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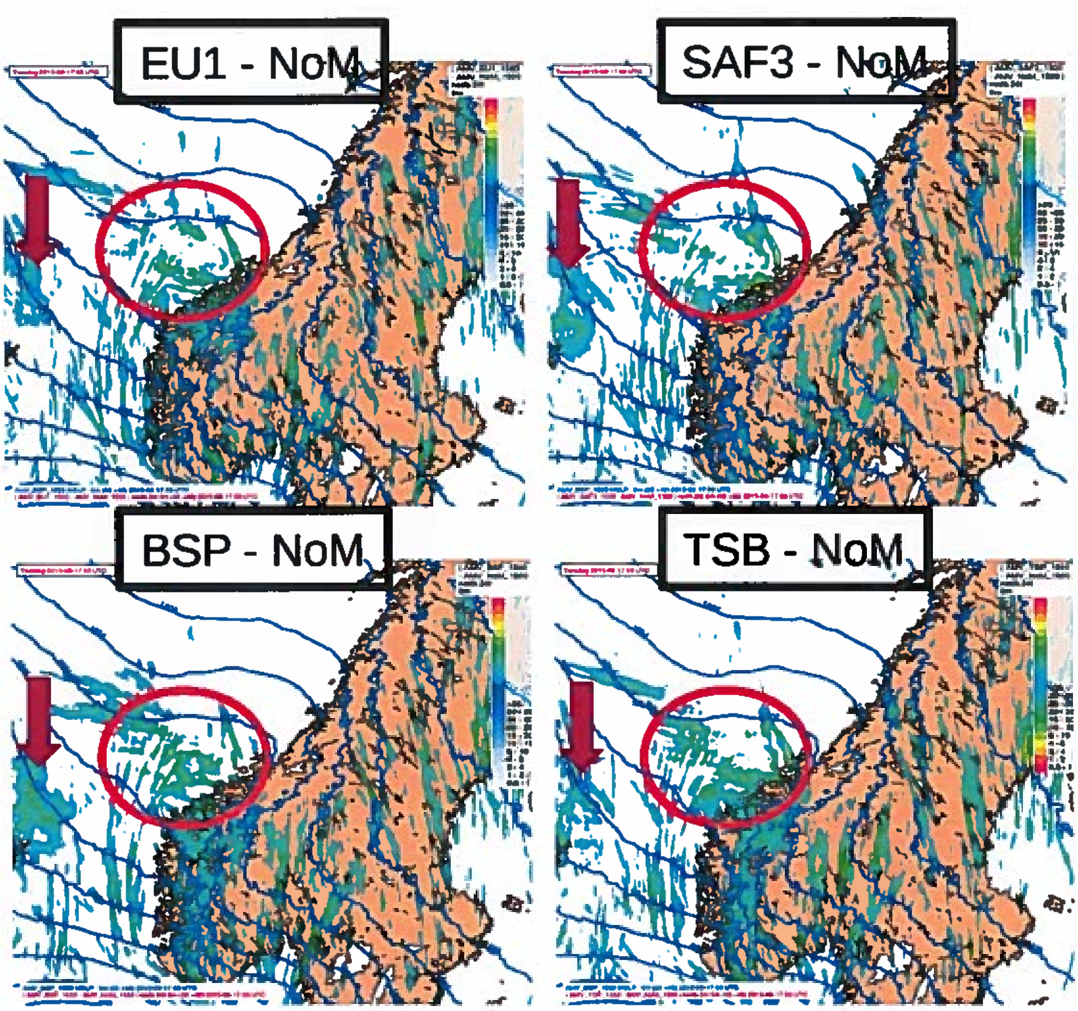

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Abstract

After the successful SAWIRA1 project, which investigated the access to AMV observations at MET Norway, SAWIRA2 assessed the impact of potential for operational use AMV data in our operational mesoscale NWP models: AROME-MetCoOp and AROME_Arctic.

The AROME-MetCoOp was used to check the impact of all selected AMV data, while the AROME-Arctic was used to check the impact of the polar winds. The impact of the AMV data was evaluated over two periods: September 2015 and July 2016. These periods were chosen randomly, and the final choice was driven by the availability of all three kinds of potential AMV. Adding the AMV data into the assimilation system influenced the assimilation of other observing networks, in particular surface wind and surface pressure respectively from surface and buoy measurements. To evaluate the sensitivity of the forecast model to the AMV data, moist total energy loss was computed from run with all observations against runs without the diagnosed (withdrawn from the assimilation) observations. As overall result the AMV data provide comparable sensitivity, with all other observing system assimilated in our system, to the AROME-MetCoOp forecast. Higher sensitivity was observed in case of non-stationary or intense weather phenomena. Moderate positive rather than neutral impact of the geostationary satellite-based AMV data was found on AROME-MetCoOp upper-air analyses and forecasts. But clear positive impact was found on the forecast of precipitation. While the impact of EUMETSAT produced AMV is observed over almost all the verified precipitation intensity thresholds, the impact of locally produced (HRW) is clear in case of intense precipitation. The impact of the polar winds on the analyses and forecasts of the AROME-Arctic, in verification against observations, is clearly positive for both surface and upper-air variables. Using the polar winds together with the HRW significantly improved the accuracy of the analyses and forecasts of the AROME-MetCoOp model for both surface and upper-air levels. Using all the three available wind data sets together did not provide further improvement. In opposite, it showed loss of accuracy in forecasts of precipitation, for example. This somehow indicates that we may had a redundancy problem with geostationary AMV data in the system. Through case study we discussed the verification results shown in this report and their correspondence to the evaluated cases. Similar to the impact of the geowinds on 3-hourly cycling, in rapid-refresh system moderate impact on forecasts of precipitation and cloudiness was observed. The HRW and polar winds were suggested for operational implementation in both mesoscale NWP models.

Keywords

Atmospheric motion vectors, observation impact, 3h RUC, rapid-refresh

Disiplinary signature   Responsible signature

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After the successful SAWIRA1 project, which investigated the access to AMV observations at MET Norway, SAWIRA2 assessed the impact of potential for operational use AMV data in our operational mesoscale NWP models: AROME-MetCoOp and AROME_Arctic. The AROME-MetCoOp was used to check the impact of all selected AMV data, while the AROME-Arctic was used to check the impact of the polar winds. The impact of the AMV data was evaluated over two periods: September 2015 and July 2016. These periods were chosen randomly, and the final choice was driven by the availability of all three kinds of potential AMV data.

Adding the AMV data into the assimilation system influenced the assimilation of observations from other observing networks, in particular surface wind and surface pressure respectively from surface and buoy measurements. To evaluate the sensitivity of the forecast model to the AMV data, moist total energy norm loss was computed from run with all observations against runs without the diagnosed (withdrawn from the assimilation) observations. As overall result the AMV data provide comparable sensitivity, to all other observing networks assimilated in our system, to the AROME-MetCoOp forecast. Higher sensitivity was observed in case of non-stationary or intense weather phenomena.

Moderate positive rather than neutral impact of the geostationary satellite-based AMV data was found on AROME-MetCoOp upper-air analyses and forecasts. But clear positive impact was found on the forecast of precipitation. While the impact of EUMETSAT produced AMV is observed over almost all the verified precipitation intensity thresholds, the impact of locally produced (HRW) is clear in case of intense precipitation.

The impact of the polar winds on the analyses and forecasts of the AROME-Arctic is clearly positive for both surface and upper-air variables. Using the polar winds together with the HRW significantly improved the accuracy of the analyses and forecasts of the AROME-MetCoOp model for both surface and upper-air levels. Using all the three available wind data sets together did not provide further improvement. In opposite, it showed loss of accuracy in forecasts of precipitation, for example. This somehow indicates that we may had a redundancy problem with geostationary AMV data in the system.

Through case study we discussed the verification results shown in this report and their correspondence to the evaluated cases.

Similar to the impact of the geowinds on 3-hourly cycling, in rapid-refresh system moderate impact on forecasts of precipitation and cloudiness was observed.

The HRW and polar winds were suggested for operational implementation in both our mesoscale NWP models.

The front cover figure: 24-hour accumulated precipitation difference between the run with and without AMV data. Respectively, from left to right, then top to bottom, difference with E-geowind, HRW, HRW plus polar winds, and all three AMV data together.

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1 Introduction

Weather prediction has a long history of obtaining benefits and steps forward in quality from the application of satellite observations. In Norway the Norwegian Space Centre has supported important novel developments in the initial development phase for using satellite data such as scatterometer, sounding data from ATOVS and more recently IASI infrared interferometric observations. This initial research and development has then been brought forward by MET Norway to become important parts of the operational forecasting service.

