The satellite winds in the operational NWP system at Météo-France

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Abstract

A major upgrade of the global model ARPEGE of Météo-France took place in April 2015, with a resolution increase, additional observations and the use of a larger ensemble assimilation. In this new frame, the replacement of MTSAT-2 by the new Japanese satellite Himawari 8, of third generation, with the 16 channels imager AHI, was prepared. This new AMV product broadcast by JMA allows to increase the number of assimilated AMVs, with a better agreement with the model background. An assimilation experiment of this data showed a neutral impact on the forecast scores with respect to the use of MTSAT-2 AMVs only, and a clear improvement in the southern hemisphere when no Japanese AMV is used in the reference. Side scatterometry, the activity has focused on the assimilation of the oceanic surface winds from the instrument RapidSCAT, installed by NASA on the ISS in September 2014, after the loss of OSCAT some months before. The evaluation of data provided by the KNMI in the frame of the EUMETSAT OSI-SAF showed statistics of departure against the model background similar to statistics with the other instruments as ASCAT. The assimilation of this data, in an optimized configuration, improves the global forecast scores and the tracking of the tropical cyclones, allowing to mitigate the shut-down of OSCAT. These different studies led to the use of these new datasets in the operational assimilation during an NWP configuration update done in December 2015.

1. INTRODUCTION

The operational numerical weather prediction (NWP) system of Météo-France uses different models, whose the characteristics depend on their application. Each growth in computing power, as recently at Météo-France, is an opportunity to improve this system, by downscaling, by more complex or wider calculations for a better representation of the atmosphere or still by using more observations and better. A first paragraph will give details about the last upgrades done in the global configuration, in which the assimilation of observations is usually tested, at least those with a global coverage as the satellite winds, and in particular the major update on the April, 15th 2015. In the frame of this improved configuration, a new dataset of Atmospheric Motion Vectors (AMVs) from the satellite Himawari 8 is studied. Himawari 8 is the new satellite of last generation launched by the Japanese Meteorological Agency (JMA); at the end 2015, and with on board the 16 channels imager Advanced Himawari Imager (AHI). The departure to the global model background is evaluated and different experiments are led for measuring the impact of this data in assimilation. The results will be shown in the second part of this paper. Last, a similar work was done but this time on the oceanic surface winds from the instrument RapidSCAT installed by the National Aeronautics and Space Administration (NASA), in autumn 2014, on the International Space Station (ISS). The studied wind dataset is provided by the KNMI (Koninklijk Nederlands Meteorologisch Instituut) in the frame of its activity for the EUMETSAT Satellite Application Facility Ocean Sea Ice (OSI-SAF) from the L1B product (backscatter measurements) broadcast by the Joint Propulsion Laboratory (JPL) of NASA. The evaluation and assimilation experiments results will be shown in the third and last part of this article, before to conclude.

2. THE NWP CONFIGURATION

Météo-France uses an operational numerical weather prediction system with different models for different applications. The model ARPEGE is used for the global forecasts. PEARP is its ensemble version with 35 members. ARPEGE is a spectral model with a vertical hybrid coordinate. The predictions are done until 114 hours ahead on a stretched grid with a maximum of resolution over the western

Europe, and a lower resolution towards the Antipodes, in the south-west Pacific. Its assimilation uses a 4D-Var algorithm and runs every 6 hours (with a 6 hours assimilation window centred on an analysis time at each synoptic hours) and is coupled to an ensemble assimilation AEARP. This ensemble assimilation provides an updated B-matrix of variances covariances of background error which characterizes the confidence to give to the model background in the assimilation process and so in function of the current meteorological situation. Over France, a limited-area model AROME run with a resolution which allows to resolve explicitly the convection in a none-hydrostatic way and with a lateral boundary conditions (LBC) coupling with ARPEGE. AROME has also its own assimilation algorithm (3D-Var) with the use of specific data dedicate to the high resolution as ground radar data. For the French overseas territories (4 domains), a limited-area version of ARPEGE is used, so called ALADIN overseas, with an higher resolution than ARPEGE and with a coupling for its LBC either with ARPEGE (La Réunion configuration) or the ECMWF's model, for the other domains and also with a 3D-Var assimilation process. As the ARPEGE resolution increases, these ALADIN configurations will be replaced by AROME versions in 2016, with an higher resolution but in smaller domains and initially in dynamic adaptation only.

