On using an alternative snow thermal conductivity scheme in CTSM

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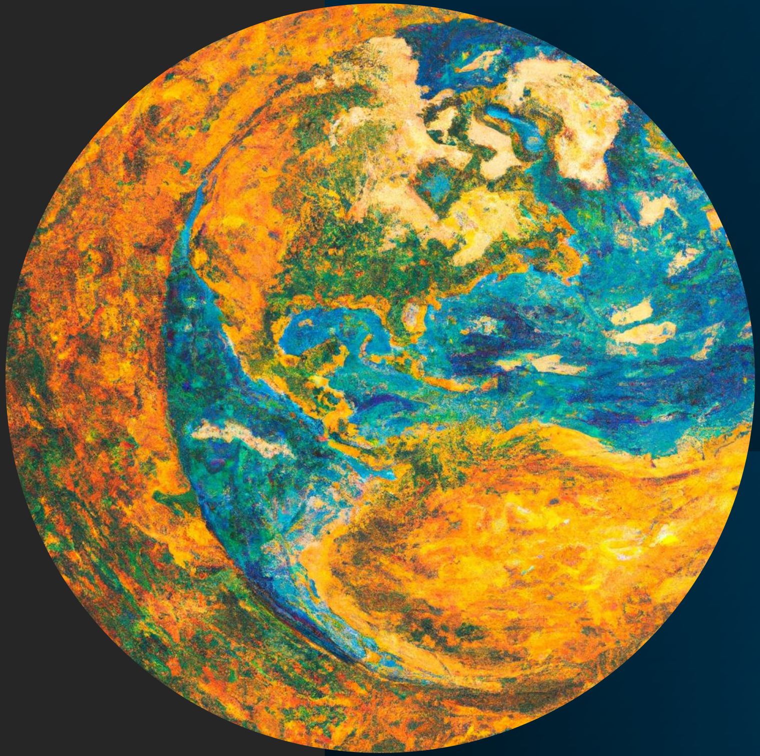


a Van Gogh painting of a globe over the Arctic

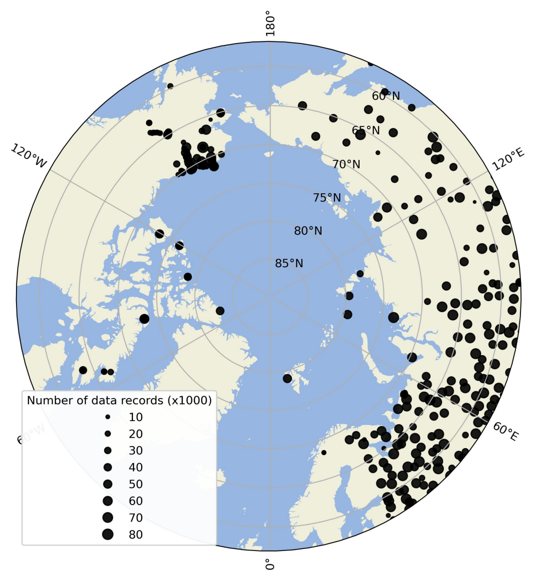
by Dall-E

Model setup

CTSM version 5.1.dev086	**Compset** 2000_DATM%GSWP3v1_CLM50% SP_SICE_SOCN_SROF_SGLC_SWAV	**Grid** Arctic domain above 57°N Icosahedral grid (240860 p) resolution = 12 km²
Atmospheric forcings ERA5 from1980-2021	**Spin-up** 30 years loop from 1980 to 1989	**Snow parameter** reset_snow = .true. h2osno_max = 800

Observation products

ESACCI products	In-situ observations
• From the ESA Climate Change Initiative • Remote sensing products • Domain resolution 1 km² • Soil temperature (at 1, 5 and 10m), and ALT • Year averages (1997-2019) • Period averaged	• From Russia, Canada, USA, Norway and Europe • 295 borehole stations • Soil temperature at 300 different depths • Monthly averages (1980-2021) • At least 20 measurements/month



