Terrestrial Ecosystems Verified Full Greenhouse Gas Accounting

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Abstract

We present an integrated methodology of the terrestrial ecosystems verified full greenhouse gas account (FGGA) which takes into account the fuzzy character of the accounting systems. The methodology is based on integration, harmonization and multiple constraints of results obtained by independent methods. IIASA's landscape-ecosystem approach (LEA) is used for designing the account boundaries and "semi-empirical" assessment of major pools and fluxes. An Integrated Land Information System (ILIS) serves as the information background of the FGGA. The methodology has been applied to territories of Russia. On average, terrestrial ecosystems of Russia served as a sink in range of 0.5-0.7 Pg C-CO2 yr-1 during the last decade, exceeding the technosphere's emissions of the country by about one third. Including emissions of methane from natural sources almost balances the ecosystems sink. Forests serve as a major component of the sink (~90% of the country's total). Disturbed forests and peatlands, cultivated agricultural lands and some northern areas on permafrost are a relatively small carbon source. Combination of major methods of carbon accounting results in the overall uncertainties of the Net Ecosystem Carbon Balance at ~25% (CI 0.9).

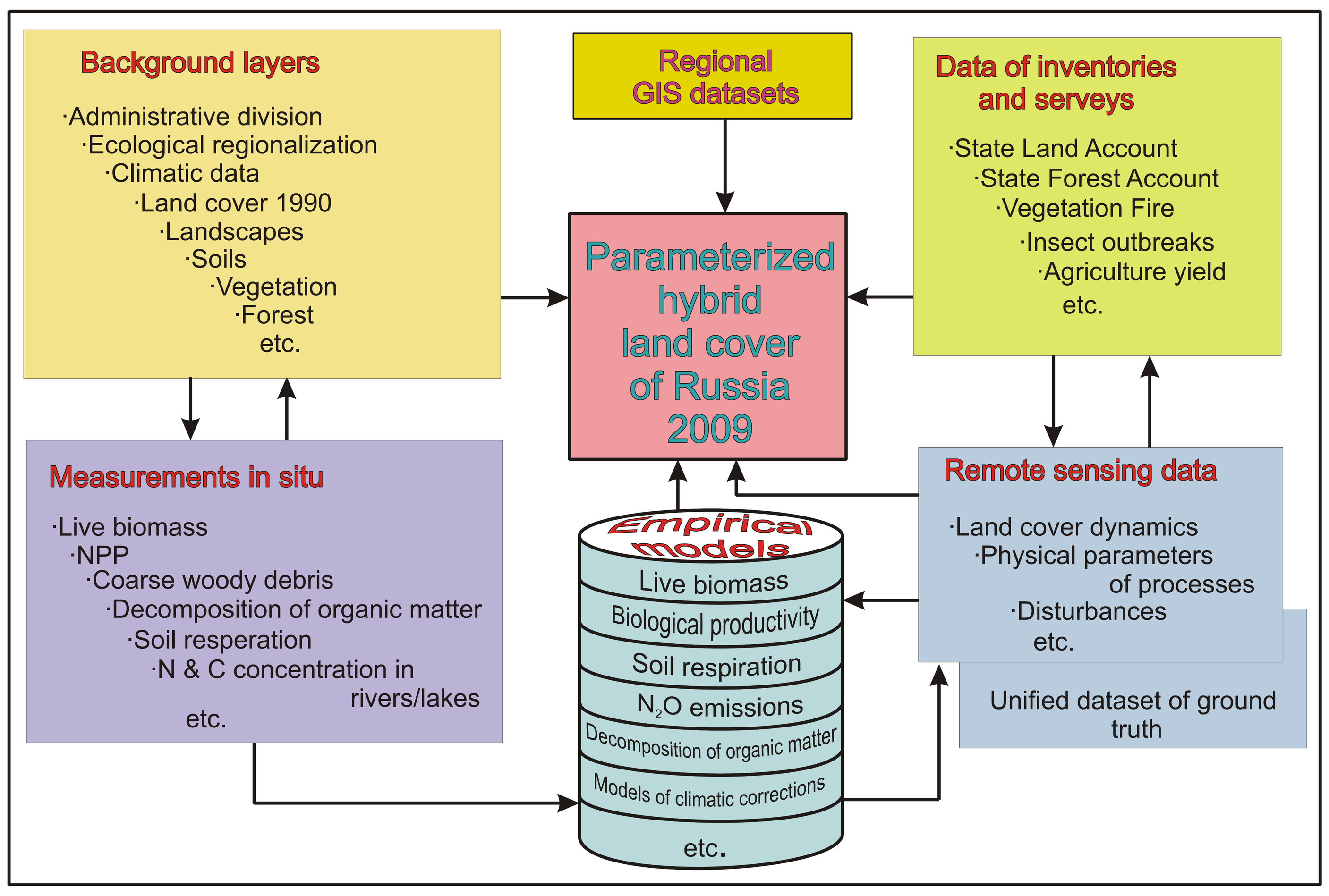
Introduction

International efforts to mitigate climate change require a verified terrestrial ecosystems full greenhouse gas account (FGGA). The FGGA supposes that (1) the accounting should include all ecosystems and all processes in a spatially and temporally explicit way; and (2) uncertainties are assessed comprehensively and transparently at all stages and for all modules of the account. The Full carbon account (FCA) serves as an information and methodological nuclei of the FGGA. The FGGA is a complicated stochastic dynamic underspecified (fuzzy) system ("full complexity problem") that cannot be directly verified due to evident cost and resource limitations. Fuzziness of the FGGA/FCA defines that any approach of carbon accounting, being individually implemented, is not able to recognize structural uncertainties, and the reported uncertainties represent only the "within model" part of the overall uncertainties. This shortcoming is eliminated by integration of major methods of GHG accounting.

