AMV investigation

Document NWPSAF-MO-TR-028

Version 0.4

04/10/13

Comparing AMVs over the Indian Ocean

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This documentation was developed within the context of the EUMETSAT Satellite Application Facility on Numerical Weather Prediction (NWP SAF), under the Cooperation Agreement dated 29 June 2011, between EUMETSAT and the Met Office, UK, by one or more partners within the NWP SAF. The partners in the NWP SAF are the Met Office, ECMWF, KNMI and Météo France.

Change record			
Version	Date	Author / changed by	Remarks
0.1	04/04/13	J Cotton	First draft
0.2	15/07/13	J Cotton	Add section with trial results
0.3	18/07/13	J Cotton	First version for review
0.4	04/10/13	J Cotton	Minor updates following comments from J. Eyre and P. Francis.

Contents

1 Introduction

A number of meteorological satellites are in operation over the Indian Ocean region, defined by CGMS as the area covering 36℃-108℃. These include Meteosat-7 operated by EUMETSAT, Kalpana-1 and INSAT-3A operated by ISRO, Elektro-L operated by ROSHYDROMET and FY-2D/E operated by CMA. Atmospheric Motion Vectors (AMVs) are being routinely produced and made available to NWP centres from four of these platforms: Meteosat-7, FY-2D/E and Kalpana-1.

The EUMETSAT Satellite Application Facility for Numerical Weather Prediction (NWP SAF) AMV monitoring website (http://research.metoffice.gov.uk/research/interproj/nwpsaf/satwind_report/index.html) hosts information on how AMVs are assimilated at different NWP centres. All centres which have provided this information (DWD, ECMWF, Environment Canada, JMA, Meteo France, Met Office and NCEP) utilise geostationary AMVs produced from the same five satellites: Meteosat-7 (Indian Ocean), Meteosat-10 (0 degrees), GOES-13 (GOES-East), GOES-15 (GOES-West) and MTSAT-2 (W. Pacific). Meteosat-7 is unanimously used by these NWP centres to provide Indian Ocean Data Coverage (IODC). A recent impact study coordinated by the International Winds Working Group (IWWG) confirmed that Meteosat-7 data continues to have a positive impact on NWP (Payan and Cotton, 2012). For example, Figure 1 shows how the different AMV satellite/channel combinations contribute towards reducing 24-hour forecast error evaluated using the adjoint-based Forecast Sensitivity to Observations (FSO) method. Meteosat-7 accounts for roughly 10-14% of beneficial AMV impact in these systems.

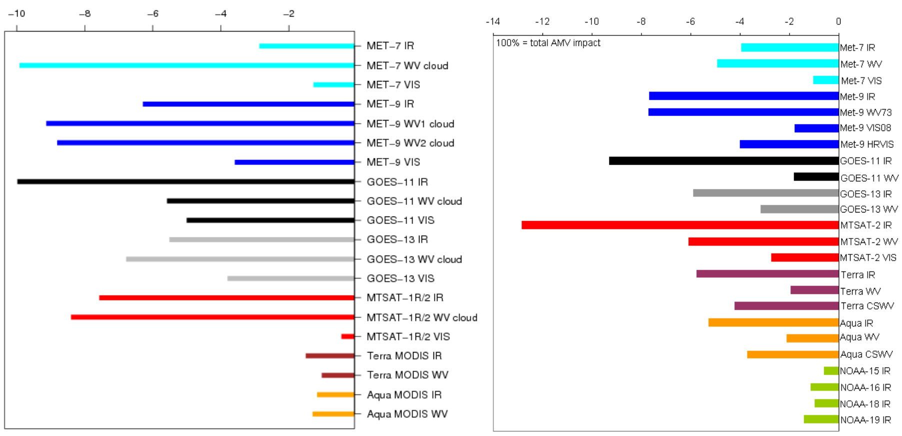

Figure 1. Relative contribution to the total AMV FSO from each satellite/channel combination: ECMWF result (left), UKMO (right). The bars are the relative impact (%) out of the total AMV impact i.e. 100% = total AMV impact. Negative values indicate a positive influence in terms of forecast error reduction from the observations. Taken from Payan and Cotton (2012).

The provision of the Meteosat IODC service is not a primary mission of EUMETSAT. Instead this mission is a ‘best-efforts’ undertaking which makes use of a residual Meteosat First Generation (MFG) capacity to bridge a (temporary) gap in data coverage. Whilst a residual MSG capacity (e.g. Meteosat-8) may become available following commissioning of MSG-4 in around mid-2015, the extension of MFG remains the only agreed approach to continue the IODC mission. Given the uncertainties in the long-term provision of IODC, the purpose of this investigation is to re-evaluate the current alternatives to Meteosat-7 from China and India. AMV products from Meteosat-7, FY-2D/E and Kalpana-1 are the subject of this inter-comparison study

2 AMVs from IODC satellites

2.1 Overview of Meteosat-7, FY-2D/E and Kalpana

An overview of the main satellite and AMV characteristics for each of the IODC satellites is presented in Table 1.

	Meteosat-7	FY-2D	FY-2E	Kalpana-1
Location	57.5E	86.5E	105E	74E
Launch	1997 (IODC from 2006)	2006	2008	2002
Operator	EUMETSAT	CMA	CMA	ISRO
Imager channels	IR (11.3 μm) VIS (0.7 μm) WV (6.3 μm)	IR (10.8 μm) IR12 (12.0 μm) SWIR (3.8 μm) VIS (0.7μm) WV (6.8 μm)	IR (10.8 μm) IR12 (12.0 μm) SWIR (3.8 μm) VIS (0.7μm) WV (6.8 μm)	IR (11.5 μm) VIS (0.65 μm) WV (6.4 μm)
Pixel Resolution at SSP	5.0 km: IR, WV 2.5 km: VIS	5.0 km IR, WV 1.25 km VIS	5.0 km IR, WV 1.25 km VIS	8km: IR, WV 2km: VIS
AMVs	IR, VIS, WV, CSWV	IR, Mixed WV	IR, Mixed WV	IR, Mixed WV
AMV target size	32x32: IR, CSWV 16x16: WV, VIS			
Full disk cycle	Every 30 mins	Every 30 mins	Every 30 mins	Every 30 mins
AMV temporal resolution	1.5 hr	6 hr 03,09,15,21 UTC	6 hr 00,06,12,18 UTC	3 hr
AMV coverage (approx)	4W-118E 60S-60N	32E-142E 54S-54N	50E-160E 52S-52N	22E-128E 48S-49N

Table 1. General characteristics of Meteosat-7, FY-2D, FY-2E and Kalpana. IR = infrared, SWIR = shortwave IR, WV = cloudy water vapour, CSWV = clear-sky water vapour, VIS = visible.

Meteosat-7 is the last remaining platform of the Meteosat First Generation Programme and has been stationed over the Indian Ocean since its relocation in December 2006. It carries the Meteosat Visible Infra-Red Imager (MVIRI): a 3-channel imager covering the infrared (IR), visible (VIS) and water-vapour (WV) bands. Pixel resolution is 5 km for IR and WV and 2.5 km for VIS and full disk images are available every 30 mins. AMVs are derived every 90 mins and quality indicators (QI) are provided following the standard EUMETSAT methodology. For more information on the Meteosat-7 AMV derivation see Schmetz et al. (1993).

FY-2D and FY-2E are the current operational geostationary satellites operated by the Chinese Meteorological Agency (CMA) and carry a 5-channel imager. Full disk images are produced every 30 mins and AMVs are currently extracted in the IR and WV channels at 5 km pixel resolution. CMA provide the clear-sky and cloudy WV winds in one product. However it would be more useful if they were available separately as geostationary clear-sky WV winds are usually of poorer quality. AMVs are derived every 6 hours and FY-2D winds are offset by 3 hours relative to FY-2E with the aim of obtaining 3-hourly winds for the overlap areas of 2D and 2E. However, the 3 hour shift away from standard synoptic times means it is not possible to compare FY2D winds with radiosonde data. FY-2D is less well-calibrated, images are known to be affected by stray-light and the spectral response of the WV channel is not well-defined. The FY-2F satellite was launched in January 2012 but for the time-being CMA plan to use 2F for rapid scanning for severe weather. It is not yet clear when FY-2F may replace FY-2E (with FY-2E to replace FY-2D).

Kalpana-1 is the first geostationary meteorological satellite developed and operated by the Indian Space Research Organisation (ISRO). It carries a 3-channel imager with 8 km pixel resolution for IR/WV and 2 km for VIS. Full disk images are available every 30 mins and IR and WV AMVs are derived every 3 hours. Like CMA, ISRO also provide the clear-sky and cloudy WV winds in one product. Until May 2013, height assignment has been based on the Genetic Algorithm (GA): an empirical method that tries to reproduce Meteosat-7 heights without the use of an NWP background. An improved AMV derivation scheme presented at the recent International Winds Workshop (see Deb et al., 2012) has recently been implemented operationally (31 May 2013) but has yet to be stored at the Met Office due to corrections in the BUFR format. As such the Kalpana data discussed in this report are from the old GA algorithm. A complication with the Indian winds is that Kalpana winds are generated at India Meteorological Department (IMD) using software provided by the research team at ISRO which can lead to delays in the implementation of changes. AMV products from the alternative INSAT satellite series have yet to be made operational. The latest satellite, INSAT-3D, is due to be launched in 2013 and will carry a GOES-type imager.

2.2 Data coverage

Plots showing the spatial coverage of AMVs from the different satellites are given in Figure 2. Kalpana lies over the centre of the Indian Ocean region and is closest to the position of Meteosat-7. However, the square-shaped coverage area of Kalpana extends to only around 49°N/S compared to 60°N/S for Meteosat -7. FY-2D and FY-2E are separated by only 19 degrees and so have a large overlap region but are much further east than Meteosat-7. FY-2E (the better satellite) is located in the ‘primary’ CMA position at 105°E which unfortunately covers less of the Indian Ocean region than FY-2D. Meteosat-9 is able to cover the far west of the basin but use of FY2-E alone for IODC would result in data gaps in the mid-latitudes. FY-2D has a slightly larger latitudinal coverage at 54°N/S but both are short of Meteosat-7.

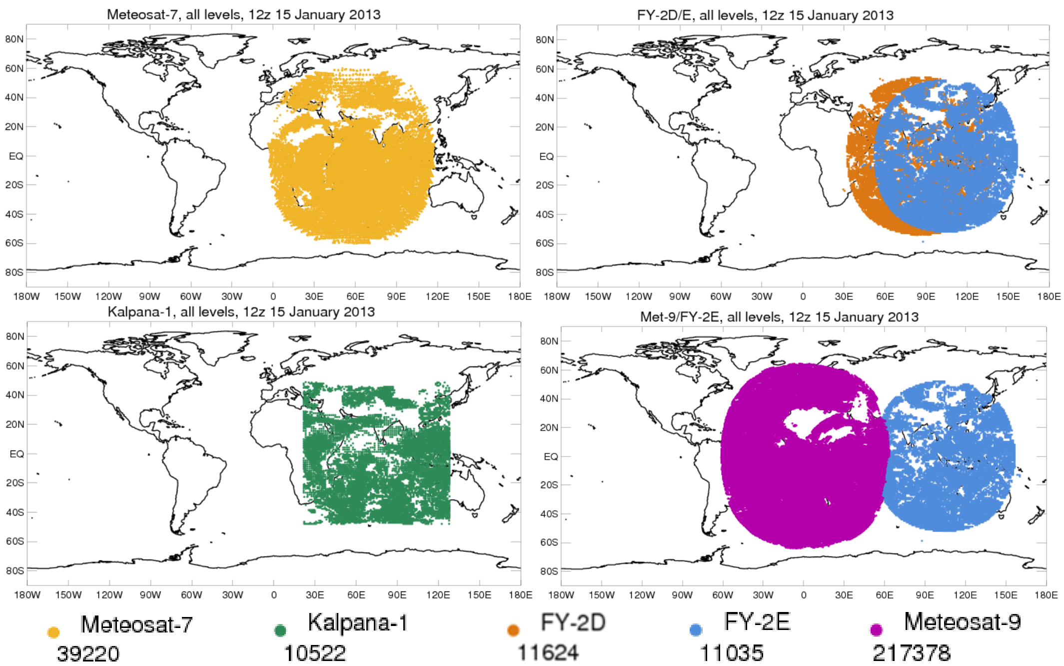

Figure 2. Data coverage plots for a 6-hour period centred at 12 UTC on 15 January 2013: Meteosat-7 (top left), FY-2D/E (top right) and Kalpana-1 (bottom left) AMVs. Meteosat-9 is also shown compared with FY-2E as this extends into the far west of the Indian Ocean (bottom right).

2.3 Data volume

Figure 3 compares the data volume of the EUMETSAT and CMA winds during January 2013. Data volumes are around 25% and 100% higher for Meteosat-7 IR and WV channels respectively compared to FY-2E. There are substantially fewer WV winds from FY-2D and FY-2E despite the inclusion of the clear sky targets in the mixed WV product (Met-7 cloudy WV only). The number of IR winds is more similar, especially considering the Meteosat-7 winds are produced 4x more frequently.

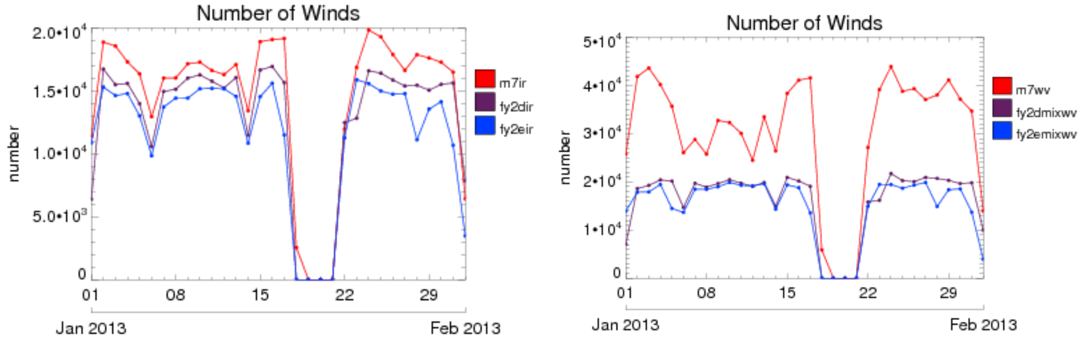

Figure 3. Number of Meteosat-7, FY-2D and FY-2E winds during January 2013: IR (left) and WV (right). Data has been filtered for QI2 > 80. The dropout from 18-20 January was due to monitoring job failures and is unrelated to the data supply.

