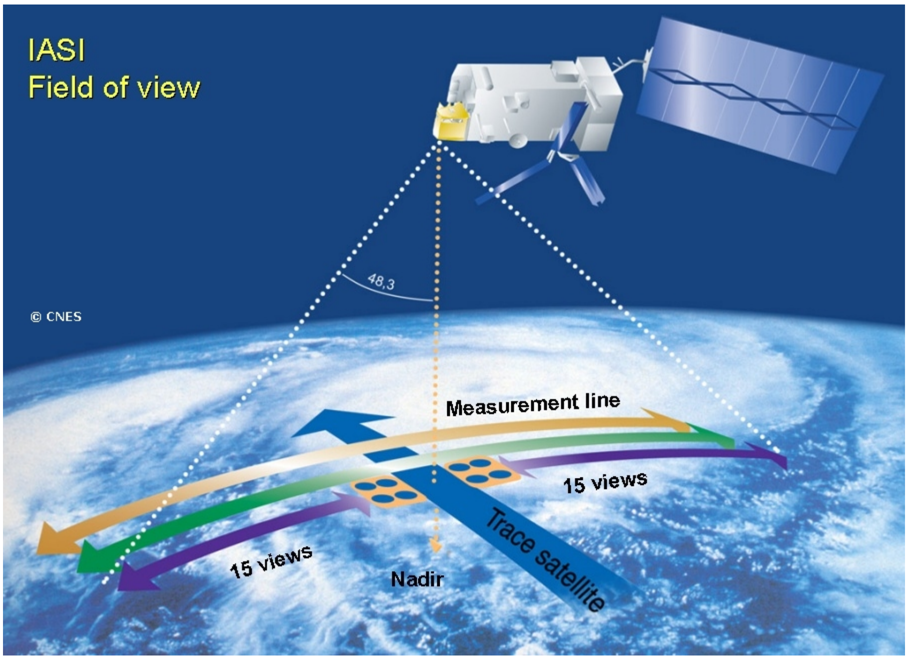
Assimilation of IASI data III

report from LACE stay in Budapest, 23/09/2013 - 31/10/2013



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Contents

1 Introduction

The Infrared Atmospheric Sounder Interferometer (IASI) is currently flying on MetOp-A since October 2006. This instrument provides information on atmospheric temperature and humidity in thousands channels, with horizontal resolution of 12km at nadir. The accuracy is expected to be better than 1K for temperature retrievals and 10% below 500hPa for relative humidity retrievals with a vertical resolution finer than 1km (Diebel et. al, 1996). The instrument is used to improve weather forecasting in the model as well as climate monitoring and atmospheric chemistry (for more details see EUMETSAT web pages).

IASI radiance are successfully assimilated in several NWP centers, see for example the overview by Hilton et al (2010), Collard and McNally (2009), Guidard et al (2010) or Randriamampianina et al (2011). The aim of this study is to assimilated IASI data from the satellite MetOp-A in ALADIN 3D-VAR system at Hungarian Meteorological Service (HMS).

This work follows the progress of previous studies by Trojakova (2011) and Benacek (2012), which have brought neutral or negative satellite impact on the forecast. Current study aim to reveal weaknesses from the previous studies focusing on the quality check of the assimilated data.

We introduce satellite data used in the section 2. The methods of data pre-processing is described in the section 3. At first have been the Variational bias correction (VarBC) applied to correct satellite systematic errors (biases). Secondly, methods for an active IASI channels selection were used and finally a quality of the data was investigated for different scan angles and terms of scan. Impact of IASI data have been evaluated in the section 5 and the last section 6 brings a summary.

2 Background

2.1 Data

Data from satellite MetOp-A and the instrument IASI were used for this study. Although the instrument provides information about atmospheric temperature and humidity in 8461 channels, a set of 366 channels available through EUMETCAST (or from September 2011 also provided to LACE Members via OPLACE) was used for this study, more details about this selection can be found in Collard (2007) and Collard and McNally (2009).

The instrument IASI is an across track scanning system with 30 scan positions towards the Earth and two calibration views. The useful field of view at each scan position consists of a 2×2 matrix of so-called instantaneous field of view (FOV), see the figure in the report's title. Each FOV has a ground resolution of 12km at nadir and it decreases at the end of IASI scan lines (connected with higher satellite bias described in the chapter 3.2).

Satellite has a circular sun-synchronous orbit and flies over the LACE domain twice a day. Most of the observations are measured at 9:30±1h and 19:30±1h. Taking into account that data are selected from the assimilation time-window $\pm 3h$ around the analysis time (0,6,12,18UTC), we get different data coverage over the domain for each analysis term, figured in Fig.1. It's obvious that each term is characterized by different data quality (described in the chapter 3.2).

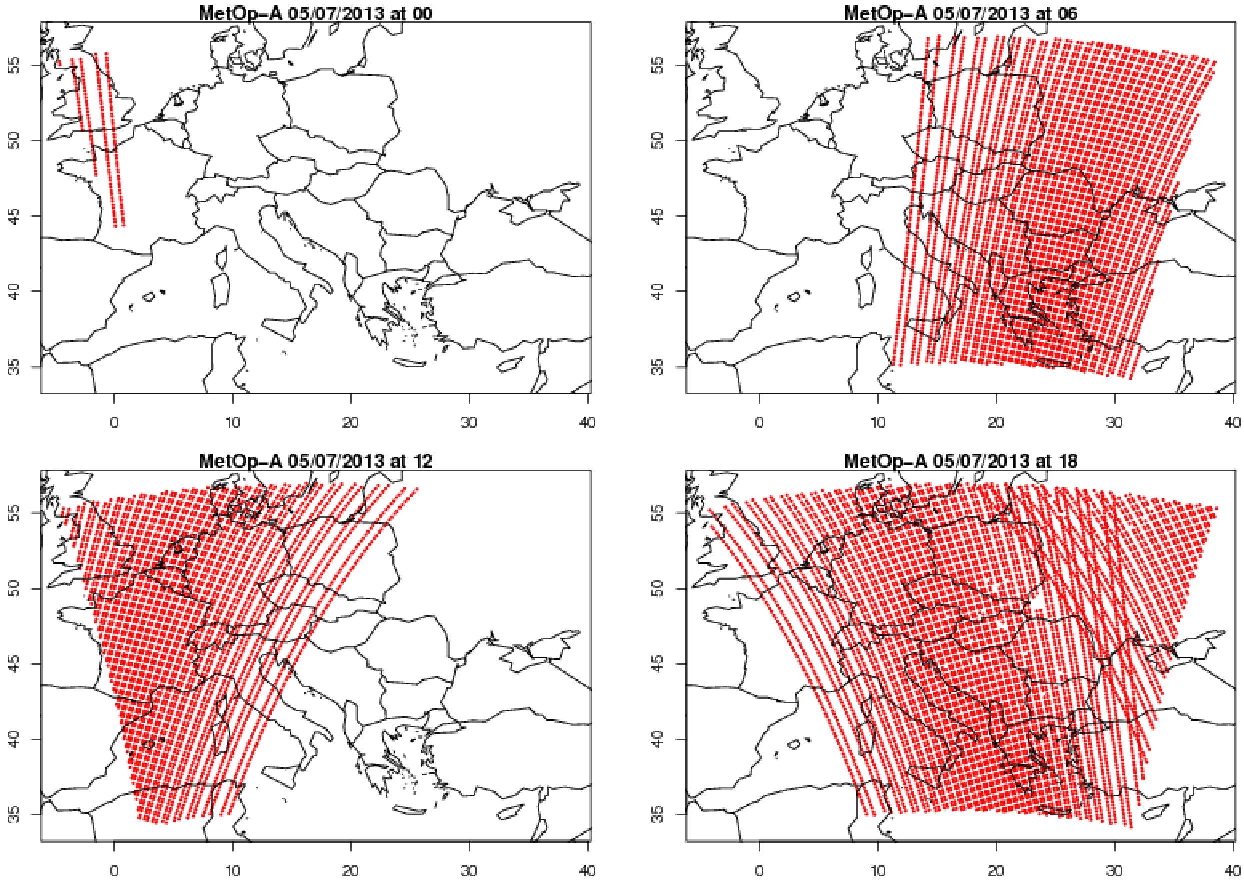

Figure 1: Orbits for MetOp-A

3 Methods

3.1 Satellite bias correction

Satellite bias was corrected using VarBC method. This method is based on the multivariate linear regression implemented into the variational algorithm 3DVar. The set of predictors are described in the Tab.1. The stratospheric predictors 5 and 6 were not used due to the spare model levels in the stratosphere. Regression coefficients β have been initialized from global model ECMWF (warmstart) and updated in each term (24-h cycling). Satellite data have been assimilated passively (setting of passive experiment in A).

