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Replacement of GOES-15 with GOES-17 AMVs

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Executive summary

GOES-17 is the second new generation satellite in the GOES-R series, after GOES-16, carrying the Advanced Baseline Imager (ABI) from which Atmospheric Motion Vectors (AMVs) are derived. It replaces GOES-15 as the primary satellite in the GOES-West position at 137.2°W. Being the same generation as GOES-16, both satellites carry the same imaging instrument while also using the same wind derivation algorithm. Consequently, it would be reasonable to expect the data quality of GOES-17 to be very similar to GOES-16. However, onboard issues with the cooling system have been found to be periodically degrading the performance of the GOES-17 infrared channels which are essential to the production of AMVs. The problem leads to intervals where the imager data are unusable during local night-time with transition times where data quality is variable.

During times unaffected by the cooling issues, the combination of the different instrument and algorithm results in a large increase in the number of AMVs and changes in data characteristics compared to it's predecessor, GOES-15. Similar changes were observed in earlier work when moving from GOES-13 to GOES-16 (Lean and Bormann, 2019). Analysis using first guess departure statistics further shows that there is good agreement in the overlap region with GOES-16 while the instrument is operating normally. However, during transitional times where onboard cooling issues are in effect there is a decline in AMV numbers and a noticeable degradation in the quality. There are large differences in the assigned pressure of the AMVs between GOES-17 and GOES-16 indicating that the degradation in the infrared channels has a significant impact in the performance of the optimal estimation height method.

Assimilation experiments tested the replacement of GOES-15 with GOES-17 using different levels of restriction on use of the data around periods affected by the cooling issues. Results show that GOES-17, even with the strictest screening option that removes all data from 9-17Z, has a positive impact. Significant reductions in the vector wind forecast error were observed in the verification against own analysis. Small positive changes were also present in the fit of independent observations to the model background such as conventional wind over the Americas and humidity sensitive channels on the Advanced Technology Microwave Sounder (ATMS) in the southern hemisphere. Changes were generally comparable or in some cases exceeding the impact from GOES-15. Active assimilation of GOES-17 AMVs started on 10th December 2019.

1 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 1st March 2018, GOES-17 was launched and initially stationed at 89.5°W. After a commissioning phase, the satellite was drifted to its final position at 137.2°W, arriving 13th November 2018. It became recognised as the operational GOES-West satellite, taking over from GOES-15, on 12th February 2019. GOES-15 remained in operation until 2nd March 2020 although its position drifted from 135°W to 128°W to accommodate its successor. This provided a good length of parallel data reception from both satellites for comparison while the adjacent and overlapping coverage from GOES-16 was also used for the assessment. Operational monitoring of GOES-17 AMVs at ECMWF started on 19th November 2019 while active assimilation began on 10th December 2019.

Key attributes of GOES-15 and -17 relevant for the AMVs are summarised in Table 1. GOES-17 is the second in the third generation of GOES satellites after GOES-16. It carries the Advanced Baseline Imager (ABI) which is more advanced than its predecessor, the IMAGER instrument, on GOES-15 with 16 channels compared to 5 channels previously. This results in five channels available for AMV cloud and water vapour tracking whereas three were used on GOES-15. In practice, although there are three water vapour channels, cloud tracked winds are currently only produced from the shortest wavelength (6.15μm), as for GOES-16. ABI also has a higher temporal and spatial resolution. Due to restrictions in the scanning sequence of GOES-15, the coverage in the southern hemisphere stopped around 45°S and also did not cover the full extent on the east side of the disk. By contrast, GOES-17 now provides winds over the full disk as illustrated in figure 1.

Coupled with a new instrument, the AMV derivation algorithm for GOES-17 (and GOES-16) is also considerably different from GOES-15. GOES-15 uses long-established tracking and height assignment methods and 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-17, this auto-editor step is removed and both the tracking and height assignment steps use new techniques. The tracking step is now carried out using a nested tracking technique which derives vectors from multiple targets within a search box and uses a cluster analysis algorithm to get the dominant motion (Daniels et al., 2012). Meanwhile, the height assignment is now carried out by an optimal estimation technique. The ABI Cloud Height Algorithm (ACHA) is used to derive cloud parameters including the cloud top height for use in the AMV product (Bresky et al., 2012; Heidinger, 2013). Further discussion and analysis of the impact of the algorithm change can be found in Lean and

Table 1: Instrument details for IMAGER on GOES-15 and ABI on GOES-17. (IR = Infrared, Vis = Visible, WV = Water Vapour)

	GOES-15	GOES-17
Position	128°W	137.2°W
Imaging instrument	IMAGER	ABI
Channel wavelengths for cloud tracked AMVs (μm)	IR (10.7) Vis (0.65) WV1 (6.55)	IR (10.3) Vis (0.64) WV1 (6.15)
Pixel resolution (at sub-satellite point)	1km (Vis), 4km (IR, WV)	0.5km (Vis), 2km (IR, WV)
Time between full disk images	30 mins	10 mins

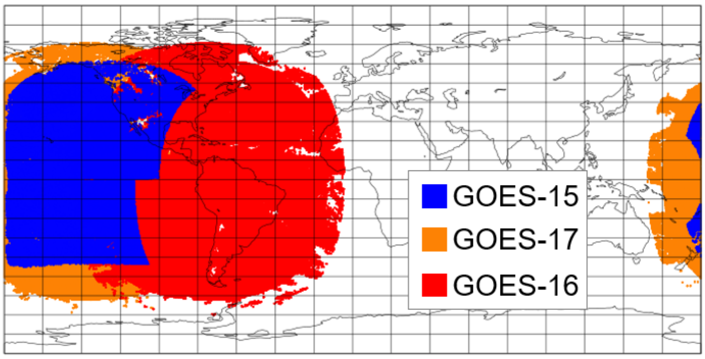

Figure 1: Typical coverage for a model cycle (00Z 1st Feb 2020) for GOES-17, -16 and -15 AMVs.

Bormann (2019) which details the transition from GOES-13 to GOES-16.

Strong similarity between GOES-17 and GOES-16 was expected, however there are issues with the onboard cooling system on GOES-17 which regulates the temperature of the ABI detectors for the infrared channels. The severity of the issue varies on a longer seasonal timescale linked to the illumination of the sun with the worse affected periods in the pre- and post-weeks of the spring and autumn equinoxes (Seybold, 2018). There is also diurnal variation with issues only during the local night-time (e.g. Mozer et al. (2019), latest estimates at `https://www.goes-r.gov/users/GOES-17-ABI-Performance.html`, visited 31st March 2020). As the sun illumination increases the detectors cannot be maintained at the cold operating temperature required. At a relatively small increase in temperature the noise increases or there may be striping features in the imagery. At the worst affected times during much higher temperatures, total saturation of the channel occurs and the data are unusable. The point at which a channel becomes saturated also varies according to the temperature - some channels reach saturation at a lower temperature, with the 13.3μm channel (which is used in the height assignment) being one of the first affected by rising temperature. This clearly impacts the derivation of winds so an important aspect of this assessment is to determine when the data are of sufficient quality to use.

After summarising the data sources, availability and limitations due to the cooling issues in section 2 the data quality assessment of the GOES-17 AMVs is presented (section 3). Here, first guess departure statistics (differences between observations and model background values provided by a short T+12 hour forecast from the previous model cycle) are used to characterise the AMVs and allow comparison to GOES-15 and overlapping regions with GOES-16. The relatively stable characteristics of NWP provide an effective method of assessing anomalies in the observations such as those expected by the cooling issues. In section 4 results from the assimilation of the GOES-17 will be presented and section 5 will summarise the work and look at future use of GOES-17. The focus in this report is the replacement of the AMVs however, a Clear Sky Radiance product from GOES-17 is also still in development for use at ECMWF.

2 GOES-17 data

2.1 Data sources

Data from GOES-17 were initially received and stored from 7th May 2019 through a FTP site (`https://www.star.nesdis.noaa.gov/smcd/opdb/goes/g17_dmw/`) in Binary Universal Form for the Representation of meteorological data (BUFR) format. Later in October 2019 a switch was made to acquire data via the Global Transmission Service (GTS) which is also used for GOES-15 and -16.

For the initial data quality assessment statistics are calculated using the difference between observations and the model background provided by experiments using a reduced resolution version ($T_{Co}399$ (25km)) of cycle 46r1 of the model which was the operational system at the time. In this experiment, GOES-17 AMVs were only monitored and not assimilated. At ECMWF, only AMVs derived from cloudy scenes are assimilated, so the analysis presented here will only include the infrared, visible and single water vapour channel used for cloud tracked winds.

