Seasonal and Interannual Variability in Boreal and Arctic Water Cover Observed by QuikSCAT

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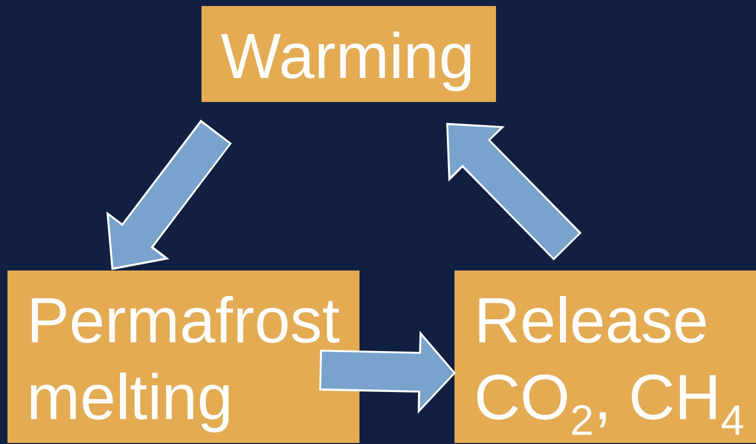
Background:

- Average arctic temperatures increased at almost twice the global average rate in the past 100 years (IPCC 2007).
- **Carbon reservoir in frozen soil, mainly in Siberia and central Alaska: ~1000 GtC > global vegetation (650 GtC), ~200 times of global annual fossil fuel burning.**
- ~30% of carbon in permafrost is decomposed by microbes and converted to methane;
- **Beginning of the Holocene: ~500 GtC released from permafrost (~100 years of fossil fuel burning a the current rate).**

A positive feedback:



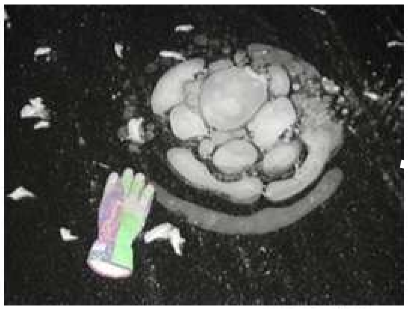
Significance to global climate:

- The Positive feedback can create a vicious cycle and greatly amplify the warming due to anthropogenic emission of greenhouse gases.

Scientists Find New Global Warming 'Time Bomb'

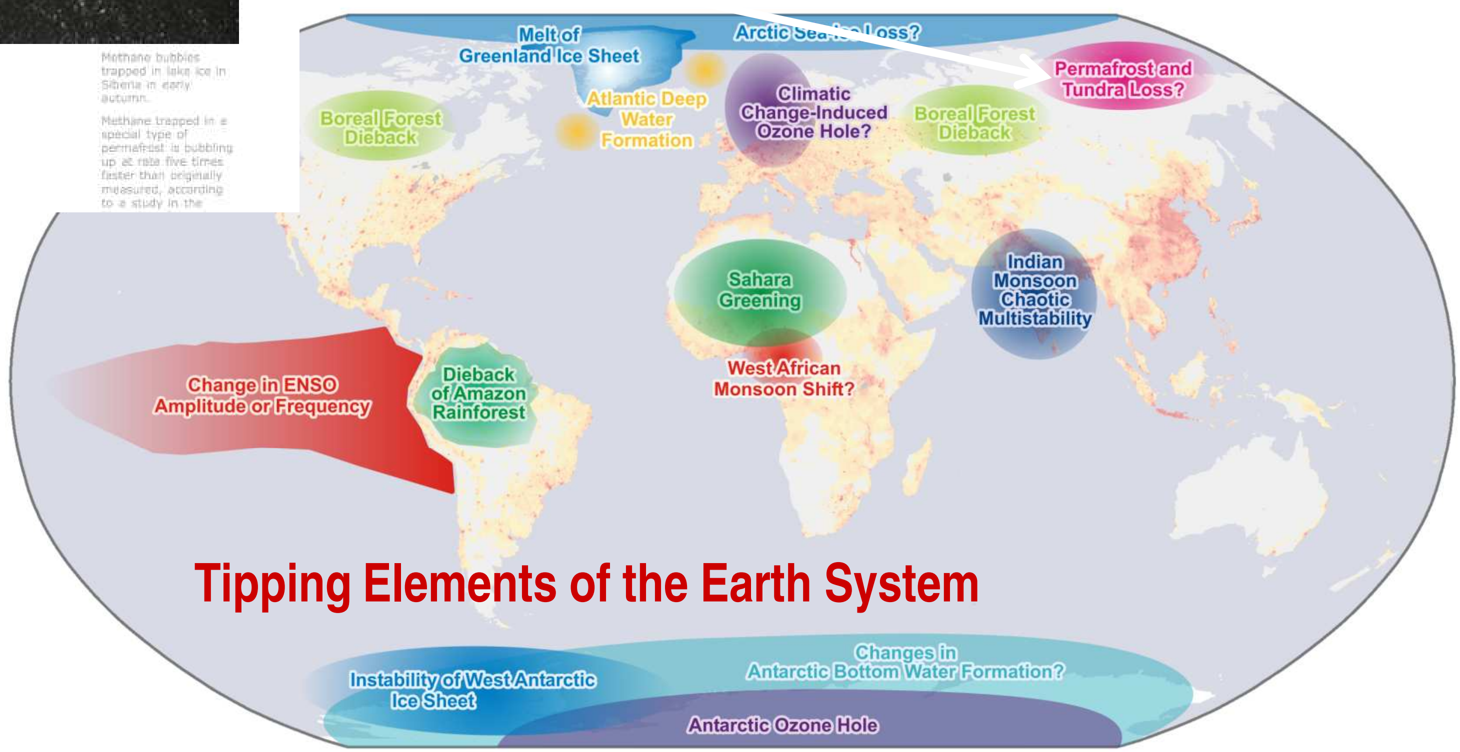
by Seth Borenstein

WASHINGTON — Global warming gases trapped in the soil are bubbling out of the thawing permafrost in amounts far higher than previously thought and may trigger what researchers warn is a climate time bomb.



Methane bubbles trapped in lake ice in Siberia in early autumn.

Methane trapped in a special type of permafrost is bubbling up at rate five times faster than originally measured, according to a study in the



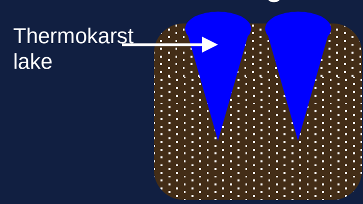
(Lenton et al. 2008 PNAS)

Lakes and permafrost:

- Indicator of changing permafrost conditions
  - Thermokarst - lake creation as permafrost degrades
  - Draining of lakes when deep permafrost disappears
  - So, appearance or disappearance of lakes in arctic can give clues to changing permafrost conditions

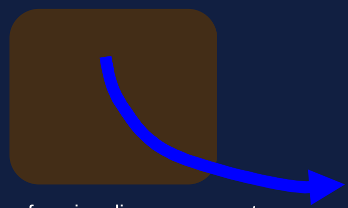
1 - Frozen ice rich permafrost

2 - Initial stages of thaw

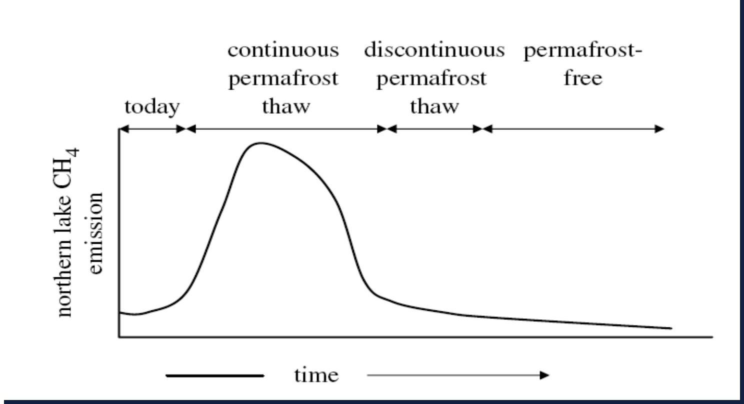


Perched water table where water cannot drain due to ice below it - see Lakes at the surface

