

The contribution of snow condition trends to future ground climate

David Lawrence¹

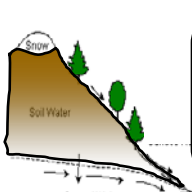
Andrew Slater²



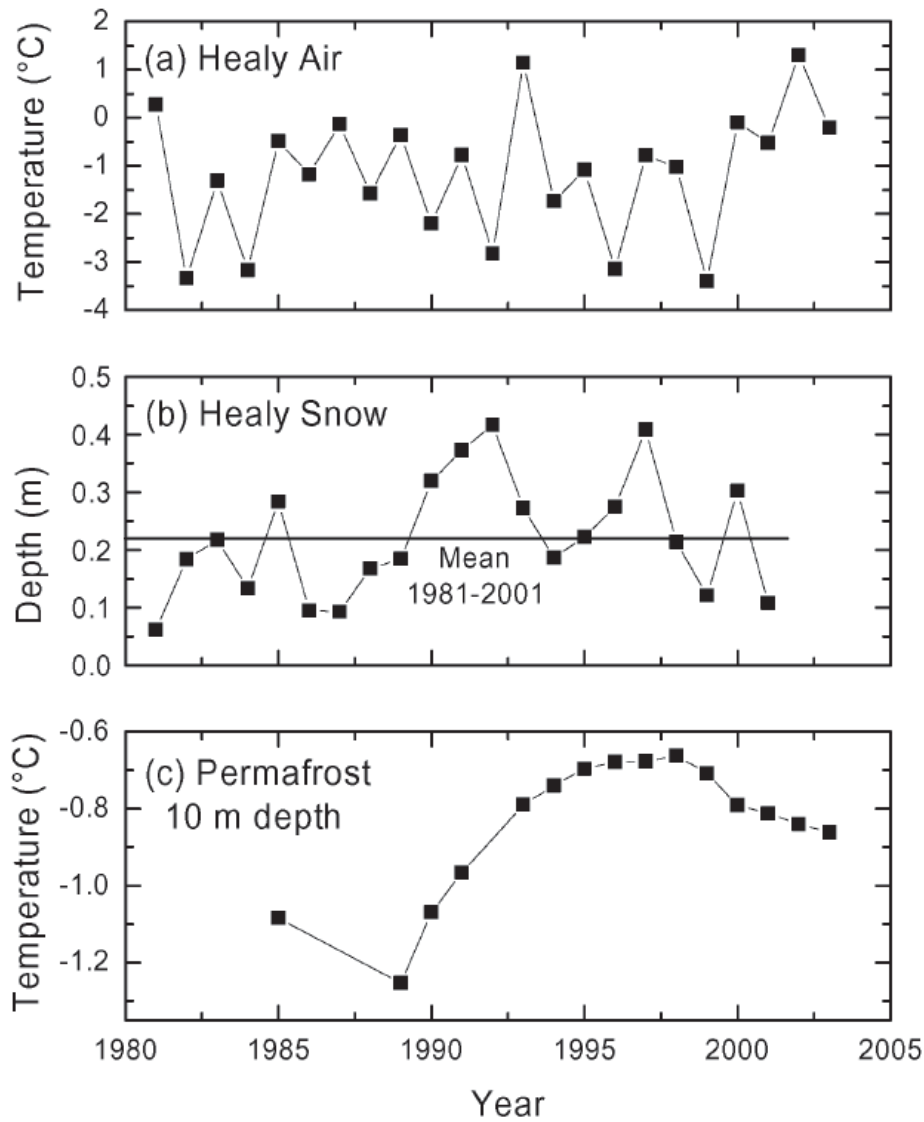
¹ NCAR / CGD
Boulder, CO



² NSIDC / CIRES
Boulder, CO

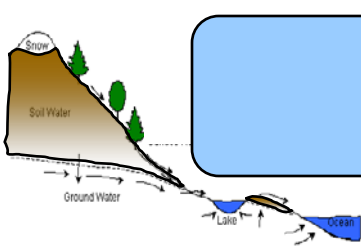


Snow vs T_{air} influence on T_{soil} trends



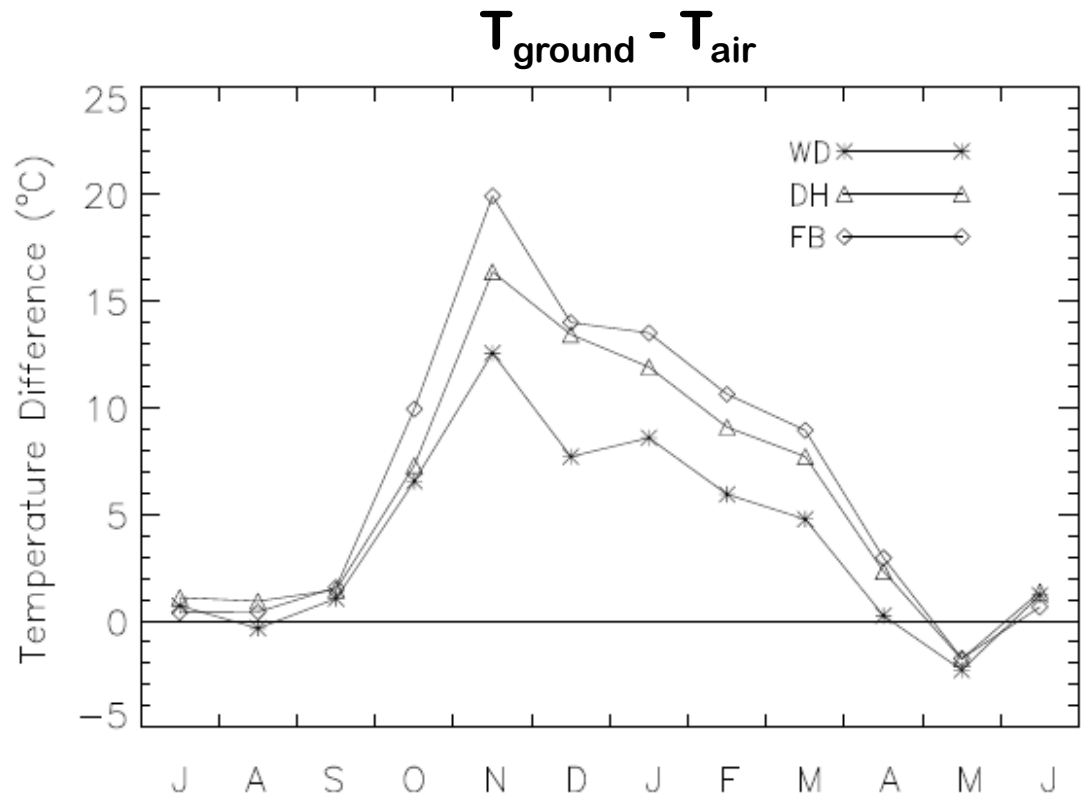
“There is a perception that climatic warming was the [principal] cause of 20th century warming and thawing of permafrost ... While pertinent data are sparse, published results do not support this viewpoint [Zhang *et al.*, 2001; Osterkamp, 2007]. This brief report reviews the warming of permafrost in Alaska ... and shows that snow cover has played a significant role in it.”

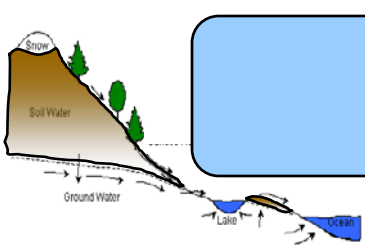
Snow influence on soil temperature



Depends on:

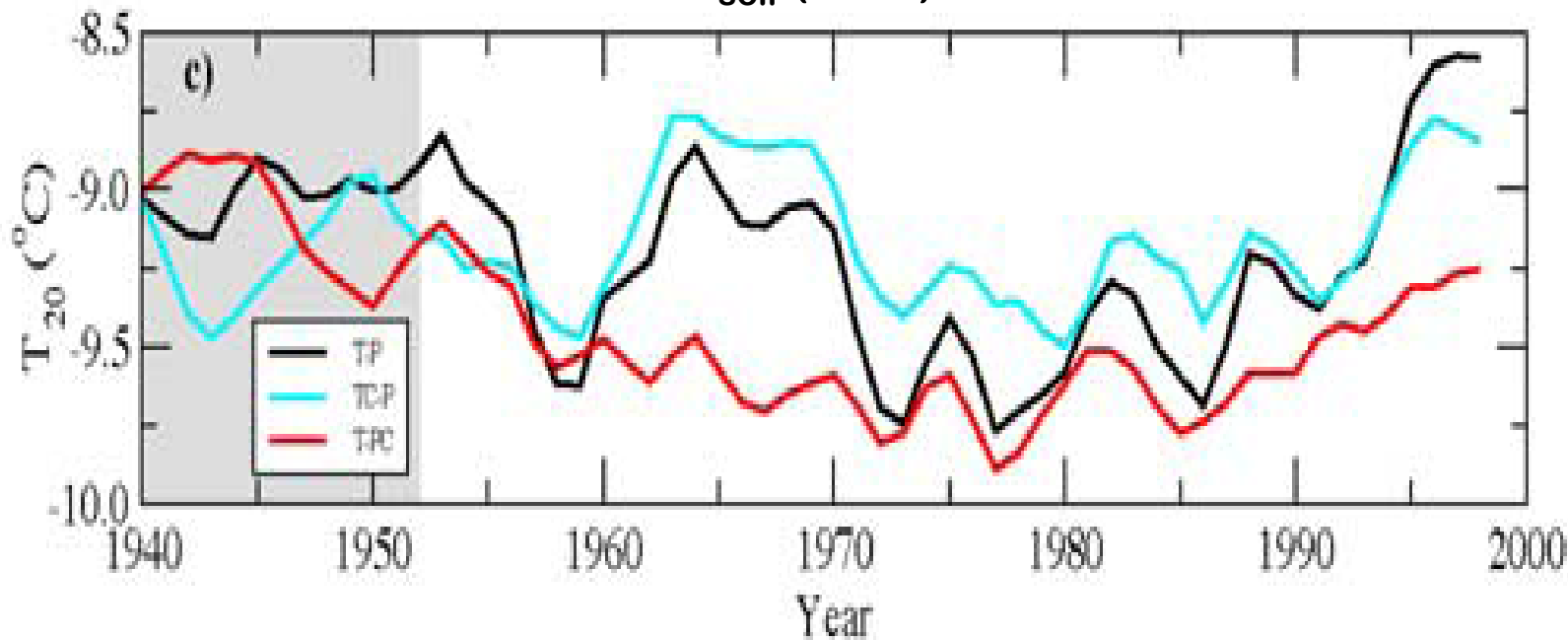
- Thickness
- Duration of snow season
- Snow onset date
- Snow melt date
- Density (thermal conductivity)



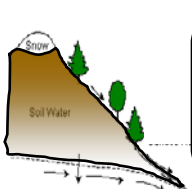


Snow vs T_{air} influence on T_{soil} trends

Modeled T_{soil} (20m) at Barrow

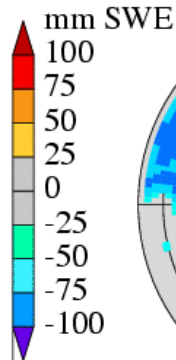
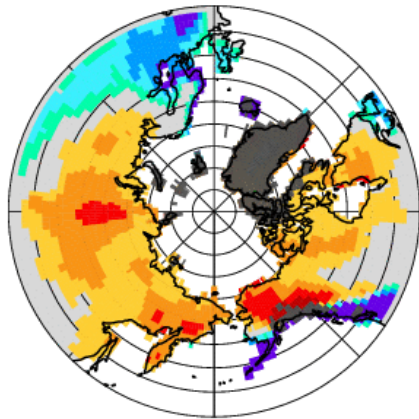


