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

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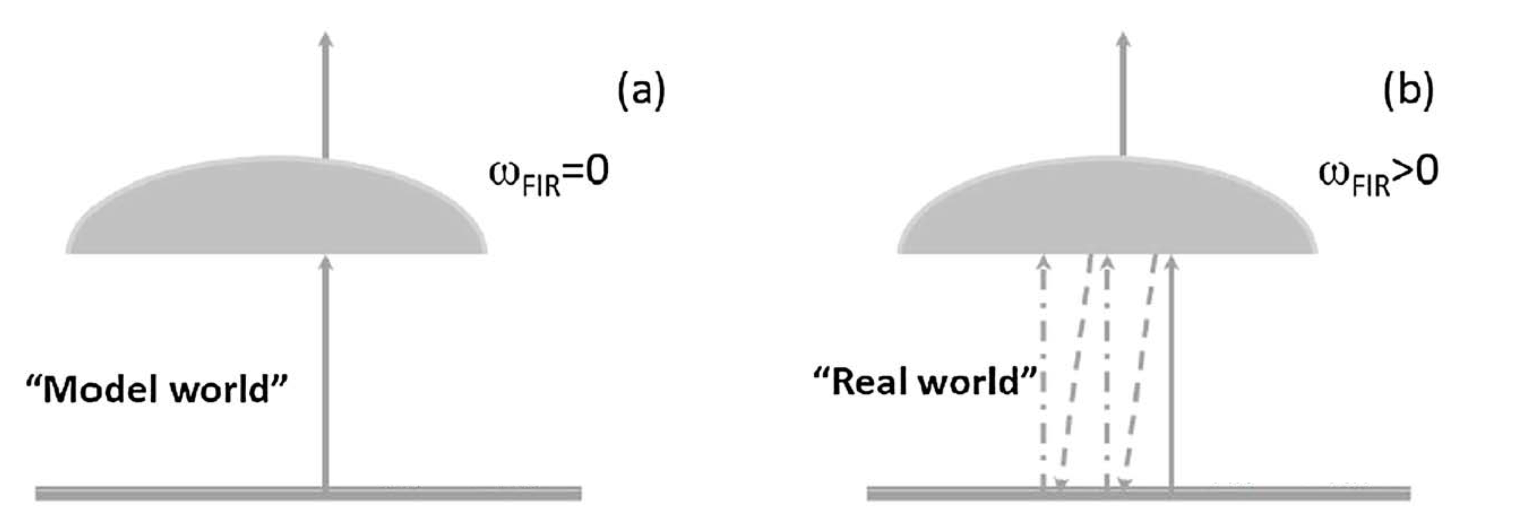
Introduction and Objective

- 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)

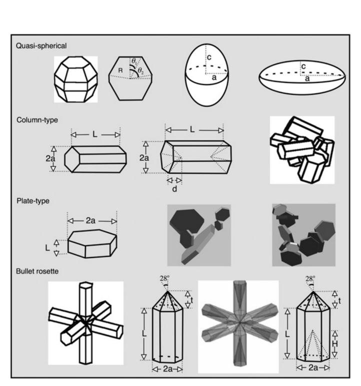
Method

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.



