Impact of Thin Cirrus Clouds on Humidity in the UT/LS

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Stratospheric water vapor

- stratospheric ozone chemistry; climate (particularly sensitive to water vapor in the TTL *Solomon et al. 2010*)
- methane oxidation; transport from troposphere
- Lagrangian models give (inter)annual variabilities but dry-biased (30%).
Factors determining dehydration

- Temperature: Mean upwelling through tropopause
- Spatial and temporal variations from waves:
  - Joan and Ji-Eun’s talks
  - Dinh et al. 2012 and 2014 ACP
What about cloud processes?

- Ice absorption of radiation $\rightarrow$ heating $\rightarrow$ increases temperature
- Cloud heating $\rightarrow$ circulation $\rightarrow$ increases ice mass \cite{Dinh2010, Dinh2012}
- How much do cloud radiation and dynamics change temperature?
- Is relative humidity $\neq 100\%$?
- $q_v = RH \times q_s(T)$
Model 2D setup

- $\Delta x = 5 \text{ km}; \triangle z = 30 \text{ m}; \text{TTL domain 3200 km, 90 days (large cloud ensemble)}$
- Mean upwelling constant with mass flux in atmosphere
- Waves $\rightarrow$ Inhomogeneous cloud fields
- Equilibrium state: cloud heating balanced by Newtonian cooling
Three experiments

- **Rad-None**: No radiation
- **Rad-Mean**: Cloud radiative heating applies to entire horizontal domain. Domain warms but no cloud-scale dynamics.
- **Rad-Dynamics**: Warming and cloud-scale circulation are resolved.
Rad-None

Figure: Relative humidity and clouds in Rad-None.

To get 1:1 scale (compare with observations): stretch figure horizontally 300 time.
Rad-Mean

Intermediate simulation: Not shown
Figure: Relative humidity and clouds in Rad-Dynamics.

To get 1:1 scale (compare with observations): stretch figure horizontally 300 time.
Cloud simulations

Ice mixing ratio

Temperature

Relative humidity

Vapor mixing ratio

\( q_i \) (kg kg\(^{-1}\)) \times 10\(^{-7}\)

\( T \) (K)

\( q_v \) (kg kg\(^{-1}\)) \times 10\(^{-5}\)
Cloud simulations

Ice mixing ratio

Radiative heating

Feedback mechanism:

\[ Q_{\text{rad}} \rightarrow \text{Cloud dynamics} \rightarrow \text{Ice mass} \rightarrow Q_{\text{rad}} \]
Table: Cold point tropopause statistics

<table>
<thead>
<tr>
<th></th>
<th>Rad-None</th>
<th>Rad-Mean</th>
<th>Rad-Dynamics</th>
</tr>
</thead>
<tbody>
<tr>
<td>RH$_i$ (%)</td>
<td>112</td>
<td>111</td>
<td>103</td>
</tr>
<tr>
<td>$T$ (K)</td>
<td>190</td>
<td>191</td>
<td>192</td>
</tr>
<tr>
<td>$q_s$ ($10^{-6}$ kg kg$^{-1}$)</td>
<td>2.1</td>
<td>2.6</td>
<td>3.2</td>
</tr>
<tr>
<td>$q_v$ ($10^{-6}$ kg kg$^{-1}$)</td>
<td>2.3</td>
<td>2.8</td>
<td>3.3</td>
</tr>
</tbody>
</table>
When cloud radiation and dynamics are considered:

- $\text{RH}_i$ decreases by less than 15%.
- $q_s$ increases by 55% because of temperature increase.
- $q_v$ increases by 40%.
Interactions between small-scales and large-scales

Cloud-scale processes affect large-scale (tropics-wide) temperature and water vapor