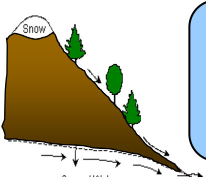

Arctic relevant LMWG changes for CLM4

- Soil hydrology
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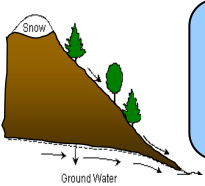
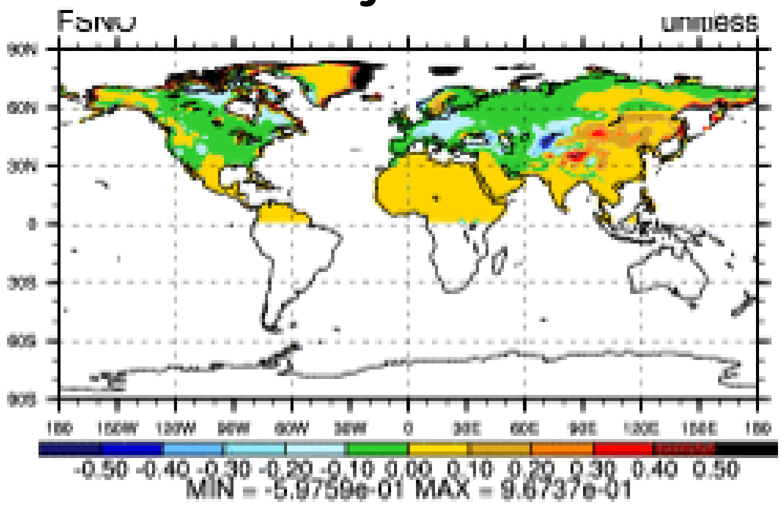
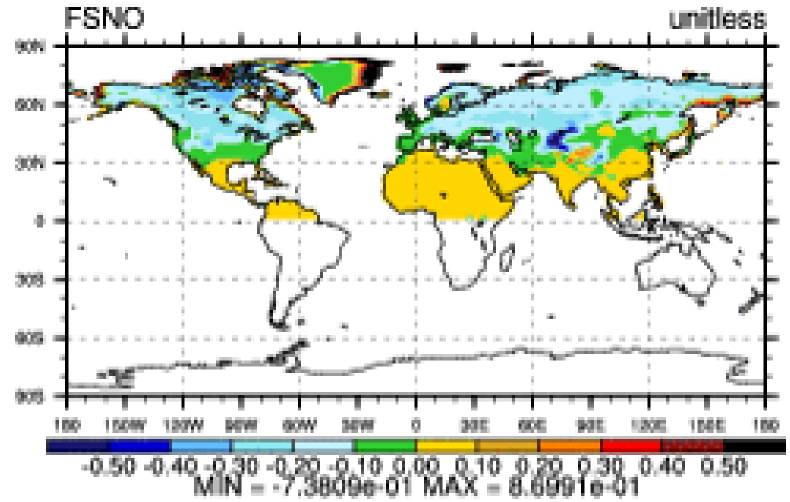


Results from Community Snow Project: Snow Cover Fraction (ANN)

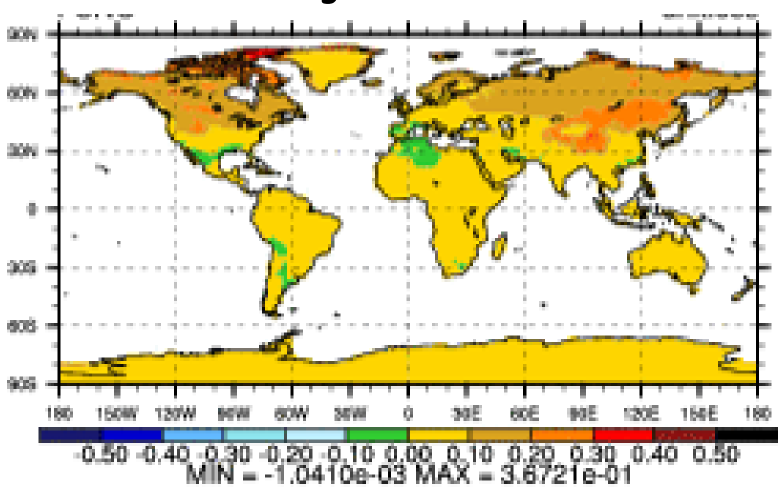
Community Snow - Obs



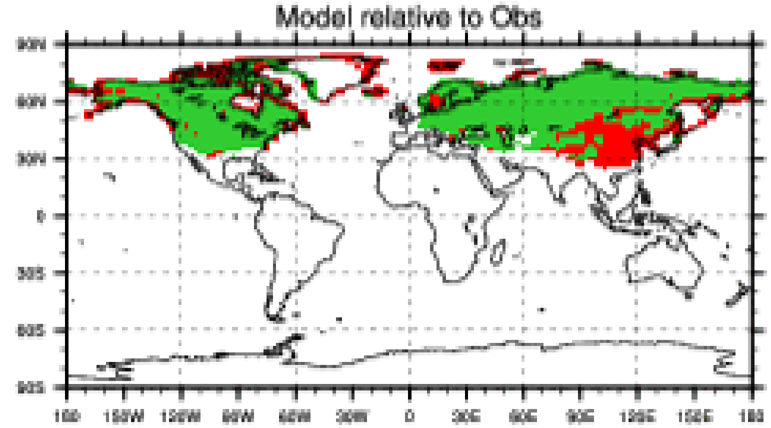
Control - Obs

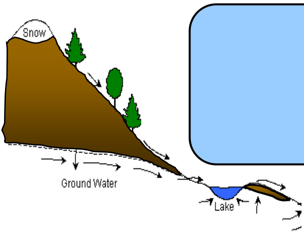


Community Snow - Control



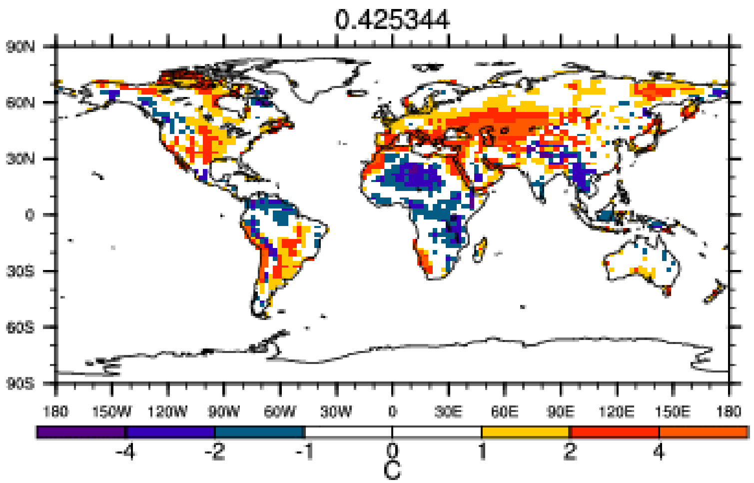
Case1+ (green) and Case2+ (red) relative to obs



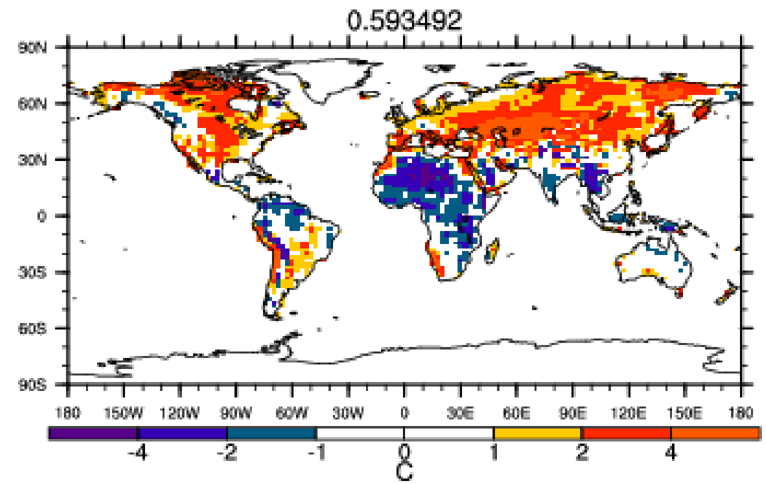


Results from Community Snow Project: Surface air temperature (ANN)

