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Use of Reprocessed AMVs in the ECMWF Interim Reanalysis

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Abstract

Recent work on the impact of reprocessed Meteosat AMVs in ECMWF's Interim reanalysis (ERA-Interim) is presented. Reanalysis is an important activity that benefits a wide range of communities by providing long homogeneous datasets of meteorological information. It makes use of the more modern NWP systems available today to reproduce past atmosphere, sea- and land-surface conditions using past observations. Following two successful reanalysis projects, ERA-40 and ERA-15, ECMWF is continuing this work by conducting an interim reanalysis from 1989 up to real-time.

In support of this, EUMETSAT have used state-of-the-art processing algorithms to reprocess AMVs from past observations. The data are assimilated using the more advanced data assimilation techniques available at ECMWF today. Several impact trials were carried out to look for changes in the forecast. A first trial, which looked at reprocessed Meteosat-3 data for 3 months in 1989, clearly showed the benefits of the newly reprocessed data, notably with a positive impact in the low-level winds in the Tropics. A second trial was carried out to look at the forecast impact of using a more extensive reprocessed data coverage. During the extended Atlantic Data Coverage (XADC) period Meteosat-3 was leased over to NOAA to replace a faulty GOES satellite. The impact of reprocessed AMVs from Meteosat-5 (operational over 0º) and Meteosat-3 (73ºW) in the ERA Interim is a strong positive impact on the extra-tropics but a negative impact in the mid-to-high levels in the Tropics.

INTRODUCTION

The ERA-Interim (Simmons *et al*. 2007, Uppala *et al*. 2008) sets up the ground work for the next reanalysis, estimated to start at the beginning of the next decade, responding to a request by reanalyses users to have a dataset that extends as close to real time as possible. The ERA-Interim aims to cover the 1990s and 2000s continuing until replaced by the new extended reanalysis, ERA-75. It makes use of the continuously evolving and expanding observational dataset throughout this period as well as the developments in data assimilation and forecasting techniques since its predecessor, ERA-40.

The Atmospheric Motion Vector (AMV) product itself has evolved considerably since it was introduced in NWP. In the early days, AMVs were derived using a combination of manual and automatic techniques principally from IR images. AMVs are now extracted and produced fully automatically from IR, VIS, clear and cloudy Water Vapour (WV) images, achieving a higher spatial and temporal coverage. Another improvement comes from the availability of the automatic quality indicator (QI) in the reprocessed product. The quality indicator (QI) was introduced by the wind producers in the last decade (Holmlund 2001, 1998) for greater control of the usage of the data in NWP. Further information on EUMETSAT's reprocessing of AMVs can be found in Gustafsson *et al*. (2002).

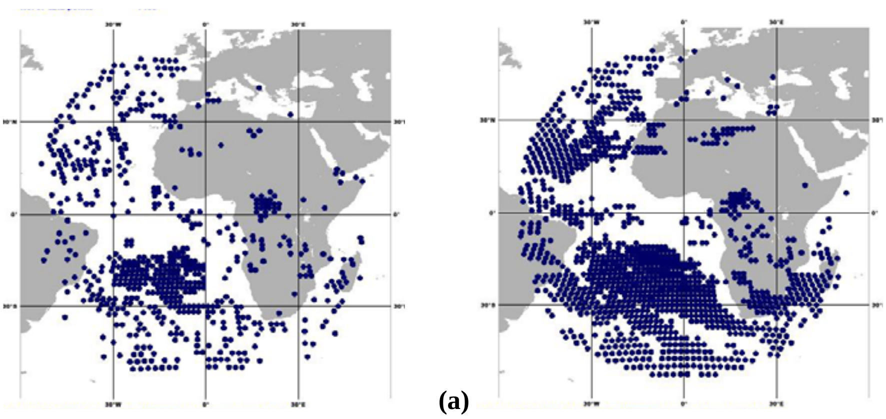
Two studies are presented in this paper. The first looks at the performance of Meteosat-3 (Met-3) reprocessed AMVs for 3 months in 1989 in the ERA-Interim. The second looks at 3 months during the extended Atlantic Data Coverage (XADC) period when Meteosat-5 (Met-5) was operational at 0º over the equator and Met-3 was positioned at 75ºW, replacing a faulty GOES satellite. EUMETSAT have reprocessed AMVs from both satellites. This has given us the opportunity to look at the effects of a more extensive coverage of reprocessed AMVs in the ERA-Interim.

