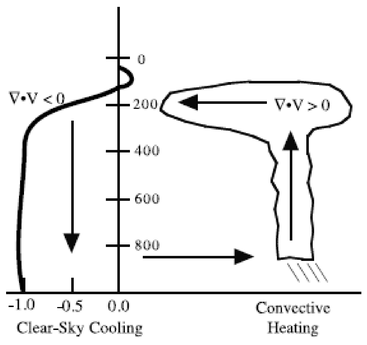
The role of TTL water vapor and ozone in the anvil detrainment of tropical deep convection – a modeling study

Bryce Harrop and Dennis Hartmann
Department of Atmospheric Sciences, University of Washington, Seattle, WA

Background

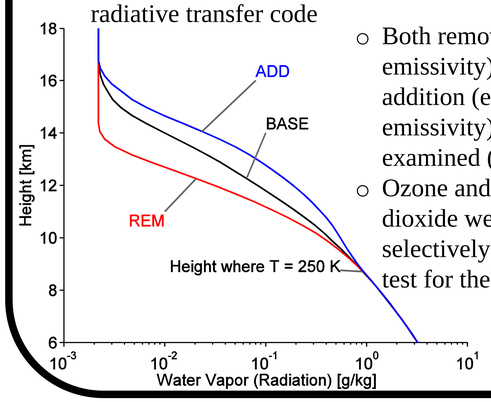
- Hartmann and Larson (2002) proposed a constraint on the cloud top temperature of anvil clouds derived from the Clausius-Clapeyron relation and the emission lines of water vapor.
- Water vapor is the principal emitting gas in the upper tropical troposphere and its decline in concentration is a function of temperature, causing atmospheric cooling to fall off as a function of temperature.
- The Fixed Anvil Temperature (FAT) hypothesis suggests that anvil cloud detrainment occurs at the level where radiative cooling becomes inefficient, thus fixing the cloud top temperature.
- Observational and modeling evidence show support for FAT
- FAT suggests a positive longwave cloud feedback



Hartmann and Larson (2002)

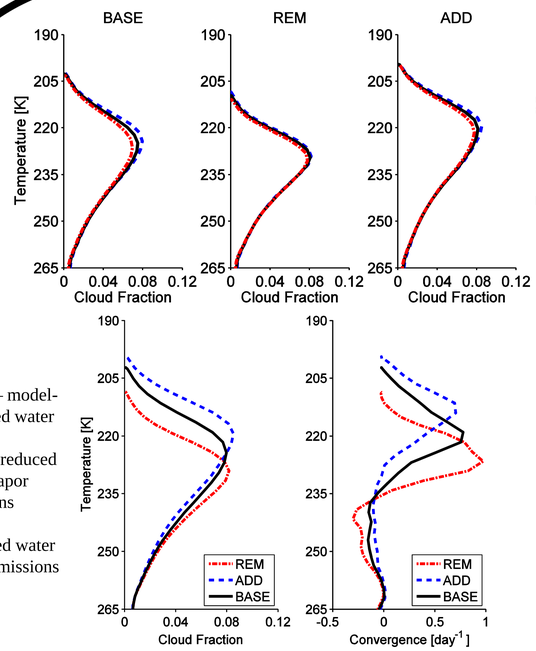
Setup

- Results are generated using a 3D cloud resolving model with a fixed sea surface temperature run out to radiative-convective equilibrium.
- Water vapor emissivity is altered by changing the water vapor concentration values passed to the radiative transfer code
  - Both removal (lowered emissivity) and addition (enhanced emissivity) cases are examined (see left)
  - Ozone and carbon dioxide were selectively removed to test for their impacts.



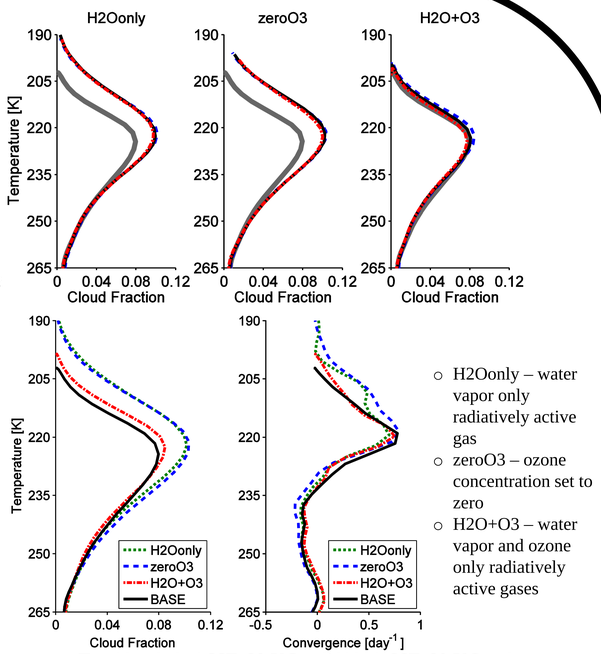
Water vapor and ozone

- BASE – model-predicted water vapor
- REM – reduced water vapor emissions
- ADD – enhanced water vapor emissions



Top: blue dashed SST=28.5°C, solid black SST=30.5°C, red dashed-dotted SST=32.5°C
Bottom: blue dashed ADD, black solid BASE, red dashed-dotted REM; showing cloud fraction (left) and radiatively driven convergence (right).

