Assimilation of Reconstructed Radiances from PC compressed Hyperspectral Sounder IASI data in the ICON EnVar

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Silke May, Christina Köpken-Watts, Robin Faulwetter, Olaf Stiller, Roland Potthast
German Meteorological Service DWD, Offenbach, Germany

I) Introduction and motivation

How best to exploit the large data volume of new hyperspectral sounders (e.g. MTG-IRS, IASI-NG) in a technically efficient manner?

- Extremely **high data rates** and a **large number of channels**
- Dissemination as PC compressed data

The use of reconstructed radiances (**RecRad**) computed from the operational EUMETSAT principal component scores data stream of IASI (Infrared Atmospheric Sounding Interferometer) has been investigated in comparison to raw radiances (**RawRad**) used in the global operational ensemble variational data assimilation system (**EnVAR**) of Deutscher Wetterdienst (DWD).

II) Principal Component Analysis (PCA)

Principal **c**omponent **a**nalysis reduces a dataset containing a large number of observed variables (e.g. 8461 IASI channels) to a dataset containing significantly less new variables called **principal components**. These new ones are linear combinations of the original ones. The first PC score is the **linear combination** which has got the largest variance. PCA examine the data cloud along which dimension is the greatest amount of variability by using eigenvalue decomposition. **Truncating** the PC set in PC space (not radiance space) approximately only noise is left out. So a subset of leading PC's (e.g. the first 300) contain most of the **information**.
Definition of PC score:

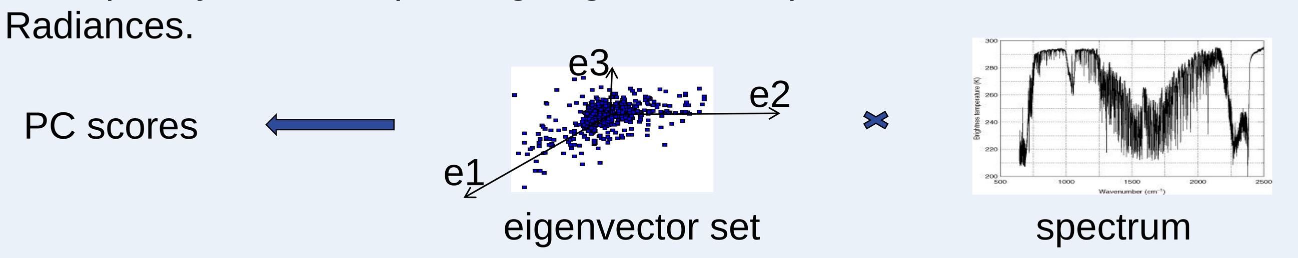
$$p = E^T * N^{-1} * (x - \bar{x}) \in \mathbb{R}^s$$

Definition of Reconstructed Radiances:

$$\tilde{x} = N * E * p + \bar{x} \in \mathbb{R}^m$$

IASI L1C spectra: $\mathrm{x} \in \mathbb{R}^{mxn}$
pc scores : $p \in \mathbb{R}^s$
mean of noise-normalised data set: $N^{-1} * \bar{x} \in \mathbb{R}^m$
covariance of noise-normalised data set: $C \in \mathbb{R}^{mxm}$
s most significant eigenvectors of C: $E \in \mathbb{R}^{mxs}$
number of channels: m
number of spectra in data set: n

Each of the IASI spectra is represented by a small number of PC scores. Now the aim is to **reconstruct** noise-reduced approximation of spectra from the scores using the delivered eigenvectors. Subsequently the corresponding brightness temperatures are calculated from Reconstructed Radiances.



➢ **PCA: data compression and noise reduction**

III) Global operational DA system at DWD

Operational global NWP model at DWD is **ICON** (**Ico**sahedral **N**on-hydrostatic model, operational since Jan. 2015). This non-hydrostatic model is formulated on an icosahedral grid with 90 vertical levels up to 75km/~2.6Pa. The deterministic run is at 13km horizontal resolution and using two-way nesting higher resolution forecasts are generated at 6.5km over Europe area/domain.

The **ICON E**nsemble **D**ata **A**ssimilation **EDA** is a hybrid system consisting of **EnVar** coupled with **LETKF** and operational since January 2016 (Fig.1).

