Use of satellite data in ALADIN-HARMONIE/Norway

Andrea Storto and Roger Randriamampianina

Norwegian Meteorological Institute, Oslo Norway

andrea.storto@met.no, rogerr@met.no

Abstract

The ALADIN/HARMONIE three-dimensional variational data assimilation system is being implemented at the Norwegian Meteorological Institute. Use of satellite observations is very important to improve numerical weather prediction in high latitude regions. Our poster will present the implementation of most of the available satellite data in the ALADIN/HARMONIE-Norway analysis system (microwave: AMSU-A and AMSU-B/MHS; infrared: Seviri and IASI; GPS: ground-based zenith total delay; humidity retrievals from CloudSat). This document will also discuss two ways (the so-called NMC and the ensemble-based method) of estimation of background error covariances as well as the use of off-line predictors computation and variational bias correction methods to correct radiance bias.

Introduction

Within the ALADIN/HIRLAM cooperation agreement, a new assimilation and forecast system is being developed with the aim of providing a reliable framework for both research and operational purposes, especially for high resolution applications. The system has been named HARMONIE (Hirlam Aladin Regional/Meso-scale Operational NWP In Europe), and its forecast models are now used operationally in many HIRLAM national meteorological services (see e.g. Andrae 2007), either using non-hydrostatic physics at cloud-resolving resolution or hydrostatic physics at synoptic scale. The Norwegian Meteorological Institute (Met.no) is putting many efforts in building the assimilation counterpart of the system, whose core is based on the spectral upper-air three-dimensional variational assimilation (3D-Var) of the ALADIN model, operational since 2005 at the Hungarian Meteorological Service (Bölöni 2006) and at the French Meteorological Service (Fischer et al. 2005).

The assimilation system (hereafter HARMONIE-3DVar) is currently used at Met.no mainly for two research projects, the Eumetsat funded "Assimilation of binary cloud cover" and the IPY-THORPEX that aims to investigate the importance of remote-sensed observations in forecasting polar lows; there are also plans to operationally run HARMONIE-3DVar in the near future. Basic configuration of the system consists of using a 6 hours forecast from previous cycle as background (first guess), i) updating the sea surface temperature (SST) through the ECMWF SST analysis; ii) extracting and pre-processing all the available and supported observations; iii) performing a surface assimilation based on the ALADIN community Optimal Interpolation software (CANARI) to analyze surface parameters over land (skin temperature, soil water content); iv) performing the spectral upper-air analysis for vorticity, divergence, temperature, specific humidity and surface pressure, v) running the forecast model after proper downscaling of lateral boundary conditions from the ECMWF global model.

The upper-air 3D-Var, that we will focus on in the rest of the paper, supports at the moment all the conventional observations, Atmospheric Motion Vectors, aircraft in-situ observations, microwave radiances from POESS and Metop platforms, radiances from MSG/SEVIRI Imager, and, in an experimental configuration discussed separately, also infrared radiances from the Infrared Atmospheric Sounding Interferometer (IASI), Zenith Total Delay derived from ground-based GPS stations (GPS-

ZTD), humidity retrievals from the CloudSat CPR radar. Assimilation of scatterometer observations from ASCAT aboard Metop is currently under development. In order to optimally exploit the information contained in space-borne instruments, which are very important for limited area assimilation systems, a number of questions should be addressed, such as channel selections for multi-channel instruments, tuning of observational errors, choice and implementation of bias correction strategies, assessment of background error covariances and relative impact of the observing network on analyzed fields. In the following part of the paper, these issues will be discussed together with an overview of the assimilation system and some remarks about the actual use of some observations; finally, results from sensitivity studies of analysis and forecasts to different observation groups will be presented as diagnostic tool for understanding the relative importance of observations in the system.

Observations in the reference assimilation system

HARMONIE-3DVar currently supports the assimilation of a number of observations, schematically reported in Table 1. The table also presents the average horizontal thinning distance between assimilated observations. All the conventional observations are assimilated (radiosondes, synoptic land and ship stations reports, buoys and drifting buoys measurements, wind profilers). Additionally, aircraft observations (AMDAR/AIREP), Atmospheric Motion Vectors (AMV) provided by EUMETSAT and derived from Meteosat Second Generation satellites (MSG) are extracted and assimilated, microwave radiances from the Advanced Microwave Sounding Unit (AMSU) and the Microwave Humidity Sounder (MHS) aboard NOAA and Metop polar satellites are exploited. Only MSG/SEVIRI supplies infrared radiances. Further to satellite bias correction, also daytime temperature measurements from radiosondes are bias-corrected through ECMWF flat bias correction values, which depend on instrument characteristics.

