

# Diagnosis and Prognosis of Effects of Changes in Lake and Wetland Extent on the Regional Carbon Balance of Northern Eurasia

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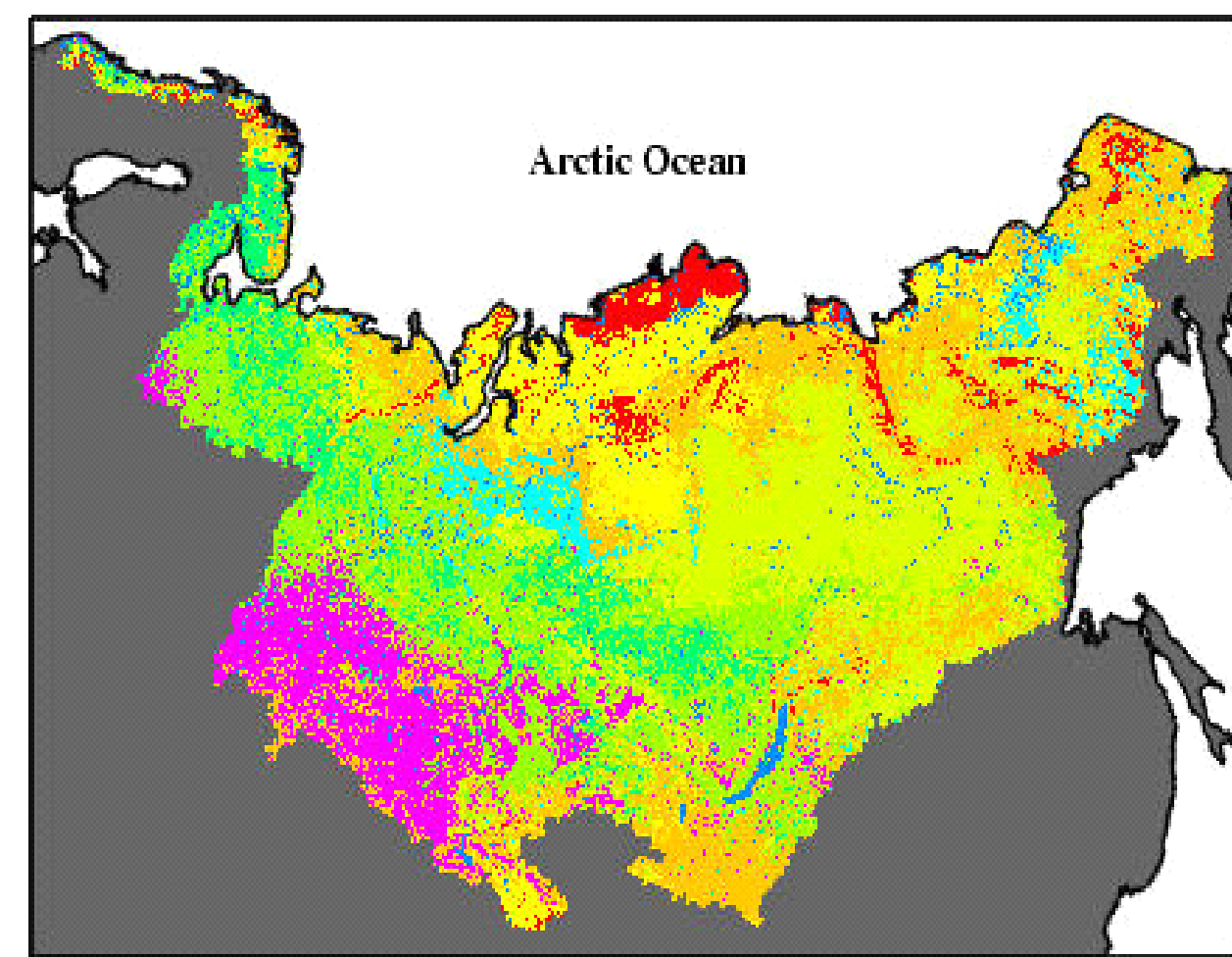
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## ABSTRACT

