Towards a More Realistic Simulation of Clear-Sky Conditions in GCMs For Fairer Comparison to Observations

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Introduction and Methods

Global Climate Models and observations have unique limitations that make comparisons between the two challenging. Considered in this work, the treatment of clear-sky conditions in a model differs from reality and from how clear scenes are observed by satellites. For instance, climate models diagnose clear-sky radiative fluxes using "all-sky" humidity and temperature profiles assumed to be uniform across a large model grid that is often comprised of both clear and cloudy conditions at the subgrid level. Likewise, standard grid-mean diagnostics of climate variables from GCMs are often compared to satellite observations retrieved predominantly from true clear scenes, done so in an effort to avoid cloud contamination in those products. The cloud-clearing methodology used to retrieve geophysical parameters from IR Sounders serves as one example:

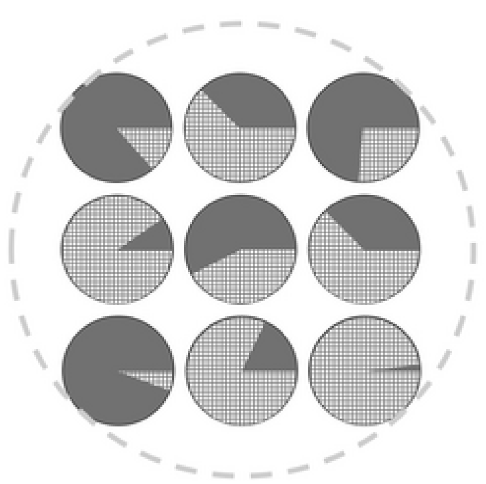

Figure 1. From N. Smith et al. (2023). An example of a satellite retrieval sampled from the cloud-free portions of a field-of-view (dark gray), ignoring cloudy portions (light gray)

Following work by Kim et al. (2020), here we modify an in-development version of GFDL-AM5 and CESM2 to compute clear-sky, all-sky and cloudy-sky outgoing longwave radiation using humidity profiles that are more representative of those respective states.

To do so, we assume saturated conditions in the fraction of the grid with clouds, compute a saturated humidity profile accordingly and, using the grid-mean all-sky diagnostics as a constraint, estimate a true "clear-scene" humidity profile that is ultimately used to compute a more realistic clear-sky OLR, whereby:

$$Q_{\text{mean}} = fQ_{sat} + (1-f)Q_{clr}$$

Given a **Grid-Mean** T, Q, Cloud Fraction (f)

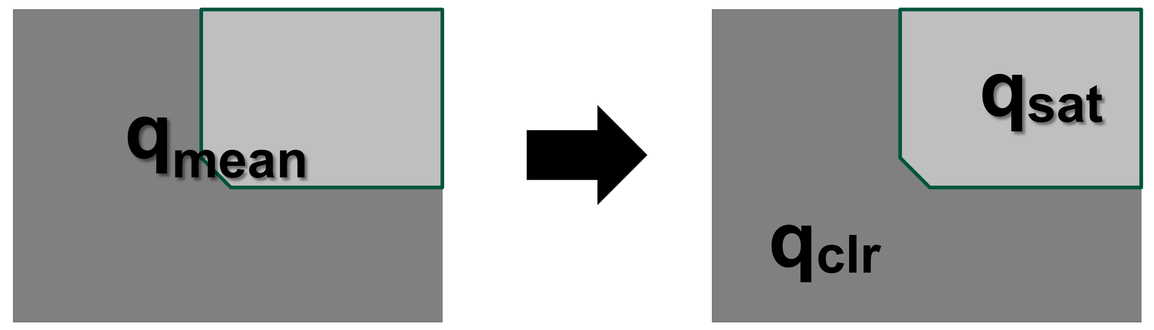

Figure 2. Traditional GCM humidity from an "all-sky" grid mean versus our modified radiation scheme whereby humidity is defined separately for cloudy (light gray) and clear (dark gray) fractions of the grid.