Table 1: Observations and horizontal thinning distance used in HARMONIE-3DVar

Observations	Parameters (channels) assimilated	Horizontal thinning
SYNOP LAND	Z	-
SYNOP SHIP	Z	-
AIREP/AMDAR	U, V, T	25 Km
AMV	U, V	25 Km
DRIBU/BUOY	Z	-
EUROPROFILER	U, V	-
RADIOSONDES	Z, U, V, T, Q	-
AMSU-A	Tb	80 Km
AMSU-B/MHS	Tb	80 Km
MSG/SEVIRI	Tb	60 Km

Quality control and rejection of observations is carried out through a few steps, consisting in duplicated reports check, background quality control, redundancy check and spatial and temporal thinning.

Satellite radiances assimilation

The observation operator for satellite radiances is the Radiative Transfer for TOV (RTTOV) in his version 8.5, developed by the Numerical Weather Prediction Satellite Application Facility (NWP-

SAF). Table 2 reports the list of channels assimilated from NOAA and EUMETSAT polar satellites.

Table 2: Use of ATOVS microwave channels in HARMONIE-3DVar

SATELLITES	AMSU-A									AMSU-B		
	5	6	7	8	9	10	11	12	13	3	4	5
NOAA-15	Y	N	Y	Y	Y	Y	N	Y	Y	Y	Y	S
NOAA-16	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	S
NOAA-17	N	N	N	N	N	N	N	N	N	Y	Y	S
NOAA-18	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	S
METOP-A	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	S

N: Not assimilated; Y: Assimilated; S: Assimilated over sea only

For microwave instruments, bias correction has been performed by applying the Harris and Kelly (2001) scheme, which uses air-mass and scan-angle predictors to compute the bias. The predictors chosen are 1000-200 hPa thickness, 100-50 hPa thickness, skin temperature, integrated water vapor, scan-angle and his square and cubic power. The coefficients have been computed from a two-months period dataset of forecasts initialized by dynamical adaptation from the ECMWF global model. Results from the implementation of variational bias correction scheme will be briefly discussed later. A detailed study of innovations and residuals statistics for all couples channel/satellite separately for each network (00, 06, 12, 18 UTC) is currently under evaluation, with the aim of blacklisting satellite channels whose observations amount at certain hours is poor in the computational domain and can cause unreliable computation of bias correction coefficients.

Assimilation of MSG/SEVIRI infrared radiances takes advantage of the Nowcasting Satellite Application Facility (NWC-SAF) that is used for brightness temperature recalibration, I/O handling. Cloud type and cloud top height products, still from NWC-SAF, are used for eventually black-listing radiances data, according to Table 3. Channel 4 is not assimilated because RTTOV does not reproduce accurately radiances for very broad channels (Brunel and Turner 2003), while the ozone channel is not used at all. Possibility to extend the assimilation of channel 11 also when low-level clouds are detected will be investigated in the future. Only radiances relative to Meteosat-9 scans starting at 05.45, 11.45, 17.45 and 23.45 UTC are considered, and only one pixel over 4 (~ 8 Km resolution) is retained in the observational database. The air-mass scheme for bias correction is the same as the one used for microwave radiances, but bias correction coefficients are assumed latitudinally (along scanline) constant. Radiances that are far away from Meteosat-9 position (latitude > 65° N) are rejected.

Table 3: Use of MSG/SEVIRI thermal channels in HARMONIE-3DVar

Channel	Spectral Band	Use in 3DVar
4	IR3.9	Monitored
5	WV6.2	Over sea and land; clear sky and above mid-level clouds
6	WV7.3	Over sea and land; clear sky and above mid-level clouds
7	IR8.7	Over sea; clear sky only
8	IR9.7	Over sea; clear sky only
9	IR10.8	Not Assimilated (Ozone channel)
10	IR12.0	Over sea; clear sky only
11	IR13.4	Over sea; clear sky only

Fig. 1 shows the impact of MSG-2/SEVIRI assimilation through radiosondes verification scores: the impact is in general slightly positive and, as expected, humidity fields are the most benefited, especially after 24 hours of forecasts.