As a piece of the continuous development of this NWP configuration, the growth of the computing and archive resources is essential, typically every 3/4 years. The last contracted HPC solution, based on INTEL processors on scalar machines, by the firm BULL, has allowed to increase the power computing of a factor 24 in 2 steps since mid-2012, opening the way to a major update of the Météo-France NWP configuration in April 2015. We will focus on the changes regarding the global model ARPEGE, as this ones is the usual frame for testing the satellite wind datasets, even if similar changes are applied for the other configurations in limited-area. The increase of the computing resource is often the opportunity to increase the model resolution. Now, the truncation of ARPEGE is T1198C2.2, meaning a grid spacing between 7.5 km centred over France and 37 km towards the antipodes, with 105 levels between 10 meters and 0.1 hPa (around 65 km). The 6 hours window used for the 4DVar assimilation is now split in timeslots of 30 minutes, allowing to use more observations (every hour in the former configuration). The resolution of the analysis increment is also increased with a first internal loop at T149C1 (regular grid of 135 km), and a second at T399C1 (~50 km), and at each step 40 iterations for the minimization. The coupled ensemble assimilation inherits of the vertical and timeslots downscaling from the deterministic run, with a coarser horizontal resolution T479C1, around 42 km on a regular grid. Now, there are 25 members, with the covariances averaged on one moving day and half (150 realisations), updated at each analysis time. The single inner loop is the same as the first inner loop of the deterministic run.

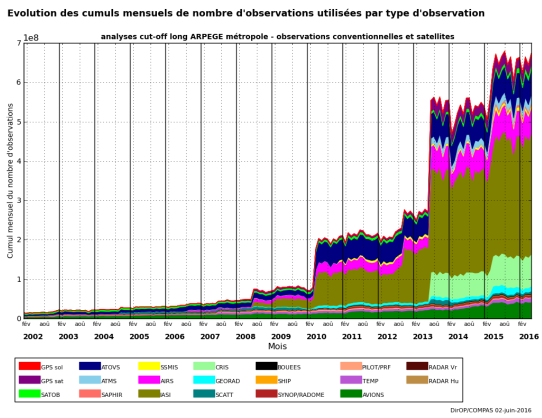

Figure 1: **evolution of monthly number of assimilated observations in the global model ARPEGE between February 2002 and April 2016. The contribution by observation type is given by the colour panel, bottom the Figure.**

In the same time, a significant amount of new observations were added in the assimilation, mainly from radiometer or sounder instruments, either by the adding of new channels of already used instruments (CRIS, IASI, GNSS) or the consideration of new datasets (CSRs from Meteosat 7 and still MTSAT-2, EARS ASCAT-B) or new instruments as SAPHIR on Megha-Tropiques (microwave), GNSS from Tandem-X, Grace-B. A second model update in December 2015 has allowed to introduce again additional channels from CRIS, the Himawari 8 AMVs and the RapidSCAT winds. Finally, these are 20% of further data, which was added in the assimilation system (Figure 1). Regarding our specific topic of satellite winds, the dual-MetOp AMVs and the NPP AMVs are also monitored, respectively since April and December operational model upgrades.

In the current configuration, the radiances dominate largely the distribution of observations number by type, representing around 85 % of assimilated data, whose 50 % from twice IASI (MetOp-A and MetOp-B) In this context, the satellite winds (AMVs and Scatterometers) represent only 3 % of total. Actually, regarding the AMVs, a large amount is available (around 1.3 millions by 6 hours assimilation window), but only around 4 % are used after quality control and thinning, or are only monitored (not still tested or validated for an operational assimilation). Nevertheless, this observation type has a significant role in the assimilation system (Figure 2, right), as even if the AMVs represent only 2.2 % of used data, their weight in the analysis, as computed by the Degrees of Freedom for Signal diagnostic (DFS, Chapnik et al, 2006), is at 7.2 % of total content in information from observations (whose 1.8 % coming from the addition of Himawari-8 AMVs in December 2015).