One of the gaps identified in many studies of the present atmospheric observing system is the limited amount of upper-air wind observations (see for instance recent simulation studies on the positive impact on forecasts of adding wind data to the present observing system by *Riishojgaard et al, 2012* and *Garand et al 2013*). The planned Aeolus mission (*Stoffelen et al, 2005*) is expected to demonstrate use of spaceborne LIDAR for the purpose of filling part of this gap, but there are presently no plans for any operational follow-on. The only other presently available satellite based wind observation dataset is the so-called Atmospheric Motion Vectors (AMVs), where the winds are indirectly derived from displacements in consecutive satellite images. However, these winds have earlier had problems of long latency, limited coverage, in particular at high latitudes, and quality problems, partly connected to height assignment. Applying these data for forecasting for Norwegian and Arctic areas has therefore not been so interesting up to now.

We have recently seen progress in international research which has lead to improved AMVs and new products from recent satellite programs. There are now products with better horizontal resolution and in addition novel AMV products from polar orbiting satellites which have increased the coverage at high latitudes dramatically. There has also been an evolution in the ground infrastructure and processing, giving a potential for faster delivery well suited for our purposes in regional weather prediction with rapid updating. There is reason to believe that there is a significant potential for benefit from assimilating these data in our regional numerical weather prediction (NWP) system for application both in rapid update cycling over a Nordic area and over an Arctic domain.

The First phase of the SAWIRA (Satellite Winds for Rapid-refresh weather prediction) project gave a framework to assess the availability of the AMV data at MET Norway and also offered the possibility of testing their use in our regional NWP models (AROME-MetCoOp[1] and AROME-Arctic) (*Randriamampianina et al., 2016*). The second phase opened the opportunity of studying the impact of both geostationary- and Polar satellite-based AMV data in our operational systems, as well as in our experimental nowcasting system based on a non-cycling rapid-refresh assimilation system.

While Section 2 describes the data and method applied in this study, Section 3 discusses the impact of the AMV data on analyses and forecasts supported by case study, and Section 4 summarises concluding remarks drawn from this study.

1Meteorological Cooperation for Operational NWP. The cooperation is between MET-Norway, the Swedish Meteorological and Hydrological Institute (SMHI) and Finish Meteorological Institute (FMI).

2 Data and method

2.1 The available AMV data

In this study we use the AMV data which are 1) retrieved from geostationary (geowind hereafter) and polar orbiting (polar wind hereafter) satellites, produced at EUMETSAT (E-geowind hereafter) and received through EUMETCast. Using the satellite application facilities for nowcasting (SAF/NWC), we also produce high resolution AMV locally (HRW hereafter). The geostationary wind data have a latency of about 9 minutes, which makes them accessible for a nowcasting system like rapid-refresh system (see more about this scheme in section 2.3). The timeliness of the polar winds derived from dual Metop satellites is about 1 hour to 1 hour and 30 minutes. This makes the polar winds accessible for our operational systems having cut-off (time used to collect the observation before starting the assimilation system) of 1 hour 15 minutes for the main production times (00, 06, 12, 18 UTC) and relatively longer for the remaining intermediate assimilation times (03, 09, 15, 21 UTC). AMV data derived from American satellites are accessible at MET Norway with relatively longer timeliness, which makes these data not available for our operational systems. Hence, we did not check their impact in this study. Table 1 describes the availability of the E-geowind and HRW at each assimilation time in the 3 hour cycling system.

Table 1: The inversion techniques and the available AMV data at different assimilation time. Where WVCL1, WVCL2, IR3, VIS2, VIS3 are, respectively, HRVIS, VIS08, IR108, WV062, WV073. Similarly, WVMW1, WVMW2, IR3, VIS2, VIS3 are, respectively, HRVIS, VIS08, IR108, WV062, WV073. The difference is on the processing and coding of the wind data in EUMETSAT's processing and SAF/NWC packages.

	Geowinds from EUMETSAT (retrieval technique used)	Locally produced geowinds (retrieval technique used)	Polar winds(retrieval technique used)
00 UTC	WVCL1, WVCL2, IR3	WVMW1, WVMW2, IR3	
03 UTC	WVCL1, WVCL2, IR3	WVMW1, WVMW2, IR3	
06 UTC	WVCL1, WVCL2, IR3, VIS2, VIS3	WVMW1, WVMW2, IR3, VIS2, VIS3	IR
09 UTC	WVCL1, WVCL2, IR3, VIS2, VIS3	WVMW1, WVMW2, IR3, VIS2, VIS3	IR
12 UTC	WVCL1, WVCL2, IR3, VIS2, VIS3	WVMW1, WVMW2, IR3, VIS2, VIS3	IR
15 UTC	WVCL1, WVCL2, IR3, VIS2, VIS3	WVMW1, WVMW2, IR3, VIS2, VIS3	IR
18 UTC	WVCL1, WVCL2, IR3, VIS2	WVMW1, WVMW2, IR3, VIS2, VIS3	IR
21 UTC	WVCL1, WVCL2, IR3, VIS2	WVMW1, WVMW2, IR3	IR

2.2 The utilized conventional and satellite radiances

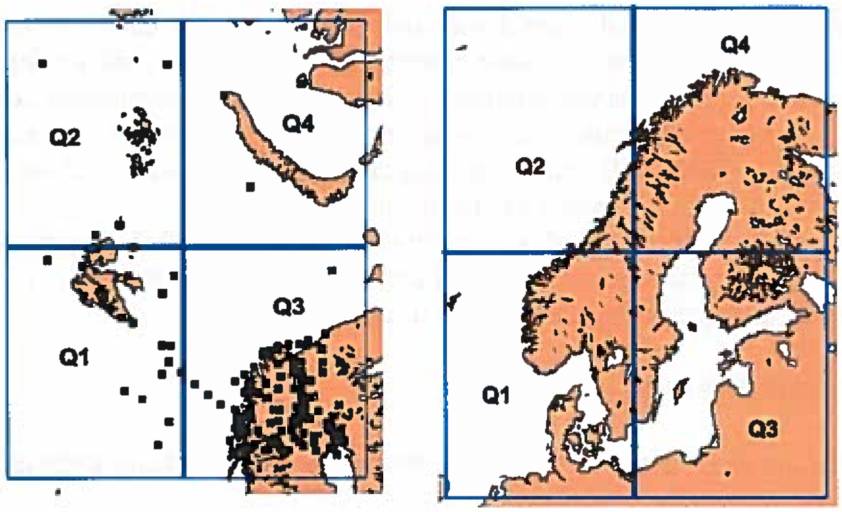
We used all available surface observations, such as SYNOP, ship, and drifting buoys (DRIBU). When available, aircraft, pilots and radiosonde observations, as well as radiances sensed by Advanced TIROS Operational Vertical Sounder (ATOVS: AMSU-A and AMSU-

B/MHS) and by the Infrared Atmospheric Sounding Interferometer (IASI) instruments were assimilated. The radiance data were used in their full grid resolution (*Randriamampianina, 2006a*), and their systematic bias is corrected using a variational technique (*see Randriamampianina et al., 2010 for more details*).

2.3 The assimilation scheme and the forecast model

In this study we used the configuration of the operational limited-area models (LAMs) at MET-Norway – the AROME-MetCoOp and the AROME-Arctic. Figure 2 shows the models' domain extension. The forecast model is the HARMONIE-AROME (Bengtsson et al, 2017) cy38h1.2 using a slightly modified version of the AROME physics developed at Météo-France (*Seity et al., 2011*), and non-hydrostatic dynamic (*Bubnová et al., 1995; Benard et al. 2010*). In this experiment we use hourly ECMWF forecasts as lateral boundary conditions (LBC). Although, the default setting in the Harmonie system uses the spectral blending of the coupling (ECMWF) field at initial time (*Vignes, 2011*), this option is switched off in order to better account the impact of the observations on the mesoscale phenomena. Both the surface and the upper-air atmospheric fields are updated, respectively, using optimum interpolation (called OI_main) and three-dimensional variational analysis (3D-VAR) (*Fischer et al., 2005*) schemes. The horizontal resolution of both the models is 2.5 km (750x960 grid points) with 65 vertical atmospheric levels ranging from roughly 12m (level 65) till 10 hPa (level 1). Both models setup uses 3-hourly cycling, performing analyses at 00, 03, 06, 09, 12, 15, 18, and 21 UTC. Also, for verification purposes, longer forecasts ranges (48 hours) are performed at 00 and 12 UTC. An other purpose of this study is to check the impact of AMV data in nowcasting system. For this goal, a 1-hour non-cycling assimilation system (also called rapid-refresh) is tested. Table 2 shows the available most fresh or "youngest" model forecasts applied in rapid-refresh system. Note that these most fresh forecasts can vary from one centre to another, also they can change after a computing facilities updates. So, this is very relative to the operational constraint at each NWP centre. Table 2 shows the situation we had at MET Norway in 2015.

While the observation cut-off for the 3-hourly system is 1 hour 15 minutes, 15 minutes is used for the rapid-refresh system.



Figures 1. The AROME-Arctic (left) and the AROME-METCOOP (right) models domain. The different quarters are defined for the sensitivity study, which is described in Section 2.4.

Table 2. The most fresh forecasts (in hour, second row) at each restart (first row in UTC) of the rapid-refresh system.

