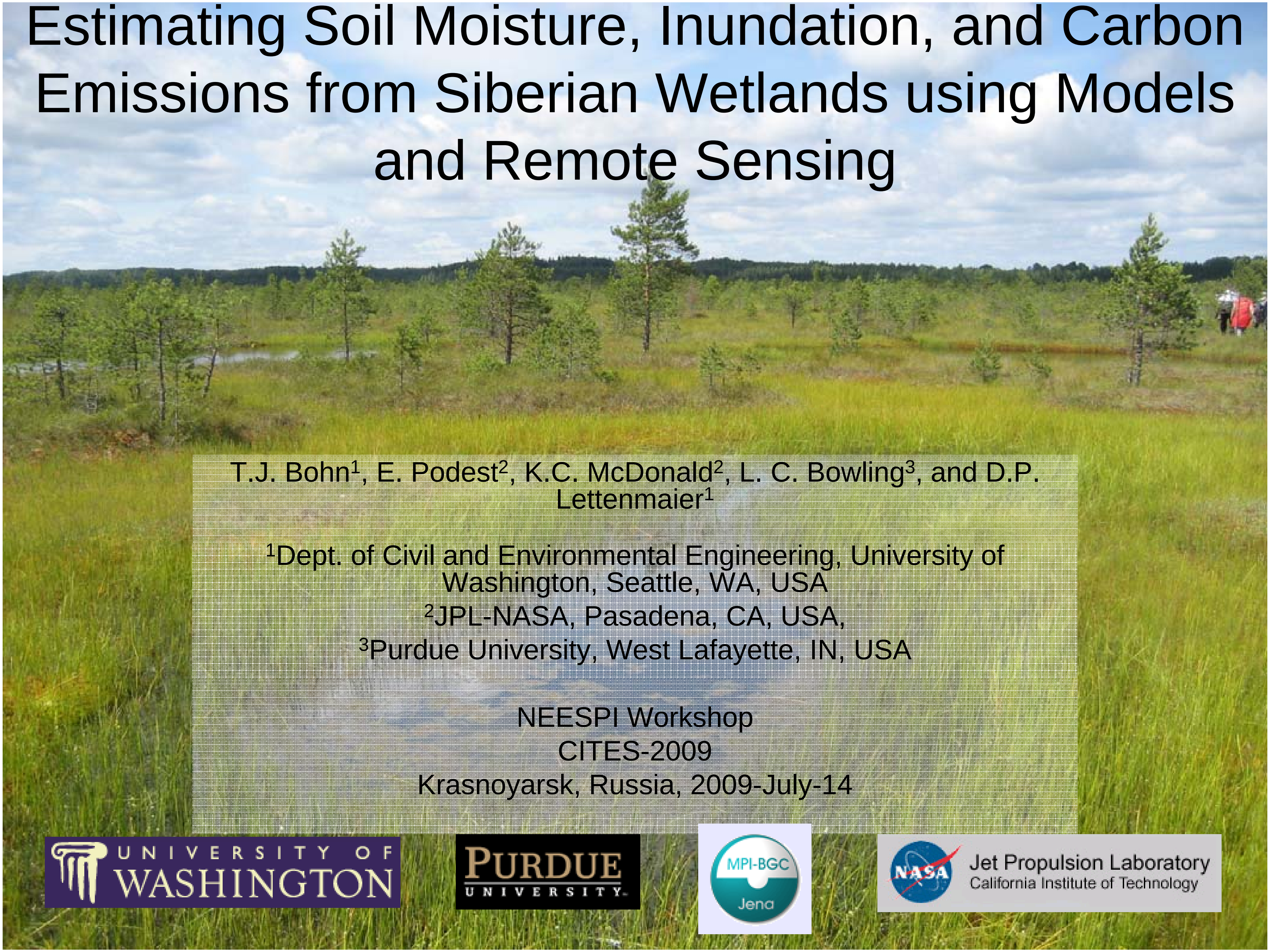
Estimating Soil Moisture, Inundation, and Carbon Emissions from Siberian Wetlands using Models and Remote Sensing



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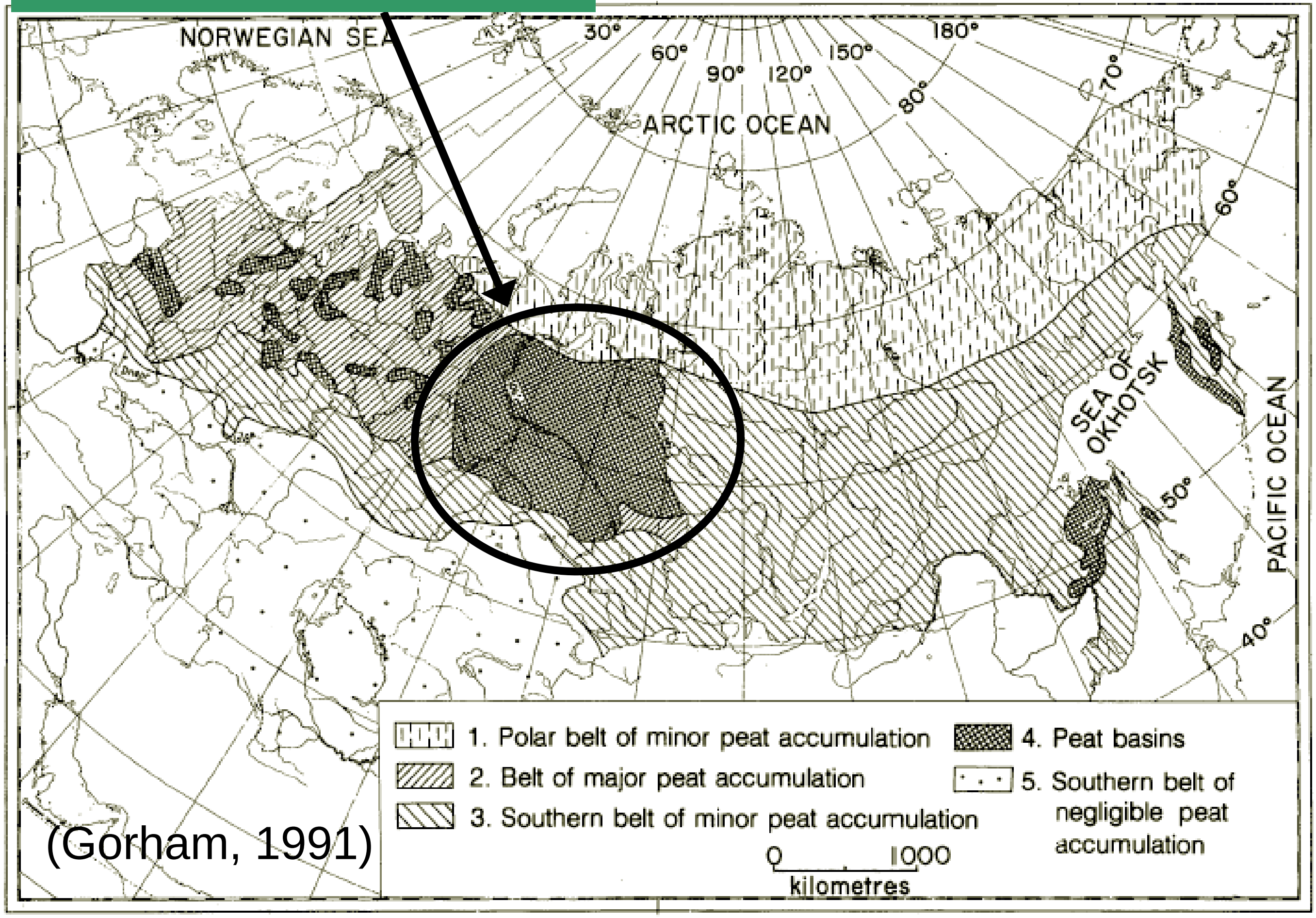
Krasnoyarsk, Russia, 2009-July-14