In a previous study on the impact of reprocessed AMVs on ERA-40 Re-analysis (Bormann 2003, Gustafsson *et al*., 2002), it was found that using the reprocessed High Resolution Visible Winds (HRVW) instead of the extended low resolution (ELW) visible winds had a neutral to slightly negative impact on the performance of the forecast. For this reason, the studies presented here make sole use of the ELW data (which include VIS, IR and cloudy WV).

FIRST STUDY

IFS configuration

The ERA-Interim configuration of ECMWF's Integrated Forecast System (IFS) contains some significant changes to the ERA-40 configuration (ECMWF Newsletter nº110). It makes use of ECMWF's 4DVAR assimilation algorithm, with a 12 hour window, and runs forecasts at T_L 255 (≈ 80 km) with an incremental analysis resolution T159 (≈ 125 km) with 60 levels in the vertical (with a model top at 0.1 hPa). A version of IFS cycle 31R2, adapted for the ERA-Interim, was used for this experiment.



(a) (b)

Figure 1 **: Sample of used AMV coverage around the 00z cycle on the 6th Feb 1989: (a) old operational data (1460 data points) and (b) new reprocessed data (6928 data points).**

Quality control

The control contains the old operational Met-3 winds over the 0º Meteosat region, whilst the experiment contains the new reprocessed ones. The quality control for the old data is based on the operational approach at the time. The quality control for the new data mirrors the current operational set up for the pre-MSG satellites (i.e. Meteosat 5, 6 and 7) which includes selecting AMVs by first guess dependent QI thresholds. An exception is over the Tropics where the QI threshold is tighter than in current operations as a result of the findings from previous ERA studies (Bormann 2003). In both control and experiment, AMVs over land at all levels in the northern extra-tropics (north of 20N) and above 500 hPa in other areas are excluded. Also, the data are subjected to an asymmetric first guess check where slow winds are rejected in order to counter the existence of a slow speed bias.

Both the old and new AMVs are thinned horizontally per 140 km x 140 km, and vertically, per standard pressure level. In the case of the new AMVs, the AMV with the highest QI is selected per box. Note that the current operational thinning uses 200 km x 200 km boxes, a precaution taken to account for the problem of horizontal correlations which are not factored for in the current assimilation system (Bormann *et al.* 2003).

Results

The biggest difference observed between the old operational and the new reprocessed data is the number of AMVs both made available for and used in the assimilation (Fig. 1). This can be attributed to the increase in frequency of data but also to the additional coverage at the low levels and high levels from extra contributions from the Visible (Vis) and Water Vapour (WV) channels. Met-3 WV AMVs are known to be poorer in quantity and quality than the IR AMVs as a result of extra noise in the imagery. Furthermore, variations in the imagery received for alternating slots (1 IR + 2 VIS for odd slots and 1 IR + 1 VIS + 1 WV for even slots) has implications for the quality and number of AMVs. One effect is that it renders the semi-transparency correction method less effective.

