Anomalous dehydration of the TTL during January 2013: evidence from balloon, aircraft and satellite observations

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To cite this version:

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Abstract

The goal of this study is to comprehensively document an anomalous dehydration of the Tropical Tropopause Layer (TTL) related to a major Sudden Stratospheric Warming (SSW) in January 2013. The analysis involves the data of balloon soundings of water vapour at various tropical locations using FLASH-B, Pico-SLDA and CFH hygrometers as well as NOAA Water Vapor Imager onboard high-altitude Global Hawk aircraft. Simultaneous water vapour and backscatter measurements by FLASH-B and COBALD sondes provide information on tropopause cloud formation process. Satellite water vapour data by Aura MLS are used to derive the deviation from climatological values. ‘Hypolite’ modeling is applied for locating the tropical cold point potential temperature (Tropical CP) within the TTL to reveal dehydration sources. The TTL dehydration process is characterized after combining the in situ and satellite water vapour observations. All data sets provide evidence of rapid and anomalous dehydration of the TTL throughout the tropical belt shortly after the onset of SSW. In situ measurements around the Cold Point Tropopause (CPT) show up to 2 ppmv of negative deviation from MLS 10-year climatology with extreme water mixing ratios below 1 ppmv in the Western Pacific region.

In situ observations of dehydration

Comparison of selected in situ H2O profiles with the nearest MLS profiles and MLS climatology

Meteorological situation during boreal winter 2012/13

Rapid cooling and lifting of the tropical tropopause linked with Sudden Stratospheric Warming (SSW) on Jan 4, 2013 results in anomalous drying (up to 40% in near-maximal) of the TTL.

Dehydration mostly above WP (21°S..15°N) at large latitudes, with the driest level at each sounding location.

Location of dehydration spots

• In order to find out where the sampled air masses were dehydrated, back trajectories were calculated of backward trajectories ending at the sounding locations were calculated.
• Hypolite model driven by GDAS meteorological analysis (10.5 ± 2.5 horizontal resolution, 95 pressure levels up to 10 hPa, 5 levels in TTL).
• Ensembles of 500 trajectories, spaced by 0.1 / 100 m steps from a 1 x 1 km domain centred at the dew point at each sounding location.
• Calculation of saturation mixing ratio with humidity changes as the sample air were the sampled air could have been dehydrated

Dehydration mostly above WP

Summary

• Major SSW developed on January 6, 2013 resulted in a rapid increase of stratospheric polar temperatures by ~50 K.

• Tropical stratospheric temperatures dropped at the same time;

• As a result of the easterly shear QBO phase and the SSW, the tropical tropopause in January 2013 was anomalously cold (~5 K anomalously and elevated (85 hPa));

• Zonal mean CPT temperature and tropical water vapour mixing ratio decreased by ~2 K and ~0.8 ppmv within the first 15 days of January;

• The water vapor change was likely a result of dehydration associated with the rapid cooling of the tropical CPT during that period;

• High-resolution in situ measurements of water vapour at different tropical locations consistently showed large negative anomalies compared to MLS climatology, reaching ~2 ppmv (70%);

• A revised lifting ratio of 0.54 ppmv (±25%) was detected by CFH above Biak in the Western Pacific region, where cooling and drying were largest according to satellite observations by COSMIC and MLS;

• Trajectory modeling using in situ and MLS data shows that the air sampled in isolated sounded in these different locations has been by sub-sound temperature predominantly above Western Pacific;

• Balloon soundings in Brazil within TroPico-2 campaign:
- Excellent agreement between FLASH-B and Pico-SLDA allows combining their profiles into a single WV series

• Formation of sub-visible cirrus clouds at CPT level with extreme supercooling

Measurement campaigns during January-February 2013

Extensive in situ observations of water vapour all around the tropical belt during the dehydration period

TroPico-2 balloon campaign: Bauru, Brazil (22.5 S, 49 W);

FLASH-B Lyman-alpha and Pico-SLDA TTL balloon-borne hygrometers

SOWER-2013 balloon campaign.

Biak, Indonesia (1.4 S, 136 E) and Hanoï, Vietnam (21 N, 106 E): CFH sondes.

ATTREX aircraft campaign. Tropical Central Pacific;

NOAA H2O instrument onboard Global Hawk UAV,


Location of sounding points

Ensembles of backward trajectories (3 h steps) showing the dehydration spots

Colored markers show where the sampled air was cooled below the frost point

Tabular data and H2O profiles from in situ and satellite observations

• All in situ profiles reveal negative deviation from MLS climatology, reaching ~2 ppmv (~70%);

• Minimum mixing ratio above Western Pacific (0.6 ppmv ±15%), detect ever;

• In situ H2O profiles from Bauru and Pico-SLDA above Bauru and MSL H2O South America 2013

Colored markers show where the sampled air was cooled below the frost point.

Water vapor profiles from FLASH-B and Pico-SLDA, TroPico-2 balloon campaign (Bauru, 22S, 50W) and MSL H2O South America 2013

Hygrometers intercomparison

Comparison of water vapor profiles from 2 hygrometers

• Excellent agreement between FLASH-B and Pico-SLDA above tropics into single WV series

Formation of sub-visible cirrus clouds at CPT level with extreme supercooling

Bauru, 22S

Global Hawk unmanned aircraft during ATTREX (NASA)

Comparison of satellite observations of water vapour implication CASI (NOAA)

Formation of sub-visible cirrus clouds at CPT level with extreme supercooling