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

Ebell[1], K., E. Orlandi[1] , A. Hünerbein[2], S. Crewell[1] and U. Löhnert[1]

[1] Institute of Geophysics and Meteorology, University of Cologne, Cologne, Germany, kebell@meteo.uni-koeln.de [2] Leibniz-Institute for Tropospheric Research, Leipzig, Germany

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

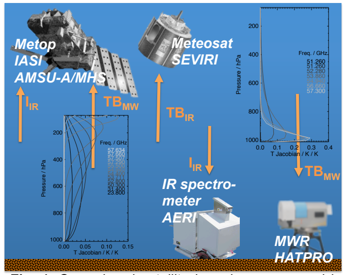


Fig. 1: Ground and satellite based sensors used in this study for T and q profiling together with temperature jacobians for the AMSU-A and HATPRO frequencies.

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 [1]

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

- calculation of the posterior error covariance matrix **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**

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

- **assuming optimal retrieval performance, the maximum information content is estmated**

Sensors:

Table 2*: Sensors and channels used in this 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	538-1354 cm^{-1}	390	1.8/0.25 RU	LBLRTM [3]
IASI	675-1350 cm^{-1}	554	0.23/0.43 RU	LBLRTM [3]
SEVIRI	6.2-13.4 µm	7	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]

- error covariane matrix $\mathbf{S}_e$ includes typical random instrument noise and forward model parameter uncertainties due to uncertainties in trace gas concentrations (CH_4, N_2O, O_3) and in surface emissivity

Prior T and q information:

- climatological mean profile ($\mathbf{x}_a$) and corresponding $\mathbf{S}_a$ 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

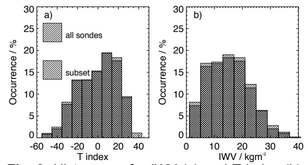


Fig. 2: Histograms for IWV (a) and T index (b) for the whole data set and for the selected subset. The T index is defined as $\sum_{z=0}^{12\,km} \left(T(z) - \bar{T}(z)\right)/\sigma(z)$.

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 quantiles (box boundaries), minimum and maximum values (whiskers) of the profile sample.

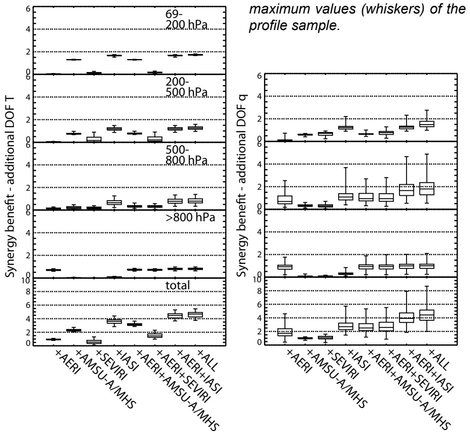
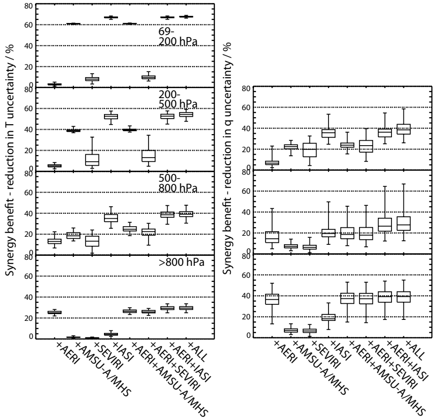


Fig. 4: Same as Fig. 3 except for the synergy benefit in terms of reduction of uncertainty (in %) in the T (left) and q profile (right) compared to the HATPRO-only retrieval.



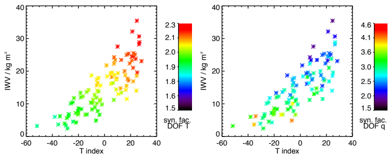


Fig. 5: T (left) and q (right) synergy factor (=$DOF_{all\ sensors}$/ DOF_{HATPRO}) as a function of T index and IWV

Table 2*: Synergy factor (=$DOF_{sensor\ comb.}$/DOF_{HATPRO}) for different instrument combinations*

Instruments: HATPRO+	Synergy factor temperature min	max	median	humidity min	max	median
AERI	1.18	1.25	1.22	1.17	2.99	1.74
AMSU-A/MHS	1.46	1.63	1.52	1.28	1.52	1.42
SEVIRI	1.03	1.13	1.30	1.15	1.68	1.45
IASI	1.64	2.02	1.82	1.64	3.37	2.13
AERI+AMSU-A/MHS	1.65	1.83	1.72	1.48	3.31	2.07
AERI+SEVIRI	1.22	1.53	1.34	1.35	3.39	2.09
AERI+IASI	1.83	2.22	2.02	1.76	4.27	2.63
ALL	1.85	2.26	2.06	1.83	4.59	2.84

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 ObservatorY for Cloud Evolution (JOYCE)

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