2.4 Timeliness

An important consideration for use of new data products in operational NWP is the timeliness in which the observations are received. The NWP SAF monitoring website (http://research.metoffice.gov.uk/research/interproj/nwpsaf/satwind_report/index.html) hosts information on the time requirements for several NWP centres. In general it is desirable that data are received as soon as possible. Figure 4 compares the timeliness of Meteosat-7, Kalpana-1 and FY-2D/E observations received from EUMETSAT, ISRO and CMA respectively during January 2013. Nearly all data from Meteosat-7, Kalpana-1 and FY-2E were received in less than 3 hours, meaning a significant amount of data would have been available for use in assimilation. FY-2D was less timely with only 40% of data arriving in less than 3 hours and only 4% arriving in time for the main forecast run. Meteosat-7 data was the timeliest with a mean delay of just over 30 minutes. Data availability throughout January 2013 was good from EUMETSAT and CMA but the winds received from ISRO were patchier with missing time slots on around 2 out of every 3 days.

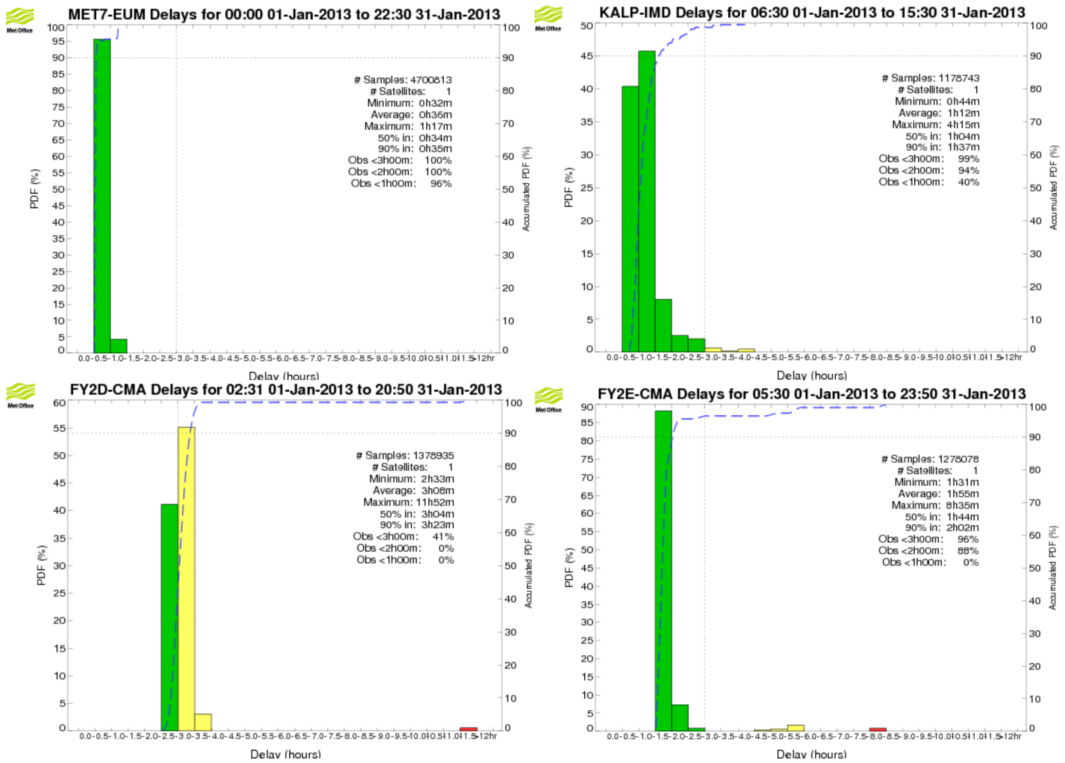

Figure 4. Histograms showing the time delay in hours for AMVs received at the Met Office during January 2013: Meteosat-7 (top left), Kalpana-1 (top right), FY-2D (bottom left) and FY-2E (bottom right). The delay time is defined as the difference between the observation time and the receipt time in the Met Office Meteorological Database (MetDB).

3 CGMS statistics

A snapshot of AMV quality from the IODC satellites can be gathered from CGMS (Coordination Group for Meteorological Satellites) approved monthly statistics calculated routinely at the Met Office (see IWWG, 1996). These standard O-B statistics are calculated against the Met Office global model background for AMVs with QI>80% for IR and WV winds (cloudy and mixed), QI>65% for VIS winds and QI>50% for clear sky WV winds. The quality indicator used is that including the model first guess check (QI1) and the geographical boundaries are as follows: NH is the northern hemisphere extratropics north of 20N, SH is the southern hemisphere extratropics south of 20S and TR is the tropics between 20N-20S.

CGMS statistics for the IODC satellites are presented in Table 2 through Table 5 for January 2013. Note that Kalpana winds are not supplied with standard EUMETSAT QI values so these statistics are instead calculated for all winds supplied by ISRO.

3.1 IR winds

At high level (above 400 hPa) the Meteosat-7 IR winds show a strong dependence on latitude. In the extratropics the winds exhibit a significant negative wind speed bias of nearly 3 m/s and increased levels of RMSVD. The slow speed bias is slightly worse in the northern hemisphere and is linked to the increase in observed wind speed. In the tropics, where there are a large number of winds, data quality is good. At mid level (400-700 hPa) the IR winds are generally poorer in quality but tempered by the fact fewer winds are derived here. The tropical winds at mid level exhibit a positive speed bias of around 2 m/s. At low level (below 700 hPa) the observed wind speed is much lower and the AMVs are generally of good quality with neutral wind speed bias and low levels of RMSVD. The exception is for a very small number of winds extracted in the NH.

As there is a high degree of overlap between the coverage of FY-2D and FY-2E the two CMA platforms can be compared more directly. In general the O-B statistics for the two satellites are broadly similar. At high level, the negative speed bias is around 5 m/s in the northern hemisphere and RMSVD values are high at over 9 m/s. In the tropics however, there are a large number of good quality winds and the RMS vector differences are slightly better by around 0.5 m/s for FY-2E compared to FY-2D. The statistics at mid level follow a similar pattern. The number of winds extracted at low level is comparably low for both satellites. Rather unusually, for FY-2D there are more winds at mid level than there are at low level. Outside the northern hemisphere, the quality of the low level winds is reasonable with RMSVD values of 3.5 m/s in the tropics.

The Kalpana winds are generally of poor quality with high RMS vector differences observed at all levels. In comparison to Meteosat-7 and FY-2D/E, there are an unusually high number of winds assigned to mid level.

3.2 WV winds

The Meteosat-7 WV winds are extracted from tracking cloudy targets only and so virtually all winds are located at high level. In the extratropics the negative speed bias of around 1 m/s is significantly smaller in magnitude than that seen for the IR winds. However the tropical WV winds have more of a positive speed bias and higher RMSVD compared to the IR.

The WV winds from FY-2D and FY-2E are a derived from tracking a mixture of clear and cloudy targets and so are located across a much larger depth of the troposphere. The statistics show that in general the FY-2E WV winds are of a much higher quality than FY-2D with RMS vector differences around 0.5-2.0 m/s lower for FY-2E. This is likely due to known issues with the FY-2D WV channel (spectral response not well characterised). It is also noticeable that the WV winds show smaller departures compared to the IR winds. For example, at high and mid level the negative speed bias in the extratropics is only around 1-2 m/s for FY-2E WV winds versus around 3-6 m/s for the IR winds. In general the FY-2E WV winds appear to be of good quality at mid-high level.

Departures for the Kalpana mixed WV winds are large and variable.

3.3 Summary

Although not a direct like-for-like comparison due to the differences in geographical coverage, the statistics can still offer a broad relative comparison between the platforms for January 2013. The Meteosat-7 IR AMVs are of slightly higher quality than the IR winds from FY-2D and FY-2E. In particular, the negative speed bias in the northern hemisphere appears more pronounced in the data from CMA. This is despite the fact that Meteosat-7 data captures a higher mean wind speed. Generally in the tropics, the statistics from Meteosat-7 and FY-2D/E are very comparable and at mid level the CMA data doesn't exhibit the positive speed bias seen in the EUMETSAT data. Further investigation would be needed to ascertain whether this is due to geographical differences.

Interpreting the differences in the WV winds is not straightforward due to the fact the CMA winds are also tracking clear-sky targets. At high level, the negative speed bias in the northern hemisphere is again slightly worse for FY-2E compared to Met-7. However, in the topics and southern hemisphere the high level statistics from FY-2E are more favourable. At mid level the number of winds from FY-2E is a factor of 10 greater due to the additional tracking of clear-sky targets and RMS vector differences here are smaller than seen from Meteosat-7.

Kalpana AMVs making use of the old GA algorithm are generally of poor quality and so will not be considered any further in this study.

Met-7 IR
Jan-13

	ALL	NH	TR	SH
ALL LEVELS				
RMSVD	6.1	8.1	5.2	6.1
BIAS	-0.7	-1.6	0.2	-1.5
SPD	16.6	27.1	10.9	19.8
NUMBER	440733	66553	214843	159337
Above 400 hPa				
RMSVD	6.6	7.6	5.8	7.6
BIAS	-1.1	-2.9	0.1	-2.5
SPD	21.2	33.2	13.4	31.2
NUMBER	230686	40714	133502	56470
700-400 hPa				
RMSVD	8.6	8.9	7.0	8.8
BIAS	-1.0	0.4	2.1	-2.8
SPD	19.4	18.7	7.9	22.9
NUMBER	58106	22125	7359	28622
Below 700 hPa				
RMSVD	3.4	9.3	3.5	2.6
BIAS	0.0	0.9	0.2	-0.1
SPD	8.4	10	6.8	9.9
NUMBER	151941	3714	73982	74245

Met-7 WV
Jan-13

	ALL	NH	TR	SH
ALL LEVELS				
RMSVD	6.9	7.1	6.7	7.4
BIAS	0.3	-1.0	1.3	-0.7
SPD	21.5	31.2	14.3	29.6
NUMBER	920599	185799	508603	226197
Above 400 hPa				
RMSVD	6.9	7.1	6.7	7.4
BIAS	0.3	-1.1	1.3	-0.7
SPD	21.4	31.6	14.3	29.6
NUMBER	908785	177957	508407	222421
700-400 hPa				
RMSVD	7.4	7.0	10.8	8.1
BIAS	0.7	1.1	5.0	-0.4
SPD	24.5	21.8	13.1	30.7
NUMBER	11814	7842	196	3776

Table 2. CGMS statistics for Meteosat-7 IR (left) and WV (right) AMVs in January 2013. RMSVD = root mean square vector difference, SPD = mean wind speed, BIAS = mean O-B speed.

FY2D IR
Jan-13

	ALL	NH	TR	SH
ALL LEVELS				
RMSVD	7.0	9.3	5.7	7.1
BIAS	-1.8	-4.5	-0.4	-2.0
SPD	15.7	22.4	9.3	19.8
NUMBER	408501	75154	178998	154349
Above 400 hPa				
RMSVD	7.1	9.2	6.1	7.5
BIAS	-1.7	-4.5	-0.6	-2.2
SPD	17.3	25.8	10.0	26.4
NUMBER	250576	40115	137362	73099
700-400 hPa				
RMSVD	8.7	9.6	5.7	8.5
BIAS	-3.5	-4.7	0.6	-3.5
SPD	17.7	19.3	6.8	19.2
NUMBER	82175	32548	10521	39106
Below 700 hPa				
RMSVD	4.3	7.6	3.6	4.5
BIAS	-0.3	-2.3	-0.3	-0.2
SPD	8.3	10.0	7.0	9.1
NUMBER	75750	2491	31115	42144

FY2D MIXWV
Jan-13

	ALL	NH	TR	SH
ALL LEVELS				
RMSVD	7.4	8.9	6.4	7.5
BIAS	-1.0	-3.3	0.6	-1.5
SPD	17.3	23.5	9.3	23.0
NUMBER	518110	119801	219833	178476
Above 400 hPa				
RMSVD	7.2	9.0	6.4	7.4
BIAS	-0.6	-3.2	0.7	-1.4
SPD	17.3	27.1	9.3	24.4
NUMBER	410726	65944	205573	139209
700-400 hPa				
RMSVD	8.1	8.9	6.2	7.6
BIAS	-2.5	-3.3	-0.4	-2.1
SPD	17.4	19.1	9.9	17.8
NUMBER	107384	53857	14260	39267

Table 3. CGMS statistics for FY-2D IR (left) and mixed WV (right) AMVs in January 2013. RMSVD = root mean square vector difference, SPD = mean wind speed, BIAS = mean O-B speed.

FY2E IR
Jan-13

	ALL	NH	TR	SH
ALL LEVELS				
RMSVD	6.7	9.5	5.3	6.9
BIAS	-1.8	-5.1	-0.6	-2.0
SPD	14.6	21.8	9.4	18.4
NUMBER	374216	62639	181220	130357
Above 400 hPa				
RMSVD	6.7	9.4	5.6	7.5
BIAS	-1.7	-5.1	-0.8	-2.5
SPD	15.8	26.6	10.0	25.6
NUMBER	220888	25922	140575	54391
700-400 hPa				
RMSVD	9.0	10.4	5.5	8.5
BIAS	-3.9	-6.0	0.6	-3.5
SPD	17.6	21.0	7.0	18.1
NUMBER	68870	26698	9993	32179
Below 700 hPa				
RMSVD	4.4	6.5	3.5	4.3
BIAS	-0.5	-2.5	0.0	-0.4
SPD	9.0	11.4	7.2	9.6
NUMBER	84458	10019	30652	43787

FY2E MIXWV
Jan-13

	ALL	NH	TR	SH
ALL LEVELS				
RMSVD	6.0	7.6	5.5	5.7
BIAS	-0.3	-1.7	0.6	-0.8
SPD	15.3	21.5	9.3	20.5
NUMBER	478356	89204	230680	158472
Above 400 hPa				
RMSVD	6.0	8.5	5.6	5.7
BIAS	-0.1	-2.3	0.7	-0.7
SPD	15.0	27.2	9.3	21.8
NUMBER	365623	38589	215110	111924
700-400 hPa				
RMSVD	6.0	6.7	4.9	5.5
BIAS	-0.9	-1.1	0.1	-1.0
SPD	16.1	17.3	8.3	17.5
NUMBER	111808	49762	15559	46487
Below 700 hPa				
RMSVD	9.2	9.3	13.4	7.5
BIAS	-2.6	-3.0	4.0	1.4
SPD	13.2	13.4	6.1	12.2
NUMBER	925	853	11	61

Table 4. CGMS statistics for FY-2E IR (left) and mixed WV (right) AMVs in January 2013. RMSVD = root mean square vector difference, SPD = mean wind speed, BIAS = mean O-B speed.