00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
6	7	2	3	4	5	6	7	2	3	4	5	6	7	2	3	4	5	6	7	2	3	4	5

2.4 The sensitivity and impact studies

The sensitivity of the data assimilation system to the utilized different observations was estimated through computation of the degrees of freedom for signals (DFS) defined as the derivative of the analysis increments in observation space with respect to the observations used in the analysis system. *Chapnik et al. (2006)* illustrated ways of its computations, among others computation through a randomization technique is described in *Randriamampianina et al. (2011)*.

The sensitivity of the forecast model to different observations used in the analysis system is evaluated by computing the energy norm loss attributed to each individual observation using the MTEN (Moist Total Energy Norm) tool. The technique is described in *Storto and Randriamampianina (2010)* and it can evaluate the impact of each observation on the forecast model without indication of whether it is positive or negative. So, it is more meaningful to combine this technique with other standard verification techniques like comparison against observations, for example. The MTEN tool allow to assess the influence of observations to the forecast model in different parts of its 3 dimensional domain: horizontally (see Figs 1) and vertically (Storto and Randriamampianina, 2010). Vertical assessment of the impact is not discussed in this report.

The accuracy of our operational systems with and without the AMV data was checked by comparing the forecast parameters against observations (surface and radiosonde). The observation denial experiments was conducted within two periods: September 2015 and August 2016. These periods were chosen because of the completeness of all needed observations. The HARMONIE system has integrated point verification tool for comparison against observations, which provides a range of skill scores.
We also checked the performance of our system with and without AMV data in case of interesting meteorological events, like case of blocking anticyclone and when the regional model domain is dominated by cyclonic scale troughs.

3 Results and discussion

3.1 The sensitivity of the analysis system to the observations with presence of AMV data

The sensitivity of the analysis system to observations was estimated using the following randomly chosen assimilation times: 5th of September 00 UTC, 7th of September 06 UTC, 10th of September 12 UTC, and 12th of September 18 UTC. The number of active AMV data is relatively smaller (Fig. 2, top graph) than that of most of the used observation types. Still, adding them in the analysis system influences the assimilation of certain observations like for example DRIBU and surface winds (SYNOP U) (Fig. 2, bottom graph). Looking to the two runs using HRW (SAFW and SAFMN), we can see the importance of tuning of the observations to have better fit to all existing observations for better balance in the analysis, and hence for an accurate forecasts. We can see for example the impact of HRW on the assimilation of radiosonde temperature (TEMP T) or radiances (AMSU-A and AMSU-B).

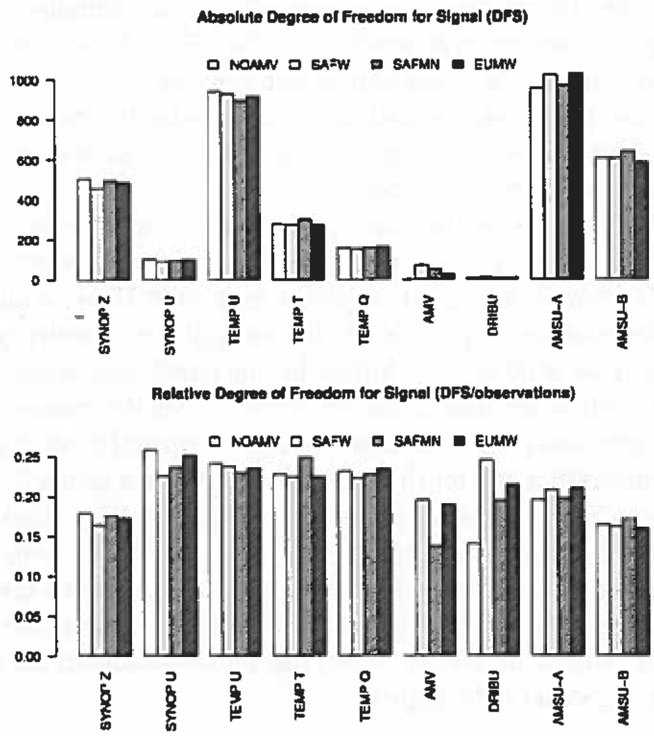


Figure 2: Average absolute and relative DFS estimated from different assimilation times (see text above). Where NOAMV is a system without AMV; SAFW and SAFMN are systems using tuned HRW data; and EUMW is the system using AMV winds produced at EUMETSAT.

3.2 The sensitivity of the forecast model to the AMV data

The sensitivity of the HARMONIE forecast model to the observations is assessed using the MTEN tool. To have the possibility for evaluation of the relative influence of the AMV observations compared to that of the other observations used in our data assimilation system, MTEN was also applied to some of the active observations. In particular, it was applied to all aircraft (AIREP in the graphs), drifting Buoys (BOUY in the graph), AMSU-A, AMSU-B/MHS, radiosonde (TEMP), and IASI observations. Based on the verification results and on the impact of both geostationary AMV retrieved locally and from EUMETSAT, we based our sensitivity study to the found best combination with the polar winds: HRW together with polar winds. That is why we do not have the EUMETSAT produced winds evaluated in this part of our study, because it was not included in the full system taken as reference for the MTEN assessment.

The sensitivity study was conducted for the following dates: 5, 10, 15, 20, and 30 September 2015 with the MetCoOp model. Both 00 and 12 UTC cases were analysed separately to have the analysis of as much as possible meteorological events. As example and for information, in 5th of September, the southern part of the model is occupied by a passing cyclone with complex frontal systems. The 10th of September, a large anticyclone dominated the whole model domain, producing nice weather over Sandinavia. The 15th of September, the weather condition inside MetCoOp domain was influenced by two synoptic scale meteorological phenomena: a blocking large anticyclone located just outside and at its eastern part, and a slowly developing cyclone from its western side. See the Section on case study to learn more about weather condition during this study period.

As expected, the forecast model is as sensitive to the AMV data as to the other observations assimilated in the system. For certain cases, for example 10, 15, 30 September at 00 UTC, the impact of loosing the AMVfrom the assimilation system, especially HRW, is higher than that of the other assimilated observations (Fig. 3). Analysing carefully the sensitivity of the forecast model to the AMV data at 00 and 12, during the one month test period, we observe more often higher impact of the AMV data in case of 00 UTC. One the reasons for this difference can be that we have less observations at this time compared to what are available at 12 UTC, when more aircraft traffics and much more radiance data are available (Fig. 4).

The forecast model seems to be less sensitive to the polar winds (forth bar from right in Fig. 3 and Fig. 4) compared to geowinds (3rd bar from right in Fig. 3 and Fig. 4) in the investigated days. Possible explanation for this can be that in these days most of sensible meteorological events dominated mostly the southern part of the model domain. In the north, events like polar lows are very active during winter. So, we can expect that the sensitivity of the model forecast to AMV (polar winds) during winter to be higher.

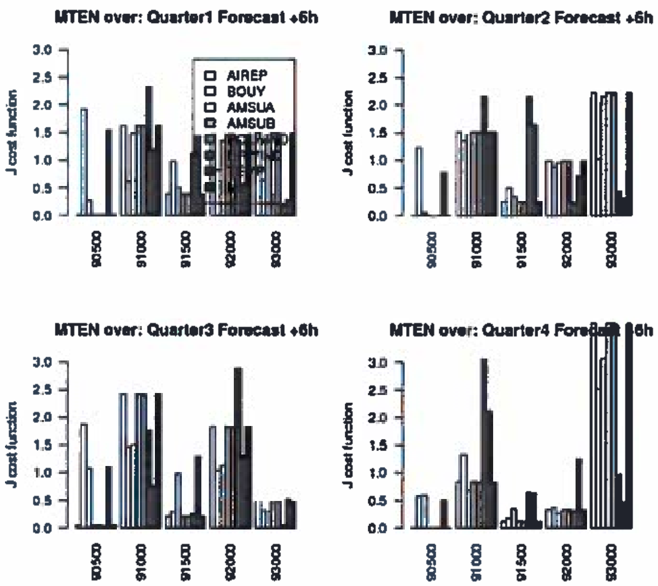


Figure 3. Normalised cost function showing the moist total energy norm loss in the forecast model when losing different observations from the analysis system. This shows how sensitive the model forecast to these observations. The order of observations from white to dark black

is AIREP, BOUY, AMSUA, AMSUB, POLWIND, HRW, TEMP; and IASI. For example, the HRW is the 3rd bar from right. See Fig. 1 for the emplacement of Q1, Q2, Q3, and Q4 inside MetCoOp domain. The horizontal label is showing month, day and hour. For ex. 90500 means 5th of September 00 UTC.

