

Use Of Satellite Radiance Data In The Global Meteorological Model Of The German Weather Service DW



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Operational assimilation of remote sensing data in the global model GME

The 3D-Var assimilation system at the DWD

The Global MEteorological model (GME) is the global model of the DWD for use in the numerical weather prediction (NWP). The GME is a hydrostatic model based on an icosahedral horizontal grid. It provides global NWP forecasts in and provides boundary and initial conditions for the local model COSMO. In the current version, the GME has a horizontal resolution of 30 km. Vertically, it is composed of 60 layers, reaching up to 5 hPa (sigma hybrid coordinates).

The NWP model is corrected by observational information in the data assimilation step, resulting in the analysis. For the GME, for data assimilation a three-dimensional variational (3D-Var) is used. Observational (Y) and GME model background (X_b) information is combined in a statistically optimal way, taking into account background and observation error covariance matrices B and R . A cost function

$$J(x) = J_b + J_o = (x - x_b)^T B^{-1} (x - x_b) + (y - H(x))^T R^{-1} (y - H(x))$$

is minimized to yield the analysis x .

The minimization is done in observation space to (physical space assimilation system - PSAS) to reduce the dimensionality of the numerical problem. A combination of conjugate gradient and Newton method is used to solve the minimization problem, accounting for nonlinearity in the forward operator $H(x)$. The global analysis is calculated eight times daily, with a 3h assimilation time window.

Satellite data operationally assimilated in the GME

AMSU/MHS: Currently, AMSU-A radiances from NOAA-15, -18, -19 and Metop-A are operationally assimilated (cloud free FOVs of upper-air channels only, thinned to 240 km horizontal distance). Work on assimilation of AMSU-B/MHS is on the way.

IASI: Assimilation of IASI radiances is under development. At present, the cloud detection scheme is being tuned for use in the 3D-Var (scheme according to: A.P.McNally, P.D.Watts: A cloud detection algorithm for high-spectral-resolution infrared sounders, Q.J.R. Meteorol. Soc. 129, p. 3411, 2003)

Atmospheric motion vectors (AMV): AMV data of the geostationary satellites GOES 11 and 12, Meteosat 8 and 9 and MTSAT-1 are assimilated, together with AMV data from the polar orbiting satellites TERRA, AQUA (both MODIS instruments), NOAA 16-18 and Metop-A (AVHRR instruments).

Scatterometer: Currently, scatterometer data from ASCAT onboard Metop-A is assimilated.

GPS radio occultation: Assimilation of radio occultation data of the COSMIC satellites and Metop-A (GRAS instrument) is in an experimental level.

The IASI instrument

The Infrared Atmospheric Sounding Interferometer (IASI) on-board Metop-A is a Fourier transform spectrometer, providing infrared spectra with high resolution between 645 and 2760 cm⁻¹ (3.6 m to 15.5 m). The IASI mission is designed to measure atmospheric emission spectra in order to derive temperature and humidity profiles with high vertical resolution and accuracy. In addition to this, IASI observations allow the determination of trace gases such as ozone, carbon dioxide, methane, and nitrous oxide. Other parameters to be derived from IASI radiances are cloud properties as well as land-and sea surface temperature and emissivity.

IASI Level 2 products

IASI Level 2 products are disseminated since 25 September 2007. At the DWD, the level 2 product containing temperature, atmospheric water vapor and surface skin temperature (product code "TWT") is received as a BUFR file via GTS. The vertical sampling of temperature and humidity is at 90 pressure levels, with a horizontal sampling of about 25 km at nadir. The vertical profiles are retrieved from the IASI L1C data. The IASI Level2 product makes use not only of the IASI Level 1c radiance spectra but also of measurements of the ATOVS instruments onboard Metop-A. The data included in the preprocessing of the IASI level 2 data are IASI L1c, AMSU-A L1b, AVHRR L1b, MHS L1b and ATOVS L2 products. Aside from these observational data, NWP data is made use of. The BUFR data file also contains a number of flag and code tables, giving additional information on metadata and the pre-processing.

P. Schluessel et al.: Generation and assimilation of IASI level II products. http://www.ecmwf.int/news_events/meetings/workshops/2009/IASI_data/presentations/Schluessel.pdf, 2009.