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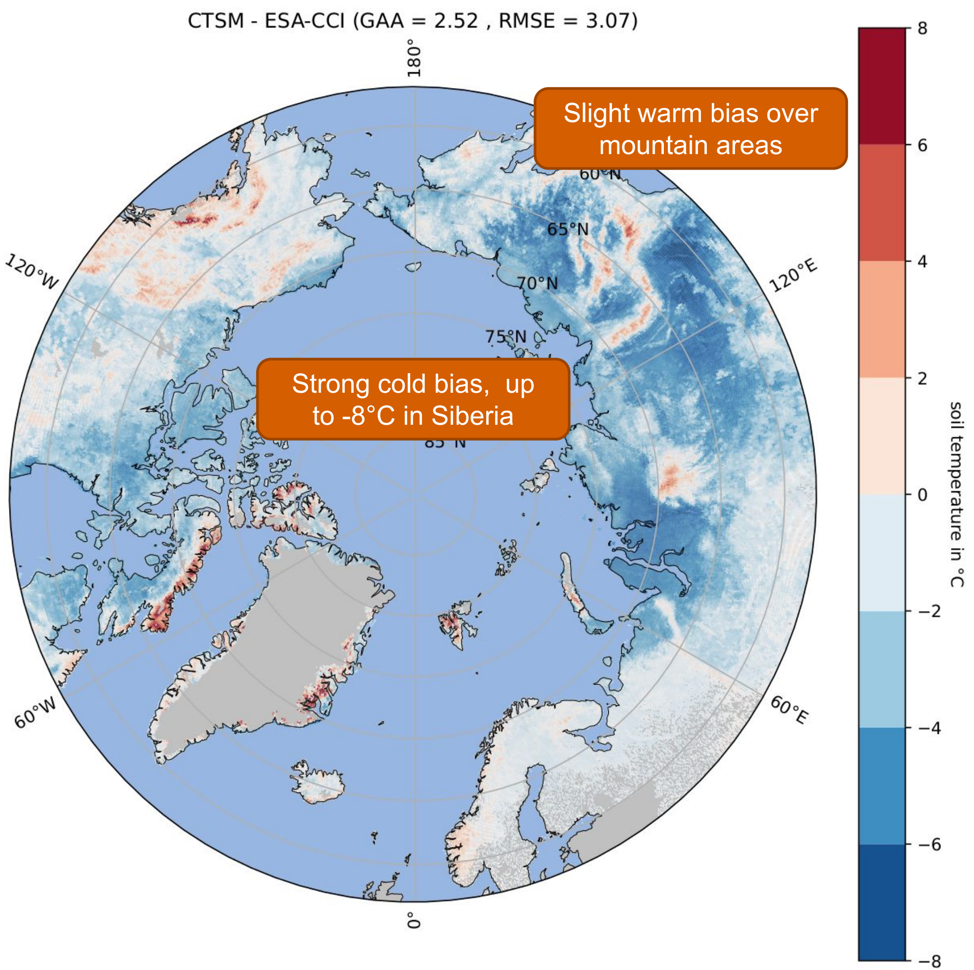
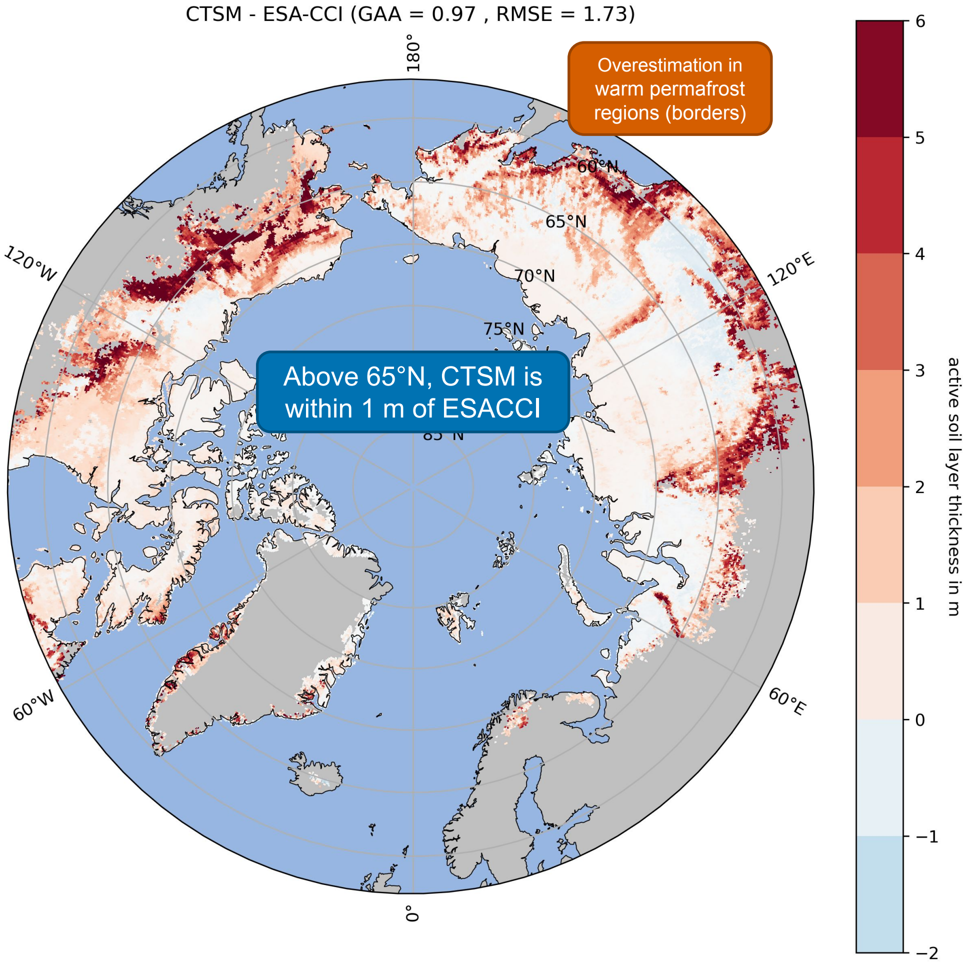
Soil temperature difference at -1 m CTSM – ESACCI
full period year averaged

- More significant over Siberia, less over Canada
- Same in -5 and -10 m (additional slides)



