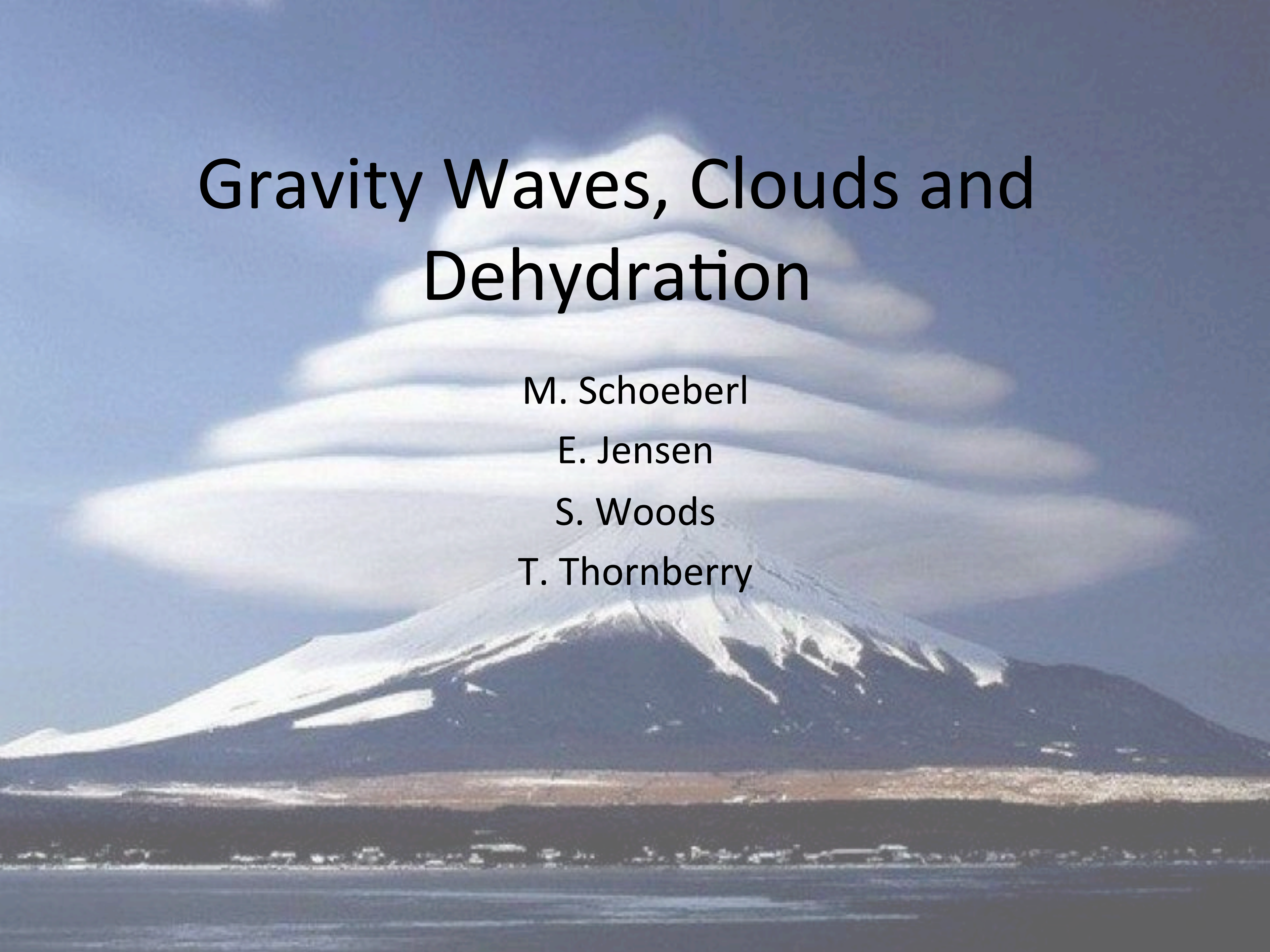
Gravity Waves, Clouds and Dehydration

M. Schoeberl

E. Jensen

S. Woods

T. Thornberry



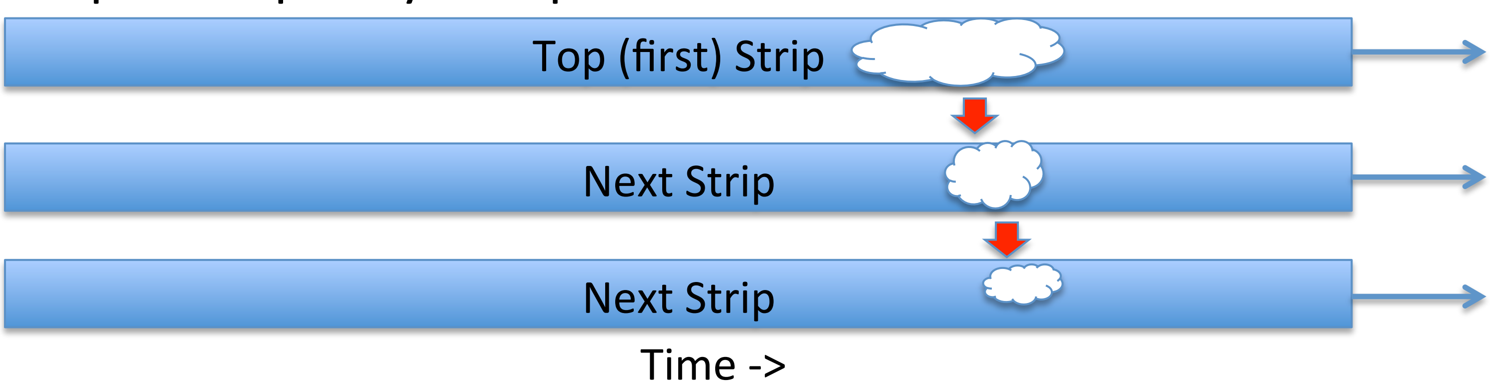
How do gravity waves affect the dehydration process?

- Gravity waves are ubiquitous in the TTL region
- The shorter period waves are not well represented or resolved in global reanalyses.
- The gravity wave lowers the temperature encountered by the parcel (say ~ 1.6K, Kim and Alexander, 2015)

The gravity wave temperature oscillation also affects nucleation and cloud formation – and, ultimately, dehydration efficiency.

