



Understanding the controls on the Arctic surface energy budget

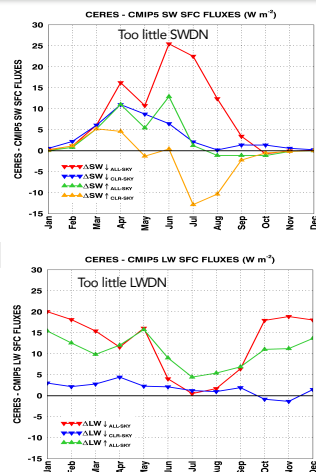
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1. Introduction and Motivation

The rapid, and in many cases, unprecedented changes in the Arctic climate system observed since 1979 are having devastating impacts on both natural and human systems. These changes are marked by warming Arctic temperatures, rapid declines in sea ice and snow cover, permafrost thaw, mountain glacier melt, and Greenland Ice Sheet mass loss. A common thread through each of these changes is the impact on the surface energy budget. However, our understanding of the controls on and variability of the Arctic surface energy budget is incomplete and this contributes to the significant biases in the climate models.

To better understand the controls on the variability of the Arctic surface energy budget and CMIP5 model biases, we use an atmospheric regime-based perspective of the Arctic surface energy budget decomposing variability by atmospheric dynamic and thermodynamic properties.

Figure to the right shows (left) LW and (right) SW CERES minus CMIP5 LW surface radiative flux monthly differences.



2. CERES Surface EBAF data and MERRA-2

• CERES Surface EBAF provides monthly-averaged surface radiative fluxes at $1^\circ \times 1^\circ$ resolution constrained by CERES TOA fluxes (https://ceres.larc.nasa.gov/order_data.php).

• MERRA-2 has a horizontal resolution of 0.5° latitude $\times$ 0.625° longitude and vertical resolution of 72 hybrid-eta levels. Variables used include 500 hPa vertical velocity, lower tropospheric stability, surface and lower tropospheric temperature and humidity, and relative humidity.

3. Methodology: Regime Definition

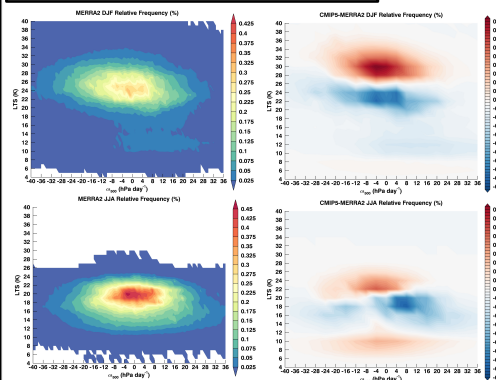
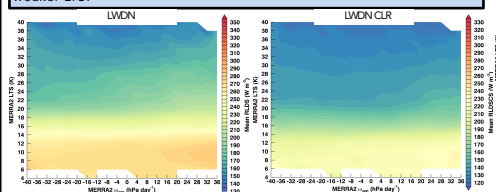


Figure to the left shows (top, left) the DJF joint frequency of occurrence of Arctic atmospheric regimes using lower tropospheric stability (LTS) and 500 hPa vertical velocity, (bottom, left) the same for JJA, (top, right) the difference between MERRA-2 and the CMIP5 ensemble for DJF and (bottom, right) same for JJA.

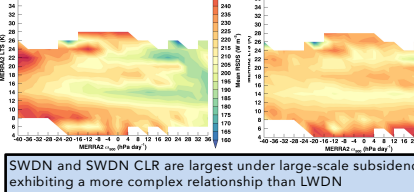
- Overall, CMIP5 models produce very similar frequency distributions of the LTS- ω 500 bins.
- In winter, CMIP5 models more frequently produce stronger lower tropospheric stability relative to MERRA-2.
- In summer, CMIP5 models produce a broader frequency distribution of LTS than MERRA-2.

4. CERES Surface Radiation Fluxes and Cloud Radiative Effects by Atmospheric Regimes

LWDN and LWDN CLR are largest under large-scale rising motion and weaker LTS.



