AVHRR POLAR WINDS DERIVATION AT EUMETSAT: CURRENT STATUS AND FUTURE DEVELOPMENTS

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Abstract

Polar Winds are being derived from the Advanced Very High Resolution Radiometer (AVHRR) instrument, which is on board the polar orbiting EUMETSAT Metop-A satellite, launched in October 2006. This paper describes the prototyping, operational implementation and initial validation steps undertaken at EUMETSAT to derive the winds. It provides some initial results, including incorporation of the Metop-A Infrared Atmospheric Sounder Interferometer (IASI) instrument collocated heights, discusses the error sources and lists future developments to be undertaken.

1. BACKGROUND

The Metop-A polar orbiting satellite was launched in October 2006. The EUMETSAT (EPS) Metop mission series is the European contribution to a joint European-US satellite system, the Initial Joint Polar Satellite System (IJPS). One of the on-board instruments is the Advanced Very High Resolution Radiometer (AVHRR/3) which provides global imagery twice a day at 1km (nadir) resolution in the visible, near-IR and IR channels. EUMETSAT are in the advanced stages of Day-2 preparation activities to produce AVHRR polar winds from the IR 10.8 µm channel.

Section 2 provides an overview of the EUMETSAT implementation approach. Section 3 summarises the prototyping activities undertaken, based on the production code provided by CIMSS, and also provides preliminary assessment of collocated IASI instrument derived heights. Section 4 discusses the operational implementation, with preliminary validation results. Section 5 highlights a number of error sources in the derivation of polar winds, while Section 6 concentrates on assessing the relative impact on wind quality of large time intervals between successive images. Section 7 outlines future developments to be undertaken.

2. IMPLEMENTATION APPROACH

EUMETSAT have used a copy of the CIMSS AVHRR polar winds code and modified it to interface with the Metop-A AVHRR Level 1b data derived in the EUMETSAT EPS Ground Segment. This has been used as a prototype to run test cases and support the operational development of the EUMETSAT AVHRR Winds Product Processor.

The EUMETSAT AVHRR Polar Winds Product Processor Facility (PPF) has been developed as a separate implementation to run in an operational environment. Validation of the PPF has consisted of comparing winds with the prototype, ECMWF re-analysis and radiosonde data. This validation is currently at an advanced stage.

Once the validation is successfully completed, a Demonstration Service will become available to disseminate the AVHRR polar winds. Further analysis at ECMWF will assess observation departures and forecast impact, before any necessary fine-tuning of the PPF, leading to routine operations.

3. PROTOTYPING

The polar winds prototype at EUMETSAT is an off-line post-processing tool adapted from the CIMSS polar winds code, and capable of ingesting Metop-A AVHRR Level 1b data. Key features are:

- Mapping is onto a common polar stereographic grid (winds output twice per orbit)
- Winds are generated using triplets, ie sequences of 3 overlapping orbits
- Forecast data is used to provide a first guess of the tracked target position
- Height assignment uses the IR window method, adjusted using the Recursive Filter Function

3.1 Prototype and IASI Collocated Height Production Data Sets

As part of the prototyping activities, a one month data set (January 2009) of EUMETSAT derived Metop-A AVHRR Level 1b data was processed and a corresponding set of polar winds produced.   In addition, as previously reported in Dew (2008), the IASI instrument on board Metop-A provides an opportunity to improve the height assignment accuracy of the AVHRR winds. Its wide range of channels affords a better accuracy for thin/semi-transparent clouds, by using the CO_2 absorption height method. Hence, the corresponding set of polar winds output from the prototype was also collocated with IASI information to provide alternative height assignment estimates.

Two data sets were created, identical apart from height, of winds collocated with the IASI cloud top information, one with the prototype heights, and the other with IASI heights. The winds were collocated to within 20 km of IASI derived heights, with fractional cloud coverage in the IASI pixel at least 80%.

3.2 ECMWF Analysis Experiments

The data sets were compared with the ECMWF background and analysis, and Figure 1 summarises the bias and standard deviation of the wind departures.
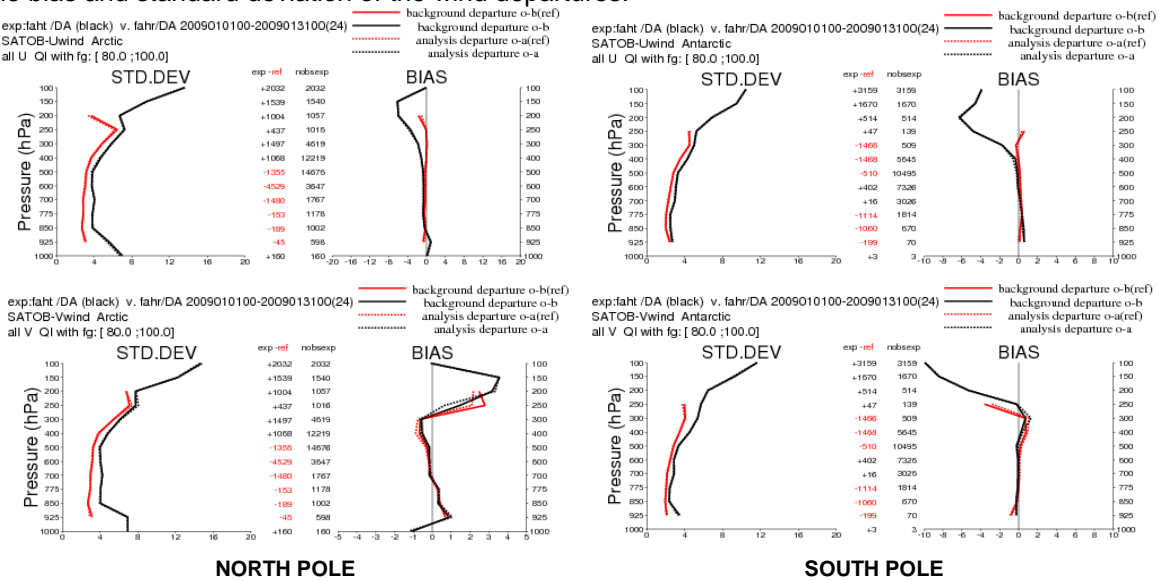