- T_{air} and P time series
- T_{air} climatology; P time series
- T_{air} time series; P climatology

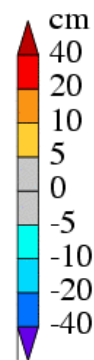
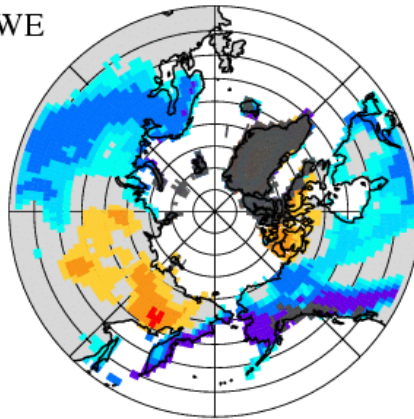


Projected snow changes in CCSM3 (2080-99 – 1950-69)

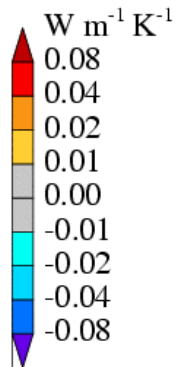
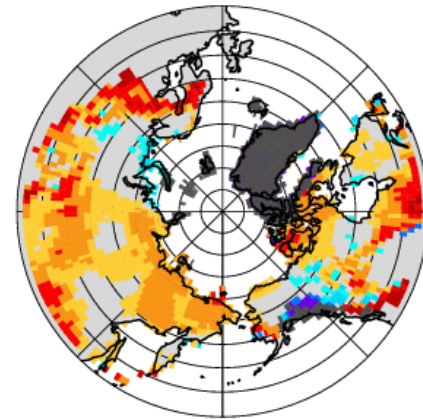
NDJFM Snowfall



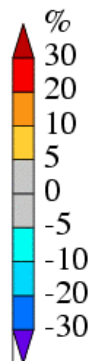
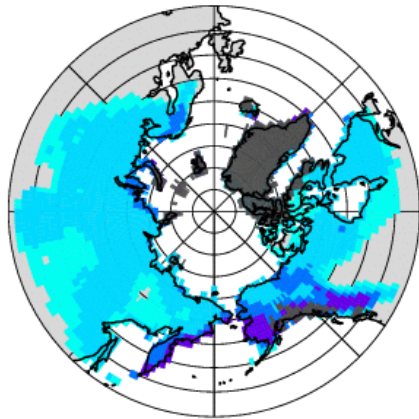
Max Snow Depth



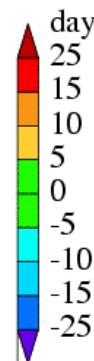
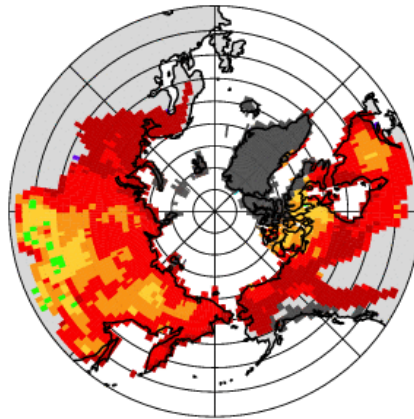
Snow Thermal Conductivity



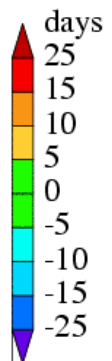
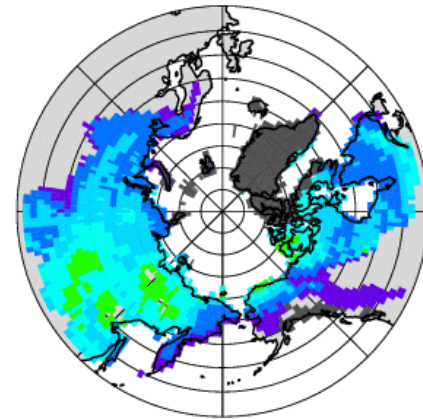
AMSO Snow Cover Fraction



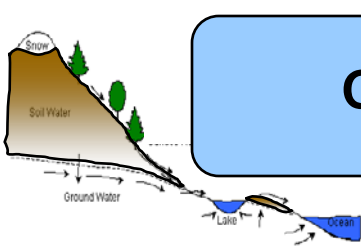
Day of First Autumn Snow Accum



Day of Spring Snow Melt



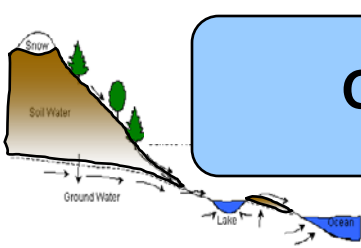
Controlled Snowfall and Prescribed Snow Experiments



Two sets of offline expts with CLM for the period 1950 to 2100

- **Controlled snowfall expts**
 - MID20C_FALL: snowfall rates held at 1950-1969 levels
 - TRND_FALL: with snowfall trend (smoothed with 9-yr run. avg.)
- **Prescribed snowfall expts**
 - Isolate role of snow season length and snow depth trends on T_{soil}
 - Prescribe linear transitions in snow season length and snow depth

Controlled Snowfall and Prescribed Snow Experiments



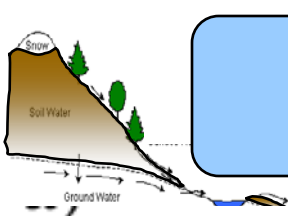
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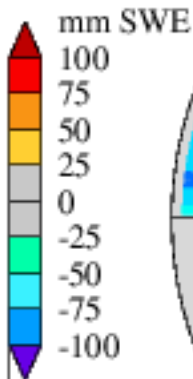
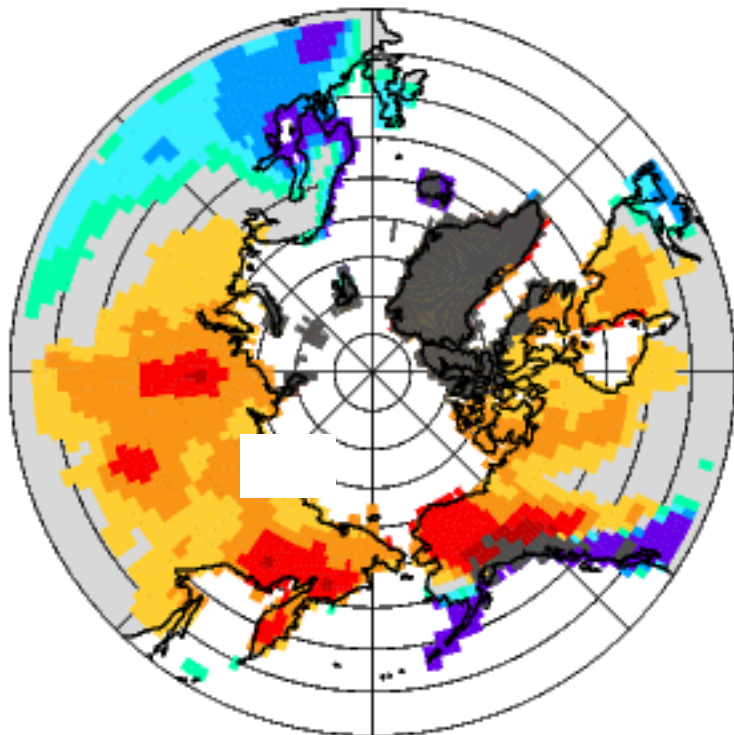
- **Prescribed snowfall expts**

- **Isolate role of snow season length and snow depth trends on T_{soil}**
- **Prescribe linear transitions in snow season length and snow depth**



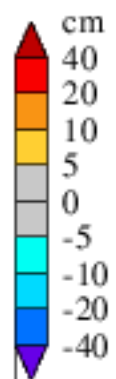
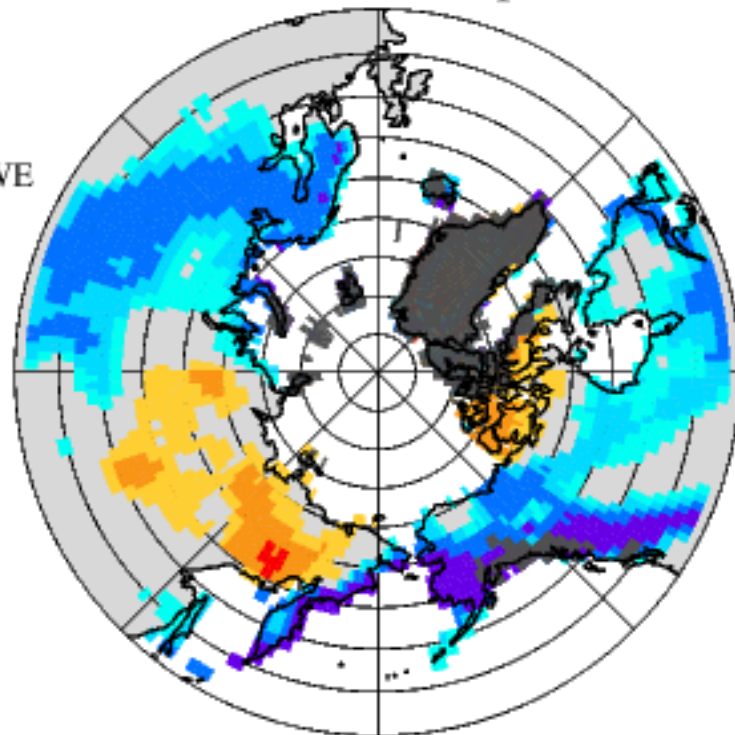
CCSM3 Projected snow changes A1B, 2080-2099 minus 1950-1969