Table 1: A set of predictors used for sensor IASI in VarBC.

.

Channels	**Predictors**
380-1180, 1820-2200	0,8,9,10
others	0,1,2,8,9,10

We faced a problem with IASI data rejection (in quality control) due to the cloud contamination. This problem is related with cloud detection algorithm used for hyper-spectral satellite instrument like IASI, AIRS and CrIS. This algorithm is based on the assumption that observation-minus-guess departures are unbiased. However, the satellite data are for passive assimilation experiment still biased, which leads to a data rejection (problem is related mainly with low/middle peaking channels). The problem have been solved by re-tunnig of detection scheme and fast bias correction (described in Appendix B).

Finally, a selection of clear-sky radiance was validated for random day to check running of the detection scheme. We compared a clear-sky pixel selection with cloud-type (CT) from NWC-SAF for selected IASI channels. The validation is shown for the middle-peaking channel 246 in the Fig.2. It is obvious that the pixels (red points) are selected from the clear-sky conditions, whereas data contaminated by high/middle cloud types (pink/white color) are rejected. Note that clear-sky radiation for middle-peaking channels are also selected over very-low clouds (the orange points over the North Sea).

3.2 Channel selection

After passive assimilation experiments, active IASI channels were selected. This was based on the three steps:

1. **Removing stratospheric channels** – all channels having a peak of weight function over 5hPa (top of model) were removed. This decision criteria is shown for the IASI channels 57(active) and 72(removed) in the Fig.3.

2. **Bias monitoring** – applying monitoring technique described in Randriamampianina et al. (2011). Time series of bias evolution of observation-minus-guess (OMG) were studied for each channel. We were looking for channels displaying bias reduction in time. The channels that have bias value lower than 0.1K were selected. The bias was studied for land and sea pixels separately. The channels Monitoring for the IASI channel 246 is shown in the Fig.4

3. **Channel reduction** – standard deviation (STD) of the IASI channels have been compared for each atmospheric level to reduce the channels with higher STD. The channel reduction based on STD is shown for the high and middle-peaking IASI channels in the Fig.5.

3.3 Data selection

Satellite bias was monitored with regard to a scan angle and compared for different analysis terms:

1. **Scan terms reduction** – the LACE domain coverage of IASI data is figured for different analysis terms in the Fig.1. At 00UTC is available small amount of observation from the end of scan lines. The amount of observation increases at 06UTC/12UTC, including right/left edge of scan view with respect to the nadir direction. The domain is fully-coveraged at 18UTC. The values of STD were compared between each analysis term to reduce the term with inappropriate data quality.

2. **Scan angle** – the higher scan angle (FOV) the higher satellite bias and STD is. The bias was monitored depending on the scan angle. Measurements at the end of IASI scan lines were reduced. The Fig.6 shows bias value depending on the scan angle at 06 and 12UTC for high-, middle- and low-peaking IASI channels. Note that the data quality decreases near the right edge (12UTC) and left edge (06UTC) of scan lines.

4 Results

4.1 Passive experiment

Satellites and sensors from the table Tab.2 were passively assimilated to warm-up VarBC scheme. Passive assimilation was run during the period 02/06/2013 - 15/07/2013 (for 44 days). The regression coefficients β have been initialized from ECMWF VarBC file (warmstart). VarBC coefficients for sensor IASI have been modified in the beginning of passive experiment as described in Appendix B. Technical detail could be found in Appendix A.

Table 2: Satellites and sensors used in passive experiments.

Satellite [satid]	**Sensor**
NOAA 16 [207]	AMSU-A,B
NOAA 18 [209]	AMSU-A,B
MetOp-B [004]	AMSU-A, MHS, IASI
MSG 10 [073]	SEVIRI

4.2 Data pre-processing

Channels selection

According to the section 3.2, the following stratospheric IASI channels were rejected:

- $16, 59, 66, 70, 72, 74, 89, 92, 95, 97, 99, 101, 106, 113, 119, 125, 131, 138, 144, 151, 157, 163, 170, 176, 183, 189, 195, 83, 49, 133, 81, 79, 111, 301, 303$

According to the section 3.2 the bias monitoring and channel reduction were applied. Selected active channels are described in the table 3. The channels were separated according to the spectral bands. CO_2 channels have impact to the atmospheric temperature. High and middle-peaking channels were used over all types of surface. Low-peaking channels and atmospheric windows (WIN) are used only over sea due to poor description of surface temperature and surface emissivity by model. The water vapor channels were not used to avoid the problem with inter-channel observation error correlation described in Bormann (2010). Finally, the channels with spectral bands around O_3, CO, N_2O, CH_4 were not used (not supported by RTTOV version 9.2).

Table 3: The channel selection used for active IASI assimilation experiments.

Group	**Channel**	**Impact**
High CO_2 (allsurf)	$51, 57, 63, 87, 109, 116, 122, 128, 135, 141, 148, 154$ $161, 167, 173, 179, 180, 185, 187, 193, 199, 205, 207, 210$	high-tropospheric T
Middle CO_2 (allsurf)	$212, 217, 219, 224, 226, 230, 232, 236, 239, 246, 249$ $254, 256, 260, 262, 267, 269, 280, 282, 294, 335, 347, 389$	middle-tropospheric T
Low CO_2 (sea)	$286, 290, 308, 310, 316, 323, 356, 360, 366, 373, 379, 381, 426$	low-tropospheric T
WIN (sea)	$1191, 1194, 1271$	near-surface T

Data reduction

According to the chapter 3.3 first and last 10 FOV of IASI scan lines were removed and IASI measurements at 0UTC analysis time were rejected.

4.3 Active experiments

IASI data was assimilated actively with the following setting:

- during the period 01/07/2013 - 31/07/2013 (for 31 days)
- VarBC parameters initialized from passive experiment (see the chapter 4.1)
- not used predictors 5 and 6 (see Tab.1)
- IASI channels used from the Tab. 2
- actively assimilated all 4FOV
- first/last 10FOV from IASI scan lines rejected
- IASI observation at 0UTC analysis time not used
- a thinning distance for IASI data 80km

Active experiments are described in 4.3.
They have been verified using Harmonie monitoring system against radiosondes.

Experiment Name	Verification Name	Description
Oper	AREF	operative settings
RefIASI	NREF	operative settings + VarBC initialized from passive experiment
IASI36e4	IAS4	RefIASI + IASI (used $\mathbf{CO_2}$ and **WIN** channels)
IASI36e5	IAS5	IASI36e4 + IASI (used **WV** channels)

5 Impact on the forecast

5.1 AREF-NREF

New VarBC file initialized from passive assimilation experiment had neutral impact to the surface and slight impact to the forecast of upper-air parameters. Slightly negative impact was detected for temperature (the top Fig.7) in the level 100 and 500hPa (T100hPa and T500hPa) and for relative humidity in the high troposphere (RH300-RH200hPa). Slightly positive impact was detected for T925hPa (the bottom Fig.7). Regarding precipitation surface skill scores KSS(Kuiper Skill Score) is shown in the Fig.9 (see AREF-NREF). The VarBC file had negative impact for forecast of a weak precipitation up to threshold 1mm/12h, however it improved precipitation forecast above 10mm/12h.