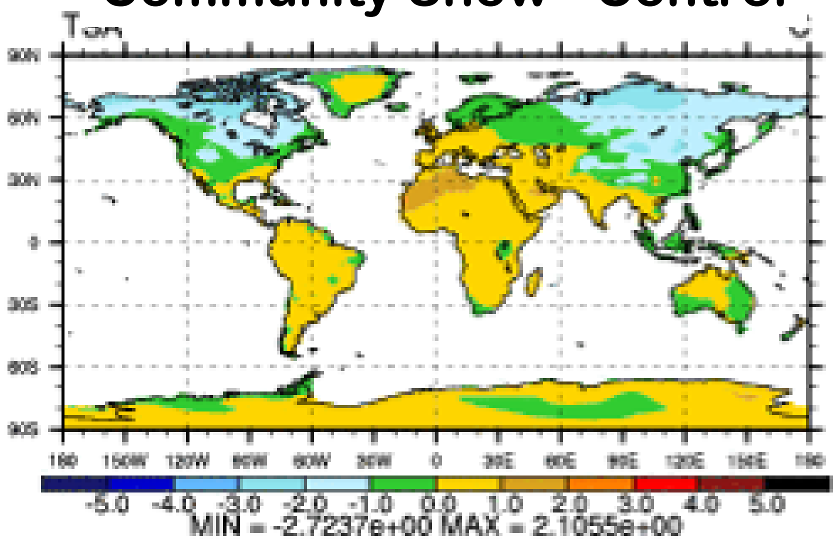
Community Snow - Obs

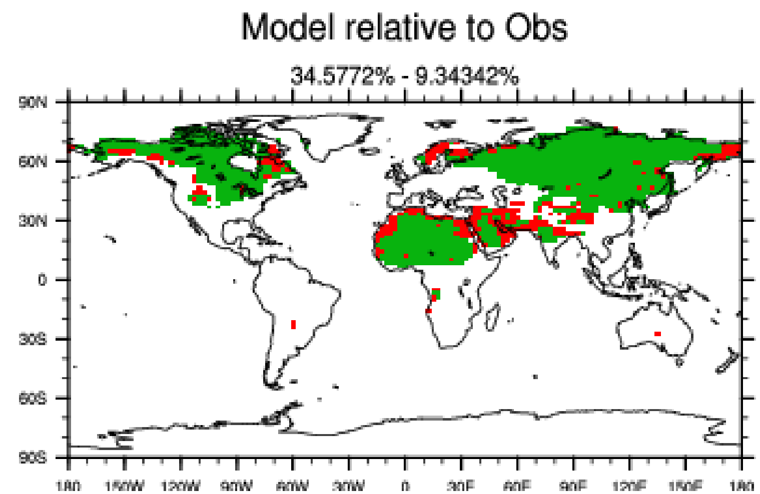


Control – Obs

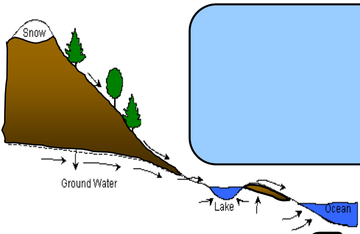


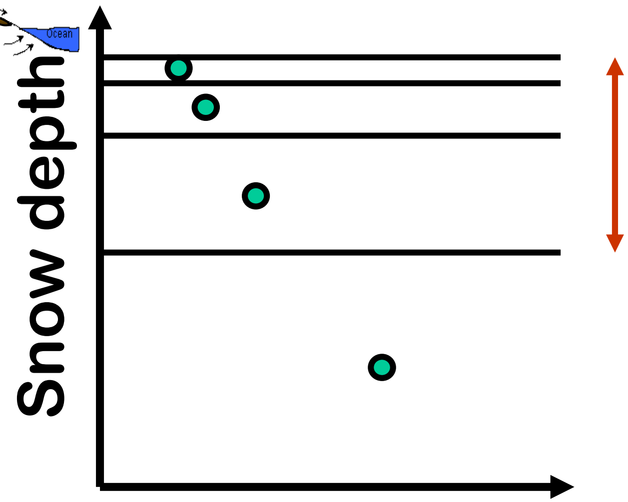
Community Snow - Control

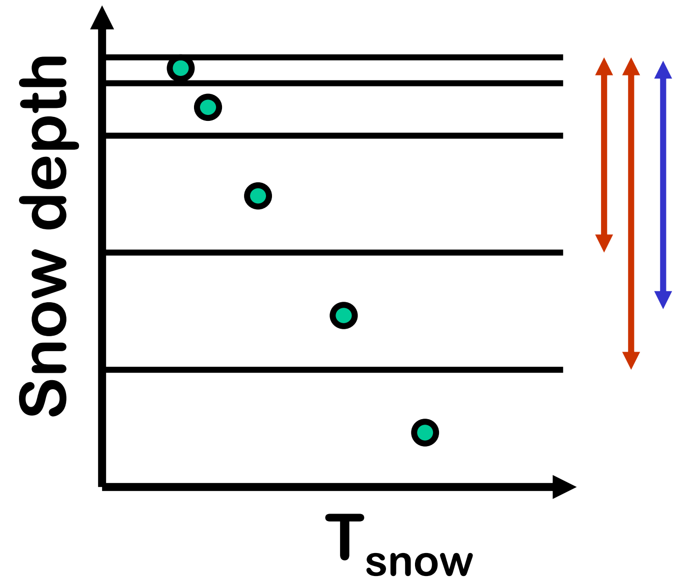


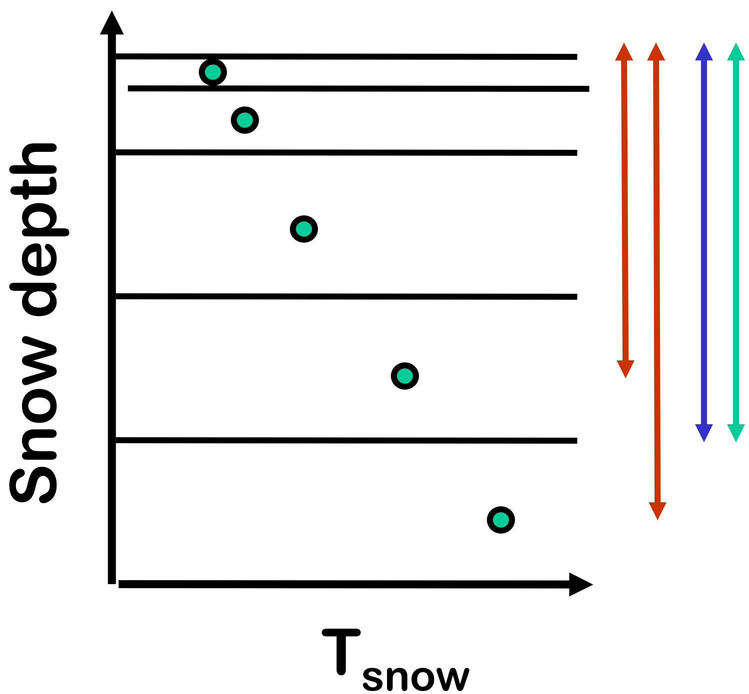


Snow compaction

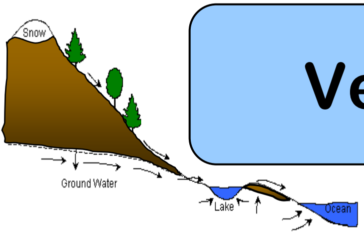




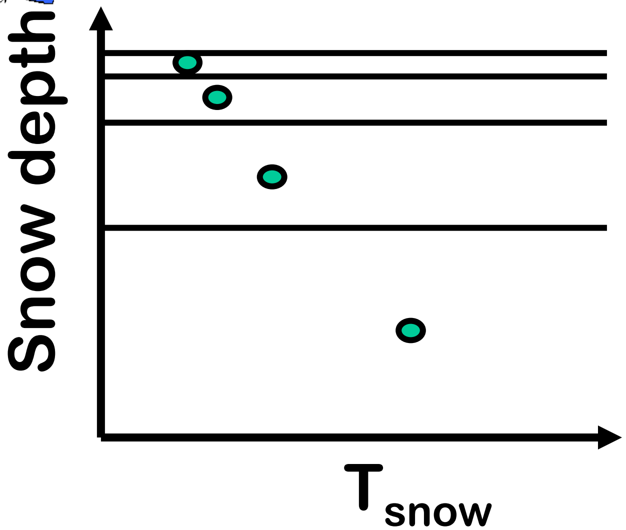


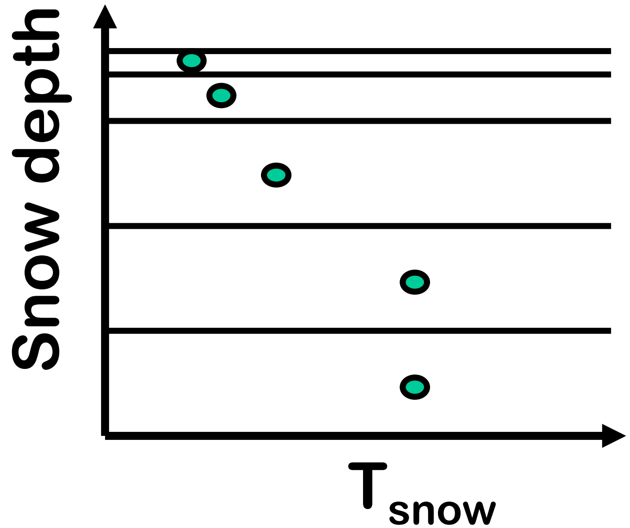


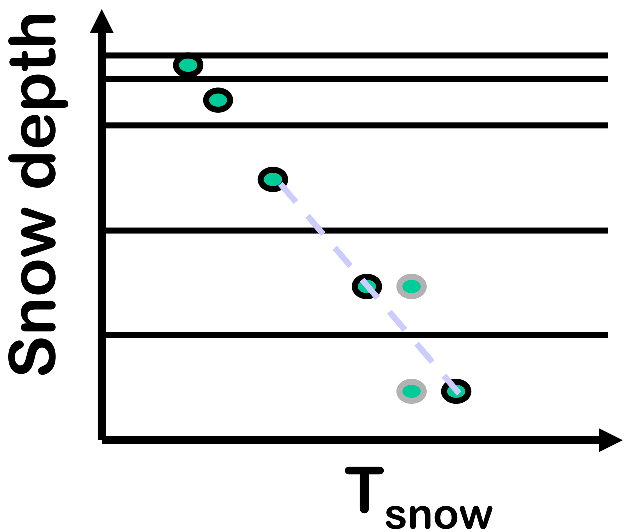
Impact: 10-20% shallower snow pack

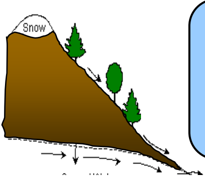


Vertical temperature profile after layer splitting









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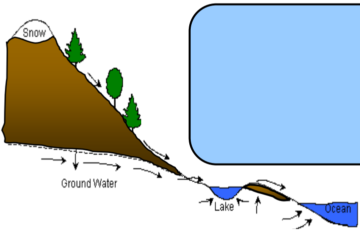
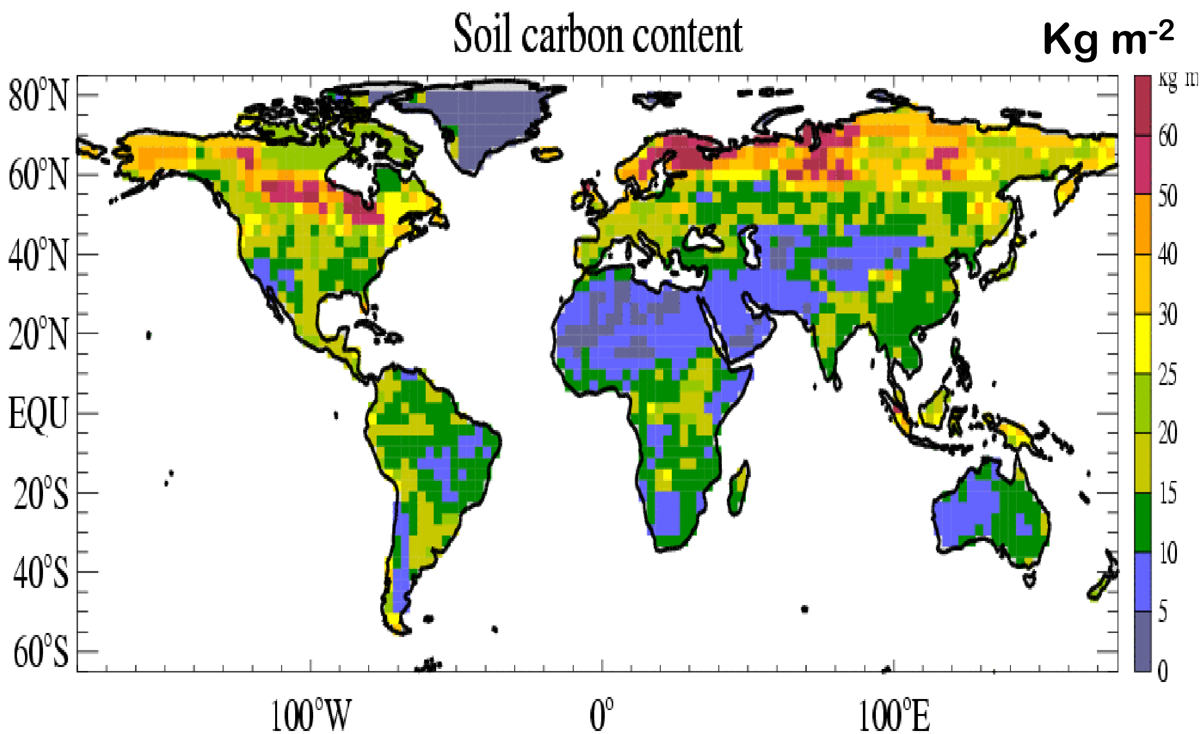
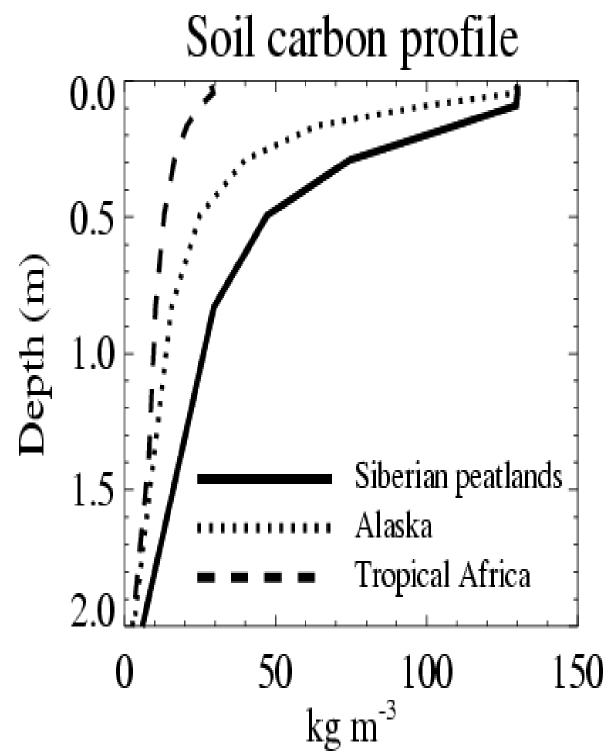


CLM soil carbon density dataset
Source data from Global Soil Data Task

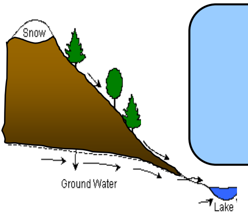




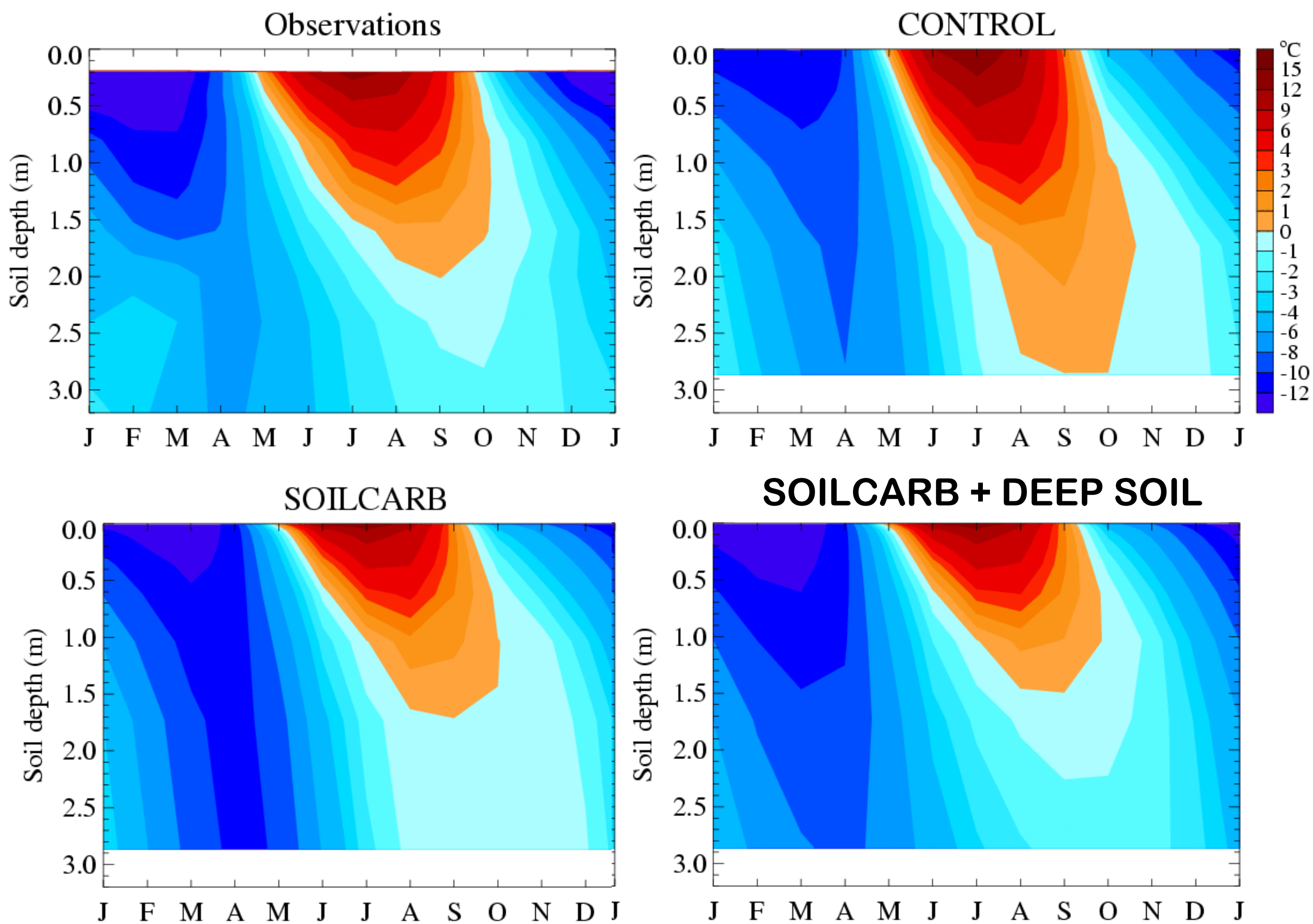
$f_{sc,I} = \rho_{sc,i} / \rho_{peat}$ fraction of layer *i* that is organic matter

i = 1, 2, 3, … 10 soil layers

Lawrence and Slater, 2007

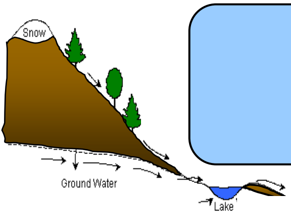


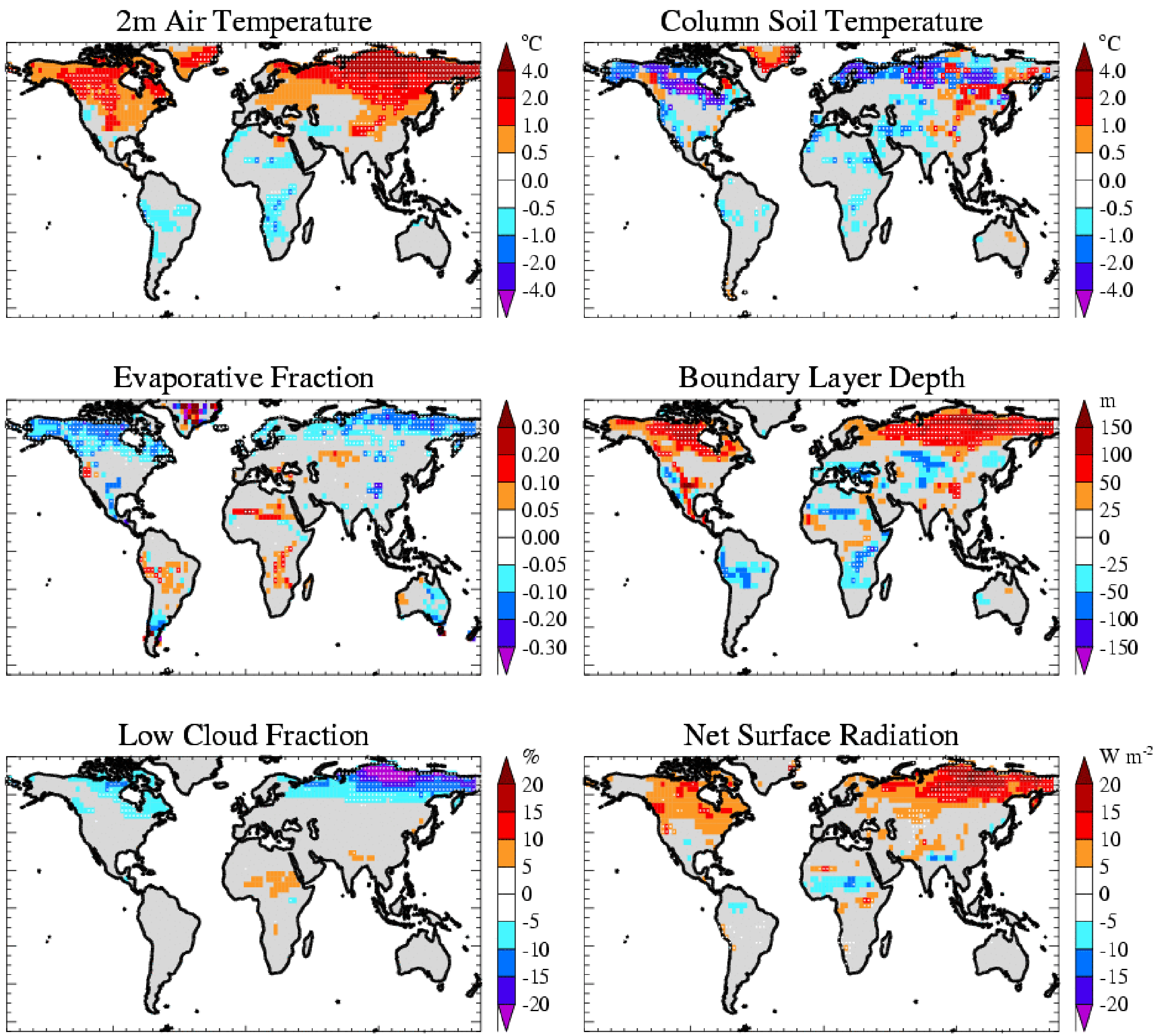
Annual cycle-depth soil temperature plots
Siberia