NORTH POLE   **SOUTH POLE**

Figure 1: Prototype Data Sets ECMWF Observation Departures: QI ≥ 80 - Prototype Heights (red), IASI Heights (black)

The first key thing to note is that, for the prototype data set heights, the observation departures against both background and analysis fields are relatively minor, which confirms the prototype as a basis against which to perform validation of the operational PPF. The second key point is the relatively large observation departures at high levels in the atmosphere for the IASI height data set. This is further emphasised by reference to Figure 2 which shows the relative distribution of prototype(CIMSS) and IASI derived heights. Here is clearly seen a significant distribution of very high level IASI heights, which are the cause of the relatively high observation departures.

The relatively poor performance of the IASI height assignment data set has been traced to the fact that the implementation of the CO_2 absorption height method adopted for the IASI instrument was in a state of flux during the timescales of the data set. A change was made to the implementation on January 27th 2009, which re-adjusted a significant number of extreme high level winds downwards in the atmosphere. This change would have been expected to improve the observation departures but was not implemented for a long enough period to affect the overall statistics for January 2009. There are

further improvements to the IASI CO_2 absorption height method in the pipeline for 2010, and the use of the IASI height assignment is still foreseen as a future benefit to AVHRR derived polar winds.
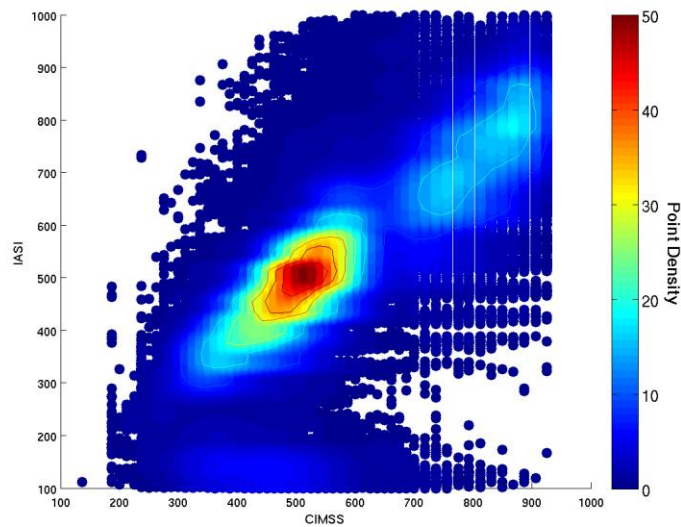