5.2 NREF-IAS4

The IASI data assimilation has slightly positive impact on a temperature, wind speed and main positive impact was detected in a precipitation. Scores for temperature vertical profile is shown in the top Fig.8. The positive impact is obvious in bias for T500hPa and T100hPa, that was possibly connected with degradation using new regression coefficients in reference experiments NREF (see Fig.7). Furthermore, we got slightly positive impact in lower troposphere for T700hPa and T925hPa (the bottom Fig.8).

Using IASI data produced also slight improvement of wind speed from 300hPa to 700hPa (not shown). Slight degradation in wind was detected in 925hPa (not shown).

The impact of IASI data on a precipitation is shown in the Fig.9. There are surface skill scores KSS at initial time 12UTC(bottom) and 00+12UTC(top) for experiments AREF(green), NREF(red) and IAS4(blue). The best score for KSS is 1, no skill 0. The precipitation score for both initial time (the top figure) shows slight degradation between thresholds 0.1 and 1mm/12h and considerably improvement for precipitation above 10mm/12h. More details is obvious from the precipitation score at 12UTC (the bottom figure). Although the IASI data assimilation improved forecast of precipitation above 1mm/12h (NREF-IAS4), this threshold improvement was probably connected with reference degradation (compared NREF-AREF). However, IASI assimilation considerably improve a forecast of precipitation above 3mm/12h, whereas we got negative impact on precipitation between 0.1 and 1mm/12h.

6 Summary

We assimilated IASI data from MetOp-A into the model ALADIN at HMS. At first, the data were passively assimilated to update bias parameters including in VarBC file. We solved a problem with application of cloud detection scheme on biased IASI data (in Appendix B) and prepared VarBC files for individual satellite channels (described in the table2).

Secondly the quality of bias correction and IASI channels selection were investigated according to the methods described in the chapter 3.2. IASI data were also reduced according the quality for each FOV and term of scan (described in the chapter 3.3).

Finally, the selected IASI channels were actively used in the assimilation system. Active experiments (described in Tab 4.3) were initialized by VarBC file. Impacts on forecast were verified using Harmonie monitoring system. Using new VarBC file has slightly negative impact on upper-air scores for temperature (Fig.7) and relative humidity and negative impact on a weak precipitation (for threshold 1mm/12h). Slightly positive impacts were on T925hPa and a precipitation above 10mm/12h.

IASI data assimilation has slightly positive impact on temperature for a lower troposphere (T700hPa and T925hPa) and wind speed in a middle troposphere (W300hPa-W700hPa). Slightly degradation was detected for wind speed in W925hPa. The main impact of IASI data was evaluated for precipitation. We evaluated improvement for forecast of precipitation above 3mm/12h and degradation of precipitation between 0.1 - 1mm/12h (Fig.9).

A Assimilation scripts

A.1 Passive assimilation

Passive assimilation of satellite data demands set `fail(EXPERIMENTAL)` for selected statid and press in `mf_blacklist.b`. Our modification could be found in
`wfma:/home/bpatrik/pack/varbccomp/src/local/bla/mf_blacklist.b_passive`
and the executable file in
`wfma:/home/bpatrik/pack/varbccomp/bin/MASTERODB_passive.exe`

List of modifications:

```
arp/obs_preproc/screen.F90   # AT
arp/op_obs/hradpad.F90 # AT
arp/op_obs/hradp.F90 # AT
arp/op_obs/hradptl.F90 # AT
arp/canari/canari.F90 # AT
arp/module/varbc_pred.F90 # AT
arp/module/varbc_rad.F90 # predictors 5 and 6 not used
bla/mf_blacklist.b # passive satellite data assimilation
```

The modifications marked as `AT` were made by Trojakova (2011). Scripts for passive assimilation could be found in
`wfma:/home/bpatrik/VarbcIASI/warmstart3_$NT`

A.2 Active assimilation

Active assimilation experiments were run under SMS client. Modifications were same as passive experiment, except of:
`wfma:/home/bpatrik/pack/varbccomp/src/local/bla/mf_blacklist.b_RefIasi`
`wfma:/home/bpatrik/pack/varbccomp/src/local/bla/mf_blacklist_IASI36e3`

Executable files are in
`wfma:/home/bpatrik/pack/varbccomp/bin/MASTERODB_RefIasi.exe`
`wfma:/home/bpatrik/pack/varbccomp/bin/MASTERODB_Iasi36e3.exe`

Assimilation scripts are available in
`wfma:/home/bpatrik/SMS/`

B Cloud detection scheme problem

The current assimilation system allows to use only clear-sky radiance, therefore the cloud contaminated channels should be rejected. For the cloudy-channels detection the scheme described by McNally et al (2003) was used. In summary, this cloud detection algorithm works by taking the observation-minus-guess departures (OMG) and looking for the signature of opacity that is not included in the clear-sky calculation (i.e. cloud or aerosol). To do this, at first the channels are ordered according to their height assignment (with the highest channels first and the channels closest to the surface last). The resulting ordered OMG are then smoothed with a moving-average filter in order to reduce the effect of instrument noise (a detailed description is given by McNally et al (2003)).

This algorithm works well on condition that OMG departures are unbiased. However, that is not true in case of passive assimilation until regression coefficients are updated. Biased data are evaluated as a cloudy data and rejected through a quality control (mainly low/middle peaking channels). It leads to a problem with cloud-channel detection and problem with updating regression coefficients.

Solution:

- detection scheme was re-tunned for selected clear-sky days (5.6.-9.6.2013)
- OMG departures for each channel were detected in these days (Fig.10)
- BT thresholds were modified (according to the detected biases) to ensure passing the data through quality control
- bias correction using NGB_IASI=500 was done during the clear-sky period
- BT thresholds were returned back to default values
- clear-sky pixel selection was validated using cloud types from NWC-SAF (Fig.2)

BT threshold was modified in `arp/obs_preproc/cloud_detect_setup.F90` for each spectral band: `R__BT_Threshold(1:N__Num_Bands) = (/ 3, 3, 1, 0.5, 0.5 /)`

References

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`http:www.rclace.euFileData_Assimilation2012IASI_report.pdf`

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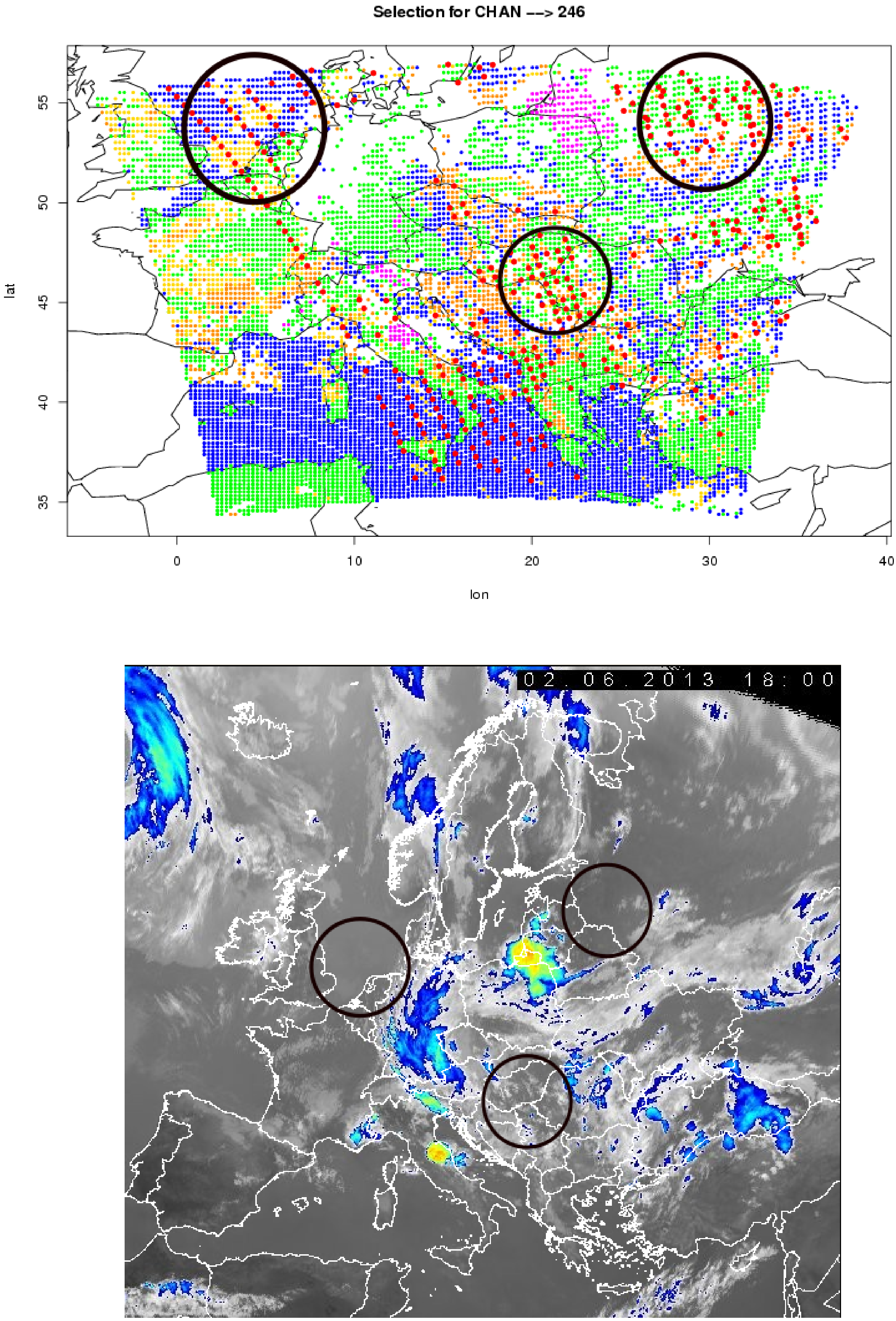


