Synthesis and Integration of Recent Research Characterizing the Carbon Cycle of Northern Eurasia

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NASA Carbon Cycle Science - NNX11AR16G

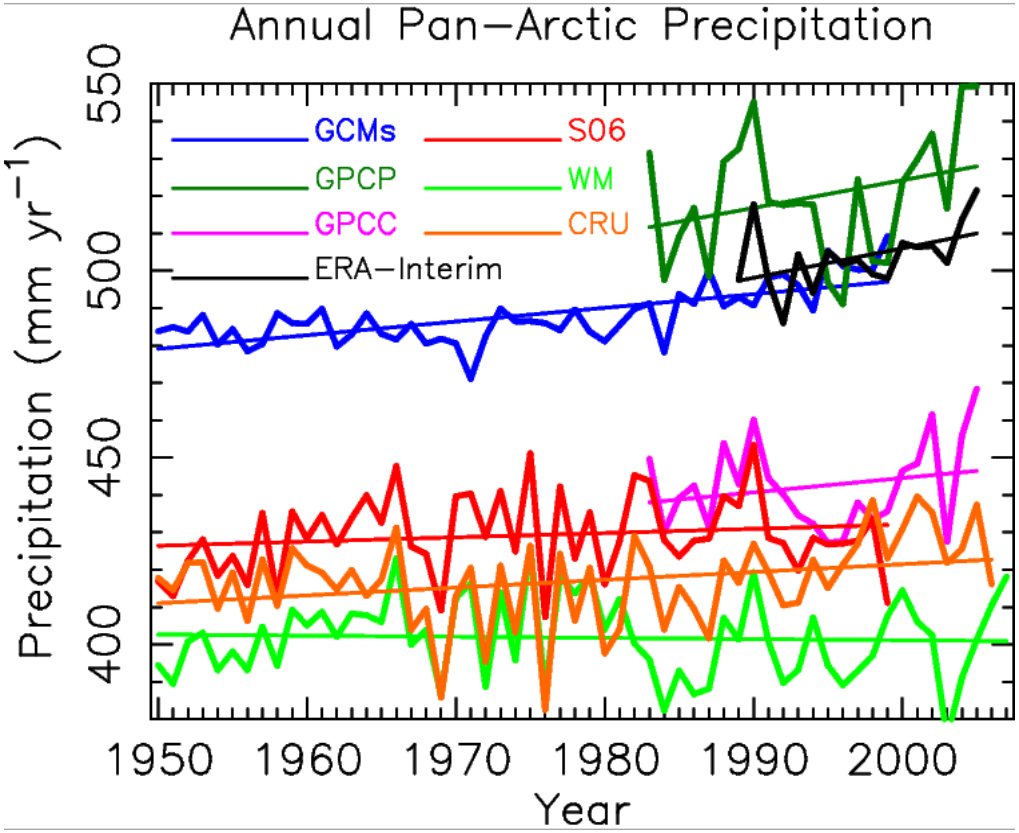
A Warming Climate Is Being Manifested Across The Arctic In:

- **A More Intense Hydrologic Cycle**
- **Thawing Permafrost**
- **Shrub Expansion**
- **Alteration in Surface Water Amounts**

Domain of Interest:

Northern Eurasia

Synthesis of data sets point to intensification of arctic freshwater water cycle as predicted by models



Data Set	Trend (mm yr^{-2})
GCMs	0.29
GPCP	0.74
GPCC	0.38
WM	-0.03
ERA-Interim	0.79
CRU	0.21
Sheffield et al.	0.11

Rawlins et al., J. Climate, 2010

Yedoma

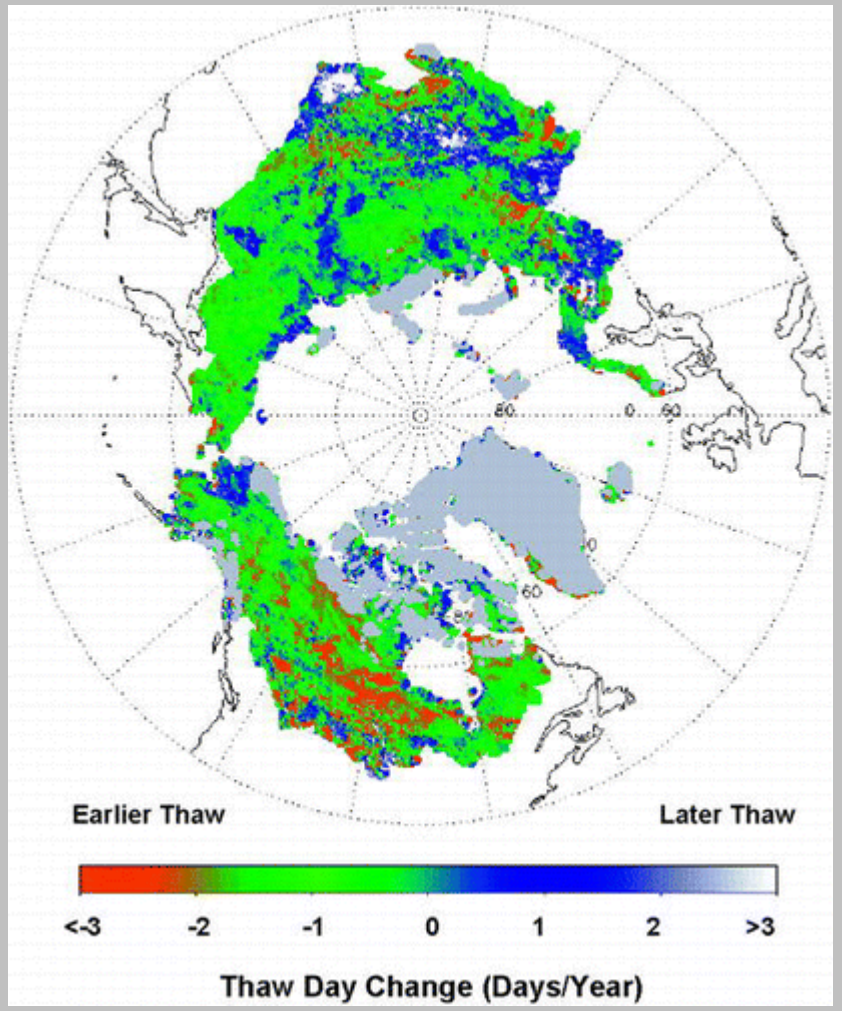
- carbon-rich permafrost

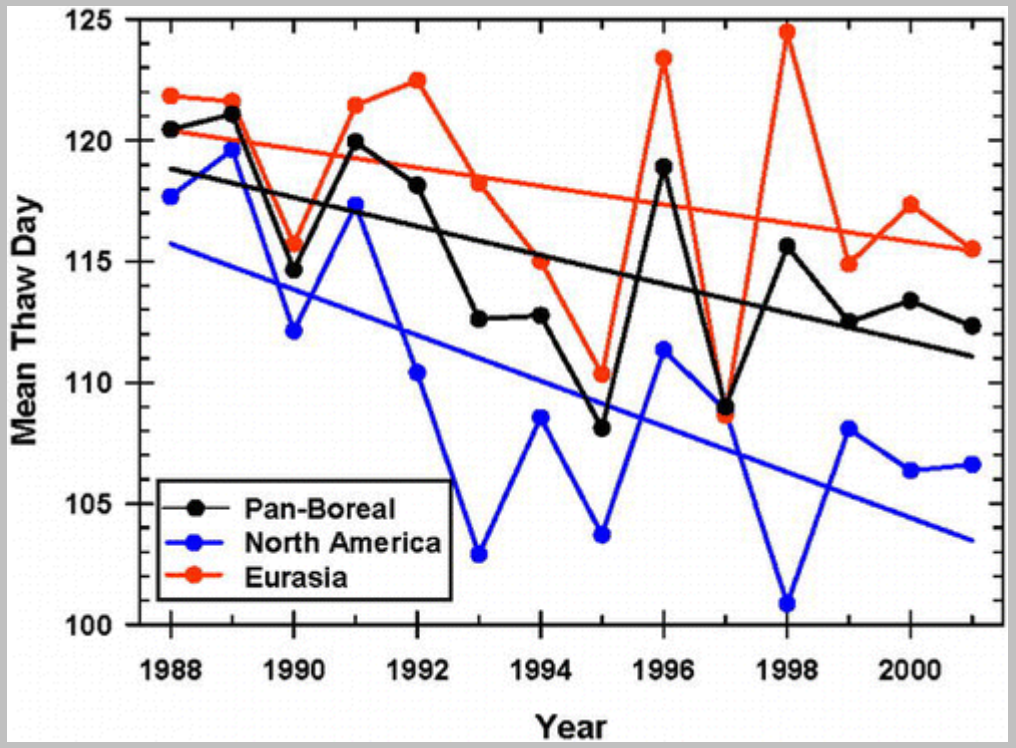
- formed during the last Ice Age

- high ice content

- contains 1-5% carbon

The Arctic is exhibited a trend toward earlier seasonal thawing and growing season onset





Thaw day estimates derived from SSM/I passive microwave radiometer data

McDonald et al., 2004, Env. Res. Lett.

