Assimilation of SEVIRI data

report from LACE stay in Budapest, 18/9/06-10/11/06

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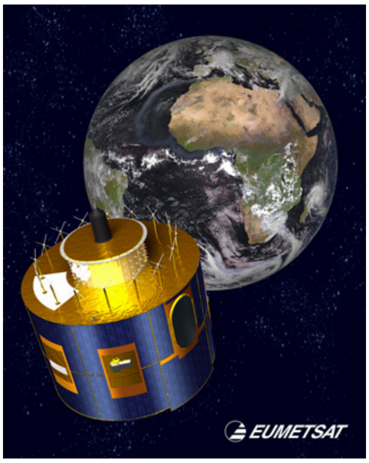

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1 Introduction

The Spinning Enhanced Visible & Infrared Imager (SEVIRI), on board of the Meteosat Second Generation (MSG) satellites (from Meteosat-8 onwards), observes the Earth in 12 spectral bands of the electromagnetic spectrum at a resolution of 3 km at the sub-satellite point and delivers a picture every 15 minutes. This allows to follow closely the development of rapidly evolving weather phenomena like storms, blizzards and fog.

Following the positive impact of an assimilation of SEVIRI data at Météo-France reported by Montmerle (2005a), the aim of the stay was to get knowledge of the data preprocessing and perform impact studies with ALADIN/HU 3DVAR assimilation system. In following sections at first a local data processing is described in section 2, then the modifications to read SEVIRI data in Section 3. Section 4 is dedicated to the bias correction and Section 5 to the single observation experiment. The first impact studies are presented in Section 6 and in the last section conclusion and future plans are drawn.

2 Data processing

An attempt was done to create locally the same SEVIRI product as is used in Toulouse (obtained from CMS (Météo-France / Centre de Méteorologie Spatiale, Lanion, France). This product is a single file in GRIB format which consists of

- the SEVIRI brightness temperatures for channels 3.9 μm, 6.2 μm, 7.3 μm, 8.7 μm, 9.7 μm, 10.8 μm, 12.0 μm, 13.4 μm (8 components)
- the associated constant fields: date, longitude and latitude position, azimuth and zenith angles (5 components). It should be noted that the date does not contain information about the time of the scan in UTC, but the time from the beginning of the scan from the south to the north.
- the cloud type and cloud top pressure with theirs quality flags (4 components)

A data processing currently used in Hungarian Meteorological Service (HMS) is shown schematically on Fig 1 and all 17 components will be briefly described in following subsections.

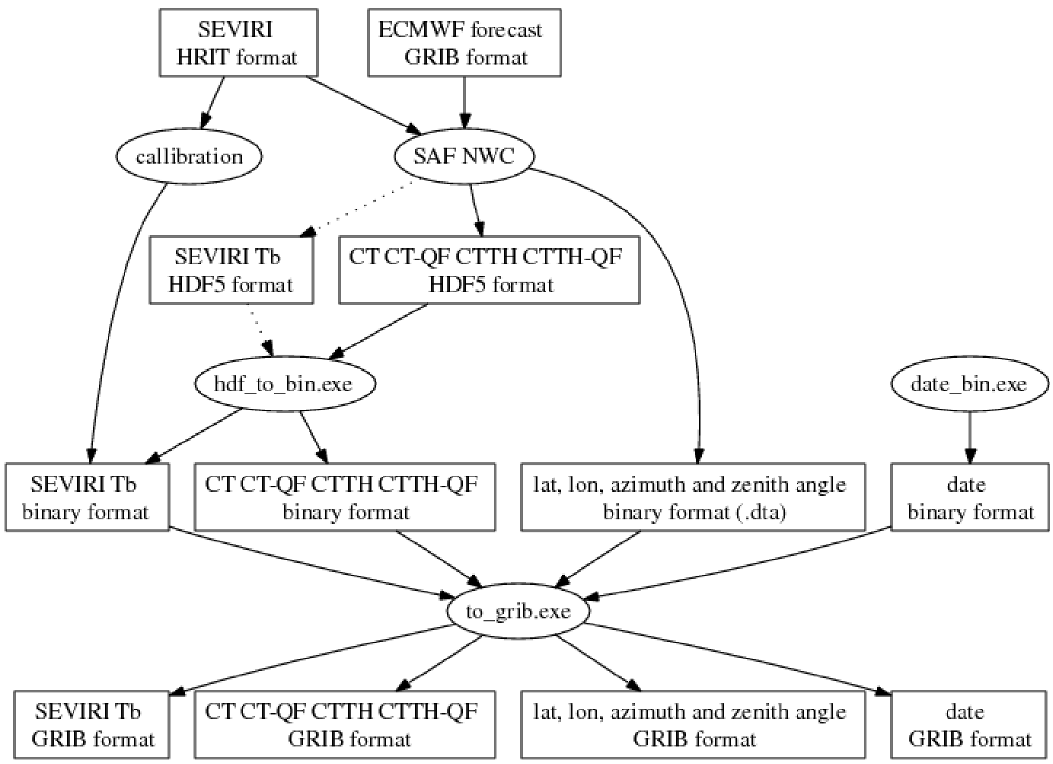

Fig. 1: Data processing at HMS.

2.1 SEVIRI data

The SEVIRI images and other meteorological data are disseminated by the satellite via Low or High Rate Information Transmission (LRIT/HRIT). After local calibration to brightness temperatures are converted to GRIB format. Received SEVIRI data can be used as an input to the SAF NWC, described later in this report, which can among others provide also calibrated brightness temperatures.

2.2 SAF NWC

The general objective of the Satellite Application Facility on Support to Nowcasting and Very Short-Range Forecasting (SAF NWC) is to provide operational services to ensure the optimum use of meteorological satellite data in Nowcasting and Very Short Range Forecasting by the targeted users. This section doesn't intend to be a comprehensive documentation about SAF NWC, which is available on http://nwcsaf.inm.es, but introduces the products needed for the assimilation of SEVIRI data. From the list of products developed by the SAF NWC we are going to use following:

- **cloud type and cloud type quality flag**
  The main objective of this product is to provide a detailed cloud analysis and may serve as input to mesoscale models. This product is essential for the generation of the cloud top temperature and height product. It contains information on the major cloud classes : fractional clouds, semitransparent clouds, high, medium and low clouds (including fog) for all the pixels identified as cloudy in a scene. The main product output consists of the twenty-one categories. Description of all categories can be found on SAF NWC web page and example of cloud type product is plotted on Fig 2. The quality itself is described by 10 bits and contains information about illumination and viewing conditions, used SEVIRI input data, NWP input data and the quality of the processing itself.

- **cloud top pressure and cloud top pressure quality flag**
  The cloud top temperature and height product contains information on the cloud top pressure, the cloud top temperature, the cloud top height and theirs quality flag information for all pixels identified as cloudy in the satellite scene. An example of cloud top pressure is plotted on Fig 3.

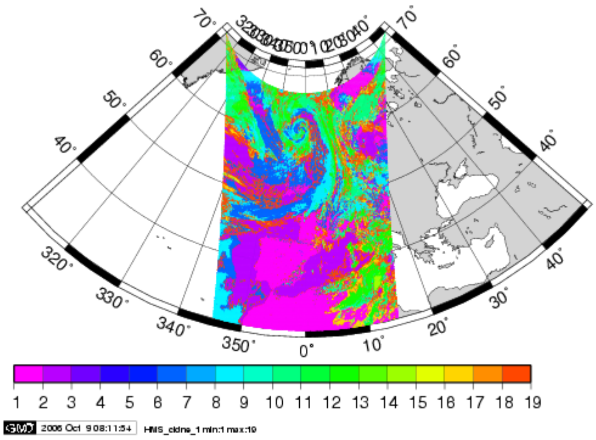

Fig. 2: Cloud type.

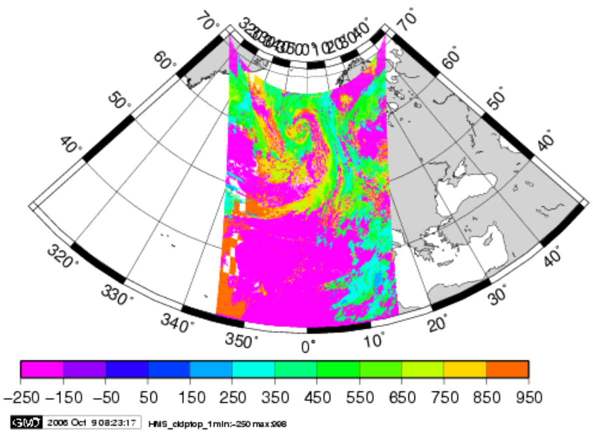

Fig. 3: Cloud top pressure.

Both products are available in raster (HDF5 format) and then are converted at first to binary format (by hdf_to_bin.exe) and then to GRIB format (by to_grib.exe). Programs were kindly provided by CMS. Intermediate binary format is needed because consequent conversion to GRIB works only with float and real number representation. Concerning list of inputs there are not only SEVIRI data, but also NWP data (in GRIB format) essential to obtain high-quality results. In HMS ECMWF 3h-forecast are used with 0.5x0.5 degree resolution.

As noted in Montmerle (2005b), the cloud type product is used to select channels: the 8.7 μm, 10.8 μm and 12.0 μm IR channels are kept only in clear-sky condition, the 13.4 μm is also kept above very low clouds and the two WV channels (6.2 μm and 7.3 μm) are considered even above mid-level clouds.

2.3 Constant fields

The associated constant fields (longitude and latitude position, azimuth and zenith angles) are obtained from SAF NWC in binary format (.dta) and then are directly converted to GRIB format. For creation of date component, which contains time from the beginning of the scan, a special executable (date_bin.exe) and its corresponding namelist is needed. Both were provided by CMS.

3 Bator

Next issue after preparation of an input file is to read the data by the model, which is done by the program BATOR. A new development in program BATOR was needed due to problem related to the use of RGB (**R**ead **G**rib from **B**DAP) library at HMS. An optional read by GRIBEX library was added. All source code modification are described in appendix (A) and an example of data coverage over operational domain of HMS can also be found there.

4 Bias correction

In order to correctly assimilate satellite data, biases between the observed measurements and those simulated from the model first guess, must be corrected. As show by Dee (2005) the systematic errors in models and observations can cause problems to assimilation system as for example suboptimal use of observations, biases in assimilated fields, non-physical structures in assimilated fields, extrapolation of biases due to multivariate background constraints or spurious trends due to changes in the observing system.

In ARPEGE/ALADIN model the method suggested by Harris and Kelly (2001) is used for correcting radiance-biases. This scheme applies two different bias corrections: a latitudinally dependent scan correction and air-mass dependent one. The air-mass predictors are computed from the background field, since the background field contains a more consistent representation of the air mass and surface characteristics then the observed radiance. Following four predictors can be used: 1000-300 hPa thickness, 200-50 hPa thickness, skin temperature and total column water vapor.

For computation of input innovation biases bias correction (bcor_dat file) from Météo-France was used. From this input we computed an air-mass dependent bias correction with above mentioned 4 predictors over 14 days from 2006081200 till 2006082600. Such short period was used due to lack of available data and time. Results can be seen on Fig 4., that shows the monitoring of an obs-guess, obs-analysis with theirs standard deviation for an experiment without any bias correction (bcor_dat file contained only zeros) and with computed air-mass bias correction applied for channel 2.