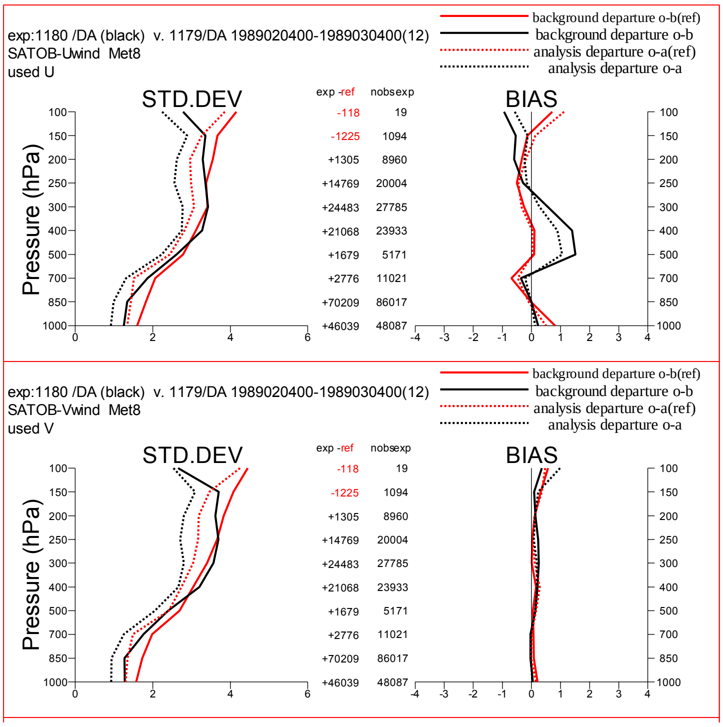


***Figure 2*: Profile of standard deviation and bias statistics of background (solid line) and analysis (dotted line) departures for the u and v components of the used wind (over the Meteosat region at 0º over the equator) for the experiment (containing reprocessed AMVs) in black and the control (original operational AMVs) in red.**

Forecast Day		1000 hPa	850 hPa	500 hPa	200 hPa
NH	2				
	3	10%			
	5				
	7	**10%**			
Tropics	2	**0.2%**	**0.1%**		**10%**
	3	**0.5%**	**0.1%**	**10%**	**0.2%**
	5	**2%**	**1.0%**	**5%**	**5%**
	7	**5%**	**10%**		
SH	2				
	3		10%	10%	
	5				
	7				
Europe	2			**2%**	**10%**
	3			**10%**	
	5		**5%**	**10%**	**10%**
	7	10%			

***Table 1*: Statistical significance levels (%) from a t-test of the differences in RMS of the vector wind forecast errors between the experiment (reprocessed AMVs) and the control (old operational data) for selected regions and levels, for 90 cases. Improved scores are in bold and degraded ones in normal print. The smaller the value the more statistically significant the impact is. No entry means that there is not enough significance (> 10%). Differences calculated against ERA-40 analysis.**

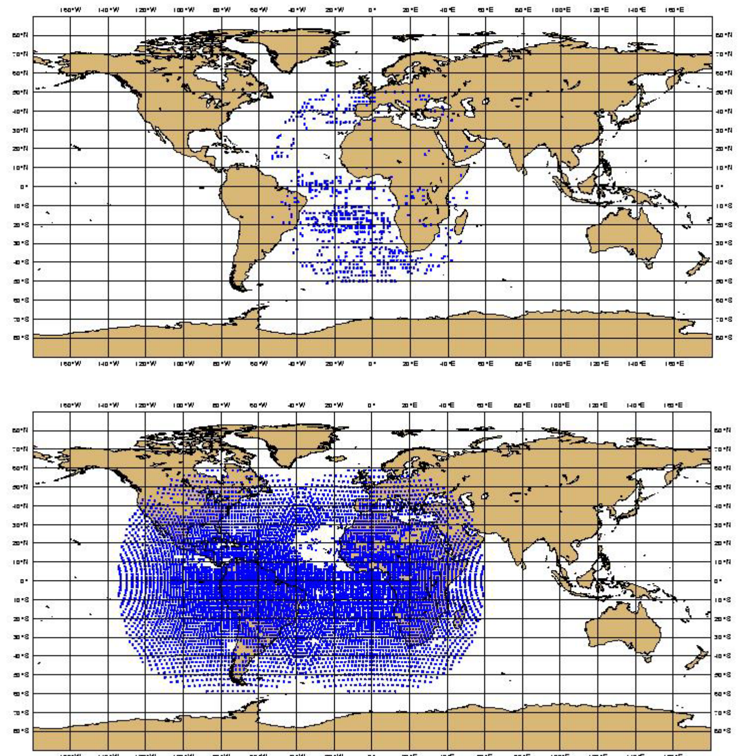
The irregularity in the application of the semi-transparency correction method could explain the positive bias in the mid-to-high levels observed in the departure statistics (Fig. 2). The uncorrected AMVs derived from images containing semi-transparent clouds will be assigned too low. Whilst the asymmetric first guess check contributes to the fast bias it appears not to be the root cause. Despite this result, the reprocessed AMVs (black line) show some positive characteristics notably with a reduced standard deviation compared to the original AMVs (red line) and a large increase in numbers used in the assimilation (see numbers between the two profiles).