Science Questions and Objectives of Study

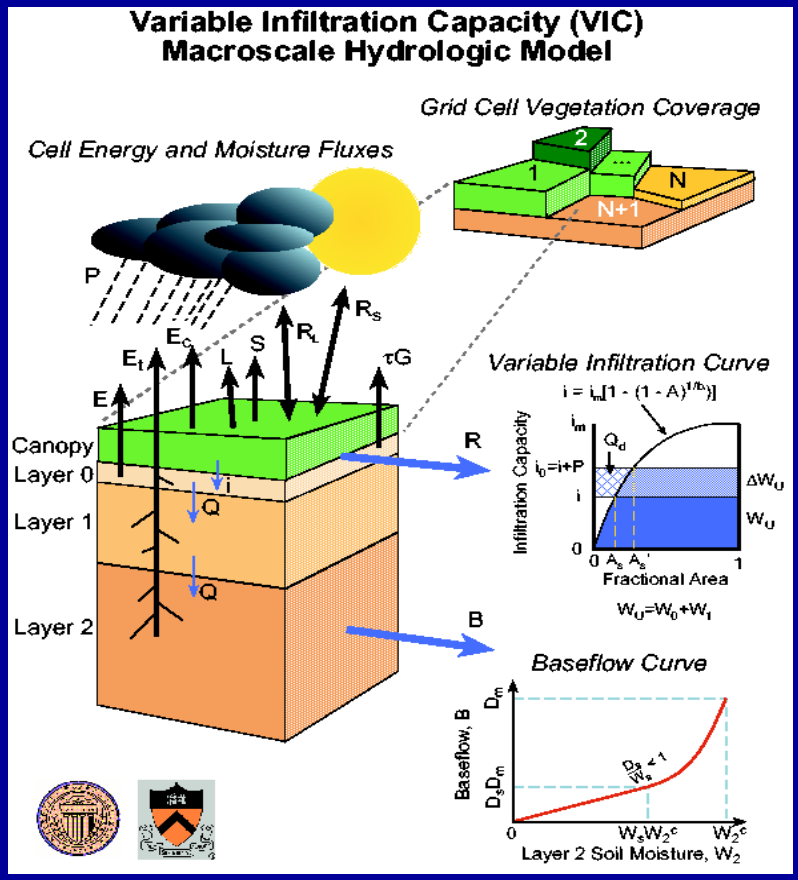
- What is the magnitude of CO_2 and CH_4 fluxes from the land surface, including soils, wetlands and lakes, over seasonal and annual timescales. Which areas are sources and which are sinks?

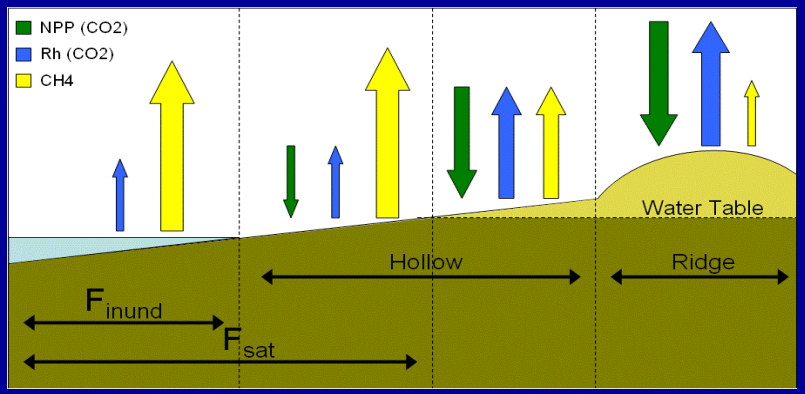
- How will terrestrial ecosystems in Northern Eurasia respond to continued warming, and what are the dominant processes likely to affect future spatial and temporal carbon cycle dynamics?

- Can models which assimilate remote sensing and flux tower data accurately predict carbon spatio-temporal dynamics, from local scales to large region estimates?

Modeling Framework

- VIC hydrology model
  - Large, "flat" grid cells (e.g. 100x100 km)
  - Mosaic of land cover tiles
  - On hourly time step, simulate:
    - Soil T profile (and permafrost)
    - Water table depth Z_{WT}
    - NPP, Rh, Soil Carbon
  - Dynamic Lake-wetland model (Bowling and Lettenmaier 2010)
  - Wetland microtopography
- Link to CH4 emissions model (Walter & Heimann 2000)

