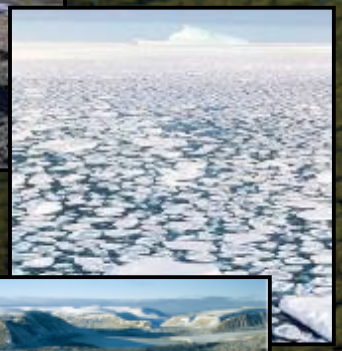
The terrestrial Arctic response to (and role in) local and global climate change



David Lawrence

NCAR Earth System Laboratory
Boulder, CO

NCAR is sponsored by the National Science Foundation

NCAR Sea Ice Prediction Pool Results 2008-2010

Organized by Jennifer E. Kay
(jenkay@ucar.edu)

Predictions for mean September ice extent submitted on June 1 (~20 entries each year)

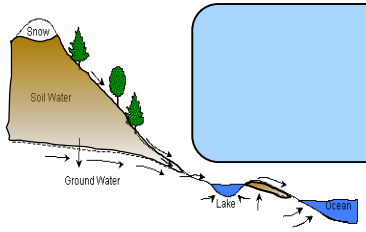
Owner of best guess gets ice cream from worst guess

NCAR ensemble mean prediction error

2008: 0.00 (-0.11) million km^2

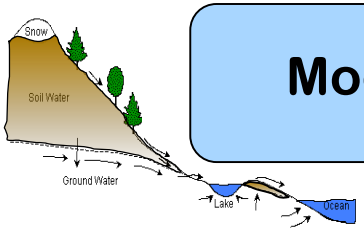
2009: -0.63 (-0.73)

2010: -0.01 (-0.11)



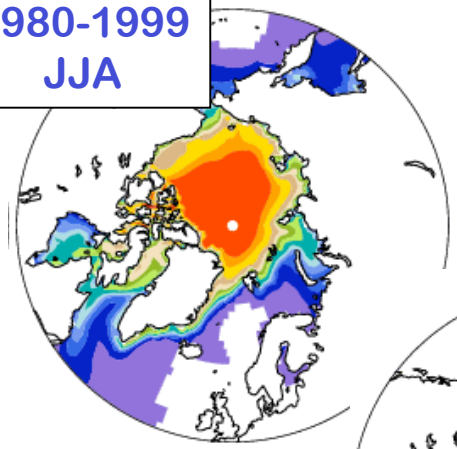
Topics for today

- Impact of sea ice loss on terrestrial Arctic climate
  - T, P, Snow
  - Rate of ice loss
  - Compare impact of sea ice loss to terrestrial snow extent decrease
- Terrestrial Arctic feedbacks
  - Example of shrub cover expansion



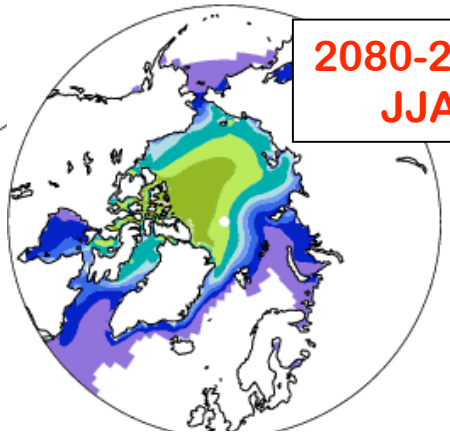
Modeled impact of sea ice loss on terrestrial Arctic climate

1980-1999
JJA



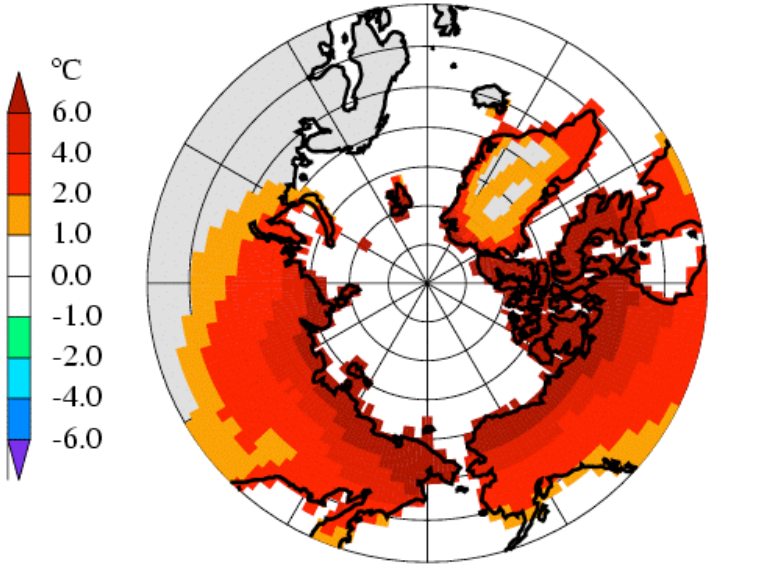
AMIP-type expts with prescribed ice extent and thickness from CCSM3

2080-2099
JJA

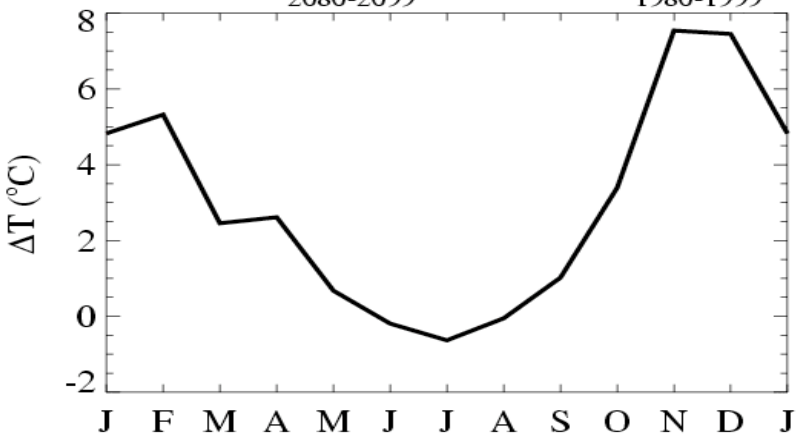


Ice concentration

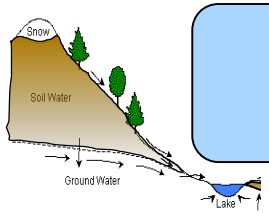
ΔT (OND)
$SEAICE_{2080\text{-}2099} - SEAICE_{1980\text{-}1999}$



$SEAICE_{2080\text{-}2099} - SEAICE_{1980\text{-}1999}$



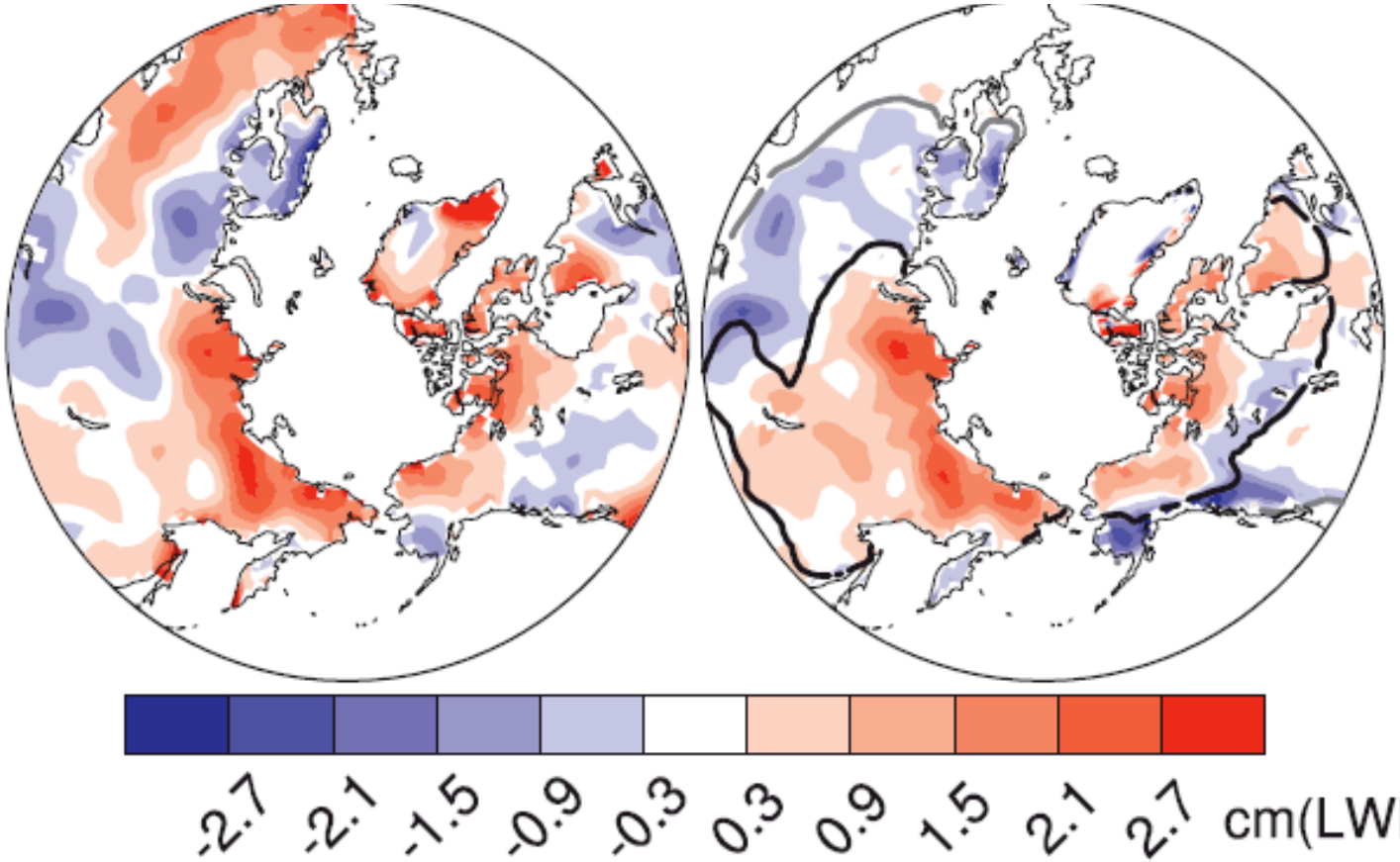
Deser et al., J. Climate (2010)



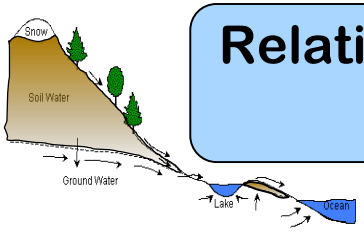
Modeled impact of sea ice loss on terrestrial Arctic climate

Change in accumulated Oct to Mar precip

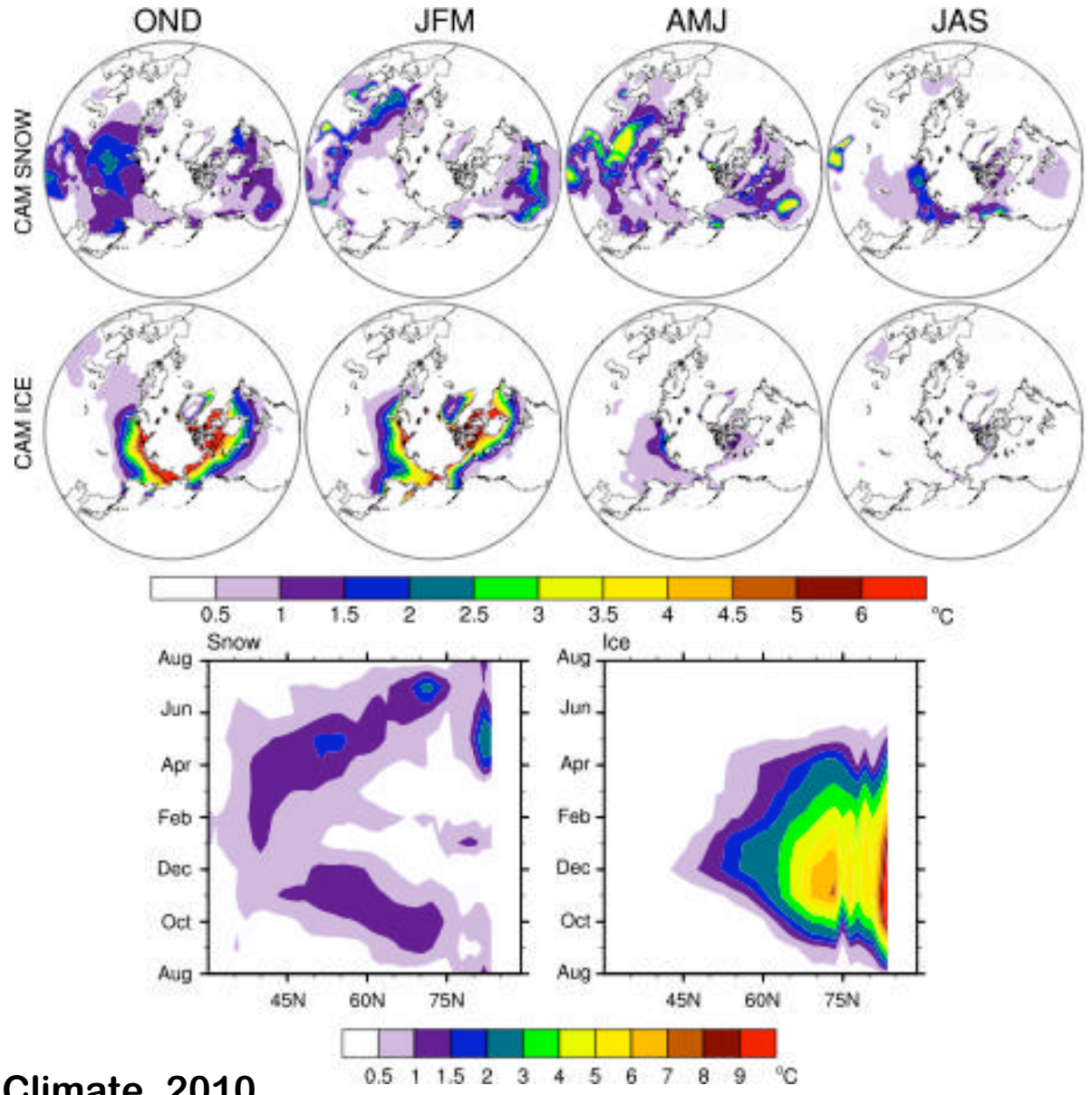
Change in March snow depth



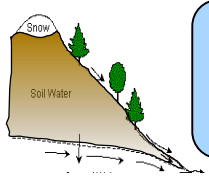
-2.7 -2.1 -1.5 -0.9 -0.3 0.3 0.9 1.5 2.1 2.7 cm(LWE)



