Assessing the impact of pre-GPM microwave precipitation observations in the Goddard WRF ensemble data assimilation system

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Introduction

The assimilation of satellite precipitation data in global NWP systems has been shown to improve weather and hydrological forecasts as well as climate analyses (Marécal and Mahfouf, 2002 ; Hou et al., 2004 ; Mahfouf et al., 2005 ; Hou and Zhang, 2007 ; Bauer et al., 2010 ; Geer et al., 2010). However, special challenges remain in the assimilation of space-borne observations of cloud and precipitation (Errico et al., 2007 ; Bauer et al., 2011). In recent years, there have been considerable advances in the development of ensemble data assimilation techniques. Ensemble approaches estimate the flow-dependent background error covariance based on an ensemble of forecasts, and use an ensemble of nonlinear forward model simulations to link model space and observed space. Taking advantage of these properties of ensemble assimilation framework, the Goddard Weather Research Forecast (WRF) Ensemble Data Assimilation System (**Goddard WRF-EDAS**) has been developed to assimilate precipitation-affected MW radiances from satellite instruments (Zupanski et al., 2011b). This system uses the **WRF model** with **NASA microphysics** (Tao, 2003), the **Goddard Satellite Data Simulator Unit** (G-SDSU) (Matsui et al., 2009) for the observation operator of cloud/precipitation-sensitive radiance, and a **maximum likelihood ensemble filter** (Zupanski, 2005 ; Zupanski et al., 2008).

Single observation experiments

The sensitivity of analysis to the background error covariance and the observation error covariance can be tested through single observation experiments. Considering the flow-dependency of the background error covariance, two single observation locations are selected within different precipitation systems : for the white colored cross, **analysis is expected to reduce precipitation**, for the black colored cross, **analysis is expected to increase precipitation**.

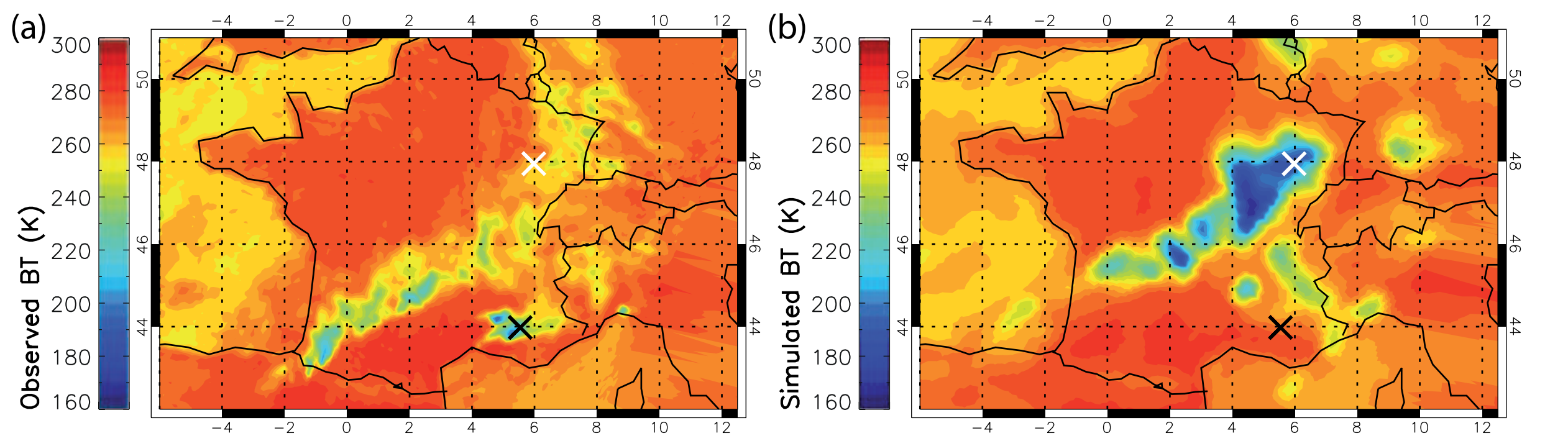

Fig.1 : Observed (left figure) and simulated brightness temperature of SSMIS at 91VGHz.