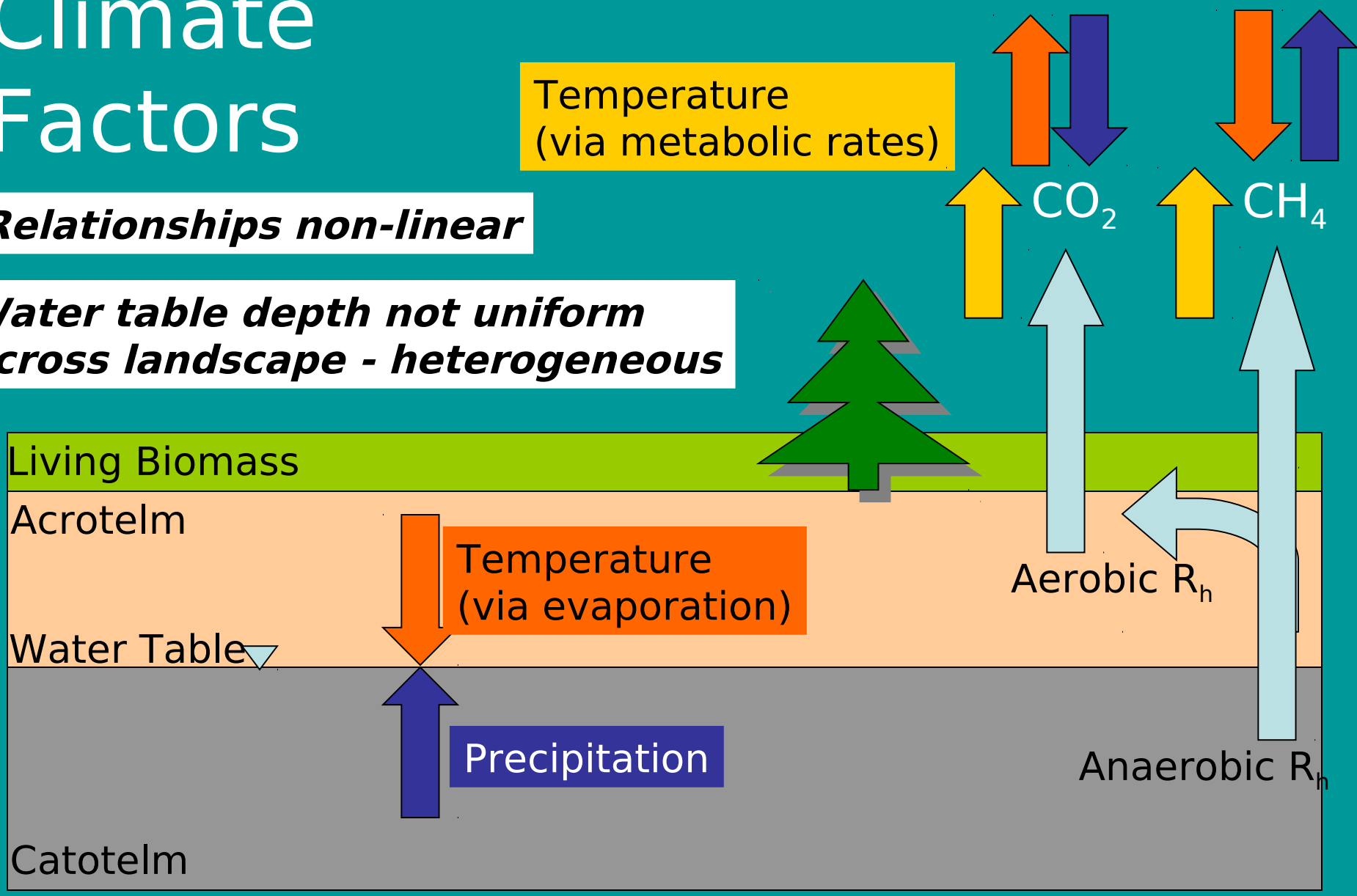




Climate Factors

Relationships non-linear

Water table depth not uniform across landscape - heterogeneous



Note: currently not considering export of DOC from soils

Validation and Parametrization of Models

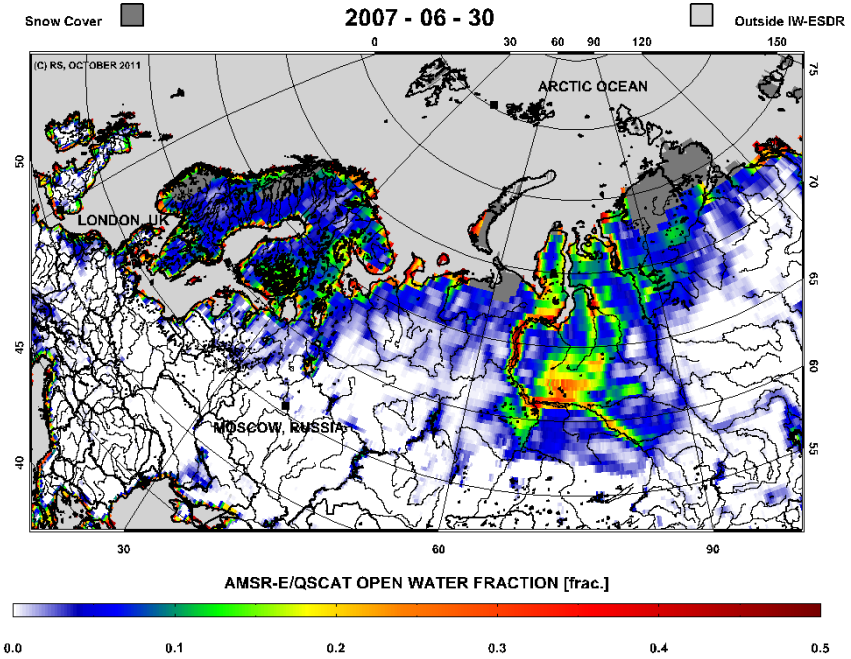
Remote sensing products of fractional inundation extent (25x25 km) are used to capture seasonal and interannual variation of surface water across the NEESPI region

This moderate resolution product is being evaluated against high-resolution PALSAR data for dates on which both are available

Satellite Microwave Remote Sensing of Inundated Wetlands

Eurasia, Wetland Extent Map

– Record Discharge of 2007 –**



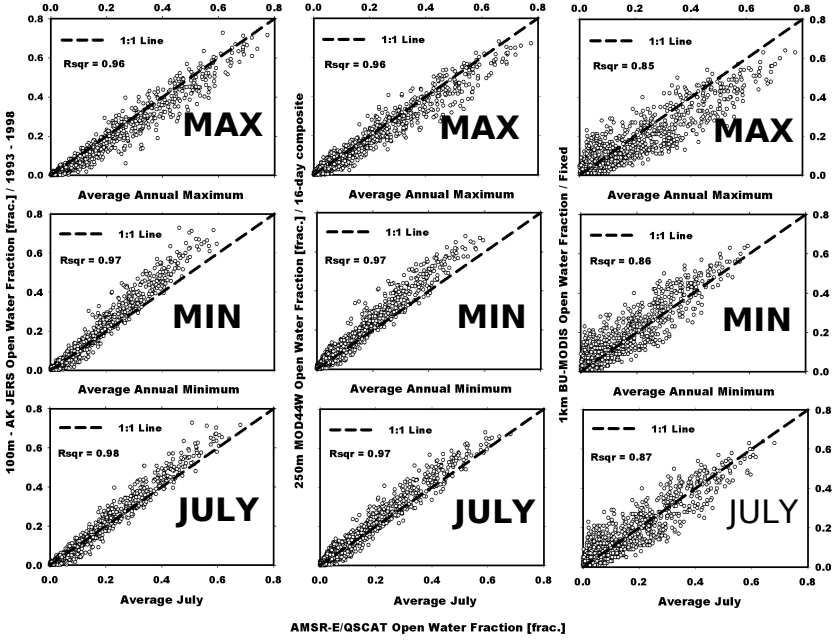
Sensors: AMSR-E/QuikSCAT (IW-ESDR)

Spatial/Temporal Resolution: Global @ 25 km Equal-Area-Grid
Daily/10-Day Averages, 2002-2009,
Limited to Non-Frozen Period

