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Options for filling the LEO-GEO AMV Coverage Gap

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Contents

1 Background: The LEO-GEO Gap and Gap-Filling AMV Datasets

A sequence of three or four overlapping images is normally used for tracking tracers to derive Atmospheric Motion Vectors (AMVs). For polar-orbiting satellites, the area of overlapping imagery from a single satellite is restricted to the polar regions. For geostationary imagery, these sequences are available over their full scan disc. This leaves a 'LEO-GEO' coverage gap between the polar and geostationary AMVs which falls within the 40-70° N/S latitude bands (Figure 1), with a width varying with longitude and time of day. Particularly in the southern hemisphere (SH) coverage gap, there are few other upper tropospheric wind observations available. For numerical weather prediction (NWP), it is important to measure the wind in these regions as they contain the polar jet streams. Three AMV datasets are available which have the potential to help fill this coverage gap, all using AMVs derived from infra-red (IR) imagery. In this investigation, the datasets are analysed using observation-minus-background (O-B) statistics and assimilation trials.

1.1 EUMETSAT Single-Metop

One way to extend AMV coverage into the LEO-GEO gap is to use a sequence of two images rather than three. This gives a larger area of overlap for the Single-Metop dataset, extending as far equatorwards as 50° N/S. By not waiting for a third image, which would take around 100 minutes, timeliness is also improved. Using image triplets it is possible to check that the tracked motions between the first and second images and the second and third images are similar; this is not possible when using only two images. However, a measure of tracking consistency can still be obtained by performing the tracking forwards and backwards in time and comparing these vectors for consistency [1]. Height assignment (HA) is by IR-window method [1] or by co-located IASI cloud-top pressures [2].

1.2 EUMETSAT Dual-Metop

By taking advantage of Metop-A and Metop-B's similar orbits (around 50 minutes apart), the EUMETSAT Dual-Metop dataset provides AMVs using one image each from Metop-A and Metop-B. The image time difference is reduced to around 50 minutes and overlapping imagery is available globally. The greater overlap area and smaller time difference allow derivation of AMVs from less persistent clouds than can be used for the Single-Metop AMVs. The Dual-Metop AMVs are derived with the same algorithm as the Single-Metop winds.

[1] Fits infrared brightness temperature (BT) of the cloud top to model temperature profile to assign a pressure. In this case the BT is that of the of the pixels that contributed most to the tracking step.

[2] Used if IASI footprint collocated within 5km of barycentre of CCC pixels [2]. Roughly 5% of the September 2014 Single-Metop and Dual-Metop AMVs used this height assignment method.

1.3 CIMSS LeoGeo

By combining geostationary and polar imagery from multiple platforms into sequences of composite images, features can be tracked in the coverage gaps. The LeoGeo winds from CIMSS do this using satellites from a mix of operators [3] to derive the composites.

The composites are formed by reprojecting the satellite images onto a polar stereographic grid, with one composite for each pole every 15 minutes. Each composite image can include imagery from $\pm$15 minutes of the composite image time. The true observation times are stored as pixel-level metadata. Sequences of three images are used for the tracking and the LeoGeo AMVs are not derived equatorwards of 50° N/S. In each image of the triplet, the pixels making up a feature must be from one satellite only. The resulting AMVs are a mix of LEO-LEO, LEO-GEO, and GEO-GEO, roughly in the proportions 10%, 25%, 65% respectively. Height assignment is then done by IR-window or cloud base. [3]

2 Comparison of the Datasets

The three AMV datasets were compared against the Met Office global model's background fields (3 hour forecasts), using only the data with QI2[4] $>$ 80, for September 2014. High, mid and low-level refer to AMVs with heights above 400 hPa, between 700-400 hPa and below 700 hPa, respectively.

2.1 Spatial Coverage and Data Volume

The current spatial distribution of AMVs assimilated in the Met Office global model can be seen in Figure 1. The gap between the geostationary and polar AMVs is wider in the SH hemisphere than the NH, particularly in the South Pacific where the GOES AMV coverage only reaches as far as 45°S.

The LeoGeo AMVs have coverage as far equatorwards as 50° N/S, with a higher density of winds in the NH than the SH (Figure 2). At some longitudes LeoGeo has a higher density of AMVs than either of the Metop datasets. However, regions where LeoGeo has high data density often overlap with areas already well observed by Meteosat-10 and GOES 13/15 AMVs. There are few or no LeoGeo AMVs at 90° E/W in both hemispheres or at around 105° W and 35° W in the NH.

The Single-Metop dataset has coverage as far equatorwards as 50° N/S, while the Dual-Metop AMVs provide global coverage. As well as having greater coverage than Single-Metop due to the use of the Metop tandem orbits, the Dual-Metop dataset also has a higher density of data in the 50-70° N/S gap than Single-Metop. The Metop datasets have more winds in the SH than the NH for the month studied.

[3]Satellites used during September 2014: Meteosat-10, FY-2D, GOES-13/15, MTSAT-2, NOAA-15/18/19, Metop-A/B, Terra, Aqua.

[4]Quality indicator provided with each AMV without using first-guess check.

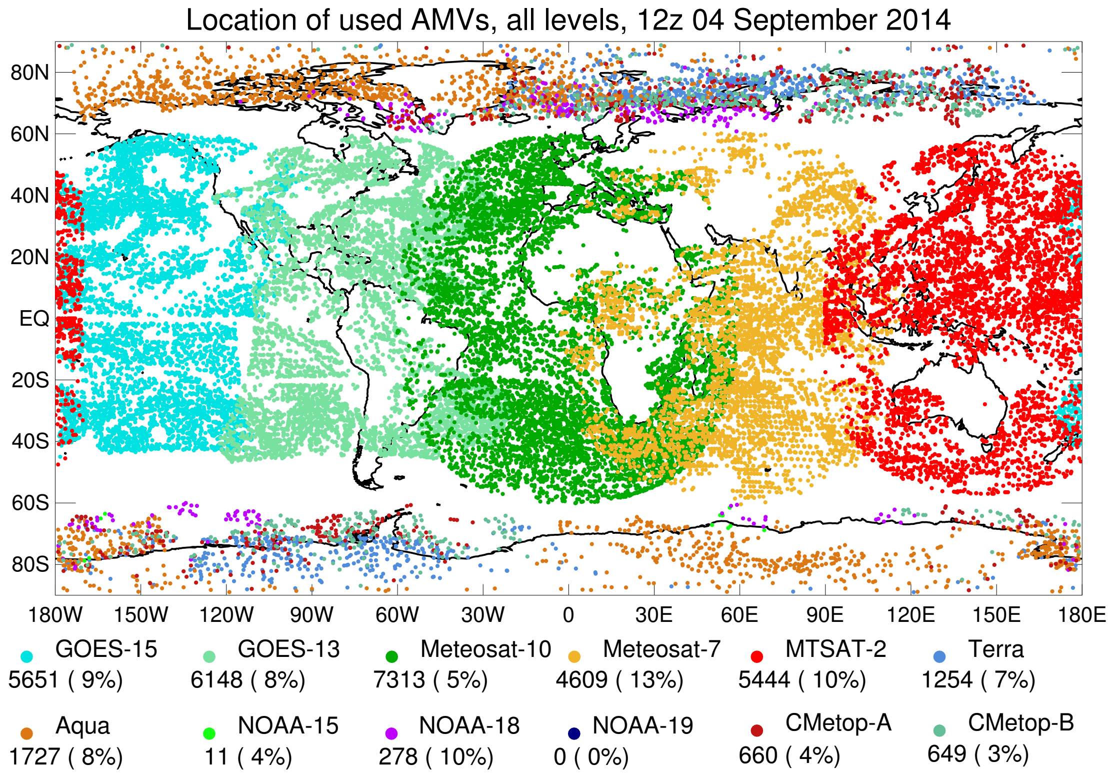


Figure 1: Example coverage of AMVs used in one assimilation cycle of the Met Office global model. There was an outage of NOAA-19 data at the time of the plot. The percentages are the proportions of received data that were assimilated.

2.2 Timeliness

The Metop datasets' average timeliness benefits from the use of the Antarctic Data Acquisition service to downlink Metop-B data at McMurdo station. For the Single-Metop AMVs, the Metop-B data arrives faster (average time lag 1 hour 16 minutes, see Figure 3) than the Metop-A data (average time lag 2 hours 5 minutes), since Metop-B is the prime satellite and so is given preference in the data-downlinking and processing. Since the Dual-Metop derivation uses one image from each Metop satellite for each AMV, it follows that it has an average time lag halfway between the two Single-Metop datasets at 1 hour 47 minutes. The Dual-Metop timeliness distribution is broader than either of the plots for Single-Metop. This is partly because they can be from a Metop-A/Metop-B image pair (46 minute difference) or a Metop-B/Metop-A image pair (55 minute difference) [2], and partly due to the difference in the time taken to downlink each Metop's data.