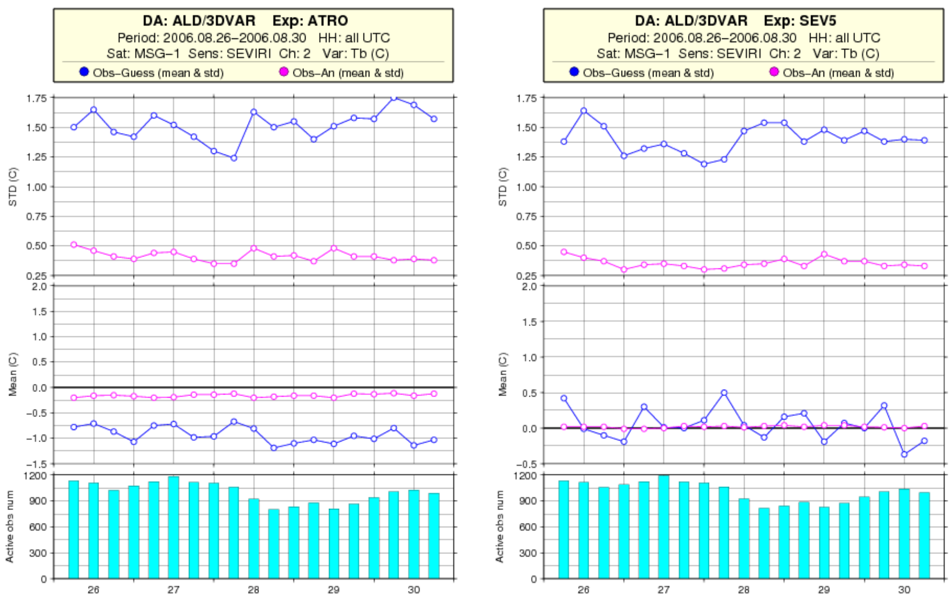

Fig. 4: Time-Series of statistics for channel 6.2 μm. No bias correction (bcor_dat file only with zeros) on the left and with applied bias correction on the right for the end of August 2006.

Details about technical implementation and the source code modification are described in appendix (B).

5 Single observation experiment

In order to check correct analysis behavior a single observation experiment was performed. One pixel from channel 6.2 μm was selected approximately in the center of the domain (lat=44.35, lon=10.5, T_b=234.5 K, (obs-guess)=-3.911570 K and (obs-anal)=-0.200353 K). The 3DVAR analysis increment for temperature, spec. humidity and wind component on model level 16 are on Fig. 5.

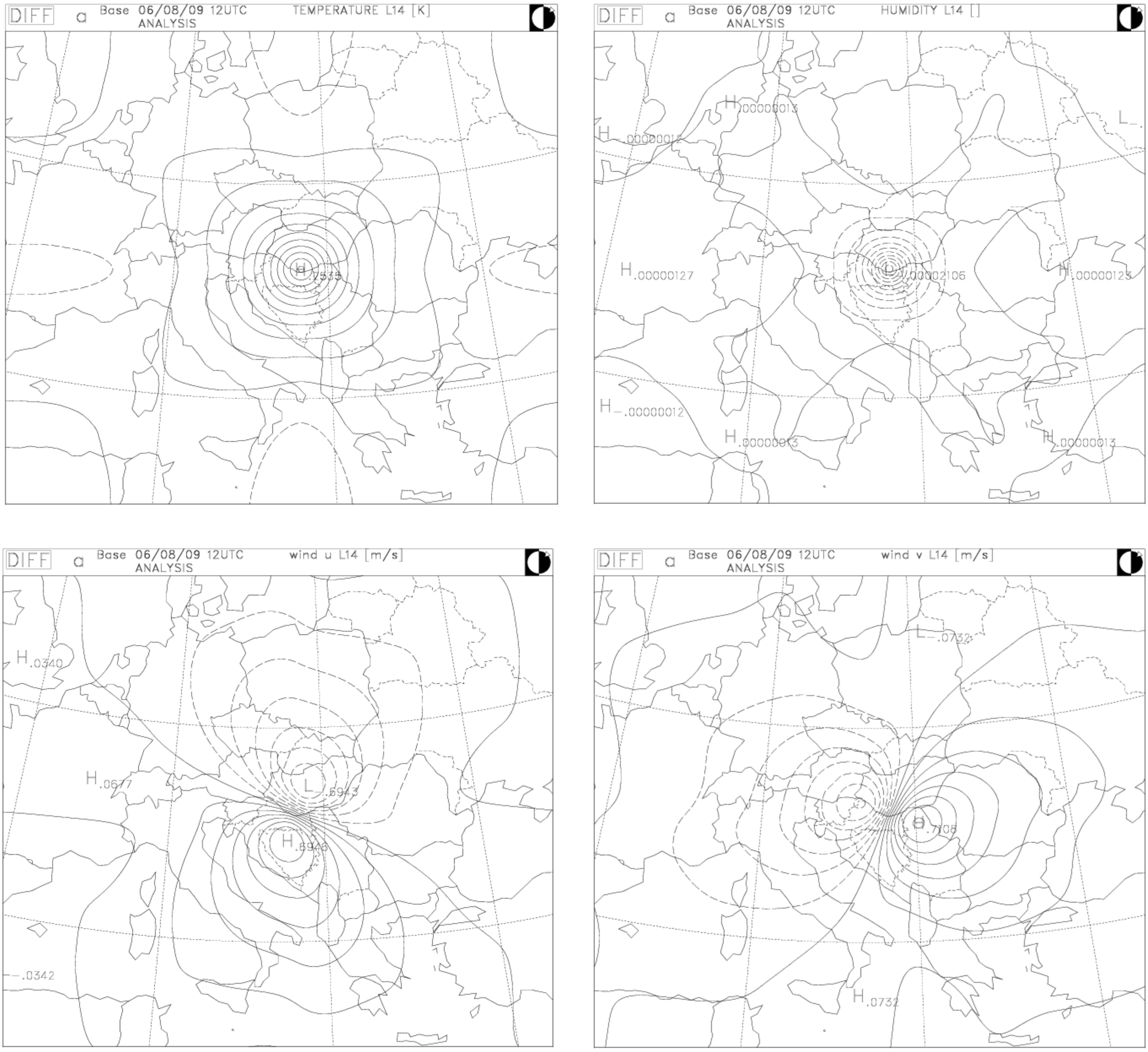

Fig. 5: 3DVAR analysis increment on model level 16 due to single observation of SEVIRI channel 6.2 μm for T,q, u and v component.

6 Impact studies

Due to lack of time (mostly spent on processing of SEVIRI data) only a few impact studies were performed. In this section we present results of comparison of one reference run and two runs with SEVIRI data.

6.1 Experimental settings

All experiments were performed with 3D-VAR ALADIN/HU described in details by Boloni (2005). Just brief summary of its main characteristic follows:

- cycle 30t1
- linear grid, 8km horizontal resolution and 49 vertical levels
- domain covers roughly the same area as the formal LACE domain
- 6h assimilation cycle (00, 06, 12, 18 UTC)
- surface (soil) analysis is taken from ARPEGE - long cut-off analysis
- upper air fields are provided by the 3DVAR analysis
- B matrix is computed following the standard NMC method

and used observations:

- SYNOP surface reports (geopotential)
- TEMP upper air reports (temperature, wind, geopotential, specific humidity)
- ATOVS satellite observations AMSU-A radiances and due to some problems only part of AMSU B radiances
- AMDAR aircraft reports (temperature, wind)

On the top of above mentioned observations we used also Atmospheric Motion Vector (AMV) following Randriamampianina (2006), let call this experimental setting as reference **REF1**. In order to estimate the impact of SEVIRI data with different thinning we performed two experiments **SEV3** and **SEV5**, where in case of

- **SEV3** one pixel of 3 was extracted from dataset and thinning box of 35 km was applied during screening

- **SEV5** one pixel of 5 was extracted from dataset and thinning box of 70 km was applied during screening

It should be mentioned that near IR 3.9 μm, the ozone 9.7 μm and 13.4 μm channels were blacklisted following Montmerle (2005a) and the bias correction was computed as described in section (4).

6.2 Adaptation of assimilation scripts

In order to use SEVIRI data, some modifications had to be done in assimilation scripts. Technical description of the scripts adaptation can be found in appendix (C).

6.3 Results

6.3.1 Period and verification methods

For computation of our experiments we took period from 20060826 00 UTC till 20060923 12 UTC. First 2 days were taken as warming up of assimilation cycle and the rest 27 days for impact studies. All experiments started from the same first guess at 20060826 00 UTC which was computed by reference run REF1. Reference experiment was started at 20060810 00 UTC, but as it was mentioned in section (4), period from 20060812 00 UTC till 20060826 00 UTC was used for bias correction computation. We provided 48 hours forecast from 00 and 12 UTC analysis.
For verification of scores we used the period from 20060828 00 UTC till 20060923 12 UTC. The objective scores were evaluated by VERAL and OVISYS (Hungarian local verification software based on similar method as VERAL, but doesn't use model obs operators to obtain forecasted value). The bias and root-mean-square error (RMSE) were computed from differences between the forecast and observations (SYNOP and TEMP were used). And as well scores of forecast and long cut-off ARPEGE analyses were evaluated. Significance tests described in Fisher (2001) of the objective verification scores were performed. The significance was examined based on statistical t-test regarding the difference in the expected values of the RMSE scores of the compared experiments. Plots were provided together with error bars that represent the interval in which the RMSE difference falls within 90% confidence. Thus we considered a difference to be significant if the corresponding error bar did not include the zero difference line. In the comparison the first model is better than second one if the mean scores are negative, indicating an average reduction of the error. For subjective comparison of precipitation we used HAWK-2 (Hungarian Advanced WorKstation).

6.3.2 Verification against observations

There are not big differences between SEVIRI and reference experiments in RMSE. Some differences worth to notice are in BIAS. After careful analysis of the scores we can state the following:

- Cloudiness:
  The only apparent positive impact of SEVIRI data is shown on Fig. 6. While BIAS is in principle almost the same, RMSE for analysis and forecast ranges 6 and 12 of SEVIRI run is clearly better than for reference run.

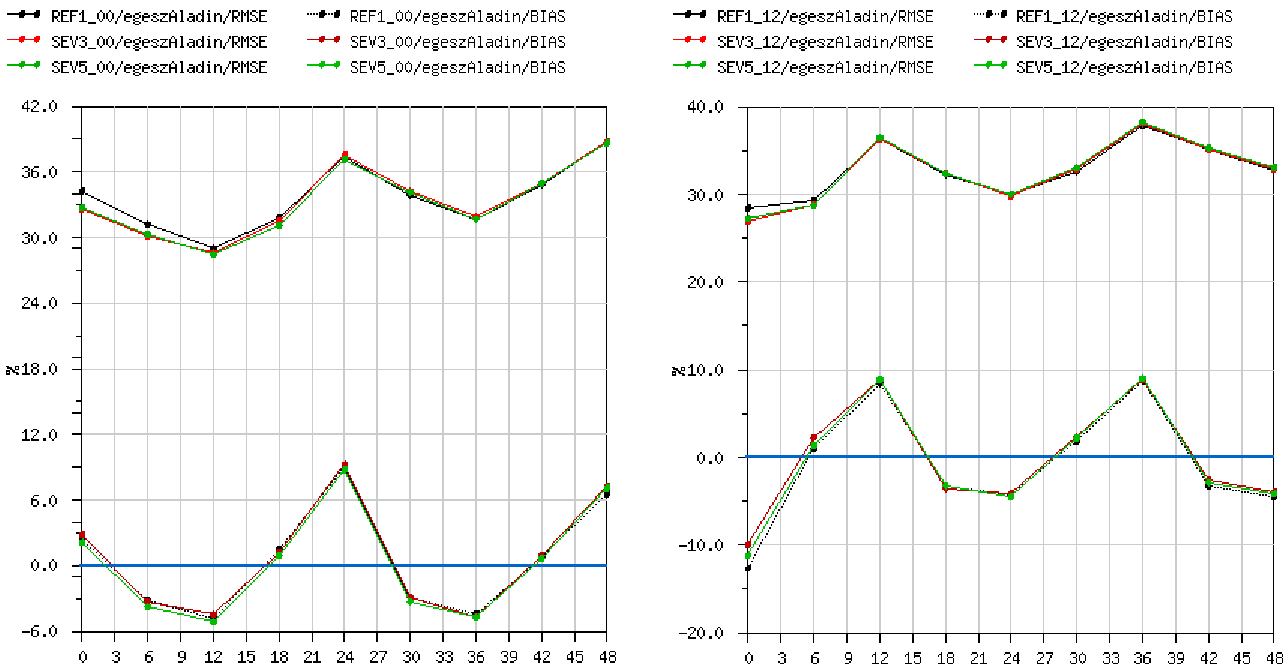

Fig. 6: RMSE and BIAS for cloudiness for all ranges of both 00 (left) and 12 (right) UTC production runs. The statistic were computed for the period from 20060828 till 20060923.