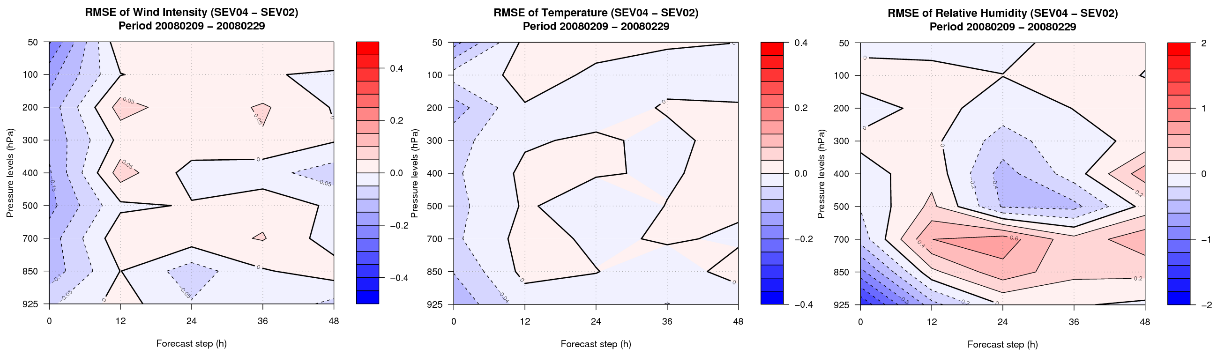

Fig. 1: Difference of root mean square errors between a reference experiment and an experiment with SEVIRI data assimilation against radiosonde observations. Where positive (red), SEVIRI observations have a positive impact.

Finally, Table 4 reports the brightness temperature observation errors for all satellite data currently assimilated. An ongoing work is dealing with satellite-specific brightness temperature errors using diagnostics from the Desroziers method (Desroziers et al. 2005); partial results suggest that errors were in general over-estimated and important differences are found between different satellite errors in a limited area model, e.g. Metop/MHS diagnosed errors are significantly smaller than NOAA-16/AMSU-B.

Table 4: Brightness temperature observation errors (K)

AMSU-A									AMSU-B			MSG/SEVIRI					
5	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**3**	**4**	**5**	**5**	**6**	**7**	**8**	**10**	**11**
0,45	0,35	0,35	0,35	0,35	0,35	0,5	0,8	1,2	3	2,5	2	1,05	1,7	1,7	1,05	1,05	1,05

Variational Bias correction

Variational bias correction has been implemented and it's now used for all satellite radiances. Main advantages of such a method are the improved separation between model and observation contribution to the total bias, and the possibility of automatically computing bias correction coefficient, otherwise very expensive for high spectral resolution instruments (i.e. AIRS and IASI). In the Met.no configuration, bias coefficients are initialized from previous assimilation cycle and the departures of from such values are minimized in the 3DVar cost function as additional term. At the end of the minimization, the coefficients are then suitable for initializing next assimilation coefficients. At implementation time, this procedure is iterative, starting from zeroed bias coefficients (cold start), and has been observed to converge to reliable values (i.e. unbiased observation minus analysis differences) in less than a one-month period of 6 hourly assimilations. Results (reported in Randriamampianina and Storto 2008 in these same proceedings) show a very positive impact on assimilation statistics and forecasts scores. The use of coefficients from 24 hours old instead of from the previous 6 hours old cycle to respect network characteristics (amount of radiances and scan-angles distribution in the LAM domain) is currently under evaluation.

Importance of the background error covariances assessment

Specification of background error covariances (B matrix) for use in the 3DVar algorithm may affect the impact of observations, since spatial auto-covariances as well as cross-covariances between different state parameters lead in turn to different weights given to observations in the analysis system. In HARMONIE-3DVar we have obtained background error statistics through the application of two different methods: the “NMC” method, which derives error statistics from a dataset of differences of couples of forecasts valid at the same time but initialized at different time (we used 48-24 hours forecasts); the ensemble method that in the Met.no configuration uses differences of 6 hours ensemble forecasts minus the ensemble mean, using 10 members derived from downscaling ECMWF/IFS ensemble analysis; these ones had been obtained through observations perturbation (to simulate analysis errors) and spectral backscatter scheme (to simulate forecast errors) from Isaksen et al. (2007) experiment. In both cases, the B matrix formulation follows Berre (2000), that assumes isotropic and homogeneous but vertically varying covariances and cross-covariances computed through multiple linear regression. Main differences between the two methods rely to the broader vertical correlations of background errors for the NMC method, excepted at very small horizontal scales. Fig. 2 shows for instance the vertical correlations of temperature between level 48 (about 850 hPa) and the other model levels as function of horizontal scale (wavenumber); statistics retrieved via the NMC method present a large-scale vertical correlation reaching downward the surface and upward around 100 hPa.

This finding becomes very noticeable in satellite radiances single observation experiments for high-peaking channels that involve many model levels. Fig. 3 reports the temperature analysis increments of a single observation experiment for channel 9 of AMSU-A (aboard NOAA-18) with a brightness temperature innovation of 2 K, using an NMC B matrix computed over three months forecasts in winter (DJF 2006/2007) and an Ensemble B matrix from downscaled ensemble analysis with 10 members for the period from 20061025 to 20071125. We want to stress that much broader vertical error correlations generated by applying NMC method cause unrealistic analysis increments at very high levels, even reaching model top, while ensemble errors do not.