Kalpana IR
Jan-13

	ALL	NH	TR	SH
ALL LEVELS				
RMSVD	11.4	13.9	10.9	10.0
BIAS	2.5	-0.3	3.0	3.8
SPD	13.3	20.2	8.8	14.1
NUMBER	572248	133859	243240	195149
Above 400 hPa				
RMSVD	9.5	12.1	8.4	9.9
BIAS	-0.1	-4.2	0.8	2.2
SPD	15.5	26.8	10.9	19.0
NUMBER	213625	44976	136312	32337
700-400 hPa				
RMSVD	13.8	14.2	13.9	12.9
BIAS	4.4	0.9	6.7	6.8
SPD	14.1	18.0	6.1	17.3
NUMBER	191586	77525	59969	54092
Below 700 hPa				
RMSVD	10.5	17.8	12.7	8.2
BIAS	3.6	6.3	4.8	2.7
SPD	9.6	9.2	6.4	11.0
NUMBER	167037	11358	46959	108720

Kalp MIXWV
Jan-13

	ALL	NH	TR	SH
ALL LEVELS				
RMSVD	11.9	14.8	10.3	12.1
BIAS	3.0	-0.7	3.9	5.2
SPD	13.9	24.6	8.9	15.3
NUMBER	393987	94649	227230	72108
Above 400 hPa				
RMSVD	10.3	13.9	9.2	11.2
BIAS	2.8	-1.8	3.5	4.0
SPD	13.0	29.0	9.2	16.1
NUMBER	219675	32177	158317	29181
700-400 hPa				
RMSVD	13.6	15.3	12.5	12.6
BIAS	3.3	-0.2	4.8	6.1
SPD	15.0	22.3	8.5	14.8
NUMBER	174312	62472	68913	42927

Table 5. CGMS statistics for Kalpana IR (left) and mixed WV (right) AMVs in January 2013. RMSVD = root mean square vector difference, SPD = mean wind speed, BIAS = mean O-B speed.

4 Long-term trends

Met Office CGMS statistics accumulated from the past several years can be used to investigate seasonal and long term trends in AMV quality. The stability of the products is an important factor to consider for NWP.

Figure 5 to Figure 7 show the variation in RMSVD, mean O-B speed bias and mean observed speed from January 2008 until March 2013 for data from Meteosat-7 and FY2-C/D/E. It is clear from the CGMS statistics that whilst the Meteosat-7 data has remained very stable over the past 5 years, there have been significant changes in the data characteristics from CMA. There have been three (known) major derivation changes made by CMA during this time: late 2009, January 2011 and September 2011. Information on the changes as supplied by CMA is available in the Appendix.

The impact on the CMA data can be clearly seen in Figure 5 which shows IR winds at high level. If we first consider the northern hemisphere (top plot) then we see that through 2008 and 2009, FY2-C and FY-2D both exhibit a large and variable seasonal bias. For FY-2D, the negative speed bias and RMSVD peak at -15 m/s and 22 m/s respectively and clearly coincides with the peak in wind speed in northern hemisphere winter. After the first CMA update in late 2009 we lose data from FY-2C, but for FY-2D we can observe that the peak in bias/RMSVD in January 2010 is reduced compared to levels of February 2009. From April 2010 the Met Office began monitoring data from FY-2E and initially the data quality appears slightly worse than FY-2D. Following the CMA update in January 2011 we notice several changes: 1) loss of data from FY-2D, 2) sharp reduction in RMSVD and speed bias, 3) sharp drop in the mean observed wind speed. These are largely the result of changes to the QI characteristics as, after the update, there are very few AMVs with high observed wind speeds that have QI1 > 80. For FY-2D it was found that all winds had a QI value of 50 and therefore no data at all remained above the monitoring threshold. From September 2011 the faster AMVs are once again retained with no obvious impact on wind vector quality. RMSVD and bias levels are closer to Meteosat-7 but are still slightly higher for FY-2E. More recently, FY-2D has reappeared from October 2012 onwards and also note the dip in observed wind speed in January 2013.

A similar pattern of changes can be observed in the southern hemisphere but with a few small differences (bottom panel of Figure 5). Following the September 2011 change the southern hemisphere AMVs from FY-2E appear much closer in quality to Meteosat-7 and in fact have a lower RMSVD and bias from around April-November 2012. In the most recent months, data quality from all three satellites appears similar, although observed wind speeds from FY-2D/E remain lower.

The plot of high level IR data in the tropics also tells a similar story of gradual improvement in AMV quality from CMA (middle panel of Figure 5). Note the change in scale of the wind speed axis from the extratropics.

Figure 7 shows that the low level IR winds are generally now quite similar in quality. The mean wind speed bias from Meteosat-7 is around a few tenths of m/s above zero, whilst the mean bias from FY-2D/E is around a few tenths of m/s below zero.

If we consider just the WV (cloudy for Meteosat-7, mixed for FY2) winds at high level as shown in Figure 6 then we observe a similar pattern of changes to that of the IR. For the northern hemisphere (top panel), the CMA winds at the start of 2009 again have a large bias coinciding with the winter months. From a peak in bias and RMSVD of -15 m/s and 22 m/s respectively (same as IR) in February 2009, a gradual trend towards a reduction in peak levels of bias can be seen for the following two winters up to January 2011. Following the changes in 2011, FY-2E data quality appears much more stable and similar to that of Meteosat-7. Although the mean observed wind speed recovered following the September 2011 change it still remains several m/s lower than Meteosat-7.

In the southern hemisphere and tropics (bottom and middle panels of Figure 6), the mixed WV winds from FY-2E actually have lower RMSVD values than Meteosat-7 following the September 2011 change.

The high level FY-2E WV winds are of a higher quality than FY-2D. There are two reasons why we might expect AMVs in general from FY-2D to be of lower quality (ref CMA, October 2011):

1. The image calibration of FY-2D is worse than FY-2E
2. The time schedule of FY-2D at 03,09,15,21 UTC (3 hour departures from FY-2E) means than it is not possible to compare with radiosonde data. Algorithm changes are therefore prepared and tested with FY-2E and then directly applied to FY-2D.

The results presented here show that only the WV winds are inferior for FY-2D so this probably due to the known issues with the FY-2D WV channel spectral response function.

Figure 5. Time series of monthly CGMS statistics for Meteosat-7 (black lines), FY-2E (dark blue), FY-2D (pink) and FY-2C (aqua) from January 2008 to March 2013. Statistics calculated against the Met Office global model background for AMVs with QI1 > 80%. IR winds above 400 hPa by latitude band: north of 20°N (top panel), tropics 20°S-20°N (middle) and south of 20°S (bottom).

Figure 6. As Figure 5 but for WV winds above 400 hPa. Meteosat-7 data are cloudy WV only, FY-2 data are mixed WV.

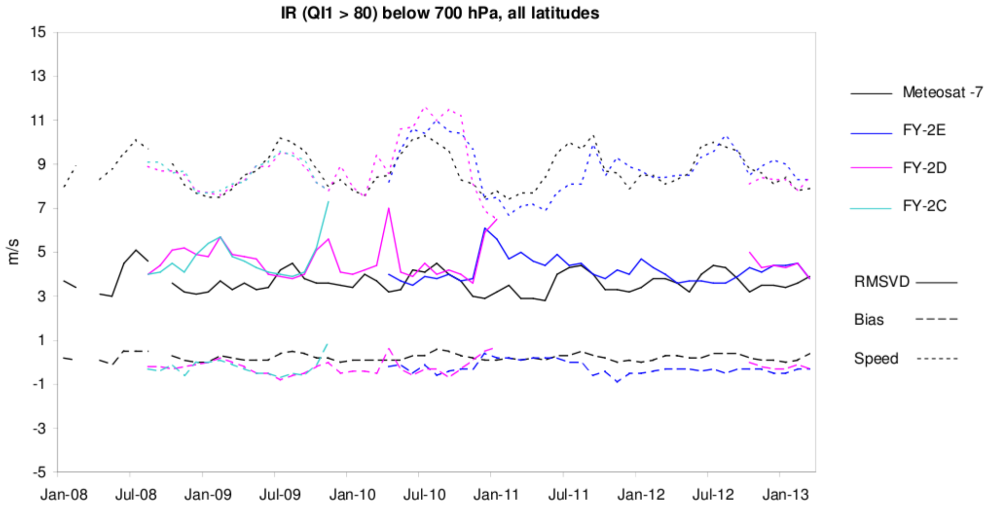

Figure 7. Time series of monthly CGMS statistics for Meteosat-7 (black lines), FY-2E (dark blue), FY-2D (pink) and FY-2C (aqua) from January 2008 to March 2013. Statistics calculated against the Met Office global model background for AMVs with QI1 > 80%. IR winds below 700 hPa.

5 NWP SAF plots

The NWP SAF AMV monitoring website hosts a long-term (up to 3 years) archive of monthly O-B monitoring plots for a comprehensive range of geostationary, polar and mixed satellite AMVs. Of the IODC satellites, Meteosat-7 and FY-2E are currently monitored routinely and made available on the external website. Until reliability improves FY-2D will continue to just be monitored internally.

In the sections below we present an analysis of the NWP SAF data from Meteosat-7 and FY-2E. For geostationary AMVs, the plots on the website and those reproduced in this section are produced using observations with QI2 (without first-guess check) greater than 80. Note this is different to the CGMS statistics already presented.

5.1 January 2013

IR high level

As shown by Figure 8, both Meteosat-7 and FY-2E IR winds have a negative speed bias at high level in the extratropics which is worse in the northern hemisphere. Speed bias standard deviation is actually smaller for FY-2E as Meteosat-7 has a greater asymmetry in distribution with a longer tail of negative O-B's. In the tropics the biases are smaller but the density plots show there are very few FY-2E winds above 40 m/s.

The map plots (Figure 10 and Figure 11) show that the slow bias at high level is particularly prominent for the FY-2E in two areas: 1) to the NE of India and 2) towards the East China Sea and Japan. As FY-2E lies slightly further east than FY-2D it is likely to cover more of the slow bias region near Japan. This may explain why in the CGMS statistics FY-2E has a larger speed bias in northern hemisphere than FY-2D. The slow bias near Japan coincides with the (peak) fast winds of the strong upper level jet stream as captured by the model. The slow bias to the NE of India appears not to be associated with the jet stream but instead occurs over the very high terrain north of the Himalayas and over Western China.

IR mid level

At mid level (not shown) the IR speed bias statistics are generally poor in the extratropics. The CMA winds show a larger negative speed bias but Meteosat-7 shows greater variation and poorer correlation.

IR low level

For low level IR data (Figure 9) Meteosat-7 shows some spuriously fast winds, particularly in the tropics and northern hemisphere where there is a marked asymmetry. The CMA winds in the northern hemisphere also show poorer statistics and continue to show a negative speed bias. In the tropics the CMA winds are less biased than Meteosat-7. In the southern hemisphere Meteosat-7 has a neutral wind speed bias and lower O-B standard deviation than FY-2E.

The FY-2E low level map (Figure 13) shows that northern hemisphere negative speed bias for the CMA winds is localised to a region near Korea/Japan. The vector plots show that this bias is the result of observations not properly capturing the strength of winds flowing off the Asian continent (winter monsoon). Mean vector differences are also quite high off the West coast of Australia. The Meteosat-7 winds over sea are mostly unbiased (Figure 12). Over land however, many of the winds show a significant fast bias, particularly north of the equator over Africa, the Arabian Peninsula and Northern India. This bias coincides with the position of the upper level jet (Figure 10) and is indicative of a large height assignment error in these cases.

WV high level

The speed bias characteristics of the high level WV winds are similar to that described for the IR. The main difference is that the negative speed bias for the CMA winds is reduced for the mixed WV winds compared to the IR. Outside the northern hemisphere, mean speed bias and vector differences are low for FY-2E and clearly lower than Meteosat-7 in the overlap region (Figure 14).

Zonal plots

The high-mid level slow bias is the dominant feature of the FY-2E IR zonal plot (Figure 15). The CMA winds also have a slow bias at very high level (above 150 hPa) in the tropics. Meteosat-7 IR has strong biases located around 500-600 hPa: a slow bias near 40S and a fast bias near 20N. The FY-2E WV winds are derived much deeper in the troposphere and are assigned to more discrete height bands below about 350 hPa. The fast bias for Meteosat-7 WV winds extends from around 20°N to 40°S.