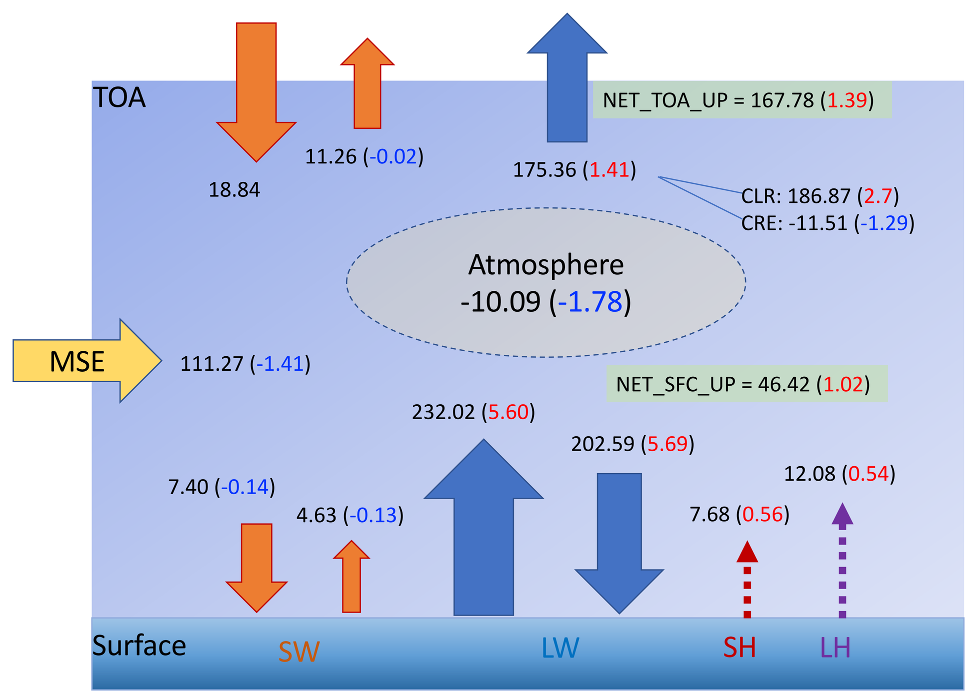
Yang et al. (2013)

- **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.

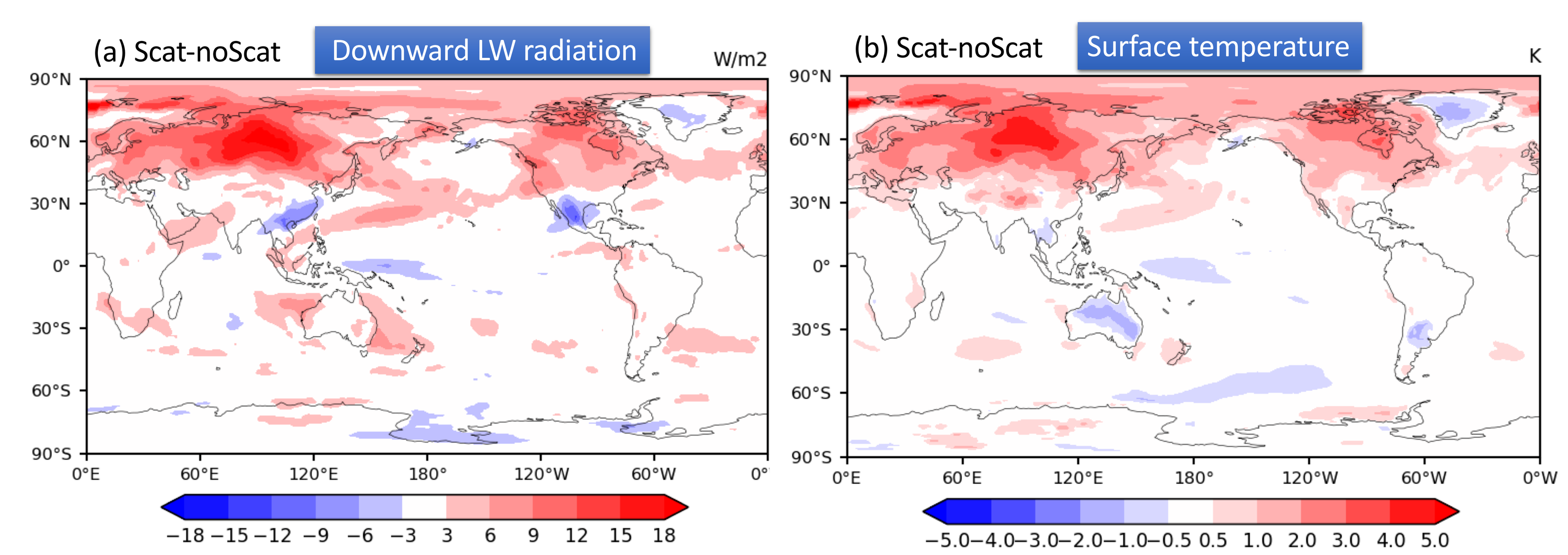


Fig. 2 Differences in the simulated (a) downward longwave radiation flux at surface and (b) the surface temperature.

