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GOES-16 AMV DATA EVALUATION AND ALGORITHM ASSESSMENT

Katie Lean and Niels Bormann

ECMWF, Shinfield Park, Reading, UK

Abstract

GOES-16 is the first of the third generation of GOES satellites and in December 2017 replaced GOES-13 as the primary satellite in the GOES-East position. GOES-16 carries the Advanced Baseline Imager (ABI) instrument from which Atmospheric Motion Vectors (AMVs) can be derived. ABI is a more advanced instrument than its predecessor on GOES-13. A new AMV derivation method has also been developed which employs a nested tracking method to calculate the initial vector and uses an optimal estimation approach for the height assignment. The combination of new instrument and algorithm has led to a significant increase in the number of AMVs and changes in the characteristics of the data.

A quality assessment using first guess departure statistics showed that after appropriate quality control measures GOES-16 was able to achieve Root Mean Square Vector Difference (RMSVD) values that were generally similar to GOES-13/-15 and improved in the overlap region with Meteosat-10. The speed bias was more mixed with larger negative biases at low pressures and larger biases particularly in the tropics. Early test data where the GOES-16 algorithm had been modified and applied to GOES-13/-15 data presented different speed bias patterns with generally more positive/less negative speed biases. This advanced preview of the algorithm unfortunately could not be used as a reliable prediction of the behaviour of the algorithm once applied to the newer satellite.

With more conservative spatial blacklisting employed, the GOES-16 data were tested in assimilation experiments. Forecast impacts were generally neutral but encouragingly, small reductions in the vector wind error (verified against own analysis) were seen at short range forecasts at low levels and in the southern hemisphere. Changes to the fit of independent observations to the model background were also mostly neutral with indications of positive benefit in some humidity sensitive microwave sounding channels. Operational monitoring of GOES-16 AMVs at ECMWF started on 17th April 2018 while active assimilation began on 22nd May 2018.

Note that material presented here has also been submitted by the same authors as part of proceedings papers for the 14th International Winds Workshop (Jeju Island, South Korea, 23rd - 27th April 2018).

INTRODUCTION

At ECMWF, there are traditionally five geostationary satellites that provide AMV and Clear Sky Radiance/All Sky Radiance (CSR/ASR) coverage for the tropics and mid-latitudes. On 17th November 2016, GOES-16 was launched and initially stationed at 89.5°W. After a long commissioning phase, the satellite drifted to 75.2°W and became recognised as the operational GOES-East satellite, taking over from GOES-13, on 18th December 2017. Once in the new orbit position, the time overlap with GOES-13 was very short with parallel activities ending on 8th January 2018. Work presented here will address the AMV data but details can be found on the replacement of the CSR data in Burrows, 2018.

Key attributes of GOES-13 and -16 relevant for the AMVs are summarised in Table 1. GOES-16 carries the ABI instrument which has five channels available for AMV derivation compared to three channels previously. However, in practice, cloud tracked winds are only derived by NOAA from the shortest wavelength (6.15µm) of the three water vapour channels. In addition to higher temporal and spatial resolution instrument, the AMV derivation algorithm also changed considerably. GOES-13 uses longestablished tracking and height assignment methods (e.g. CO_2 slicing technique) and also employs an auto-editor which adjusts the assigned heights and speeds of selected winds, leading to more dependence on Numerical Weather Prediction (NWP) data (Nieman et al., 1997; Velden et al., 1998). For GOES-16, the initial tracking vector is acquired through a nested tracking approach which aims in particular to reduce slow speed biases (Bresky et al., 2012). The height assignment uses an optimal estimation technique for the cloud tracked winds in all the channels (Bresky et al., 2012; Heidinger, 2013). Notably the auto-editor step is no longer used therefore removing this element of dependence on NWP.