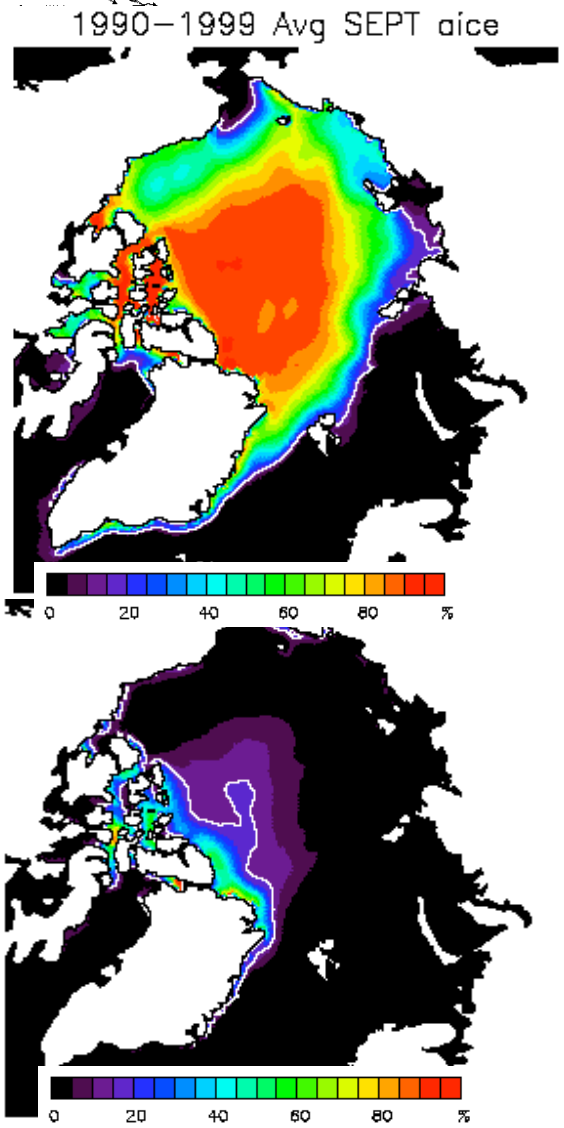
Relative influence of projected sea ice vs snow cover change on Arctic terrestrial T_{air}

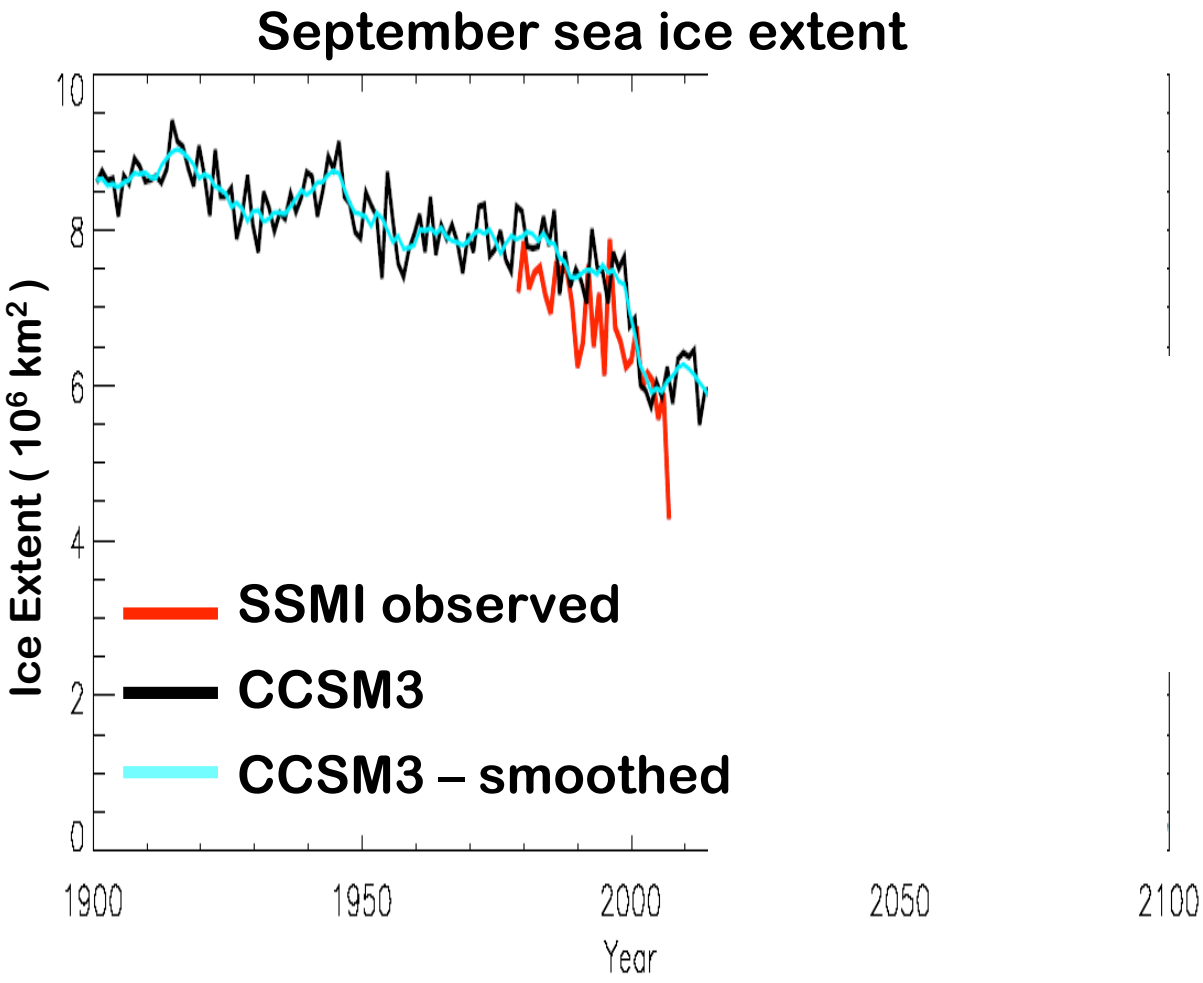


Alexander et al., J. Climate, 2010

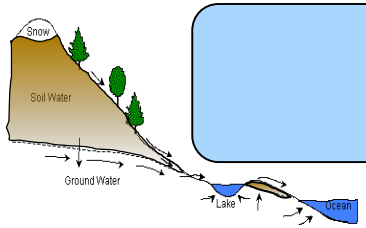


Abrupt reductions in the September sea ice cover CCSM3

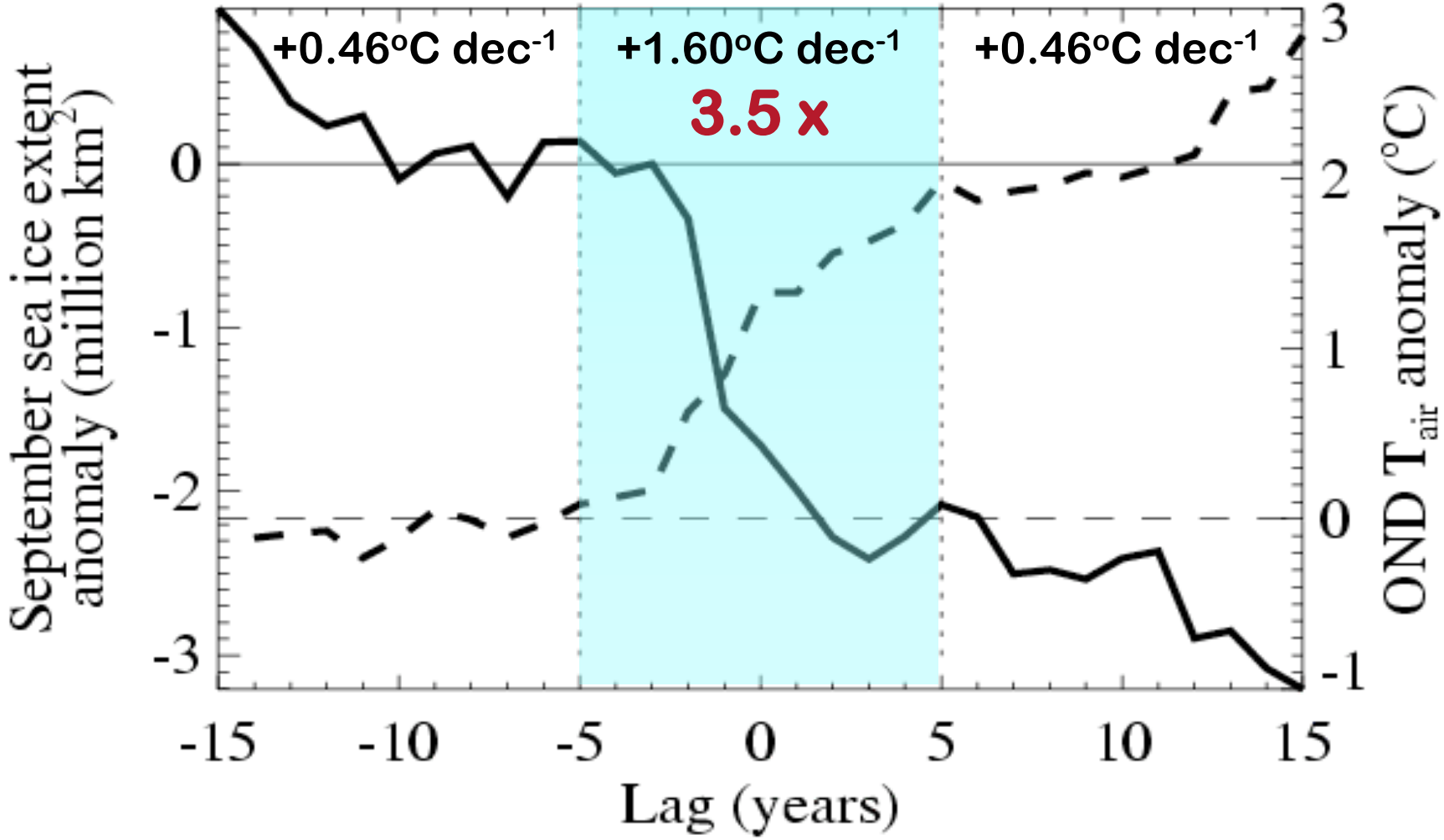


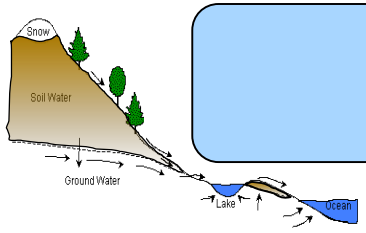


Holland et al., GRL, 2006

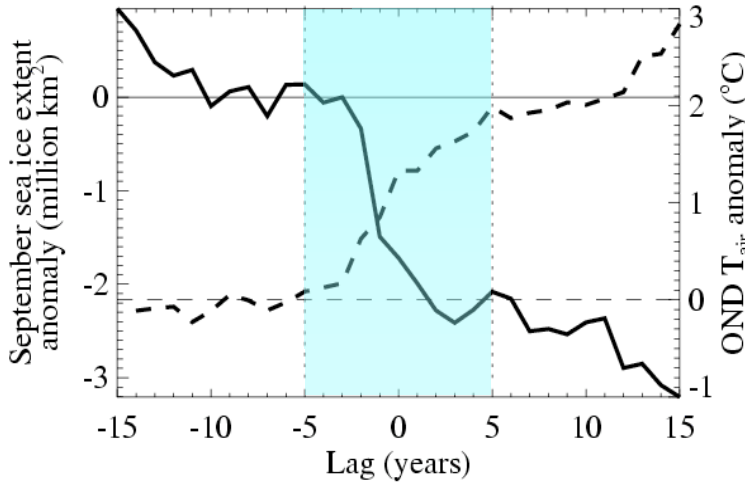


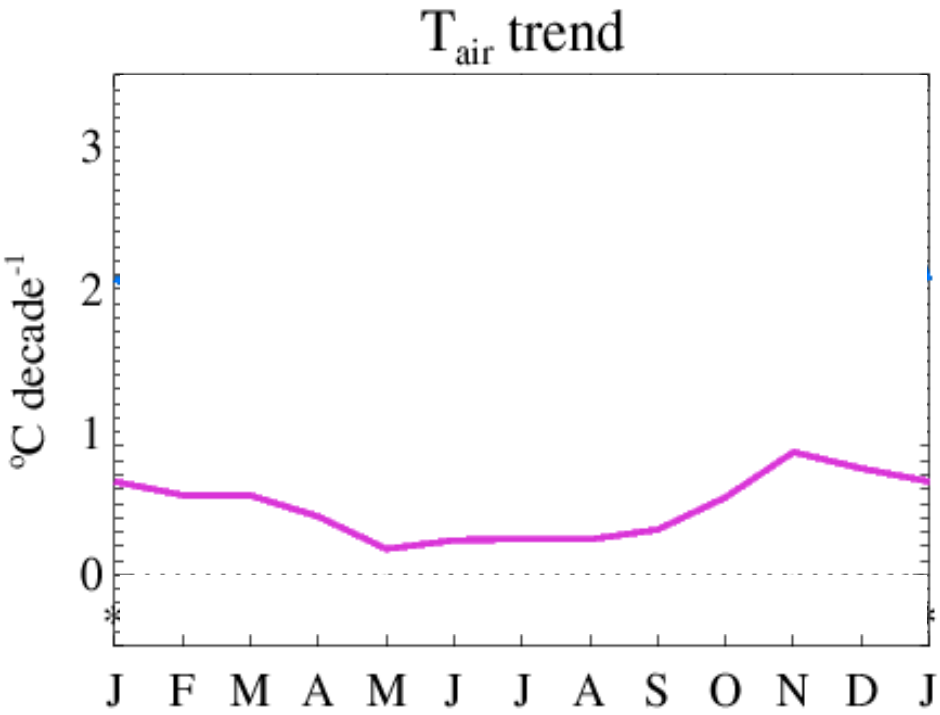
Lagged composite: sea ice extent and western Arctic land T_{air}