For the month of September 2014, the LeoGeo AMVs were received by the Met Office on average 4 hours 39 minutes from their observation time. No LeoGeo AMVs arrived within 4 hours of their observation time. The length of the LeoGeo time lag relative to the Metop AMVs is mostly due to the scheduling of generating the composite images which is done 3 hours from real time [3].

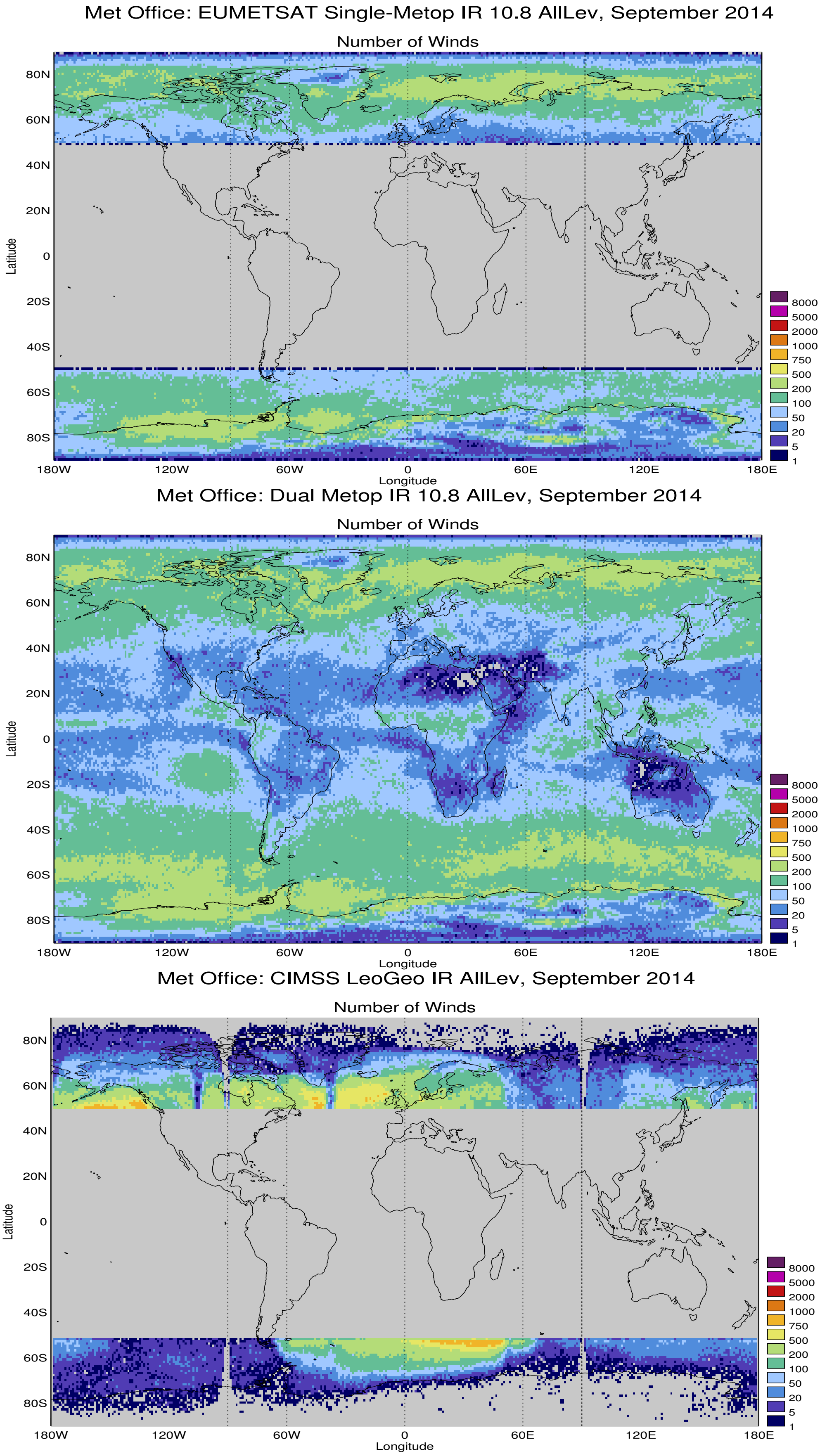


Figure 2: Data coverage of the three datasets for September 2014.

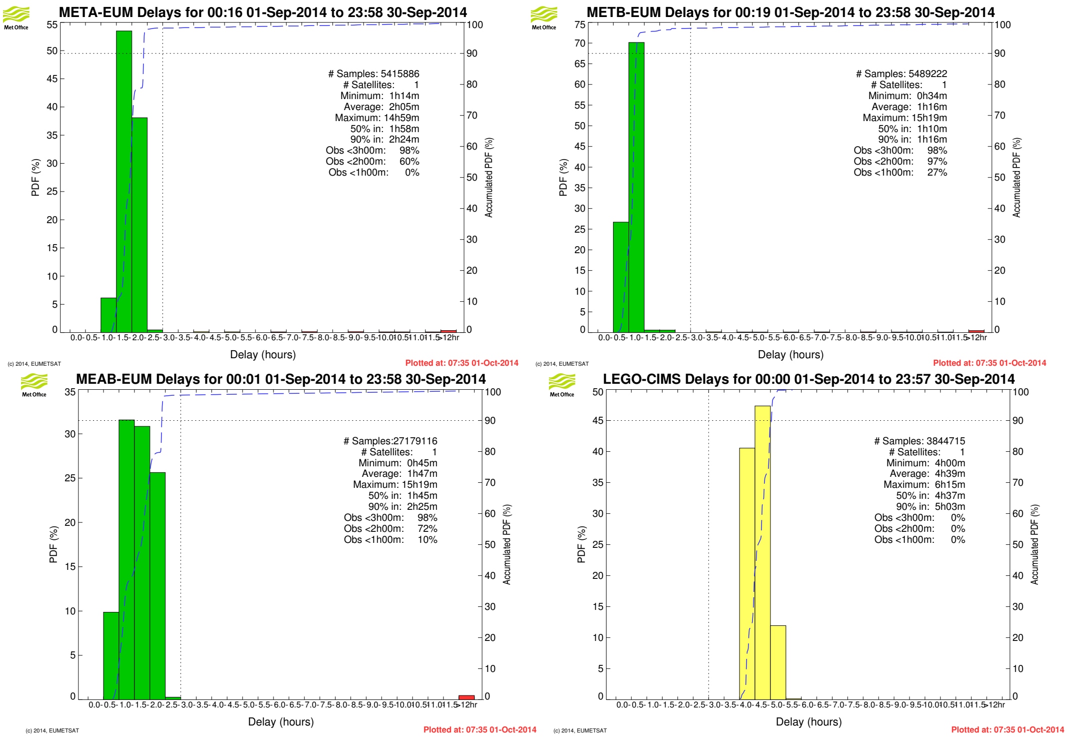


Figure 3: Timeliness distributions of the AMV datasets for September 2014. Clockwise from top left: Single-Metop-A, Single-Metop-B, LeoGeo, Dual-Metop. Green, yellow and red bars correspond to AMVs which arrived in under 3 hours, 3 to 6 hours, or more than 6 hours, respectively.

2.3 Observation - Background Statistics

For all three datasets, most AMVs have small O-B differences (Figure 4). For each dataset the majority of data is at mid-level, with the LeoGeo data having the smallest O-B differences of the three datasets here. In the Metop data, mid-level bias is small polewards of 60° N/S, but a slow bias up to 2 m/s in magnitude, occasionally up to 3 m/s, (Figure 5) is present in the gap region. Of the two Metop datasets, Dual-Metop records the higher wind speeds both in the gap region specifically (Figure 5) and as a whole dataset (Figure 6).

The high-level AMVs show many of the same features, but exaggerated. The Metop O-B slow bias is larger at more than 3 m/s over most of the gap region (Figure 7). For Dual-Metop, the high-level slow bias is also seen when compared to geostationary AMVs [5]. The RMSVD and standard deviation of all three datasets are also larger than at mid-level (Figures 8 and 7). The LeoGeo O-Bs remain small where the density of data is high (Figure 7). The lack of a high-level LeoGeo slow bias may be due to speed boosts from the auto-editor [4]. Dual-Metop records the highest maximum wind speeds of the three datasets (Figure 8) as its extra coverage provides more observations of the high-level fast winds of the polar jet streams [2].

