Evaluation of the Arctic Surface Radiation Budget in CMIP5 models

GOAL

Determine biases in the representation of the Arctic surface radiation budget annual cycle and discover the physical processes that explain the significant spread in projected Arctic warming.

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The Arctic climate is rapidly changing

Arctic surface temperature is increasing at a rate outpacing the rest of the globe, and the projected Arctic temperature response to increasing CO$_2$ is larger than that for the tropics.

Studying the Arctic climate presents unique challenges.

- The largest intermodel spread in projected surface temperature warming is found in the Arctic.
- Satellite observations are difficult, lack of in-situ measurements

Understanding and reducing intermodel spread in the simulation of the surface energy budget can improve future projections.
Radiative and non-radiative feedback processes lead to polar warming amplification

**Surface Albedo Feedback**
- The surface warms
- Snow and ice retreat
- Less reflective land and ocean surface are exposed
- Additional solar radiation is absorbed

**Atmosphere and ocean dynamical transport feedbacks**
- Poleward ocean heat transport increases
- Sea ice retreats and thins
- Thinner and less extensive sea ice amplifies the surface albedo feedback

**Cloud feedbacks**
- Arctic cloud cover increases
- More clouds increase downward longwave radiation at the surface
- Positive feedback
- Clouds increase albedo and reduce downward shortwave radiation
- Negative feedback

In summer, these effects compete. In winter (in the absence of solar radiation), the longwave cloud radiative effect dominates.
Use the concept of cloud radiative forcing to evaluate the influence of clouds on shortwave and longwave fluxes at the surface.

\[
CRE = (SW_{\downarrow} - SW_{\downarrow\text{clr-sky}}) \cdot (1 - \alpha) + (LW_{\downarrow} - LW_{\downarrow\text{clr-sky}})
\]

“Cloud Radiative Effect”

Terms in the equation represent cloud influence on solar and infrared radiation

\((SW_{\downarrow} - SW_{\downarrow\text{clr-sky}}) \cdot (1 - \alpha)\)

- **Shortwave cloud radiative forcing (SW CRE)**
  - Usually negative because downwelling solar flux decreases with the presence of clouds
  - Magnitude of SW CRE is smaller over a white surface than over ocean

\((LW_{\downarrow} - LW_{\downarrow\text{clr-sky}})\)

- **Longwave cloud radiative forcing (LW CRE)**
  - Usually positive because downwelling longwave radiation increases with the presence of clouds
Longwave Surface Fluxes

**All-Sky**

- Annual Mean All-Sky LW Down, ensemble $= 218.69 \text{ W/m}^2$
- Annual Mean All-Sky LW Down, CERES-EBAF $= 230.47 \text{ W/m}^2$

**Clr-Sky**

- Annual Mean Clr-Sky LW Down, ensemble $= 183.69 \text{ W/m}^2$
- Annual Mean Clr-Sky LW Down, CERES-EBAF $= 190.69 \text{ W/m}^2$
Longwave Cloud Radiative Effect

The large discrepancy in wintertime cloudiness is due to the representation of low clouds (Karlsson 2011).
What causes differences in LW CRE?

\[
\text{LW CRE} = \text{LW}_{\text{all}} - \text{LW}_{\text{clr}} = N(F_{\text{clrd, lw}} - F_{\text{clr, lw}})
\]

\[
\delta \text{LW CRE} = \delta N(F_{\text{clrd, lw}} - F_{\text{clr, lw}}) + N \times \delta F_{\text{clrd, lw}} - N \times \delta F_{\text{clr, lw}}
\]

- **Cloud Fraction Component**
- **Cloud Property Component**
- **Clr-Sky Component**

(grey shaded region is the ensemble mean +/- one standard deviation)
For some models, changes in LW CRE are closely coupled to changes in cloud fraction.
Shortwave Surface Fluxes

**All-Sky**

Annual Mean All-Sky SW Down, ensemble = 93.54 W/m^2
Annual Mean All-Sky SW Down, CERES-EBAF = 95.92 W/m^2

**Clr-Sky**

Annual Mean Clr-Sky SW Down, ensemble = 132.47 W/m^2
Annual Mean Clr-Sky SW Down, CERES-EBAF = 127.64 W/m^2
Generally, models with higher surface albedo have a weaker SW CRE and vice versa.
Net Cloud Radiative Effect

Annual Mean NET CRE, ensemble = 16.86 W/m²
Annual Mean NET CRE, CERES-EBRF = 22.79 W/m²
Regressions between cloud fraction and net CRE show whether a model is more strongly forced by a \textit{cloud albedo effect} or a \textit{cloud greenhouse effect}.

Net CRE is the result of adding the longwave and shortwave forcings.
How will Arctic surface temperature change in the future?

Future surface temperature is obtained using the RCP 8.5 simulation (Radiative Concentration Pathway 8.5, a projection dataset with an 8.5 W/m² forcing)

RCP 8.5 runs from 2006 to 2100. Temperature change is calculated as follows:

\[ \Delta T_{\text{surf}} = \text{Mean } T_{\text{surf}} \text{ for the last 20 years of the simulation} - \text{Mean } T_{\text{surf}} \text{ for the first 20 years of the simulation} \]

(grey shaded region is the ensemble mean +/- one standard deviation)
The sensitivity of a model to changes in clouds is correlated to projected surface temperature change. The slope of the regression line from the $\delta N$ vs $\delta LW$ CRE is compared to projected $\Delta T_{surf}$ for CMIP5 models and C3M observations.

Using the model line fit and the C3M regression slope, a predicted $\Delta T_{surf}$ for observations is $\sim 13.6$ K.
Questions?

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