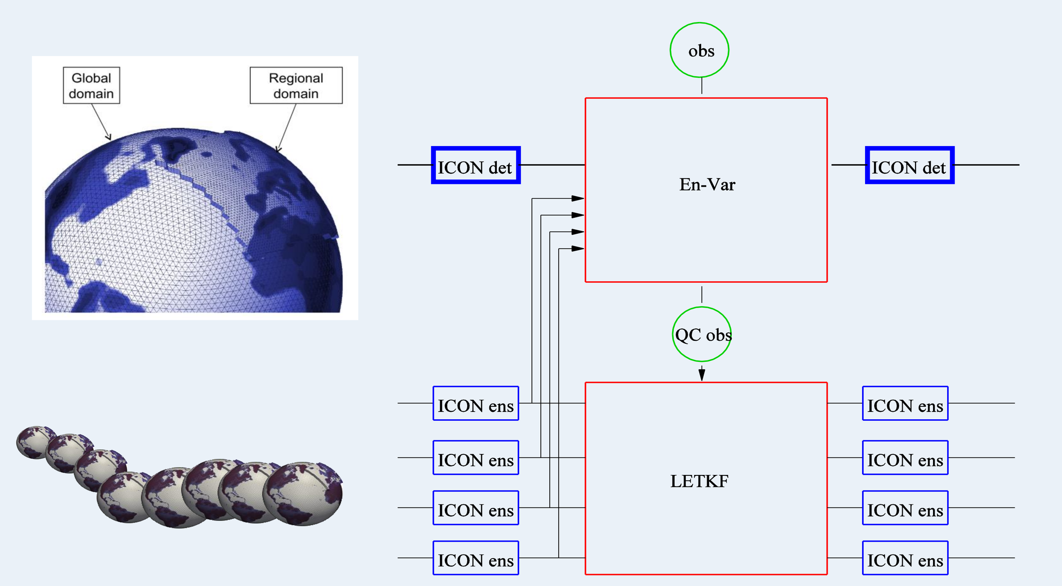


Fig 1: Schematic diagram of the global NWP system at DWD:

- ICON ens. (#40), 40 km global/20 km Europe nest resolution, updated by LETKF ens analysis
- ICON det. (#1), 13 km global/6.5 km Europe, updated by EnVar analysis
- EnVar hybrid B-matrix: 70% ensemble B and 30% climatological B
- Quality control (QC)

IV) Use of IASI radiances

DWD is assimilating **46** channels from the temperature band out of **8461** IASI channels on Metop-A and Metop-B. Additionally, 16 channels sensitive to humidity and RTTOV v12 become operational on 14th March 2018.
The cloud detection scheme is based on the McNally&Watts (2003) scheme.
EUMETSAT disseminates IASI data in two types:

- Raw radiances level1b
- PC product with **300** pc scores, eigenvector base, mean and noise matrix

VII) Results and Outlook

➢ Technical implementation of IASI PC compressed data from EUMETSAT in operational global NWP system of DWD
➢ OBS-FG statistics for IASI are improved
➢ Cloud detection scheme rejects more data
➢ Forecast scores in assimilation are neutral to slightly positive
➢ As expected inter-channel correlations of RecRad are larger than those of RawRad

Outlook:
➢ Winter experiment: 12/17 to 02/18 including also IASI channels sensitive to humidity, RTTOV12
➢ Observation error tuning
➢ Implementing non-diagonal R-matrix in assimilation code
➢ Derivation of suitable non-diagonal R-matrix for assimilation (based on Desroziers diagnostics)
➢ Routine monitoring of Reconstructed Radiances

V) Experimental setup

IASI principal component (PC) compressed data have been technically implemented. Initial experiments have been run assimilating PC data in the form of reconstructed radiances (RecRad) treating the RecRad in a first approach like raw radiances not taking in account inter-channel correlations.