The vector wind forecast error is used to determine the forecast impact of introducing reprocessed AMVs into the ERA-Interim reanalysis run. The experiment is verified against an earlier experimental ERA-40 analysis without the reprocessed AMVs. The impact in the extra-tropics is found to be relatively neutral, but a statistically significant positive impact is recorded in the low level Tropics (Table 1).

SECOND STUDY

The XADC period is particularly interesting as it allows us to assess reprocessed datasets from two Meteosat satellites in parallel. Met-5 was operational at 0º over the equator and Met-3 had been moved to 75ºW to replace a faulty GOES satellite. The study described in this section looks specifically at the quality and forecast impact of introducing reprocessed AMVs from both Meteosats into the ERA-Interim for the months January to March 1995.

The same experimental set up (IFS configuration and quality control) was used as in the previous experiment.



(a)

(b)

***Figure 3*: Example of (a) original operational Met-5 AMV coverage and (b) reprocessed Met-5 and Met-3 AMV coverage a around the 00 UTC cycle on the 2nd January 1995.**

Figure 3 illustrates the data coverage of the reprocessed AMVs (Fig. 3b) compared to the original operational ones (Fig. 3a). There were no AMVs disseminated from Met-3 at the time. As in the previous experiment, the reprocessed dataset is much larger than the original operational one. However note that the coverage plots show the coverage of AMVs received by the users. As the quality control was principally done by the producers in 1995, only the good quality AMVs were sent to the users. In contrast, for the dissemination of reprocessed AMVs, a similar approach is adopted to current practice, which lets the users perform their own quality control. All reprocessed AMVs with a minimum selection of QI > 30 are sent to the users.

The advantage of looking at two datasets of reprocessed AMVs is that the data can be compared. The quality of the Met-3 and Met-5 AMVs show some differences (Fig. 4) notably in terms of number of AMVs used in the assimilation. The number of IR AMVs from Met-5 is less than from Met-3. The WV images are known to be fewer and noisier so Met-3 WV AMVs are expected to fare slightly worse. In terms of biases, both datasets show positive biases of as much as 2-3 m/s around 400-300hPa. This is also apparent in Figure 5 which shows the departures of the first guess and analysis in terms of bias and standard deviation. The prominent bias already recorded in the 1989 experiment is still present. For this experiment, the Tropics are also affected. It is possible that this is due again to problems with the application of the semi-transparency correction method.

