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Supporting Information for

The Warming Physics of Tropic World: Part 1 Mean State

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Introduction

We provide here text and figures that could not be fit into the main text.

Text S1. Forcing with CO_2 or Insolation.

The basic responses of Tropic-World to warming are fairly insensitive to the method of forcing, whether insolation increases or CO_2 increases. To illustrate this we have done a series of experiments in which the insolation is set and then the CO_2 is increased by a factor of 2 or 4. Figure S1 shows that the SST dependence of the temperature contrasts, the greenhouse effect, precipitation, subsiding fraction, relative humidity and planetary albedo are relatively insensitive to whether the warming is caused by insolation or CO_2 increase.

Text S2. Solar absorption by water vapor

As the climate warms the relative humidity in the rising and subsiding regions stays approximately constant as a function of temperature, but the specific humidity increases a great deal. This means that the absorption of solar radiation by water vapor increases. Figure S2 shows the solar heating rate as a function of pressure for the subsiding region for average and clear conditions.

In the region between 250 and 150hPa the shortwave heating rate increases about 0.5K/day in going from the C342 case to the C390 case. How much energy does this represent? We can integrate the heating rate in degrees per second through mass to obtain an energy rate using equation (3). Using a heating rate of 1K/day across a pressure depth of 100 hPa we obtain an energy rate of ~12 Wm^{-2}. An albedo change of 1% gives and energy rate of ~4 Wm^{-2}, if the insolation is 400 Wm^{-2}. So the increases in shortwave absorption by water vapor shown in Figure S2 give an absorption increase that is sufficient to cancel small albedo increases associated with low cloud water increases in the control series of experiments.

Text S3. 1-D RCE with ozone
Figure S3 shows the 1-D RCE calculations in which the ozone is specified using the tropical profile as a fixed function of pressure. Compare to Figure in the main text for the case with no ozone. Note that the temperature where the lapse rate kink occurs is 20K warmer with ozone than without. The lapse rate at this kink also becomes smaller as the surface warms when ozone is present.

Text S4. Relative Humidity and FAT
The relative humidity at the top of the troposphere declines with warming in the control simulations. From equation (9) in the main text we see that relative humidity enters in both the emission and the transmission terms of the cool-to-space approximation. To make a quantitative estimate of the effect of such changes on the convective heating structure we apply the relative humidity structures shown in Figure S4b. In order to remove temperature effects and isolate the relative humidity effects, the insolation was adjusted to give the same surface temperature as the relative humidity was changed. The ozone is set to a very small value. The temperature and heating rate solutions for these cases are shown in Figure S4a,c,d. While the temperature profile changes very little because of the assumption of a moist adiabatic lapse rate, the convective heating rate and lapse rate kink shift to warmer temperatures by about 5K.

