Simulated effects of overshooting convection on water vapour in the tropical UTLS (upper-troposphere/lower-stratosphere)

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1. Introduction

As a phenomena, the overall influence of overshooting convection on the water budget of the Tropical Tropopause/Transition Layer (TTL) is still open to question.

While there have been arguments that overshooting convection either causes a net dehydration effect or a net moistening effect in the UTLS region, the primary mechanisms/processes governing such water vapour tendencies remain unclear.

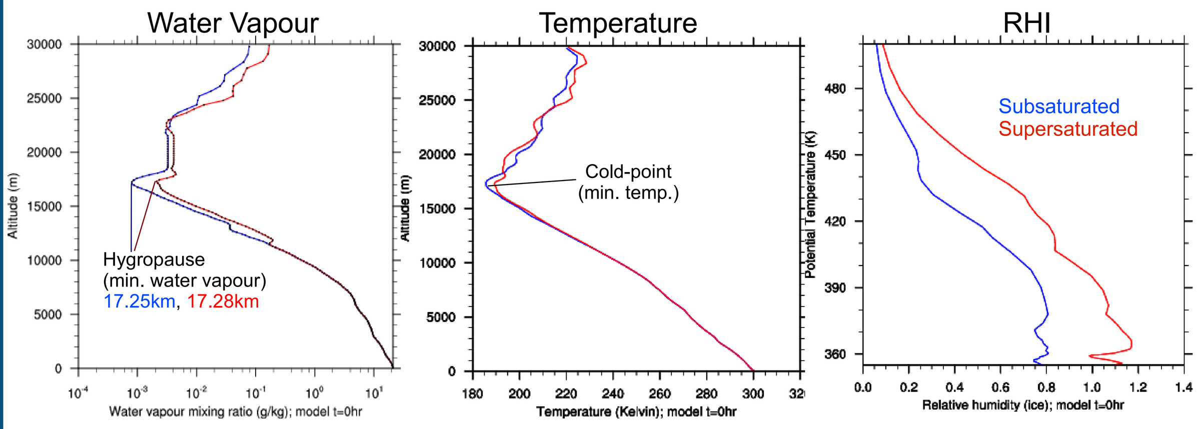
Given that global overshooting events are occurring more frequently than previously thought (e.g. Liu and Zipser, 2005; Dessler et al., 2006; Rossow and Pearl, 2007), it becomes necessary to understand how overshooting convection might regulate the humidity of the UTLS.

In this study, we investigate the dominant processes responsible for any moistening or dehydrating effects by using two 3-D, idealised, cloud-resolving WRF simulations of overshooting convection that penetrates into either a sub-saturated or super-saturated background TTL environment. The aim is to better understand the role that overshooting convection might play as a moisture regulator in the TTL.