Lower tropospheric stability and clouds

Lower tropospheric stability

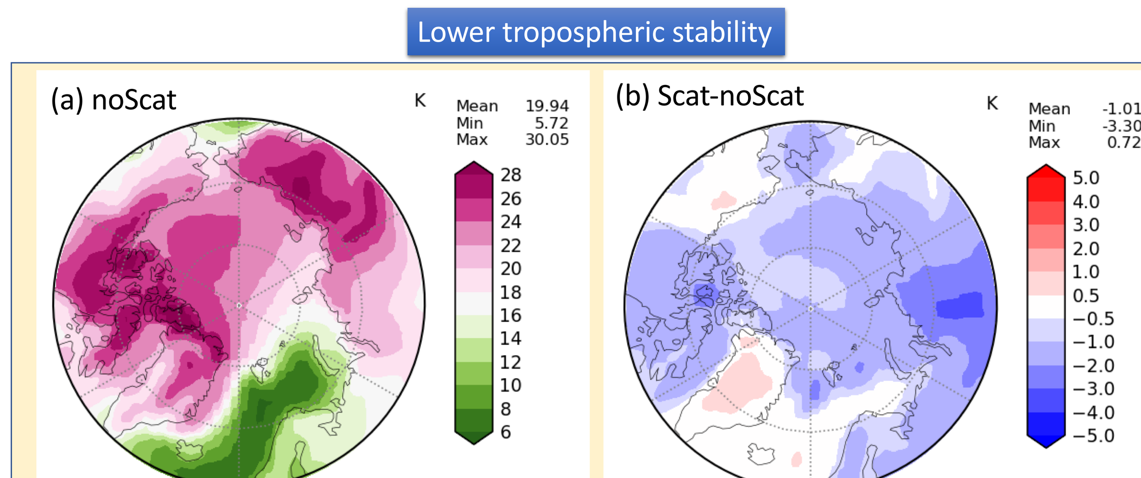


Fig. 3 (a) The noScat simulated Lower tropospheric stability defined as the difference in potential temperature between 700 hPa and surface; (b) the difference between Scat and noScat.

Liquid water path

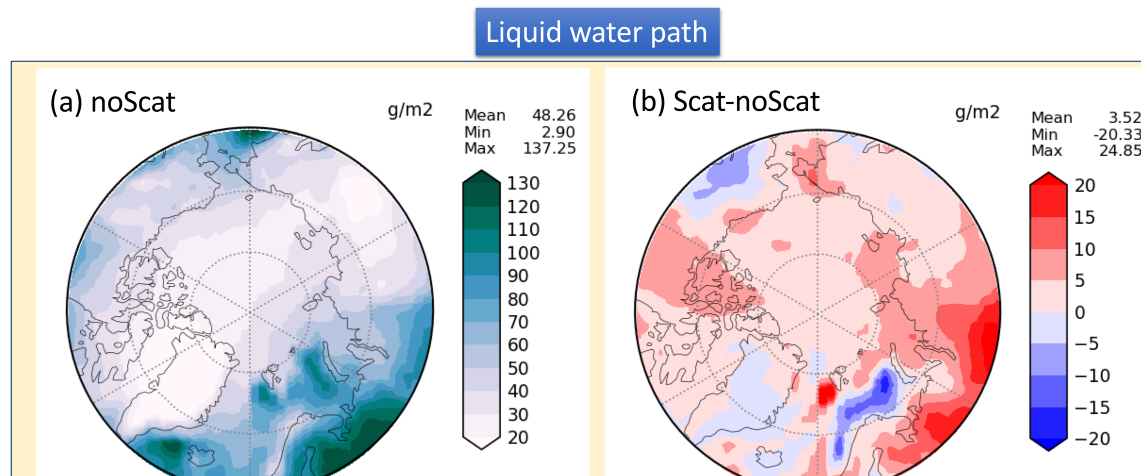


Fig. 4 The same as Fig.3 but for liquid water path.

