An analytical model for the H_2O greenhouse effect: state dependence, spatial variations, and nonlinearities

Questions:

- How does OLR depend upon RH when conditioned upon Ts?
- How does CO_2 affect this relationship? OR Something about the fundamental physics of the log dependence, and capturing it with a simple model.
- Should the nonlinear relationship affect how we interpret climate models? (i.e. Why should the broader community care about this paper?)

Figure 1: A global snapshot of OLR, RH, and Ts. This figure highlights the nonlinear relationship between OLR, RH, and Ts. This study differs from others like Koll and Cronin (2018) and Zhang et al., (2020) who study the OLR conditioned upon RH. We will study the OLR conditioned upon Ts. Others have studied RH dependence but with regression (Allan, Shine, … 1990s).

Figure 2: Scatterplot of OLR vs RH conditioned upon Ts. We descend the hierarchy because there is something to be learned at each step, e.g. The 1st panel includes the 6-hourly reanalysis data with PyRADS with CO_2; it points us to column RH's effect on OLR vs RH. The 2nd panel includes PyRADS with and without CO_2; it points us to CO_2's effect on OLR vs RH. The 3rd panel includes PyRADS without CO_2 and PyRADs without CO_2 and continuum; it points us to the continuum's effect on OLR vs RH. The 4th panel includes PyRADS without CO_2 and continuum and the pen-and-paper theory; it points us to thinking about radiation with the CTS approximation and the tau=1 law and the effect on OLR vs RH.

Figure 3: Plot T_{em} vs nu (wavenumber) conditioned upon RH=1 and Ts. We descend the hierarchy because there is something to be learned at each step, e.g. The panels represent each level of the hierarchy and we plot unit optical depth contours. When relevant, we decompose the CO_2 and H_2O contributions.

Figure 4: Plot T_{em} vs nu (wavenumber) conditioned upon RH and Ts with annotations for the contribution to difference in greenhouse effect. In the 1st panel, use PyRADS with CO_2 and continuum. In the 2nd panel use pen-and-paper theory. This is the graphical representation of the pencil and paper theory proposed, i.e. the main conceptual result of the paper.

Figure 5: Scatterplot of OLR vs RH conditioned upon Ts with 6-hourly and monthly reanalysis data. We anticipate a difference in OLR vs RH because of suggestions by Pierrehumbert (1999) and because of the nonlinear relationship explored here. We summarize this result with "the average of the log does not equal the log of the average". We

summarize with a short mathematical expression for why OLR(<RH>) =! <OLR(RH)>. This will tie our theory with radiator fins and the general circulation.

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Note: I don't *need* the following figures to tell my story. These figures deserve their own deep dives and detract from the main story. Instead, make a figure that compares the slopes of OLR vs RH ie. dOLR/dLog$_2$RH vs RH.

Figure 6: GCM experiment in Isca of artificially setting RH and examining the change in globally averaged greenhouse effect. This is similar to a result in Wolf and Toon (2014), but we are more systematic in our exploration. We will also compare this to a planet with a realistic RH distribution. This experiment will tie our theory with radiator fins and the general circulation.

Figure 7: Comparison with clouds as a motivation for the next paper???

Notes:

- Should we parametrize the continuum with an effective absorption coefficient?
- Should we compare results to cloudy data?
- Should we expand upon the climatological impact on radiator fins?
- Should we fix specific humidity (column integrated or at a specified level) rather than relative humidity?
- Does the tropopause temperature in PyRADS matter?