Figure 2: Clear-sky pixel selection was validated against CT from NWC-SAF. In the top figure are shown radiance (red points) from middle-peaking IASI channel 246 and different cloud types from NWC-SAF (land/green, sea/blue, low-clouds/orange, middle-/white, high-/pink). There is a control MSG channel IR10.8 in the bottom figure.

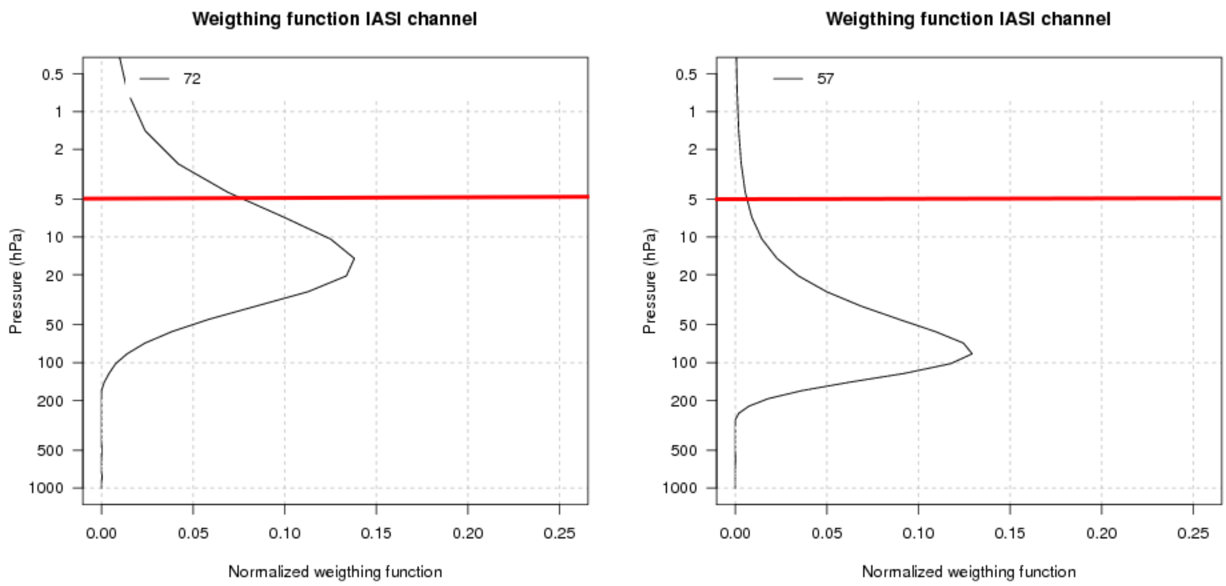


Figure 3: Weighting function for the IASI channels 72 and 57. The channels that have peak over 5hPa have been removed (chan72 on the left), otherwise channels peaking under 5hPa have been selected (chan57 on the right).

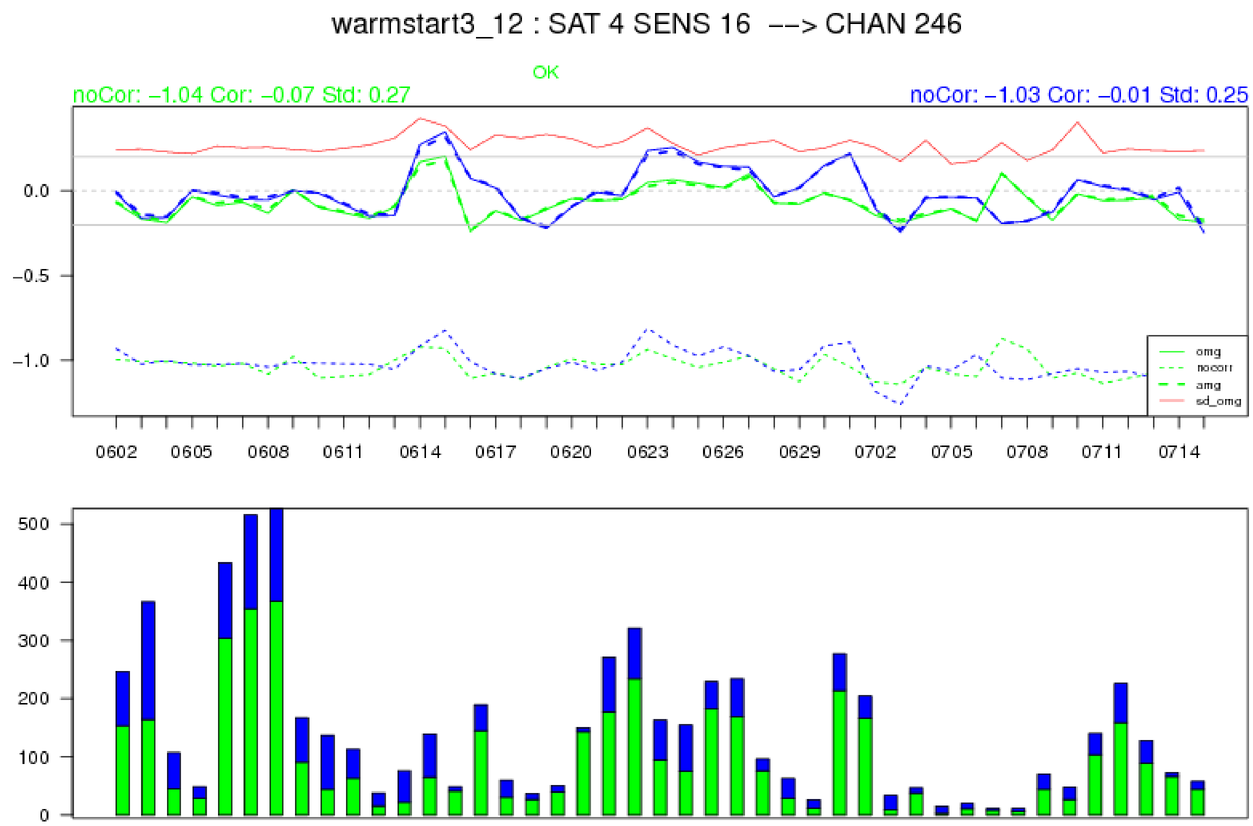
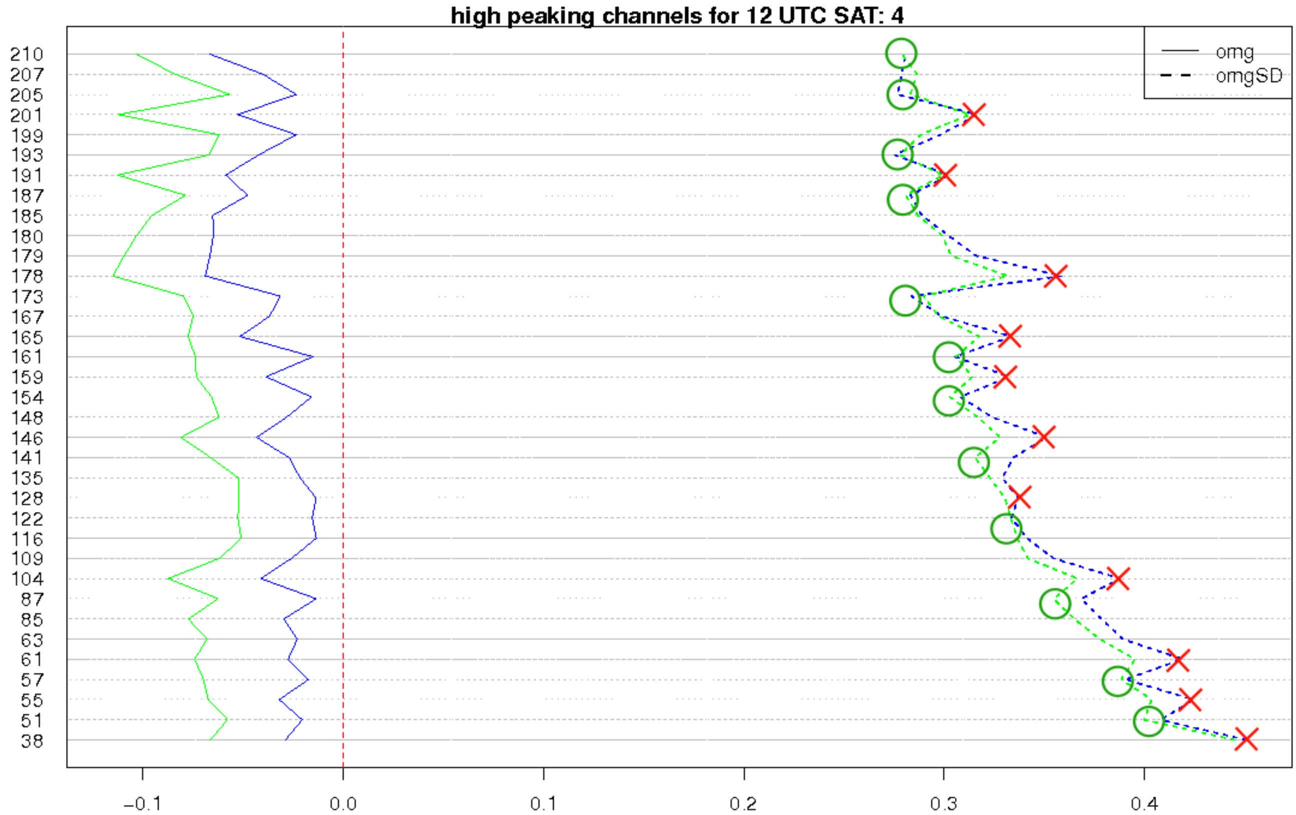