NDJFMA Snowfall

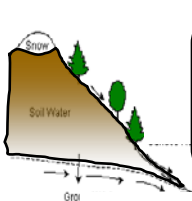


10 – 30% increase in winter snowfall

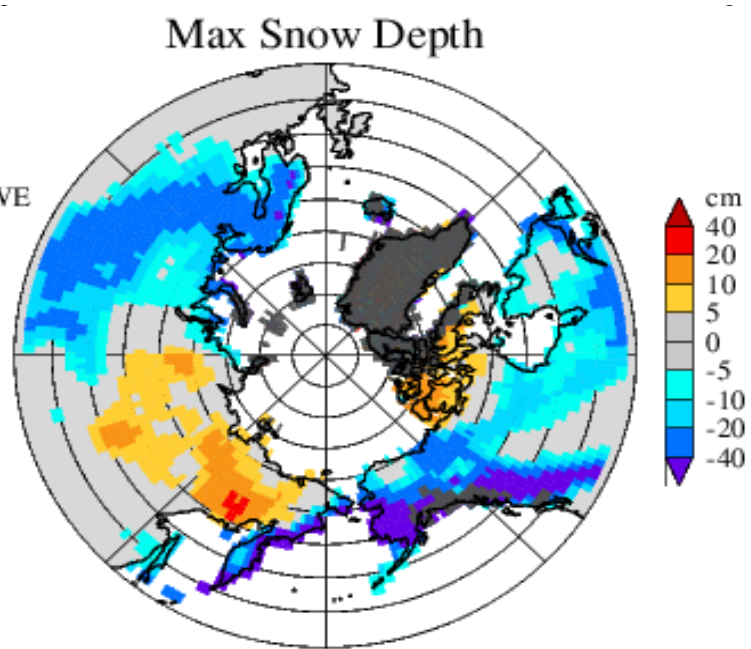
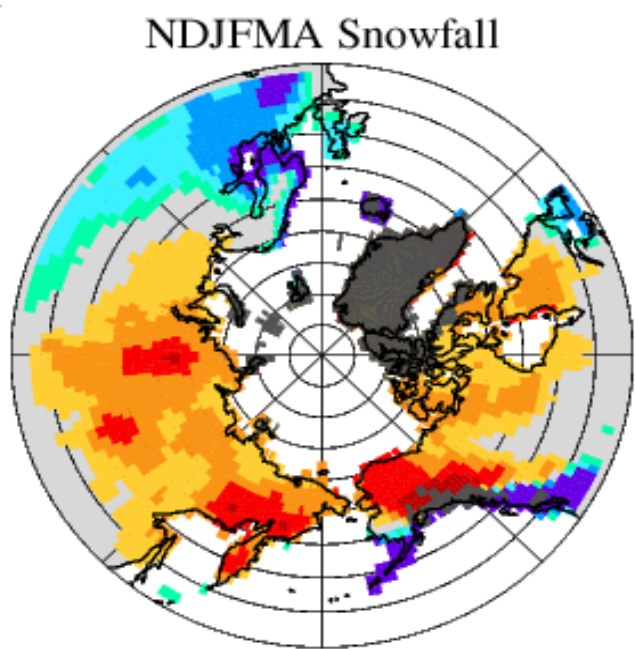
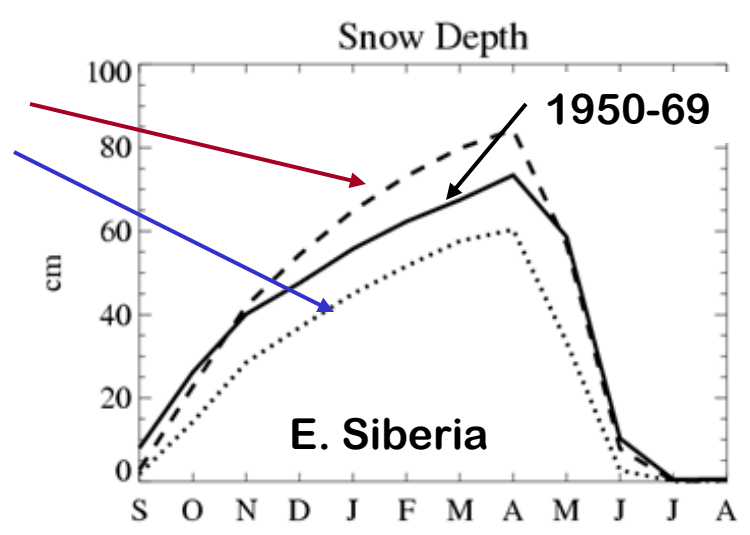
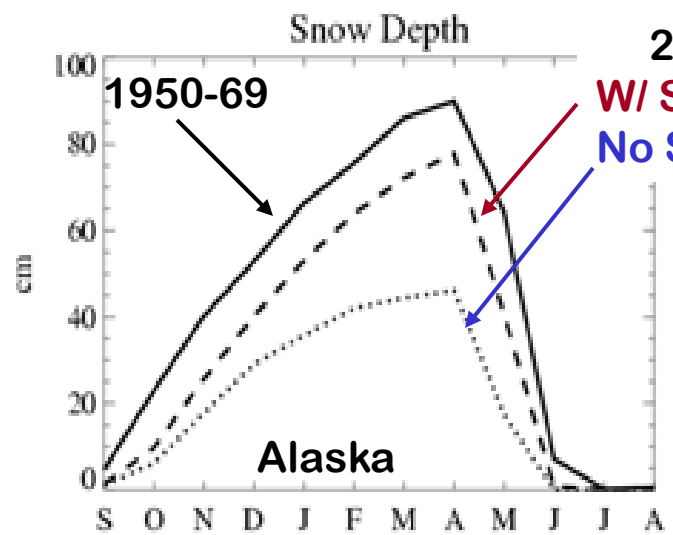
Max Snow Depth

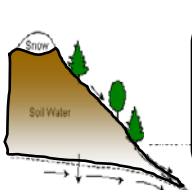


→ deeper OR shallower snowpack



CLM offline controlled Snowfall experiment

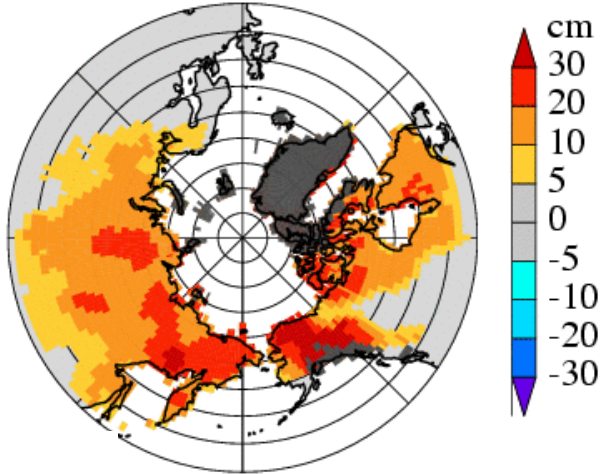




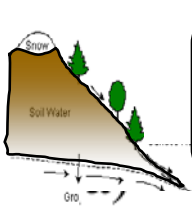
Effects of increasing snowfall

TRND_FALL – MID20C_FALL (2080-2099)

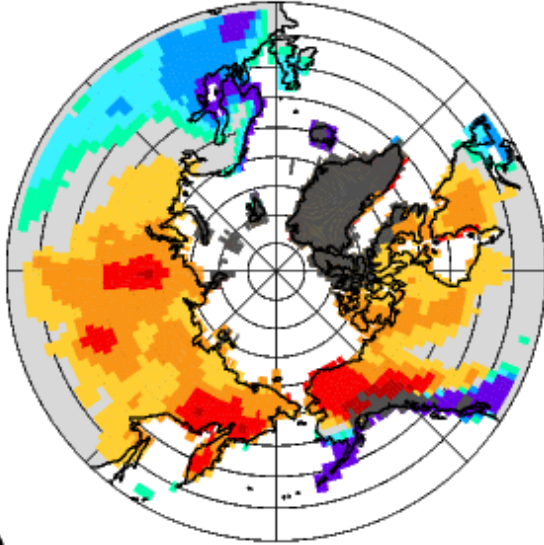
SNWDP_{max}



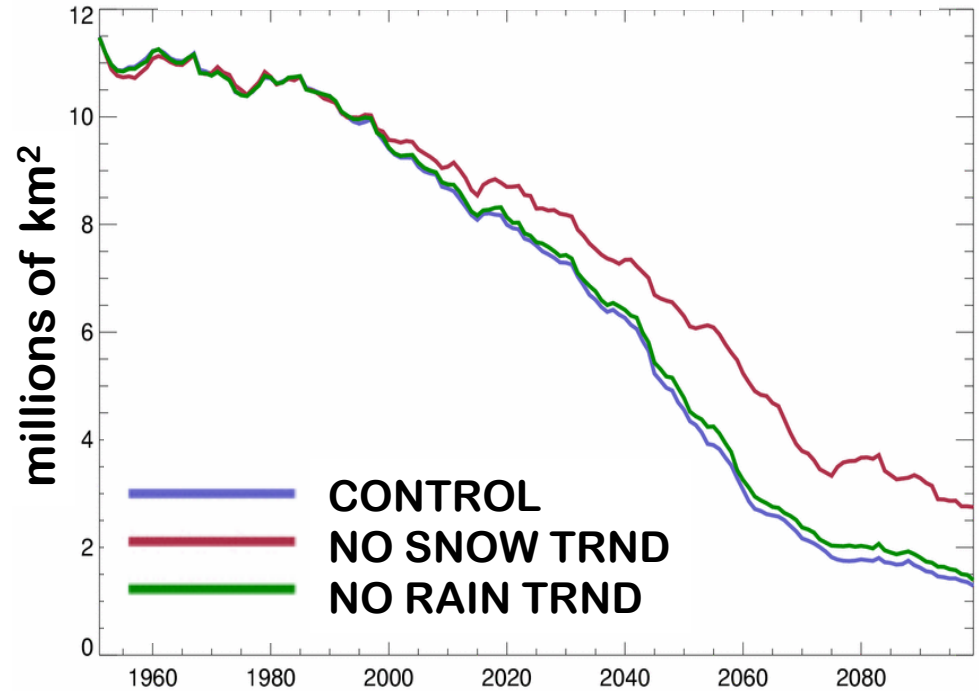
Offline controlled snowfall experiment



NDJFMA Snowfall



Integrated area with permafrost within 3m of surface

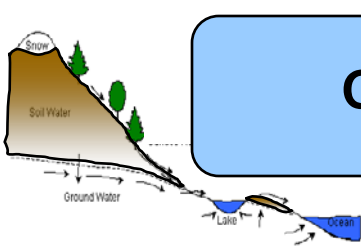


Increasing snowfall is effectively a soil warming agent

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

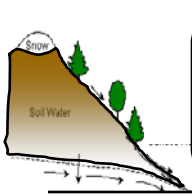
~16% contraction of near-surface permafrost

Controlled Snowfall and Prescribed Snow Experiments



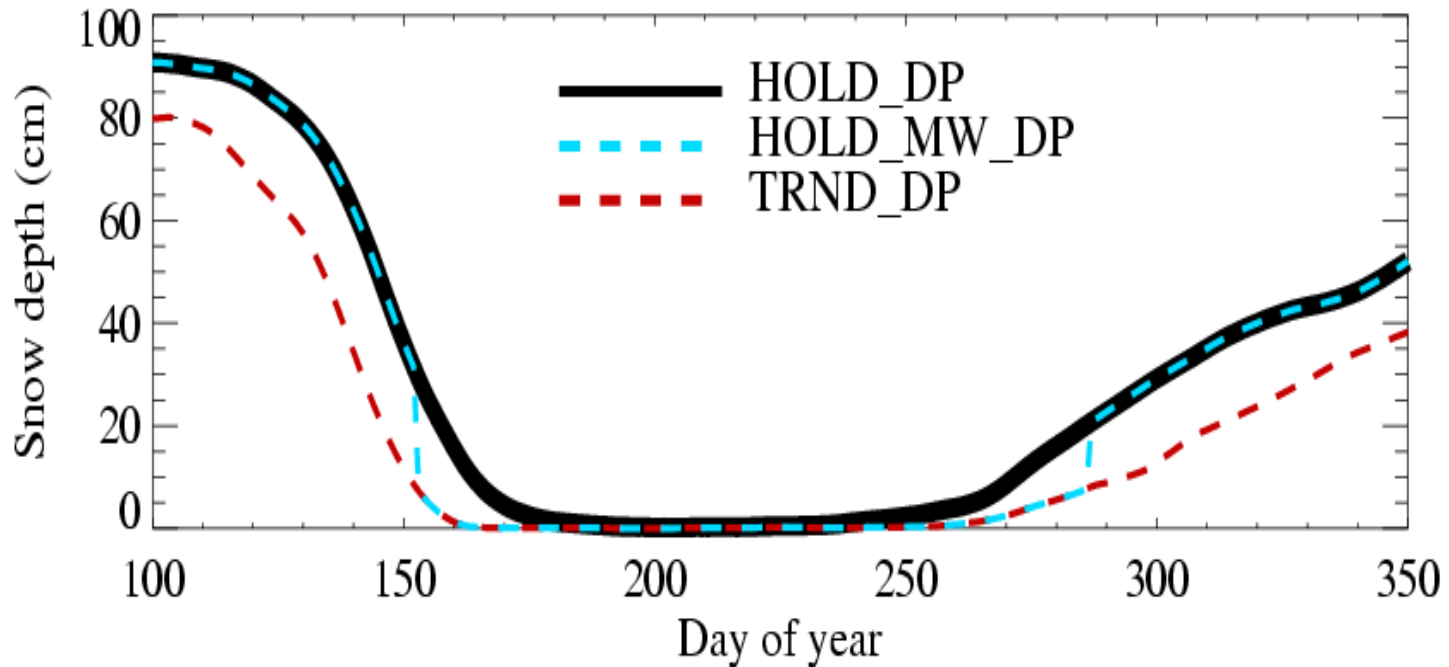
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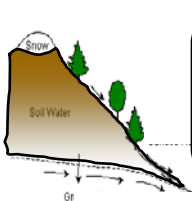


