The relative impact of satellite observations in the HARMONIE/Norway

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Introduction

Assessing the relative impact of the observations in an operational meteorological model is an important diagnostic, which might be of benefit for improving the current meteorological observing network, as well as for refining the assimilation techniques for the most impacting observations, in accordance with their availability. Recently, many formalisms have been introduced in order to compute a metric able to represent the sensitivity of the analysis and the forecasts to different observation types. Traditional approaches are based on the verification scores of long data-denial experiments, the so-called Observing System Experiments, OSEs (e.g. Louis *et al.*, 1989; Bouttier and Kelly, 2001; Zapotocny *et al.*, 2002), which are very effective for evaluating the actual impact of different observation types and their synergic effect with other observations. The same strategy can be applied to synthetic observations to test the hypothetical impact of potential or forthcoming observing networks (the Observing System Simulation Experiments, OSSEs, see e.g. Randriamampianina and Borisenkov, 1997). Nevertheless, OSEs and OSSEs are very expensive when one wants to assess the impact of many observation types, and are almost unaffordable if one wants to evaluate the impact of many satellite channels. The adjoint sensitivity (e.g. Langland and Baker, 2004) is a newer technique to project the forecast error contribution of different observations backwards to the analysis. In a similar way, Desroziers et al. (2005) proposed to estimate the forecast impact by projecting forward in time through the tangent-linear version of the forecast model a proper metric which quantifies the analysis impact. These strategies assume that the sensitivity of the analysis to the observations propagates linearly within the forecast model, thus neglecting the effects of order higher than first in the model evolution; further, they need the tangent-linear and eventually the adjoint version of the forecast model to be coded, which is very onerous when not available.

The aim of this short paper is to present a simple and relatively cheap method for evaluating the impact of different set of observations on the forecast, emphasising the hierarchy of satellite channels. Unlike OSEs, the method is statistical in the sense that does not require a long enough cycle of assimilation and forecasts, being much cheaper if the individual impact of satellite channels needs to be assessed. It does not require the coding of the adjoint version of the forecast model like in the adjoint-based sensitivity studies; further, it is able to reproduce the effects of the non-linearities of the impact of the observations.

The assimilation and forecast system

The assimilation system consists of i) updating the Sea Surface Temperature (SST) by using the ECMWF global SST analysis, ii) performing a surface Optimal Interpolation for updating soil moisture and skin temperature fields through a univariate analysis of 2 meters temperature and relative humidity using the synoptic stations network (SYNOP); iii) performing a spectral upper-air three dimensional variational data assimilation, which takes advantage of the SYNOP stations from ships and land for the surface pressure and for the 10 meters wind over sea only, the radiosonde network for the multi-layer observations of wind, temperature, humidity and geopotential, the wind profilers for the multi-layer observations of wind, the air-borne observations of temperature and wind, the surface pressure measurements from the oceanographic buoys, the wind vectors deducted from cloud-drift satellite images (Atmospheric Motion Vectors, AMV), the microwave radiances from AMSU-A, AMSU-B/MHS and IASI from the polar-orbiting satellites of NOAA and from MetOp.

Type	Parameter (Channel)	Bias correction	Thinning
TEMP	U, V, T, Q, Z	Only T using ECMWF tables	No
SYNOP	Z	No	Temporal and spatial
PILOT (Europrof.)	U, V	No	Redundancy check against TEMP
DRIBU	Z	No	Temporal and spatial
AIREP	U, V, T	No	25 km horizontal
AMV	U, V	No-Use of quality flags	25 km horizontal
AMSU-A	5 to 13	Variational	80 km horizontal
AMSU-B, MHS	3, 4, 5	Variational	80 km horizontal
IASI	41 channels	Variational	80/120 km horizontal
GPS	available but not used in	Static	No
MSG/SEVIRI	this experiment	Variational	60 km horizontal