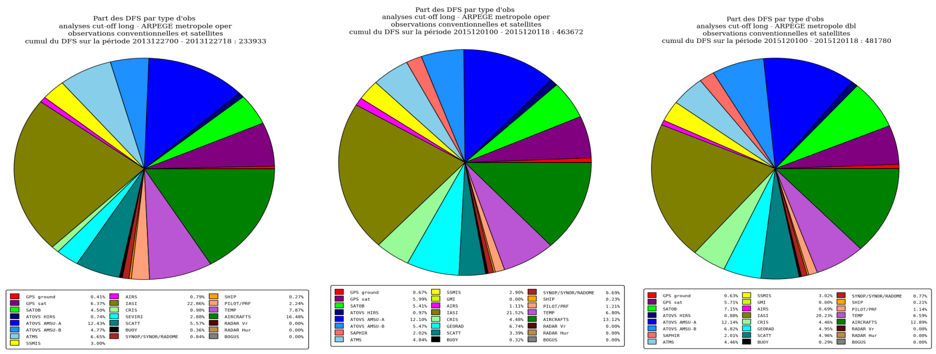

Figure 2: **distribution of Degrees of Freedom for Signal (DFS) by obstype in percentage of total DFS in the global model ARPEGE, at different time of its evolution (computed on 1 day). Left, December 2013 with ASCAT-A, ASCAT-B and OSCAT surface winds assimilated, December 2015 in middle with only ASCAT-A and ASCAT-B used (before the model upgrade on the 15th) and right, always December 2015 but in The observation type and their exact percentage in the DFS contribution are given by the colour panel table bottom the Figure (the same as Figure 3).**

Side scatterometer winds, the progrid orbit of the ISS aboard which the instrument RapidSCAT is installed may be a good complement of ASCAT A and B coverage, depending on its daily orbit, and the assimilation of this latter data allows to mitigate the loss of the Indian scatterometer OSCAT (aboard Oceansat2, ISRO) in February 2014, according the DFS evolution for this data type along these last years (Figure 2).

3. HIMAWARI 8 AMVS ASSIMILATION

Himawari 8 is the first satellite of a series so-called of third generation around the world, with on-board an imager AHI with 16 channels. This satellite was launched by the JMA on the October, 7th 2015 for replacing the operational geostationary meteorological satellite MTSAT-2, which covers the Far East and the western Pacific. The first AMV data began to be available in early May 2015 for the start of their assessment as part of the global model ARPEGE. As the replacement of MTSAT-2 by Himawari 8 was initially announced on July, 7th, a first assimilation experiment was quickly led, first based on the MTSAT-2 AMVs usage in a conservative way, and on a period of 2 months, between May, 14th and July 13th. In this experiment, MTSAT is discarded, simulating its replacement by Himawari 8, and the new Himawari 8 AMV product is assimilated. First, the AMV number from Himawari 8 with respect to the MTSAT-2 volume is consequent. Himawari 8 volume represents 5 times the MTSAT-2 volume. The Figure 3 shows the vertical profiles of the departures of the AMVs against the model background and the analysis, in mean and in root mean square (RMS), for each wind components (zonal/meridian), and by latitude bands (northern hemisphere (lat > 20°), tropics (abs(lat) < 20°), southern hemisphere (lat < -20°)). With respect to the operational statistics (including the MTSAT-2 AMVs), here as reference, the RMS statistics are generally improved. We may have also some differences on bias, but not always in the right direction. The addition of Himawari 8 allows also to improve the background fit to the drop winds above 500 hPa, but with a degradation below 700 hPa (not shown).

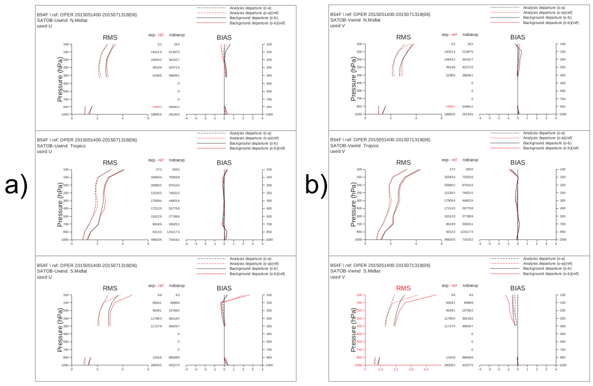

Figure 3: **global model ARPEGE fit to used AMVs with Himawari 8, without MTSAT-2 in the test (black), with MTSAT-2, without Himawari 8, in the reference (operational run, red), background (solid line), analysis (dashed), between the May 14th and the July 13th 2016. RMS and bias profiles by latitude bands, in m.s^{-1}. a) zonal component , b) meridian component.**

