Impact of including the longwave scattering effect of clouds on the Arctic energy budget and climate in winter

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Abstract

Scattering of longwave radiation by cloud particles has been regarded unimportant and hence commonly neglected in global climate models. However, it has been demonstrated by recent studies that cloud longwave scattering plays an unignorable role in modulating the energy budget of the Earth System. Offline radiative transfer calculation showed that excluding cloud longwave scattering could overestimate outgoing longwave radiation and underestimate downward irradiance to the surface, and thus impose excessive cooling onto the atmosphere column. How this physical process interacts with other processes in the Arctic climate system, however, has not been thoroughly evaluated yet. Given the fact that the melting of ice and snow that cover the vast surface of the Arctic region is sensitive to energy budget, and such melting may trigger further feedback mechanisms, the neglection of cloud longwave scattering could bias the regional climate simulations to a considerable extent. We have incorporated cloud longwave scattering into the NCAR CESM and the DoE E3SM and this study analyzed the impact on the simulated polar climates in both earth system models. Cloud longwave scattering leads to a warmer surface air temperature in both models, especially over the wintertime. A detailed surface energy budget analysis is performed, for both the mean state and the temporal variability. Preliminary results suggest that the leading change is downward longwave flux and upward longwave flux, followed by the changes of turbulent heat flux. How the longwave scattering treatments can couple with cloud microphysics and precipitation physics to affect Arctic precipitation is further explored.

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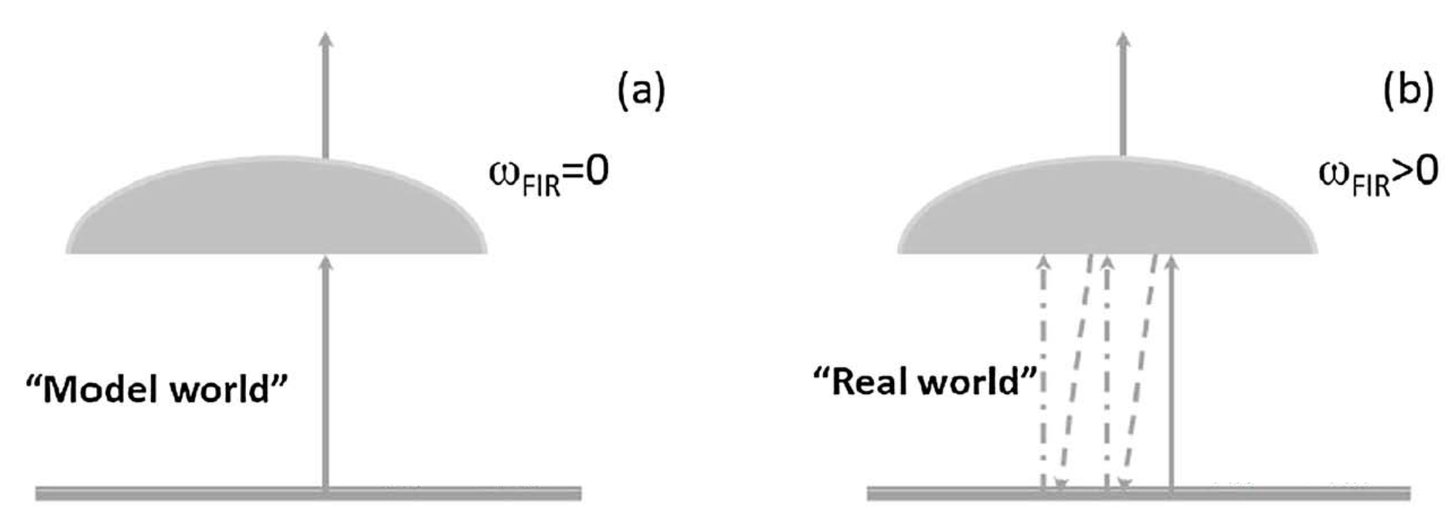
Introduction and Objective

- Scattering of longwave radiation by clouds is regarded unimportant and neglected in global climate models.
- However, recent studies demonstrated **the nonnegligible role of cloud longwave scattering**, especially by ice clouds, in modulating the energy budget of the Earth System.
- It's not known **how this could affect the simulated Arctic climate**, considering the prevailing ice phase clouds and the dominance of longwave radiation during winter darkness.
- **We implemented the longwave scattering of ice clouds into the DoE newest earth system model, E3SM and assessed the impacts on the simulated Arctic winter (DJF) energy budget and climate.**



Chen et al. (2014)

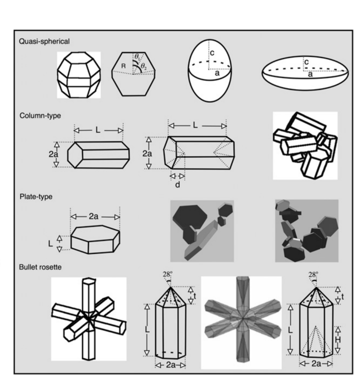
Method

Model

- DoE Energy Exascale Earth System Model (E3SM v1; Golaz et al., 2019).