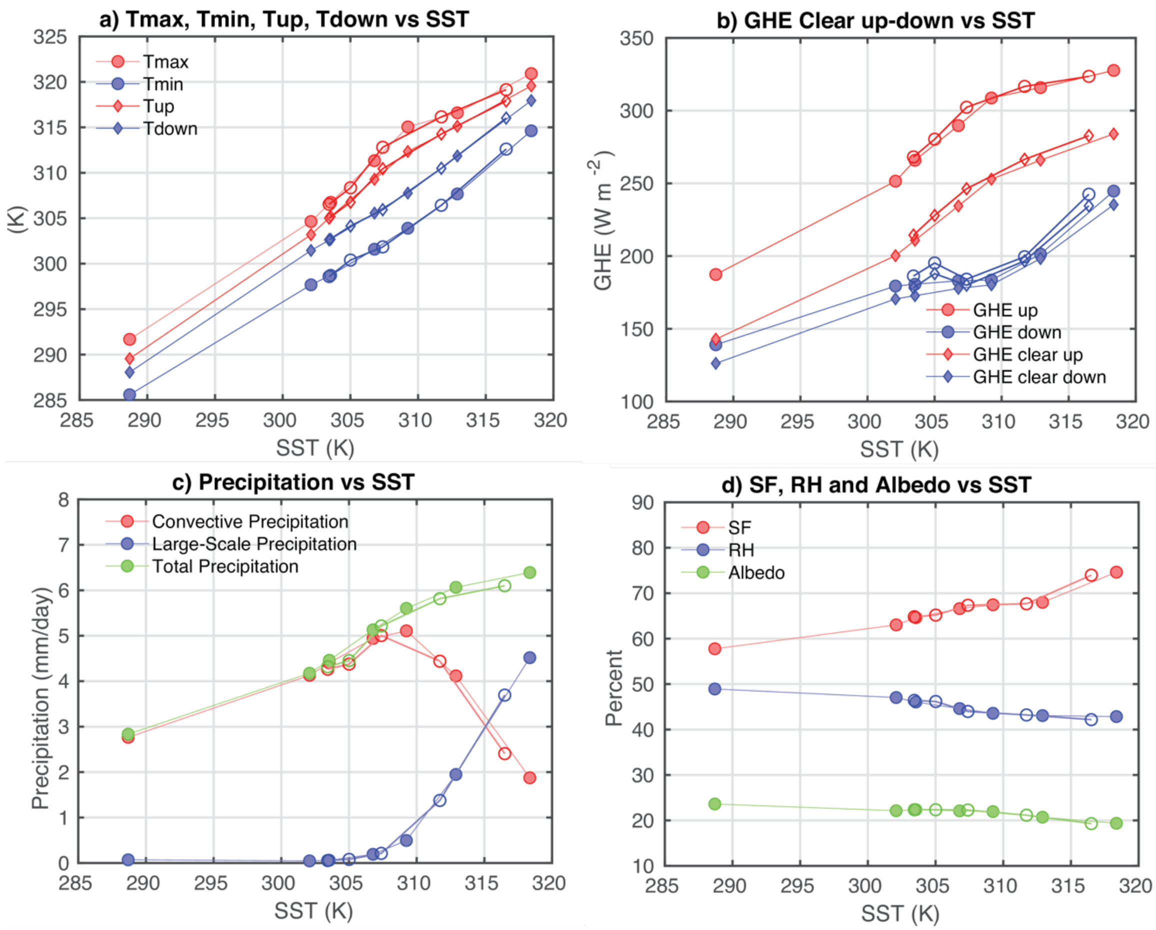

Figure S1. a) Tmax, Tmin, Tup, and Tdown, b) All-sky and clear-sky greenhouse effect in the rising and subsiding regions, c) Total, convective and large-scale precipitation and d) subsiding fraction (SF), mass-averaged relative humidity (RH) and global albedo. Closed circles represent the control simulations forced by insolation increases. Open circles are experiments where the SST was increased by increasing the CO_2 concentration.

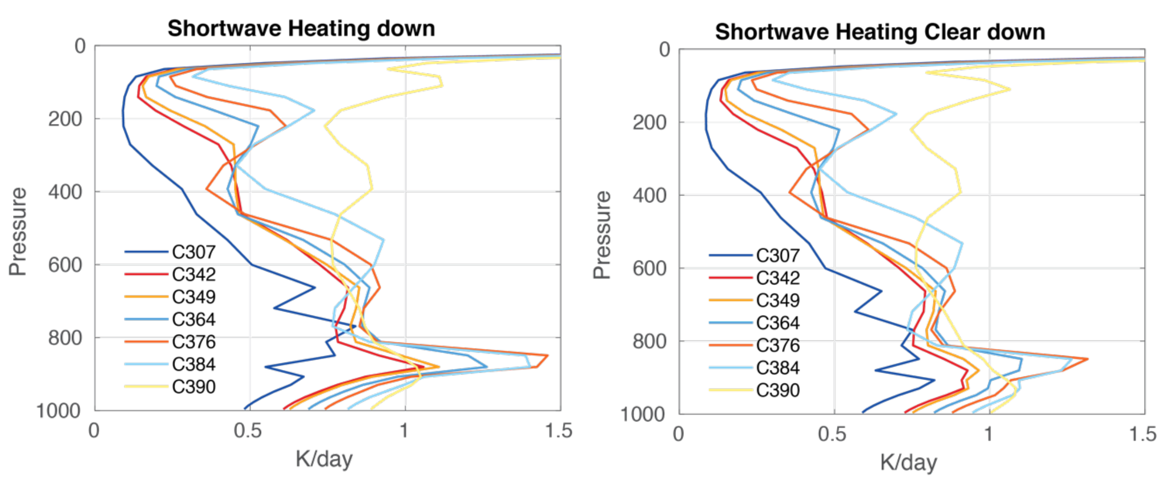

Figure S2. Shortwave radiative heating rate in the subsiding region as a function of pressure for the control cases.