- Humidity:
  Model with SEVIRI data is more moist than reference run (REF1) in lower troposphere, but is drier in higher levels. An illustration of this behavior can be seen on Fig. 7., where is also a singular reduction of RMSE for the first 12 hours of forecast at 300 hPa. Complete objective scores against observation are on Fig. D1-D4 in appendix (D).

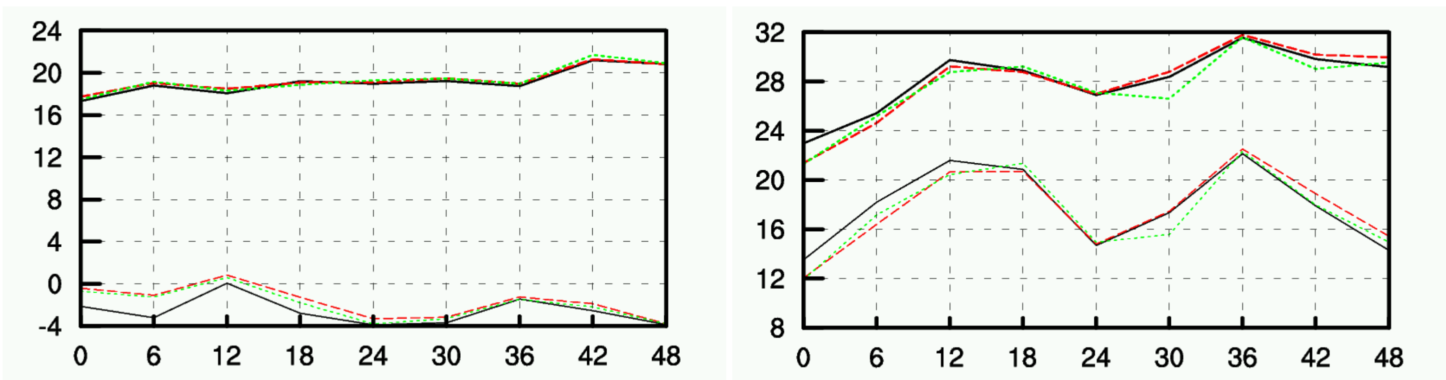

Fig. 7: RMSE and BIAS for relative humidity at 850 hPa (left) and 300 hPa (right) for all ranges of 00 UTC production runs. The statistic were computed for the period from 20060828 till 20060923 and experiment REF1 is in black, SEV5 in green and SEV3 in red.

- Geopotentiel:
  Model with SEVIRI data is producing lower geopotentiel than REF1 in lower troposphere (up to 500hPa) and higher geopotentiel in upper troposphere (between 500hPa and 200hPa). Above 200hPa there is no difference.

- Mean sea level pressure:
  There is very small underestimation against REF1 in model with SEVIRI data.

- Temperature:
  Model with SEVIRI data is cooler than REF1 in 850hPa and above 200hPa. It is warmer in upper troposphere (between 500hPa and 300hPa). There is no difference in 700 hPa.

- Precipitation:
  No improvement - rather some degradation of precipitation forecast - mostly at the beginning of forecast. Situation is the same for both 6- and 24-hour precipitation amount.

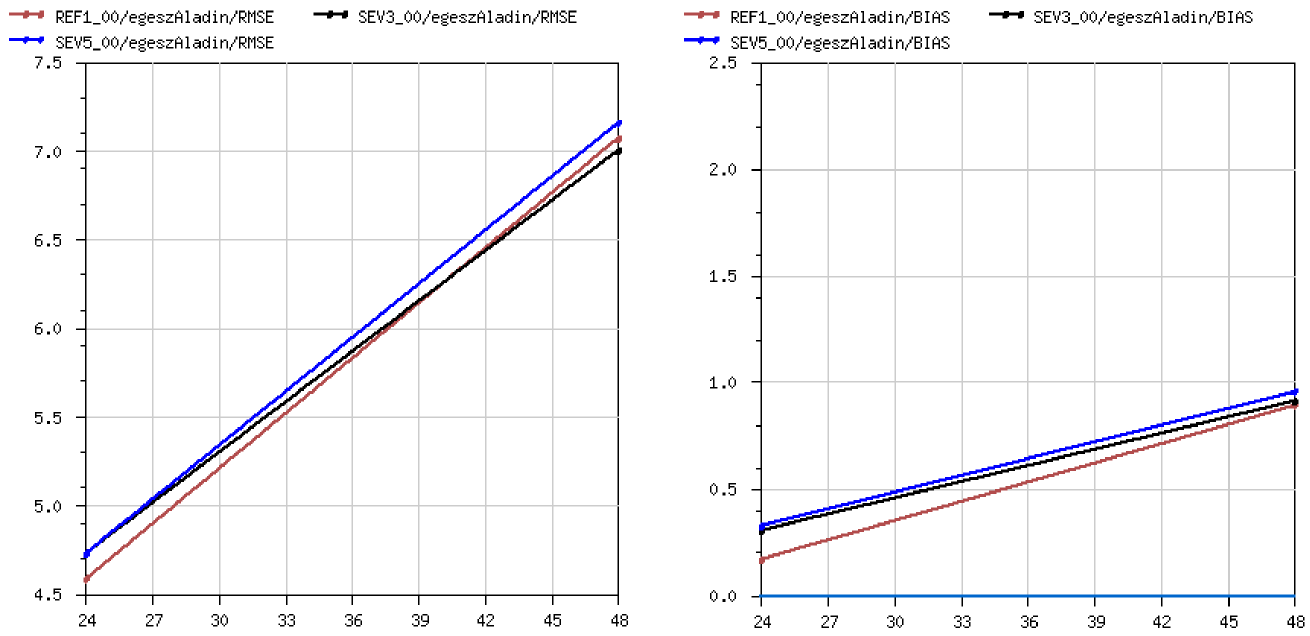

Fig. 8: RMSE and BIAS for 24-hour precipitation amount for all ranges of 00 UTC production form 20060828 till 20060923.

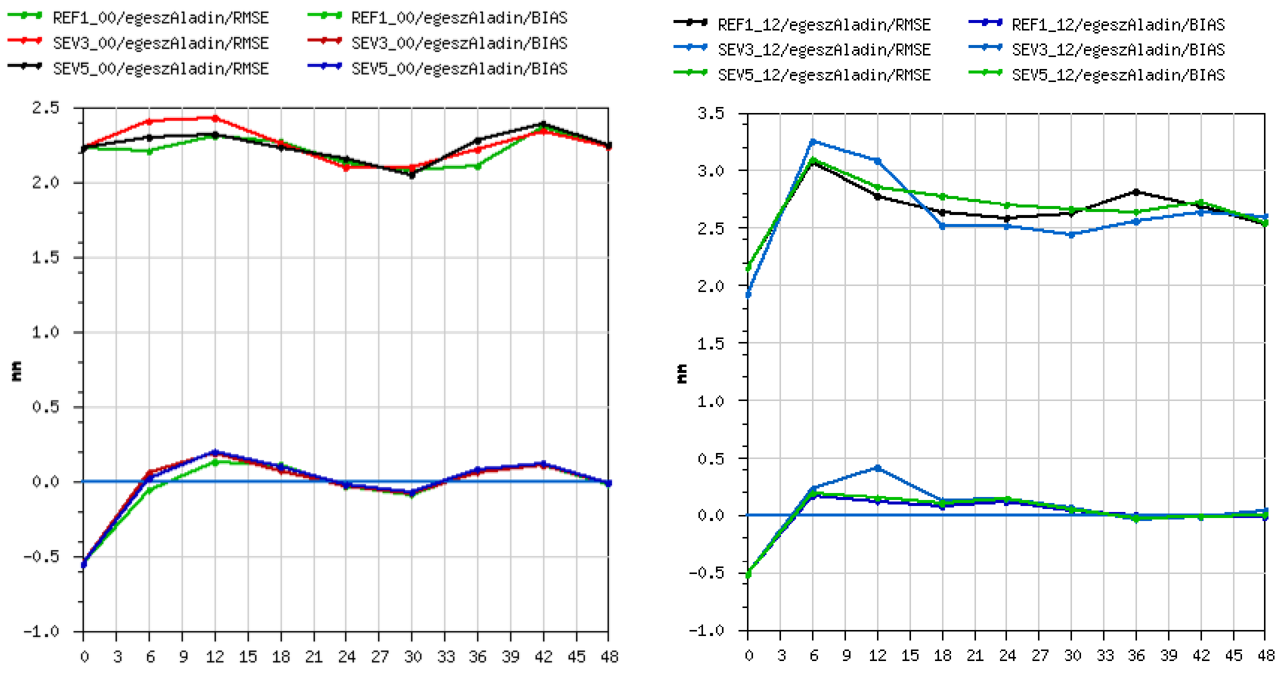

Fig. 9: RMSE and BIAS for 6-hour precipitation amount for all ranges of 00 (left) and 12 (right) UTC for period from 20060826 till 20060923.

6.3.3 Case study

It is worth to mention that though there is no improvement for precipitation amount, there are some differences in field of forecasted precipitation what can be seen in Fig. 10. This can be interesting in some cases, but because of lack of time we didn't analyze it deeper.

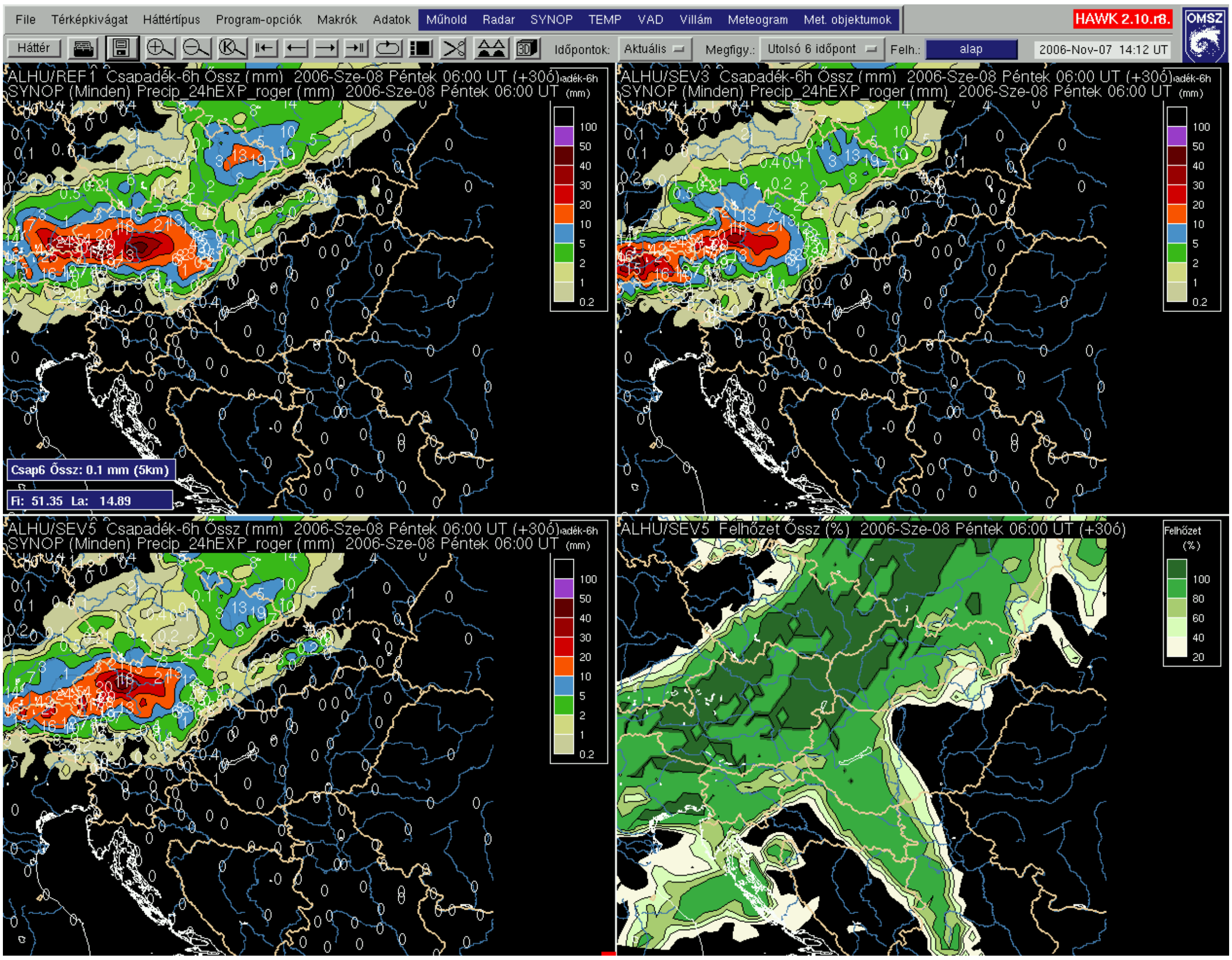

Fig. 10: Subjective comparison of 6-hour precipitation for +36H (upper-left REF1,upper-right SEV3 and bottom-left SEV5) from 8th September 2006.