Data Download: wetlands.jpl.nasa.gov

Alaska, Accuracy Assessment

– JERS Wetland Map, MOD44W, BU-MODIS –



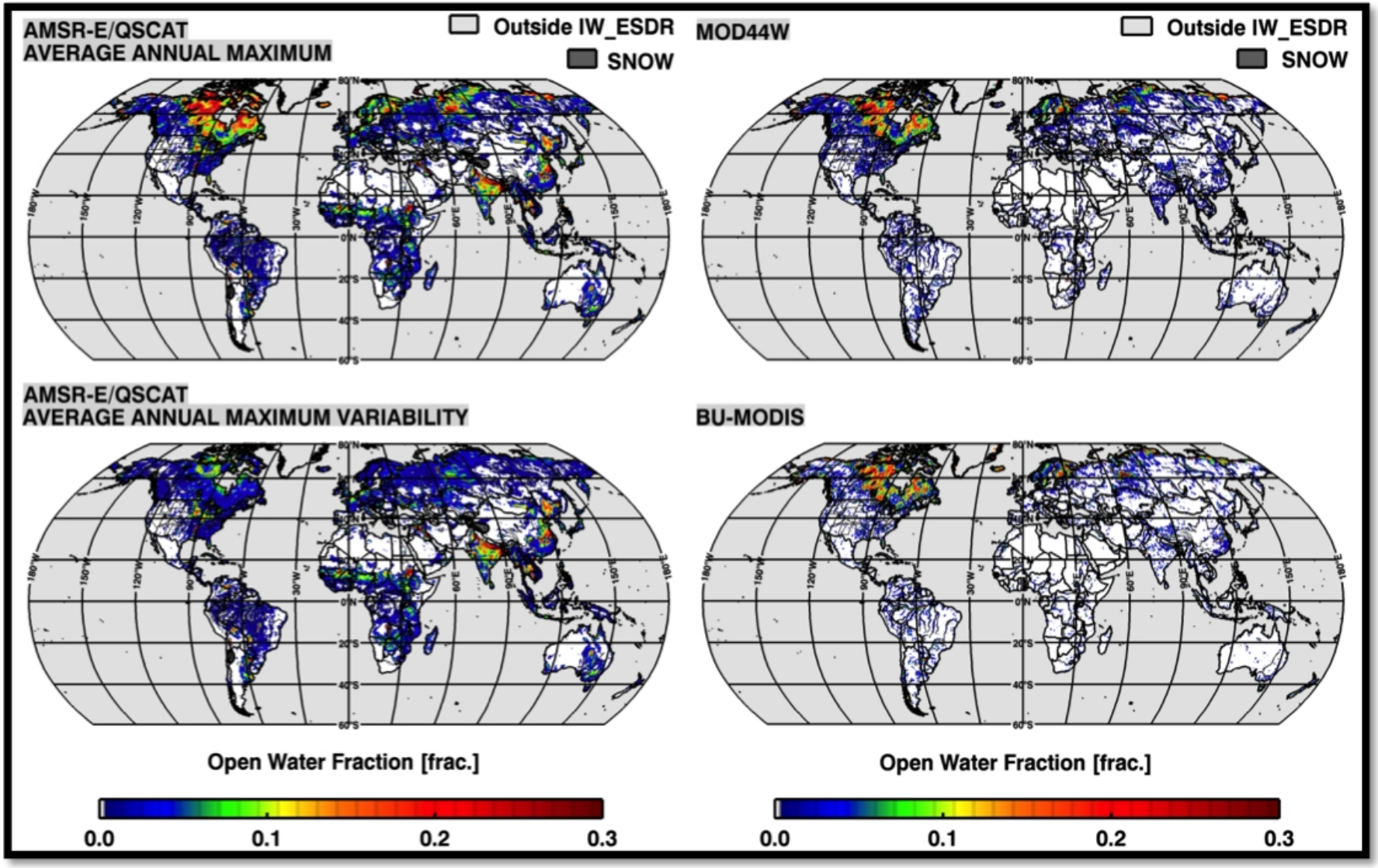
JERS **MOD44W** **BU-MODIS**

JERS wetland extent map**

* Schroeder et al. 2010 * Rawlins et al. 2009

** Whitcomb et al. 2009

Inundated Area 25x25km Global Product Derived From A Combination of AMSR-E and QSCAT Data



Project Co-I Kyle McDonald (CCNY/JPL); PhD Ronny Schroeder (CCNY)

State/Fluxes, 2001-2010

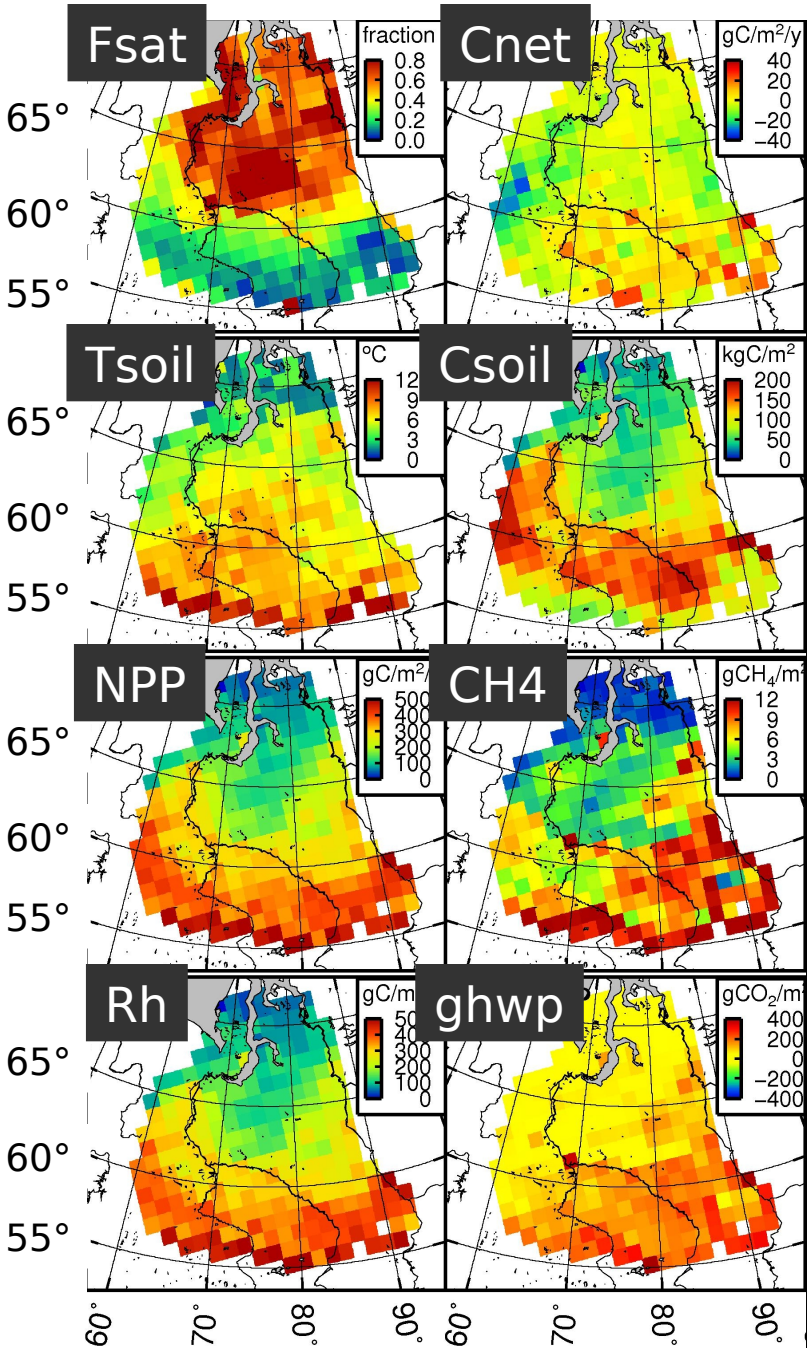
Strong anti-correlation between soil moisture and carbon fluxes

- Fsat (saturated fraction) highest ***north of 60 N***
- Carbon fluxes are highest ***south of 60N***

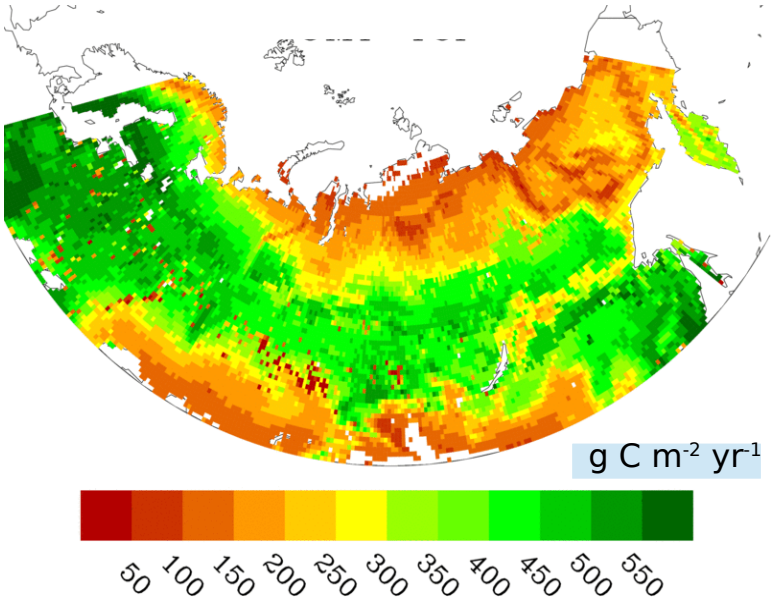
All carbon fluxes very low in continuous permafrost