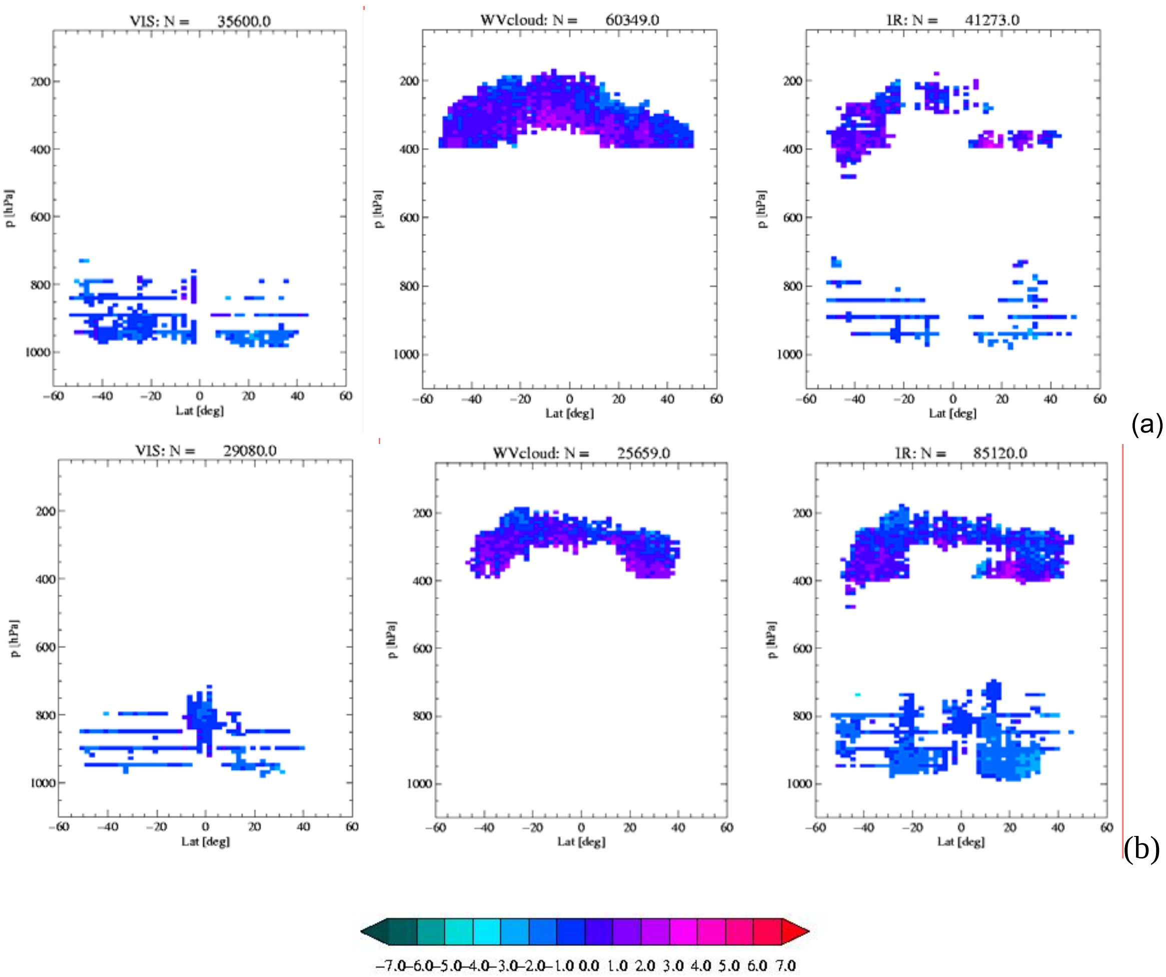


Figure 4: **Zonal mean speed bias (observation minus first guess) (m/s) for used reprocessed (a) Met-5 and (b) Met-3 AMVs for the period 1-15th January 1995.**

