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

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Abstract

The Advanced Very High Resolution Radiometer (AVHRR) is one of the instruments on board the polar orbiting Metop-A satellite, which was launched in October 2006. The EUMETSAT Polar Satellite (EPS) Metop mission series is the European contribution to a joint European-US satellite system, called the Initial Joint Polar-Orbiting Operational Satellite System (IJPS). The 1 km pixel resolution at nadir provides the opportunity to derive polar winds from consecutive orbits. This paper describes the initial steps undertaken at EUMETSAT to derive polar winds. It provides some initial results from derivation of winds in the IR 10.8 µm channel, discusses the challenges encountered so far and lists the 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 (0.63, 0.86 µm), near IR (1.6 µm - day only) and IR (3.7 - night only), 10.8, 12.0 µm) channels. The AVHRR has applications in meteorology and oceanography and provides inputs for other Metop instrument processor activities (eg Infrared Atmospheric Sounder Interferometer (IASI)).

There is an EPS End User Requirement to derive polar winds using AVHRR. The production of AVHRR winds is a planned Day-2 activity driven by the original EUMETSAT End User Requirements Document. The IJPS agreement foresees that both NOAA and EUMETSAT derive and provide polar wind data to users. NOAA are currently generating polar winds data from the Metop-A AVHRR, based on their generic winds production code.

EUMETSAT have commenced Day-2 preparation activities to produce AVHRR Winds from the IR 10.8 µm channel. Section 2 briefly summarises the programme activities, Section 3 discusses a number of technical issues raised, including proposed differences in the wind generation approach to that of NOAA. Section 4 highlights the future developments to be undertaken in the next 2 years.

2. SUMMARY OF ACTIVITIES

EUMETSAT have been provided with a copy of the CIMSS AVHRR polar winds code (currently used as a basis for the NOAA Metop-A AVHRR polar winds derivation). This has been used to reproduce NOAA test cases and will be used to run other input data and support the operational development of the EUMETSAT AVHRR Winds Product Processor.

The EUMETSAT AVHRR Winds Product Processor Facility (PPF) is being developed as a separate implementation to run in an operational environment (there are a number of key differences in the proposed wind generation approach compared to NOAA (see Section 3 for more details)).

The activities are grouped as follows:

- Prototyping (carried out 2007/2008)
- EUMETSAT AVHRR winds PPF development environment activities – started 2008, will use winds generated from CIMSS code as a reference
- Run initial versions in EPS EUMETSAT Ground Segment – summer 2008
- Fine tuning and iterative versions of EUMETSAT AVHRR winds PPF
- Product Validation (inc. external validation)
- Make the AVHRR polar winds operational as a Day-2 product, target date end of 2008

3. TECHNICAL ISSUES

During the prototyping and early development activities a number of technical issues have been raised which are discussed under the following sections.

- Input Data and Winds Derivation
- Target Selection
- Data Mapping
- Target Tracking
- Computational Efficiency
- Height Assignment
- Use of Other Instrument Data
- Parallax
- Quality Control
- Validation

3.1 Input Data and Winds Derivation

At the Svalbard ground receiving station, a complete orbit's worth of AVHRR data is dumped at each successive pass. From this data, EUMETSAT generates Level 1b AVHRR data consisting of

- pixel radiances
- navigation information
- cloud information

This Level 1b data is available as a series of Product Dissemination Units (PDUs) which are disseminated in near-real time, each of length 3 minutes, each consisting of 1080 lines and 2048 pixels per line. There are approximately 33/34 PDUs per orbit and a complete orbit's worth of Level 1b data is processed within the time span of the next orbit (pipeline approach).

There is a rolling buffer of Level 1b data stored in the on-line ground segment. For each Level 1b (target) PDU which covers the polar region, a corresponding winds PDU will be produced.

There will be an estimated number of up to 12 wind PDUs for each orbit. These will be processed in near-real time within the duration of an orbit.

Only 2 orbits will be used to produce the winds for each PDU. For each target PDU, the 3 corresponding search PDUs in the previous orbit which overlap the target PDU will be selected, and the selected targets will be reverse tracked from the target PDU to the search PDUs. This affords a timely dissemination of the winds PDU for that PDU timestamp. A two orbit processing approach has been adopted instead of an alternative triplet (which would require 3 orbits worth of data), to try and minimise the effects of active cloud motion which would be expected to impact the tracking quality over such a long time period.