2.2 Instrument cooling issues

At certain times of the year, during the local night-time, the sun is in the exact orientation to heat the detectors on ABI but a fault in the cooling system means that it cannot maintain the stable temperature required for operation. Estimates of the peak longwave infrared focal plane temperature have been predicted by NOAA (e.g. Mozer et al. (2019) shows the 2019 estimates used to aid decisions in this report) to represent the heating extent. While the detectors are temporarily at very elevated temperatures, images can reach saturation levels that render the data completely unusable. Figure 2 shows the latest estimates of peak night-time focal plane temperatures for 2020 and the previous 2019 estimates reproduced from online documentation from NOAA (Seybold et al., 2020; Mozer et al., 2019). The severity for different infrared channels varies with temperature and therefore some are affected for longer portions of the night and on more days of the year. Figure 2 also indicates with horizontal lines the temperature threshold at which saturation is expected for the different ABI channels with channels 12 and 16 (9.7μm and 13.3μm respectively) being the worst affected.

The estimates for 2019 and 2020 have broadly similar patterns but differences include:

- Estimates for 2019 being shifted around 2-4K cooler
- A period through June/early July 2019 where the temperature remains the same (around 81K)
- Different placement of thresholds for saturation of the channels leading to slightly altered dates and ordering in which channels are estimated to reach saturation

The cause of these differences is from better understanding of the behaviour of the instrument but also from natural evolution of the situation over time (pers. comm. M. Seybold, NOAA).

Before reaching saturation, the quality of the images passes through a transitional phase which has been referred to by NOAA as the "marginal" period. During these times, the data may be affected by increases in noise and striping but are recommended by NOAA to still be of qualitative use. Figure 2 shows the transition to saturation is gradual with the number of hours affected during the local night-time also increasing. The temperature may eventually rise sufficiently on a given night for a channel to reach

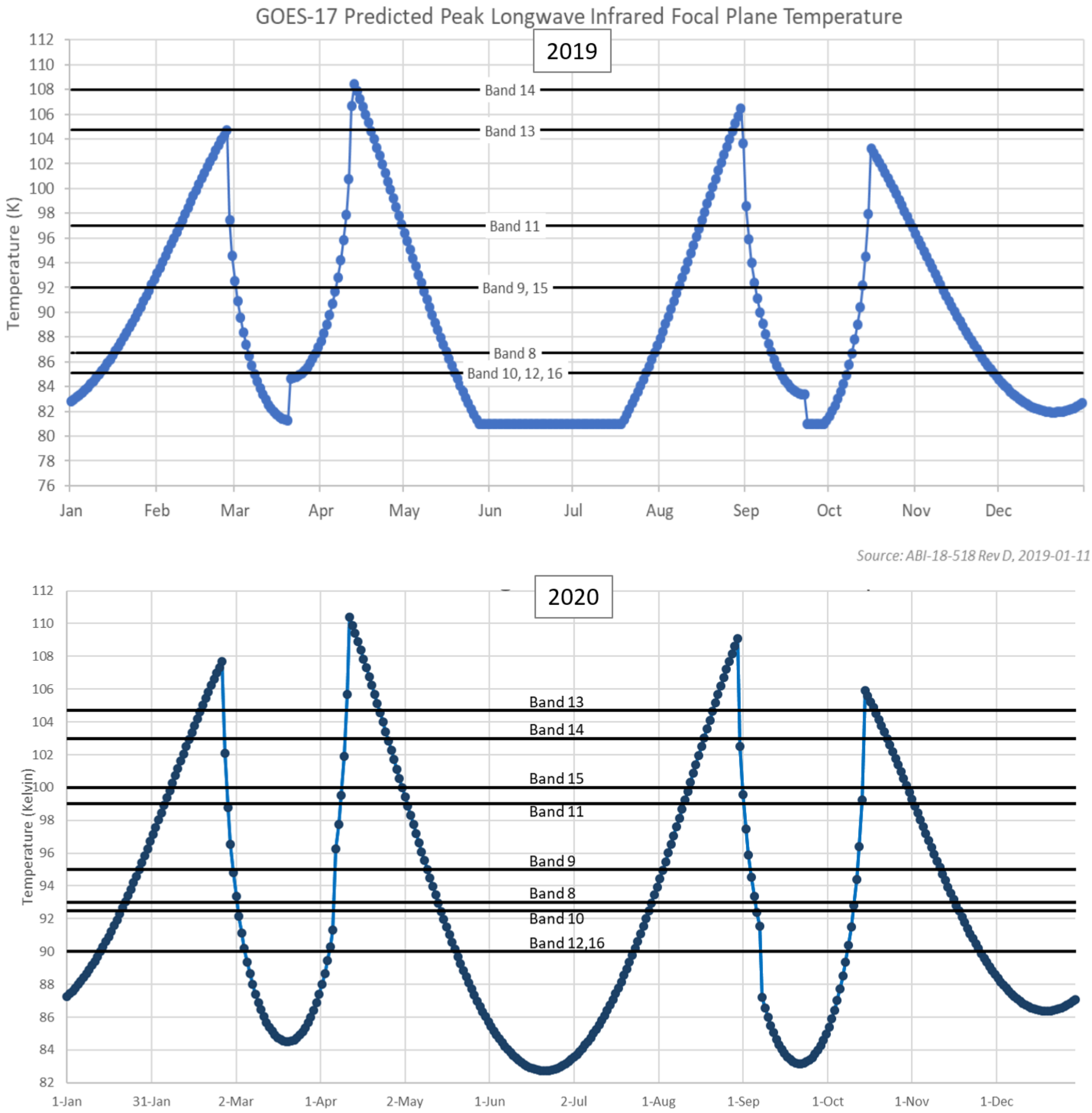

Figure 2: Time series showing the daily maximum temperature of the ABI focal plane module (occurring during the satellite local nighttime). Where the temperature exceeds the threshold for each of the instrument channels, image from that channel may be saturated and unusable. Figure is reproduced from Mozer et al. (2019) and Seybold et al. (2020) with kind permission of NOAA.

saturation but prior to entering this phase and as the instrument subsequently cools, the imagery return to the transitional situation. In this report, we will also refer to this state as the "marginal" period.

There have been efforts to understand and mitigate the effects of the cooling issues, in particular to try to improve the marginal situations. A method known as "predictive calibration" aims to use the predictable behaviour of the temperature increase to create a correction for each channel (McCorkel et al., 2019). This was applied operationally from 25th July 2019 (Lindstrom, 2019) and aims to improve the marginal periods, especially while the temperature is still relatively low, but during the occurrences of full saturation the data remains irrecoverable.

As the AMVs track features in the images and rely on the radiance measurements from a combination of infrared channels to estimate the height of the wind, increased noise and saturation of the infrared channels is clearly problematic. For the data used in this study and at the time of writing, NOAA derive AMVs whenever the algorithm is capable and all winds are subsequently subject to the same processing strategy regardless of the status of the instrument at the time. This means that at present it is left to the data user to decide the criteria for acceptable data quality. In the future, NOAA plan to make the channel selection for the height assignment adaptive to the instrument status and will reject winds based on thresholds of the focal plane module temperature (Daniels et al. (2019), pers. comm., J. Daniels, NOAA). During the worst affected times the image saturation means that relatively few winds can be produced. McCorkel et al. (2019) suggested the initial detection of features and the wind speed acquired from the tracking step was not greatly impacted by the cooling issues (before saturation occurs). However, results discussed later this report suggest that the height assignment step is significantly affected. A challenge in this investigation is to determine whether the quality of winds produced during the marginal periods is still sufficient for assimilation.

3 Initial quality assessment

3.1 Change in data volume and distribution

When looking at a timeseries of the number of AMVs for GOES-17, -16 and -15 it is clear that the cooling issues affect the ability to derive the winds. Figure 3 shows two timeseries of the daily number of high level infrared AMVs spanning three months. To distinguish the impact from the cooling issues, the data were split in times likely worst affected by the cooling issues (11-15Z) and more normal operational function outside this interval. It starts at a time where the cooling issues are predicted to have little or no effect, then the peak temperature rises through August to its estimated maximum at the end of August 2019 before reducing again through September (as illustrated earlier in figure 2).

During the period of likely normal operation (figure 3, left panel) GOES-17 numbers are similar to GOES-16 (apart from some data outages) and 4-5 times larger than GOES-15. Analysis in Lean and Bormann (2019) showed that when moving from GOES-13 to GOES-16 there was a substantial increase of around four-six times more AMVs from GOES-16. This was also accompanied by a change in distribution with AMVs more concentrated into the lower and upper troposphere for GOES-16 which is also seen here for GOES-17 and GOES-15 (not shown). Both changes in the resolution (temporal and spatial) of the imaging instrument and the algorithm change contributed to these changes.