Active Layer Thickness difference CTSM – ESACCI

full period year averaged



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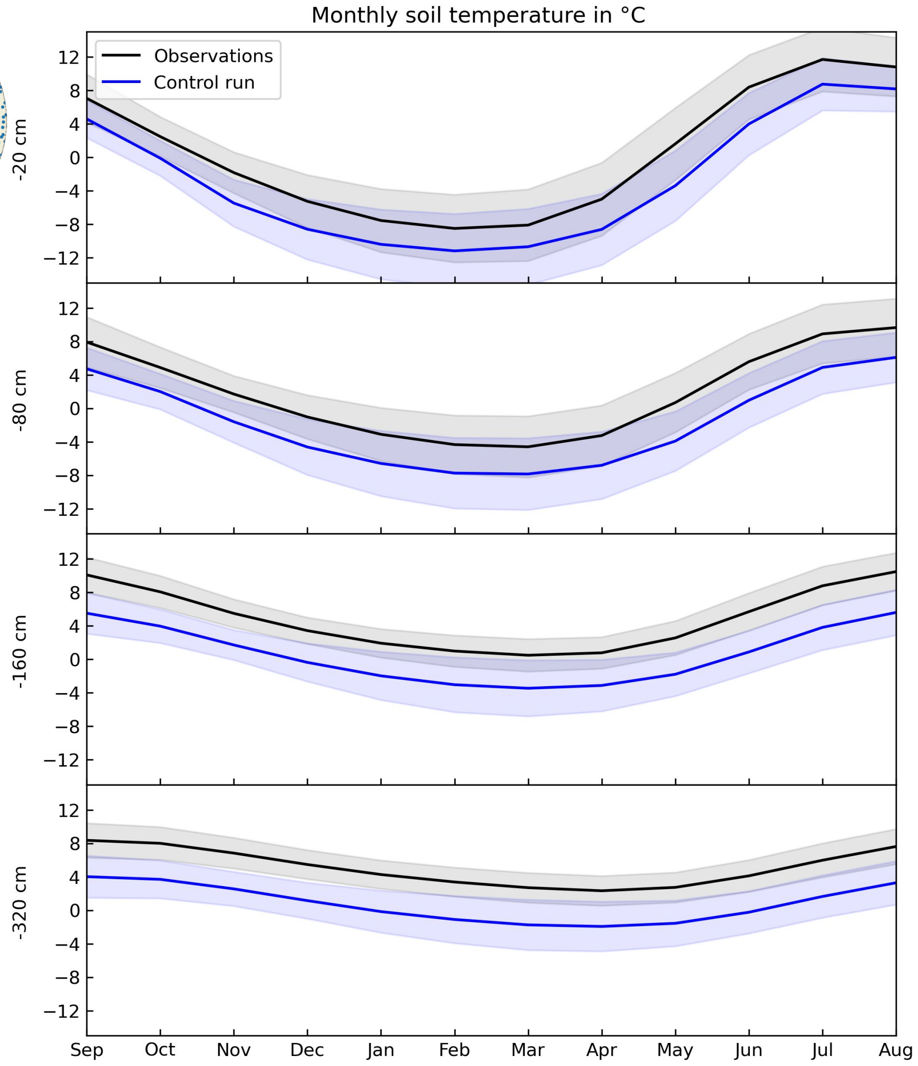
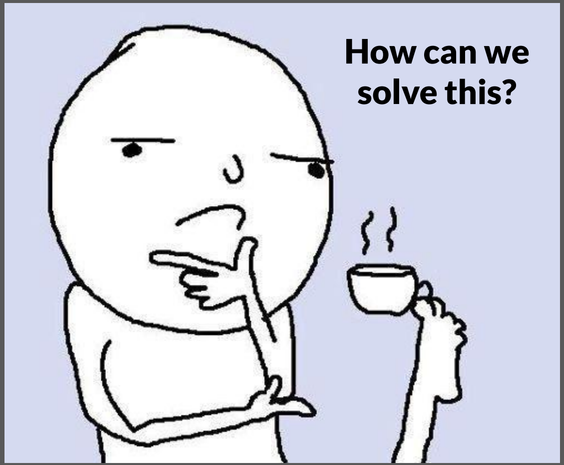
Soil temperature CTSM vs. 295 stations

Stations and period average

- Cold bias presents at every seasons and every depth





Noah-MP - Zhang et al. 2019

The largest bias of the Ts, T1, T2, and T3 occurred in the high latitudes. The underestimation of d_{snow} and the weak snow insulation dependency on d_{snow} partly induced the cold bias in the high latitudes.

ISBA (CNRM) - Barrere et al. 2017

than 1 °C until snowmelt. ES produces soil temperatures up to 8 °C colder in winter, because it highly underestimates the snow thermal insulance (Fig. 7).

JSBACH (UKESM) - Ekici et al. 2014

of the model output (Fig. 11). Figure 12 shows the spatial pattern of this cold bias. In general, permafrost temperature differs from −2 to −5 °C, except in northern Yakutia where the