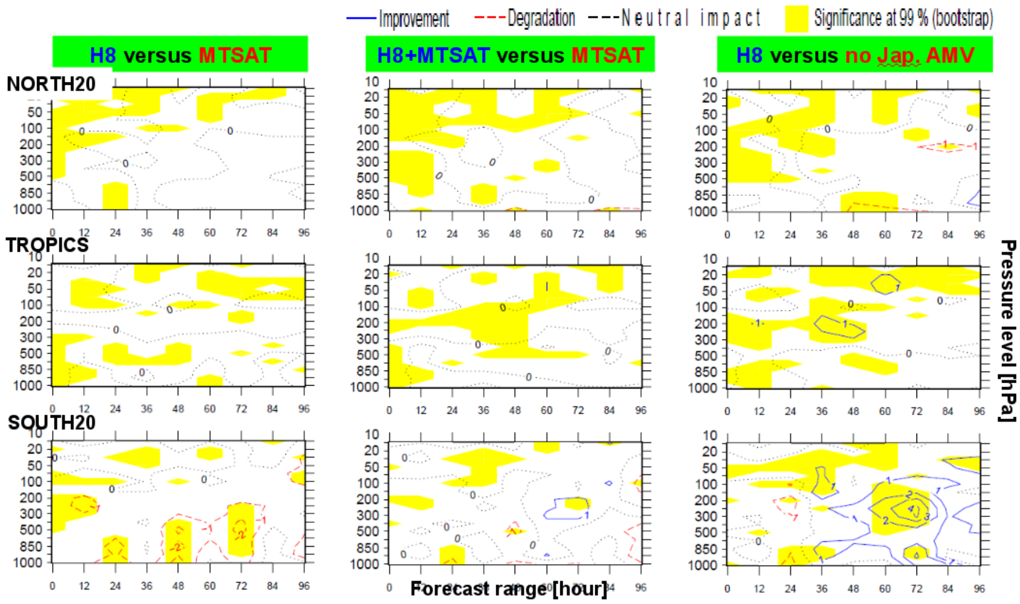

Figure 4: **normalized difference in RMS (in percent) of forecast scores on the geopotential against radiosondes, between different experiments, in function of the forecast range until 96 hours and the altitude in hPa, by different latitude bands, top area above the 20° north (NORTH20), middle between 20° north and 20° south (TROPICS) and bottom below the 20° south (SOUTH20). Left is the difference between the operational run (including the MTSAT-2 AMVs) and an experiment with Himawari 8 AMVs (MTSAT-2 discarded), middle is the difference between the operational run and a test with Himawari 8 and MTSAT-2 AMVs used together, and right is the difference between a test without MTSAT-2 and the first test with Himawari 8 only. A blue solid line (resp. red dashed line) means a reduction (resp. an increase) of the departures against the radiosondes for the second cited experiment (test) with respect to the first cited (reference) (forecast score improvement, resp. deterioration).**

In an experimental context, this is usual to look the scores of forecasts run done at 0 UTC (the major run in the operational context of Météo-France as these are the first forecasts available early in the local morning), and to compare them with respect to the forecast scores of the reference, and with a control considered as the truth (a radiosondes network of high quality, its own analysis or still an independent analysis), and whose the departure to forecasts of the test will define a forecast error. The Figure 4, left, shows the normalized RMS of scores difference on the geopotential forecast (in percent), between the experiment with Himawari 8 AMVs, MTSAT-2 discarded, and the reference, here the operational run with MTSAT-2, each score being computed here against the radiosondes as control, for the usual latitude bands, and in function of the vertical level and the forecast range in hour until 4 days, and on the test period (61 0 UTC forecasts). The solid blue line means an improvement of the forecast (forecast departure to radiosondes decreases) due to the use of Himawari 8 AMVs, the dotted line a neutral impact, and the dashed red line a negative impact (departure increasing). The yellow shading means a significant impact with a confidence at 99%, according a bootstrap test. This first experiment shows a neutral impact in the north hemisphere and in the tropics, but some light forecast score deterioration (until 2%) appear in the south hemisphere, and which is moreover significant. As the JMA announced the continuation of the MTSAT-2 AMVs dissemination in a double stream with Himawari 8 until March 2016, for allowing to users to test the new Himawari 8 product in a longer period, 2 additional tests were led. One test with AMVs from MTSAT-2 and Himawari 8 used together, leaving the QC process to thin the datum according their Quality Index, and simulating the announced period with the both streams, one other without Japanese AMVs (neither from MTSAT-2 and Himawari 8), simulating the case of the discontinuation of the MTSAT-2 AMVs product (planned in March 2016), and its none-replacement by Himawari 8 product (as an alternative virtual reference). The Figure 4, middle, shows the forecast score variation between MTSAT-2 and Himawari 8 considered together and the operational use (with only MTSAT-2 data). In this case, the impact on the forecast score is rather neutral between the both configurations, including the south hemisphere. The Figure 4, right, is the forecast impact of Himawari 8 against the absence of all AMVs information source over the eastern Asia and the western Pacific. Whereas, the impact on the forecast score is rather neutral in the north hemisphere, some positive signals may be seen in the tropics, but mostly in the southern hemisphere. Finally, this is the configuration with the use of AMVs from the both satellites which was finally selected for the pre-operational version of the NWP system which became operational in December 2015, in preparation to the transition from MTSAT-2 to Himawari 8.

