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The Spectral Dimension of Arctic Greenhouse Efficiency Changes from 2003 to 2016: Insights from Far-IR and Mid-IR Trends

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Evaluating changes in Arctic longwave (LW) energy processes is critical for a better understanding of the amplified surface warming in the region. In addition to outgoing LW radiation (OLR), greenhouse efficiency (GHE)–the atmosphere's ability to trap LW radiation–is also an important metric as it includes radiative changes at the surface as well as the top-of-atmosphere. Radiation in the far-infrared (far-IR) contributes substantially to Arctic OLR due to cold temperatures and a relatively dry atmosphere. This implies changing water vapor can modulate both OLR and GHE in the far-IR. Furthermore, the spectral decomposition of such radiative changes, as opposed to the traditional broadband approach, can reveal more clues about the mechanisms that drive OLR/GHE variations, especially when considering the synergy between the far-IR and mid-IR spectral regions.

In this study, we examine the trends of both spectral OLR and GHE for the Arctic region using a spectral OLR data set from 2003 to 2016 as derived from collocated AIRS and CERES observations. We focus on March, July, and September, key transition periods in the sea ice melt season. The surface temperatures used to compute upwelling surface LW fluxes are taken from ECMWF ERA-interim reanalysis. We also use AIRS Level-3 retrievals to simulate clear-sky OLR/GHE trends. Sensitivity analyses are performed to quantify the individual contributions from changing surface temperature, air temperature, and humidity to such trends.

The trend results indicate that OLR changes in the mid-IR and far-IR dirty window are significant in March and July with the sign and magnitude depending on the calendar month. In contrast, the GHE trends are mostly positive and statistically significant for the far-IR and 6.7 μm water vapor bands. By comparing clear-sky and all-sky trends, it appears the role of clouds is to dampen OLR increases and increase GHE for all months. The simulations using AIRS Level-3 data can largely capture the major features of the linear trends derived from the clear-sky spectral OLR data set. Sensitivity analyses indicate that increased surface temperature is the dominant contributor to changes in both OLR and GHE across the LW spectrum. However, non-negligible contributions from water vapor and atmospheric temperature were simulated particularly in mid-IR window and far-IR dirty window. Our study suggests that the relationship between far-IR OLR and humidity changes is complex and depends on both the vertical profile of temperature and the pressure level in which water vapor changes occur.