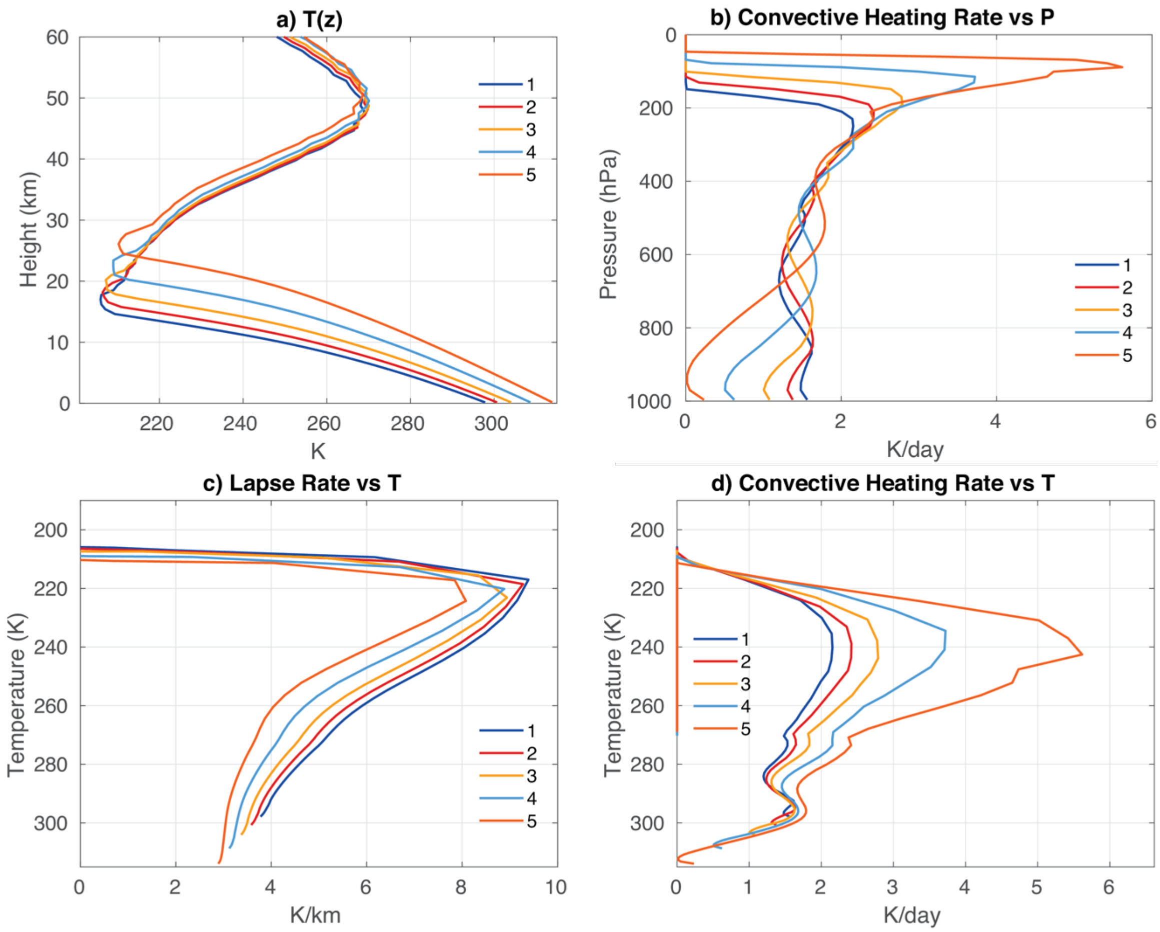

Figure S3. Same as Fig. 10 in the main text, except for the case in which the ozone is fixed to the climatological tropical profile as a function of pressure.

