GPS derived water vapor in aLMo:
status and outlook

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Motivation

- **Water vapor** plays obviously a key role in the correct simulation of atmospheric processes (e.g. hydrological cycle, atmospheric radiation, atmospheric stability, ...)

- Quantitative precipitation forecast with **explicit convection** at kilometric scale are very sensitive to temperature and humidity structures [Ducrocq, 2002]

- Humidity structures show a **high temporal and spatial variability**

- **Water vapor observations** are rare compared to other quantities; currently the main sources of information over land are
  - radiosoundings (poor spatial and temporal resolution)
  - 2m level humidity (representativity is problematic)

- **Water vapor observations by GPS network** is promising
  - all weather system
  - high temporal resolution (better than 1 hour)
  - good spatial resolution in some regions (e.g. Swiss net with 50km spacing)
Quality of GPS ZTD data

- **Integrated water vapor** (IWV) can be retrieved by ground based GPS with the same level of accuracy as radiosondes and microwave radiometers
  - both post-processed and near real time data, with occasional smoothing in the latter case

- For the period January to June 2003, an **intercomparison** of GPS with radiosonde and radiometer produced the following results [Guergana]:

<table>
<thead>
<tr>
<th></th>
<th>IWV 00 UTC</th>
<th>IWV 12 UTC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bias [mm]</td>
<td>Std [mm]</td>
</tr>
<tr>
<td><strong>GPS vs. radiometer (Bern)</strong></td>
<td>0.34</td>
<td>1.36</td>
</tr>
<tr>
<td><strong>GPS vs. radiosonde (Payerne)</strong></td>
<td>-0.57</td>
<td>1.47</td>
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</table>

Summer bimodal day/night distribution of gps-radiosonde bias (~1mm) has been documented elsewhere [Ohtani, 2000 / Haase, 2002], as a radiosonde midday dry bias.
Quality of GPS ZTD data

- IW V Daily cycle, May – October 2002
- 14 Swiss GPS sites, within ± 50m of model topography
- Only conventional observations assimilated in aLMo

- GPS or model bias?

Discrepancy between GPS data and aLMo could be related to:
- Vaissala RS dry bias due to chemical contamination of sensor [MAP – up to 15% IW V]
- RS dry bias during summer day time
Impact of GPS ZTD on humidity field

- Dependent on weather regime and season; typical maximal impact on IW V aLMo analysis is
  - January: ±10% (average IW V 10mm)
  - September: ±20% (average IW V 20mm)
  - June: ±30% (average IW V 32mm)
  ±20% up to +30h forecast

- The implemented scheme corrects a large part of IW V deficiencies observed in the reference experiment

![Graph showing IWV and ZTD at station PAYE (Payerne, CH): 18 – 24 06 2002]
Impact of GPS ZTD on precipitation

• Previous experiments at MeteoSwiss [Guergana]
  - Weak impact both on January and September experiments (5 days each)
  - Both positive and negative impact on the June experiment (7 days, 6h sum); 15% positive, 25% negative, 60% neutral / increased positive precipitation bias

• New experiment at MeteoSwiss, June 2002, with latest model version and reduced horizontal scale [Zingg]
  - free soil humidity (3 days, 6h sum): 15% positive, 8% negative, 75% neutral
  - soil humidity constraints by IFS (30 days, 24h sum): mainly neutral impact, 1 clear positive case
GPS ZTD - Summary

- **Data quality and data impact**
  - Data quality comparable to radiosonde
  - Large impact on humidity field
  - Cases with remarkable positive impact on precipitation fields, but also negative impact observed
  - Mainly neutral statistical scores
  - Similar conclusions by others, e.g., Japan [Nakamura] and the US [Gutman]

- **Main problems, possible solutions**
  - **vertical distribution** of observation increments (e.g., [Tomasini])
    - tomographic approach
    - same problem with a 4D Var system [Nakamura]
  - isotropic **horizontal weight**, for largely anisotropic structures (e.g., front)
    - anisotropic weights, defined according to measured or model humidity gradient
  - better humidity does not necessarily produces better precipitation
    - shall one tune the model for specific applications?
GPS Tomography – Voxel Model

- Based on Swiss AGNES GPS network (30 sites, 50km mean spacing)
  - 3x6 mesh elements, open elements at the boundaries
  - 15 levels between 0 and 8000 meters; 1 more level aloft

- Under-determined system, needs additional information
  - inter-voxels constraints between contiguous voxels
  - a-priori values for uppermost layer, option for lowest layers values from ANETZ data

- Output 18 hourly humidity profiles over Switzerland
GPS Tomography – Data flow

1. Output from GPS processing
   - Processing of double differences
   - Implementation of zenith delays

2. A priori refractivity information
   - Intervoxel constraints

3. Optional input of other measurements, i.e. from radiometer, solar spectrometer, radio sondes

least squares adjustment

refractivity of voxels
GPS Tomography – Some results

Humidity profiles at Payerne; tomographic solutions compared with radiosonde and aLMo.

Improved solution when taking into account additional data (ANETZ).

Comparison of all 12 tomographic profiles with aLMo analysis: time serie of rms.

Worse results by rapidly changing weather situation (3, 6, 9.11)
GPS derived water vapor - Outlook

- **Tomography** is a promising method for regions with **dense** GPS network
  - All weather, high spatial and temporal resolution, humidity profiles over land

- Tomography should be completed with **additional data** source to produce **consistent quality** profiles
  - GPS occultation (transverse data)
  - Satellite aloft cloud cover, in the upper part of the atmosphere
  - Lidar and other operational humidity data where available
  - Model analysis could possibly be used as first guess data (iterative procedure)

- The tomography technique developed at ETHZ can be seen as a pre-processing tool to **integrate** different sources of humidity information and provide humidity profiles directly usable by the LM nudging scheme

- A proposal for a **European** project on this topic is being evaluated by the ETHZ (Institute of Geodesy and Photogrammetry)
aLMo snow analysis:
Meteosat-8 snow map as additional ingredient

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Work done by:
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Snow analysis – Image classification

- Main problem: separation of snow and clouds, e.g. in the visible channels, but this can also occur in the infrared channels

- Fortunately: around 1.6 µm, snow and ice have a low albedo, and water a high albedo

- ... but even in the 1.6 µm channel some clouds look the same as snow ⇒ use contextual information to improve classification
Snow analysis – Contextual classification

- **At the moment**
  In a sequence of images, the image with the most cloud-clear view of a certain pixel (spectral features furthest away from overcast situation) is considered to reflect the surface conditions for that pixel.

- **Possible other classification features:**
  - homogeneity in \((x, y, t)\) data space \(\Rightarrow\) clouds less homogeneous than surface snow
  - consistency in \((x, y, t)\) data space \(\Rightarrow\) no snow at unlikely locations / moments
  - displacement of patterns \(\Rightarrow\) must be clouds
Snow analysis – Plan at MeteoSwiss

• Combine *in-situ* information with *satellite* data
  - adapt LM snow analysis algorithm (start summer 2005)

• Consider both **Meteosat 8** [EUMETSAT Fellowship] and **NOAA** [Uni Bern]
  - with emphasis on mountainous regions
  - main product is snow/ice cover for each element of aLM0/7 and aLM0/2 mesh
  - additional products such as snow surface temperature and albedo will also be considered