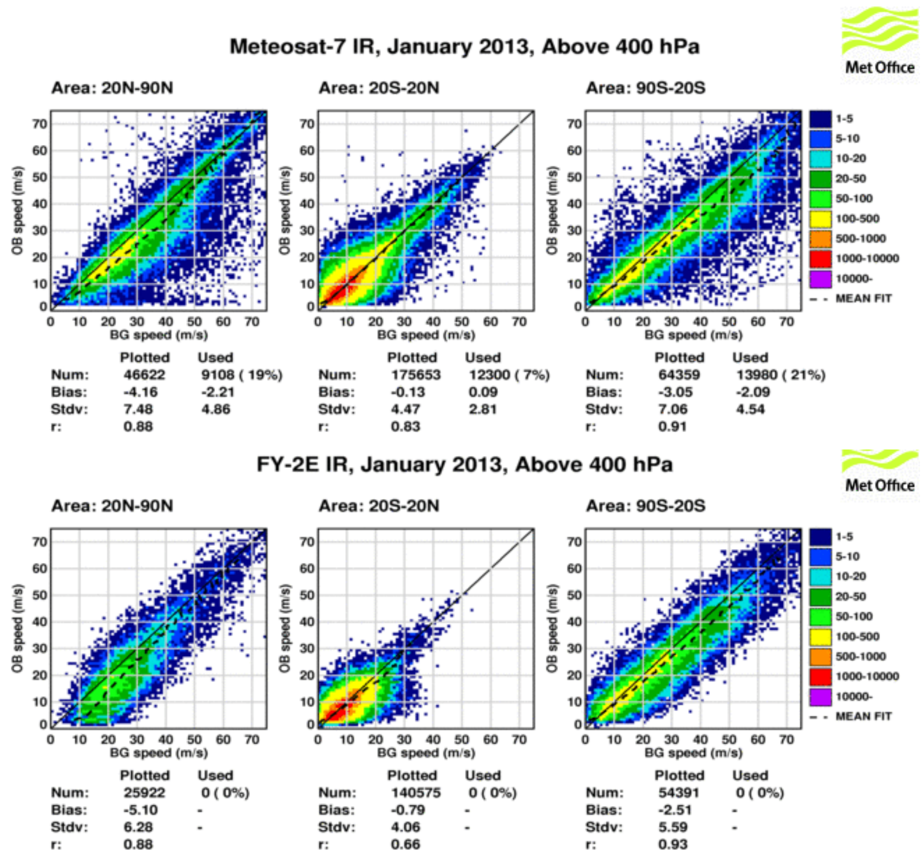

Figure 8. Density plots of observation versus model background wind speed for Meteosat-7 (top panel) and FY-2E (bottom) IR AMVs above 400 hPa. Statistics are calculated by latitude band against the Met Office global model background for January 2013.

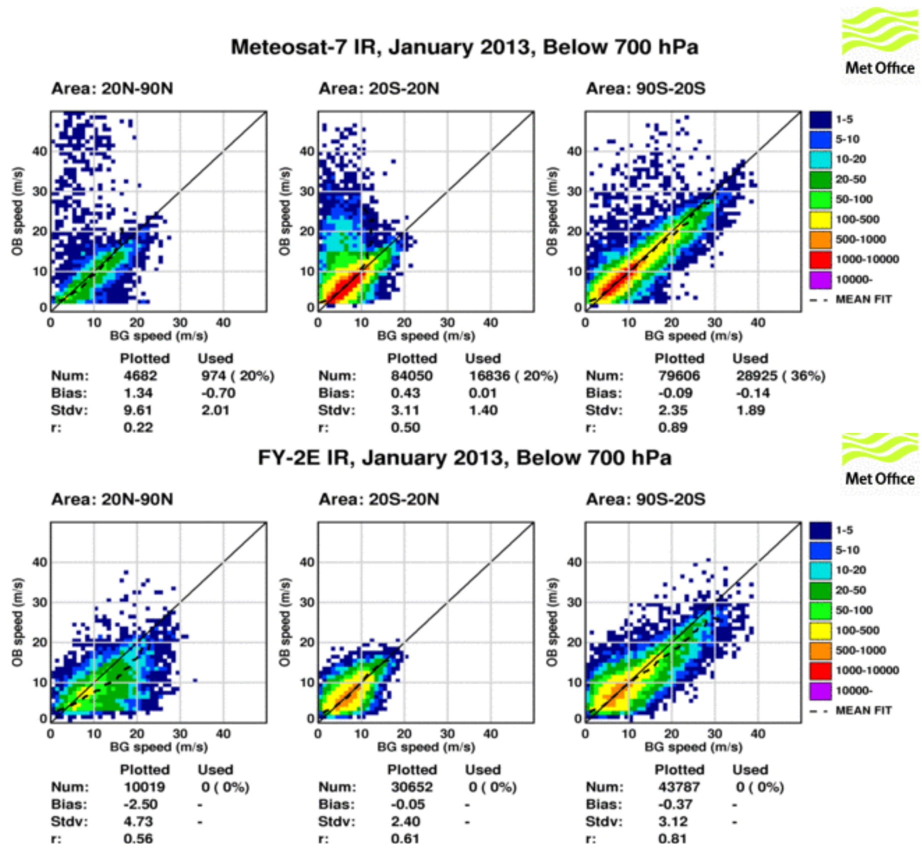

Figure 9. As per Figure 8 but for IR AMVs below 700 hPa.

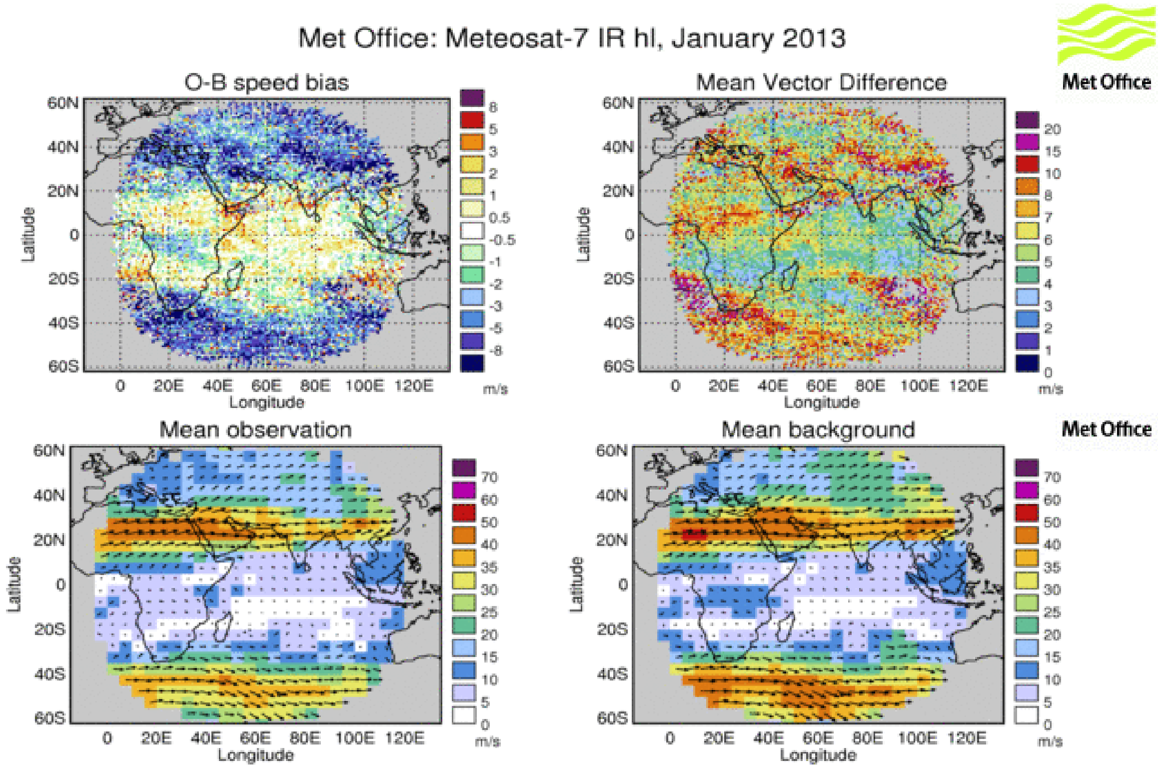

Figure 10. Map plots of O-B speed bias (top left), MVD (top right), mean observed vectors (bottom left) and mean model background vectors (bottom right). Data plotted are high level, Meteosat-7 IR AMVs in January 2013.

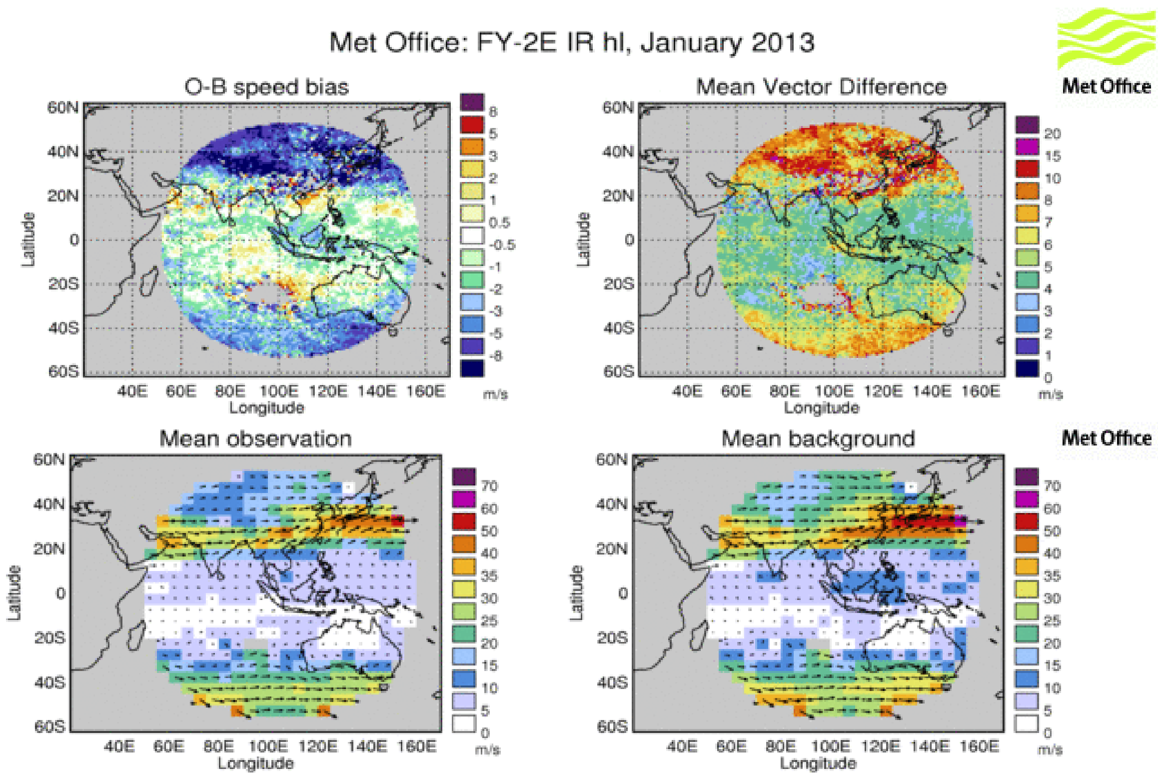

Figure 11. As Figure 10 but for high level FY-2E IR AMVs in January 2013.

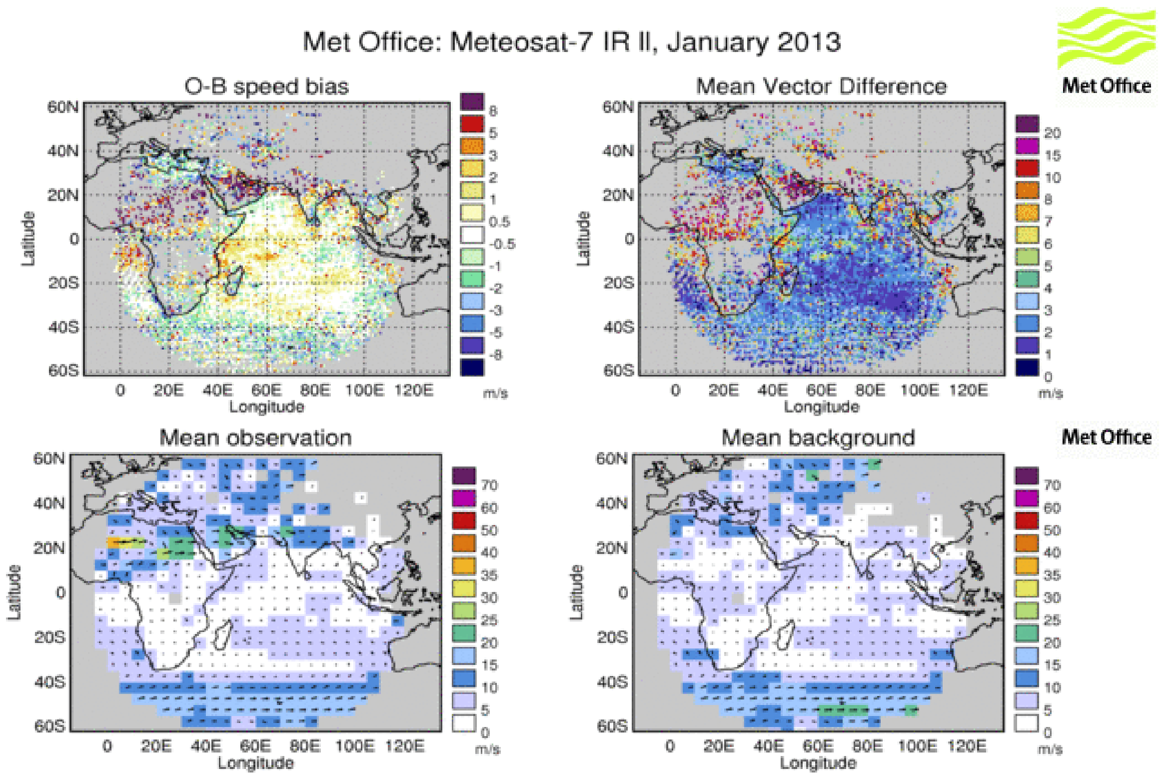

Figure 12. Map plots of O-B speed bias (top left), MVD (top right), mean observed vectors (bottom left) and mean model background vectors (bottom right). Data plotted are low level, Meteosat-7 IR AMVs in January 2013.