6.3.4 Verification against ARPEGE analysis

Figures D5-D8 in appendix (D) shows comparison against ARPEGE analysis. RMSE is mostly neutral or slightly worse for early ranges of forecast, even more for SEV5 experiment. Little bigger differences are again for BIAS.

- Humidity:
  Model with SEVIRI data is producing more moist than REF1 in all levels except of 850hPa where it is drier and 700hPa where only SEV3 is drier.

- Geopotentiel:
  Model with SEVIRI data is producing lower geopotentiel than REF1 in all levels except of 850hPa where it is producing higher geopotentiel.

- Temperature:
  In lower troposphere model with SEVIRI data is warmer than REF1.

It is interesting that overestimation and underestimation of variables in model with SEVIRI data against REF1 is behaving just opposite than in verification against observation. Where the model with SEVIRI data is producing more moist than REF1 in verification against observation, in the verification against analysis it is just opposite - it is more drier than REF1. This could be caused by different number of "verification points" which is, of course, much bigger for verification against analysis - each grid point. But this is just idea, it deserves more analyzing in the future.

6.3.5 SEV3 vs SEV5

It can be seen from the VERAL scores that there is small but still clear difference between SEV3 and SEV5 experiment. SEV5 (less SEVIRI observations) is slightly better than SEV3, mostly for analysis and first hours of forecast and significance test is approving this even more, but still not as good as REF1 (see Fig. D9-D10 in appendix (D)). Maybe number of used observation could be matter of more tuning in the future.

7 Conclusions and future work

SEVIRI data were successfully assimilated in ALADIN/HU 3DVAR system. The main aim to get knowledge of the data processing and perform impact studies what was fulfilled and here follows a short summary of what was done

- testing of local data processing, which should be ready for an operational use in HMS
- special development to read locally prepared SEVIRI data by BATOR
- porting of bias correction for SEVIRI data
- single observation experiment to check correct 3D VAR analysis behavior
- the first impact studies.

The summary of performed impact studies is following: the only positive impact is for cloudiness, there is also some significant impact on humidity, geopotentiel, temperature and precipitation, but this one is sometimes positive and sometimes negative. But it is quite clear that the impact is caused by using SEVIRI data. Finally it can be said that SEVIRI data has some impact. Although this impact is small and not positive all the time, it is quite significant and should be investigated more.

As remaining technical work there should be revisited

- BATOR extra code to read GRIB without RGB library, if there a way to use the same I/O as is used in Météo-France
- possibility to use EUMETCAST as an input of cloud type and cloud top pressure.

and further study is planned to "refinement" for a more efficient use of the data in particular to

- further tests of an optimal use of SEVIRI data, with stress on thinning distance and number of used pixels
- study of bias correction impact (how often a recomputation of bias correction or how large sample of data is necessary)
- test recommended combination of SEVIRI data with SYNOP observations
- evaluate an impact of B-matrix (use NMC or ensemble method)
- and last not least, a better understanding of obtained results and performing of more case studies.

8 Acknowledgments

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Appendix

A Bator source code modification

Following modifications concern the development in program BATOR, mainly a routine reading SEVIRI grib file. Due to the problem related to the use of RGB library at HMS an optional read by GRIBEX library was added. Use of RGB library was kept unchanged and is assumed as default option.

The name of subroutine (SUBROUTINE BATOR_LGRIB_SEV) in bator_decodgrib.F90, which decodes/reads SEVIRI grib file was changed, because different names of subroutine and of the file itself causes problem to compile the source (with gmkpack) and it also does not follow coding rules recommendation. The name of subroutine was changed to SUBROUTINE BATOR_DECODGRIB. In this routine an optional read of input grib by GRIBEX library was added.
The correction of a bug in selecting good pixel was done in the same routine. Up to now in case of finding a wrong pixel the rest of longitudinal scan band was skipped. With the modification included just this given wrong pixel is skipped. The problem can be seen from following figures. At first the same domain as Météo-France (e.g. 1150x700 pixels) and bator without any modifications was used (fig A1); no data over Eastern part of Europe. Suspecting local data processing, that probably the domain is not big enough, the domain was increased into 1500x750 pixels (fig A2); still the data are not inside all our domain of interest. After correction of bug in BATOR we could get the data over Eastern Europe (fig A3). And as last we realized that the data were already in smaller domain, as can be seen on fig (A4). At first we assumed that for Météo-France no modification are needed, but only for the countries eastward from France. But as can be seen from fig A5) and A6), Météo-France can profit from modification too.

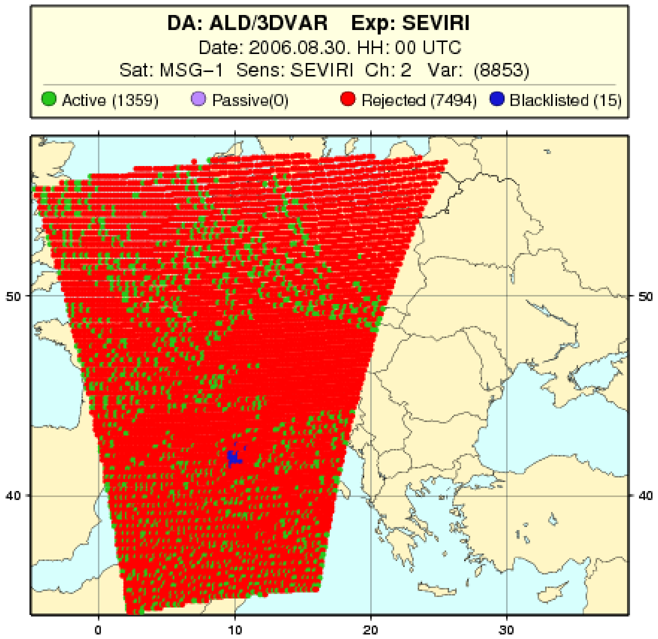

Fig. A1: 1150x700 pixels and "old" BATOR

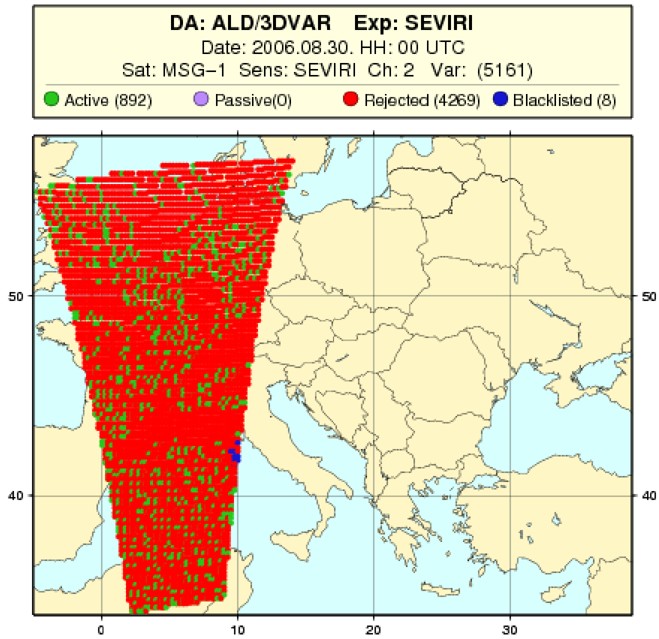

Fig. A2: 1500x750 pixels and "old" BATOR

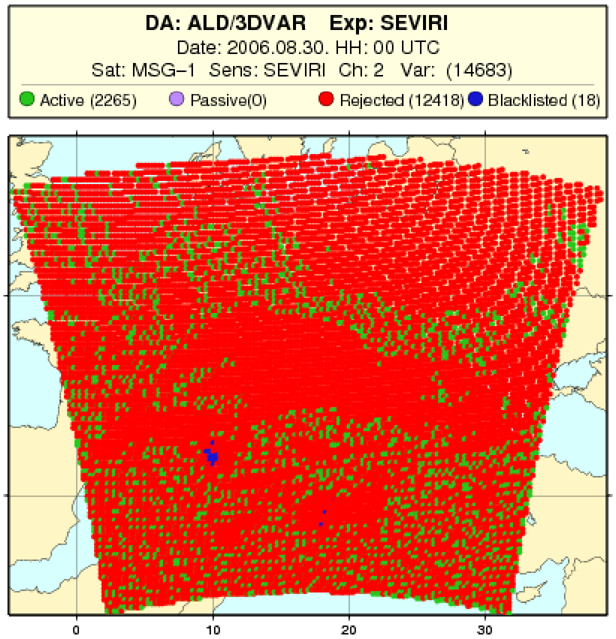

Fig. A3: 1500x750 pixels and "new" BATOR

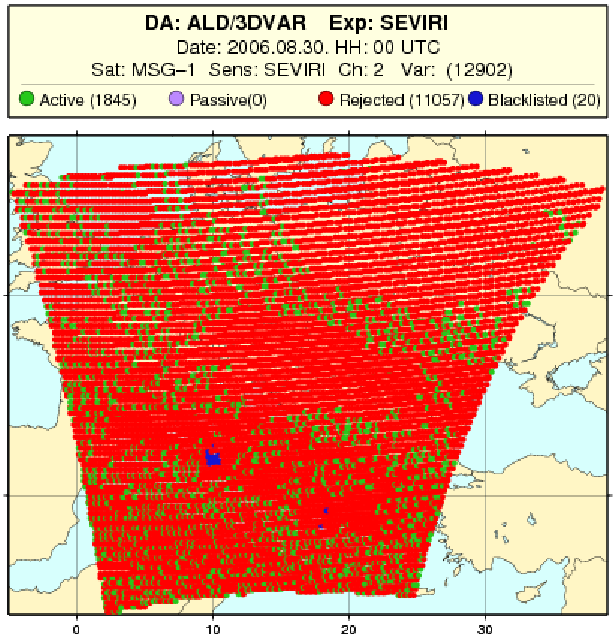

Fig. A4: 1150x700 pixels and "new" BATOR

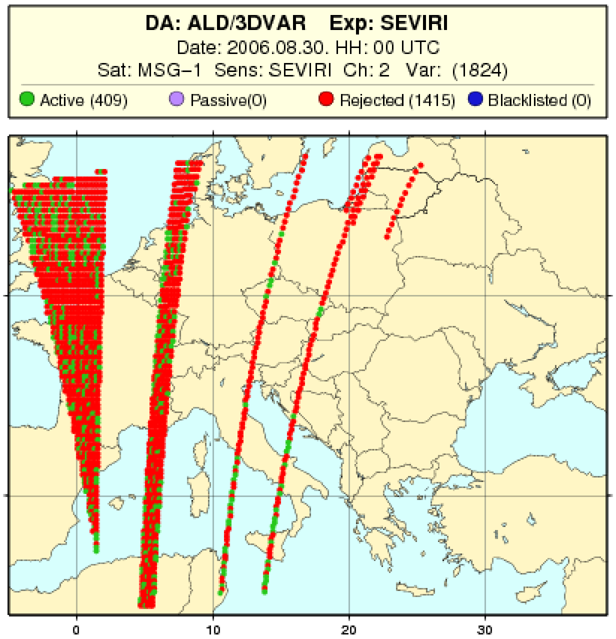

Fig. A5: 1150x700 pixels operational grib from Météo-France and "old" BATOR .