Table 1. Use of Observations in the ALADIN-HARMONIE/Norway

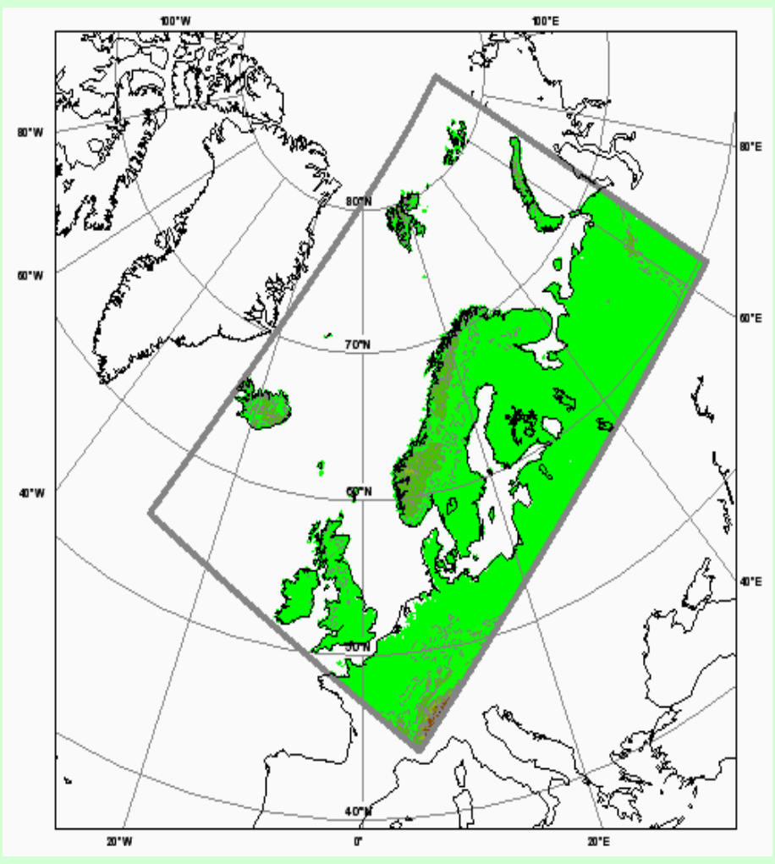

Figure 1. The ALADIN-HARMONIE/Norway domain, 11 km horizontal resolution

The forecasts sensitivity study

Methodology

The impact of the initial conditions on the forecasts at a given forecast ***time t*** may be described through a ***cost function J*** (Rabier et al., 1996) given by:

$$J=\frac{1}{2}\left\langle \mathbf{x}_{\mathbf{t}}^{\mathbf{exp}}-\mathbf{x}_{\mathbf{t}}^{\mathbf{ref}},\ \mathbf{x}_{\mathbf{t}}^{\mathbf{exp}}-\mathbf{x}_{\mathbf{t}}^{\mathbf{ref}}\right\rangle \qquad \left\langle \ldots,\ldots\right\rangle \text{ - norm operator}$$

Where X^{ref}_t - forecasts initialised with reference initial conditions;
X^{exp}_t - forecasts initialised, in general, with some modifications or perturbations of the initial conditions

The norm used for evaluating the observations impact is the moist total energy norm (MTEN, Ehrendorfer et al., 1999):

$$\left\langle \mathbf{x}_{\mathbf{t}}^{\mathbf{i}}-\mathbf{x}_{\mathbf{t}}^{\mathbf{ctr}},\ \mathbf{x}_{\mathbf{t}}^{\mathbf{i}}-\mathbf{x}_{\mathbf{t}}^{\mathbf{ctr}}\right\rangle=\int_{\eta_0}^{\eta_1}\int_{D}\left(u^2+v^2+\frac{c_p}{T_r}T^2+\frac{RT_r}{p_r^2}p^2+\frac{L^2}{c_pT_r}q^2\right)\frac{\partial p_r}{\partial\eta}\,d\eta\,dD$$

Where: ***u, v, T, p, q*** being respectively the difference of ***u***- and ***v***-component of wind, temperature, surface pressure and specific humidity between the control forecast and the one without the ***i***-th set of observations; ***cp, R, L*** are specific heat at constant pressure, gas constant of dry air, and latent heat condensation; ***Tr*** and ***pr*** are reference temperature and reference pressure; ***η*** is the vertical coordinate.

Repeating the computation of the norm for many independent simulations, we define the sensitivity of the forecasts to the ***i***-th group of observations as:

$$S^i=\frac{\sum_k f_k w_k J_k^i}{\sum_k f_k}$$

Where: ***fk*** is the occurrence frequency of the scenario for which the cost function is computed; ***Wk*** is the weight (i.e. the risk) associated with such a meteorological scenario.

***S**^i^* provides an *economical value* associated to each of the observation types.

Vertical region	Region Bottom	Region Top
Low-troposphere	850 hPa	600 hPa
Middle-troposphere	600 hPa	350 hPa
High-troposphere	350 hPa	150 hPa
Stratosphere	150 hPa	20 hPa

Table 2. Definitions of vertical sub-regions of the atmosphere for use with the localisation operator

For any subset of observations ***i*** which have been excluded from the assimilation system, we can define:

$$J^i=\frac{1}{2}\left\langle \mathbf{x}_{\mathbf{t}}^{\mathbf{i}}-\mathbf{x}_{\mathbf{t}}^{\mathbf{ctr}},\ \mathbf{x}_{\mathbf{t}}^{\mathbf{i}}-\mathbf{x}_{\mathbf{t}}^{\mathbf{ctr}}\right\rangle.$$

Where: X^i_t - is the forecast initialised without assimilating the observations belonging to the ***i***-th subset and;
X^{ctr}_t - is the control forecast with all the observations assimilated, which is assumed to give the best verifying forecasts

Further, we can define an ***operator P*** to study the sensitivity of forecasts in specific areas inside the model domain extension

$$J^i=\frac{1}{2}\left\langle \mathbf{P}(\mathbf{x}_{\mathbf{t}}^{\mathbf{i}}-\mathbf{x}_{\mathbf{t}}^{\mathbf{ctr}}),\ \mathbf{P}(\mathbf{x}_{\mathbf{t}}^{\mathbf{i}}-\mathbf{x}_{\mathbf{t}}^{\mathbf{ctr}})\right\rangle.$$

For more details see *Storto and Randriamampianina*, 2010.

