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Direct Observations of the Greenhouse Effect of CO_2 and CH4 over Greenland

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In order to empirically verify and quantify the energetic inputs into the Greenland Ice Sheet from the primary anthropogenic greenhouse gases (GHGs), we have constructed the time series of the greenhouse effect (GHE) from CO_2 and CH4 at the ice sheet surface since 2010 using in situ observations. These data were collected at the NSF Summit Station observatory located at Summit, Greenland as part of the Integrated Characterization of Energy, Clouds, Atmospheric state, and Precipitation at Summit (ICECAPS) field campaign. The GHE is derived from the downwelling infrared radiation emitted by the Earth's atmosphere by the Polar Atmospheric Emitted Radiance Interferometer (PAERI), together with coincident measurements of GHG concentrations, thermodynamic state, cloud cover, etc., using methods for CO_2 and CH4 pioneered by Feldman et al (2015 and 2018, respectively). The absolute values of the GHEs are in excellent agreement both with reference line-by-line models and with the radiative parameterizations used in Earth System Models (ESMs). The polar atmosphere is exceedingly dry at Summit: it never exceeds 1 cm PWV, is generally below 5 mm even in summer, and is generally below 1 mm in winter. Consequently, our GHE time series exhibits substantially less radiative masking by water vapor as compared to more temperate locations.

The GHEs for both CO_2 and CH4 nonetheless exhibit large, repeated seasonal cycles. Counterintuitively, the GHEs of both GHGs are completely out of phase with the observed seasonally cyclic variations in the GHG concentrations. The concentrations of CO_2 and CH4 at Summit exhibit the same well-known seasonal oscillations seen worldwide. Specifically CO_2 is highest in winter during the respiration period for vegetation in the northern hemisphere and is lowest in summer during peak photosynthetic activity. Similarly CH4 is highest in winter and lowest in summer when its oxidation by the hydroxyl radiation OH, which is produced photochemically, is maximized. We show that the out of phase relationship is explained by the temperature dependence of the GHE, and we discuss the implications of this dependence for future trends in the GHE over Greenland as the overlying atmosphere warms rapidly due to polar amplification.