4. RAPIDSCAT WINDS ASSIMILATION

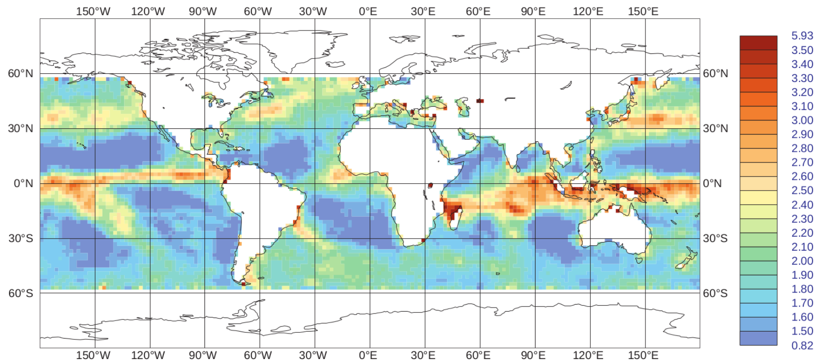

Figure 5: **RMS Vector Difference between the RapidSCAT winds, after quality control (active status), and the global model background ARPEGE at observation location, averaged by 2°x2° boxes, from January 6 and February 5 2016, in m.s^{-1}.**

RapidSCAT is a wind scatterometer built from ground spare engineering unit of the instrument Seawinds (Ku-band), which operated on board the satellite QuikSCAT from 1999 until its stop in 2009 due to a failure of the antenna motor. RapidSCAT has been installed on the ISS in September 2014 for a period at least 2 years, for among various objectives to mitigate the loss of the QuickSCAT instrument, followed by this one of OSCAT in 2014 (JPL, 2016). As for the ASCAT winds, this is usual to use the KNMI scatterometer wind product (L2B) provided in the frame of the EUMETSAT OSI-SAF. Through a close collaboration between the JPL and the KNMI, first wind data began to be available early December 2014, allowing its evaluation. In the frame of the NWP and in the objective to use this data in assimilation, we consider the 50 km resolution product, which is more or less the increment resolution in the global model, and also the effective resolution of ASCAT currently assimilated. The RMS vector difference between RapidSCAT winds and model background values, averaged on one month computed on the globe, show similar patterns to ASCAT differences, after the application of the QC, allowing mainly to remove the rain effect which affects the Ku-band. The highest differences are along the ITCZ and in the Gulf Stream and Kuroshio areas where the atmosphere is more dynamic. On average, the RapidSCAT RMSVD is close to 2.0 m.s^{-1}, 19° for the direction and 1.3m.s^{-1} for the speed in RMS (Figure 5).