In the times affected by cooling issues, the number of AMVs produced only appears to decrease during the more severe heating. Despite the 13.3μm channel being predicted to reach saturation around the last week of July, numbers seem little impacted until at least after the first week of August. For the water

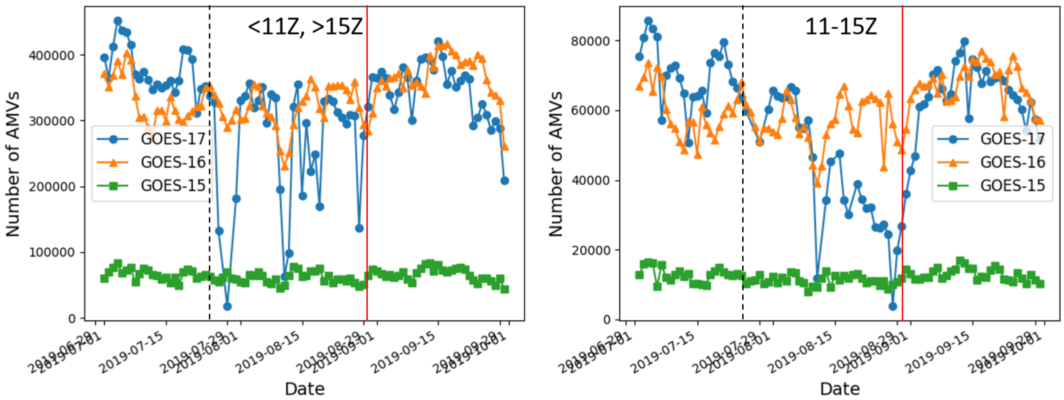

Figure 3: Time series showing the daily number of AMVs derived for the high level (P < 400hPa) infrared AMVs from GOES-17, GOES-16 and GOES-15 for all times excluding 11-15Z (left) and only for 11-15Z (right). The black dashed line approximately indicates the point the 13.3µ is predicted to reach saturation. The red line indicates where the peak of the heating is predicted. Data are from 1st July - 30th Sept 2019. No screening has been applied.

vapour channel, the reduction in numbers is more sudden in early August to around or below GOES-15 numbers before recovering in the first week of September. In this figure we use 11-15Z to cover the worst affected hours. However, as the changes are gradual it might be that initially, for example, winds within only one hour are affected by saturated imagery with a transition ("marginal") period during the other hours. By the peak heating towards the end of August most of the time interval should have severe saturation problems across all the longwave infrared channels. Unfortunately, as this affects the infrared channels during the local night-time when visible channel winds are not available, it means that there are periods when relatively very few AMVs are available. However, even during the worst days, the number of IR AMVs is still mostly higher than GOES-15 for the 11-15Z window.

3.2 Quality indicator relationship

GOES-17, as for GOES-16 data, are distributed with the forecast independent quality indicator (QI) value. 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. When the analysis was carried out in Lean and Bormann (2019) there was a strong relationship for GOES-16 between the RMSVD and high values of QI leading to a threshold of 90 for screening. However, since that study, NOAA have applied updates to their processing which has removed this dependence, leaving a weak relationship with RMSVD as was found for GOES-13/-15. Figure 4 shows examples of the dependence of RMSVD on the QI value using the high level, northern hemisphere infrared winds for GOES-17 and GOES-16. The patterns here are representative of other geographic areas, heights and channels and data are from July 2019 when the affect from cooling issues should be minimal. The ability of the QI to identify poorer quality data around periods affected by the heating problems will be discussed later (see section 3.4).

GOES-17 and GOES-16 show good agreement in their weak dependence on QI. For GOES-15 the lack of QI dependence led to using a threshold of 50 which in practice results in all the data being used as data with lower values are not disseminated. For GOES-17 a threshold of 90 has been chosen to be consistent with the use of GOES-16. Due to the large fraction of observations with a high QI value this still permits

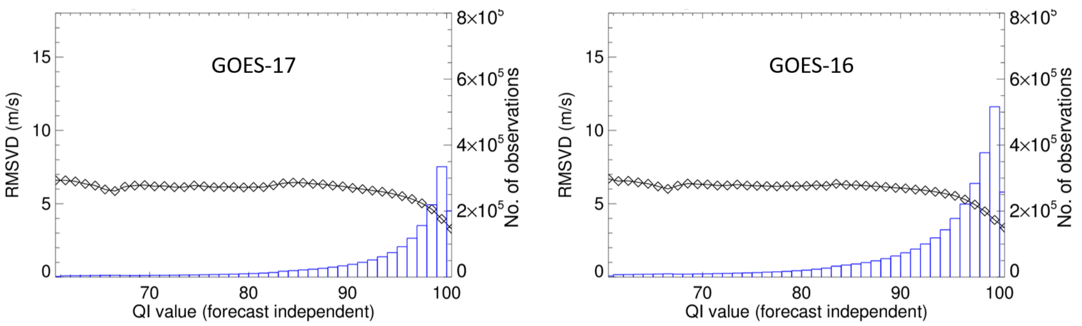

Figure 4: Relationship between the RMSVD and forecast independent QI for the infrared channel on GOES-17 (left) and GOES-16 (right). Data are for the northern hemisphere (latitude > 25°N) and low pressure (P < 400hPa). Bars indicate the number of AMVs assigned the corresponding QI value. No screening has been applied and data are from 1st - 31st July 2019.

a significant number of winds. However, in the future it would be good to revisit the threshold placed on both GOES-16 and GOES-17 to investigate whether a lower value may be more beneficial.

3.3 Data quality during normal operations

During normal operational conditions, there is very good agreement in the departure statistics between GOES-17 and GOES-16. For example, figure 5 (top row) shows similar RMSVD values and patterns in speed bias for the tropics. Differences in magnitude of the speed bias likely arise here from the different geographical coverage. While the infrared winds are presented here, equivalent results were also found for the water vapour and visible channels. The RMSVD and speed bias for GOES-17 and GOES-15 is also of similar magnitude in general across the different channels and geographical areas, however, the pattern in speed bias changes. In figure 5 (bottom right) the speed bias for GOES-15 is mostly negative while for GOES-17 it is positive apart from the low pressure (above 200hPa) where it is particularly negative. This change in characteristics is similar to the comparison of GOES-16 and -13 and can be attributed to both the changes in the algorithm and instrument. Similarity in the RMSVD values was also seen in comparison between GOES-16 and -13. GOES-17 is able to achieve a similar data quality as GOES-15 but a far greater number of winds available and using an algorithm that no longer has the stronger NWP dependence introduced by the autoeditor.

By collocating GOES-17 and GOES-16 it is possible to make a more direct comparison of the two satellites. Figure 6 (left) shows the difference in speed bias for AMVs during the period 8-12th May, excluding the times 10Z-15Z, using collocation criteria of AMVs within ±0.1°latitude/longitude and within 30 minutes. There is very good agreement as expected between the two satellites. Figure 6 (right) shows the difference in the assigned pressure which displays an east-west gradient. This is not a concerning pattern though - a feature of similar magnitude was also seen when comparing Meteosat-8 and Meteosat-10 (Lean and Bormann, 2018). It is likely due to difference in the viewing geometry - different parts of the cloud will be visible to the two satellites with more of the side of the cloud seen at the higher zenith angle leading to a lower height. Additionally the scan edges are more difficult for AMV derivation with the coarser resolution . Through the centre longitude line of the overlap where the viewing angles are equivalent, there is very little difference between the satellites.