3 - Final stages of thaw



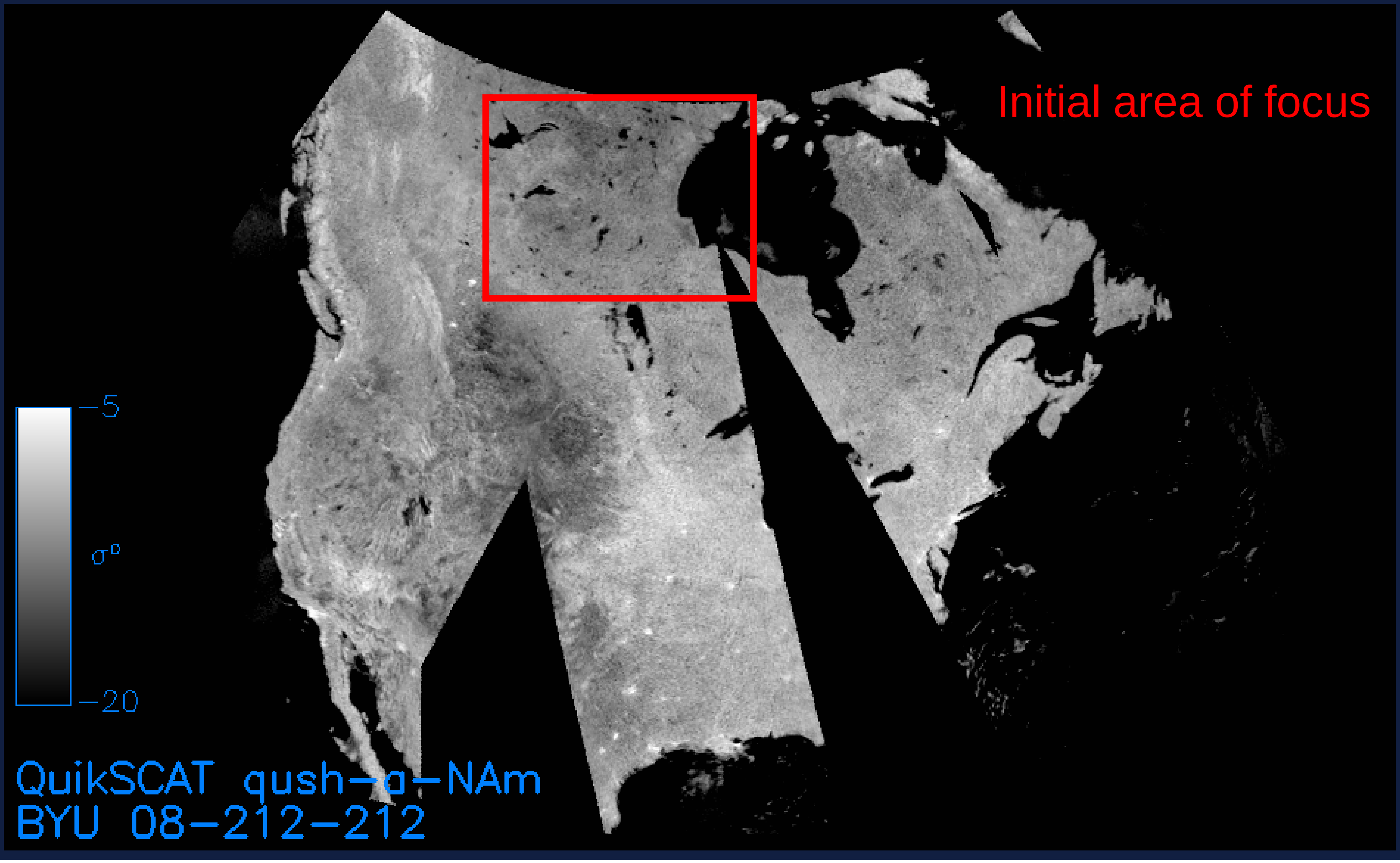
As subsurface ice disappears, water drains away leading to decreasing surface water cover