EUMETSAT: IASI Level 2 Product Guide. <http://oiswww.eumetsat.org/WEBOPS/eps-pg/IASI-L2/IASI-L2-PG-4ProdOverview.htm>, 7 Apr 2009.

Derivation of layer thicknesses from IASI I2 retrievals

The IASI level 2 data set contains temperature and humidity mixing ratio on 90 fixed pressure levels P_i : $T(p_i), m(p_i)$

The humidity mixing ratio is supposed to be close to the value of the specific humidity:

$$m(p_i) \approx q(p_i)$$

Calculate virtual temperature from temperature and humidity,

$$T_v(p_i) = T_i [T(p_i), q(p_i)] = T_i \left[1 + q(p_i) \left(\frac{R_{wv}}{R} - 1 \right) \right]$$

with the specific gas constant of dry air and water vapor:

$$R = 287.05 \text{ J kg}^{-1} \text{ K}^{-1} \quad R_{wv} = 461.51 \text{ J kg}^{-1} \text{ K}^{-1}$$

This allows the use of the barometric height relation:

$$\frac{dp}{p} = -\frac{g dz}{RT_v(p)}$$

According to the ideal gas law,

$$p = \rho RT_v$$

the geopotential increment yields

$$-\frac{1}{g} \frac{RT_v(p)}{p} dp = -\frac{p^{-1}}{g} dp = dz$$

Integration in each thickness layer j with boundaries at pressure levels P_j and P_{j+1} (at geopotential heights z_j and z_{j+1}) yields the layer thickness Δz :

$$-\frac{1}{g} \int_{P_j}^{P_{j+1}} \frac{RT_v(p)}{p} dp = \int_{z_j}^{z_{j+1}} dz = (z_{j+1} - z_j)$$

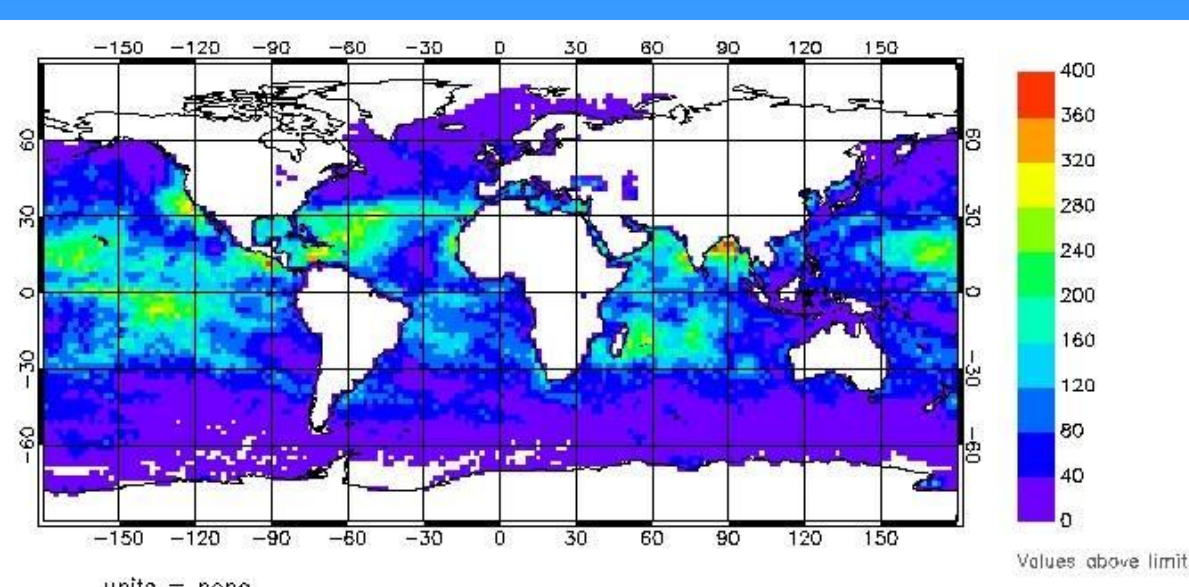
The integration is performed using a linear interpolation of the inverse density.