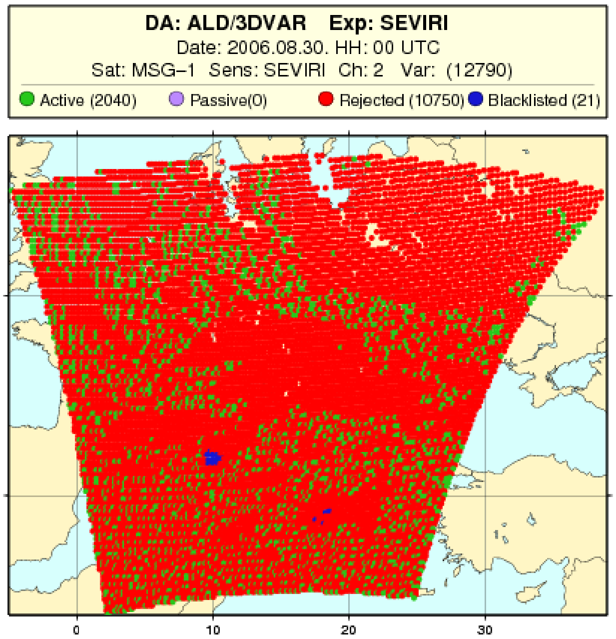

Fig. A6: 1150x700 pixels operational grib from Météo-France and "new" BATOR .

Content of modifications:

Added routines:

- uti/bator/decodegrib.F90

A new routine is based on an example routine from GRIBEX. It reads content of SEVIRI grib file into a 3D array PSEV(:,:,:) where the first two dimension correspond to the horizontal position (longitudinal and latitudinal scan band) of the pixel and the third has 17 components defining all remaining information about the pixel in following order (the order is kept the same as in original bator_decodgrib.F90):
PSEV(IP,IL,1) ! brightness temperature of channel 1 3.9 microns

PSEV(IP,IL,2) ! brightness temperature of channel 2 6.2 microns
PSEV(IP,IL,3) ! brightness temperature of channel 3 7.3 microns
PSEV(IP,IL,4) ! brightness temperature of channel 4 8.7 microns
PSEV(IP,IL,5) ! brightness temperature of channel 5 9.7 microns
PSEV(IP,IL,6) ! brightness temperature of channel 6 10.8 microns
PSEV(IP,IL,7) ! brightness temperature of channel 7 12.0 microns
PSEV(IP,IL,8) ! brightness temperature of channel 8 13.4 microns
PSEV(IP,IL,9) ! date
PSEV(IP,IL,10) ! Cloud type
PSEV(IP,IL,11) ! Cloud Top Pressure
PSEV(IP,IL,12) ! Cloud type QF
PSEV(IP,IL,13) ! Cloud Top Pressure QF
PSEV(IP,IL,14) ! Latitude
PSEV(IP,IL,15) ! Longitude
PSEV(IP,IL,16) ! Azimuthal angle
PSEV(IP,IL,17) ! Zenithal angle

Modified routines:

- uti/bator/bator_decodgrib.F90
  The subroutine was renamed correspondingly to the name of file and an optional call of new routine to decode grib with GRIBEX was added.

- uti/bator/bator_lectures.F90
  Corresponding change of a call of bator decoding routine

- uti/module/bator_module.F90
  Logical key LRGB and a new parameters NLON_GRIB, NLAT_GRIB defining horizontal dimension of the input SEVIRI grib file were added

- uti/bator/bator_init.F90
  Initialization of new namelist variables (LRGB=T, NLON_GRIB=1500, NLAT_GRIB=750)

Changes in the namelist:

- uti/bator/bator_namelist.h
  A logical key to use RGB library for decoding LRGB, new parameters NLON_GRIB, NLAT_GRIB defining horizontal dimension of input SEVIRI grib file. And already existing NFREQ_SEV was added to the namelist.

All modification are included in the pack generated via following command

gmkpack -r cy30t1 -b bf02 -v 01 -u bf04 -l ifort9_2B2 -o x -p bator

and they are stored on ALTIX in /home/guest1/pack/bf04.

B Bias correction source code modification

Again following T. Montmerle development we customized scripts for bias correction computation (from /u/gp/mrpa/mrpa666/BIAS_SEV) and took over the source code modification from tora /u/gp/mrpa/mrpa666/PACK/cy30t1_op1.05/src/local which contains following sources:

- odb/ddl/cycle_biasprep_robody.sql
- odb/ddl.ECMA/cycle_biasprep_robody.sql
- uti/extrtovs/biasconv_1c.F90
- uti/extrtovs/cycle_biasprep_1c.F90
- uti/extrtovs/cycle_bias_1c.F90
- uti/extrtovs/calc_bias_1c.F90

- uti/extrtovs/extr_init_1c.F90
- uti/extrtovs/extr_lecdata_1c.F90
- uti/module/extr_module_1c.F90
- uti/module/mod_bias_qc.F90
- uti/module/mod_rad_bias_1c_uti.F90
- uti/module/deco_bufr_1c_uti.F90

On the top of above mentioned modification, we had to modify the computation of eigenvalues or eigenvectors as in HMS (on ALTIX) there is not installed NAG library used for this computations.
Modified routines:

- uti/extrtovs/regress_one.F90
  NAG routine F02FAF was replaced by call of jacobi.F and eigsrt.F from Numerical recepies. This modification is currently used for the bias correction of ATOVS and it was just took over for SEVIRI data.

- uti/extrtovs/extr_lecdata_1c.F90
  During execution we encountered the problem of reading press_rl from ODB body (MDBPRL, pk9real value describing vertical coordinate of BDM). But as it should be the same value in press (MDBPPP, pk9real, corresponding vertical coordinate or number of channel for SEVIRI) we used press value insead of press_rl. It was verified (in Toulouse reference) that this modification has no impact on bias correction computation/results.

Added routines:

- uti/extrtovs/eigsrt.F

- uti/extrtovs/jacobi.F

A routines eigsrt.F and jacobi.F were used instead of F02FAF for computation of eigenvalues or eigenvectors.
All modification are included in pack generated via following command

gmkpack -r cy30t1 -b bf01 -v 01 -u bcor_sev -l ifort9_2B2 -o x -p
cyprep/cysele/cyscan/adscan/cascan/cybias/adbias/cabias/biascv

and they are stored on ALTIX in /home/guest1/pack/bcor_sev.

Careful checking of the modifications should be done as they don't reproduce the results from TLS exactly ! In other words the results with NAG routine are different from those obtained by eigsrt.F and jacobi.F ! But as was showed in section (4), locally computed bias correction works fine.

C Adaptation of assimilation scripts

At first we implemented new BATOR as it was mentioned in section (3). To this we added also new namelist which we copied to the working directory as NAMELIST. The structure of namelist is as follows:

```
&NADIRS
  NFREQ_SEV=3,
  NLON_GRIB=1500,
  NLAT_GRIB=750,
  LRGB=.false.
/
```

Description of individual variables can be find in appendix (A). Besides this, still we used namelist_rgb which is used for handling SEVIRI data in Météo-France. Another thing was reading grib file with SEVIRI data by BATOR. In default mode, BATOR is looking only for the OBSOUL file, but it is also possible to read different files in different formats. This is managed by the ASCII file called "refdata" which is looked over by BATOR during its startup. In "refdata" file there are defined all files which will be read by BATOR. Because of unknown reason we were not able to read both OBSOUL and SEVIRI file together, so we prepared separately 2 independent ODB sub-bases and then we merged them together in one database. For this we used 2 different "refdata" files - one for OBSOUL:

```
hms     OBSOUL  hms     20060911 12
```

and one for SEVIRI data:

```
sev     GRIB    sev     20060911 12
```

Meaning of content is following - data filename extension, format of data, kind of data or instrument, date and time of observation.

All these changes were done in BATOR part of assimilation. In addition new constant file bcor_meto.dat for SEVIRI data was added for screening. This one was computed following (4). All scripts and namelists can be found on 3700a.met.hu in directories /home/guest2/scr and /home/guest2/nam.

D Verification scores

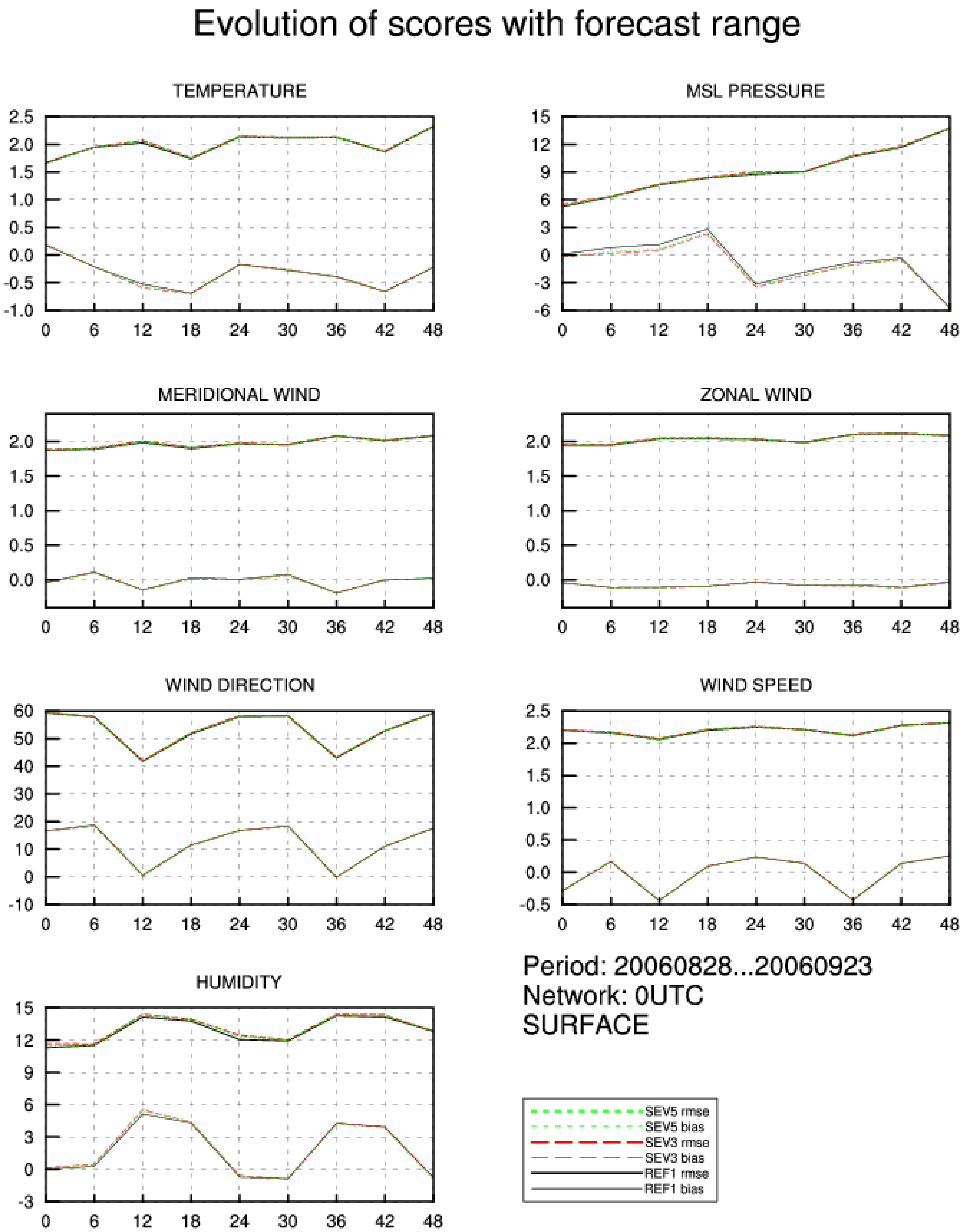

Fig. D1: Verification against observations. RMSE and BIAS for surface level for all ranges of 00 UTC production.

