Lessons learned in GCM clear-sky LW flux validation

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Motivation

The NASA Global Modeling and Assimilation Office (GMAO)'s GEOS-5 GCM has traditionally used the Chou-Suarez LW radiation code. We have been working to transition to the more modern and flexible RRTMG LW code, which we also expect to be faster for more vertical levels and to have greater support going forward. However, GEOS-5 with RRTMG LW initially appeared to under-predict clear-sky OLR against CERES EBAF 4.0. This study was motivated by this apparent problem.

Why is the RRTMG atmosphere more opaque in the LW than Chou-Suarez?

The problem is worse in the tropics, where the vapor concentrations are larger. It is also worse over the more humid oceanic regions These, and the older water vapor continuum formulation in Chou-Suarez, pointed to RRTMG having a stronger water vapor continuum absorption. The tests below show that RRTMG's water vapor continuum is significantly stronger in RRTMG than Chou-Suarez, hence its more opaque atmosphere, *for a given water vapor profile,* and its lower clear-sky OLR.

The Importance of a Valid Validation of Clear-sky OLR

Cloud-zeroed model vs. Clear-sampled CERES

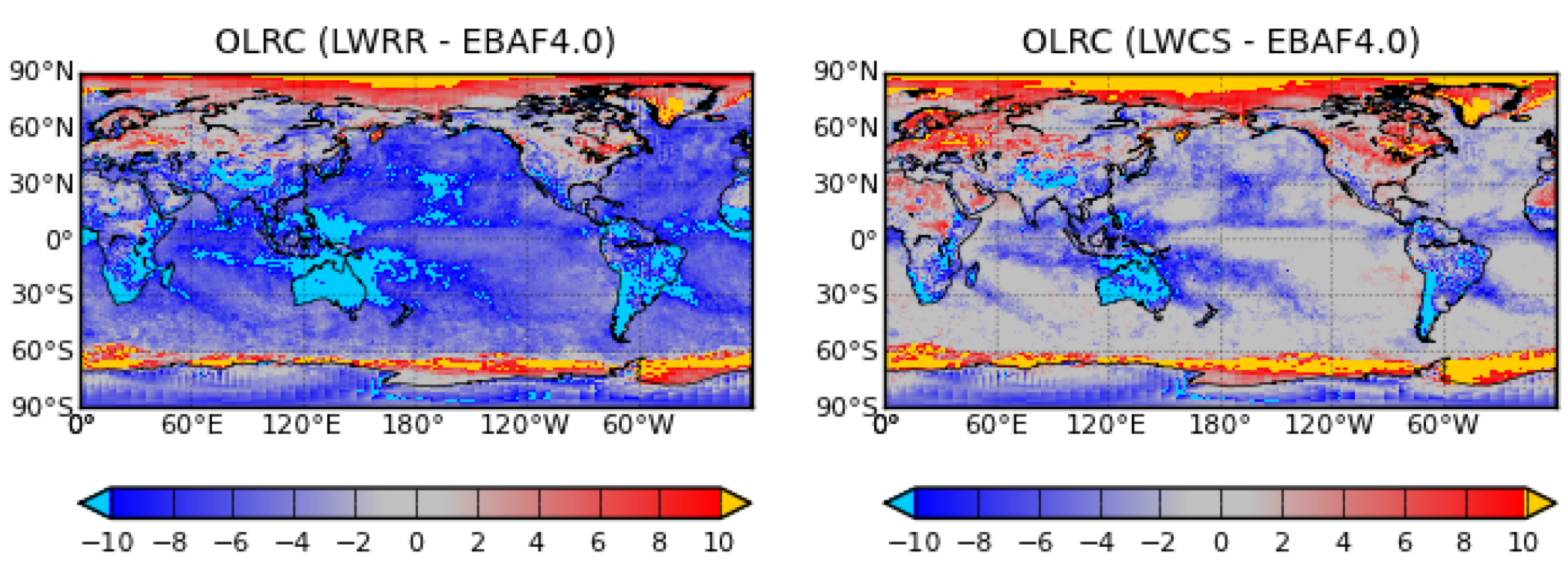


Figure 1a: The difference between the Dec 2010 monthly average of the *regular* GEOS-5 clear-sky OLR diagnostic (OLRC) and the clear-sky OLR from CERES EBAF 4.0. The RRTMG LW run (left) shows significant underprediction with respect to EBAF (about 4 W/m2 in a tropical average). The Chou-Suarez run (right) is much better. The problem with these results is that the model's clear-sky diagnostic is actually produced for *all* gridcolumns, and simply zeroes out the hydrometeors for the LW calculation. But it retains the very moist atmosphere associated with cloudy regions. The CERES EBAF validation data, conversely, is produced by sampling only over clear or near-clear CERES footprints. The model results therefore have a moist bias, producing an overly opaque atmosphere and a negative clear-sky OLR bias.

Clear-sampled model vs. Clear-sampled CERES

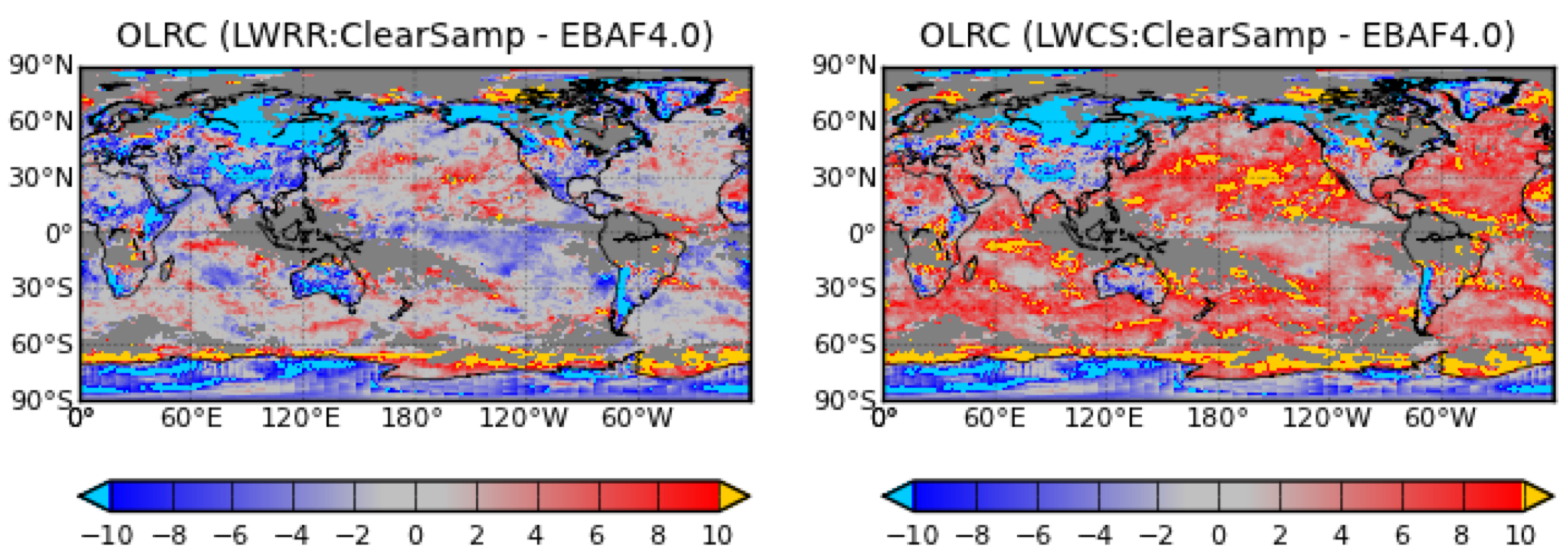
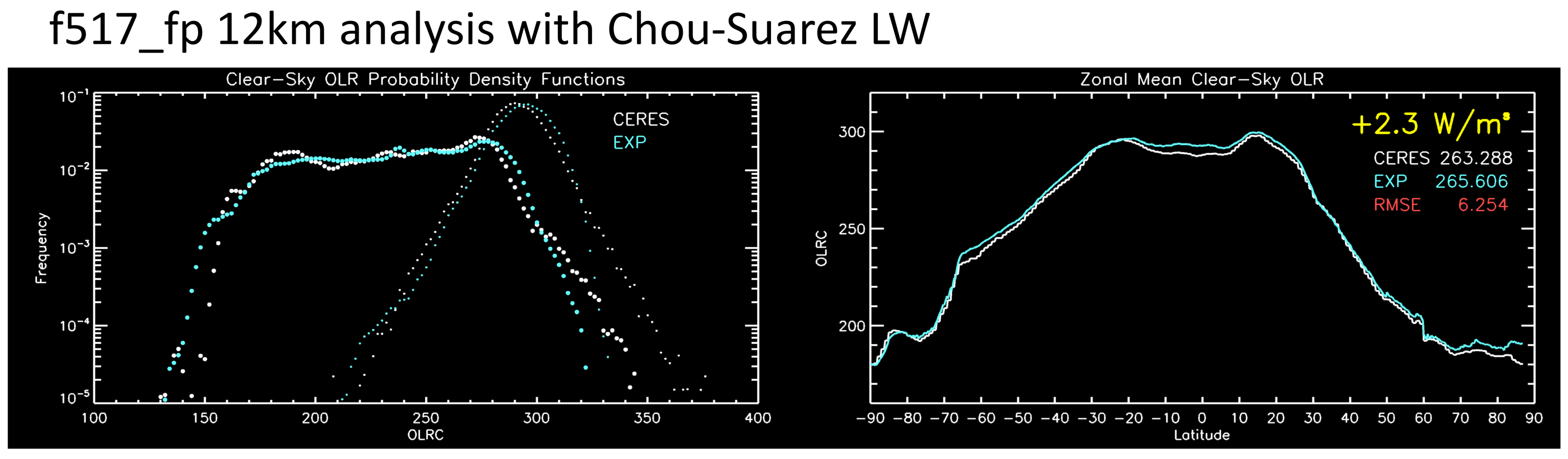