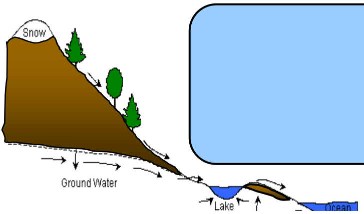


Lawrence et al., 2007

SOILCARB – CONTROL (JJA)

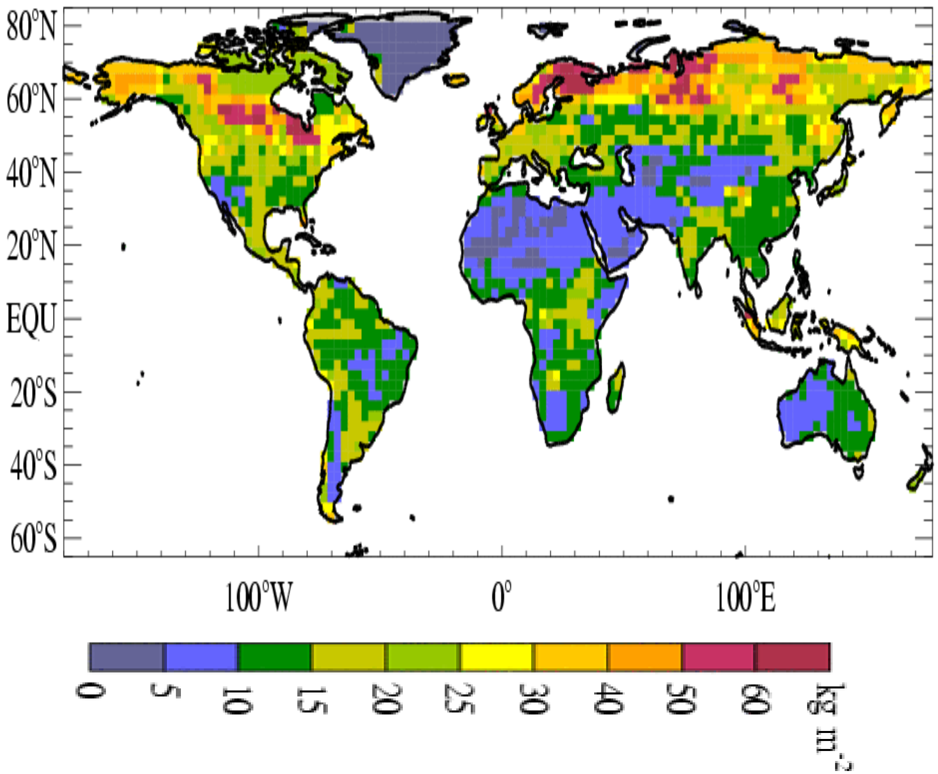




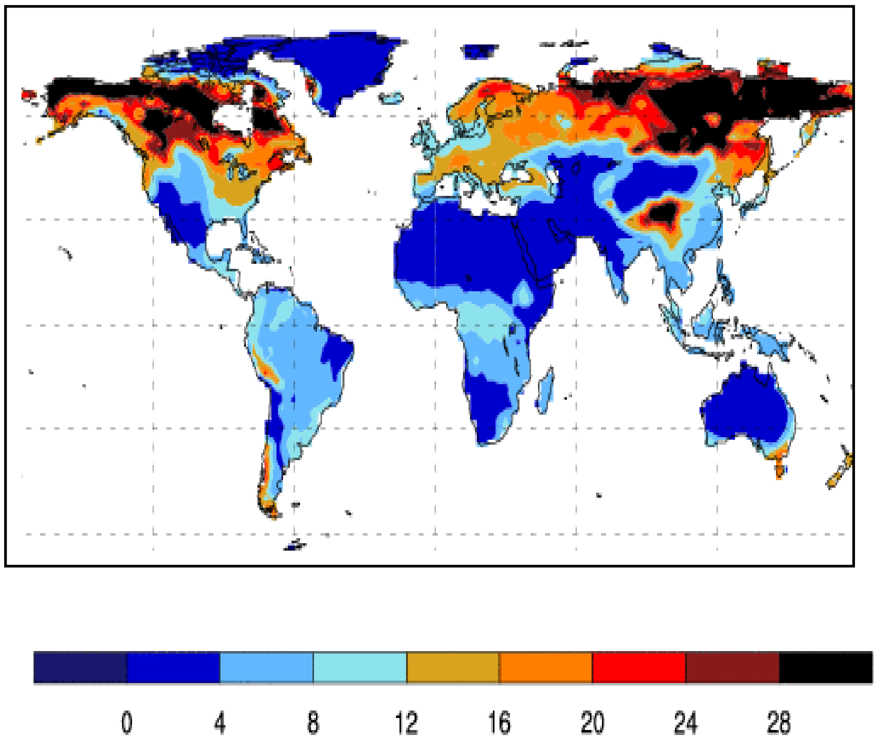


Soil carbon in CLM-CN

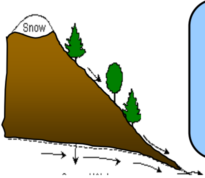
Soil carbon content: Obs



Soil carbon content: CLM-CN



Goal is to couple CLM-CN soil carbon with organic soil parameterization



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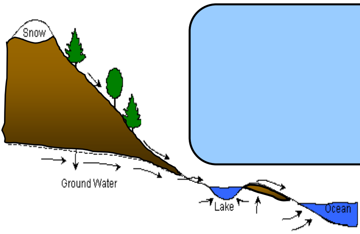
Accelerated Arctic land warming and permafrost degradation during rapid sea ice loss

David Lawrence[1], A.G. Slater[2],

B. Tomas[1], M. Holland[1], and C. Deser[1]

[1] NCAR / CGD
Boulder, CO

[2] NSIDC / CIRES
Boulder, CO



2007 – A record year in the Arctic

2007 minimum sea ice extent (Sept)

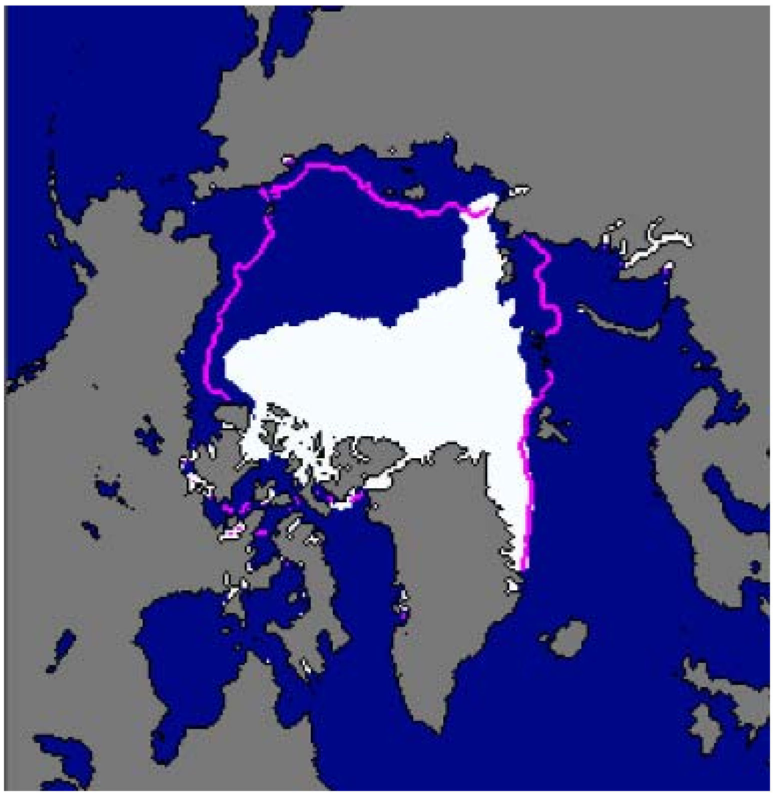


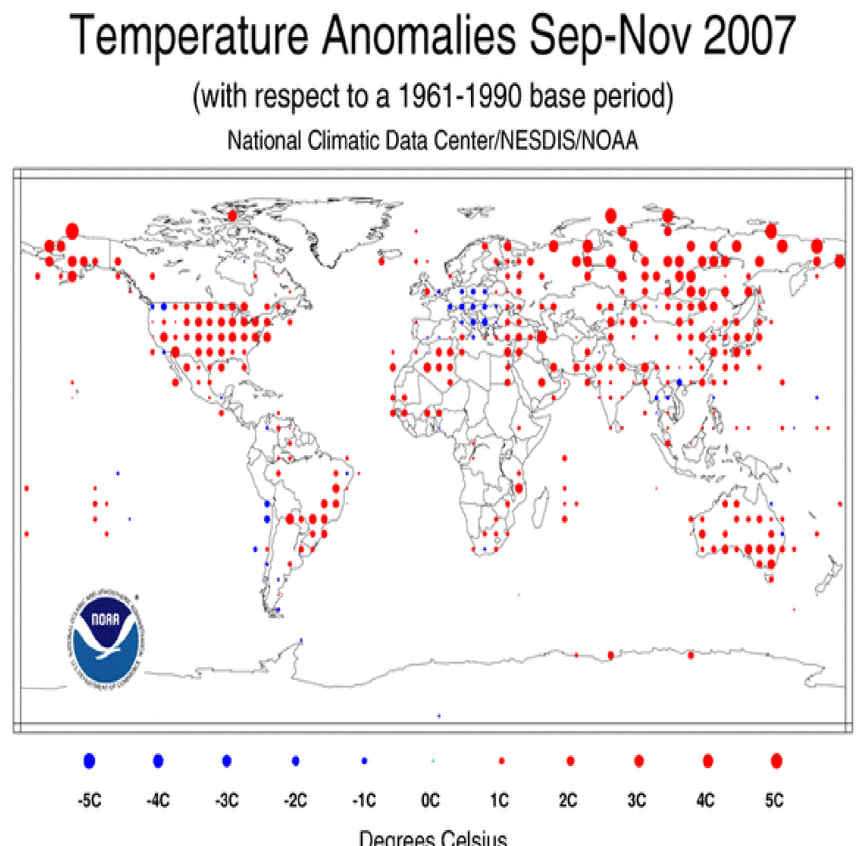
Image courtesy NSIDC

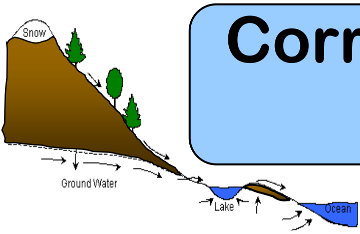
Western Arctic (Aug to Oct 2007)

warmest on record

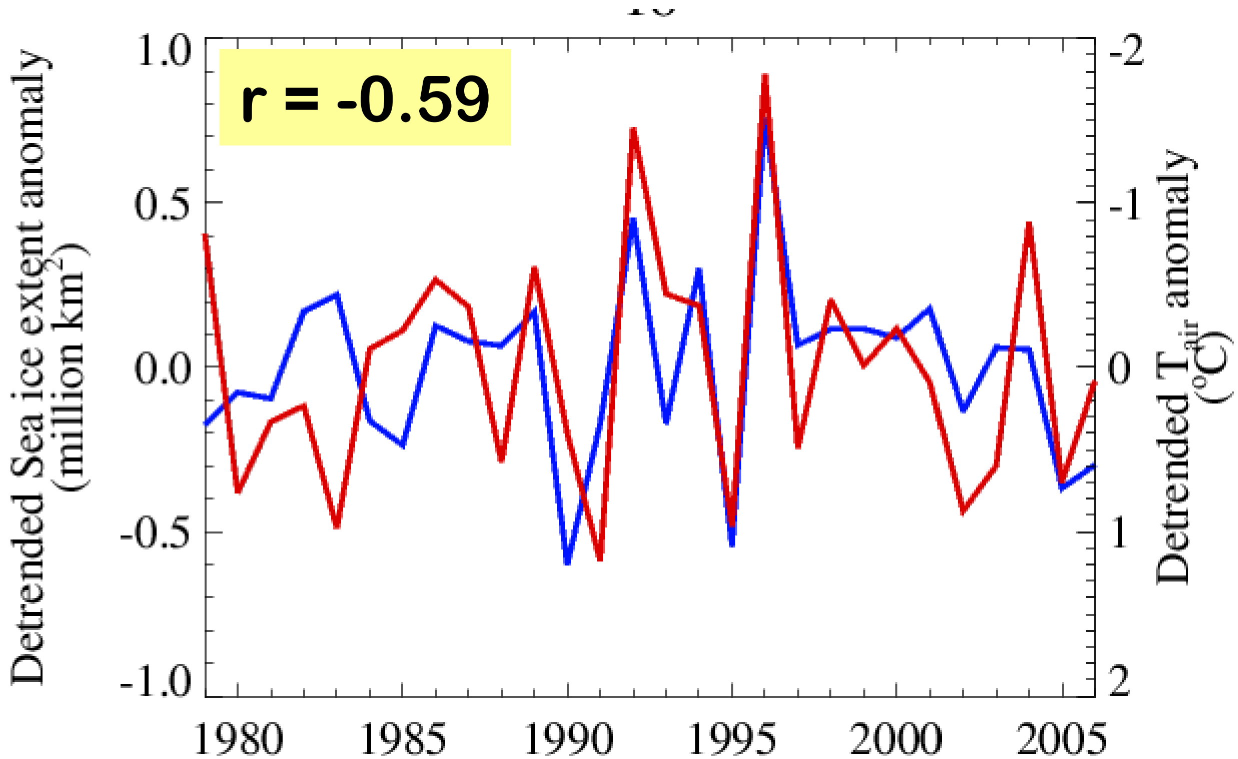
+2.3°C over 1978-2006 mean

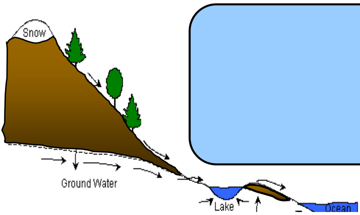
(preliminary CRU data)