Western Siberian Wetlands

West Siberian Lowlands

Wetlands:
Largest natural global source of CH_4



(Gorham, 1991)

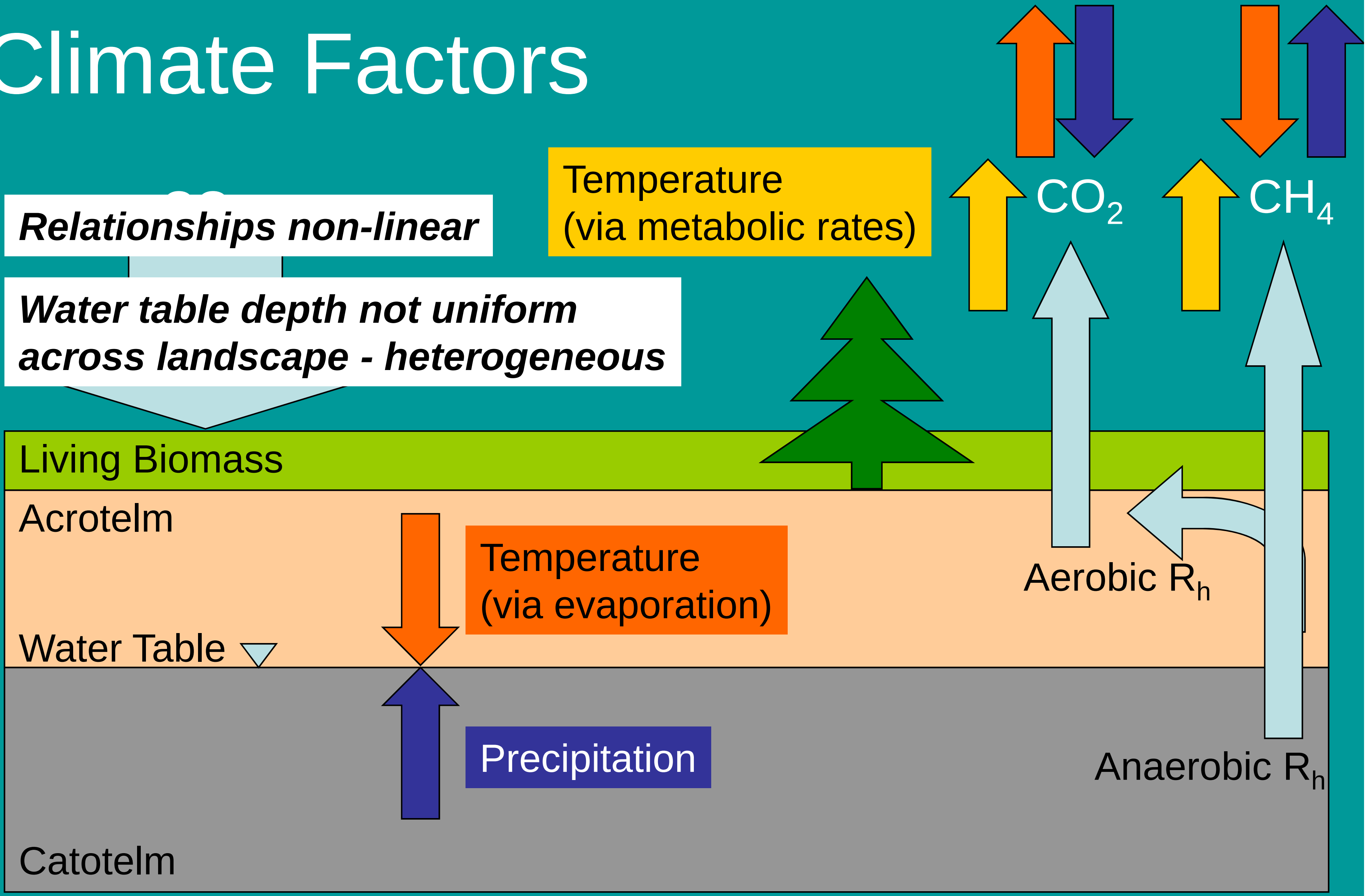
FIG. 2. The location of Soviet peatland resources (modified from Neustadt 1984).

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

High latitudes experiencing pronounced climate change

Response to future climate change uncertain

Climate Factors



Relationships non-linear

Water table depth not uniform across landscape - heterogeneous

Temperature
(via metabolic rates)

CO_2

CH_4

Living Biomass

Acrotelm

Temperature
(via evaporation)

Aerobic R_h

Water Table

Precipitation

Anaerobic R_h

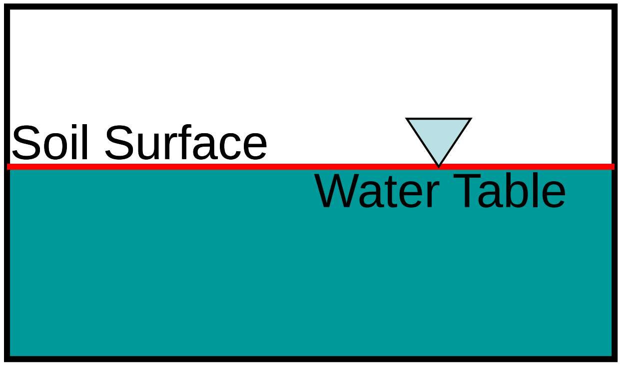
Catotelm

Note: currently not considering export of DOC from soils

Water Table Heterogeneity

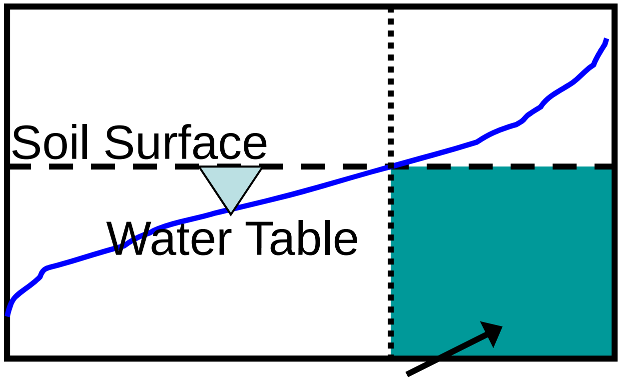
- Many studies assume uniform water table distribution within static, prescribed wetland area
  - *Can lead to “binary” CO2/CH4 partitioning*
- Distributed water table allows smoother transition and more realistic inundated area
  - *Facilitates comparisons with:*
    - *remote sensing*
    - *point observations*

Uniform Water Table



Complete inundation

Distributed Water Table



Inundated Area

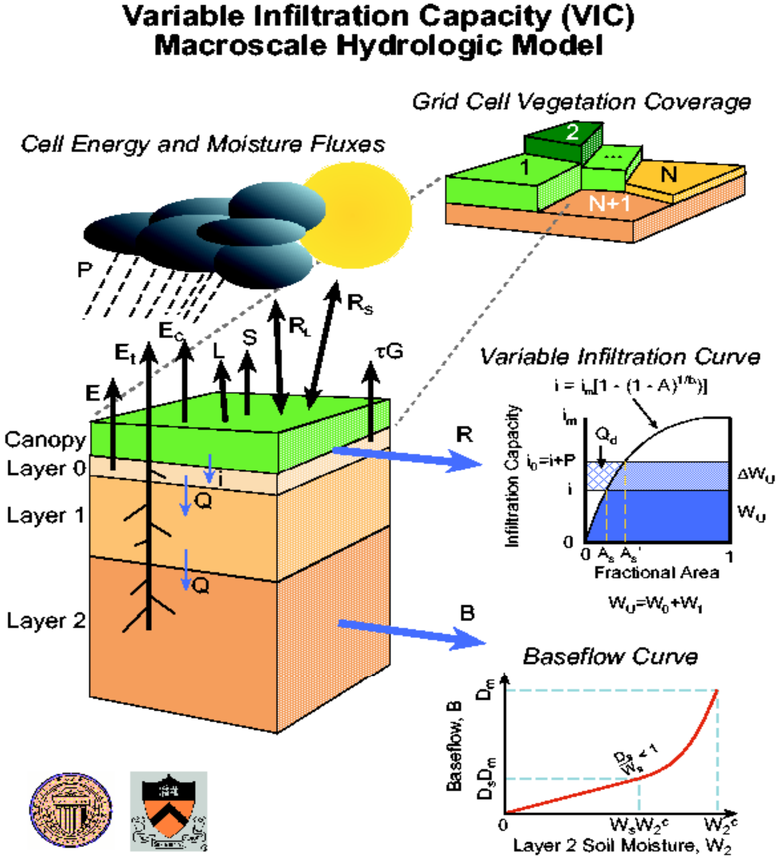
Questions

How does taking water table heterogeneity into account affect:

- comparisons of inundated area with remote sensing observations?
- estimates of greenhouse gas emissions?