Figure 2: **Prototype and IASI Data Sets Height Coverage**

Forecast impact assimilation studies were carried out for the prototype height data set and Figure 3 highlights an example of the typical performance for a forecast parameter. This figure shows the impact on the geopotential height at 4 different levels in the Northern (Top) and Southern (Bottom) Hemisphere regions (excluding Tropics). The figure illustrates the general trend shown that, while there are local positive and negative impacts, the prototype polar winds one-month data set overall has a neutral impact on the forecast.
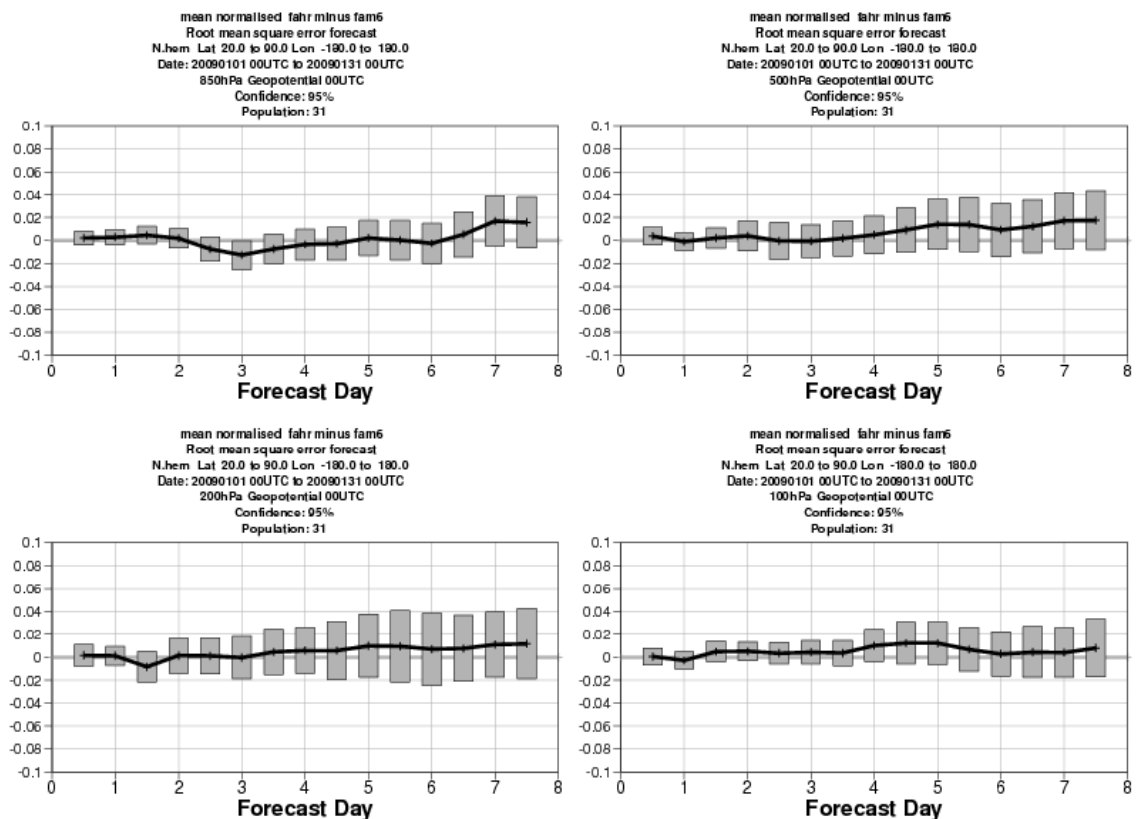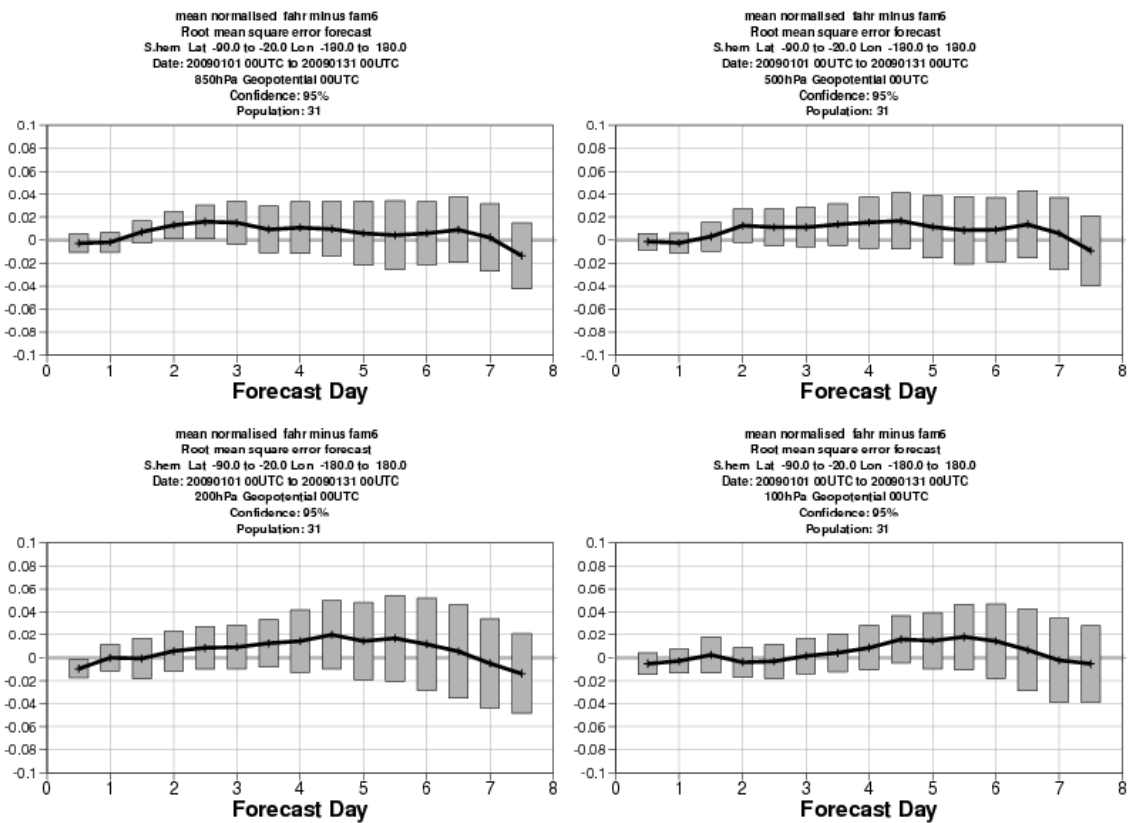
Figure 3: Geopotential Height Normalised Difference of RMS Forecast Error (Positive Difference -> Positive Impact)

4. OPERATIONAL IMPLEMENTATION

4.1 Differences to Prototype

The approach taken for the implementation of the EUMETSAT AVHRR Polar Winds PPF has differed from the prototype in a number of areas, some driven by the mechanics of the EUMETSAT EPS Ground Segment Product Generation Facility (PGF). These differences have been discussed and documented in Dew (2008), but the main differences are summarised as follows:

- Level 2 wind products are processed in near real time using 3 minute slices of image data, with nominal processing time of 3 minutes, producing slices of 3 minute (PDU) wind data
- Only 2 orbits are used to produce the winds for each PDU
- For each target PDU (3 minute slice of image data), 3 overlapping search PDUs are located from the previous orbit. These are mapped onto the target PDU co-ordinate system
- Tracking is carried out between the single pair of images (current and previous orbit)
- Dissemination time is between 90 and 110 minutes after sensing time of last image

4.2 Tracking Issues

Perhaps the biggest problem in the generation of polar winds (compared to, for example, geostationary satellite derived winds) is the relatively long time between successive images (typically about 100 minutes), during which the feature shape can change significantly as well as move a significant distance. This makes the tracking of features between successive images more difficult, even when increasing the search area appropriately, as has been highlighted in Dew (2008). A number of measures have been investigated to try and optimise the tracking:

- Use or non-use of a first guess (forecast) estimate of the tracked target position (a forecast guide is used in the prototype, but not, for instance, in EUMETSAT Meteosat derived winds)
- Different tracking methods (cross-correlation, euclidean distance, centre of mass)
- Image pixel size resolution (normal, super 3x3 or super 9x9 pixel sizes)
- Target size (28 x 28 (similar to prototype), or much larger (152 x 152))
- A pyramid based tracking approach in two stages : 1st stage a relatively large target and search area to provide an initial low resolution macro estimate; 2nd stage a smaller target and search area centred on the 1st stage estimate

The two degrees of freedom which most affected the tracking were found to be the use or non-use of forecast first guess information, and the target/search area sizes. Figure 4 provides an example of derived wind fields without the use of first guess information, for which very large search areas are required to accommodate the 100 minute wind field movement (Note: the use of optimised mixed-radix FFT cross-correlation techniques means the use of large search areas does not lead to timeliness problems). It shows that the selection of small target area sizes (for example as used in Meteosat wind derivation, and to reflect the resolution of forecast models) leads to relatively poor quality polar wind fields, and that to produce smooth fields, a large target area is required.
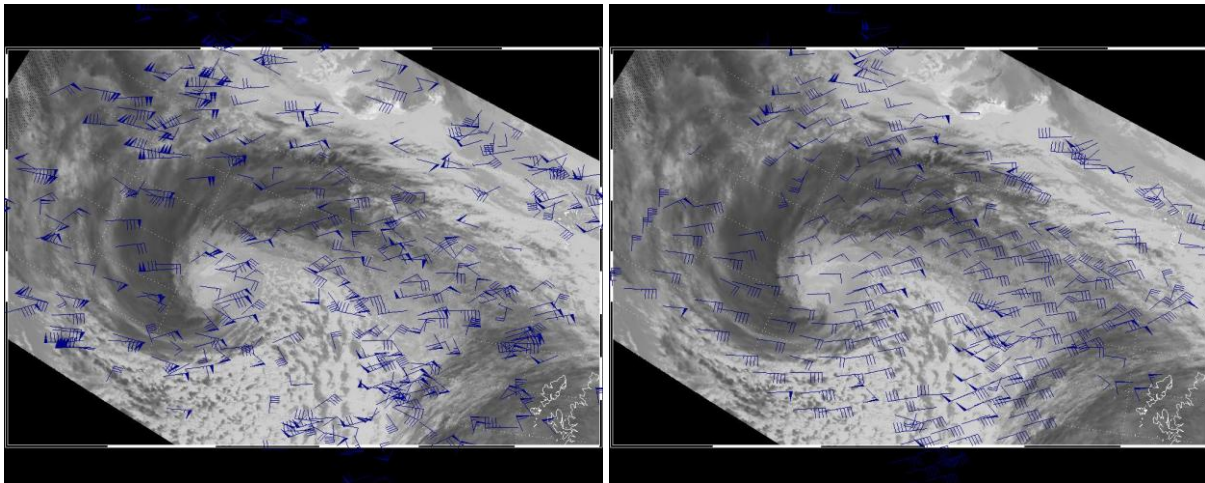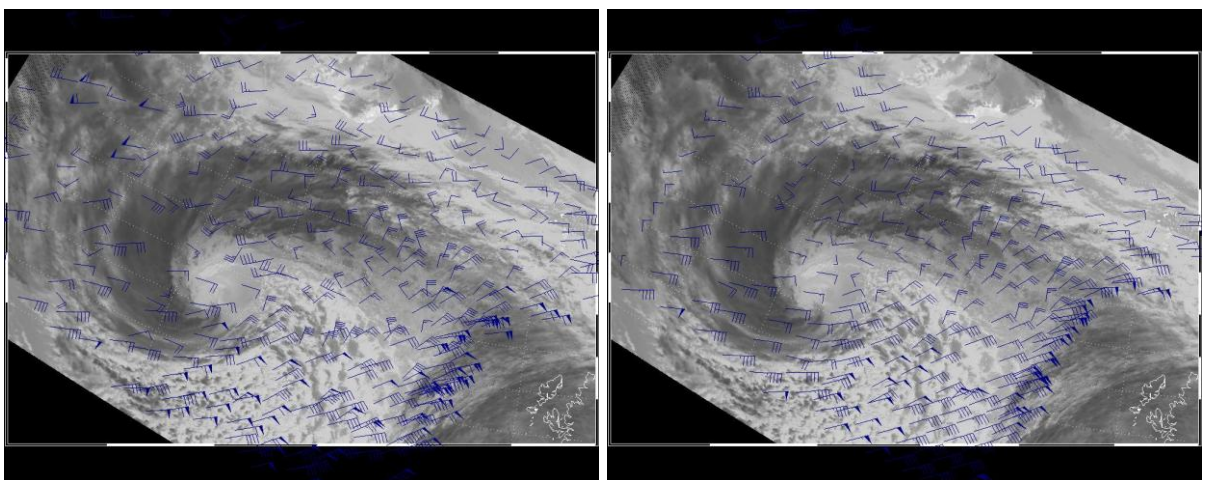

| Target Size 28 x 28 | Target Size 152 x 152 |

***Figure 4*: Derived Polar Wind Field – No Use of Forecast as First Guess (Search Size 400 x 400)**

Figure 5 provides an example of derived polar wind fields produced using first guess information. It illustrates that relatively good quality wind fields can be derived using forecast first guess information, albeit heavily influenced by the forecast first guess.

| Target Size 28 x 28 | Target Size 152 x 152 |

***Figure 5*: Derived Wind Field – Use of Forecast as First Guess (Search Sizes 100 x 100 and 224 x 224 respectively)**

Based on the above investigations, it was decided to use two separate 'pre-operational' versions for validation purposes. One which used forecast as a first guess (target size 28 x 28) and one without first guess (target size 152 x 152). The use of a large target area (152 x 152) leads to the question of whether this resolution target can accurately reflect the wind flow used in the Numerical Weather Prediction forecast models. In particular, it is interesting to note that there are some slight direction differences in the general flow of the wind fields for the different examples in the above figures.