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Reducing Biases in Clear-Sky OLR Given a More Realistic Atmospheric State

All Results for Mean of 2010 - 2014

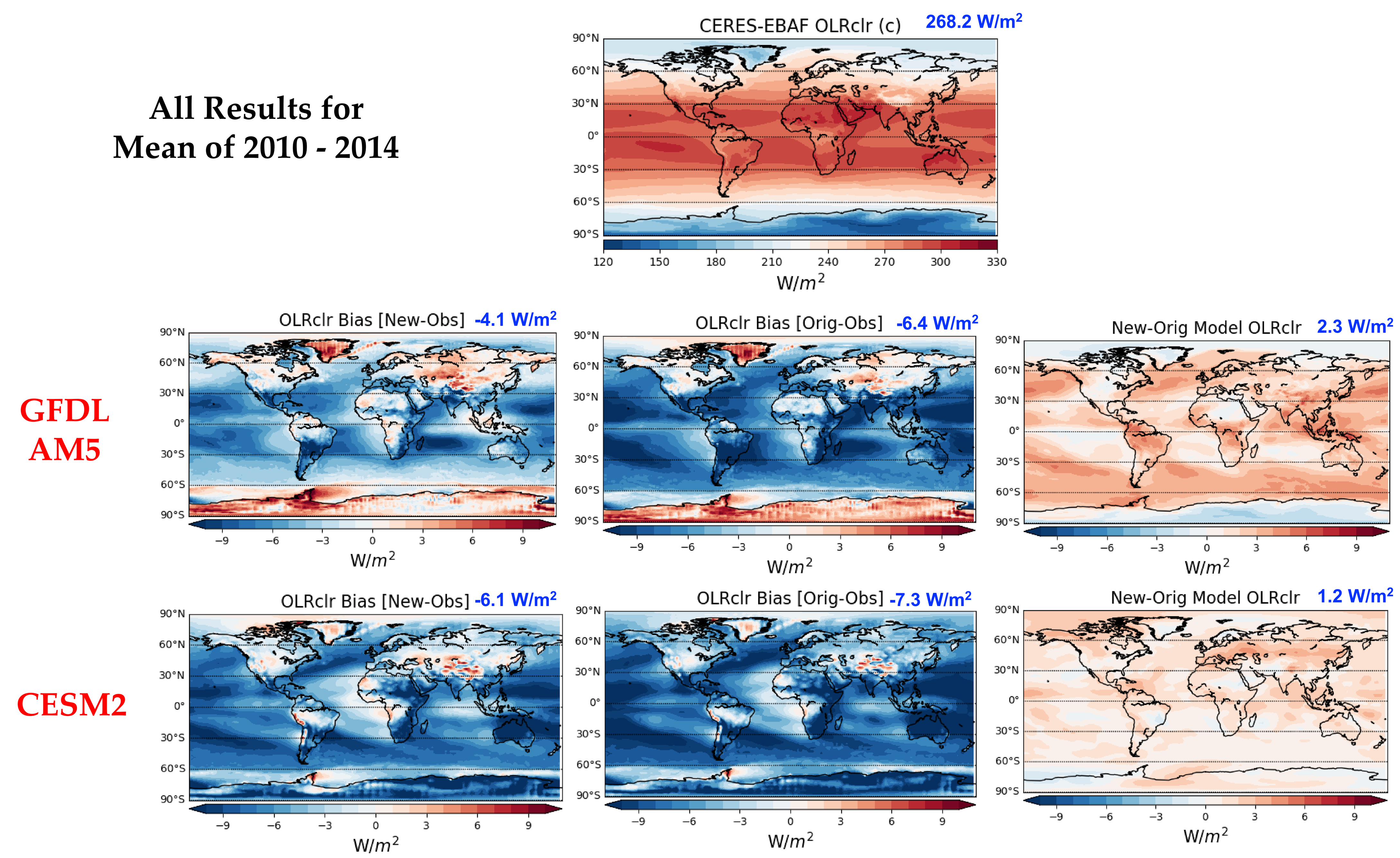
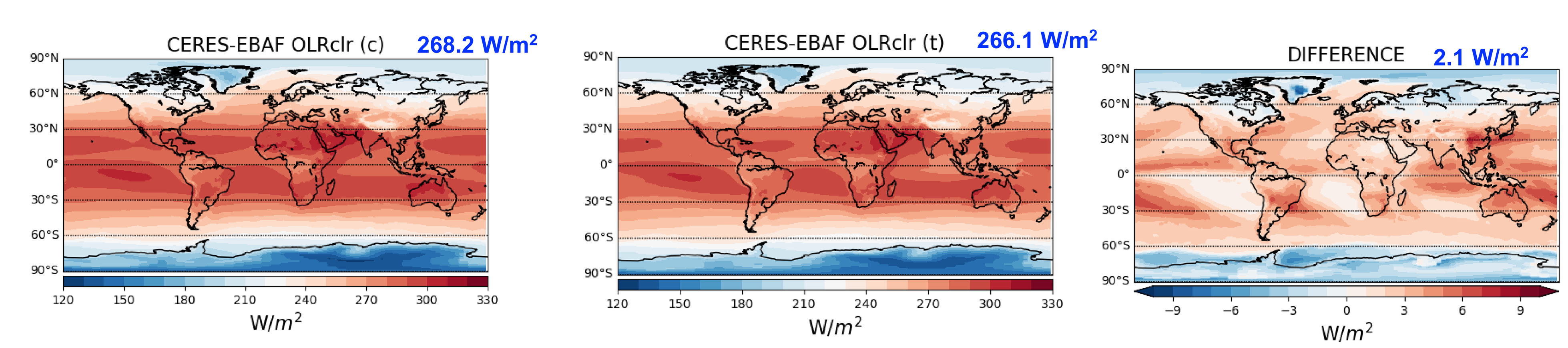