Modeling Framework

- VIC hydrology model
  - Large, “flat” grid cells (e.g. 100x100 km)
  - On hourly time step, simulate:
    - Soil T profile
    - Water table depth Z_{WT}
    - NPP
    - Soil Respiration
    - Other hydrologic variables…



How to represent spatial heterogeneity of water table depth?

Spatial Heterogeneity of Water Table: TOPMODEL* Concept

Relate distribution of **water table** to distribution of **topography** in the grid cell

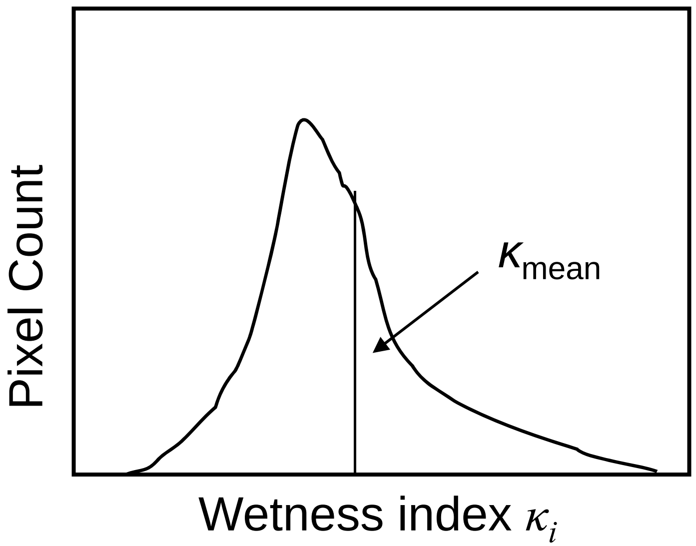
Start with DEM (e.g. SRTM3)

For each DEM pixel in the grid cell, define ***topographic wetness index***
$\kappa_i = \ln(\alpha_i / \tan\beta_i)$
α_i = upslope contributing area
$\tan\beta_i$ = local slope

Essentially:
- flat areas are wet (high κ_i)
- steep areas are dry (low κ_i)

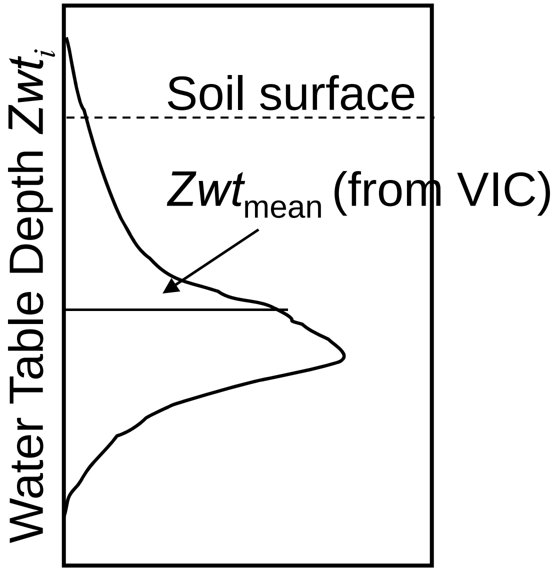
Local water table depth
$Zwt_i = Zwt_{\text{mean}} - m(\kappa_i - \kappa_{\text{mean}})$
m = calibration parameter

Wetness Index Distribution



→

Pixel Count

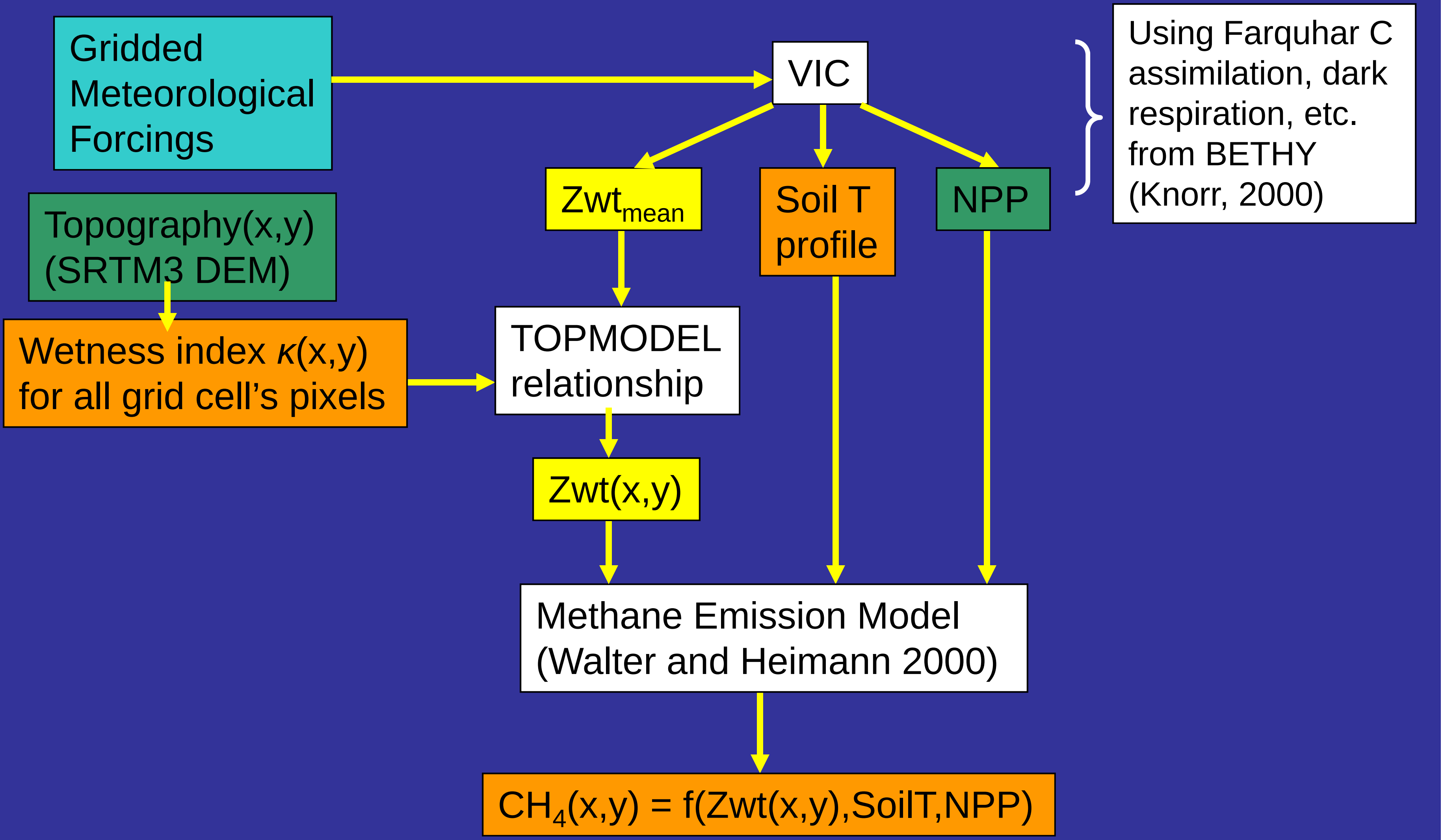


All pixels with same κ have same *Zwt*

*Beven and Kirkby, 1979

Process Flow – VBM*

* **V**IC-**B**ETHY-**M**ethane



Gridded Meteorological Forcings

VIC

Using Farquhar C assimilation, dark respiration, etc. from BETHY (Knorr, 2000)