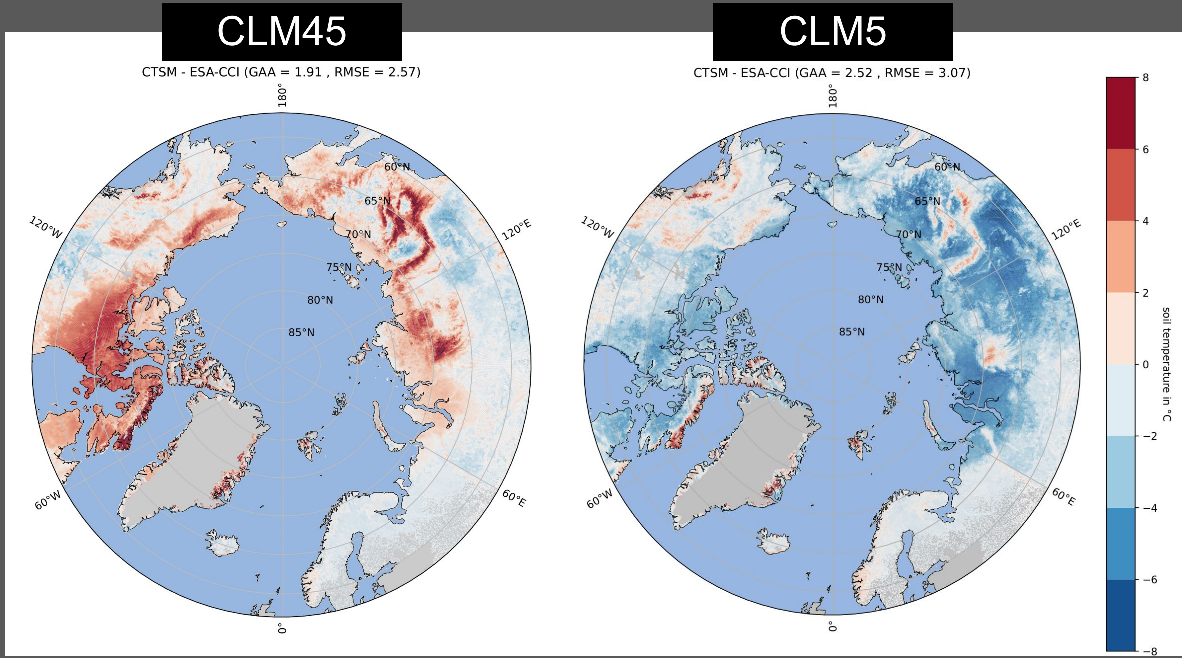
CLM5 (CESM) - Dutch et al. 2022

Simulated soil temperatures were considerably colder than observations (RMSE = 5.0 °C, bias = −2.2 °C), especially

JULES (MPI-ESM)- Dankers et al. 2011

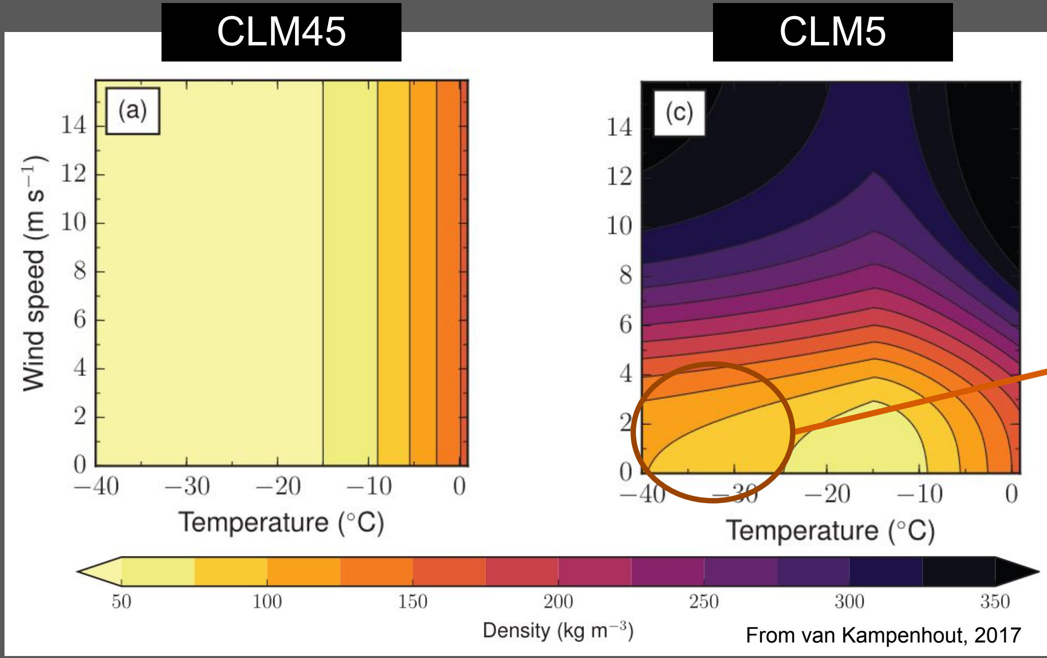
radically or only in isolated patches. Consistent with this we find a cold bias in the simulated soil temperatures, especially in winter. However, when compared with observations on