2. Model Setup

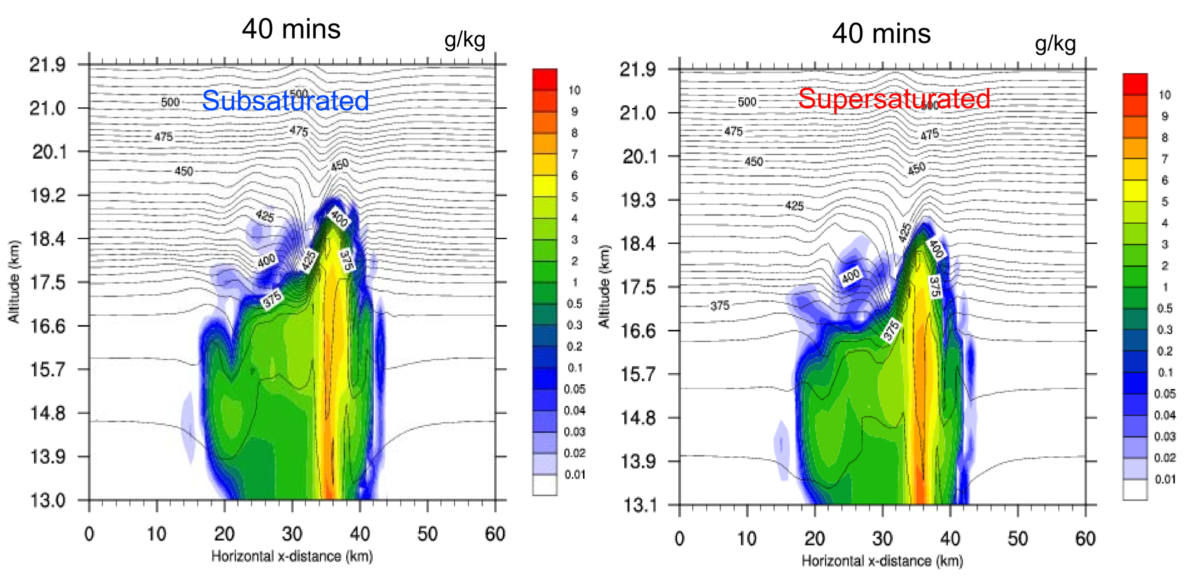
- Advanced Research WRF version 2.2
- 160 x 160 x 30km domain (top 8km Rayleigh sponge)
- $\Delta x = \Delta y = 1$km; $\Delta z = (0.15 – 0.78)$km (stretched)
- Doubly-periodic lateral boundary conditions
- Simplified physics
  - No radiation; no boundary layer scheme
  - Thompson Microphysics (modified to cater for low observed temperatures below -80°C during TWPICE)
  - 1.5 order sub-grid turbulence parameterisation
- Convection in each case is initiated by a domain-centred 3K thermal 'bubble' (20km wide by 3km high)
- 6 hr simulation time
- Incorporated passive tracers (proxies for parcel origin)
  - Initial Height tracer (initialised to geometric height of each model level)
  - Initial Water Vapour tracer (initialised to background moisture value at each model level)

3. Background Profiles



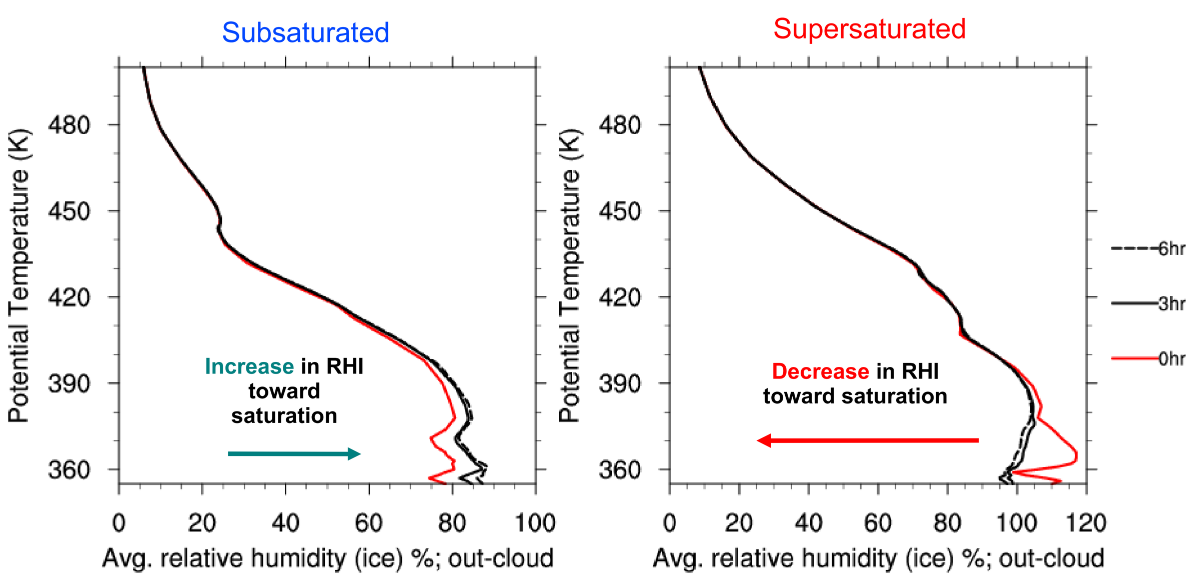
- Taken from 'dry-bias' corrected TWPICE (Tropical Warm Pool-International Cloud Experiment) soundings & smoothed 200 times iteratively
- Imposed a constant water vapour mixing ratio for each case (18.5-21km) to mitigate numerical diffusion effects
- Subsaturated TTL (see RHI vs Potential Temperature plot):
  - Used Darwin 2315 UTC 20/01/2006 sounding
- Supersaturated TTL
  - Below 11.5km – used moisture & temperature values from Darwin sounding
  - Above 11.5km – used values from Mount Bundy 0215 UTC 12/02/2006 sounding
- Both cases used the same background wind profile from the Darwin sounding
- TTL extent → 355-425K (~14.5-18.5km) from Fueglistaler et al. (2009)
  - Consider lower TTL (below 380K) and upper TTL (above 380K)