AMV data from GOES-16 were routinely received and processed at ECMWF from 15th December 2017. However, a preview of the new derivation algorithm was acquired earlier in 2017 when data were made available from GOES-13/-15 that had been reprocessed with the new derivation scheme, adapted to the older imaging instrument. The assessment of the data presented here initially uses first guess departure statistics (differences between observations and model background values provided by a short T+12 forecast from the previous model cycle) to characterise the AMVs. Insights into the algorithm from reprocessed GOES-13/-15 are also considered. Impacts on the forecast from the assimilation experiments will be discussed followed by conclusions and future steps for GOES-16.

	GOES-13	GOES-16
Position	75.0°W	75.2°E
Imaging instrument	IMAGER	ABI
Channel wavelengths for cloudy AMVs (µm)	IR (10.7) Vis (0.65) WV (6.55)	IR (10.3) Vis (0.64) WV (6.15)
Time between full disk images	30 minutes	15 minutes
Pixel resolution	1km (Vis), 4km (IR and WV)	0.5km (Vis), 2km (IR and WV)

Table 1: **Instrument details for GOES-13 and GOES-16. (IR = Infrared, Vis = Visible, WV = Water vapour)**

INITIAL QUALITY ASSESSMENT

Change in data volume and distribution

Analysis of the GOES-13/-15 data with the new and old algorithm revealed an approximate doubling of the number of AMVs through the change in algorithm alone (not shown). However, once combined with the higher spatial and temporal resolution of ABI, the number of AMVs becomes four to six times higher (Figure 1). In addition to the increase, the distribution has also changed with proportionally fewer mid-level AMVs (400-700hPa). This change in pattern was also present in the GOES-13/-15 reprocessed data suggesting that the difference can be attributed to the new algorithm.

Stronger quality indicator relationship

The AMVs from GOES-13/-15 are provided with both forecast dependent and independent quality indicator (QI) values while GOES-16 data are distributed with the forecast independent value only. Traditionally at ECMWF, a threshold has been placed on the forecast independent QI value where sensible to eliminate data of obvious poorer quality in the first step of screening. Figure 2 shows representative examples of the dependence of RMSVD on the forecast independent QI value using the high level, northern hemisphere, infrared winds. For the GOES-13/-15 operational AMVs there is a weak relationship which led to using a threshold of 50 for assimilation (which in practice results in all the data being used as lower QI values are not disseminated). For GOES-16, figure 2 illustrates the strong dependence at high QI values above 85 and generally higher RMSVD at lower QI values.

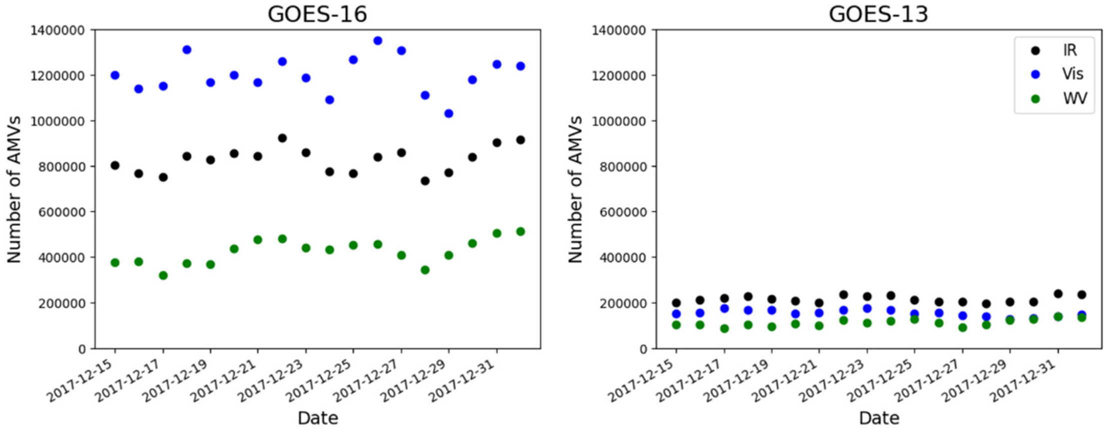

Figure 1 **Time series showing the daily number of AMVs derived for the infrared, visible and water vapour channels on GOES-16 (left) and GOES-13 (right). Data are from 15th Dec 2017 - 1st Jan 2018 and no prior screening has been applied.**