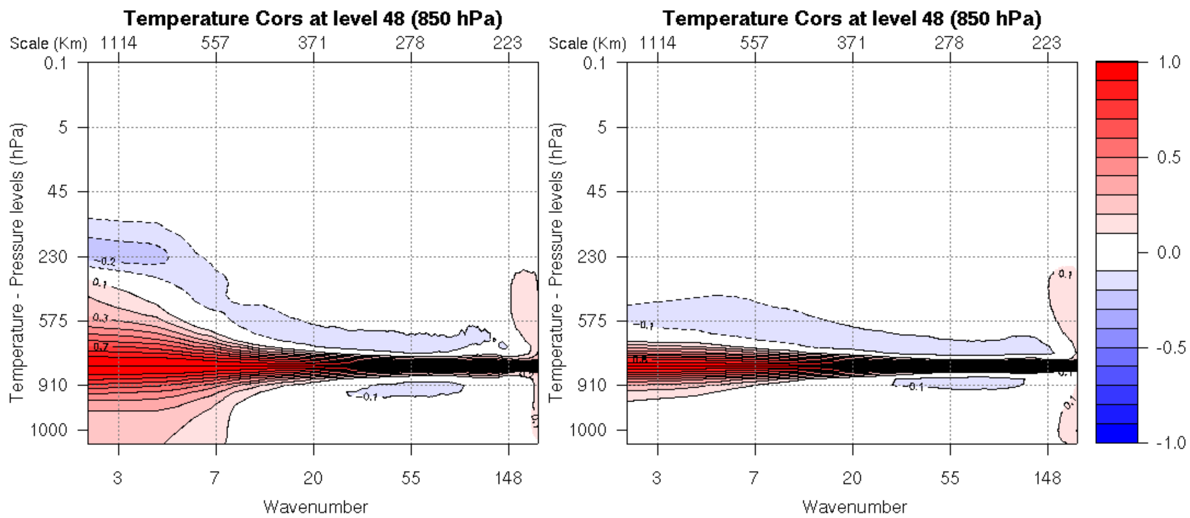

Fig. 2: Vertical error correlation of temperature between model level 48 and all the other model levels as function of horizontal scale. Left and right panel show the statistics derived via the NMC method and the ensemble method respectively.

Impact on analysis

As index to study the relative impact of observations in the assimilation system, we use Degrees of Freedom for Signal (DFS, see e.g. Cardinali et al. 2004), that is defined as the derivative of the analysis increments in observation space with respect to the observations. In practice, it is computed through a randomization technique (Chapnik et al. 2006) that reads:

$$DFS = (\tilde{y} - y) R^{-1} \left[H(\tilde{x}_a - x_b) - H(x_a - x_b) \right]$$

where $\tilde{y}$ (y) is the perturbed (unperturbed) observations vector, $\tilde{x}_a$ (xa) is the analysis vector from perturbed (unperturbed) observations, R is the observation error covariances matrix and H is the observation operator. The perturbation is performed using an unbiased Gaussian random error whose standard deviation equals the observation error; 6 assimilation cycles, 4 days far each other to ensure ergodicity of statistics, have been rerun with perturbed observations. DFS for each observation have been grouped into parameters and types categories to provide information about the weight of observations in the assimilation system. It is also possible to define Relative Degrees of Freedom for Signal as DFS divided by the number of observations in the subset, which indeed represent an index of the theoretical weight given to each single observation.

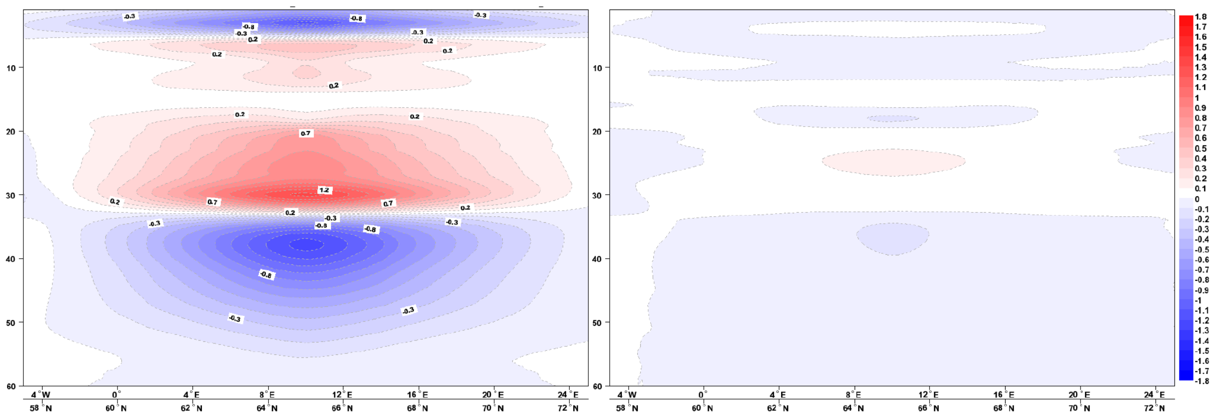

Fig. 3: Cross-sections of temperature analysis increments for brightness temperature single-observation experiments (2 K innovation for AMSU-A channel 9 aboard NOAA-18). Left and right panel show the increments using the NMC method and the ensemble method statistics respectively.

