OBSERVING SYSTEM EXPERIMENTS ON ATOVS ORBIT CONSTELLATIONS

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Abstract

Data from the ATOVS family contribute substantially to the correct assessment of the state of the atmosphere and, in turn, to the accuracy of numerical weather prediction forecasts. A large number of ATOVS instruments are currently assimilated into Numerical Weather Prediction (NWP) systems as seven polar-orbiting satellites are carrying at least some of these sensors. Future changes in the constellation of ATOVS (or equivalent) instruments might affect the skill of numerical weather prediction forecasts; therefore, studying the impact of different orbit constellations can provide valuable references for planning future observing systems which involve ATOVS-like sensors.

Here we report on observing system experiments which evaluate the benefit for NWP of having microwave sounding data both from three evenly-spaced orbits and from more than three satellites. Results show some benefit from having an evenly-spaced orbit constellation of AMSU-A sensors and a clear advantage from assimilating all available ATOVS data.

OBSERVING SYSTEM EXPERIMENTS

Clear-sky ATOVS observations from AMSU-A, ASMU-B/MHS and HIRS are assimilated directly as radiances in the ECMWF assimilation system, and have a significant impact on temperature, wind and humidity. In this paper we investigate the use of AMSU-A and AMSU-B/MHS from existing polar-orbiting satellites to evaluate the benefit for NWP of having microwave sounding data from three evenly-spaced orbits and from more than three satellites. At the time of this study, there were seven polar-orbiting satellites present in the ECMWF system carrying at least some of the ATOVS instruments: the NOAA series, NASA's Aqua satellite and the European MetOp-A satellite. Table 1 shows their orbit equatorial crossing times. We have run a set of experiments where AMSU-A and AMSU-B/MHS data from already-deployed instruments were added or denied as shown in Table 2. Only AMSU-A has been tested as an

Satellite	Local time of the ascending node
NOAA-15	16:50
NOAA-16	17:31
NOAA-17	21:34
NOAA-18	13:41
NOAA-19	13:58
Aqua	13:37
MetOp-A	9:30

Table 1: ATOVS satellite equatorial crossing times in April 2009

Experiment name	Satellite	MW sounders	
”no-MW sounder experiment”			
”two-satellite experiment”	NOAA-18	AMSU-A	MHS
	MetOp-A	AMSU-A	MHS
”NOAA-15 experiment”	NOAA-15	AMSU-A	
	NOAA-18	AMSU-A	MHS
	MetOp-A	AMSU-A	MHS
”NOAA-19 experiment”	NOAA-18	AMSU-A	MHS
	NOAA-19	AMSU-A	
	MetOp-A	AMSU-A	MHS
”all-satellite experiment”	NOAA-15	AMSU-A	
	NOAA-16	AMSU-A	(till 22June09)
	NOAA-17		AMSU-B
	NOAA-18	AMSU-A	MHS
	NOAA-19	AMSU-A	MHS
	Aqua	AMSU-A	
	MetOp-A	AMSU-A	MHS

Table 2: ATOVS MW sounders sensors available to the experiments

additional instrument in the “three-satellite experiments”, as there are not three satellites in the desired orbits carrying all functioning ATOVS instruments. AMSU-A has been shown to be the instrument with the largest forecast impact (Cardinali 2009).

In the “two-satellite experiment” AMSU-A and AMSU-B/MHS from just two satellites were assimilated in the system, namely MetOp-A and NOAA-18, respectively orbiting in the morning (a.m.) and afternoon (p.m.) orbit. The “NOAA-15 experiment” included AMSU-A data from an additional third satellite NOAA-15 in an orbit that is near-optimal to provide additional coverage to MetOp-A and NOAA-18. In contrast, the ”NOAA-19 experiment” considered as an additional third satellite NOAA-19 flying close to NOAA-18’s orbit. Figure 1 shows a sample coverage for used AMSU-A data in the “two-satellite experiment”, the “NOAA-15 experiment”, and the “NOAA-19 experiment”. The impact on global NWP of a third satellite additional to the a.m. and p.m. orbiting satellites is the central focus of these experiments. While the “NOAA-15 experiment” ensures a better sampling of the atmosphere compared to the “NOAA-19 experiment”, the constellation in the “NOAA-19 experiment” may provide a better coverage of short-term dynamic events. In order to see a greater impact of the ATOVS data on the system, we have run the same set of experiments also in the case in which the advanced sounder instruments IASI and AIRS are denied.