Different tests of assimilation are done, between December 10 2014 and January 25 2015 (47 forecasts at 0 UTC). Based on the legacy of QuikSCAT and OSCAT winds assimilations (Payan, 2010, Payan et al, 2012), both in Ku-band, the specified errors are given by the model background departure (after QC including land, sea-ice contaminations, KNMI quality flags for the rain contamination), with a dependence on the cross track position of the observation, and an azimuth check rejects data mainly in the nadir of the swath, where the diversity in azimuth angle of the field of view is the lowest. Nevertheless, whereas for the former instruments, the contribution in the cost-function was weighted by a factor 0.27, aping a 100 km thinning for a 50 km resolution of observations, it is tested that an effective spatial 100 km thinning gives better forecasts in the case of RapidSCAT. A threshold of 25 $m.s^{-1}$, instead of 35 $m.s^{-1}$, for rejecting the too high wind speed is also finally chosen. In a such configuration, the scores against the radiosondes has rather a better significant forecast skill on the geopotential in the northern hemisphere and on the wind in the tropics when RapidSCAT is used, but rather a detrimental effect in the southern hemisphere (geopotential). But if the operational ECMWF analysis is considered as control instead of the network of qualified radiosondes, the impact becomes rather positive, mainly with a significant improvement of the geopotential field near the surface, except at the first forecast ranges (below 12 hours), as RapidSCAT is not used in the control at the time of this test (Figure 6). That suggests an under-sampling of scores controlled by radiosondes in this latitude band (rarer as generally limited to land surface) or a test period too short. An other observed impact in the assimilation of RapidSCAT winds is on the Tropical Cyclones trajectories forecast which is also improved (in mean and standard deviation), with 14 phenomena tracked over the period (not shown). A similar result was obtained with OSCAT (Payan et al, 2014). So thanks these results, the RapidSCAT winds are now assimilated in the operational NWP system since its last upgrade in December 2015.

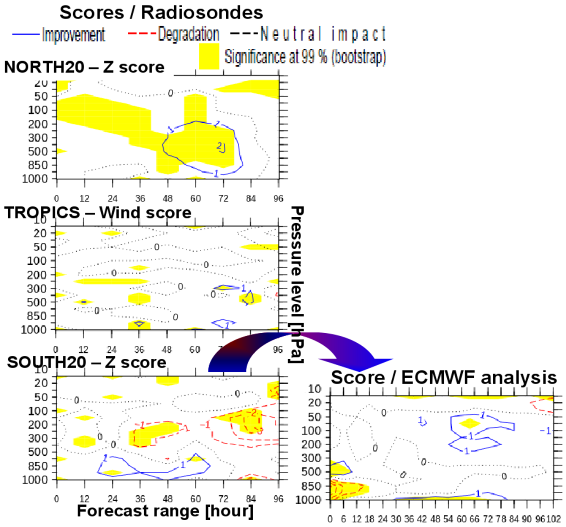

Figure 6: **normalized difference in RMS (in percent) of forecast scores against the radiosondes (similar to Figure 5). Left is the score on the geopotential for the extra-tropics domains (NORTH20 top, SOUTH20 bottom) and on the wind in the tropics (TROPICS middle). The thumbnail bottom right is also a score on the geopotential (SOUTH20) but with ECMWF analysis as control.**

But even if RapidSCAT has proven its capacity to be beneficial for the weather forecast, its life is not a long quiet way. The Figure 7 compares the daily statistics of scatterometer winds, ASCAT-A, ASCAT-B and RapidSCAT against the model background ARPEGE, after QC, and between the March 1st 2015 and the April 30th 2016. The ASCAT data availability and their statistics are very stable along the period. RapidSCAT has more variations due to ISS management (attitude, docking) or low SNR event which began in summer 2015. During the low SNR3 for third Signal Noise Ratio event (starting February 11 2016), with a strong low wind speed bias, it was decided to blacklist the instrument. After a processing adjustment side JPL, statistics are improved early March (bias correction) but the RMSVD remains a bit higher than before the SNR3 event, in the general case, and strongly higher in the right part of the swath (cross idx > 18). Before to introduce again RapidSCAT in the operational assimilation, the dataset is tested again with new observation error settings taking into account this new variation across the swath. The Figure 7 left shows the impact on 26 0 UTC forecasts in March 2016 on the geopotential score by latitude bands with radiosondes as control. The new specified RapidSCAT error settings have positive impact on the forecast scores in the northern hemisphere and in the tropics, but are rather negative in the southern hemisphere, also if the ECMWF model is considered as control. But this first test is done with a constant ensemble assimilation, from the operational run which no longer uses RapidSCAT, as also the operational 4DVar, here the reference (RapidSCAT blacklisted).