Soil temperature difference at -1 m
CTSM – ESACCI



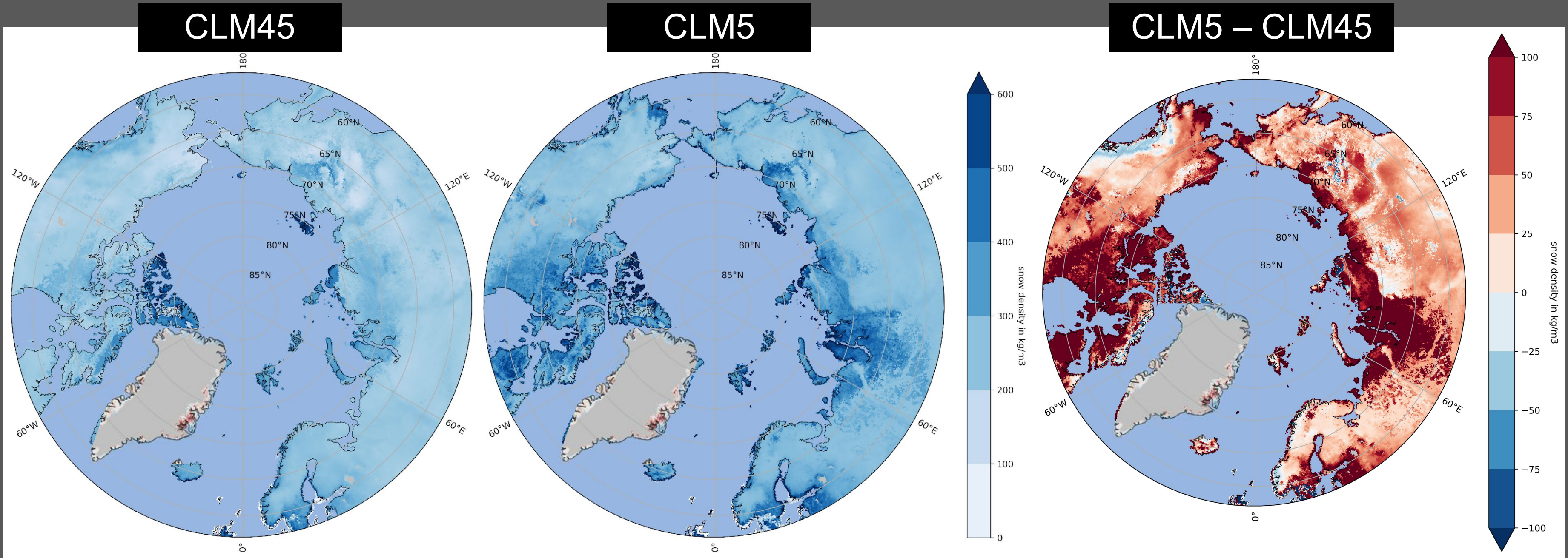
Why?

Fresh snow density as a function of temperature and wind speed



In non-glaciated polar areas, we should expect an increase in snow density

Snow density (column-averaged) difference in January 2000

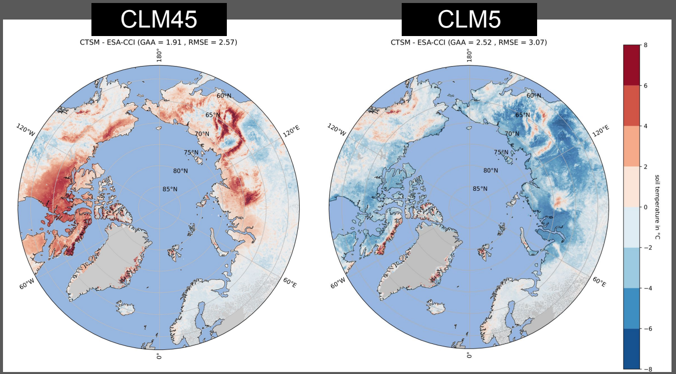


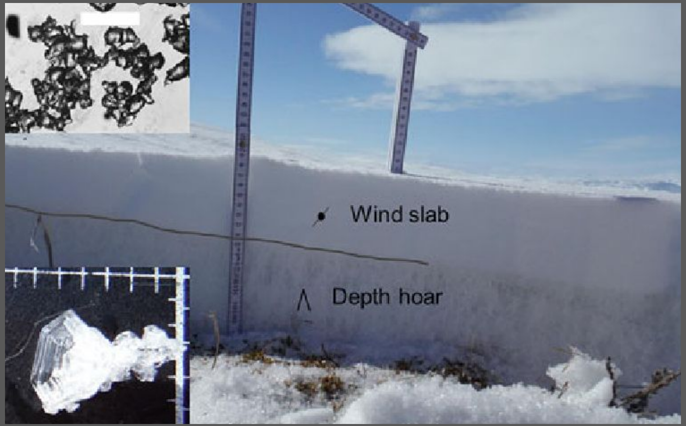
Our hypothesis

New function may have unintended consequences, making the overall snowpack too dense in the Arctic

Because CLM5 is not able to represent depth hoar (low density snow layers)
Before CLM45 low density compensates the fact that was no depth hoar.

As snow density increase:
- Increase the conductivity
- Increase heat dissipation
- Cools the soils in winter





Winter experiment

Change snow scheme used to compute snow thermal conductivity

Want to apply what Dutch et al. (2022) have done to the Arctic region

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The Cryosphere
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Impact of measured and simulated tundra snowpack properties on heat transfer

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Abstract. Snowpack microstructure controls the transfer of heat to, as well as the temperature of, the underlying soils. In situ measurements of snow and soil properties from four erties and the corresponding heat flux is important, as wintertime soil temperatures are an important control on subnivean soil respiration and hence impact Arctic winter carbon fluxes

Winter experiment

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Jordan (alpine snowpack)

by default in CTSM

$$K_{\text{eff}} = \lambda_{\text{air}} + \left(7.75 \times 10^{-5} \rho_{\text{sno}} + 1.105 \times 10^{-6} \rho_{\text{sno}}^2\right) \left(\lambda_{\text{ice}} - \lambda_{\text{air}}\right)$$