Zwt_{mean}

Soil T profile

NPP

Topography(x,y) (SRTM3 DEM)

Wetness index κ(x,y) for all grid cell's pixels

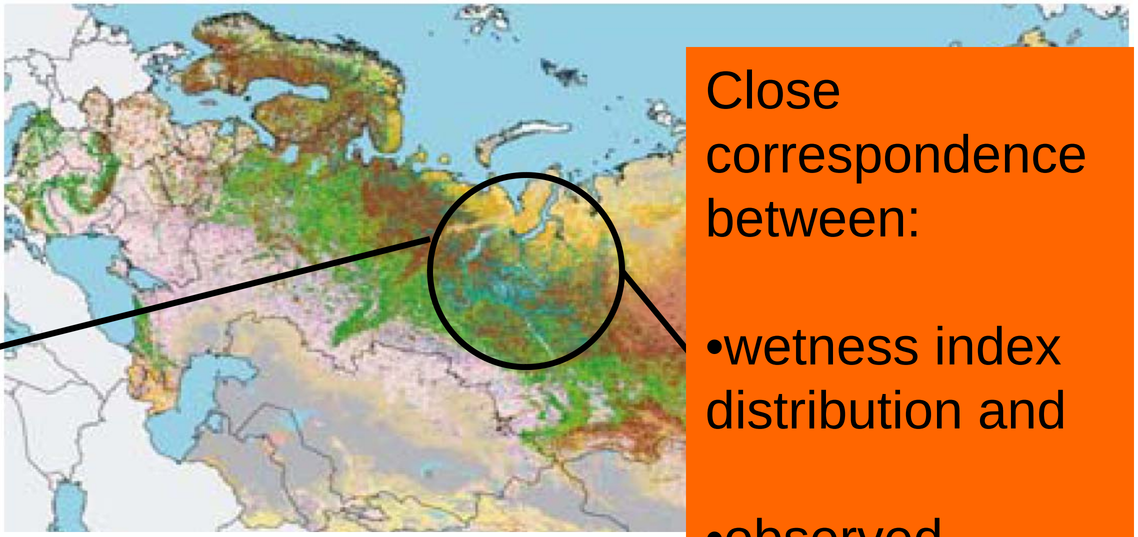
TOPMODEL relationship

Zwt(x,y)

Methane Emission Model (Walter and Heimann 2000)