Figure 3. Clear-Sky TOA Outgoing Longwave Radiation (OLRclr). Time-mean from 2010-2014 from **(top row)** CERES EBAF ed. 4.2 partial sky (c) product and **(middle row)** the OLRclr bias relative to CERES for GFDL-AM5 using a clear-scene humidity (New), using grid-mean humidity (Orig.), and the difference between the two simulations. **(bottom row)** Analogous plots are shown for CESM2. Global-means printed in blue.

When GCM radiation scheme uses subgrid clear-scene humidity profiles instead of grid-mean all-sky profiles, the clear-sky OLR biases are reduced relative to the traditionally-defined CERES (c) fluxes

Two Definitions of Clear-Sky in CERES are Reproducible in a GCM



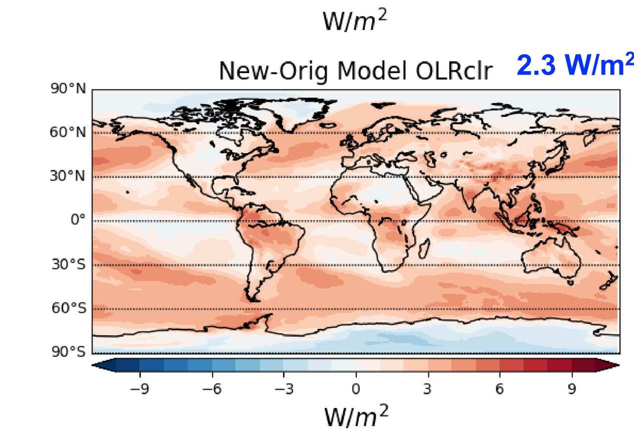


Figure 4. Clear-sky OLR from **(top left)** CERES-EBAF traditional partial-scene (c) product, **(top middle)** CERES-EBAF alternative total-scene (t) product, **(top right)** their difference. Also **(bottom right)** the difference between the "New" and "Original" clear-sky implementation in GFDL-AM5.

Alternative CERES-EBAF clear-sky product ("total scene", t) is an attempt to mimic traditional GCM clear-sky diagnostics (Orig)

Difference between the two CERES products is similar to the difference between the two clear-sky GCM implementations

Investigating All-Sky and CRE changes in CESM2

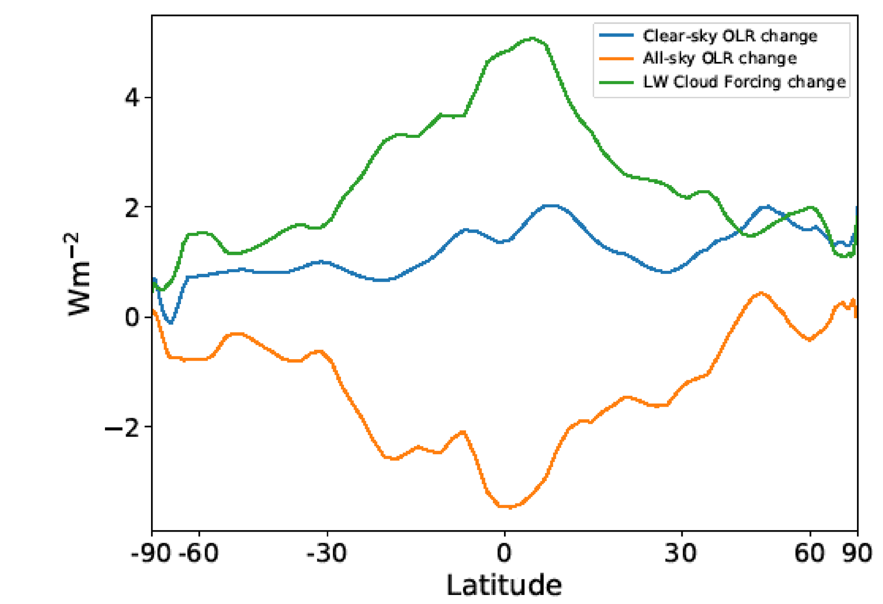


Figure 5. Difference in zonal-mean clear-sky OLR, all-sky OLR and LW CRE between CESM2 simulations using grid-mean, all-sky humidity profiles (Orig) versus subgrid clear-scene or cloudy-scene repartitioning of humidity (New)

