Water vapour transport and dehydration above convective outflow during Asian monsoon

How can we understand TTL dehydration with radiative heating rates and simple parameterizations ?

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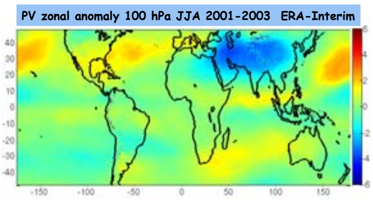
Introduction

The processes governing the entry of water vapor in the tropical stratosphere is debated between two hypotheses : a fast way by direct **convective injection**, and a **slow way** by **freeze-drying** during large-scale ascending motion.

The South Asian summer monsoon region is an area of particular interest, as it is characterized by a **persistent maximum of water vapour** extending from 150 hPa to 68 hPa **[3]**.

The aim of this study is to evaluate, exploiting new observations and new reanalysis, the respective roles of large-scale transport and convection in the formation and maintenance of the **Asian monsoon** water vapour maximum at 100 hPa.

PV zonal anomaly 100 hPa JJA 2001-2003 ERA-Interim

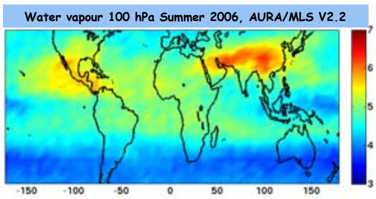


1. Observations

Water vapour measurements from MLS/AURA are obtained at 100 hPa from a version 2 level 2 (V2.2) product for boreal summers 2005 and 2006. As shown below (right), a prominent water vapour maximum of 6.5 ppmv is found at 100 hPa above Asia. This anomaly is above the precision threshold of MLS **[2]** and agrees with the persistent seasonal feature observed by AIRS and HALOE.

The left panel below displays the zonal anomalies of **PV from the ECMWF** analyses at 100 hPa for the same period. The Asian monsoon anticyclone hosting the water vapour maximum appears here as a negative center of -4 PVU, extending from 30 to 110 E and from 20 to 40 N.

Water vapour 100 hPa Summer 2006, AURA/MLS V2.2



2. Methods and Back-trajectories

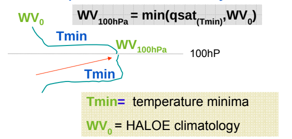
Back-trajectories are computed using reanalyses and forecasts from the ERA-INTERIM (EI) dataset **[4]**. The trajectories are computed using 3-hourly horizontal winds and EI all-sky radiative heating rates (no latent heat component). Using heating rates instead of noisy vertical velocities strongly **reduces the spurious dispersion** of trajectories.

The trajectories are stopped if they encounter a cloud top, detected by the cloud top temperature product of the **CLoud Archive User Service (CLAUS)**, and computed for 3 month otherwise.

We assume complete fall-out of condensate every time a cloud forms. Condensation occurs every time relative humidity exceeds RH_{crit}=K .160%, K accounting for sub-grid temperature variability (K=0.87). The trajectories are initialized :

- by the supersaturated **water vapour mixing ratio at the cloud** top temperature, if they encounter a cloud
- with a **HALOE climatology at their origin** otherwise

Water vapour calculation with trajectories

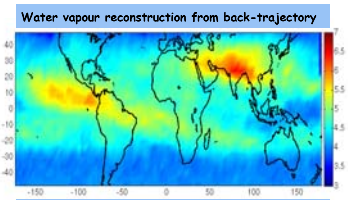


- Sursaturation allowed.
- Condensate and precipitate instantaneously.

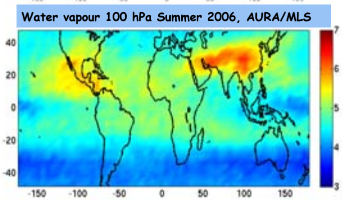
Initialisation: 50°S to 50°N at 100 hPa
Resolution : 1°x1° / 1 run per week
Simulations: from 01/07 to 31/08
Average of summers : 2001, 2002, 2003

3. Reconstructions and Sensibility

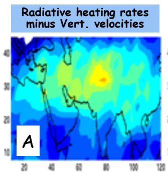
Water vapour reconstruction from back-trajectory



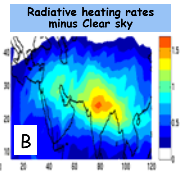
Water vapour 100 hPa Summer 2006, AURA/MLS



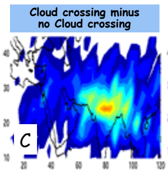
Radiative heating rates minus Vert. velocities



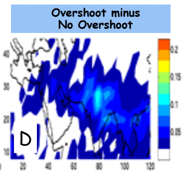
Radiative heating rates minus Clear sky



Cloud crossing minus no Cloud crossing



Overshoot minus No Overshoot



Comparison with MLS observations shows that the patterns and the absolute values of MLS water vapor at 100 hpa measurements are retrieved by our reconstruction.

The Asian monsoon water vapour maximum is reproduced with a mean mixing ratio of 6.5 ppmv extending from Irak to China Sea and from Central India to North Tibet. The water vapour mixing ratios are also retrieved reasonably well over the Oceania minimum and the winter subtropical barrier.