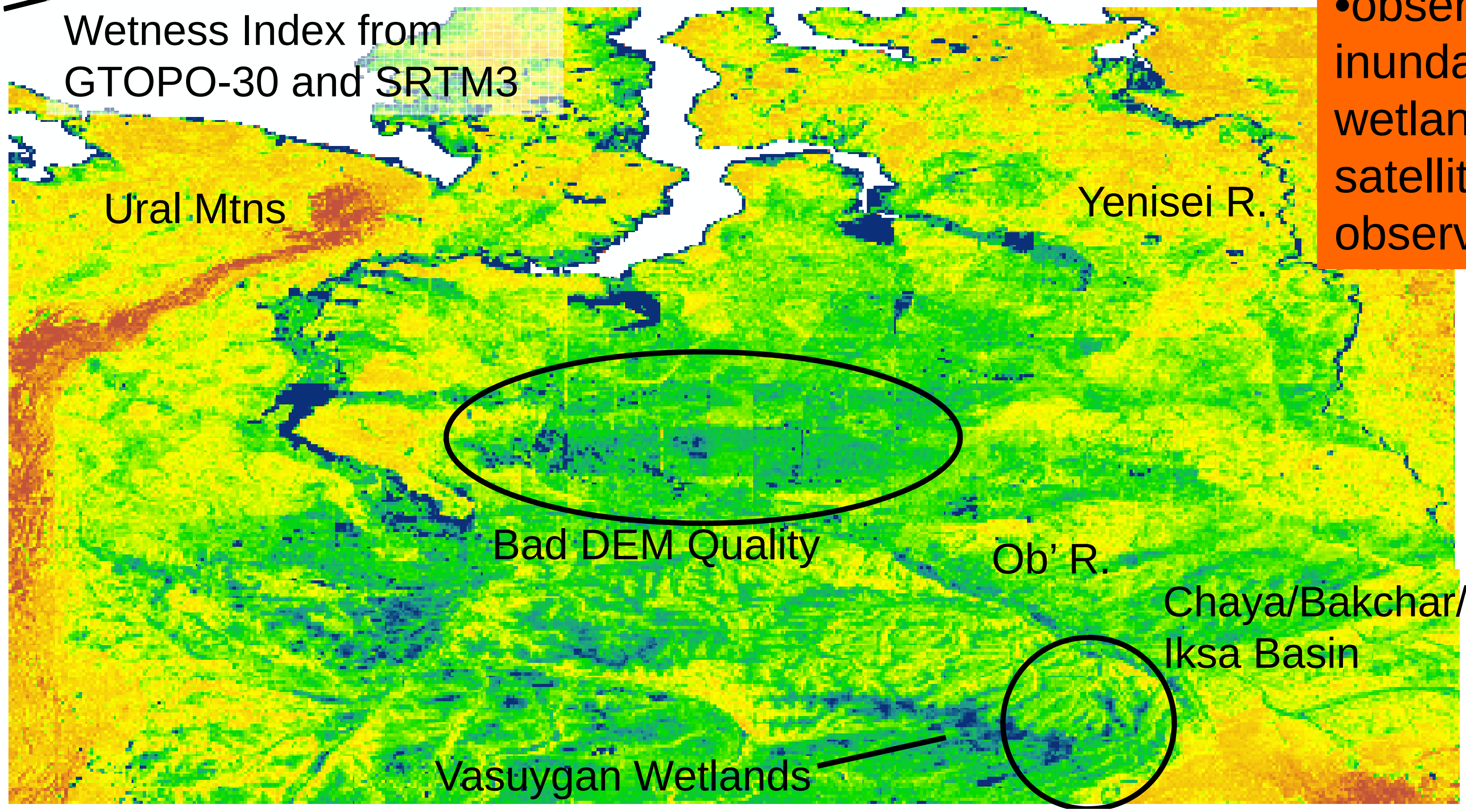
$CH_4(x,y) = f(Zwt(x,y), SoilT, NPP)$

Study Domain: W. Siberia

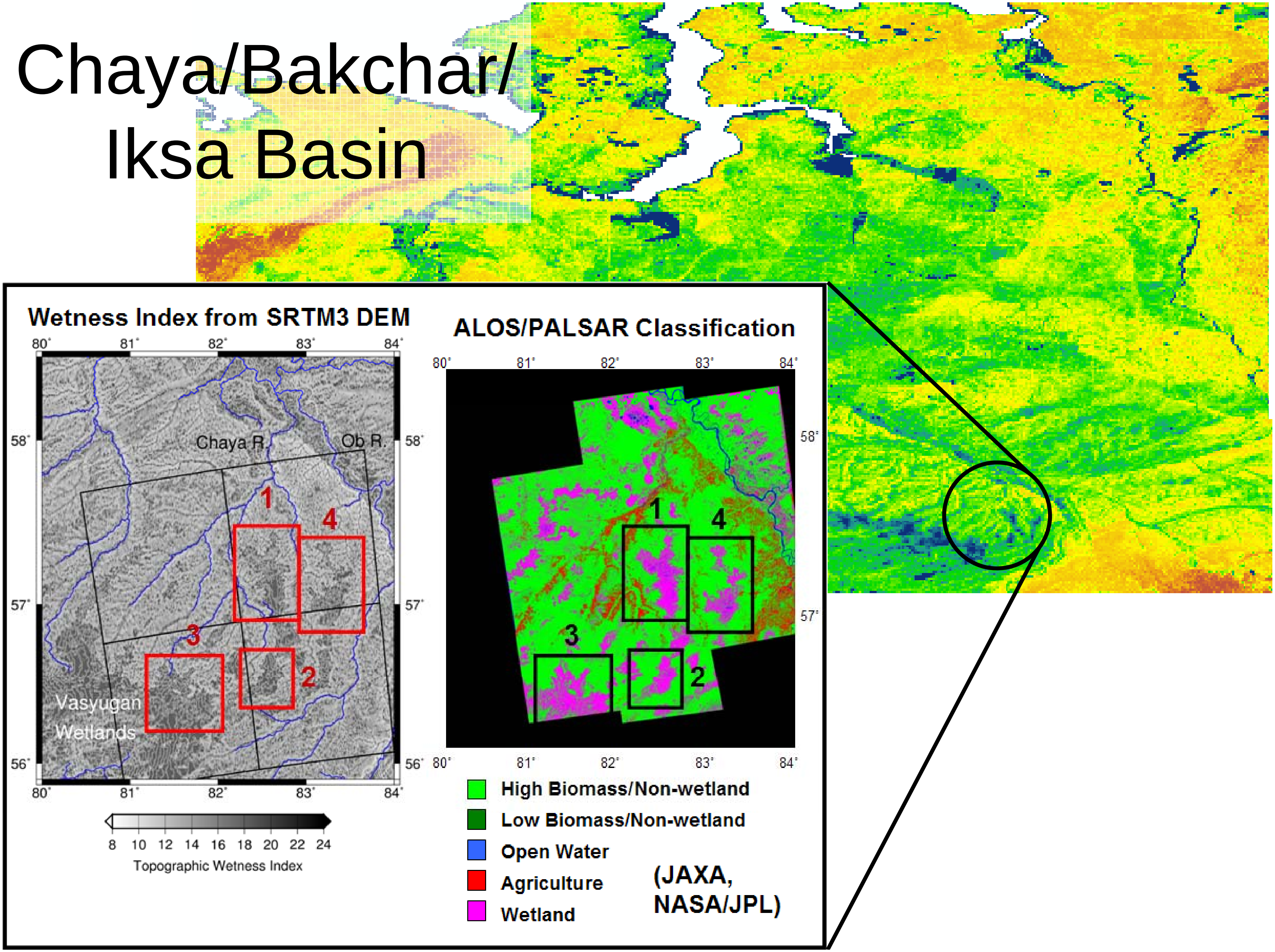


Close correspondence between:

- wetness index distribution and
- observed inundation of wetlands from satellite observations



Chaya/Bakchar/ Iksa Basin



Wetness Index from SRTM3 DEM

ALOS/PALSAR Classification

(JAXA, NASA/JPL)

Comparison with PALSAR

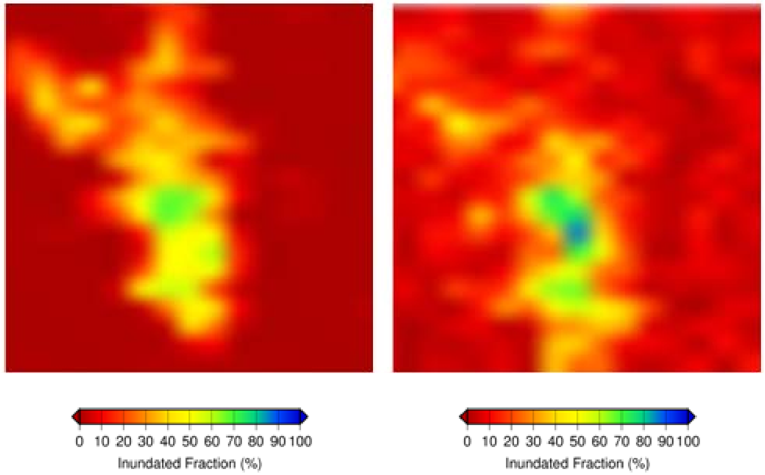
- Spatial distribution of inundation compares favorably with remote sensing
- This offers a method to calibrate model soil parameters

Observed Inundated Fraction (PALSAR Classification)

Simulated Inundated Fraction (at optimal Zwt)

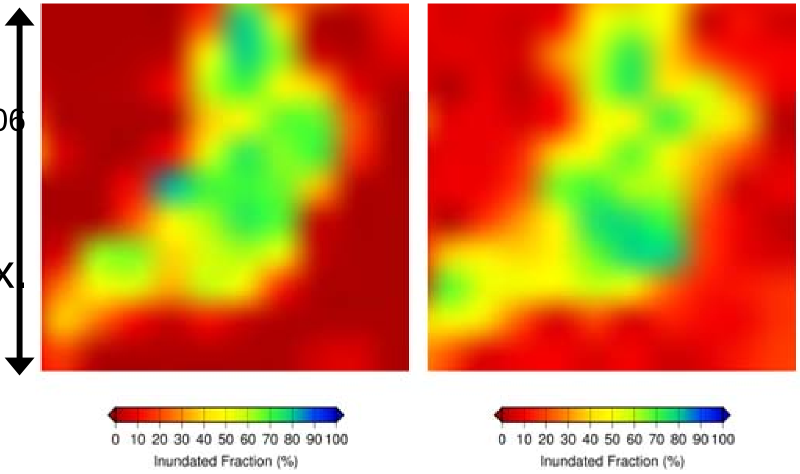
ROI 1

2006-06-09



ROI 2

2007-07-06



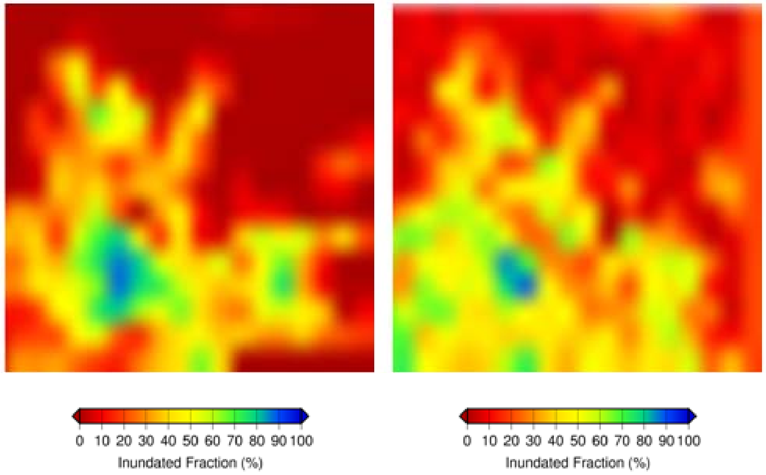
Approx. 30 km

Observed Inundated Fraction (PALSAR Classification)

Simulated Inundated Fraction (at optimal Zwt)