Prescribed snow experiments

-
- HOLD_DP** Hold SNWDP at 1950-69 levels
-
- HOLD_MW_DP** Hold mid-winter SNWDP at 1950-69 levels; shoulder season SNWDP transitions linearly from 1950-69 to 2080-2099 levels
-
- TRND_DP** SNWDP transitions linearly from 1950-69 to 2080-2099 levels
-



- HOLD_MW_DP** – **HOLD_DP** → impact of snow season length
- TRND_DP** – **HOLD_MW_DP** → impact of mid-winter SNWDP
- TRND_DP** – **HOLD_DP** → combined SNWDP and season length



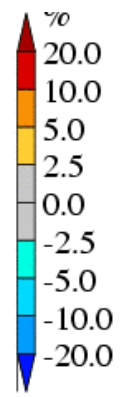
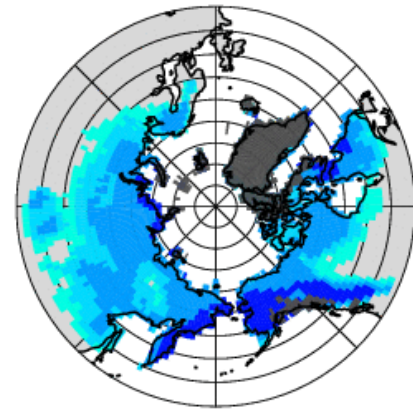
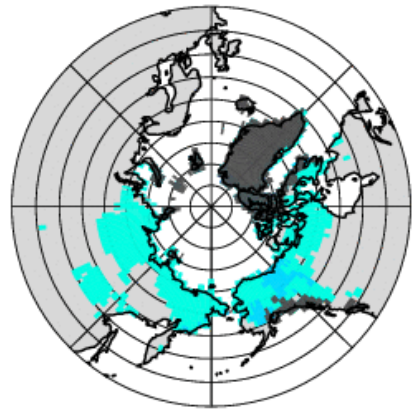
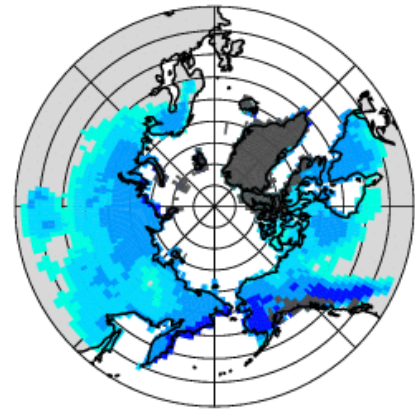
Prescribed snow experiments

HOLD_MW_DP – HOLD_DP

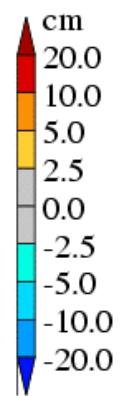
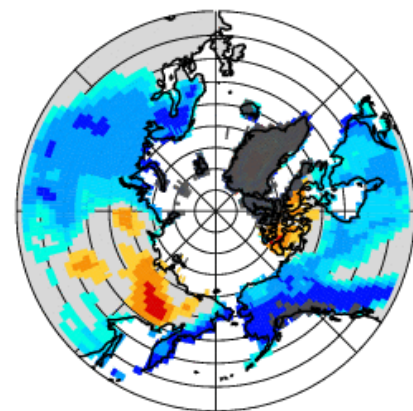
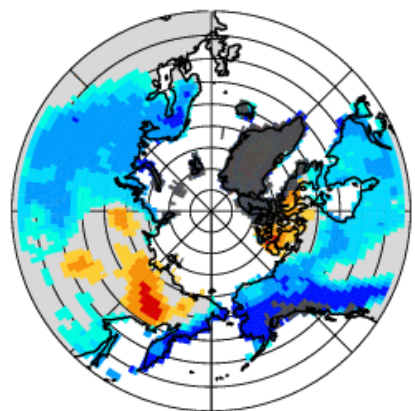
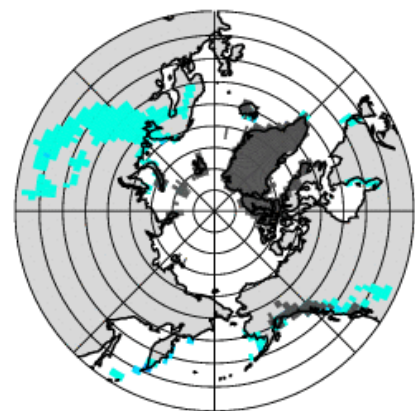
TRND_DP – HOLD_MW_DP

TRND_DP – HOLD_DP

**Snow
Cover
Fraction
(AMSO)**



**Snow
Depth
(NDJFMA)**



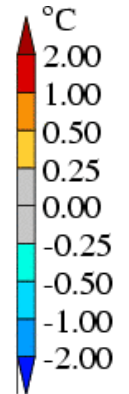
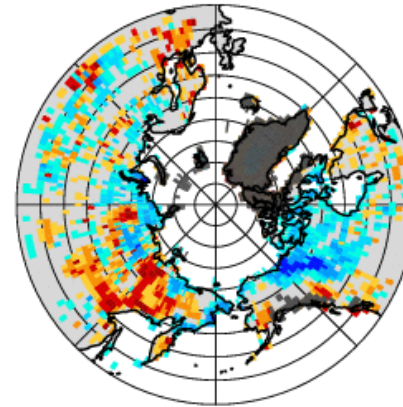
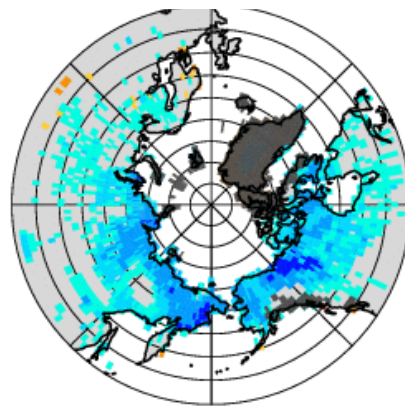
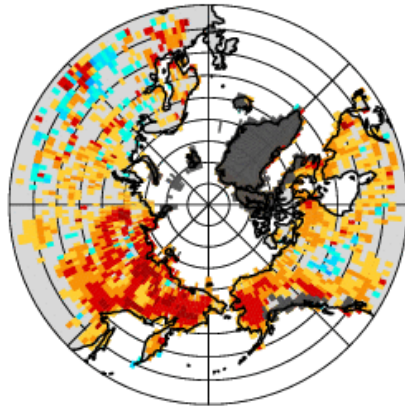
- HOLD_MW_DP – HOLD_DP** → impact of snow season length
- TRND_DP – HOLD_MW_DP** → impact of mid-winter SNWDP
- TRND_DP – HOLD_DP** → combined SNWDP and season length

HOLD_MW_DP - HOLD_DP

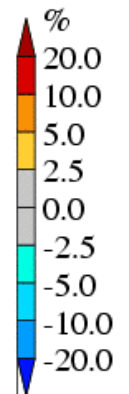
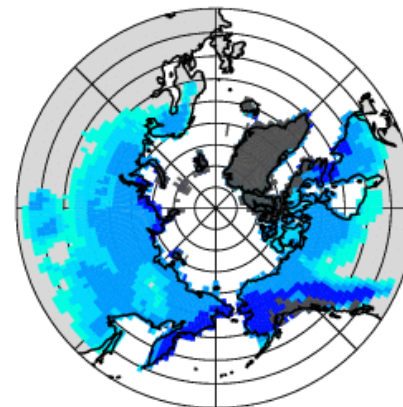
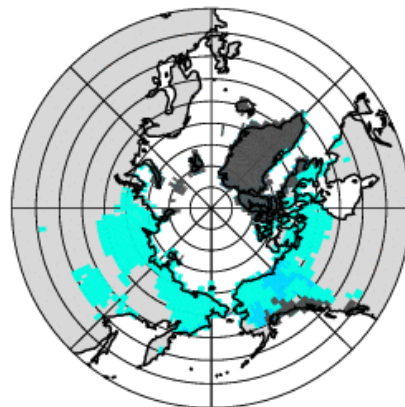
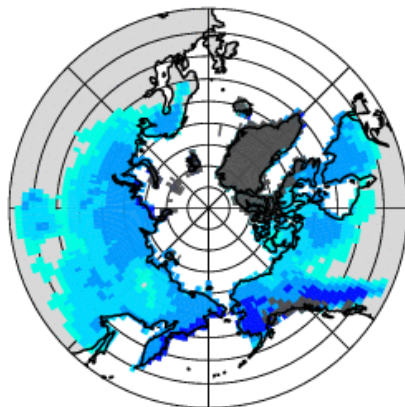
TRND_DP - HOLD_DP

TRND_DP - HOLD_DP

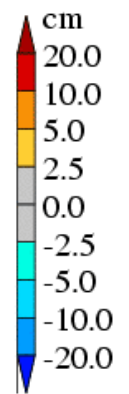
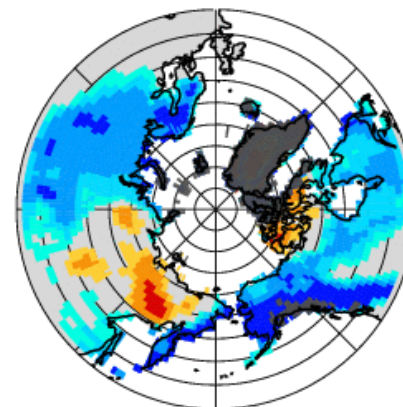
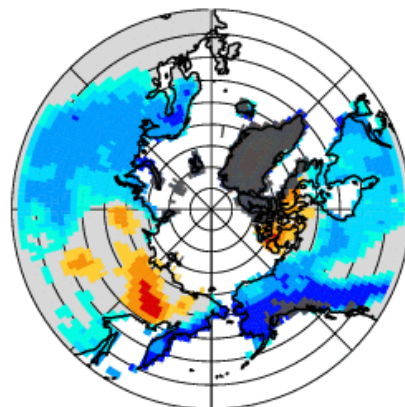
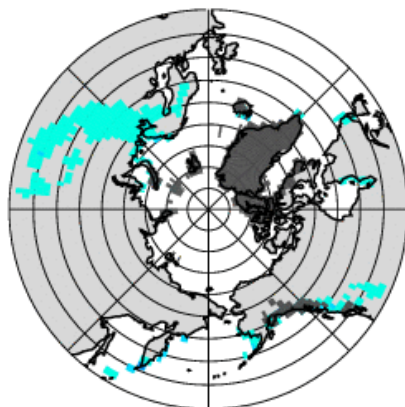
$T_{\text{soil, max}}$

