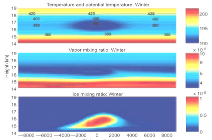
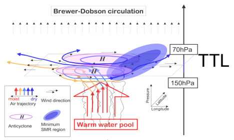
e-mail:
yinai@caos-a.geophys.tohoku.ac.jp

SOWER (Soundings of Ozone and Water in the Equatorial Region):
Dehydration in the TTL estimated from the water vapor match

Yoichi Inai, Fumio Hasebe, Masatomo Fujiwara, Masato Shiotani, Noriyuki Nishi, Shin-Ya Ogino, Holger Voemel, Takashi Shibata, Suginori Iwasaki

Introduction and Purpose


Holton & Gettelman (2001)



Hatsushika & Yamazaki (2003)

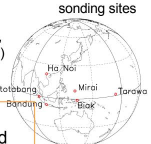
Stratospheric water vapor is controlled by the degree of dehydration the air parcels experienced on their entry into the stratosphere. The dehydration takes place in the tropical tropopause layer (TTL) over the western Pacific, where the air parcels are exposed to the lowest temperature during horizontal advection (cold trap dehydration) (Holton and Gettelman, 2001; Hatsushika and Yamazaki, 2003)).

The cold trap dehydration process (with hydration by convection) in the TTL is apparently consistent with satellite observations. (e.g., Steinwagner et al., 2010) but, it is reported:

Supersaturation inside cirrus with incompre-hensible microphysical property exists.
(e.g., Shibata et al., 2007, Peter et al., 2008, Kraemer et al., 2009, Jensen et al., 2010, ...)

The efficiency of the cold trap is not clear.
Microphysics in the TTL cirrus is not clear.

SOWER sonding sites



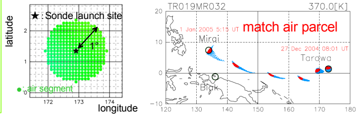
soundings of ozone and water vapor

This study: Efficiency of the cold trap dehydration is estimated by using SOWER networked sonde data and "water vapor match"

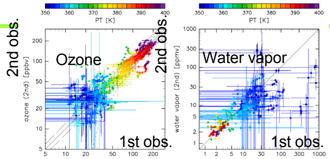
Method ~how to define the "match"~

Connecting by trajectories

"Match" is a technique proposed in studies of ozone depletion in the polar vortex, i. e., observing the same air mass more than twice.
We applied this technique to TTL dehydration.



Sonde data are assumed to be a representative of the value within the circle of 1 ° radius (match radius) centered at sonde launch site . At the grid points in the above circle, a number of isentropic trajectories are initialized. If the air segments advected in the TTL are included in the circle of match radius centered at other observations, they construct the match air parcels.



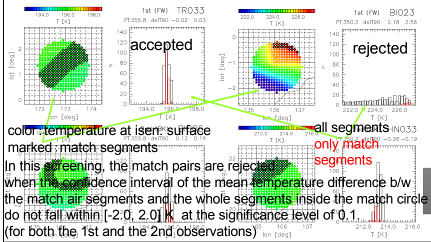
The scatter plots of the 1st v.s. the 2nd observed values of ozone and water vapor mixing ratios for all pairs connected by match air parcels.
(These colors: potential temperature).

Screening

Connected by trajectories, but .. the right side problems should be examined, So, we conduct some screening processes before analyzing "match".

i. Representativeness of match air parcel: the match air parcels must have the representativeness of some area, o/w observed values are not considered as the values of match air parcels.
ii. Validity of isentropic treatment: the isentropical trajectories will not be appropriate as the advection time grows.
iii. Convective penetration: it changes the characteristics of the air mass.
iv. Consistency between sonde data and analysis field: inconsistency b/w them may mean that either of them would have some errors.

For i (Representativeness)



In this screening, the match pairs are rejected when the confidence interval of the mean temperature difference b/w the match air segments and the whole segments inside the match circle do not fall within [-2.0, 2.0] K at the significance level of 0.1.
(for both the 1st and the 2nd observations)

Above probrems are addressed by screening with the right criteria.

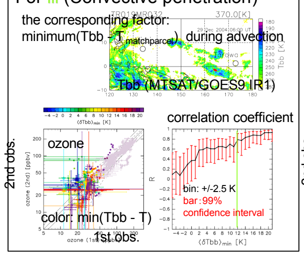
Summary of screening criteria:
For i. the difference of the mean T b/w the match air parcel and whole air segments ≦ 2 K
For ii. advection time ≦ 5 days
For iii. min (Tbb - $T_{matchparcel}$) ≧ 12 K
For iv. -4 K ≦ T_{ECMWF} − $T_{Obs.}$ ≦ 5 K
+ozone consistency b/w 1st and 2nd

The observational pairs surviving "representativeness" screening go to the next step, i.e., screening for remaining problems.

These are examined by using the conservative property of ozone.
The correlation coefficient b/w the 1st and the 2nd ozone mixing ratio is calculated for each subset binned by the value of each corresponding factor.