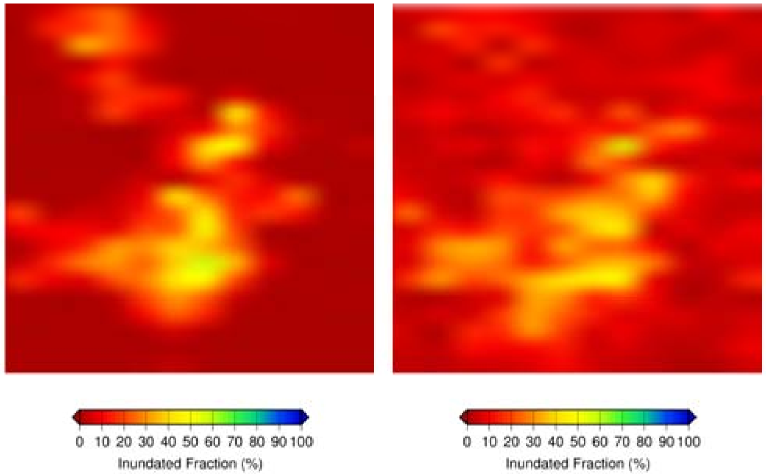
ROI 3

2006-05-28



ROI 4

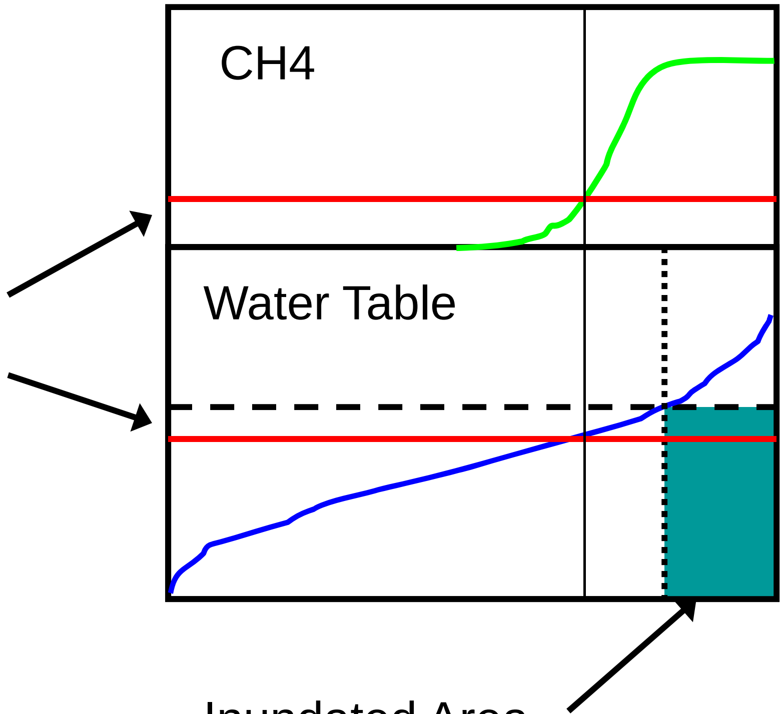
2007-07-18



How do resulting emissions differ between uniform water table and distributed water table?

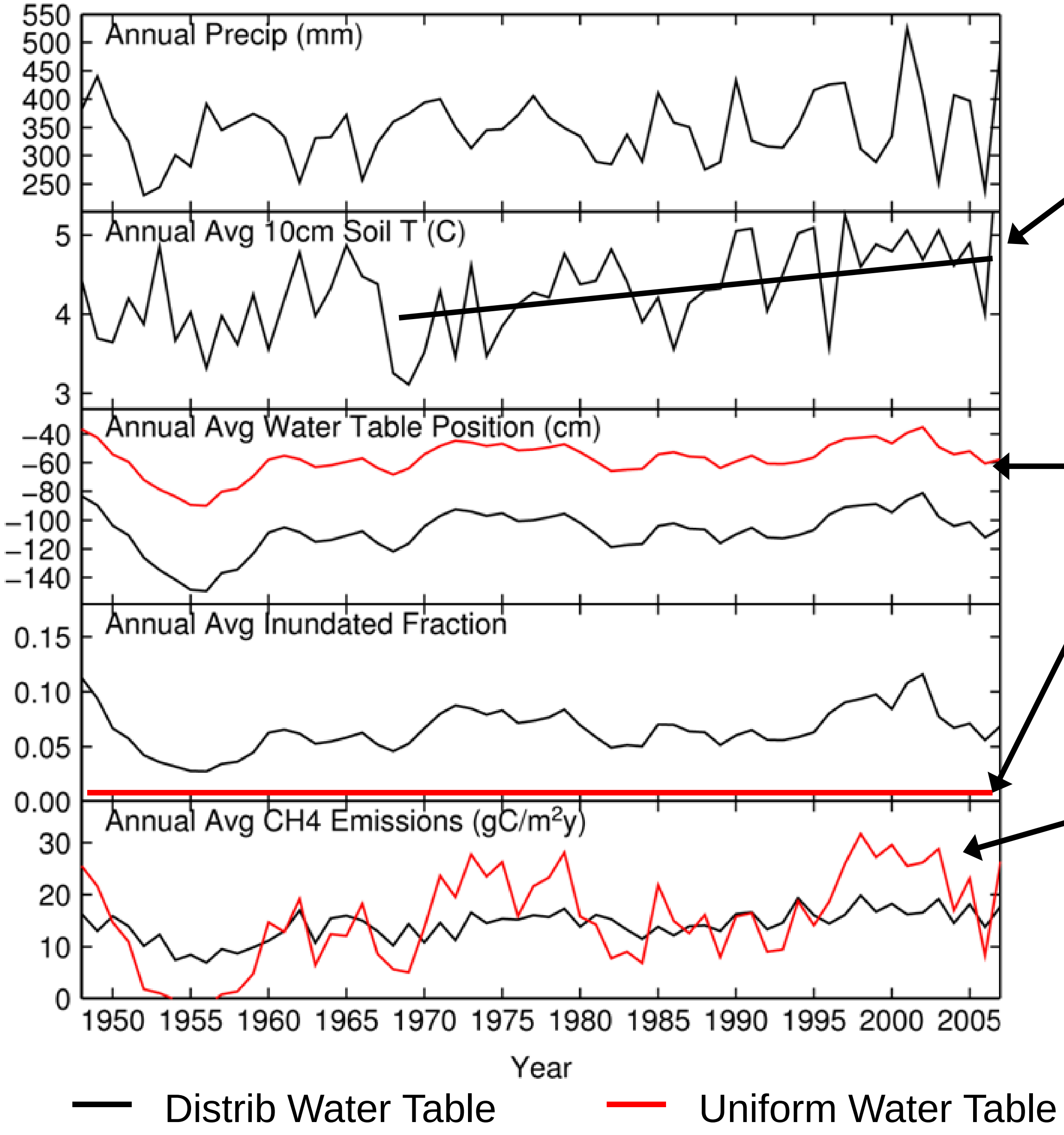
Experiment:

- Calibrate methane model to match in situ emissions at a point (Bakchar site, Friborg et al, 2003)
- **Distributed case:** calibrate distributed model water table depth to match observed inundation
- **Uniform case:** select water table timeseries from single point in the landscape having same long-term average methane emissions as the entire grid cell in the distributed case; apply this water table to entire grid cell



Inundated Area
(matching remote sensing)

Interannual Variability, 1948-2007



Possible trend in temperature, also in CH4

Uniform Water Table:

Shallower than average of distributed case

But never reaches surface; no inundation

Resulting CH4 has higher variability than for distributed case

Distributed case is buffered by high- and low-emitting regions

Impact on trends?