At low-level, each dataset has small O-B differences in most areas, with LeoGeo and Single-Metop showing very small O-B biases where their low-level data density is high (Figure 9). Dual-Metop shows a slightly bigger slow bias both in the gap region (Figure 9) and polewards of 40°

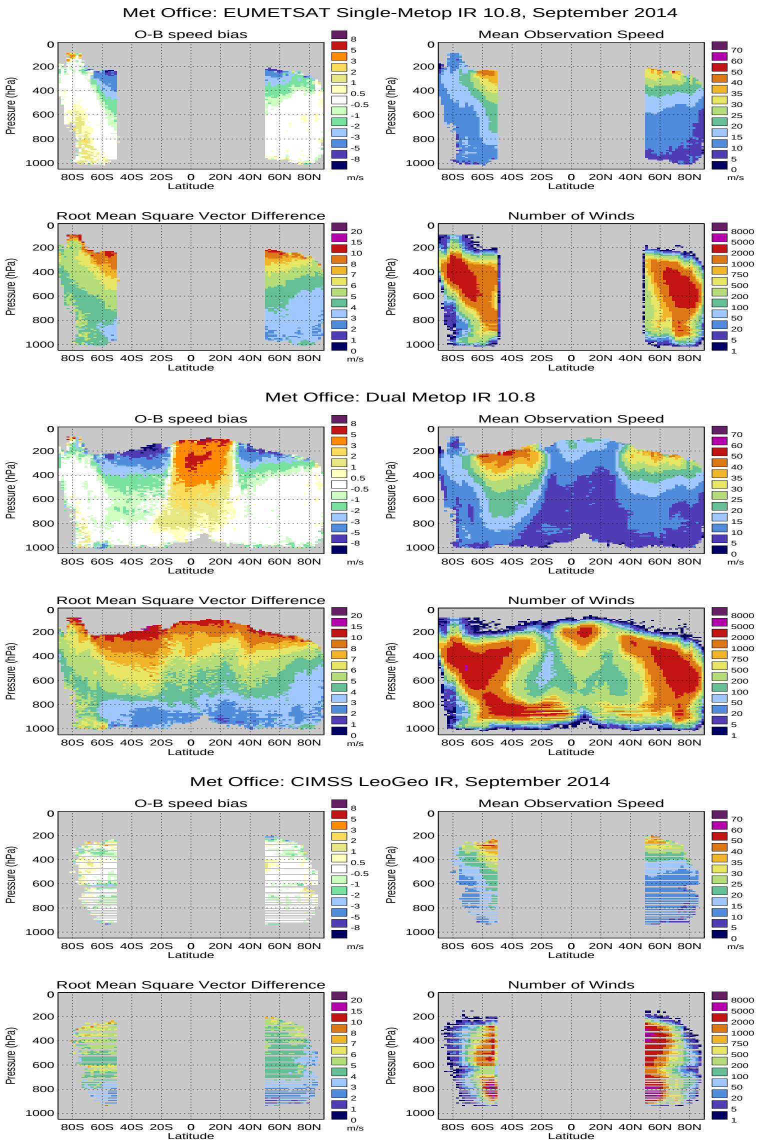


Figure 4: Zonal variation of AMV statistics.

N/S (Figure 10) than Single-Metop. One difference between the datasets at all levels is that there are some very slow AMVs in the Metop datasets with large O-B biases (Figures 6, 8 and 10). This feature has been identified previously in other AMV datasets [4], and has been handled by removing very slow AMVs before distributing the data. LeoGeo has very few AMVs with speeds below 4 m/s.

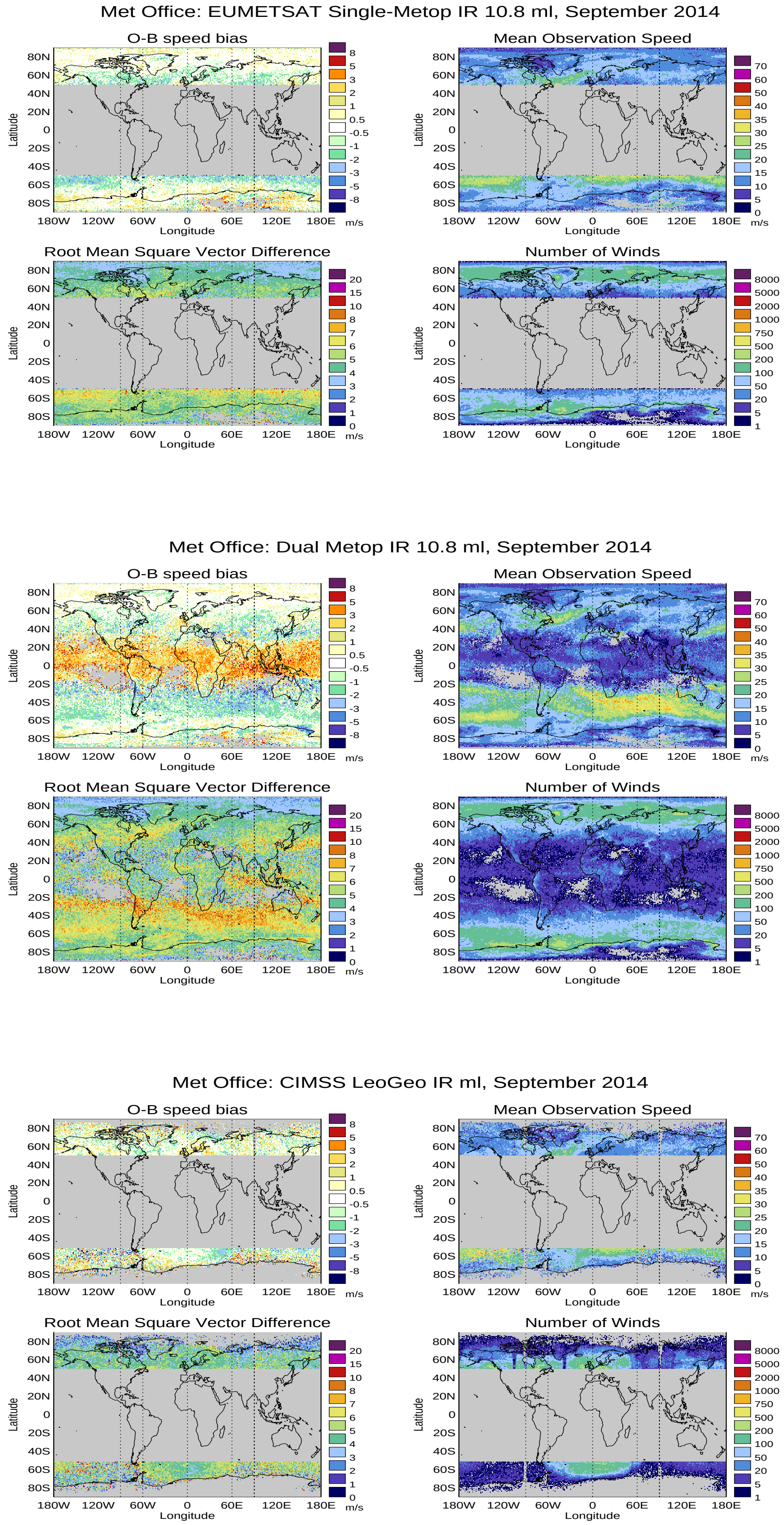


Figure 5: Maps of AMV O-B and other statistics at mid-level.