Figure 1b: As for 1a, but this time the model results are averaged over only gridcolumns for which the total column cloud fraction is no greater than 5%. This is a clear-sampling strategy much more in line with the EBAF validation data. Now the RRTMG LW clear-sky OLRC results (left) look good, whereas the Chou-Suarez values (right) are biased high.

Improvements in GEOS-5 forward processing analyses

f517_fp 12km analysis with Chou-Suarez LW



f519_fpp 12km analysis with RRTMG LW

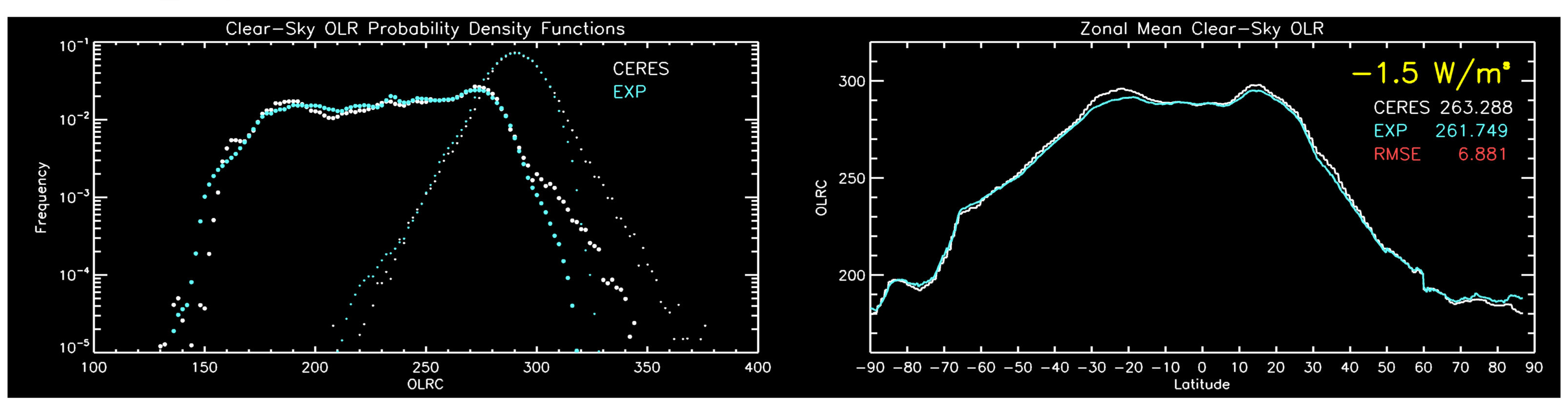


Figure 2: 13 day averages of GEOS-5 forward processing analyses with Chou-Suarez LW (top) and RRTMG LW (bottom) compared with CERES flash data for the same period. Both the zonal and global biases and the deviation of the PDFs with respect to CERES for clear-sky OLR are reduced in going to RRTMG LW. Model results are sampled at FLASH data locations, which provides an implicit clear-sky sampling.

Comparing gaseous LW absorption in RRTMG vs. Chou-Suarez

Single Column Model tests playing off MERRA's TOGA-COARE for DJF 1992.

OLRC	LWRR	CONTROL-	(CS-RR) $-\Delta_0$
TODO	*273.15*	*181.87*	*4.17*
NADA (CONTROL)	*455.02*	*0*	*0*
NADA + H_2O (Both)	*307.30*	*147.72*	*7.17*
NADA + H_2O (Line)	*331.59*	*123.43*	*4.46*
NADA + H_2O (Cont)	*345.20*	*109.82*	*55.09*
NADA + CO_2	*407.35*	*47.67*	*4.21*
NADA + O_3	*446.07*	*8.96*	*0.91*
NADA + N_2O	*446.99*	*8.03*	*3.14*
NADA + CH_4	*449.01*	*6.01*	*0.75*
NADA + N_2 (RR only)	*451.59*	*3.43*	*3.43*
NADA + O_2 (RR only)	*452.79*	*2.23*	*2.23*
NADA + CFCs	*454.60*	*0.42*	*-0.11*
NADA + Aerosols	*455.02*	*0*	*0*
NADA + CCl_4 (RR only)	*455.02*	*0*	*0*

SFCEM = 455.02 for LWRR, 455.15 for LWCS. For RR NADA OLR = SFCEM. For CS NADA, OLR = SFCEM-0.49W/m^2 (and LWS = 0.68 W/m^2). Δ_0 = -0.36 = -0.49+0.13 is the control (NADA) CS-RR difference in OLRC due to CS residual absorption and SFCEM differences.