4. Total Cloud Maximum Overshoot



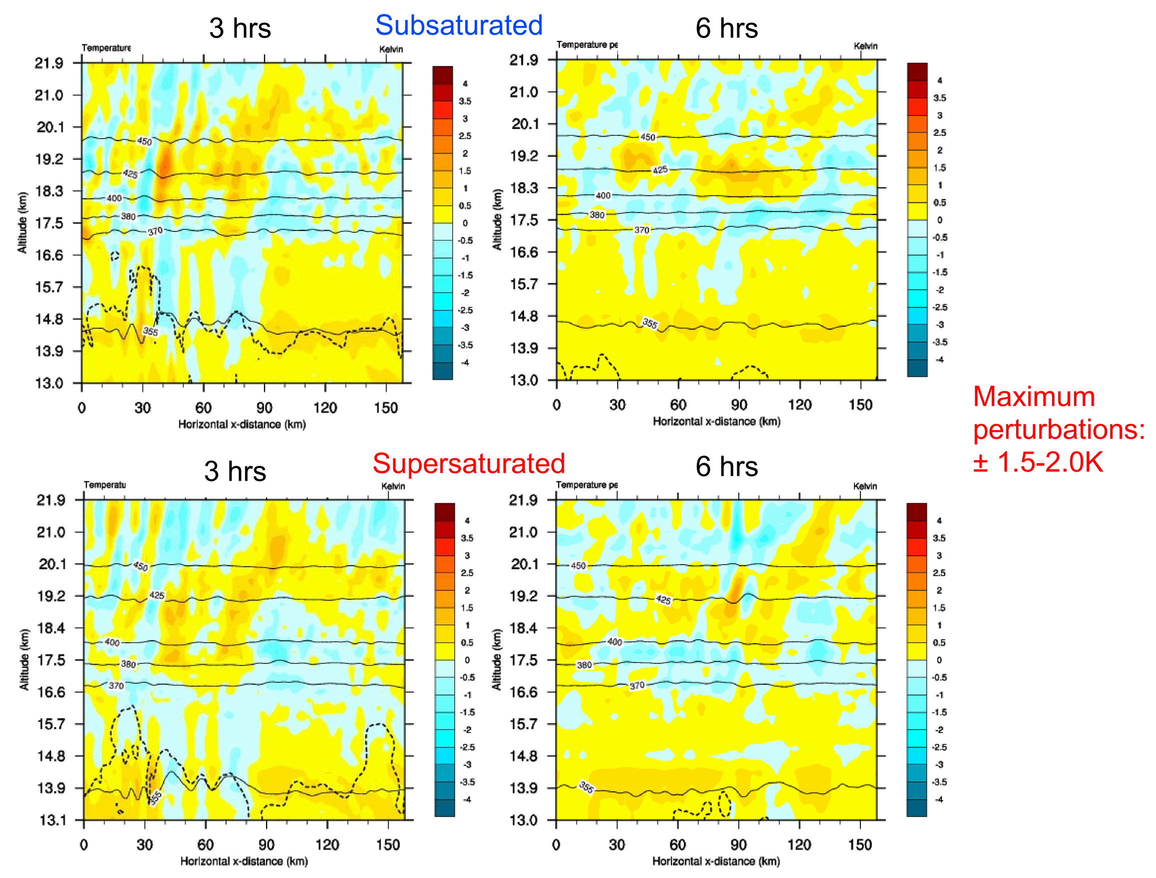
- Same moisture & temperature profiles below 11.5km means:
  - Similar convective dynamics below TTL
  - Similar updraft intensities (>45m/s)
  - Very similar overshoot depth & structure beyond cold-point & hygropause into lower stratosphere