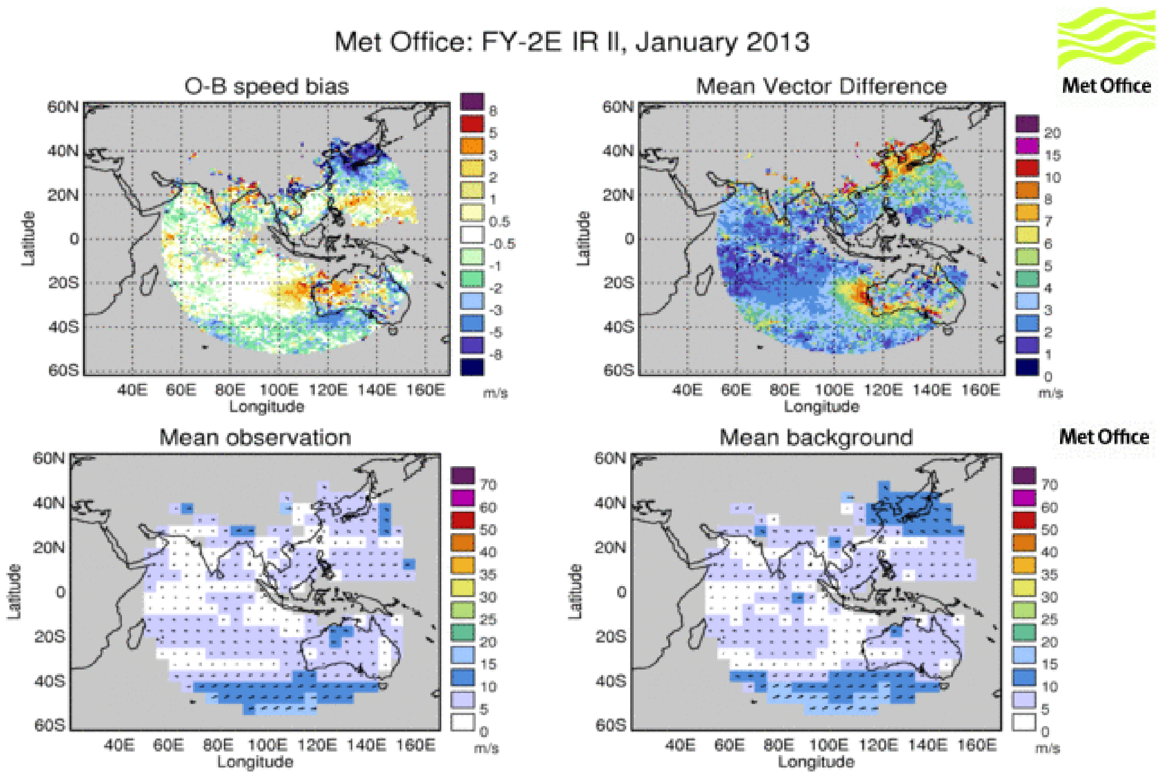

Figure 13. As Figure 12 but for low level FY-2E IR AMVs in January 2013.

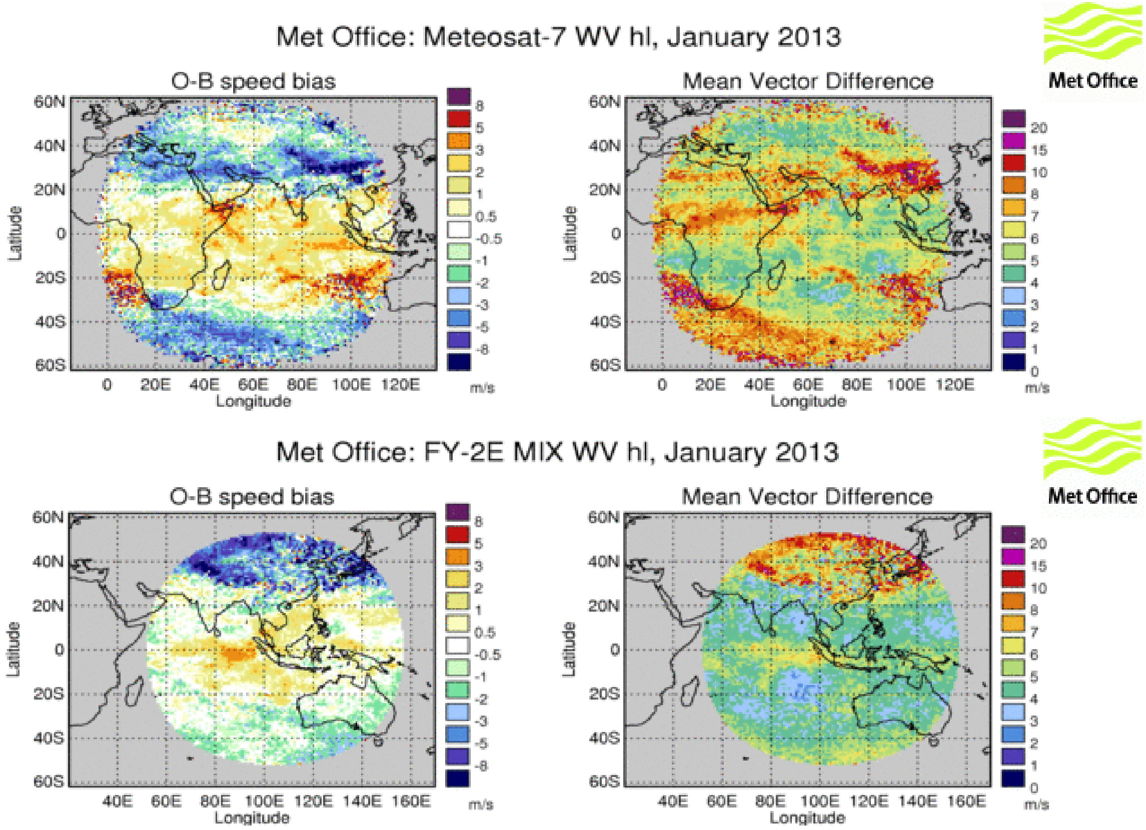

Figure 14. Map plots of O-B speed bias (left) and MVD (right). Data plotted are high level, Meteosat-7 WV (top) and FY-2E mixed WV (bottom) AMVs in January 2013.

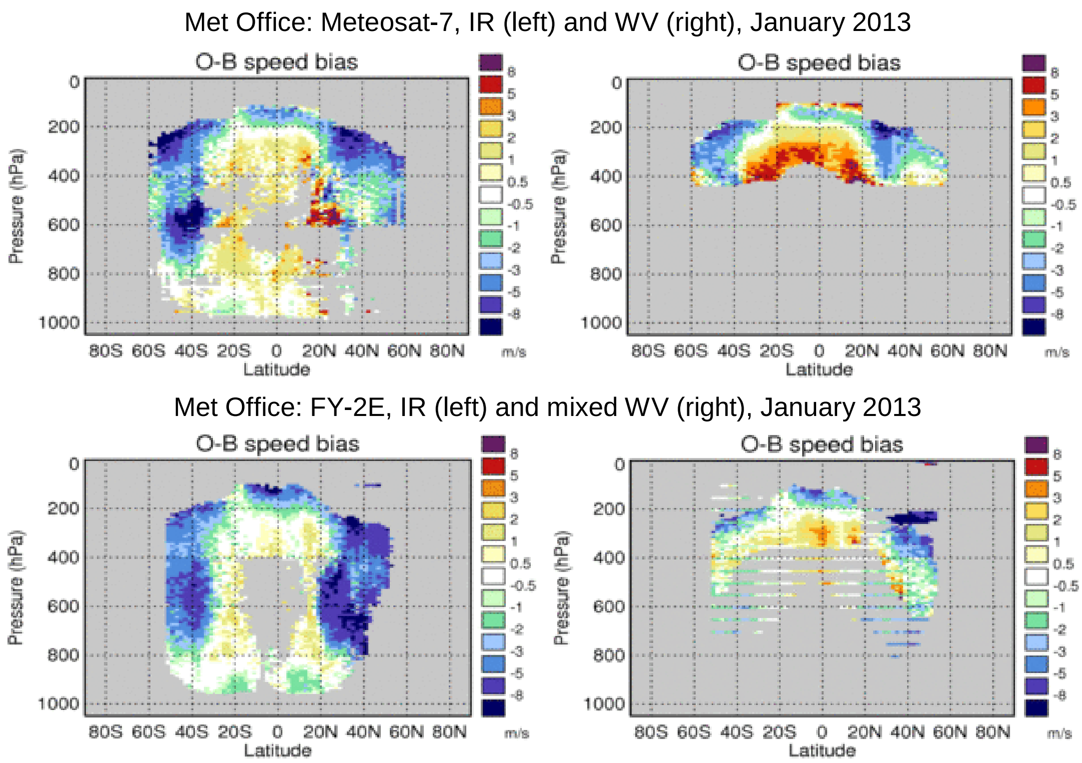

Figure 15. Zonal plots of O-B speed bias for Meteosat-7 (top) and FY-2E (bottom) for IR (left) and WV (right) AMVs in January 2013.

5.2 July 2012

Figure 16 shows zonal O-B plots for July 2012 for comparison with Figure 15 above. Note that boxes with fewer than 20 observations are not plotted. Both satellites have very few IR winds extracted below 400 hPa in the northern hemisphere. As a result the negative bias for FY-2E IR has reduced significantly and the remainder of the plot looks similar to the statistics for January 2013. For Meteosat-7 IR, the positive speed bias in the tropics has become more pronounced and is noticeably marked around 15°N at 700-800 hPa. In the southern hemisphere the strong negative speed bias is located in the position of the upper level jet around 20-30°S. For the FY-2E WV winds the positive bias in the tropics is slightly stronger compared to January. Meteosat-7 WV shows a similar negative bias in the southern hemisphere jet region to that seen in the IR and the positive bias in the tropics is also more marked in July.

Overall, Meteosat-7 data have larger speed biases than FY-2E in this season.

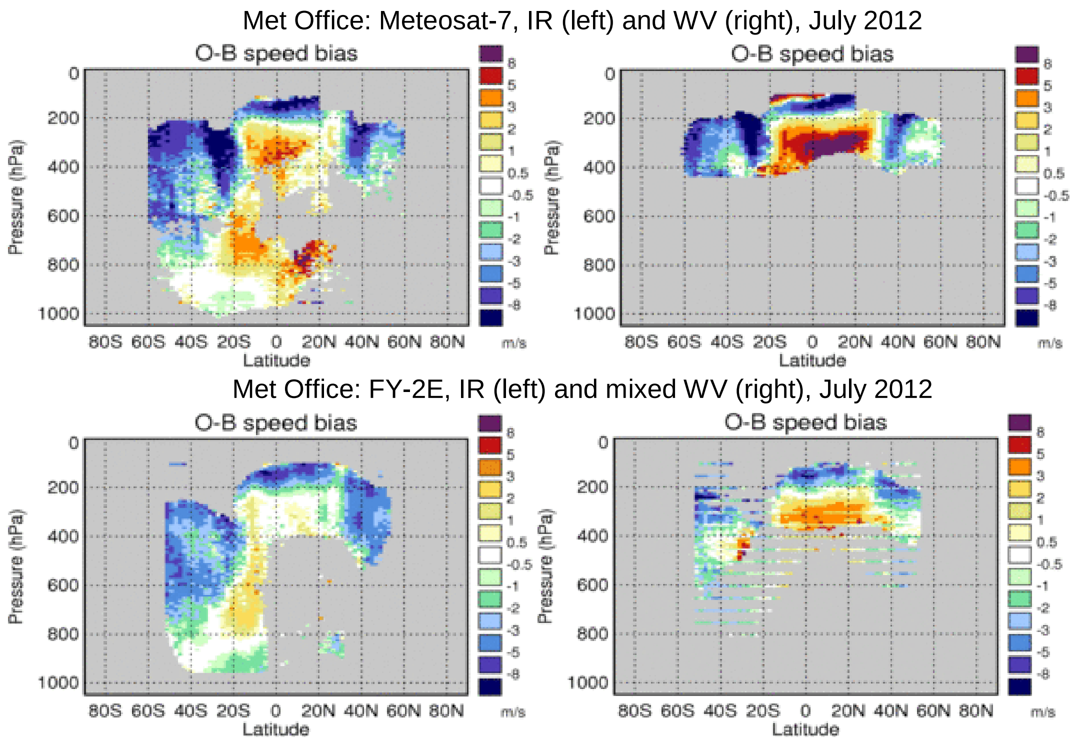

Figure 16. Zonal plots of O-B speed bias for Meteosat-7 (top) and FY-2E (bottom) for IR (left) and WV (right) AMVs in July 2012.

The South Asia summer monsoon winds are an important feature of the Indian Ocean wind field in July and August. The top right panel of Figure 17 shows the mean model background wind field produced from collocations with Meteosat-7 IR winds at low level. This shows the large-scale low level monsoon circulation: a clockwise flow towards the Indian subcontinent and the strongest winds located in the Somali low level jet off the northeast African coast. The mean observed vectors from Meteosat-7 (top left panel) highlight two areas where there are significant differences (bottom left panel) from the model forecast. To the east of India and near the Somali jet the mean observed wind vectors are very strong easterlies, in contradiction with the south westerly monsoon flow. This feature of the Meteosat-7 wind field has previously been investigated as part of the NWP SAF AMV analysis reports (Cotton and Forsythe, 2010). It was shown that in these cases the problem AMVs were likely tracking the high level cloud associated with the Tropical Easterly Jet, whilst the height assignment was based on the low level cloud within the target scene. The net result is a large error in height assignment and spuriously fast vectors at low level.

Figure 18 shows the same statistics for FY-2E IR winds at low level. Here the mean observed wind vectors (top left panel) show much better agreement with the model. There is only a small underestimation of the Somali jet wind speeds but the vector directions and magnitudes are generally consistent. The number of winds from FY-2E (bottom right panel) is fairly low for many of the FY-2E grid boxes and there are in fact quite large gaps in the wind field (not clear in the plot due to averaging the data over 5°). FY-2E is also hampered as it doesn't cover as far west as Meteosat-7 and so not all the monsoon is captured. However, this is mitigated by the fact that MSG data does cover as far east as 60°E and so is able to capture this part o f the monsoon wind field.

