

Forecast sensitivity to satellite observations at Météo-France

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Satellite observations assimilated in ARPEGE, the global model at METEO-FRANCE

The 4DVAR system used at METEO-FRANCE processes and assimilate a large amount of satellite and ground based observations.

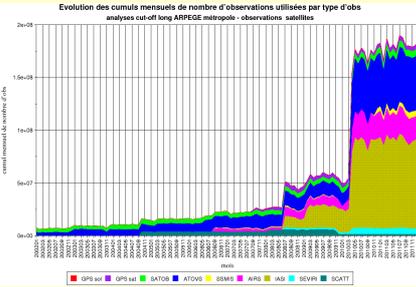


Fig 1: Satellite observations assimilated in the global model at METEO-FRANCE:

- AMSU-A
- AMSU-B
- HIRS
- SATOB
- SSMIS
- AIRS
- IASI
- SEVIRI
- SCATTEROMETRE
- Ground GPS
- GPS radio-occultation

Such a large number of observations need to be monitored to indicate their influence on analysis and forecasts.

Impact of different subsets of the observing system

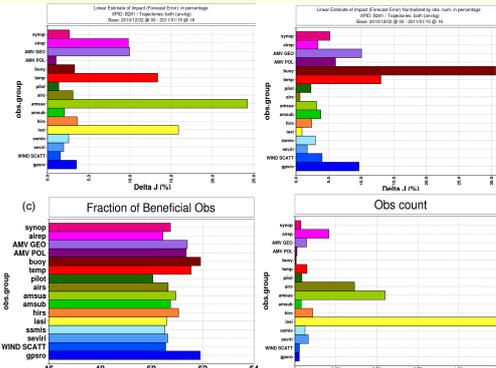


Fig 3:

Linear estimate of observations impact, averaged over the globe for a one-month and a half period (December 2010 to mid January 2011)

(a) Impact of observations assimilated in ARPEGE separated by observation group and (b) divided by observations number (c) percentage of beneficial observations and (d) observations count

AMSU-A and IASI instruments have the biggest impact on forecast error reduction. They also provide a very large number of observations. When we divide the impact by observation number, we can see that buoy individual contribution to the forecast error reduction is the biggest. Concerning other satellite observations, GPSRO, Wind scatterometer, amsub, polar AMV contribute a lot to forecast error reduction, even if they are not very numerous.

Linear (adjoint based) estimate of observation impact: A diagnostic of the data assimilation system

The diagnostic used in ARPEGE at METEO-FRANCE has been first implemented in IFS (ECMWF) by C. Cardinali and M. Fisher. It allows to evaluate observation impact on forecast skill

The analyzed initial state vector x_a is produced by combining information from observations y and from a background vector x_b

$$x_a = Ky + (I - HK)x_b \text{ where } K = (B^{-1} + H^T R^{-1} H)^{-1} H^T R^{-1} = AH^T R^{-1}$$

K is the Kalman Gain matrix and H the linearized observation operator that maps x_a into observation space. B is the background error covariance matrix and R the observation error covariance matrix.

To compute the observation impact, we define a cost function J representing the forecast error.

Here, J is the 3D integrated dry total energy of the difference between the 24h forecast and a reference state (e.g. verifying analysis)

The forecast sensitivity to observations is:

$$\frac{\partial J}{\partial y} = \frac{\partial x_a}{\partial y} \frac{\partial J}{\partial x_a} = K^T M^T \frac{\partial J}{\partial x_f}$$

$\frac{\partial J}{\partial x_a}$ is the forecast error sensitivity to the analysis (Rabier et al. 1996)

$$\frac{\partial x_a}{\partial y} = K^T = R^{-1} H (B^{-1} + H^T R^{-1} H)^{-1} = R^{-1} H A$$

M^T is the adjoint of the forecast model

The linear estimate of the observation impact on the forecast aspect ΔJ writes:

$$\Delta J = \left\langle \frac{\partial J}{\partial y}, \Delta y \right\rangle = \frac{\partial J}{\partial y} (y - Hx_b) \text{ Where } (y - Hx_b) \text{ is the innovation vector}$$

In practice, the linear estimate of forecast impact (deltaJ) requires a second order approximation (Errico, 2007).

It is then computed using both trajectories from analysis and background (as shown in fig.2):

$$\Delta J = \frac{1}{2} \left(\frac{\partial J}{\partial y_0} \Big|_a + \frac{\partial J}{\partial y_0} \Big|_b \right) (y - Hx_b) = \frac{1}{2} (R^{-1} H A) \left(M^T \frac{\partial J}{\partial x_a} \Big|_a + M^T \frac{\partial J}{\partial x_a} \Big|_b \right) (y - Hx_b)$$

deltaJ is the sum of contributions of all observations assimilated at t_0 . It is the sum of different subsets of the observing system.

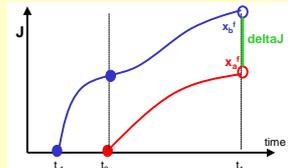


Fig. 2: schematic diagram showing 2 trajectories: from background (blue), from analysis (red), deltaJ appears in green.

Impact of satellite sounders

The impact of any instrument can be computed over the globe or only over a selected area. One can choose to compute this impact by channel. When the impact value is negative, this induces a positive influence on the forecast as it reduces the forecast error (good impact). Fig. 4 shows the impact for IASI on Metop.