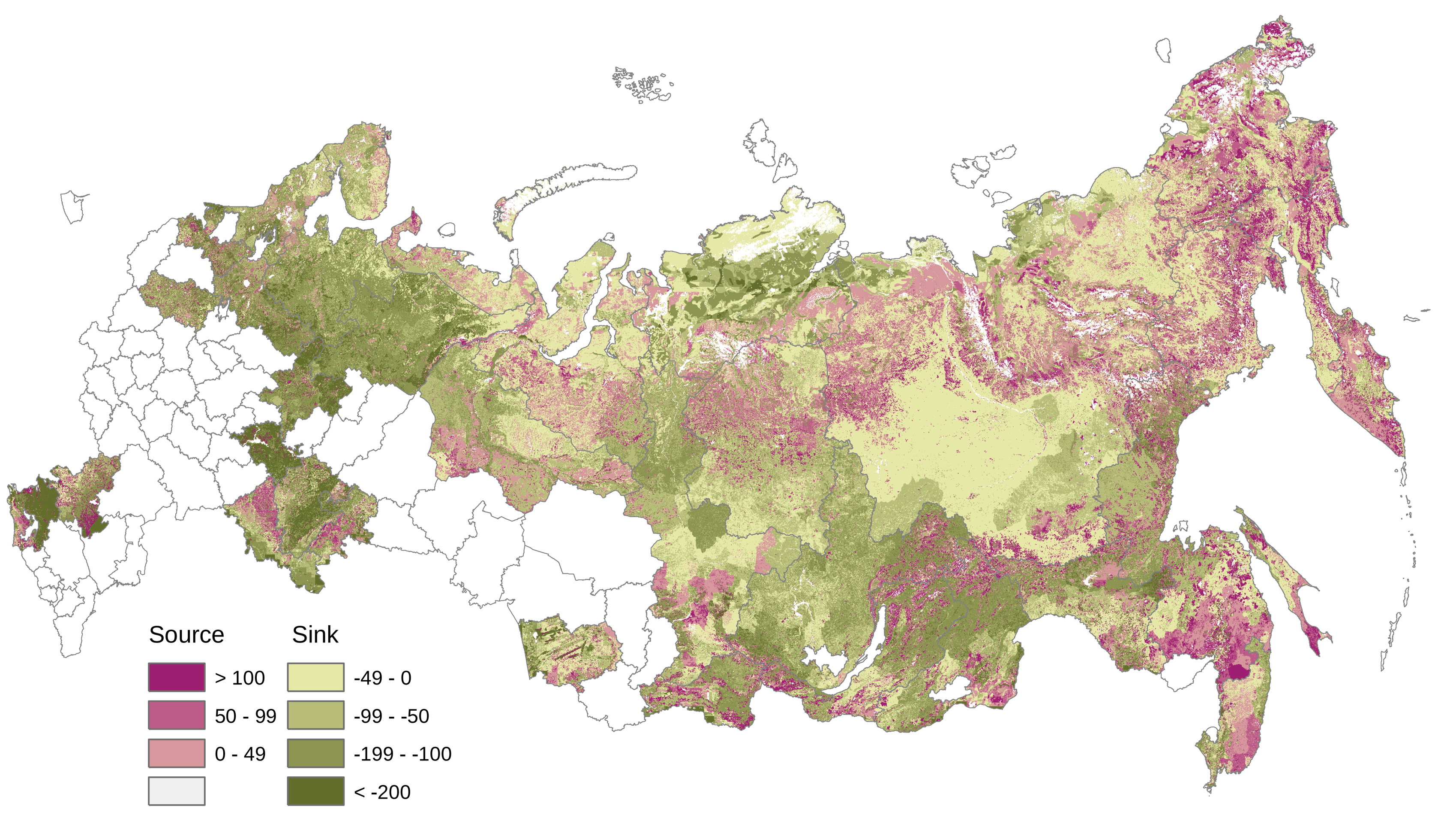
Methodology

The landscape-ecosystem approach (LEA) is an attempt to implement major requirements of applied systems analysis to the FGGA/FCA based on a comprehensive quantitative description of land and ecosystems using related empirical data and models. The LEA is used as a basis for designing GHG accounting schemes. The LEA combines pool-based and flux-based approaches. The pool-based method estimates change of ecosystems' carbon pools for a definite period of time. The flux-based approach is used as a chain of calculation of NECB = NPP – HR – D – L where NECB denotes Net Ecosystem Carbon Balance (or Net Biome Production), NPP – Net Primary Production, HR – ecosystem heterotrophic respiration, D – flux due to disturbances (including consumption of plant products), L – lateral fluxes to the hydrosphere and lithosphere. Certainty of the pool-based method is low due to poor knowledge of size and dynamics of some pools, particularly soils and dead wood. An Integrated Land Information System (ILIS) that includes (1) a hybrid land cover (HLC) at resolution of 1km at the country scale and (2) attributive databases of relevant measurements, empirical and semi-empirical aggregations serves as an information background of the LEA (Schepaschenko et al. 2010). The HLC for the Russian territory was developed based on system integration of multi-sensor and multi-temporal remote sensing concept (GLC-2000, MODIS VCF, AVHRR, LANDSAT, ENVISAT ASAR, PALSAR, many others), available on-ground data (e.g., State Land Account, State Forest Account), and other appropriate information. Extended databases and sets of different empirical models were used for assessing the major components of the FGGA/FCA (live biomass, NPP, HR, D and L) by land classes of the HLC. Long-period empirical estimates