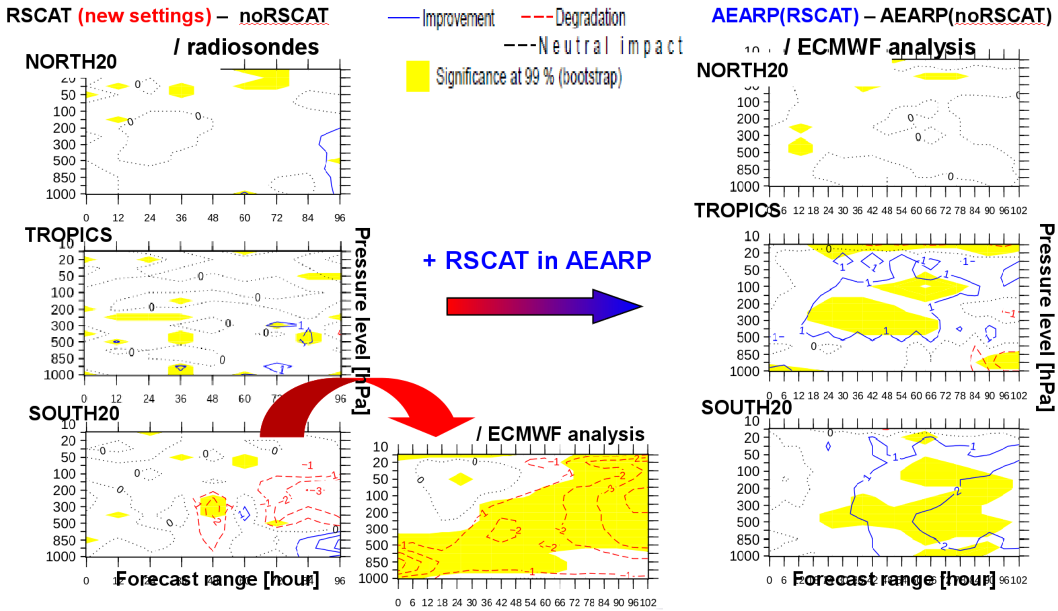

Figure 7: **normalized difference of forecast scores on the geopotential, 26 0 UTC forecasts between the March 4th and 29th 2016. Left is the difference between the operational run (RapidSCAT not used) minus RapidSCAT with new error settings, and with the B-matrix provided by the operational ensemble assimilation AEARP (also without RapidSCAT), and radiosondes as control. Middle bottom is the similar score for the southern hemisphere, but with ECMWF analysis as control. Right is a second test with its own ensemble assimilation using RapidSCAT with the same settings than the deterministic run, the reference being the first experiment with the operational AEARP, control ECMWF analysis.**

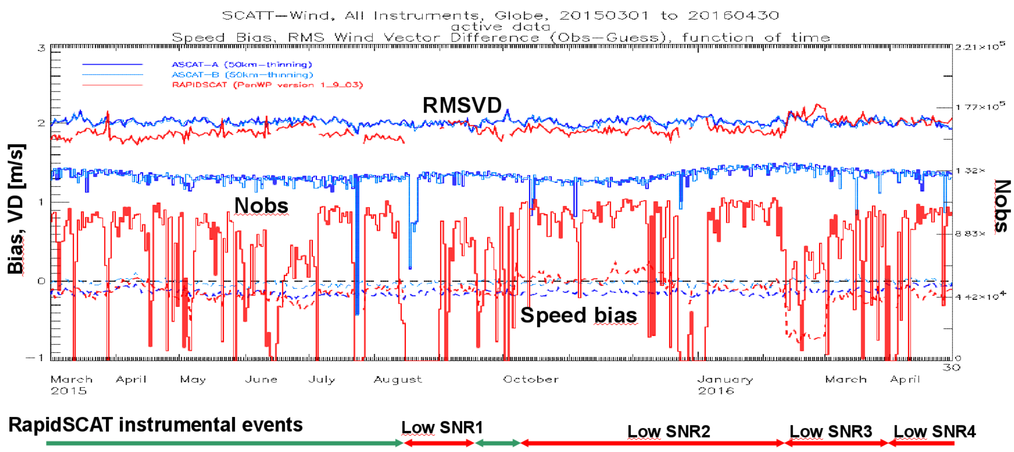

Figure 8: **daily statistics of observation minus model background of scatterometer winds used in assimilation in the global model ARPEGE from March 1st 2015 to April 30th 2016. Solid lines are for the RMSVD, dashed lines for the speed bias (m.s^{-1}), step lines are the number of observations. Blue colors are for ASCAT A and ASCAT B, red for RapidSCAT winds. Bottom is mentioned the different instrumental events of RapidSCAT on the period (mainly SNR loss).**