Net Greenhouse Warming Potential

CH4 makes up small part of C budget, but large contribution to greenhouse warming potential

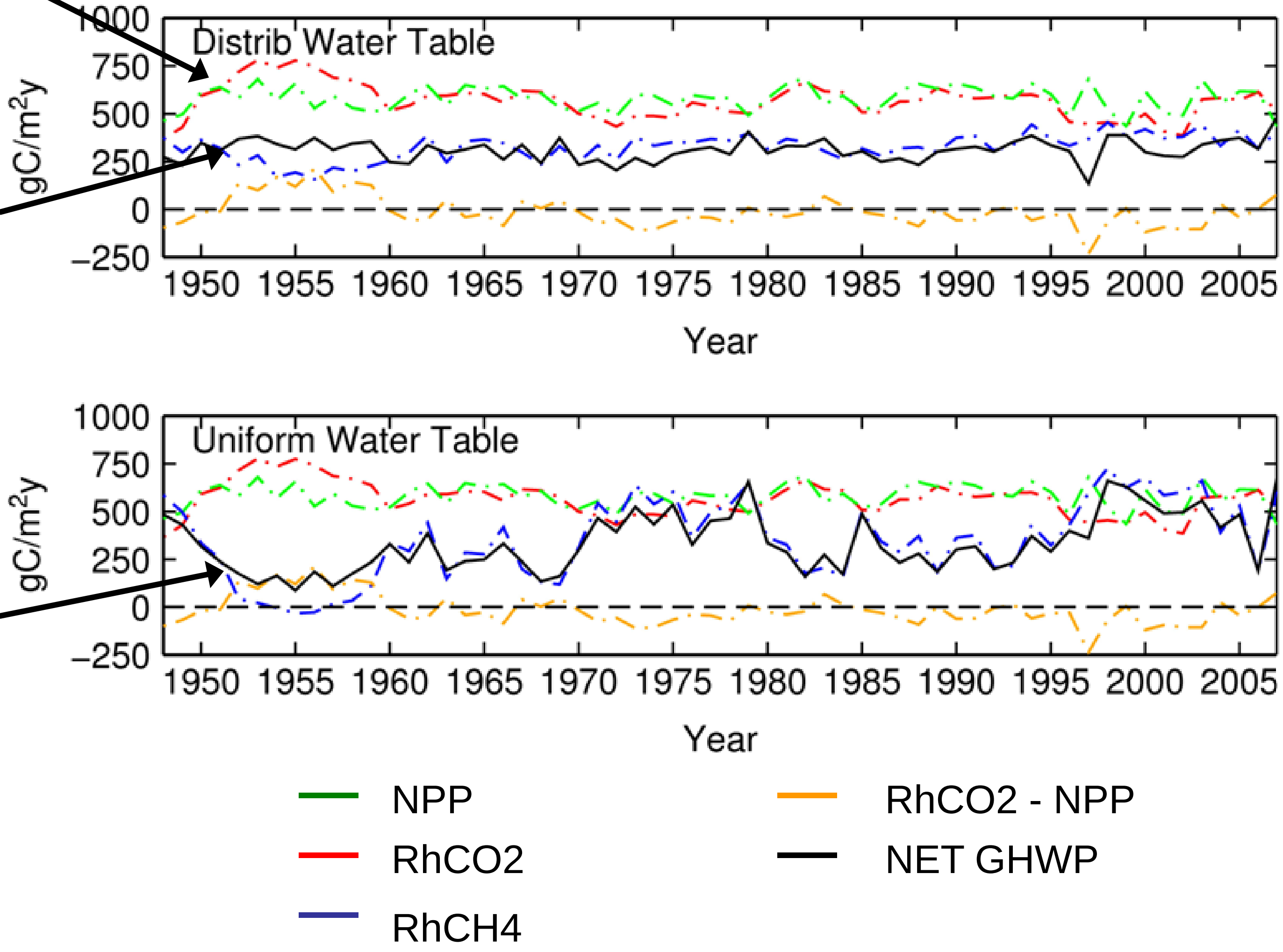
On 100-year timescale, GHWP(CH4) = approx. 23 * GHWP(CO2)

NPP and RhCO2 approximately cancel

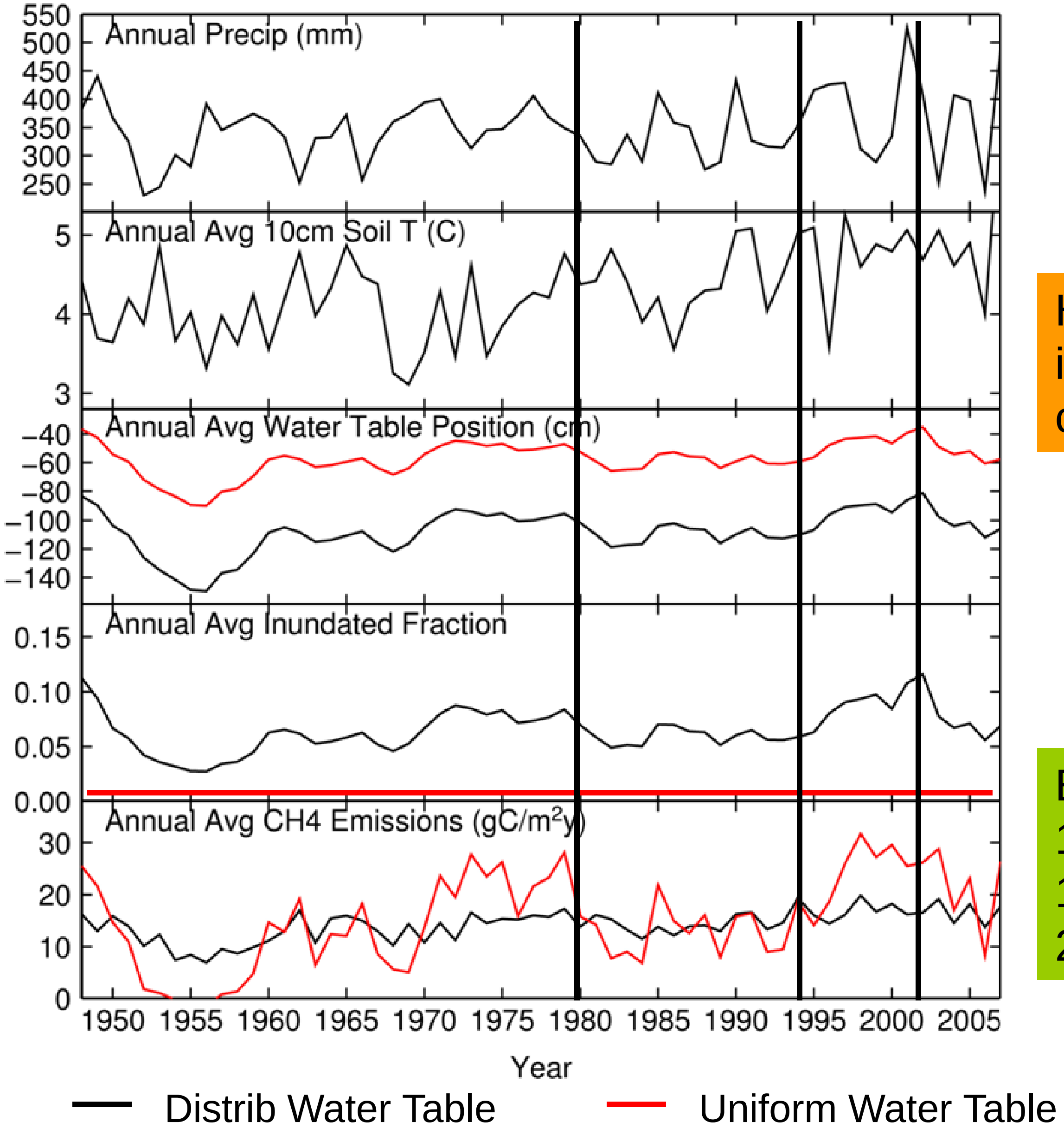
Net GHWP essentially follows GHWP(CH4)

Uniform water table:

- CH4 has larger interannual variability
- So does net GHWP
- Impact on trend assessment?



Interannual Variability, 1948-2007



How do spatial distributions of inundation and CH4 emissions change in response to climate?