=> This shows that radiative heating rates coupled to simple microphysical parametrizations retrieve accurately water vapour fields**.**

Panel A shows that using standard vertical velocities instead of radiative heating rates yields to a water vapour decreases of 1 ppmv in the Asian monsoon region
=> All-sky radiative heating rates are essential **to reproduce observations.**

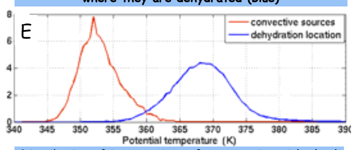
Panel B shows that reducing heating rates to the clear sky component results into much too dry air at 100 hPa.
=>Vertical transport in the TTL is strongly influenced by the radiative effect of clouds**.**

Panel C shows that when parcels are not stopped by clouds intersection, the air at 100 hPa is drier by less than 0.2 ppmv, that is a small deviation compared to the observed moisture.
=> Pure large-scale transport**, rather than convective transport, is identified as the most important component controlling water vapor budget at 100 hPa.**

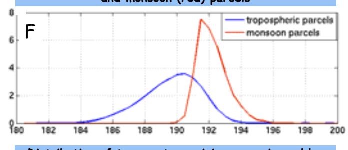
Panel D shows that adding convective overshoots in the microphysical parameterization has almost no impact.
=> Much of the imprint of the convection is 'erased' **due to high probability that overshooting parcels encounter temperatures below saturation temperatures.**

4. Dehydration processes and isolation

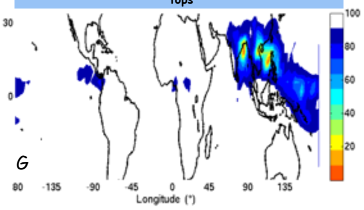
PDF altitude where parcels cross cloud top (red) and where they are dehydrated (blue)



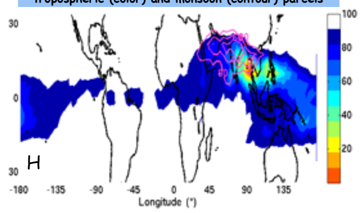
PDF of temperature minima for tropospheric (blue) and monsoon (red) parcels



Distribution of intersections of trajectories with cloud tops



Distribution of temperature minima experienced by tropospheric (color) and monsoon (contour) parcels



Panel E shows that there is little overlap between the potential temperature distributions of the convective sources levels and the dehydration levels.
=> The parcels are lifted up to 360 K by intense convection**, but are** dehydrated by large-scale transport **across the TTL temperature field.**

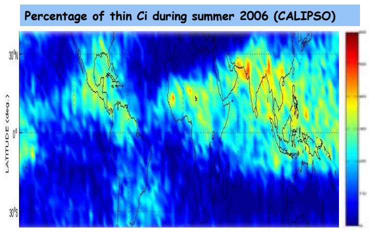
Panel F shows that 60 % of the tropospheric parcels (having experienced T<350K) originate from convective sources located over the north-west coast of the Bay of Bengal and South China sea.
=> Much more localized convective sources **than in [1], and identify little contribution from the Tibetan plateau, African and American monsoon.**

Panel G shows that temperature minima of Monsoon parcels (mixing ratio > 5 ppmv within the anticyclone) are on average 2.3 K warmer than for the tropospheric parcels (Fig. 5d).
=> This warm biais can explain an increase of 1.5 ppmv in water vapour mixing ratio.

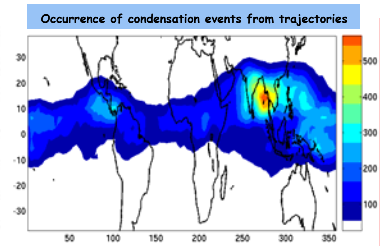
Panel H shows that 75% of tropospheric parcels (colors) are eventually dehydrated in the coldest regions of the Bay of Bengal, China Sea and the Micronesia. 60% of the Monsoon parcels (red contours) are dehydrated over the North of the Bay of Bengal, North-West India and Saudi Arabia.
=> The monsoon parcels are transported Nort-Westward from the convective sources **by the anticyclonic circulation during their** slow ascent**.**

5. Cirrus formation by large-scale ascent

Percentage of thin Ci during summer 2006 (CALIPSO)



Occurrence of condensation events from trajectories



CALIPSO data shows that, during summer, the major part of thin cirrus clouds are found over and dowstream of the Indian monsoon region (left panel). As an attempt to simulate CALIPSO data, we show the location where condensation events occur along parcels trajectories (right panel). Condensation occurs clearly upstream of the cirrus regions. The relative contribution of the Indian monsoon, the American monsoon and sub-saharien Africa regions in cirrus observation is retrieved.

=> This highlight the ability of large-scale circulation to explain **the global distribution and the formation of** cirrus clouds in the tropics**.**

Conclusions

The main result of this work is to show that the observed maximum of water vapour mixing ratio at 100 hPa within the Asian monsoon **anticyclone can be explained by the effect of** large-scale advection **which** translates the crossing of the tropopause to warmer region **than just above most active convection. It is shown that the direct moistening by** overshooting convection plays a minor role **although this conclusion does not necessarily hold for other seasons and other regions.**

Reference

[1]Fueglistaler, S., H. Wernli, and T. Peter, Tropical troposphere to stratosphere transport inferred from trajectory calculations, J. Geophys. Res., 109, D03108, doi:10.1029/2004JD004878, 2004.
[2]Livesey, N. J. et al., EOS MLS version 1.5 Level 2 data quality and description document. Technical report, Jet Propulsion Laboratory, D-32381, 2005.
[3]Randel, W. J., and M. Park, Deep convective inuence on the Asian summer monsoon anticyclone and associated tracer variability observed with Atmospheric Infrared Sounder(AIRS), J. Geophys. Res., 111, D12314, doi:10.1029/2005JD006490, 2006.
[4]Simmons, A., S. Uppala, D. Dee, and S. Kobayashi, ERA-Interim: New ECMWF reanalysis products from 1989 onwards, Newsletter 110, ECMWF, 29-35, 2007.

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