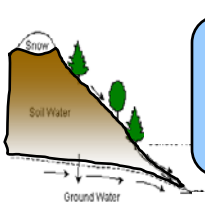


Snow
Cover
Fraction
(AMSO)



Snow
Depth
(NDJFMA)

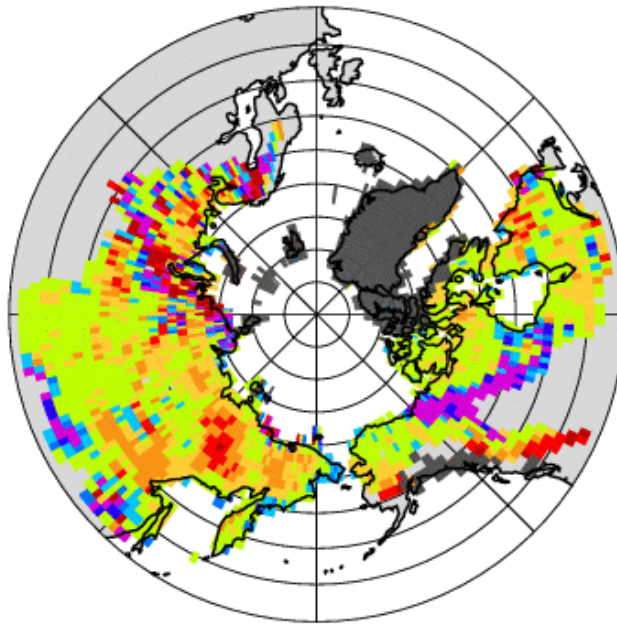




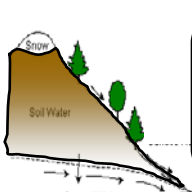
Relative influence of snow versus T_{air} change on T_{soil}

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

$\Delta = 1990-1999 - 1950-1959$



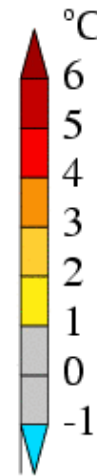
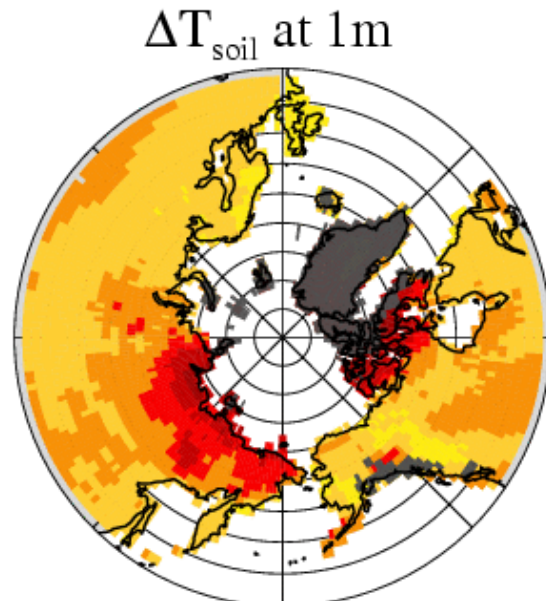
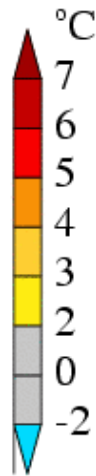
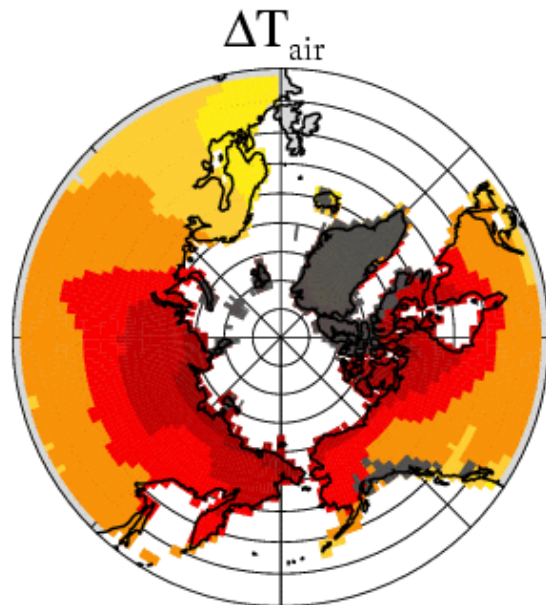
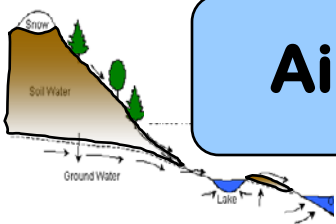
50% means that T_{soil} trend equally due to snow state and T_{air} trends



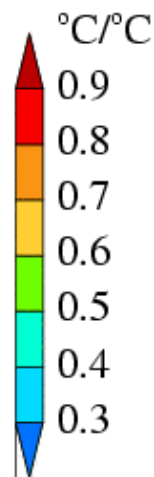
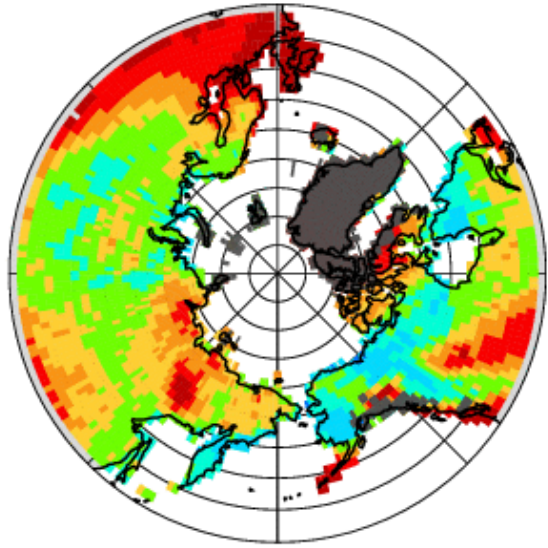
Summary (Lawrence and Slater, Clim. Dyn., 2009)

- The **deeper relative snowpack** (due to increasing snowfall) is effectively a **soil warming agent**, accounting for between 10% and 30% of total soil warming and ~16% of the simulated 21st century decline in near-surface permafrost extent.
- A **shortening of the snow-season enhances soil warming** due to an extension of the spring/summer/autumn soil heating period.
- A **shallowing of the snowpack impedes soil warming** due to weaker winter insulation from cold atmospheric air.
- The generally opposing influence of Δ *Snow-season length* and Δ *Snow depth* on T_{soil} results in cases of **enhanced soil warming and relative soil cooling** due to projected snow state changes.
- Snow and T_{air} change exert roughly equivalent forcing on T_{soil} change over the last 50 yrs of 20th century; **the relative influence of snow change diminishes under the strong projected warming of 21st century.**

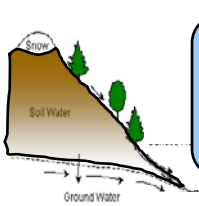
Air versus Soil temperature change (CCSM3, A1B)



$\Delta T_{\text{soil at 1m}} / \Delta T_{\text{air}}$

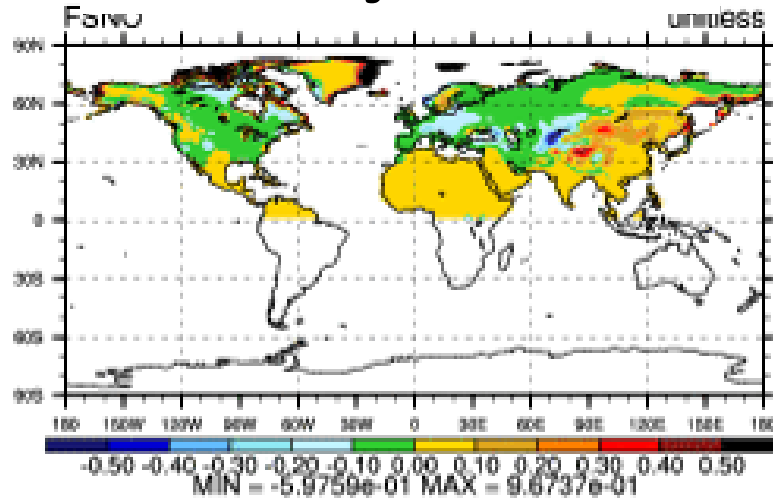


$\Delta = 2080-2099$
minus
 $1950-1969$

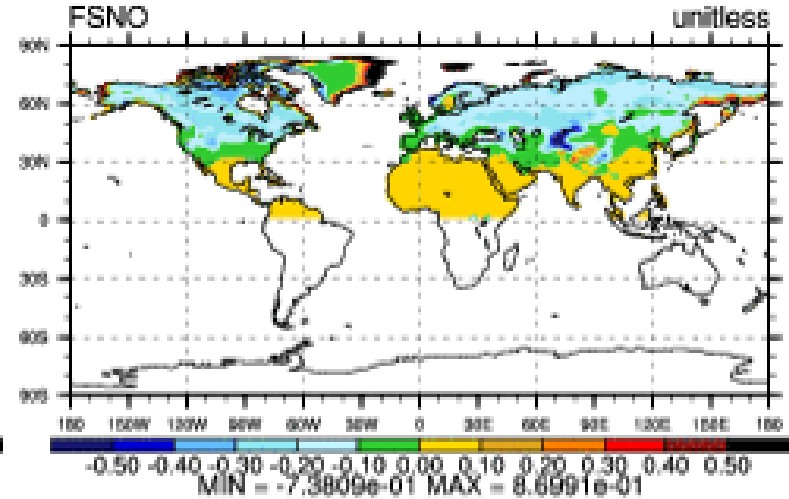


Results from Community Snow Project: Snow Cover Fraction (ANN)