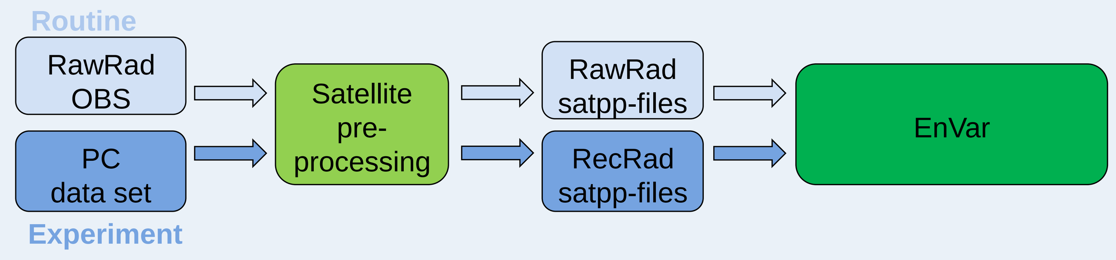


Fig 2: pre-processing of satellite data

- **Reference:** ICON EnVar @40km equivalent to operational 01.05.-31.05.2016
  - with 46 IASI Metop-A/B **RawRad** channels (sensitive to temperature band)
  - RTTOV v10
  - LETKF and online bias-correction from quasi-operational
- Experiment 1: **RecRad** instead of RawRad
- Experiment 2: **passive** monitoring of RecRad
  - takes an identical FG from reference experiment
- Experiment 3: **observation error tuning**
  - with IASI observation error variance 10% reduced
- 4) Estimation of **inter-channel error correlations** with Desroziers method (Desroziers et al. 2005) for calculating non-diagonal elements

VI) Evaluations of experiments

Exp. 1) IASI departure statistics and impact of RecRad on cloud detection

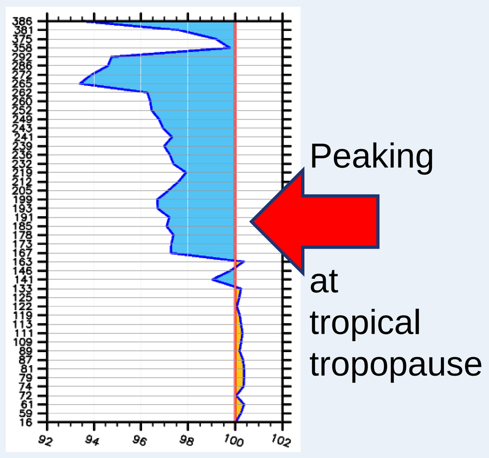


Fig 3: Number of data, relative differences RecRad (blue) to RawRad (red), (1-31 May 1206)
➢ In troposphere about 5% less observations

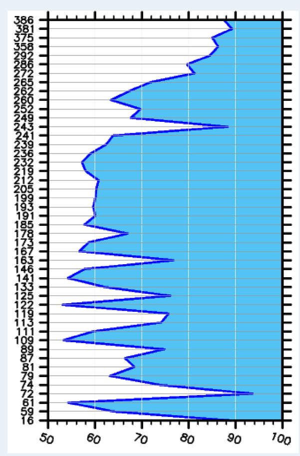


Fig 4: Standard deviation (o-f) relative differences to RawRad
➢ Stdv about 40% smaller

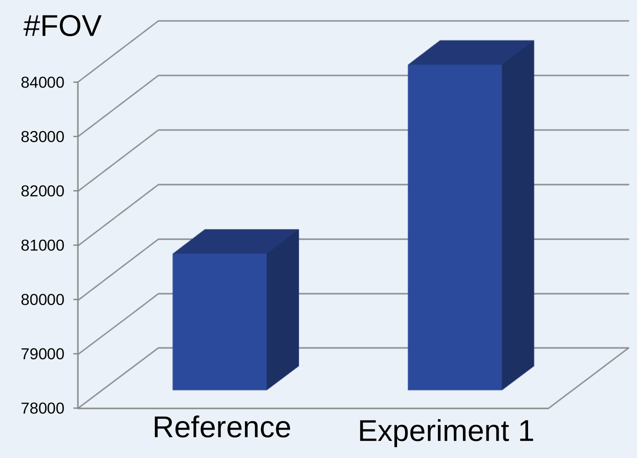


Fig 5: Number of cloud flagged data, date 2016051600, all channels
➢ Differences in number (see Fig 3) of data due to cloud detection