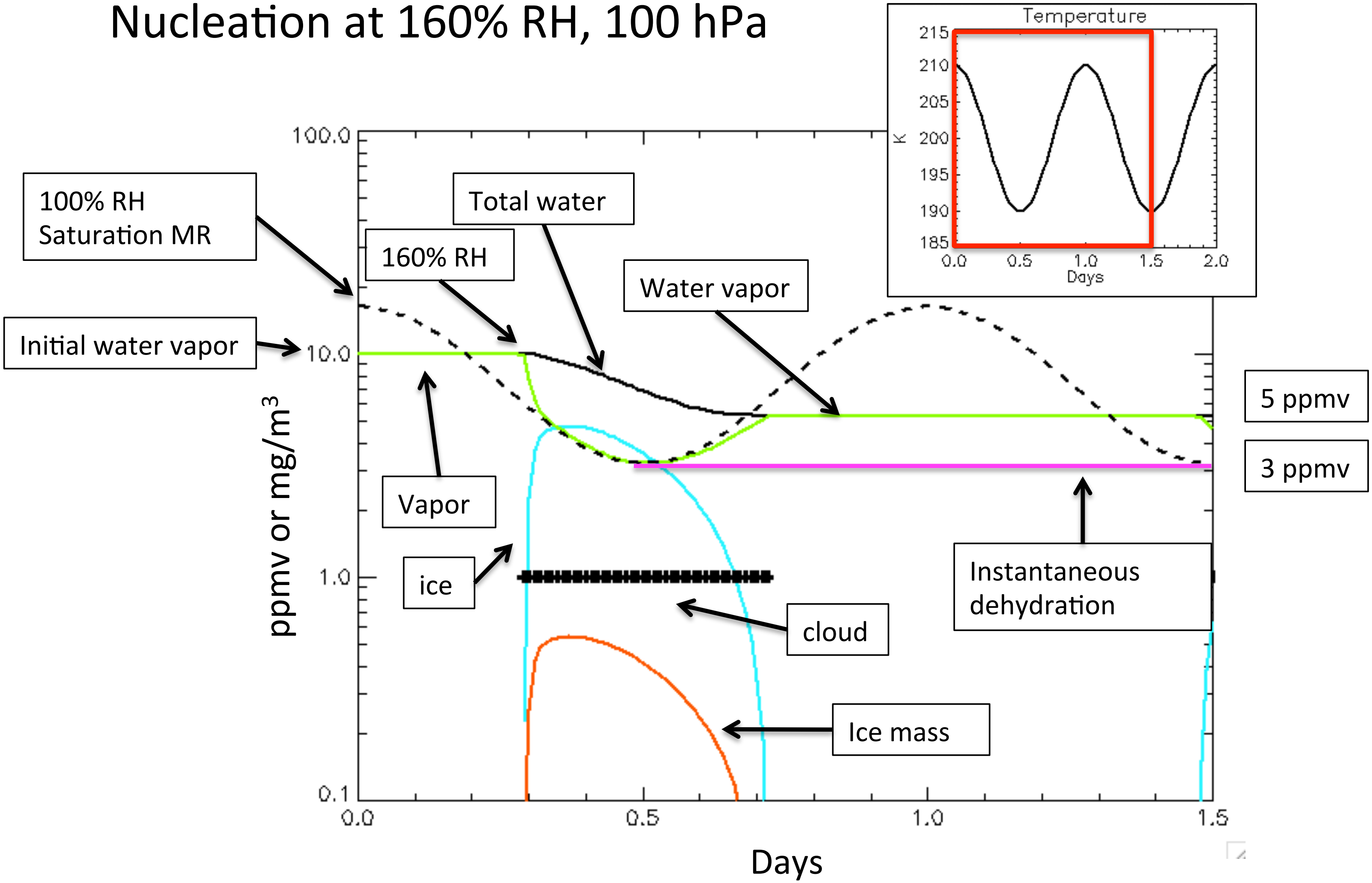
Approach

- Use our Lagrangian cloud model loosely based on Fueglistaler and Baker [2006] to simulate cloud formation and dehydration.
  - Assumes a single equivalent mode; ice particles vary in size and number concentration.
  - Ice particles are initiated at super saturation (160% RH)
  - Number of particles initiated is ~ DT/dt .. higher DT/dt, more ice crystals e.g. Krächer et al. [2006] and others.
