Vertical and horizontal transport of water vapour and aerosol in the tropical stratosphere from high-resolution balloon-borne observations

Sergey M. Khaykin[1], J.-P. Pommereau[1], E. Riviere[2], M. Ghysels[2], N. Amarouche[2], F. Ploegner[3], J.-P. Vernier[4,5], F.G. Wienhold[6], G. Held[7]

[1] **LATMOS**, CNRS, Université de Versailles St Quentin, Guyancourt, France; [2]**GSMA**, Université de Reims Champagne Ardenne and CNRS, Reims, France; [3]**Forschungszentrum Jülich**, IEK-7, Jülich, Germany; [4]Science Systems and Applications, Inc, Hampton, Virginia, US; [5]NASA Langley Research center, Hampton, Viriginia, USA; [6]**ETH** Zurich, Institute for Atmospheric and Climate Science, Zurich, Switzerland; [7]Instituto de Pesquisas Meteorológicas (**IPMet**), UNESP, Bauru, S.P., Brazil

Abstract

We present the results of accurate balloon-borne observations of water vapor, methane and aerosol obtained during a field campaign held during March 2012 in Bauru, Brazil (22.3 S) in the frame of a French TRO-Pico project. The aim of the TRO-Pico project is to characterize the variability and frequency of convective cross-tropopause injections, their contribution at the regional wet season timescale, and to improve the understanding of their role with respect to the cold trap at a wider scale. The balloon payloads flown during the campaign included Pico-SDLA IR laser hygrometers, FLASH-B Lyman-alpha hygrometers, COBALD aerosol backscatter sondes and several other instruments for measurement of gas-phase and particle constituents. An S-band radar operating on the site provided the information on cloud tops. The water vapour profiles obtained by the two different measurement techniques are in excellent agreement, demonstrating high quality of the observations.

The signatures of long-range horizontal transport are inferred from a series of vertical profiles, which show coincident enhancements in water vapour and aerosol accompanied by methane local minima at specific levels in the lowermost stratosphere. Trajectory analysis unambiguously links these features to advection from the southern hemisphere extra-tropical stratosphere, containing more water and aerosol, as demonstrated by MLS and CALIPSO global observations. The intrusion of extratropical air is successfully reproduced by CLaMS chemistry transport model simulation, showing water-rich and methane-poor filaments extending to 20 S.

The signature of local cross-tropopause transport of water is observed during a convectively active day, revealing water vapour enhancements of up to 0.7 ppmv as high as 405 K. These are shown to originate from convective overshoots upwind detected by the local S-band radar. The relative contribution of the horizontal transport and that of local updrafts to the stratospheric humidity is discussed.

Measurements and modeling setup

Measurements

- FLASH-B (Lyman-alpha fluorescence) H_2O profiles
- COBALD scattering ratio @ 940 nm
- Pico-SDLA (tunable diode laser) CH_4 and H_2O profiles
- Aura MLS water vapour v 3.3
- CALIOP scattering ratio
- GOES-12 IR brightness temperature
- IpMet S-band radar cloud tops
- Vaisala RS-92 PTU and wind

FLASH-B water vapour sonde

COBALD backscatter sonde

TRO-Pico balloon campaign, Brazil, 22°S, Feb-Mar 2012

- Zero-pressure plastic 500 and 1500 m³ balloons
- 500, 800 and 1200 g Totex rubber balloons

Launch of 1500 m³ plastic balloon carrying Pico-SDLA

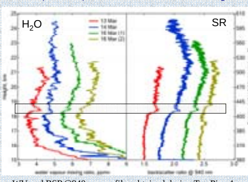
Launch of 1200 g rubber balloon carrying FLASH and COBALD

Modeling

- NOAA **HYSPLIT** model initialized by NCEP GDAS analysis (0.5° x 0.5°, 52 levels)
- FZG Julich **CLaMS** 3-D Chemistry Transport Model initialized by ERA-Interim
- **BRAMS** cloud resolving model

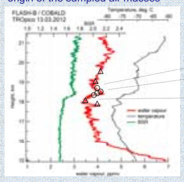
Horizontal transport

Recurring H_2O and aerosol enhancements at 420 K (18.5 km) observed in several soundings

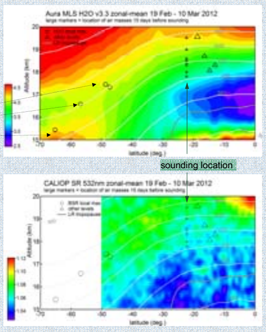


WV and BSR@940nm profiles obtained during Tro-Pico-1 campaign during March 2012. *Successive WV profiles are displaced by 1 ppmv starting from 13 Mar; successive BSR profiles are displaced by 0.3 BSR units starting from 09 Mar.*

Backward trajectories are initialized at different levels to determine the origin of the sampled air masses



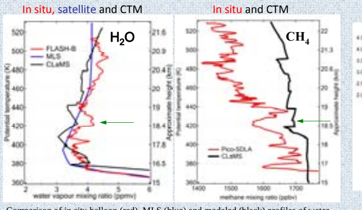
WV, BSR@940nm and temperature profiles obtained on 13 March 2012



- Trajectories initialized at the levels of WV/BSR enhancement trace back from the extra-tropical stratosphere, containing more water vapour (as observed by MLS) and more aerosol (Junge layer)
- H_2O mixing ratio (4.3 ppmv) at the local max. (18.5 km) is fully consistent with that observed by MLS in the southern extra-tropics

CTM simulations of LS composition using CLaMS

In situ, satellite and CTM — In situ and CTM

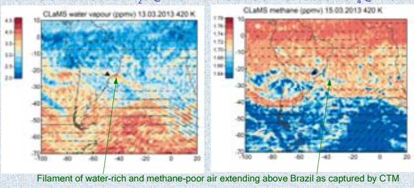


Comparison of in situ balloon (red), MLS (blue) and modeled (black) profiles of water vapour (left, 13.03.2012, FLASH-B) and methane (right, 14.03.2012, Pico-SDLA).