Seven geopotential layers with boundary pressure values P_j of 1000, 700, 500, 100, 50, 30, 10, and 0 hPa are defined.

Impact study: Assimilation of geopotential layer thickness observations derived from IASI level 2 retrievals within the 3D-Var

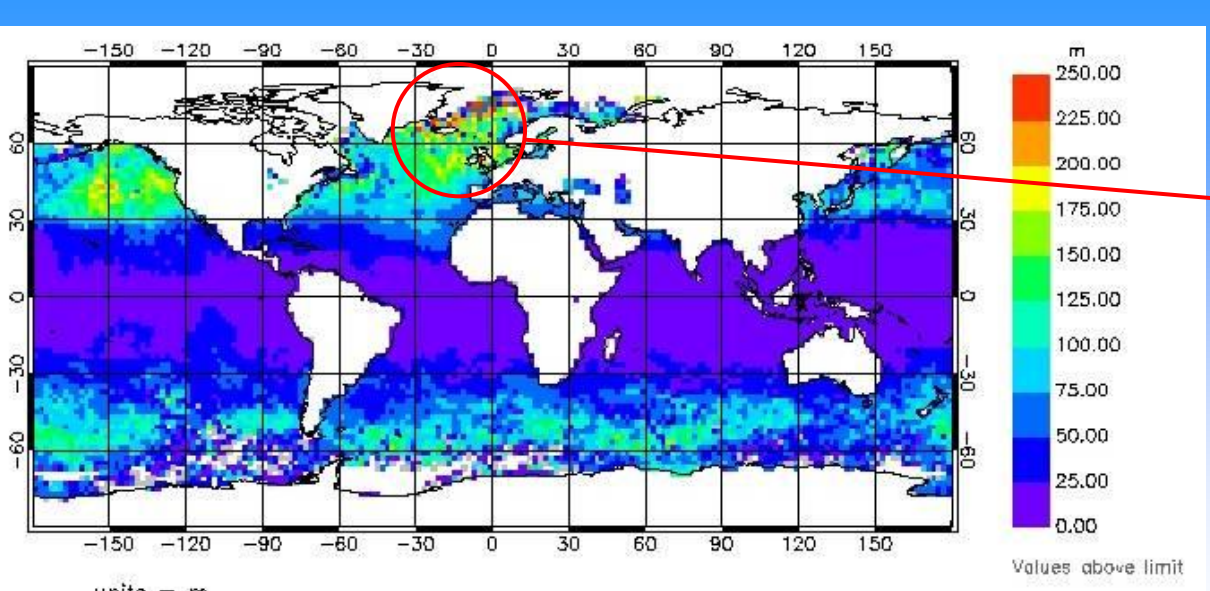
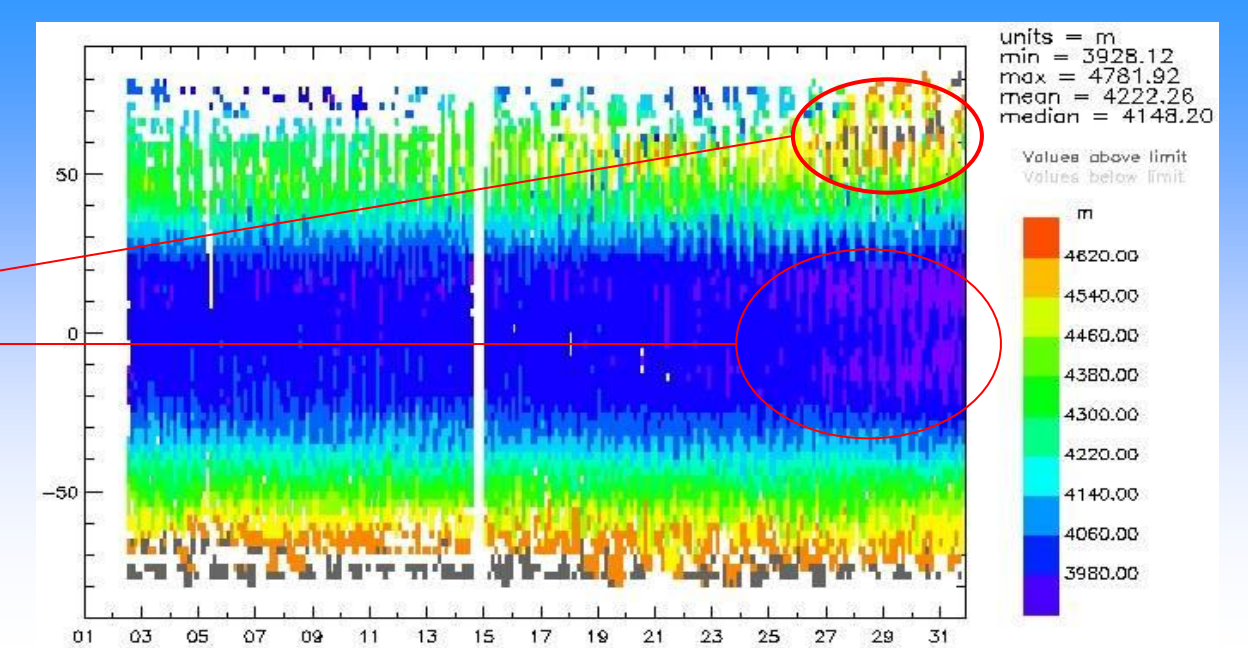
A numerical experiment is performed to assess the impact of the assimilation of IASI level 2 retrievals in the weather forecast:

