LCLUC Interactions with Arctic Hydrology: Links to Carbon Cycle

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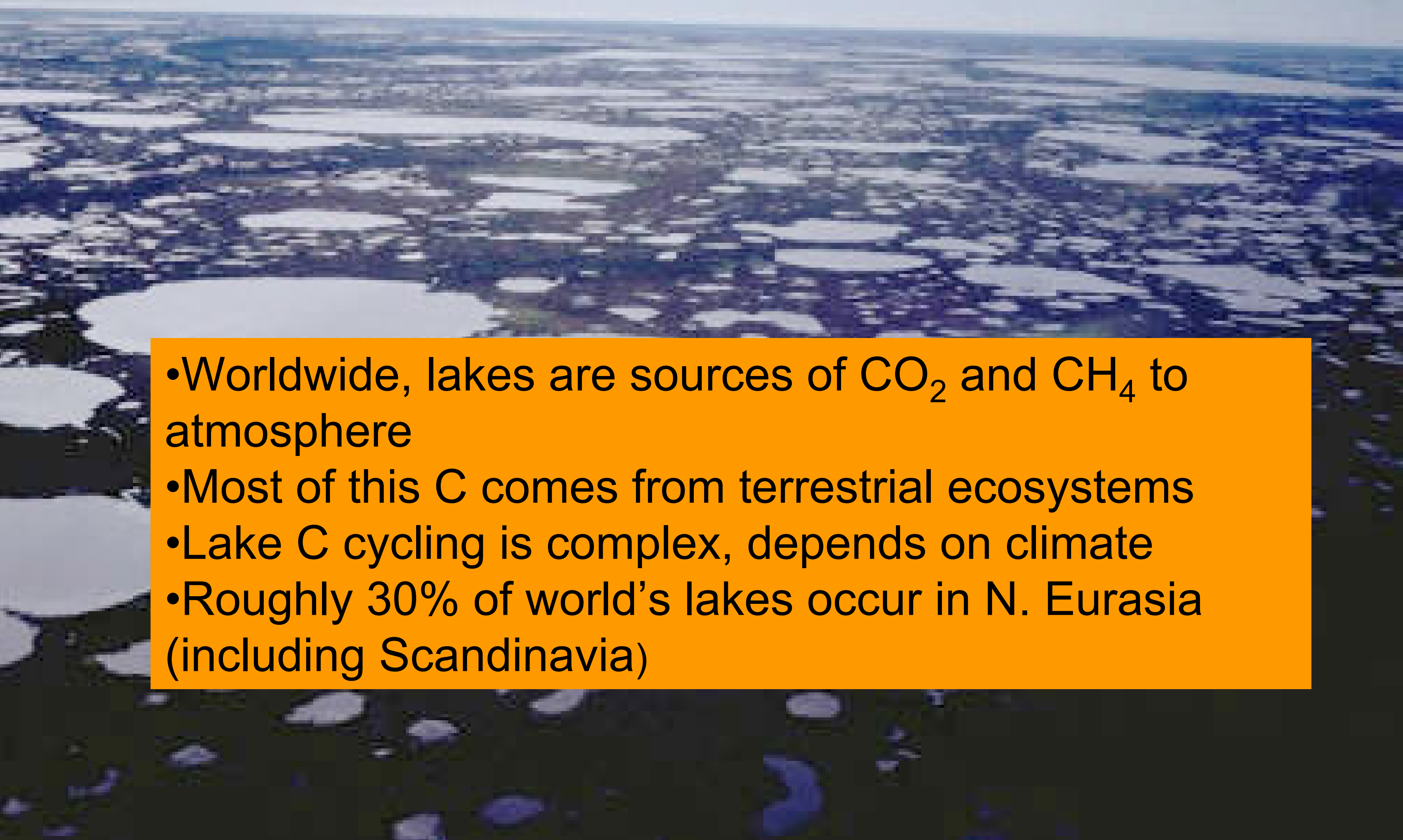
Outline

1. Lakes, Permafrost, and Methane
2. River Discharge, Frozen Soil, and DOC Export
3. Peatlands, Water Table Depth, and Greenhouse Gases
4. Remote Sensing, Hydrology, and Carbon Cycle

Lakes, Permafrost, and Methane



- Worldwide, lakes are sources of CO_2 and CH_4 to atmosphere
- Most of this C comes from terrestrial ecosystems
- Lake C cycling is complex, depends on climate
- Roughly 30% of world’s lakes occur in N. Eurasia (including Scandinavia)

Permafrost Lakes

- Permafrost impedes subsurface drainage
- Ponds/lakes form in flat areas underlain by permafrost
- Dramatic seasonal inundation cycle (snow melt)

(Bowling et al. 2003)

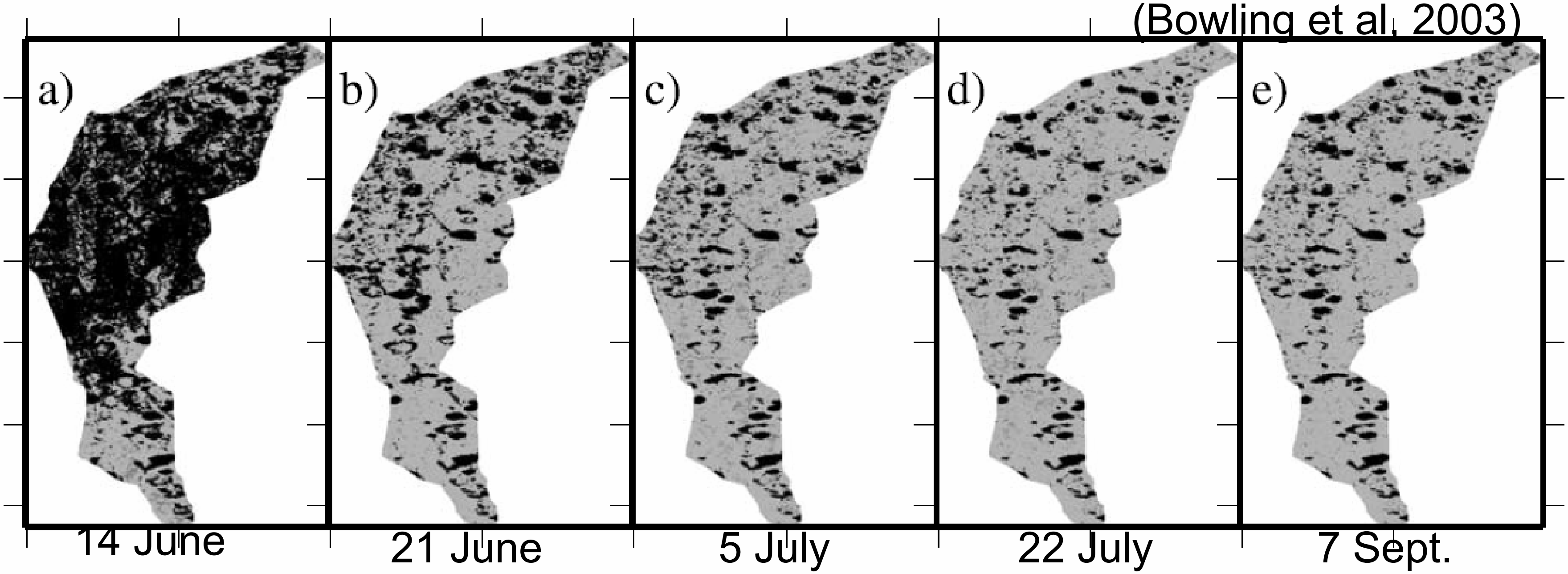
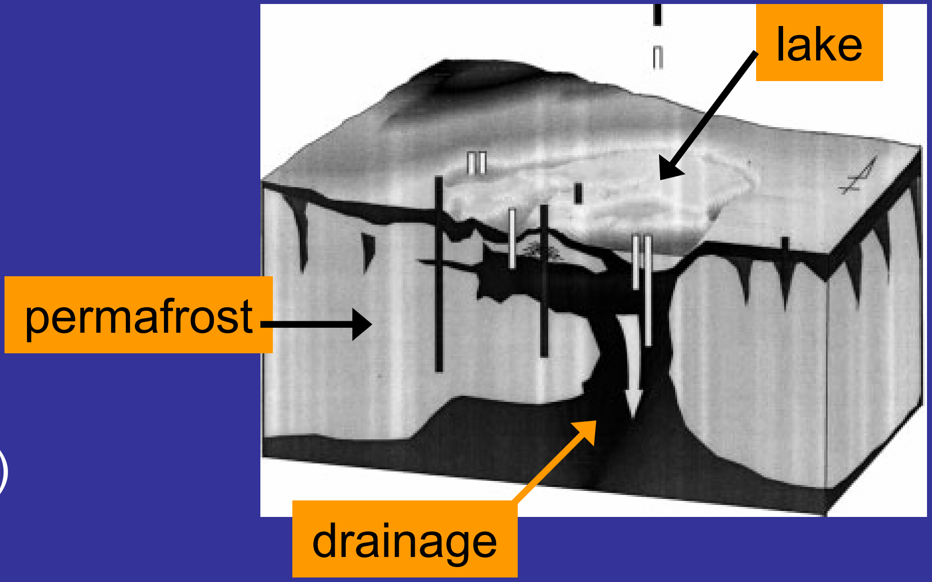


Figure 7. Change in saturated extent (solid areas) of the Putuligayuk River basin from classified SAR images: (a) 14 June 2000, (b) 21 June 2000, (c) 5 July 2000, (d) 22 July 2000, and (e) 7 September 2000.