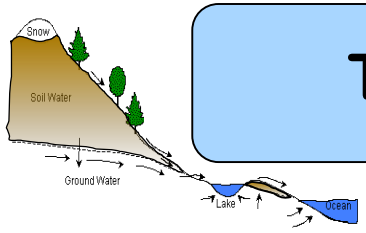


T_{air} trend over Arctic land during rapid and moderate sea ice loss





Lawrence et al., GRL, 2008

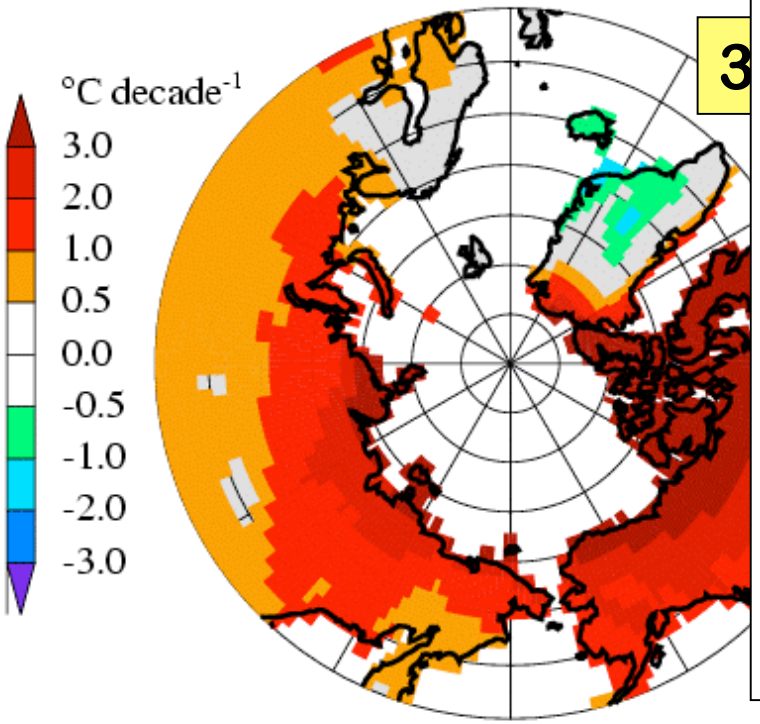


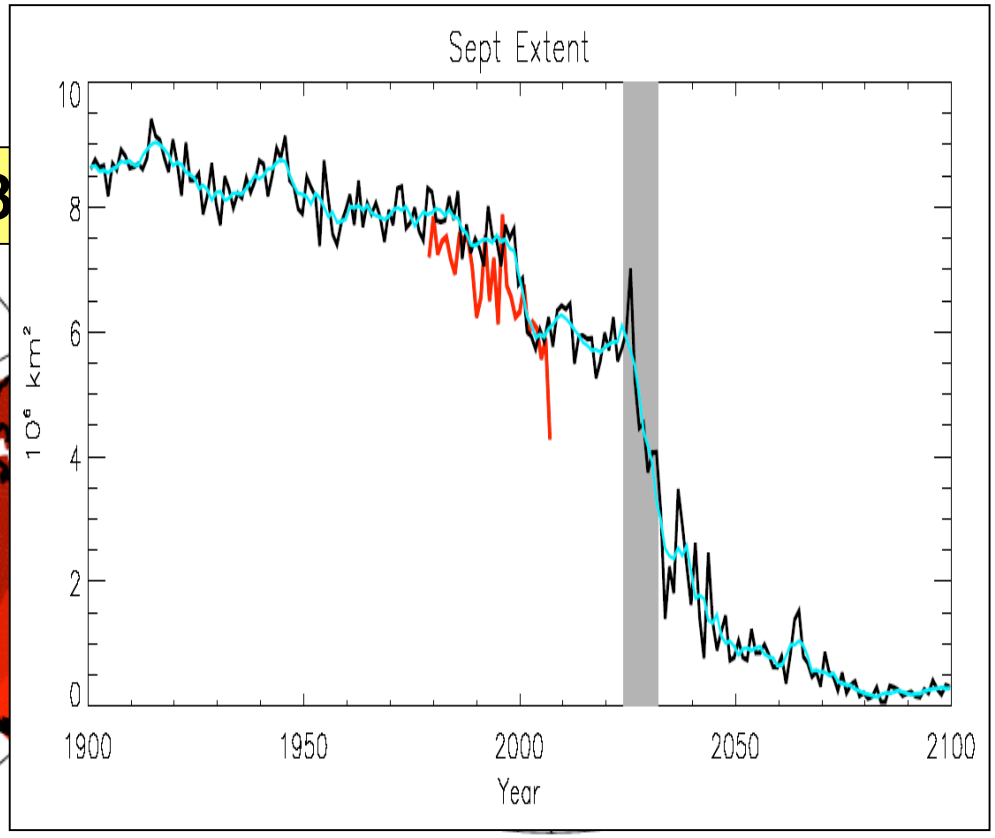
Trends during rapid vs moderate sea ice loss

Periods of rapid sea ice loss

OND

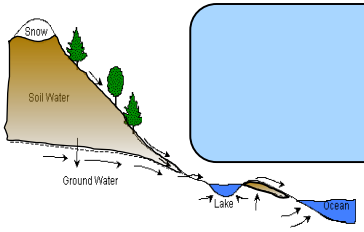
T





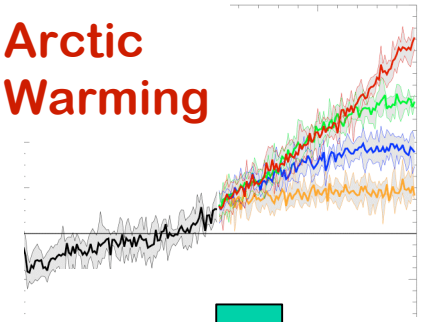
- **Similar change in trends in q_{air}, LW↓**
- **No statistically significant or spatially coherent change in trends in P, snow depth, or SW↓**