Experiments were run from 14 April 2009 to 4 August 2009. The dates were chosen taking into account both new satellite launches and instrument failures involving ATOVS instruments. The experimental system was identical to the operational system except for the thinning. Half thinning of AMSU-A data has been applied compared to the operational system, following recent experiments that show forecast improvements from using AMSU-A more densely (Bormann 2010). Furthermore for a fair comparison between the two “three-satellite experiments”, channel 6, 11 and 14 of AMSU-A on NOAA-19 were not assimilated in the “NOAA-19 experiment” as these channels are malfunctioning in AMSU-A on the NOAA-15 satellite.

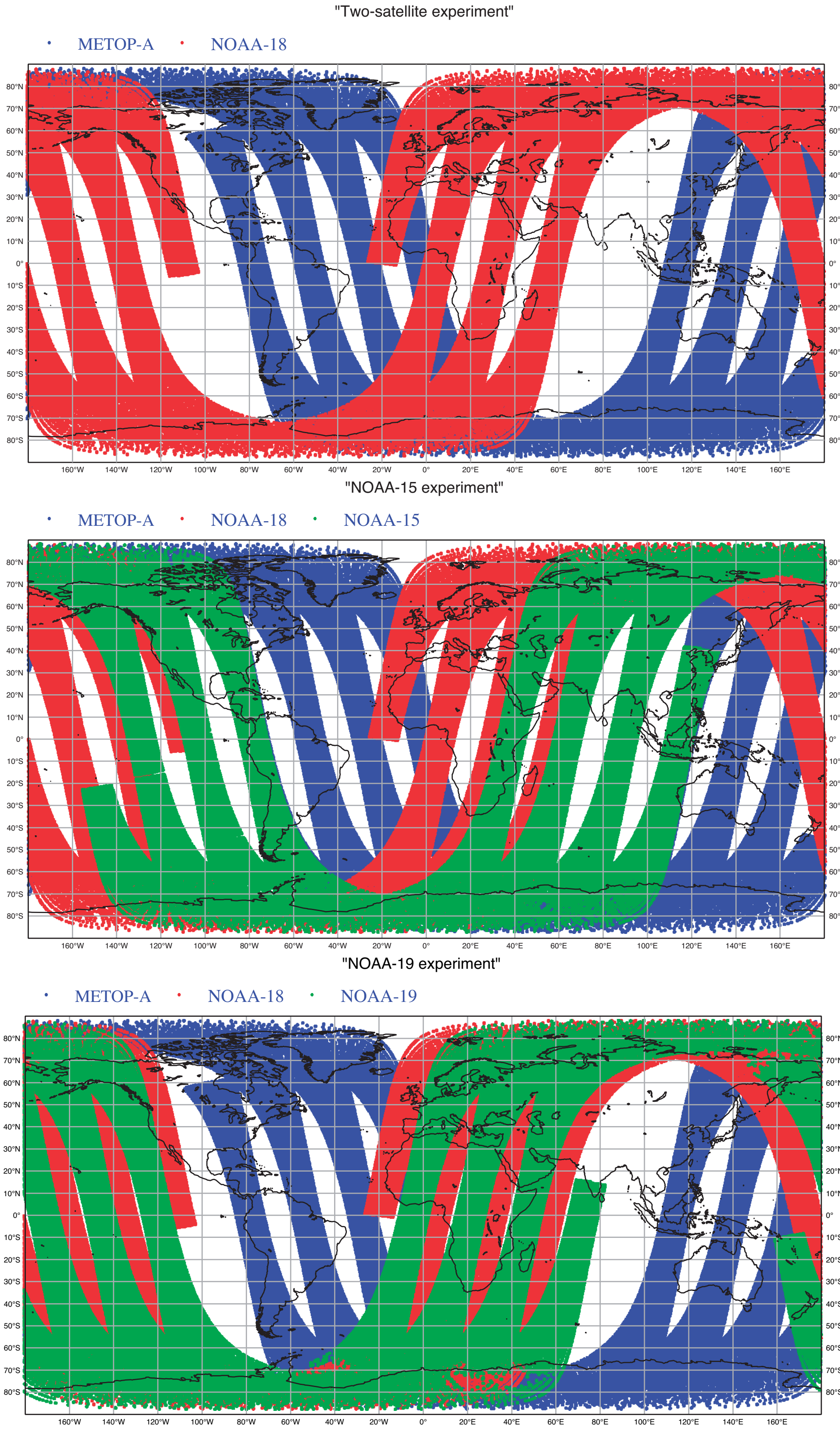

Figure 1: Sample coverage from the 6-hour period around 15 April 2009 0Z for the "two-satellite experiment" (top), the "NOAA-15 experiment" (middle), and the "NOAA-19 experiment" (bottom).