Thaw Lakes

- Lakes can actively thaw the permafrost, due to albedo feedback
- Especially active in ***thermokarst*** landscapes
- Over many years, can eventually break through permafrost and drain → lake disappears
- Natural cycle of inception, growth, drainage
- Thaw rate depends on climate



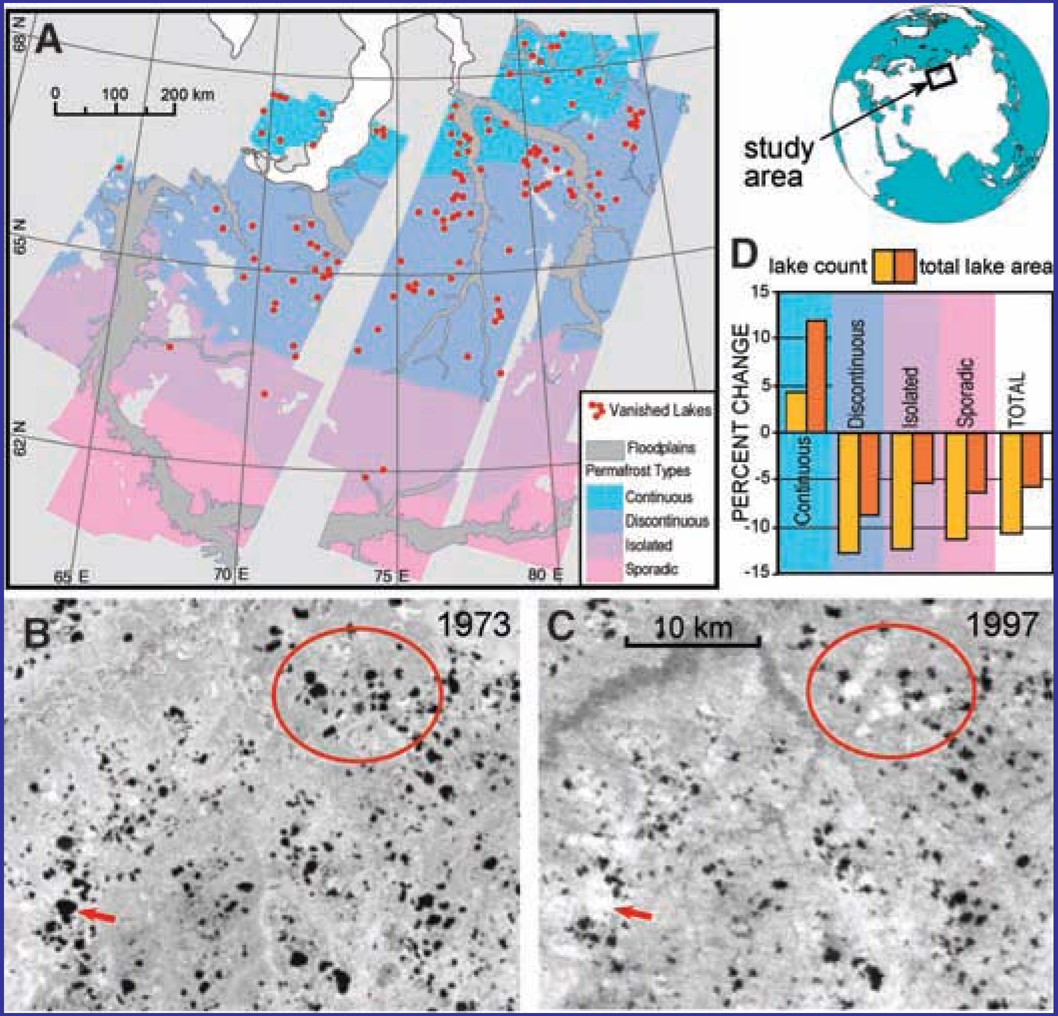
(Yoshikawa and Hinzman, 2003)

Changing Lake Extent

In W. Siberia, between 1973 and 1997:

- Continuous Permafrost: 12% ***increase*** in lake area
- Discontinuous, etc: 11-13% ***decrease*** in lake area
- Northward shift in lake distribution

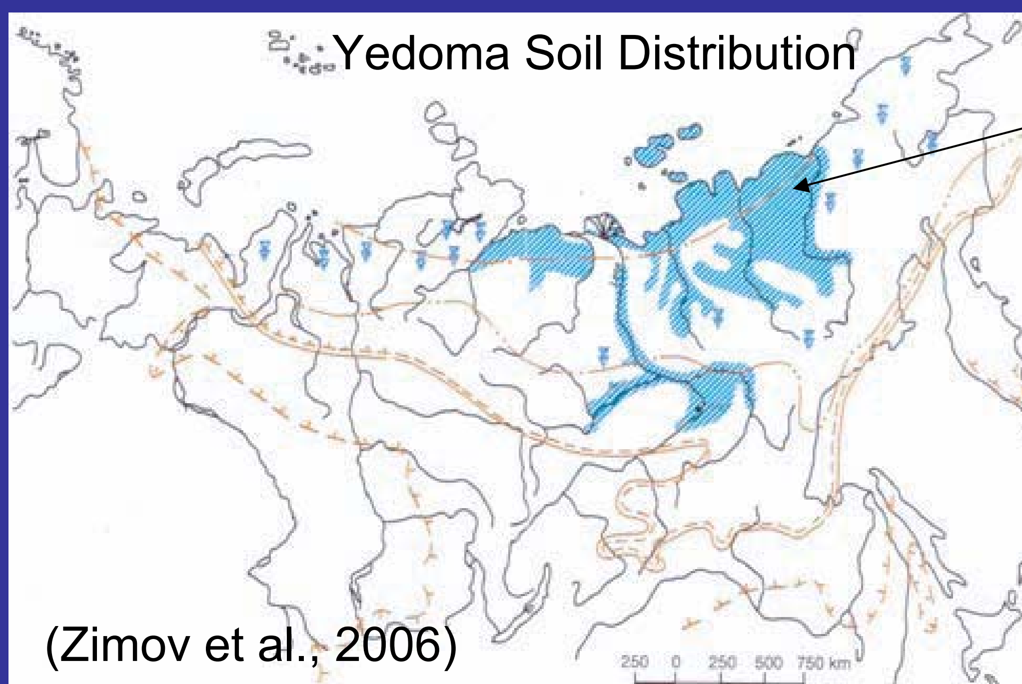
Potential for monitoring degradation of permafrost with remote sensing



(Smith et al., 2005)

Link to Carbon: Yedoma Soils

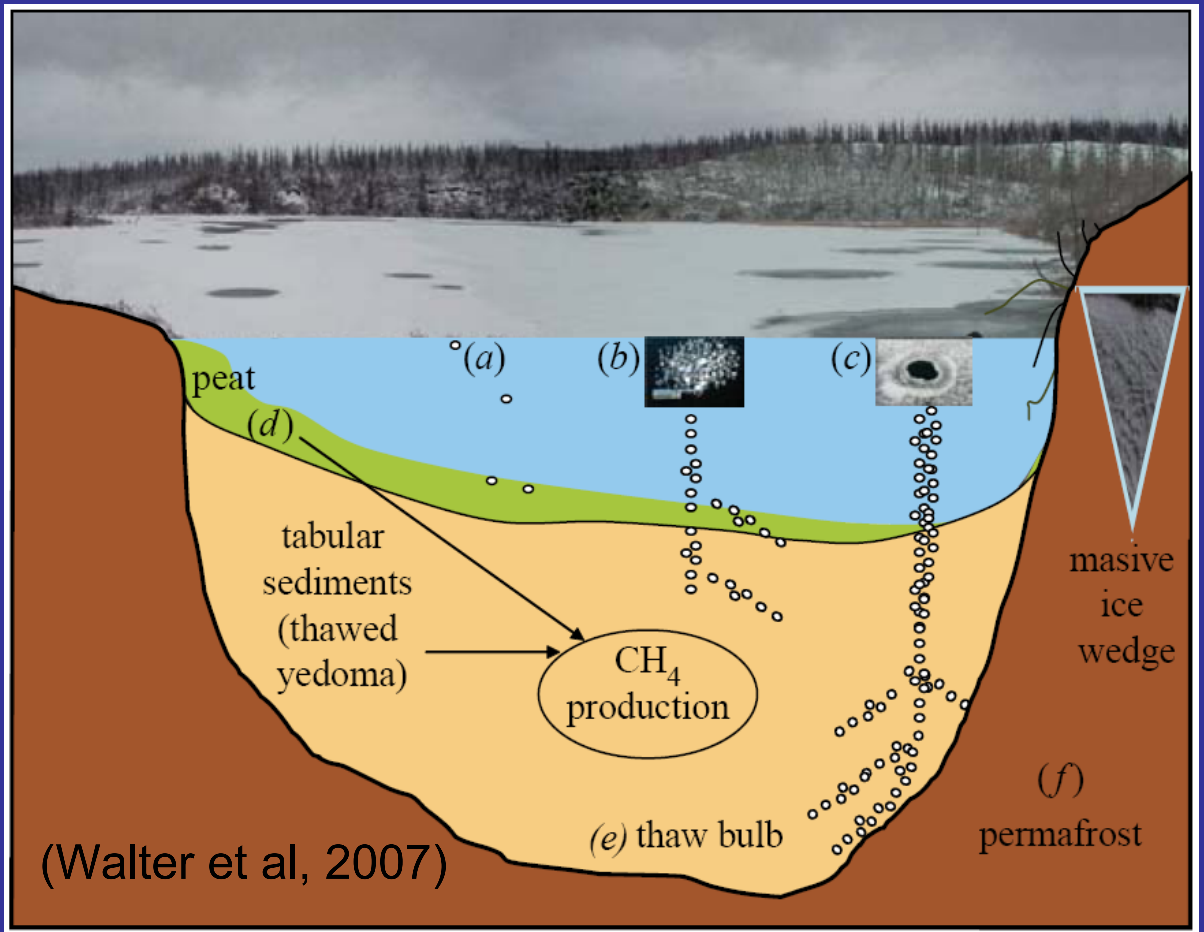
- Much of N. Eurasia was not glaciated during last ice age
- Exposed areas accumulated large amounts of C (***yedoma*** soils)
- Permafrost has stabilized labile C in soils
- No chance to decompose … yet



organic rich soil

Methane Emissions

- Thaw lakes in yedoma regions actively thaw surrounding C-rich soil
- Anaerobic respiration → methane production
- Methane emissions larger than previously thought (Walter et al, 2006)
- If all C in yedoma soils were to thaw and enter atmosphere, C content of atmosphere would double
- Growth rate of lakes is a positive feedback to permafrost melt and c release