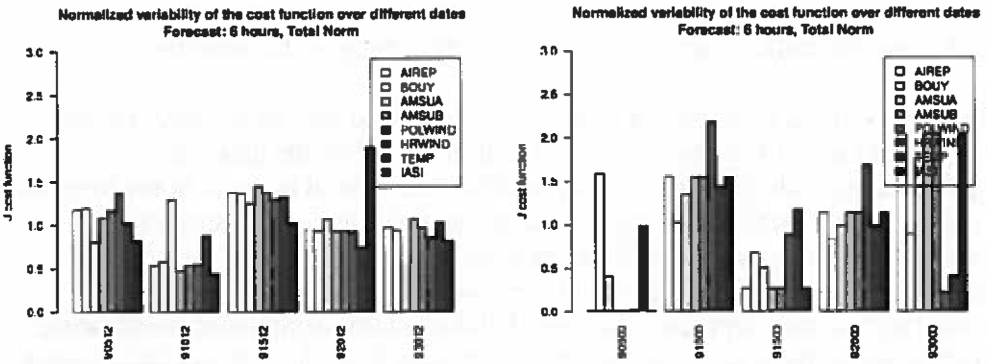


Figure 4. Same as Figure 3, but computed over the whole MetCoOp domain from 12 (left) and 00 (right) UTC runs.

3.3 Impact of the AMV data on analyses and forecasts using RUC system

To assess the impact of the AMV (geowind and polar winds) two series of experiments were carried out. The first series were conducted during September 2015, when the first full set of necessary observations were collected. The second series of experiments were conducted, taking into account the outcome of the first assessment, in July 2016. Hence, less experiments were performed in the second series.
The first series covered the following combination:
Experiments done with MetCoOp configuration:
AMV_NoM: Experiment without AMV data – reference experiment;
AMV_EU1: Experiment with geowind from EUMETSAT (E-geowind);
AMV_SAF3: Experiment with locally produced HRW;
AMV_BSP: Experiment with HRW and polar winds;
AMV_TSB: Experiment all three available AMV data.

Experiment done with the AROME-Arctic configuration:
AMV_NoP: Experiment without AMV data – reference experiment;
AMV_2MP: Experiment with polar winds.

The second series of experiments used the following combination:
Experiments done with MetCoOp configuration:
AMV_JNoM: Experiment without AMV data – reference experiment;

AMV_JBSP: Experiment with HRW and polar wind;

Experiment done with the AROME-Arctic configuration:
AMV_JNoP: Experiment without AMV data – reference experiment;
AMV_J2MP: Experiment with polar winds.

3.3.1 Impact of geowind data on analyses and forecast using RUC system

By nature of the observations, to assess the impact of the geowind data on the analyses and forecasts, the MetCoOp model was used. The impact of the HRW on the upper-air temperature, geopotential, and humidity is rather positive than neutral up to 24 hours forecast (Figs 5). The impact of both tested geowind data on analysis and forecast of surface parameters is neutral. Figure 6 shows that HRW data provide better accuracy (smaller error) in analyses and forecasts of the MetCoOp model compared to that of E-geowind. While E-geowind provides improvement on most of the thresholds used for precipitation verification, the HRW data improve the forecast of the intense precipitation (Fig. 7a). We can also observe on Fig. 7b that in lower stratosphere (850 hPa), the E-geowind data improve the flow motion (seen on wind speed) up to 12 hours forecast, while HRW improvement lasts up to 24 hours.

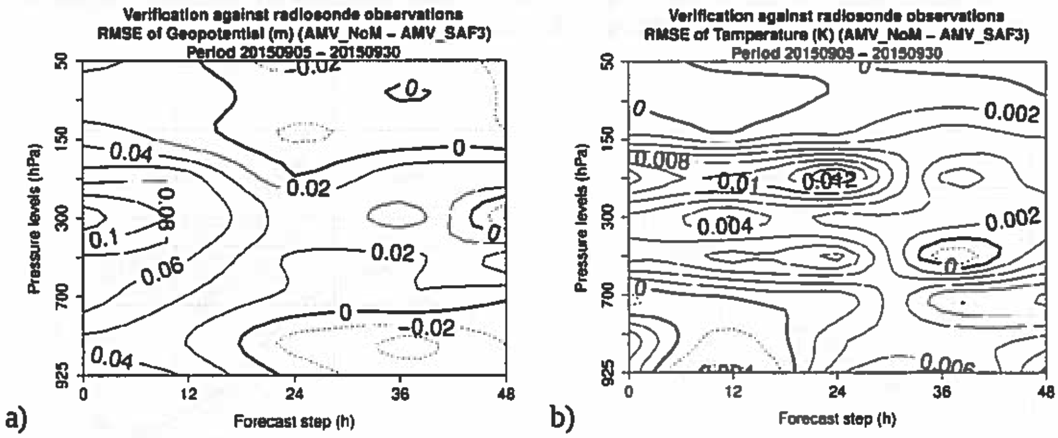
3.3.2 Impact of polar wind data on analyses and forecast using RUC system

The impact of the polar wind data was evaluated in the AROME-Arctic. Although, verification against observations over the Arctic is very limited by the number of available observations, our earlier studies also showed that the results shown by verification against the few (8) radiosonde stations represent quite well the overall performance of our model.
The verification against the 8 radiosondes shows clear positive impact of the polar winds on the atmospheric part (all verified parameters) of the AROME-Arctic (Figs. 8) up to 24 hours forecast. The impact of polar wind on mean sea level pressure is positive and even significant for day-two forecast (Figs. 9). We found better (lasting longer) impact of the polar winds in the second test period (July 2016 – not shown).

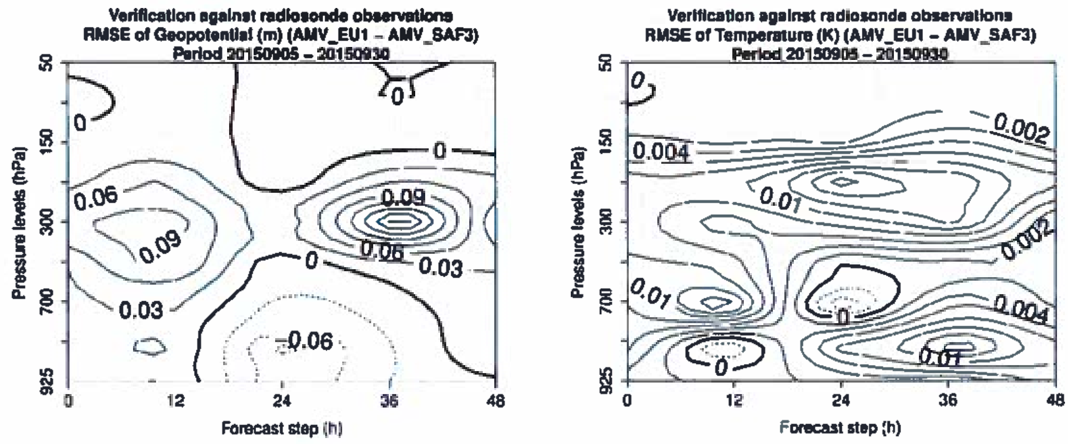
3.3.3 Impact of all AMV wind data on analyses and forecast using RUC system

Based on the above discussed impact of the geostationary and polar satellites based wind, and accounting for the computational cost of the experiments, we checked the combination of polar wind with HRW in the AROME-MetCoOp model during the second period.
Combining the HRW with polar wind improve the speed of the model flow up to 36 hours forecasts (see Fig. 7b violet line), providing positive impact on forecast of precipitation. This combination (HRW + polar winds) provides clear and significant impact on geopotential analysis and forecasts at mid-tropospheric AROME-MetCoOp model levels (Fig. 10).
Similarly, we observed clear positive impact of the AMV data on wind, humidity and temperature (not shown).

Combining all the available AMV (E-geowind, HRW, and polar winds) have comparable impact on the upper-air levels to that when HRW and polar winds are used (AMV_BSP), but with slightly reduced impact on relative humidity. The impact of all AMV winds on mid-tropospheric temperature is larger and even significant at 500 hPa (not shown) compared to that of AMV_BSP. Still, the reduction of impact on lower tropospheric humidity and precipitation open the question of redundancy in the use of geowinds. But, we learned that in NAVGEM model (NRL) all available AMV data combined together (Patricia Pauley, personal communication) and carefully assimilated can provide the highest observed impact in global model (e.g: Pauley et al., 2016). So, it can be that the small difference in the number and the quality of the two geowinds provide this "strange" impact (see also the above discussion on the impact of these geowinds).

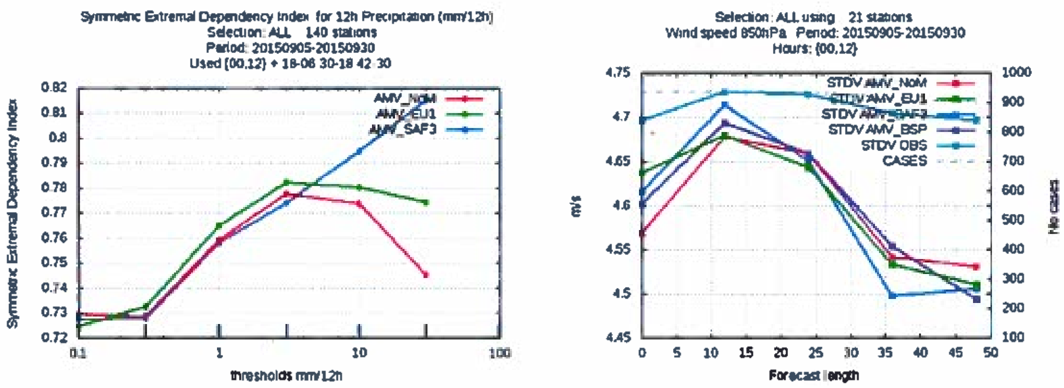


Figures 5: The vertical cross-section of the difference between the root-mean-square errors (RMSE) of runs with and without HRW data. Positive (negative) values correspond to positive (negative) impact.