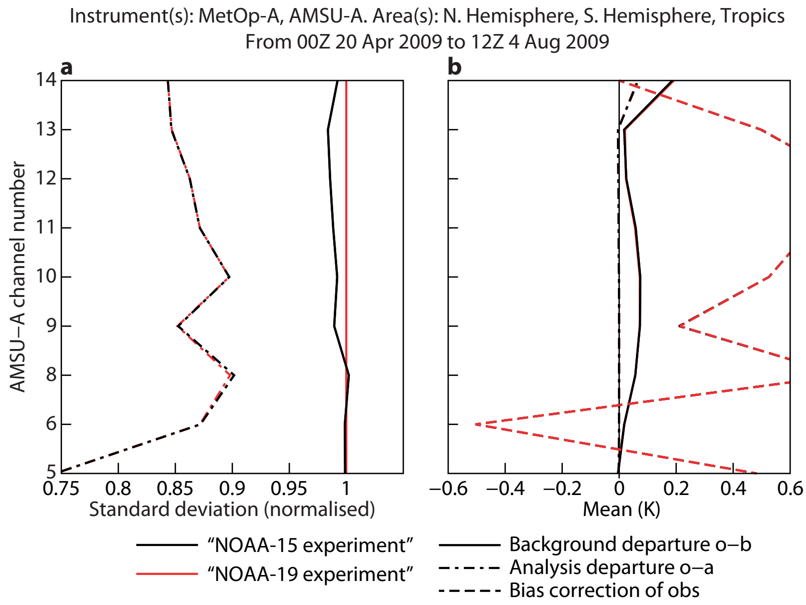

Figure 2: MetOp-A brightness temperature departure statistics for the "NOAA-15 experiment" (black) and the "NOAA-19 experiment" (red). Standard deviations have been normalised to the "NOAA-19 experiment".

RESULTS

Departure statistics of the first guess and analysis

A first way to assess the experiments is to measure the impact of the AMSU-A and AMSU-B/MHS data on the quality of the analysis and of the first guess (a short range forecast). This is done by studying the fit to conventional observations like radiosonde and aircraft temperature and humidity measurements. Departure statistics (mean and standard deviation of the differences between observations and NWP first guess) are computed over the period 20 April 2009 to 4 August 2009. Both background (first guess) departure statistics and analysis departure statistics are calculated after the bias correction of satellite radiances.

When comparing the "NOAA-15 experiment" and the "NOAA-19 experiment", there are no relevant differences in the departure statistics of the radiosonde temperatures in favour of one experiment or the other, and the differences are marginal also for the aircraft temperatures and for radiosonde humidity observations. Both NOAA-15 and NOAA-19 bring some small improvement to the fit to temperature observations, as well as to the fit to AMSU-A data already present in the system (onboard of NOAA-18 and MetOp-A) compared to the assimilation of data from just two satellites. The latter improvement is slightly greater in the "NOAA-15 experiment" than in the "NOAA-19 experiment" (see Figure 2).

As expected, departure statistics for the "two-satellite experiment" versus the "no-MW sounder experiment" show an improved first-guess of temperature and humidity observations. Note in Figure 3 also how wind information can be gained through the assimilation of ATOVS MW sounders data in the variational data assimilation framework 4DVar.

The above considerations on the departure statistics are valid in both cases when the advanced sounder instruments are denied and added.