River Discharge, Frozen Soil and DOC Export

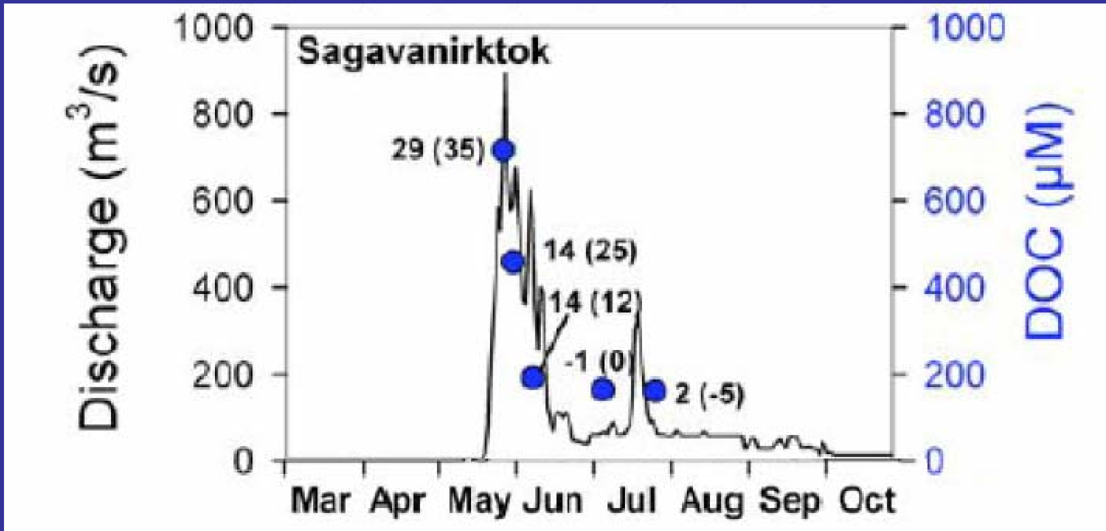
- Export to ocean of Dissolved Organic Carbon (DOC) via rivers: major loss term in terrestrial carbon budget (Kling et al., 1991)
- Not well-understood

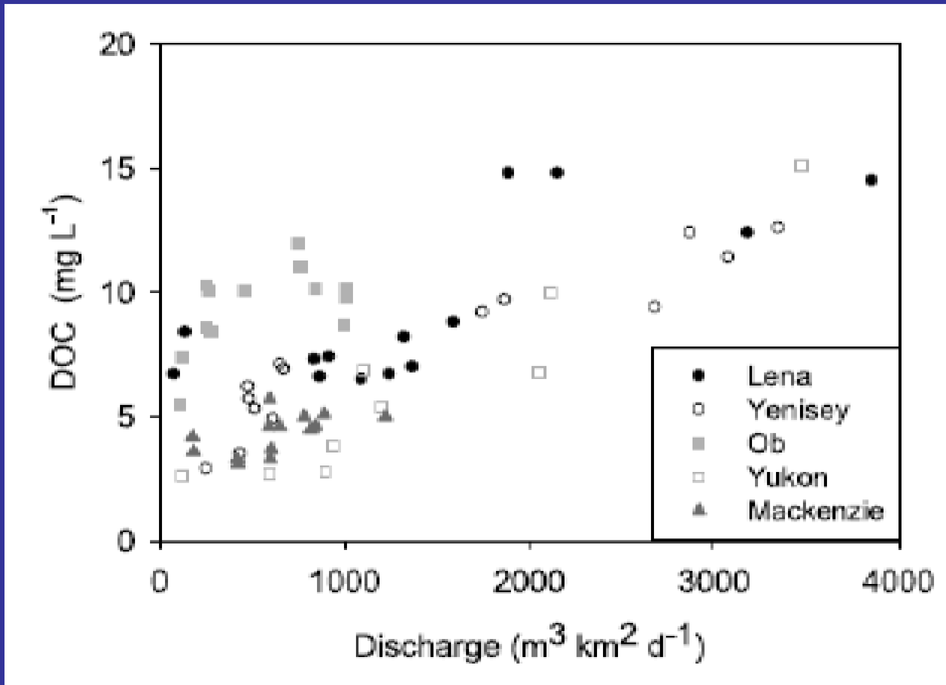
DOC and Discharge

Alaska (Holmes et al, 2008)
- Seasonal DOC proportional to discharge
- Peak DOC during snow melt freshet

Pan-Arctic (Raymond et al, 2007)
- Daily DOC proportional to discharge
- Youngest C during snow melt
- Older C during low flows

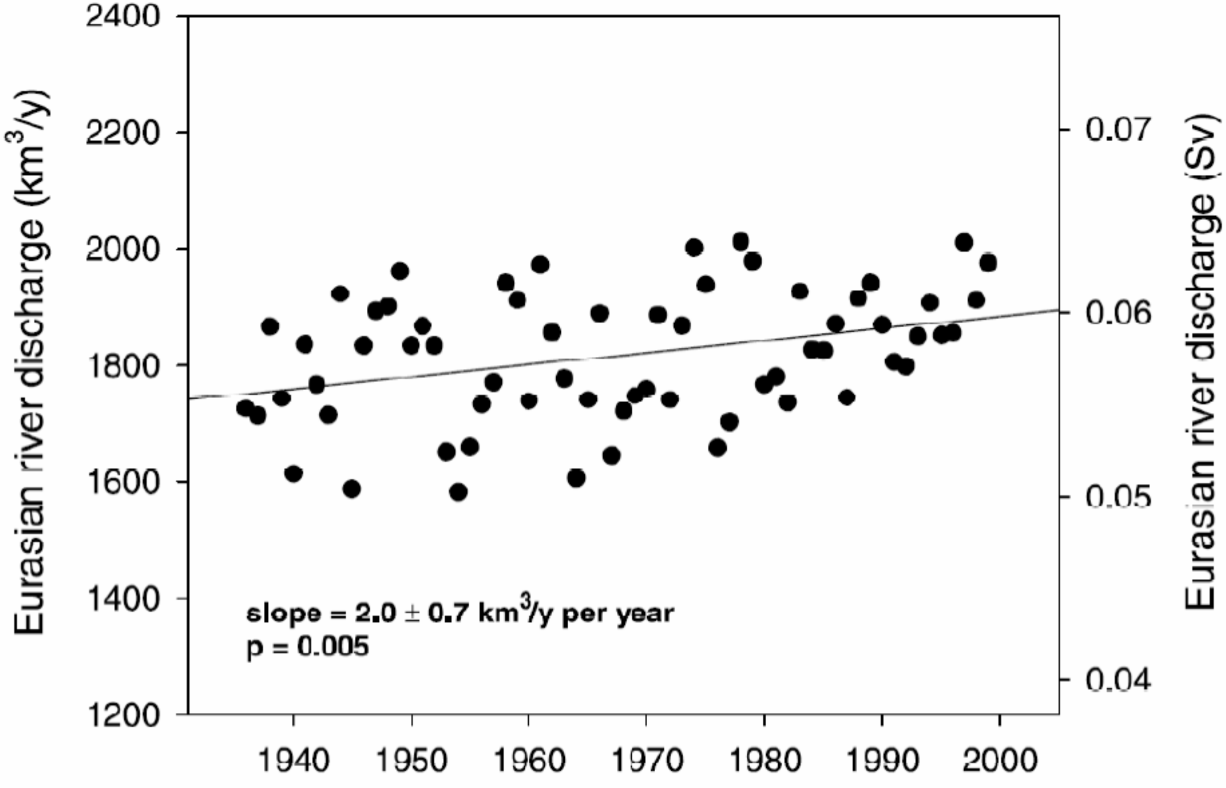
Positive relationship between DOC and flow





River Discharge Trends

- Annual discharge of major N. Eurasian rivers has increased over last 60 years (Peterson et al, 2002)
- Implications for DOC export?