Opposing changes in clear-sky and all-sky OLR lead to large bias reductions in LW CRE, as shown below

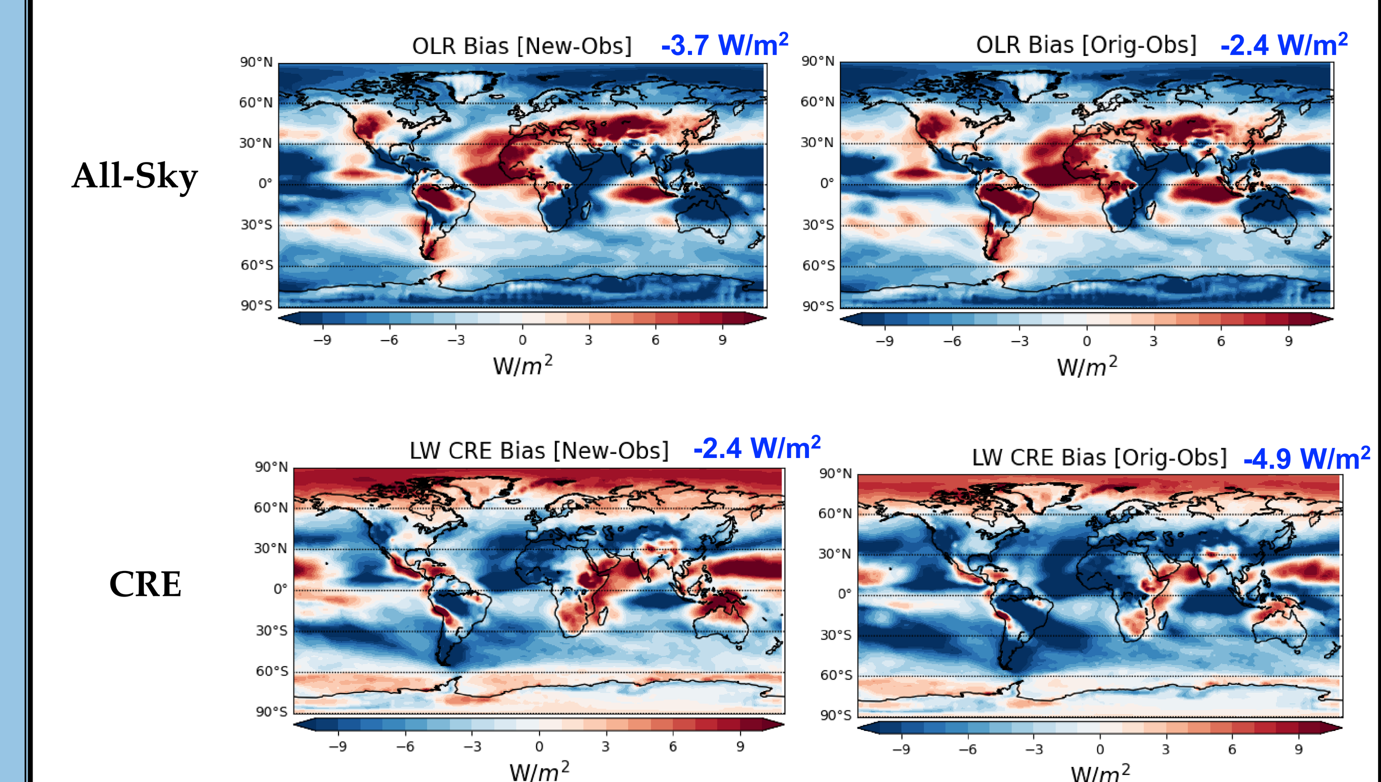


Figure 6. All-sky OLR (top row) and LW Cloud Radiative Effect (bottom row) biases relative to CERES for CESM2 using subgrid repartitioned (New) or grid-mean (Orig) humidity. Global-means printed in blue.

Conclusions

- As expected, diagnosing clear-sky OLR in a GCM using a more realistic clear-scene humidity profile reduces radiative flux biases relative to traditional clear-sky observations.
- Preliminary results suggest partitioning clear-scene and cloud-scene humidity in radiation scheme leads to reductions in LW CRE bias
- Next steps…Are trends impacted? How does the clear-scene humidity compare to remotely sensed humidity profiles?