4.3 QI Issues

The standard EUM QI spatial and forecast consistency tests are used for the polar winds QI. However, the use of only two images for the winds derivation, instead of a triplet or more images, prevents the use of the standard temporal consistency tests.

Hence, a tracking consistency test has been implemented in which, after a wind has been derived by tracking back from the current to previous orbit, the previous orbit position is used as a starting point for tracking forward to the current orbit. If no first guess is used, then this point is the search centre, otherwise it is the point where a forecast first guess is extracted, followed by a subsequent search centred about the first guess. The differences in the resolved vector, speed and direction between the tracks are used as an indication of tracking consistency.

In addition, a temporal height consistency test has been added in which the target height assignment is calculated in both orbits, the height differences used as an indication of quality.

4.4 Preliminary Validation

Preliminary validation has consisted of analysing the departure statistics against the ECMWF re-analysis. The validation has been carried out by comparing the relative performances of the prototype, and pre-operational (forecast and non-forecast guided wind) versions. QI filtering was set to remove about 50% of the winds (for the prototype only winds with QI ≥ 60 were selected, for the pre-operational versions the corresponding QI threshold was 50). Table 1 provides an example of the departure statistics as well as showing the relative distribution of heights. Figures 6, 7 and 8 show scatter plots and histograms of speed differences against the ECMWF re-analysis for respectively the prototype, forecast first guess and non-first guess cases.

	ARCTIC			ANTARCTIC		
	PROTOTYPE	FORECAST FIRST GUESS (GS2)	NO FORECAST FIRST GUESS (GS3)	PROTOTYPE	FORECAST FIRST GUESS (GS2)	NO FORECAST FIRST GUESS (GS3)
Speed Bias (m/s)	-1.21	0.87	-1.45	-0.10	1.72	-0.02
Speed RMS	2.67	4.50	8.21	2.01	3.97	5.30
Dirn Bias (deg)	1.00	0.45	5.05	0.54	2.25	11.39
Dirn RMS	8.60	15.65	59.40	13.33	38.45	66.91
Mean Spd AMV	19.47	21.52	16.90	14.69	12.83	7.65
Mean Spd Analysis	20.69	20.65	18.35	14.79	11.11	7.66
Sample Size	3988	970	1035	1503	393	947

% AMV high level	5	4	5	2	4	2
% AMV mid level	71	80	84	73	64	78
% AMV low level	24	16	11	25	32	20

Table 1: **AVHRR Polar Winds Observation Departure Statistics against ECMWF Re-Analysis and Distribution of Heights**

Table 1 shows (in particular with reference to the speed and direction RMS departures) that the prototype departures are less compared to both pre-operational versions, and that the forecast guided winds version yields better statistics. These results are re-inforced in Figures 6 to 8 by noting how the scatter distribution is lower for the prototype compared to the pre-operational versions, and largest for the version which uses no first guess. The height distribution of winds in all versions is predominantly medium level (400 to 700 hPa).
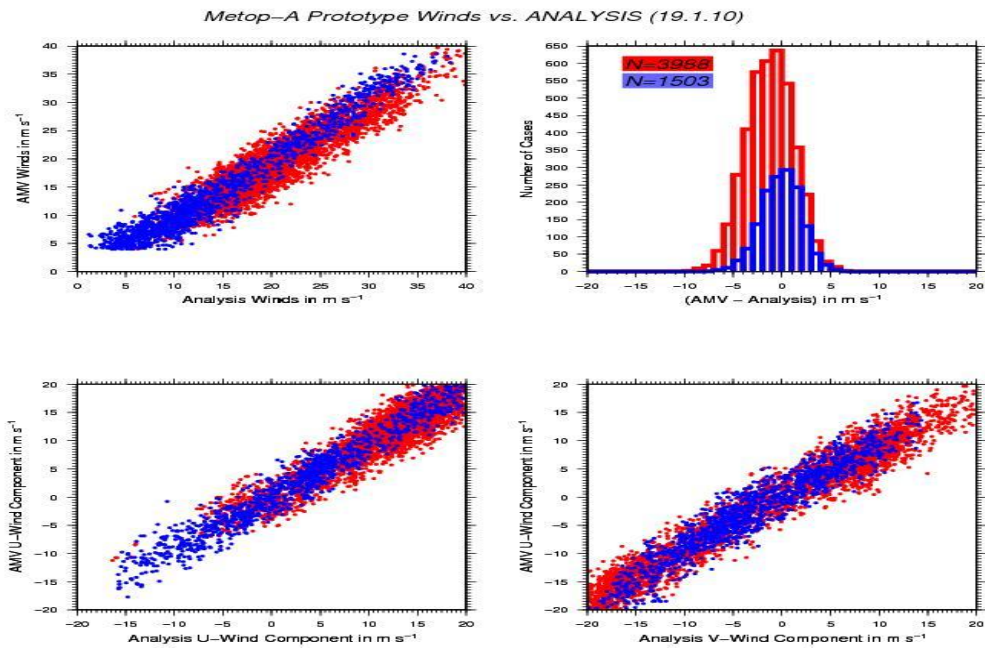
Metop–A Prototype Winds vs. ANALYSIS (19.1.10)