Modifications:

- **Longwave Scattering Database for Ice Clouds:** derived from the MODIS collection 6 (MC6) ice cloud habit model (Yang et al., 2013) by varying Ice clouds habits with treatments of severe roughness by aggregation.



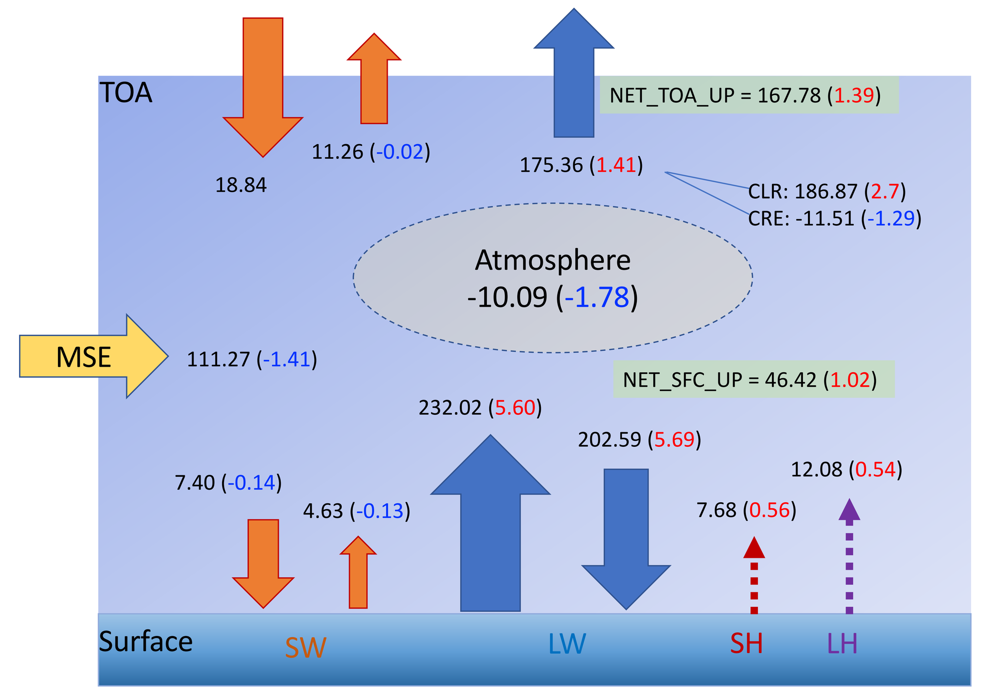
Yang et al. (2013)

- **Longwave Scattering Radiative Transfer:** The hybrid two- and four-stream radiative transfer solver (Kuo et al., 2020) was implemented to incorporate scattering calculation.

Experiments:

- 15 years of fully-coupled simulations with historical forcings (2000-2014) with (**Scat**) and without (**noScat**) longwave scattering. Output for Arctic (north of 60°N) winter are analyzed here.

Impact on Arctic energy budget



- **Downward LW radiation (FLDS)** at surface increased by as large as ~5.7 Wm^{-2} , warming the surface efficiently (Fig. 2). The increase in FLDS stems originally from the scattered LW radiation by ice clouds, and is enhanced by the moisturized atmosphere (Fig. 6).
- **Clouds** responded by slightly increased TOA longwave cloud radiative effect.
- **SH and LH** both increased by ~0.5 Wm^{-2} due to warmer surface and more evaporation.
- **Poleward MSE transport** was slightly inhibited due to reduced Tropics-Arctic meridional temperature contrast.

Fig. 1 Arctic domain-average energy budgets as simulated by the noScat version of E3SM (black numbers), as well as the differences between the Scat and noScat simulations (numbers in parentheses). **MSE**, moist static energy; **CLR**, clear sky; **CRE**, cloud radiative effect.