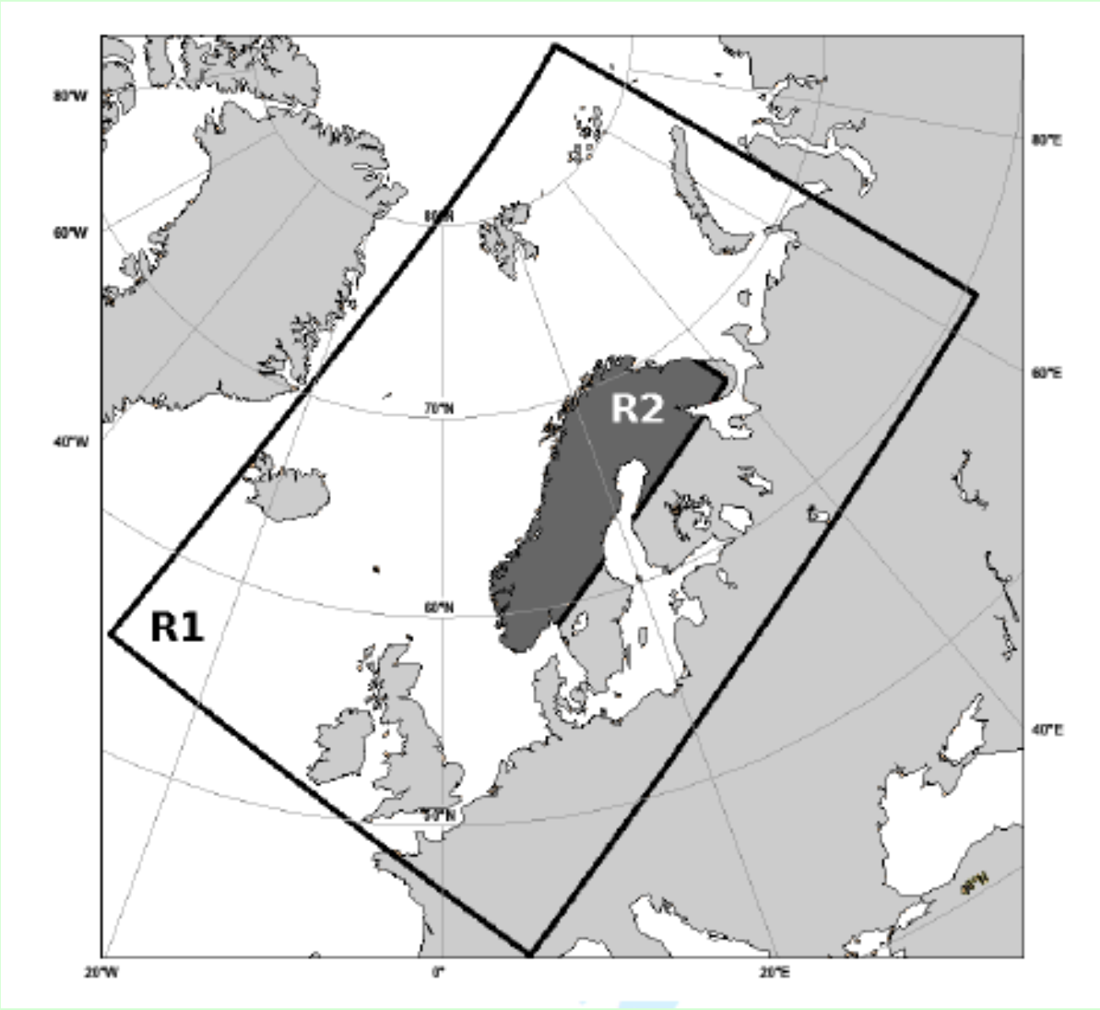

Figure 2. Definition of horizontal domains

Conclusions

- ➢The development of an energy norm-based cost function to evaluate the quality loss of the forecasts when an observation type is not assimilated in a regional model has been achieved with the aim of avoiding expensive simulations like in the OSE, or coding the adjoint version of the model, as required for adjoint sensitivity studies.
- ➢This approach has allowed us to conclude that in-situ observations, mostly radiosondes and aircraft data, are the most important for the short-range forecasts (up to 24 hours) within all the troposphere. On the contrary satellite data, and, in particular, microwave radiances from AMSU-A channels peaking within the troposphere (5 to 8) have the largest impact after 24 hours of forecast. This is even more evident in the continental area of our limited area (R2) model (not shown in this poster, see *Storto and Randriamampianina*, 2010).
- ➢A detailed study has been conducted on the moisture term of the energy norm, showing that the impact of AMSU-B is particularly seen in the low tropospheric levels.
- ➢For the middle troposphere region, the impact of SEVIRI channels 1, 2 and 3 has also significantly increased.
- ➢The IASI channel groups have different impact on different cases.
- ➢The sensitivity of the forecasts to the satellite radiances (see case of AMSU-A and IASI) is higher in unstable or convective synoptic situations.