Figure 6: Prototype versus ECMWF Re-Analysis Scatter Plots and Histogram of Speed Differences (Red – Arctic, Blue – Antarctic)

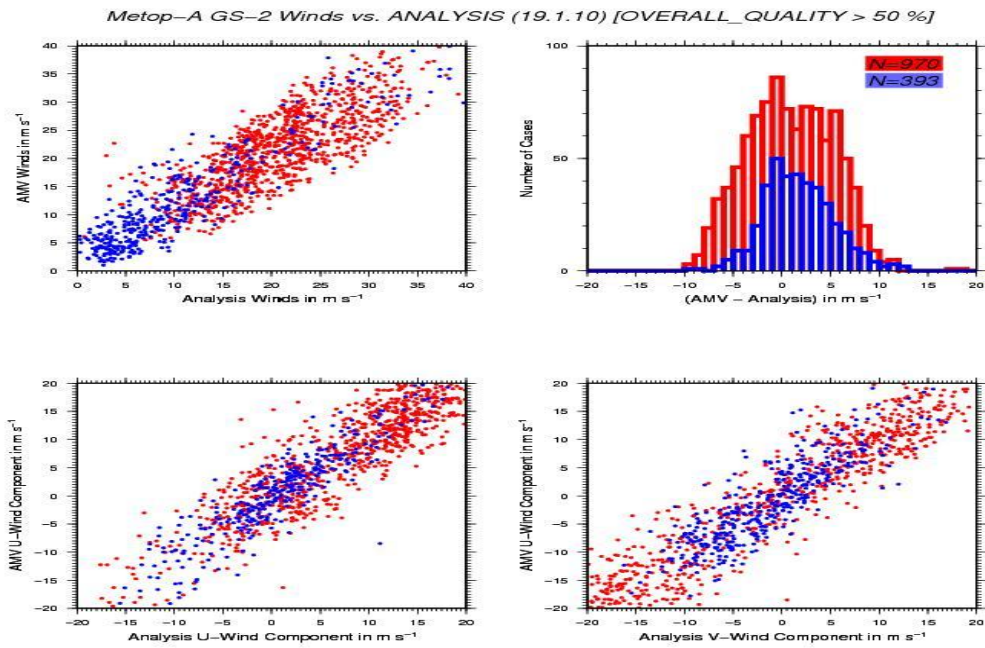Metop–A GS–2 Winds vs. ANALYSIS (19.1.10) [OVERALL_QUALITY > 50 %]

Figure 7: Forecast First Guess Version versus ECMWF Re-Analysis Scatter Plots and Histogram of Speed Differences (Red – Arctic, Blue – Antarctic)
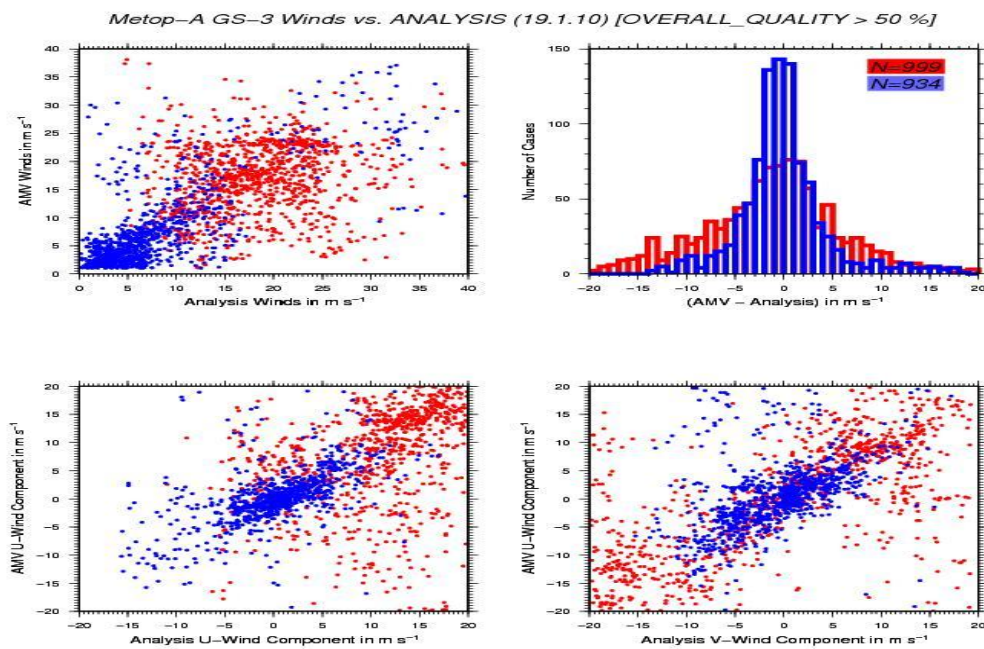
Figure 8: No Forecast First Guess Version versus ECMWF Re-Analysis Scatter Plots and Histogram of Speed Differences (Red – Arctic, Blue – Antarctic)

4.5 Validation Activities Leading Up to Operations

Further statistics will be generated for longer timescales, including against radiosondes, but the previous section has identified some clear trends. To try and improve the quality of the pre-operational versions, EUMETSAT will isolate and filter out areas in which the quality is lower. There are a number of areas which still have to be investigated for fine-tuning, for example set-up parameter thresholds for target selection, satellite viewing angle thresholds, selection of relative weights to be used for QI tests. The option to not use forecast guided winds will still be pursued, and winds derived using this method will be compared against the forecast guided winds. The avoidance of dependence on the forecast information as a first guess has worked well for the EUMETSAT geostationary winds development. But the necessarily long time intervals between images and large target sizes/resolutions required in the current AVHRR polar winds derivation scheme may limit their usefulness in ECMWF forecast assimilations, meaning a current reliance on the forecast guided winds option. The AVHRR Polar Winds PPF is configured to use either option via selection of a set-up parameter.