  - Ice particles are assumed spheres. (2DS, Hawkeye… mostly true…)
  - Cloud processes include depositional growth, sublimation.
  - Gravitational sedimentation according to Böhm (1989).
- Model is run in 2-D mode using strips – ice moves downward from strip to strip. Layer depth is 80m.



Lagrangian Cloud Model

Nucleation at 160% RH, 100 hPa



Dehydration Efficiency

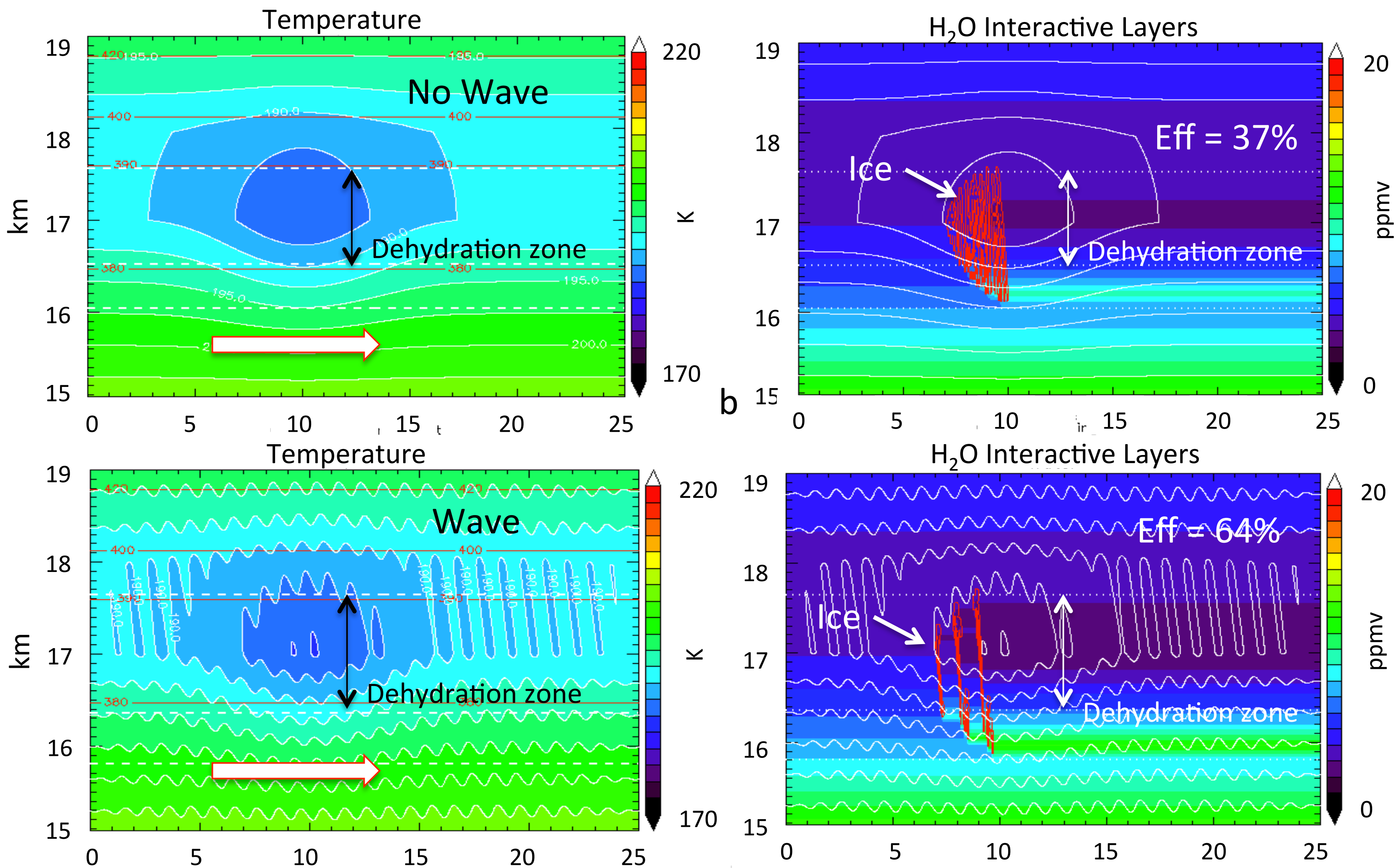
We define cloud dehydration efficiency as