References

Bouttier F, Kelly G. 2001. Observing system experiments in the ECMWF 4D-Var data assimilation system. *Quarterly Journal of the Royal Meteorological Society* 127: 1469–1488. ***Desroziers G, Brosseau P, Chapnik B.*** 2005. Use of randomization to diagnose the impact of observations on analyses and forecasts. *Quarterly Journal of the Royal Meteorological Society* 131: 2821–2837. ***Ehrendorfer M, Errico RM, Raeder KD.*** 1999. Singular-vector perturbation growth in a primitive equation model with moist physics. *Journal of Atmospheric Sciences* 56: 1627–1678; ***Langland RH, Baker NL.*** 2004. Estimation of observation impact using the NRL atmospheric variational data assimilation adjoint system. *Tellus* 56A: 189–201. ***Rabier F, Klinker E, Courtier P, Hollingsworth A.*** 1996. Sensitivity of forecast errors to initial conditions. *Quarterly Journal of the Royal Meteorological Society* 122: 121–150; ***Louis J-F, Hoffman RN, Nehrkorn T, Norquist D.*** 1989. Observing System Experiments using the AFGL four-dimensional data assimilation system. *Monthly Weather Review* 117: 2186–2203; ***Randriamampianina R, Borisenkov EP.*** 1997. Constant pressure balloon-satellite observing system simulation experiments. *Időjárás* 101: 289-305; ***Roger Randriamampianina***, 2009, Impact of IASI data on forecasting polar lows, *EUMETSAT Meteorological Satellite Conference*, Bath, United Kingdom 21 - 25 September 2009; ***Storto A. and Randriamampianina R.***, 2010, The Relative Impact of Meteorological Observations in the Norwegian Regional Model as determined using an energy norm-based approach, *Atmospheric Science Letters*; ***Zapotocny TH, Menzel WP, Nelson JP, Jung JA.*** 2002. An impact study of five remotely sensed and five in situ data types in the Eta Data Assimilation System. *Weather and Forecasting* 17: 263–285.

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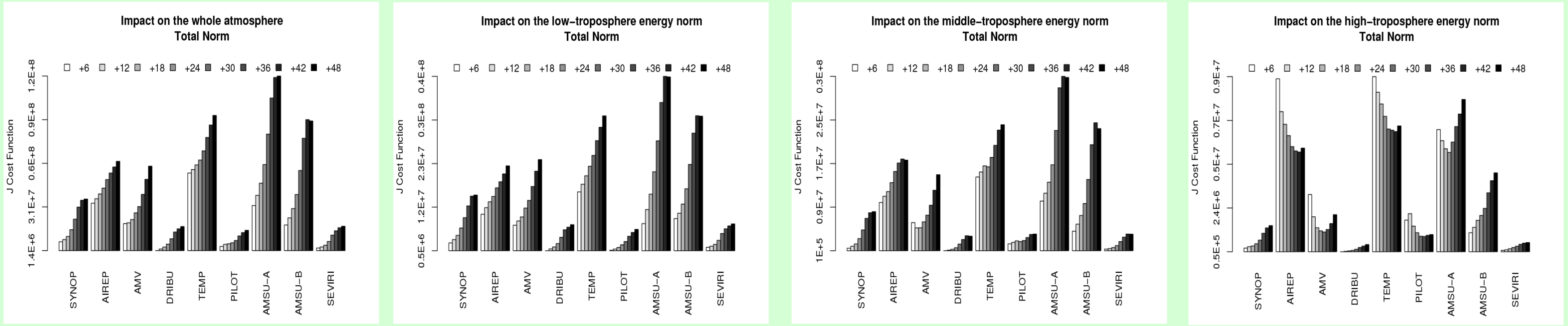
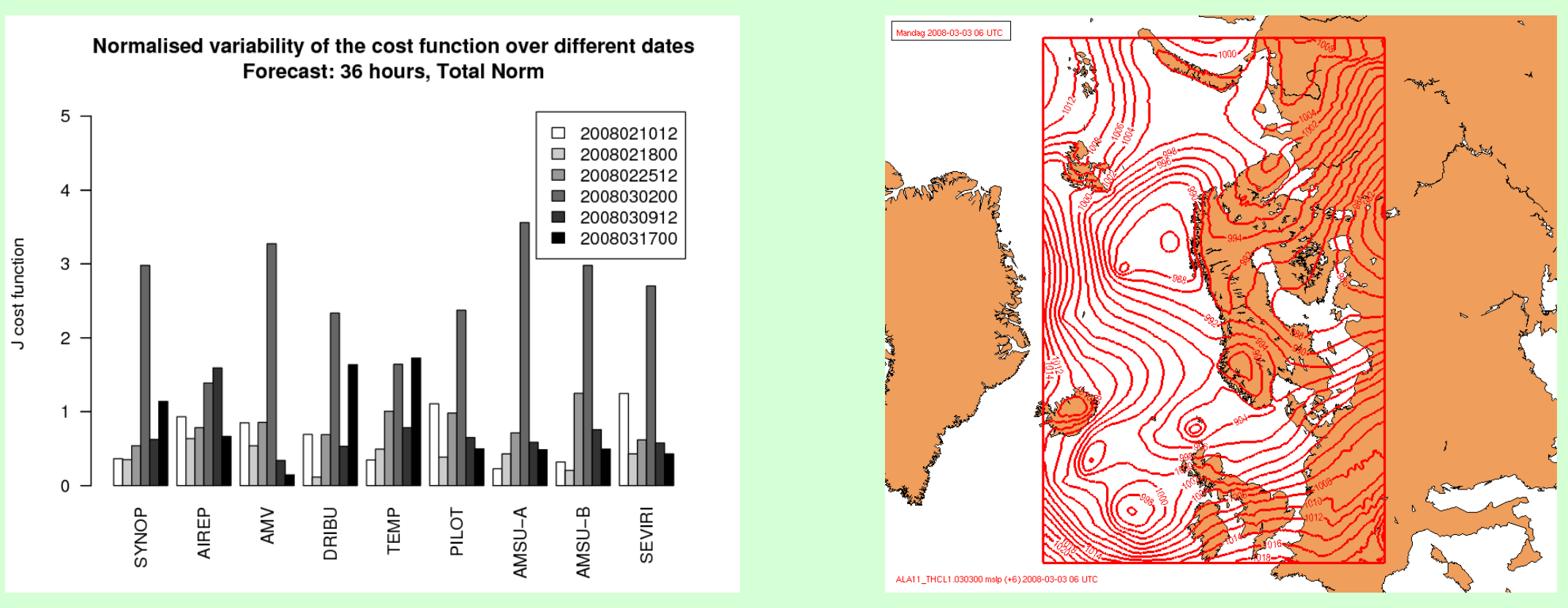
Forecast sensitivity study – Results without IASI data