Exp. 1) Evaluation of forecasts: upper air verification and verification against analysis

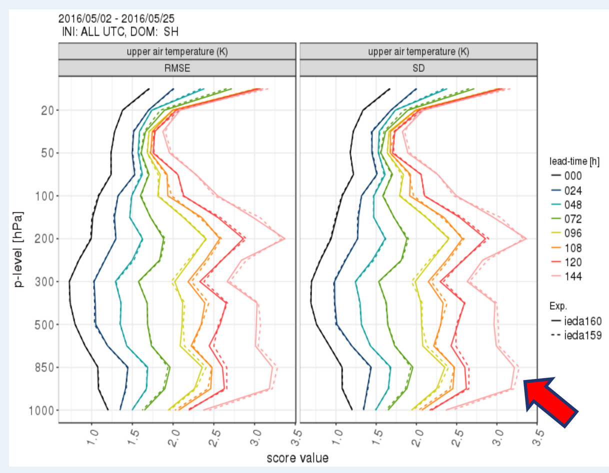


Fig 6: Quality of temperature profile versus radiosondes in SH, forecast leadtimes 0–144h, RMSE (left) and stdv (right), RecRad (solid), RawRad (dashed)
➢ SH: slightly better for RecRad experiment
➢ NH: neutral (not shown)
➢ Other variables: neutral or slightly positive (not shown)

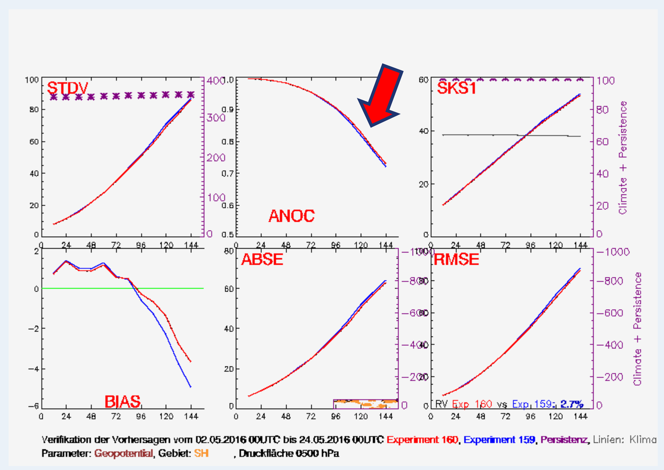


Fig 7: Forecast verification against analysis, RecRad (red) and RawRad (blue), 500hPa Geopotential
➢ Slightly positive impact in Southern Hemisphere and also (not shown) southpolar region

Exp. 2) IASI departure statistics

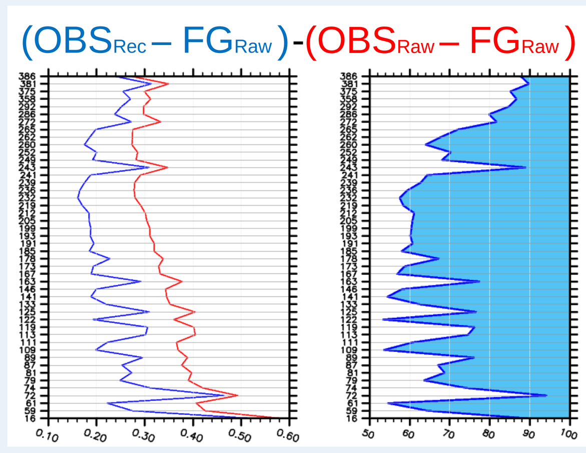


Fig 8: Standard deviation (o-f) relative differences, RecRad (blue) RawRad (red), in experiment with identical FG fields
➢ Same strong reduction of stdv for RecRad passive as in RecRad active experiment (see Fig. 4)
➢ Due to less noisy OBS
➢ Not due to changes in FG