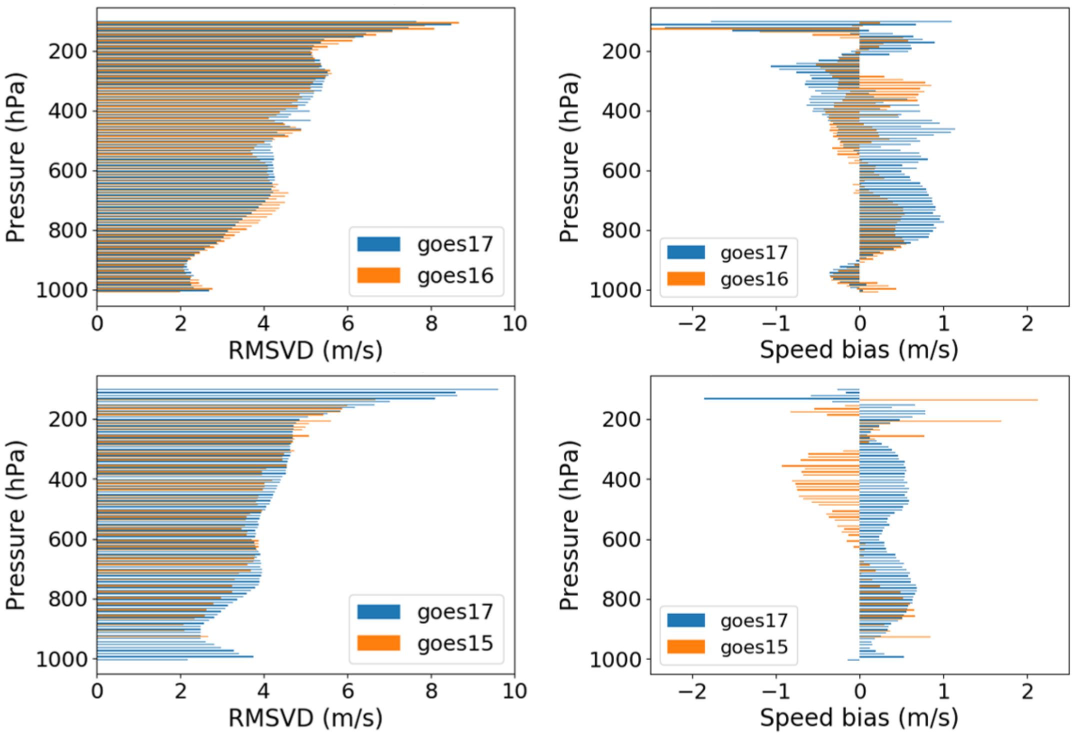

Figure 5: Top row: Bar charts for the tropics (±25°N) showing the RMSVD (left) and speed bias (right) comparing GOES-17 and GOES-16 data. Bottom row: As above, but for the northern hemisphere (>25°N) and comparing GOES-17 and GOES-15. Data are for the infrared channel using the period 1st - 31st July 2019. No screening has been applied.

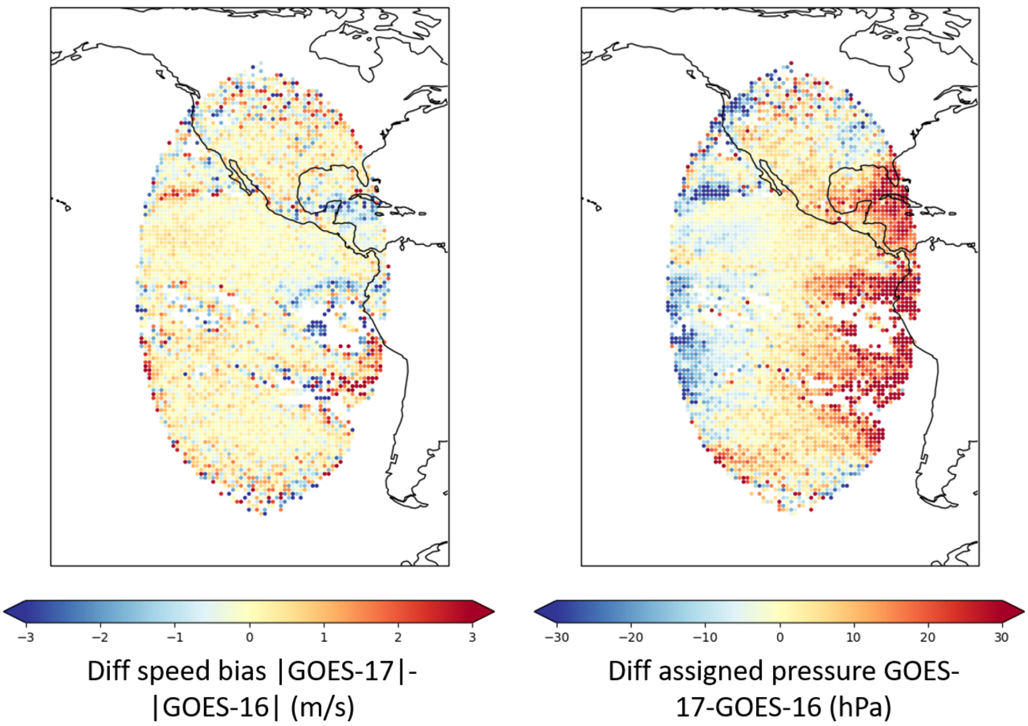

Figure 6: Difference in absolute speed bias value (left) and assigned pressure (right) between collocated GOES-17 and GOES-16 high level (P < 400hPa) infrared AMVs for the period 8th - 12th May excluding the hours 10-15Z.

3.4 Data quality affected by cooling issues

During normal operations GOES-17 is clearly performing well with close agreement to GOES-16. However, when the instrument temperature rises due to failures in the cooling system, there can be an adverse effect on both the number of AMVs and their data quality. Figure 7 shows timeseries using GOES-17 and GOES-16 high level IR winds to illustrate the problems which span July to September 2019 as used for the daily number of AMVs discussed earlier in figure 3.

When considering the corresponding data quality, GOES-17 shows a departure from GOES-16 in both the speed bias and RMSVD (figure 7 (top row)). The speed bias becomes more positive than GOES-16 particularly at the end of August and early September. Meanwhile the RMSVD shows more of a difference in August, returning to comparable values with GOES-16 almost at the beginning of September, just after the peak in heating. During the more marginal periods (in July and later in September when no channels are expected to be fully saturated), the statistics remain similar to GOES-16. Figure 7 (bottom) also reveals that the assigned pressure is also affected. Key infrared channels for the height assignment are subject to the saturation making this aspect of the derivation more sensitive to the changes. The water vapour channel also shows a difference between GOES-17 and GOES-16 mostly during August however the deviation is less pronounced (not shown). As there is a greater relative loss of water vapour winds this might indicate that during the heating period it is more difficult to produce winds at all rather than a wind but of poorer quality.

Probing the period a little further where a selection of channels, but not all, may reach saturation during the local night-time, figure 8 focuses on the hourly changes in statistics over five days (8-12th May). This corresponds to dates where the estimate of peak focal plane temperature is roughly just under half way between the peak and baseline and channels 8, 10, 12 and 16 may experience temporary full saturation. Figure 8 (top) shows the periodic drop in AMV number affecting mostly only around two hours at each instance. The impact on the corresponding RMSVD values (figure 8 (middle)) is less clear with some elevated values but less of an obvious periodic pattern. However, in the speed bias (figure 8 (bottom)) these same hour slots match the locations of discontinuities in the timeseries. Adjacent hours sometimes exhibit significant jumps in the magnitude of the bias of 5-6m/s. Generally, the obvious changes in data quality and drop in AMV number at this stage seem to be confined to fewer hours than the full at risk period of eight hours estimated by NOAA.

Though hourly averages might be a little noisy, the same plot for GOES-16 does not contain such features (not shown). These jumps are likely linked to the poorer height assignment of the winds. The average difference in assigned pressure between collocated GOES-17 and GOES-16 AMVs during potentially impacted hours (11-15Z) for the same 8-12th May period no longer exhibits the east-west pattern seen in figure 6. Instead the pattern is noisy with large differences in pressure, often in excess of 20hPa (figure 9) . The corresponding average QI value during this period showed little indication of degraded quality at these hours (not shown) making it difficult to screen by defining a threshold. However, during the worst affected times (for around 2 weeks at the latter half of August) the average QI value does fall periodically to around 50-60.