Evaluation period:
01.02.2008 - 17.03.2008

Cases used: **12.02.2008 (12 UTC), 18.02.2008 (00 UTC), 25.02.2008 (12 UTC)**
02.03.2008 (00 UTC), 12.03.2008 (12 UTC) , 17.03.2008 (00 UTC)



Figures 3. Total energy norm impacts at different levels of the atmosphere. The case-averaged values give a general idea of the different contribution of the observations to the forecast error norm for the January-February 2008 winter period.

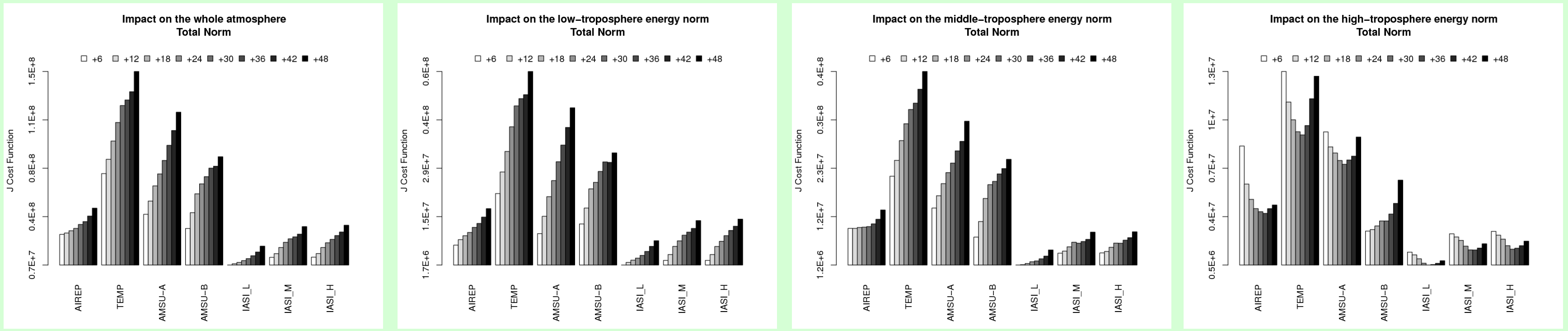


Figures 4 provide an insight of the 36-hour forecast sensitivity for each observation group in the 6 cases. The proportion of the relative impact of different observation type is in general maintained within the different cases, but the cost function absolute value may change, due to case-specific synoptic situations. For instance, the 2008030200 case, where observations have the largest impact, was characterised by a polar-low formation close to the Lofoten Islands and to a complicated low-pressure systems around the UK peninsula. Another polar low located over the Barents Sea was present for the 2008031700 case, while for the other dates stable conditions were found.

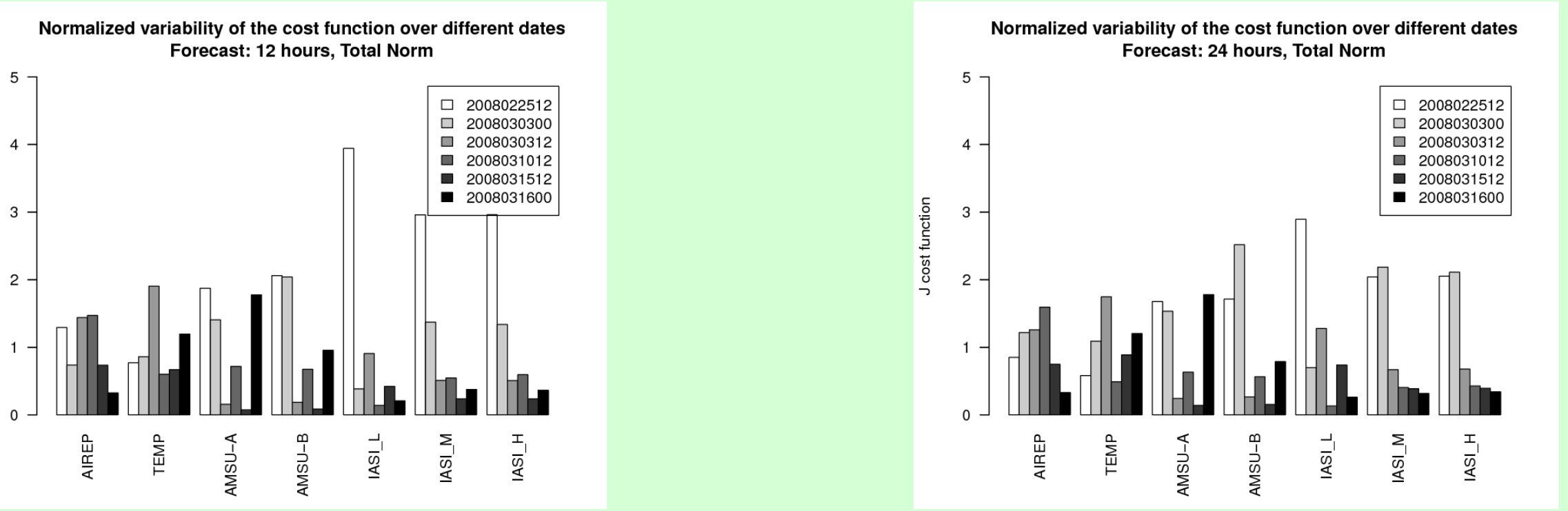
Forecast sensitivity study – Results with IASI data