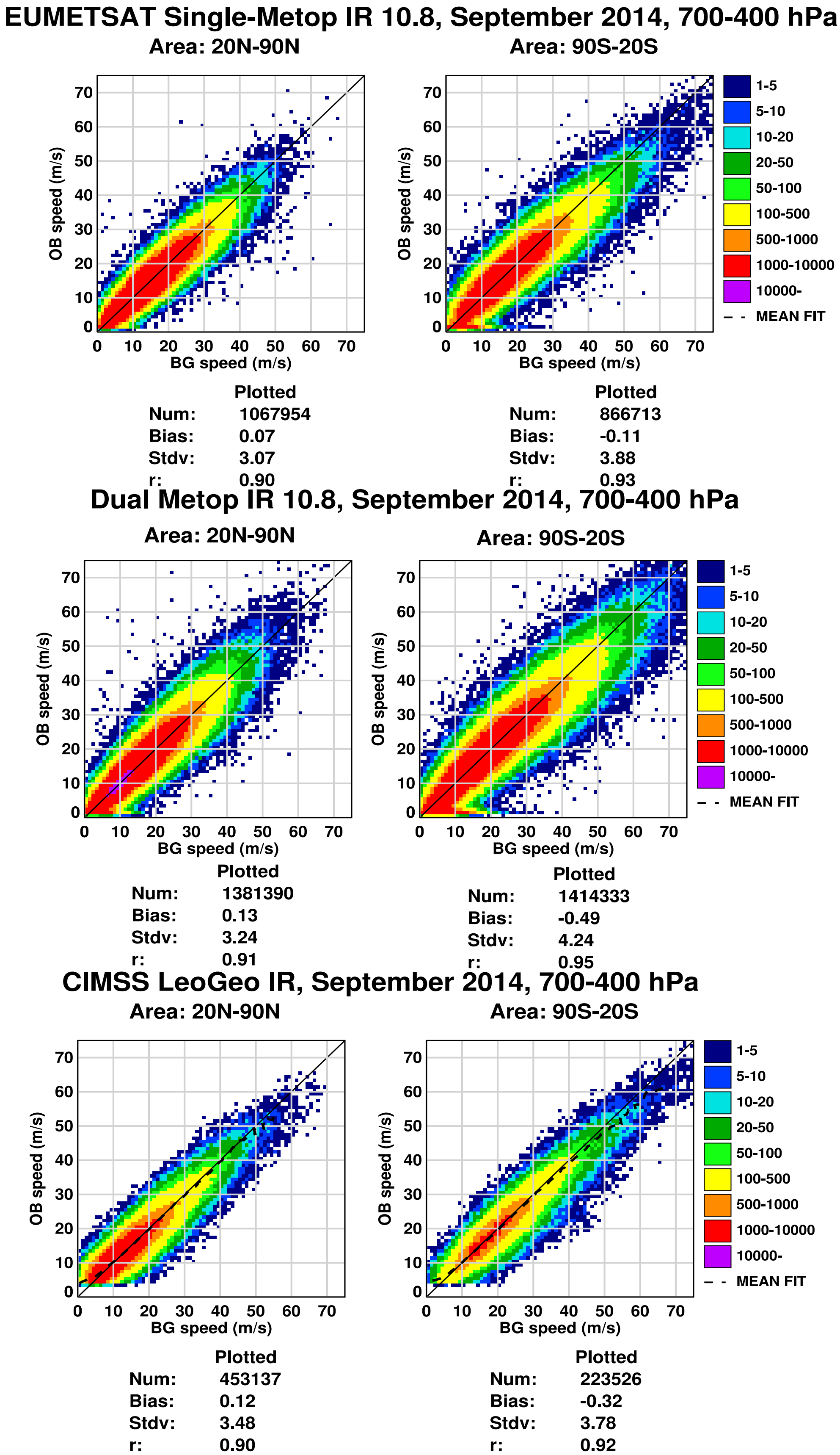


Figure 6: AMV vs model background wind speed for mid-level AMVs. Dual-Metop plot is for data polewards of 40° N/S.

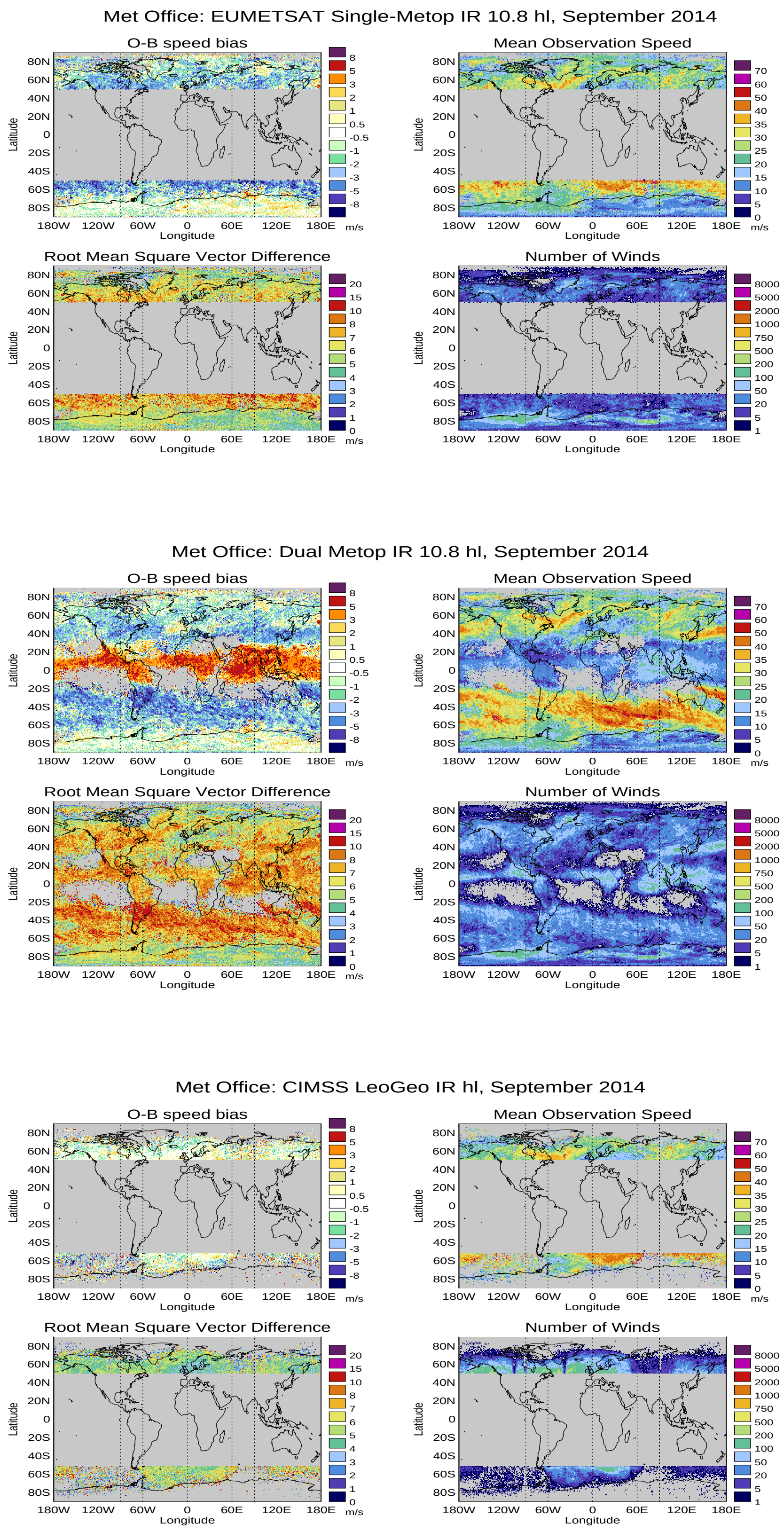


Figure 7: Maps of AMV O-B and other statistics at high-level.