Figure 4: Each IASI channel have been monitored separately for land and sea surface. Time evolution of OMG (solid line), nocorr (OMG without correction; dashed line) and STD (solid red line) are shown for the channel 246 at 12UTC. Number of observations for land/sea surface are shown on the bottom picture.



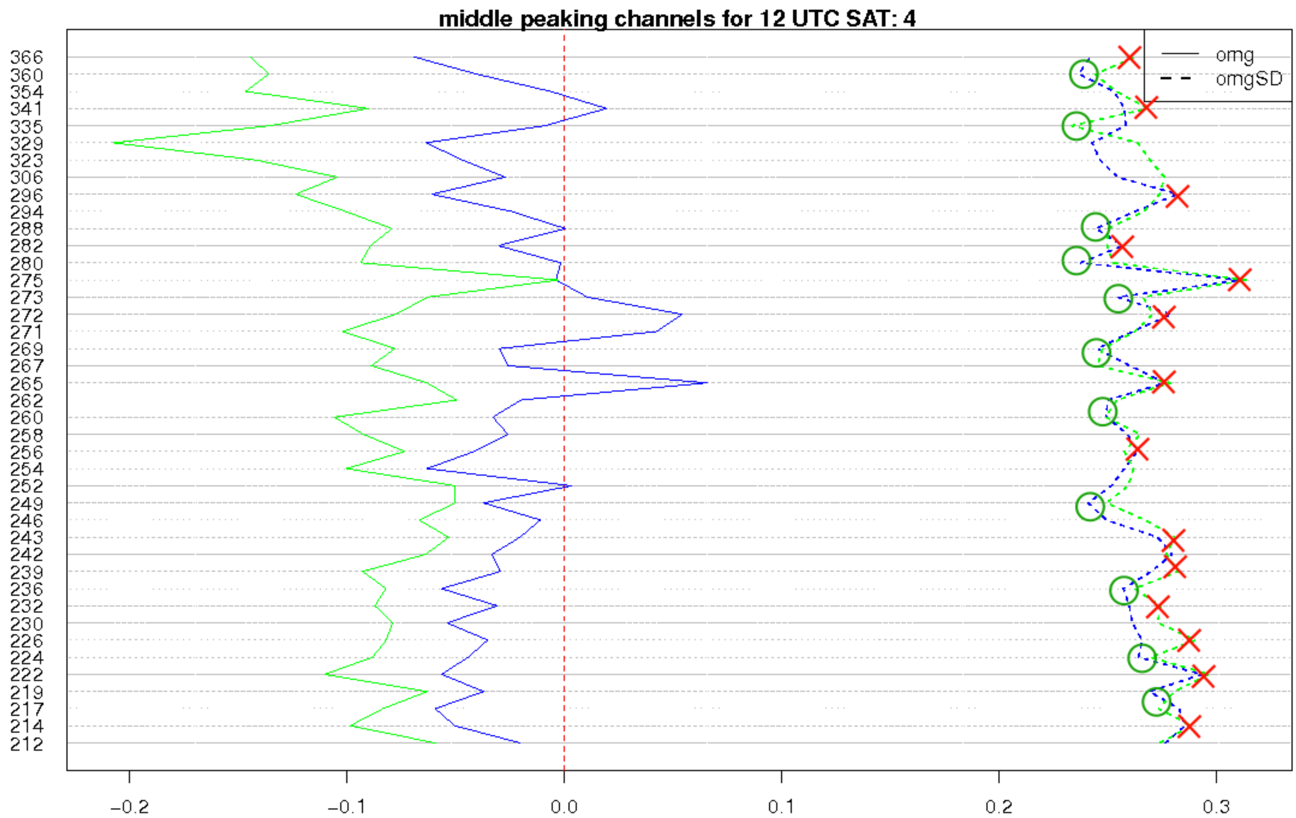


Figure 5: The IASI channels were ordered accoridng to the weighting function peak. The channels with higher STD for each atmospheric level were reduced. Red crosses mark the removed channels, whereas the green circle are the channels that were used actively.

