Convective-scale data assimilation of satellite infrared radiances over the Mediterranean: adaptation of the observation operator to the high-resolution.

METEO FRANCE
Toujours un temps d'avance
CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE
CNRM/GAME

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Motivation

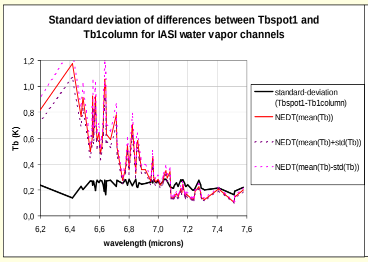
Convective-scale numerical weather prediction models have recently been developed with the specific aim to improve forecasts of high impact weather events such as Mediterranean torrential rainfalls. But their ability to simulate the dynamical and physical processes at a fine scale is not always sufficient to prevent bad forecasts: if some mesoscale key ingredients are missing in the initial conditions, the model cannot then reproduce the precipitating systems. This is particularly true for the initial moisture field: Mediterranean heavy rainfall events are very sensitive to the structure of this highly variable field (Ducrocq et al. 2002).

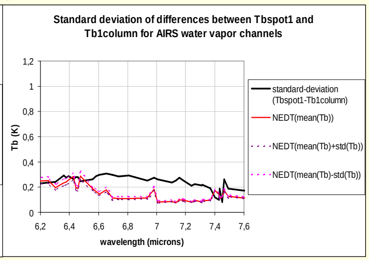
Convective-scale assimilation of observations over the Sea is a way to improve the initial conditions of kilometric scale models. Over the Mediterranean Sea, satellite data are nearly the only routinely available observations. The new infrared sounders AIRS and IASI (Chalon et al. 2001) offer high-resolution and more precise information on temperature and humidity and are therefore particularly interesting to assimilate.

However, assimilating satellite data at a convective-scale arises new problems. For example, the model mesh is now smaller than any satellite observation spot. As a consequence, we need to gather model information from different grid points to represent the whole atmosphere sounded at once by these instruments and simulate correctly the brightness temperature measured, whereas with previous larger-scale assimilation systems we could use a single model column.

This issue is examined more specifically for the newly developed convective scale 3D-Var data assimilation system of Météo-France: AROME. We explore different ways of aggregating the model information within a IASI or AIRS spot. We then compare statistically and through a case study the different brightness temperatures obtained by using RTTOV with these different aggregating methods.

Statistical evaluation of the new operators





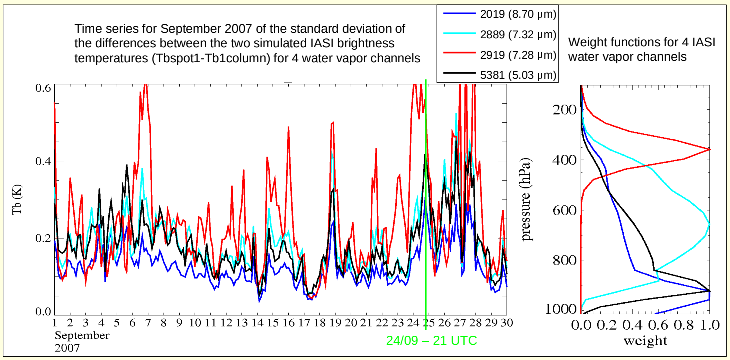
Comparison between Tbspot1 and Tb1column over the whole September 2007 month shows:

- Compared to the Noise Equivalent Differential Temperature (NEDT), only IASI water vapor channels peaking under 350 hPa (wavelength from 7 µm to 7.6 µm) show significant differences between the two observation operators.

- For AIRS, almost all the water vapor channels show significant differences.

- There are almost no differences for temperature channels (not shown).

- The averages of the differences are very close to 0: no new biases have been introduced.


Time series for September 2007 of the standard deviation of the differences between the two simulated IASI brightness temperatures (Tbspot1-Tb1column) for 4 water vapor channels

Weight functions for 4 IASI water vapor channels

The differences between the observation operators Tbspot1 and Tb1column vary with time according to the situation and the structure of the meteorological fields.

Some situations with fine-scale humidity gradients show important differences (e.g. 21 UTC, 24 Sept. 2007) whereas, in other situations, the differences are almost negligible.

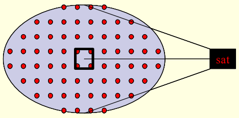
Impact of humidity in brightness temperature estimation

Impact on brightness temperature of a drying from 100 % to 80 % for IASI 2919 channel (K)	0.82
Impact on brightness temperature of a moistening from 50 % to 65 % for IASI 2919 channel (K)	-0.78
First percentile of the differences between Tbspot1 and Tb1column for IASI 2919 channel (K)	-0.94
Last percentile of the differences between Tbspot1 and Tb1column for IASI 2919 channel (K)	0.72

The relative humidity has been varied for a model column and brightness temperature estimated with Tb1column for IASI 2919 channel.

This showed that the most important differences between Tbspot1 and Tb1column are fond equivalent to moisten the column by 15 % (50 % to 65 %) or to dry it by 20 % (100 % to 80 %).

New formulations of the observation operator



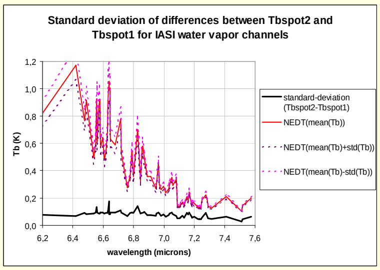
In AROME, satellite observations are simulated thanks to the RTTOV radiative transfer model (Saunders and Brunel 2005).

