1. Introduction

Context:
- Accurate profiles of temperature and humidity are essential for climate monitoring, a better process understanding and weather forecasting
- Ground-based measurements in the microwave and infrared (IR) spectrum give information on the temperature and humidity profile of the lower troposphere
- Satellite measurements provide complementary information

Key questions:
- Given some a priori knowledge on the atmospheric state as well as realistic a priori and measurement uncertainties, how much information is added by different ground-based and satellite sensors?
- Do the results depend on the atmospheric situation?

2. Retrieval strategy

- 1D-Var approach to retrieve an atmospheric profile \( x \) (here, profiles of temperature \( T \) and absolute humidity \( q \)) from observation \( y \):

  \[
  x - x = (K'S'K + S')^{-1}K'S'(y - x) + S'x
  \]

  with \( K' = F(x) \)

- Given an a priori profile \( x_a \) as well as the a priori and measurement/forward model uncertainties \( S_a \) and \( S_r \), respectively, the posterior error covariance matrix \( S \) and the degrees of freedom for signal (DOF), i.e. number of independent pieces of information from \( y \), can be calculated:

  \[
  S = (K'S'K + S')^{-1}
  \quad \text{DOF} = \text{trace}(A) \quad \text{with} \quad A = S^{-1}(K'S'K + S')^{-1}
  \]

3. Experimental setup

- analysis is performed for different clear-sky atmospheric conditions (Fig. 1)
- different combinations of ground-based and satellite MW and IR sensors (Tab. 1)
- climatological mean profile \( x_\text{clim} \) and corresponding \( S_\text{clim} \) from 12-year data set of 6-hourly clear-sky radiosonde ascents in Lindenberg, Germany
- random instrument noise \( (x_n) \) and the measurement uncertainties \( S_n \)

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Frequency/Wavenumber</th>
<th># obs</th>
<th>Noise ( \text{min}/\text{max} )</th>
<th>Forward model for ( K ) calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>MWR</td>
<td>22.2-31.4, 54.8-58.5 GHz</td>
<td>34</td>
<td>0.1/0.2 K</td>
<td>PAMTRA [2]</td>
</tr>
<tr>
<td>HATPRO</td>
<td>559-1344 cm(^{-1})</td>
<td>46</td>
<td>1.8/0.25 RU</td>
<td>LURFM [3]</td>
</tr>
<tr>
<td>AERI</td>
<td>1.9-13.4 µm</td>
<td>8</td>
<td>0.1037 K</td>
<td>RTTOV [4]</td>
</tr>
<tr>
<td>SEVIRI</td>
<td>23.8, 31.4, 50.3-57.617, 89 GHz</td>
<td>15</td>
<td>0.3/1.2 K</td>
<td>PAMTRA [2]</td>
</tr>
<tr>
<td>AMSU-A</td>
<td>89, 157, 184.311, 186.311, 190.311 GHz</td>
<td>5</td>
<td>0.22/0.51 K</td>
<td>PAMTRA [2]</td>
</tr>
</tbody>
</table>

4. Information content and retrieval uncertainty

- ground-based sensors provide most information below 500 hPa (Fig. 2)
- benefit due to satellite sensors especially in upper part of troposphere
- results depend on atmospheric condition, e.g. for HATPRO+ALL:
  - warm-humid: maximum DOF for \( T \) (7.9), minimum for \( q \) (6.0) due to saturation of IR channels
  - cold-dry: minimum DOF for \( T \) (7.0), maximum for \( q \) (10.6)
- benefit of sensor synergy hardly affected by surface emissivity uncertainties
- doubling measurement uncertainties or halving \( S_\text{clim} \) reduce information content from additional sensors by 0.1-0.3 (0.2-1) in \( T \) (q)
- variability in DOF due to atmospheric condition much higher

5. Summary and outlook

- amount of information in \( T \) (q) is roughly doubled (tripled) compared to ground-based MWR, when additional ground-based spectral IR, as well as MWR and IR observations from satellite are included
- analysis will be extended to 500 profiles which are representative of the whole data base
- full retrieval including HATPRO, AERI and SEVIRI measurements under development
- subsequent inclusion of cloud properties in the retrieval

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References:
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Figure 1: Profiles of the atmospheric conditions (Fig. 1) used in the study.

Figure 2: DOF for \( T \) (left) and \( q \) (right) close to mean profile (Fig. 1). For HATPRO, the actual DOF is depicted.