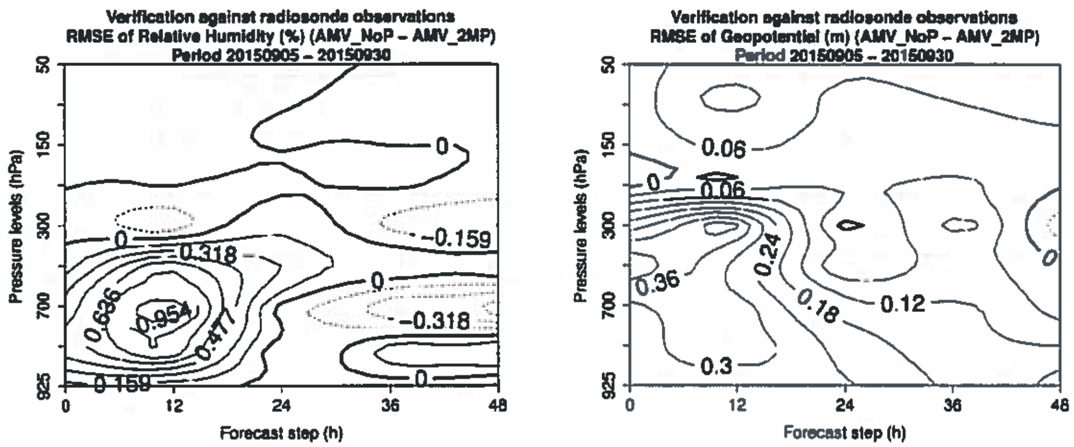
a) b)

Figures 6: Same as figure 5, but comparing runs with geowind and HRW. Positive (negative) values correspond to larger (smaller) errors in the run with E-geowind.



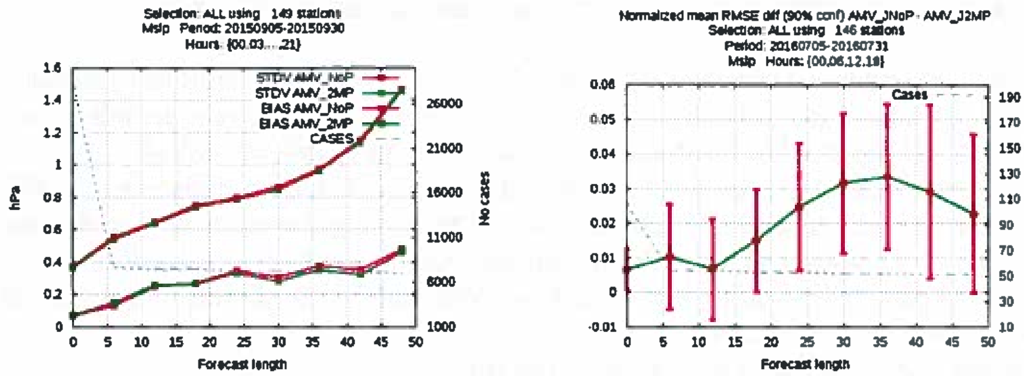
a) b)

Figure 7: Systematic extremal dependency index (SEDI) for 12 hour accumulated precipitation estimated for different thresholds (a), and standard deviation of forecast and observed wind at 850 hPa (b). Note for SEDI, the higher the value the better. On (a) graph, red, bue, and green lines show respectively the control, the run with E-geowind, and the run with HRW. On (b) graph, the same colouring rule used with violet showing the run with HRW and polar wind and light blue showing the observation.



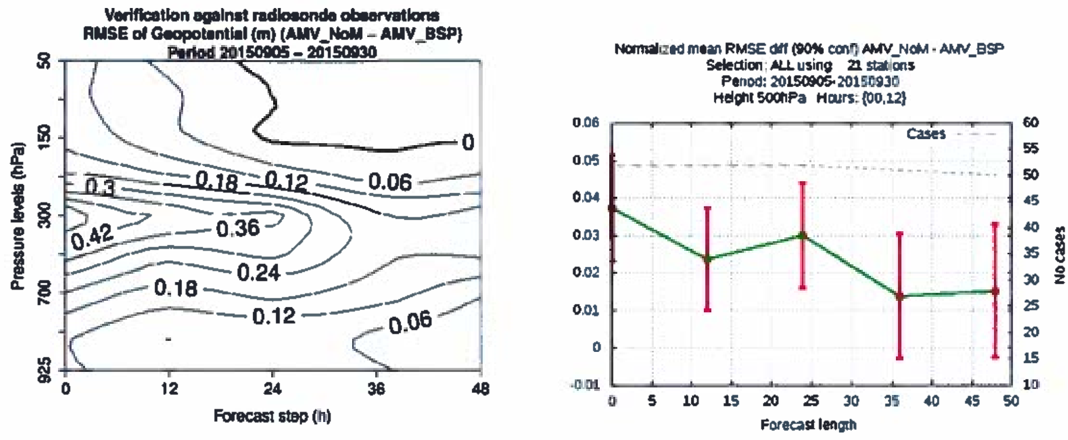
a) b)

Figure 8: The same as Figure 5, but comparing runs with and without polar winds over the AROME-Arctic domain. Positive (negative) values correspond to positive (negative) impact of the polar wind data.



a) b)

Figure 9: Error standard deviation and bias of the modelled mean sea level pressure (MSLP) with runs with (green lines) and without (red lines) polar winds. (a) is showing the analysis and forecast error in comparison against observations, and (b) is showing the respective significance test of the normalised root-mean-square error (RMSE).



a) b)

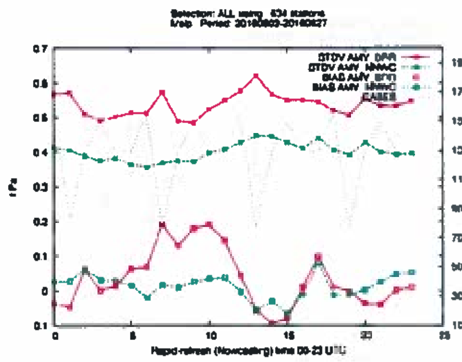
Figure 10: The vertical cross-section of the difference between the root-mean-square errors (RMSE) of runs with and without AMV (both HRW and polar winds) data. Positive (negative) values correspond to positive (negative) impact (left graph). The respective significance test of the impact at 500 hPa model pressure level is shown on the right-hand side.

3.3.4 Impact of AMV wind data on analyses and forecast using RR system

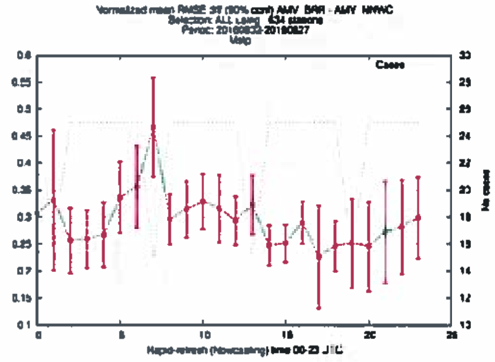
The preparation for this experiment was not easy. We had to respect all constraints necessary for both the operational RUC and the experimental RR. While for all above experiments, we used conventional and satellite data from MARS archive, in this study we took all conventional and satellite data from our operational computing system to respect the cut-off time of 1 hour 15 minutes. This is then the experiment mimicking our operational model, but run in ECMWF computing platforms. For the RR experiments we did a separate data collection respecting the cut-off time of 15 minutes. Note that the cut-off time of geowinds at MET Norway is around 9 minutes.
The following experiments were conducted for this study:
AMV_BRR: 3-hourly RUC experiment;
AMV_NNWC: RR without HRW;
AMV_NWC: RR with HRW.

The following experiments were conducted to learn more about the performance of the RR system:
AMV_ATO: RR without ATOVS radiances;

The first observed result of these experiments is that the hourly analyses (NWP nowcasting products) are significantly better than the available operational very short range forecasts (Fig. 11). This is true for 2m temperature and 2m humidity, but for 10m wind no change was observed.