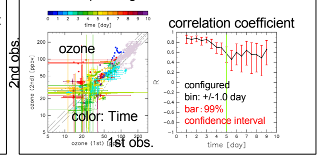
For iii (Convective penetration)

the corresponding factor:
minimum(Tbb - $T_{matchparcel}$) during advection



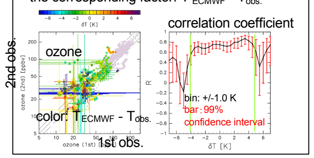
For ii (Validity of isen. treatment)

the corresponding factor: advection time



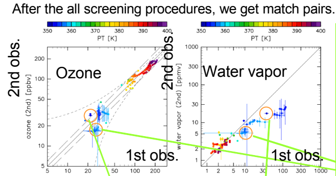
For iv (Consistency b/w sonde & analysis field)

the corresponding factor: T_{ECMWF} - $T_{obs.}$



Result ~dehydration estimated from the match~

After the all screening procedures, we get match pairs.

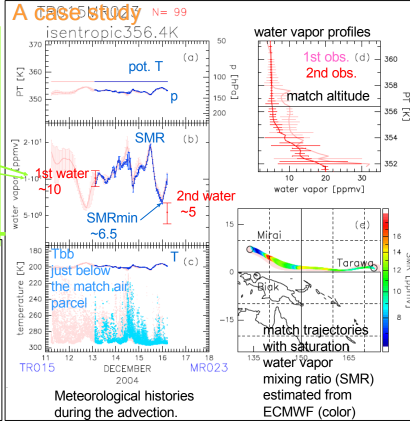


The scatter plots of the 1st v.s. the 2nd observed values of ozone and water vapor mixing ratios for all identified match pairs.

Statistical features

The argument in right fig. apply to all match cases, we found below statistical features as averaged values...
350 - 360 K pot. temperature:
Ice nucleation should start up to RHi 207 ±81% (1 σ) and the air is dehydrated to 83 ±30% (1 σ) of the SMRmin (ratio of 2nd OMR to SMRmin)
above 360 K pot. T:
Only a few dehydrated cases are found in this study.

A case study



Meteorological histories during the advection.

Obs. water vapor (OMR) :
10.2 ±1.5 ppmv (1st)
→ 5.3 ±1.1 ppmv (2nd)
the minimum saturation mixing ratio (SMRmin):
6.5 ±0.2 ppmv

This match air parcel was dehydrated.
It means the ice nucleation must have started before the relative humidity over ice (RHi) reached a value of the ratio of 1st OMR to SMRmin.
The ratio is 157 ±28% and it is the upper limit of supersaturation RHi estimated from this case.

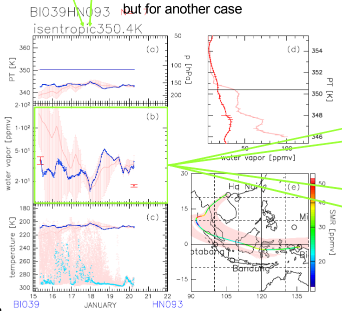
The air parcel was dehydrated to 82 ±19% (the ratio of 2nd OMR to SMRmin).

Discussion and Summary

We try to model the efficiency of dehydration in two terms; the critical value of RHi initiating the ice nucleation (RHcri), and dehydration rate defined as the relaxation time (e-folding time: τ) of supersaturated to equilibrium (100% RHi) state. (This relaxation simulates condensation of the vapor and gravitational removal of ice)

Here, τ is assumed to be independent from T and p taking the fixed value during advection.

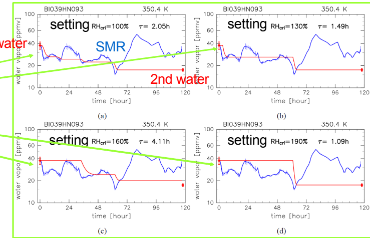
Same as previous case study, but for another case

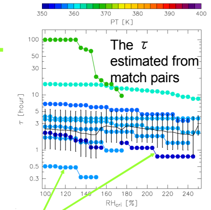


This is explained using the far right figures.

An air mass containing water vapor, the amount is equal to 1st observed water mixing ratio (OMR), is exposed the SMR history with given value of RHcri. And the e-folding time, τ , is determined as the value that produced the closest water amount to 2nd OMR.

The τ are estimated, changing the value of RHcri.





The colored lines indicate the same match but different RHcri given.

As the result, we get the combinations of τ and RHcri estimated from match pairs (this estimation uses only dehydrated cases which obtained the amount of the 2nd OMR).
The values of τ are estimated about 2 - 3 hours regardless of given RHcri values at altitude range from 350 to 360 K pot. T (their temperatures are from ~195 to ~210 K).

Therefore, it is suggested that the dehydration associated with horizontal advection is quite efficient in the lower levels of the TTL. However, the efficiency at the critical altitude (~370 K) is not clear (but, an inefficiency is suggested)

Summary

- "match" technique is applied to TTL water vapor.
- Some match cases indicate dehydration.
- In the lower TTL (350 - 360 K),
  ice nucleation should start ≦207±81%RHi
  and dehydrated to 83±30% of the SMRmin
  the efficiency is quite high (τ : ~2 - 3 hours).
- However, the efficiency at critical altitude (~370 K) is not yet clear, unfortunately.
- The inefficiency in deep TTL may be suggested(?).

SOWER REAPER SOWER
SOWER SOWER