- global assimilation with 3D-Var, 3h assimilation time window
- observational information from IASI is assimilated as layer thickness observations (see box bottom left) in addition to observation systems of the control experiment
- time period January 2009
- only IASI level2 "clear sky" observations (flag FLG_CLDFRM in the IASI level 2 data set)
- IASI I2 data over sea only (no sea ice)
- horizontal thinning of IASI I2 data to about 55 km (halves the data volume)
- control experiment: Assimilation of ground measurements, radiosondes, buoys, aircraft data, AMVs, AMSU-A



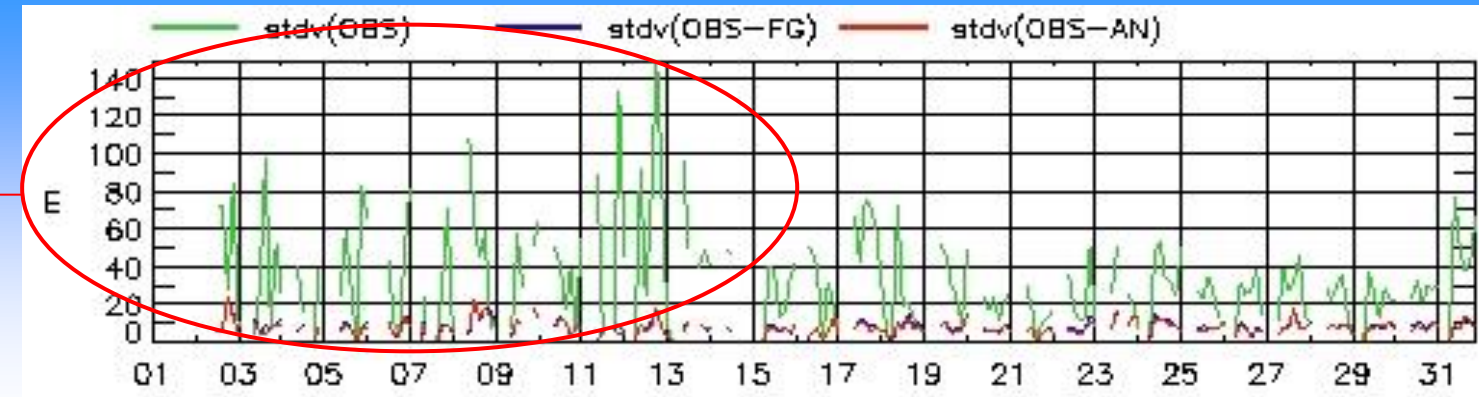
Horizontal distribution of clear sky IASI retrievals over the time of January 2009. Due to higher cloud-contamination, the mid-latitudes have a lower observation count than the tropics. Areas of remarkably high numbers of received IASI retrievals are west of India and the western Caribbean sea.