The stronger relationship and large numbers of GOES-16 AMVs with high QI suggests that a threshold of 90 might provide a good compromise between eliminating data of poorer quality while keeping a good number of observations. The presence of the stronger relationship in the new algorithm is a little unexpected however, although data producers at NOAA are confident in the outcome and proposed that the use of the auto-editor was a factor for the weak dependence in the past (J. Daniels, NOAA, pers. comm.).

Changes in speed bias and RMSVD

In the following we consider first guess departure statistics after screening has been applied, using QI thresholds and a first guess check which rejects AMVs that deviate too far from the model background value. Based on the above analysis, QI thresholds of 90, 85 and 50 were used for GOES-16, the reprocessed GOES-13/-15 and operational GOES-13/-15 data respectively. The bar charts in figure 3 give an example using the tropics of the vertical structure of the speed bias and RMSVD for the AMVs from the infrared channel in the tropics. GOES-16 and the reprocessed GOES-13 have been compared separately to the operational GOES-13 data (note that different time periods have been used). When considering the GOES-13 data using the different algorithms, the speed bias has generally become less negative/more positive while the RMSVD is mostly comparable or within 1m/s. This is similar for the other channels and geographic areas with the exception of large negative biases at low pressures (above 250hPa) in the extra tropics (not shown).

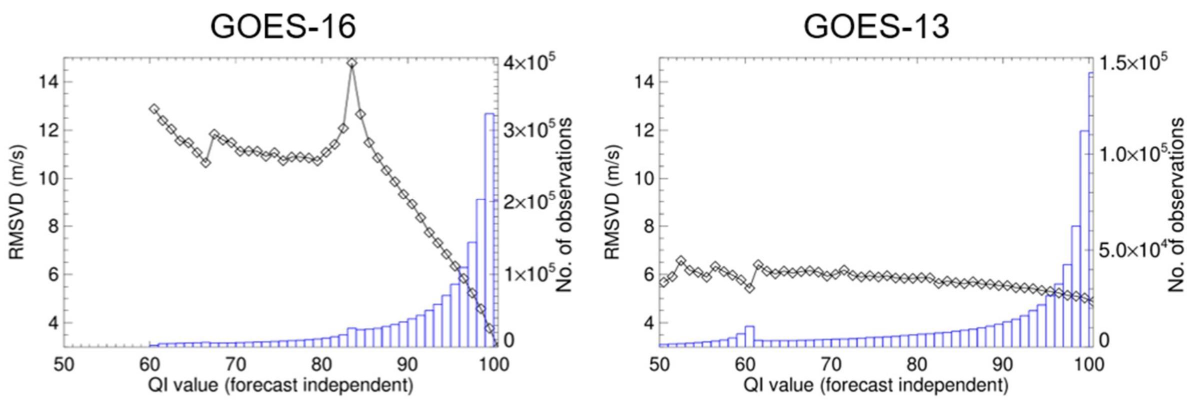

Figure 2 **Relationship between the RMSVD and forecast independent QI for the infrared channel on GOES-16 (left) and GOES-13 with the operational algorithm (right). Data are for the northern hemisphere (latitude > 25°N) and low pressure (P < 400hPa). No screening has been applied and data are from 15th Dec 2017 - 1st Jan 2018.**