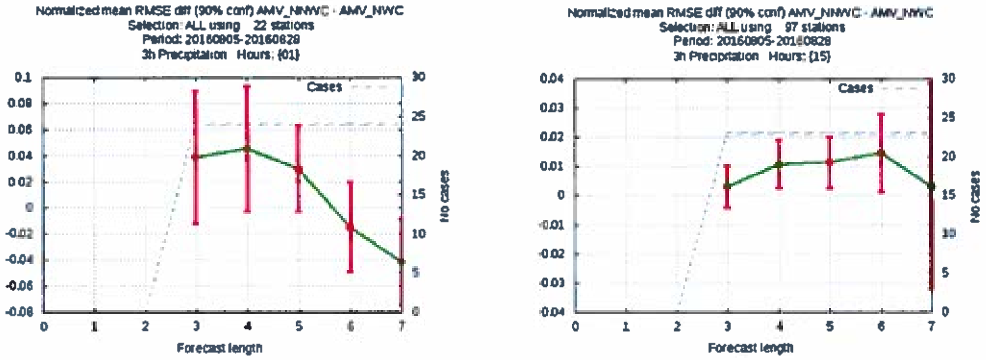
a)



b)

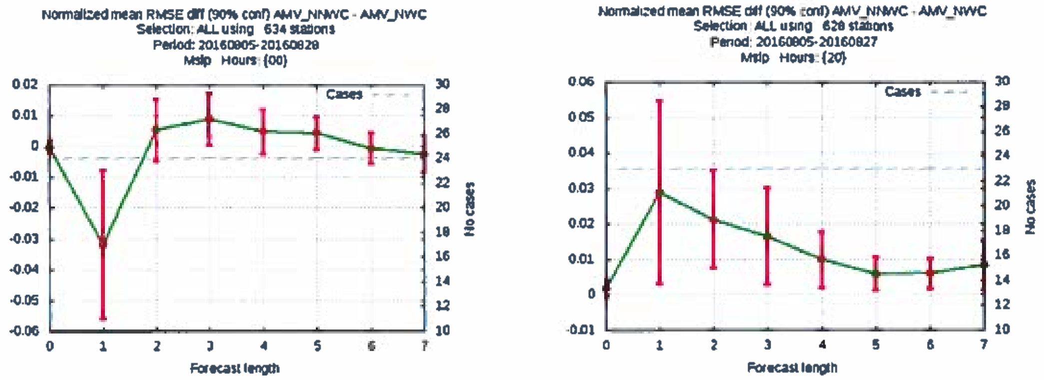
Figure 11: Standard deviation and bias of the modelled mean sea level pressure (MSLP) from 3-hourly RUC (red) and RR (green). (a) is showing the nowcasting (analysis) error in comparison against observations, and (b) is showing the respective significance test of the normalised root-mean-square error (RMSE).

Regarding the impact of the HRW on the RR system, the verification against observations shows that the impact of HRW at each nowcasting hour is varying, but with positive impact on 3-hour accumulated precipitation for most of the cases (Figs 12). Note that 3-hour accumulated observations are mainly most of the time observed in the south-east part of the MetCoOp domain. Accounting the fact that HRW are "only" available up to 60 degree north, the available precipitation observations are over the "influenced part" of the domain. The impact of the HRW on MSLP is also not always neutral. For some nowcasting times, a clear negative impact on 1 hour forecast is observed (Fig. 13), which appeared to be form the assimilation of ATOVS (AMSU-A and AMSU-B/MHS) radiances (Fig. 14). Although, we can see that HRW have slight positive impact on RR for this relatively shorter period.
The impact assessment above shows that for better evaluation of the observations impact, we need to work more on the RR settings and tuning, in particular with bias correction and channel selection for radiances, because for some hours clear problem (larger error) was seen at the beginning of the study period. Large error means that the bias coefficients estimated for 3 hourly RUC maybe not suitable for hourly RR system as we tried to implement in this study.



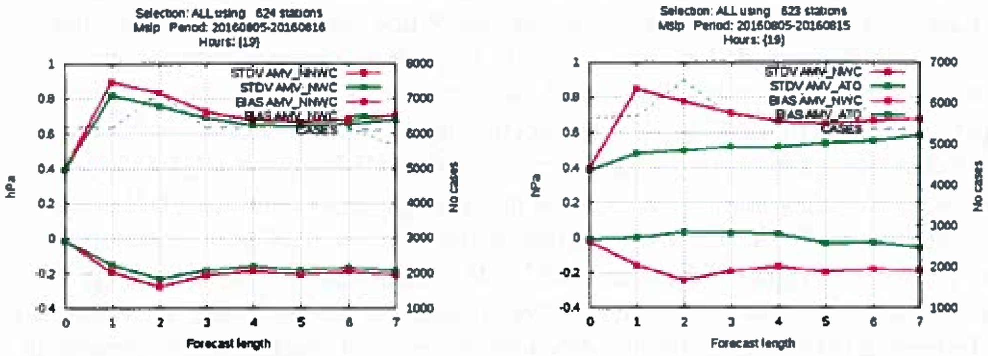
a) b)

Figure 12: Significance test of the normalised root-mean-square error (RMSE) for 3-hourly accumulated precipitation for two nowcasting times: 01 (a) and 15 (b) UTC.



a) b)

Figure 13: Same as Fig. 12, but for MSLP and for different nowcasting time.



a) b)

Figure 14: Comparison against observations showing the error standard deviation and bias of the modelled mean sea level pressure (MSLP) from RR runs with (green lines) and without (red lines) HRW (a). Right graph shows the RR runs with HRW (red lines) and without ATOVS (green lines). The statistics are related to almost the same period for both cases (a and b). The right graph shows the worst case from the series.

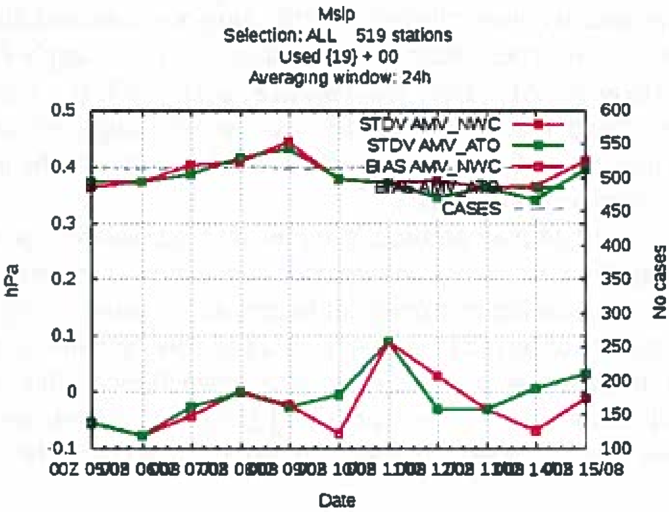


Figure 15: Comparison against observations. Time series of errors standard deviation and bias for RR runs with reference (HRW+ATOVS) (red lines) and without ATOVS (green lines).

3.3.5 Case study

When analysing the results of MTEN tool with the MetCoOp domain, as mentioned above, the forecast model shows larger sensitivity to HRW for 15th of September with forecasts from 00 UTC (Fig. 16), especially over quarter 1 (Q1). 15th of September is the case when the

MetCoOp domain is over different synoptic scale trough systems. This is due to a large anticyclone located at eastern part of the model domain. While the mentioned anticyclone continue blocking the flow inside the model domain, a cyclonic system is forming and developing at south-western corner of the model domain. This cyclone reaching a mature enough stage during night of 15th (Fig. 17), and occupying mainly the quarter 1 sub-domain. MTEN results show large sensitivity of the forecast model to HRW over the Q1 and Q2 for this case. We focus our study on the phenomenon happening mainly over the Q1. We check the impact of different AMV data over Q1 domain on the forecast of 24-hour accumulated precipitation for both first (00h – 24h) and second (24h – 48h) lapse times. While large amount of precipitation is expected in south Norway during the first 24 hours, the second 24 hour we are interested in the impact of the AMV data on the local precipitation approaching the coastal part of Møre and Romsdal region.

On figures 18 – 20 we indicate with red circle the forecast areas we are interested in. Looking to the individual forecast it was not easy to distinguish the difference between the AROME-MetCoOp forecasts, which means that the forecasts are already good enough. Although, the statistics from point verification are not the best we can have concerning precipitation and cloudiness because of the high probability of having double penalty, we can still see similarity between forecast accuracy and the verification results. Double penalty comes, among other possibilities, from verification of objects that are forecasted aside of real positions and probably with different intensity. From the point verification, we observed that the accuracy of the forecast of intense events (more than 10mm/12 hour, see for example Fig. 7-a) is better with runs using HRW (case of SAF3, BSP, and TSB in Figs 19 – 20). If we compare the outputs of SAF3 and BSP with that of EU1 or TSB, we can see a slight reduction of intensity of precipitation in the later cases. Statistics indicating such behaviour of the model exist among the verification results (not shown).

For both the first and second 24-hour accumulated precipitation differences, we can see that SAF3 is forecasting slightly more intense precipitation in the area of interest. Also, in the second case, we put arrows showing improvement in forecasting other precipitation object, where increase of intensity is observed in case of SAF3 and BSP. Somehow, for that specific object TSB and EU1 runs have less intensification of the precipitation. This coincide, for example, with the result shown on Fig. 7-a, where EU1 (with E-geowind) have also positive impact in case of intense event, but less accurate than that of SAF3 (with HRW).