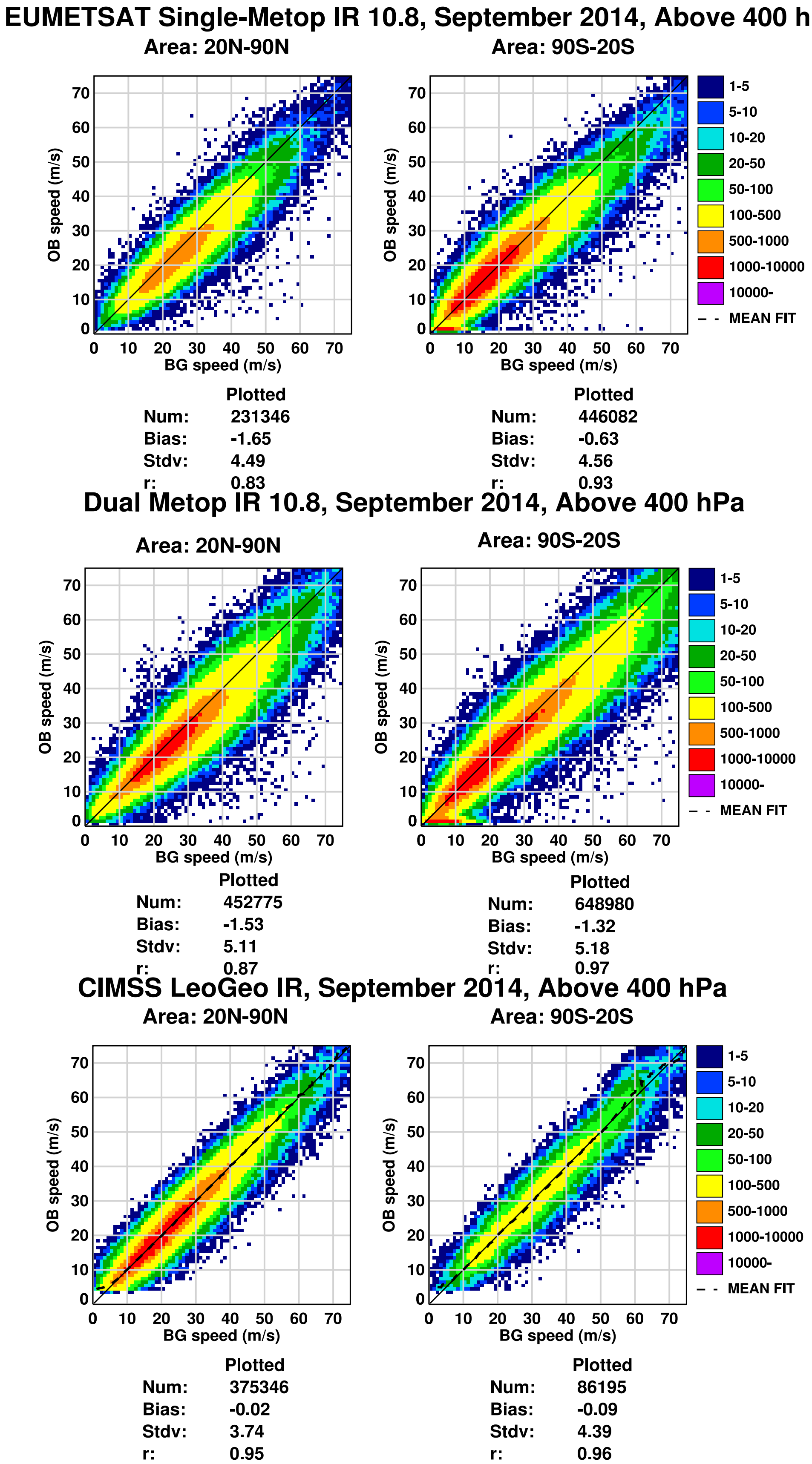


Figure 8: AMV vs model background wind speed for high-level AMVs. Dual-Metop plot is for data polewards of 40° N/S.

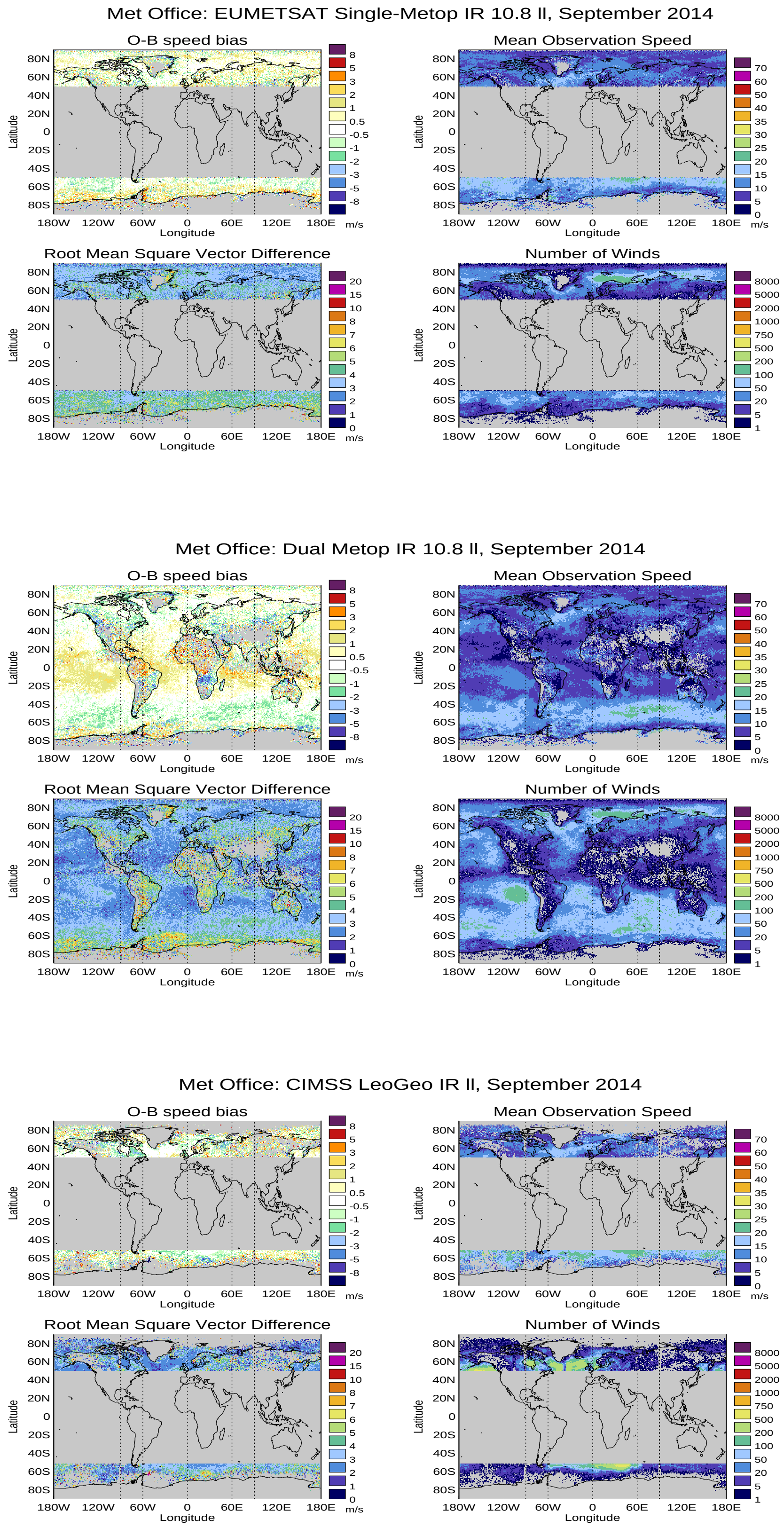


Figure 9: Maps of AMV O-B and other statistics at low-level.

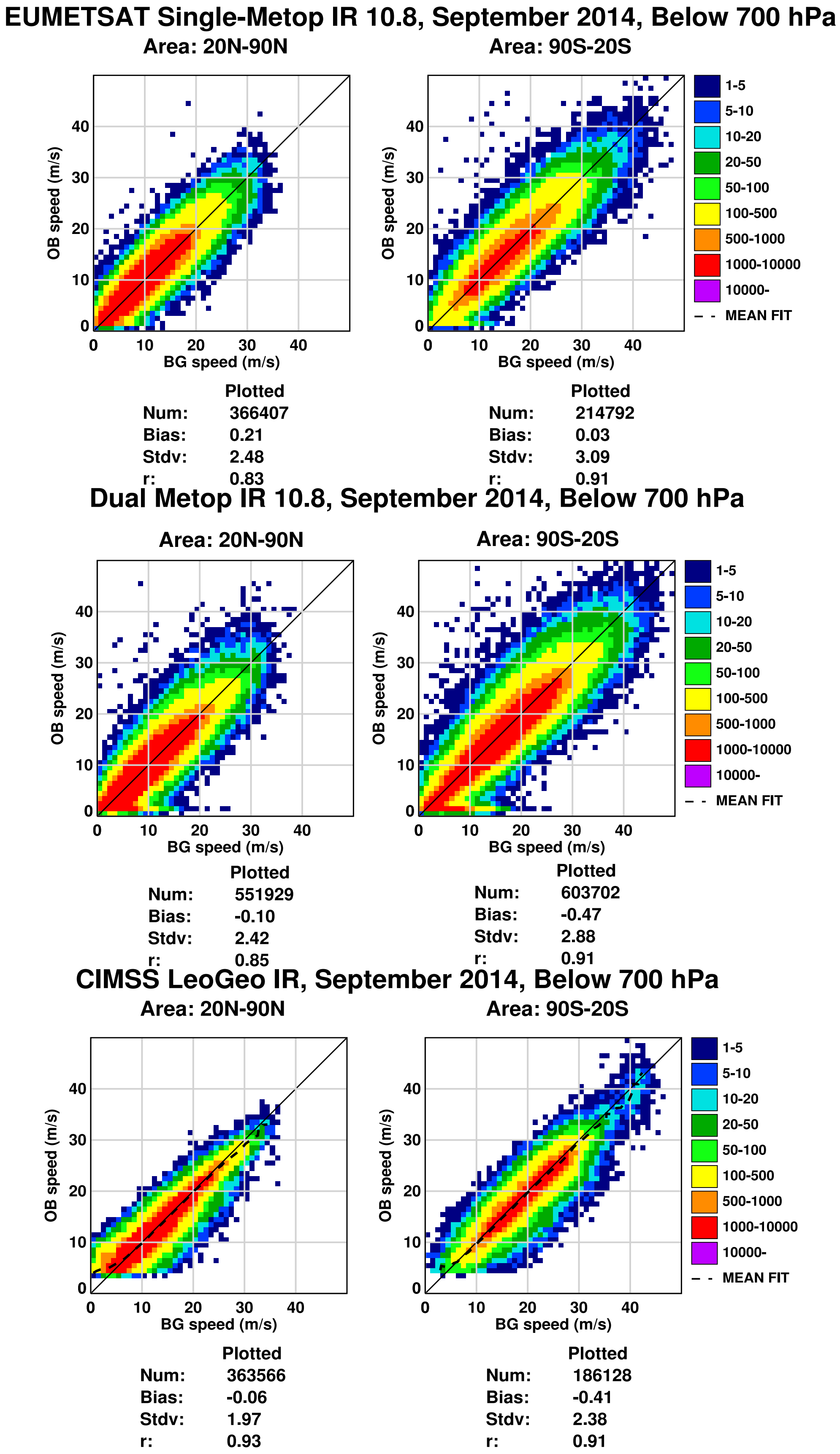


Figure 10: AMV vs model background wind speed for low-level AMVs. Dual-Metop plot is for data polewards of 40° N/S.