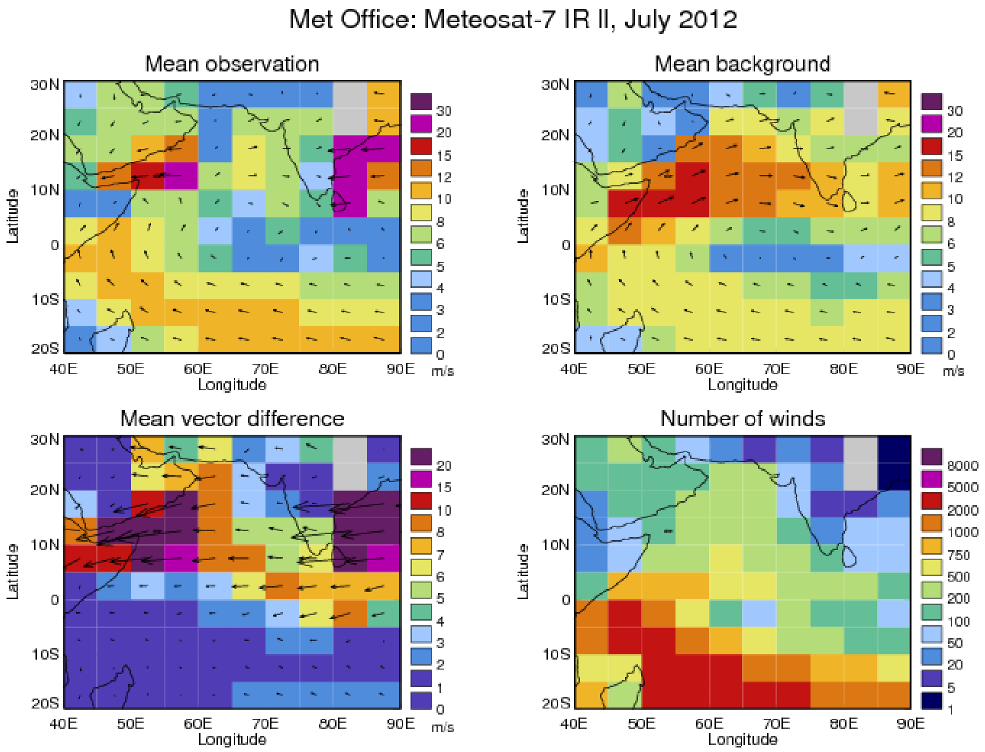

Figure 17. Mean vector (arrow) and vector magnitude (colour) for the observations (top left) and model background (top right). Also shown is the corresponding mean vector difference (bottom left) and number of winds in each 5x5 grid box. Data shown are Meteosat-7 IR AMVs below 700 hPa.

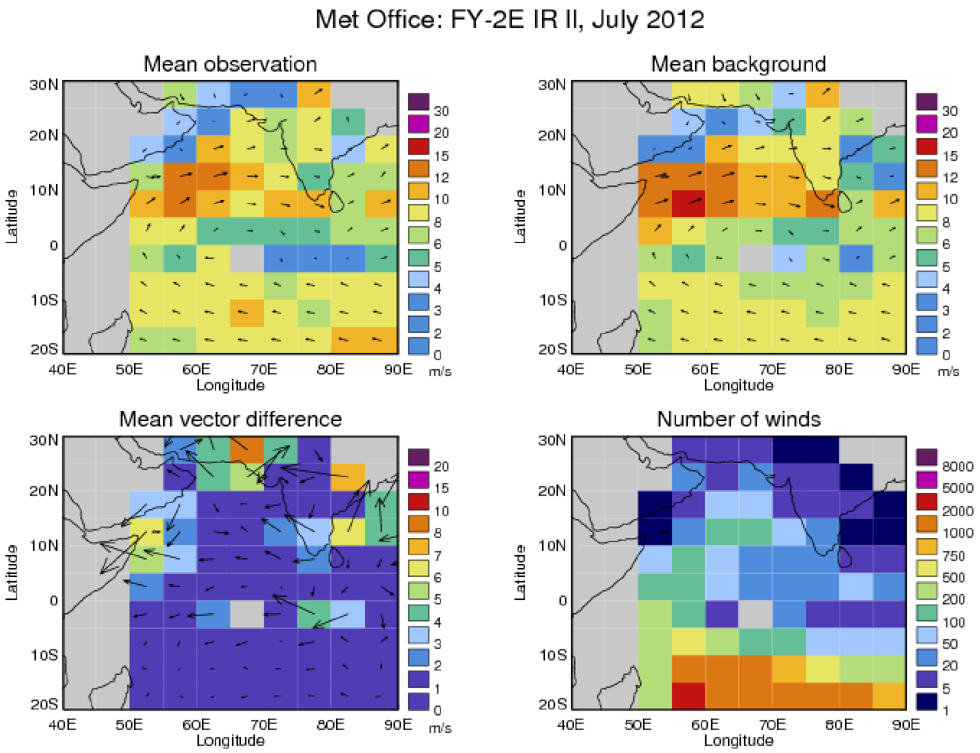

Figure 18. As Figure 17 but for FY-2E IR AMVs below 700 hPa.

6 Statistics versus QI

In this section we investigate the wind vector characteristics as a function of QI.

Meteosat-7 QI's with (QI1) and without (QI2) the first-guess check show fairly similar behaviour in terms of characterising data quality (Figure 19). For QI values above 60, RMSVD and mean speed bias reduce in magnitude with increasing QI as expected. For the IR winds there is a sharp reduction in speed bias for QI1 values around 80-85. The mean observation speed generally increases with QI such that the fastest vectors are usually the highest quality. For QI2 there are a higher proportion of winds with values greater than 90 compared to QI1.

As shown by Figure 20, both QI1 and QI2 are set to the same value for the CMA winds. The QI without first-guess check has yet to be implemented and this means that the NWP SAF statistics in the previous section (based on filtering by QI2) are not a true like-for-like comparison. The general characteristics are good with speed bias and RMSVD falling with increasing QI value. The mean observation speed doesn't vary much above QI=60 and actually falls slightly for the IR winds. There are a high proportion of winds with QI>80 and the QI behaviour for FY-2D is very similar (not shown).

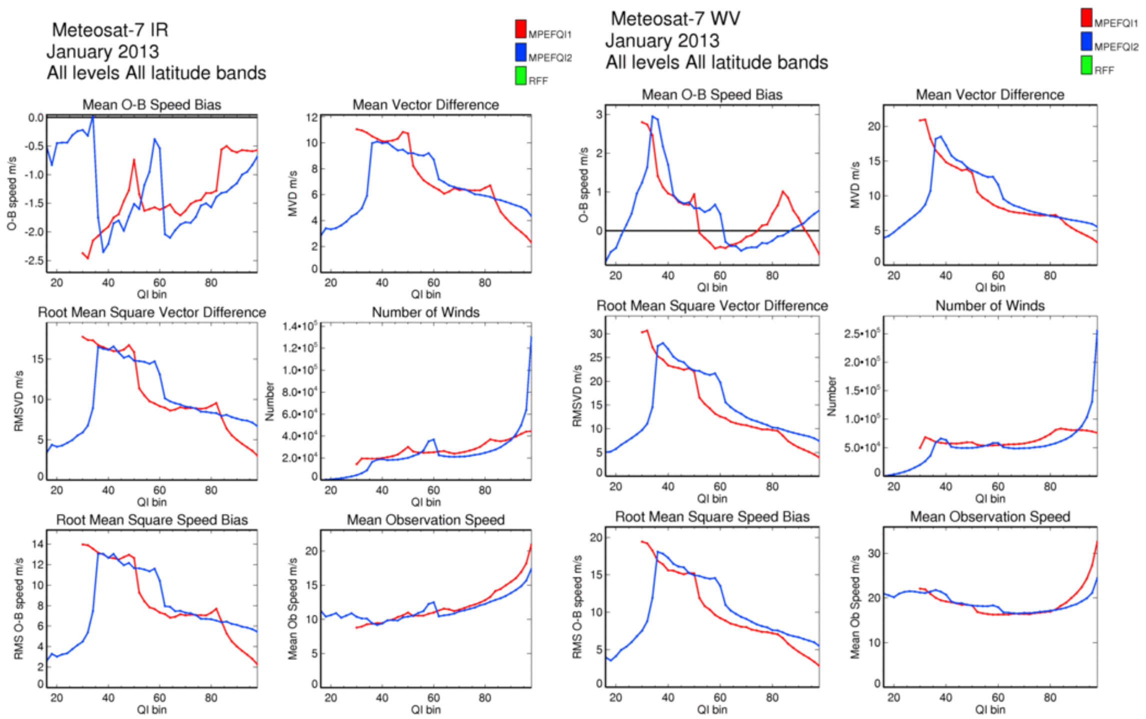

Figure 19. Statistics versus QI value for Meteosat-7 IR (left panel) and WV (right panel) winds in January 2013. The red line is the QI with first-guess check (QI1) and the blue line is the QI without first-guess check (QI2).

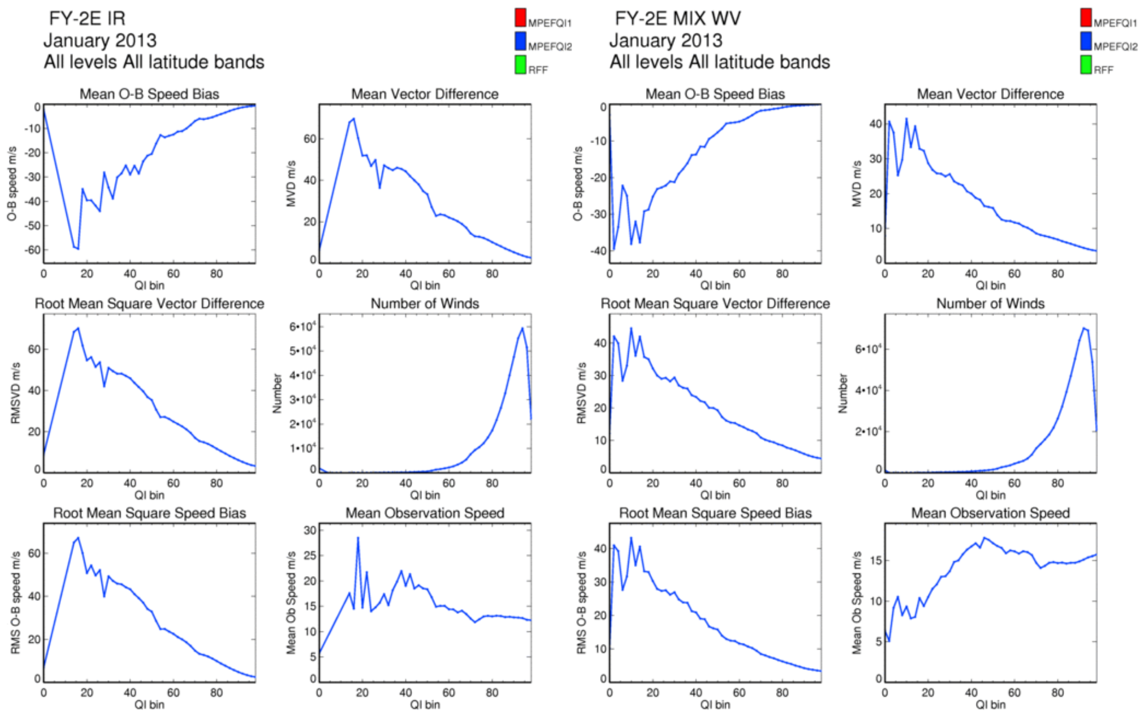

Figure 20. As Figure 19 but for FY-2E IR (left panel) and mixed WV (right panel) AMVs. The two QI values are the same (blue line plotted over red).

7 Quality control and assigned errors

In order to trial the FY-2E winds for use in NWP, the quality control procedure and observation errors need to be specified. This section outlines a proposed assimilation procedure for the Met Office experiments described in the next section. Both the IR and mixed WV winds are considered. Note that some steps, such as the background check and thinning, are generic for all AMVs.

1. QI thresholds

The QI used for quality control is that including the model first guess check (Table 6). Tighter thresholds are used in the high and mid level extratropics to reduce the impact of the negative speed bias observed in the data, particularly for the IR.

FY-2E		Extratropics			Tropics		
		HL	ML	LL	HL	ML	LL
QI1	IR	90	90	85	80	80	80
	MixWV	85	85	-	80	80	-

Table 6. QI thresholds for FY-2E (with first guess check). Tropics 20S-20N, extratropics polewards of 20S/N. HL 100-400 hPa, ML 400-700 hPa and LL 700-1000 hPa.

2. Spatial blacklisting

Generic for all winds

- Low-mid level winds dependent on topography
- All geostationary winds beyond 68° satellite zenith angle
- All winds reporting in height at or above 160 hPa and all extra-tropical (polewards of 20N/S) winds above 200 hPa

FY-2E specific

- WV winds below 500 hPa and tropical WV (20S-20N) winds below 400 hPa
- IR below 600 hPa over land

3. Thinning

- All geostationary winds thinned in 2° by 2° by 100 hPa boxes.
- Wind selected by lowest observation error for all geostationary winds
- Data assimilated in 2-hour time slots

4. Background check

Comparison with 6-hour forecast from previous model run (symmetric).

5. Observation errors

Observation errors are calculated individually for each wind using estimates of the error in vector, error in height and variation in the background wind column. For more information see Forsythe and Saunders (2008). The height errors are largely based on RMS differences of assigned pressure minus model best-fit pressure estimates (see Figure 21 and Figure 22). The largest differences are found at mid level for the IR winds where there is a high height bias and increased variation, i.e. the model suggests the AMVs have been assigned too high in the atmosphere. The mixed WV winds also show a high height bias below around 500 hPa. The uncertainly in height assignment in these areas will be reflected in the final observation error values.

The FY-2E height errors are set using a look-up table dependent on channel, model surface and pressure level (Table 7).

	Height level	950 hPa	850 hPa	750 hPa	650 hPa	550 hPa	450 hPa	350 hPa	250 hPa	150 hPa
FY-2E	IR sea	100	90	130	170	200	200	130	80	70
	IR land	200	200	180	180	190	200	140	85	80
	MixWV sea	200	200	170	100	90	80	90	70	65
	MixWV land	200	200	170	140	130	120	110	85	70

Table 7. FY-2E height error profiles based on model best-fit pressure statistics. Errors are separated by channel and model surface type.