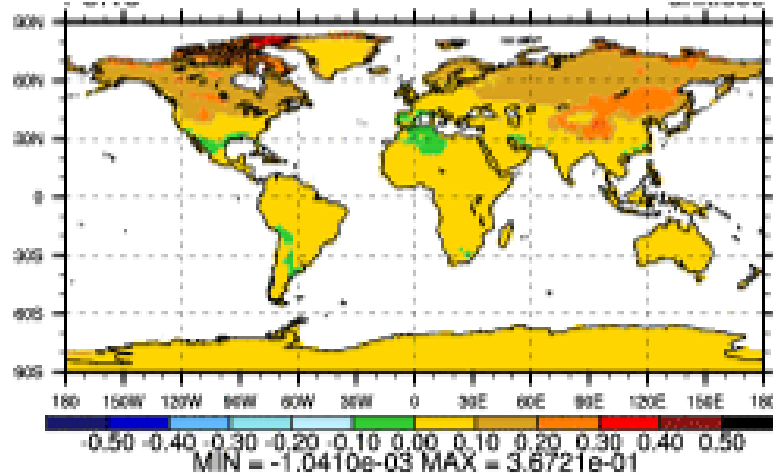
Community Snow - Obs



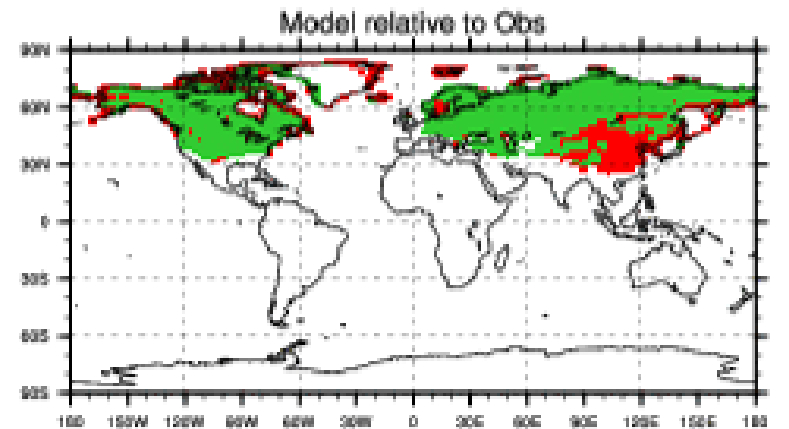
Control - Obs

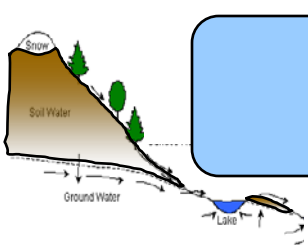


Community Snow - Control



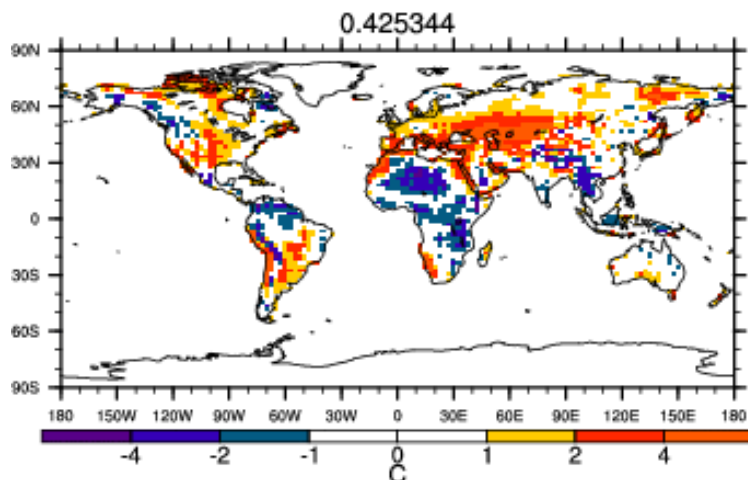
Case1+ (green) and Case2+ (red) relative to obs



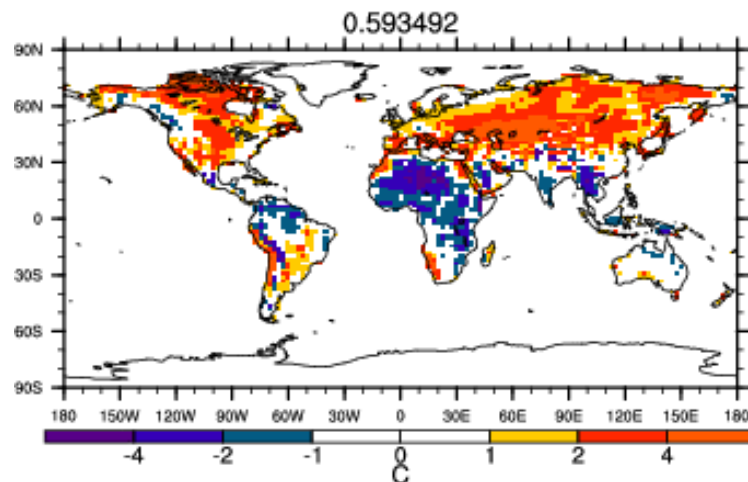


Results from Community Snow Project: Surface air temperature (ANN)

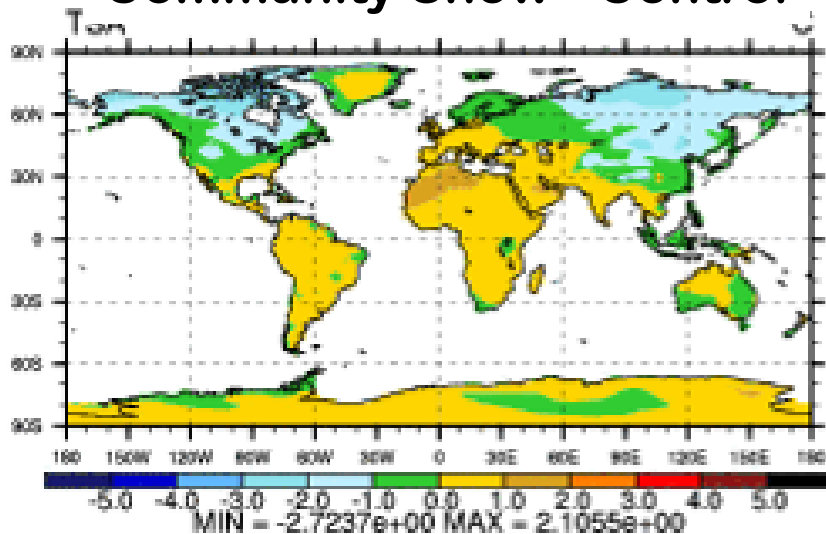
Community Snow - Obs



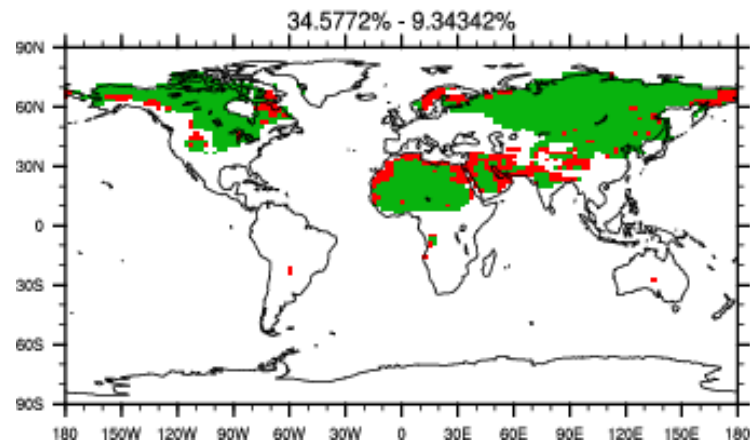
Control - Obs



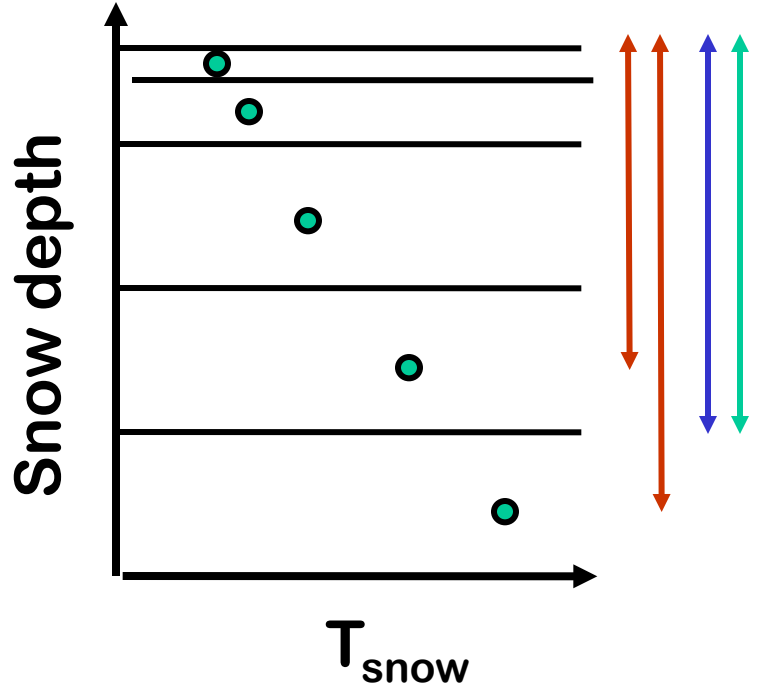
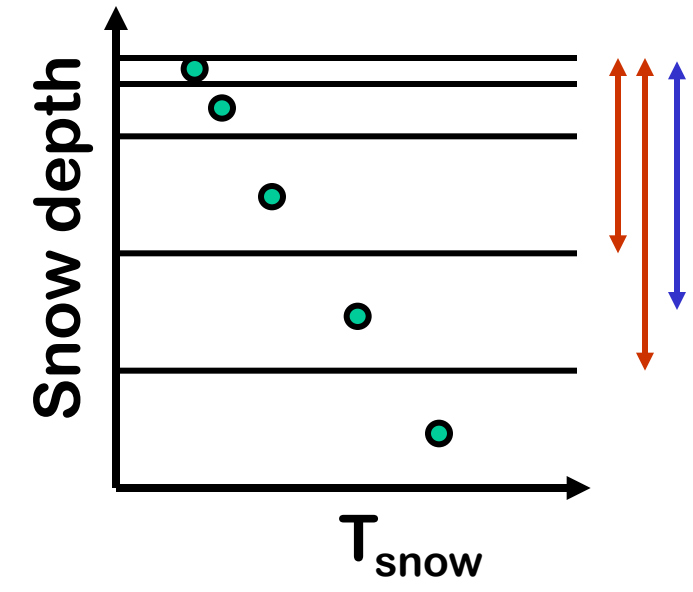
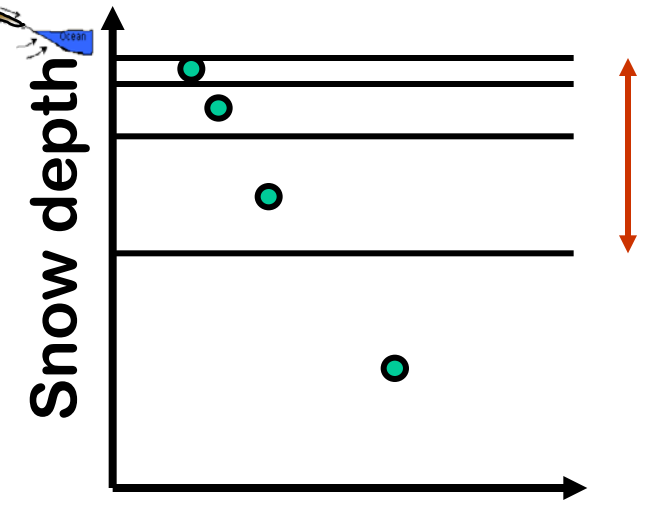
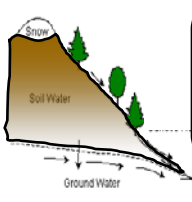
Community Snow - Control