As an example, Figure 1 shows a target PDU, and the 3 overlapping search PDUs from the previous orbit.

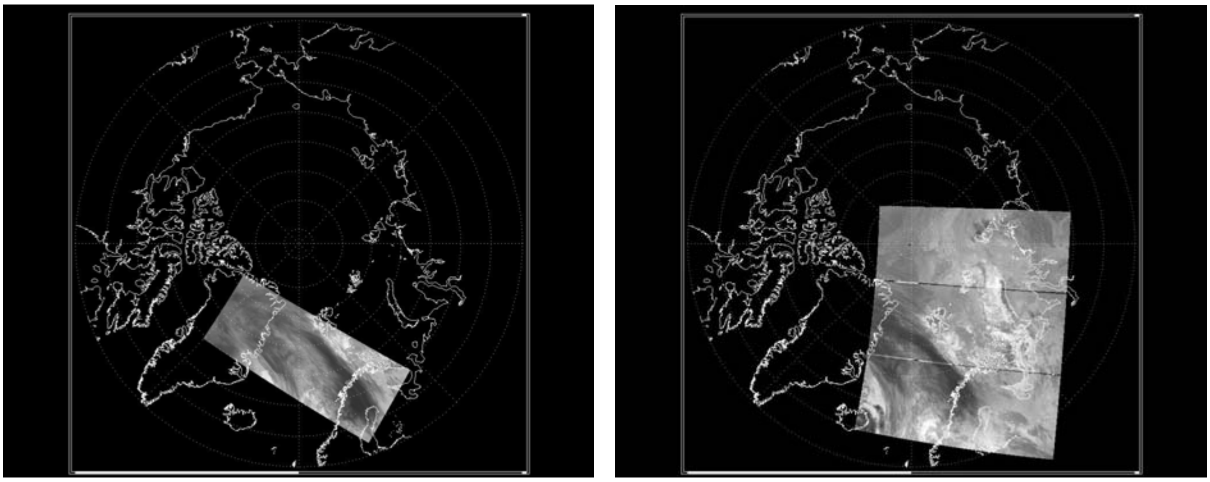

***Figure 1*: Target PDU – orbit n and Search PDUs orbit n-1**

3.2 Target Selection

Each PDU has 1080 lines and 2048 pixels per line. Targets are selected at designated locations, eg grid points at fixed locations, or the position of localised maximum contrast within expanded search (optimisation) areas. This is an approach similar to that used for the EUMETSAT Meteosat Second Generation (MSG) winds processing. There is pixel based cloud information in the EUM Level 1b product to support this process. This is available as a series of flags (eg 'cloudy', 'clear', 'test', 'failed', 'ice'), output from a number of threshold tests using different individual and combination channels. However, it should be noted the main aim of the AVHRR Level 1b cloud detection algorithm is to identify cloud free areas for subsequent sea and land surface temperature calculations, so the pixels will be biased towards being detected as 'cloudy'.

One task will be to investigate how best to optimise the use of the individual cloud test results, including filtering out ice features. It is also conceivable that improved cloud detection algorithms will need to be developed as part of this process.

3.3 Data Mapping

Target tracking requires that both target and search areas have the same geographical representation. One option is to re-project both target and search PDUs onto a common stereographic projection, centred at either the North or South Pole. However, re-projection of data implies a potential loss of information for both the target and search areas. In noting that the AVHRR wind product is a Level 2 Product, the definition of a Level 2 product is to define derived geophysical parameters at the same resolution and location as those of the Level 1 data. To better satisfy the Level 2 definition, a data mapping scheme is being investigated which only re-projects one of the target or search PDUs. So, for example, only the search PDU data is re-mapped (directly onto the target PDU co-ordinate system), or vice versa. The precise mechanics of how best to optimise the re-mapping are currently being investigated, including consideration of how best to deal with significantly different pixel resolution of overlapping target and search data, eg for instance the Level 1b pixel resolution can vary between 1 and 6 km.

3.4 Target Tracking

Once the targets have been selected and the necessary re-mapping carried out to a common co-ordinate system, the target tracking follows the approach used for the EUMETSAT MSG wind production. The best target match is found using cross-correlation with the appropriate search and target area sizes. However, with polar winds there are complications.