2.4 Quality Indicators

Filtering by Quality Indicators (QIs) is one way that high quality AMVs are selected for assimilation in operational NWP systems. For each AMV, a QI with and without first-guess check, QI1 and QI2 (respectively), is available.

Overall, both types of QI are skillful at reducing O-B differences for all three datasets. Both QI measures show skill at reducing RMSVD (Figure 11), although the reduction is slight for Dual-Metop. QI2 has skill at reducing O-B speed bias for all three datasets, although the bias increases in the Metop datasets for QI2 $>$ 95. O-B speed bias shows the same variation with QI1 as for QI2 for the Metop data, but LeoGeo shows a minimum bias for QI1 between 80 and 85.

2.5 Height Assignment Differences

Height assignment of the Metop AMVs is either by the IR-window method or using co-located IASI measurements, and the LeoGeo AMVs use either IR-window or cloud-base height assignment. Figure 12 shows that, for each AMV dataset, differences between assigned and model best-fit pressure differences are similar between height assignment methods. The same figure shows larger RMS best-fit pressure differences for Single-Metop than Dual-Metop. This may reflect the different geographical distribution of the Metop datasets with Dual-Metop having AMVs further equatorwards than the Single-Metop AMVs, so they are tracked from different types of cloud scene, which will affect how the height assignment performs.

The LeoGeo RMS assigned minus best-fit pressures are smaller than those for Single-Metop, despite covering the same latitudes (Figure 12). This may be because the auto-editor changes some of the LeoGeo AMVs' pressures to better agree with nearby observations and model background wind fields [4].

For the Metop datasets, the IASI-assigned AMVs generally have larger O-B differences than the IR-window assigned AMVs (Figure 13), although the number of AMVs assigned with IASI is small. The LeoGeo AMVs have most of their low-level AMVs assigned to cloud-base and most of their high-level AMVs assigned using the IR-window method, so O-Bs of each method could not be compared at the same height.

3 Trials

3.1 Trial Details

Separate assimilation trials were carried out for the Single-Metop and LeoGeo datasets for the period 1st June - 15th July 2014. Dual-Metop was not included as the trials were done before it became an operational product. The trials used the Met Office operational global NWP model, using 4DVAR and with resolution reduced to N320.

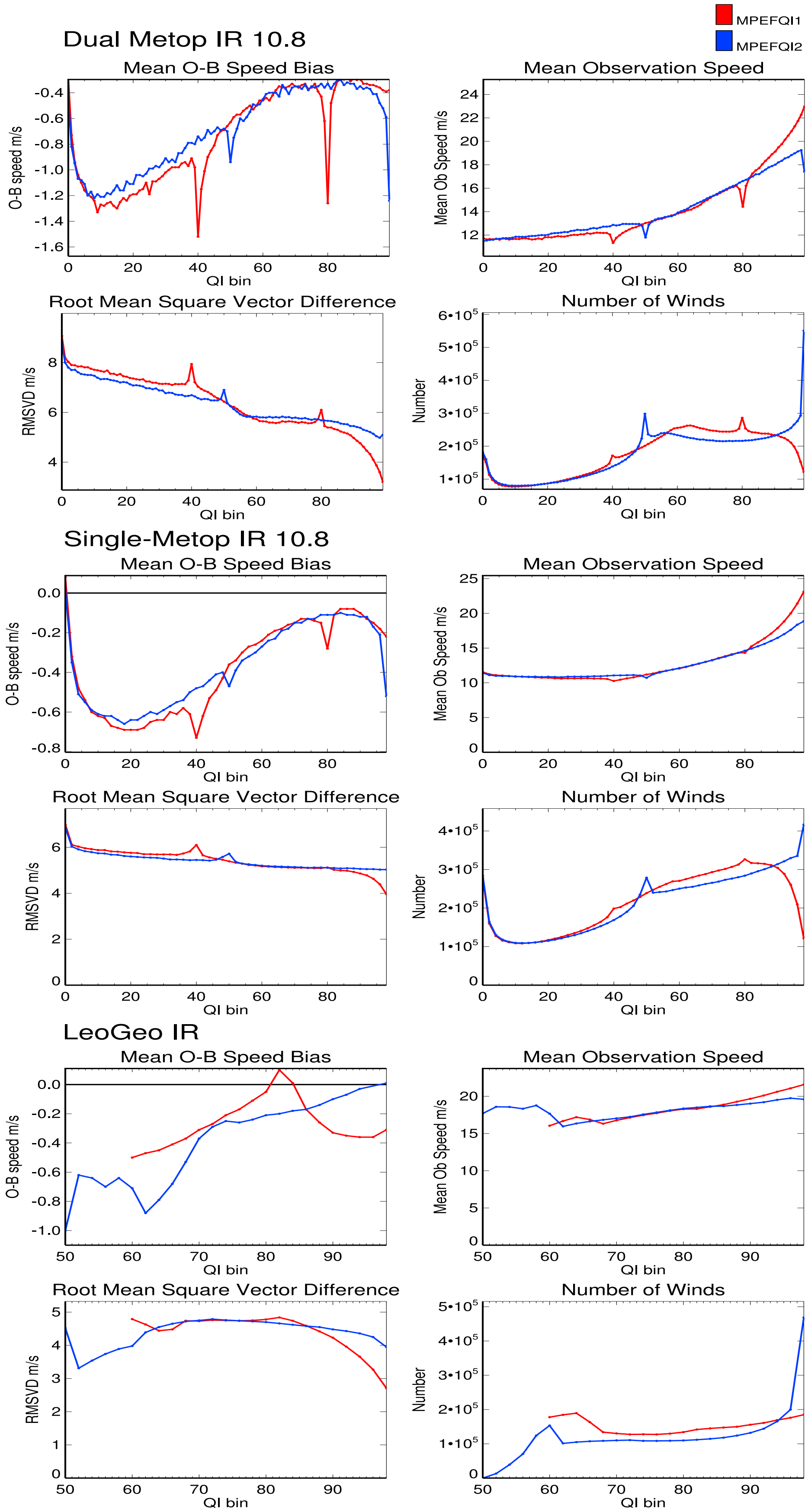
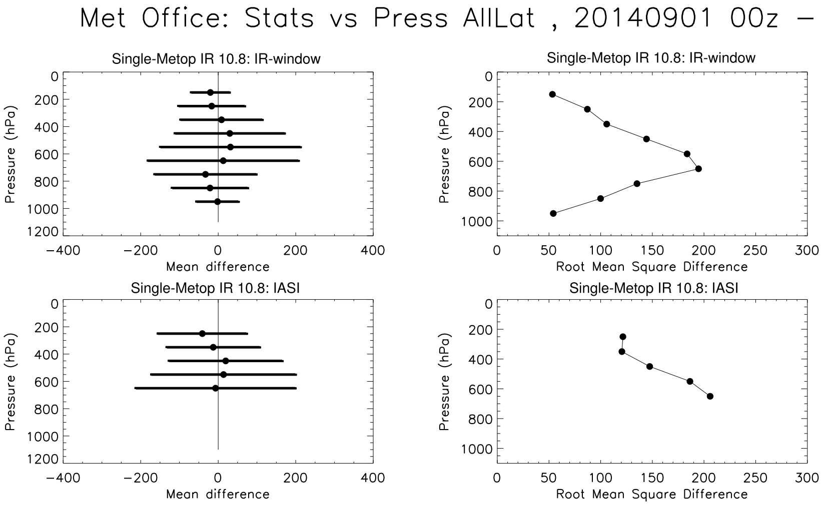
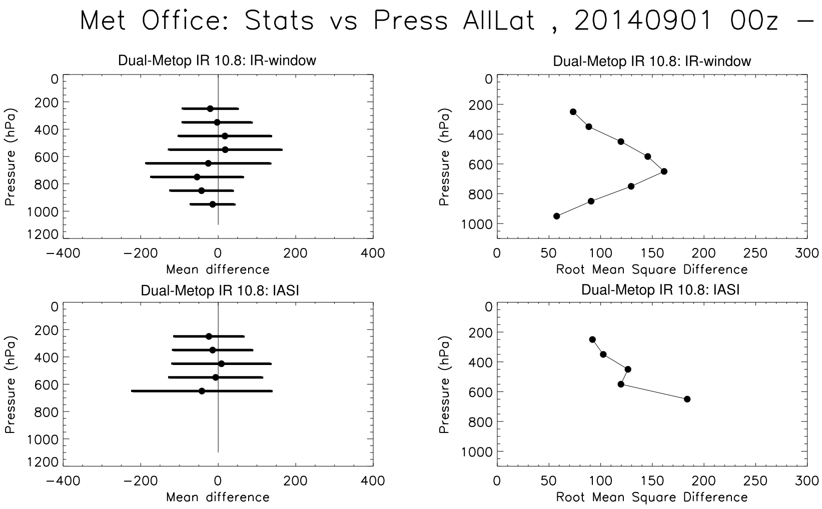