The Eurasian arctic drainage is a vast area that constitutes over 10 percent of the global land mass. Much of this region is either boreal forest or tundra, both of which are fragile ecosystems that have undergone considerable change over the last half century. The presence of permafrost and modest relief impedes the subsurface drainage of water and makes lakes and wetlands a dominant feature throughout the region. Most global carbon budgets have concluded that the boreal forest portion of the region is a net sink of as much as 0.5 Pg/year of carbon, while the tundra area is nearly in balance. However, these estimates may be considerably in error, as they account at best approximately for the contribution of methane emissions from wetlands. Methane emissions are sensitive to temperature, which has shown marked increases over the last half century, and is projected to continue to warm as the global climate changes. Furthermore, while the extent of wetlands within the region may be increasing, most estimates are based on coarse resolution (typically 1 km) satellite data, which tend to lead to substantial underestimates (by factors of two or more) of "minority" land cover classes, like wetlands.

This investigation will address the overarching science question: How have changes in lake and wetland extent in northern Eurasia over the last half-century affected the region's carbon balance, and how are changes in lakes and wetlands over the region likely to affect its carbon balance over the next century? We will employ high resolution SAR data in combination with in situ data to test and evaluate new lake and wetland, and permafrost dynamics models within the Variable Infiltration Capacity (VIC) macroscale hydrology model. The VIC model will be linked with a dynamic terrestrial carbon model, and with a lake and wetland methane model. Evaluation of the carbon and methane models will be performed with respect to large area estimates of carbon production and sequestration based on a combination of extrapolation of direct measurements, inverse modeling methods, and other modeling studies. Using the extended VIC construct, we will attempt to reconstruct the time history of terrestrial carbon and methane balances over the arctic Eurasia drainage, and, using a range of climate scenarios, to interpret how these balances might change over the next century.

## 1 Introduction



### Study Region:

- Region of Eurasia draining to Arctic Ocean
- 15 million km<sup>2</sup>
- Boreal forest: ~50%, tundra: ~15%
- Wetland extent: ~40% (uncertain)

### Primary Question:

How have changes in lake and wetland extent in northern Eurasia over the last half-century affected the region's carbon balance, and how are changes in lakes and wetlands over the region likely to affect its carbon balance over the next century?

### Topics to be Investigated:

- areas affected by changes in lakes and wetlands extents (past, present, future)
- effects of tundra changes (e.g. permafrost) on wetland dynamics and carbon balance
- ability of current sensors (MODIS, SAR) to detect changes in wetland extent; ability of high resolution SAR products to be used to extend the rapid repeat cycle of lower resolution products like MODIS to provide information about seasonal and interannual variations in lake and wetland extent

### Motivation:

- Eurasia particularly susceptible to global warming: fragile ecosystem
- shifts in controlling factors: climate, fire frequency, logging, water management, ...
- observed changes to land surface states and fluxes: wetland, boreal forest and permafrost extents; streamflow; snow cover; snowmelt; ice breakup, ...
- importance of lakes to the climate of high latitude regions; importance of high latitude ecosystems in uptake of greenhouse gases and terrestrial carbon storage
- hydrologic effects of lakes are largely neglected in most land surface models
- wetland extent uncertain
- poor state of knowledge of carbon balance in Northern Eurasia

Figure 1: Study domain – that part of Eurasia draining to the Arctic Ocean is shown with AVHRR-derived land cover from Belward (1996). Note that this relatively coarse resolution product tends to underestimate wetland and open water extent severely.