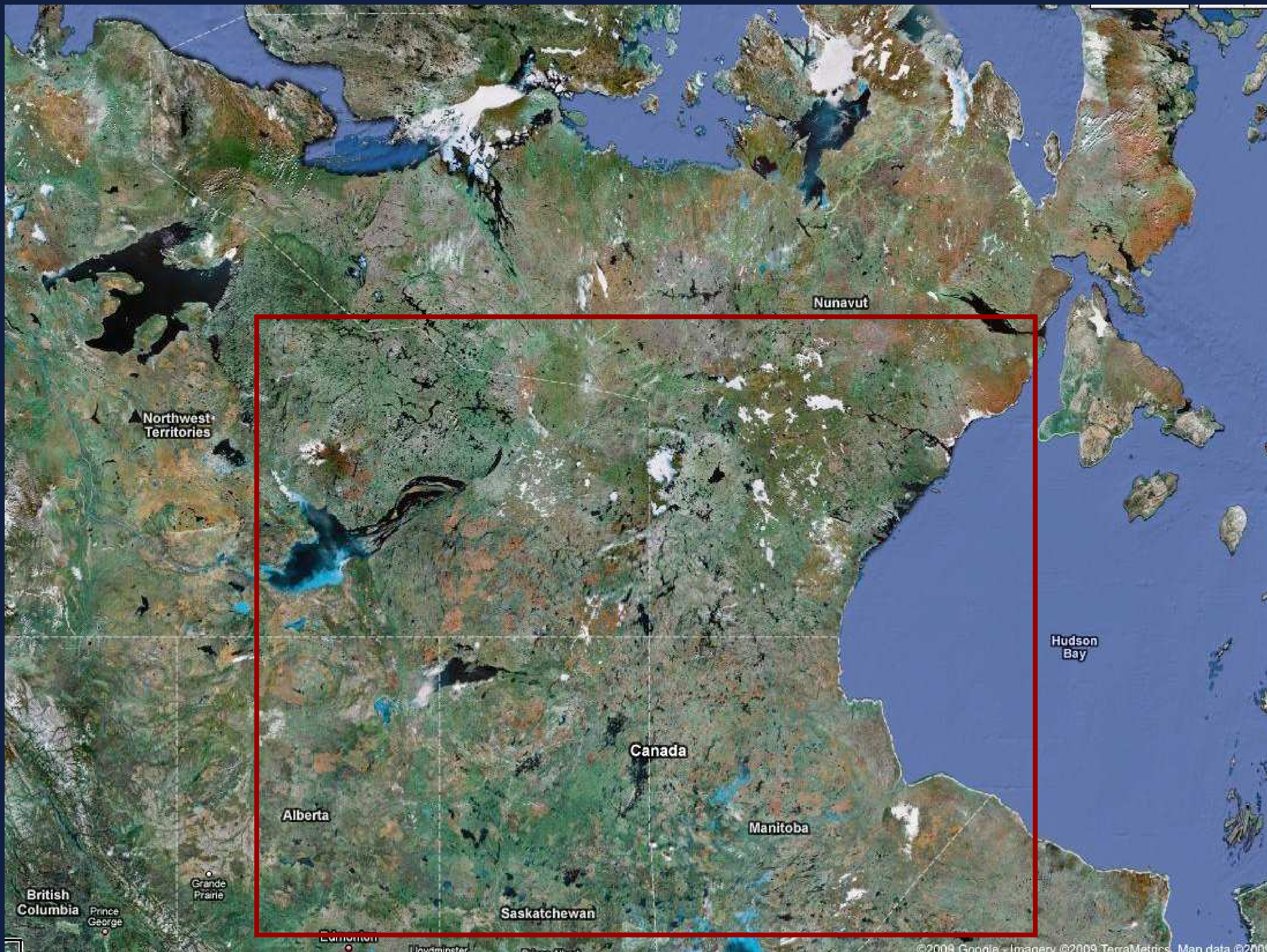


Walter et al. 2007

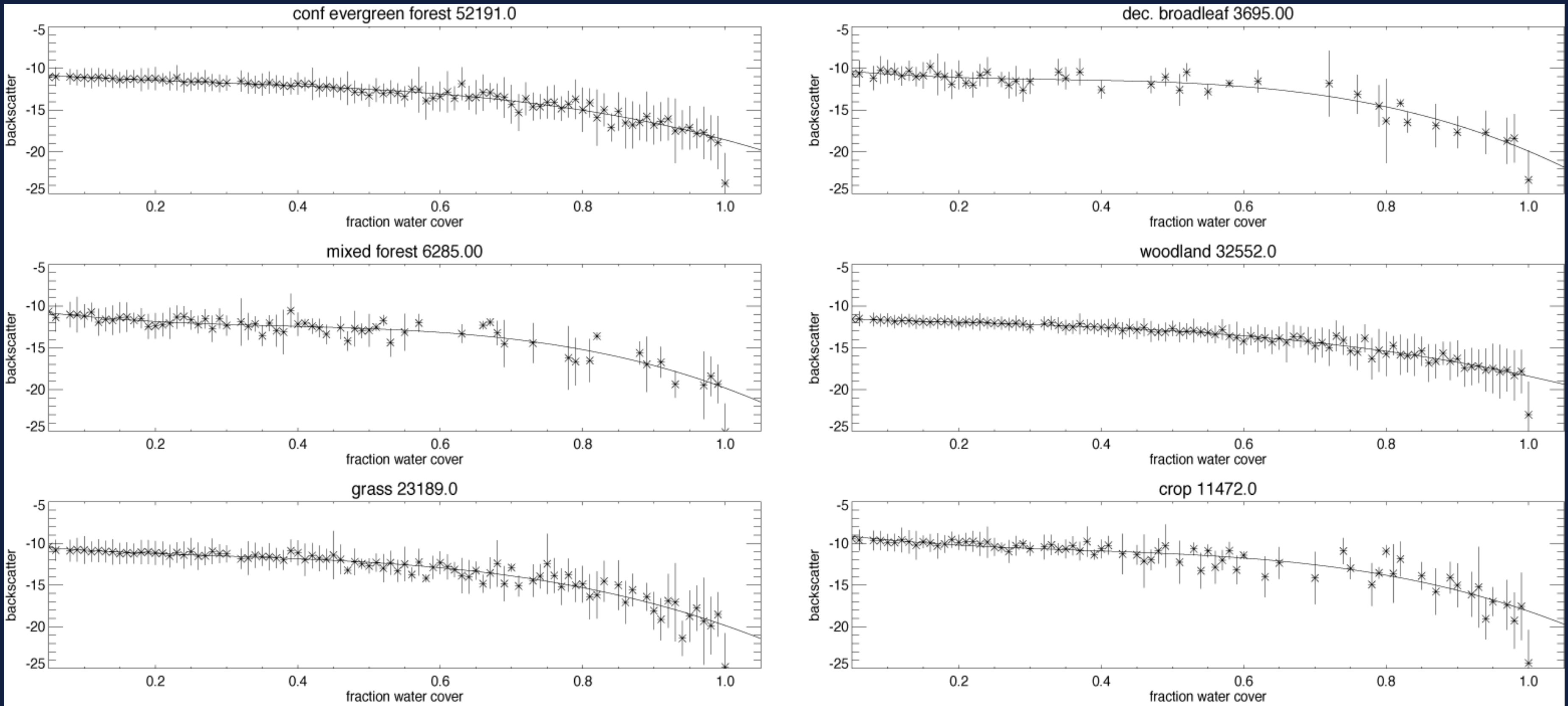
QuikSCAT

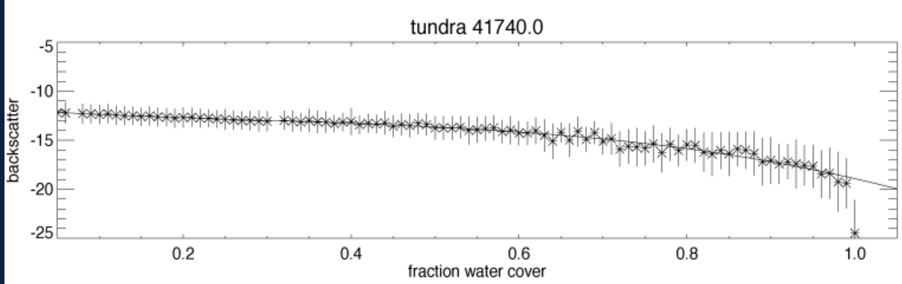
- Microwave back-scatter is highly sensitive to surface water
- Near-daily coverage since 1999
- Fewer problems with cloud contamination than AVHRR or other IR sensor




Nunavut
Northwest Territories
Hudson Bay
Canada
Alberta
Manitoba
British Columbia
Grande Prairie
Prince George
Saskatchewan
Lloydminster
Prince Albert
©2009 Google - Imagery ©2009 TerraMetrics, Map data ©2009

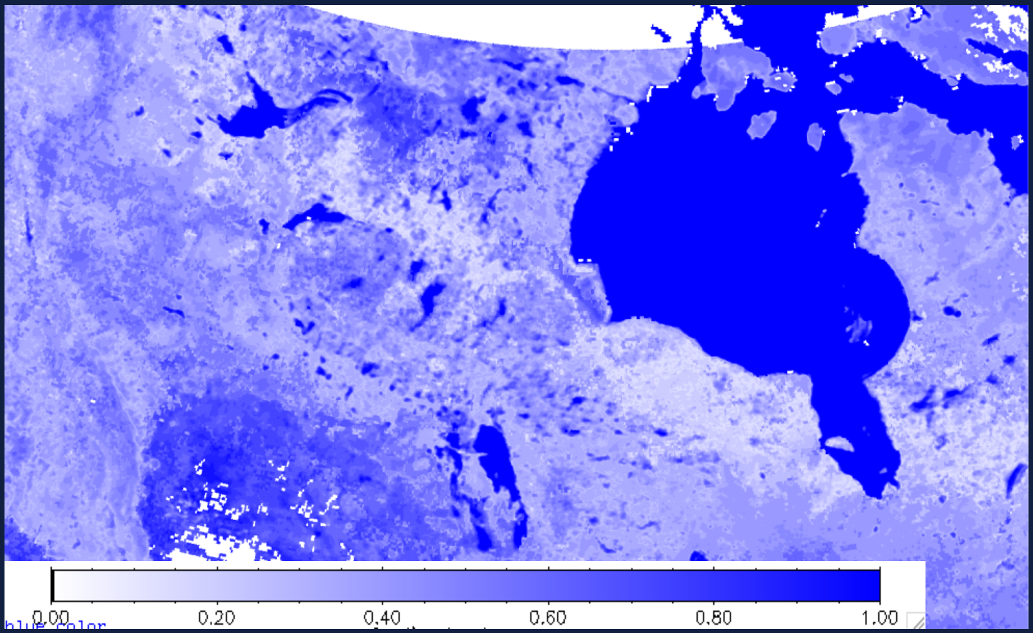
Splitting out pixels by vegetation type yields curves to predict surface water cover from σ
(this is average August H-pol slice backscatter signal for North America 1999-2008)



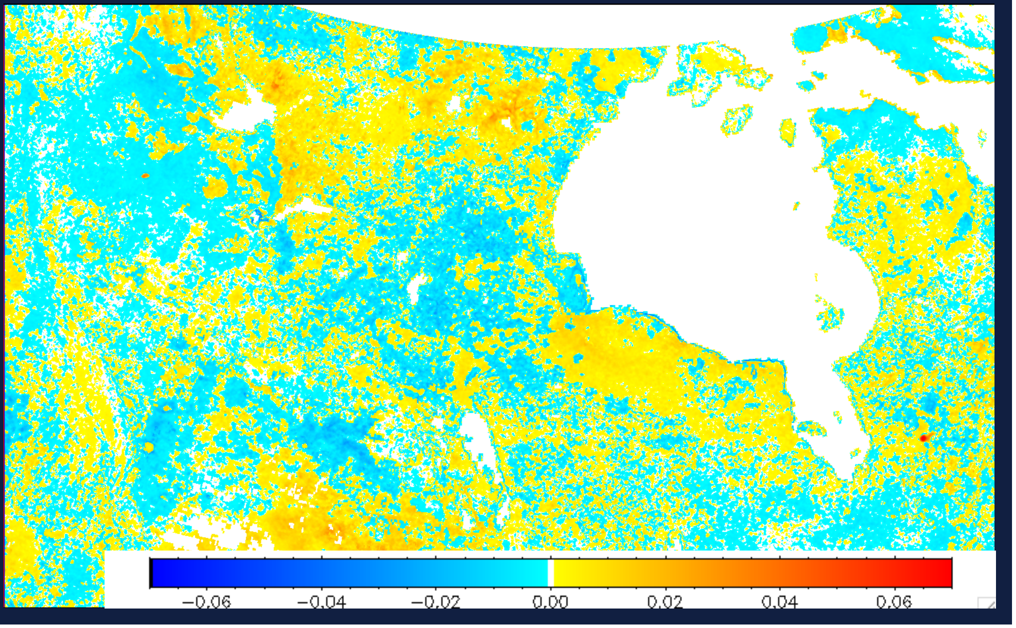


The horizontally polarized backscatter is more sensitive to fractional water cover than the vertically polarized backscatter. There was still a lot of spread in these data though

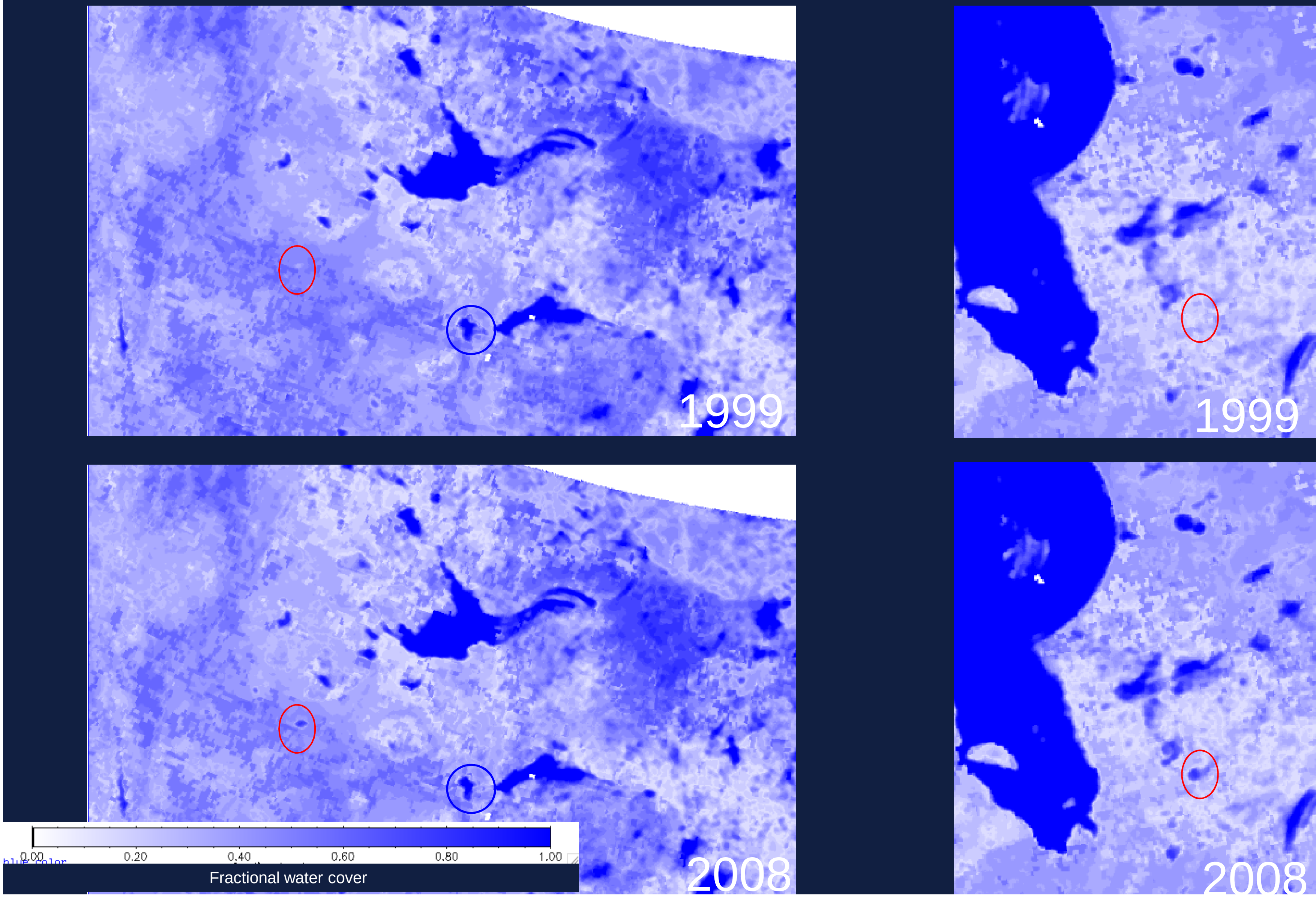
Mean Fractional Water Cover Derived from QuikSCAT