5. Net out-of-cloud effects (t = 6 hrs)



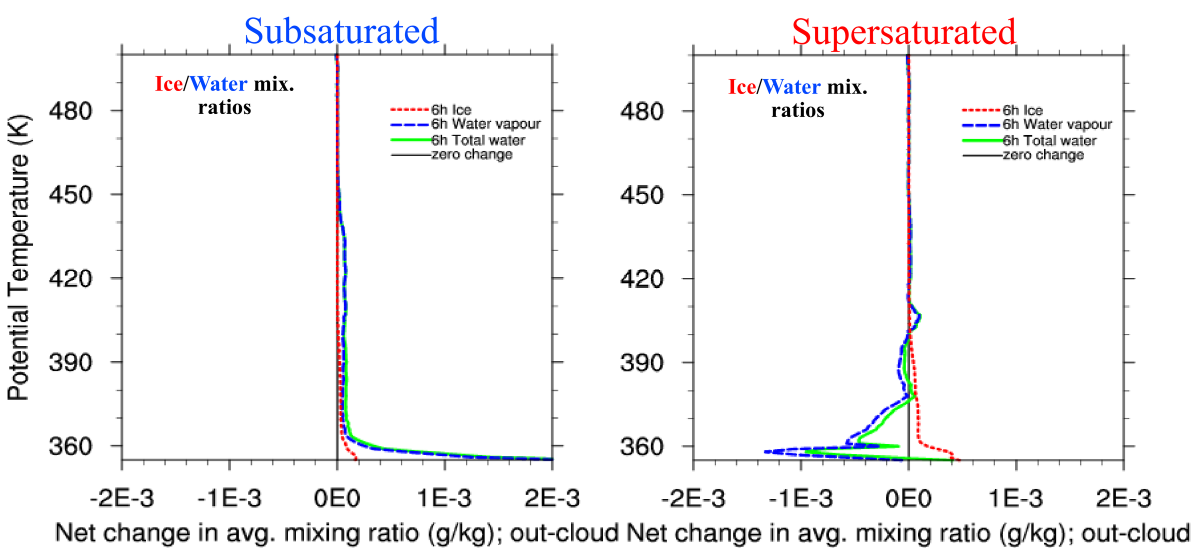
- **In both cases, the ambient environment is driven towards (ice) saturation.**
- In particular, where the lower TTL was most supersaturated (360-380K), the net reduction in RHI was, on average, larger than the increase observed at the same levels for the Subsaturated case.
- Changes in temperature do not fully account for RHI changes (similar perturbation patterns); rather, contrasting changes to the lower TTL water vapour content (up to 400K) constitute the primary cause for the RHI responses in each case.

Y=79km cross-sections of perturbation TEMPERATURE at upper levels



Dashed black line is Total Cloud (0.01g/kg)
Labelled lines are potential temperature levels