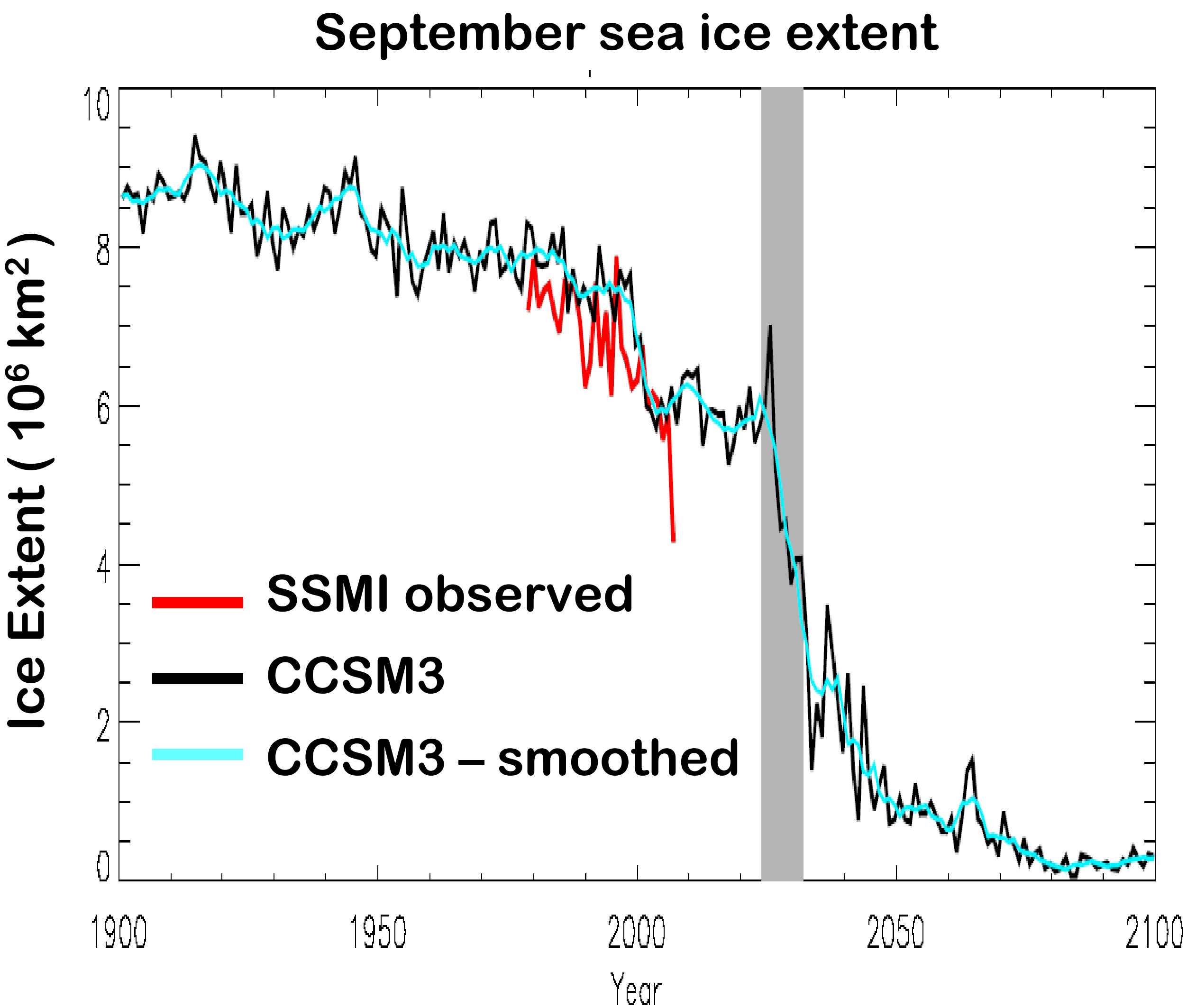


Correlation between Sept sea ice extent and western Arctic July to October T_{air} (CRU)



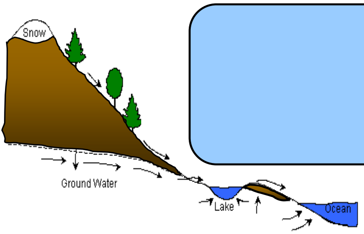


Observed and modeled sea ice extent

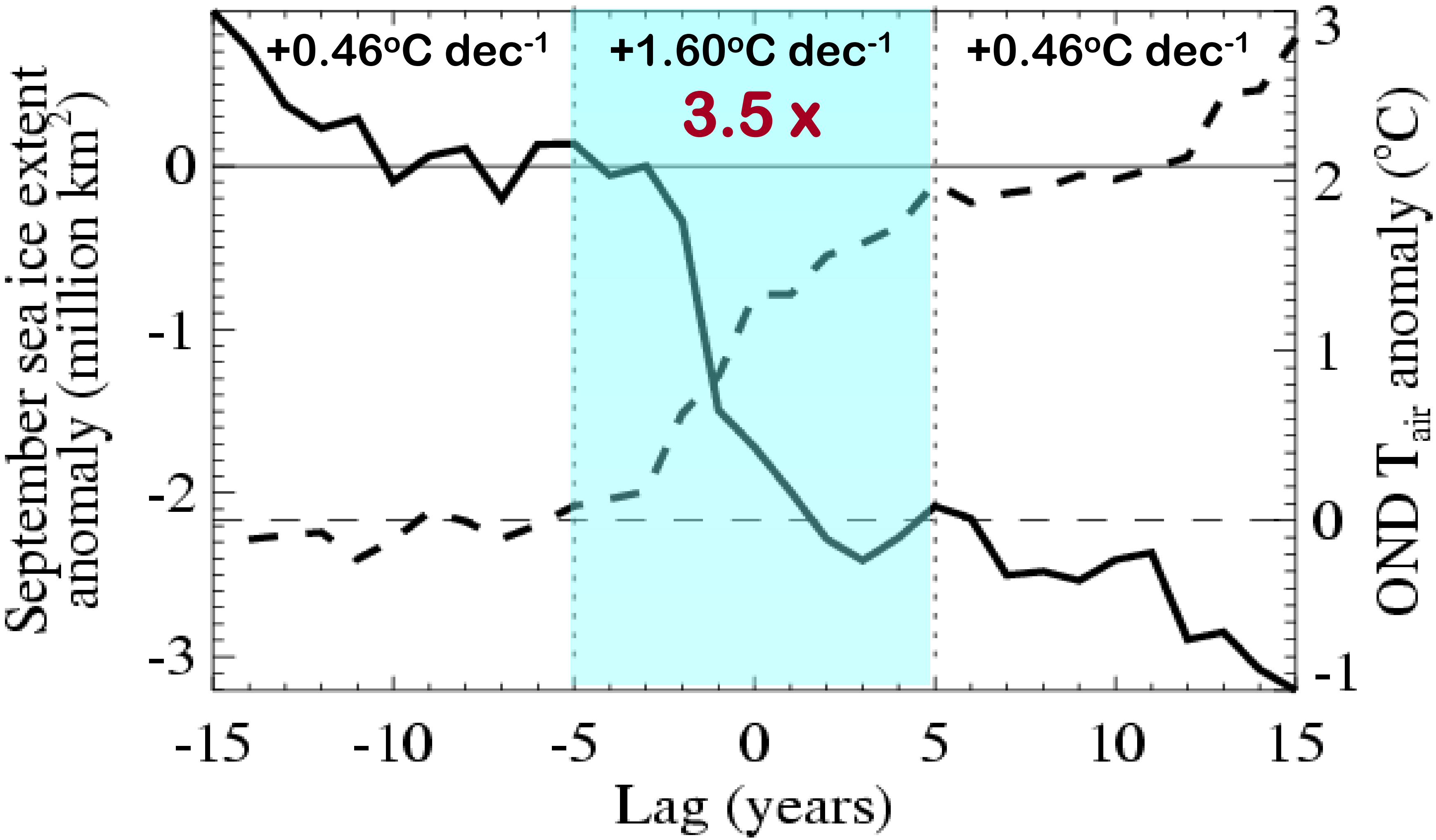


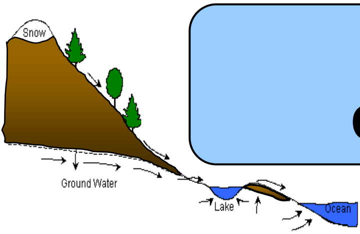
9 rapid sea ice loss events across 8-member CCSM3 A1B ensemble ranging from 2012 to 2045

(Holland et al. 2006)

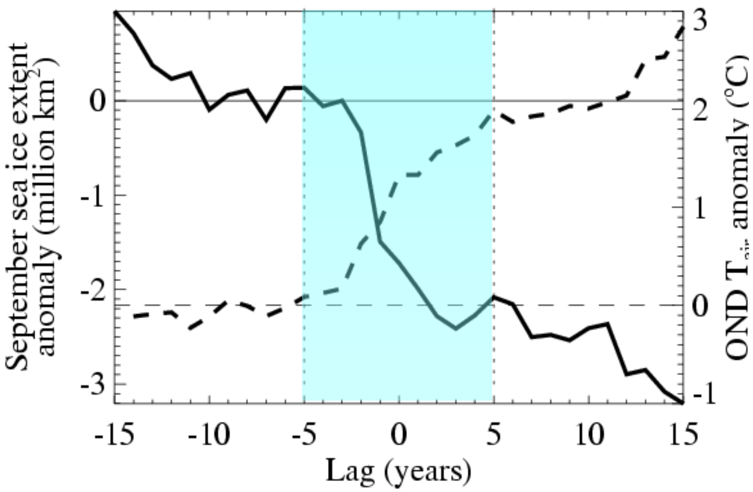


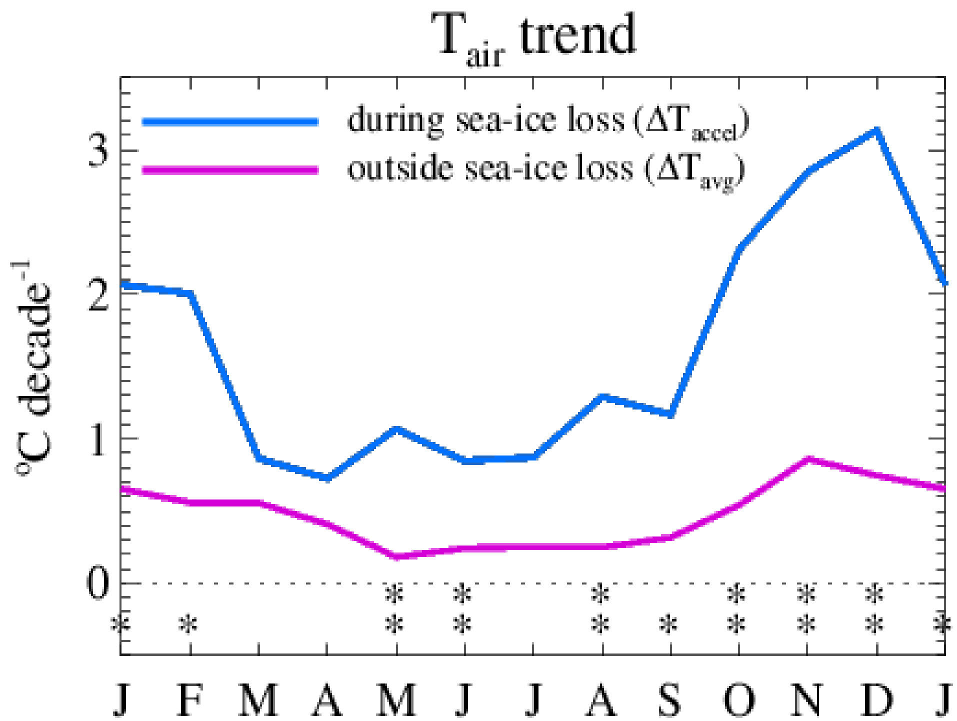
Lagged composite: sea ice extent and western Arctic land T_{air}



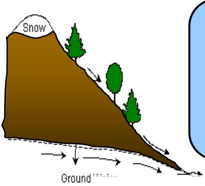


T_{air} trend during and outside rapid sea ice loss periods



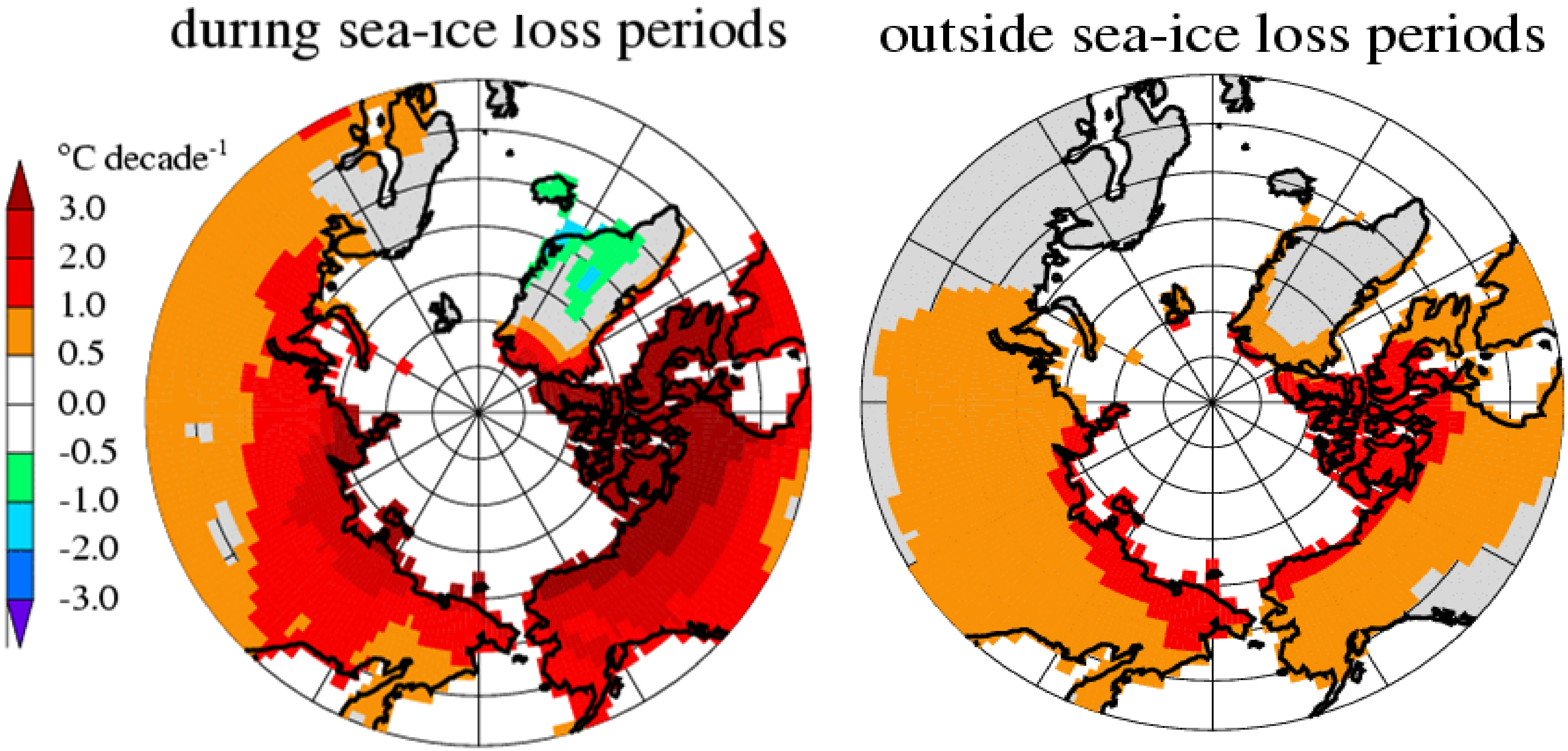


* P < 0.05
** P < 0.01



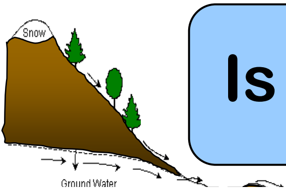
Trends during and outside rapid sea ice loss periods

T_{air} trend:



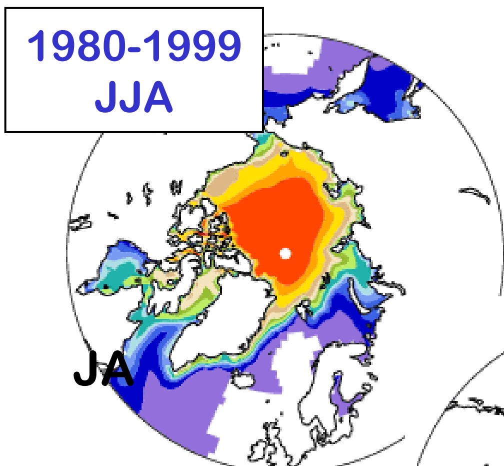
- Similar trends in q_{air}, LW↓
- No statistically significant or spatially coherent trends in P, snow depth, or SW↓, P

Is warming a response to or a forcing of sea ice loss?