Peterson et al. (2002) Science

Seasonal Trends

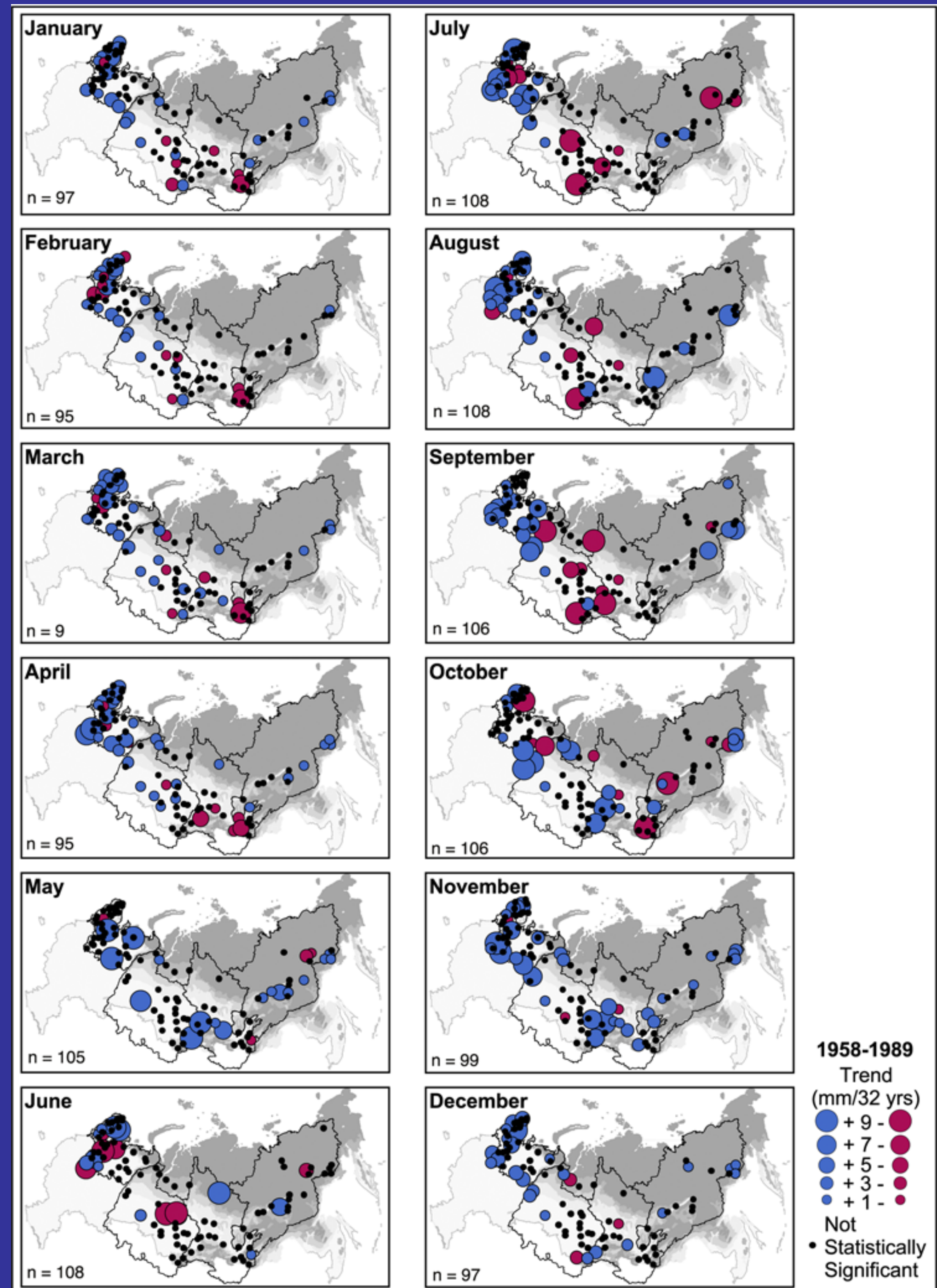
1958-1989 and 1933-1999

- Significant increases in monthly flows widespread for ***low-flow*** months (Nov-May)
- True for both permafrost and non-permafrost basins

(Smith et al, 2007)

- Fewer significant trends in high flows

(Shiklomanov et al, 2007)



Causes?

- Increasing low flows: increased groundwater flux
- Both permafrost and non-permafrost regions: permafrost degradation doesn’t explain everything
- Less severe soil freeze in winter (greater permeability) (Frauenfeld et al, 2004)?
- Changes in precipitation?

Implications for C budgets

- Increasing annual discharge: greater DOC export?
- Increasing low flows: greater export of older, less labile C?
- Probability of respiration en route to ocean vs burial in sediments?

DOC and Permafrost
(Frey and Smith, 2005)

Warm/non-permafrost basins:

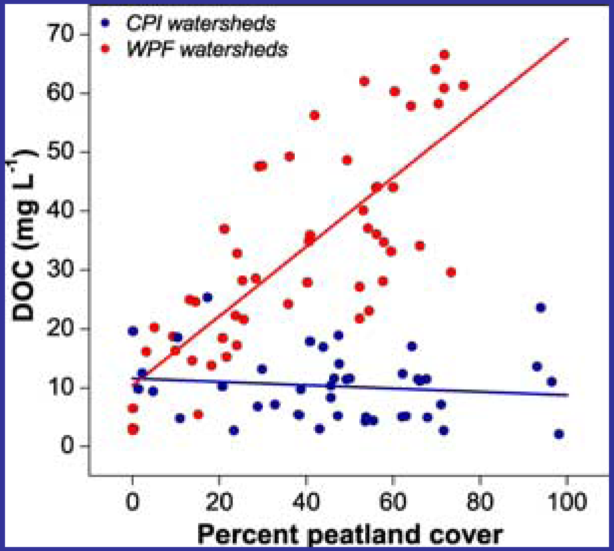
- DOC proportional to
  - Mean Annual Air Temp (MAAT)
  - Percent peatland cover

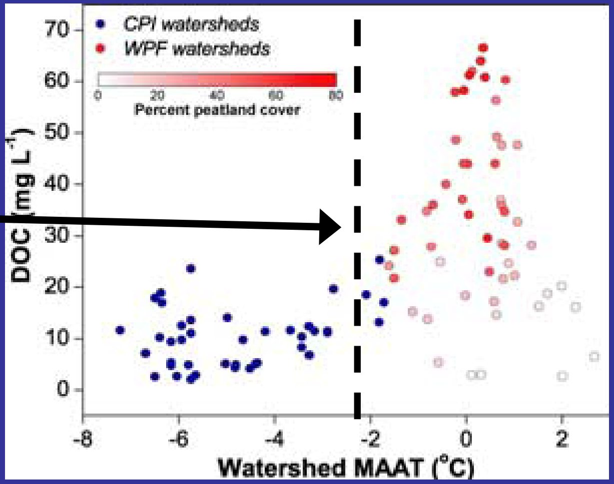
Cold/Permafrost basins:

- Constant low DOC

Division between cold/warm basins: MAAT = -2 °C

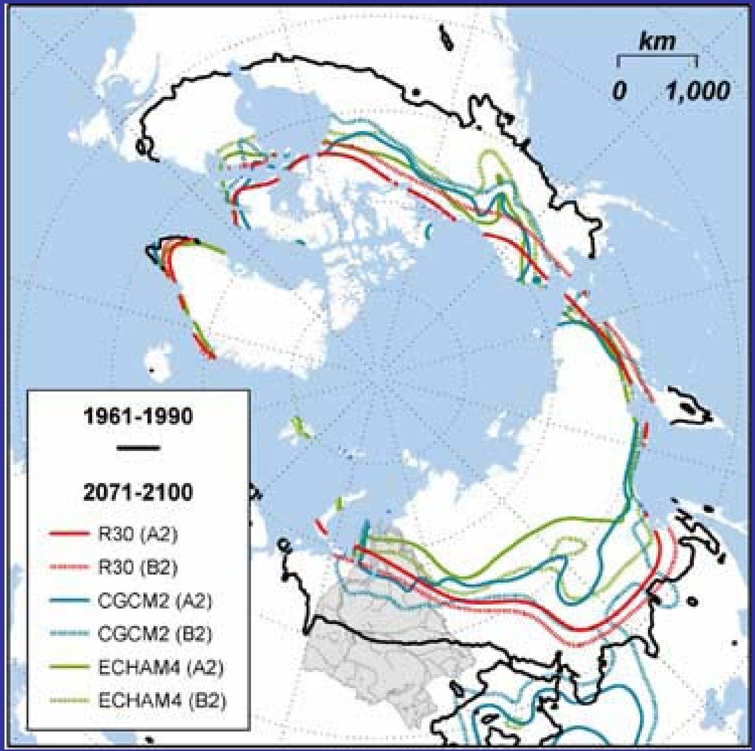
Does permafrost degradation mobilize DOC?