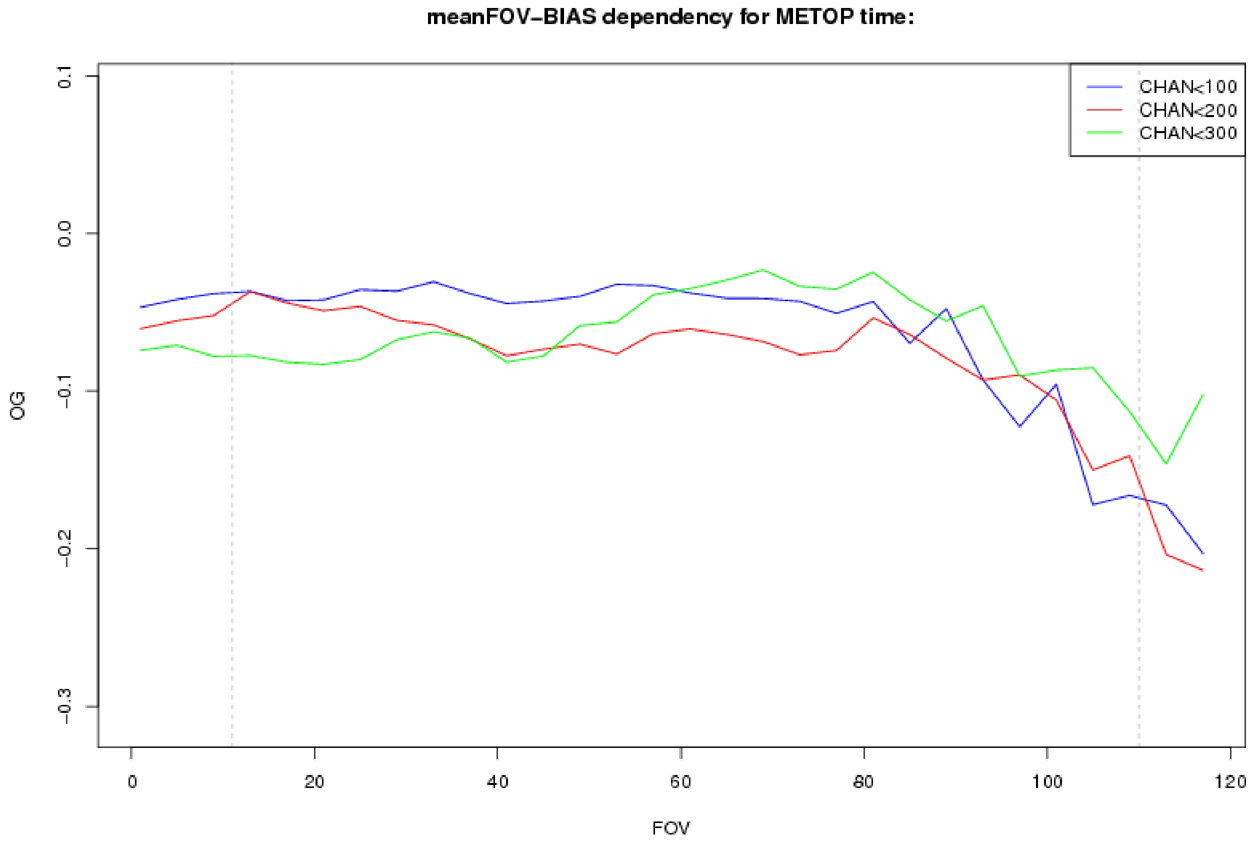
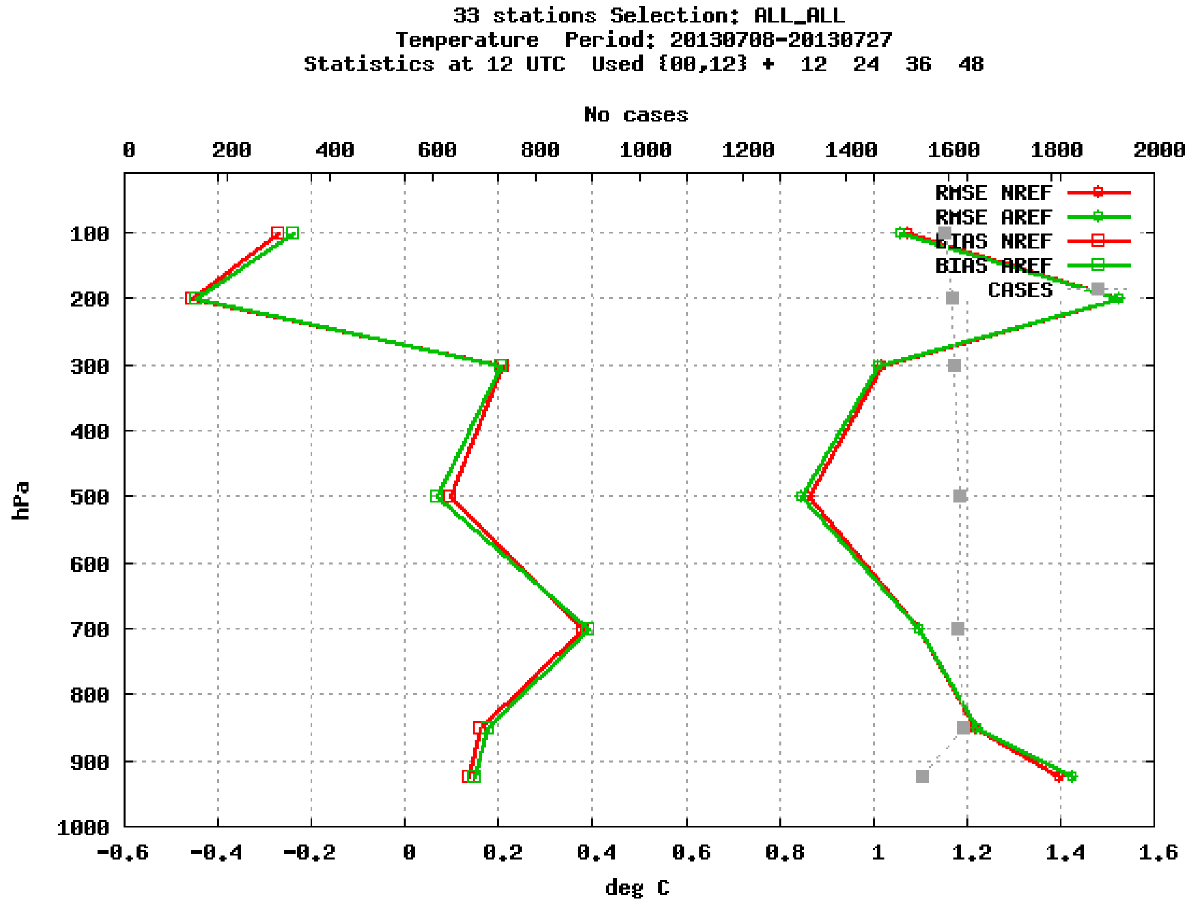


Figure 6: Data reduction were applied for the end of IASI scan lines due to increase of satellite bias. The figures show bias dependency (after correction) on scan angle (FOV) at 12UTC (top) and 06UTC (bottom) for the IASI high (blue), middle(red) and low-peaking(green) data. Last and first 10 FOV were rejected (grey line).