Efficiency (%) =

100* water vapor (wv) actually lost / max possible wv loss

Note that many trajectory calculations assume 100% dehydration efficiency.

A simple experiment with and without a gravity wave. Column of air slowly passes through a cold pool. Initial water profile from a Ticosonde sounding



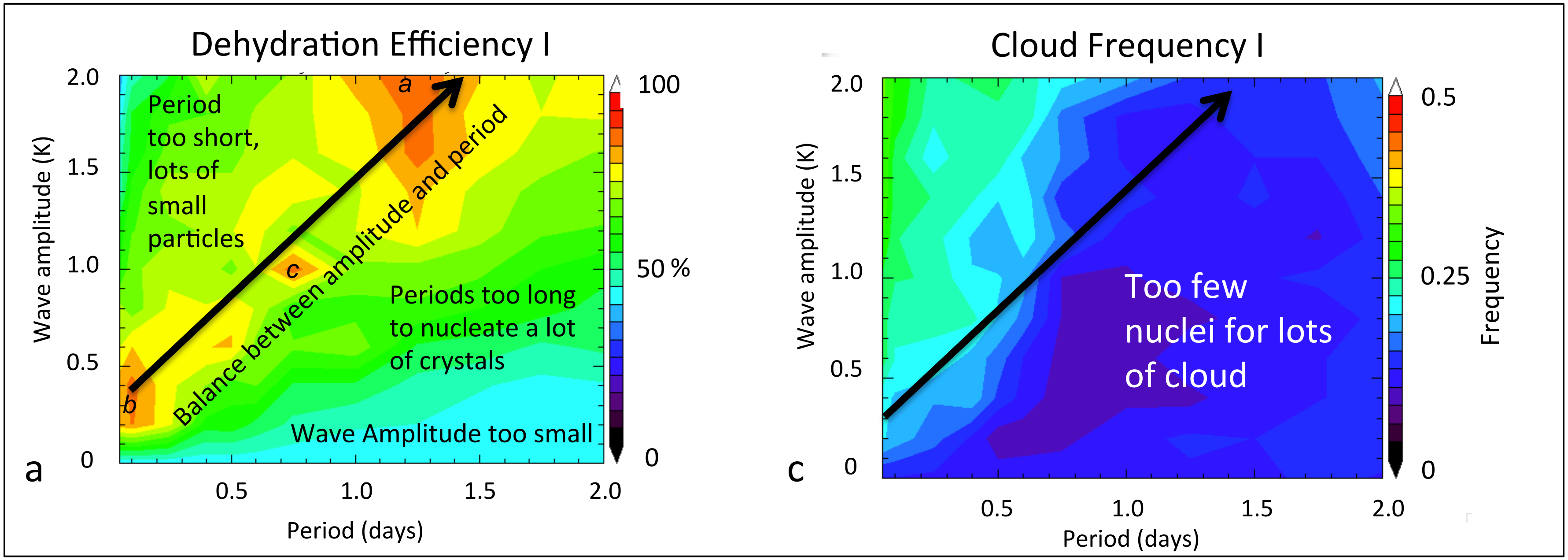
Why does the presence of gravity waves make a big difference?