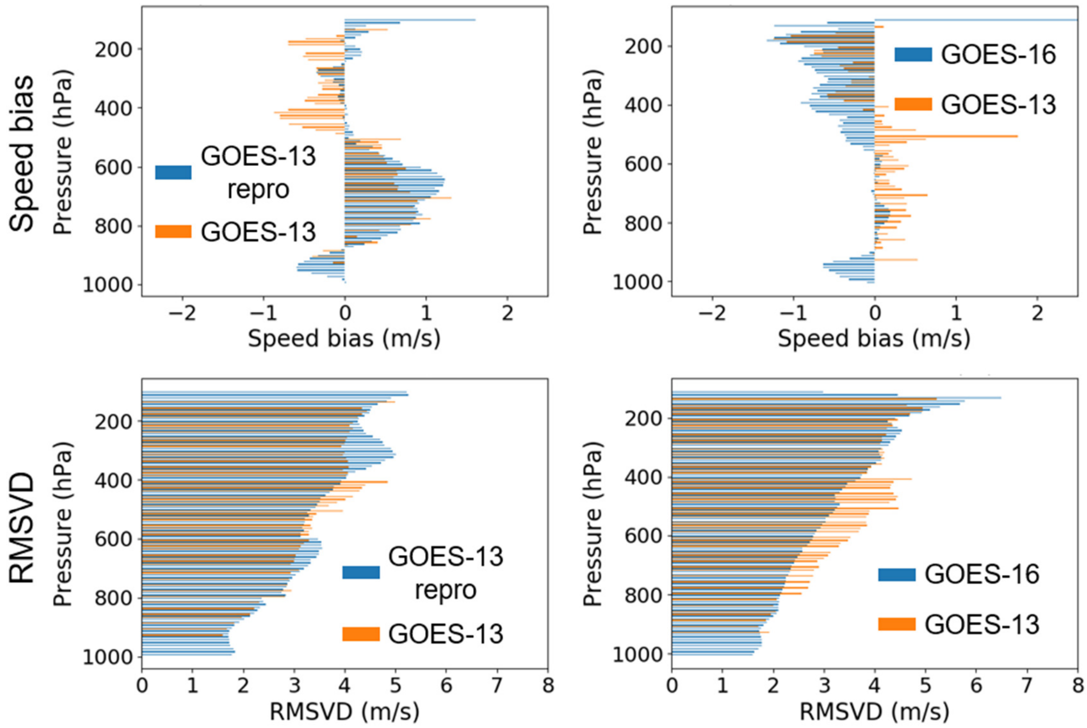

Figure 3 **Bar charts for the tropics (±25°N) showing the speed bias (top row) and RMSVD (bottom row) for the GOES-13 data using the new algorithm and operational (left column) and GOES-16 compared to GOES-13 (right column). Data are for the infrared channel using the period 1st March - 14th April 2016 for the reprocessed GOES-13/operational GOES-13 comparison and from 15th Dec 2017 - 1st Jan 2018 for the comparison of GOES-13/GOES-16. Data have been screened using satellite specific QI thresholds and first guess check.**

In contrast, figure 3 shows that when the algorithm is applied to GOES-16 in the tropics, the speed bias actually tends to be less positive/more negative. The large negative biases also appear in the extra-tropics at low pressure. This is in spite of the nested tracking approach in the algorithm which was intended to reduce negative speed biases. In the extra tropics, the infrared channel shows an area of positive speed bias (0.5-1m/s) around 400hPa, while the water vapour channel exhibits larger positive speed biases (2-2.5m/s) around 300-350hPa (not shown). The RMSVD for all three channels, however, is largely comparable and even a little improved in the tropic mid-levels for the infrared channel.

The regions of overlap of GOES-16 with adjacent satellites (GOES-15 to the west and Meteosat-10 to the east at the time of testing) were also considered. Maps of the differences in speed bias highlighted larger magnitude biases in GOES-16 at high levels in the tropics compared to both Meteosat-10 (figure 4) and GOES-15 (not shown). At lower levels (not shown), differences are smaller and more mixed between the satellites. For the RMSVD, values compared to Meteosat-10 are broadly smaller by 10-20% (figure 4). The difference with GOES-15 is more mixed though, for example with higher values for GOES-16 at high levels in the tropics while at low levels the agreement is similar.