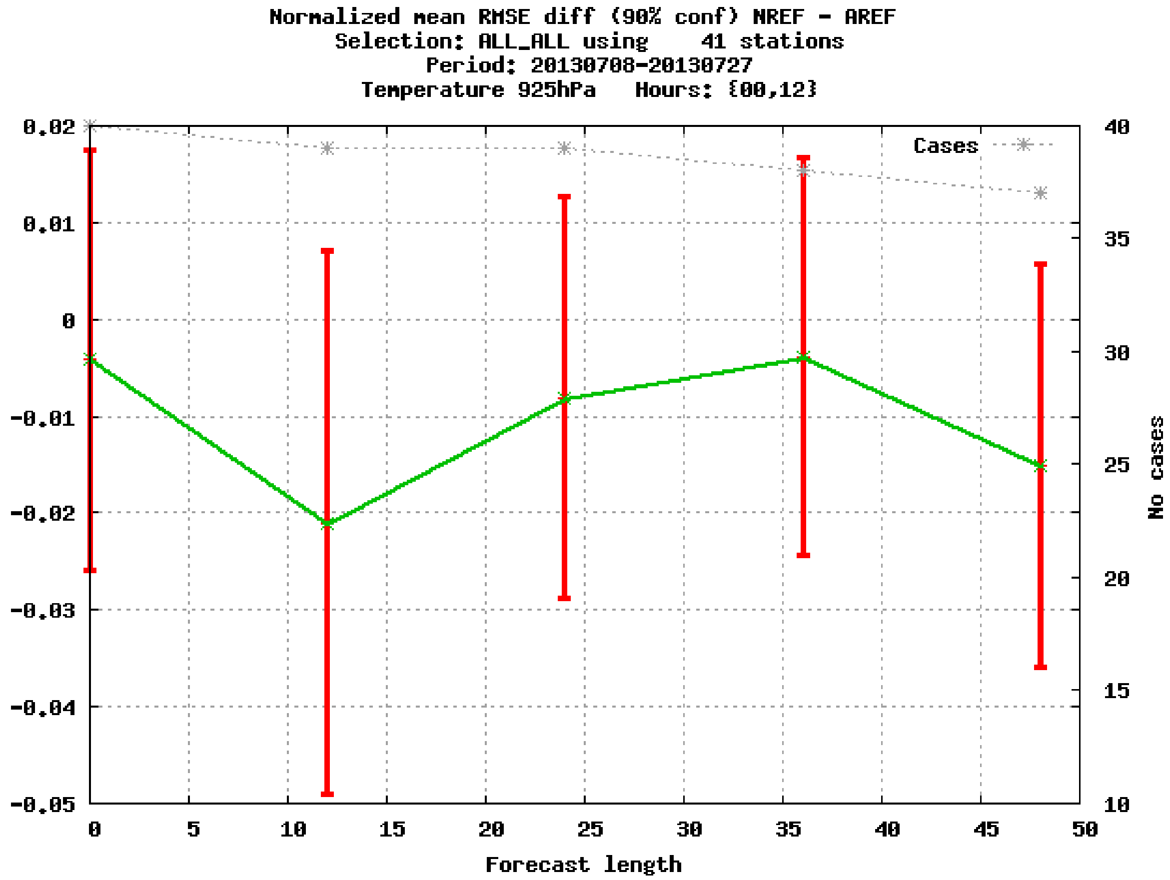
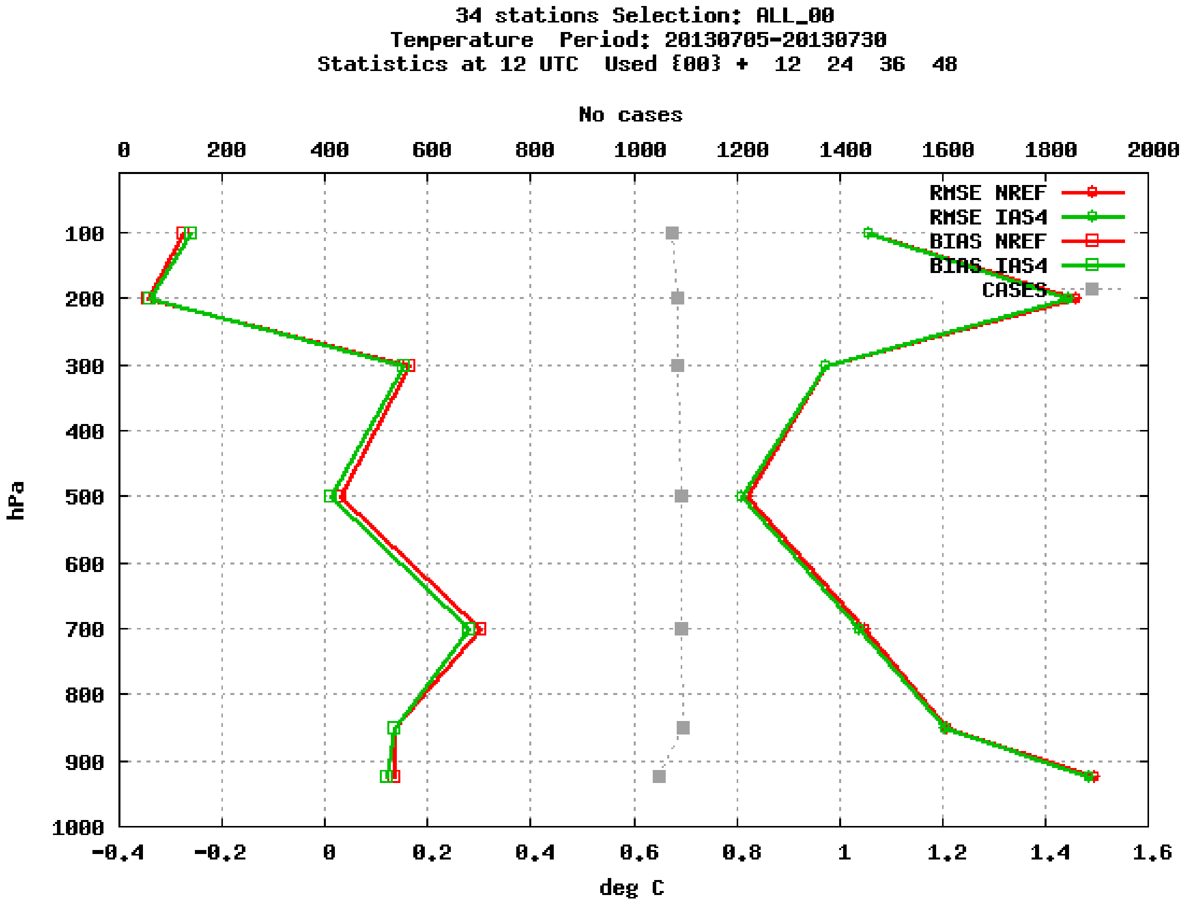


Figure 7: Bias and rmse scores for temperature vertical profile for AREF-NREF experiment (in the top figure). There are shown a slight negative impact on bias for T100hPa and T500hPa and a slight positive impact for T925hPa. Significance test for T925hPa is shown in the bottom figure.



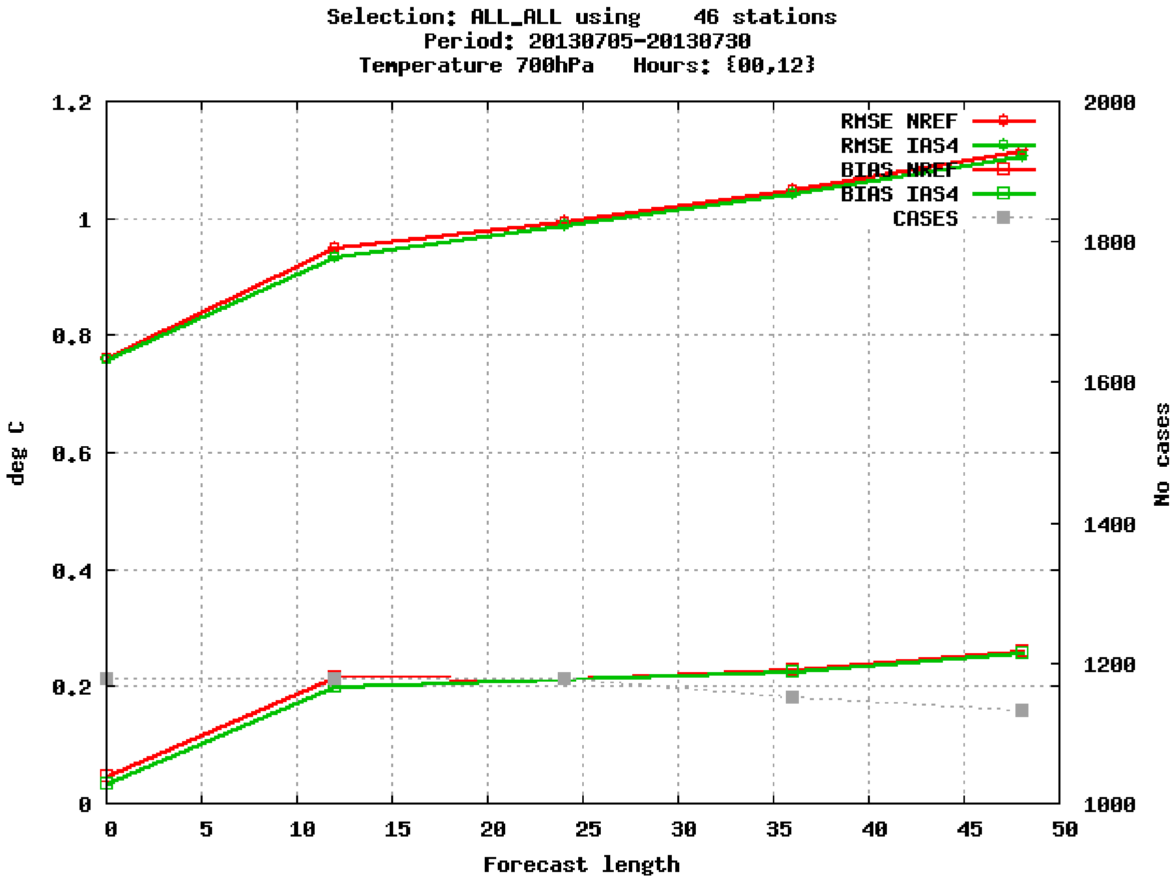


Figure 8: Scores for temperature vertical profile for NREF-IAS4 experiment is shown in the top figure. There are slight positive impacts on a temperature in a low troposphere T700hPa and T920hPa. The positive impact on T700hPa for all forecast ranges is shown in the bottom figure.