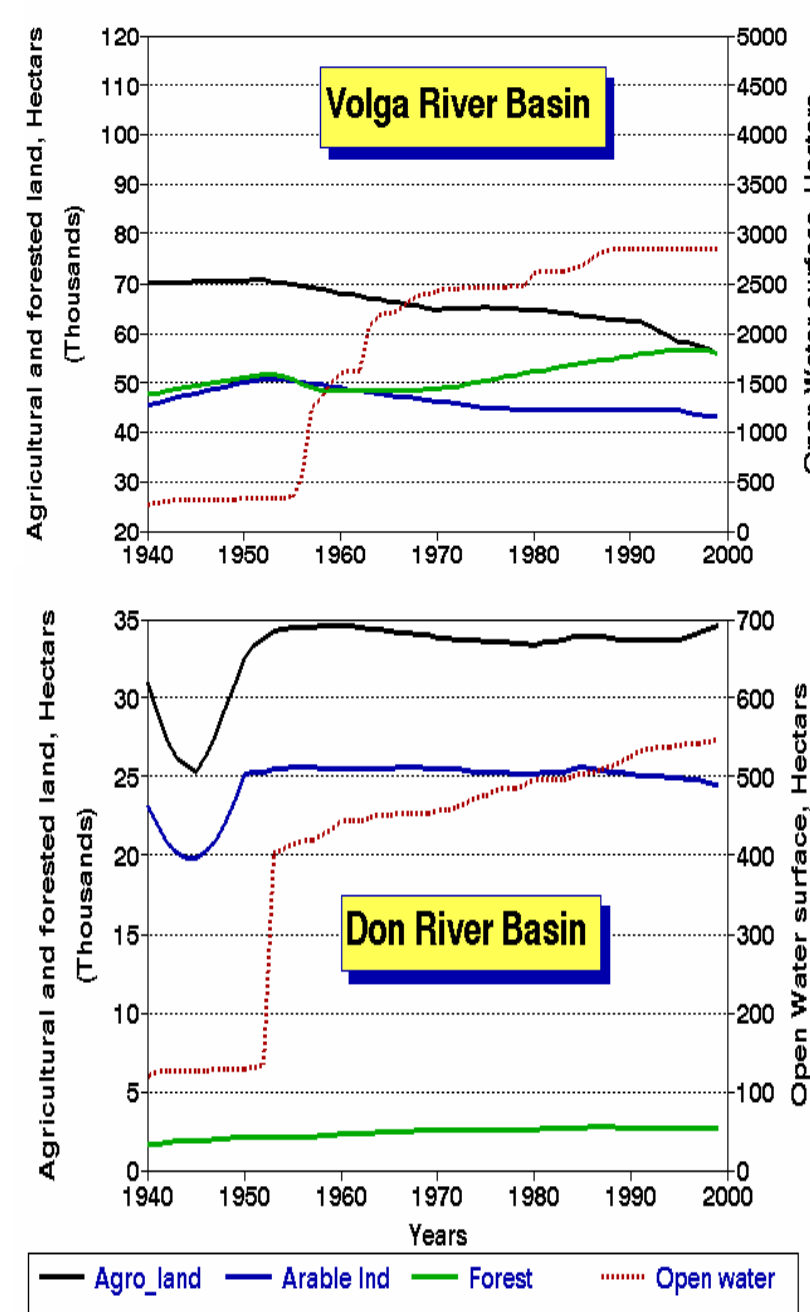


Figure 2: Changes in land cover in the Volga and Don River basins. The dominant change is an increase in open water extent (apparently primarily due to dam construction); similar data for the Severnaya Dvina and Zapadnaya Dvina basins show little such change. Source: Golubev et al (2003).