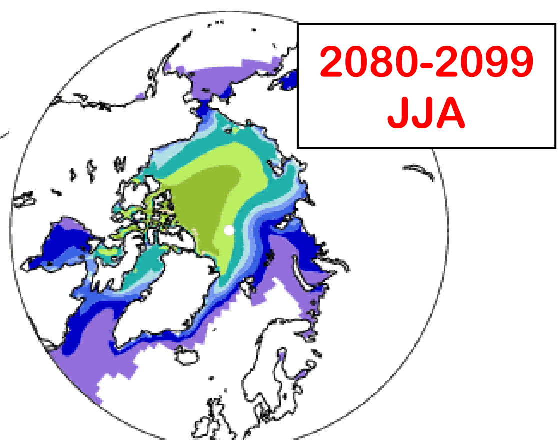


Impact of sea ice on climate experiments

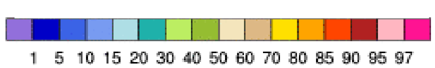
Climate Analysis Working Group

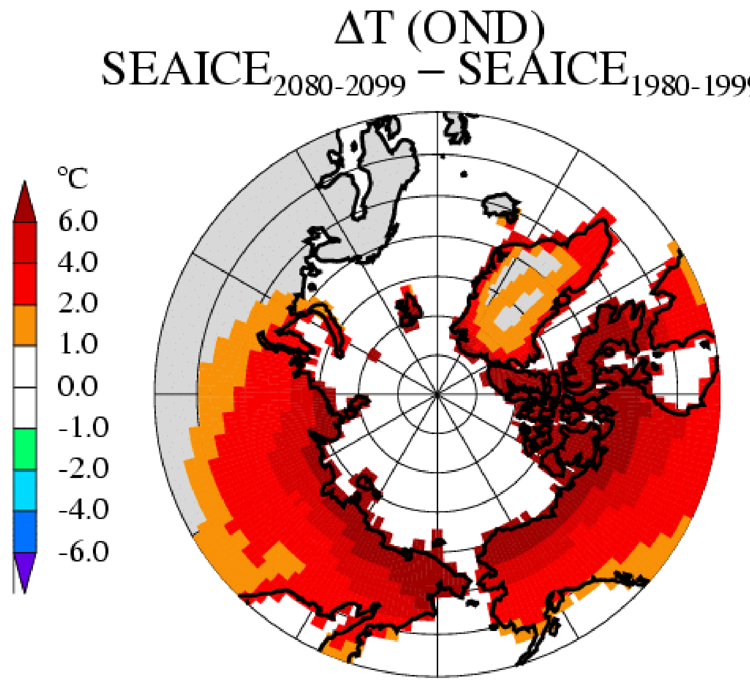


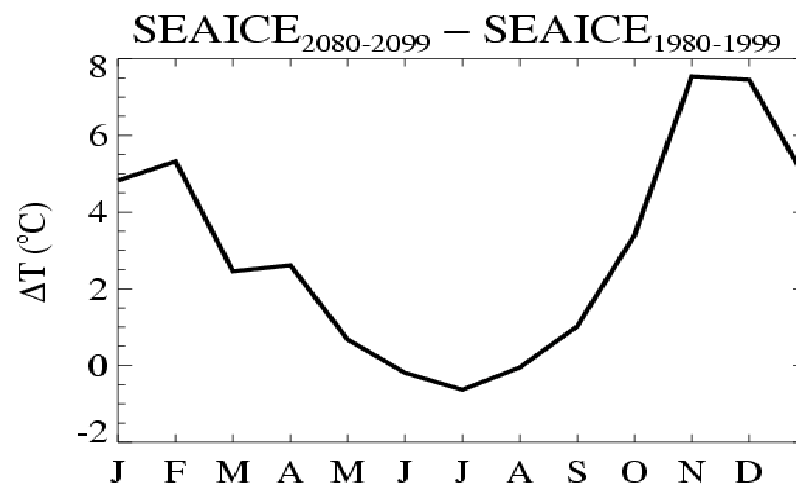
AMIP-type expt. with prescribed CCSM3 ice extent and thickness

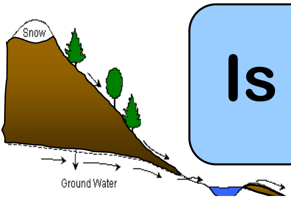


Ice concentration



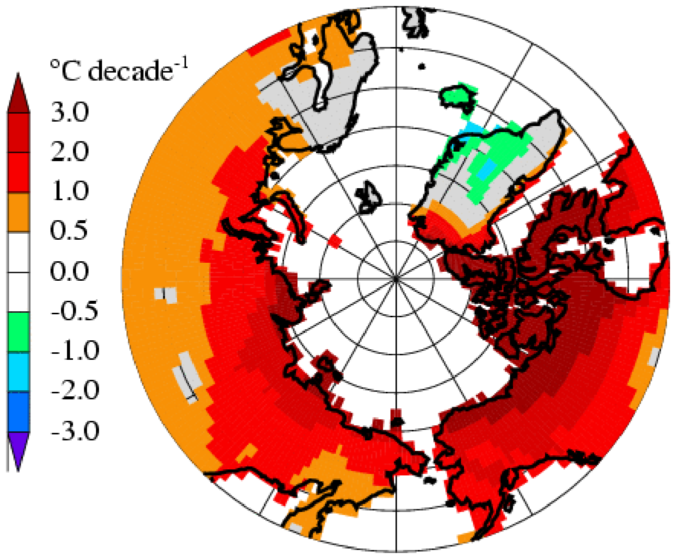




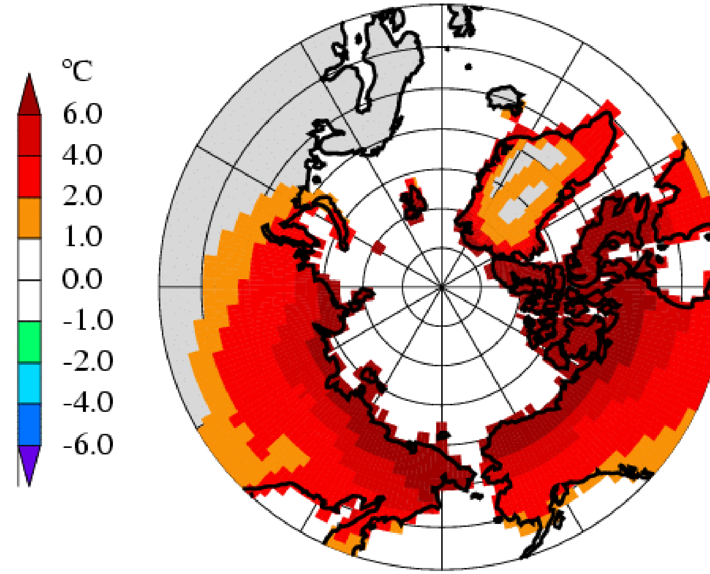


Is warming a response to or a forcing of sea ice loss?

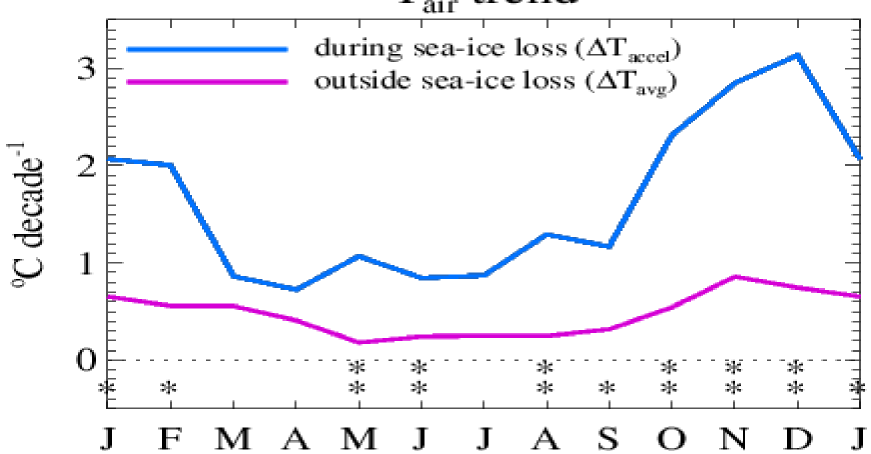
ΔT_{air} (OND)
during sea-ice loss periods



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



T_{air} trend



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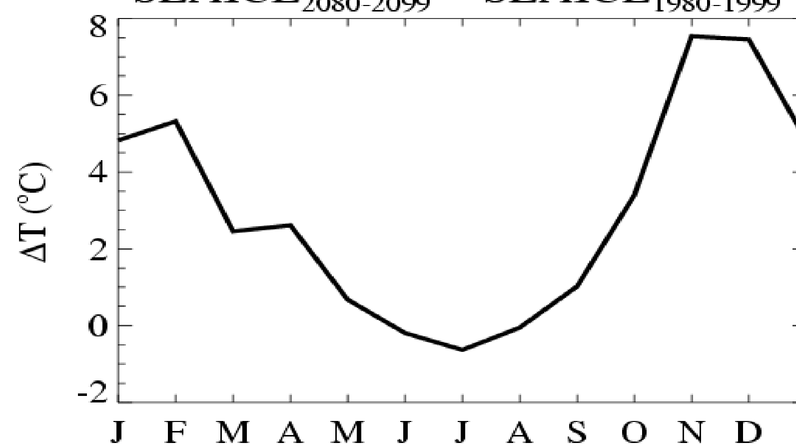
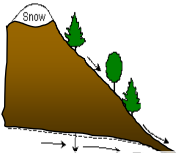
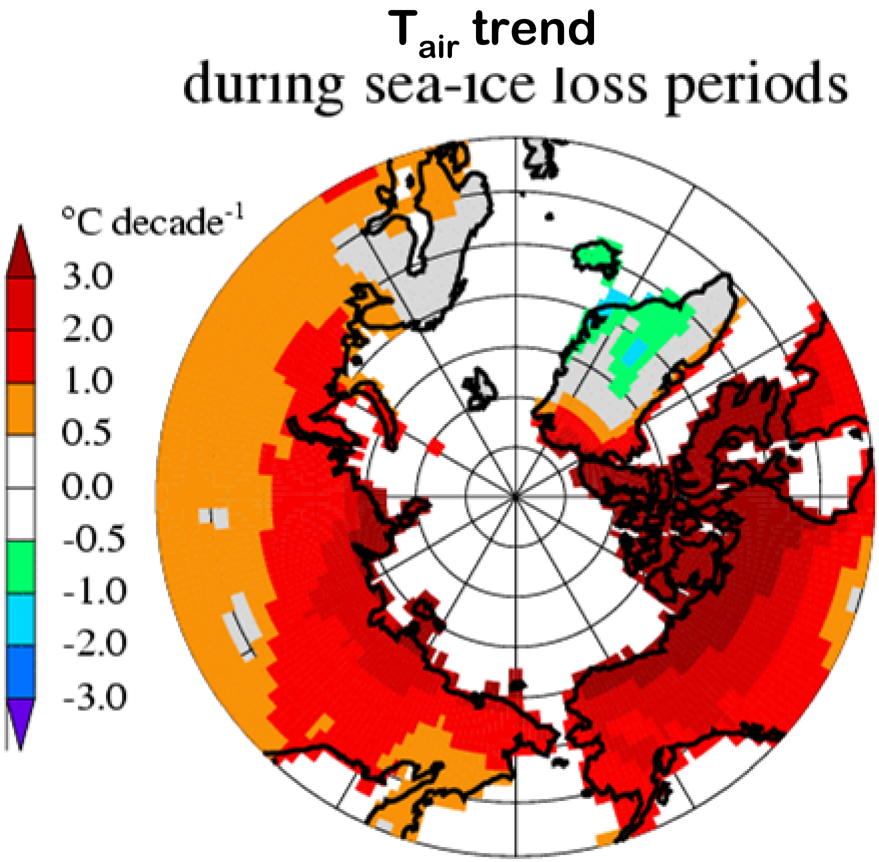
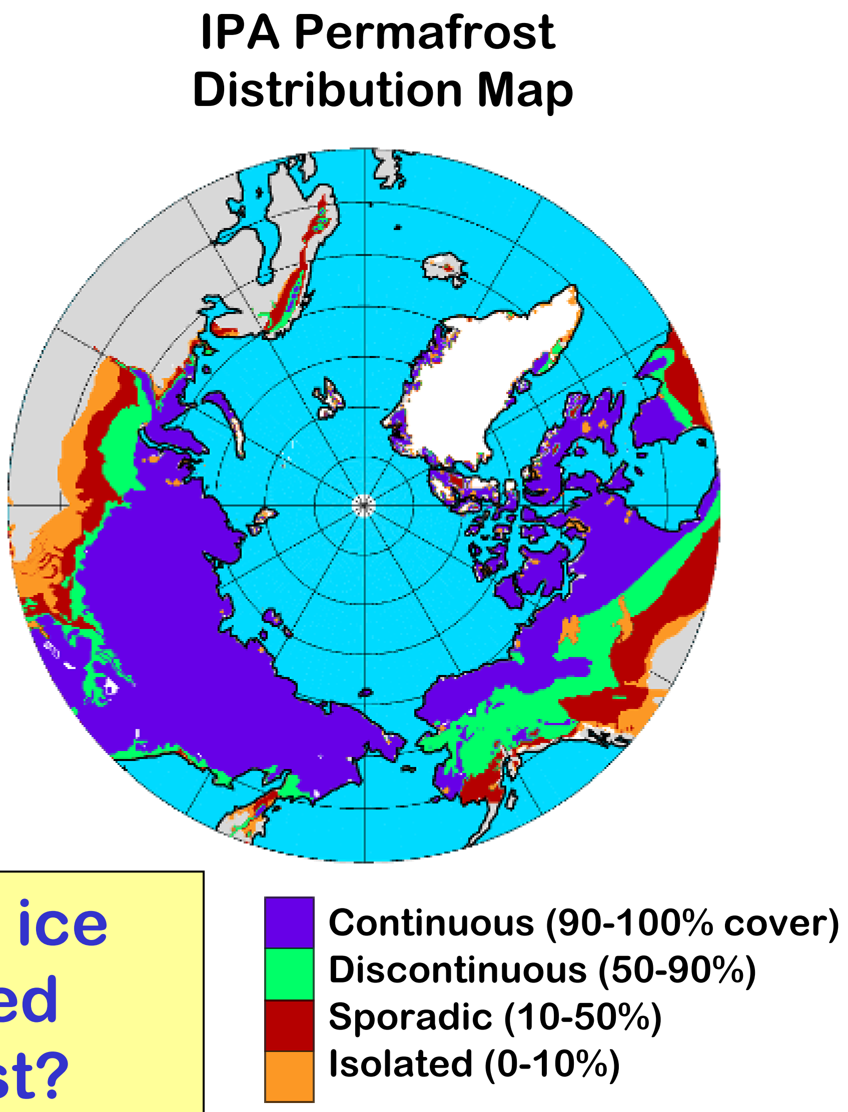


