Assessing Uncertainties and Approximations in Solar Heating of the Climate System

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In calculating solar radiation, climate models make many simplifications, in part to reduce computational cost and enable climate modeling, and in part from lack of understanding of critical atmospheric information. Whether known errors or unknown errors, the community's concern is how these could impact the modeled climate. The simplifications are well known and most have published studies evaluating them, but with individual studies it is difficult to compare. Here we collect a wide range of such simplifications in either radiative transfer modeling or atmospheric conditions and assess potential errors within a consistent framework on climate-relevant scales. We build benchmarking capability around a solar heating code (Solar-J) that can be readily adapted to consider other errors and uncertainties. The broad classes here include: use of broad wavelength bands to integrate over spectral features; scattering approximations that alter phase function and optical depths for clouds and gases; uncertainty in ice-cloud optics; treatment of fractional cloud cover including overlap; and variability of ocean surface albedo. We geographically map the errors in W m^{-2} using a full climate re-creation for January 2015 from a weather forecasting model. For many approximations assessed here, mean errors are ~2 W m^{-2} with greater latitudinal biases and are likely to affect a model's ability to match the current climate state. Combining this work with previous studies, we make priority recommendations for fixing these simplifications based on both the magnitude of error and the ease or computational cost of the fix.

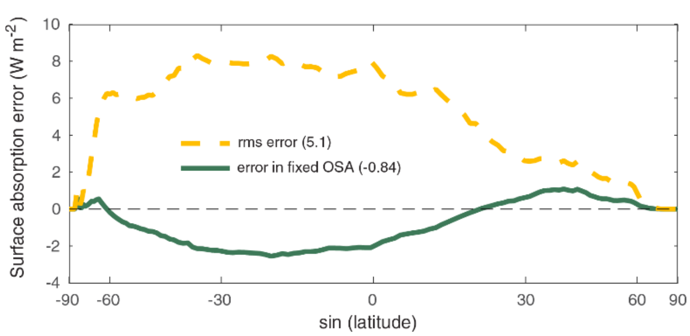

Figure. Zonal mean error (mean and rms in W m^{-2}) for fixed ocean surface albedo (OSA) versus interactive OSA that depends on wavelength, incident angle and wind.