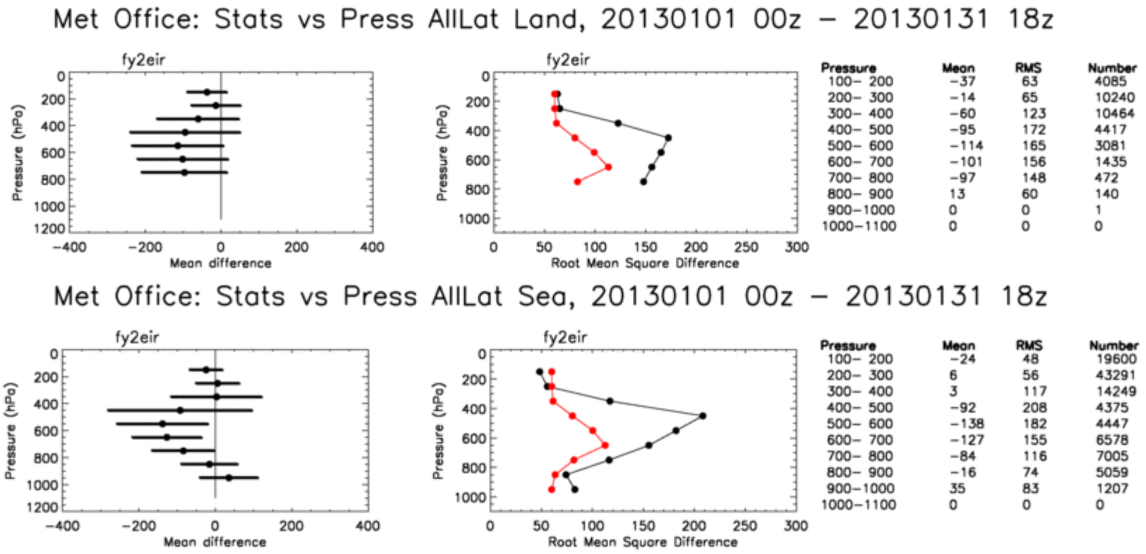

Figure 21. Model best-fit pressure statistics for IR FY-2E winds in January 2013, separated by model surface type (land/sea). Left panels show the mean pressure difference (assigned minus best-fit) with one standard deviation error bars. Right panels show the RMS pressure difference in black. The red points just show the code default pressure errors and can be ignored.

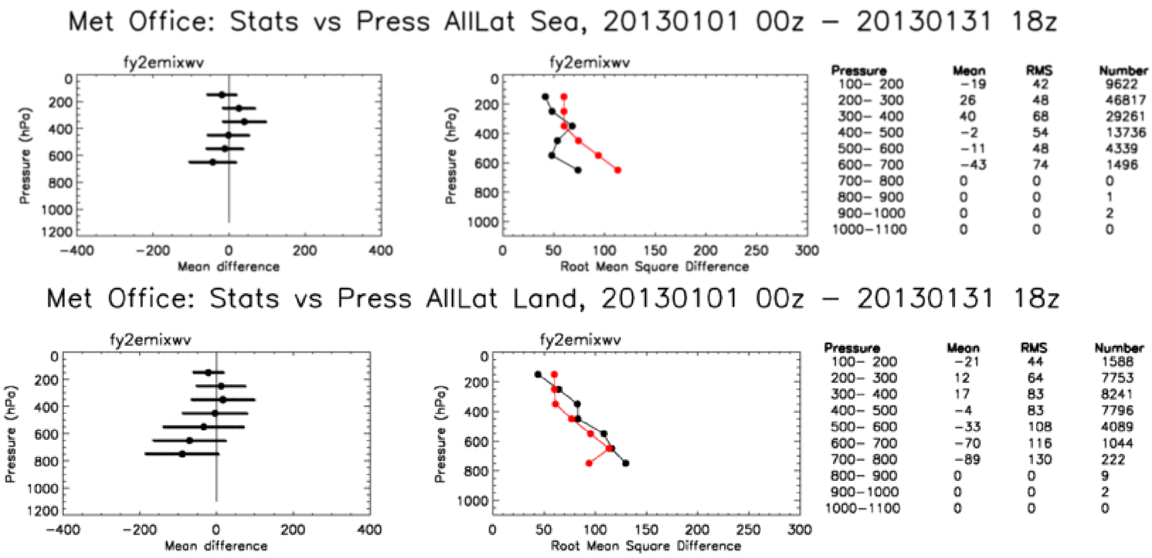

Figure 22. As Figure 21 but for mixed WV FY-2E winds.

8 Assimilation experiments

To compare the impact of AMVs from Meteosat-7 and FY-2E a set of assimilation experiments were performed for the period 1 February 2013 to 25 March 2013, giving 52 days of verification. The experiment configurations were based on Parallel Suite 31 (PS31): the operational suite from January 2013. To save on computational resources the horizontal forecast resolution was reduced to N320 (from N512) which equates to approximately 40 km at mid-latitudes. The vertical grid dimensions were as per operations with 70 vertical levels. Global analyses were created four times each day at

0, 6, 12 and 18 UTC using 4D-Var and forecasts were run at 0 and 12 UTC out to a lead time of six days. A control suite (sjftb) was run with data-use closely matching that in operations at the time, but with no AMVs over the Indian Ocean region. Experiments sjcna and sjfte were then designed to measure (separately) the impact of adding the Meteosat-7 and FY-2E winds respectively. For experiment sjcna the Meteosat-7 IR, visible and cloudy WV winds were used as per the current operational configuration (see NWP SAF website for details). For experiment sjfte the FY-2E IR and mixed WV winds were used as outlined in the previous section.

An important metric for accessing forecast impact at the Met Office is the global NWP index which is a weighted skill score combining improvements in forecast skill for a number of atmospheric parameters. Note that the NWP index was substantially updated in 2012 to give a more equal weight across lead times and some of the observations used to verify each parameter have been revised. The change in forecast RMS (experiment-control) for the NWP index parameters is given in Figure 23. The overall distribution of impact looks rather similar. Both Meteosat-7 and FY-2E result in a small negative impact of -0.20 points (~0.2%) when verified against quality controlled observations. In the northern hemisphere the change in RMS is almost identical for the two satellites with a negative impact on mean sea level pressure (PMSL) but a neutral-positive impact on 500 hPa geopotential height and winds at 250 hPa. In the tropics both have a positive impact on upper level winds, but Meteosat-7 has a better impact on the low level 850 hPa winds compared to FY-2E. It is in the southern hemisphere where most of the forecast degradation occurs with all three index parameters showing a consistent increase in RMS. Winds at 250 hPa in particular are degraded. The negative impact appears slightly worse for Meteosat-7 as the poorest verification for FY-2E (RMS increase greater than 0.5%) is mainly limited to the longer forecast ranges.

The NWP index is representative of a small subset of forecast parameters but a wider picture of forecast impact can seen by comparing plots of the full ‘extended’ index as in Figure 24. Now the impact looks more favourable for Meteosat-7 in the northern hemisphere and tropics with an overall small positive impact. Improvements are observed for forecasts of temperature at 250 hPa (tropics and NH) and winds at 100 hPa. The impact of FY-2E appears more neutral in these regions, but there are still improvements for high level temperature scores at 100 hPa and 250 hPa. The southern hemisphere is where the differences between the two satellites are most prominent. Both satellites have a clear negative impact on PMSL, wind and geopotential height scores, but the impact appears worse for Meteosat-7. The main negative impact for FY-2E is mainly restricted to T+120 and T+144.

Figure 25 shows the mean analysed 250 hPa wind field for the control experiment sjftb. This shows the main feature of the upper level winds over the IODC region – the mid latitude jets located over northern India and in the southern Indian Ocean. The impact on the 250 hPa winds of assimilating Meteosat-7 AMVs can be seen in Figure 26 and Figure 27. There is a deceleration of the jet stream by up to 1 m/s in the southern hemisphere mid-latitudes (40-60S) and the edge of the Meteosat-7 disc is clearly marked by the change in wind speed. The slowing down of the southern hemisphere jet is associated with an increase in the level of 500 hPa geopotential height and an increase in surface pressure in the same region (not shown). The NWP index scores would strongly suggest that these changes are not beneficial. Figure 28 shows that at T+48 there is an increase in forecast error of 500 hPa geopotential height located to the south of Australia, downstream of the changes in the upper level winds observed in the analysis. In the northern hemisphere the impact on the winds is much smaller. In the tropics Meteosat-7 is generally speeding up the wind field and increasing the northerly component of the flow near India.

FY-2E also has the effect of slowing down the jet stream in the southern hemisphere mid-latitudes (Figure 26) but only by up to 0.3 m/s – much less than Meteosat-7. The difference in satellite coverage means that FY-2E observes less of the peak jet region than Meteosat-7 (Figure 25), but even in the overlap regions FY2E has less of an impact on slowing the analysis. In the tropics the impact on the upper level winds is less clear, but in common with Meteosat-7 there is an area of acceleration to the south of India.

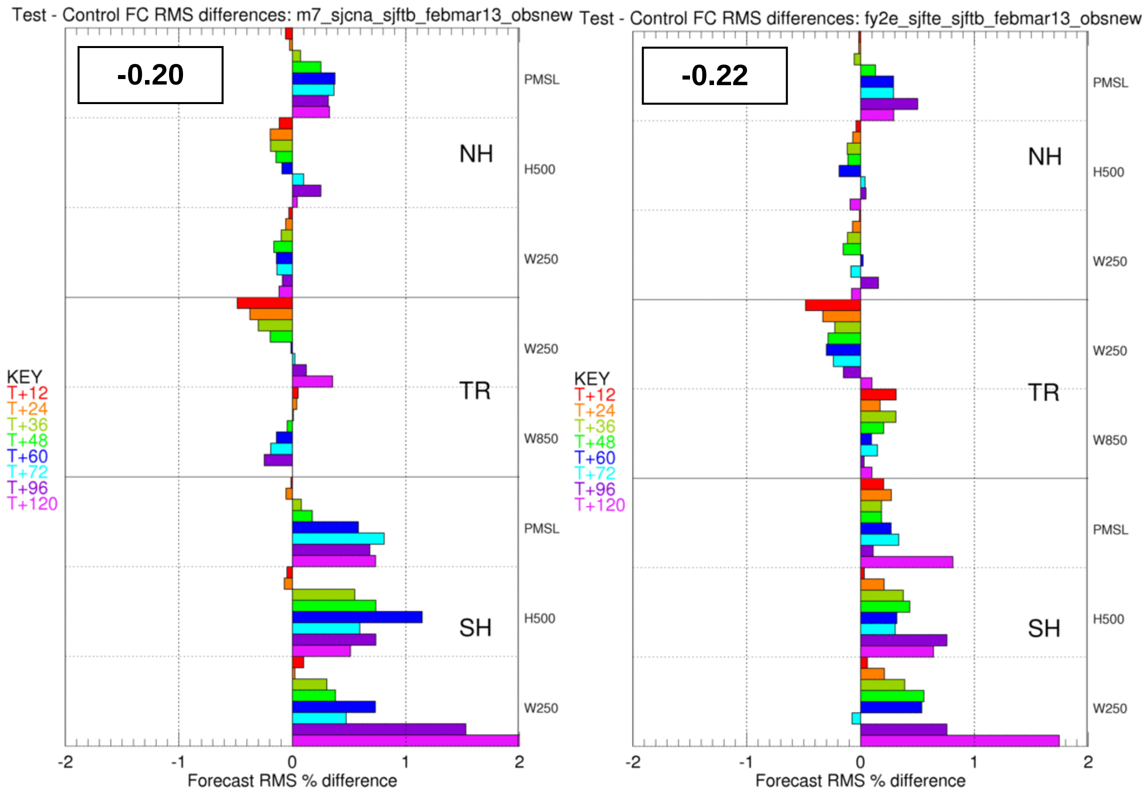

Figure 23. Percentage change in forecast RMS error (forecast minus observations) for the Met Office global NWP index parameters. The colour of the bars represents the different forecast lead times and negative values indicate a reduction in forecast error. Impact of assimilating Meteosat-7 (left) and FY-2E (right) versus a no IODC control. The NWP index score is shown in the top left.

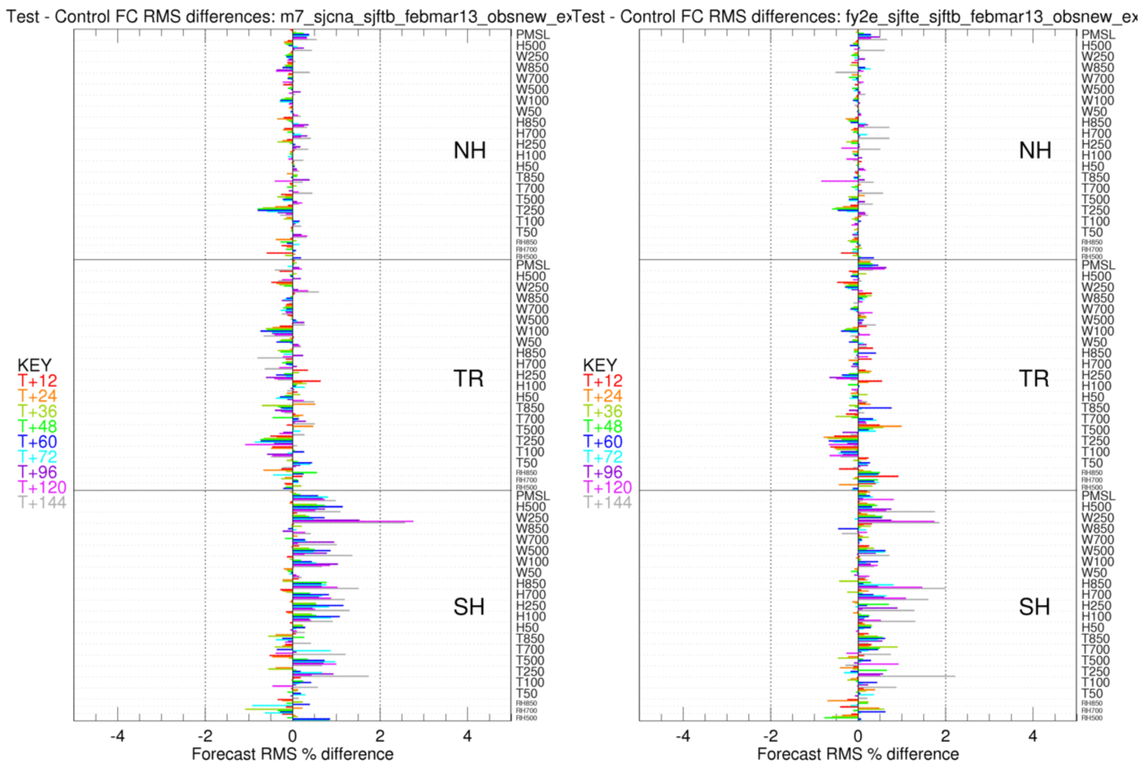

Figure 24. As Figure 23 but for the extended index of parameters.