Bohn et al., 2013 Biogeosciences, submitted

Fluxes per unit wetland area



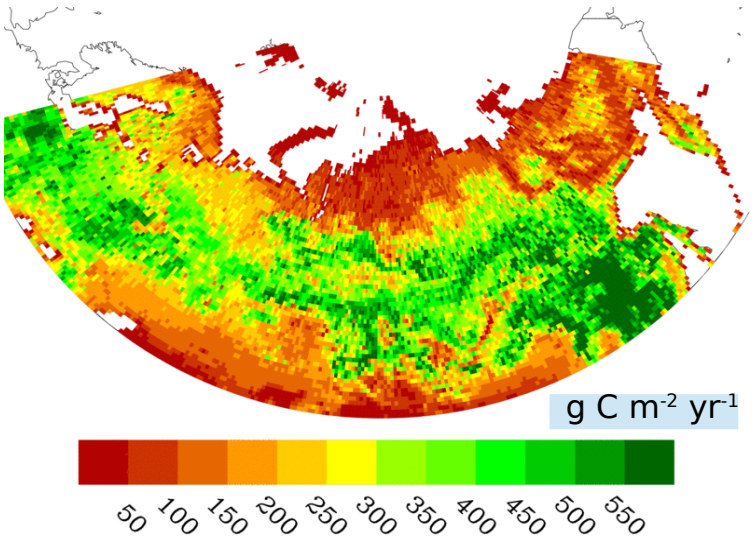
Terrestrial Carbon Flux Model



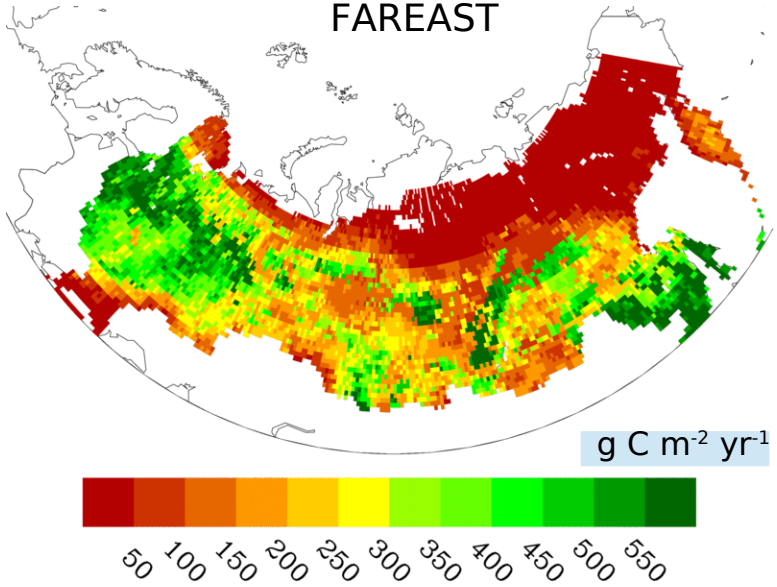
Net Primary Productivity across NEESPI region from three models

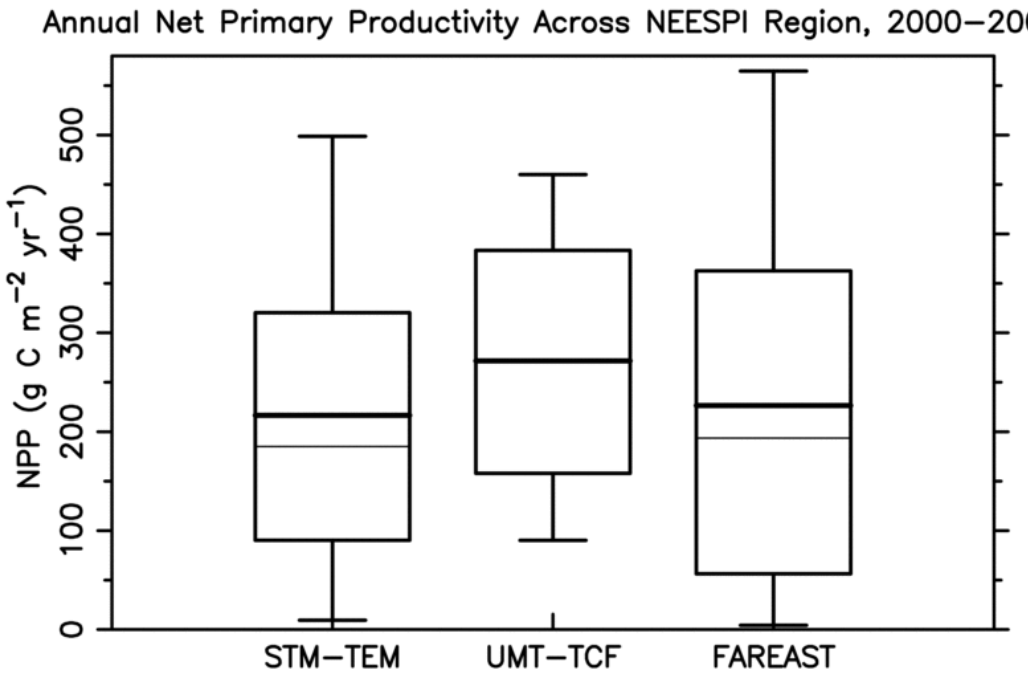
Data courtesy of collaborators A. Dave McGuire (U. Alaska – Fairbanks); Dan Hayes , (ORNL) John Kimball (U. Montana), Hank Shugart (U. Virginia)

TEM6

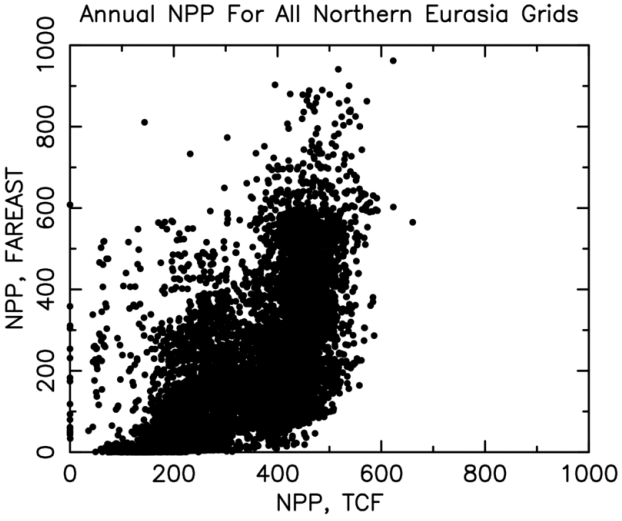


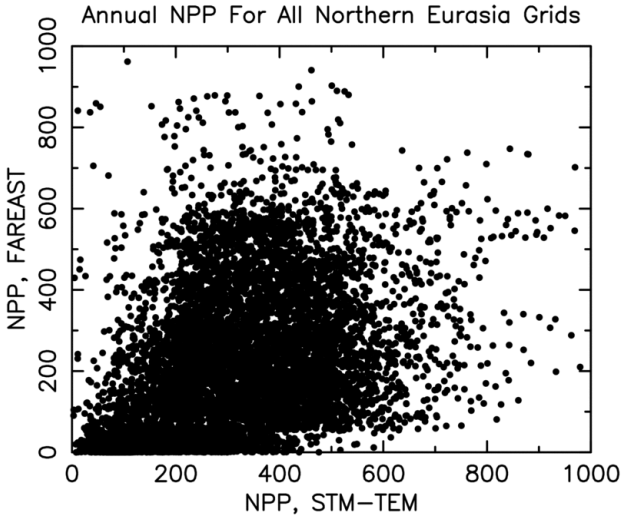
FAREAST

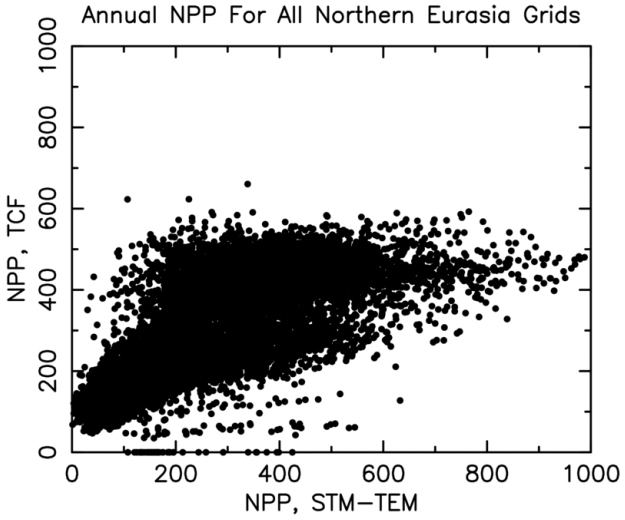




- FAREAST exhibits largest range
- TCF maximum of 450 g m^{-2} yr^{-1}
- Grid-to-grid correlations are limited as expected
- Are interannual variations correlate among models?