The repeat cycle time (time between the successive orbits) is of the order of 100 minutes, significantly larger than the MSG 15 minute value. This ordinarily impacts on the size of the chosen target and search areas, which has implications for computational run-time (see Section 3.5). In addition, the contour/contrast features can potentially change significantly in this time period and the tracer may not be passive.

One way to counter this is to use first-guess information for the location of the matched position. This enables smaller target and search areas to be used. However, if the forecast data is sufficiently inaccurate, a good match will not be found, and a potentially 'good' wind will have been missed. An approach has therefore been considered to exclude the use of first-guess information, leading to the necessity of larger target and search areas.

Clearly the required search area size is going to be larger than the equivalent of MSG (which also does not use first-guess information), and initial tests have also confirmed that the target area needs to be larger than typically 100 x 100 pixels. It is easier to track a larger feature over this time period than a smaller contrast feature, because the smaller feature can change relatively more significantly in 100 minutes.

The nature of the cross-correlation technique is to track a contrast edge and in the case of the EUMETSAT AVHRR polar winds application, the issue of whether this is the best technique to track a target will need to be addressed. There is another standard template matching technique which can be used, Euclidean Distance. A comparison between the Euclidean Distance and Cross-Correlation methods has previously been discussed (Dew (2004)). However, some research may need to be undertaken to assess appropriate tracking techniques which concentrate on tracking a "centre of mass" feature rather than the edge.

An example to show how the target area size impacts the tracking quality can be illustrated. Figure 2 illustrates the overlapping target and search PDUs, while Figures 3 and 4 zoom in on a cloud feature shown by the dark swirling open-hoop feature.