A second test coupled with its own ensemble assimilation using RapidSCAT with the same error settings as the first experiment allows after all to improve the RapidSCAT impact (Figure 7, right). The comparison with the operational forecasts shows an improvement in the southern hemisphere with RapidSCAT but rather a neutral impact in the northern hemisphere (with RapidSCAT used also in AEARP), suggesting a lower contribution of RapidSCAT in the forecast skill with respect to the first evaluation one year before (not shown). If this is usual to test changes with a constant ensemble assimilation, generally from the operational run, which is often also the reference context, it appears in this case that do not propagate the new RapidSCAT error settings in the ensemble assimilation may lead to opposite conclusions. Even if this seems logical to evaluate an assimilation system as a whole, this is not neutral in term of IT resources as reported in the Table 1, which lists the number of requested core units, the required time for running here the assimilation and forecast test on 24 days of simulation and the volume of produced data, for each test, the assimilation and forecast run only and the same run but coupled with its own ensemble assimilation.

HPC resources / Configuration	4DVAR alone	4DVAR + AEARP
Requested processor cores	243 960	1M374 (5.6)
Run time (real)	9 days	15 days (1.7)
Output volume	20 Tb	100 Tb (5.0)

Table 1: **IT resources required according the experimental configuration for a RapidSCAT test over 26 days, with a 4DVAR alone or with the same 4DVAR coupled with its own ensemble assimilation. The number in brackets in the last column is the ratio of the second configuration values with respect to the first.**

Nevertheless, following the feedback by KNMI towards JPL about the statistics variations across the swath, a final adjustment is done early April allowing a back to statistics similar to before the February 11th. Finally, RapidSCAT is reintroduced in assimilation on the April 25th with its unchanged settings.

5. CONCLUSION

The recent increase of computing power, and also the archive capacity not described here, allowed a major upgrade of the operational NWP system of Météo-France in April 2015, with vertical and horizontal downscaling, a B-matrix better defined by a larger and more precise ensemble assimilation and the use of a significant amount of new observations. In this context, the number of used satellite winds remains modest with respect to other observation systems, and specially radiances, but an objective measurement of their contribution in the assimilation, the DFS, indicates a weight in term of information content clearly superior to their relative number in the system. The Himawari 8 AMVs represents a large increase of available data with respect to MTSAT-2 product, and with a better agreement with the model. The replacement of MTSAT-2 by Himawari 8 leads to mixed results, and specially a negative impact in the southern hemisphere, which would need further investigation. Finally, in the context of a double stream (MTSAT-2 and Himawari 8) for several months, this is the assimilation of the both stream which gives the best forecast skill on the test period. The impact of Himawari 8 in absence of MTSAT-2 is also verified, aping the stop of MTSAT-2 AMVs product in March 2016, and gives positive impacts. Finally, the Himawari 8 AMVs are set in the operational assimilation during the NWP system update in December 2015. The new dataset of oceanic surface winds from the scatterometer RapidSCAT in Ku-band (SeaWinds model), on board ISS, provided at 50km of resolution by the EUMETSAT OSI-SAF (KNMI), from raw data broadcast by JPL, has a quality similar to ASCAT product, even slightly better at the first age. After different tests and settings, a positive impact of this data on the forecast skill, including the tropical cyclones tracking, is obtained and the RapidSCAT winds are added in the operational assimilation also during the December 2015 upgrade. But various instrument events since summer 2015 lead to revise the observation error settings in March 2016. At this occasion, the importance of such data in the ensemble assimilation is confirmed, as a test with its own coupled ensemble assimilation including the RapidSCAT winds is required for having a positive impact on the forecasts, which is not without consequences on the required IT resources for such testing.

REFERENCES

Chapnik, B., Desroziers, G., Rabier, F. and Talagrand, O. (2006), Diagnosis and tuning of observational error in a quasi-operational data assimilation setting. Q.J.R. Meteorol. Soc., 132: 543–565. doi: 10.1256/qj.04.102

JPL (2016), RapidSCAT mission
http://winds.jpl.nasa.gov/missions/RapidScat/#sci_ob accessed in October 2016

Payan, C, (2010), Improvements in the use of scatterometer winds in the operational NWP system at Météo-France. International Winds Workshop (IWW10) Proceedings, Tokyo (Japan), February 2010

Payan, C, Boullot, N., Mekies, D. (2014), Satellite winds activities at Météo-France. International Winds Workshop (IWW12) Proceedings, Copenhagen (Denmark), June 2014