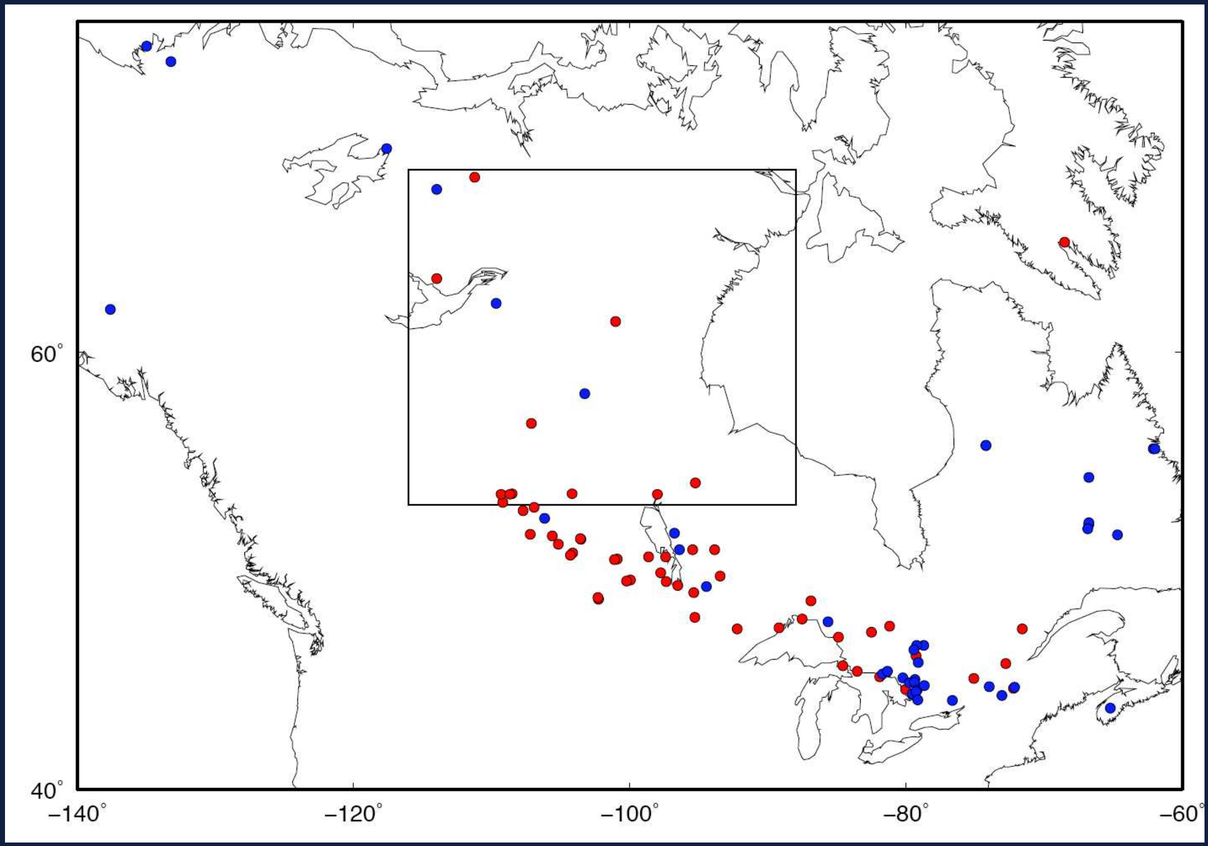
Trend in water cover from 2000 to 2008



Appearance/Disappearance of Lakes

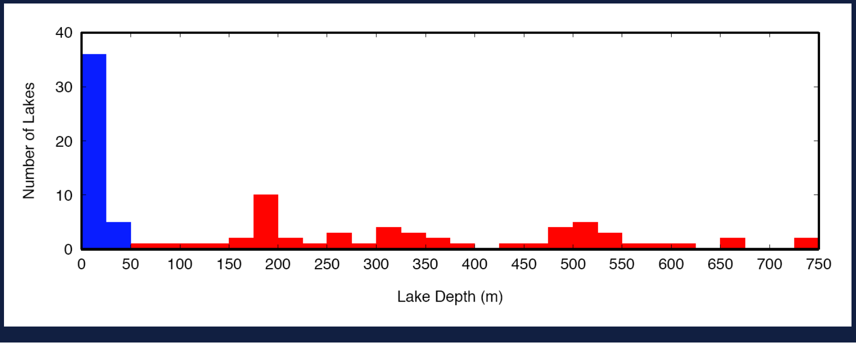


Validation: Comparison with lake depth data

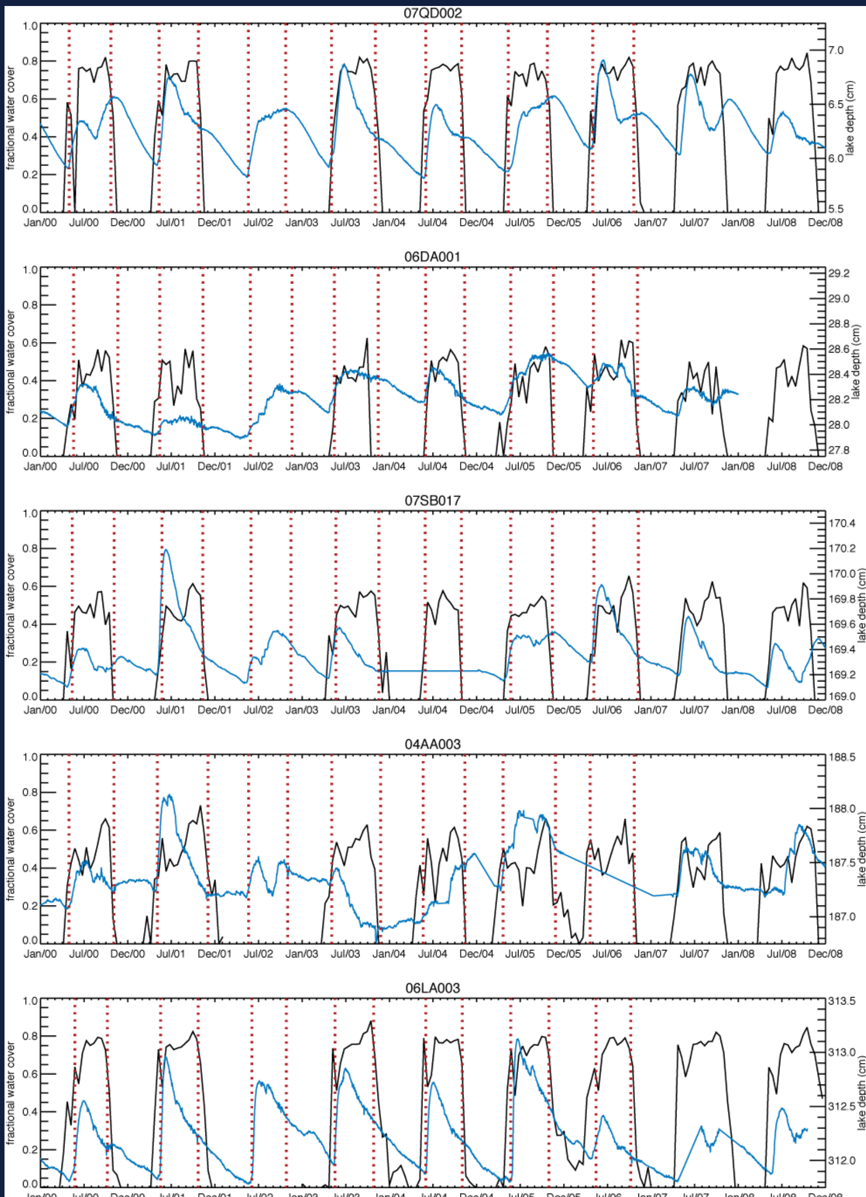


Water Survey of Canada archives lake depth data for selected sites.