of fluxes are corrected based on weather conditions of individual years. Other methods of GHG accounting (measurements of Net Ecosystem Exchange by eddy covariance; global dynamic global vegetation models (DGVM); and inverse models) are used for harmonization and multiple constraints of independent results (Shvidenko et al. 2010a). Uncertainties are defined within each method and between those. Results of DGVM applications are used as an average by ensembles of models. Eddy covariance data serve mostly for parametrization of models. Inverse modeling presents independent data for top-down constraints of uncertainties.

Structure of the Integrated Land Information System



Net Ecosystem Carbon Balance for 2009, g C m^{-2} y^{-1}



Implementation

The above methodology has been applied to ecosystems of Russia (state of 2009). Major organic carbon pools obtained by LEA are: live biomass by components (43.5 Pg C including 86% in forests), dead wood (8.6 Pg C above ground, 5.6 Pg C below ground), and soil carbon (336.5 Pg C of which 23.5 Pg C are in on-ground organic layer). Major carbon fluxes are presented in Table. Uncertainty of NECB (within LEA) is estimated at ±26%.

Upscaling of eddy covariance measurement gave NEE at -1.033 Pg C yr-1. However, uncertainty of this result is very high due to a small amount of measurement sites in Russia. Application of an ensemble of DGVMs resulted in NPP 4712±1780 Tg C yr-1 (inter-model variability) and NBP – at -199±160 Tg C yr-1 in 1990-2008. Assessment by 12 inversion schemes for different periods from 1992-2008 resulted in 690±246 Tg C yr-1 (inter-scheme variability), the estimates of individual models vary from +27 to – 1140 Tg C yr-1 (Gurney et al. 2012). Net methane emissions from natural ecosystems (mostly wetlands and water bodies) are estimated at 13.6 Tg C-CH4 yr-1.