Lawrence et al., GRL, 2008

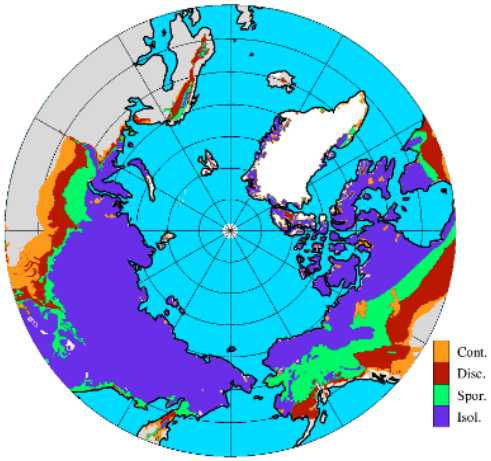


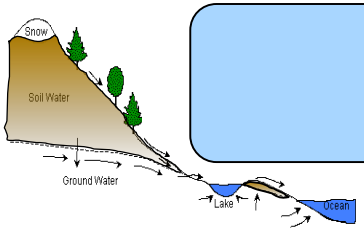
Permafrost thaw

Arctic Warming

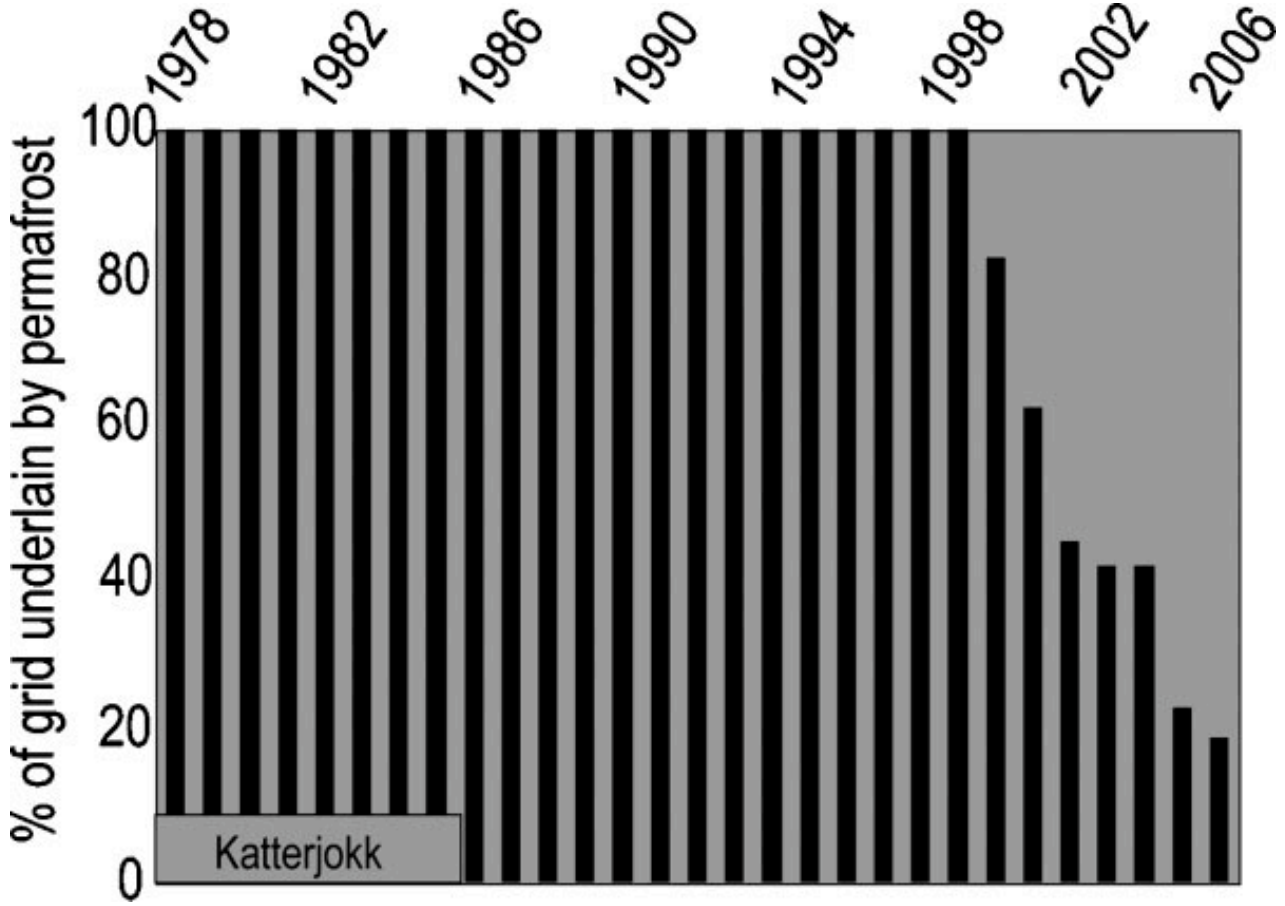


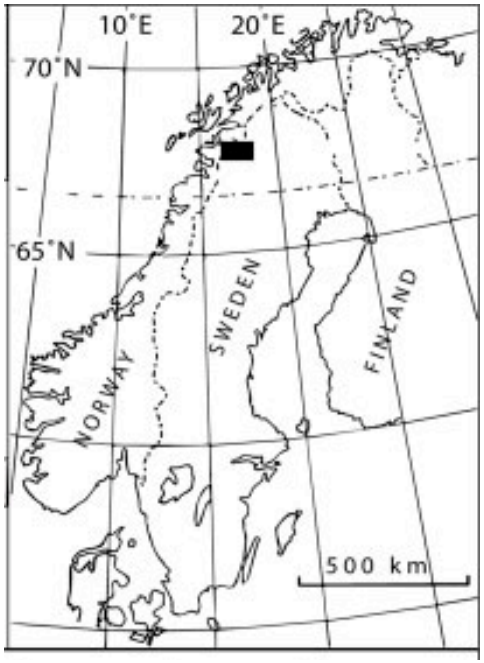
Permafrost warms and thaws



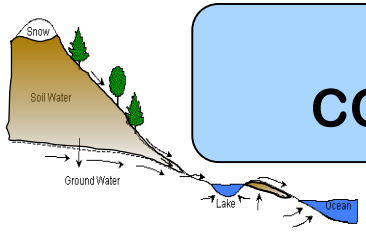


Observed permafrost degradation

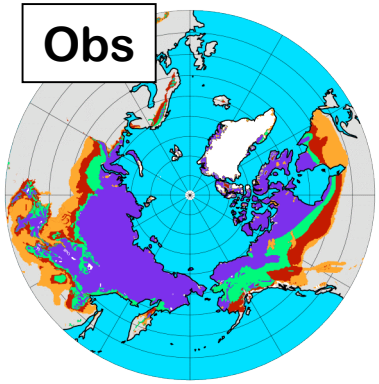


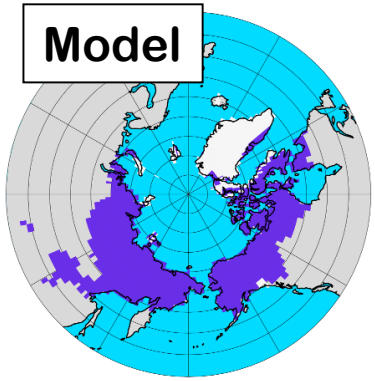


Akerman and Johansson, 2008

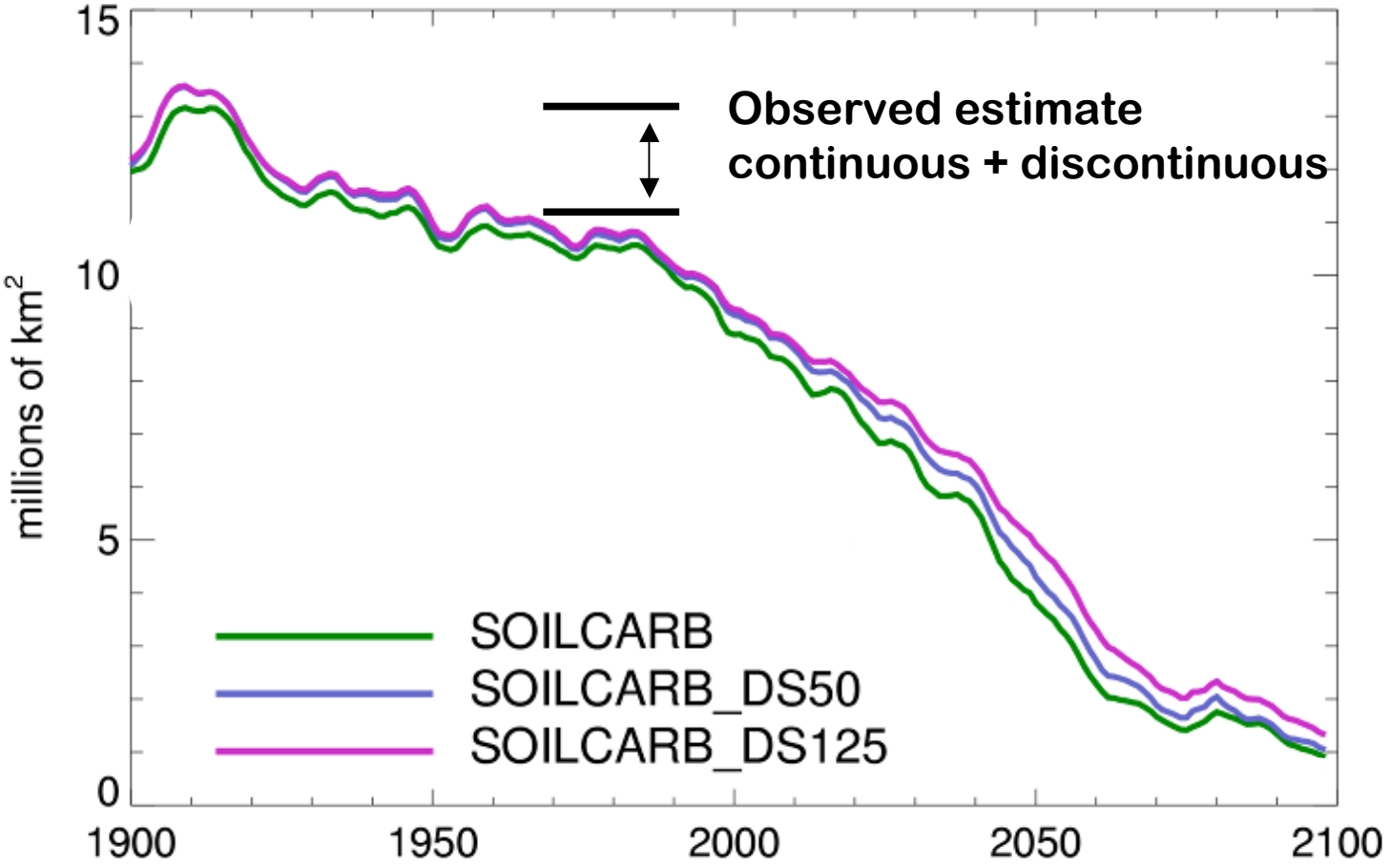


Projected near-surface permafrost degradation
CCSM3 20C+A1B forcing, land as in Lawrence et al. 2008



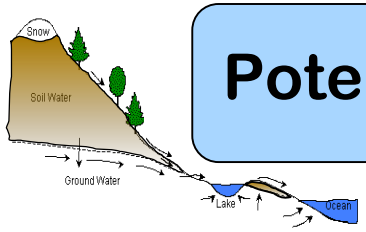


Integrated area with permafrost within 3m of surface

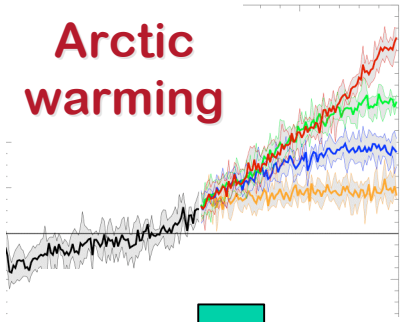


Lawrence et al., JGR, 2008

Potential Arctic terrestrial climate-change feedbacks



Arctic warming



Carbon sequester

Shrub growth

Enhanced [nitrogen]

Microbial activity increases

Permafrost warms and thaws

Expanded wetlands

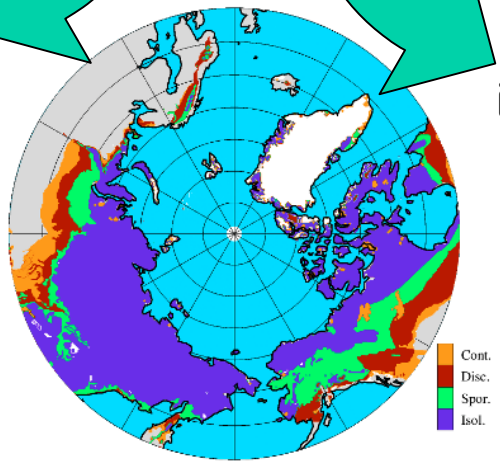
Lakes drain, soil dries

Arctic runoff increases

CO_2 efflux

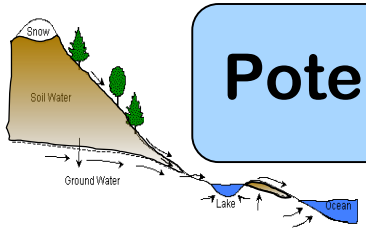
CH_4 efflux

Global warming



Adapted from McGuire et al., 2006

Potential Arctic terrestrial climate-change feedbacks



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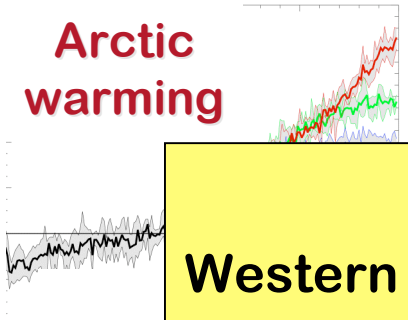


Carbon sequester

Global warming

CO_2 efflux

CH_4 efflux

Perm
war
th

Hydrology

Western Siberia lake area:

+12% in Continuous

-6 to -9% in Disc., Isol., Spor.

(Smith et al., 2005)

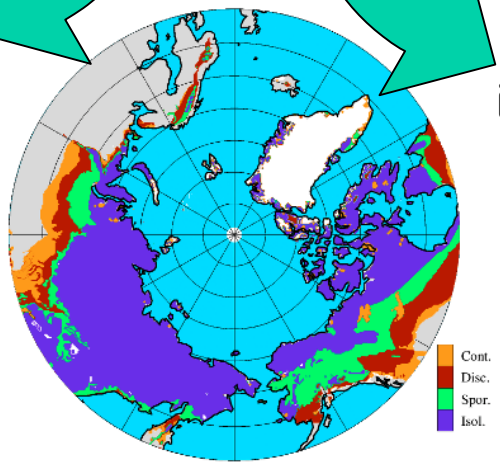
Increases in runoff and enhanced winter baseflow

(Dai et al., 2009; St Jacques and Sauchen, 2009)

activity increases

Expanded wetlands

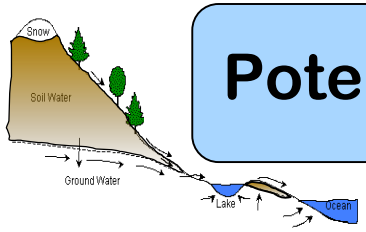
Lakes drain, soil dries



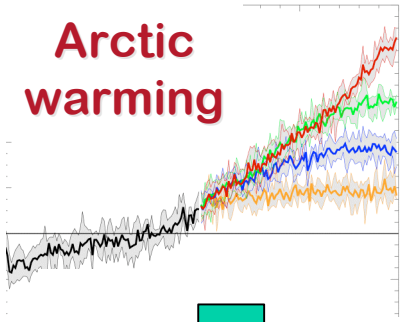
Arctic runoff increases

Adapted from McGuire et al., 2006

Potential Arctic terrestrial climate-change feedbacks



Arctic warming



Carbon sequester

Shrub growth

Global warming

CO_2 efflux

CH_4 efflux

Carbon stocks in permafrost-affected soil

~ 1700 PgC (Tarnocai et al., 2009)

Atmos carbon content

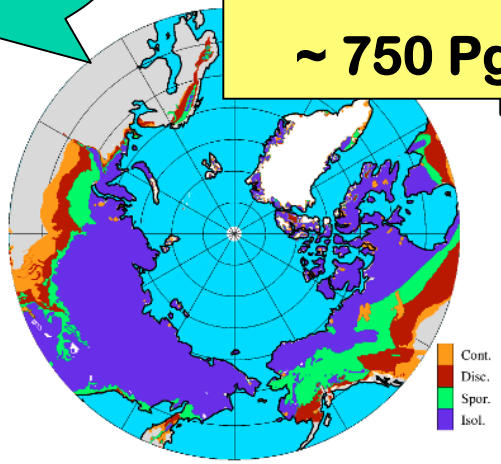
~ 750 PgC + ~9 PgC yr^{-1}

Perm
warm
tha

Expanded wetlands

Lakes drain, soil dries

Arctic runoff increases



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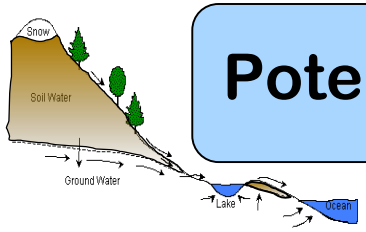
Potential Arctic terrestrial climate-change feedbacks



Arctic warming

Carbon sequester

Global warming

Surface energy partitioning

Soil moisture and permafrost state affects partitioning of net radiation into sensible, latent, and ground heat fluxes

CO_2 efflux

CH_4 efflux

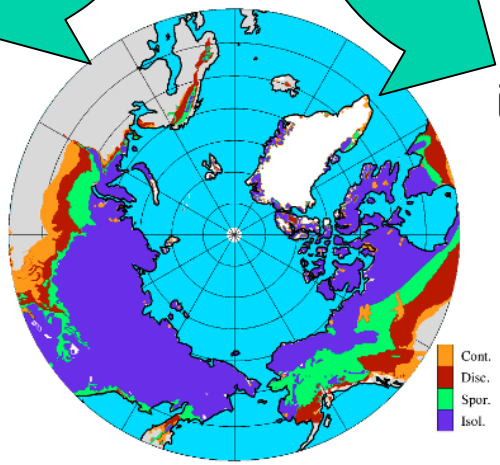
Permafrost warms and thaws

Enhanced [nitrogen]

Expanded wetlands

Microbial activity increases

Lakes drain, soil dries



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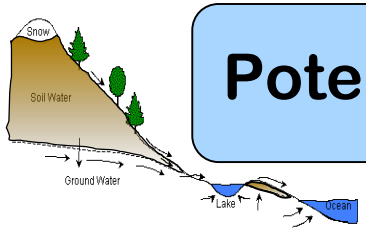
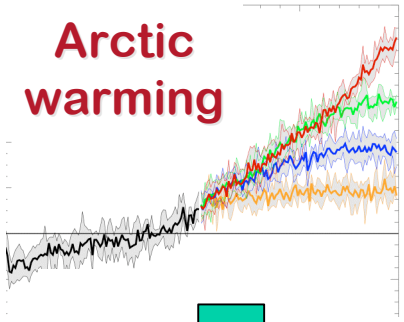
Adapted from McGuire et al., 2006

Potential Arctic terrestrial climate-change feedbacks



Arctic warming



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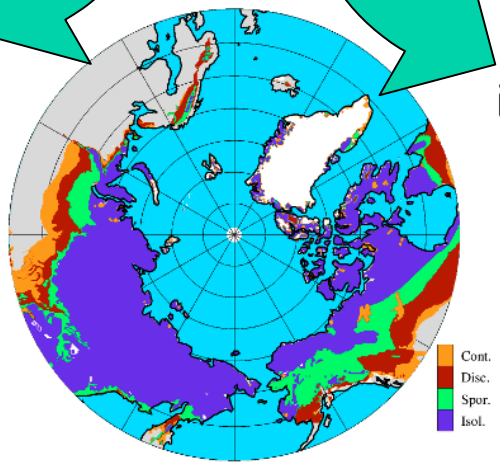

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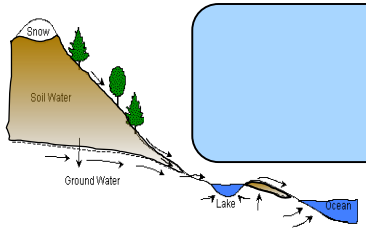