↓

Sturm (tundra snowpack)

$$K_{\text{eff}} = \begin{cases} 0.023 + 0.234 \cdot \rho_{sno}, & \text{if } \rho_{sno} < 0.156 \\ 0.138 - 1.01 \cdot \rho_{sno} + 3.233 \cdot \rho_{sno}^2, & \text{if } 0.156 \leq \rho_{sno} \leq 0.6 \end{cases}$$

Winter experiment

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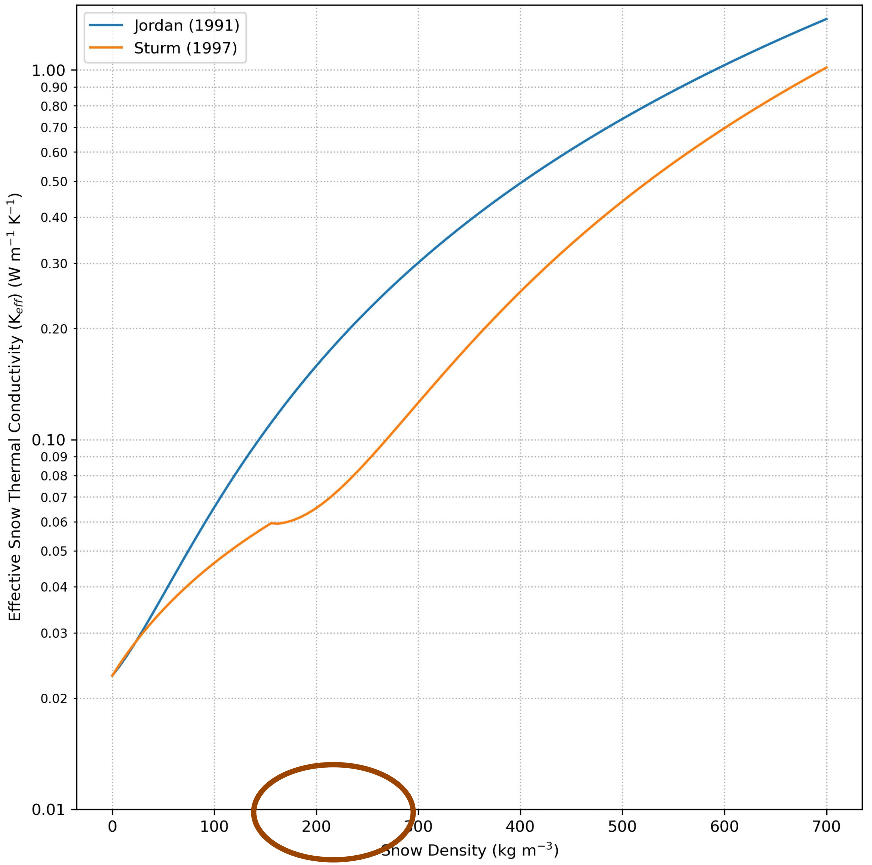
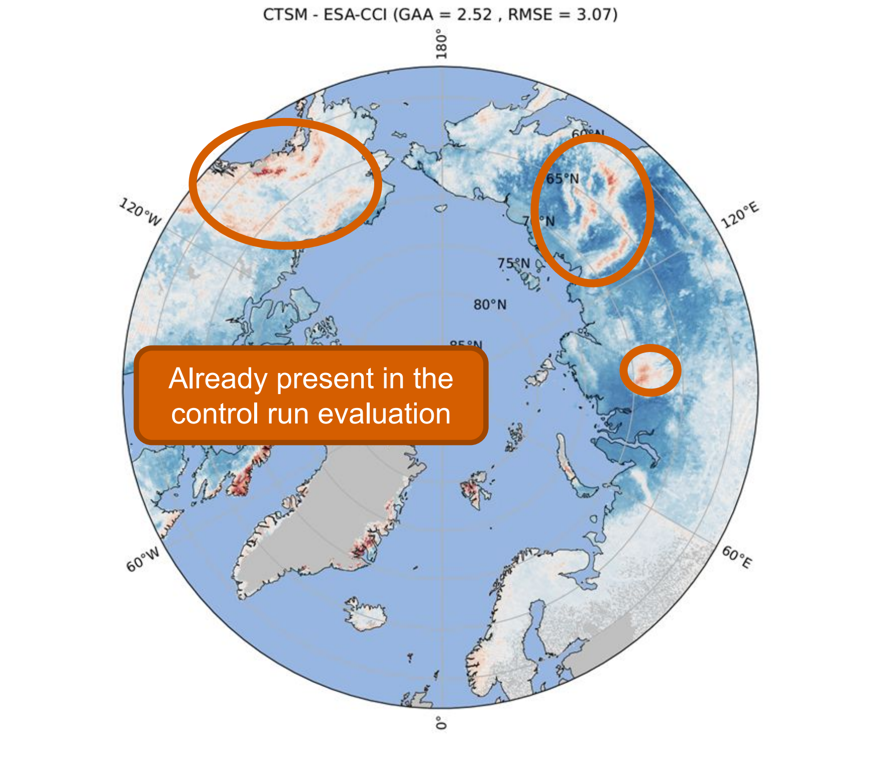
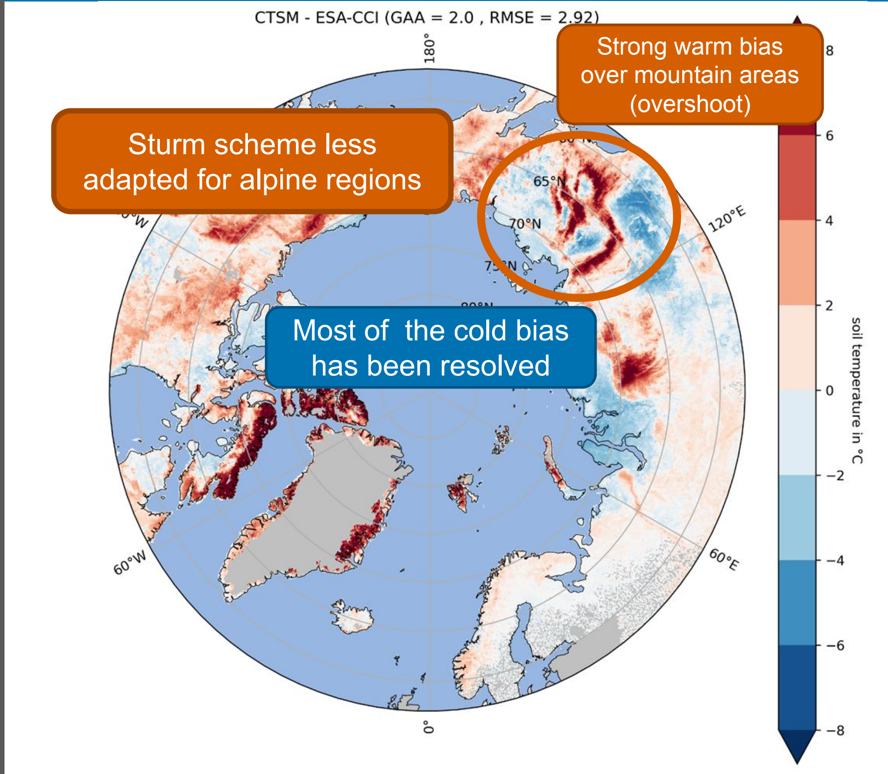