Possible Future DOC Export
(Frey and Smith, 2005)

- Simulations: -2 °C Isotherm predicted to shift northward substantially by 2100
- If current relationships between DOC and MAAT continue to hold, annual DOC export to Arctic Ocean could increase by 29-46%



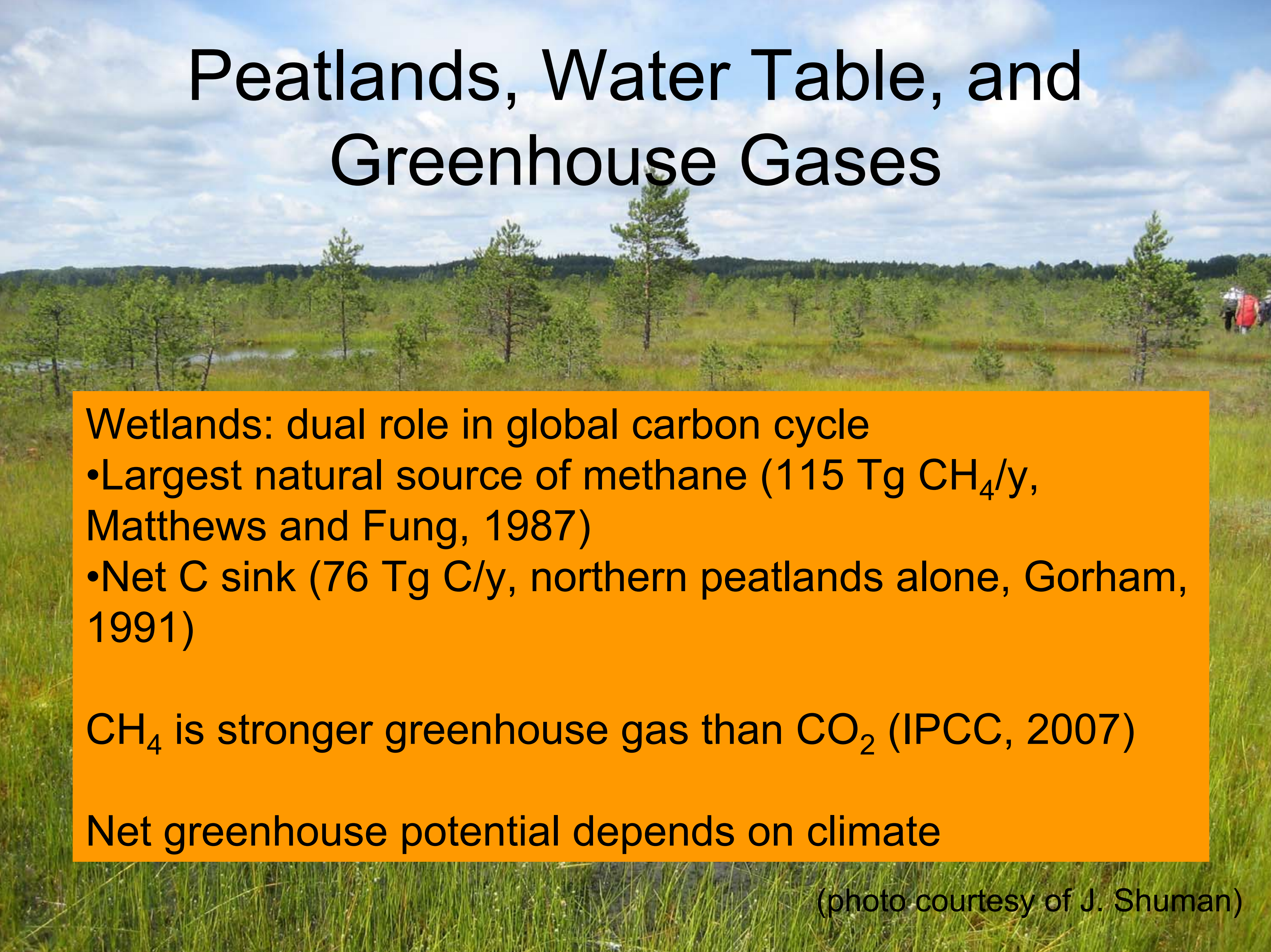
Peatlands, Water Table, and Greenhouse Gases

Wetlands: dual role in global carbon cycle

- Largest natural source of methane (115 Tg CH_4/y, Matthews and Fung, 1987)
- Net C sink (76 Tg C/y, northern peatlands alone, Gorham, 1991)

CH_4 is stronger greenhouse gas than CO_2 (IPCC, 2007)

Net greenhouse potential depends on climate

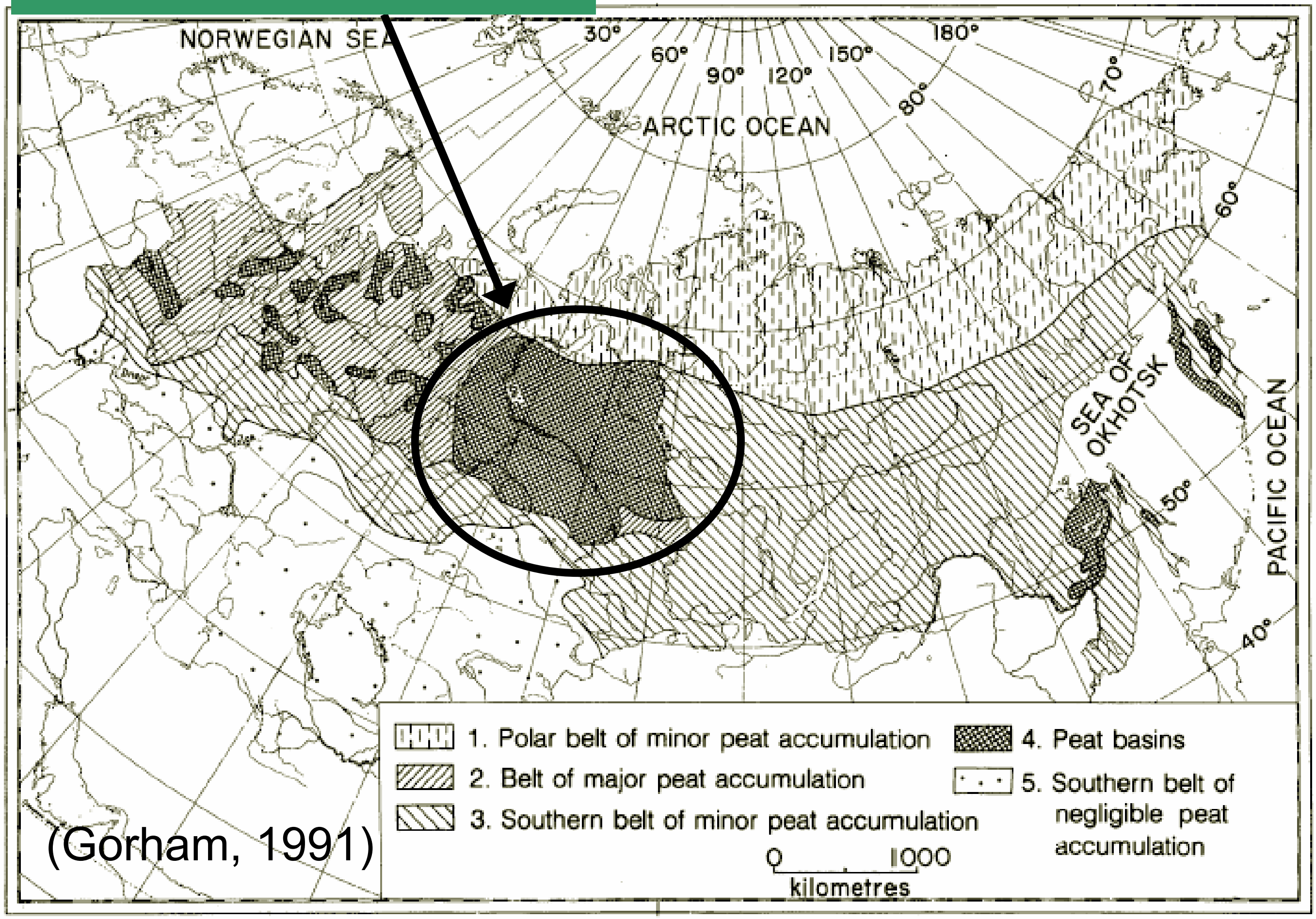


(photo courtesy of J. Shuman)

Western Siberian Wetlands

West Siberian Lowlands

Wetlands:
Largest natural global source of CH_4



(Gorham, 1991)

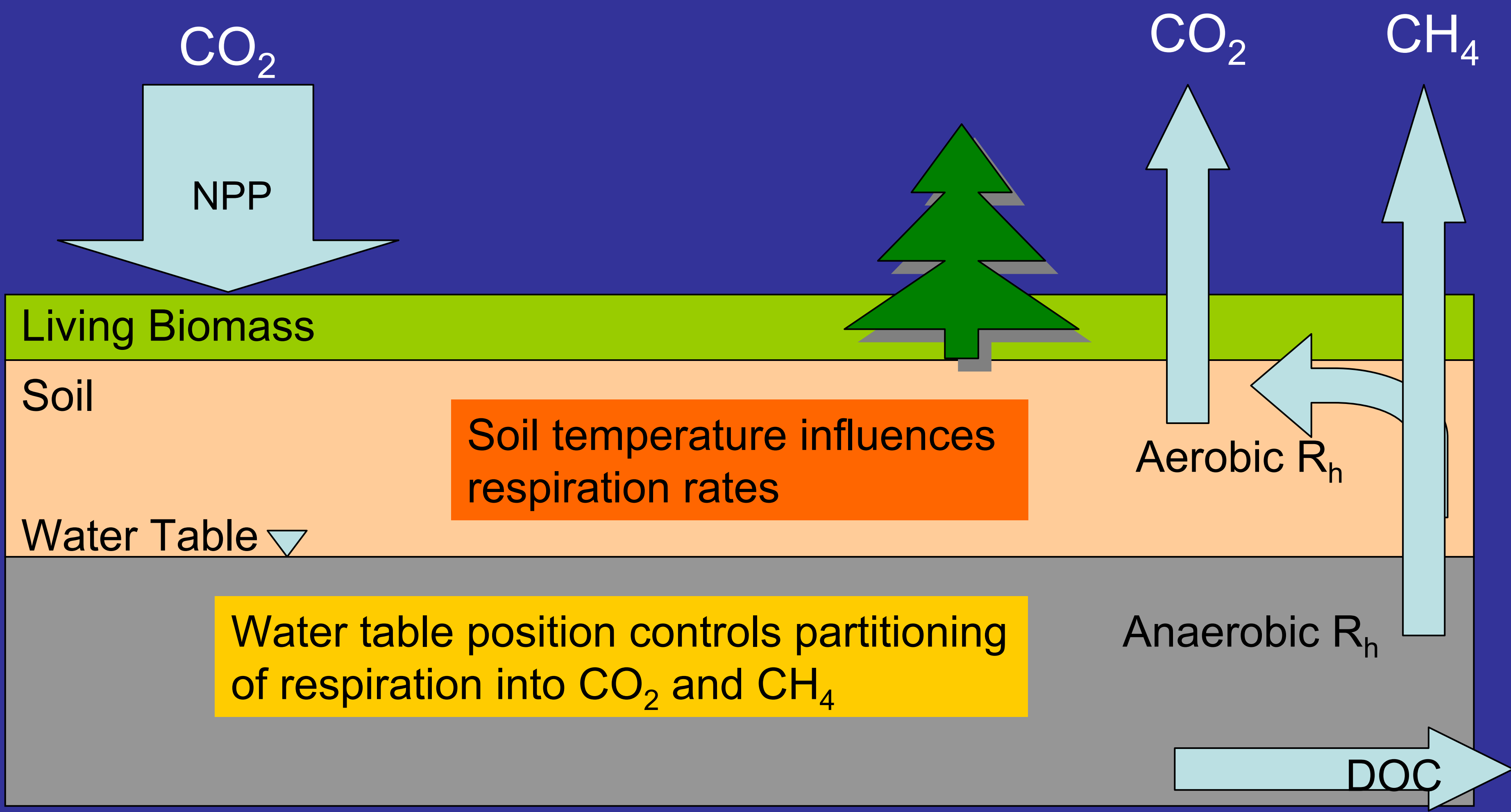
FIG. 2. The location of Soviet peatland resources (modified from Neustadt 1984).