Results (Fig. 4) show the large importance of wind observations, emphasizing the role of aircraft and AMSU-A observations in the HARMONIE-3DVar system. Use of variational bias correction increases the weights given to observations, not only for remote-sensed observations. Humidity measurements and humidity-related observations (SEVIRI Water Vapor channels, AMSU-B) are very important in relative terms, but less crucial in the actual assimilation system because of the small amount, compared to other observations.

Sensitivity of forecasts

Further to standard verification scores against SYNOP and TEMP reports and against ECMWF analysis, sensitivity of forecasts to different observation types has been studied through a randomization technique. Each group of observations has been perturbed independently, and we can define a forecast cost function J such as:

$$SOF_i = \frac{\partial J}{\partial x_a} \frac{\partial x_a}{\partial y_i} = \frac{\partial J}{\partial y_i}$$

In particular, we have defined J as the percentage variation of the root mean square errors of forecasts against analysis valid at the same time for an all-observations experiment. Computations refer to a few assimilation cycles, assumed representative for different synoptic conditions and observations availability.

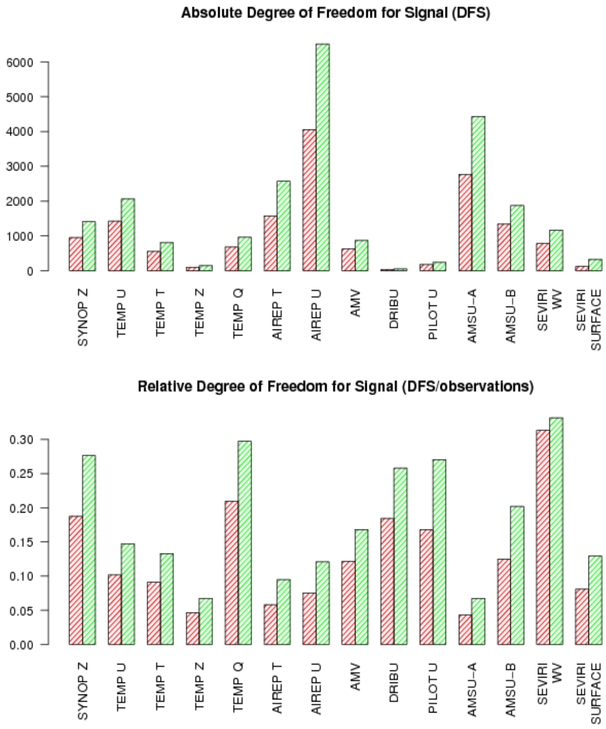

Fig. 4: Absolute and relative DFS. Red bars refer to Harris and Kelly bias correction scheme experiment for AMSU and SEVIRI; green bars for variational bias correction experiment.

This technique provides an estimation of which observations do affect forecasts the most for different atmospheric parameters, and is much cheaper than Observing System Experiments (OSE). When the assimilation of all the observations is known to provide the best forecasts, SOF can also be used as index of the influence of each observation type on the forecast quality; in general, it only indicates how observations influence the forecasts, without any guarantee about the sign of the impact. For dynamical parameters (see mean sea level pressure Fig. 5), microwave radiances from AMSU-A seem to play the most important role at almost all the time ranges, followed by radiosondes. Aircraft data and AMV are important especially in forecasting mass fields at short-range and at high atmosphere, and AMSU-B is seen to be critical in forecasting humidity fields in the low and high atmosphere.

Experimental observations

The assimilation of a number of experimental and new observations is under development within the HARMONIE-3DVar system at Met.no. We summarize in the sequel strategies and main results. The reader can refer to Randriamampianina and Storto (2008) in these conference proceedings for issues concerning the assimilation of IASI radiances.

Humidity retrievals from CloudSat

The Cloud Profiling Radar aboard CloudSat supplies vertical cross-sections of radar power return, which are converted into cloud-fraction profiles through a simple algorithm that derives the cloudiness from the ratio between the net received power and the noise power standard deviation. An additional clutter filter is implemented for screening the surface return. Cloud fraction data are then used in a standalone Bayesian Analysis to retrieve humidity corrections by the use of a simplified large-scale condensation scheme. Humidity retrievals are computed also in case of clear-sky, unless the observation minus first guess departure is zero in cloud fraction space, to avoid information redundancy (background fields are used twice, in the Bayesian analysis as well as in 3DVar). Humidity retrievals thus obtained are assimilated in HARMONIE-3DVar.