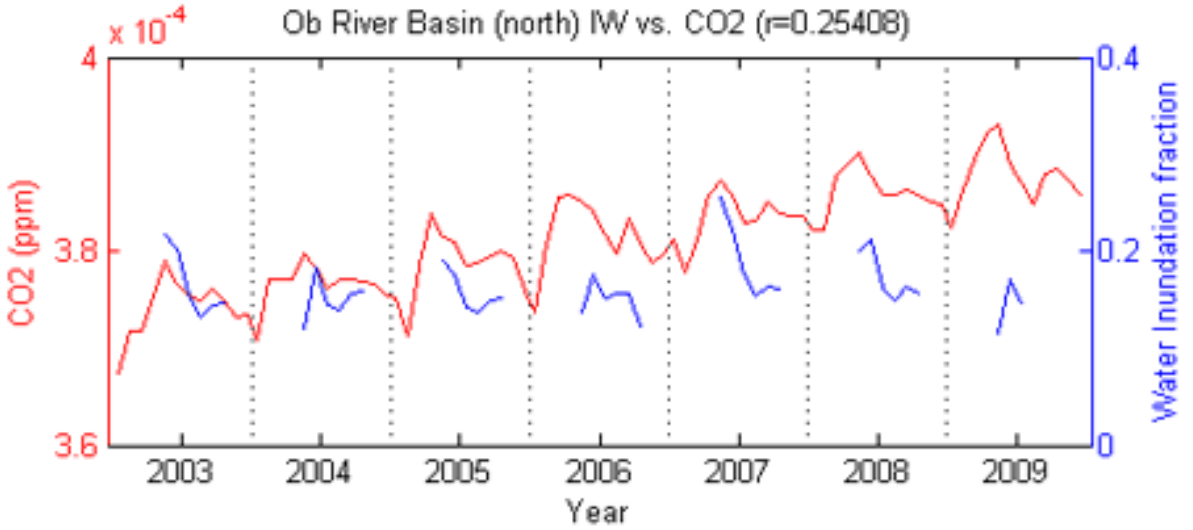
Other TEM6 flux data:

- total carbon emitted in fire
- total carbon emitted in fire as CO_2 (as opposed to CH_4, CO, etc)
- total carbon emitted from the decay of harvested forest and agricultural products
- total flux of dissolved organic carbon (DOC)
- total carbon balance
- net ecosystem exchange (NEE)

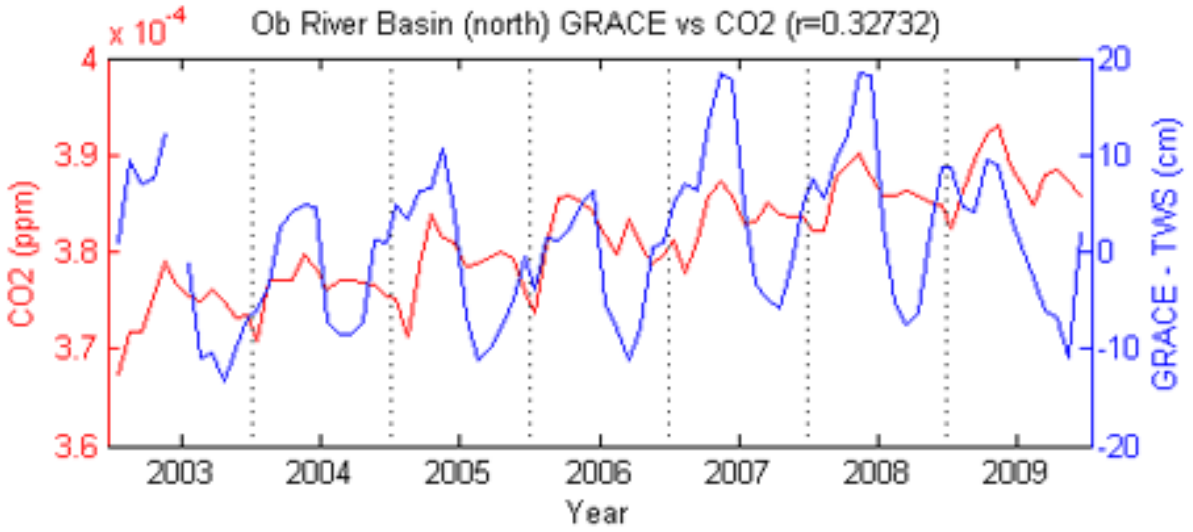
data described in McGuire et al., 2010, Tellus

Correlative analysis between atmospheric carbon and inundated wetland/water storage variations, 2002- 2009

Ob River Basin



AIRS CO_2 is **positively correlated** with surface inundated area

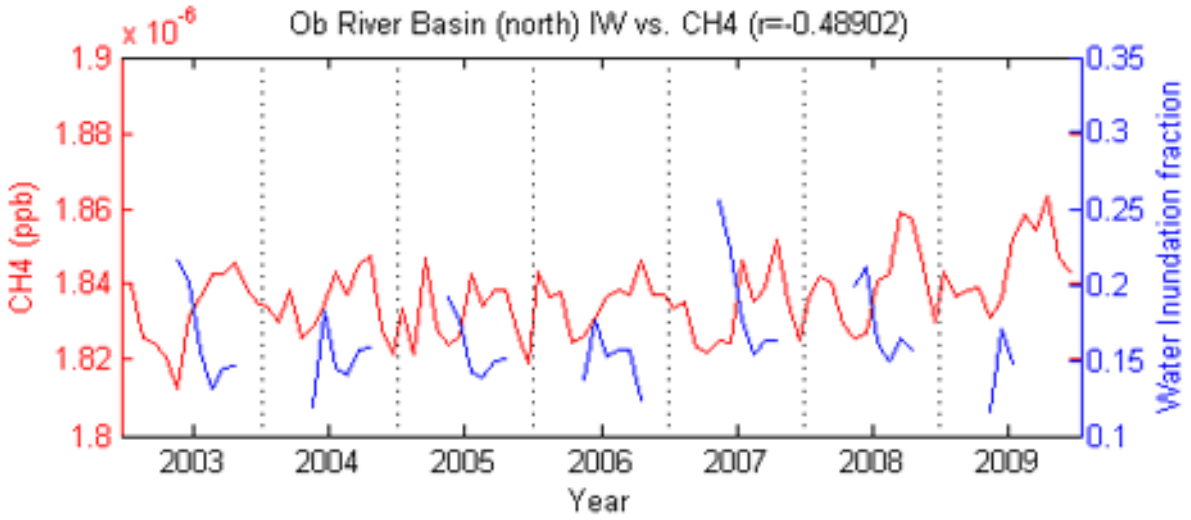


AIRS CO_2 also shows a positive correlation with Total Water Storage

Project Co-I Kyle McDonald (CCNY/JPL); PhD students Ronny Schroeder and Kat Jensen (CCNY)

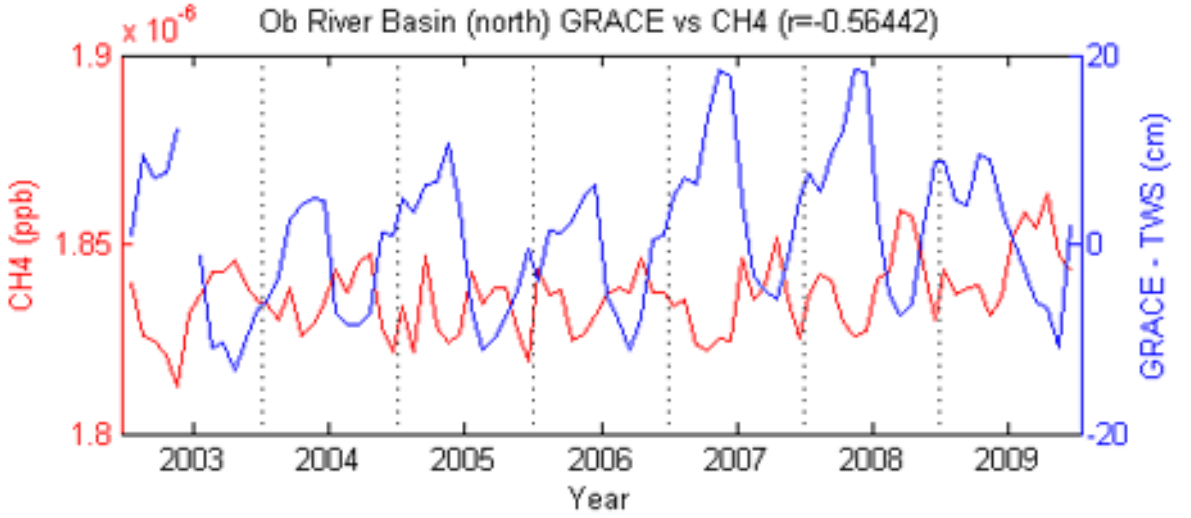
Correlative analysis between atmospheric carbon and inundated wetland/water storage variations, 2002- 2009

Ob River Basin



Land surface methane flux from AIRS is **positively correlated** with surface inundated area