It is expected that a Demonstration Service of the AVHRR polar winds will be made available by mid-2010, subject to a successful review of the validation results and the availability of upgraded hardware in the EPS Ground Segment.

5. ERROR SOURCES

Tracking and height assignment are the major error sources in the current derivation of polar winds.

For tracking, errors can be caused by the fact that the feature changes significantly in 100 minutes, meaning the correlation surface is poorly defined. Also there can be parallax errors - in which the actual position of a cloud is different to its perceived one – which are worse at extreme viewing angles.

In addition, for relatively low resolution (large target area) derived winds, the question is – how representative are they of the modelled state of the atmosphere ?

Height assignment errors can occur for thin, semi-transparent clouds, for which the IR window tracking method is not suitable. There are also many instances of temperature inversions in polar regions, which have yet to be accounted for in the modelling. In addition, when a forecast first guess is used, height assignment errors will impact the location of the first guess, with a corresponding impact on tracking. Forecast first guess location will also be affected by inaccuracies in temporal interpolation of forecast data.

The next section concentrates on highlighting a major problem associated with the tracking of polar winds, which is the large time interval between successive images, while the final section summarises how some of these errors will be addressed in the future.

6. DEGRADATION OF TRACKING QUALITY WITH INCREASING TIME INTERVAL

By way of an aside, but which will subsequently be seen as relevant to the polar winds derivation, to illustrate the deterioration in tracking quality as the time interval between successive images increases and the feature correspondingly changes, a series of examples using Meteosat Second Generation images were used, in which winds were derived at tracking intervals of 15, 30, 45, 60, 75 and 90 minutes. The search area was increasingly expanded with time about the target centre to contain the feature movement. The tests were carried out for both the IR channel (24 x 24 target size; 3km pixel resolution at sub-satellite point) and the HRVIS channel (32 x 32 target size; 1 km pixel resolution).

The results and conclusions were the same for both the IR and HRVIS channels, and Figure 9 shows an example of the wind fields derived in the HRVIS channel. It is clear how the relative number of good quality winds reduces as the time interval increases. The experiments have indicated that tracking is severely degraded at time intervals above 60 minutes, even if the feature is contained in the search area, and even if the forecast were to provide a good first guess. The degradation can be reduced by increasing the target size, as has been previously discussed in Section 4.2. Figure 10 illustrates the improvement in tracking quality if the target size is increased (the fields can be directly compared with the 60 min smaller target size field in Figure 9).

The relevance of these experiments is to demonstrate that the tracking quality for polar winds cannot be expected to be good for tracking intervals greater than 60 minutes, even if the feature is contained in the search area. However, the tracking quality of the AVHRR polar winds can potentially be improved in the future after the launch of the Metop-B polar orbiting satellite, which will closely replicate the orbit of Metop-A with a 50 minute separation. It is recommended to combine the images generated from Metop-A and B to provide winds separated by 50 minute intervals. The Metop-B is currently scheduled to launch in April 2012.
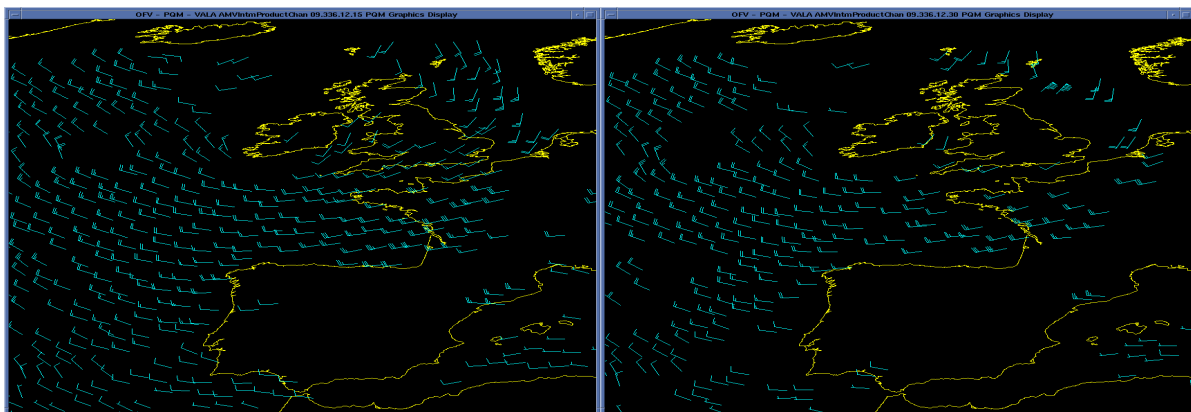