Shrub cover increasing in Arctic

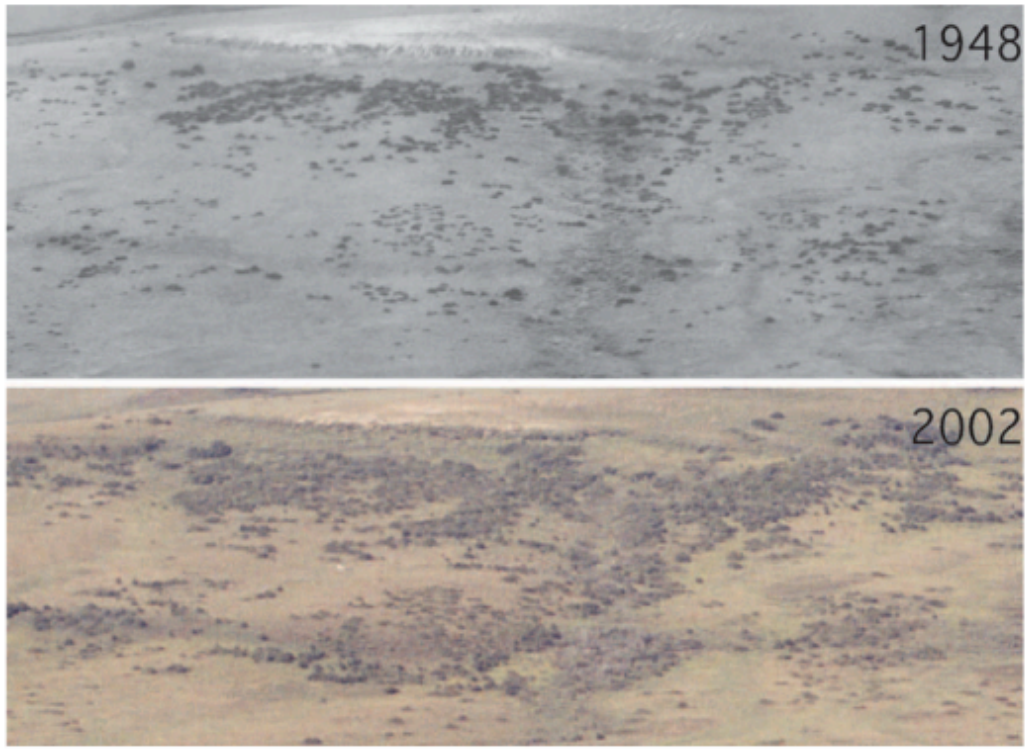
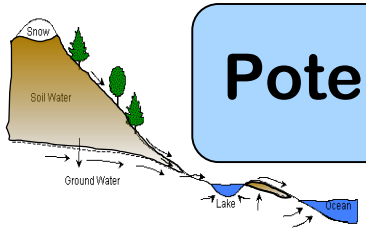


Figure 1. Increasing abundance of shrubs in arctic Alaska. The photographs were taken in 1948 and 2002 at identical locations on the Colville River (68° 57.9' north, 155° 47.4' west). Dark objects are individual shrubs 1 to 2 meters high and several meters in diameter. Similar changes have been detected at more than 200 other locations across arctic Alaska where comparative photographs are available. Photographs: (1948) US Navy, (2002) Ken Tape.

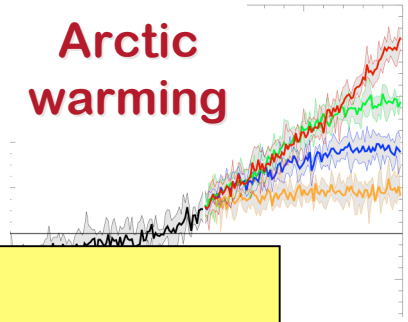
- **Shrub cover increasing in N. Alaska at 1.2% per decade since 1950, 14% to 20% cover (Sturm et al. 2001)**
- **Shrub cover can increase much quicker in response to climate shifts than forest cover since shrubs already exist across most of the Arctic**

Sturm et al. 2001

Potential Arctic terrestrial climate-change feedbacks



Arctic warming

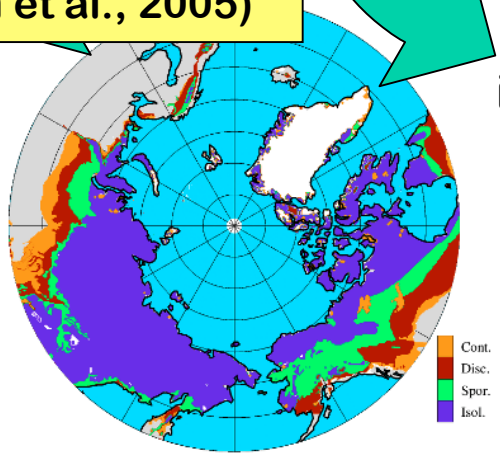


Carbon sequester

Shrub growth

Enhanced [nitrogen]

Microbial activity increases



Lakes drain, soil dries

Arctic runoff increases

Global warming

Vegetation

Radiative forcing of complete conversion tundra to shrubland

+8.9W m^{-2} (4.2W m^{-2} GHG)

(Chapin et al., 2005)

Since 1950, 14% to 20% cover

(Sturm et al., 2005)

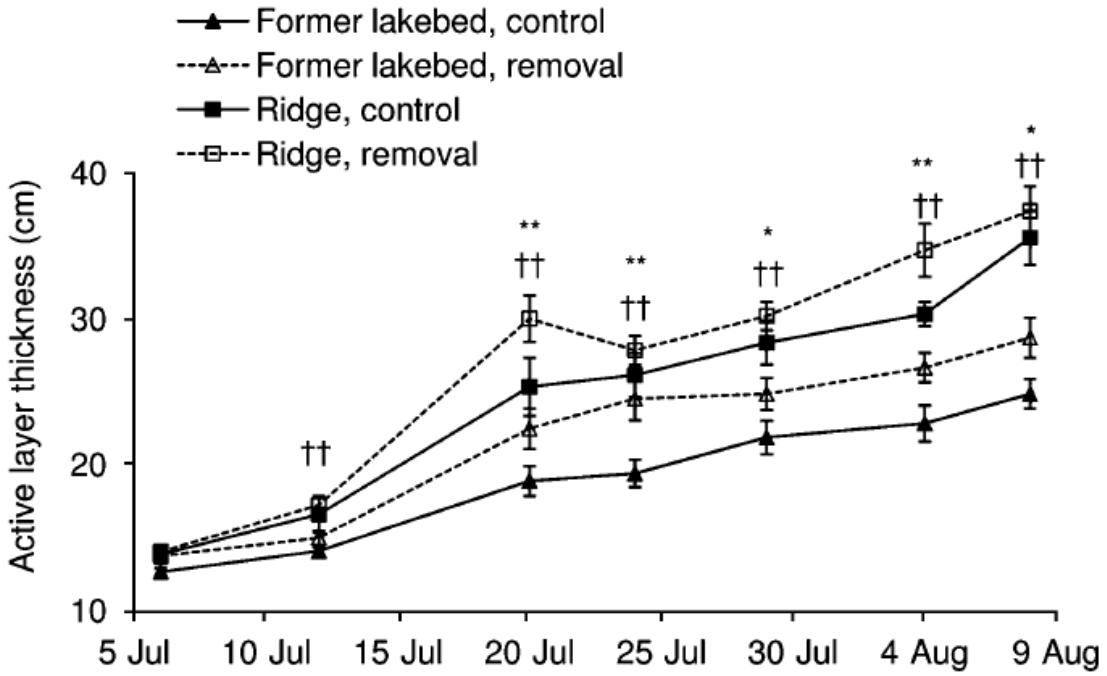
Adapted from McGuire et al., 2006

Global Change Biology

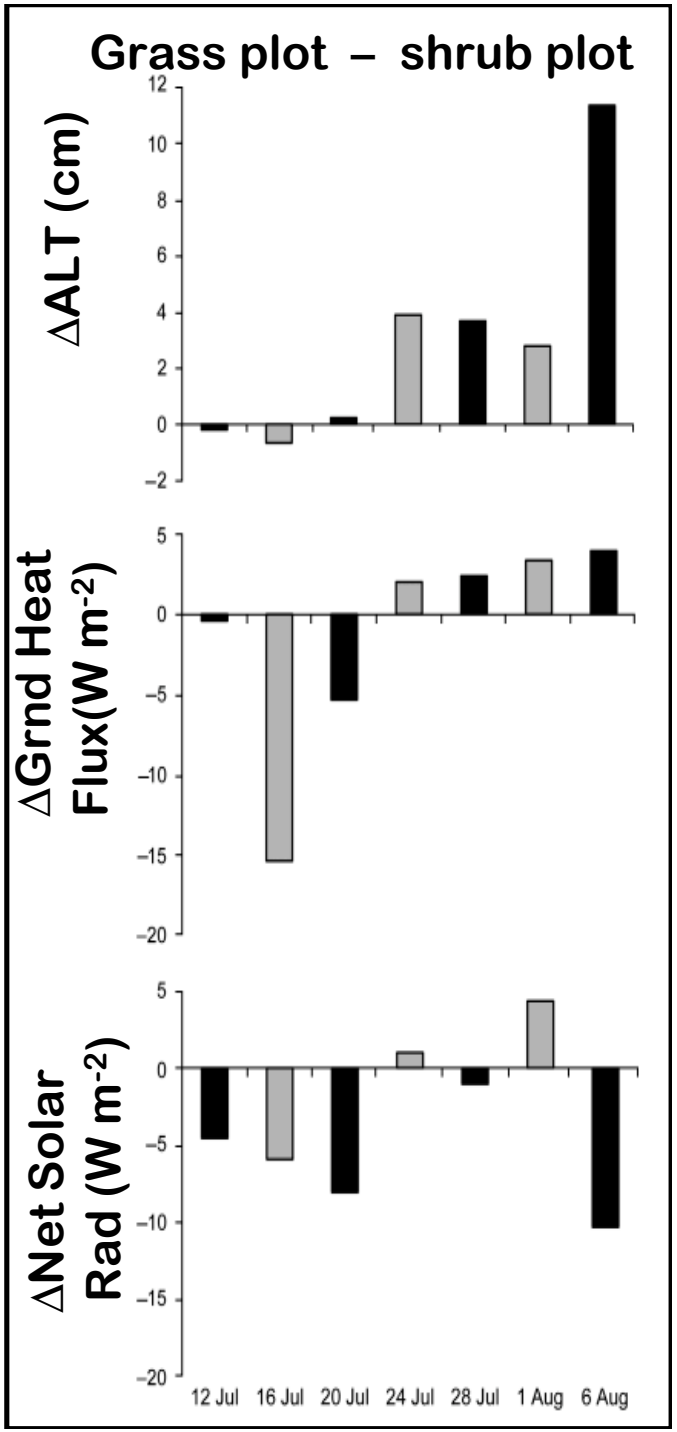
Global Change Biology (2010) 16, 1296–1305, doi: 10.1111/j.1365-2486.2009.02110.x

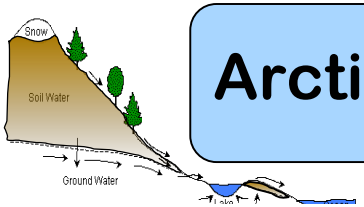
Shrub expansion may reduce summer permafrost thaw in Siberian tundra

D. BLOK*, M. M. P. D. HEIJMANS*, G. SCHAEPMAN-STRUB*†, A. V. KONONOV‡, T. C. MAXIMOV‡ and F. BERENDSE*

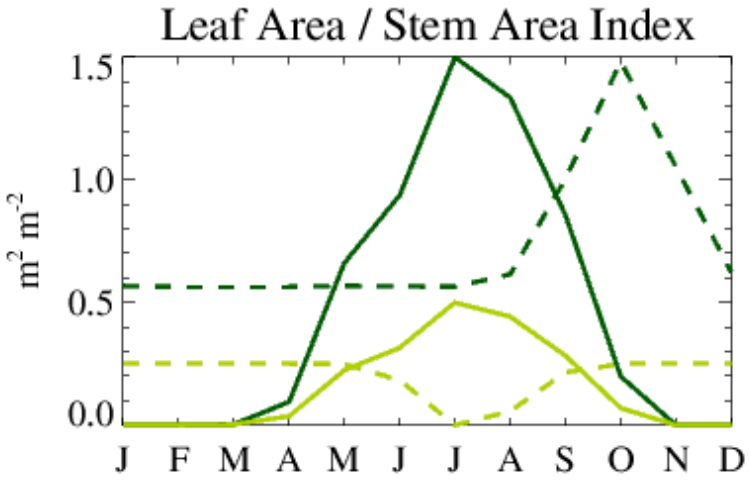


"These results suggest that the expected expansion of deciduous shrubs in the Arctic region, triggered by climate warming, may reduce summer permafrost thaw."