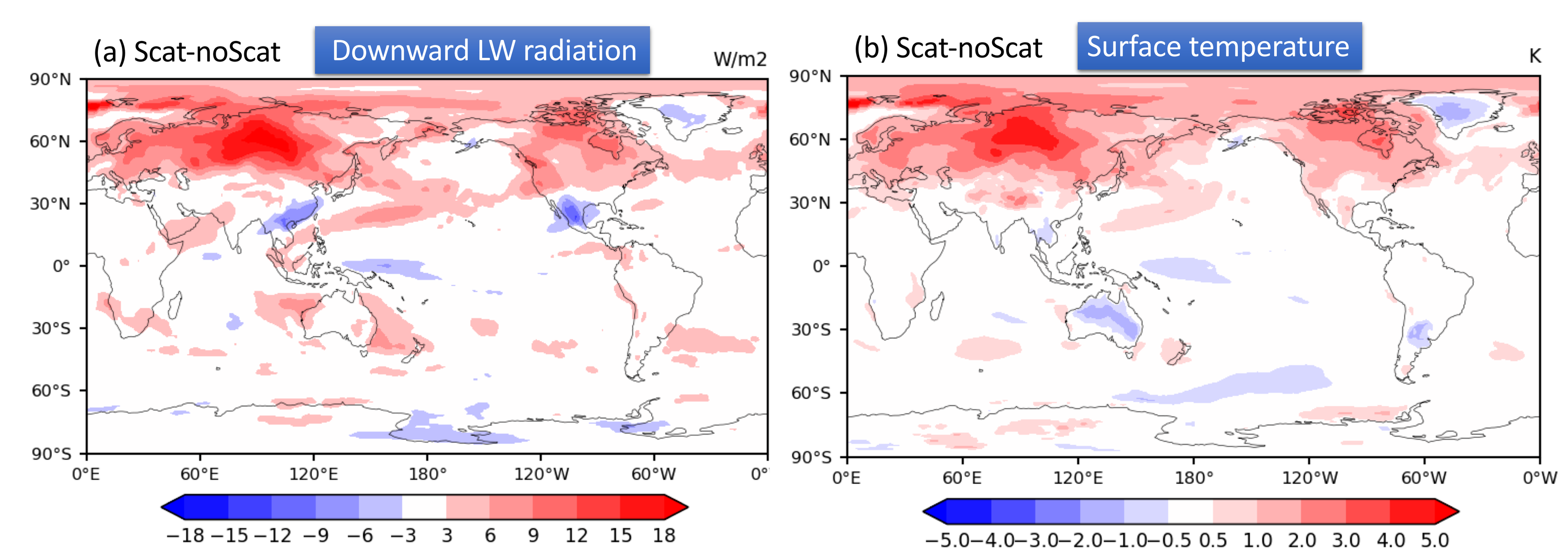


Fig. 2 Differences in the simulated (a) downward longwave radiation flux at surface and (b) the surface temperature.

Lower tropospheric stability and clouds

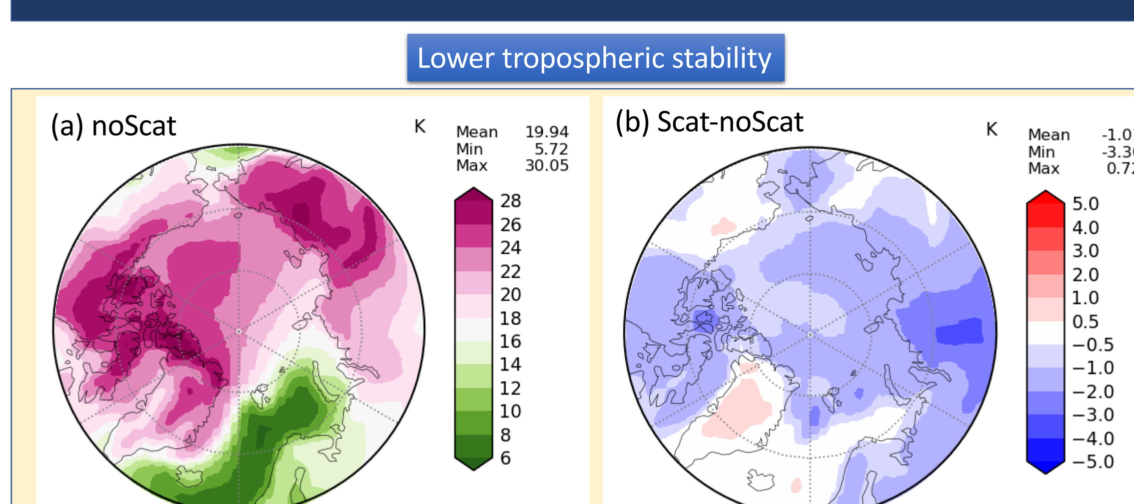


Fig. 3 (a) The noScat simulated Lower tropospheric stability defined as the difference in potential temperature between 700 hPa and surface; (b) the difference between Scat and noScat.