The layer thicknesses values display a trend in the second half of January 2009 in the upper troposphere/lower stratosphere: The IASI retrieval tend to lower temperatures (i.e. smaller values of layer thickness) in the tropics, and to higher temperatures in the areas north of 50 degree latitude.



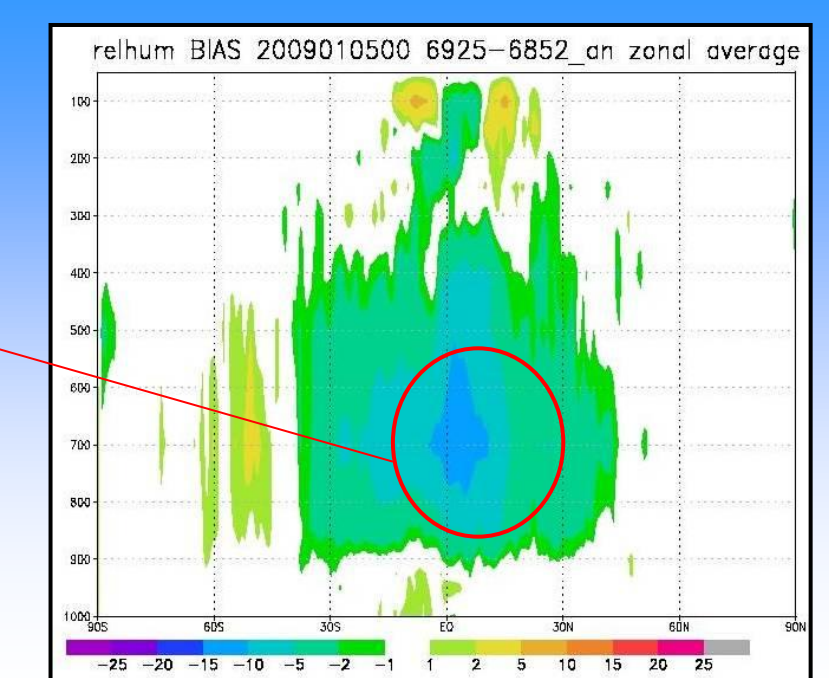
High horizontal variability of the averaged observational values in the northern Atlantic above 300 hPa (shown is the standard deviation of the observations in the layer 100-300 hPa). This feature is visible up to the height of 10 hPa.

Time series monitoring of the north pole region (latitude in [60,90]) suggest that the large values of the observation standard deviation (shown above) seem to occur predominantly in the first half of the month (there might be an influence of the ice mask).



Difference of temperature field to control experiment, day 5 of experiment: A vertically oscillating temperature bias builds up against the control in the tropics and mid-latitude. Its vertical structure resembles the thickness layer levels. It is likely that this structure has its origin in the use of thickness layers (with only small variations of the analysis increment within each layer) rather than assimilating smoother retrieval profiles. Probably a latitude-depending bias correction of the layer thicknesses could be an advantage for the assimilation.

A negative bias in the relative humidity field builds up in the tropics and the lower latitudes. The position of the extrema of the bias coincides with the height at which the temperature bias changes from positive to negative (bottom to top). Therefore it is most probable that the thermal instability induced by the temperature bias results in enhanced convection. This in turn results in an increase of precipitation and therefore in a loss of humidity in the height.



Anomaly correlation coefficient (ANOC): In the northern hemisphere and in Europe, the impact of IASI observations is more or less neutral (shown: geopotential 500 hPa). In the tropics and in the southern hemisphere, a slight degradation of the ANOC with IASI level2 data occurs (not shown)

Layer thickness observational error:

(according to: G. Kelly and J. Pailleux: Use of satellite vertical sounder data in the ECMWF analysis system. Technical memorandum 143, ECMWF, Reading, United Kingdom, 1988.)