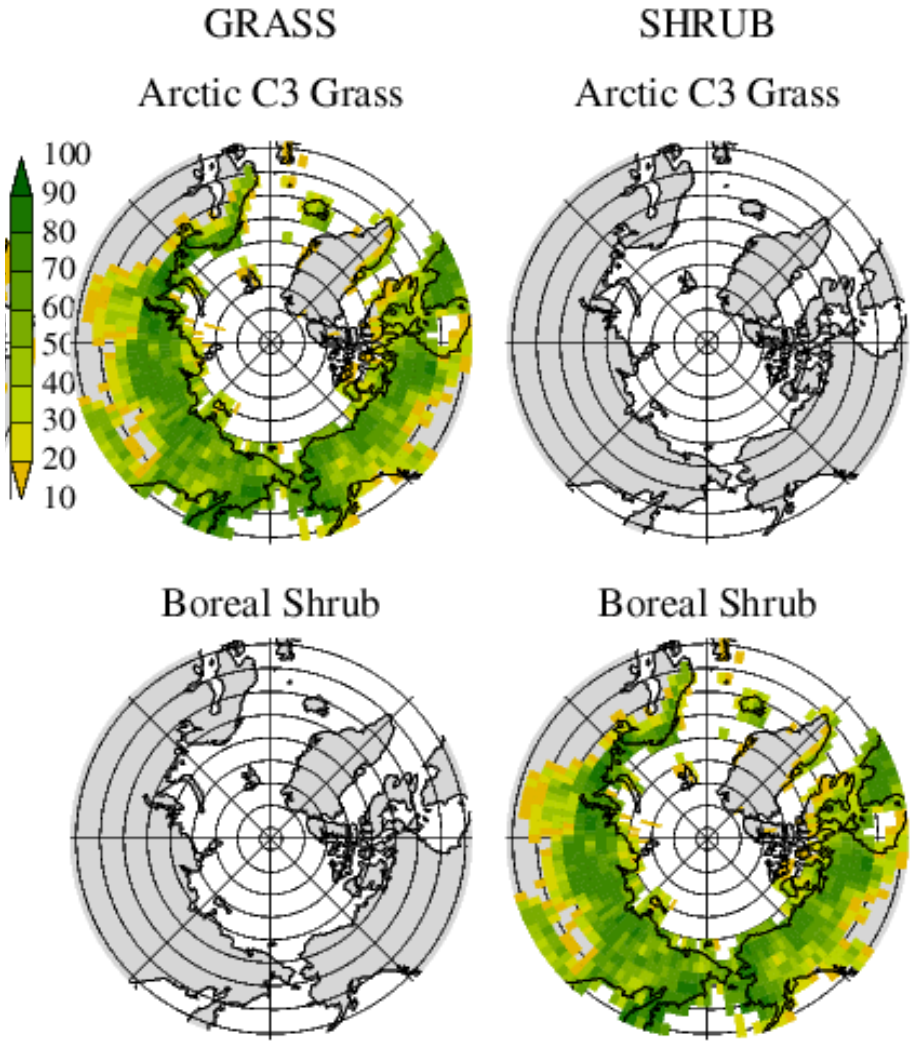


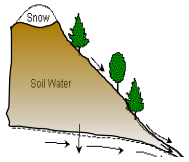


Arctic tundra vegetation experiments with CLM/CESM

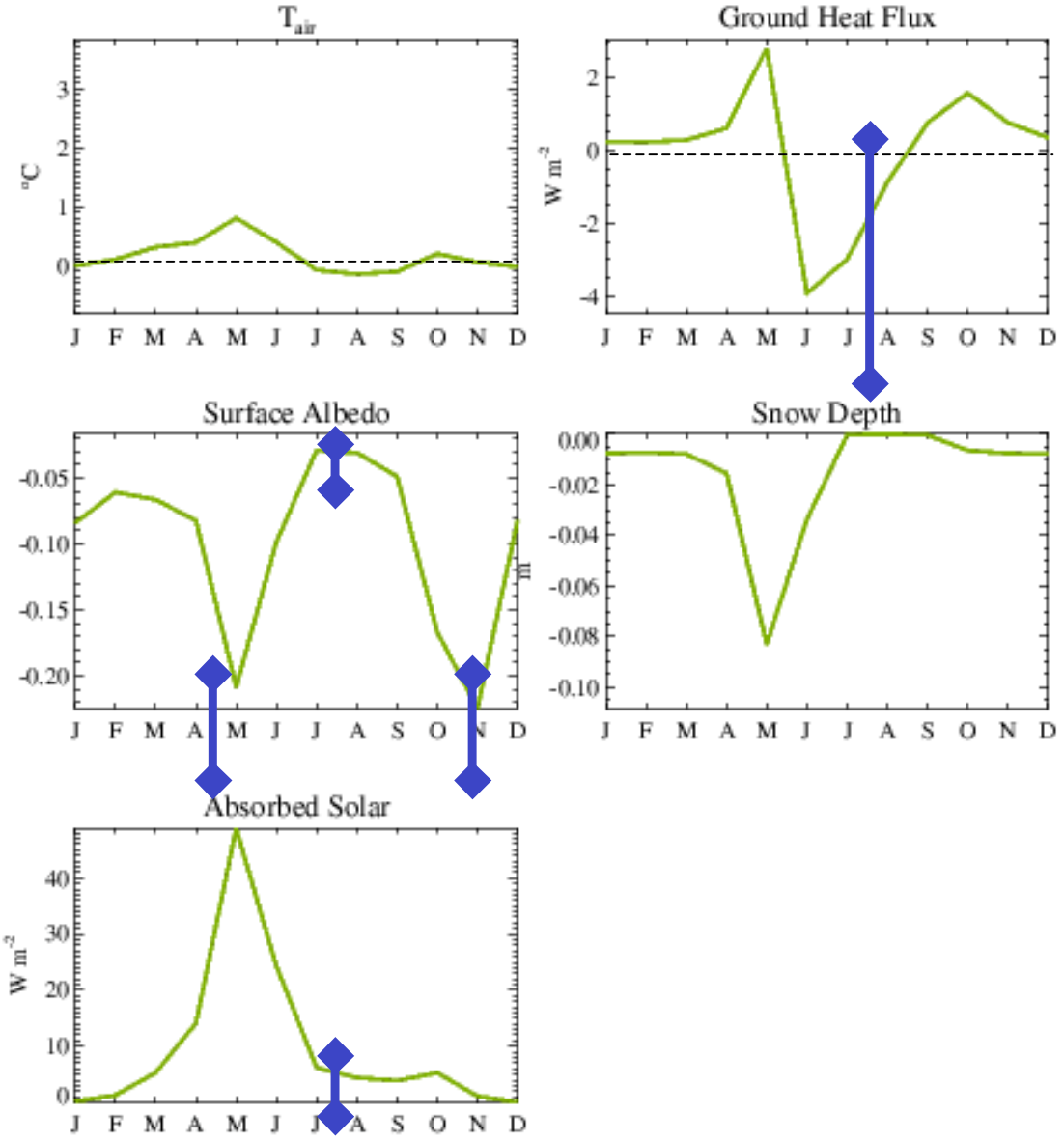


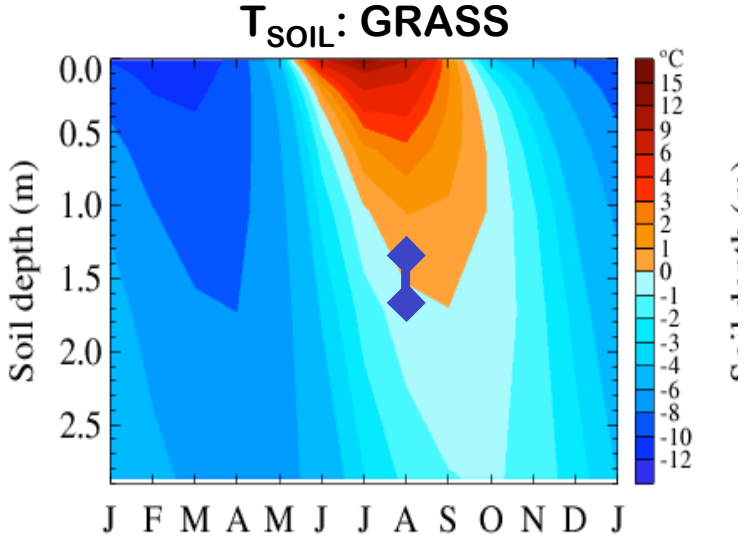
Grass (LAI)
Shrub (LAI)
Grass (SAI)
Shrub (SAI)

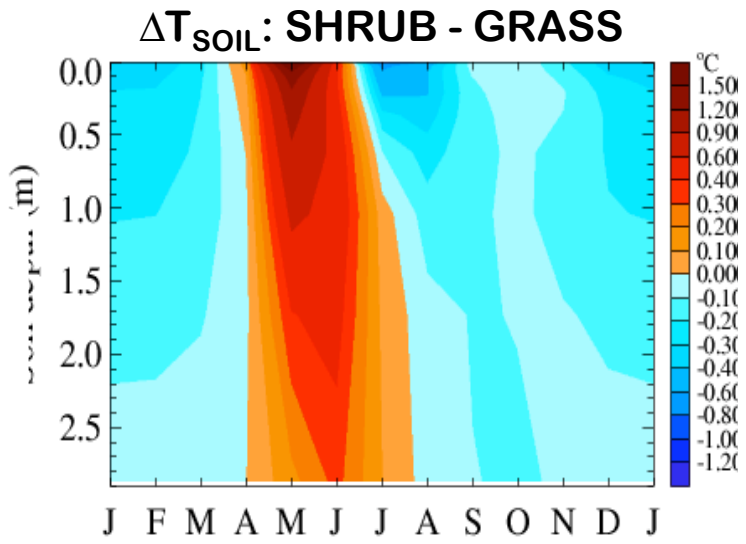


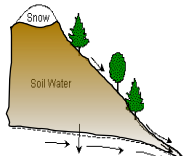


Offline CLM4: SHRUB expt – GRASS expt







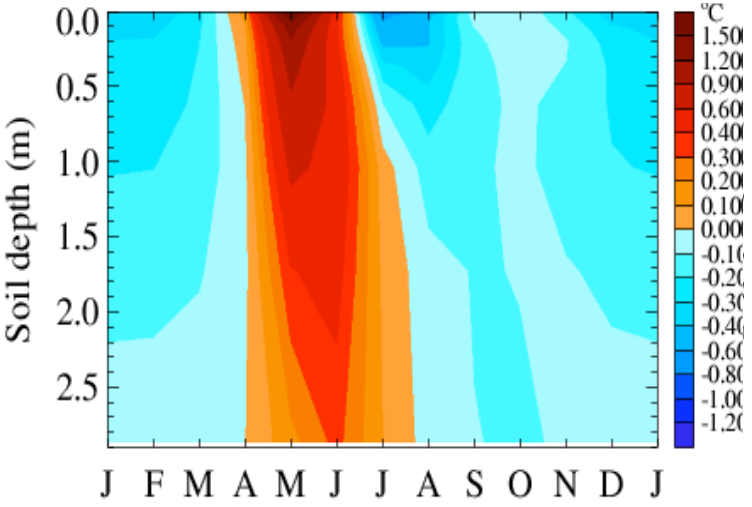


Coupled CAM4/CLM4: SHRUB expt – GRASS expt

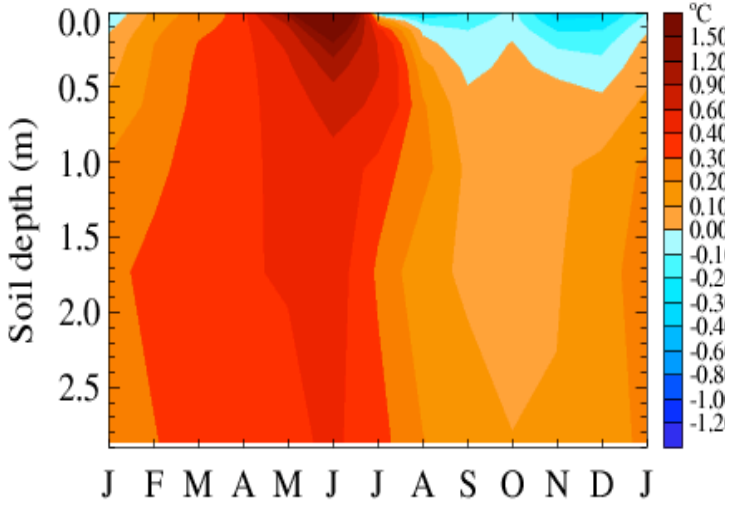
The impact of expanded shrub cover is significantly different in coupled vs offline expts (i.e., increasing vs decreasing ALT)

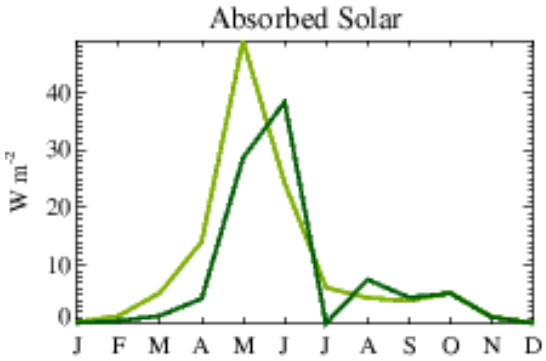
Offline expts roughly mimic a field manipulation study - i.e., surface properties change from grass to shrub but forcing (T, P, Solar, etc) is the same

ΔT_{SOIL}: SHRUB – GRASS (Offline)



ΔT_{SOIL}: SHRUB - GRASS (Coupled)

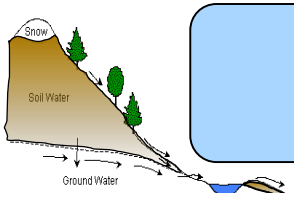




SHRUB – GRASS

Offline

Coupled



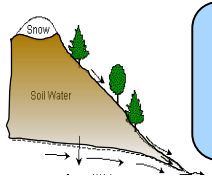
Summary

- Sea ice loss leads to substantial warming over land, peaking in autumn and winter. In CCSM3, the sea ice loss induced warming extends over 1500km inland.

- The rate of sea ice loss may exert a significant control on rate of terrestrial Arctic climate change. Many terrestrial systems may be sensitive to the rate of change.

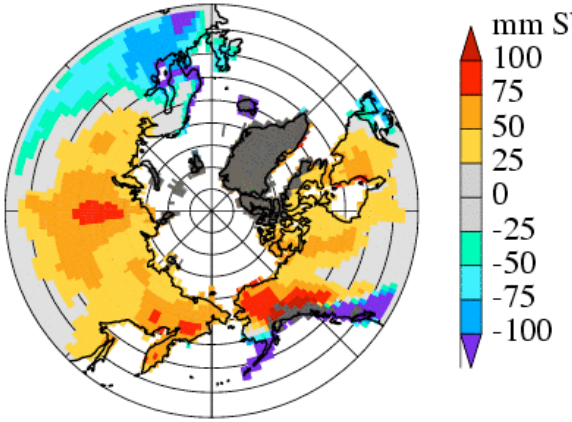
- Projected warming is likely to result in considerable near-surface permafrost thaw, which could initiate positive (and negative) feedbacks that may be relevant on decadal timescales.