- If the cooling is slow only a few particles are nucleated once you hit saturation
  - These few ice crystals are not very efficient dehydrators and the system sits near the nucleation threshold, 160% RH, for the whole cooling period.
- When waves are present, the cooling rate is larger many and more ice crystals are nucleated
  - More ice crystals means that the dehydration is generally more efficient. The RH falls below 160%.

Gravity waves improve the dehydration efficiency.

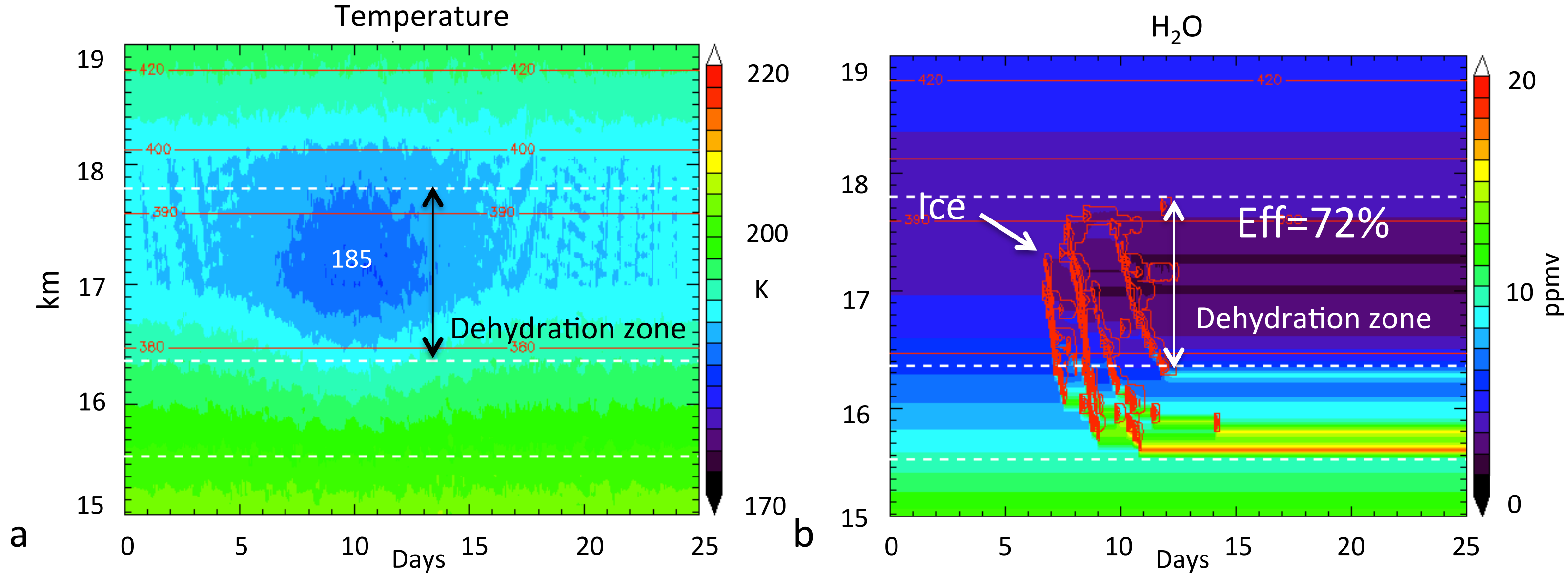
What is the optimal dehydration efficiency?

Maximum dehydration efficiency occurs when a large number of crystals form and remain long enough to grow and settle. If too few crystals form, dehydration is incomplete. If too many crystals form then they grow too slowly – inefficiently dehydrate and then they evaporate in the warm phase.