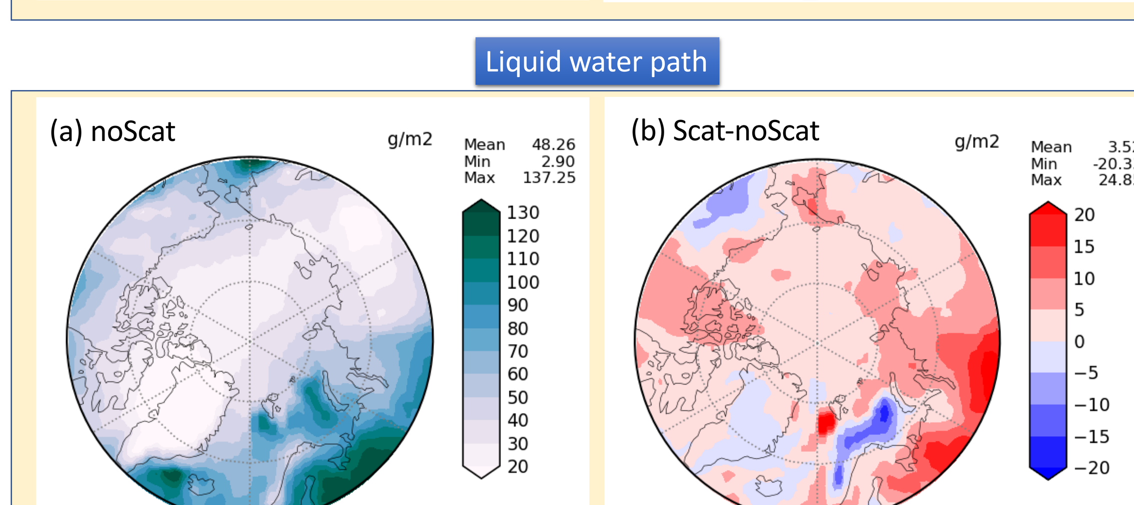


Fig. 4 The same as Fig.3 but for liquid water path.

- Increased surface temperature significantly **reduced lower tropospheric stability**, especially over high-latitude continent and Arctic ocean (Fig. 3).
- These regions features high stability and resilience of boundary layer mixed-phase clouds, thus the reduction in stability lead to more turbulence and uplift of water vapor, **favoring cloud growth** (Fig.4b) **as well as the potential phase shift.**

Circulation and water vapor transport

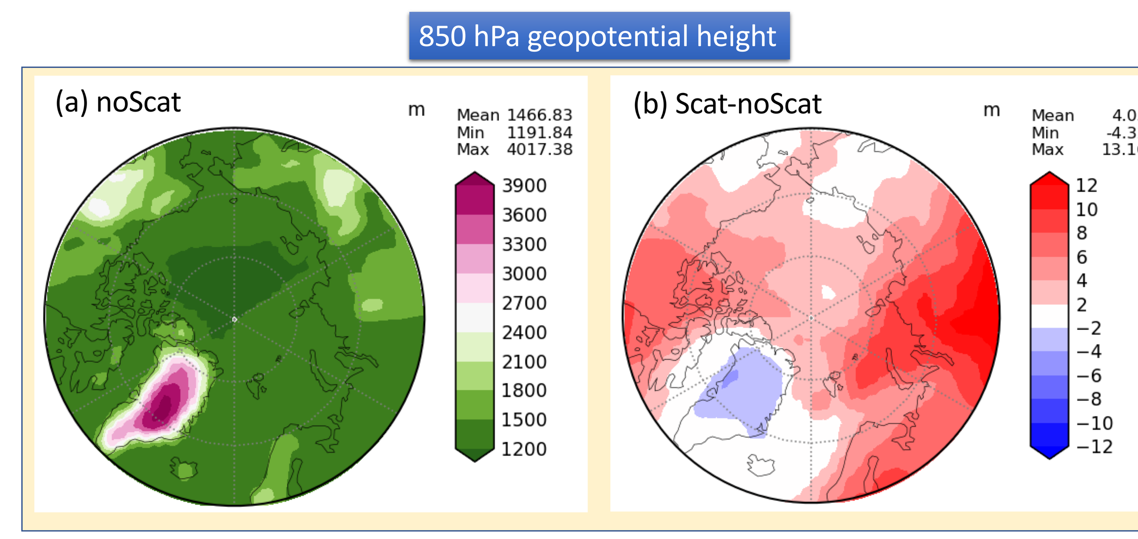


Fig. 5 (a) The noScat simulated 850 hPa geopotential height; (b) the difference between Scat and noScat.