## 2 Approach

### Part A Test and Evaluate New VIC Lake and Wetland and Permafrost Dynamics Model

- use a high resolution SAR data (primarily from JERS) in combination with in situ data provided by Russian colleagues Speranskaya and Tsytsenko at the Russian State Hydrological Institute (St. Petersburg), and Kozlov and Bochkarev at the Moscow State University

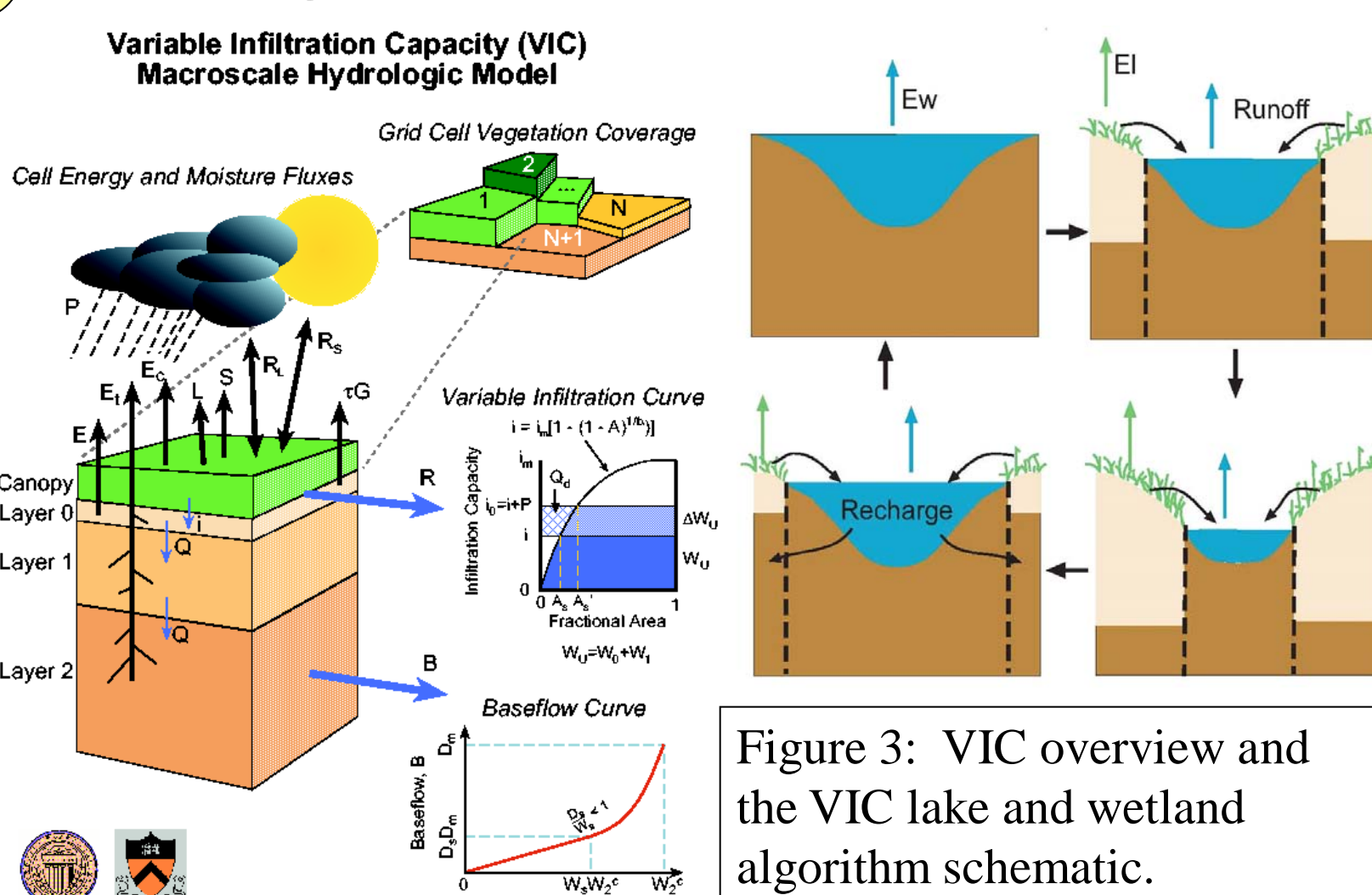
### Part B Run New VIC linked with BETHY and a Lake and Wetland Methane Model