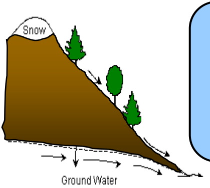
Collocation of accelerated warming with permafrost zones



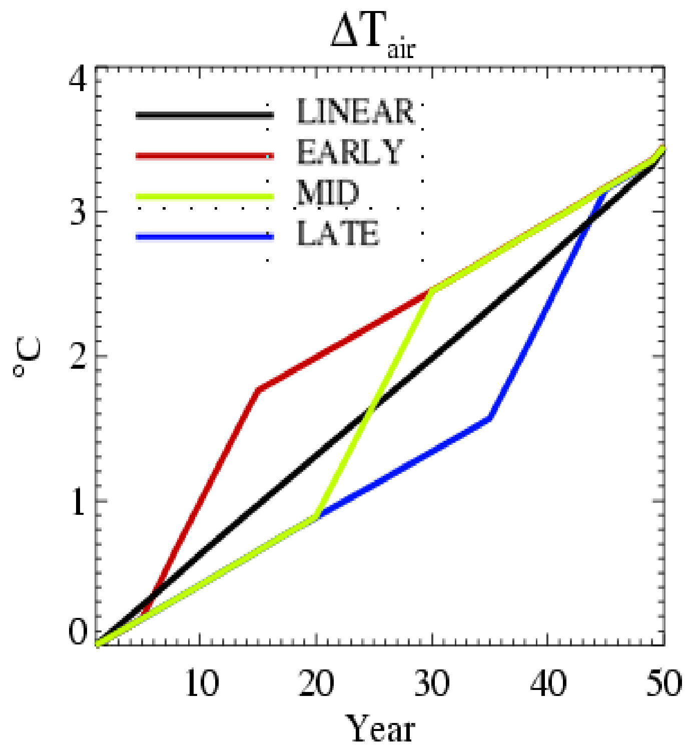


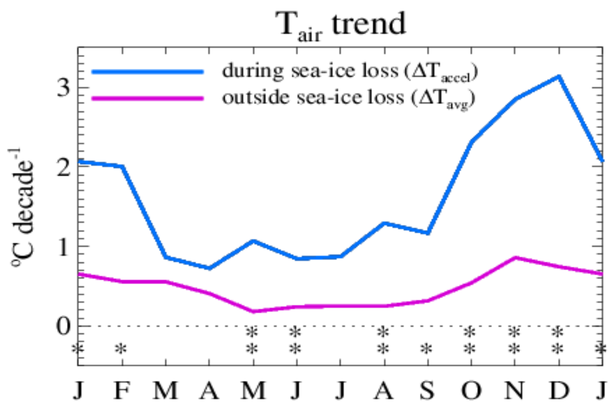


Question: How does rapid sea ice loss and associated accelerated land warming affect permafrost?

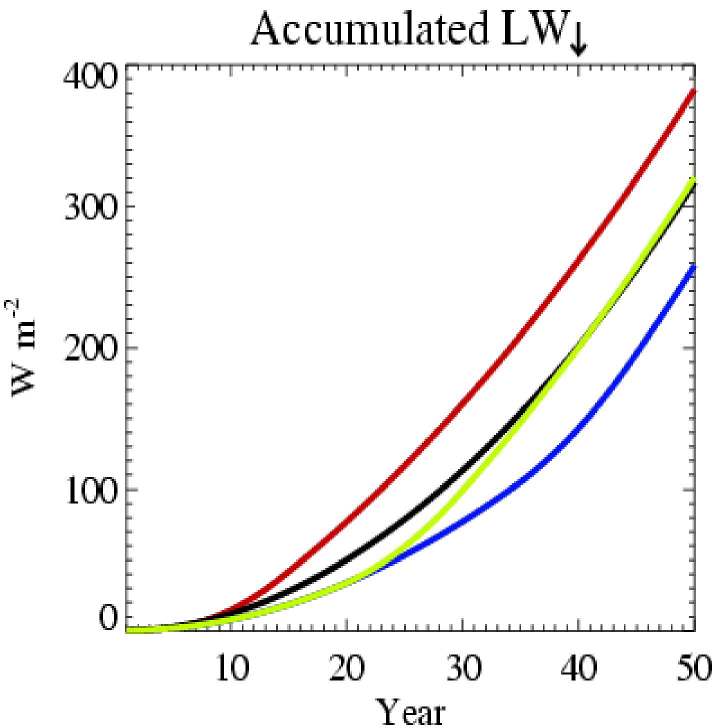


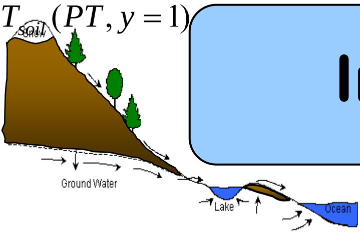
Idealized CLM forcing scenarios



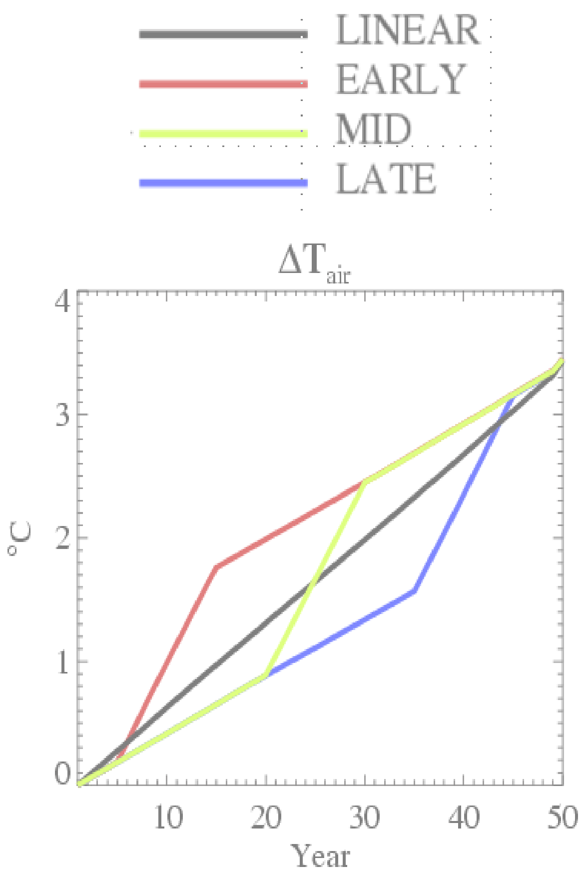


- Generate four meteorological forcing data sets by adding ΔT_{air} anomaly time series to observed year 2000 forcing.
- q_{air} also adjusted to conserve RH.





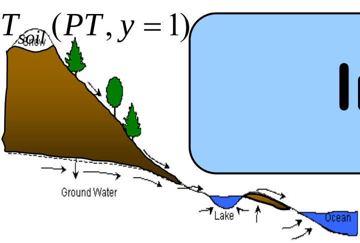
Impact of accelerated warming on permafrost

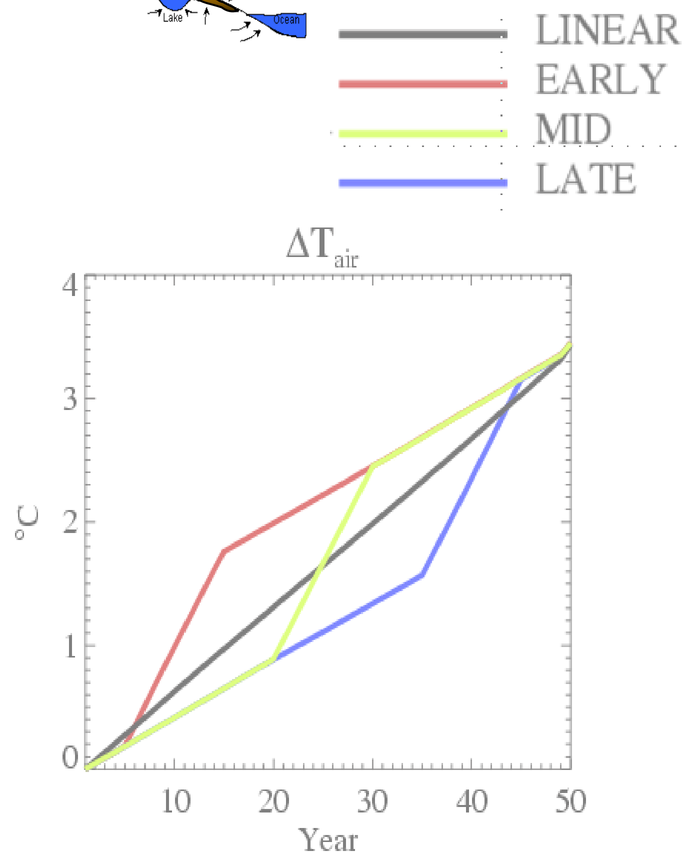


Experimental design

- Use CLM3.5 with improved permafrost dynamics
- Spin up for 400 years with repeat year 2000 forcing
- Force CLM with idealized scenario experiments
- Consider only points where Δsnow_depth < 10%

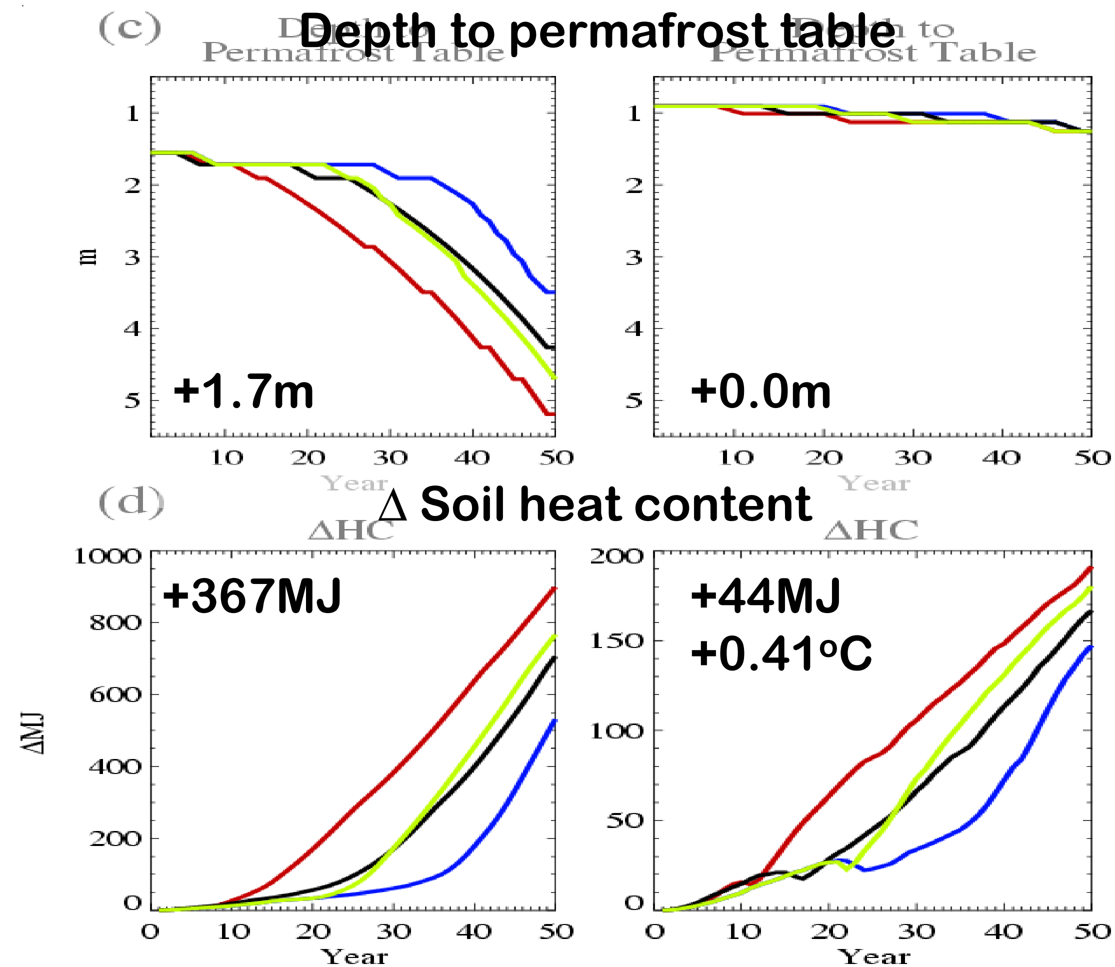
Impact of accelerated warming on permafrost





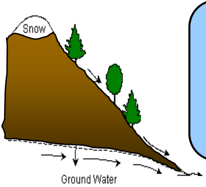
Warm $\overline{T_{soil}(PT, y=1)}$ **Cold**