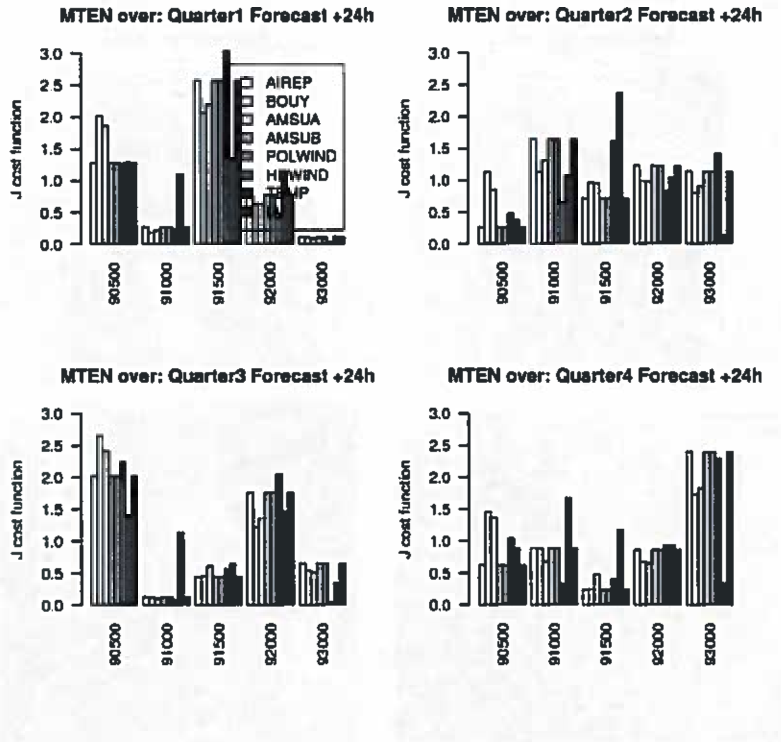


Figure 16: Same as Figure 3, but for 24 hour forecast.

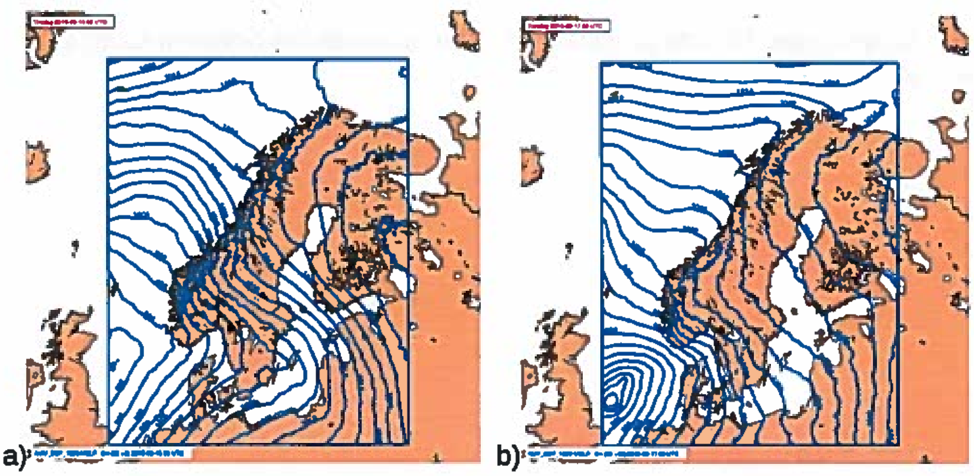


Figure 17: Weather condition at the start of the forecast model (initialised analysis – (a)), and the 48-hour forecast (b) for the case of September 15, 00 UTC.

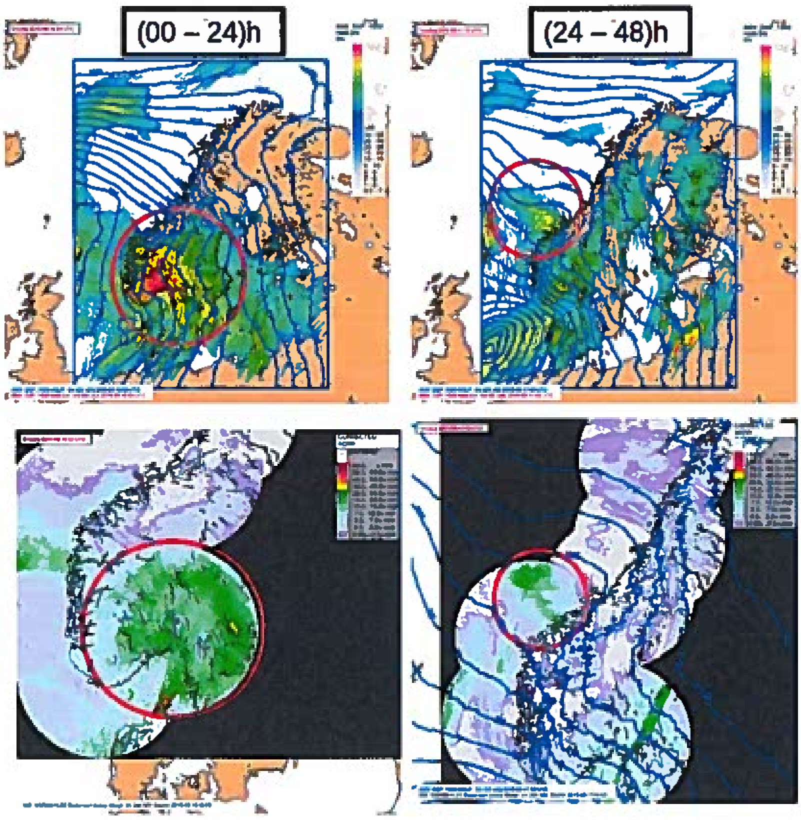


Figure 18: Accumulated 24-hour precipitation radar observations (lower graphs) and forecasts (upper graphs).

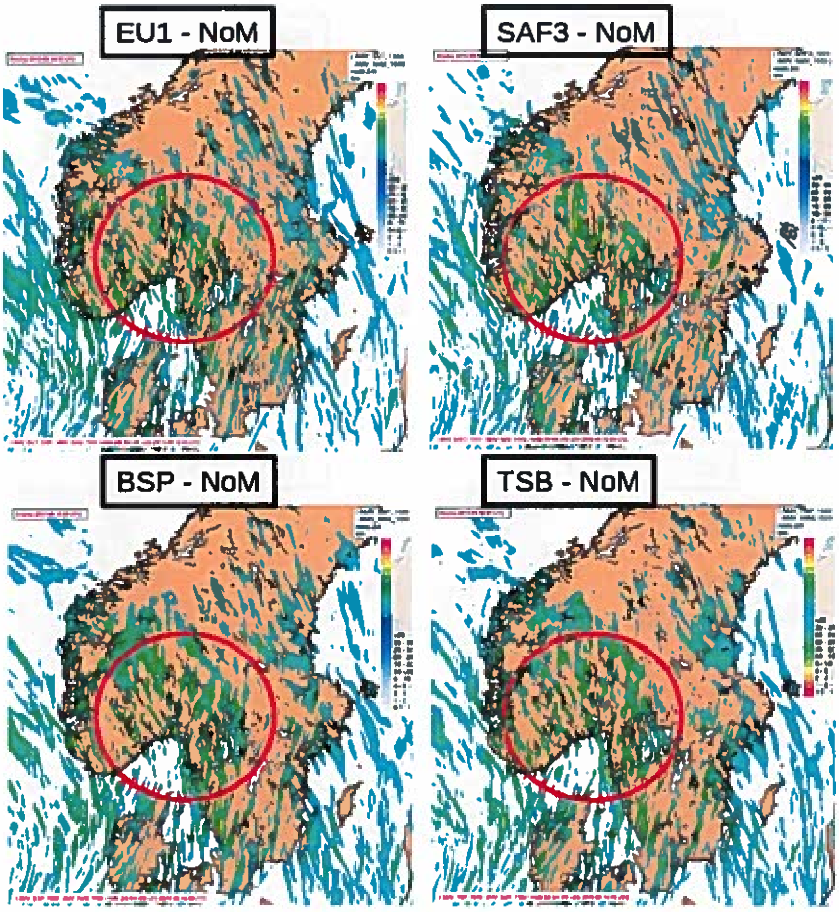


Figure 19: First 24-hour accumulated precipitation difference between the run with and without AMV data. Respectively, from left to right, then top to bottom, difference with E-geowind, HRW, HRW plus polar winds, and all three AMV data together.