- carried out by MPI collaborators Schnur and Knorr; testing of the carbon and methane models performed with respect to large area estimates of carbon production and sequestration performed via a combination of extrapolation of direct measurements, inverse modeling methods, and other modeling studies

### Part C Reconstruction and Prediction of Terrestrial Carbon and Methane Balances

- uses VIC construct; over northern Eurasia domain; use a range of climate scenarios to interpret how these balances might change over the next century

## 3 Modeling Construct



### Land Surface Hydrology Model

- Variable Infiltration Capacity (VIC) Model (Liang et al. 1994)
- water and energy balance closure
- macroscale
- spatially-distributed
- land cover classification sub-grid variability
- recent additions for cold land processes (Cherkauer et al. 2003)
- implemented in arctic regions by Bowling et al. (2000) and Bowling et al. (2003)
- energy balance of lake

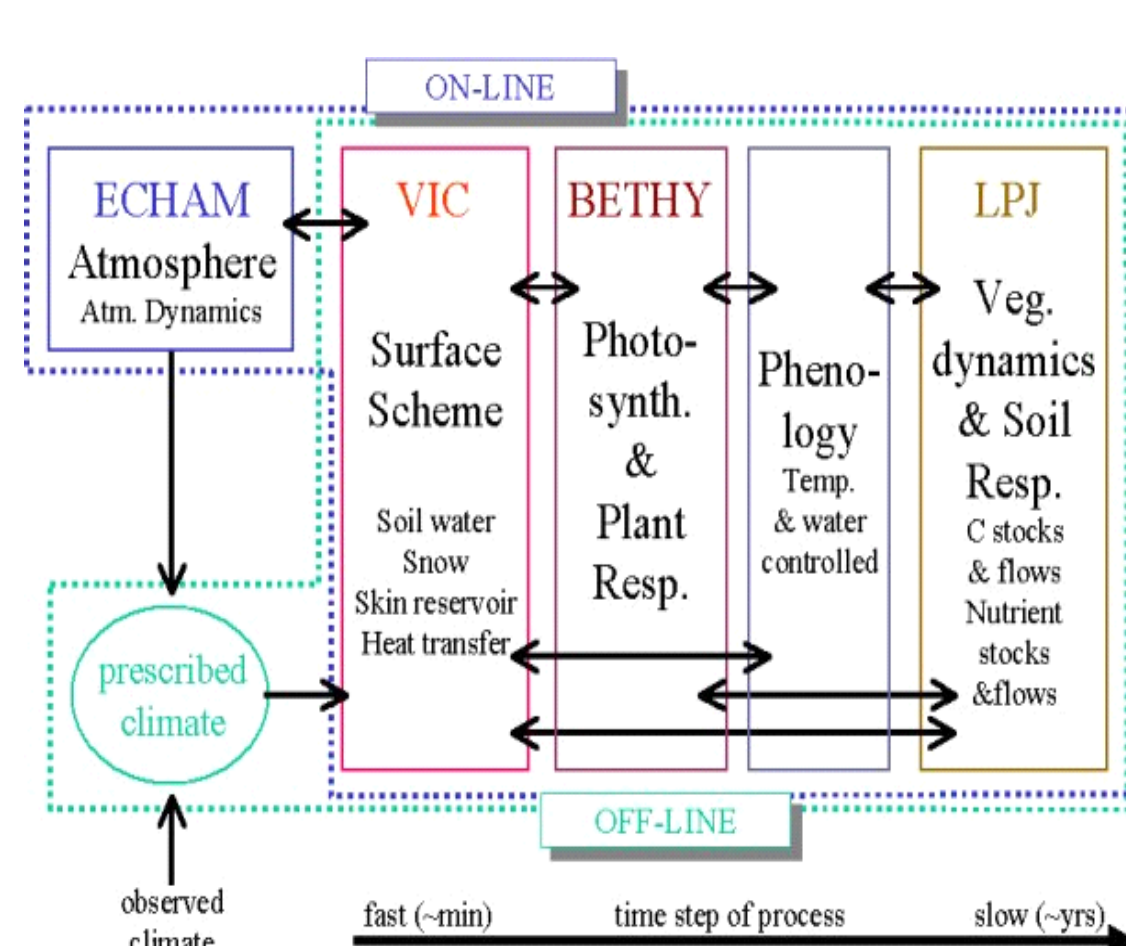


Figure 4: JSBACH schematic. For this proposal, we will focus on off-line implementation (linkages within green dashed line), and will add the Walter et al. CH4 model, which will link with the VIC soil moisture and temperature, and LPJ soil respiration models.

### Methane Model

- Walter and Heimann (2000) with modifications described in Walter et al (2001a)
- soil methane production, and transport of methane by diffusion, ebullition, and through plants modeled explicitly
- methane production occurs in the anoxic soil: bottom of the soil column to the water table
- methane production rate controlled by soil temperature and NPP
- time evolution of soil temperature will come from VIC

## 4 Observations

### Remotely-Sensed Data

- JERS-1 Synthetic Aperture Radar (SAR): an L-band (1.2 GHz) HH-polarization imaging radar that was operated by the National Space Development Agency of Japan (NASDA)
- L-band: useful for identification of inundated areas with partial vegetation cover because the long wavelength allows vegetation penetration
- sun-synchronous polar orbit with 44-day repeat cycle and a 35 degree incidence angle
- allows evaluation of the models ability to predict interannual variations in wetland extent over large geographic areas for the current climate
- collaboration between the Eurasia and North America components of GBFM