The poorer performance of the GOES-16 data at high levels, in terms of RMSVD and speed bias, might be linked to sub-optimal height assignment identified by NOAA. A new version of the product is expected to be released in the near future. This aims to address slow biases observed in their own analysis found at low pressures, peaking at around 200hPa and at 500-600hPa in addition to positive speed biases in mid latitudes around 400-500hPa (e.g. presented at the 14th International Winds Workshop, 2018, http://cimss.ssec.wisc.edu/iwwg/iww14/talks/01_Monday/1400_IWW14_ABI_AMVs_Daniels.pdf, retrieved 6th Nov 2017). It is also important to remember that when comparing the new algorithm to the operational algorithm the auto-editor gives an unfair advantage. While statistics may look 'better' for the operational product, this is at the expense of independence from NWP and smaller first guess departures will be partially as a result of agreement between the ECMWF and NCEP model wind fields.

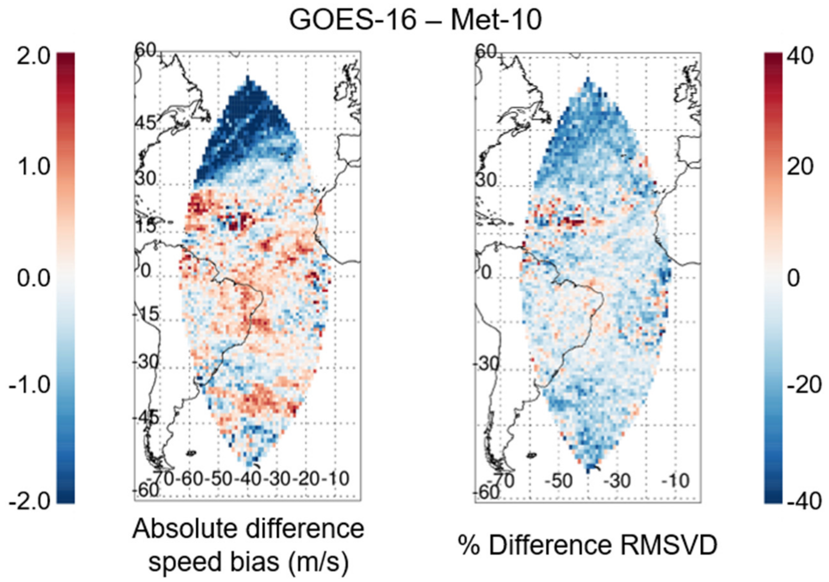

Figure 4 **Maps showing the difference in absolute value of speed bias (left) and RMSVD (right) for GOES-16-Meteosat-10 at low pressure. Blue colours indicate a speed bias closer to zero or lower RMSVD for GOES-16. Data are from the infrared channel after QI and first guess screening have been applied and for the dates 15th Dec 2017 - 14th Jan 2018.**

ASSIMILATION EXPERIMENTS

Experiment configuration

With encouraging first guess departure statistics for GOES-16, the next step was to consider the impact on the forecast by assimilating the data. To do this a control run was completed using a lower resolution version (T_{Co}399 (55km)) of the operational forecast system (cycle 43r3 at the time of testing). This contains the full observing system apart from AMVs from a GOES-East satellite. Experiments were then run which added the GOES-16 AMVs in various configurations. Verification focuses on two areas: changes in the fit of independent observations to the model background and the changes in RMSE error for various forecast variables (e.g. vector wind, humidity) at different lead times verified against the corresponding own analysis. Results presented here are for the period 20th December 2017 - 9th March 2018. This is a relatively short experimentation period for such a change, and results may therefore not be as robust as usually preferred. However, the short experimentation period was chosen in order to minimise the time without a GOES-East satellite due to the extremely short overlap period of GOES-13 and GOES-16.