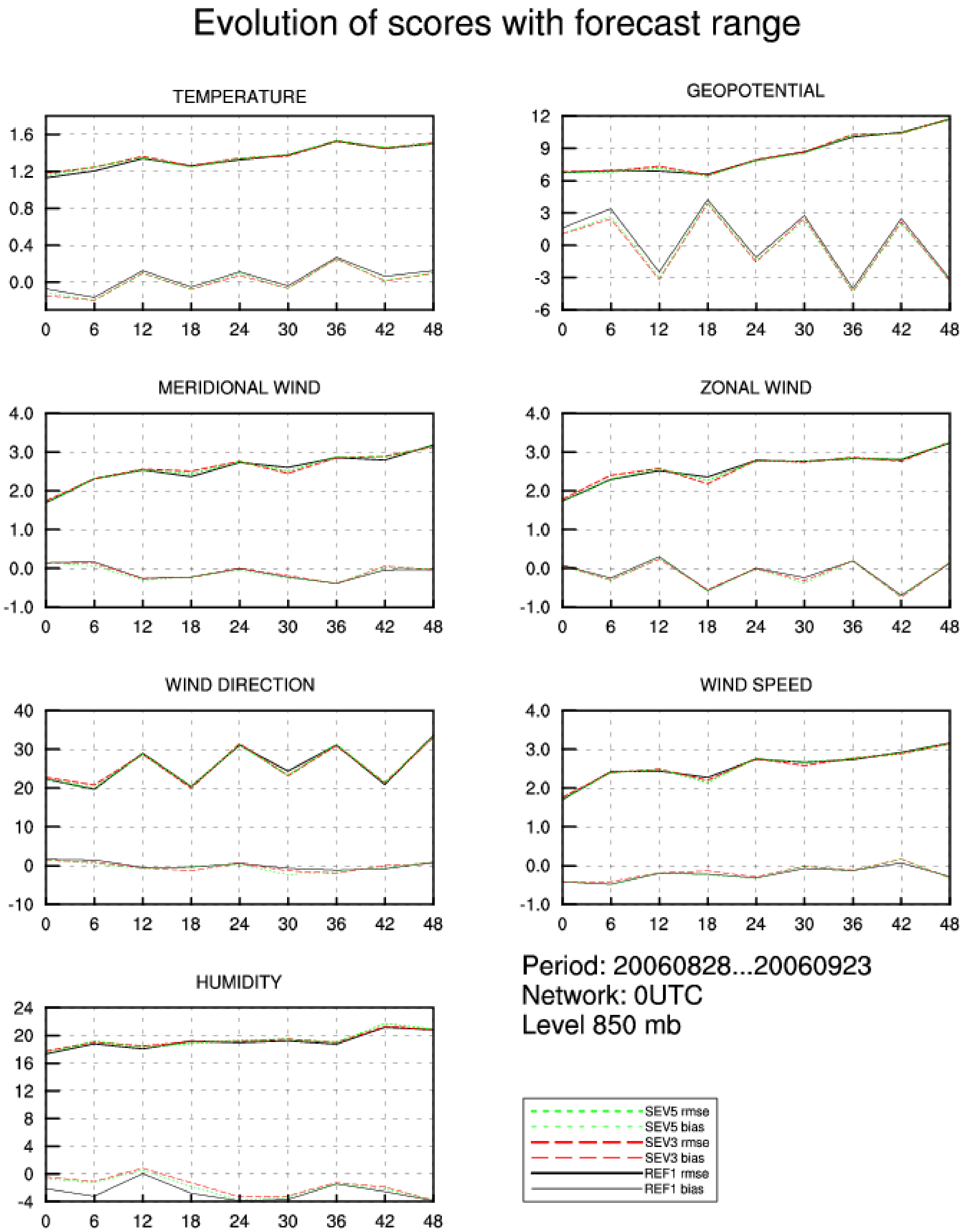

Fig. D2: Verification against observations. RMSE and BIAS for 850 Pha level for all ranges of 00 UTC production.

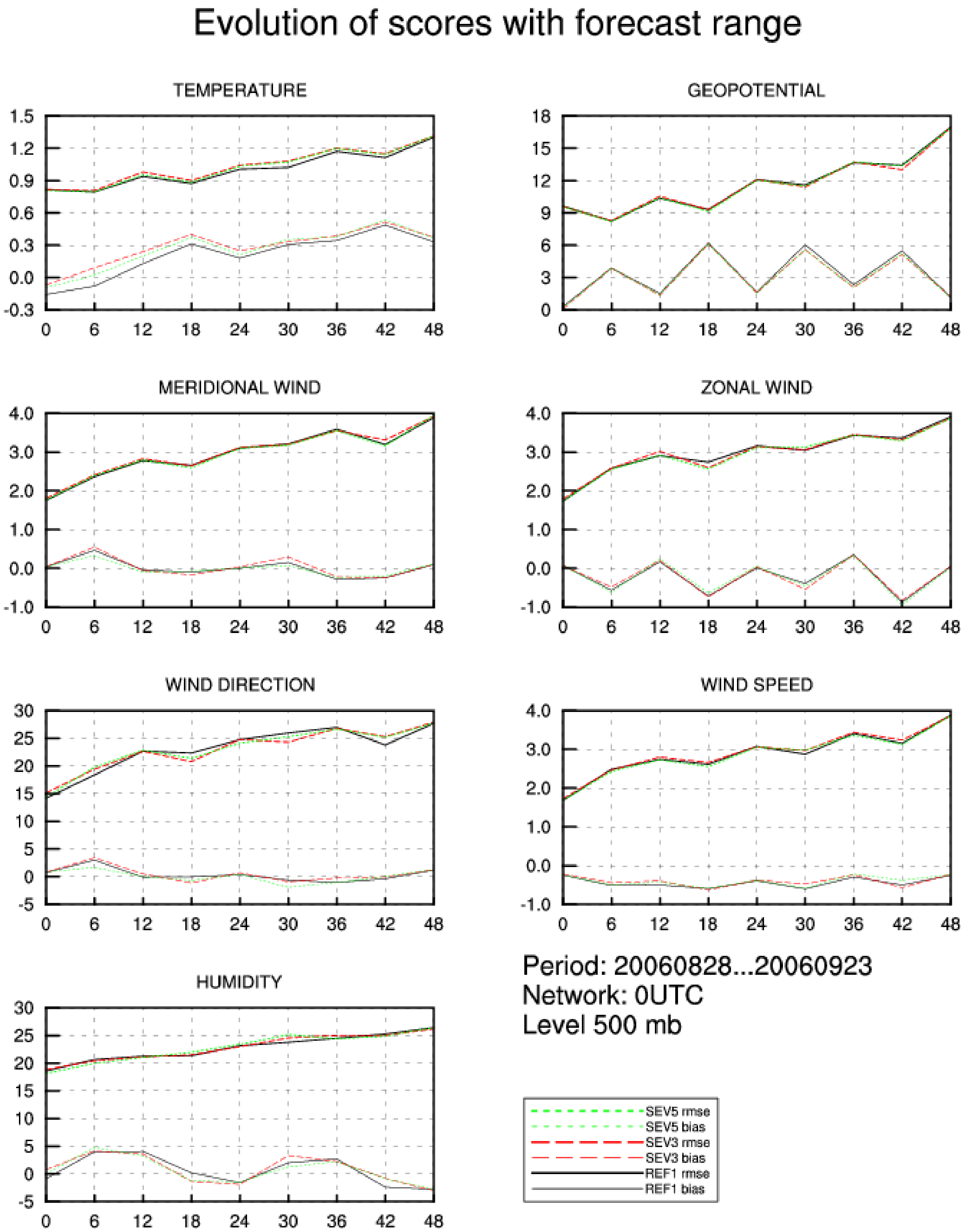

Fig. D3: Verification against observations. RMSE and BIAS for 500 Pha level for all ranges of 00 UTC production.

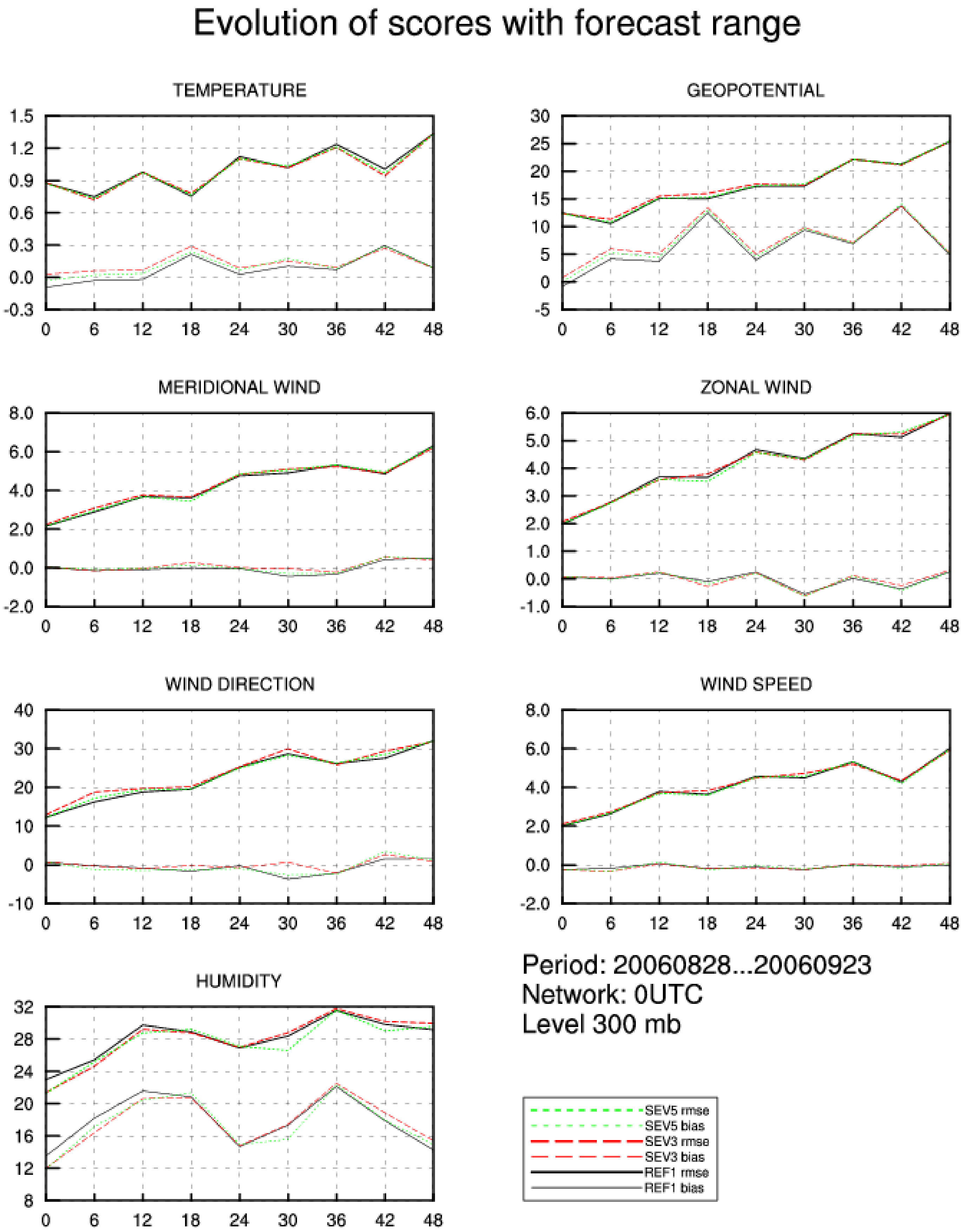

Fig. D4: Verification against observations. RMSE and BIAS for 300 Pha level for all ranges of 00 UTC production.