- 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

850 hPa geopotential height

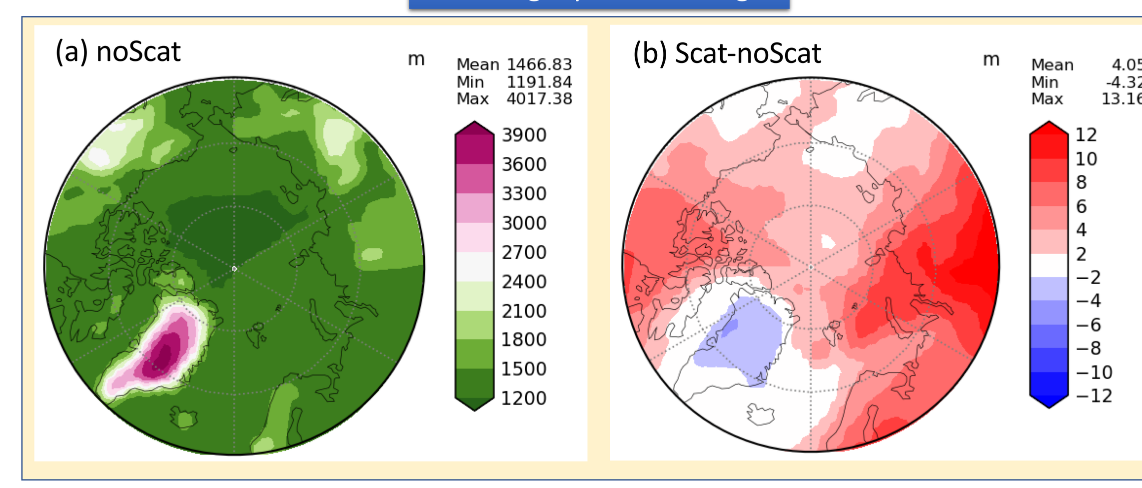


Fig. 5 (a) The noScat simulated 850 hPa geopotential height; (b) the difference between Scat and noScat.

850 hPa wind and precipitable water

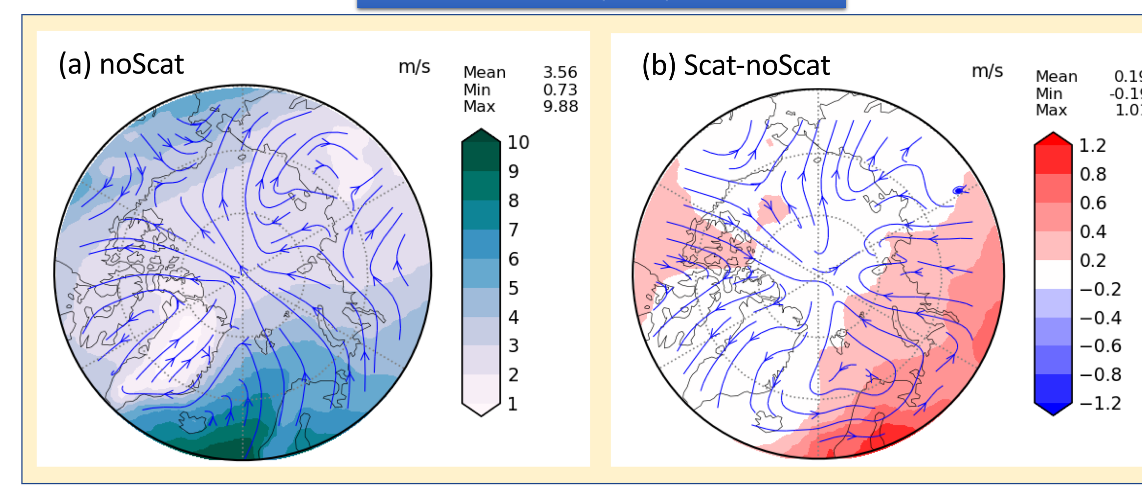


Fig. 6 (a) The noScat simulated precipitable water (shaded) and 850 hPa wind; (b) the difference between Scat and noScat.

- 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:

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