Figure 11: Variation of AMV statistics with QI for the three AMV datasets, September 2014. Dual-Metop data polewards of 40° N/S.



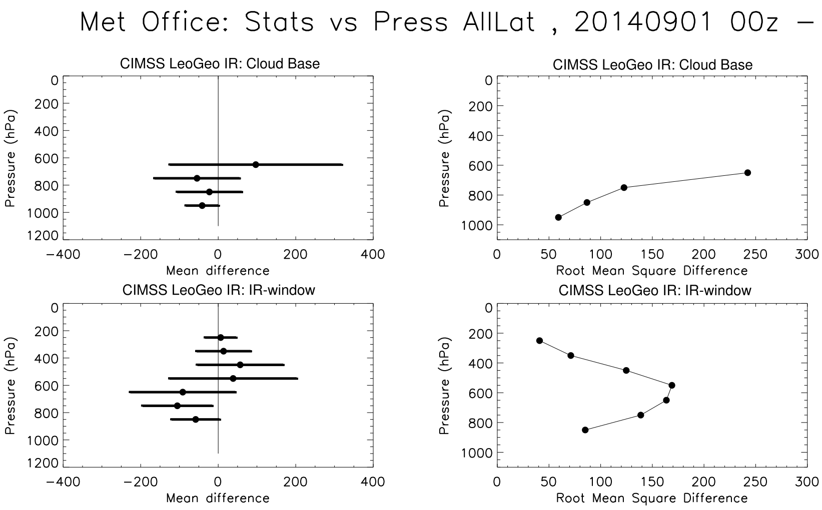
Pressure	Mean	RMS	Number
100– 200	−20	53	1601
200– 300	−17	87	39090
300– 400	9	106	175926
400– 500	30	144	211306
500– 600	32	184	151831
600– 700	13	195	82908
700– 800	−33	135	41907
800– 900	−21	100	29102
900–1000	−2	54	16442
1000–1100	0	0	13

Pressure	Mean	RMS	Number
100– 200	−167	226	126
200– 300	−41	122	1225
300– 400	−13	121	3529
400– 500	19	147	3049
500– 600	14	186	1703
600– 700	−7	206	430
700– 800	−64	161	71
800– 900	0	0	1
900–1000	0	0	1
1000–1100	0	0	0



Pressure	Mean	RMS	Number
100– 200	0	0	1
200– 300	−21	73	77969
300– 400	−3	89	290676
400– 500	17	120	308486
500– 600	18	146	208955
600– 700	−26	161	117241
700– 800	−54	130	75924
800– 900	−43	91	76301
900–1000	−14	57	30896
1000–1100	16	59	135

Pressure	Mean	RMS	Number
100– 200	0	0	1
200– 300	−24	92	2604
300– 400	−14	103	8034
400– 500	8	126	6190
500– 600	−7	120	2786
600– 700	−42	184	874
700– 800	−70	159	131
800– 900	0	0	11
900–1000	0	0	1
1000–1100	0	0	0



Pressure	Mean	RMS	Number
100– 200	0	0	0
200– 300	0	0	0
300– 400	0	0	0
400– 500	0	0	0
500– 600	0	0	0
600– 700	97	242	4902
700– 800	−55	123	29837
800– 900	−23	87	24542
900–1000	−41	59	832
1000–1100	0	0	0

Pressure	Mean	RMS	Number
100– 200	0	0	3
200– 300	6	41	39115
300– 400	14	71	131938
400– 500	57	125	98860
500– 600	39	169	51397
600– 700	−91	164	13502
700– 800	−105	139	7024
800– 900	−58	85	1984
900–1000	0	0	2
1000–1100	0	0	0

Figure 12: Mean and root-mean square pressure differences of AMVs' assigned pressures compared to their model best-fit pressures, September 2014. Dual-Metop figures are for data polewards of 40° N/S only.

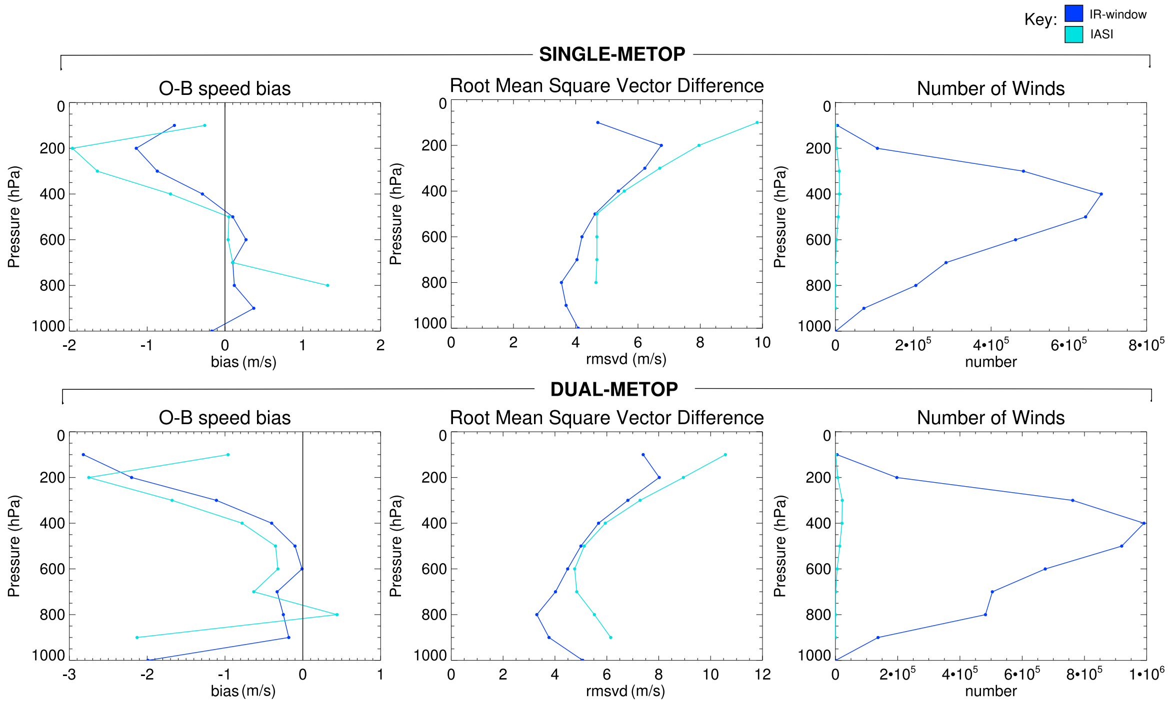


Figure 13: AMV statistics as function of pressure, split by HA method, for the two Metop datasets. Data from September 2014 and polewards of 40° N/S.

In the trial and control, all AMVs were thinned into 200km by 200km by 100 hPa thinning boxes. The usual polar AMV blacklisting was also applied to LeoGeo and Single-Metop[5]. LeoGeo had an additional blacklist of all winds above 300 hPa, and a QI1 threshold of 70. The LeoGeo AMVs also had a 'ThinScore' of 1 to ensure that they would not be used where there was already a conventional AMV available in the same thinning box. The Single-Metop AMVs were used with a QI1 threshold of 80 and a minimum speed threshold of 2 m/s. The EUMETSAT Single-Metop AMVs were trialled on top of the CIMSS Metop AMVs that are already used operationally.