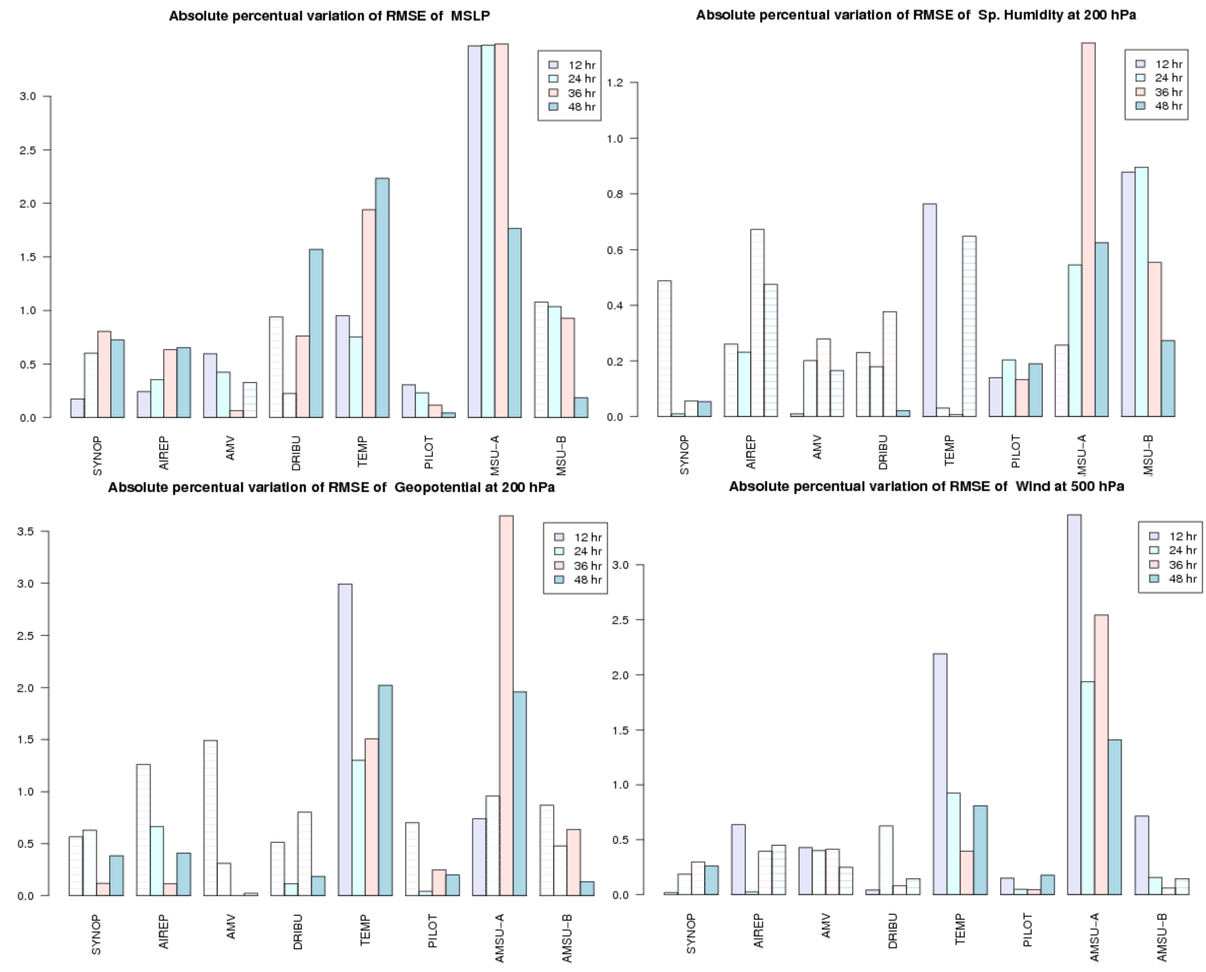

Fig. 5: SOF: relative variation of RMSE of forecasts against reference analysis for different observation groups and relative to (from top-left panel clockwise) mean sea-level pressure, 200 hPa specific humidity, 500 hPa wind and 200 hPa geopotential.

First experiments have been carried out setting small observation errors, and showed a very encouraging impact of CloudSat derived observations, especially on wind and temperature fields. In Fig. 6 verification against radiosonde observations at different forecast ranges are shown for wind intensity, temperature and relative humidity. Unfortunately, CloudSat data dissemination is affected by a 6 hours delay, which doesn't allow operational use of those observations.