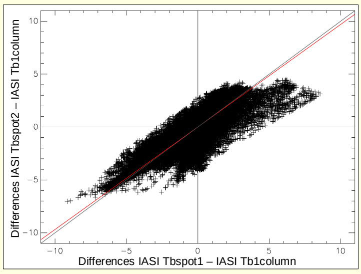
The brightness temperature is currently estimated at the center of the satellite observation spot using the four closest model columns surrounding this point. Such a procedure, hereafter referred to as Tb1column, is however very rough for a 2.5 km resolution model: a single AIRS or IASI observation spot covers more than 12 AROME grid points at nadir, about a hundred at swath edge, and all these points contribute similarly to the measure (the instrument point spread function is quasi-uniform over the spot).

We have modified the observation operator to aggregate the model information within the satellite spots. It now computes the mean of all the model columns situated in the observation spot before estimating the brightness temperature with RTTOV using this mean model column. This new operator is called hereafter Tbspot1. The impact of this adaptation of the observation operator is presented below.

In order to be further close to the way of how the instrument measurement is achieved, we also average the brightness temperatures estimated for each model column in the spot rather than estimate the brightness temperature from an averaged model information. This version of the observation operator, called Tbspot2, has been also evaluated here even though it is too computing time consuming for an operational use.

AIRS and IASI brightness temperatures have been simulated using the three observation operators at each model grid-point:
- of the AROME analyses (2.5 km mesh)
- over the Mediterranean Sea
- in clear-sky conditions (detected from model variables)
- for the maximum scan angle
- every 3 hours, during all September 2007

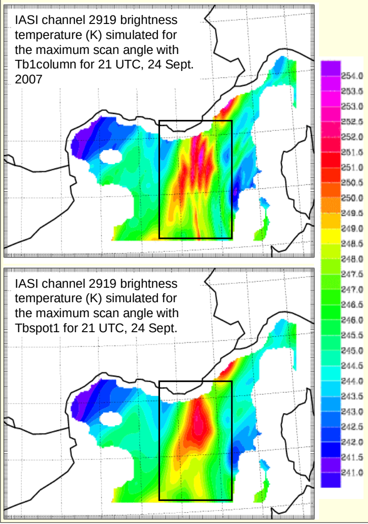




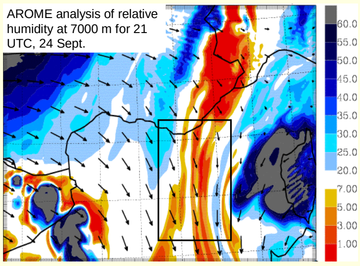
There are almost no significant differences between Tbspot1 (where model information is averaged before applying the radiative transfer) and Tbspot2 (where the brightness temperatures are estimated for each model column in the spot before being averaged). The standard deviation of their differences is below the NEDT for both AIRS (not shown) and IASI.

As shown by the scattering plot (right panel), Tbspot2 gives weaker differences with Tb1column than Tbspot1, in particular when we have large differences with Tb1column. Using Tbspot1 may therefore induce slightly overestimated differences.

Case study (24 September 2007)


IASI channel 2919 brightness temperature (K) simulated for the maximum scan angle with Tb1column for 21 UTC, 24 Sept. 2007

IASI channel 2919 brightness temperature (K) simulated for the maximum scan angle with Tbspot1 for 21 UTC, 24 Sept.


AROME analysis of relative humidity at 7000 m for 21 UTC, 24 Sept.

With Tbspot1, the fine-scale structures in the AROME humidity field are filtered which is not the case with Tb1column.

Tbspot1 provides thus brightness temperature fields at a scale which is more comparable with IASI and AIRS instruments.

Using Tb1column can lead to large differences when observations and first guess are compared in the assimilation, resulting in the rejection of the observations or in too large analysis increments.

Conclusions and outlooks

Aggregating the model information within the satellite spot as it is done in Tbspot1 and Tbspot2 leads to significant differences for water vapor channels only (above 7 µm for IASI).
Tbspot1 and Tbspot2 provide brightness temperature field at a scale which is more comparable with IASI and AIRS instruments.
Averaging before applying the radiative transfer (Tbspot1) or after (Tbspot2) leads in most cases in no significant differences.
Future work will focus on the comparison of the brightness temperatures simulated by the several observation operators with the IASI and AIRS observations and on their possible implementation in the 3D-Var AROME assimilation scheme.

References

Chalon G., F. Cayla, D. Diebel, 2001: IASI: an advande Sounder for Operational Meteorology, in 52nd Congress of IAF (1-5 Oct. 2001, Toulouse France), *proceedings*.
Ducrocq, V., D. Ricard, J.-P. Lafore. and F. Orain, 2002: Storm-scale numerical rainfall prediction for five precipitating events over France: on the importance of the initial humidity field, *Wea. Forecasting*, **17**, 1236-1256
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This work has been sponsored by the CYPRIM project (Cyclogeneses and Precipitation Impacting the Mediterranean) of the program ACI-FNS "Aléas et Changements Globaux" of the French research ministry.

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International TOVS Study Conference, 16th, ITSC-16, Angra dos Reis, Brazil, 7-13 May 2008. Madison, WI, University of Wisconsin-Madison, Space Science and Engineering Center, Cooperative Institute for Meteorological Satellite Studies, 2008.