Figure 3: In a series of GEOS-5 single column model experiments replaying from MERRA at a TOGA-COARE tropical site for DJF 1992, all absorbers are stripped from the LW radiation code (the "NADA" control) and then individual absorbers are added back (e.g., NADA + CO_2). The "TODO" row has all absorbers for reference. The second column ("LWRR") shows the clear-sky OLRC average from runs with RRTMG LW. The third column ("CONTROL-") shows the control OLRC minus the second column, and therefore measures the strength of each absorber when it is the *only* absorber. The fourth column shows the difference in OLRC between Chou-Suarez and RRTMG LW runs. For reference, the TODO run shows that the RRTMG LW atmosphere is about 4 W/m^2 more opaque than the Chou-Suarez LW atmosphere with all absorbers present. Different single absorbers alone each contribute several W/m^2 in opacity difference, except for the water vapor continuum, for which RRTMG is about 55 W/m^2 more opaque than Chou-Suarez, showing that the continuum is the major contributor to the difference in OLRC between the two codes.

Conclusions

- RRTMG LW is now giving a better validation of clear-sky OLR against CERES EBAF 4.0 than Chou-Suarez.
- The real issue was making sure the model's clear-sky OLR diagnostic was "clear-sampled", like EBAF, not "cloud-zeroed" as before.
- RRTMG has a stronger and more up-to-date water vapor continuum absorption than Chou-Suarez.
- For a correct validation, it is also necessary to constrain the model's moisture and temperature fields with observations, e.g., by using replay runs from the MERRA-2 reanalysis.

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