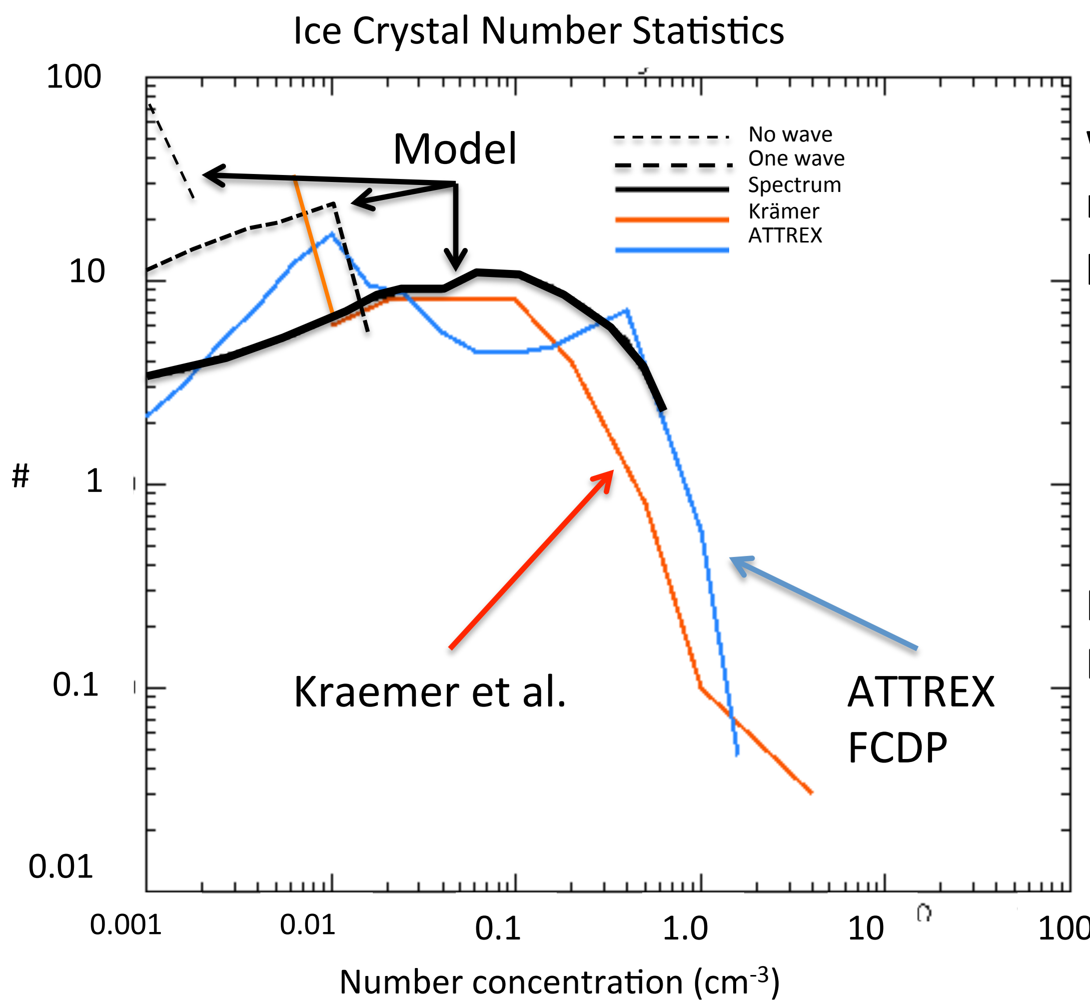


Simulation with a Wave Spectrum

Use a the gravity wave spectrum from Jensen and Pfister [2004] and neglecting periods longer than 2 days with random wave phase and random vertical wavelength between 2-4 km.



Comparison with Observations



With a wave spectrum we get a reasonable distribution of ice particle numbers.