Zenith Total Delay from ground-based GPS stations

Delay of GPS satellite signal measured when ground-based stations point at zenith contains information about the vertical profile of atmospheric refractivity, providing therefore information about temperature profile and integrated vertical moisture content. The observation operator comes from Poli et al. (2007) and links the control state with the delay processed by different centers throughout Europe. Flat bias correction is applied to a number of couples of stations and processing centers whose data supply is regular and whose background departure follows a Gaussian probability density function. Observation errors, specified separately for each station, have been obtained from inflating down empirically the standard deviations of observation minus guess differences and diagnostic statistics (not shown here) suggest that they have been however overestimated. After having screened irregular, unreliable and duplicated stations, 54 stations have been selected inside the HARMONIE-3DVar domain, and the impact of those observations has been studied over a one-month assimilation period. Results (Fig. 7) show a slightly positive impact of GPS-ZTD, especially for mass fields.

Possibility to improve bias correction procedures by the use of a predictors-based scheme for taking into account observation operator error derived by model orography displacement and other sensitive parameters is currently under evaluation, together with a more robust definition of observation errors.

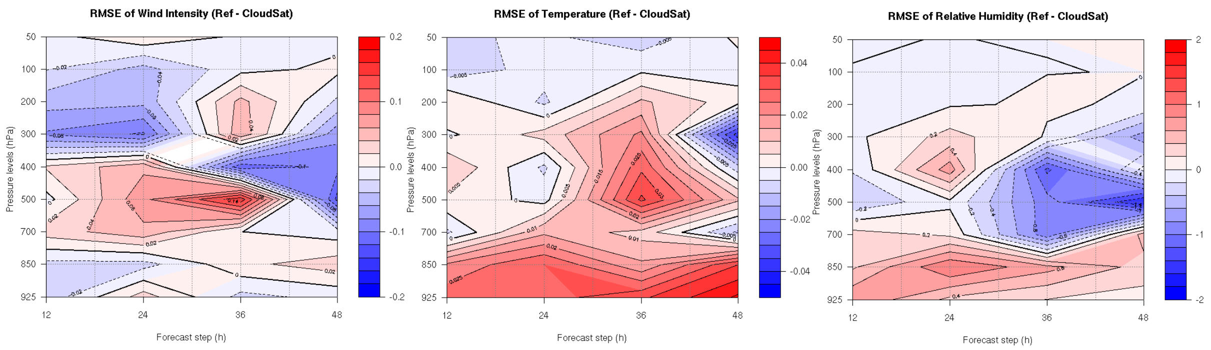

Fig. 6: Difference of root mean square errors between a reference experiment and an experiment with CloudSat data assimilation against radiosonde observations. Where positive (red), CloudSat observations have a positive impact.

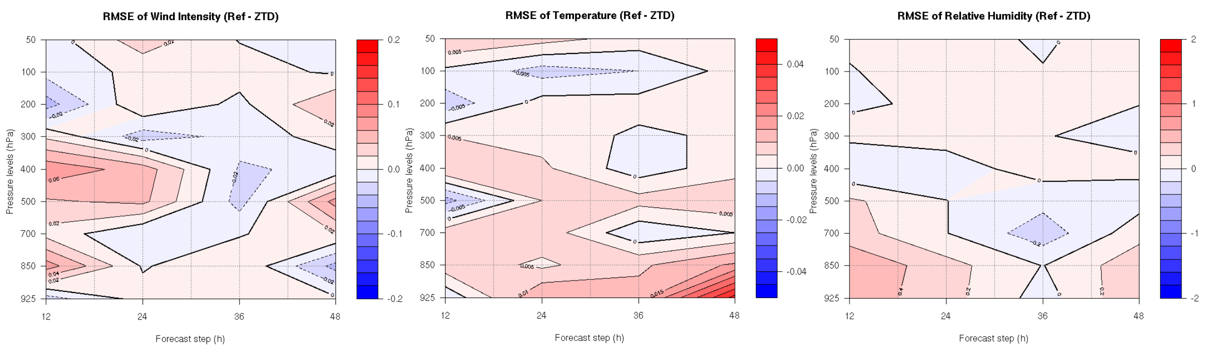

Fig. 7: Difference of root mean square errors between a reference experiment and an experiment with GPS-ZTD data assimilation against radiosonde observations. Where positive (red), GPS-ZTD observations have a positive impact.

Conclusions

As the ALADIN/HARMONIE three-dimensional variational assimilation is being developed at the Norwegian Meteorological Institute, a lot of scientific choices and practical issues have to be coped with. A brief overview of the system, able to assimilate both conventional and remote-sensed data, has been given. Satellite observations are very important for enhancing forecast verification scores: we are now assimilating ATOVS/AMSU-A, AMSU-B and MHS radiances by using the RTTOV transfer model, and MSG/SEVIRI infrared radiances pre-processed through the NWC-SAF software. Detailed selection of channels for each satellite at each network (0, 06, 12, 18 UTC) is a delicate task in limited area assimilation systems, and will be completed soon. Comparisons between different bias correction strategies has been dealt with: variational procedure leads to easy bias correction procedure for high spectral resolution sounders, and shows positive impact in terms of both unbiased residuals (analysis minus observation) statistics and verification scores. Use of ensemble methods for estimating background error covariances provides less broad vertical correlations than the ones derived via the NMC method. This avoids that high-peaking channels generate unrealistic analysis increments at many vertical levels, reaching the model top.