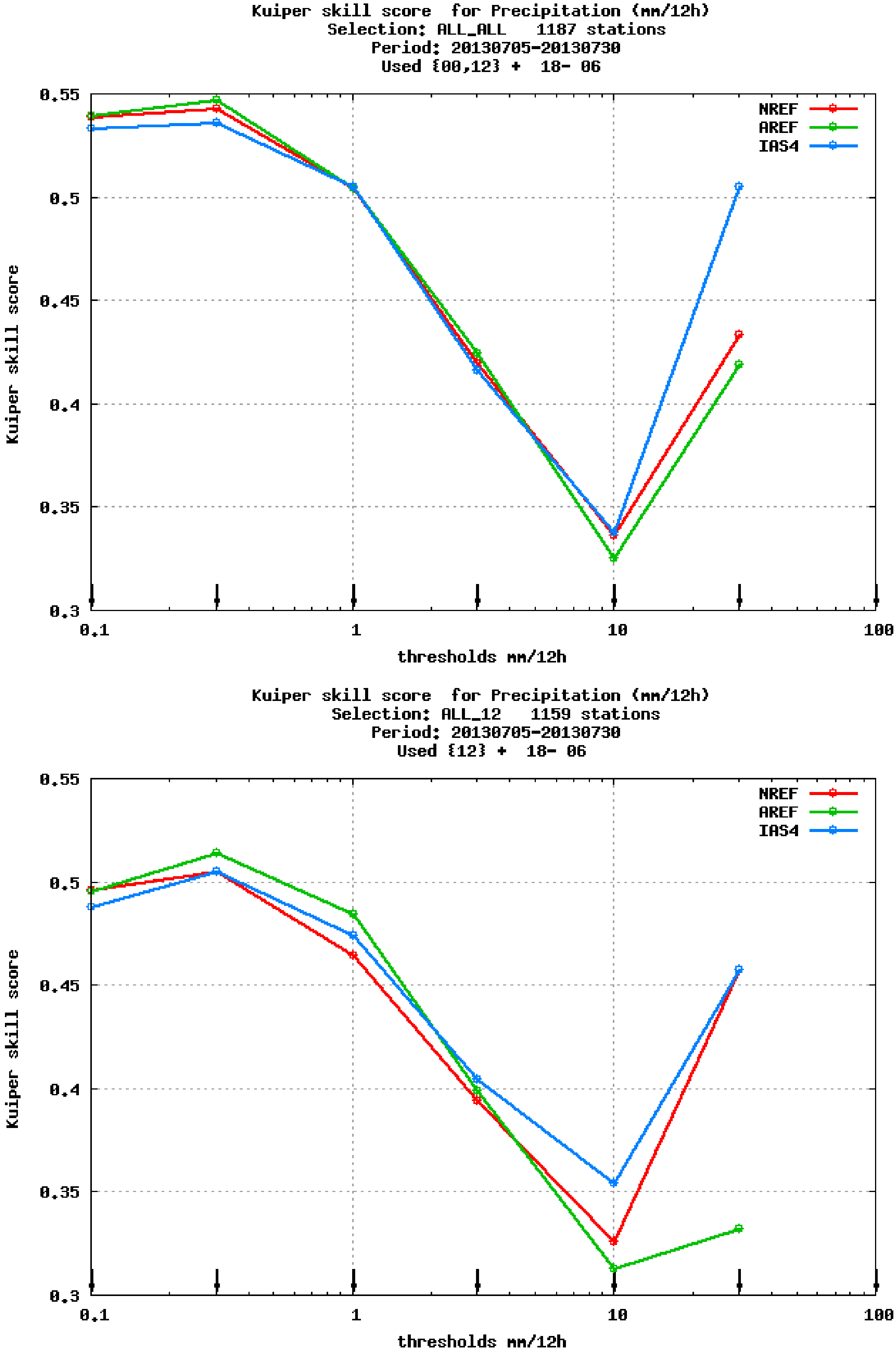


Figure 9: Surface skill scores KSS(top) and EDI(bottom) for precipitation and experiments AREF(green), NREF(red) and IAS4(blue). The best score is 1 and no skill 0.

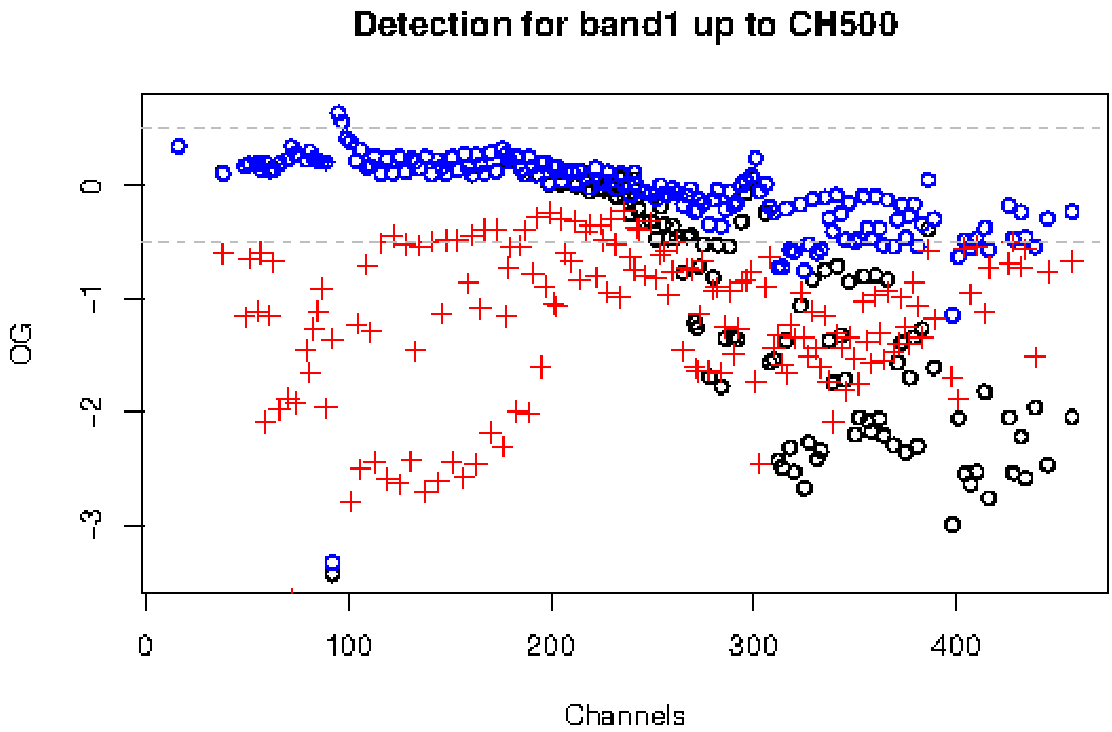


Figure 10: OMG departures for selected channels (spectral band1) for clear-sky day 8.6.2013 at 06UTC. Blue points represents clear-sky channels, black points represents cloudy-channels and red cross represents the values of bias correction. The figure was used to re-tuning BT thresholds (IASI channels in band1) for cloud detection scheme.