SWDN and SWDN CLR are largest under large-scale subsidence exhibiting a more complex relationship than LWDN



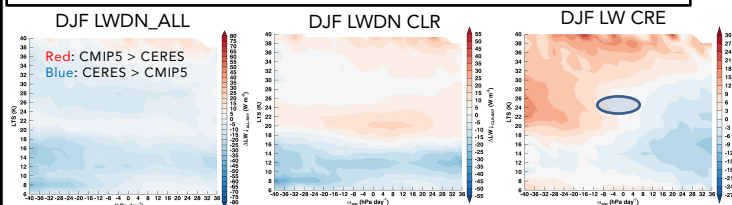
6. Conclusions

- (1) Arctic surface energy budget variability is explained largely by atmospheric variability
- (2) Clear-sky and cloud radiative effects are both important to this variability
- (3) The ability of CMIP5 models to capture the observed regime-dependence varies

Takeaways:

- A regime approach allows a better assessment of the influence of model processes on the surface energy budget as well as the influence of surface energy budget errors on processes.
- Results suggest a slew of relevant and important biases in CMIP5 relative to CERES
- Negative winter LWDN bias is primarily due to too little LW CRE in regimes characterized by large-scale ascent. LWDN CLR biases are positive in the most frequently occurring regimes.
- Negative summer SWDN bias is primarily due to too negative SW CRE (too much cloud reflection) under moderate LTS values and large-scale ascent.
- Since Net CRE changes sign with atmospheric regime, a future shift in the frequency of occurrence in these regimes could change the role of clouds in the Arctic climate.

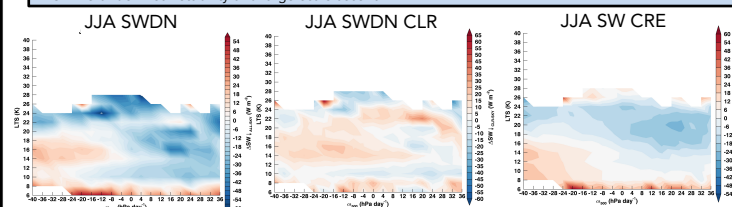
5. CMIP5 Surface Energy Budget Biases by Atmospheric Regimes



Figures above shows biases in the CMIP5 ensemble LW downwelling radiation relative to CERES Surface EBAF (CMIP5 minus CERES) in Winter (DJF).

LWDN CMIP5 biases in DJF:

- CMIP5 LWDN too low in most atmospheric regimes, however this results from compensating biases in the clear-sky fluxes and LW CRE.
- CMIP5 LWDN CLR is larger than CERES in the most frequently occurring regimes (LTS: 18-24 K).
- CMIP5 LW CRE at the surface is larger than CERES under strong stability and large-scale subsidence, and lower than CERES under weak stability and large-scale ascent.

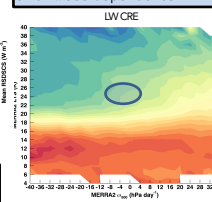


Figures above shows biases in the CMIP5 ensemble SW downwelling radiation relative to CERES Surface EBAF (CMIP5 minus CERES) in Summer (JJA).

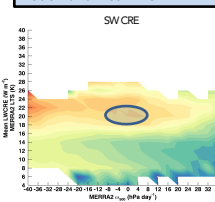
SWDN CMIP5 biases in JJA:

- CMIP5 SWDN too low under weak stability and large-scale ascent.
- CMIP5 SWDN CLR is larger than CERES in the most regimes, with a complicated structure.
- CMIP5 SW CRE at the surface more negative than CERES under moderate stability and large-scale ascent, and less negative under weak stability and large-scale subsidence.

LW CRE (DJF) has its largest effects under weak LTS with a small ω 500 dependence.



SW CRE (JJA) has its largest effects under large-scale rising motion and weak LTS.



Net CRE indicates that the overall sign change changes sign with atmospheric regime.

