Mountain wave induced transport of water vapor across the tropopause (DEEPWAVE campaign)

SPARC Gravity Wave Symposium 2016
18th May 2016

Romy Schlage¹, Stuart Beaton², Andreas Dörnbrack¹, Stefan Kaufmann¹, Markus Rapp¹, Johannes Wagner¹, Christiane Voigt¹

¹ DLR, Germany
² NCAR, USA
Why looking into gravity wave induced water vapor transport?

Changes in the distribution of climate sensitive gases have a strong impact on radiation budget of the UTLS and on surface temperatures.
Why looking into gravity wave induced water vapor transport?

Changes in the distribution of climate sensitive gases have a strong impact on radiation budget of the UTLS and on surface temperatures.

Water vapor profile in the atmosphere

Solomon et al., 2010
Measurements during DEEPWAVE

Gas phase H$_2$O:
- VCSEL Vertical-cavity surface-emitting laser (open path)
- CR-2 dewpoint mirror

Meteo data

DLR Falcon-20

NSF/NCAR GV Hiaper

VCSEL data by Stuart Beaton
Case study on 4th July 2014

- GW event with strongest energy fluxes during the DEEPWAVE campaign
- Coordinated flights of Falcon & GV

Water vapor distribution: CR-2 (Falcon) and VCSEL (GV)
Vertical water vapor flux

Fluctuation \[ q'(t) = q(t) - \bar{q} \] \( q(t) \) ... measurement, \( \bar{q} \) ... running mean

Vertical flux \[ \overline{w'q'} = \frac{1}{t_2-t_1} \cdot \int_{t_1}^{t_2} q'(t) \cdot w'(t) dt \]
Vertical water vapor flux

Fluctuation  \[ q'(t) = q(t) - \bar{q} \quad q(t) \ldots \text{measurement, } \bar{q} \ldots \text{running mean} \]

Vertical flux  \[
\overline{w'q'} = \frac{1}{t_2-t_1} \cdot \int_{t_1}^{t_2} q'(t) \cdot w'(t) dt
\]

Example for FF05: Leg 1 @ ~ 8 km
Water vapor fluxes from Falcon FF05 and GV RF16

- Up- and downstream region: no significant water vapor flux
- Waves are propagating through tropopause
Water vapor fluxes from Falcon FF05 and GV RF16

- All GV legs @ 12200 m

Water vapor flux @ each leg +/- 4 [ppmv*m/s]

- Time developing over 5 hours

- Amplitude decreases with time → gravity wave event weakened
Mean water vapor fluxes

- Vertical mean flux over whole legs is small but high local max. and min. values show significant transport.
- Tendency indicates mixing processes but scale cannot be resolved by the measurements.

<table>
<thead>
<tr>
<th>FF05</th>
<th>Mean vertical H₂O flux [ppmv*m/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leg1</td>
<td>-3.19</td>
</tr>
<tr>
<td>Leg2</td>
<td>0.78</td>
</tr>
<tr>
<td>Leg3</td>
<td>0.17</td>
</tr>
<tr>
<td>Leg4</td>
<td>(-0.002)</td>
</tr>
</tbody>
</table>
Mean water vapor fluxes

- Vertical mean flux over whole legs is small but high local max. and min. values show significant transport
- Tendency indicates mixing processes but scale cannot be resolved by the measurements

**Integrated water vapor flux for FF05**

<table>
<thead>
<tr>
<th>Leg</th>
<th>Mean vertical H$_2$O flux [ppmv*m/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leg1</td>
<td>-3.19</td>
</tr>
<tr>
<td>Leg2</td>
<td>0.78</td>
</tr>
<tr>
<td>Leg3</td>
<td>0.17</td>
</tr>
<tr>
<td>Leg4</td>
<td>(-0.002)</td>
</tr>
</tbody>
</table>
Can models help to answer the question of irreversible trace gas transport?

- WRF simulations: $\Delta x = 2\text{km}, \Delta z = 80 - 600 \text{m}$
- Comparison of vertical profiles from 3 different sections of a flight: upstream, mountain, downstream

**WRF cross section along FF05: mean profiles of humidity mixing ratio**

**Tropopause region: differences in the profiles $\rightarrow$ explained by mixing**

Dynamic tropopause
Tracer-tracer correlation for all Falcon flights

Shape of the correlation:
- Non-GW flights: ideal L-shape \(\rightarrow\) indicates no (less) mixing in the tropopause region

\(\text{H}_2\text{O}\)
strong gradient
in troposphere

\(\text{O}_3\)
strong gradient
in stratosphere

Ozone data by Hans Schlager
Tracer-tracer correlation for all Falcon flights

**Shape of the correlation:**

- Non-GW flights: ideal L-shape $\rightarrow$ indicates no (less) mixing in the tropopause region
- GW flights: smoothed profiles $\rightarrow$ indicate mixing processes

Mixing is induced by processes connected to mountain waves (turbulence, ...)

Ozone data by Hans Schlager
Summary

- Transport of water vapor in the UTLS region induced by mountain waves
- WRF vertical profiles indicate mixing over the mountains
- Campaign tracer-tracer-correlation also suggest mixing in the tropopause region
- Additionally, turbulence analysis is needed to investigate the small-scale mixing