Table. FCA for Russian territories (2009). Sign "-" denotes carbon sink

Land class and processes	Area, mln ha	Carbon flux, Tg C-CO_2 yr^{-1} by source					
		NPP	HSR	DEC	Fire	Insect	Balance
Forest	820.9	-2,610.2	1,637.0	175.0	55.5	50.8	-691.9
Arable	77.8	-409.1	330.4		0.4		-78.3
Hayfield	24.0	-109.1	79.5		1.1		-28.5
Pasture	68.0	-330.8	212.0		1.7		-117.1
Fallow	19.0	-21.2	16.7		0.3		-4.2
Abandoned arable	29.9	-151.6	104.5		1.0		-46.1
Wetland	144.6	-395.2	317.5	3.3	21.0		-53.4
Open woodland	85.1	-84.2	116.0	2.8	5.7		40.3
Burnt area	23.7	-32.9	38.9	13.4	1.4		20.8
Grass & shrubland	315.7	-618.8	611.4	13.2	9.2		15.0
Water bodies	44.0						11.8
Biosphere total *	1709.8	-4,763.2	3,463.8	201.4	97.2	50.8	-761.3

* Flux due to consumption of plant product and trade (+170 Tg C yr-1) and area of non-vegetated land 57.1 Mha are not indicated in table.

Conclusion

Based on the LEA, Russian ecosystems were estimated as a net carbon sink in the range of 0.5 to 0.7 Pg C yr-1 during the last 10 years. This result is very close to the recent estimates of NECB of Russian land obtained by a set of inverse schemes. An ensemble of DGVMs gave a very close mean value of NPP; however the estimates of NBP (NECB) are about 30% of the LEA/inverse models' results. The pool-based estimates of forest NECB for Russia for 2000-2007 (Pan et al. 2011) are consistent with this study. Eddy-covariance measurements are basically in the range of the LEA estimates for individual land classes but lack spatial gradients for reliable upscaling. Overall, uncertainties of major carbon fluxes are in limits of 10% (CI 0.9) and of NECB - in range of 25-30%. They could be decreased by about one-third if longer time series and the latest remote sensing methods are implemented. The results of the study confirm that verified full GHG accounting in the biosphere is a promising tool for post Kyoto developments.

References

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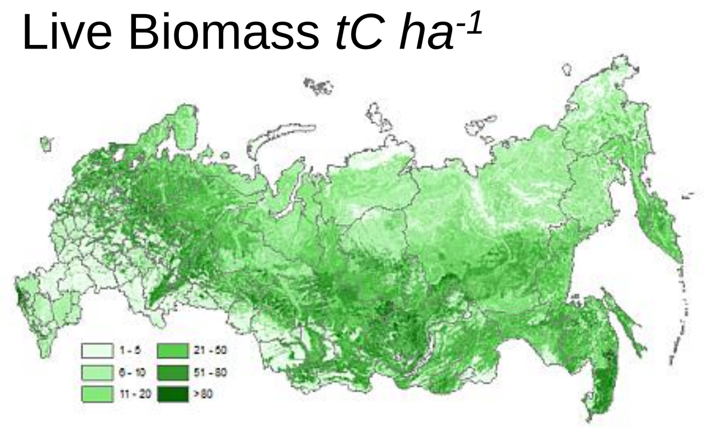
Live Biomass *tC* ha^{-1}

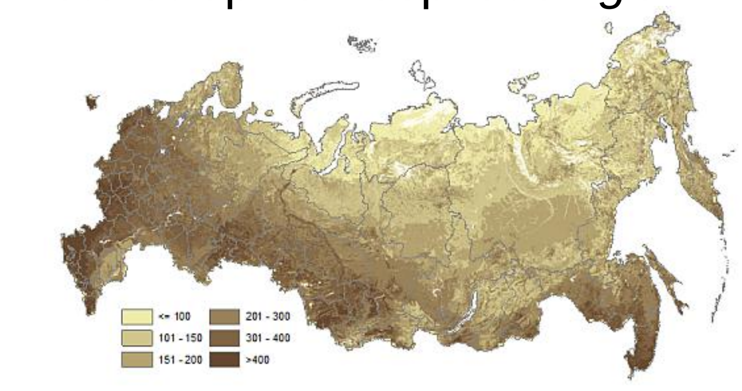


The estimate of the total live biomass for all vegetative land is 43.5 Pg C, including 37.5 Pg C in forests

Net Primary Production *gC* $m^{-2}y^{-1}$

Unbiased estimate of Net Primary Production of terrestrial ecosystems is 5.14 Pg C y^{-1}

Heterotrophic Respiration *gC* $m^{-2}y^{-1}$



Heterotrophic respiration of soil is estimated to be 3.47 Pg C y^{-1}. This value does not include decomposition of dead wood (0.25 Pg C y^{-1})

Forest Fire Area and Emissions