During assimilation, the AMVs are subject to screening by QI, first guess check and satellite specific spatial blacklisting. There are then spatial and temporal thinning procedures. For all AMVs, the horizontal thinning uses 200x200km boxes while vertically the thinning distance varies 50-175hPa. Temporal thinning for AMVs is set at 30 minutes. However, for GOES-13/-15 the winds were only used three hourly after experiments with the hourly product gave negative results (Salonen and Bormann, 2013a). The hourly product for GOES-16 was used in this first implementation but in future investigations, it would be worth exploring whether different temporal thinning would be beneficial.

Initially, less conservative use of the data was trialled - in addition to screening using a QI threshold of 90 (as discussed earlier) and the first guess screening, the spatial blacklisting of the data was more relaxed compared to other geostationary satellites. However, significant negative impacts were seen at high levels in the tropics both in the fit of conventional wind observations to the model background and an increase in RMSE in the short range forecast vector wind field. The tropics are an area where it has been more challenging to add AMVs - both Himawari-8 and the two Meteosat satellites currently in operational use have screening applied in the mid and low levels. GOES-16 unusually presented a stronger signal at the upper levels which may be linked to sub-optimal height assignment and has the potential to be improved in the future changes from NOAA. For now, more restrictive use of the data in the tropics was sufficient to eliminate this negative signal.

Based on first guess departure statistics and using the experience from the initial experiments making bolder use of the data, the configuration proposed for GOES-16 is to allow AMVs derived from each channel as follows:

- Visible: pressure > 700hPa for all latitudes
- Infrared: pressure > 150hPa for |latitude| ≥ 25, 200hPa < pressure < 300hPa for |latitude| < 25
- Water vapour: 150hPa < pressure ≤ 300hPa for |latitude| ≥ 25 and 200hPa < pressure for |latitude| < 25

The above spatial blacklisting is in addition to more general screening for geostationary satellites which results in GOES-16 AMVs also being removed for zenith angles above 64°, over land at all pressures for latitudes northwards of 20°N, and all AMVs over land with pressure > 500hPa at other latitudes. Despite the stricter spatial blacklisting, two to three times more AMVs pass the combined quality control and blacklisting applied to GOES-16 compared to GOES-13 over the disk as a whole. This is primarily due to the higher density of GOES-16 AMVs and due to using the winds hourly rather than 3-hourly.

Prior to testing in assimilation, components for the AMV observation errors are also calculated. AMVs use situation dependent observation errors which combine the tracking error and error in speed due to error in height (Salonen and Bormann, 2013b). In practice, the same values for the tracking error are used for all geostationary satellites with values ranging from 2-3m/s depending on height. These were found to be appropriate also for GOES-16. For the error in the height assignment, statistics for GOES-16 (calculated after the spatial blacklisting described above) were similar to GOES-13/-15 and Meteosat-10.

Experiment results

In the verification against own analysis, the addition of GOES-16 reduces the RMS vector wind error particularly at high pressures and in the southern hemisphere in the very short range forecast ranges up to T+48 (Figure 5). Considering maps of the impact (not shown) there is a clear area of vector wind error reduction in much of the ocean region of the GOES-16 disk at 850hPa and over South America at 200hPa.