4 Assimilation experiments

First guess departure analysis shows that at times unaffected by the cooling issues, the performance of GOES-17 is very similar to GOES-16. The next step is to assess the impact of the data on the forecast through assimilation experiments. For times of normal operation, the same configuration already in use

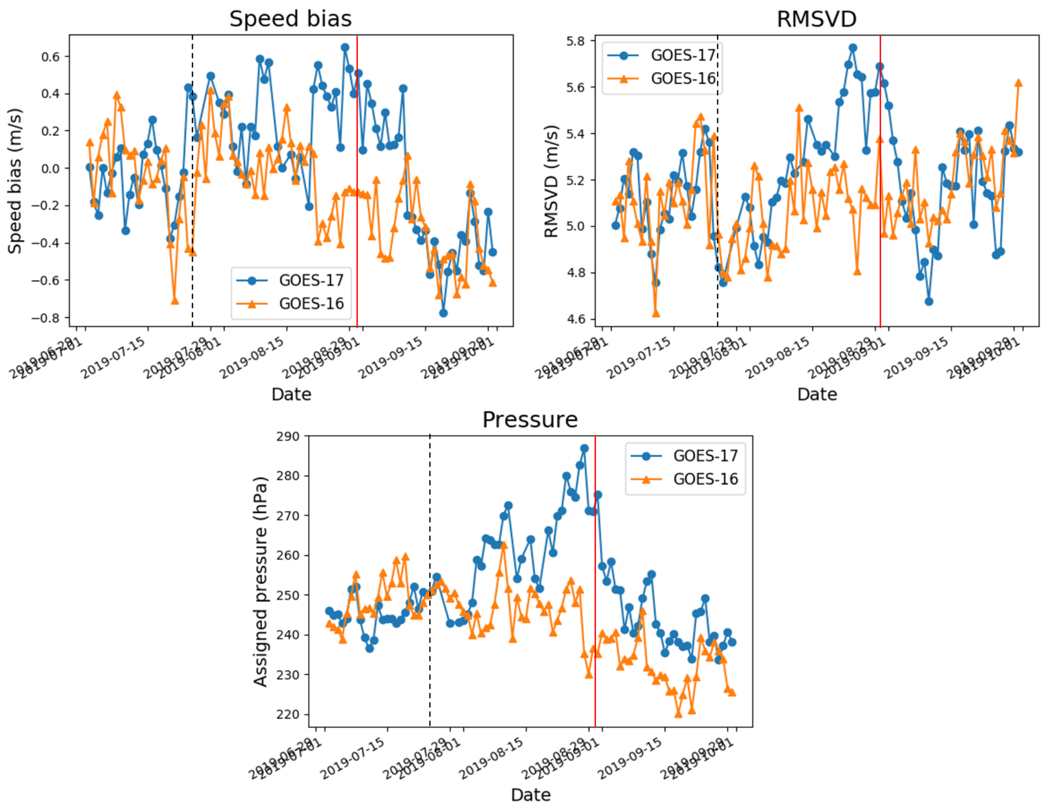

Figure 7: Timeseries of the daily average of speed bias (top left), RMSVD (top right) and assigned pressure (bottom) for high level infrared AMVs from GOES-17 and GOES-16 for the period 1st July - 30th Sept for the hours 11-15Z only. The black dashed line approximately indicates the point the 13.3µ is predicted to reach saturation. The red line indicates where the peak of the heating is predicted.

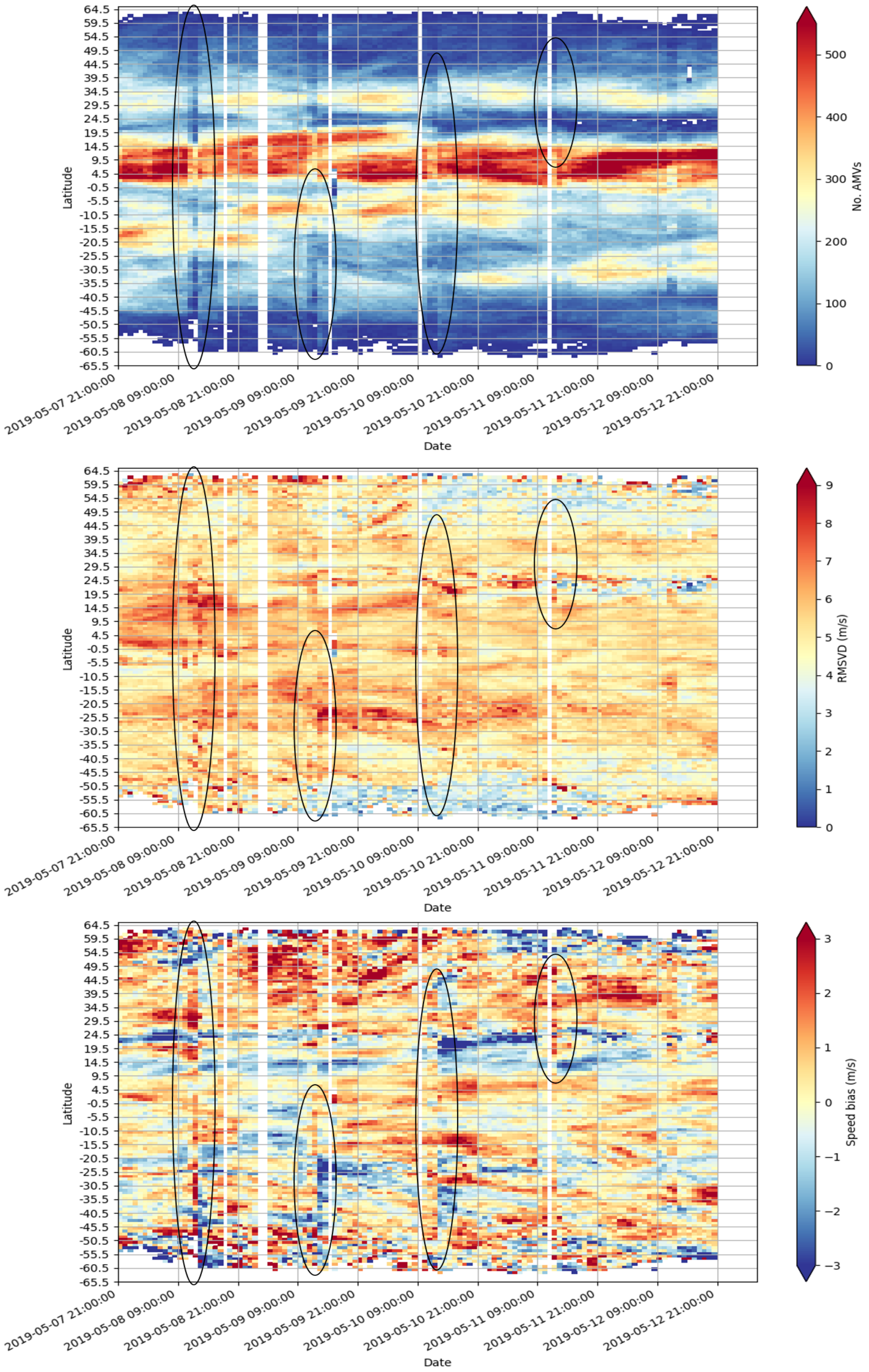

Figure 8: Hovmoller plots of the number of AMVs (top panel), RMSVD (middle panel) and speed bias (bottom panel) for hourly high level infrared AMVs from GOES-17 from 8-12th May 2019. Circles highlight possible degradation from cooling issues. No screening has been applied.

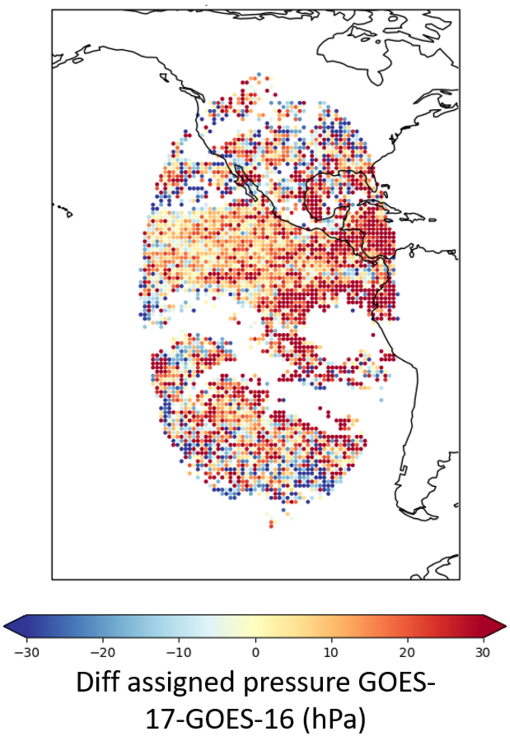

Figure 9: Difference in assigned pressure (right) between collocated GOES-17 and GOES-16 high level (P < 400hPa) infrared AMVs for the period 8th - 12th May for only the hours 10-15Z.

for GOES-16 would be a consistent and natural choice. The detrimental impact when the instrument is functioning less optimally means that additional measures need to be considered to cope with periods of potentially poorer quality data.

A set of assimilation experiments was run to assess the impact of using GOES-17 AMVs, applying different screening for the data affected by the cooling issues. The experiments use 12-h 4D-Var, with a lower model resolution (T_{Co}399 (25km)) compared to the operational forecast system. The control run includes the full observing system apart from AMVs from a GOES-West satellite. Experiments were then run which use GOES-17 AMVs in different configurations as further described below. In addition, another experiment was run in which GOES-15 AMVs were added instead, using settings as in operations for comparison. 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 6-month period 7th May 2019 - 14th November 2019.

During assimilation, all AMVs are subject to screening by QI, first guess check and satellite specific spatial blacklisting. There are then common 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. As for GOES-16, the hourly product is used for GOES-17.