Soil temperature bias: Control – Sturm run vs ESA-CCI

Control run

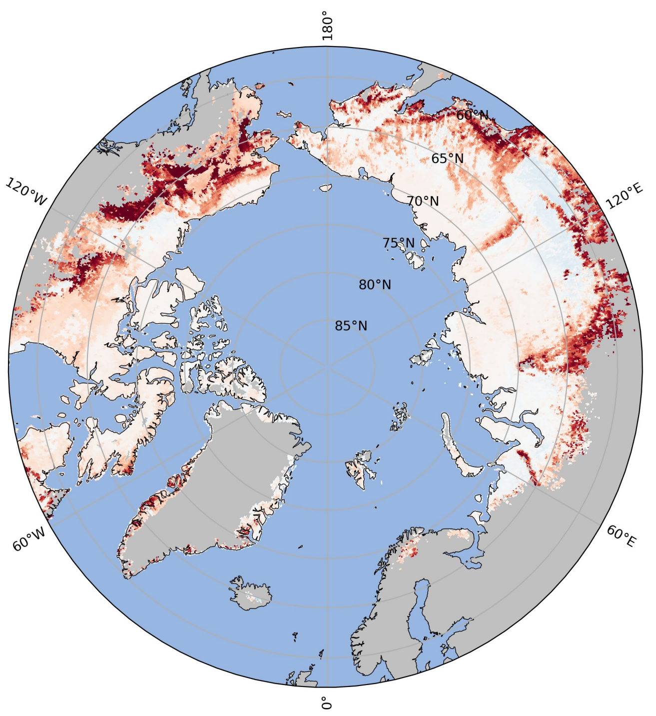


Sturm run

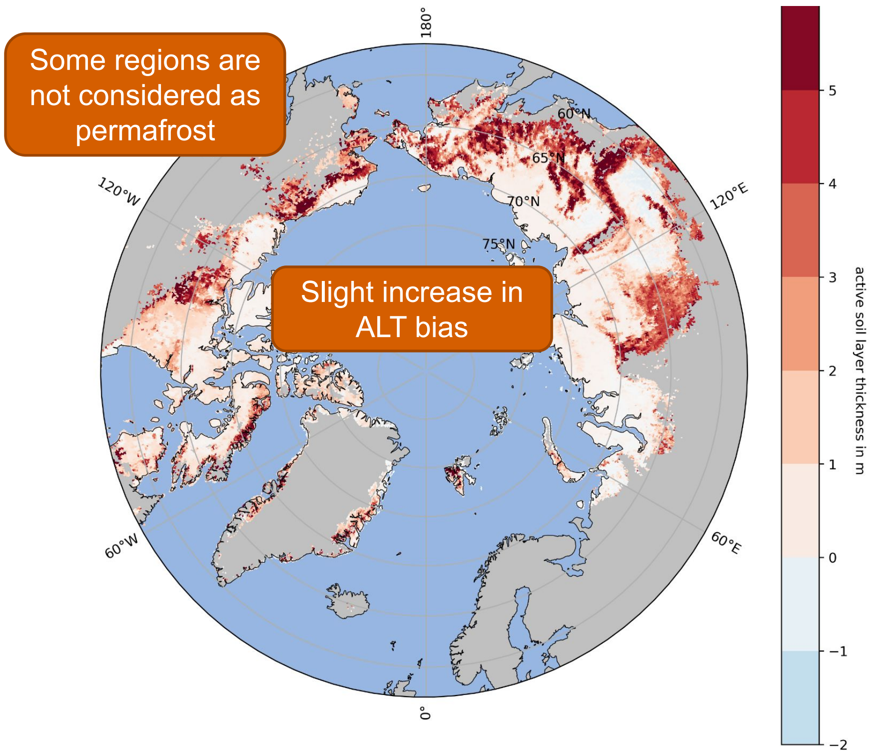


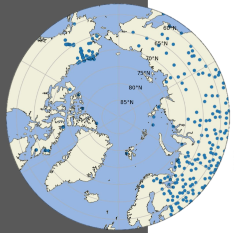
ALT difference: Control – Sturm run vs ESA-CCI

Control run



Sturm run

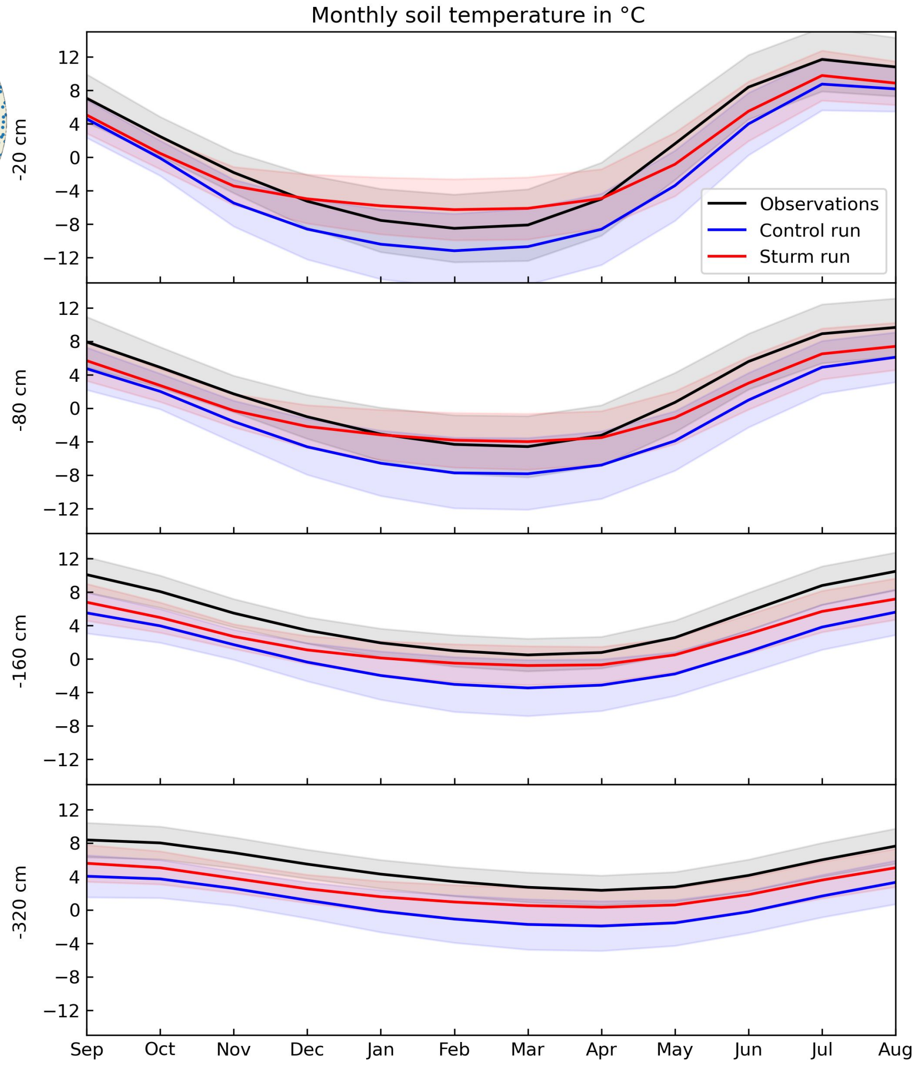




Soil temperature CTSM vs. 295 stations

Stations and period average

- Cold bias resolved mostly in winter and in upper layers
- Overshoot in winter top layers



Main conclusions

Contact me at
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Github:
https://github.com/AdrienDams

Thank you for staying until the end!

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CTSM evaluation

- Multiple observations datasets shows a strong cold temperature bias over the Arctic, especially over Siberia
- Cold bias presents at every seasons and every depth
- Active layer thickness is in strong agreement with ESACCI (slight overestimation over warm permafrost)

Sturm experiment

- Sturm scheme offsets the impact of increased density on soil temperatures
- Cold bias resolved mostly in winter and in upper layers
- Strong warm bias over mountain areas (overshoot)
- Slight ALT bias increase, but mostly over MA

Discussion

- Sturm is not adapted to all snowpacks. How can we include Sturm scheme in CLM5?
- Using different schemes on glacier/land?
- Using an altitude threshold for different schemes?