Model relative to Obs

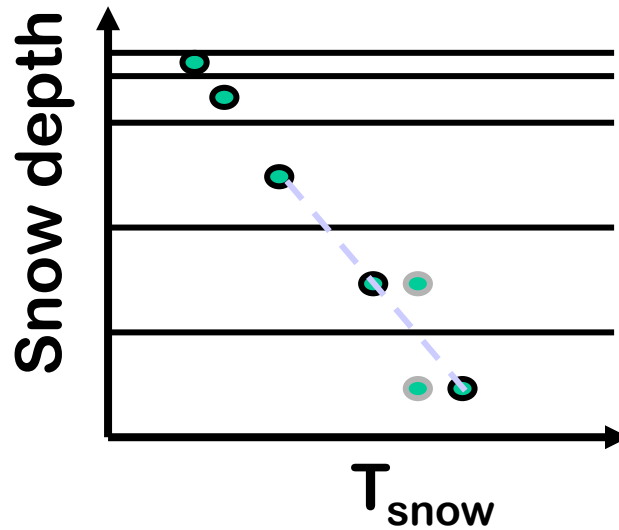
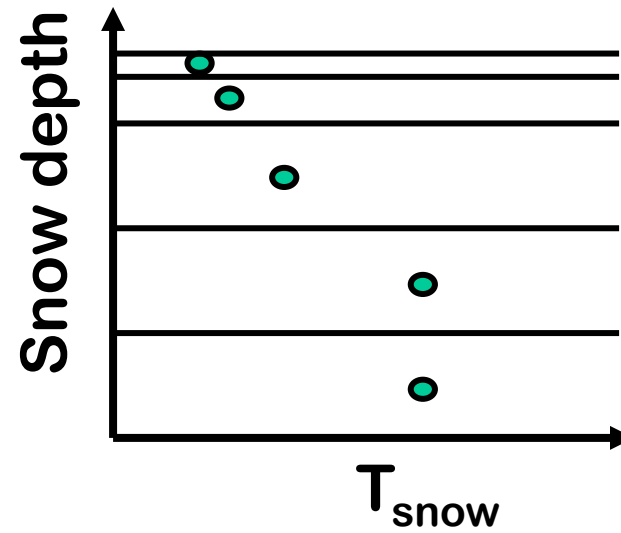
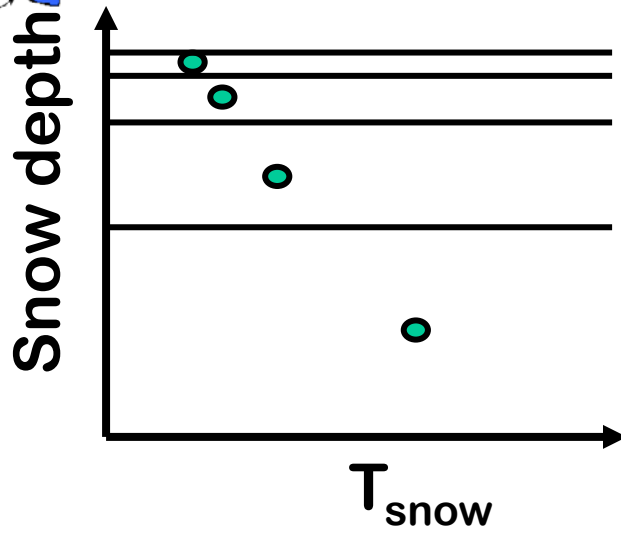
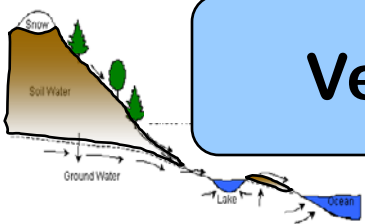


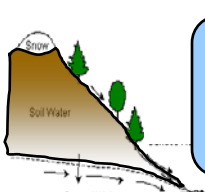
Snow compaction



Impact: 10-20% shallower snow pack

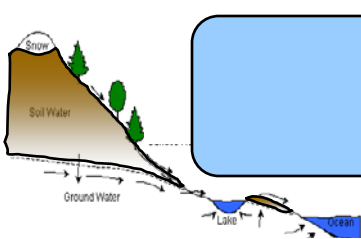
Vertical temperature profile after layer splitting





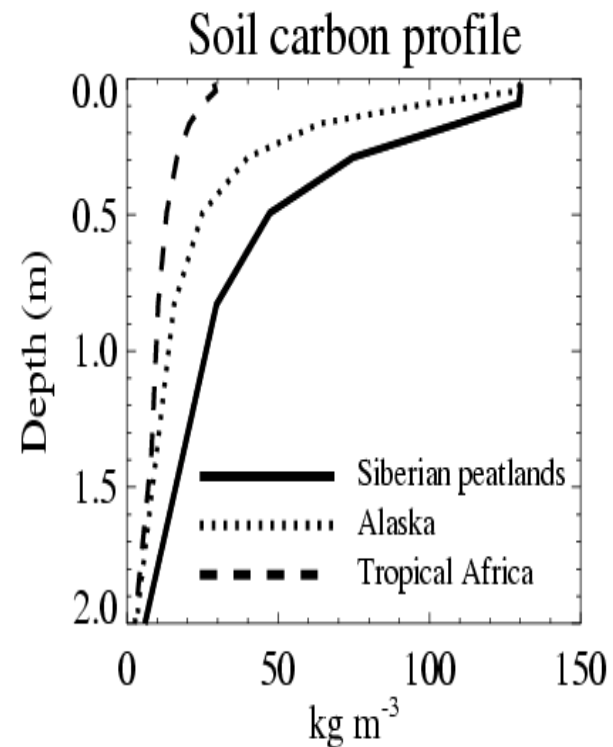
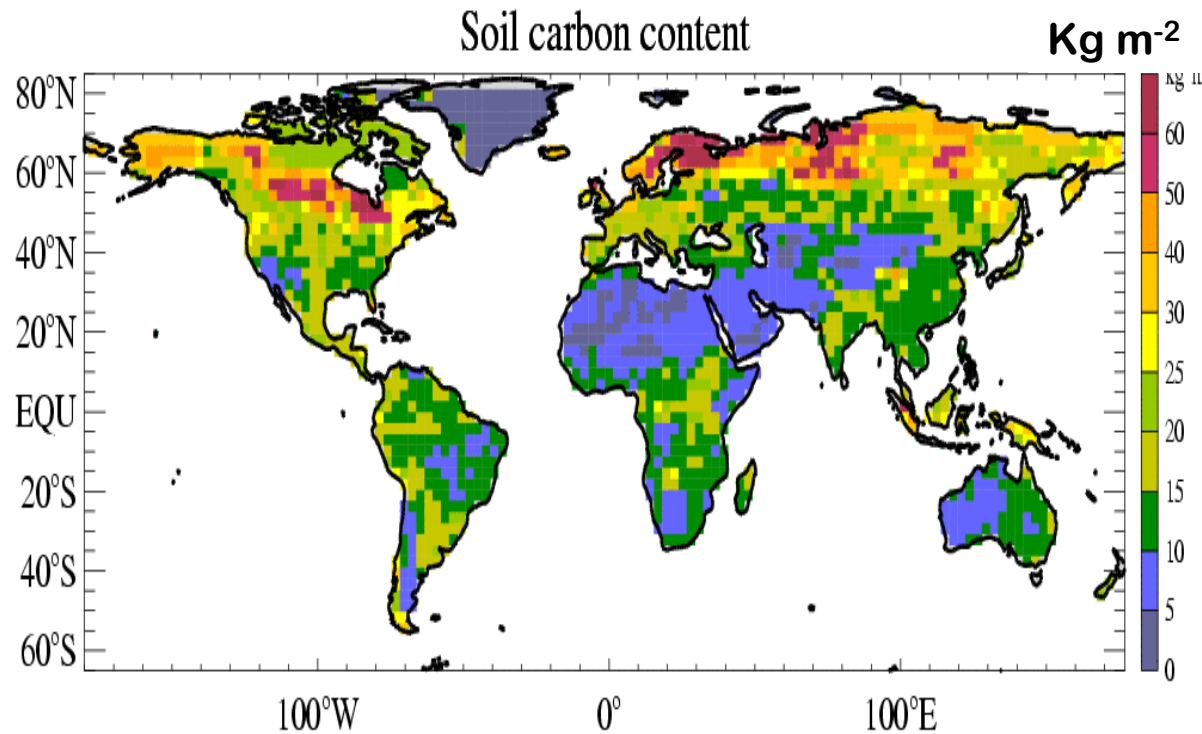
Arctic relevant LMWG changes for CLM4

- **Soil hydrology**
 - permit supercooled water (CLM3.5)
 - revision of infiltration into/through partially icy soil (CLM3.5)
- **Snow model**
 - snow cover fraction
 - snow burial fraction for short vegetation
 - adopt SNICAR (snow age, vertically resolved heating in snowpack, aerosol deposition)
 - snow compaction
- **Organic soil – physical properties (possibly integrate with CN)**
- **Deeper soil column (~50 m, 15 soil levels)**
- **Shrub vegetation type in CLM-CNDV (Dynamic vegetation)**
- **Dynamic wetlands (lakes)**
- **Methane emission model**



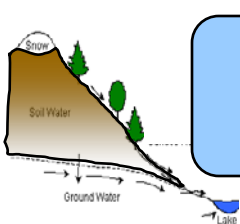
CLM soil carbon density dataset

Source data from Global Soil Data Task

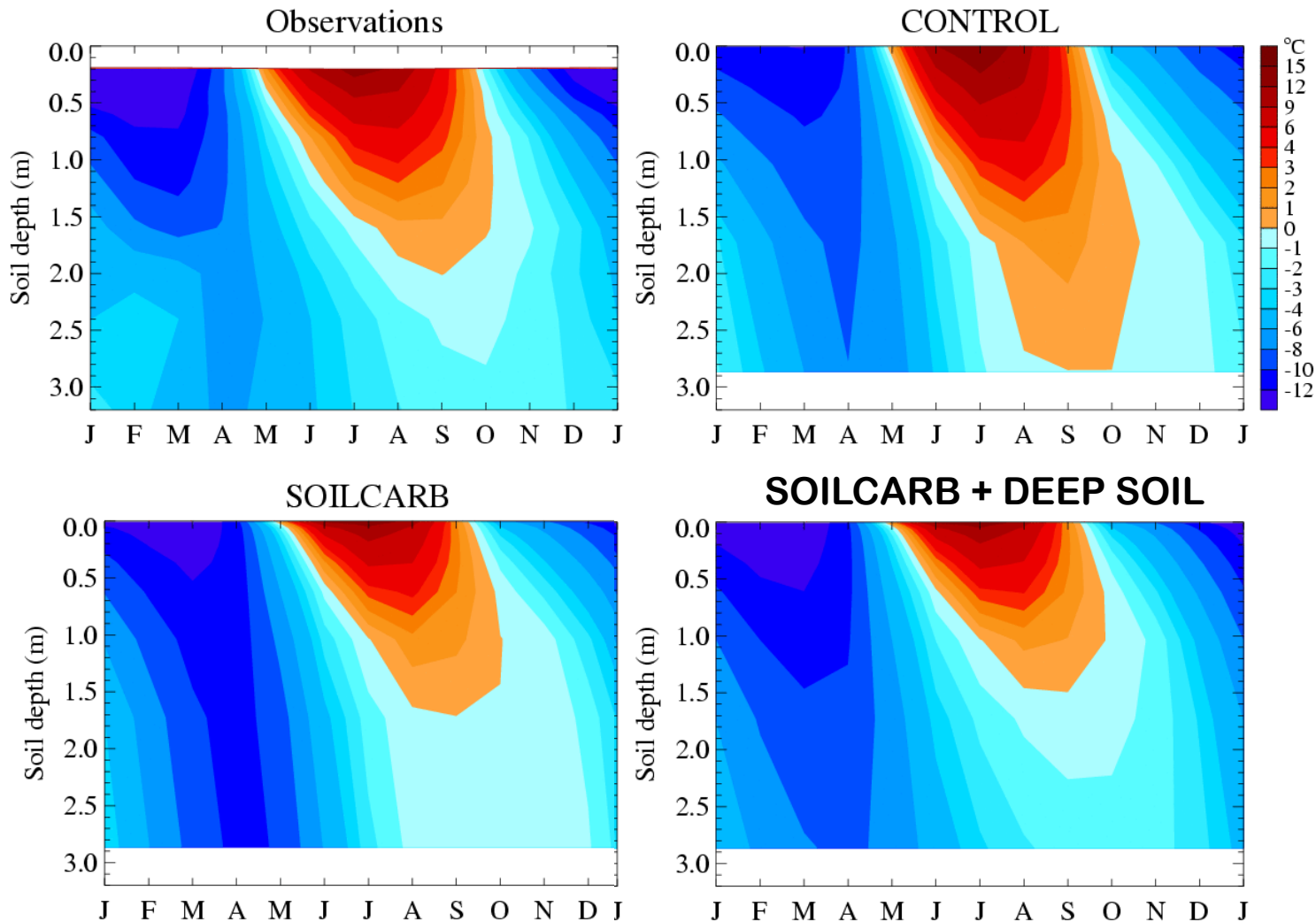


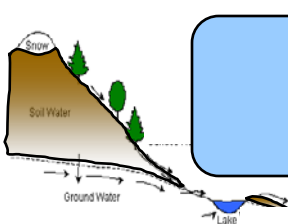
$f_{sc,i} = \rho_{sc,i} / \rho_{peat}$ fraction of layer i that is organic matter