4.1 Blacklisting choices and observation error

Due to the strong similarities with GOES-16 during normal operation, the same spatial blacklisting is applied to GOES-17 for these times (see also Lean and Bormann (2019)). The screening allows data for:

- Visible: pressure $>$ 700hPa for all latitudes
- Infrared: pressure $>$ 150hPa for $|\text{latitude}| \geq 25$ and 200hPa $<$ pressure $<$ 300hPa for $|\text{latitude}| < 25$
- Water vapour: 150hPa $<$ pressure $\leq$ 300hPa for $|\text{latitude}| \geq 25$ and 200hPa $<$ pressure for $|\text{latitude}| < 25$

To address the issues due to the cooling problems at the instrument, we test here three configurations of additional quality control specific to GOES-17 AMVs. The choices considered are:

- Removing all data 9-17Z for all dates: This is the most conservative approach and safely avoids any of the affected data by always excluding data over an 8-hour period around the local mid-night for GOES-17 for all times of the year.
- Removing all data 9-17Z 15th Jan - 10th Mar, 1st Apr - 15th May, 1st Aug - 15th Sept, 5th Oct - 25th Nov: This removes data during local night-time as before, but only for the periods with the worst instrument anomalies, whereas for other periods of the year all GOES-17 AMVs are considered for assimilation. The periods were chosen based on an analysis of the first guess departures, in combination with the time-series of the peak focal plane temperature. Screening aims to exclude the periods exceeding a peak temperature of around 86K. This is the point at which some of the ABI channels begin to experience saturation (Mozer et al., 2019) which includes 6.15μm - used for the cloudy water vapour tracking - and 13.3μm - used in combination with two further channels in the height assignment calculation (Heidinger, 2013).

- Allow data at all times: This tests whether the existing quality control is already sufficient to identify AMVs of detrimental quality by allowing all available AMVs to be considered for assimilation. Since the number of available AMVs is greatly reduced during the affected periods and there are strict quality control measures in place using a QI threshold and first guess check, it may be acceptable to proceed without temporal screening.

The first two choices clearly introduce a daily gap of several hours in coverage, at least for parts of the year. It is worth considering where these temporal gaps are located in the assimilation windows of the ECMWF analysis system. For the 12-hour assimilation cycles used in this report, observations for analysis times of 00Z and 12Z are collected over 21-9Z and 9-21Z respectively. While 00Z cycles hence remain unaffected by the temporal screening of GOES-17, for 12Z cycles data are only be available in the final four hours of the time window. Recent work at ECMWF showed that data in the latter part of the window were the most influential with the last 3 hours even able to outperform data from the first six hours of the window (McNally, 2019). So despite the potential loss of a large volume of data for the 12Z cycles, the remaining AMVs are available at a particularly influential part of the assimilation window for these cycles.

It should be noted, however, that for the operational assimilation system, the main high-resolution forecast is produced from analyses calculated using 8-hour assimilation windows, with the 00 and 12Z cycles using windows covering 21-5Z and 9-17Z, respectively (Lean et al., 2019) . In the operational configuration, the final short cut-off 12Z assimilation window will therefore not benefit from any GOES-17 AMVs directly when the temporal screening is active. The first guess for the shorter window assimilation is however provided by the short-range forecast from the longer window assimilation which does include GOES-17. In any case, as there is some overlap in coverage from Himawari-8 and GOES-16, partial mitigation is available through AMVs from these other satellites over the GOES-17 region.

The above spatial and temporal blacklisting is in addition to more general screening for geostationary satellites which results in GOES-17 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.

Observation errors for GOES-17 AMVs are assigned using a model that accounts for the situation-dependence of error contributions from the tracking and the height assignment step (Salonen and Bormann, 2013). Given the similarity in the departure statistics, the same parameters are used as for GOES-16.

4.2 Experiment results

In general, there were consistent signals across the different configurations of GOES-17 for improvements in the vector wind field when verified against the own analysis of each experiment. Improvements were also seen in some of the fits of independent observations related to wind and humidity. Results shown here will be taken from the experiment where screening 9-17Z was consistently applied. Discussion of the relative merits of the different screening will be presented later in this section. The fit of the background to independent conventional wind observations is mostly neutral or shows small, but not significant, signals for improvements over larger areas such as the northern hemisphere (figure 10 (left panel)). However, in recalculating the changes just focusing on the main area of impact over the disk of GOES-17 and the Americas, the verification shows encouraging small positive changes (figure 10 (right panel)). The results in these cases are comparable to GOES-15.

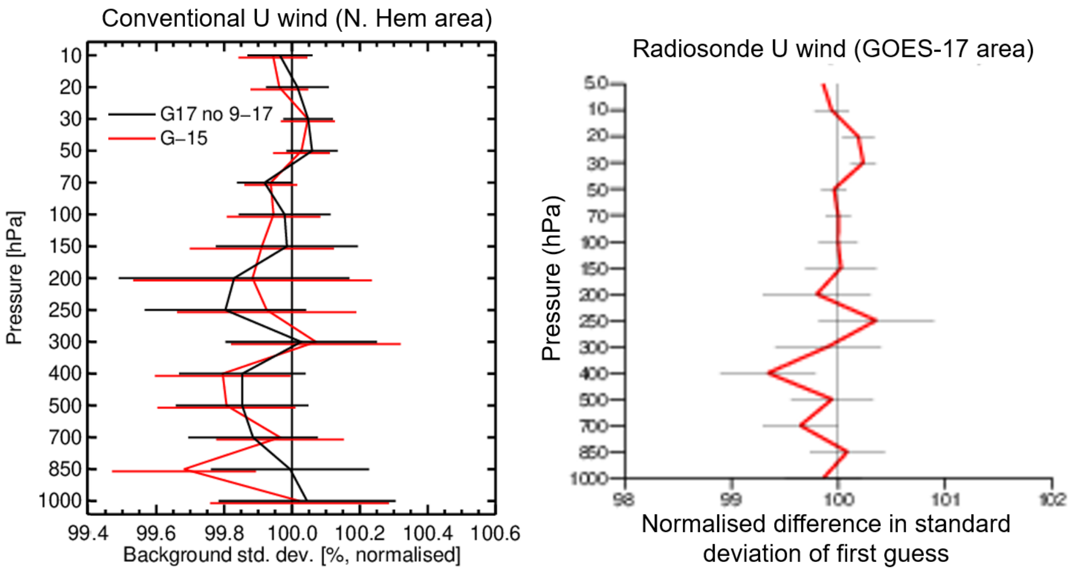

Figure 10: Change in the standard deviation of the first guess U component for all conventional observations in the Northern Hemisphere (left panel) for the addition of the GOES-17 (black) and GOES-15 (red) compared to the control with no GOES-W AMVs. Right panel shows change in standard deviation of first guess for U component of radiosondes for the addition of the GOES-17 compared to the control with no GOES-W AMVs in the area ±60°N, 40-130°W (right). Data in both plots are from 7th May - 14th November 2019. Error bars indicate significance at the 95% level.

In addition to positive impacts on independent wind observations, the use of GOES-17 has a positive change in the fit of some humidity and cloud sensitive observations. There are small (around 0.1%) but significant changes in the humidity sensitive channels (18-22) of the Advanced Technology Microwave Sounder (ATMS) instrument for the tropics (figure 11 (left panel)) and southern hemisphere (not shown). Other humidity sounding instruments such as the Microwave Humidity Sounder (MHS) show a positive tendency but not at the 95% significance level (not shown). There is also a positive impact on channels on microwave imagers which are also sensitive to cloud due to their use in all sky situations (Geer et al., 2017). Figure 11 (right panel) illustrates the impact on Advanced Microwave Scanning Radiometer 2 (AMSR2) showing a reduction in error of around 0.3-0.4% in the tropics. This may indicate that GOES-17 has a positive influence on the representation of low level cloud in the model.

In the verification of various forecast ranges against own analysis, zonal plots show that there are significant reductions in the RMS error of the vector wind field in the short range forecast, particularly in the tropics and southern hemisphere (figure 12). Similar plots for GOES-15 show a smaller impact (figure 12). On average, more AMVs are assimilated from GOES-17, despite conservative screening, compared to GOES-15. In addition, extra impact may come from the improved coverage of the Southern Ocean where there are few other direct wind observations. Global maps of the impact reveal that the vector wind error reduction is mostly in the region of the GOES-17 disk over the Pacific Ocean and especially around 200hPa and low levels (not shown) which also coincides with layers which contain the highest density of AMVs.