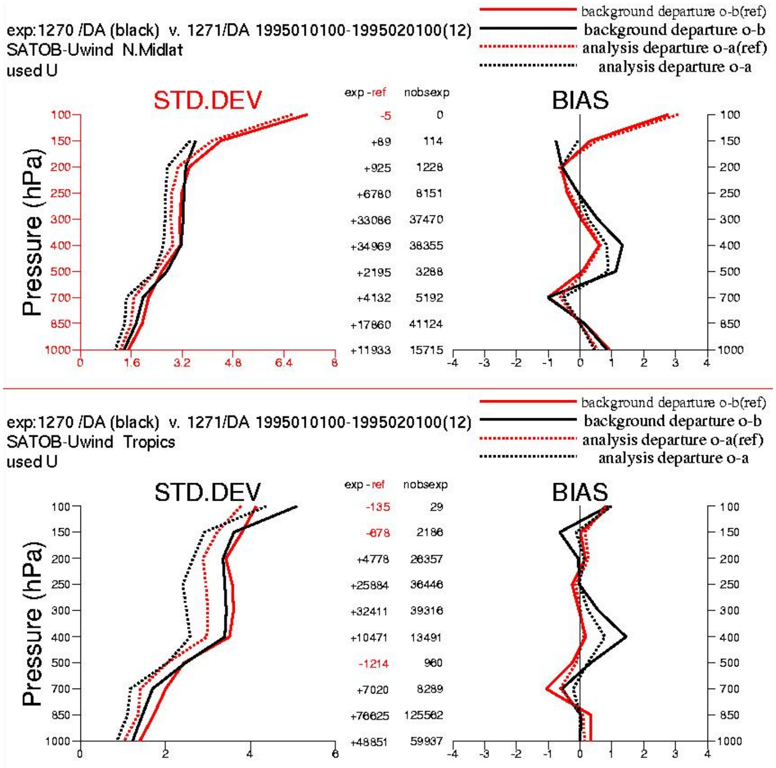


***Figure 5*: Profile of standard deviation and bias statistics of background (solid line) and analysis (dotted line) departures for the u component of the used wind in the Northern Hemisphere Extra-Tropics (top) and the Tropics (bottom) for the experiment (containing reprocessed AMVs) in black and the control (original operational AMVs) in red.**

	Forecast day	2	3	4	5	6	7
1000hPa	NH	**0.5%**	**0.1%**	**10%**			**2%**
	SH						
	Tropics			**10%**		**10%**	
850hPa	NH	**0.5%**	**1%**	**5%**		**5%**	**0.2%**
	SH						
	Tropics		**5%**				
500hPa	NH	**10%**	**5%**			**5%**	**0.5%**
	SH	**5%**	**10%**				
	Tropics		2%	5%	5%	1%	
200 hPa	NH						**10%**
	SH	**10%**	**2%**	**5%**			
	Tropics	2%	0.2%	0.5%			

***Table 2*: Statistical significance levels (%) from a t-test of the differences in RMS of the vector wind forecast errors between Experiment 1 (reprocessed Met-3 and Met-5 AMVs) and the control (old operational Met-5) for selected regions and levels, for 90 cases. Improved scores are in bold and degraded ones in normal print. The smaller the value the more statistically significant the impact is. No entry means that there is not enough significance (> 10%). NH and SH refer to the Extra-Tropics and differences are calculated against ERA-40 analysis.**

Forecast Impact

A forecast impact experiment was set up to see the impact of introducing reprocessed AMVs from both Met-5 and Met-3 instead of the original Met-5 AMVs in the ERA-Interim. Table 2 shows the statistical significance levels from a t-test of the differences in the root mean square of the vector wind forecast error between the experiment (reprocessed AMVs) and the control (original AMVs). Two more experiments were set up to try and determine the contribution of each individual satellite. The first looked at comparing reprocessed Met-5 with the original Met-5 AMVs (Table 3) and the second, reprocessed Met-3 and the original Met-5 with the original Met-5 AMVs (Table 4). The verification is against ERA-40.

	Forecast day	2	3	4	5	6	7
1000hPa	NH		**5%**			**5%**	
	SH	**2%**	**5%**		**10%**		
	Tropics		**10%**				
850hPa	NH						
	SH	**2%**	**10%**			10%	
	Tropics		**5%**				
500hPa	NH					**10%**	
	SH	**5%**	**1%**	**10%**	**10%**		
	Tropics	0.5%	0.1%	5%		5%	10%
200 hPa	NH	2%	5%			**10%**	**10%**
	SH	**10%**	**1%**	**2%**	**5%**	**10%**	**10%**
	Tropics	0.2%	2%	10%			