$i = 1, 2, 3, \dots, 10$ soil layers



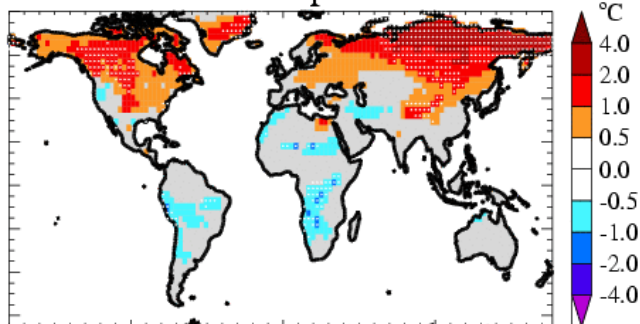
Annual cycle-depth soil temperature plots Siberia



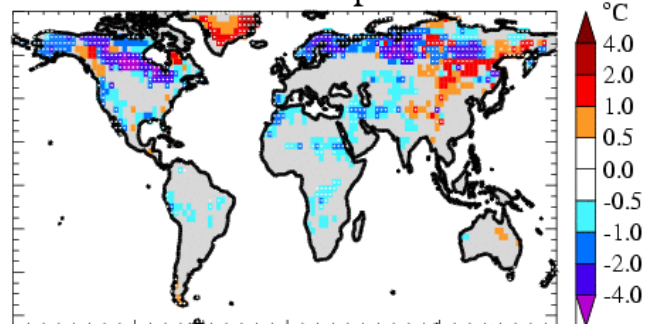


SOILCARB – CONTROL (JJA)

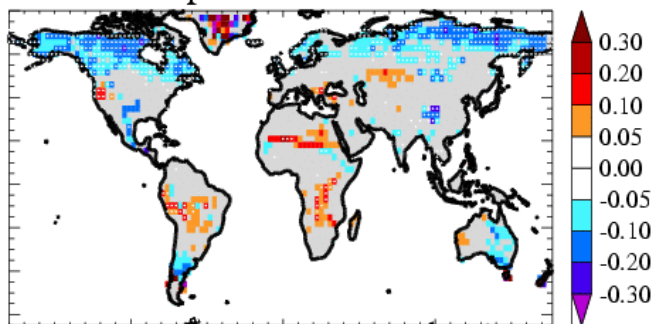
2m Air Temperature



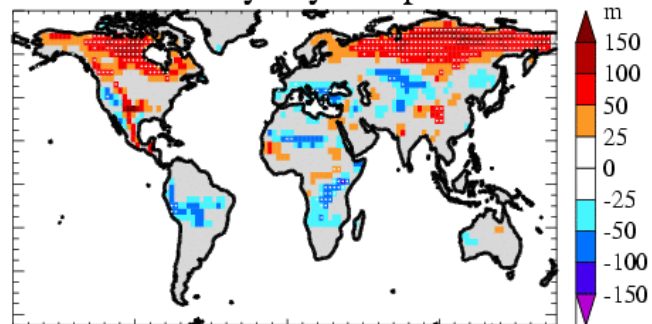
Column Soil Temperature



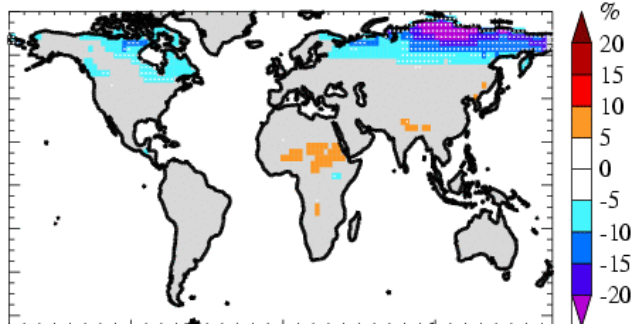
Evaporative Fraction



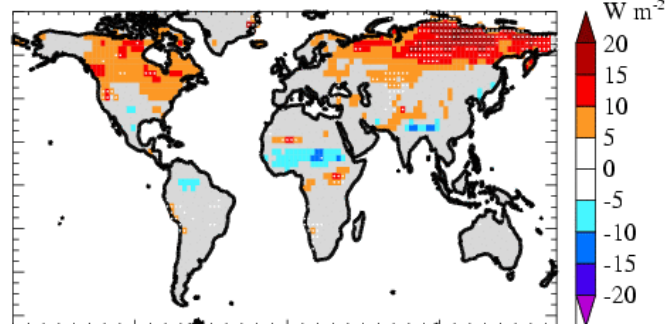
Boundary Layer Depth

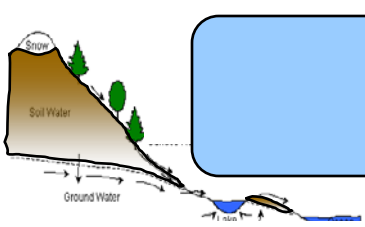


Low Cloud Fraction



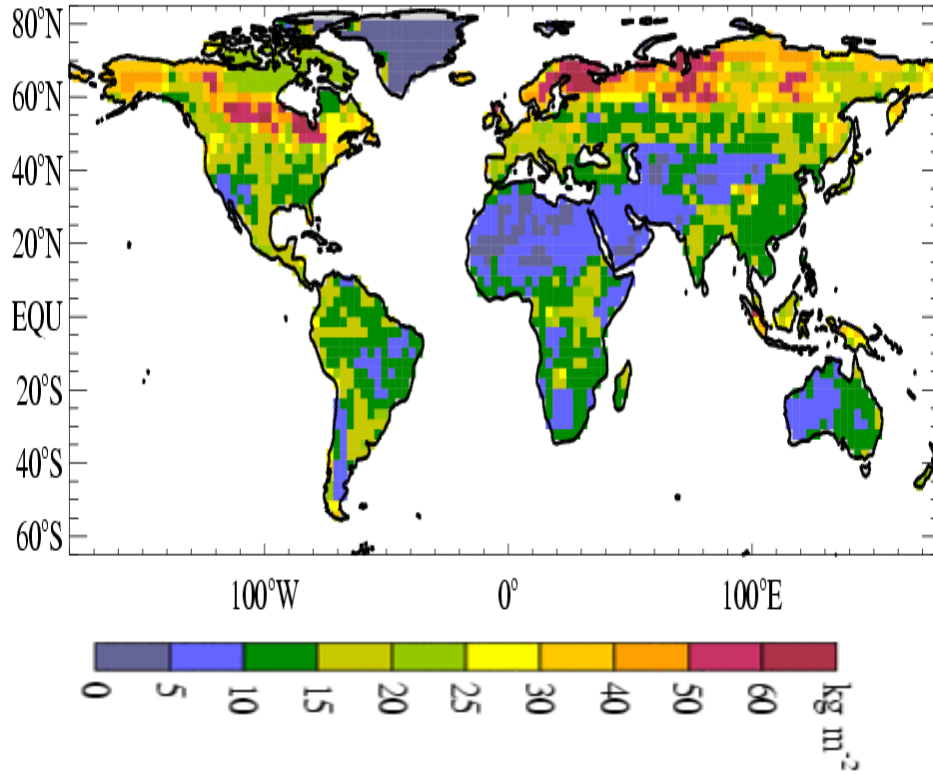
Net Surface Radiation



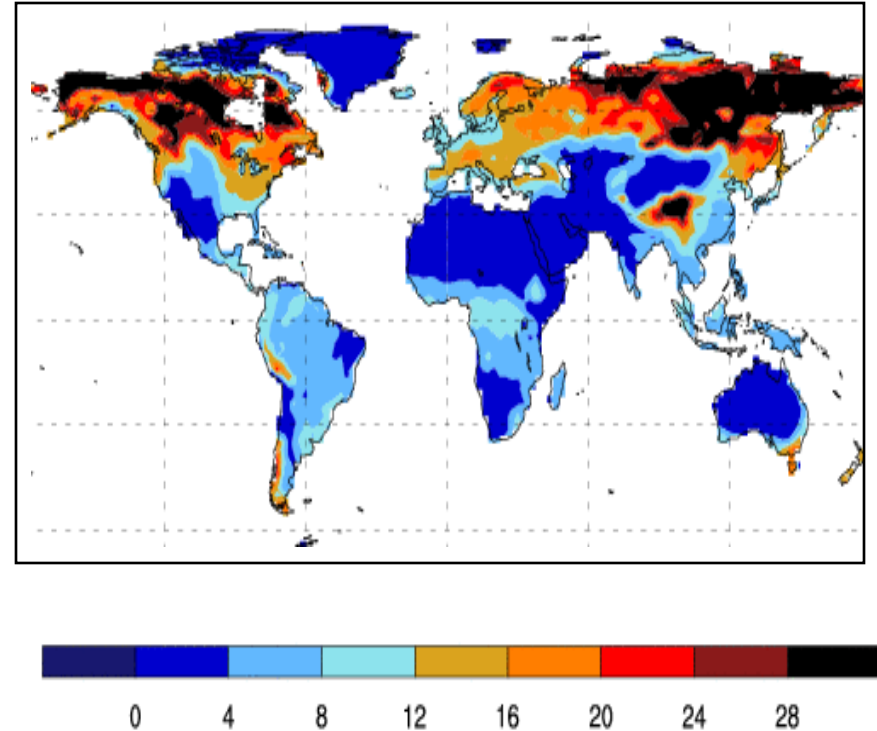


Soil carbon in CLM-CN

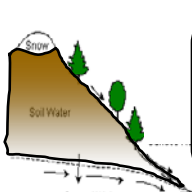
Soil carbon content: Obs



Soil carbon content: CLM-CN

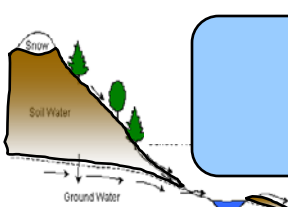


Goal is to couple CLM-CN soil carbon with organic soil parameterization



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Improvements to albedo (no snow cover)

Improvements due to new grass optical properties and revised assumptions about how to treat herbaceous understory in Plant Function Type framework