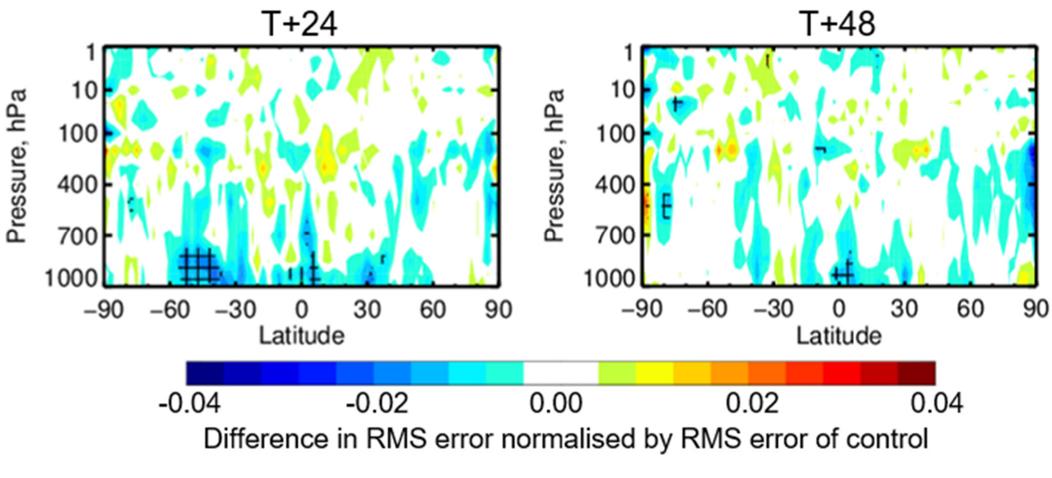

Figure 5 **Zonal plots of the change in vector wind RMS error verified against own analysis for 24 and 48 hour lead times comparing the addition of the GOES-16 to the control with no GOES-E AMVs. Data are from 20th Dec 2017 - 9th March 2018. Blue colours signify improvement for adding GOES-16 and black hatched lines indicate significance at the 95% level.**

Considering the change of other observations to the model background, over large geographic areas (e.g. the tropics) the impact on conventional wind observations was neutral. When focusing the verification over the area of disk of GOES-16 (±60°N, 0-150°W), changes were either neutral or small positive though not consistently seen in both radiosonde and pilot balloon verification (figure 6). A longer experiment period may help to reduce the uncertainties in the impacts and reveal any significant changes. The introduction of wind observations can also indirectly lead to effects on the humidity fields. Over the same GOES-16 region, the humidity sensitive channels of the Advanced Technology Microwave Sounder (ATMS) show a significant reduction in standard deviation of around 0.5% (not shown).