Exp. 3) Evaluation of forecasts: upper air verification

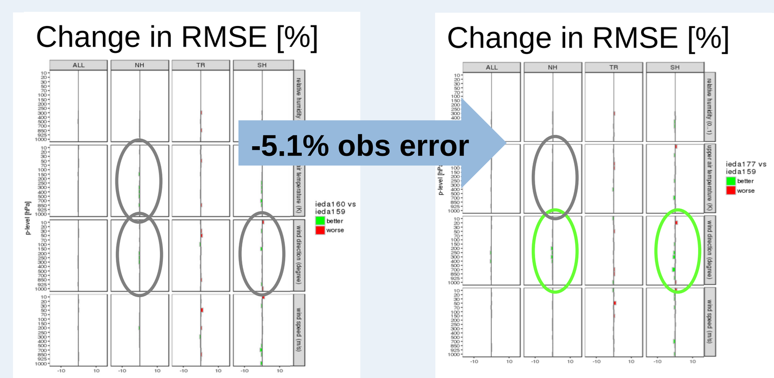


Fig 9: Verification against radiosondes observations, green indicates improvement compared to reference
➢ Experiment with reduced observation errors has neutral to slightly positive impact
➢ Further testing may be beneficial

4) IASI Inter-channel error correlations (Desroziers diagnostic)

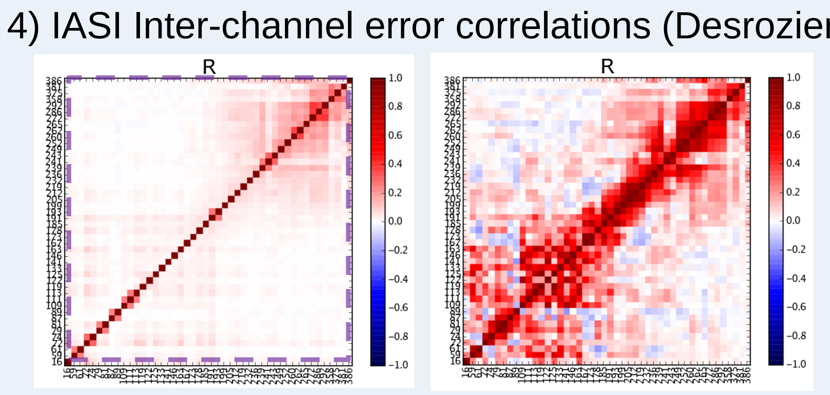


Fig 10: R-matrix for IASI RawRad (left) and RecRad (right)
➢ Much larger inter-channel correlations diagnosed for RecRad
➢ Estimation of full R-matrix structure

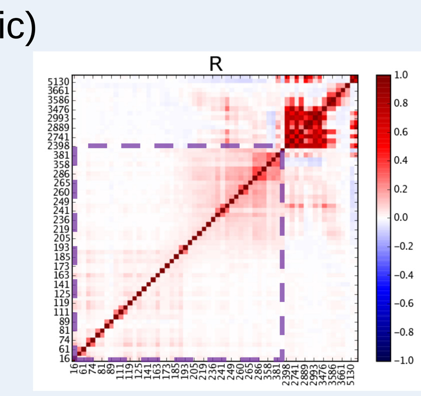


Fig 11: For comparison: estimated R-matrix for larger RawRad channel set including selected 16 humidity channels, temperature channels in purple box
➢ Larger correlations for channels sensitive to water vapour than for temperature

Contact: silke.may@dwd.de , **Data Assimilation Section, DWD (German Meteorological Service)**

References:

- Andrey-Andrés, J. 2017: Impact of Principal Components compression on the assimilation of Hyperspectral infrared data. EUMETSAT Fellowship Report
- Desroziers, G. et al. , 2005: Diagnosis of observation, background and analysis-error statistics in observation space. *Q. J. R. Meteorol. Soc.* **131,** 3385–3396.
- Matricardi, M. and McNally, A. P. 2014: The direct assimilation of principal components of IASI spectra in the ECMWF 4D-Var. Q.J.R. Meteorol. Soc., **140**: 573–582. doi:10.1002/qj.2156.
- Matricardi, M. 2015: The direct assimilation of principal components of IASI spectra in the ECMWF 4D-Var and the training of PC_RTTOV over land surfaces. EUMETSAT Contract No. EUM/CO/07/4600001011/PS.
- McNally, A. P. and Watts, P., 2003: A cloud detection algorithm for high-spectral-resolution infrared sounders. *Q. J. R. Meteorol. Soc.*, **129,** 3411-3423.