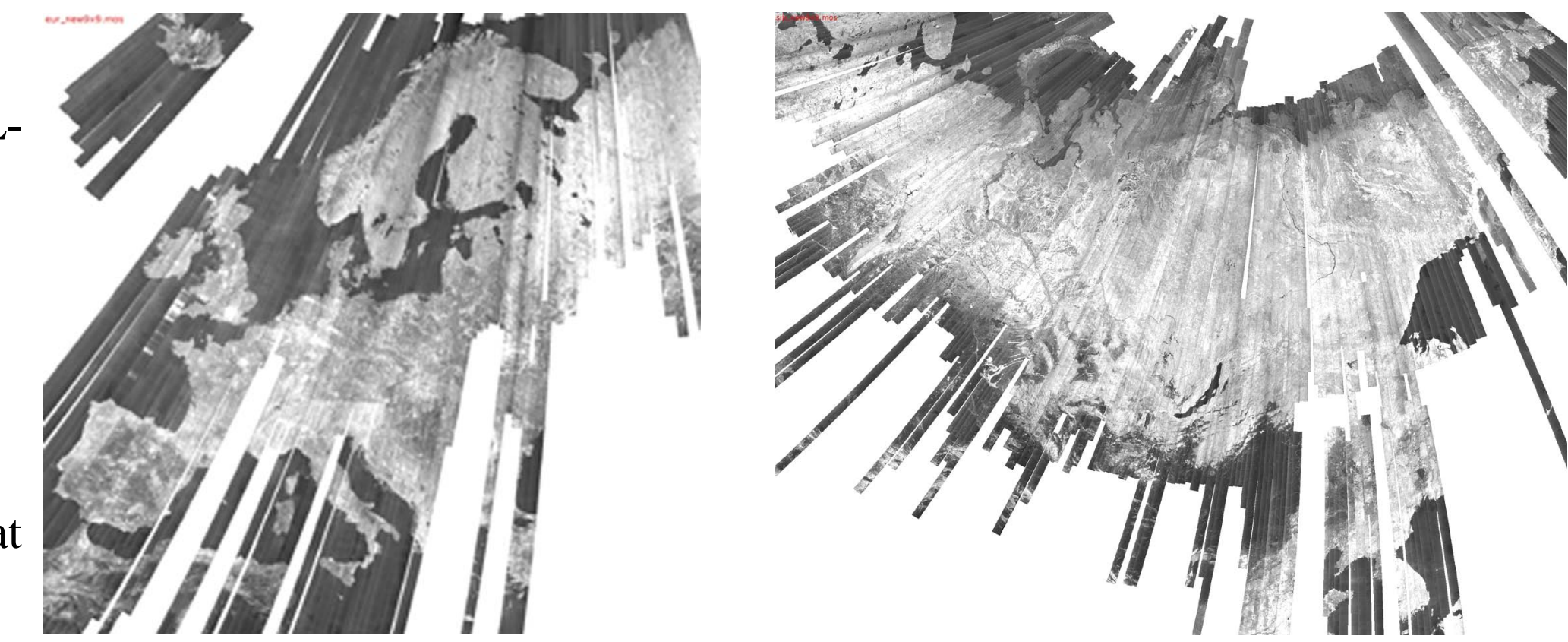


Figure 6: JERS-1 L-band Synthetic Aperture Radar mosaics of eastern and western Eurasia. These products were created as part of the Global Boreal Forest Mapping (GBFM) Project (DeGrandi et al. 2003). The mosaics were assembled from SAR summer imagery collected primarily during 1997-1998. The very high (100 m) spatial resolution provides the best available data on lake and wetland extent over the entire study region.