Studied configurations are : **(i)** use SSMIS 91V with observation error standard deviation of 25 K, ensemble size of 32 members in estimation of background error covariance ; **(ii)** same as (i), but with ensemble size of 64 members ; **(iii)** same as (i), but with observation error standard deviation of 5K ; **(iv)** use SSMIS 183+/-7 GHz with observation error standard deviation of 25 K, ensemble size of 32 members

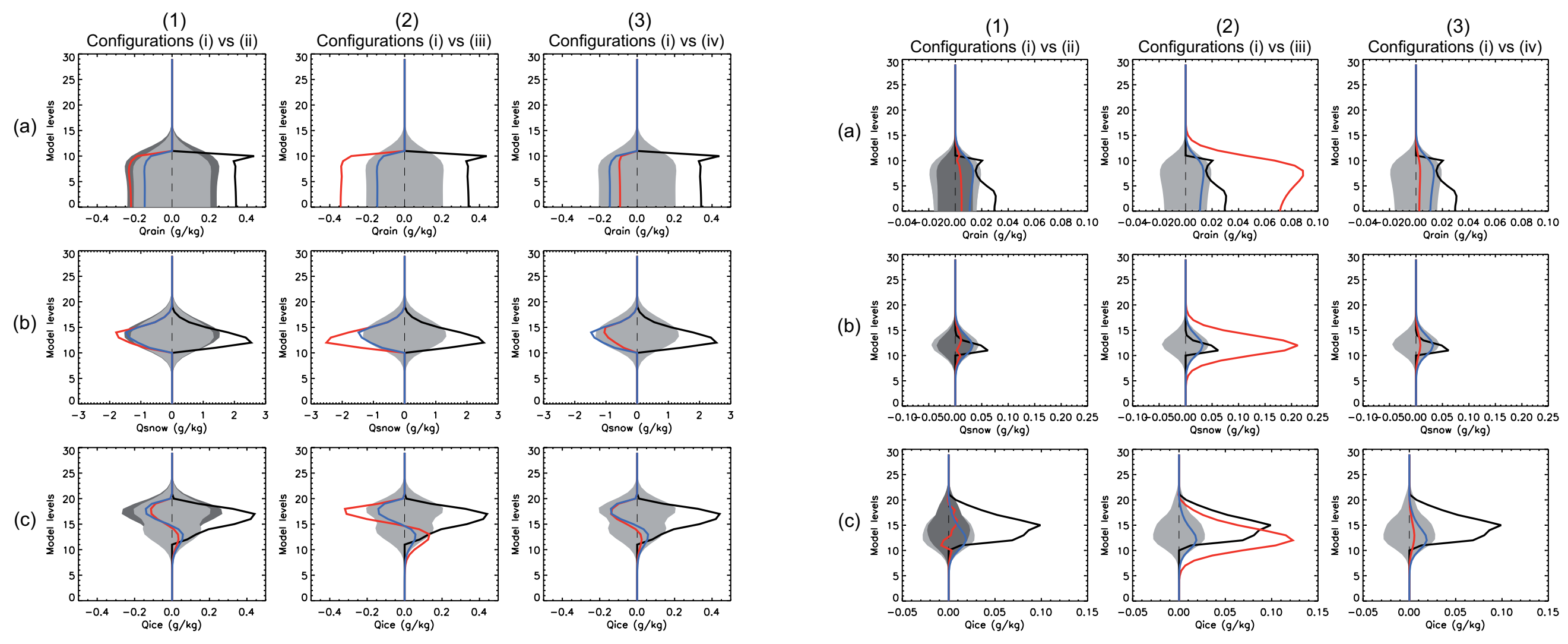

Figure 2 : White cross single obs (left) sensitivity studies, Black cross single obs (right) sensitivity studies

These results illustrate the **capability of the Goddard WRF-EDAS when the model forecast produces excessive precipitation**. The discrepancy between the simulated and observed brightness temperatures is effectively reduced and corresponding **corrections to microphysical variables are applied** through analysis. Doubling the ensemble size has a considerable impact on the background error covariance and the assimilation solution. For the case where the model fails to forecast the precipitation process that is observed by the single observation of SSMIS radiance. There are very few precipitating hydrometeors in the background, in particular frozen precipitation. The **small ensemble spread indicates that the observed convective precipitation is not represented in the ensemble**. There is little sensitivity in the precipitation observation operator.