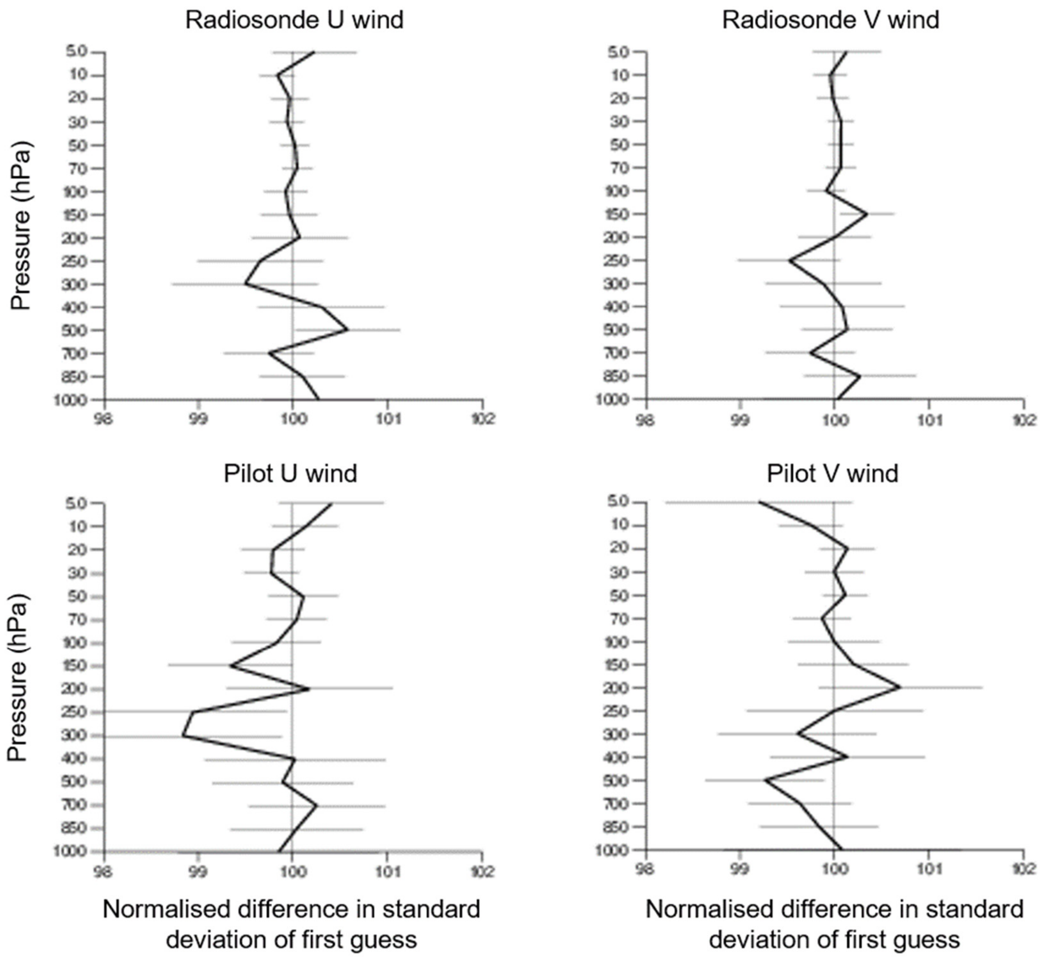

Figure 6 **Change in the standard deviation of the first guess U component (left) and V component (right) of wind for the radiosonde (top row) and pilot balloons (bottom row) for the addition of the GOES-16 compared to the control with no GOES-E AMVs. Points to the left of the 100% line indicate a reduction in standard deviation and therefore improvement to the background through introduction of GOES-16 AMVs. Data are from 20th Dec 2017 - 9th March 2018 and restricted to the area ±60°N, 0-150°W. Error bars indicate significance at the 95% level.**

The impact from GOES-16 shows promising results, despite more conservative use. With the improvements to the height assignment anticipated from NOAA it is hoped that the impact will be further improved in the future and the blacklisting can eventually be less restrictive.

SUMMARY AND FUTURE WORK

GOES-13 AMVs have been replaced by GOES-16, after a gap in coverage, on 22nd May 2018. In moving to a newer generation satellite with a more advanced imaging instrument combined with a new AMV derivation algorithm, there is an over four-fold increase in the number of AMVs available. The distribution has also changed with AMVs concentrated more into narrower bands in the upper and lower troposphere. GOES-13/-15 data reprocessed with the new algorithm suggested a change in data quality characteristics. In particular, the speed biases appeared less negative or more positive. However, it transpired that these results were not a reliable indicator of the behaviour of the algorithm once applied to the newer satellite where speed biases were in fact often less positive or more negative. A stronger relationship with the QI was also found with GOES-16 allowing an appropriate threshold to be chosen for screening poor quality observations. After basic screening steps, data quality was broadly comparable with GOES-13/-15 and even improved in RMSVD over Meteosat-10. There were also some specific areas likely related to a suboptimal height assignment where GOES-16 exhibited worse agreement with the model background. More conservative spatial blacklisting was required in assimilation in order to avoid negative impacts in the high level tropical wind fields. Impacts were largely neutral although there were some significant reductions in the vector wind error at short forecast lead times in the low levels.

Improvements to the height assignment stage of the AMV algorithm are anticipated from NOAA in the near future. These are expected to address some of the data quality issues particularly at high levels and reassessment is anticipated. Due to the time constraints with getting GOES-16 into operational use it was not possible to run as extensive testing as usual and with the change to the derivation coming soon, the decision was made to wait for the next version of the data before trying to refine the configuration such as considering different temporal thinning options or modified observation errors.

It is hoped that further benefit can be extracted from GOES-16. Looking ahead to GOES-17, it may be useful to keep in mind some of the characteristics seen here, however, the issues identified with the instrument regarding the cooling system required for the infrared channels (e.g. https://www.nesdis.noaa.gov/content/experts-moving-closer-resolving-troubles-noaas-goes-17-abi, retrieved 6th Nov 2018) will present new challenges in best using the data.

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