Figure 9a: HRVIS Wind Field QI > 80 for Tracking Intervals: Left 15 min, Right 30 min
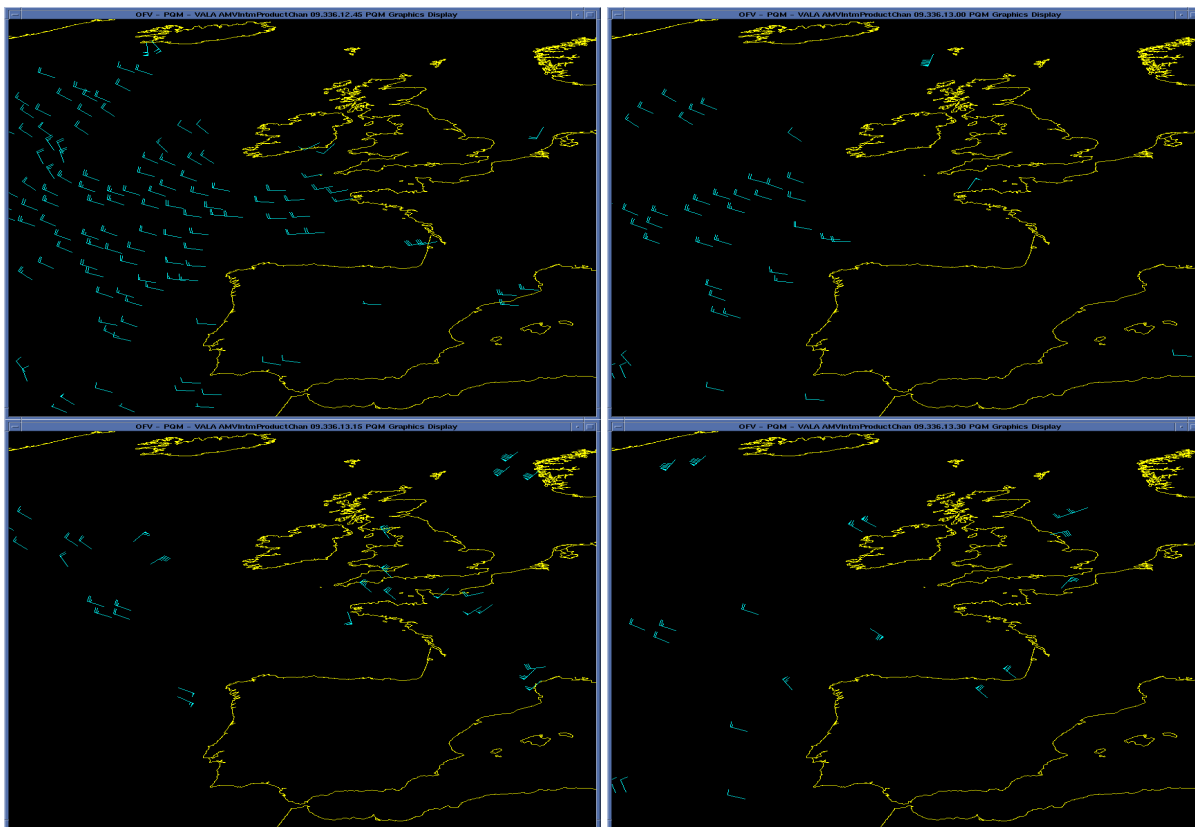
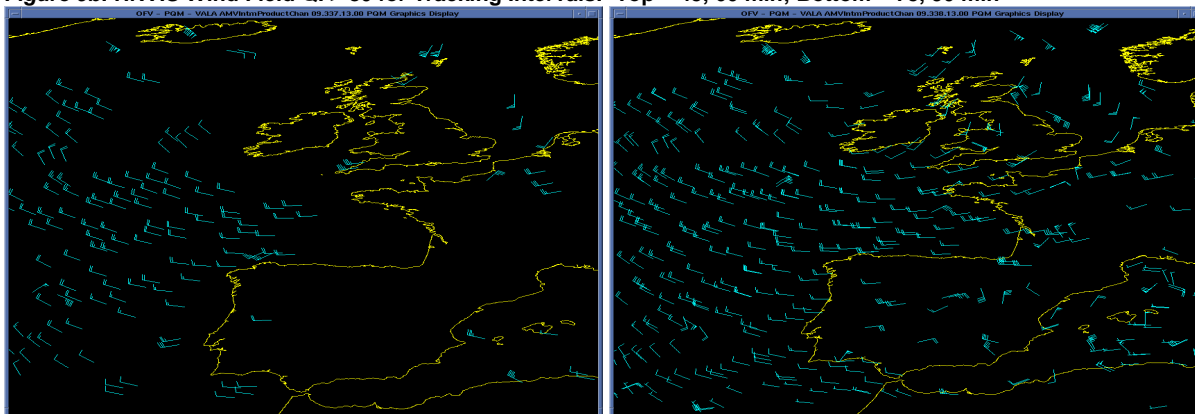**Figure 9b**: HRVIS Wind Field QI > 80 for Tracking Intervals: Top – 45, 60 min; Bottom – 75, 90 min

Figure 10: HRVIS Wind Field QI > 80 for 60 min Tracking Interval: Target Sizes 48x48 (left) and 96x96

7. FUTURE DEVELOPMENTS

Once a Demonstration Service of AVHRR polar winds products becomes available, further development will concentrate on improving the height assignment and tracking. The use of collocated IASI height assignment information would be expected to improve the height assignment. Parallax errors will also be considered, or large satellite viewing angles filtered out. The use of a 3rd orbit (further back in time) is a possibility to provide a temporal consistency check. A more rigorous correlation surface peak analysis would also provide a better estimate of the target position. The precise tuning of consistency tests and relative weights for the final QI still need to be optimised, together with other set-up parameters. These developments are expected to be completed prior to the launch of the Metop-B satellite, whose images can potentially be used in conjunction with Metop-A.

REFERENCES

Dew, G. (2008) AVHRR Polar Winds Derivation at EUMETSAT: Current Status and Future Developments. Proceedings of the 9th International Winds Workshop, Annapolis, USA, EUM.