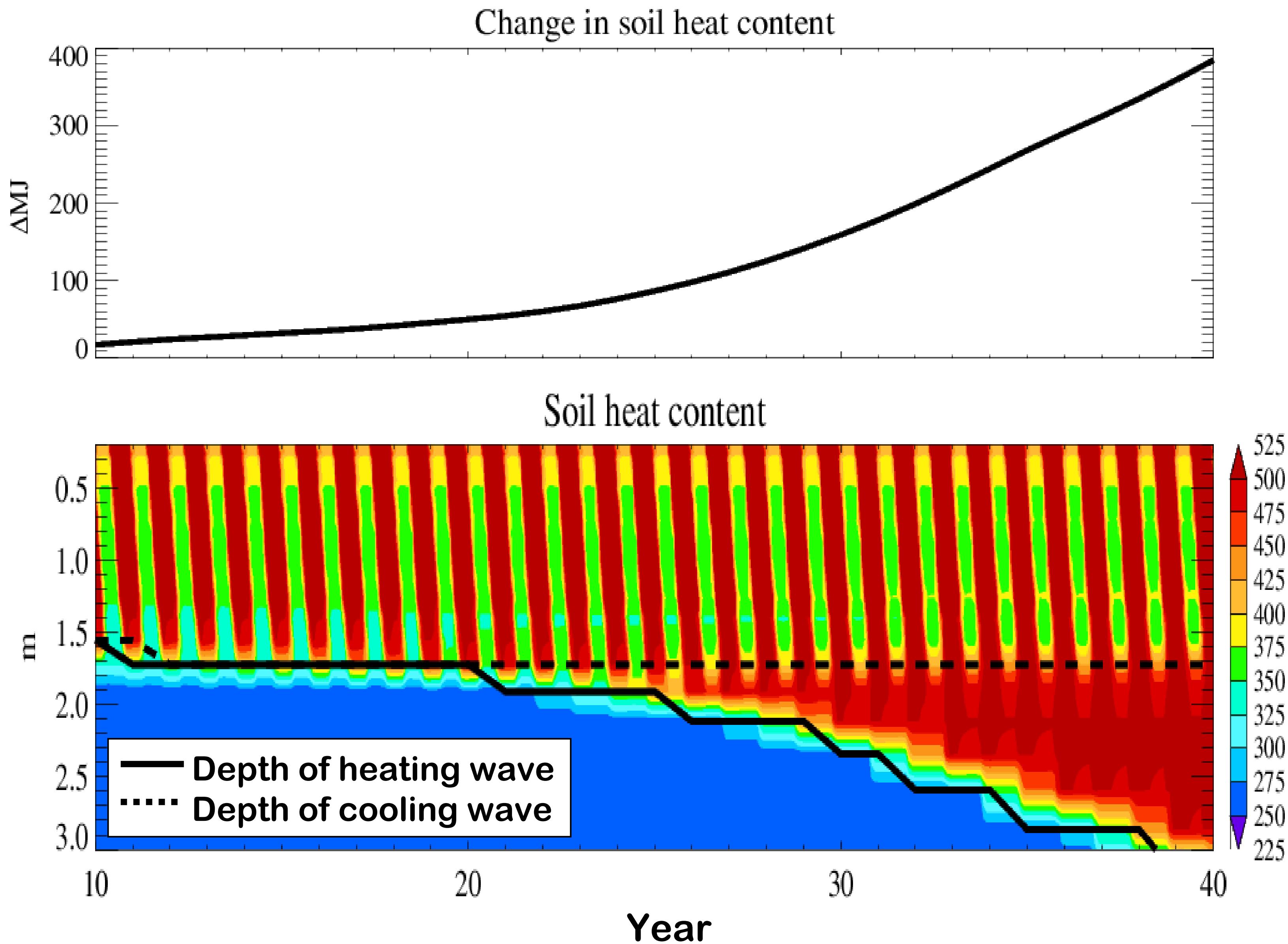
–0.3°C **–5.8°C**

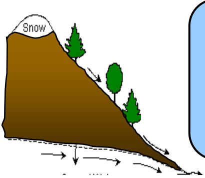


Beltrami et al. (2002) estimate avg land heat gain 1950 to 2000 of 70MJ

Soil heat accumulation
Warm permafrost case, LINEAR expt

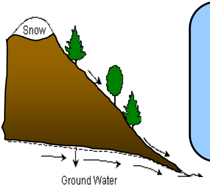




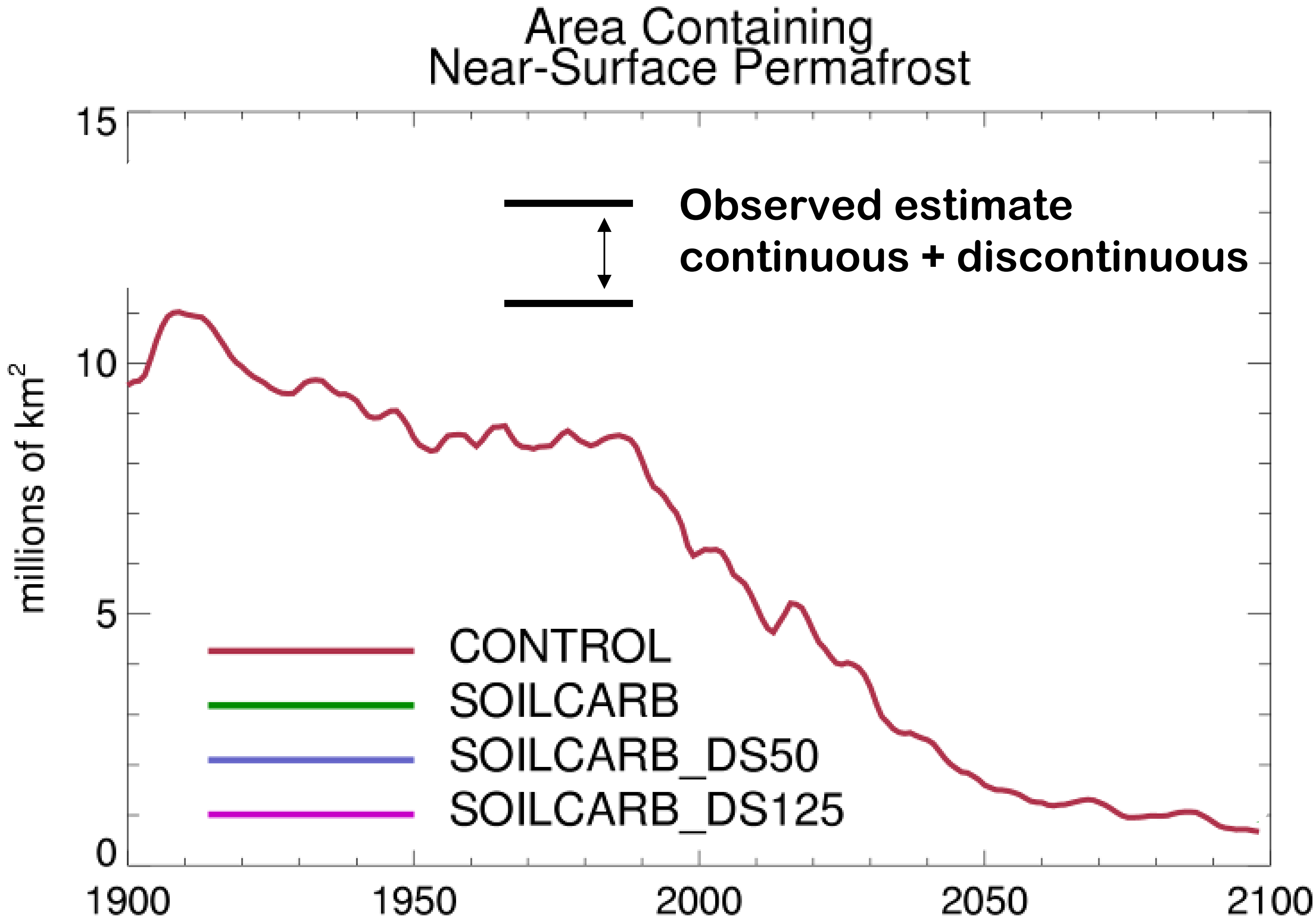


Summary

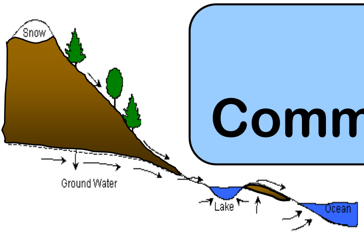
- Periods of rapid sea ice loss in CCSM3 induce a 3.5x increase in warming trends compared to secular climate-change trends for western Arctic. This is consistent with 2007 events.
- Accelerated warming signal extends up to 1500km inland and is apparent throughout most of the year, peaking in autumn.
- Accelerated warming substantially increases ground heat accumulation – the earlier the event the greater the long-term impact.
- Enhanced heat accumulation can lead to rapid degradation of warm permafrost and preconditions colder permafrost for earlier and/or more rapid degradation.
- Accelerated warming is likely to have broader impacts on vulnerable Arctic ecosystems, biogeochemical cycling, infrastructure.



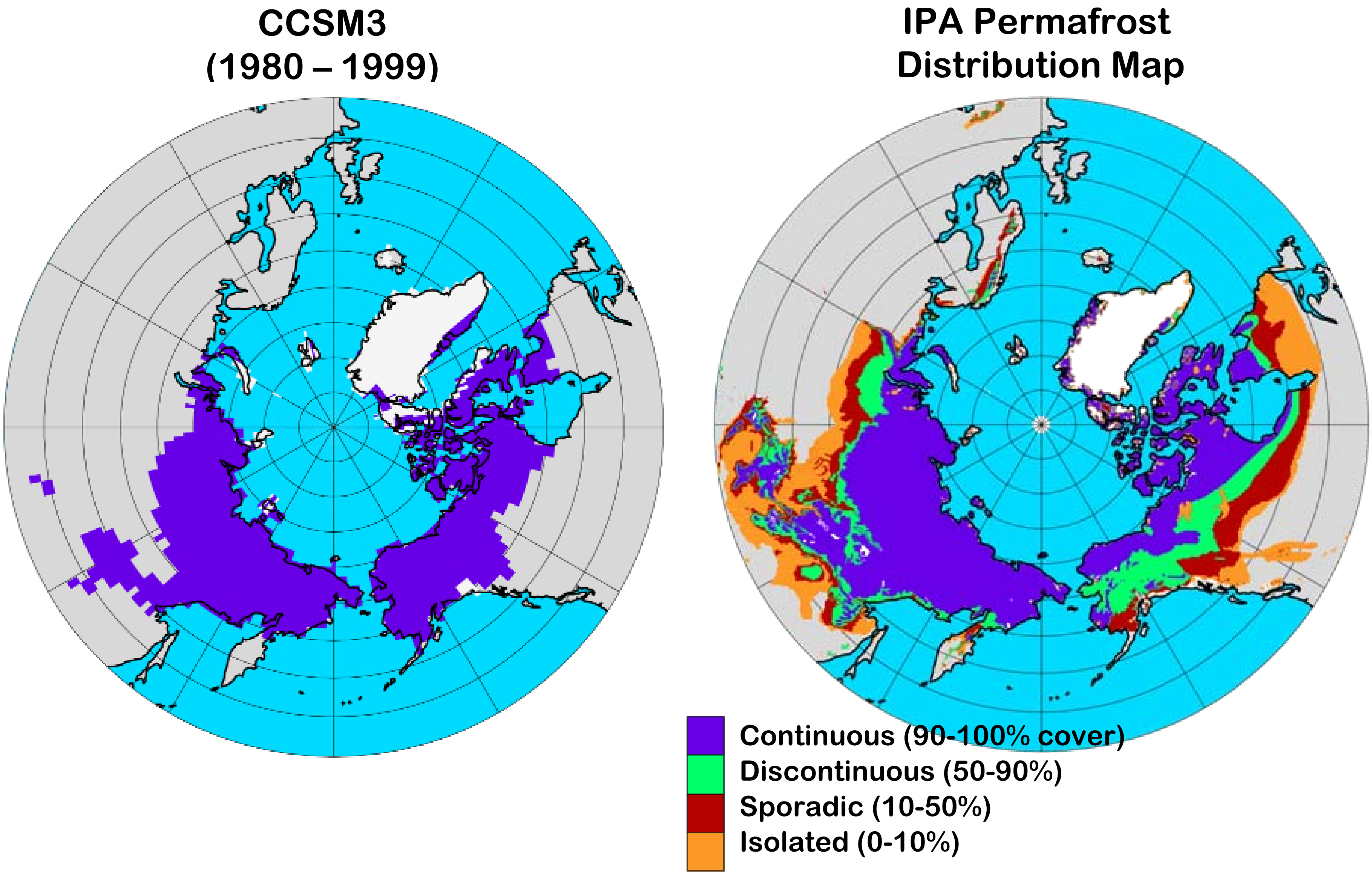
Near-surface permafrost degradation

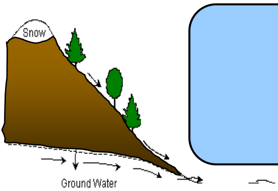


Lawrence et al., 2007



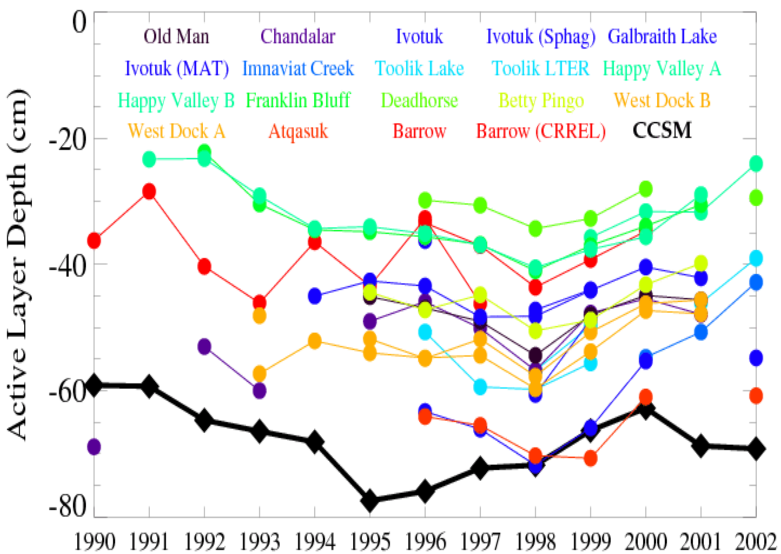
Near-surface permafrost distribution in Community Climate System Model (CCSM3) IPCC AR4 Ensemble

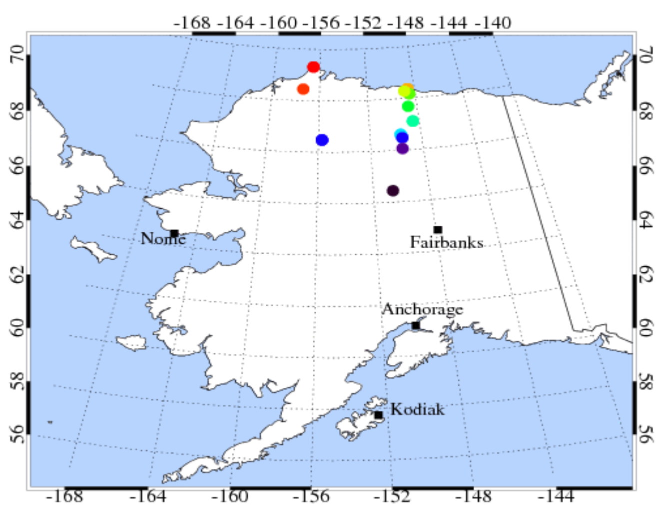




Potential sources of bias in the CCSM3 permafrost simulation

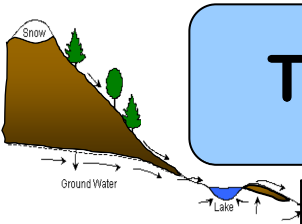
CALM Monitoring Sites





- Biases in the simulated climate
  - T_{air}, snow, variability
- Errors due to common simplifications in GCM land-surface schemes
  - soils represented as pure mineral soils (sand, silt, clay) no organic soil
  - shallow soil column (~3m), small number of soil levels

- no excess soil ice
- no vertical heat advection by water
- lack of subgrid scale features, thermokarst, aspect, microtopography



Thermal and hydraulic parameters for organic soil

Soil type	λ_{sat}	λ_{dry}	Θ_{sat}	k_{sat}
Sand	**3.12**	**0.27**	**0.37**	**0.023**
Clay	**1.78**	**0.20**	**0.46**	**0.002**
Peat	**0.55**	**0.05**[a]	**0.9**[a,b]	**0.100**[b]

$$\Theta_{sat,i} = (1 - f_{sc,i})\,(\,0.489 - 0.00126\,\%sand_i\,) + f_{sc,i}\,\Theta_{sat,sc}$$