***Table 3*: Same as Table 2 but for Experiment 2 (comparing the impact of using reprocessed Met 5 AMVs instead of the orginal Met5 AMVs).**

	Forecast day	2	3	4	5	6	7
1000hPa	NH	**0.1%**	**0.1%**	**0.1%**			**2%**
	SH	**10%**					
	Tropics						
850hPa	NH	**0.2%**	**0.5%**	**10%**		**10%**	**0.5%**
	SH	**10%**					
	Tropics	0.1%	0.5%	2%	5%		
500hPa	NH						**5%**
	SH	**10%**	**5%**	**5%**			
	Tropics	0.1%	0.1%	0.1%	0.5%	2%	0.5%
200 hPa	NH						**5%**
	SH	**10%**	**5%**	**5%**			
	Tropics	0.1%	0.1%	0.1%	0.5%	2%	0.5%

***Table 4*: Same as Table 2 but for Experiment 3 (comparing the impact of using reprocessed Met3 and the original Met5 AMVs instead of the orginal Met5 AMVs).**

DISCUSSION

The primary result of this study is a very positive impact in the Extra-Tropics but also a negative impact in the Tropics at high levels. Met-5 appears to contribute more to this degradation than Met-3. The Tropics is a difficult area to validate with few observations available (i.e. in terms of radiosondes).

The quality of the data suggested that some AMVs with positive biases were being assimilated (Fig 4 and 5). In view of this a stricter blacklist was tested to establish whether removing these could improve the forecast in the Tropics. 500-300 hPa between 30ºS-30ºN was identified as the region to be blacklisted in addition to the existing blacklist. The impact experiment testing this new blacklist resulted in a local improvement, but an even stronger negative impact at 200 hPa. It is likely that other aspects contribute to the negative impact.

The model is not well constrained in the Tropics and may be very sensitive to new data for example in terms of the location and intensity of the converging low level winds and diverging high level winds that make up the ITCZ but also of the subtropical jet region. Indeed the differences in the mean wind analysis of the experiments (containing reprocessed AMVs) and the control (containing original AMVs) are strongest in the high level subtropical jet regions. Furthermore, looking at changes in the observing system between the 1989 experiment and the 1995 experiment, which show different impact in the Tropics, ERS-1 wind scatterometer data is the only new dataset. It would be interesting to investigate whether and how input of wind data at the surface can affect the higher levels.

CONCLUSIONS

The quality and use of reprocessed AMVs on ERA-Interim reanalyses and forecasts were investigated during two periods. The first looked at 3 months in 1989 where Met-3 was operational at 0º over the equator whilst the second focussed on the XADC period (1995) where reprocessed AMVs were available from both Met-3 (75ºW) and Met-5 (0º). The main results were as follows:

- Reprocessed AMVs benefit from a higher temporal and spatial sampling than the original dataset. The availability of the QI is also advantageous as it enables the user to have better control over the usage of the data.

- For both experiments the departure statistics showed a better standard deviation in the reprocessed dataset but a positive bias of 2-3m/s in the mid-to-high levels thought to be caused predominantly by problems with the application of the semi-transparency method.

- For the 1989 experiment the forecast impact of replacing the original Met-3 AMVs with the reprocessed ones was mostly neutral in the Extra-Tropics but positive in the low level Tropics.

- For the XADC period, the forecast impact of replacing the original Met-5 AMVs with the reprocessed ones and adding the reprocessed Met-3 AMVs, was a very positive impact in the Extra-Tropics, neutral in the low level Tropics but a persistent negative impact at the mid-high levels. Met-5 AMVs appeared to contribute to this degradation more strongly than Met-3.

The reprocessing of satellite products is an important and on-going component in the reanalysis activities. The task needs to be well coordinated between satellite and reanalysis agencies to allow evaluation of reprocessed data before the reanalysis production stage and to optimise the use of the data. Reprocessed AMVs have been included in the final ERA-Interim reanalysis for the years 1995 to 1997.

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