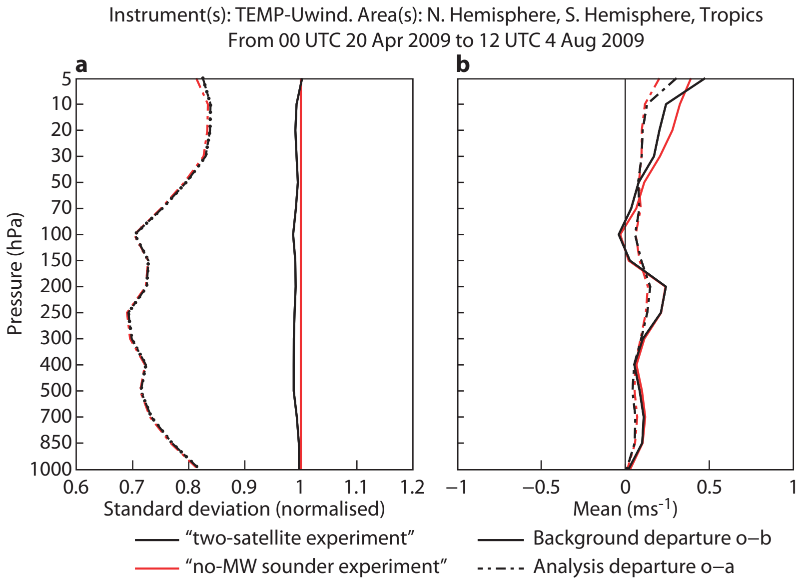

Figure 3: Radiosonde wind departure statistics for the "two-satellite experiment" (black) and the "no-MW sounder experiment" (red). Standard deviations have been normalised to the "no-MW sounder experiment".

Forecast impact

The experiments' impact on the forecast is studied for different variables, regions and forecast ranges. Forecast results are computed for 107 days of assimilation experiments over the period 20 April 2009 to 4 August 2009. When averaged over the extra-Tropics the impact for the forecast of the geopotential of the "NOAA-15 experiment" versus the "NOAA-19 experiment" is neutral to slightly positive. For the forecast of the temperature it is also quite neutral, with a positive impact in the Southern Hemisphere that appears statistically significant at the 95% level about the 5 day forecast at 1000 hPa and 850 hPa (see Figure 4).

Both the assimilations of NOAA-15 and NOAA-19 data have a clearly positive forecast impact in the Southern Hemisphere compared to the use of two satellites only, and the presence in the system of all satellites has, as expected, an even more positive impact especially in the Southern Hemisphere (see Figure 5 for the forecast of the geopotential in the "two-satellite experiment", "NOAA-15 experiment" and the "all-satellite experiment", with an improvement statistically significant at the 95% level in the Southern Hemisphere). This provides a reassuring confirmation of the benefit of having ATOVS data from seven satellites assimilated at the moment in the ECMWF system. It also suggests that the benefit of ATOVS-like data is not saturated yet with a three-satellite configuration.

The above results refer to the case in which the advanced sounder instruments IASI and AIRS are added into the system. When IASI and AIRS are denied, the results show in general a stronger positive impact when additional ATOVS data are assimilated into the NWP system.

CONCLUSIONS

In conclusion, when comparing microwave sounder data from two different sets of three satellites, the constellation of more evenly-spaced orbits (MetOp-A, NOAA-18 and NOAA-15) performs better than the constellation with a less optimal coverage (MetOp-A, NOAA-18 and NOAA-19): it results in a better fit to radiance observations and a slightly larger positive forecast impact in the Southern Hemisphere. The assimilation of data from an additional third AMSU-A (in both the above constellations) has a clear

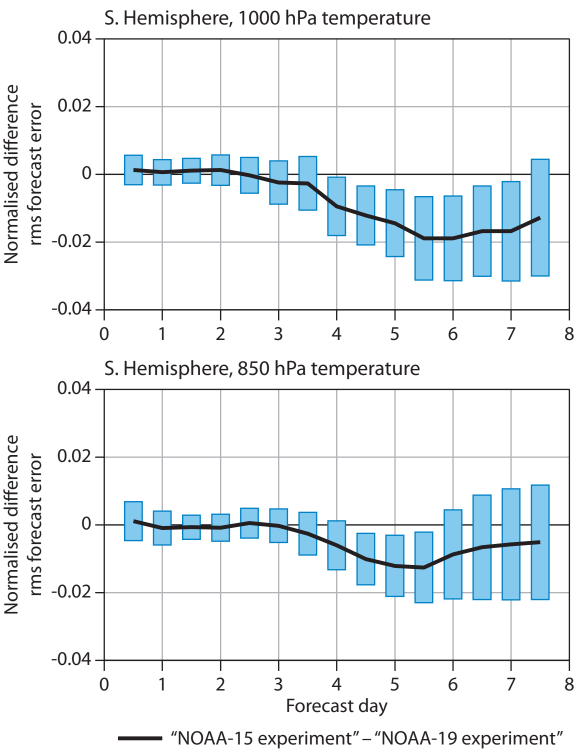

Figure 4: Normalised differences in the root mean squared forecast error between the "NOAA-15 experiment" and the "NOAA-19 experiment" for the 0Z forecast of the 1000 hPa and 850 hPa temperature for the Southern Hemisphere (extra Tropics). Verification is against the operational analysis. Negative values indicate that the "NOAA-15 experiment" has smaller RMS errors than the "NOAA-19 experiment".