Inundated area time series is limited to thawed period



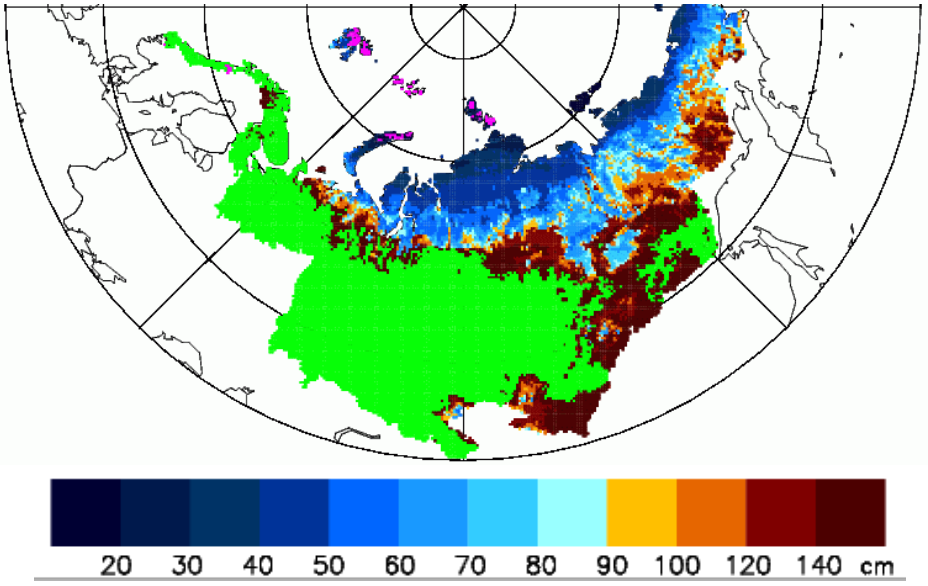
Methane flux and terrestrial water storage from GRACE are **inversely correlated**

Project Co-I Kyle McDonald (CCNY/JPL); PhD students Ronny Schroeder and Kat Jensen (CCNY)

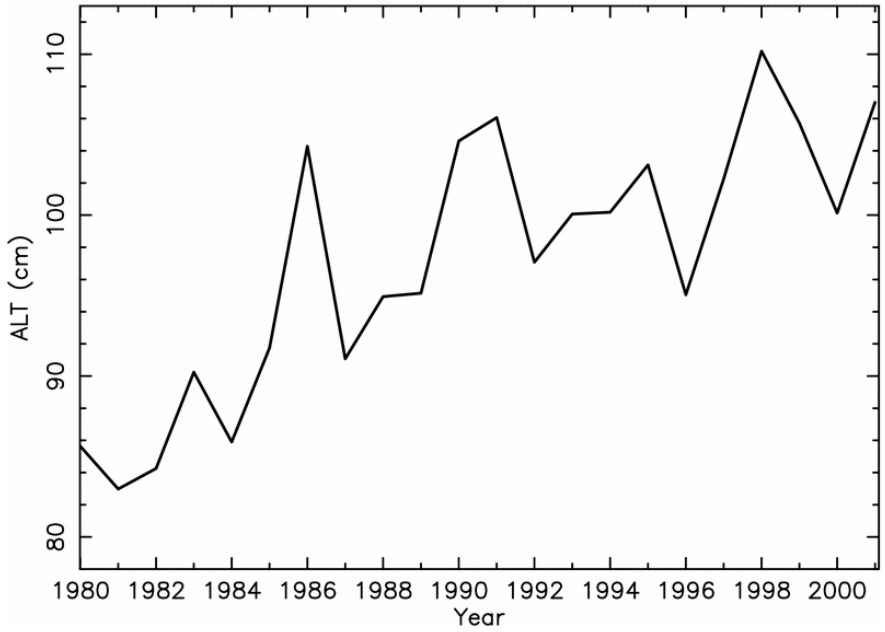
Estimates of maximum seasonal active layer thickness (ALT) from Pan-Arctic Water Balance Model (PWBM)

Mean Over 1980-1999

Rawlins et al., JAMES, submitted



Average ALT for region of continuous permafrost in Lean River Basin



Can validate VIC and PWBM models with International Permafrost Association's International Polar Year Thermal State of Permafrost (TSP) observations

NASA project: Permafrost Dynamics within the Northern Eurasia Region and Related Impacts on Surface and Sub-Surface Hydrology, PI: V. E. Romanovsky

Romanovsky et al., 2010, Permafrost and Periglacial Processes

Wetland Model Intercomparison over West Siberia

- Bohn et al (in preparation)
- Analyze results of the WETCHIMP wetland model intercomparison project (Melton et al., Biogeosciences, 2013)
- Compare to:
  - In situ CH4 observations of Glagolev et al. (2011)
  - Remotely sensed observations of inundation, saturation (Schroeder et al., 2010; Papa et al., 2010; Bohn et al., 2013)
- Overarching Question:
  - What is the present state of large-scale modeling of boreal wetland methane emissions?
- Subsidiary Questions:
  - How sophisticated must a wetland model be to reproduce observed large-scale CH4 emissions?
  - How much error comes from estimates of contributing area vs. per-unit-area CH4 fluxes?

Project Next Steps

- Incorporate DOC leaching into VIC lakes model

- Use in situ soil temperature observations to validate model estimate of freeze/thaw dynamics

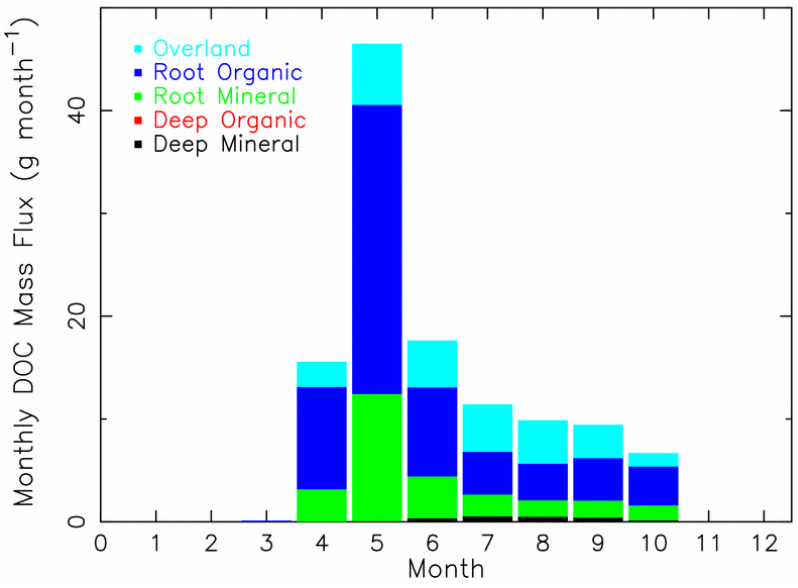
- Link FAREAST vegetation stand model with VIC in interactive simulation

- Apply model framework to full NEESPI region

- Synthesis of results

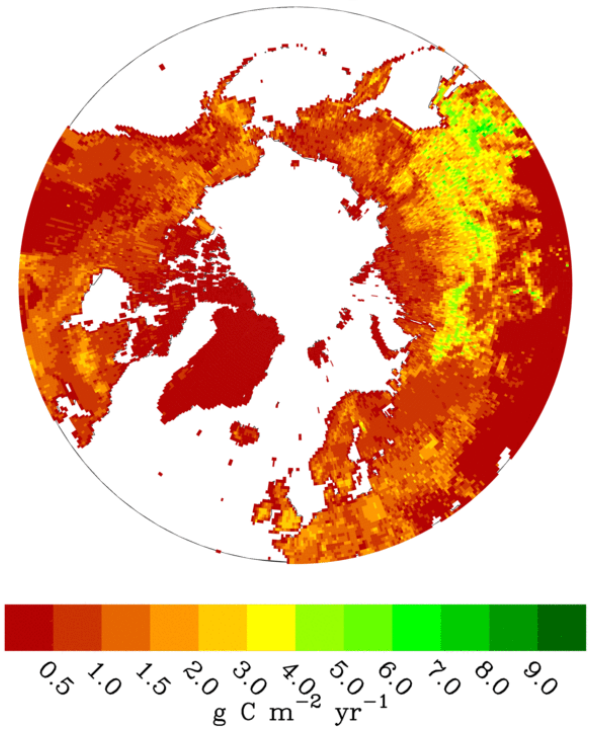
Methodology for DOC leaching

- Follows recent work using TEM6 model
- Incorporate GPP/NPP and landcover from remote sensing data products
- Parameterize DOC leaching as a function of soil temperature, soil moisture, density of soil carbon in model layer(s)
- Route water through stream networks of river basins to Arctic ocean