Layer (hPa)	clear (m)	clear (K)	cloudy (m)	cloudy (K)
10-30	74.0	2.29	74.0	2.29
30-50	36.0	2.38	36.0	2.38
50-100	33.0	1.62	33.0	1.62
100-300	53.0	1.64	56.0	1.74
300-500	25.0	1.65	31.0	2.05
500-700	17.0	1.72	20.0	2.02
700-1000	27.0	2.56	33.0	3.13

Nominal layer thickness observation error

Nominal layer thickness observation error correlations "clear"

Layer (hPa)	10-30	30-50	50-100	100-300	300-500	500-700	700-1000
10-30	1.0	0.27	0.0	0.0	0.0	0.0	0.0
30-50	0.27	1.0	0.0	0.15	0.0	0.0	0.0
50-100	0.0	0.0	1.0	0.0	0.16	0.0	0.0
100-300	0.0	0.15	0.0	1.0	-0.16	0.0	0.0
300-500	0.0	0.0	0.16	-0.16	1.0	0.27	-0.18
500-700	0.0	0.0	0.0	0.0	0.27	1.0	0.22
700-1000	0.0	0.0	0.0	0.0	-0.18	0.22	1.0

Layer (hPa)	10-30	30-50	50-100	100-300	300-500	500-700	700-1000
10-30	1.0	0.27	0.0	0.0	0.0	0.0	0.0
30-50	0.27	1.0	0.0	0.2	0.0	0.0	0.0
50-100	0.0	0.0	1.0	0.0	0.0	0.0	0.0
100-300	0.0	0.2	0.0	1.0	-0.29	-0.25	0.0
300-500	0.0	0.0	0.0	-0.29	1.0	0.22	-0.34
500-700	0.0	0.0	0.0	-0.25	0.22	1.0	0.22
700-1000	0.0	0.0	0.0	0.0	-0.34	0.22	1.0

Nominal layer thickness observation error correlations "cloudy"

Ongoing work: Satellite bias correction

Study 1: Online estimation of bias correction coefficients

There are many sources of systematic errors that can affect the assimilation of observational data, in particular satellite observations. A bias correction is applied to the observational data to remove part of these systematic errors. This is done by modifying the radiance departures

$$y - H(x)$$

with the observation vector y , the model vector x , and the observation operator $H(x)$.

The bias correction is applied to the radiance departure, which is equivalent to the definition of a modified observation operator

$$\tilde{H}(x, \beta) = H(x) + \sum_{i=0}^N \beta_i p_i(x)$$

with the N different predictors β_i , and the corresponding coefficients p_i . The coefficients are obtained in a "training process" by finding the best compromise between the model and the observations, i.e. as the minimum of the cost function

$$J(\beta) = \frac{1}{2} [y - \tilde{H}(x, \beta)]^T [y - \tilde{H}(x, \beta)]$$

Operationally, the bias correction coefficients for the 3d-Var are calculated statically, based on a one-month data set of observational and model data. The main drawback of this method is the necessity of repeated offline calculations and the lack of continuity of the resulting bias correction.

In this study an adaptive online bias correction scheme is applied.

The investigated method of online bias correction:

- Calculate the statistics required to estimate the bias correction coefficients based on data of current assimilation interval
- Update statistics:
 - down-scale old statistics with appropriate factor
 - add new statistics to old one (this corresponds to an exponentially decaying influence of older data)
- Estimate new bias correction coefficients from the updated statistics.

The bias coefficients derived by this method can be compared with those calculated offline. A good consistency has been achieved for a one month test period.

This bias correction scheme serves as an intermediate step towards a variational bias correction scheme, which has the additional advantage to better discriminate between errors from the observation system and the NWP model (see e.g. D.Deer: Bias and data assimilation, Q.J.R. Meteorol. Soc 131, p.3323, 2005).

Study 2: Estimation of the impact of model predictors on the bias correction

To assess the impact of different model predictors on the bias correction, the related normalized bias coefficients are compared.

First, remove the FOV-dependent bias.

Calculate bias coefficients β_k for each instrument and channel.