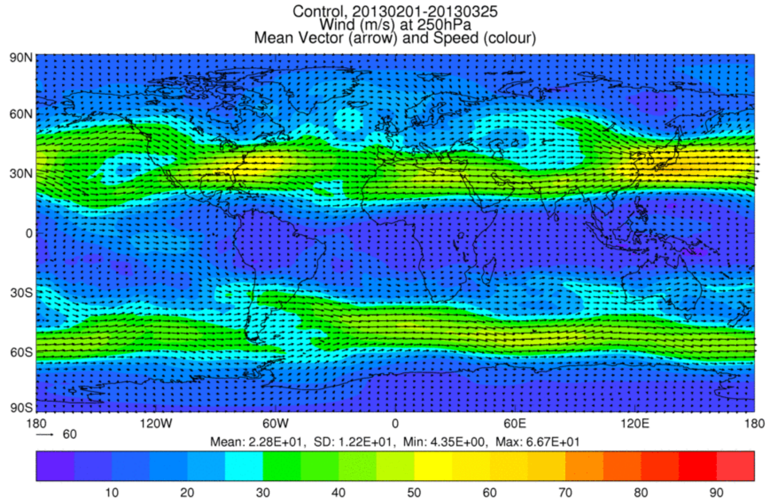

Figure 25. Mean analysis of wind vectors at 250 hPa for the control experiment sjftb.

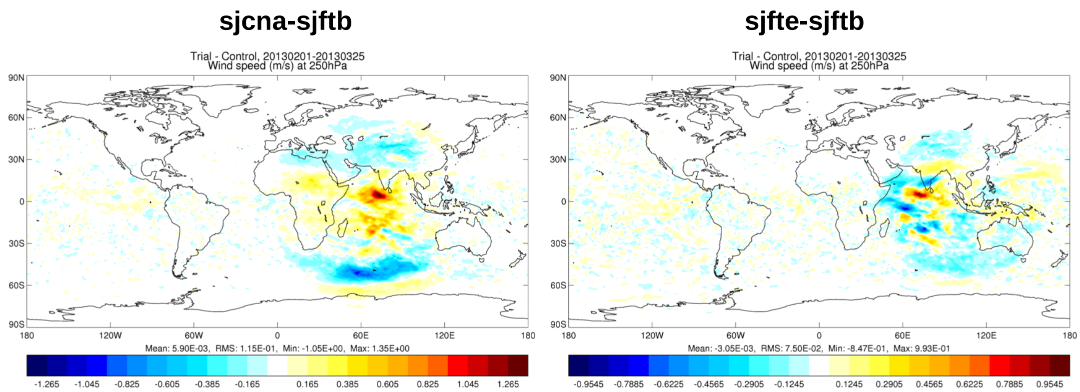

Figure 26. Mean wind speed difference between the trial and control analyses at 250 hPa. Meteosat-7 experiment (left) and FY-2E experiment (right).

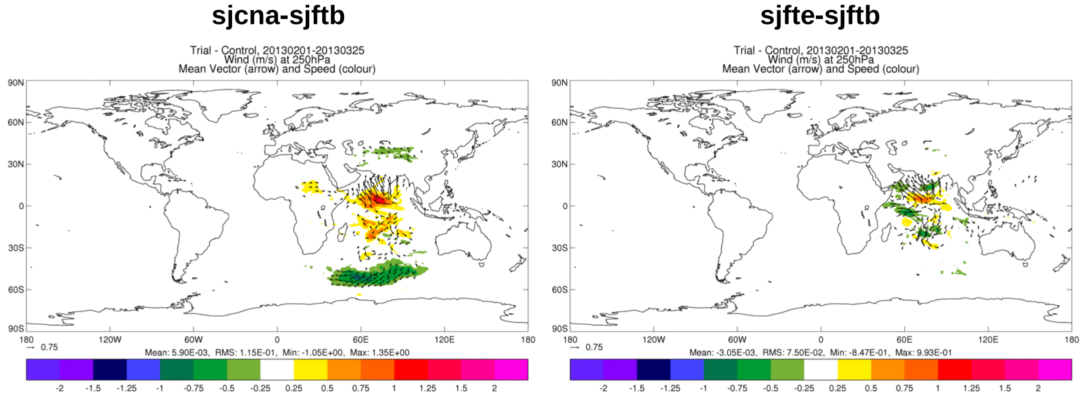

Figure 27. Mean vector difference (arrows) and mean wind speed difference (colour shading) between the trial and control analyses at 250 hPa. Meteosat-7 experiment (left) and FY-2E experiment (right).

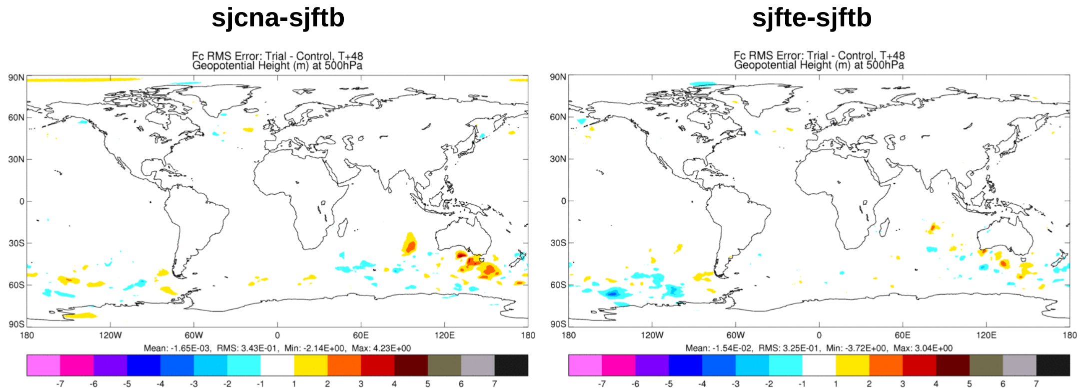

Figure 28. Change in RMS error of forecasts of 500 hPa geopotential height at a lead time of 48 hours. Meteosat-7 experiment (left) and FY-2E experiment (right).

9 Conclusions

Meteosat-7 is the prime satellite for the provision of AMV coverage over the Indian Ocean. Of all the IODC satellites it offers the best geographical coverage; the data are produced more frequently and are available within the shortest delay time.

The best alternative to Meteosat-7 is currently FY-2E although it has several limitations: there are no visible channel winds, the clear sky and cloudy WV winds are combined in one product, model-dependant QI only, the data are only produced every 6 hours and the satellite is located the furthest east (covers less of the Indian Ocean). Meteosat-9 at zero degrees covers the far west of the basin but use of FY2-E alone for IODC would result in data gaps in the mid-latitudes. Although the 3 hour offset of FY-2D in theory allows winds every 3 hours in the large overlap region, FY-2D in general has more issues with data quality and has not yet proven reliable enough to consider for use. The Indian Kalpana satellite is not considered a viable alternative. A new derivation scheme has been implemented from June 2013 but this has yet to be assessed.

Comparing data from Meteosat-7 and FY-2E we find that data volumes are around 25% and 100% higher for Meteosat-7 IR and WV channels respectively. Meteosat-7 data have an average delay of just 35 mins, compared to around 2 hours for FY-2E but importantly nearly all FY-2E data are received within 3 hours.

Long-term data monitoring shows that the quality of the CMA winds has improved markedly in the past 3-4 years as a result of improvements to the derivation. The changes haven't been exclusively beneficial, and FY-2D in particular has been less stable, but the overall progress is very encouraging. In general the IR winds from FY-2E are now quite similar in quality to Meteosat-7 in the southern hemisphere and tropics.

However in the northern hemisphere the FY-2E data still exhibit a larger RMSVD and negative speed bias, particularly in the winter months. This is despite the fact that Meteosat-7 data captures a higher mean wind speed, most likely due to greater coverage at higher latitudes. Map plots show that as FY-2E is further east it observes more of the strongest part (peak) of the jet stream located over Japan. This is one of the reasons why the (negative) speed bias statistics are worse for FY-2E compared to Met-7 in the northern hemisphere. At low level, both Meteosat-7 and FY-2E have significant localised biases. FY-2E fails to capture the strength of winter monsoon winds flowing off the Asian continent. Meteosat-7 has some spuriously fast winds at low level due to large height assignment errors and this leads to a poor representation of the South Asia summer monsoon. FY-2E more accurately captures the summer monsoon flow and the low level Somali Jet.

For WV at high level, the negative speed bias in the northern hemisphere is again slightly worse for FY-2E. Following changes made in 2011, the mixed WV winds from FY-2E actually have lower RMSVD values than Meteosat-7 In the southern hemisphere and tropics.

Results of a single-season assimilation experiment show that overall both Meteosat-7 and FY-2E have a small negative impact on forecast errors as measured by the global NWP index. Verification for Meteosat-7 is more favourable in the northern hemisphere and tropics with improvements observed for forecasts of upper level temperatures and winds. The impact of FY-2E appears more neutral in these regions. The southern hemisphere is where the differences between the two satellites are most prominent. Both satellites have a clear negative impact on PMSL, wind and geopotential height scores, but the impact appears worse for Meteosat-7. The main negative impact for FY-2E is mainly restricted to longer forecast ranges. The degradation for Meteosat-7 is linked to a slowing down of the southern hemisphere jet stream by around 1 m/s. FY-2E has much less of an impact on the upper level winds despite having a larger negative speed bias. It is possible that the Meteosat-7 observations are being given too much weight in forming the analysis.

Despite the small negative result found in this investigation, recent FSO results still indicate a positive impact from Meteosat-7. This study has highlighted that there is room for improvement in the assimilation of Meteosat-7 but also that FY-2E has good potential for use in NWP but further testing is required.

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Appendix – CMA derivation changes

Late 2009 update. Details received from Qifeng Lu 27/01/2010.

The retrieval algorithm for FY2 AMVs has been improved, and the operational GTS-based broadcast of FY2 AMVs based on the new algorithm also was switched. For FY2C/D/E, new algorithm data were switched on from Sep 2009/Nov 2009/Jan 2010 respectively. The change from the old algorithm are as follows:

1. Calculation scope

Previously, the calculation scope is 50 degrees to the four sides of sub-satellite point. At present, the calculation scope is within 70 degrees for the nadir angle.

2. NWP data

To convert the temperature of the cloud to the height of the cloud, NWP grid data is need. Now, T639 data is used, rather than previous T213. T639 is much improved than T213.

3. The theoretical IR/WV relationship for opaque clouds

For semi transparent cirrus clouds, height assignment needs two infrared/water vapour relationships, one is calculated from NWP data, and the other is from satellite observation.

The infrared/water vapour relationship for opaque clouds are calculated by a radiation model based on NWP parameter fields. The NWP parameter fields are improved:

① At present, T639 data is used rather than original T213.

② The vertical extension of the NWP parameter fields is expanded from the original surface-100hPa to the present surface-10hPa. By doing so, high level atmospheric status is considered.

③ For atmospheric compositions other than water vapour, originally, one set of climate values from American standard Atmosphere was used to represent the whole earth disk area; while At present, climate values from 5 regions are used: tropical, mid-latitude summer, mid-latitude winter, high-latitude summer, high-latitude winter. By doing so, radiation contributions from other radiation active gases are better considered.

④ NWP parameter layers are increased. Originally, data from 38 layers are used. At present, data from 120 layers are used. From 10 to 1200 hPa, a 10 hPa interval is a layer.

⑤ For temperature profile data resolution, originally the data interval is 10 degree. At present, the data interval is 5 degree.

⑥ For humidity profile data resolution, originally, there are 10 humidity status. At present, there are 20 humidity status:0.1, 1, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95%。

4. The observational IR/WV relationship for semi-transparent clouds

Theoretically, for the satellite observation, the linear infrared / water vapour relationship is only effective for radiation energy. Now, the statistics is based on observational energy. While previously, the statistics is based on observational brightness temperature which was not correct.

5. A rough evaluation at distinguishing high and low clouds

It is difficult to distinguish very thin cirrus from low clouds. At NSMC/CMA, the infrared/water vapour correlation on the scope of the tracer is calculated. With which the tracers are roughly evaluated to distinguish if it is high level or low level wind. The tracers with high relations are possible cirrus clouds; while the tracers with low relations are possible low clouds. At present, low level targets with infrared/water vapour relationships greater than the threshold are eliminated; high level targets with infrared/water vapour relationships greater than the threshold are accepted. This is a strong threshold. Although this threshold eliminated some good low level winds, It ensures the high level winds from thin cirrus are not been put at low levels.

6. Height assignment for water vapour channel at dense high cloud area

Previously, at dense high cloud area, height assignment for water vapour channel is the same as infrared channel. Now, brightness temperature are used directly to give height for water vapour channel at dense high cloud area.

7. Quality indexes

EUMETSAT QI definition is adopted with the following differences:

The integer value of QI/200 is the QI with numerical comparisons; while the residue of QI/200 (QI-QI/200) is the QI without numerical comparisons.

For quality indexes with odd values, the tracer heights are normally assigned; for quality indexes with even values, the tracer heights are over adjusted or are considered not as reliable as winds with odd QI. Winds with even QI should be treated more carefully.

For water vapour winds, if in the tracer area (1024 pixels), there are more than 102 pixels with IR-WV bright temperature difference less than 15 degrees, this tracer is considered with high level clouds in it, the wind height is considered more reliable, the QI is given an odd number; if in the tracer area (1024 pixels) there are less than 102 pixels with IR-WV bright temperature difference less than 15 degrees, this tracer is considered without high level clouds in it, the wind height is considered less reliable, the QI is given an even number.

For water vapour channel winds, AMVs with heights higher than 150hPa is adjusted to 150hPa. Those winds are given an even value QI.

For IR channel winds, if wind direction is more than 60 degrees depart from NWP, it is given an extreme low QI value1.

Such QIs do not reflect real quality of the winds. Winds with low QI values are often very good ones.

2011 updates. Details received from Xu Jian Min 05/10/2011
Since mid- January, 2011, IR algorithm is improved. The major improvements are as follows:

1) The fitness between the theoretical IR/WV relationship for opaque clouds and the observational IR/WV relationship for semi-transparent clouds are improved.
2) Surface point is involved at making IR/WV relationship with semi-transparent clouds
3) Contribution to coefficient for individual pixels (ccij) are considered at height assignment.
4) Quality index (QI) definition with consideration of level information is adopted.

Since mid-September, 2011, WV algorithm for FY2E is improved. (FY2D algorithm for WV has not yet been improved.) The Major improvements are as follows:

1) For tracers with high level clouds, contribution to coefficient for individual pixels (ccij) are considered at height assignment.
2) For tracers without high level clouds, height adjustments are made.
3) Quality index (QI) definition with consideration of level information is adopted.

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