Parcels end up at 120-130% RH
Efficiency = 72%

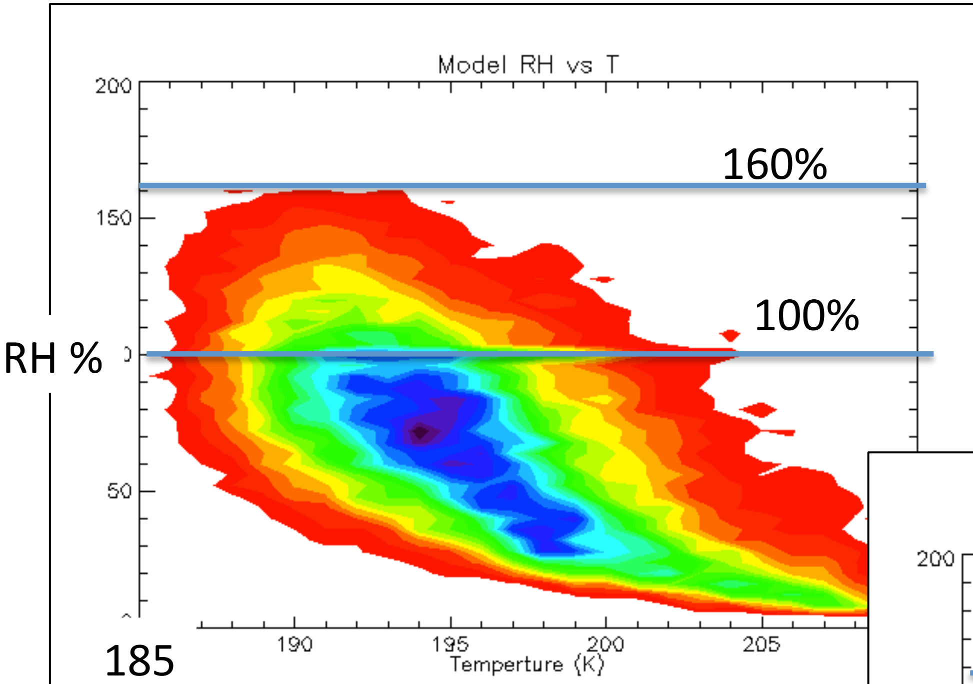
Very Thin Cirrus

Very Thick Cirrus

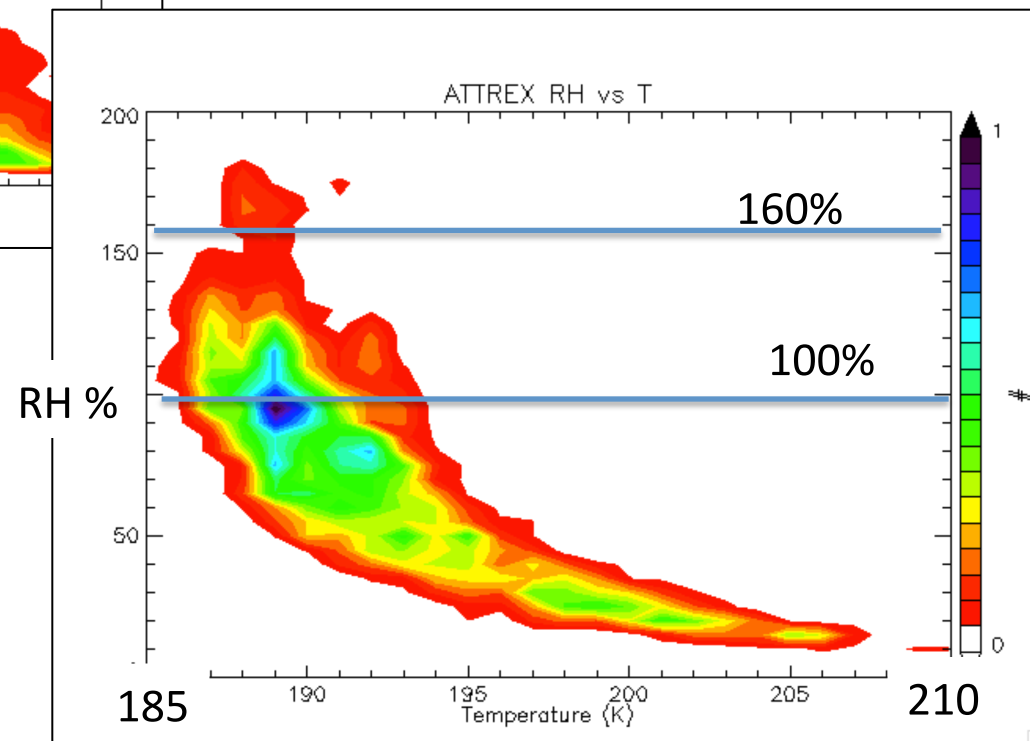
Model & ATTREX RH vs T

No clouds

Model



ATTREX (NOAA)