Compared satellite derived fractional water cover with lake depth in natural (i.e. non-dammed) lakes that had > 1 year of data overlapping with QuikSCAT (n=5)



Lake Depth Data Comparison



shallower → deeper

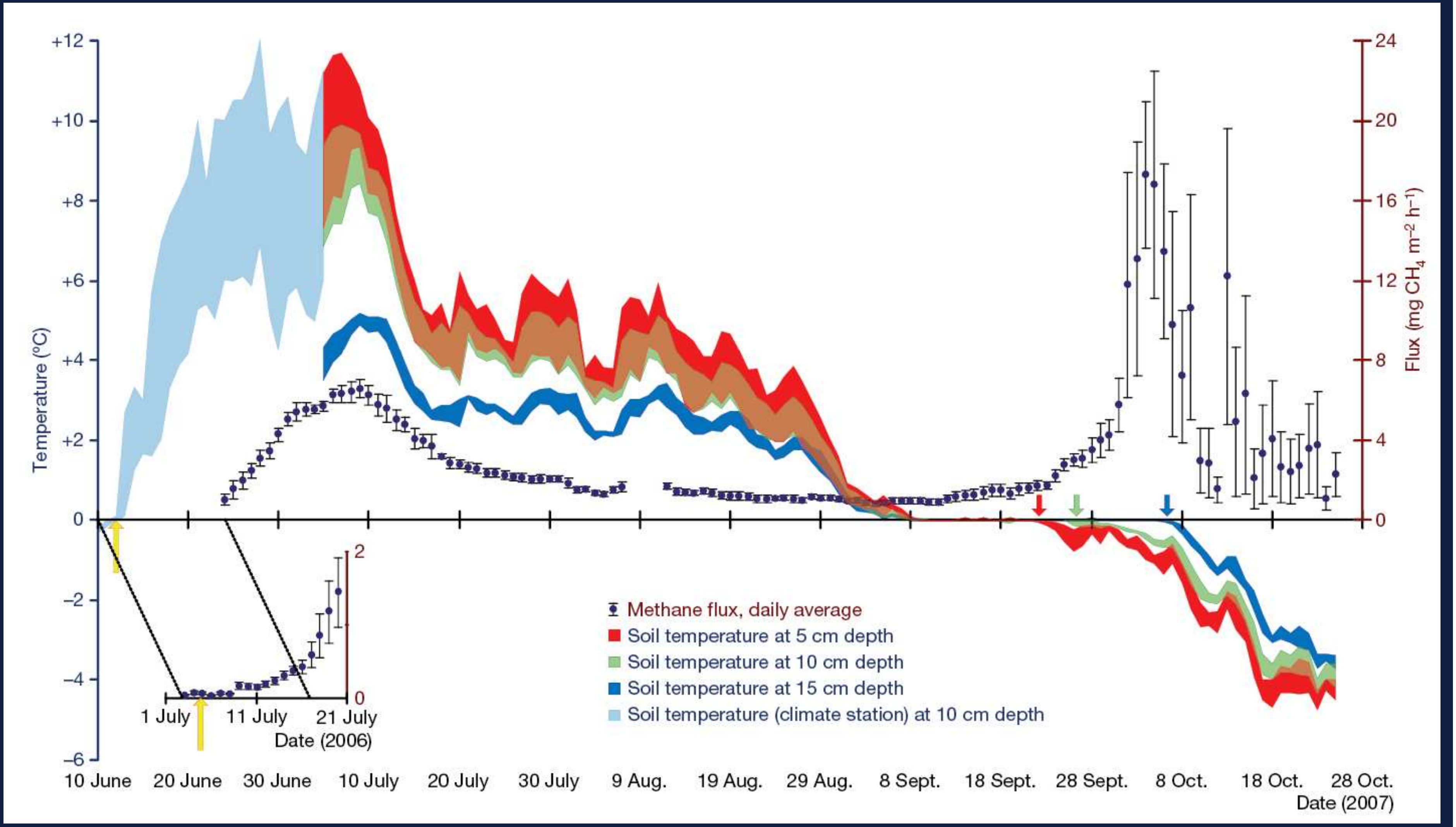
- QuikSCAT gets spring flush very well
- Works best for shallower lakes
- Late season dropoff in lake depth does NOT compare well
- QuikSCAT signal compares well to SSM/I derived dates of thaw/freeze (1° x 1°)

QuikSCAT f_{water}

Lake Depth

SSM/I Date of thaw and freeze [Smith et al. 2004]

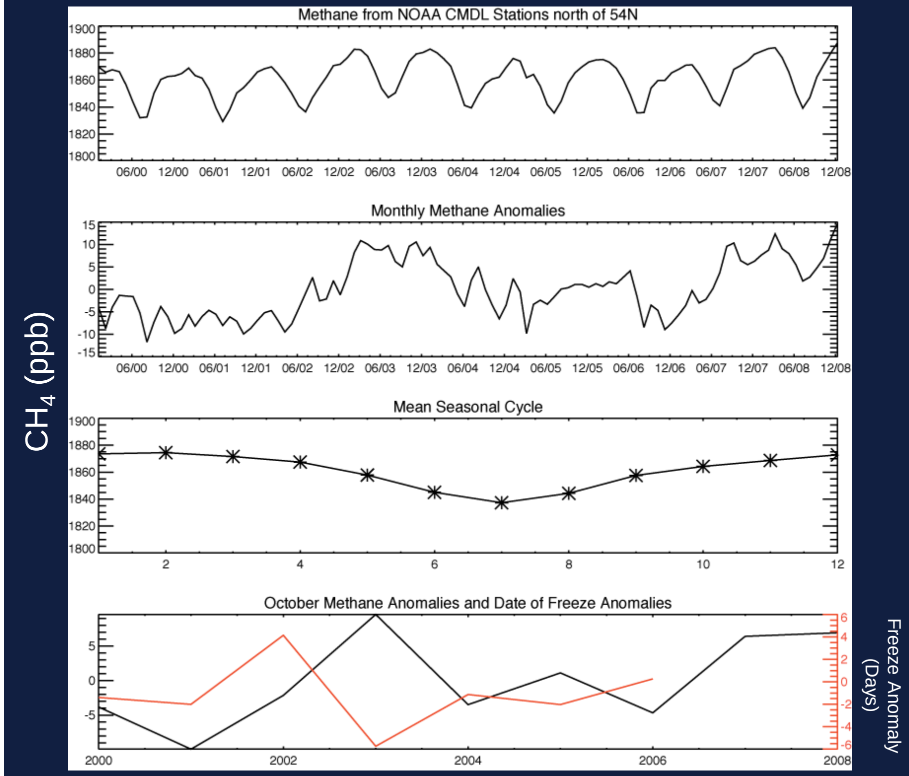
Emissions of CH_4 during wetland freeze

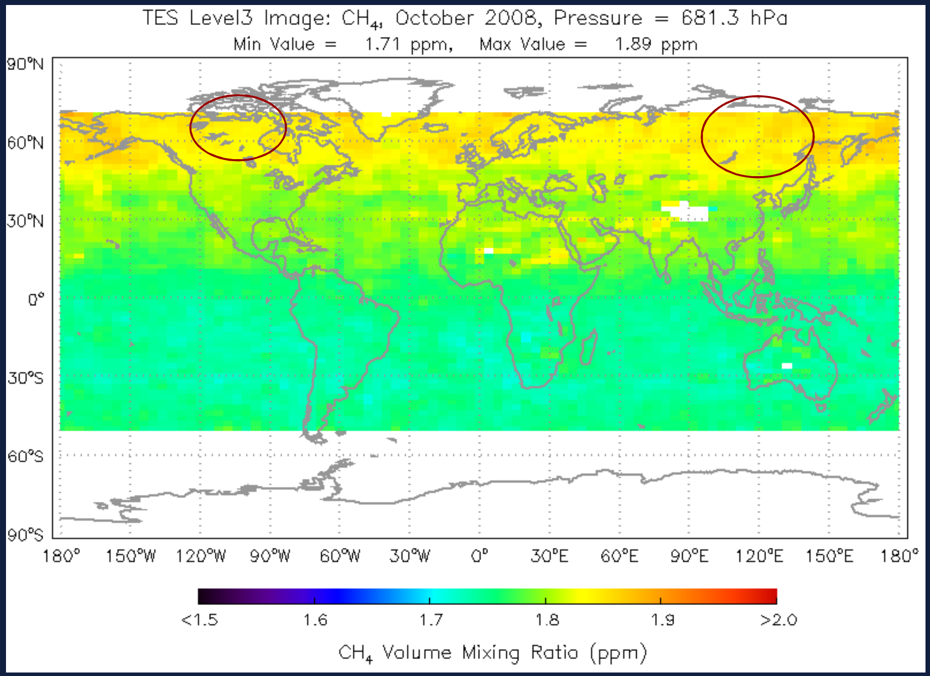


Mastepanov et al. 2008 (Nature)