For diagnostics, calculate normalized bias correction coefficients

$$V_k = \beta_k \frac{\sigma_{pred}}{\sigma_{bt}}$$

σ_{bt} : standard deviation in the data set

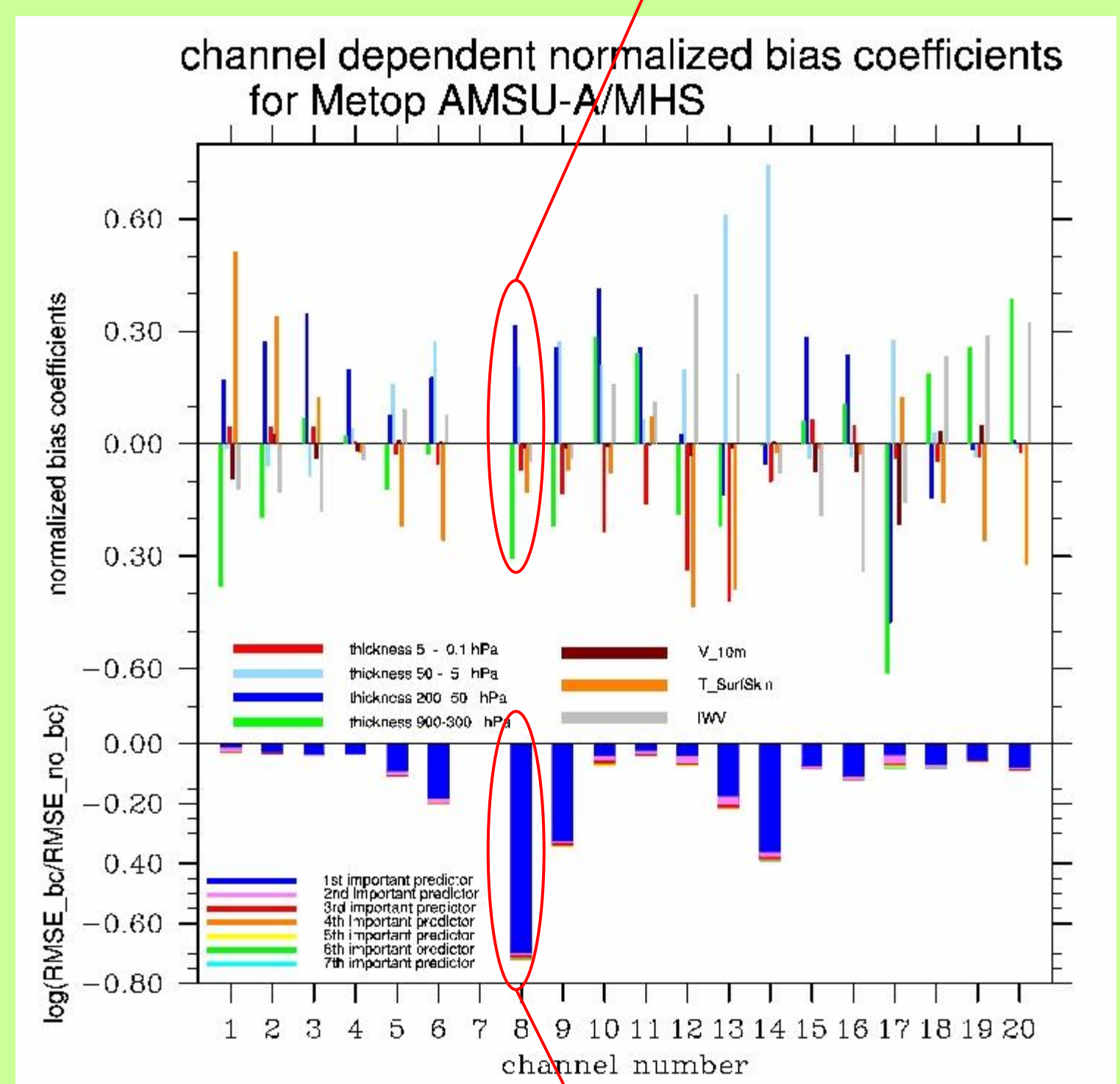
σ_{pred} : standard deviation of predictor

The absolute value of the normalized coefficients V_k measure the impact of the predictors on the bias correction.

In all, 16 model predictors and combinations of them are considered in the study.

For each channel, find the set of predictors with maximal impact for all satellites.

normalized bias correction coefficients for each channel



reduction (log scale) of RMSE applying coefficients of the most important predictors

For more information ...

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International TOVS Study Conference, 17th, ITSC-17, Monterey, CA, 14-20 April 2010.
Madison, WI, University of Wisconsin-Madison, Space Science and Engineering Center,
Cooperative Institute for Meteorological Satellite Studies, 2011.