Bias in MW rainy and cloudy departures

A non-zero mean of FG departures of precipitation-affected radiances represents the **combined bias** from any of the following errors error sources :

- **Instrument calibration**, scan geometry, orbital drift (e.g. Bell et al., 2008)
- **Inaccuracies in RTM** with assumptions and approximations on hydrometeor properties (e.g. Petty and Huang, 2010)
- Uncertainty in **land surface emissivity** and skin temperature (e.g. English, 2008)
- **Misplaced** rain locations, **excess/shortage** of clouds and precipitation (e.g. Bauer et al., 2010 ; Lang et al., 2011 ; Geer and Bauer, 2011)

FG departures of SSMIS are collected from various meteorological conditions that occurred in Western Europe during the 2010 and 2011 September-to-December periods. Figure 3a shows the FG departure bias at 150 GHz binned as a function of SIL (Scattering Index over Land ; Grody, 1991 ; Wilheit et al. 2003) for observations (SIL_{OBS}) and FG (SIL_{FG}). To avoid the asymmetric sampling problem, we use an **averaged Scattering Index as the predictor** for an empirical bias correction model (Figure 3e).
However this bias correction based on all FG departure sampling fails to reduce the bias effectively ; the bias in the area of similar SILAVG (along the diagonal) becomes larger as shown in Figure 3b.

Indeed, the bias correction encounters **two underlying asymmetries** in the FG departure distribution : the warm bias of FG brightness temperatures indicated by the consistent negative values along the diagonal and the excessive scattering occurrence frequency in FG as shown in Figure 3d.