Evaluation period: 25.02.2008 - 17.03.2008

Cases used: **25.02.2008 (12UTC), 03.03.2008 (00 UTC),**
10.03.2008 (12UTC), 16.03.2008 (00 UTC)



Figures 5. Total energy norm impacts at different levels of the atmosphere



Figures 6. Normalised variability of the cost function over different dates

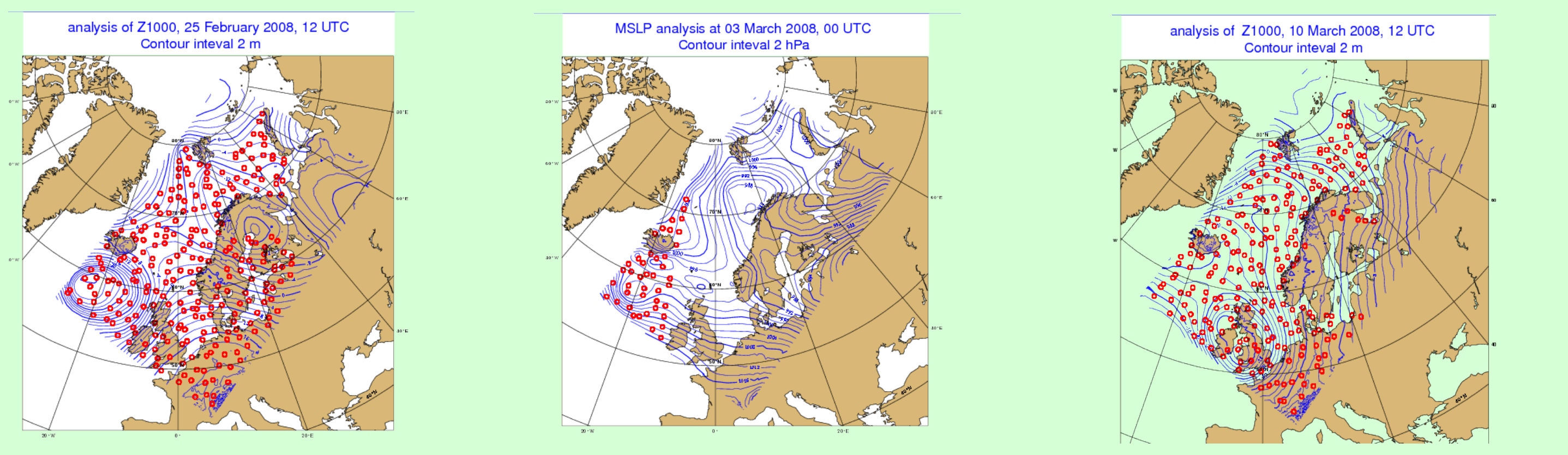


Figure 7. Some studied cases for forecasts sensitivity. Red circles represent the active IASI pixels.