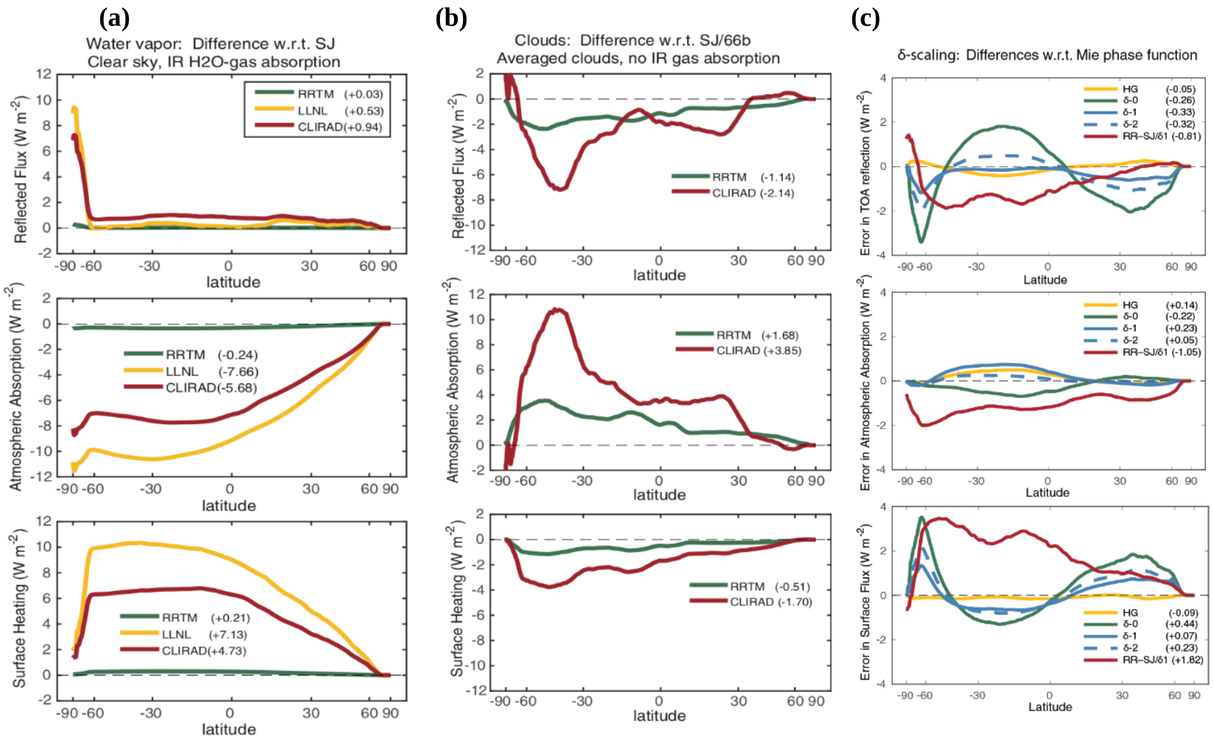

Figure Monthly zonal mean flux differences (W m^{-2}) as a function of latitude for January 2015 with three vertical panels showing reflected, atmospheric absorption, and net surface heating (top down). **(a)** Case study for H_2O-gas absorption and clear sky, comparing models with different numbers of infrared sub-bins. Differences are relative to standard Solar-J (*SJ*). RRTM refers to the very high-resolution (*SJ/RRX* in Table S1); CLIRAD and LLNL, to the courser resolutions (*SJ/CLIRAD* and *SJ/LLNL*). **(b)** All sky with averaged clouds and no infrared (IR) gas absorption, emphasizing the resolution of cloud absorption. Differences are relative to *SJ-66b* (high-resolution infrared bins for clouds). *SJ/noIR* has the standard 9 IR RRTMG bands, and *SJ/CLIRAD/noIR* has 3. **(c)** Averaged liquid-only clouds shown for a range of re-scalings of the Mie scattering phase function (HG, δ-0, δ-1, δ-2). These are all evaluated within the 8-stream *SJ* code. Also shown is the difference *RRTMG* minus *SJ/δ1***,** where much of the difference, especially in atmospheric heating, is due to the 2-stream minus 8-stream difference. See Table S1 for a complete description of code versions.

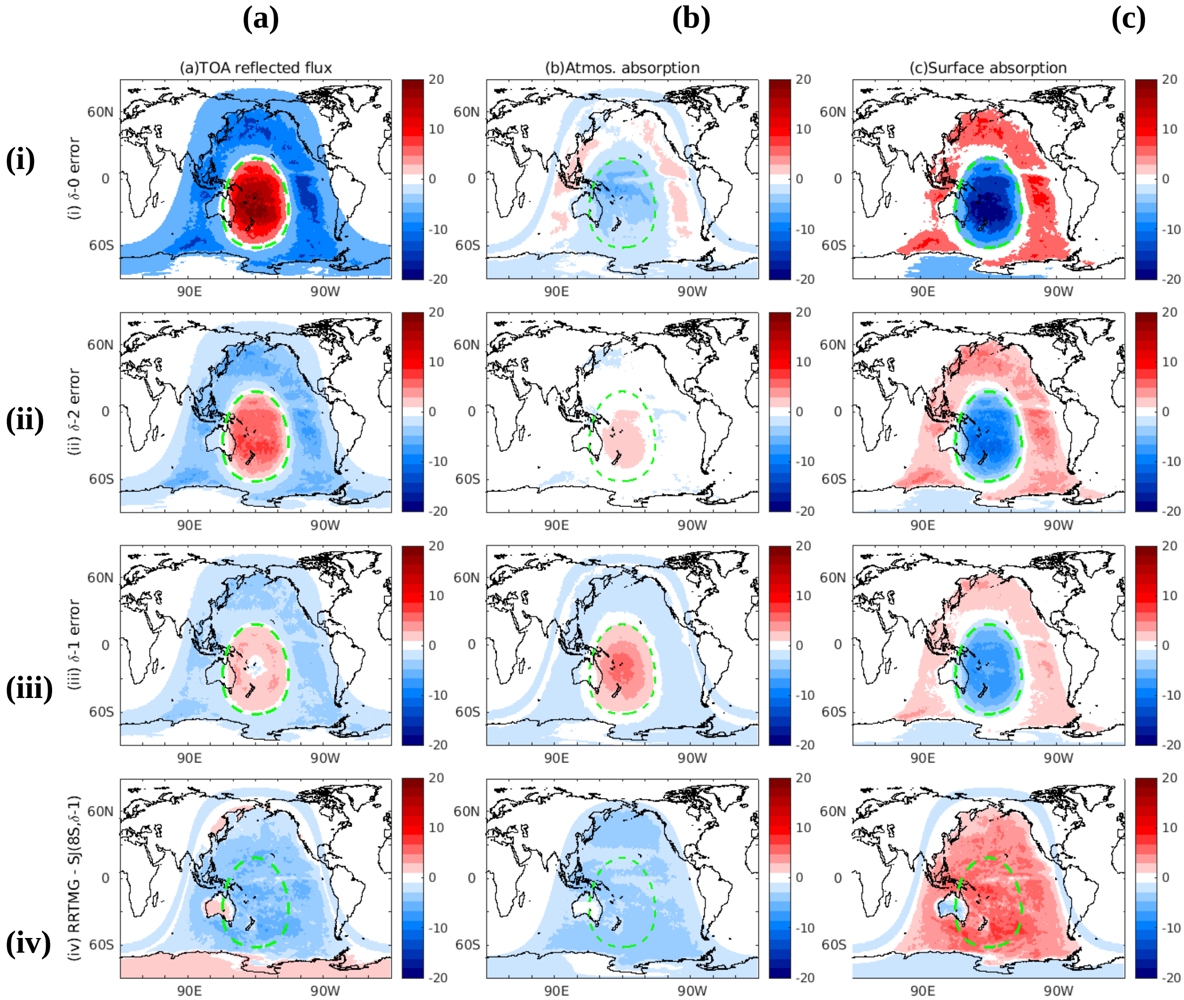

Figure. Geographic map of model differences in solar heating terms (W m^{-2}) averaged over 31 days in January at 00Z (sun over the Dateline), with columns show **(a)** reflected flux, **(b)** atmospheric absorption and **(c)** surface absorption. Rows **(i)**, **(ii)** and **(iii)** show the errors for δ-0, δ-2 and δ-1, respectively, calculated with Solar-J 8-stream scattering relative to the standard Mie phase function, see Table 2. Row **(iv)** shows the difference, *RRTMG* minus *SJ/δ1*. All calculations use grid-cell averaged liquid clouds only. The green dashed line encloses the region with SZA < 40º.