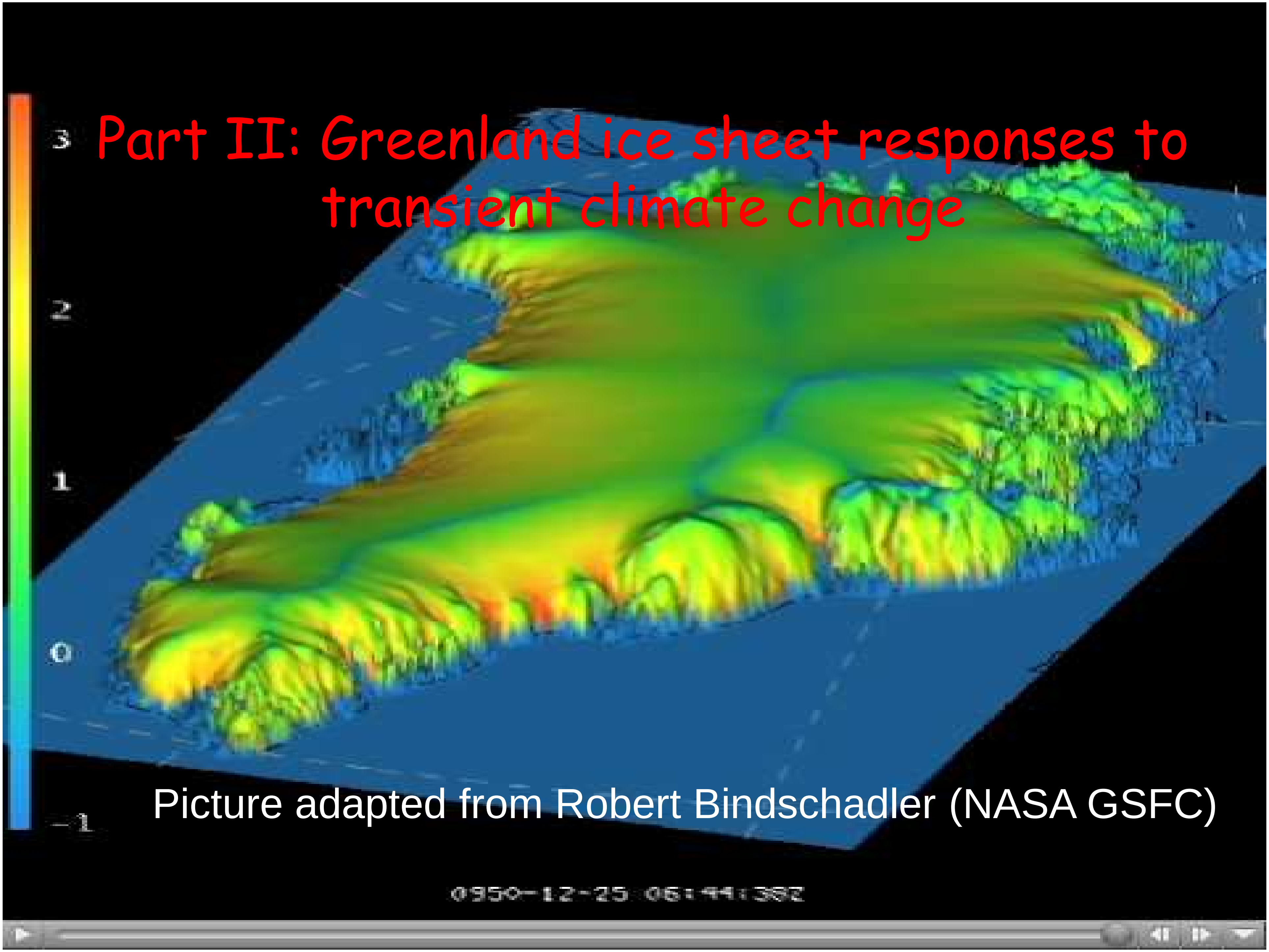
Research Plan

- Compare QuikSCAT freeze anomalies to satellite based CH_4 observations from TES (Aura)





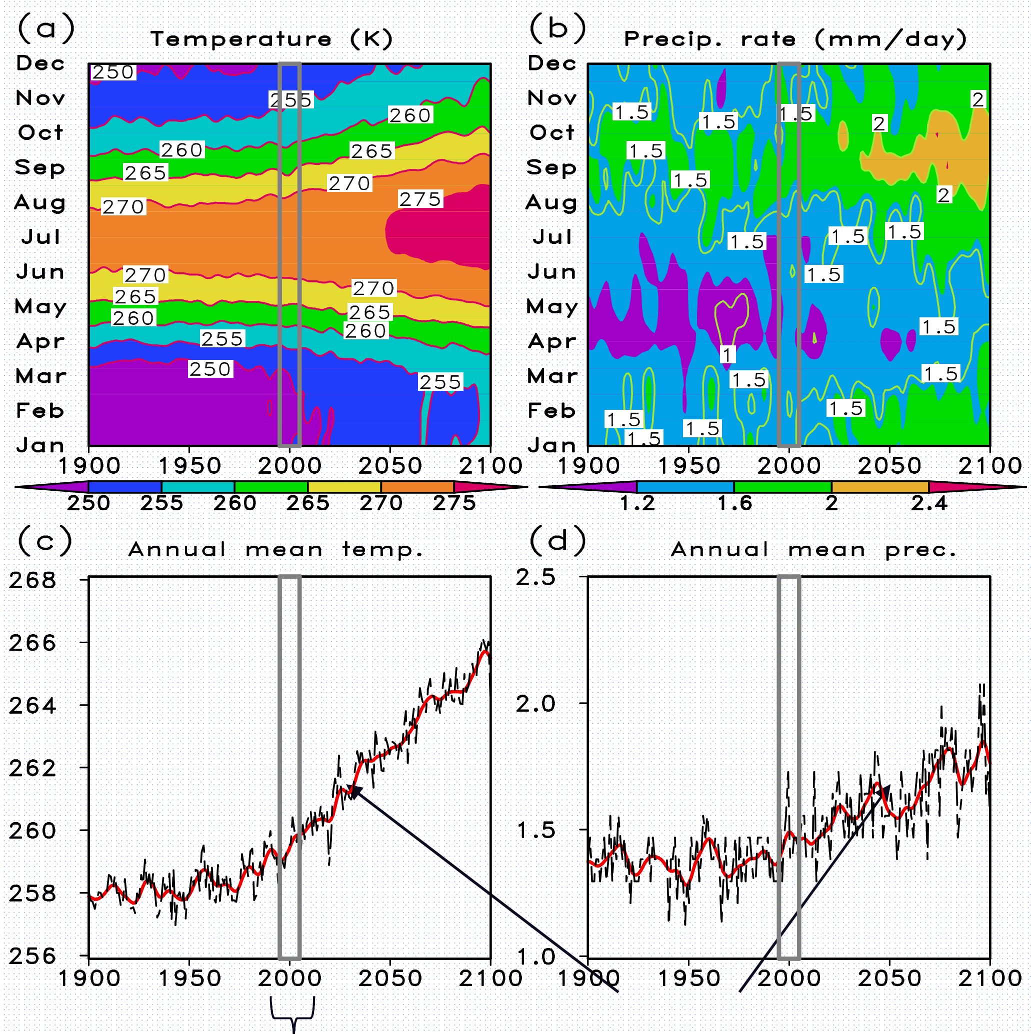
Part II: Greenland ice sheet responses to transient climate change



Picture adapted from Robert Bindschadler (NASA GSFC)

Climate is warming up

- MIROC-hires♣ simulated spatially averaged surface air temperature (*a* & *c*) and precipitation rate (*b* & *d*) trends over GRL
- The annual mean temperature (*c*) increases by ~4 ° C over the next century. Mean while, the annual mean precipitation (*d*) increases by 0.3 mm/day
- Without robust long-term modeling estimations, it thus is unclear whether GRL loses mass due to climate warming
- During the surveyed period (confined by the vertical grey lines), both temperature and precipitation trends are large within the 20th century but are modest when compared with the future ~100 years



Decadal survey period **21-year low-pass filtered**

♣ Center for Climate System research, University of Tokyo; NIES; Frontier Research Center for Global Change

