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

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CT3LS workshop, Boulder CO, July 2013
Temperature and water vapour anomalies, 2012-2013

COSMIC GPS temperature anomaly @ 82 ± 6 hPa, zonal mean, 2012-2013

Cold anomaly of -5 K

Collocated dry anomalies at 82 hPa and wet anomalies at 146 hPa
Measurement campaigns in Jan-Feb 2013

MLS H2O zonal mean @ 82 hPa, 2013-2013
solid contours=departures from MLS climatology
dashed contour= -2 K temperature anomaly @ 82±6 hPa (COSMIC)

SSW onset, Jan 6
Measurement campaigns in Jan-Feb 2013

**SOWER-2013 balloon campaign.** Biak, Indonesia (1.4 S, 136 E) and Hanoi, Vietnam (21 N, 106 E): CFH sondes.

**ATTREX aircraft campaign.** Tropical Central Pacific. NOAA water instrument onboard Global Hawk

**TroPico-2 balloon campaign.** Bauru, Brazil (22 S, 49 W): FLASH-B Lyman-alpha and Pico-SDL TDL balloon-borne hygrometers

**TicoSonde balloon campaign.** San Jose, Costa-Rica (10 N, 84 W). CFH sondes.
ATTREX – Central Pacific

- Hysplit model driven by GDAS meteorological analysis (0.5° x 0.5° horizontal resolution, 55 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° x 1 km domain centered at the driest level at each sounding location
- Calculation of saturation mixing ratio along each trajectory shows where the sampled air could have been dehydrated

21 days backward traj. from ATTREX GH flight 27 Feb 2013
sub-frost point exposure dates: 18 - 23 Feb 2013
max. time below frost point for 1.5 ppmv: 11 h
SOWER – Hanoi, South-East Asia

CFH @ Hanoi (21 N, 106 E) 12 Jan 2013, 40 s running mean
- blue: ascent
- red: descent

MLS v3.3, Hanoi, 12 Jan 2013, 5° (lat) x 10° (long) x 5d
- black: mean over period/domain (6 profiles)
- green: climatology (119 profiles)
- grey area: range of MLS values

10 days backward trajectories from Hanoi 12 Jan 2013
- sub-frost point exposure dates: 4 - 6 Jan 2013
- max. time below frost point for 2 ppmv: 9 h
SOWER – Biak, Western Pacific

CFH @ Biak (1.4 S, 136 E) 10 Jan 2013 low pass
- ascent 14h
- descent 14h

MLS v3.3, Biak, 10 Jan 2013, 4° (lat) x 10° (lon) x 3d
- mean over period/domain (7 profiles)
- climatology (50 profiles)
- grey area = range of MLS values

0.66±25% ppmv: is it realistic?

0.7 ppmv

8 days backward trajectories from Biak 10 Jan 2013
- sub-frost point exposure dates: 5 - 8 Jan 2013
- max. time below frost point for 0.8 ppmv: 27 h

s.m.r. down to 0.4 ppmv along the trajectories
COSMIC measurements above Western Pacific

**How cold?**

COSMIC temperatures, Western Pacific
6-9 January 2013; 3 S .. 7 N; 150E .. 175 E

177 K

**Where coldest?**

COSMIC saturation mix. ratio @ CPT
7 - 9 January 2013

**How long?**

COSMIC temperature profiles
Western Pacific (10 S .. 10 N, 150 E .. 170 E)
Tro-Pico balloon soundings

TRO-Pico balloon campaigns, Brazil, 22°S, Feb-Mar 2012, Jan-Feb 2013
to study the impact of convective overshooting on stratospheric water budget