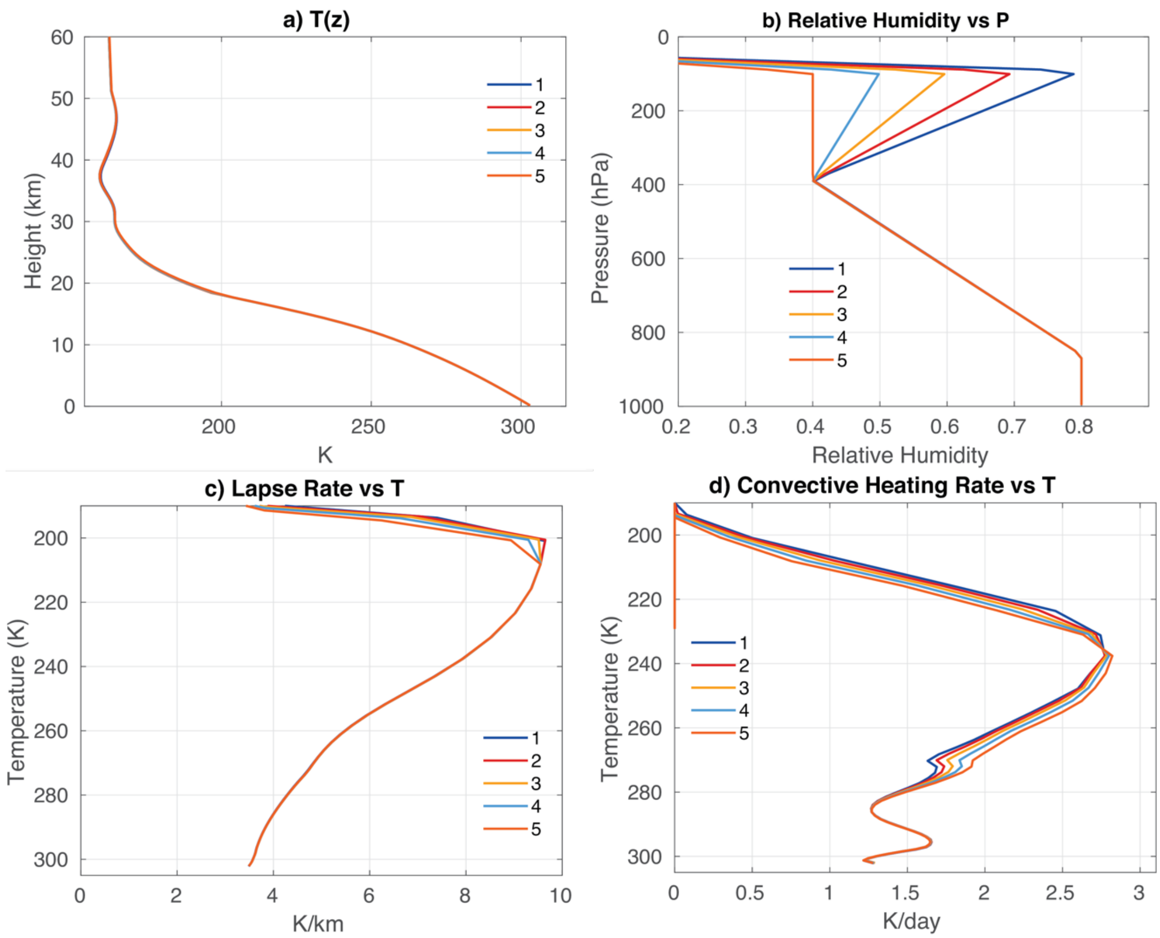

Figure S4. a) Temperature versus height, b) relative humidity versus pressure, c) lapse rate versus temperature and d) convective heating rate versus temperature for cases meant to study the effect of upper tropospheric humidity on the temperature at which the convective heating rate peaks for 1-D RCE calculations to test the sensitivity of the convective heating to relative humidity.

End of Supplementary Information