Case study: Impact of the IASI data on forecasting the Polar lows

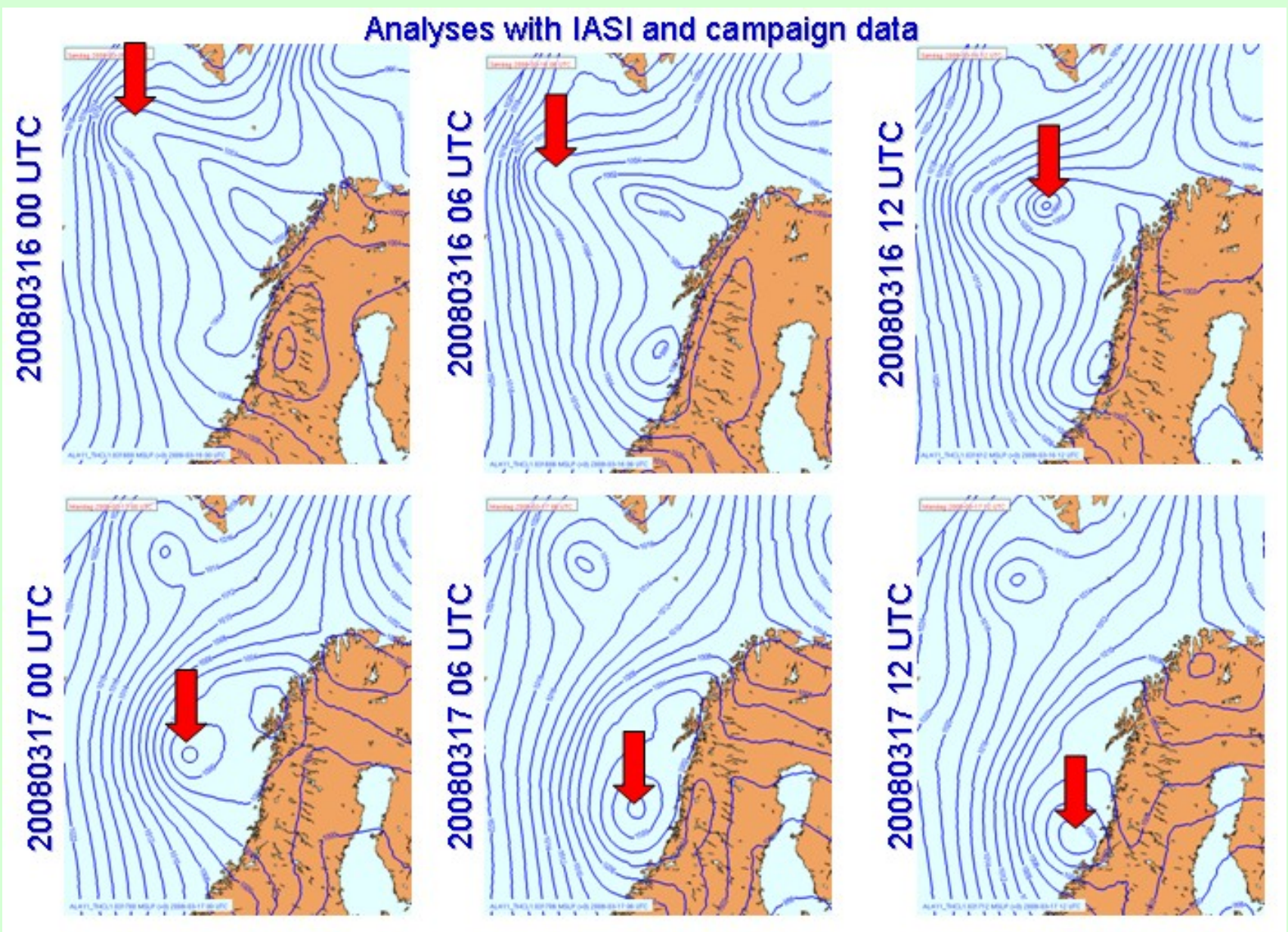


Figure 8. Analyses at different times of the run with IASI and campaign observations. One can see how fast the low is developing.

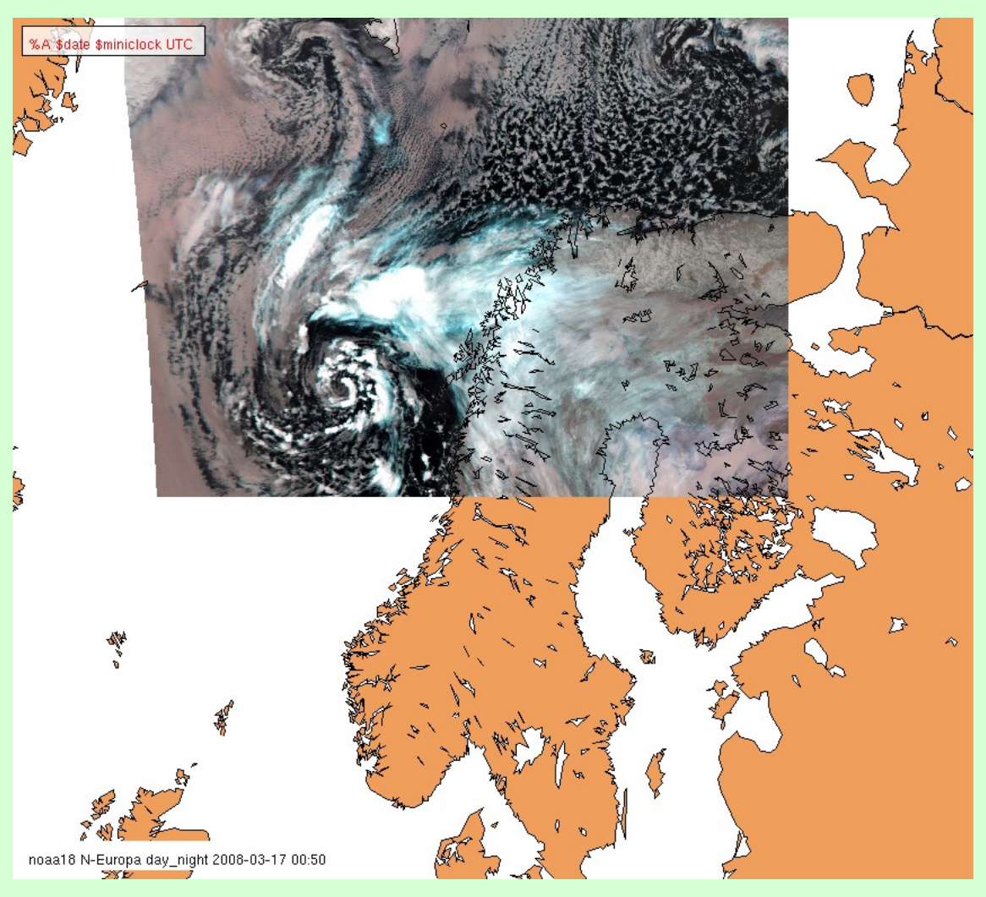


Figure 9. Intensity and position of the low at 00:50 UTC, 17 March 2008.

