Investigating the diurnal cycle of outgoing longwave radiation

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1. Background

The diurnal cycle refers to patterns that occur within a 24-hour period caused by the rotation of the Earth. The diurnal cycle is one of the fundamental modes of variability associated with solar forcing [1]; diurnal cycles of precipitation, convection, outgoing longwave radiation, and many other variables have been extensively studied by climate scientists for decades. A long-standing issue of many climate models is their inability to accurately represent the diurnal cycle, and studies that have attempted to determine the source of these errors have attributed them to imperfect cloud and convective parameterizations. Many scientists have upheld the importance of climate models reproducing sub-daily fluctuations in order to accurately make long-term climate predictions.

2. Aims

This study aimed to look at a selection of climate models in the latest project phase of the Coupled Model Intercomparison Project (CMIP6) and investigate the key differences between the model-simulated diurnal cycles of outgoing longwave radiation and observational data.

3. Methodology

Data for the top-of-atmosphere outgoing longwave radiation was retrieved from simulations of 5 models at 3-hourly resolution over the period 2000–2014. For a given grid cell, season, and model, the average diurnal cycle was calculated, from which parameters such as the mean, phase, and amplitude could be retrieved. These parameters can be used to recreate the sinusoidal diurnal cycle [2], shown in Fig. 1, and a coefficient of determination between the two datasets gives an indicator of the diurnal cycle signal strength. Grid cells with an R^2 value of less than 0.6 were screened out.

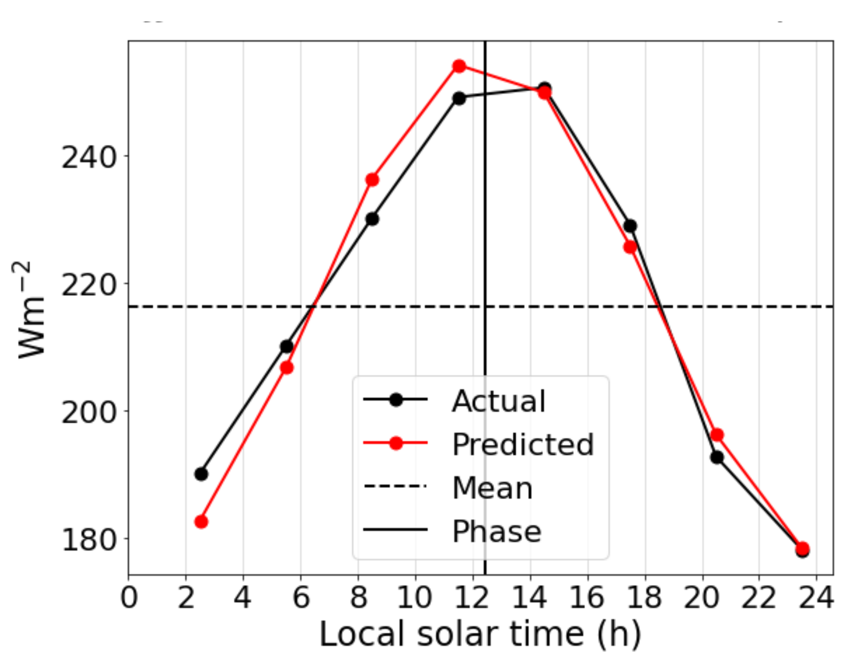

Figure 1: Plot showing the diurnal cycle averaged over the period 2000–2014 for June, July, and August (JJA) for a single grid cell. The black diurnal cycle is from the low-resolution Max Planck Institute Earth System Model (MPI-ESM1.2-LR), and the red curve shows the recreated diurnal cycle. The coefficient of determination between the two datasets gives an indicator of the signal strength. The R^2 value is 0.98.

The observational data used is from the Clouds and the Earth's Radiant Energy System (CERES) measurements.