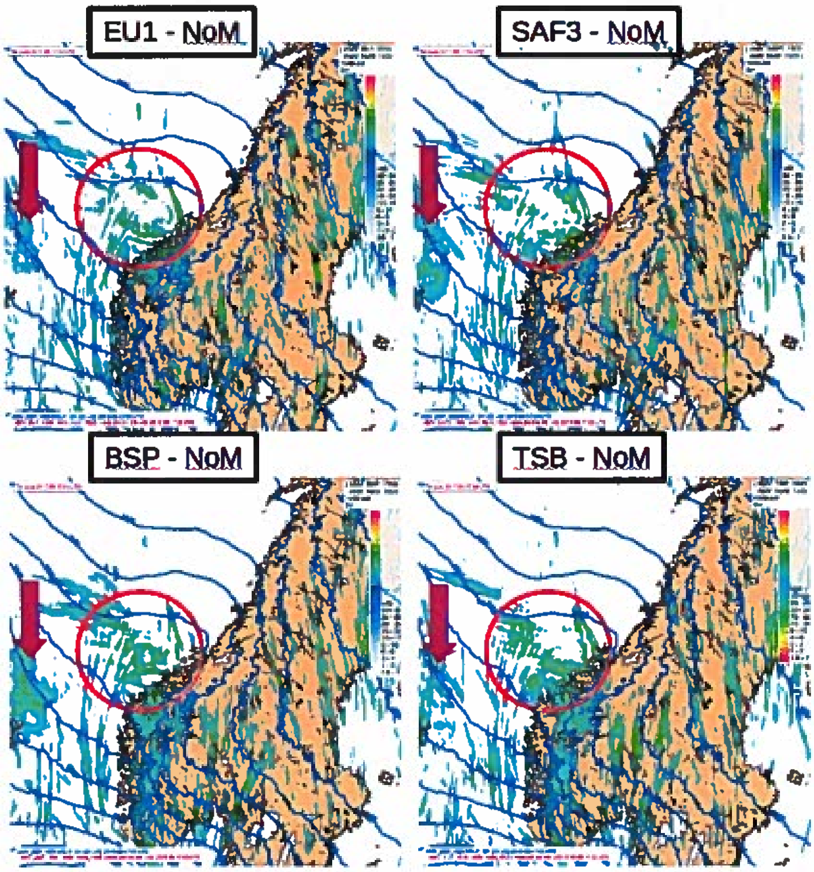


Figure 20: Same as figure 19, but for the second 24 hour from 24 to 48 hour forecast.

4 Concluding remarks

While SAWIRA PHASE 1 assessed mainly the different ways to access to the AMV data at MET Norway, SAWIRA2 studied the impact of all potential available AMV data in our operational mesoscale NWP systems – AROME-MetCoOp and AROME-Arctic. The MetCoOp model is very well located to test both the geostationary and polar satellite based AMV data. Thanks to enormous effort done at EUMETSAT and in Wisconsin University, many new and more accurate AMV became available nowadays. In this study polar winds retrieved using dual Metop (B-A) satellites were tested. Concerning the geostationary satellite-based AMV, next to the ones produced at EUMETSAT (E-geowind), we also produce them locally with higher resolution (HRW).

The impact of the AMV data was evaluated over two periods: September 2015 and July 2016. These periods were chosen randomly, and the final choice was driven by the availability of all three kinds of AMV.

Moderate positive rather than neutral impact of the geostationary satellite-based AMV data was found on AROME-MetCoOp upper-air analyses and forecasts. But clear positive impact was found on the forecast of precipitation. While the impact of E-geowind is observed over almost all the verified precipitation intensity thresholds, HRW impact is a clear forecast accuracy in case of intense precipitation.

The impact of the polar winds on the analyses and forecasts of the AROME-Arctic is clearly positive for both surface and upper-air variables. A similar impact was observed from the experiments done on both tested periods.

Using the polar winds together with the HRW significantly improved the accuracy of the analyses and forecasts of the AROME-MetCoOp model for both surface and upper-air levels.

Using all the three available wind data sets together did not provide further clear improvement. In opposite, it showed loss of accuracy in forecasts of precipitation, for example. This somehow indicates that we may have a redundancy problem with geostationary AMV data in the assimilation system.

Through evaluation of degrees of freedom for signals (DFS), the AMV data shows clear influence on the use of surface wind and surface pressure from Buoys observations. This means that the AMV data influence the analysis producing different impact from the other observing systems. For example somehow less impact from surface wind and more sensitivity from Buoys is observed.

The sensitivity of the AROME-MetCoOp forecast model to the AMV (HRW and polar winds) was estimated by computing the moist total energy loss in the forecasts attributed to the withdrawn observations from the analysis system (Storto and Randriamampianina, 2010). The sensitivity of the model to the AMV data is comparable to that of the other observing systems used the analysis in case of non-stationary or intense weather phenomena.

Through case study we discussed the verification results shown in this report and their correspondence to the evaluated cases. Indeed HRW provide more accurate (compared to radar data – Fig. 18 bottom right and Fig. 19) intense precipitation compared to the E-geowind.

Taking into account the timeliness of the geostationary and polar winds, we decided to test only the geostationary winds (HRW) in the 1-hourly non cycling rapid-refresh (RR) system, which is under development at MET Norway. This system is developed for nowcasting. Similar to the impact of the geowinds on 3-hourly cycling, in RR we found moderate impact of HRW on forecasts of precipitation and cloudiness. We also discussed that the HRW was tested in a RR system, which needs further development, in particular with the assimilation of radiances data.

The HRW and polar winds were suggested for operational implementation in both our mesoscale NWP models.

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References

Benard, P., J. Vivoda, J. Masek, P. Smolikova, K. Yessad, C. Smith, R. Brozkova , and J.-F. Geleyn, 2010: Dynamical kernel of the Aladin-NH spectral limited-area model: Revised formulation and sensitivity experiments. *Quart. J. Roy. Meteor. Soc.*, *136*, 155–169.

Bengtsson et al., 2017: The HARMONIE-AROME model configuration in the ALADIN-HIRLAM NWP system, accepted for publication in Monthly Weather Review. DOI: http://dx.doi.org/10.1175/MWR-D-16-0417.1

Bubnová R., G. Hello, P. Bénard, J.-F. Geleyn, 1995: Integration of the fully elastic equations cast in the hydrostatic pressure terrain-following in the framework of the ARPEGE/ALADIN NWP system. *Mon. Wea. Rev.*, **123,** 515–535.

Fischer, C., T. Montmerle, L. Berre, L. Auger, and S. E. Stefanescu, 2005: An overview of the variational assimilation in the Aladin/FranceNWP system. *Quart. J. Roy. Meteor. Soc.*, *131*, 3477–3492.

Garand, L., J. Feng, S. Heilliette, Y. Rochon, and A. P. Trishchenko, 2013: Assimilation of Circumpolar Wind Vectors Derived from Highly Elliptical Orbit Imagery: Impact Assessment Based on Observing System Simulation Experiments. J. Appl. Meteor. Climatol., 52, 1891–1908. doi: http://dx.doi.org/10.1175/JAMC-D-12-0333.1

Key, J.R., D. Santek, C.S. Velden, N. Bormann, J.-N. Thépaut, L.P. Riishøjgaard, Y.Zhu, and W.P. Menzel 2003: Cloud-drift and water vapor winds in the polar regions from MODIS. IEEE Trans. Geosci. Remote Sens , 41 , 482-492.

Randriamampianina, R., 2006a: Impact of high resolution observations in the ALADIN/HU model., *Időjárás*, *110*, 329-349.

Randriamampianina, R. 2006b. Investigation of the AMV data derived from METEOSAT-8 in the ALADIN/HU data assimilation system. Proceedings of the 8th International Winds Conference, Beijing, China, 21 April – 1 May, 2006. available in-line at: www.eumetsat.int/groups/cps/documents/document/pdf_conf_p47_s2_06_randriama_v.pdf .

Randriamampianina R, Iversen T, Storto A. 2011. Exploring the assimilation of IASI radiances in forecasting polar lows. *Q. J. R. Meteorol. Soc.* **137**: 1700–1715. DOI:10.1002/qj.838

Riishojgaard, L. P., Z. Ma, M. Masutani, J. S. Woollen, G. D. Emmitt, S. A. Wood, and S. Greco, 2012: Observation system simulation experiments for a global wind observing sounder, Geophys. Res. Lett., 39, L17805, doi:10.1029/2012GL051814.

Pauley P, R Pauley, N Baker, R Stone, 2016: Overview of Satellite Derived Winds in NAVGEM, 13th INTERNATIONAL WINDS WORKSHOP, 27 June 2016 - 1 July 2016,

Monterey, California. Available from:
http://cimss.ssec.wisc.edu/iwwg/iww13/talks/02_Tuesday/1320_IWW13_NAVGEM_Pauley.pdf
Stoffelen, A., J. Pailleux, E. Källén, J. M. Vaughan, L. Isaksen, P. Flamant, W. Wergen, E. Andersson, H. Schyberg, A. Culoma, R. Meynart, M. Endemann, and P. Ingmann, 2005: The atmospheric dynamics mission for global wind field measurement. Bull. Amer. Meteor. Soc., 86, 73–87. doi: http://dx.doi.org/10.1175/BAMS-86-1-73.
Vignes O., 2011,A simple strategy to take advantage of boundary (ECMWF) forecast quality in Harmonie 3D-Var cycling, available on
https://hirlam.org/trac/attachment/wiki/HarmonieSystemDocumentation/lsmixbc.ppt