- Many of these feedback mechanisms are not represented in current generation Earth System Models. Hence, models are missing processes that could be a (small) source of decadal predictability.

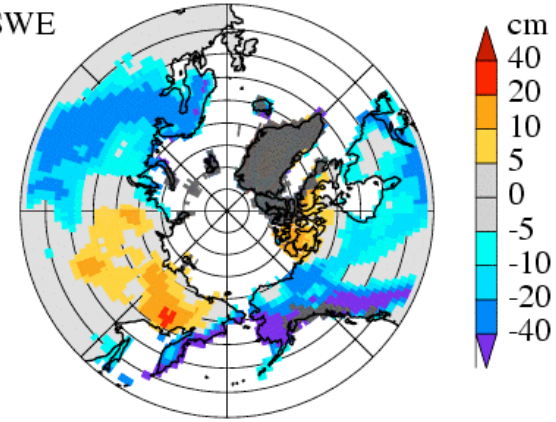


Projected snow changes in CCSM3 (2080-99 – 1950-69)

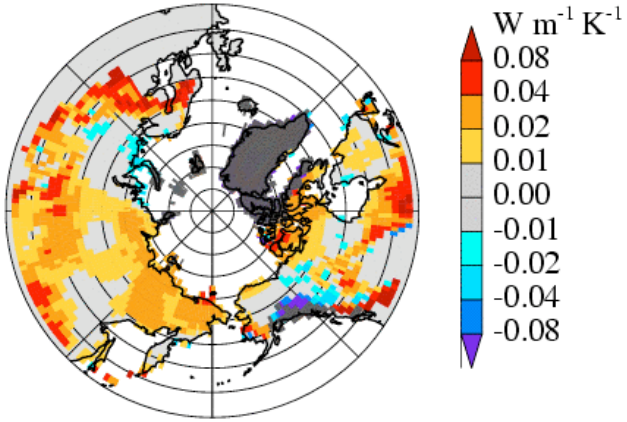
NDJFM Snowfall



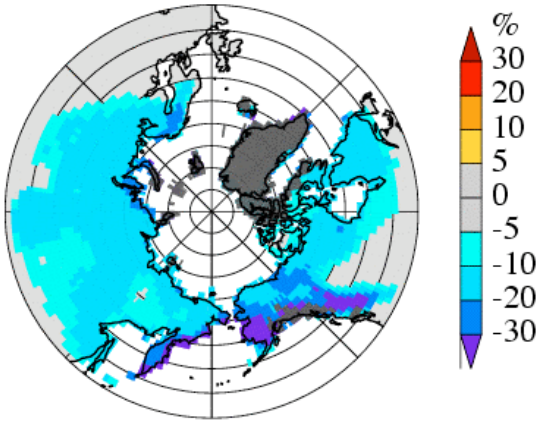
Max Snow Depth



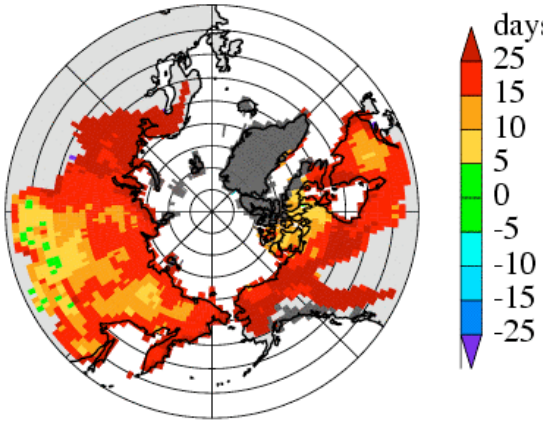
Snow Thermal Conductivity



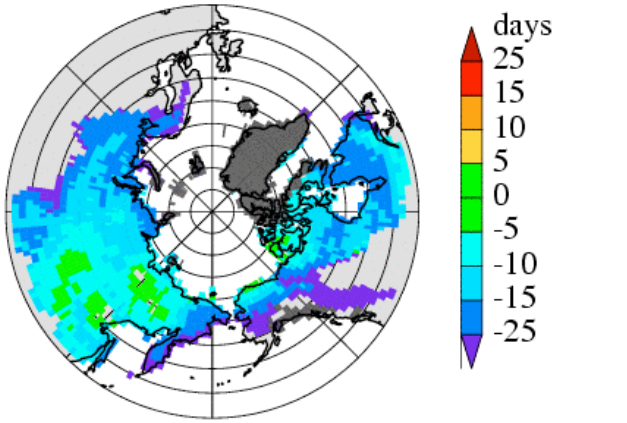
AMSO Snow Cover Fraction

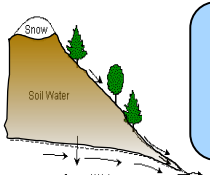


Day of First Autumn Snow Accum



Day of Spring Snow Melt





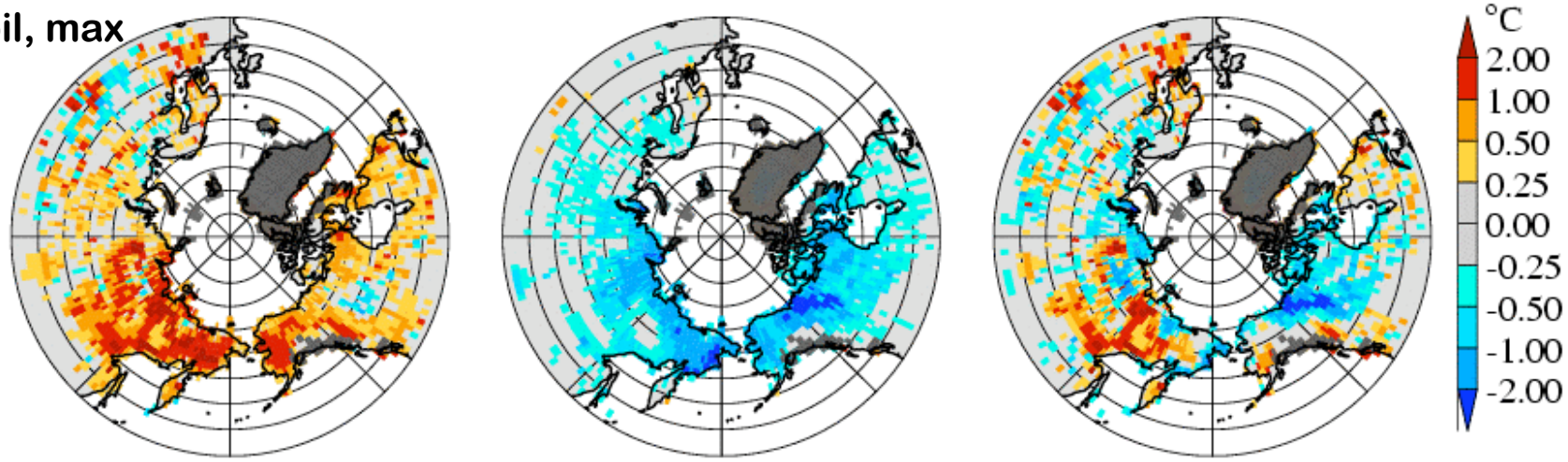
Prescribed snow experiments

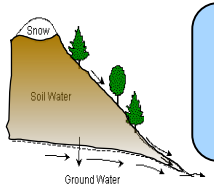
Snow Season Length
HOLD_MW_DP – HOLD_DP

Snow Depth
TRND_DP – HOLD_MW_DP

Combined
TRND_DP – HOLD_DP

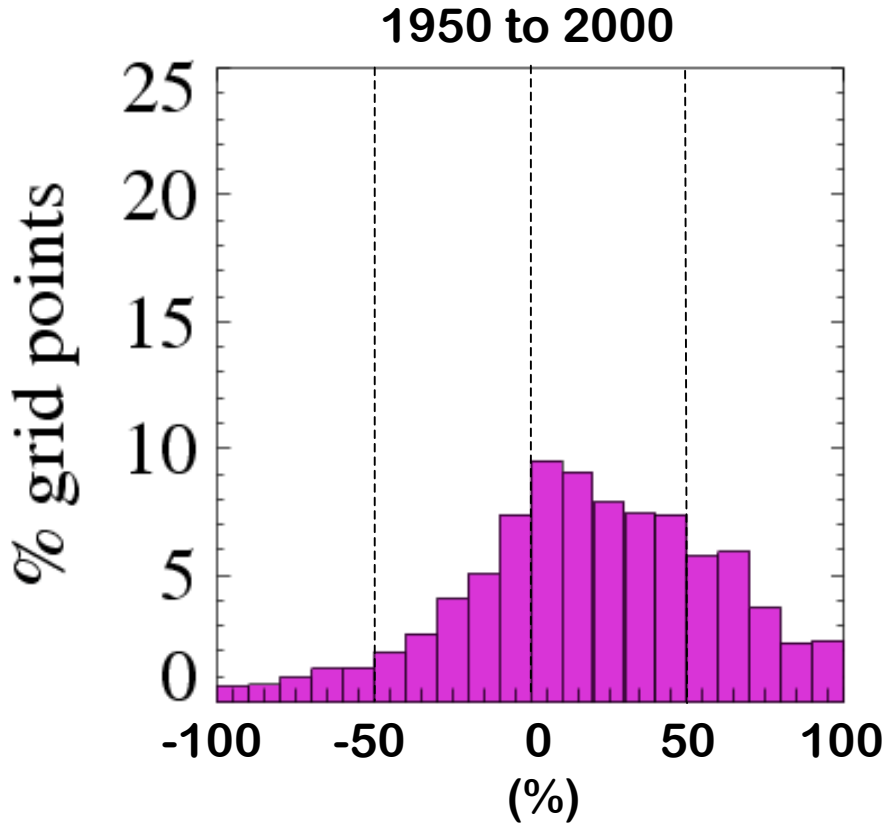
$\Delta T_{soil,\ max}$



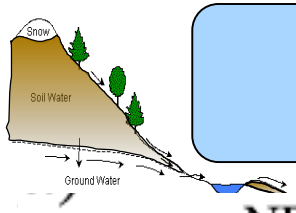


Relative influence of Δsnow vs ΔT_{air} on ΔT_{soil}

% of $\Delta T_{soil,max}$ (1m depth) attributable to snow state trends for the period …

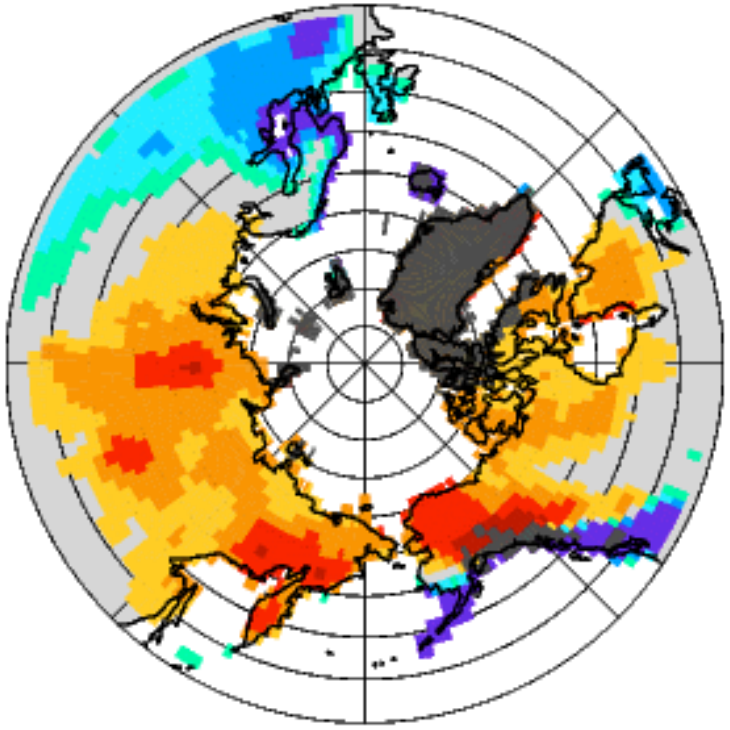


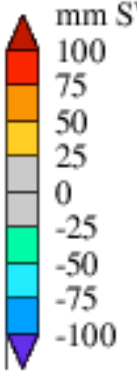
50% means that T_{soil} trend equally due to snow state and T_{air} trends



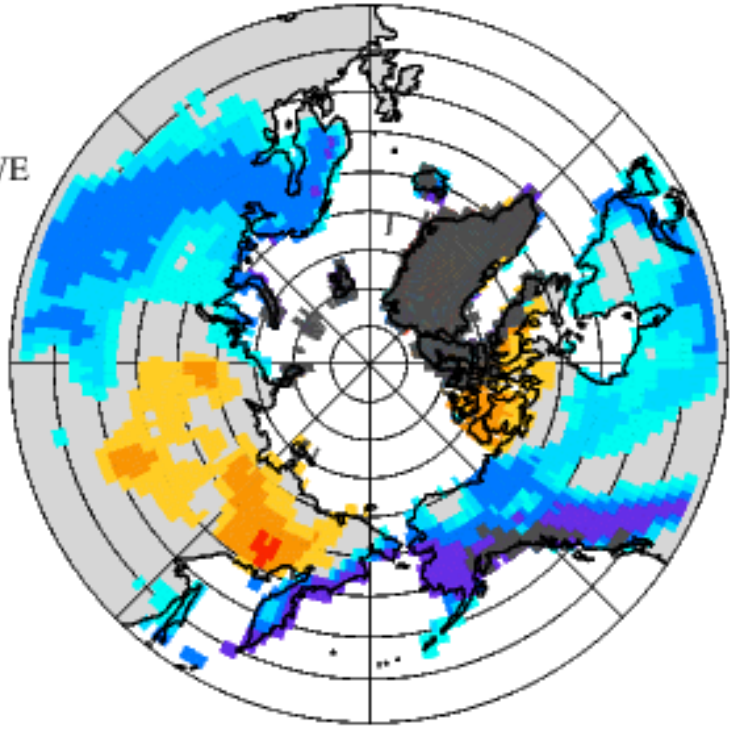
CCSM3 Projected snow changes
A1B, 2080-2099 minus 1950-1969