4. Results

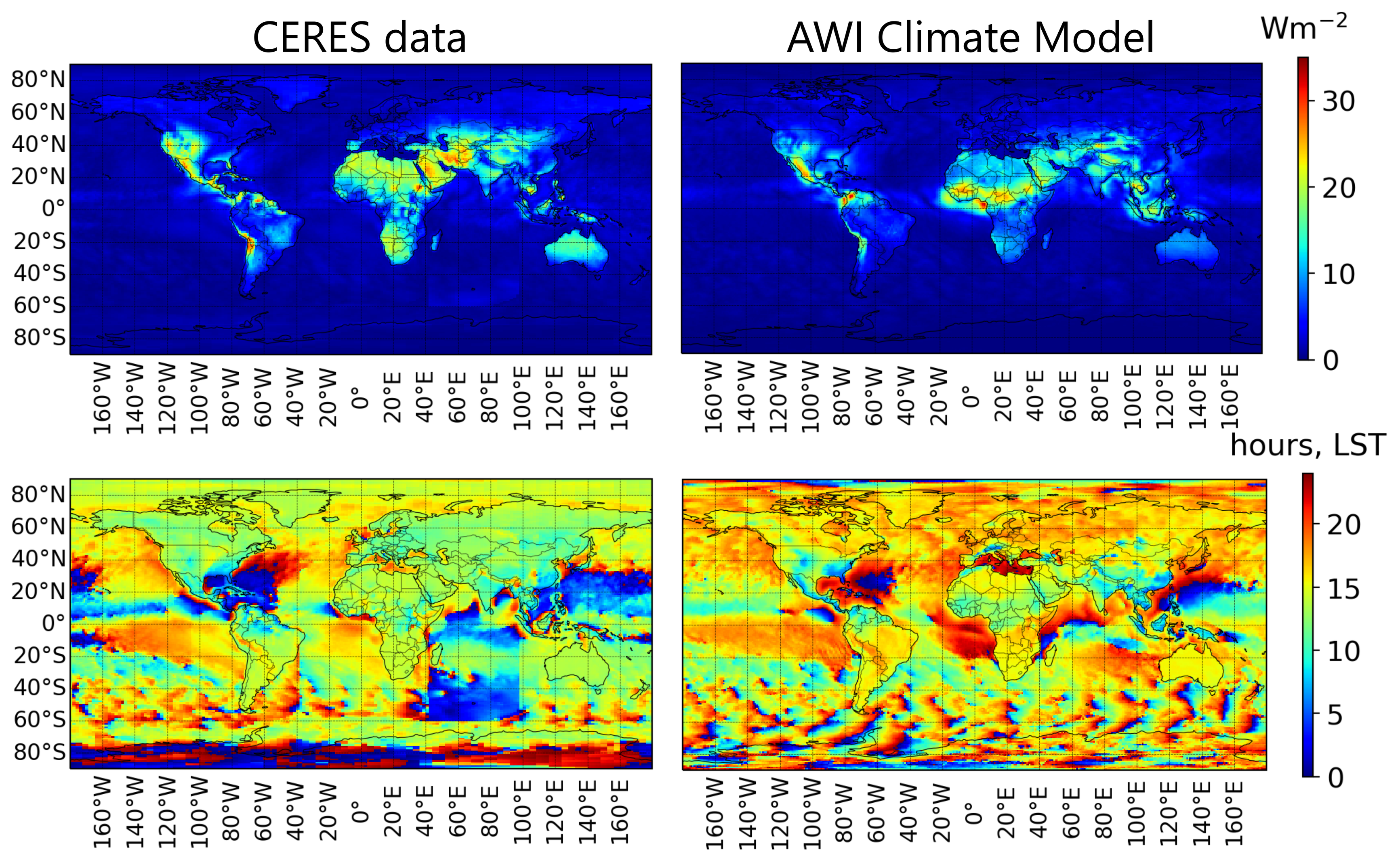

Figure 2: From top to bottom: amplitude and phase calculated from the diurnal cycle averaged over the period 2000–2014 for JJA for CERES satellite data (left) and the Alfred Wegener Institute Climate Model (AWI-CM) (right). Mean and amplitude are expressed in Wm^{-2}, and phase is expressed in hours, given in Local Solar Time (LST).