30% of world's wetlands are in N. Eurasia

High latitudes experiencing pronounced climate change

Response to future climate change uncertain

Peatland C Fluxes



Dependence on Climate

- Higher air T → greater production of both CO_2 and CH_4
- Higher air T → deeper water table depth, via evapotranspiration → shift respiration towards CO_2
- Higher precipitation → shallower water table depth → shift respiration towards CH_4
- Net effect?

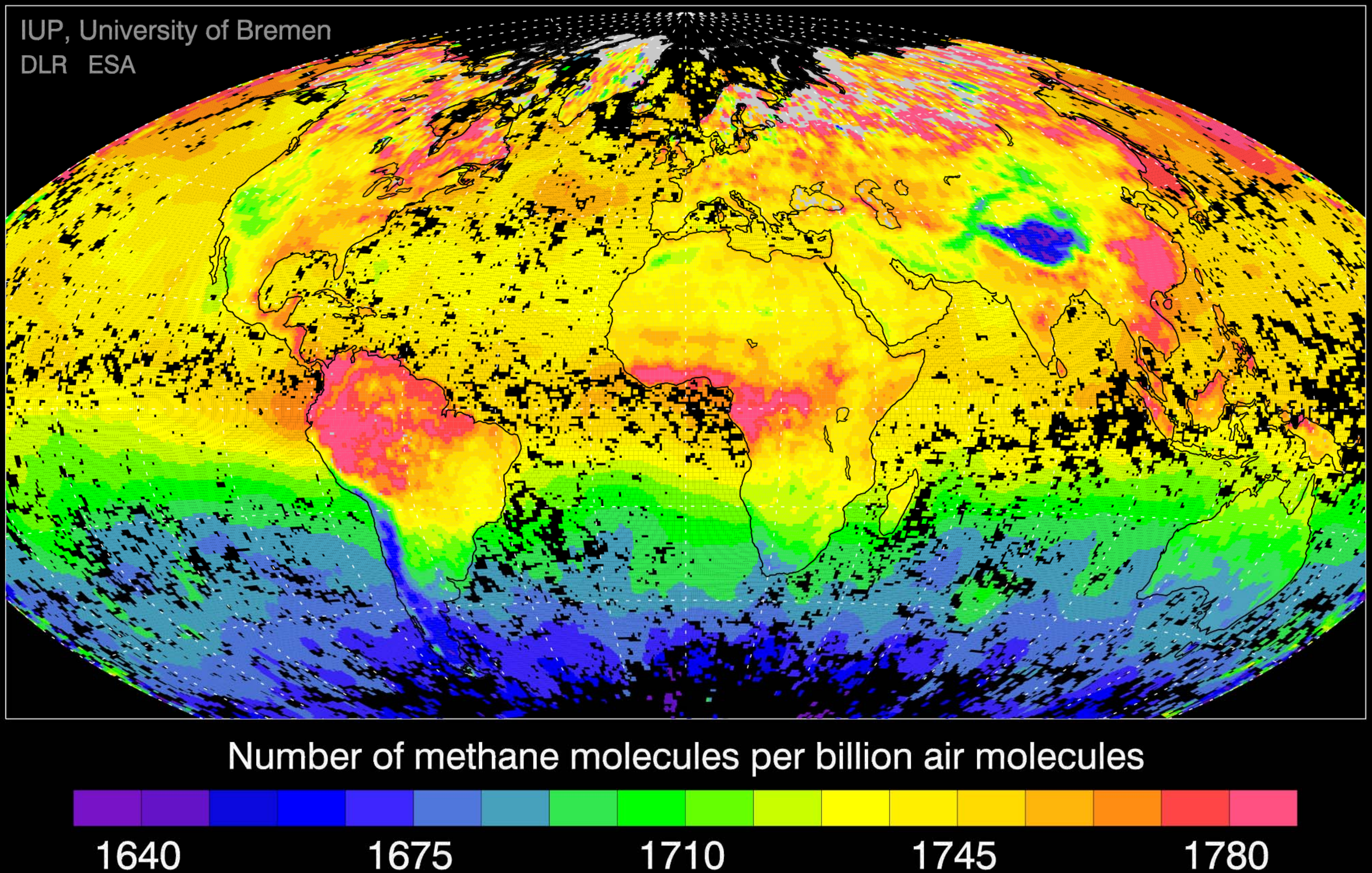
Observations

- Water table depth and methane emissions vary widely within a single wetland (e.g. Saarnio et al, 1997)
  - Microtopography
  - Vegetation
- Water table drawdown (Strack and Waddington 2007):
  - Peat subsidence limited the effects
  - Change in veg communities over time
  - Topographic highs and lows respond differently
  - Net effects depend on relative proportions of microtopographic features

Remote Sensing, Hydrology, and Carbon Cycle

- Satellite-based Measurements of CH_4 are beginning to evolve
  - SCIAMACHY (ENVISAT)
    - Trace gases in troposphere and stratosphere
  - AIRS
  - GOSAT will be launched this year
- Satellites can measure land surface processes and environmental factors that control C fluxes
  - Lake/wetland extent
  - Inundation / soil moisture
  - NDVI
  - River stage