Review of previous studies

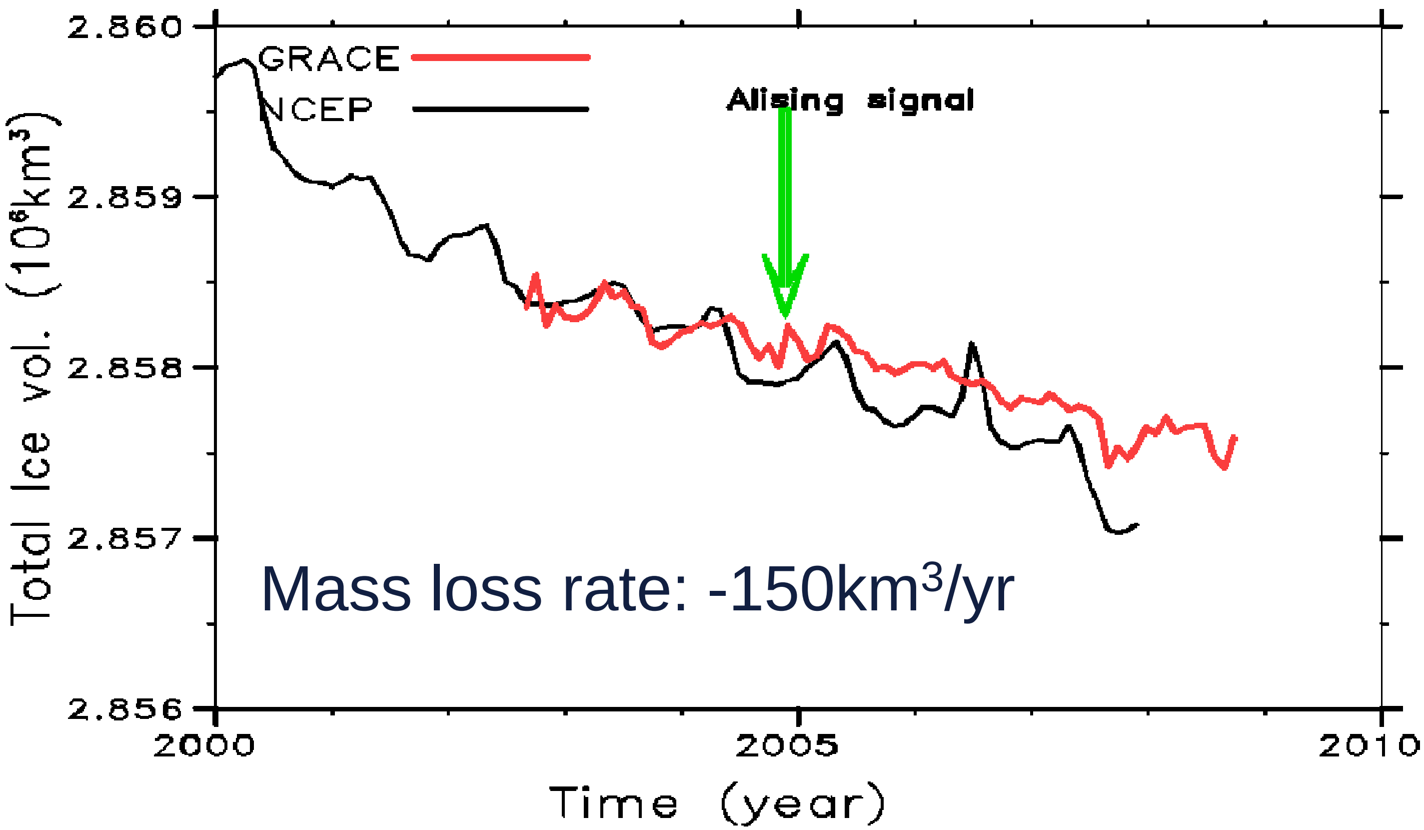
- Reactions of the Greenland ice sheet to climate changes have already been investigated by
  - Kuhn (1981) and Ambach (1985) as sensitivity studies
  - Huybrechts et al. (1991), van de Wal and Oerlemans (1997), and Greve (2000)
  - Ohmura et al. (1996) using a general circulation model (GCM) provided forcing series of temp. & precip. rate
  - van der Wal and Oerlemans (1994) suggests a net melting of 0.52 cm yr^{-1}. In contrast, Huybrechts (1994) gives a thickening at a rate of ~ 1cm yr^{-1}, while Ohmura et al. (1996) gives yet another picture. Although the latter's estimate of precipitation is about 25% above observational estimates, its conclusions are echoed recently by Meier et al. (2007)
  - Observational research: Zwally et al. (1990) , Douglas et al. (1990) ; Rignot & Kanagaratnam, 2006; Ashcraft and Long (2006); Mote (2007)
- It would be ideal to study this issue in a fully coupled modeling system. Unfortunately, few present coupled ocean-atmosphere climate models (CGCMs) include the interactive land ice flow dynamics (R. Binschandler, personal communication, 2006; M. Openheimer, personal communication, 2007)
- The IPCC AR4 (http://ipcc-wg1.ucar.edu/wg1/wg1-report.html) used only a surface-mass-balance estimation in sea-level predictions, stating that "quantitative projections of how much the accelerated ice flow would add (to sea level rise) cannot be made with confidence, owing to limited understanding of the relevant processes (Subsection 5.1)."

Modeling of Greenland Surface Melt

- Accurate prediction of future sea level rise requires models that have the skill of reproducing and explaining the recent observed dramatic Greenland ice sheet behavior

- This study presents a new multi-phase, multiple-rheology, scalable and extensible geofluid model of the Greenland ice sheet that shows the credential of successful reproducing the mass loss rate derived from the Gravity Recovery and Climate Experiment (GRACE) and the microwave remote sensed surface melt area over the past decade

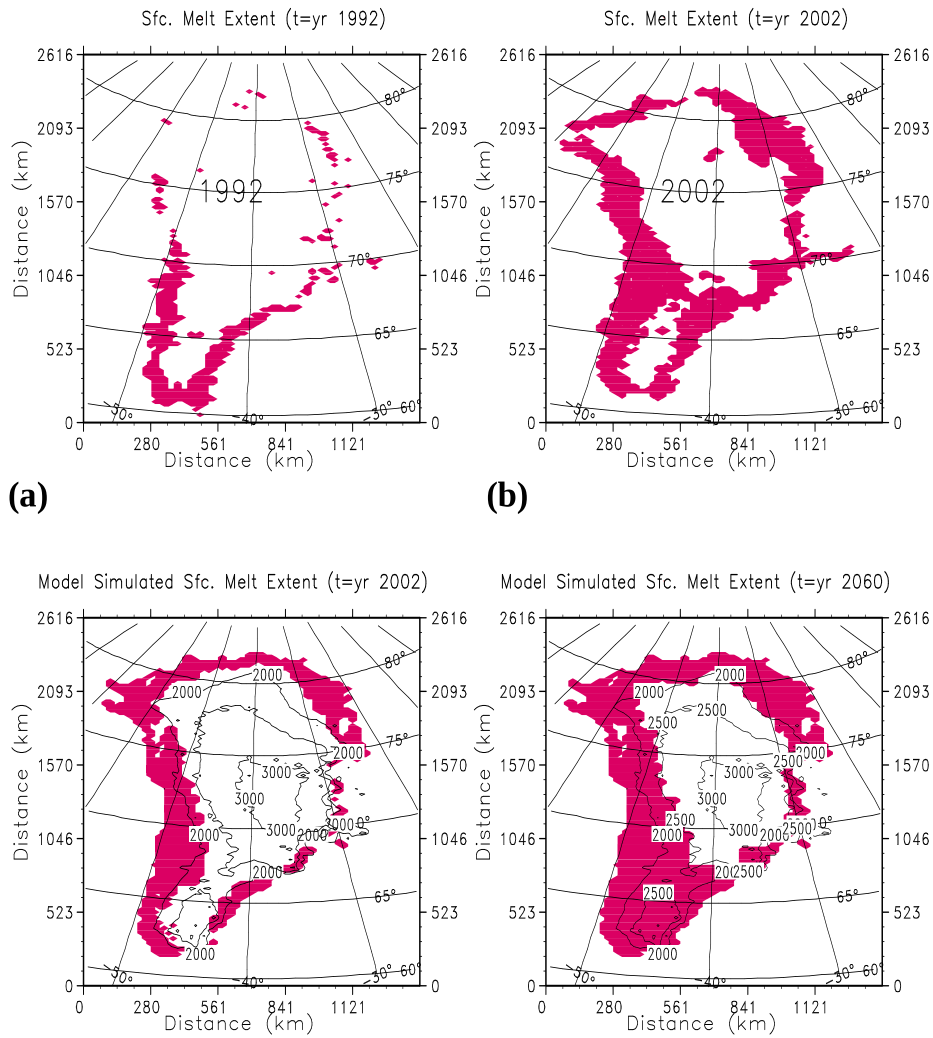
Modeling of Greenland Ice Sheet Mass Loss



Comparison b/t the Gravity Recovery and Climate Experiment (GRACE, redline, 2002-2008) measured total mass change with model simulation driven by NCEP/NCAR provided meteorological parameters