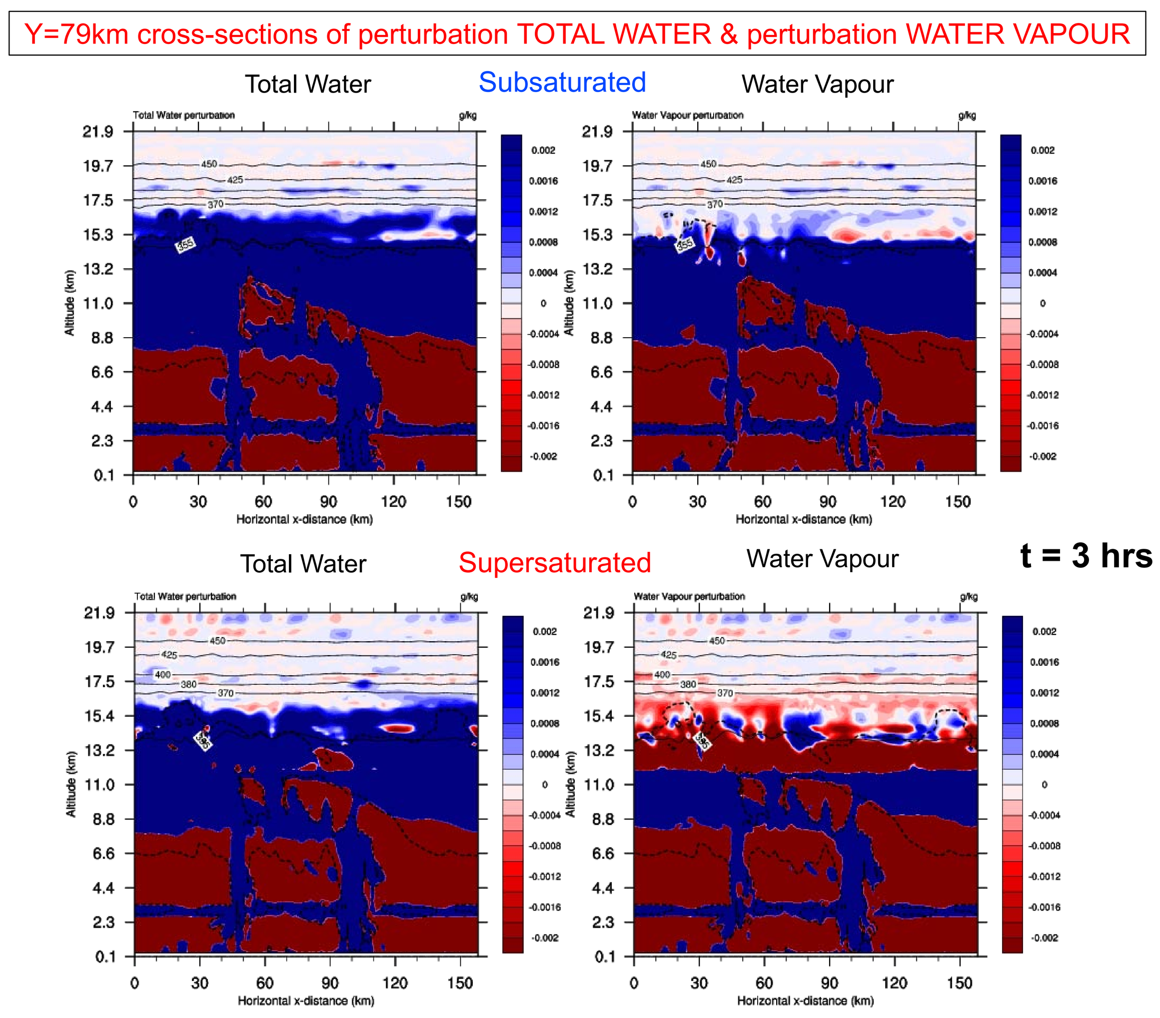
Net change in Total Water vs Potential temperature at t = 6hrs



- Moistening observed in Upper TTL up to 450K in both cases (not discussed here)
- Magnitude of net moisture loss in Supersaturated case between 360-380K exceeds magnitude of net moisture gain in Subsaturated case at same levels.
- Note the presence of ice in both cases in the TTL up to 400K even at simulation end (t=6hrs)

6. 'Ice-Scavenging' effect (Saturation Adjustment)