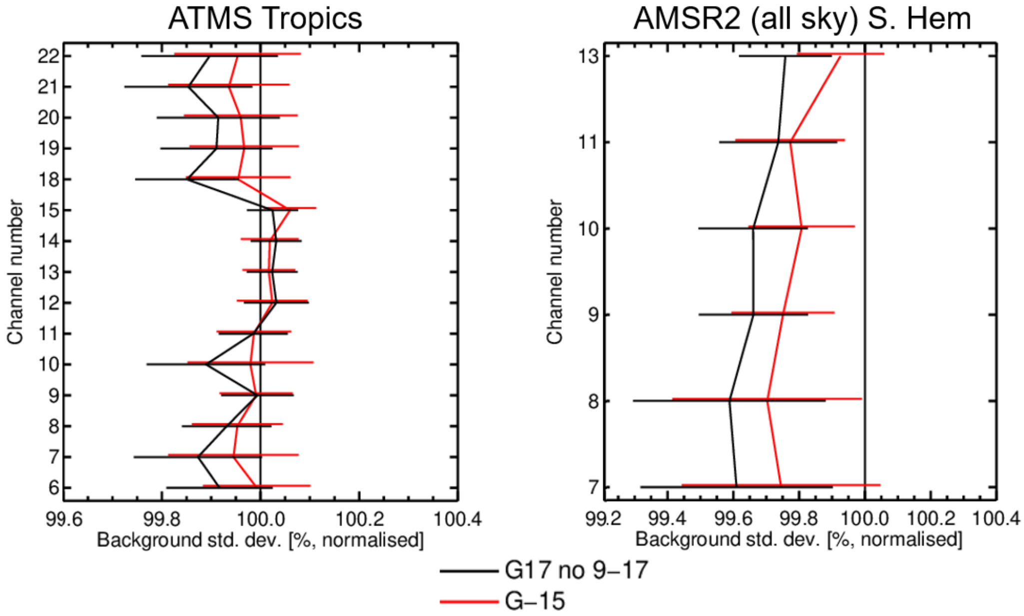

Figure 11: Change in the standard deviation of the first guess brightness temperatures of ATMS (left) and AMSR2 (right) for the addition of the GOES-17 with screening of 9-17Z (black) and GOES-15 (red) compared to the control with no GOES-W AMVs. Data are from 7th May - 14th November 2019. Error bars indicate significance at the 95% level.

4.2.1 Temporal screening impacts

Across much of the verification measures there was little statistical significance between the three options with frequent agreement in the areas of improvement. However, there were small tendencies towards the option of screening 9-17Z at all times being more favourable in the fit of conventional wind observations. For example, figure 13 shows signals that there might be less positive impact on the fit to conventional wind observations when using all the data or even under varying date restrictions compared to conservative screening.

When removing all data 9-17Z, the remaining observations late in the assimilation window appear to be able to reproduce much of the impact from having all the data. There is no clear advantage to trying to use GOES-17 during at risk hours. There are obvious issues with data quality seen in the first guess departures and despite strict quality control procedures otherwise in the assimilation, it seems there may be a small but adverse effect by allowing some of these data. Figure 14 shows the actively used high level AMVs from the experiment where no temporal screening is employed. It reveals that after quality control and thinning procedures, the number of infrared channel AMVs is now relatively much closer to GOES-16 compared to considering all the data earlier in figure 3. With fewer winds available, the thinning might remove a smaller proportion of the GOES-17 data. The number of AMVs from the water vapour channel is however greatly impacted through a large interval in August. Importantly, figure 14 also reveals that the remaining infrared AMVs continue to show a departure in RMSVD from GOES-16 mostly through the latter half of August. The inclusion of this data in assimilation could be detrimental. For the experiment using date dependency in the screening, it may also be that data quality is only suitable for even shorter periods than those defined in the experiment.

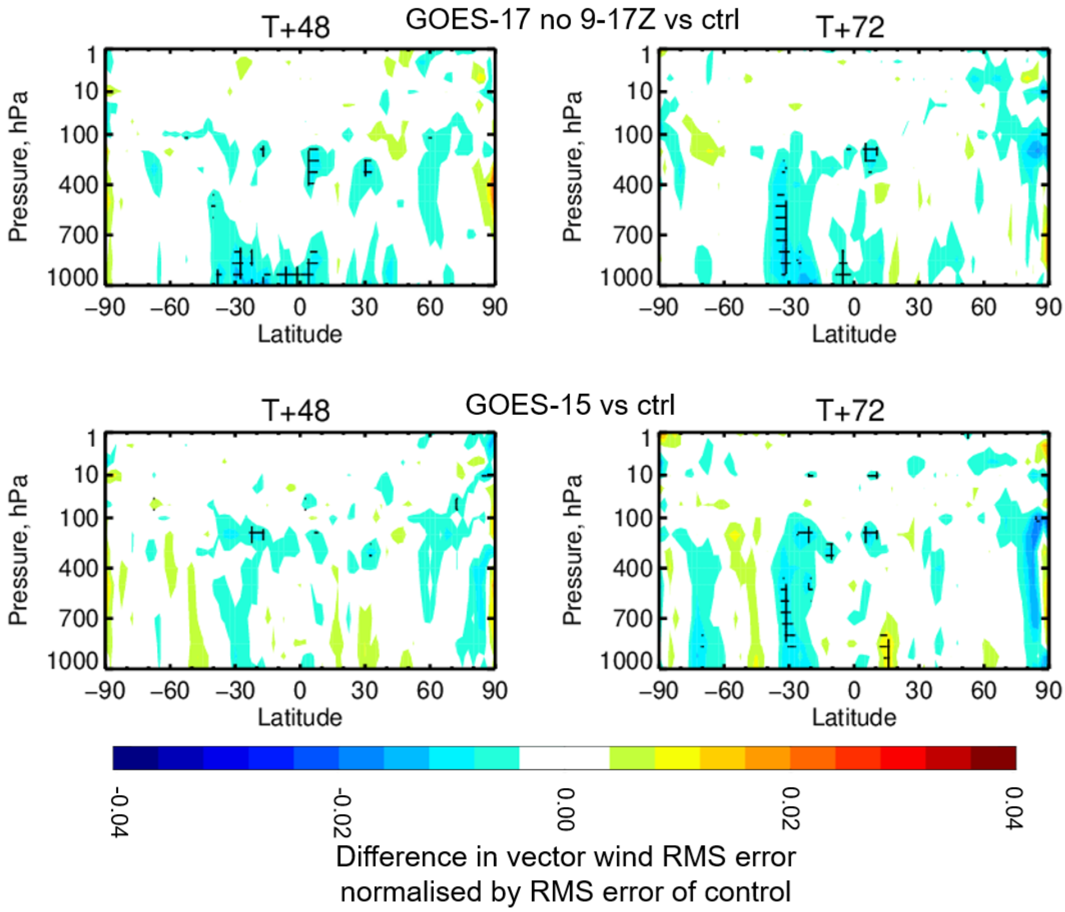

Figure 12: Zonal plots of the change in vector wind RMS error verified against own analysis for 48 and 72 hour lead times comparing the addition of the GOES-17 (top row) and GOES-15 (bottom row) to the control with no GOES-W AMVs. Data are from 7th May - 14th Nov 2019. Black hatched lines indicate significance at the 95% level.

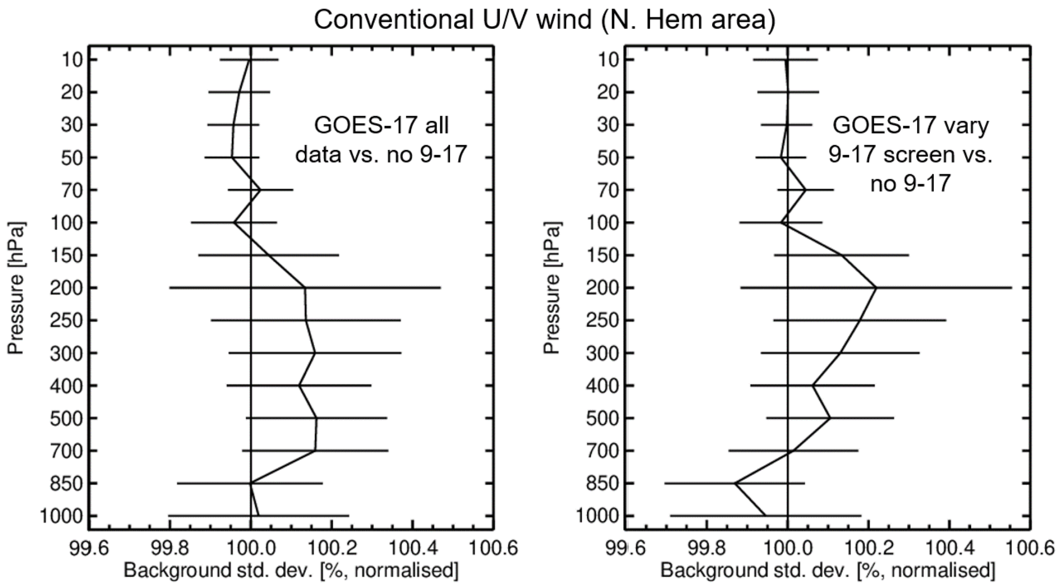

Figure 13: Change in the standard deviation of the first guess conventional U and V components of wind for the Northern Hemisphere area (latitude > 20°N) for the addition of GOES-17 with no temporal screening (left panel) and GOES-17 with date dependent screening of 9-17Z (right panel) vs. GOES-17 screening 9-17Z on all days. Results are for 7th May - 14th Nov 2019.