The study of the impact of observation subgroups on the analysis and forecasts has been performed by using randomization techniques: AMSU-A and wind measurements, especially from airborne instruments, result the most important observations as seen from the analysis, while the impact on forecasts, computed using an RMSE-based cost function, shows the great importance of AMSU-A radiances for all dynamical parameters at all forecast ranges; aircraft and AMV data seem to affect significantly short-range forecasts for temperature fields, while AMSU-B plays an important role for humidity fields.

Promising results have been obtained by the experimental assimilation of humidity retrievals from the CloudSat spaceborne radar and from the zenith total delays from ground-based GPS stations.

Acknowledgments

The authors would like to thank the Meteo-France/GMAP staff for their help, in particular Bernard Chapnik for his suggestions in the computations of DFS and Loik Berre for his precious comments on the background error statistics. Help from Alena Trojakova (Czech Met Inst) and Gergely Bölöni (Hungarian Met Service) in the assimilation of Seviri data is also acknowledged. The authors want also to thank Lars Isaksen of ECMWF for having kindly provided the ensemble analysis used for computing background error covariances

References

Andrae, U., 2007: Daily runs with ALADIN and AROME at SMHI. *2007 HIRLAM All-Staff Meeting/17th ALADIN Workshop*, Oslo Norway, 23 - 26 April, 2007.

Auligné, T., A. P. McNally and D. P. Dee, 2007: Adaptive bias correction for satellite data in numerical weather prediction. *Q. J. R. Meteorol. Soc.*, **133**, 631-642.

Berre, L., 2000: Estimation of synoptic and mesoscale forecast error covariances in a limited area model. *Mon. Wea. Rev.*, **128**, 644–667.

Bölöni, G., 2006: Development of a variational data assimilation system for a limited area model at the Hungarian Meteorological Service, Idöjárás, 110, 309–327

Brunel, P. and S. Turner, 2003: On the use of Planck-weighted transmittances in RTTOV, *Proceedings of International TOVS Study Conference*, Ste Adele, Canada 29 Oct – 4 Nov 2003.

Cardinali, C., S. Pezzulli and E. Anderson, 2004: Influence-matrix. diagnostic of a data assimilation system. *Q. J. R. Meteorol. Soc.*, **130**, 2767–2786

Chapnik, B., G. Desroziers, F. Rabier, and O. Talagrand, 2006: Diagnosis and tuning of observational error in a quasi-operational data assimilation setting. *Q. J. R. Meteorol. Soc.*, **132**, 543–565.

Desroziers, G., L. Berre, B. Chapnik and P. Poli, 2005: Diagnosis of observation, background and analysis-error statistics in observation space. *Q. J. R. Meteorol. Soc.*, 131, 3385–3396.

Eyre J. R., 1991: A fast radiative transfer model for satellite sounding systems. *ECMWF Research Dept. Tech. Memo*. **176**.

Fischer, C., T. Montmerle, L. Berre, L. Auger, and S. Stefanescu, 2005: An overview of the variational assimilation in the ALADIN/FRANCE NWP system. *Q. J. R. Meteorol. Soc.*, **131**, 3477–3492.

Harris, B.A. and Kelly, G., 2001: A satellite radiance-bias correction scheme for data assimilation. *Q. J. Roy. Meteor. Soc.*, **127**, 1453-1468.

Isaksen, L., M. Fisher, and J. Berner, 2007: Use of analysis ensembles in estimating flow-dependent background error variance. *ECMWF Workshop on Flow-dependent aspects of data assimilation*. 11–13 June 2007, Reading, United Kingdom.

Poli P., P. Moll, F. Rabier, G. Desroziers, B. Chapni, L. Berre, S.B. Healy, E. Andersson, F. El Guelai, 2007: Forecast impact studies of zenith total delay data from European near real-time GPS stations in Météo France 4DVAR. *J. Geophys. Res.*, **112**, D06114.

INTERNATIONAL ATOVS WORKING GROUP

Proceedings of the Sixteenth International TOVS Study Conference

Angra dos Reis, Brazil

7-13 May 2008

Sharing ideas, plans and techniques to study the earth's weather and climate using space-based observations

The 16th International TOVS Study Conference (ITSC-16) Angra dos Reis, Brazil

PROCEEDINGS ADDUNDUM