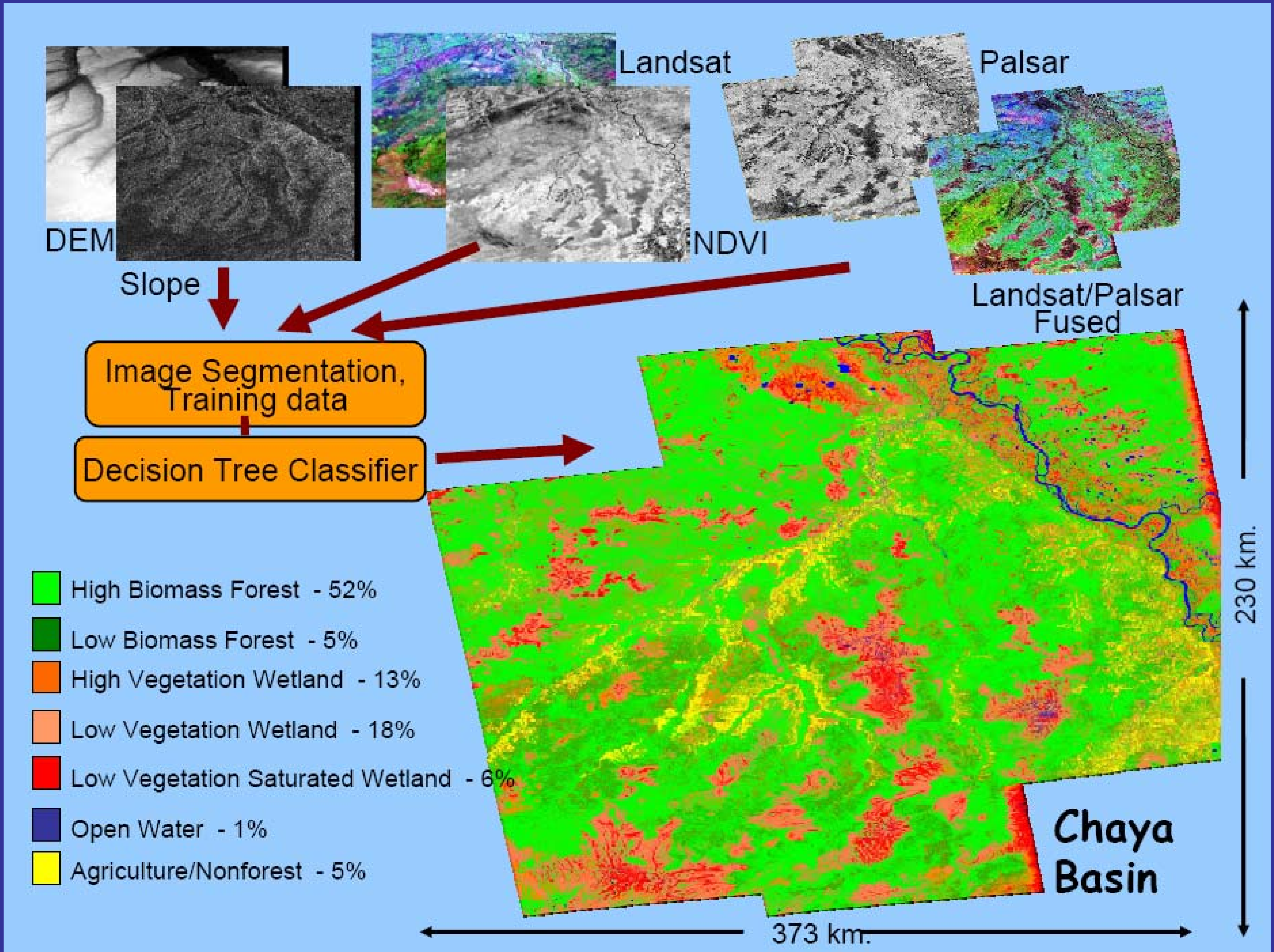
Methane SCIAMACHY/Envisat 2004



SCanning Imaging Absorption SpectroMeter for Atmospheric CHartographY

Lake/Wetland Extent

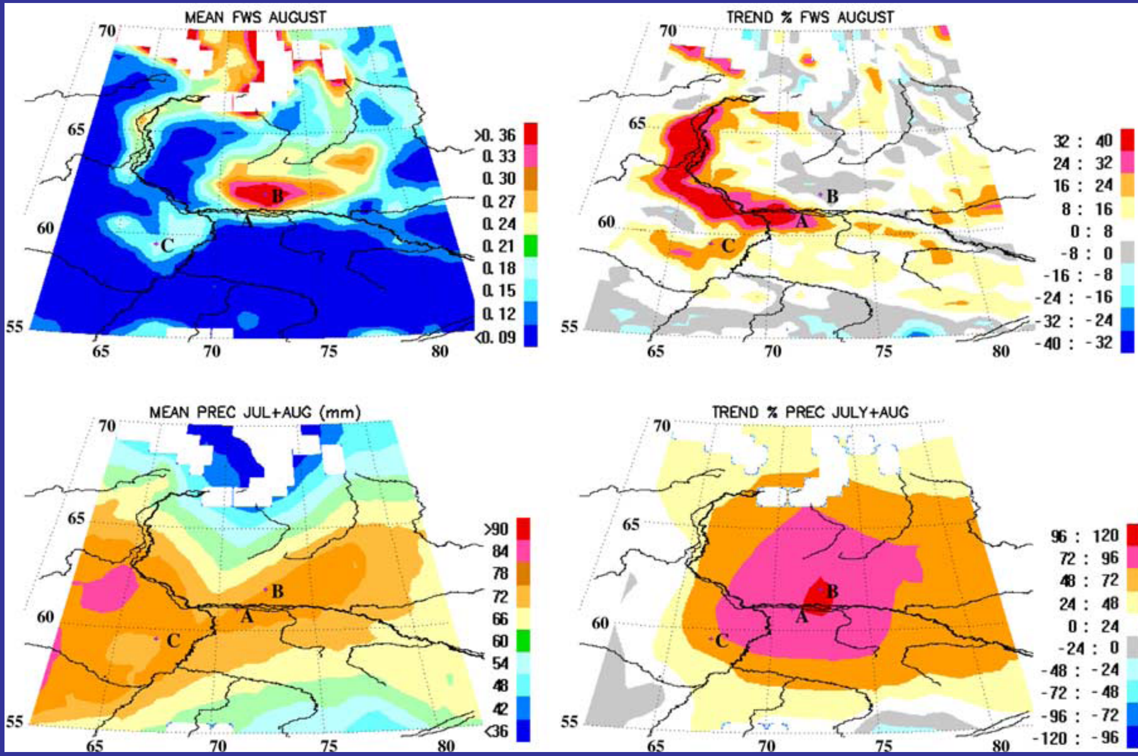
- PALSAR-based land cover



Seasonal Inundation

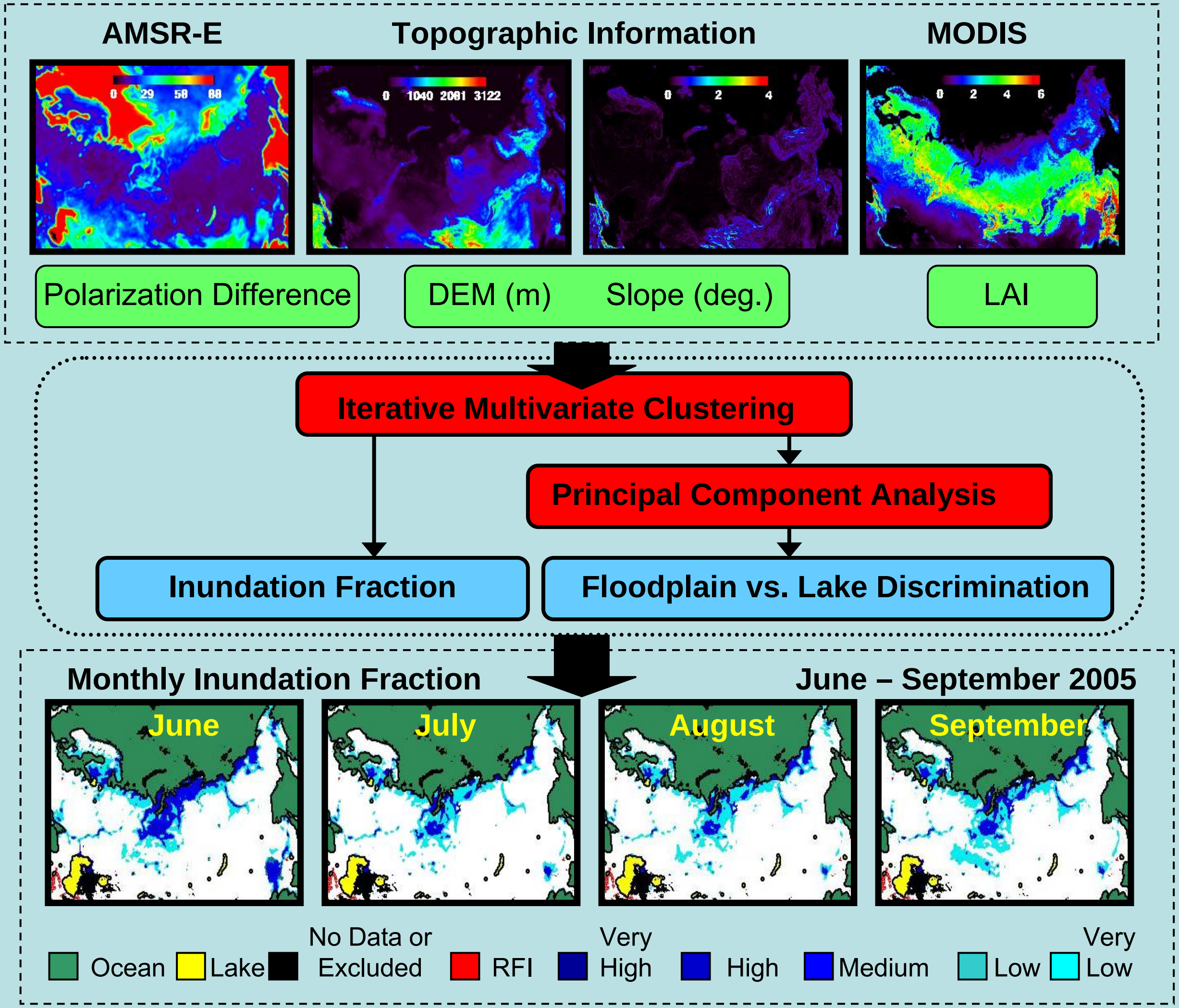
- Open water signal from SSMI passive microwave time series (Grippa et al, 2007)

- Trends in open water extent in West Siberia, 1988-2002:
  - Increase in open water along Ob River mainstem
  - No trend in open water in main lake/wetland areas
  - Permafrost degradation & increased drainage?
- Consequences for CH_4 emissions?