The diurnal variation in impact was also considered to investigate any impact from the removal of a large proportion of data contributing to the 12Z cycle. The verification against own analyses and change in the fit to conventional wind observations was calculated for 00Z and 12Z cycles separately. There is a more positive signature for the 00Z cycle, both in the conventional wind observations (not shown) and in the short range forecast (day 2-3) (not shown). However, similar differences in impact between the 00Z or 12Z cycles are also seen for GOES-15 and GOES-17 experiments where data are not temporally screened. The irregular distribution of data in the 12Z cycle does not seem to have an adverse effect. In fact, this kind of diurnal change in AMV volume already occurs with the visible winds. Differences between the cycles may be dominated by other effects such as the GOES-17 visible winds (which are present mostly in the 00Z cycle only) or this could also indicate possible diurnal variation in the accuracy of the model winds. However, the investigation of this effect is outside the scope of this report.

5 Summary

GOES-17 replaced GOES-15 in active assimilation on 10th December 2019. The satellite carries the same generation imager as GOES-16 but it is afflicted by cooling issues resulting in degradation of the infrared channels varying in time. For operational use, the GOES-17 AMVs are all rejected between 9-17Z as a precaution to avoid small degradations when allowing this data either during restricted date intervals or for all dates. During normal operation, the AMV numbers and distribution are similar to GOES-16 and a large increase from GOES-15, as expected with the newer generation instrument and different derivation algorithm. First guess departure statistics showed strong agreement with GOES-16 and changes in the pattern of speed bias with GOES-15, as was seen in earlier work comparing GOES-16/-13.

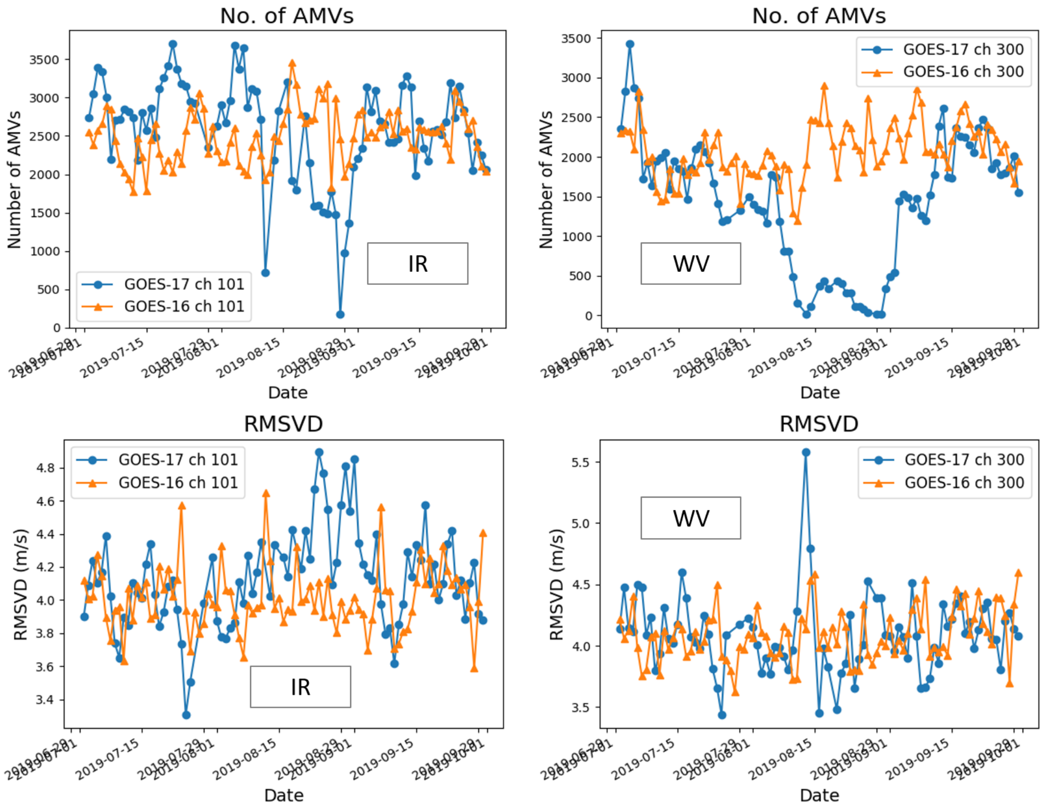

Figure 14: Top row: Timeseries of the daily average of the number of AMVs for actively used high level infrared AMVs (left) and water vapour AMVs (right) from GOES-17 and GOES-16. Bottom row: as above but for RMSVD. Data are for the period 1st July - 30th Sept for the hours 11-15Z only and from the experiment where no temporal screening is applied.

During times affected by the cooling issues the number of AMVs remains reasonably unaffected at times when the peak temperature is rising but has not reached saturation for any channels. However, the volume of winds becomes severely reduced at the peak of the impact. Of those AMVs able to be derived, the average data quality is impacted with rises in RMSVD and unrealistic jumps in speed bias. Saturation of key infrared channels used in the height assignment appears to seriously impact the assigned pressures of the winds. While at peak periods it is quite obvious that the quality is degraded, when the peak temperature is relatively low, even in the days after the first channels are estimated to be affected by saturation, the changes can be more subtle and defining date ranges for sufficient data quality is challenging.

With good quality data during normal operations, the same assimilation configuration for GOES-16 was applied to GOES-17. However, additional temporal screening of 9-17Z was found to be appropriate. When data for this time period was allowed on all days or on selected dates that aimed to avoid the peak saturation problems, there was no clear advantage. There were signals, particularly of concern in the fit of independent wind observations, that suggested the extra data might in fact have a negative impact. Results from assimilation experiments adding GOES-17 were very encouraging with positive impacts on the forecast despite conservative screening, similar to or even exceeding GOES-15 in some measures. There were significant reductions in the vector wind error at short forecast lead times and positive signals in both conventional wind observations and humidity sensitive observations. The good impact from GOES-17 appears to exceed the change seen previously when introducing GOES-16. In particular, the verification of the vector wind fields against own analysis shows a larger area of impact in the tropics lasting out to around day 5 in the forecast. A possible explanation is that GOES-17 has a much higher coverage of the ocean than GOES-16 where direct wind observations are otherwise more sparse.

5.1 Future options

In the results presented here we have used a research configuration with 12 hour assimilation windows but it was noted that the 12Z analyses in the operational system, having only a 8 hour window for observations, will only include GOES-17 information indirectly through the first guess. In the near future, an upgrade to the ECMWF system will see the analysis from the short window assimilation in turn be used as a first guess in the long window assimilation (Hólm et al., 2020). A lack of direct observations from a key geostationary satellite in the shorter window 12Z could create a diurnal pattern in the quality of the mean wind analysis. However, the information contained in the first guess, overlap from neighbouring satellites and the expected availability of many AMVs (including a large increase from having visible channel winds) in the alternate 00Z cycle should help to mitigate the impacts.

NOAA are considering a dynamic channel selection for the height assignment which would aim to make more optimal channel choices based on the instrument state (Daniels et al., 2019) and provide an accompanying flag with each wind to alert users which strategy was used. In addition, NOAA will reject winds if the temperature of the focal plane module exceeds predefined limits for various key channels (pers. comm. J. Daniels, NOAA). As the issues with GOES-17 become better understood, predicted and even mitigated it may be worth revisiting the screening procedures in the future. In order to use more data, it may also be useful to investigate adapting the observation errors such that larger errors can be assigned to AMVs potentially affected giving them less weight in assimilation. Additionally, improvements to the height assignment stage of the AMV algorithm are anticipated from NOAA in the near future affecting both GOES-17 and GOES-16. These are expected to improve the data quality, particularly at high levels. Re-evaluation may also give the opportunity to refine the use of both satellites including choice of appropriate QI thresholds.

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