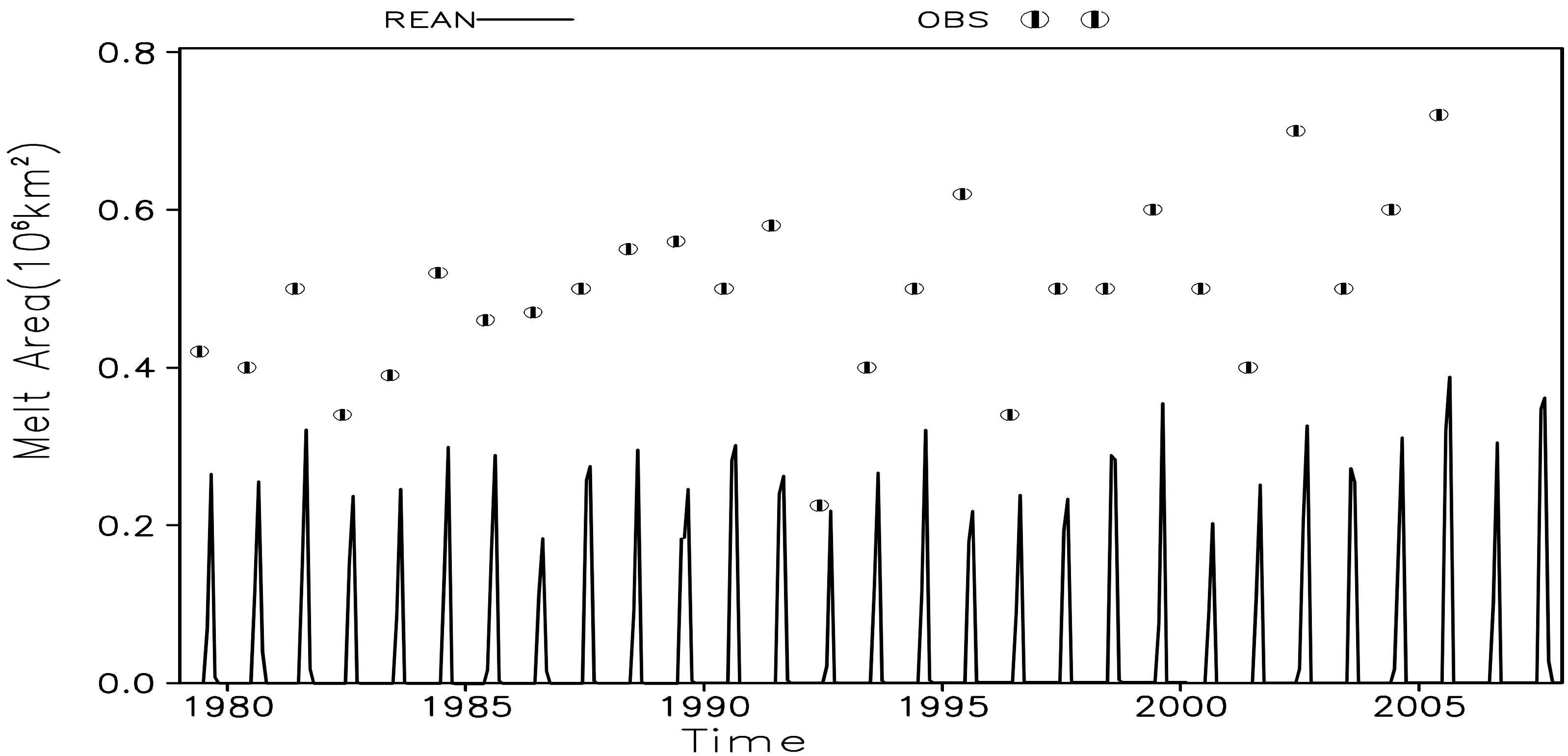
Summer maximum surface melt extent (SME)

- Microwave mts. obtain good estimation of the ice sheet sfc. melt extent and duration because T_b and σ_0 both are sensitive to liquid water present in snow (Ashcraft and Long 2006)
- Observed (upper panels) and simulated (lower panels) SME (melting areas are in red)
- 'near-surface forcing criteria' for surface melting is stipulated as a $T_{2m} > -5\,°\,C$ & $R_{net} > 170\ W\ m^{-2}$ (L.Thompson, May 2007, personal communication)
- The model simulated yr 2002 melting extent (*c*) is very close to that observed (*b*)
- Panels (a) and (b) are adapted from Chapter 6 in ACIA2005, and originally from K. Steffen, CIRES/U. Colorado at Boulder



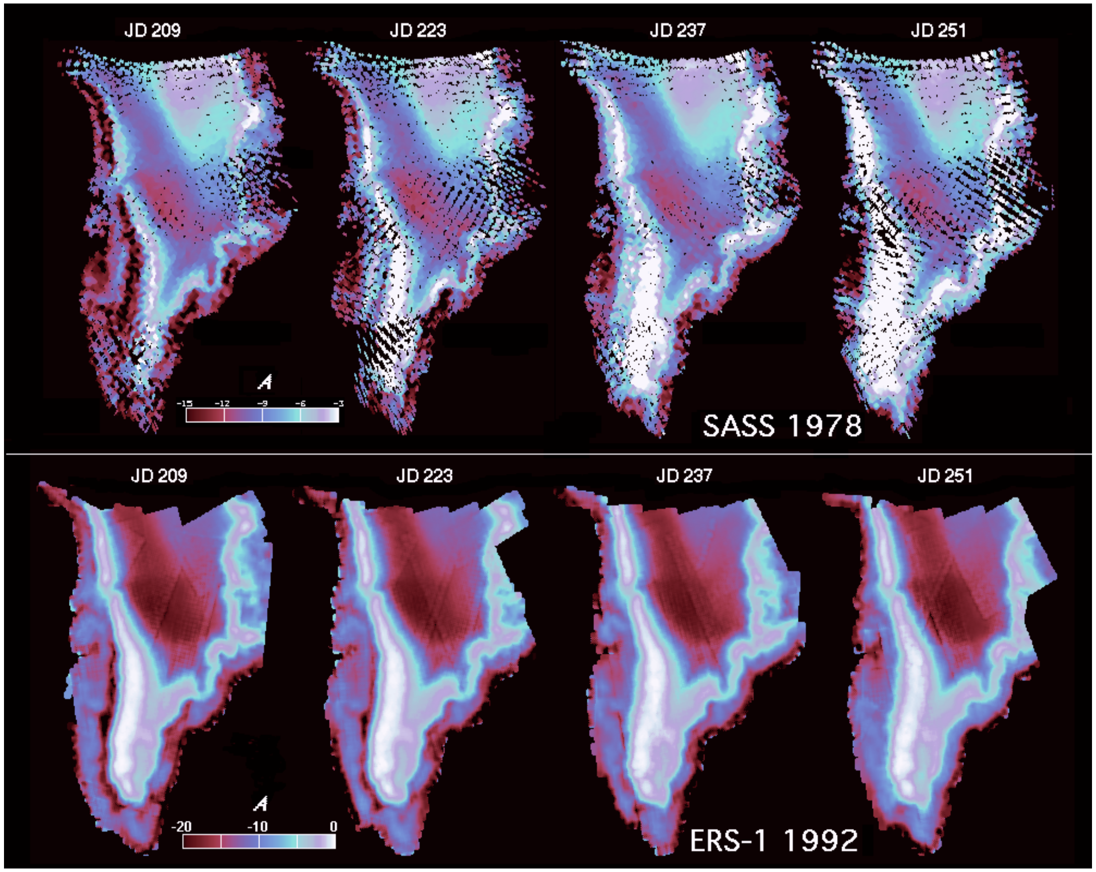
MIROC-hires

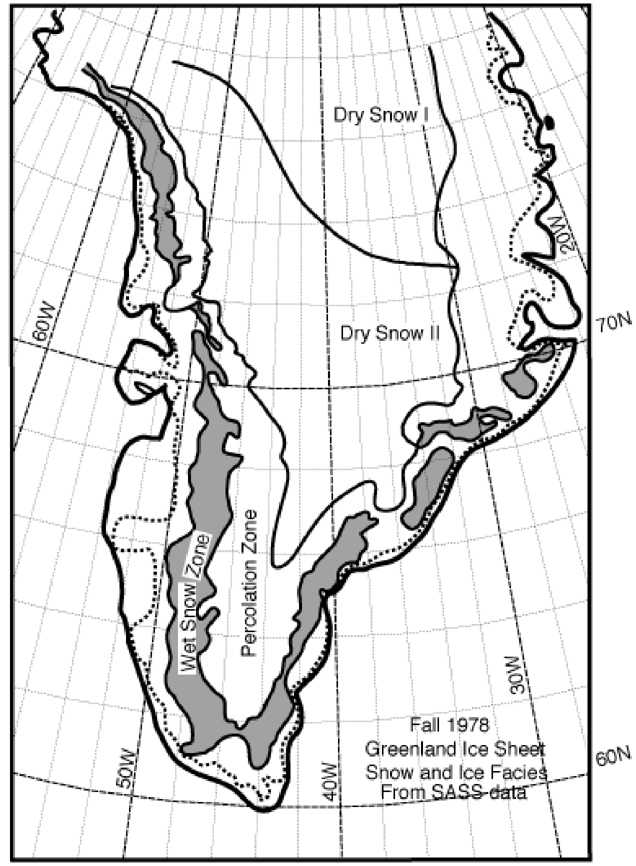
Modeling of Greenland Ice Sheet Melt Area



- ✓ The seasonal surface melt extent on the Greenland ice sheet has been observed by satellites since 1979 and shows an increasing trend
- ✓ Obs. re-procesed based on National Snow and Ice Data Center (NSIDC) archive of T_b at 25 km reso. on a NPS progection. See total ice cover of ~1.7 million km^2 close to what the model see
- ✓ Different definition of surface melt may account for the differences in magnitude

Observed Greenland Ice Sheet Melt Area





Long and Drinkwater, Greenland Observed at high resolution by the Seasat-A Scatterometer, J. Glaciology 60(12), 1994

http://www.mers.byu.edu/Green.html