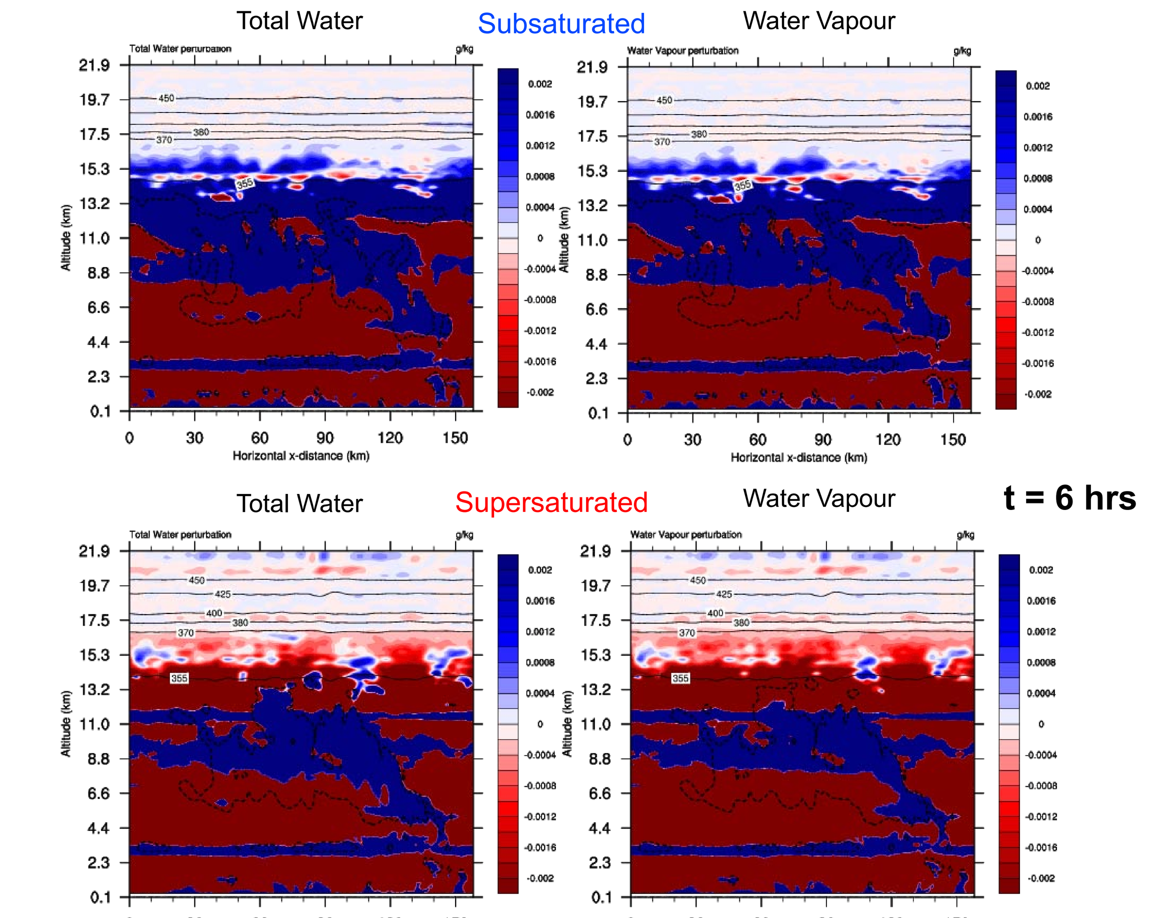
Y=79km cross-sections of perturbation TOTAL WATER & perturbation WATER VAPOUR



- Significant amounts of ice are present in the lower TTL of both cases at 3hrs
- Clear differences in the perturbation Water Vapour fields are seen
- Indicative of the 'ice-scavenging effect' in Supersaturated case, where ice grows immediately by deposition at the expense of excess water vapour
  - When parcel is ice supersaturated, it is extremely supersaturated with respect to water