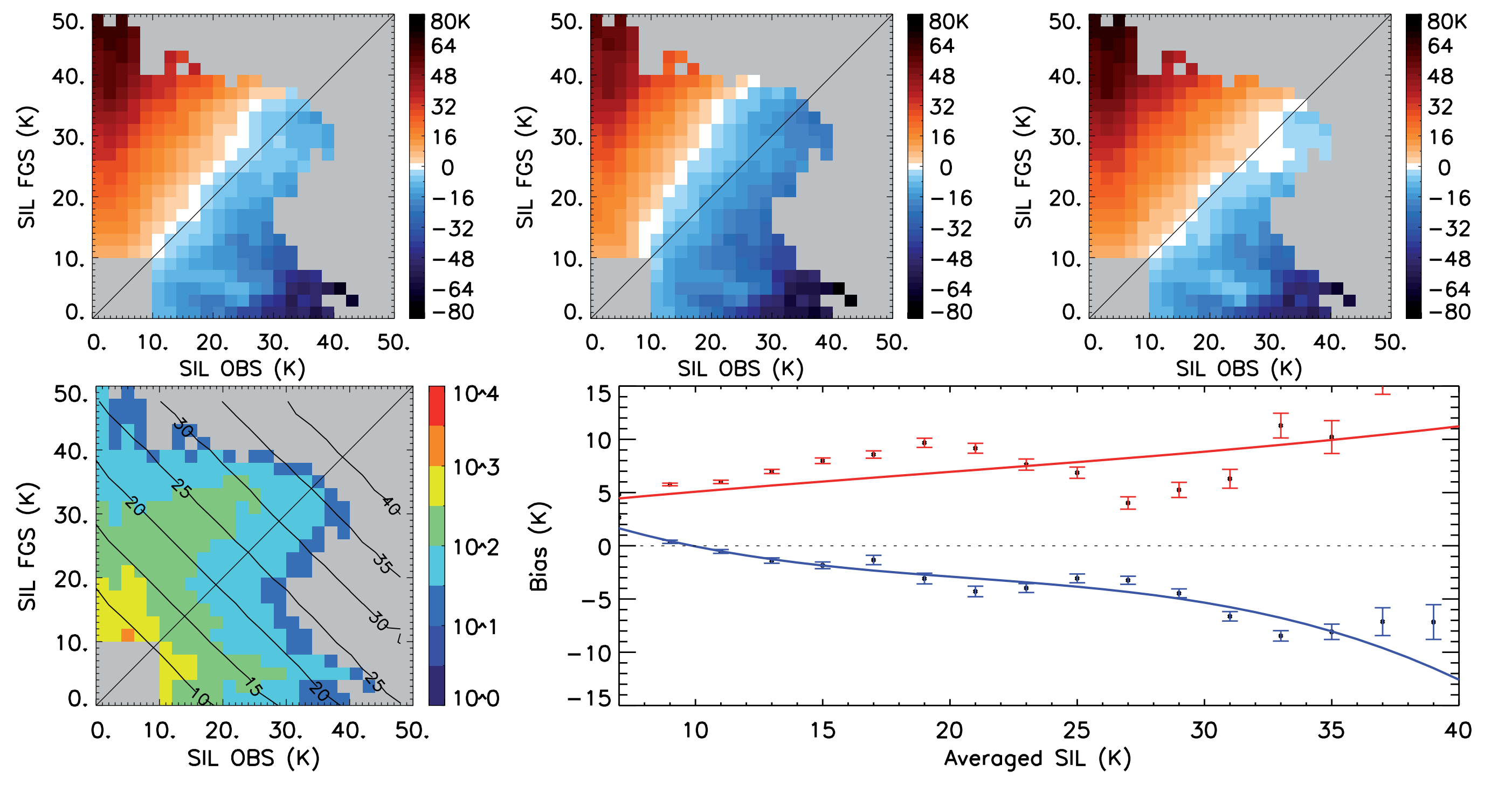

Fig.3 : Bias of FG departures of SSMIS at 150 GHz as function of Scattering Index of FG and OBS (a). Corrected bias with symmetric predictor and all samples taken into account (b). Corrected bias with symmetric predictor and samples under similar scattering conditions only (c). Number of samples (d). Bias correction of (b) (red curve). Bias correction of (c) (blue curve)

To avoid attributing systematic model errors in the background state to observations, we limit the samples for estimating bias correction polynomial coefficients to those along the 1 :1 line in Figure 3a. As shown in Figure 3c, the FG departure distribution after this bias correction **reduces the bias in higher scattering situations**, with overall bias along the diagonal reduced to 0.09 K from -1.6 K in the original distribution. Short-term assimilation experiments (with and without bias correction) indicate a positive impact on two-day accumulated rainfall forecast for this particular event (3.5% improvement of the RMSE and 1.3% of the bias with respect to surface radar data). Hence, the bias correction is applied to SSMIS radiances in the experiments below.

Case study

We configure three experiments, with the assimilation cycling period from 1200 UTC 6 September 2010 to 1200 UTC 8 September 2010 : (a) CNTL : the control experiment assimilating conventional observations, with ensemble size of 32 members and 3-hour assimilation cycles. (b) EXP32-3H : the MW experiment assimilating all data as in CNTL and precipitation-affected radiances from SSMIS, AMSRE and MHS. (c) EXP32-1H : same as (b), but with 1-hour assimilation window.

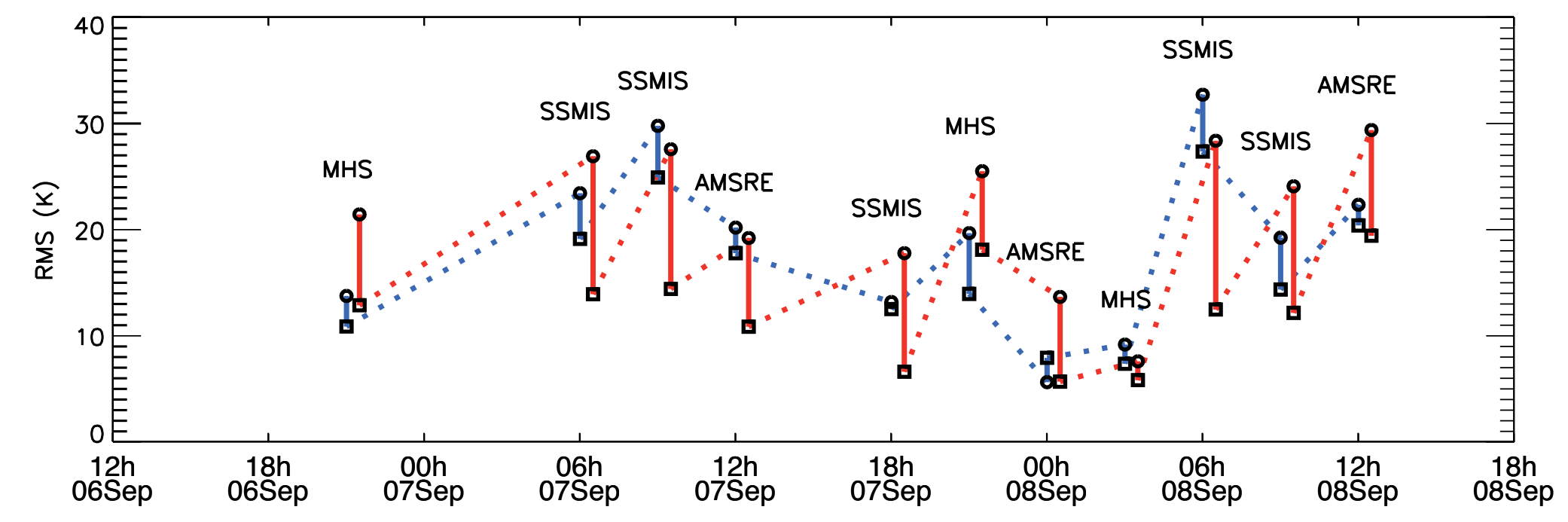

Fig.4 : Time series of RMSE of FG departures and RMSE of analysis departures of SSMIS MHS and AMSRE at 91V, 91GHz and 89V respectively (b). The red curve (respectively blue curve) corresponds to the reduction of RMSE for samples with positive departures (respectively negative departures). Circles show the RMSE of FG departures and squares show the RMSE of analysis departures.

