Combining ground-based and satellite measurements in the atmospheric state retrieval: assessment of the information content

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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**:

optimal estimation equation [1]

$$\mathbf{x}_{i+1} = \mathbf{x}_i + \left(\mathbf{K}_i^T \mathbf{S}_e^{-1} \mathbf{K}_i + \mathbf{S}_a^{-1}\right)^{-1} \times \left[\mathbf{K}_i^T \mathbf{S}_e^{-1} \left(\mathbf{y} - \mathbf{y}_i\right) + \mathbf{S}_a^{-1}\left(\mathbf{x}_a - \mathbf{x}_i\right)\right] \quad \text{with} \quad \mathbf{K}_i = \frac{\partial \mathbf{F}(\mathbf{x}_i)}{\partial \mathbf{x}_i}$$

- Given an a priori profile $\mathbf{x_a}$, as well as the a priori and measurement/ forward model uncertainties $\mathbf{S_a}$ and $\mathbf{S_e}$, 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:

posterior error

$$\mathbf{S} = \left(\mathbf{K}^T \mathbf{S}_e^{-1} \mathbf{K} + \mathbf{S}_a^{-1}\right)^{-1}$$

degrees of freedom for signal

$$\text{DOF} = trace(\mathbf{A}) \quad \text{with} \quad \mathbf{A} = \mathbf{S} \cdot \left(\mathbf{K}^T \mathbf{S}_e^{-1} \mathbf{K} + \mathbf{S}_a^{-1}\right)$$

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 ($\mathbf{x_a}$) and corresponding $\mathbf{S_a}$ from 12-year data set of 6-hourly clear-sky radiosonde ascents in Lindenberg, Germany
- random instrument noise (Tab. 1) used in $\mathbf{S_e}$

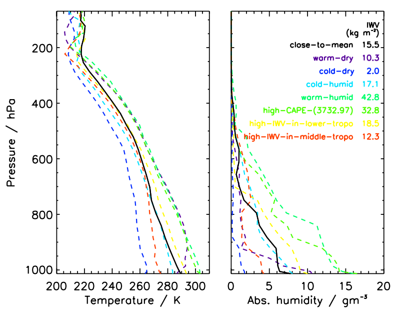

Figure 1*. T (left, in K) and q (right, in gm^{-3}) profiles of the analysed atmospheric conditions. IWV values (in kgm^{-2}) are reported close to the profile names.*

Table 1*. Sensor names and channels included in the study. Since measurement noise depends on the channel, values are given as min/max. RU is mW/(m^2 sr cm^{-1}).*

Sensor	Frequency, Wavenumber/-length	# obs	Noise min/max	Forward model for K calculation
MWR HATPRO	22.24-31.4, 54.94-58 GHz (zenith + elev. scans)	34	0.1/0.2 K	PAMTRA [2]
AERI	559-1344 cm^{-1}	46	1.8/0.25 RU	LBLRTM [3]
SEVIRI	3.9-13.4 µm	8	0.1/0.37 K	RTTOV [4]
AMSU-A	23.8, 31.4, 50.3-57.617, 89 GHz	15	0.3/1.2 K	PAMTRA [2]
MHS	89., 157., 184.311, 186.311, 190.311 GHz	5	0.22/0.51 K	PAMTRA [2]

4. Information content and retrieval uncertainty

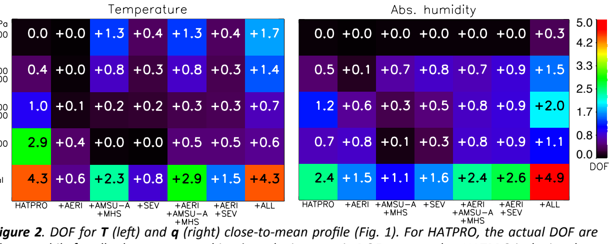

Figure 2*. DOF for **T** (left) and **q** (right) close-to-mean profile (Fig. 1). For HATPRO, the actual DOF are shown, while for all other sensor combinations the increase in DOF compared to HATPRO is depicted.*

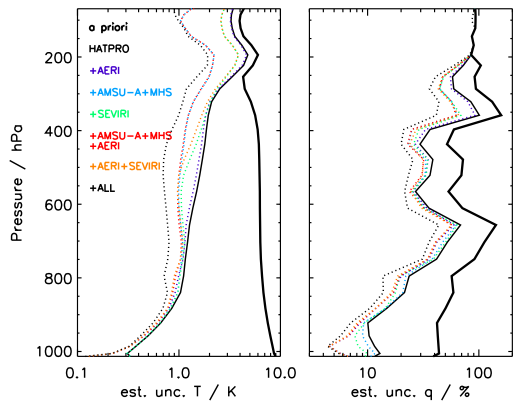

Figure 3*. : Estimated uncertainties in T (left, in K) and q profiles (right, in % relative to radiosonde truth) for different sensor combinations. Close-to-mean profile.*

- 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** (9.7), minimum for **q** (6.0) due to saturation of IR channels
  - cold-dry: minimum DOF for **T** (7.9), maximum for **q** (10.6)
- benefit of sensor synergy hardly affected by surface emissivity uncertainties
- doubling measurement uncertainties or halfing $\mathbf{S_a}$ 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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