Synergy benefit in temperature, humidity and cloud property profiling by integrating ground based and satellite measurements

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1. Motivation

Context:
- ground-based measurements in the microwave (MW) and infrared (IR) spectrum give information on the temperature (T) and humidity (q) profile of the lower troposphere
- satellite measurements provide complementary information
- use synthetic observations of state-of-the-art ground based and satellite passive MW and IR sensors in order to assess the synergy benefit in clear-sky T and q profiling

Key questions:
- How much T and q information is added by further ground-based and satellite sensors to the information of ground based MW radiometer (MWR) measurements?
- Do the results depend on the atmospheric situation?

2. Experiment setup

Strategy:
- 1D-Var approach to retrieve an atmospheric profile x = [T, q] from the observation y:
  - optimal estimation equation [T] = \frac{\mathbf{S}^{-1} \mathbf{x}}{\mathbf{H}^T \mathbf{S}^{-1} \mathbf{H}}
  - calculation of the posterior error covariance matrix \mathbf{S} and the degrees of freedom for signal (DOF), i.e. number of independent pieces of information from y:
  - posterior error degrees of freedom for signal
    \text{DOF} = \text{max}(\mathbf{A}) \times \text{min}(\mathbf{S}/\mathbf{S}^T)
- assuming optimal retrieval performance, the maximum information content is estimated

Sensors:

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Frequency, Wavenumber/Length</th>
<th># obs</th>
<th>Noise min/max</th>
<th>Forward model for K calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>MWR</td>
<td>22.24-31.4, 54.92-58 GHz</td>
<td>34</td>
<td>0.1/0.2 K</td>
<td>PAMTRA [2]</td>
</tr>
<tr>
<td>AERI</td>
<td>538-1354 cm−1</td>
<td>390</td>
<td>1.8/0.25 RU</td>
<td>LBRRTM [3]</td>
</tr>
<tr>
<td>IASI</td>
<td>675-1350 cm−1</td>
<td>554</td>
<td>0.23/0.43 RU</td>
<td>LBRRTM [3]</td>
</tr>
<tr>
<td>SEVIRI</td>
<td>6.2-13.4 µm</td>
<td>7</td>
<td>0.1/0.37 K</td>
<td>RTTOV [4]</td>
</tr>
<tr>
<td>AMSU-A</td>
<td>23.8, 31.4, 50.3-57.617 GHz</td>
<td>15</td>
<td>0.3/1.2 K</td>
<td>PAMTRA [2]</td>
</tr>
<tr>
<td>MHS</td>
<td>89, 157, 184-211, 185-311, 190-311 GHz</td>
<td>5</td>
<td>0.22/0.51 K</td>
<td>PAMTRA [2]</td>
</tr>
</tbody>
</table>

error covariance matrix \mathbf{S} includes typical random instrument noise and forward model parameter uncertainties due to uncertainties in trace gas concentrations (\text{CH}_4, \text{N}_2, \text{O}_3) and in surface emissivity

3. Synergy benefit

Fig. 3: Synergy benefit in terms of additional DOF compared to HATPRO-only retrieval in the T (left) and q profile (right). Median (line in box), 0.25 and 0.75 quartiles (box boundaries), minimum and maximum values (whiskers) of the profile sample.

Fig. 4: Same as Fig. 3 except for the synergy benefit in terms of reduction of uncertainty (% RU) in the T (left) and q profile (right) compared to the HATPRO-only retrieval.

4. Conclusions and outlook

- IASI and AMSU-A/MHS increase the T information by a factor of 1.8 and 1.5, respectively, with highest benefit in warm and/or humid conditions
- highly spectrally resolved IR observations from ground or space improve the vertical information on q especially in dry and cold situations, i.e. DOF more than tripled compared to the ground based MWR-only retrieval
- satellite measurements significantly reduce retrieval uncertainties in the middle and upper troposphere
- ongoing studies to assess the ground based and satellite synergy in the retrieval of cloud properties
- application to real observations of the Jülich Observation’s for Cloud Evolution (JOYCE)

Prior T and q information:
- climatological mean profile (\text{x}_0) and corresponding \text{S}_0 derived from 8-year data set of 4854 clear-sky radiosonde ascents in Lindenberg, Germany
- analysis is performed for a subset of 98 profiles representing the interannual variability of the atmospheric conditions in Lindenberg

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