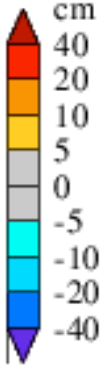
NDJFMA Snowfall





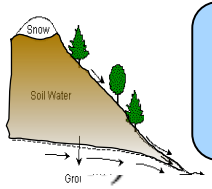
Max Snow Depth





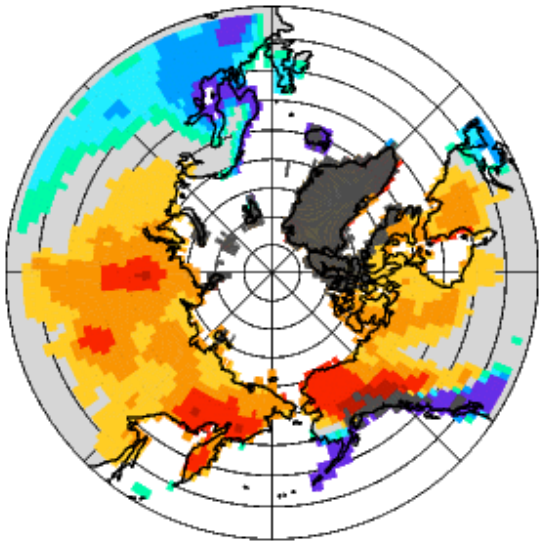
10 – 30% increase in winter snowfall

→ deeper OR shallower snowpack

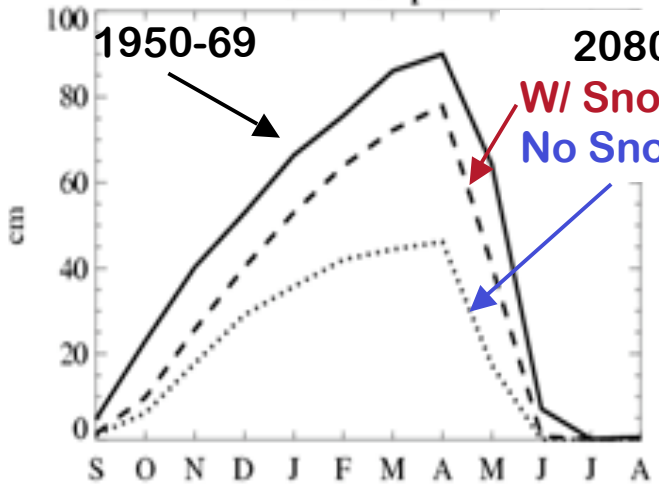


Offline controlled snowfall experiment

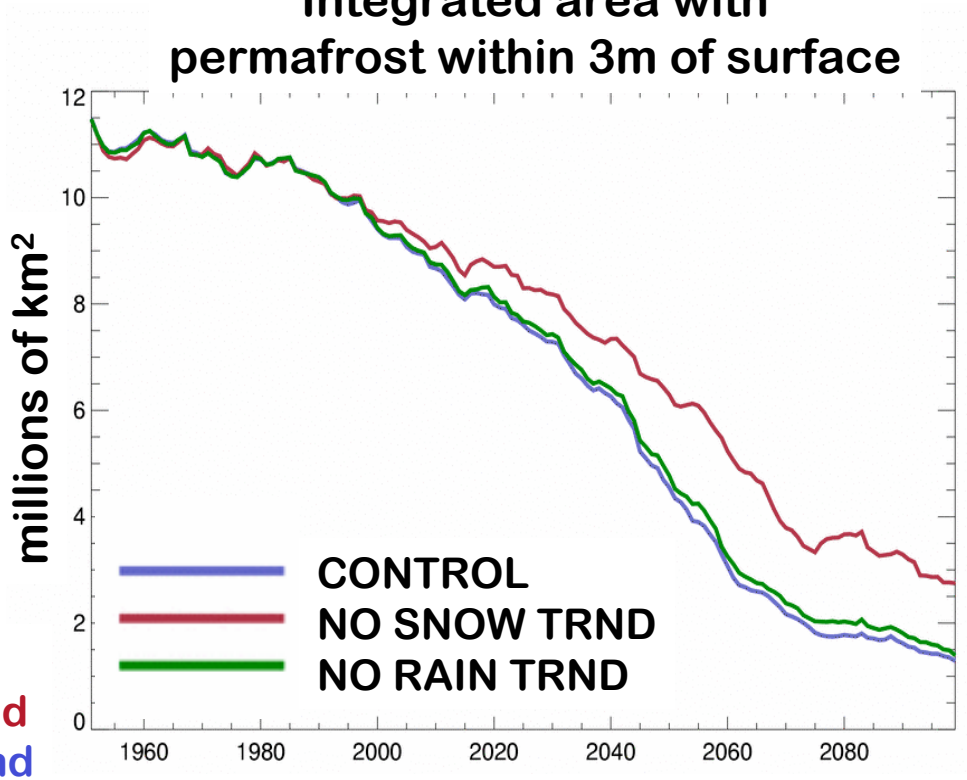
NDJFMA Snowfall



Snow Depth



Integrated area with permafrost within 3m of surface

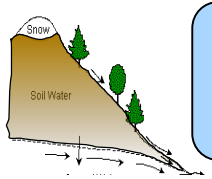


Increasing snowfall is effectively a soil warming agent

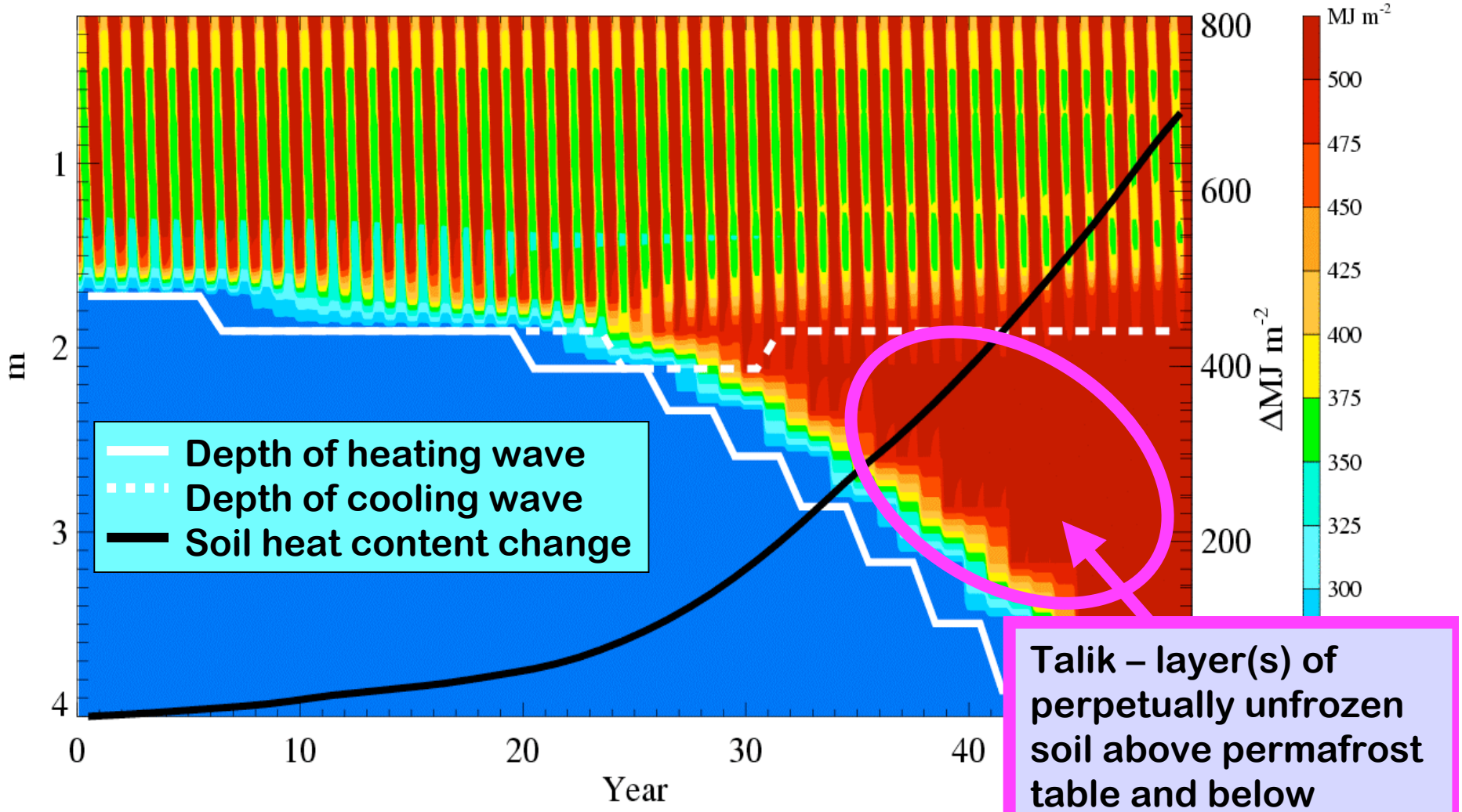
10%–30% of total soil warming at 1m depth

~16% contraction of near-surface permafrost

Lawrence and Slater, 2009

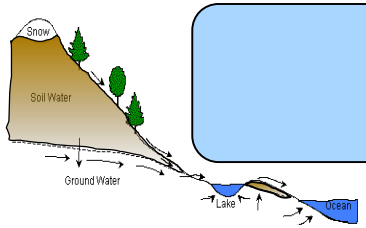


Soil heat accumulation
Warm permafrost case, LINEAR warming expt

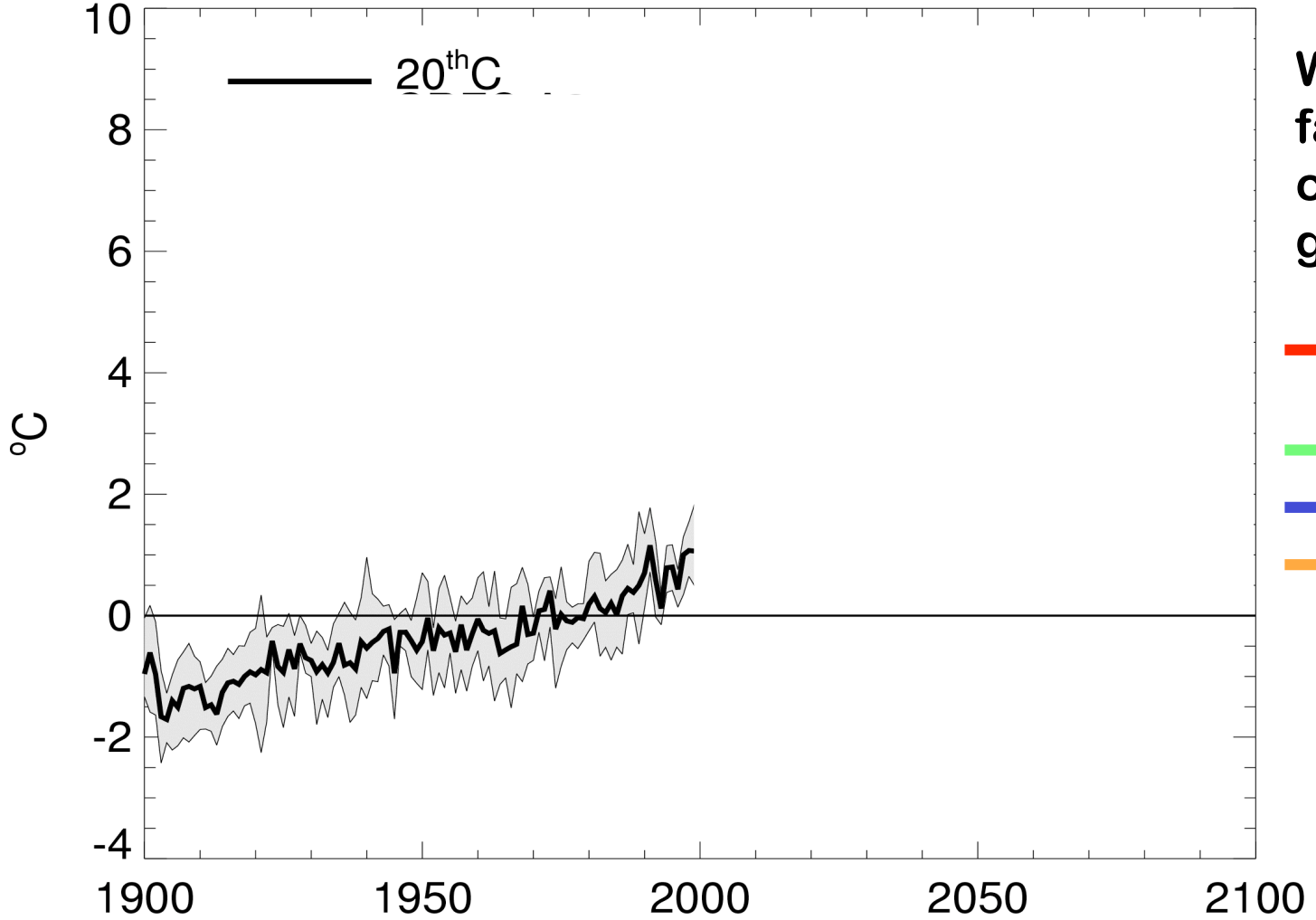


Talik – layer(s) of perpetually unfrozen soil above permafrost table and below seasonally frozen ground

Lawrence et al., GRL, 2008



Surface air temperature change (CCSM3): Arctic land area



Warming is ~2x faster in Arctic compared to global average

Global