From Fig. 2, we can see that neither the phase nor amplitude is perfectly simulated by the AWI Climate Model, especially the phase. On a global scale we can see that observations show the phase over land is usually around 1200 LST, however the model shows the phase over land to be much later. Neither the phase nor amplitude is simulated well over deep convective regions, such as over Africa.

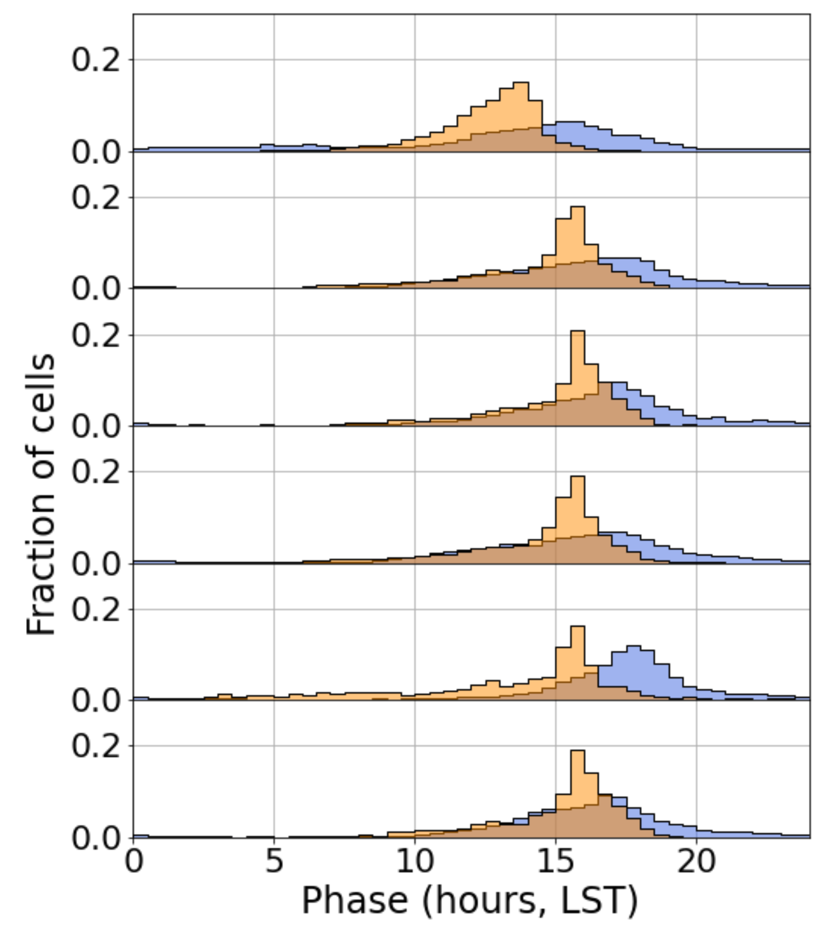

Figure 3: Histograms showing the diurnal cycle phase distribution for land (orange) and ocean (blue) grid cells between 60ºN and 60ºS. From top to bottom: CERES observational data, AWI-CM, AWI-ESM, MPI-ESM-HR, MPI-ESM-HAM, MPI-ESM-LR. All are calculated from the period 2000–2014 for JJA.

From Fig. 3, we can see the phase distributions are relatively similar for the 5 climate models, with a peak at around 1600 LST, which is about 2–3 hours earlier than is seen in the observational data.

5. Conclusions

The simulation of the diurnal cycle of outgoing longwave radiation is still problematic even with the latest climate models. The phase distribution is found to peak over land 2–3h too early. The phase and amplitude are not well-represented in regions of deep convection, confirming that convective parameterizations are an issue for models.

References

[1] Smith, G. L., & Rutan, D. A. The Diurnal Cycle of Outgoing Longwave Radiation from Earth Radiation Budget Experiment Measurements, Journal of the Atmospheric Sciences, 60(13), 1529-1542. (2003). https://doi.org/10.1175/2997.1

[2] Yin, J., & Porporato, A. Diurnal cloud cycle biases in climate models. Nat Commun 8, 2269 (2017). https://doi.org/10.1038/s41467-017-02369-4