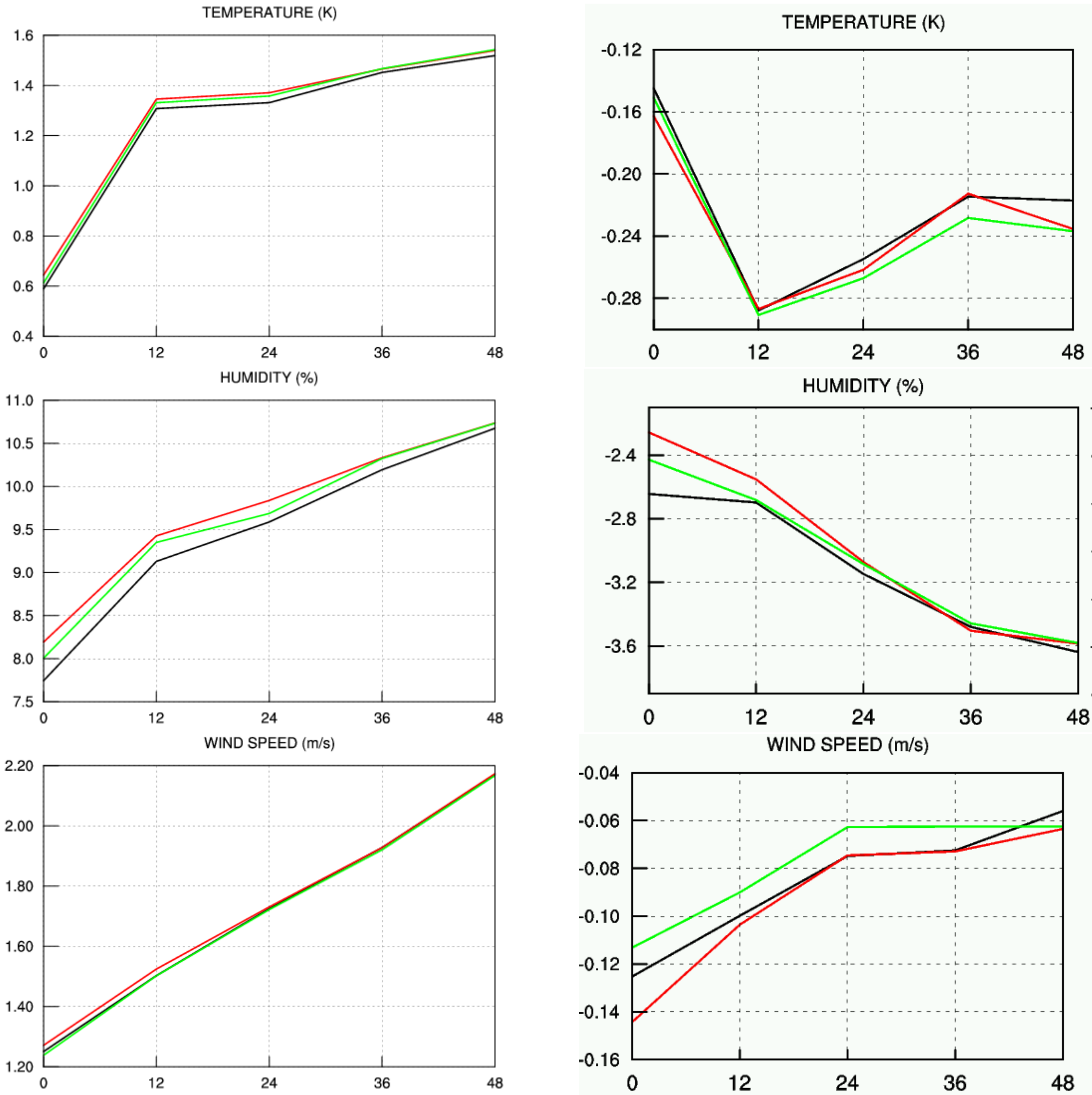

Fig. D5: Verification against analysis. RMSE (left) and BIAS (right) for surface level for all ranges of 00 and 12 UTC productions for period from 20060828 till 20060923. Experiment REF1 is in black, SEV5 in green and SEV3 in red.

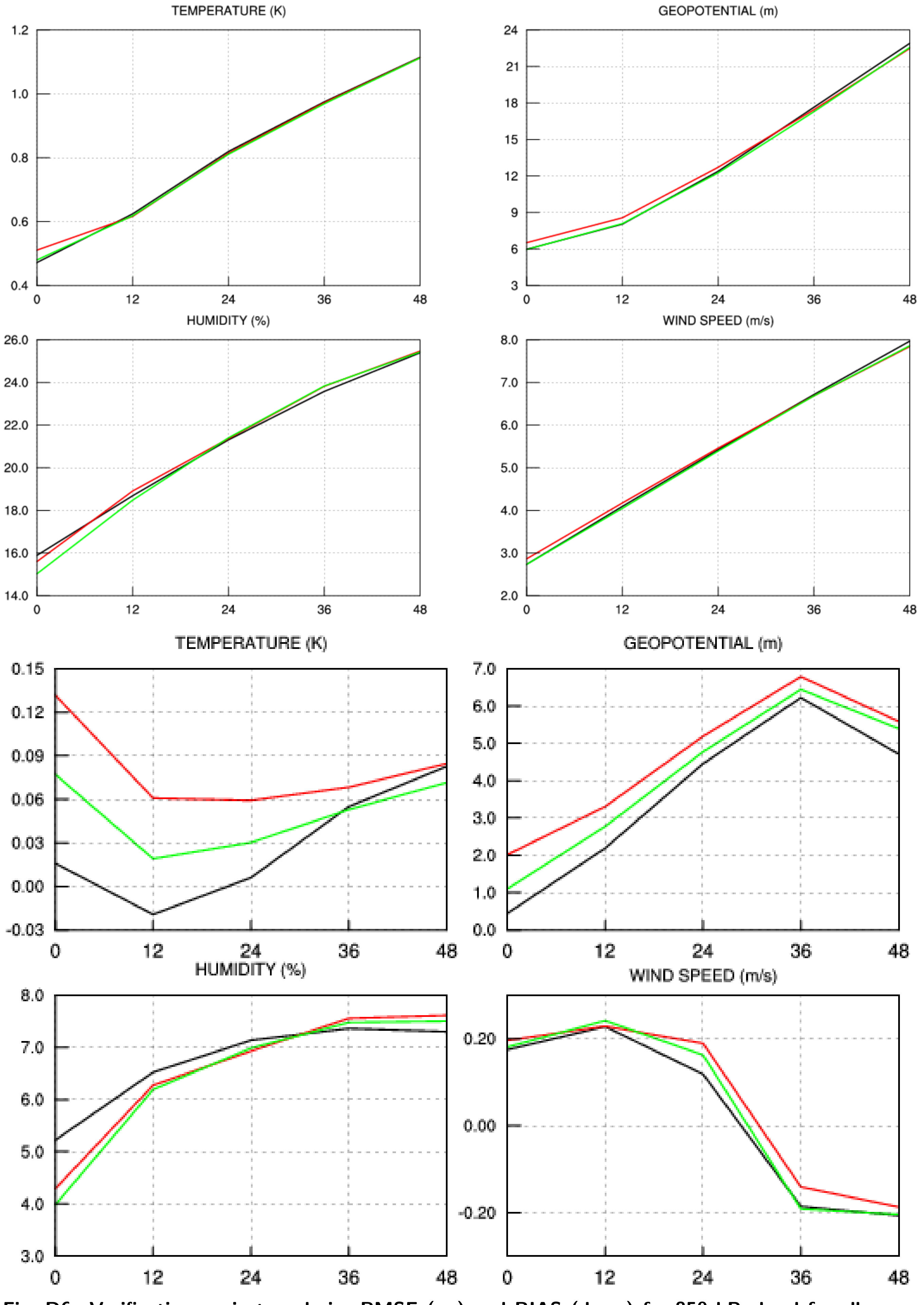

Fig. D6: Verification against analysis. RMSE (up) and BIAS (down) for 850 hPa level for all ranges of 00 and 12 UTC productions for period from 20060828 till 20060923. Experiment REF1 is in black, SEV5 in green and SEV3 in red.

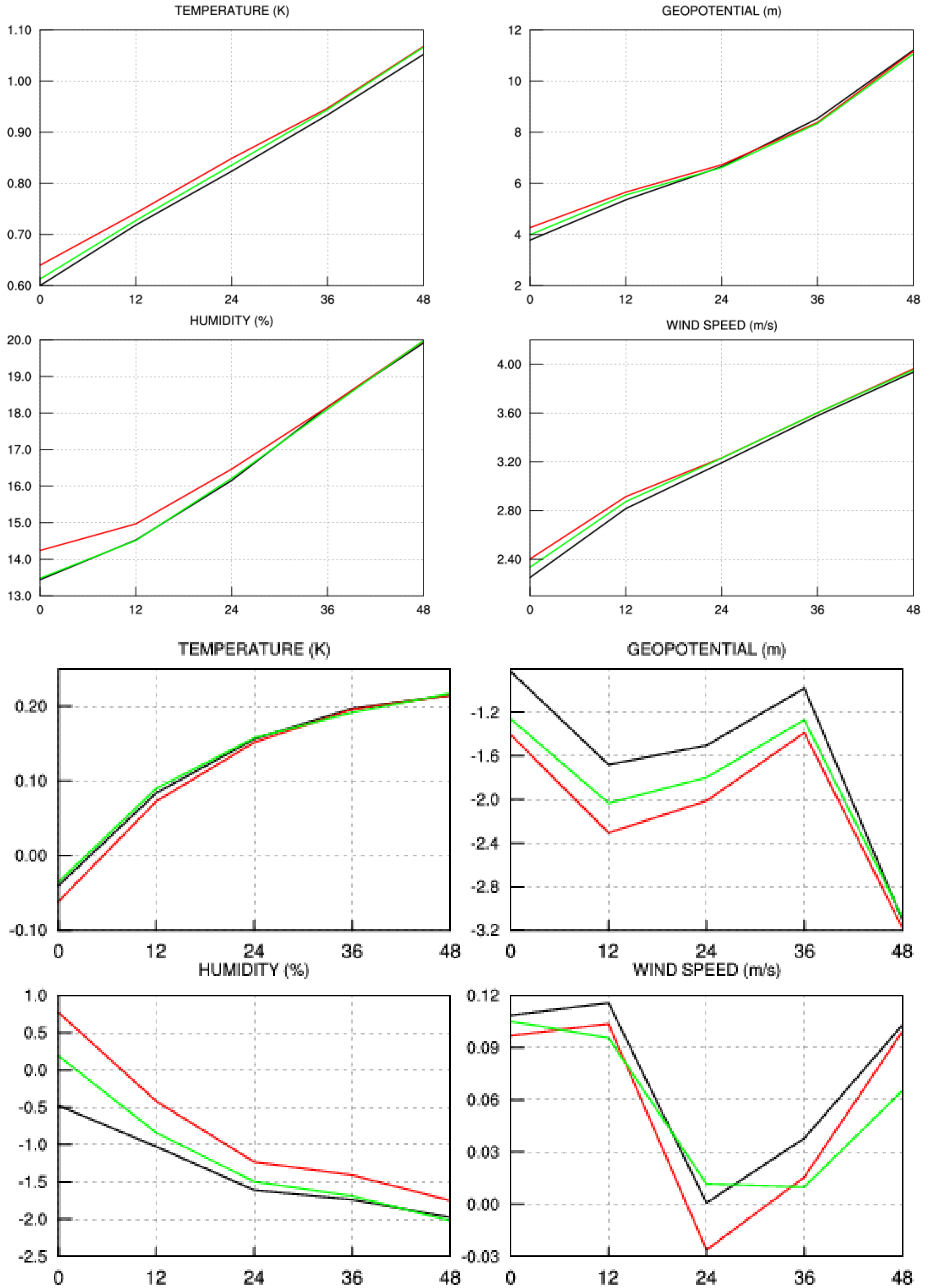

Fig. D7: Verification against analysis. RMSE (up) and BIAS (down) for 500 hPa level for all ranges of 00 and 12 UTC productions for period from 20060828 till 20060923. Experiment REF1 is in black, SEV5 in green and SEV3 in red.