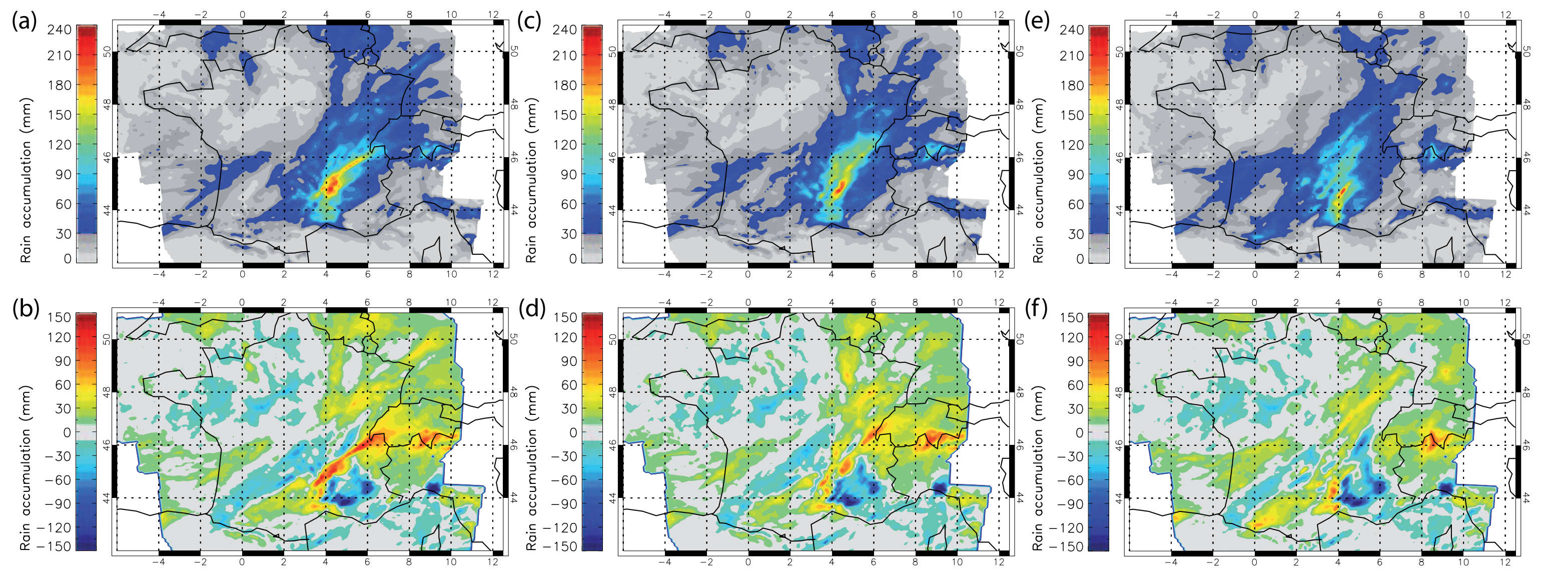

Fig.5 : Two-day rain accumulation of WRF model forecasts from four experiments (first row) and the corresponding difference maps between forecasts and radar surface rain estimates (second row), from 1200 UTC 6 September 2010 to 1200 UTC 8 September 2010 at 9 km resolution. 1st col. (a and b) : CNTL, 2nd col. (c and d) : EXP32-3H, and last column (e and f) : EXP32-1H.

Conclusions and Perspectives

Results show that the assimilation of MW precipitation observations from a satellite constellation mimicking GPM has a positive impact on the accumulated rain forecasts verified with surface radar rain estimates. The experiment with 1-h assimilation window increases the temporal data coverage as anticipated in the GPM constellation. Considering the fast evolution of storm structure and location, rapid-update assimilation allows the analysis to be more frequently constrained by observations and to a better forecast with smaller root mean square errors compared to that of 3-h analysis interval experiments.
The data impact studies also expose unresolved issues : for instance, in both single observation experiments and full data assimilation experiments, the ensemble-estimated background error standard deviations of hydrometeors are negligible in the convective storm region with non-precipitating background but precipitating observations. Future development will incorporate approaches that include hybrid variational-ensemble method for background error estimation (Zhang and Zhang, 2012) and ensemble estimation with displacement error correction (Anoashi and Eito, 2011).