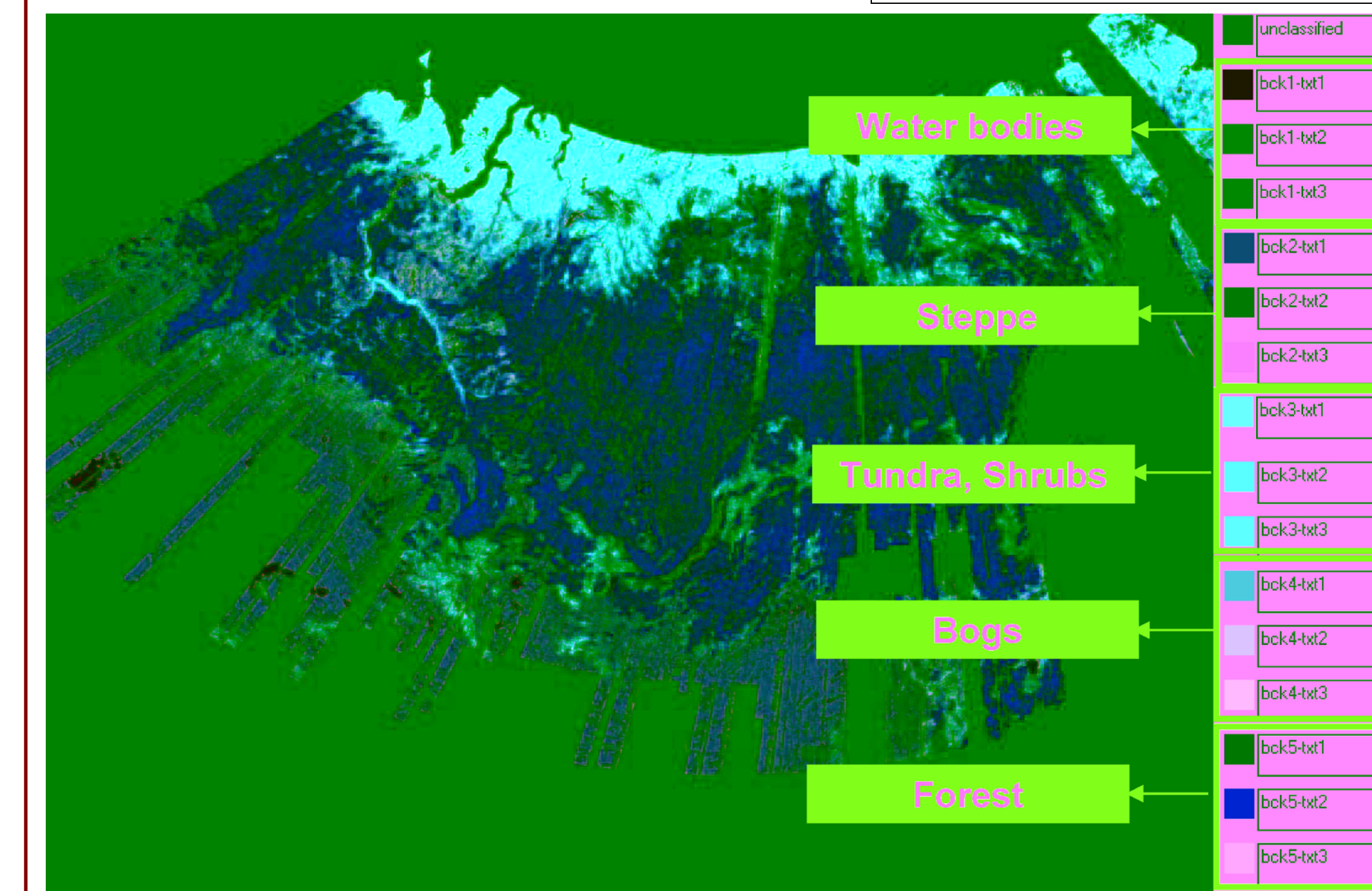


Figure 7: Continental scale classification of the JERS mosaic for the eastern part of Eurasia.

### In Situ Data

- dynamics of open water surface area, and forest and bog areas collected over European Russia from the 1950s through the 1990s:
  - water and vegetation data sets based on inventories performed every 3 to 5 years: archived at the Russian State Hydrological Institute (SHI)
  - quantitative assessments of landscape elements are available for 54 regions with areas from 3900 to 161,000 km<sup>2</sup>
- monthly evaporation from selected open water and soil surfaces during the warm months:
  - weighing lysimeter data available at 60 sites; pan evaporation observations available at 103 sites; soil moisture and temperature data also available
- tower flux and related observations:
  - Central Forest Biosphere Reserve (CFBR)

## 5 Strategy for Constructing Carbon and Methane Balances

### Retrospective Reconstruction of Regional Carbon Balance

- Following model development and testing, lake and wetland extent and associated carbon and methane fluxes will be reconstructed
- period: 1950 to 2000, using gridded hydrologic forcing data developed at the University of Washington
- half degree to one degree spatial resolution
- work with Russian collaborators to assemble additional data over the region that can be used to assess the model predictions

### 21<sup>st</sup> Century Regional Scenario Analysis

- downscale selected GCM runs archived by the IPCC using probability mapping downscaling methods similar to those described in Wood et al (2004)
- use either new model runs for the upcoming IPCC report or those used in previous studies, e.g. Parallel Climate Model runs (e.g. Christensen et al., 2004)
- purpose will be to explore, in carefully controlled and bias-corrected simulations of the range of climate conditions predicted for the next century, the net carbon balance of the region

## 6 Outline of Tasks

- Task 1: Model improvements.
  - Task 1a. VIC Lake and Wetlands model extensions.
  - Task 1b. Methane model extensions.
  - Task 1c. Integration of VIC in MPI VIC/BETHY/LPJ framework.
- Task 2: Data preparation and analysis.
  - Task 2a. In situ data.
  - Task 2b. Satellite data.
- Task 3: Model testing and evaluation.
- Task 4: Retrospective reconstruction of regional carbon balance.
- Task 5: 21<sup>st</sup> century regional scenario analysis.

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