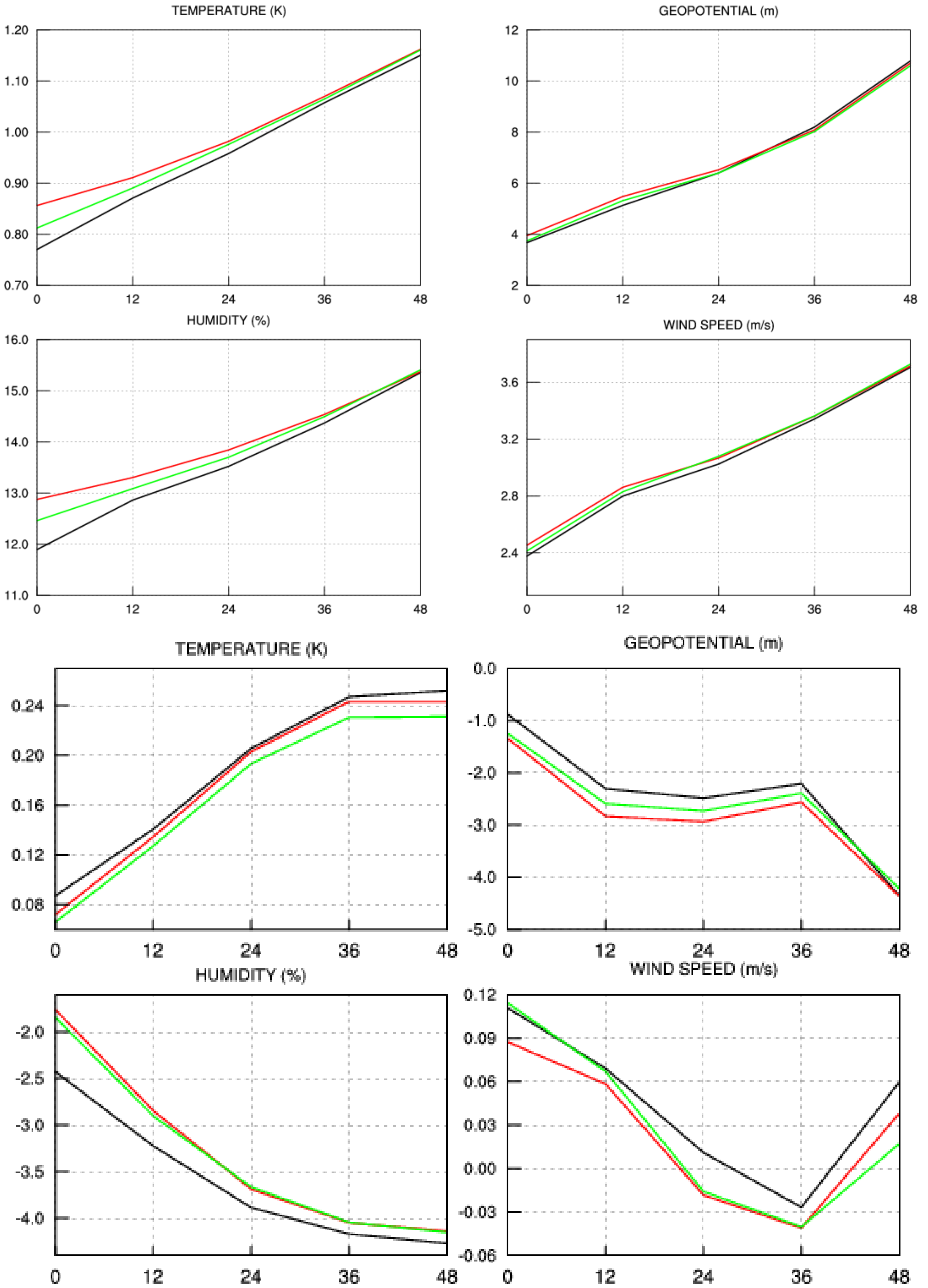

Fig. D8: Verification against analysis. RMSE (up) and BIAS (down) for 300 hPa level for all ranges of 00 and 12 UTC productions for period from 20060828 till 20060923. Experiment REF1 is in black, SEV5 in green and SEV3 in red.

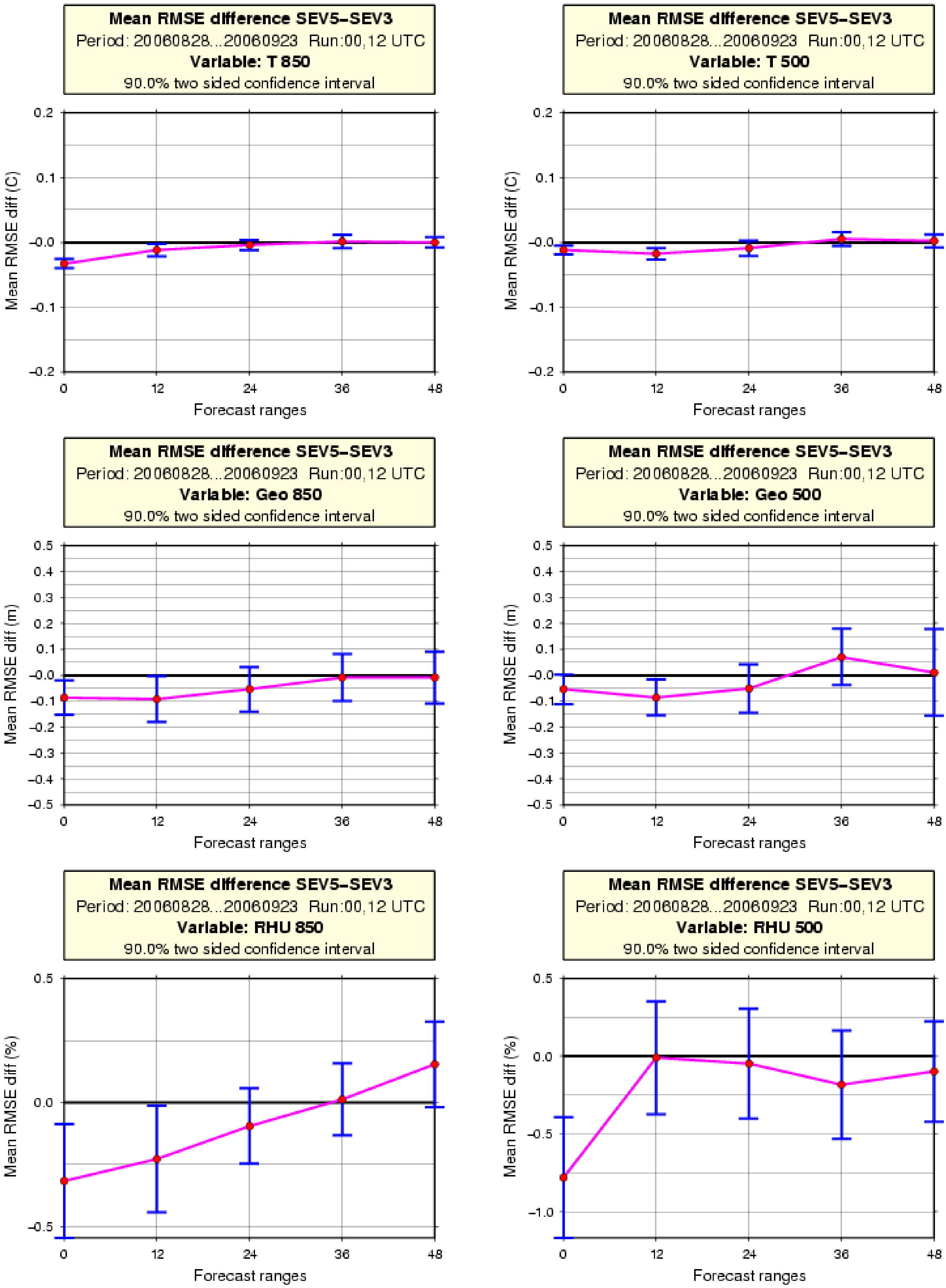

Fig. D9: Example of significance test between SEV5 and SEV3 experiments provided form verification against observation

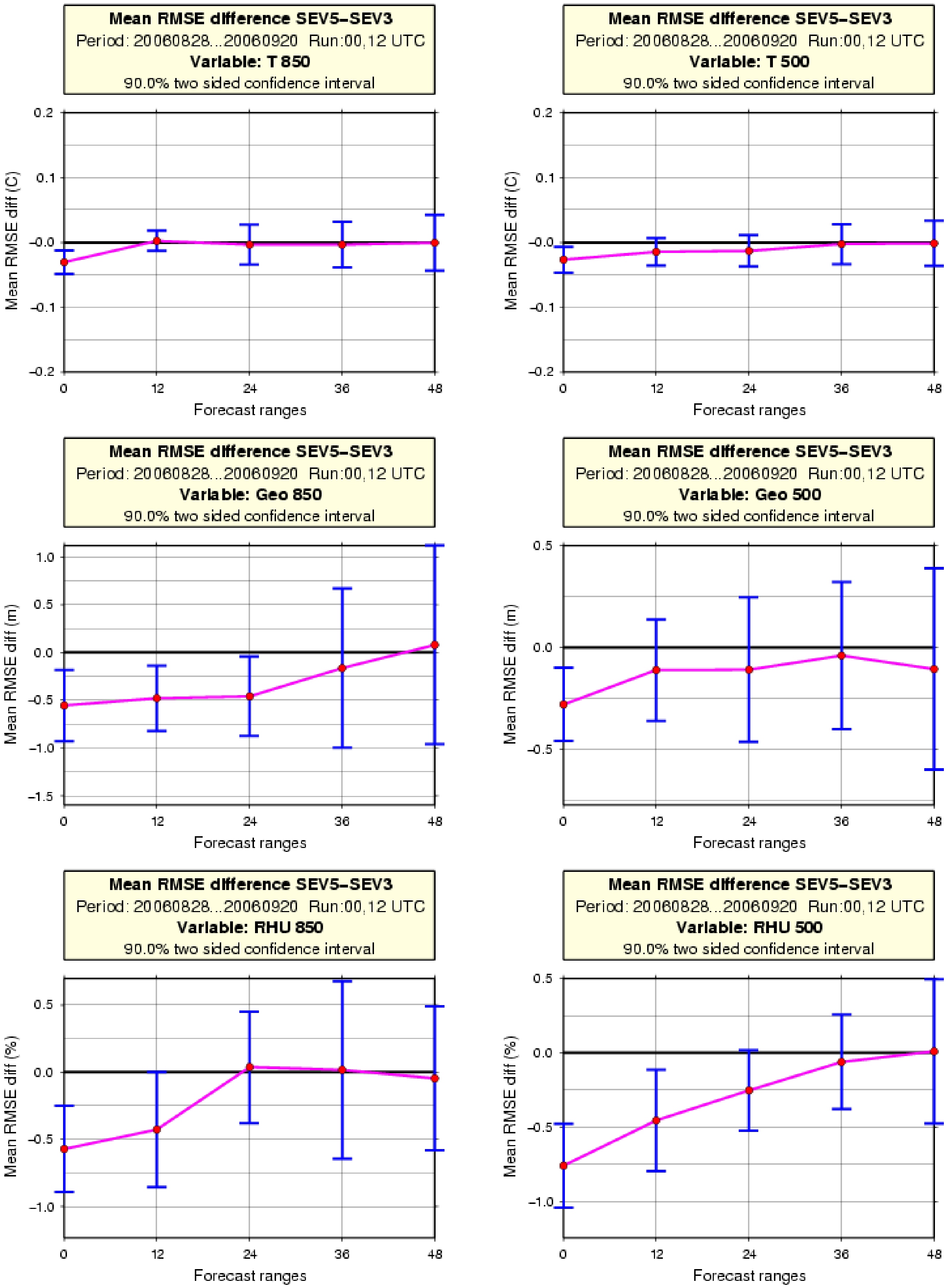

Fig. D10: Example of significance test between SEV5 and SEV3 experiments provided form verification against ARPEGE analysis