In this case study we show the impact of the assimilateded IASI data on forecast of a very fast developing polar low. This low appeared almost at the end of the campaign period. This case was followed by dropsondes operated on 16th of March from 11:00 to 14:30 UTC (Fig. 10) and 17th of March from 05:00 to 08:30 UTC. As one can see, the life of this polar low was roughly one and half - two days. Using the IASI data in both combinations (with or without additional campaign observations – mainly dropsondes) the forecasts are less deep than in the cases without them (Figs 11). The best forecast was achieved when the additional dropsondes were assimilated together with the IASI soundings.

Figure 10. Flight plan for March 16 with takeoff at 11:00 UTC, duration 3:30 hours. Red boxes show the planed sounding positions.

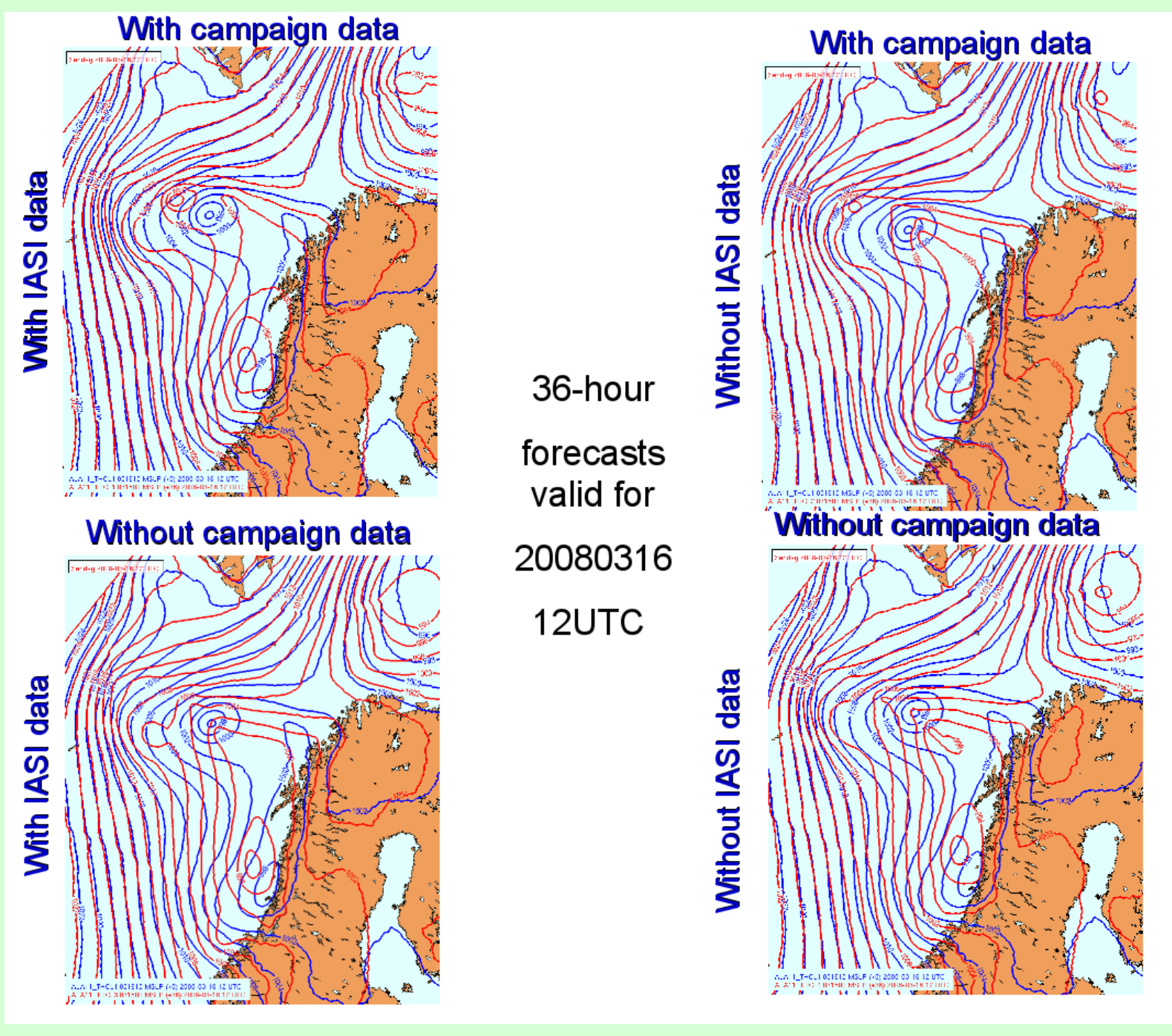


Figure 11. Different scenarios of forecasts (red lines) valid for 16 March 2008 a 12 UTC, superposed with the analysis (blue lines). One can see that the combination of campaign and IASI observation (upper left panel) have the best 36-hour forecast of the polar low.

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