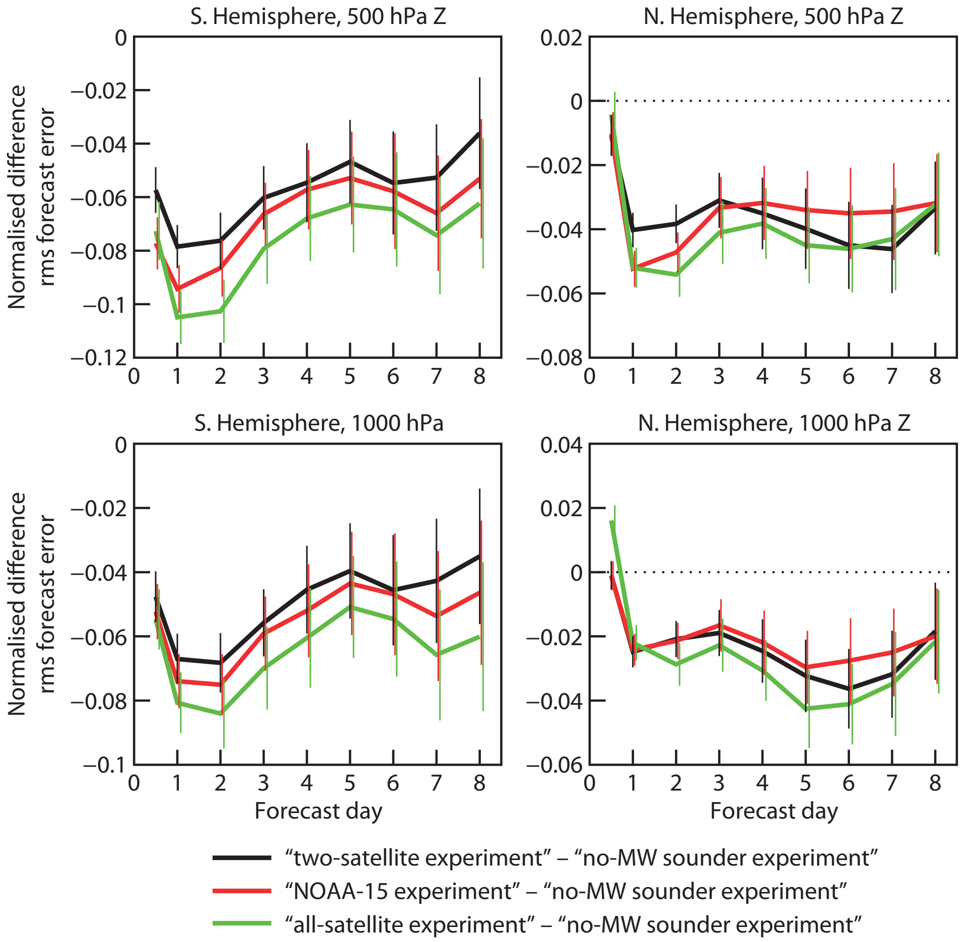

Figure 5: Normalised differences in the root mean squared forecast error between the "two-satellite experiment" and the "no-MWsounder experiment" (black), between the "NOAA-15 experiment" and the "no-MWsounder experiment" (red), and between the "all-satellite experiment" and the "no-MWsounder experiment" (green) for the 0Z forecast of 500 hPa and 1000 hPa geopotential for the Southern and Northern Hemisphere (extra Tropics). Verification is against the experiment own-analysis. Negative values indicate that the "two-satellite experiment", "NOAA-15 experiment", and "all-satellite experiment" have smaller RMS errors than the "no-MWsounder experiment".

benefit in the Southern Hemisphere when compared to the assimilation of only two AMSU-A, flying in the morning and afternoon orbits. Experiments show however that the benefit of microwave sounder data is not saturated yet with a three-satellite configuration: the configuration of six AMSU-A and four AMSU-B/MHS instruments outperforms the other constellations where less sensors are being assimilated.

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