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

<table>
<thead>
<tr>
<th>Flight train</th>
<th>Species</th>
<th>Nb of flights in 2012, 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pico-SDLA H₂O + LOAC</td>
<td>H₂O and aerosol</td>
<td>1 1 2</td>
</tr>
<tr>
<td>Pico-SDLA CH₄</td>
<td>CH₄</td>
<td>1 1 2</td>
</tr>
<tr>
<td>Pico-SDLA CH₄ + Pico-SDLA H₂O</td>
<td>H₂O and CH₄</td>
<td>0 2 2</td>
</tr>
<tr>
<td>Pico-SDLA CO₂ + Pico-SDLA H₂O</td>
<td>H₂O and CO₂</td>
<td>0 3 3</td>
</tr>
<tr>
<td>Pico-SDLA H₂O</td>
<td>H₂O</td>
<td>2 1 3</td>
</tr>
<tr>
<td>Pico-SDLA H₂O dry / wet transition period (SMOP)</td>
<td>H₂O</td>
<td>4 3 7</td>
</tr>
<tr>
<td>Mini-SAOZ</td>
<td>O₃, NO₂, H₂O, H₂CO, BrO</td>
<td>2 0 2</td>
</tr>
<tr>
<td>FLASH and COBALD</td>
<td>H₂O and aerosol</td>
<td>7 6 13</td>
</tr>
<tr>
<td>FLASH + COBALD + LOAC</td>
<td>H₂O and aerosol</td>
<td>0 2 2</td>
</tr>
<tr>
<td>COBALD</td>
<td>aerosol</td>
<td>0 1 1</td>
</tr>
<tr>
<td>RS92 radiosonde, series of ~4 RS a day (in number of days)</td>
<td>P, T, U</td>
<td>10 15 25</td>
</tr>
</tbody>
</table>
Balloon soundings is Brazil

TroPico-II balloon campaign, Brazil, 22°S, Jan-Feb 2013

Comparison between FLASH-B and Pico-SDLA hygrometers

Excellent agreement between FLASH and PicoSDLA
Rapid drop of water from 4 to 2 ppmv over a few days
Global evolution of water vapour fields

Aura MLS v4.2 H2O @ 82 hPa 2013 day 1 - 8

7-day averages, stepping forward by 1 day
Clouds and dehydration

FLASH and COBALD flight sampling the same air mass at CPT twice

Cirrus with extreme supersaturation (165%) and low backscatter

Subsaturated cirrus with high backscatter
Summary

- As a result of enhanced tropical upwelling (PW activity related) in January 2013 the LS was anomalously cold (-5 K) and dry (-0.8 ppmv) in the zonal-mean.

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

- A record-low mixing ratio of 0.66 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 analysis suggests that the air sampled by in situ instruments at different locations has been processed by sub-frost point temperatures predominantly above Western Pacific.

- Balloon soundings in Brazil within TroPico-2 campaign:
  - Excellent agreement between FLASH and Pico-SDLA allows combining their profiles into a single WV series.
  - Temporal evolution of dehydration revealed by the balloon profiles is captured by MLS synoptic-scale averages.
  - Simultaneous water and aerosol measurements by FLASH-B and COBALD sondes reveal two types of TTL cirrus clouds with different dehydration potential.
Relationship between temperature and water

MLS tropical (15 S .. 15 N) water vapour at 82 hPa during Austral summer 2012/2013 (blue), 10 year MLS climatology (black) and saturation mixing ratio (dashed blue) calculated from COSMIC GPS temperature and pressure.
Highlights of water vapour anomaly spatial distribution

Early Jan 2013: second drying episode, SSW-related. Maximum drying above most convective regions

Late Jan 2013: development and spreading of dehydration
**Light-weight instrumentation for water vapour and aerosol**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Range of water vapour measurements</strong></td>
<td>0.5...1000 ppmv</td>
</tr>
<tr>
<td>Detection limit</td>
<td>0.1 ppmv</td>
</tr>
<tr>
<td>Integration time</td>
<td>4 s</td>
</tr>
<tr>
<td>Vertical resolution</td>
<td>~ 20-150 m</td>
</tr>
<tr>
<td>Measurement precision</td>
<td>5 %</td>
</tr>
<tr>
<td>Total uncertainty</td>
<td>&lt;10 % (1σ)</td>
</tr>
<tr>
<td>Height range</td>
<td>350...5 hPa</td>
</tr>
<tr>
<td>Weight</td>
<td>0.4 kg w/out batteries</td>
</tr>
<tr>
<td><strong>Light sources</strong></td>
<td>2 LED’s $\lambda_1 = 455$ nm, $\lambda_2 = 870$ nm</td>
</tr>
<tr>
<td><strong>Detector</strong></td>
<td>Wide range silicon detector</td>
</tr>
<tr>
<td><strong>Angle</strong></td>
<td>$\theta = 174°..180°$</td>
</tr>
<tr>
<td><strong>Response time</strong></td>
<td>1s</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>~ 0.5 kg</td>
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</tbody>
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