Wetland Characterization with Microwave Remote Sensing

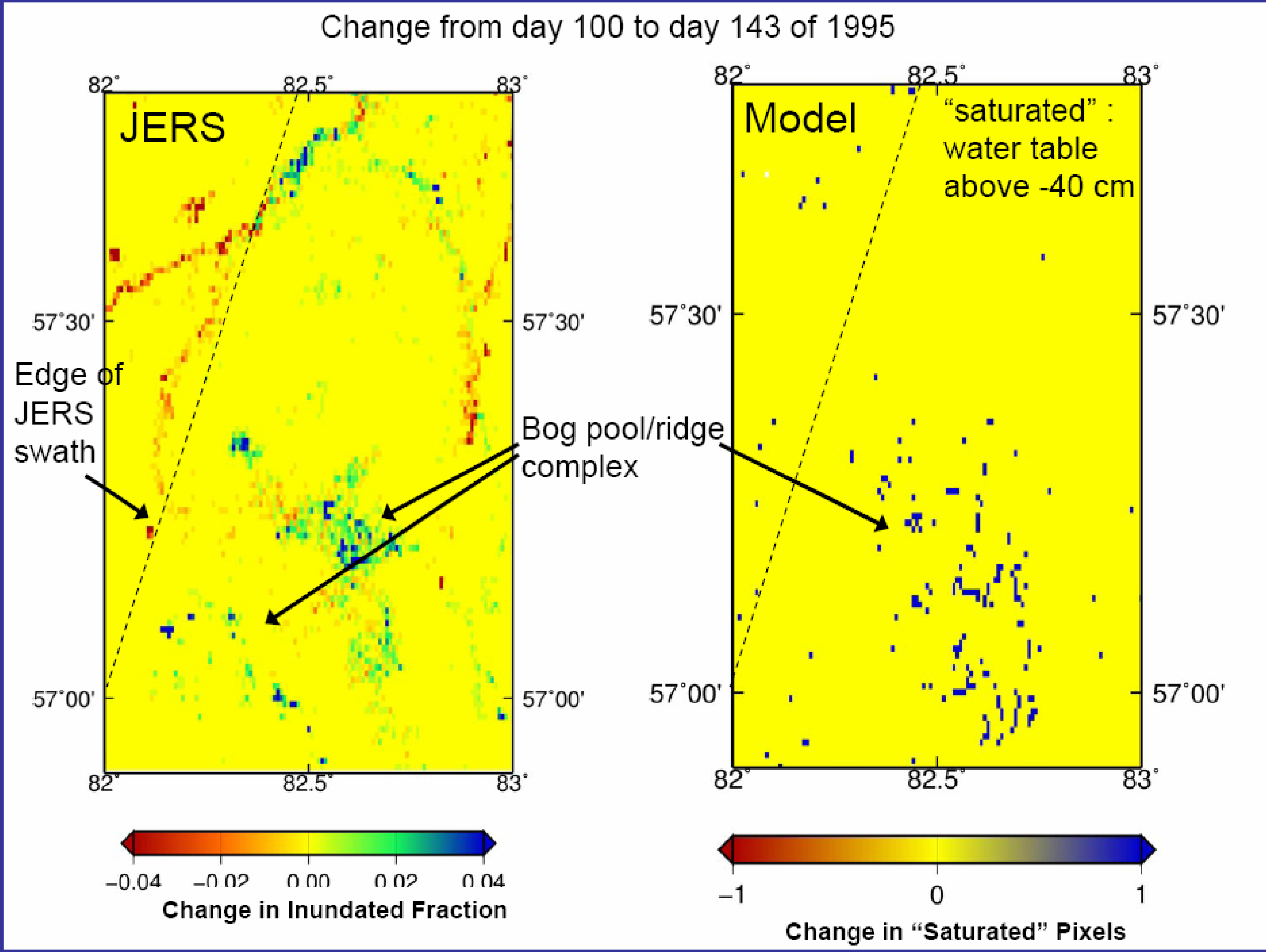
Inundation Monitoring with AMSR-E and MODIS



Construct for derivation of monthly inundation data sets, showing example products for the NEESPI domain. Algorithm input data sets include AMSR-E brightness temperature and polarization difference, topography, and MODIS-based leaf area index (LAI). An iterative unsupervised multivariate clustering approach is employed to identify potential inundated areas and the corresponding inundation fraction, and principal component analysis applied to differentiate critical features within the inundated regions. The derived data sets show monthly mean relative inundated area fraction. The algorithm is applied globally and shown here for the NEESPI region

Seasonal Inundation

- SAR-based open water extent



Conclusions

- Hydrologic cycle plays large role in carbon cycle of N. Eurasia
- Changing hydrologic cycle → changing C cycle
- Combination of models and remote sensing can improve our understanding of hydrologic and carbon cycles

Backup

Thaw lake dynamics (simulated)

Growth rates of lakes and thaw bulbs beneath lakes (***taliks***) are function of:

- Soil temperature
- Ground ice content
- Lake area

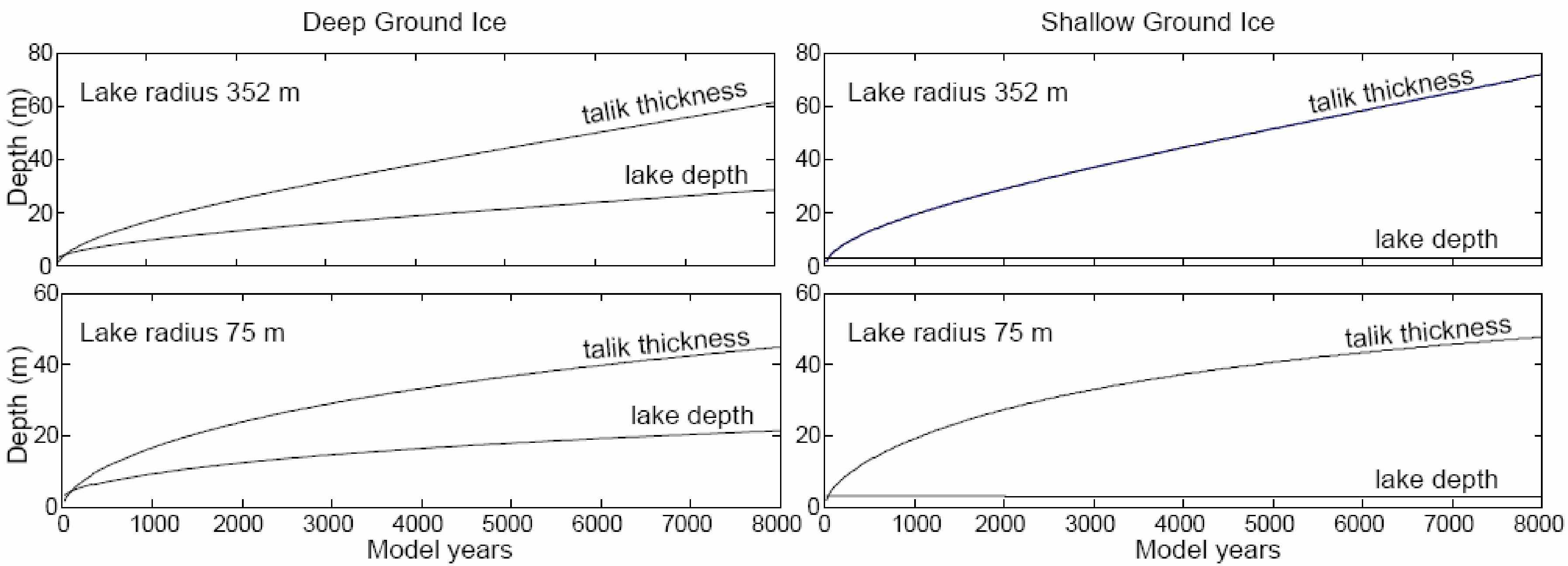
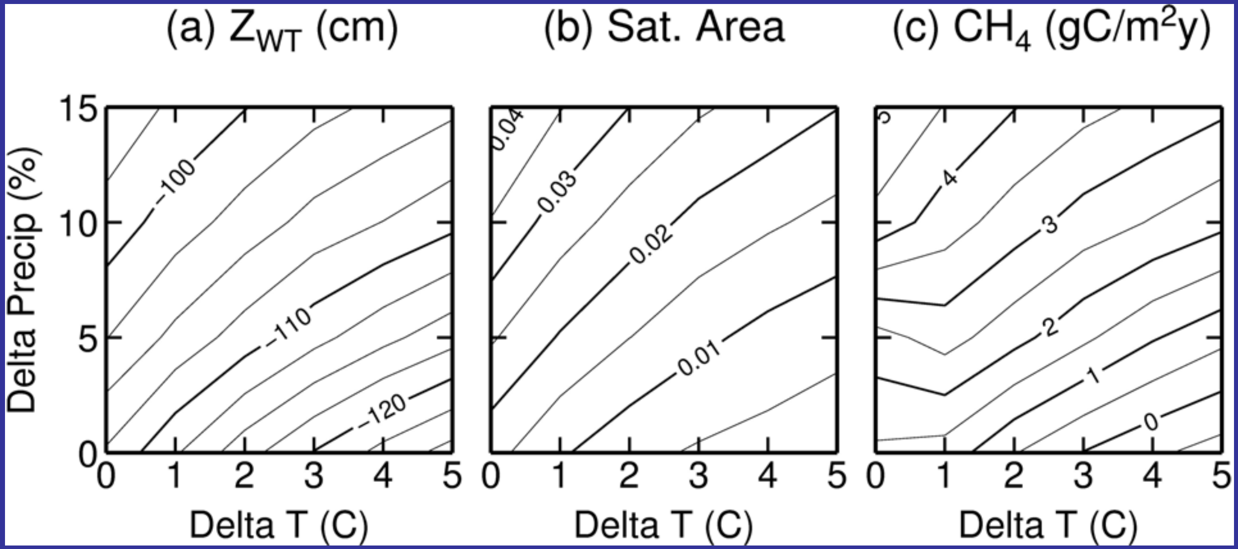


Figure 2. Modeled lake depth and talik thickness, beneath the lake's center, over 8000 year for small and larger lakes in deep ground ice (left panel) and shallow ground ice environments (right panel).

(West and Plug, 2007)

Simulations

- Large-scale biogeochemical models agree:
  - Siberian wetland CH_4 emissions will roughly double by 2100 (Bohn et al., 2007; Zhuang et al., 2006; Gedney et al., 2004; Shindell et al, 2004)
  - T and Precip changes exert competing influences on water table depth and CH_4 emissions
- Bohn et al., 2007: small-scale extent of saturated soil is important



(Bohn et al., 2007)