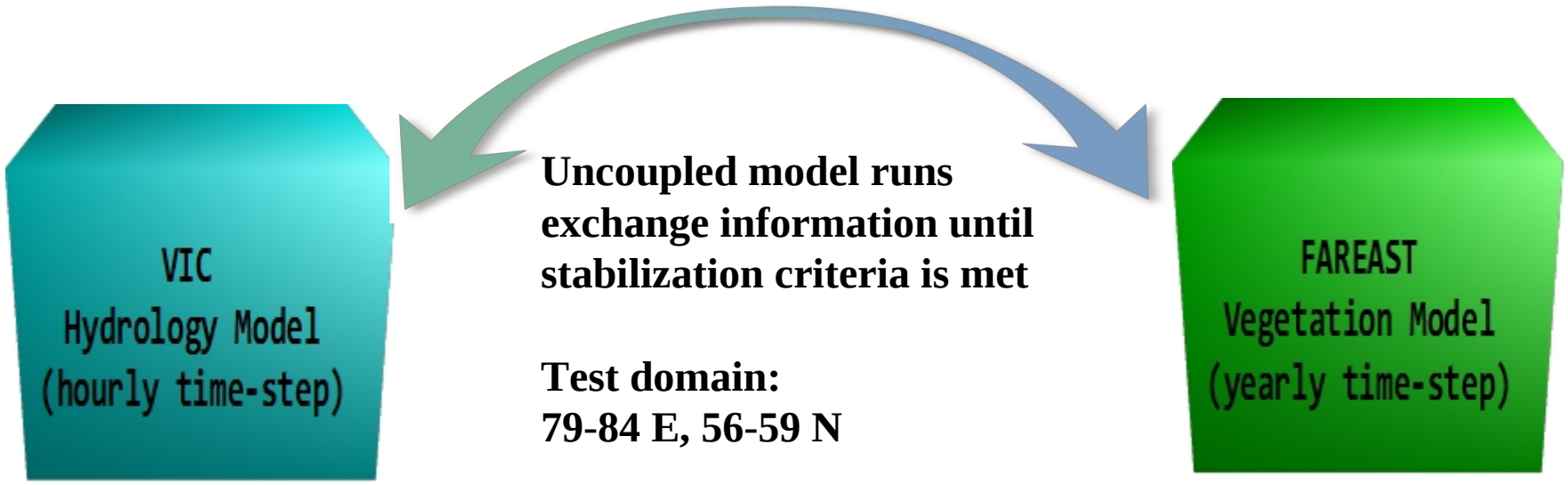
Initial tests of DOC leaching as a function of water yield using Pan-Arctic water Balance Model (Rawlins, 2003)

TEM6 DOC Leaching Rates



data from collaborators A. D. McGuire and Dan Hayes

Coupling of VIC and FAREAST Vegetation Model



Uncoupled model runs exchange information until stabilization criteria is met

Test domain:
79-84 E, 56-59 N

Inputs from FAREAST
-Dynamic forest cover statistic- forest areal extent, species
-percentage, average tree height, leaf area index (LAI)
-Soil water content

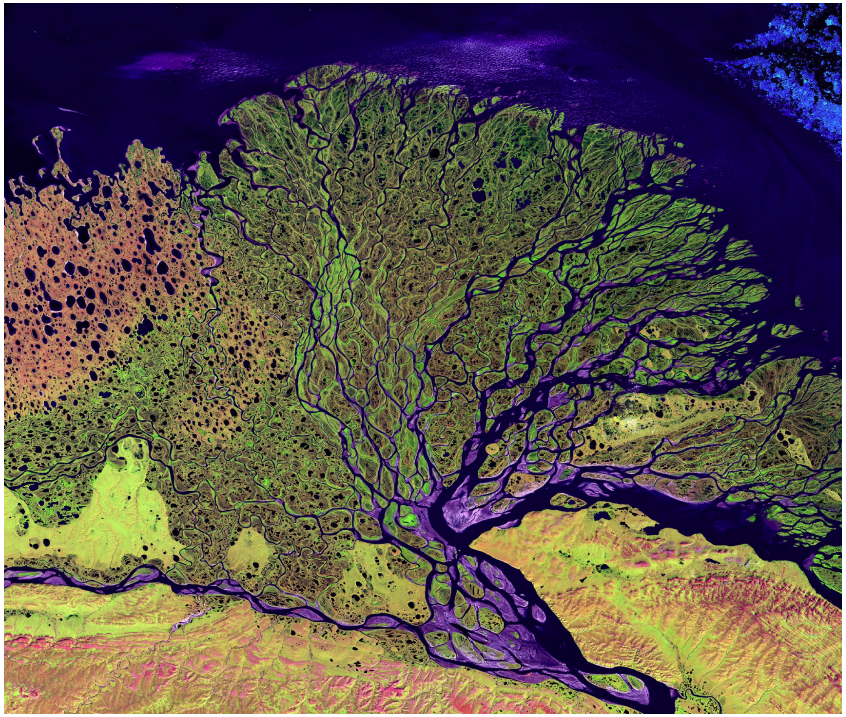
Outputs to FAREAST
-Evapotransipiration output
-Soil moisture percentiles
-Carbon fluxes

Inputs from VIC
-Evapotranspiration (mapped photosynthesis and species)
-Soil moisture
-Carbon fluxes for forest domain

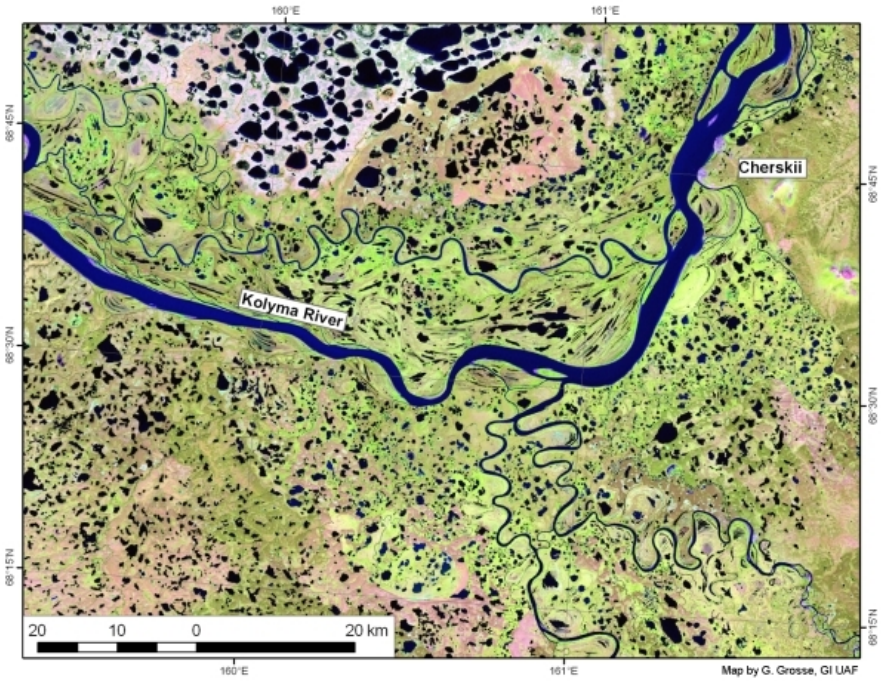
Outputs to VIC
-Dynamic forest cover statistics (% of grid cell defined as ‘forest’
-Soil water content

Major Research Challenge: upscaling methane fluxes from thermokarst lakes

Efforts are needed to better understand the relationship between soil and peat carbon inputs to lakes via thermokarst erosion and methane emissions from lakes at the regional scale.



The Lena River Delta, dominated by Yedoma uplands and thermokarst lakes. Image taken by LANDSAT (source: NASA).
http://geolog.egu.eu/2013/03/25/imaggeo-on-mondays-alas-allases-are-abound/



Map by collaborator Guido Grosse, U. Alaska-Fairbanks