7. Efficiency of 'Ice-scavenging' effect

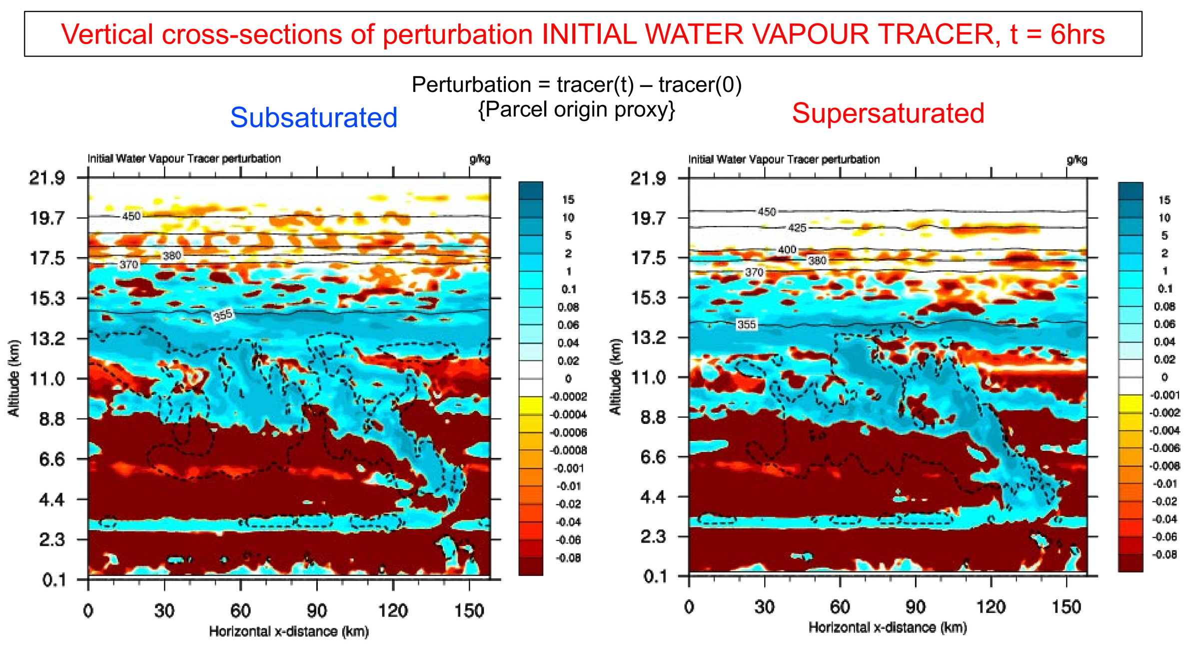
Y=79km cross-sections of perturbation TOTAL WATER & perturbation WATER VAPOUR



- 'Ice-scavenging' effect *does occur* in the Subsaturated case (*but not as pronounced or efficient as in Supersaturated case*)
- However, there is a compensating effect from sublimation due to ice being present in a sub-saturated environment.
- Possible reason as to why the average magnitude of RHI response in the lower TTL differs between the two cases.
- Further saturation adjustments may possibly lead to more hydration (drying) as remaining ice sublimates (grows/sediments) in the two different TTL environments
- Questions: Is the contrast between the two cases caused by different transport? And therefore, how important is overshooting convection to this humidity-regulating process?

8. 'Catalyst' role of overshooting convection

Vertical cross-sections of perturbation INITIAL WATER VAPOUR TRACER, t = 6hrs



- Similar amount/pattern of transport (mainly from below) into lower TTL region between 355-370K for both cases
- Net contrast between the two cases is therefore not because of different transport
- Transport of ice mass in TTL by overshooting convection is an important requirement/catalyst for humidity regulation in the UTLS
  - Sensitivity runs with no and <0.5K thermal perturbations show that TTL supersaturation is maintained when no convection penetrates into the lower TTL.

9. CONCLUDING REMARKS

- Overall influence modulated by ambient relative humidity
  - Net moistening when TTL initially sub-saturated
  - Net dehydration when TTL initially super-saturated
- Microphysics plays dominant role in lower TTL → tends to drive local environment towards (ice) saturation
  - 'Ice scavenging effect' is most efficient when TTL supersaturated → on average, a larger RHI reduction in Supersaturated case was seen compared to the smaller increase observed in Subsaturated case
  - Ice scavenging also occurs in Subsaturated case but is positively compensated by sublimation of ice transported from below TTL
- Results consistent with recent modelling studies (e.g. Jensen et al., 2007; Grosvenor et al. 2007)
  - We simulated TTL dehydration with 3-D dynamics → small-scale mixing better captured; Grosvenor et al. attributed their modelled drying due to the use of 2-D and lack of mixing
- "Overshooting convection plays the important role as catalyst in the process of driving the localised, ambient TTL environment towards saturation"

Acknowledgement

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References

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