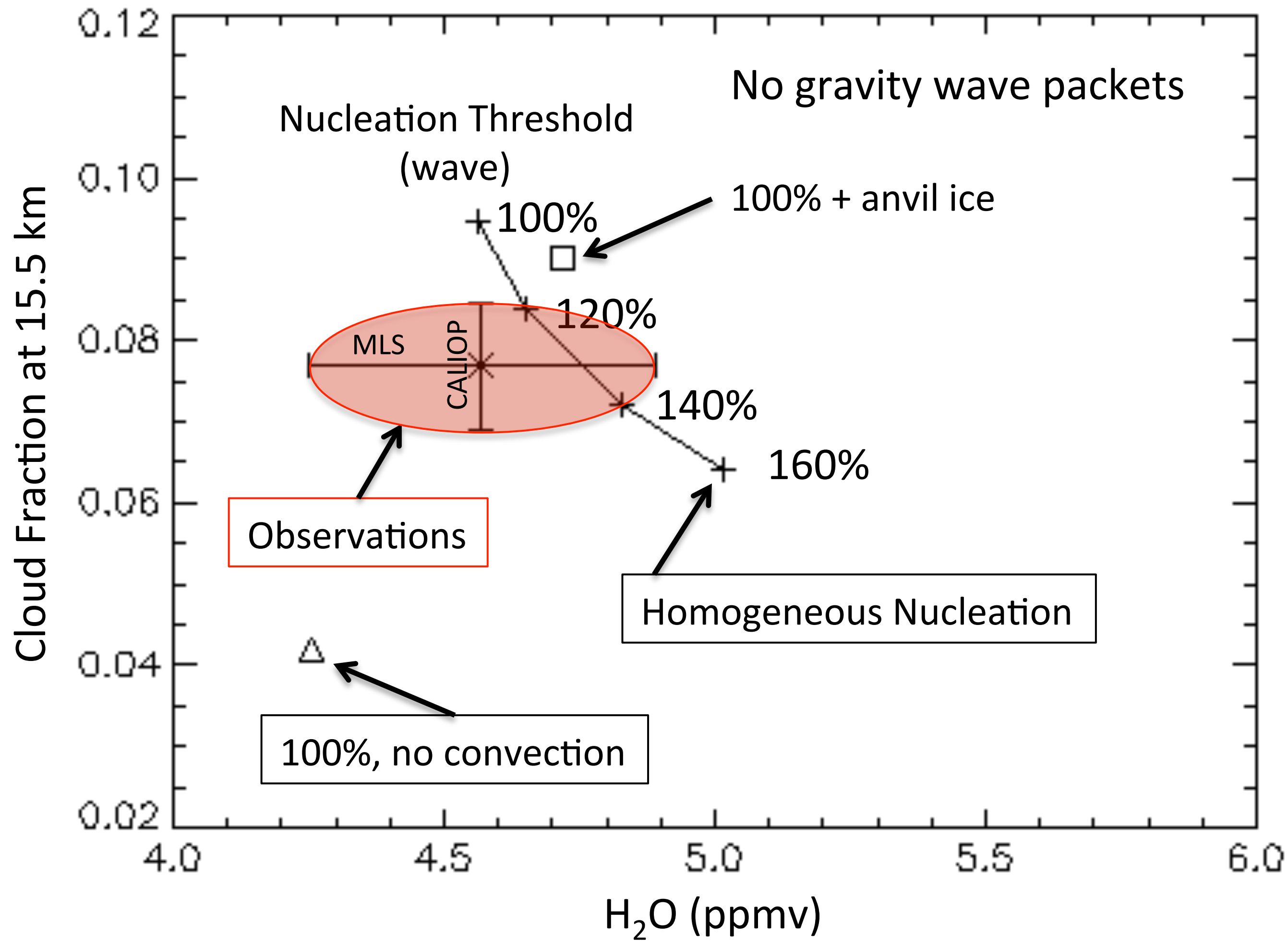


What about the heterogeneous nucleation?

- Heterogeneous nucleation likely occurs at lower threshold than 160% if plenty of IN
- PALMS measurements show that there is plenty of possible IN “stuff” in the upper troposphere
- Thus, from a global perspective, the nucleation threshold might be lower than 160%
- Run the SDW domain filling trajectory model with cloud model* for different nucleation thresholds and compare to observations.

*See Schoeberl et al. [2014], ESS

Effect of Changing Nucleation Threshold



Increasing the nucleation threshold decreases cloud amount and increases water.
Suggests that global average nucleation threshold is below 160%

Summary

- Gravity waves likely play a critical role in dehydrating the TTL
  - Without waves too few ice crystals form to efficiently dehydrate.
- Even with gravity waves present, the dehydration process is not 100% efficient.
- To simulate both the cloud amount and the stratospheric water vapor, global nucleation threshold value of ~130% seems to match the observations - but without g-wave packets. Packets would likely improve agreement with observations.
- Why do models using 100% dehydration work? Basic answer is that the reanalysis used by the models has too warm a tropopause – so using 100% dehydration unwittingly compensates for this error.

Thank you:
ATTREX Project
NASA Grants
NNX13AK25G and NNX14AF15G
L. Pfister, T. Wang and A. Dessler