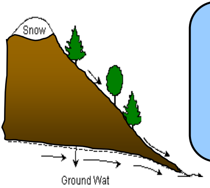
λ_{sat} sat. thermal conductivity

λ_{dry} dry thermal conductivity

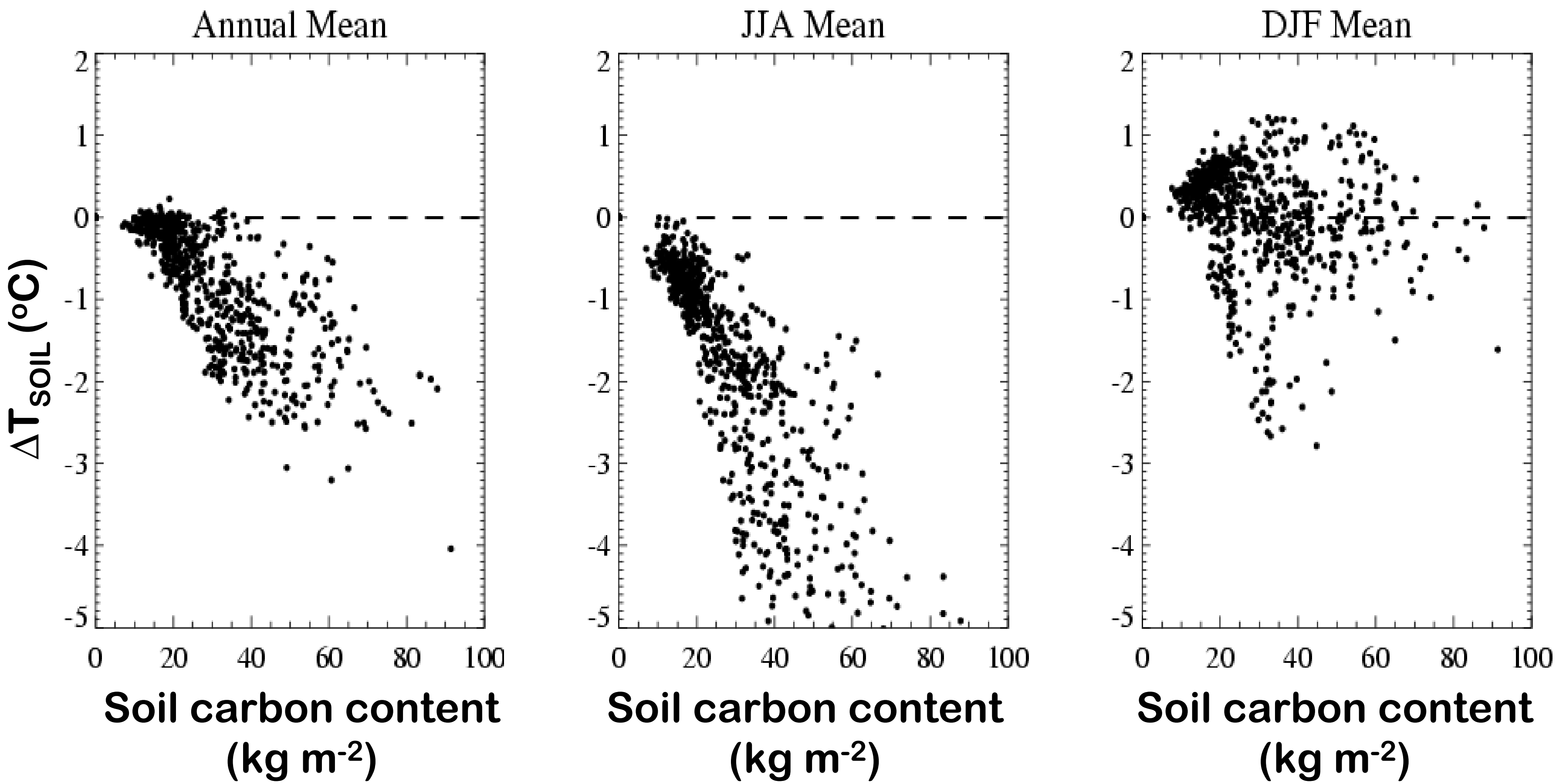
Θ_{sat} volumetric water at saturation

k_{sat} sat. hydraulic conductivity

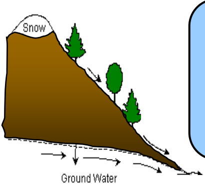
[a] Farouki (1981), [b] Letts et al. (2000)



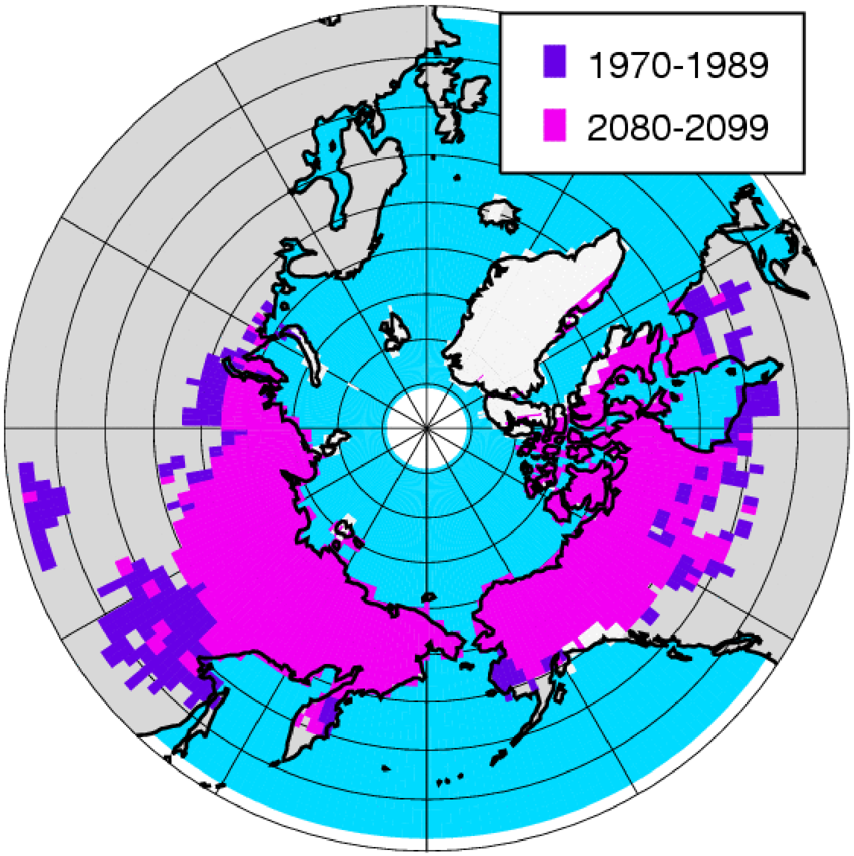
Impact on soil temperature (SOILCARB – CONTROL)



Organic soil layers cool soil temperatures by up to -3°C

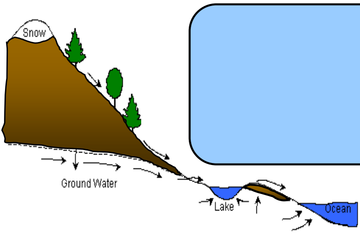


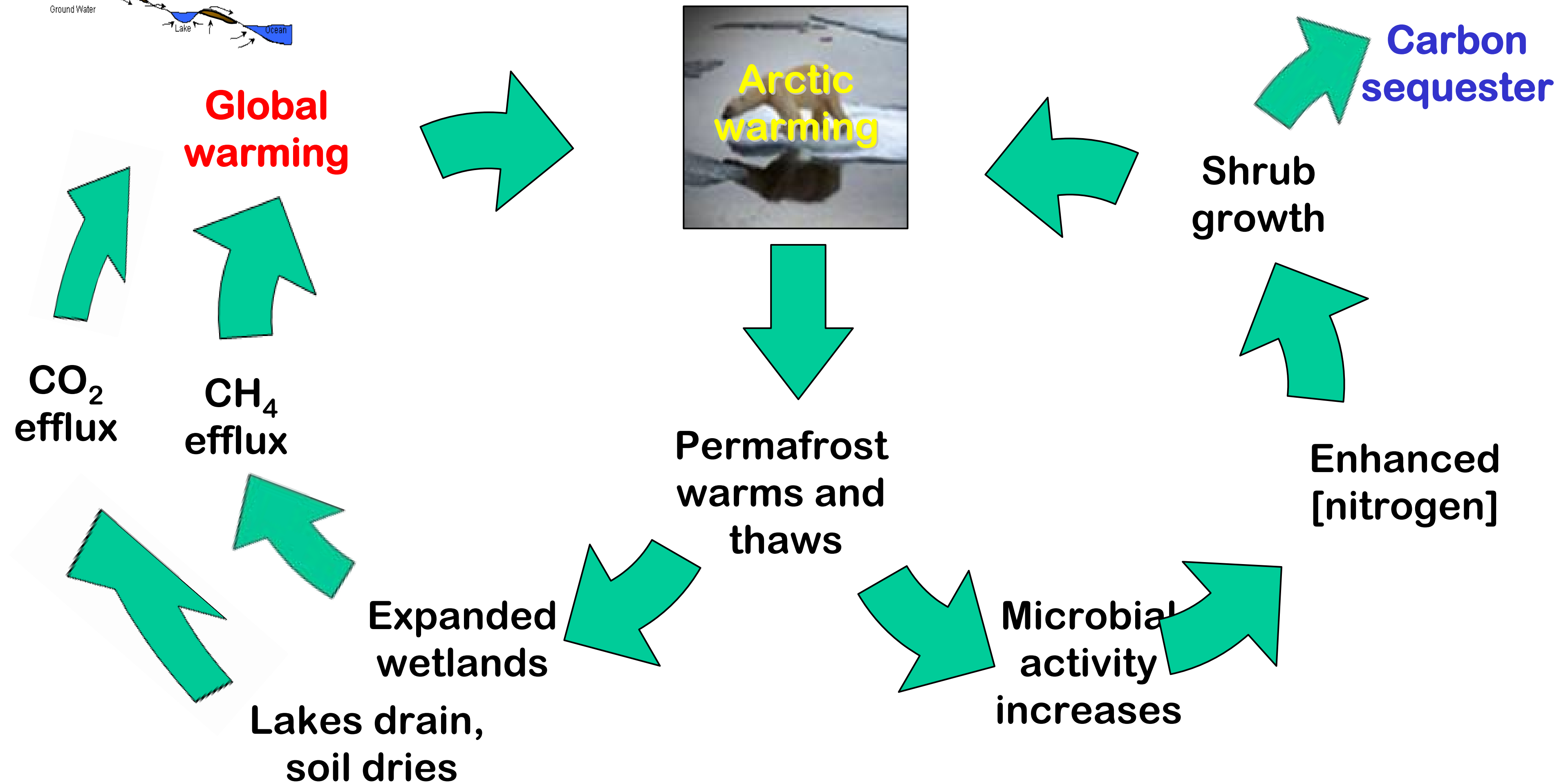
Deep permafrost (10-30m)



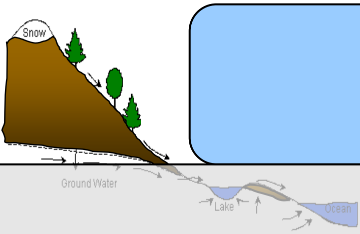
Most deep permafrost still exists at the end of the 21st century

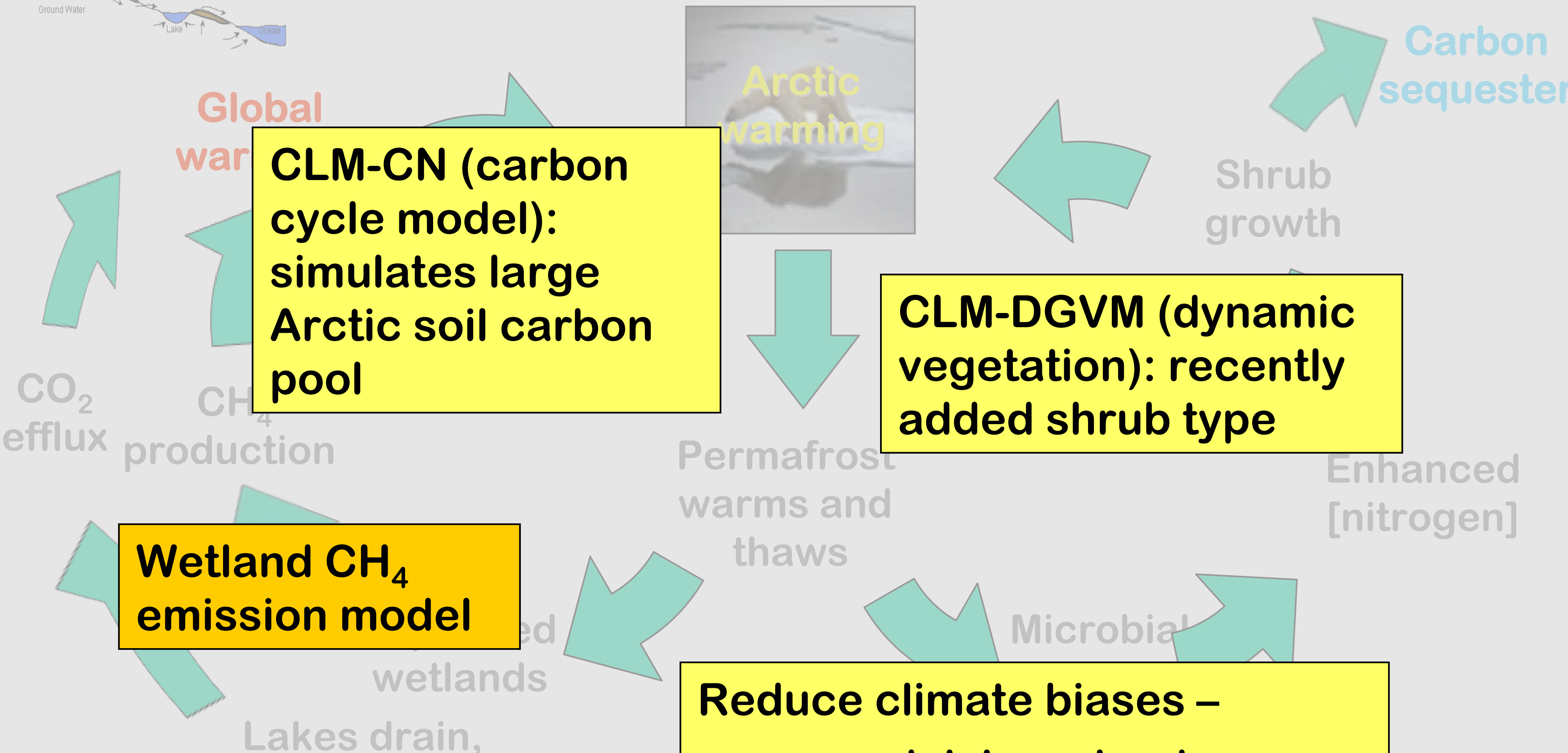
Future Work: Simulating Arctic terrestrial feedbacks in CCSM





Future Work: Simulating Arctic terrestrial feedbacks in CCSM





CLM-CN (carbon cycle model): simulates large Arctic soil carbon pool

CLM-DGVM (dynamic vegetation): recently added shrub type

Wetland CH_4 emission model

Dynamic wetlands, soil subsidence, thermokarst

Reduce climate biases –

snow model, low clouds, resolution in boundary layer, cold region hydrology