Using the spread of AMV assigned pressures versus model best-fit pressures over a 3-month period, height error profiles were made for the Single-Metop and LeoGeo AMVs (Figure 14).

3.2 Trial Results

From Table 1 it can be seen that, averaged over a selection of variables and forecast lengths, there was a small improvement to Met Office global model forecasts from assimilating LeoGeo or Single-Metop AMVs. The benefit is larger when the trials are verified against analyses than against observations.

The most significant forecast improvement was seen in the Single-Metop trial in the SH, especially when verifying against analyses (see Figure 15). Some benefit is also seen in the LeoGeo trial verified against analyses in the NH and for forecast lengths up to T+96 in the SH. Other than

[5]Blacklist below 600 hPa over land and sea-ice, and below 400 hPa over Greenland and Antarctica. Also blacklist above 200 hPa.

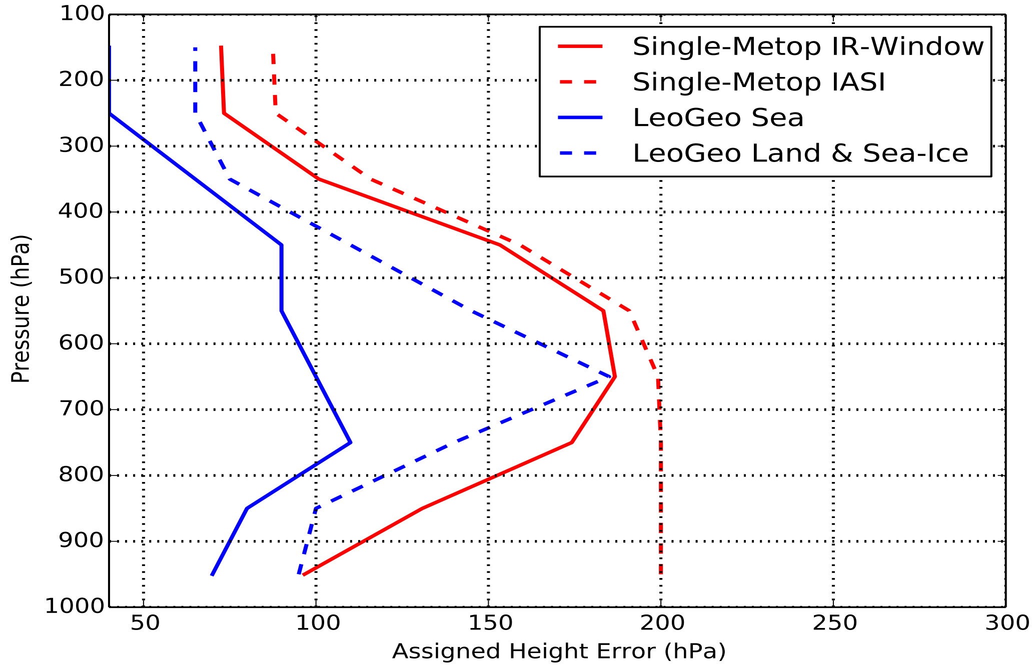


Figure 14: Height error profiles derived from best-fit pressure statistics for the Single-Metop and LeoGeo AMVs. In the Single-Metop trial, 12 separate profiles were used, split by hemisphere, surface type and height assignment method. Averages for each Single-Metop height assignment method are shown here.

AMV Dataset	**New Index vs Observations**	**Old Index vs Observations**	**Old Index vs Analyses**
Single-Metop	+ 0.05 %	+ 0.03 %	+ 0.11 %
LeoGeo	+ 0.07 %	+ 0.04 %	+ 0.09 %

Table 1: Index score percentage changes. The NWP index is a weighted average of forecast error across various model variables and forecast lengths.

that the trials mostly showed small improvements at shorter forecast lengths in the extratropics, and more mixed results in the tropics. On average, per 6-hour assimilation cycle, there were about 1,600 and 3,200 (4.6 % and 9.2 % increase) more AMVs assimilated in the Single-Metop and LeoGeo trial respectively.

4 Conclusions

Three AMV datasets with the potential to help fill the LEO-GEO coverage gap were analysed. The LeoGeo AMVs had a close O-B fit, possibly due to stricter quality control by the producers, but their coverage was densest near to existing geostationary AMVs. The two Metop AMV datasets had similar O-Bs to LeoGeo, but with a larger slow bias at high-level. Assimilation experiments were carried out for the Single-Metop and LeoGeo datasets which showed modest improvements in the

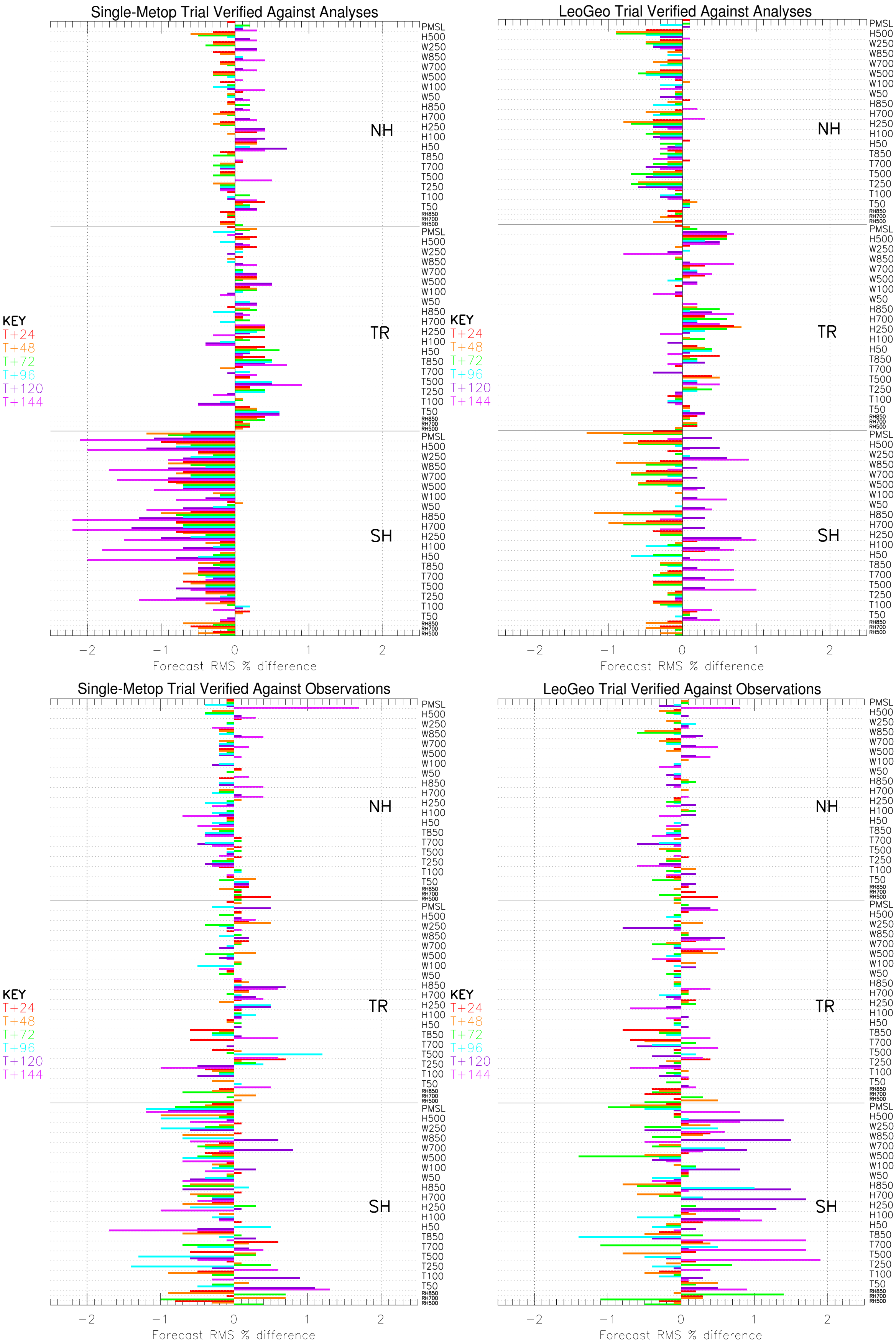


Figure 15: Bar plots of the change in forecast root-mean-square error for trial minus control i.e. trial forecast improvement is to the left of zero.

forecasts, overall. Single-Metop and LeoGeo were made operational in the Met Office global model in February 2015. Dual-Metop could provide additional forecast improvements on top of those from LeoGeo and Single-Metop because of the denser coverage of Dual-Metop AMVs in the LEO-GEO gap and the extra coverage in the South Pacific.

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