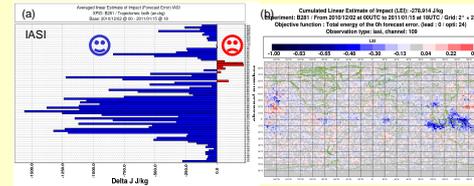


Fig. 4: Global impact of IASI on METOP (a) per channel number and (b) averaged on a 2x2 degrees grid. Evaluation over a one-month and a half period during December 2010 and mid January 2011

Over the calculation period, we can see on fig. 4 that most of IASI channels improve the 24h-forecast. The nine water vapour channels bring a good impact (on the top of fig. 4a). Among the others, the biggest impact comes from Temperature channels pointing the UTLS. However, we can see that a small number of channels degrade the 24 hour forecast. This has to be investigated and confirmed over another period or using a classical OSE for example. One has to keep in mind that the impact calculation uses a tangent linear approximation. Fig. 4 (b) is an example of 2x2° gridded averaged impact for channel 109 of IASI.

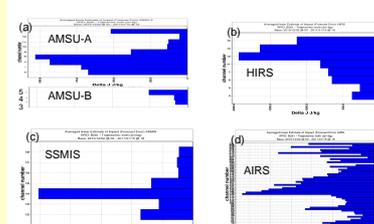


Fig. 5: Global impact per channel number for (a) AMSU-A and AMSU-B/MHS (b) HIRS (c) SSMIS and (d) AIRS

Fig. 5 shows the impact of other sounders, depending on the assimilated channel. The impact is generally good, except for one AIRS channel. The best impacts come from:
 AIRS: temperature channels at the UTLS level.
 AMSU-A: channel 7 and 8, in the upper troposphere; channel 13 points at the highest level and controls the high stratosphere.
 AMSU-B: channel 5, humidity between 2 and 4 km high.
 HIRS: water vapour channel 12, in the middle troposphere and infrared channels 14 and 15 in the lower troposphere.
 SSMIS: channel 14, in the lower troposphere.

Other satellite instrument impact

GPS radio-occultation

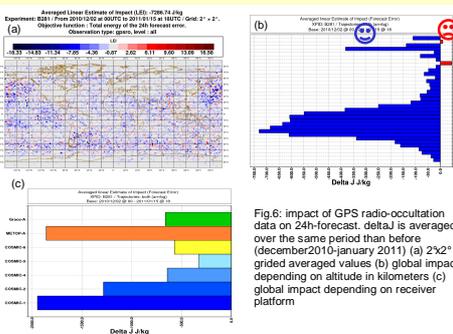


Fig 6: impact of GPS radio-occultation data on 24h-forecast. deltaJ is averaged over the same period than before (december 2010-january 2011) (a) 2x2° gridded averaged values (b) global impact depending on altitude in kilometers (c) global impact depending on receiver platform

GPS radio-occultation data are assimilated in the global 4DVAR and European LAM 3DVAR since September 2007:

- Bending angles are assimilated using 1D operator + TLAD from GRAS-SAF.
- Data used in this experiment come from GRACE-A, FORMOSAT-3/COSMIC-1/6, GRAS on Metop.
- Rising and setting occultations are used up to 36 km altitude. Lower limit depend on latitude: from 1 km (pole) to 6 km (tropics).
- A vertical thinning is operated (1 datum per model vertical layer).

Fig. 6 shows a good global coverage and every LEO (Low Earth Orbit satellite) brings a good impact on forecast error reduction but this impact depends strongly on altitude. A study has to be made to investigate the bad impact at 29 and 35 km height.

Atmospheric Motion Vector

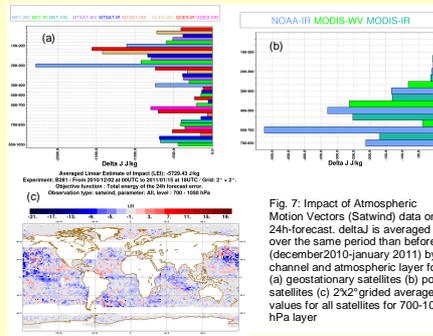


Fig. 7: Impact of Atmospheric Motion Vectors (Satwind) data on 24h-forecast. deltaJ is averaged over the same period than before (december 2010-january 2011) by channel and atmospheric layer for (a) geostationary satellites (b) polar satellites (c) 2x2° gridded averaged values for all satellites for 700-1050 hPa layer

Atmospheric Motion Vector (or satwind) are measured on board geostationary and polar satellites. Fig. 7 is an example of how observation impact can be computed on different observations subsets.

(a) and (b) show the impact by channel, by atmospheric layer and by platform. (c) is a 2x2° gridded averaged impact in the lower troposphere.

Conclusion and references

In order to improve weather forecasts and assimilations, the capability to compute the forecast sensitivity to observations has been implemented at Météo-France. This technique (Langland and Baker, 2004) is now commonly used as a complement to data denial experiments. The linear estimate of each observation contribution to the forecast improvement is computed using the adjoint model.

This diagnostic tool allows to monitor the influence of a large number of observations used in the data assimilation system. Accounting for the approximation made, the linear estimate and can only be used to compute observation impact on a short range forecast, such as 24 hours and must be further investigated, using classical OSEs or on other periods for example.

References:

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