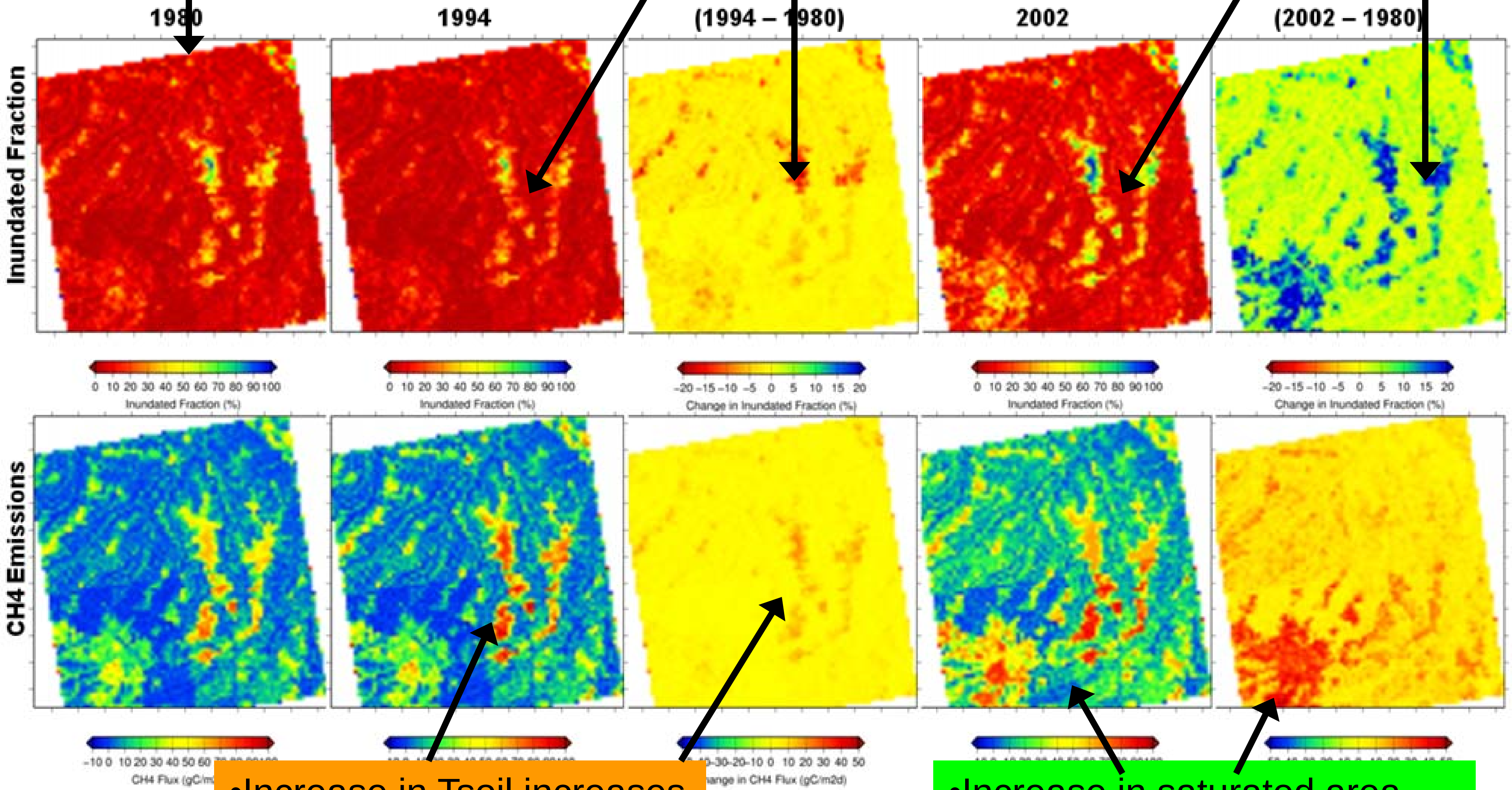
Example Years to investigate:
1980: “average”
1994: warm, dry
2002: warm, wet

Response to Climate

1980 = “average” year, in terms of T and Precip

1994 = Warm, dry year
- Less inundation

2002 = Warm, wet year
- More inundation



- Increase in Tsoil increases CH4 emissions in wettest areas only

- Increase in saturated area causes widespread increase in CH4 emissions

Conclusions

- Advantages of distributed water table:
  - Facilitates comparison with satellite measurements and point measurements
  - More realistic representation of hydrologic and carbon processes

- Spatial distribution of water table has large effect on estimates of greenhouse gas emissions and their trends

Thank You

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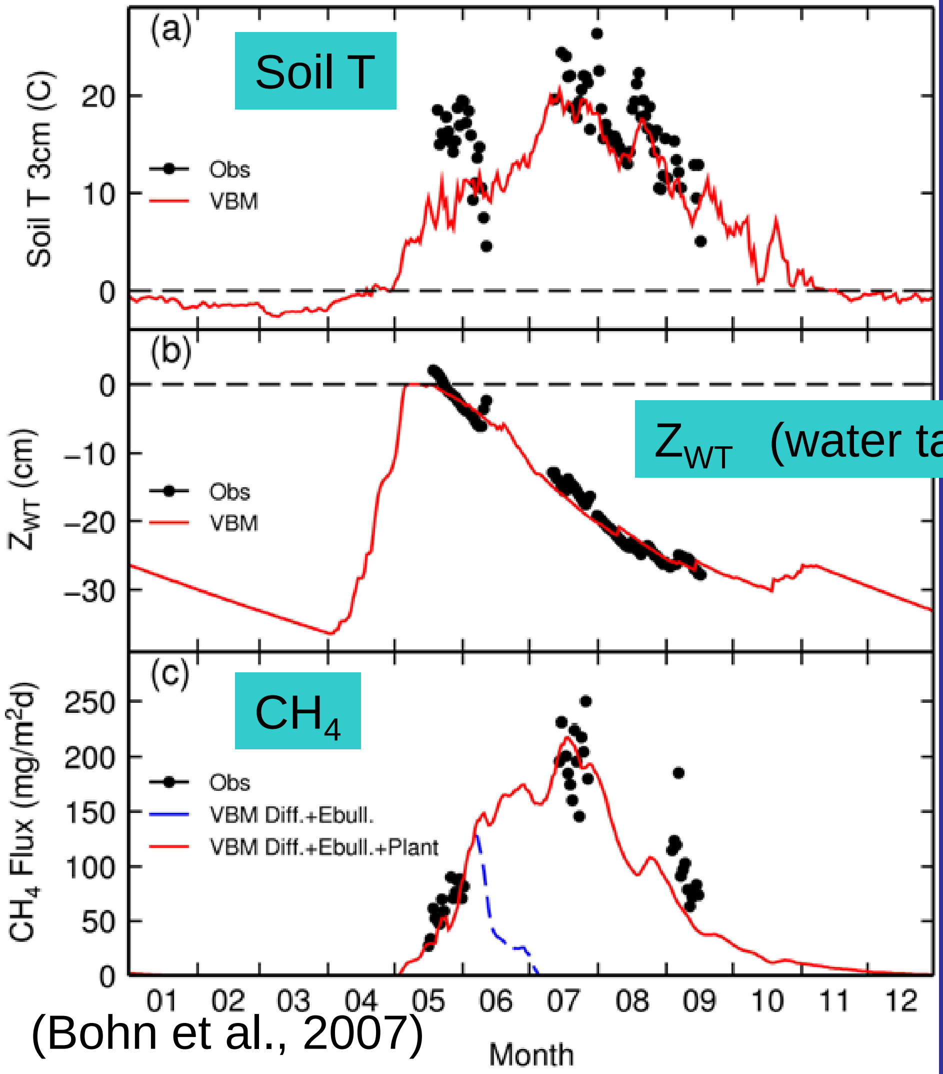
Calibration – Bakchar Bog, 1999



Soil T

Z_{WT} (water table depth)

CH_4

(Bohn et al., 2007)

VBM = **V**IC-**B**ETHY-**M**ethane