⇒ MLS does not resolve vertical structures but reports consistent values and gradient;

⇒ CLaMS is capable of resolving the process of in-mixing, which is often inaccessible from space-borne observations

CLaMS CTM simulation: H_2O @ 420 K — CLaMS CTM simulation: CH_4 @ 420 K



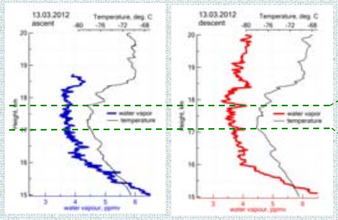
Filament of water-rich and methane-poor air extending above Brazil as captured by CTM

CLaMS simulated fields of water vapour (left) and methane (right) at 420 K with ERA-Int winds superimposed. Sounding location is marked by a triangle..

=> CLaMS reproduces the in-mixing from the extra-tropical overworld: a filament of water-rich and methane poor air at 420 K extending above the sounding location is clearly visible

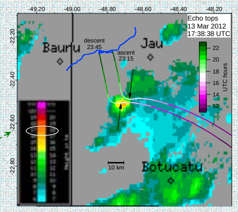
Vertical transport

- Water vapour enhancements at 17.1 and 17.8 km observed in descent and (of lesser amplitude) in ascent profiles are associated with convective overshooting cells upwind detected by the radar 6 hours before the balloon sounding
- Trajectory analysis shows precisely that the air in both humid layers originates from the two different convective cells reaching above 17 km altitude as seen from the radar echo-top images

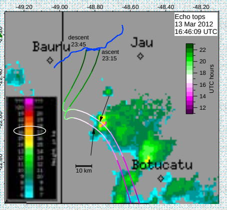


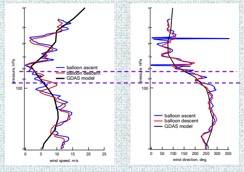
Water vapour and temperature profiles obtained on 13 March during balloon ascent and descent. Horizontal dashed lines at 17.8 km and 17.1 km indicate the levels, at which backward trajectories shown on the right were initialized.

- Larger amplitude of WV enhancements in descent profile than in the ascent profile can be explained by the closer overpass of backward trajectories above overshooting cells in both 17.1 and 17.8 km cases
- Amplitude of WV enhancements related to vertical transport (overshooting) varies between 0.2 and 0.7 ppmv depending on the size of the respective convective cell (3 - 5 km in diameter)

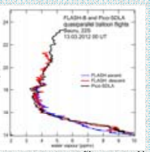


Balloon trajectory (blue curve) on 13 Mar and backward trajectories initialized at the time when the balloon payload was crossing 17.8 km (upper panel) and 17.1 km (lower panel) altitude during ascent and descent. The trajectories are color-coded by UTC time. The black arrows show the location of airmasses along the trajectories at the time of radar image.





Comparison of RS wind speed (left) and direction (right) profiles against GDAS analysis profiles interpolated to the measurement location. Horizontal dashed lines mark 82 hPa and 93 hPa levels, where hydration signatures was observed.

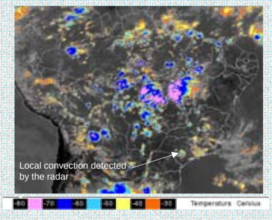


Comparison between water vapour profiles measured by FLASH-B and Pico-SDLA hygrometers flown in parallel on separate balloons launched with a time interval of 40 minutes.

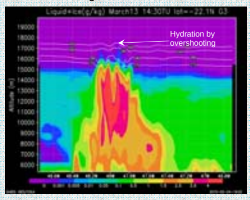
⇒ Accuracy of trajectory calculations is confirmed by the comparison between the measured wind and GDAS analysis

⇒ Accuracy and precision of water vapour measurements are confirmed by the agreement between FLASH-B and Pico-SDLA measurements

GOES-12 IR brightness temperature
13 March 2012 17:30 UTC



BRAMS cloud resolving model simulation for 13 Mar 2012



⇒ CRM reproduces direct injection of water observed in situ

Summary

Observed features in LS water vapour, aerosol and methane vertical distribution are explained by in-mixing from the extra-tropical stratosphere and local vertical transport (convective cross-tropopause overshooting)

⇒ Confirmed accuracy and precision of water vapour profiles and trajectory analysis

Horizontal transport (in-mixing):

- Coincident layers of enhanced water vapour and aerosol result from advection of water/aerosol -enriched, methane-poor air masses from the extra-tropical overworld
- In-mixing event is successfully reproduced by CLaMS CTM

Vertical transport (convective overshooting)

- Sharp peaks in H_2O profile detected on 13 March 2012 are caused by local overshooting hydration produced by small convective cells upwind
- Injection of water directly in the LS at 17.8 km is reproduced by BRAMS CRM

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Presenter info:
Dr. Sergey M. Khaykin
Sergey.Khaykin@latmos.ipsl.fr
LATMOS CNRS, Quartier des Garennes
11 Boulevard d'Alembert, 78820 Guyancourt, France
Tel: + 33 (0)1 80 28 52 06
Mobile: +33 (0) 6 66 88 19 59