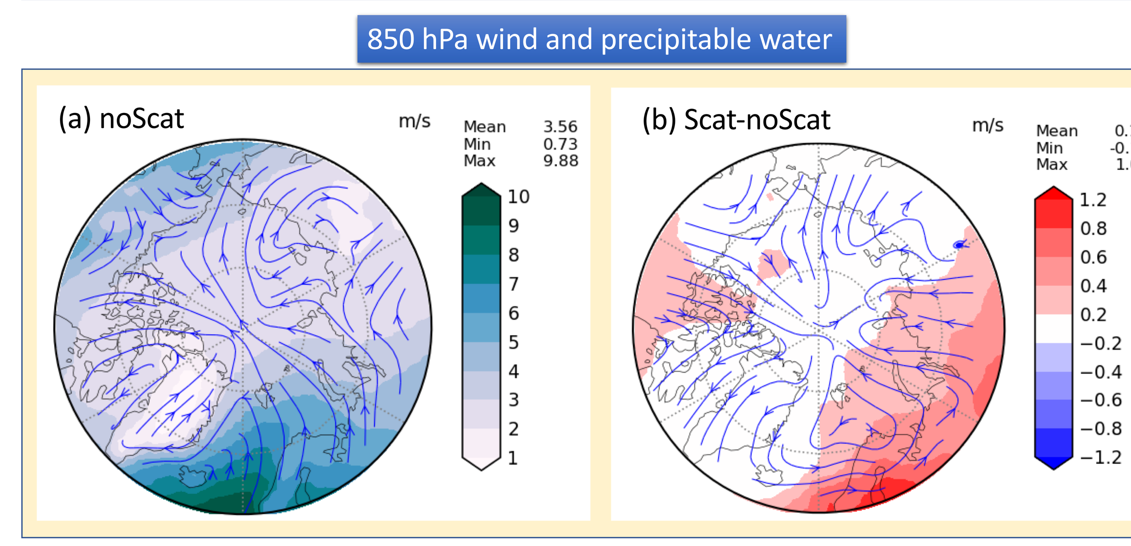


Fig. 6 (a) The noScat simulated precipitable water (shaded) and 850 hPa wind; (b) the difference between Scat and noScat.

- The **850 hPa geopotential height increased** over most of the Arctic region owing to the expansion of lower troposphere resulted from warmer surface.
- The larger increase of geopotential height over continental areas than over the Arctic oceans led to **poleward trend of wind** (Fig. 6b), conveying the increased water vapor at lower latitudes into the Arctic Circle.
- **Enhanced water vapor transport** further increased FLDS to warm the Arctic surface, manifesting a positive feedback.

Conclusions

1. Longwave scattering of clouds increases downward LW flux, thus **increasing wintertime polar surface temperature**.
2. **Reduce lower troposphere stability** by surface heating, facilitating turbulence and cloud development.
3. **Enhance water vapor transport** to Arctic from continental region.
4. **Local thermodynamics and large scale circulations interplay with each other** to affect Arctic energy budget.

References:

1. Chen, X., X. Huang, and M. G. Flanner, 2014. Sensitivity of modeled far-IR radiation budgets in polar continents to treatments of snow surface and ice cloud radiative properties. *Geophys. Res. Lett.*, 41.
2. Golaz, J.-C., P. M. Caldwell, L. P. Van Roekel, et al., 2019. The DOE E3SM coupled model version 1: Overview and evaluation at standard resolution. *J. Adv. Model. Earth Sys.*, 11, 2089–2129.
3. Yang, P., L. Bi, B. A. Baum, et al., 2013. Spectrally Consistent Scattering, Absorption, and Polarization Properties of Atmospheric Ice Crystals at Wavelengths from 0.2 to 100 µm. *J. Atmos. Sci.*, 70, 330–347.
4. Kuo, C-P, P. Yang, X. Huang, et al., 2020. Assessing the accuracy and efficiency of longwave radiative transfer models involving scattering effect with cloud optical property parameterizations. *J. Quant. Spectrosc. Radiat. Transf.*, 240, 106683.

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