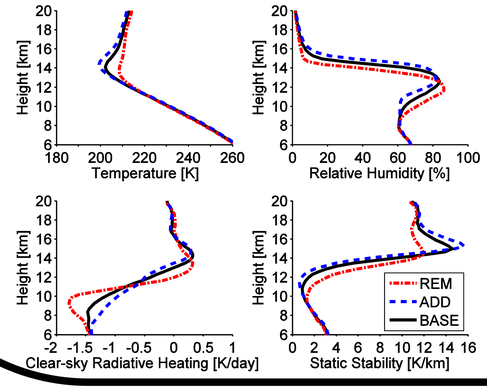
- H2Oonly – water vapor only radiatively active gas
- zeroO3 – ozone concentration set to zero
- H2O+O3 – water vapor and ozone only radiatively active gases



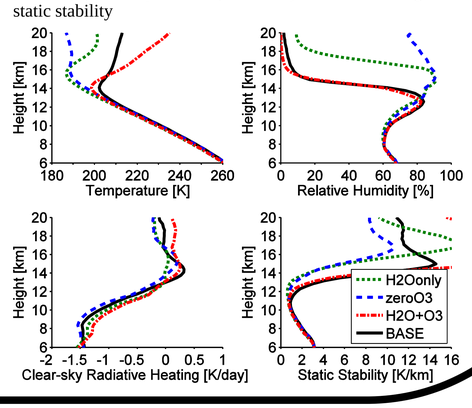
Top: blue dashed SST=28.5°C, solid black SST=30.5°C, red dashed-dotted SST=32.5°C, gray solid BASE with SST=28.5°C shown for reference
Bottom: black solid BASE, blue dashed zeroO3, red dashed-dotted H2O+O3, green dotted H2Oonly; showing cloud fraction (left) and radiatively driven convergence (right).

- Clear sky radiatively driven convergence profiles align with cloud fraction profiles consistent with changes in radiatively active gases
- Changes to water vapor emissivity create significant differences in cloud top temperature
- Increases in SST yield slight increases in cloud top temperature due to fixed ozone profile
- In the absence of ozone, cloud top temperatures are steady with increasing sea surface temperatures
- Carbon dioxide plays only a minor role in these experiments

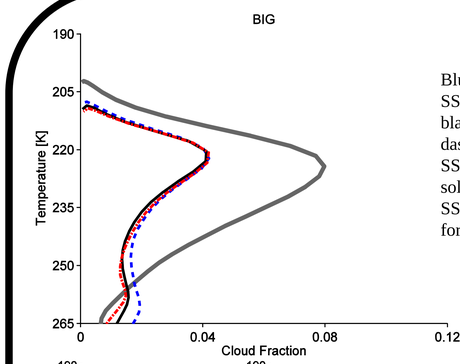
Below: blue dashed ADD, black solid BASE, red dashed-dotted REM; showing temperature, relative humidity (with respect to ice), clear-sky radiative heating, and static stability



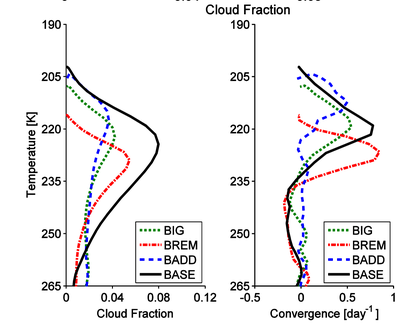
Below: black solid BASE, blue dashed zeroO3, red dashed-dotted H2O+O3, green dotted H2Oonly; showing temperature, relative humidity (with respect to ice), clear-sky radiative heating, and static stability



Cloud aggregation



Blue dashed SST=28.5°C, solid black SST=30.5°C, red dashed-dotted SST=32.5°C, gray solid BASE with SST=28.5°C shown for comparison



- BIG – self-aggregated cloud field
- BREM – same as REM but with self-aggregated cloud field
- BADD – same as ADD but with self-aggregated cloud field

- The same emissivity experiments are performed on a larger domain allowing for self-aggregation of convection to occur, creating a separation between clear and convective regions. The emissivity changes yield the same cloud temperature changes as those in the un-aggregated experiments.
- Even in the presence of ozone, there is no change in cloud top temperature with increasing sea surface temperature.

Conclusions

- Radiative cooling in the clear-sky is shown to be the dominant control of anvil cloud top temperature in the Tropics
- Water vapor is the primary control of cooling; however, ozone and carbon dioxide play non-negligible roles (primarily in the stratosphere where water vapor concentrations are low and ozone concentrations are high).
- Ozone heating (a function of pressure in our model) causes a slight warming of the clouds with increasing SSTs.
- Under self-aggregation, the slight warming of the clouds with increasing SST caused by ozone is diminished.

Acknowledgments

Select References: Hartmann and Larson (2002), Kuang and Hartmann (2007), Kubar et al (2007), Xu et al (2007), Zelinka and Hartmann (2010). Special thanks to Peter Blossey, for help with modeling work. Work funded by NSF grant AGS0960497.