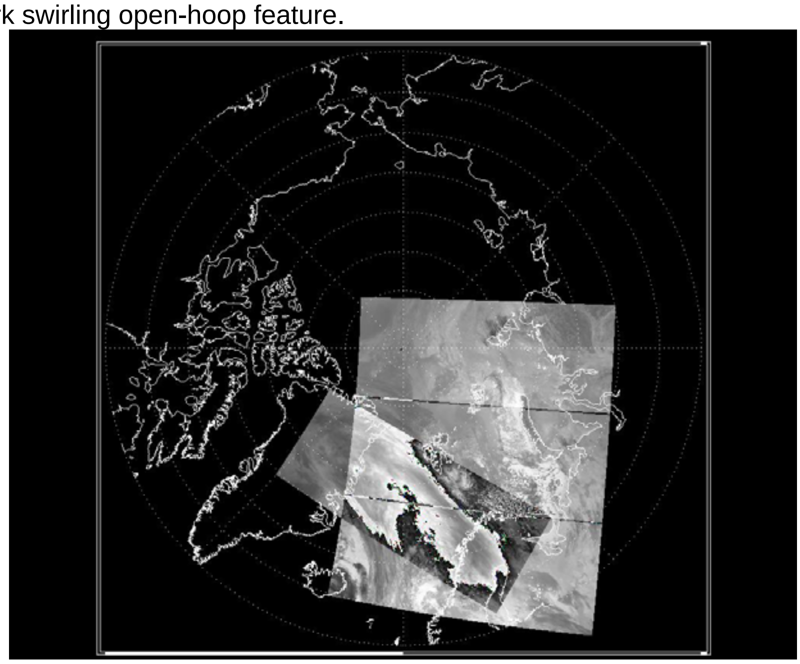

***Figure2*: Overlapping Target and Search PDUs**

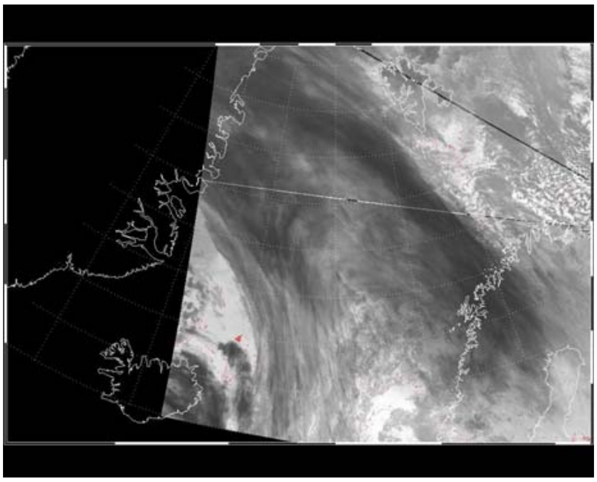

***Figure3*: Search orbit n-1**

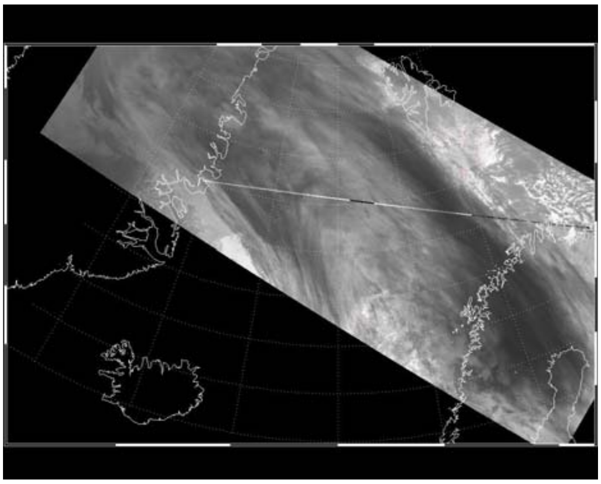

***Figure4*: Target orbit n**

The general feature movement can be distinguished with the eye (better when flicking between successive slides of the image) but clearly there is also some active cloud formation which will impact the quality of the tracking.

Figures 5 and 6 show the resulting wind field for two test cases (distinguished only by the size of the target area), when reverse tracking from target orbit n to search orbit n-1.

The AVHRR Level 1b target PDU time coverage is 20th February 2008, 11:25z to 11:28z.
The AVHRR Level 1b search PDUs cover the times 09:40z to 09:49z.
PDU size: 1080 x 2048 pixels
Target Area: Case 1 (Figure 5) 80 x 80 pixels
Case 2 (Figure 6) 140 x 140 pixels
Search Area: 300 x 300 pixels
Targets selected at grid positions 80 pixels apart.

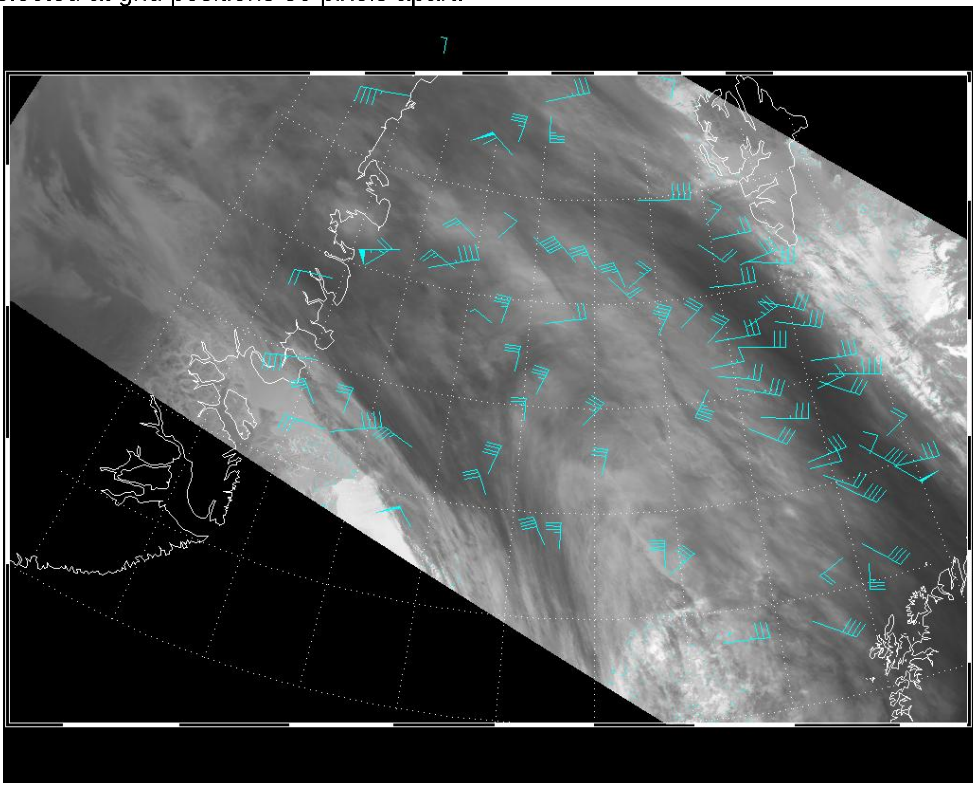

***Figure5*: Target Area 80 x 80**

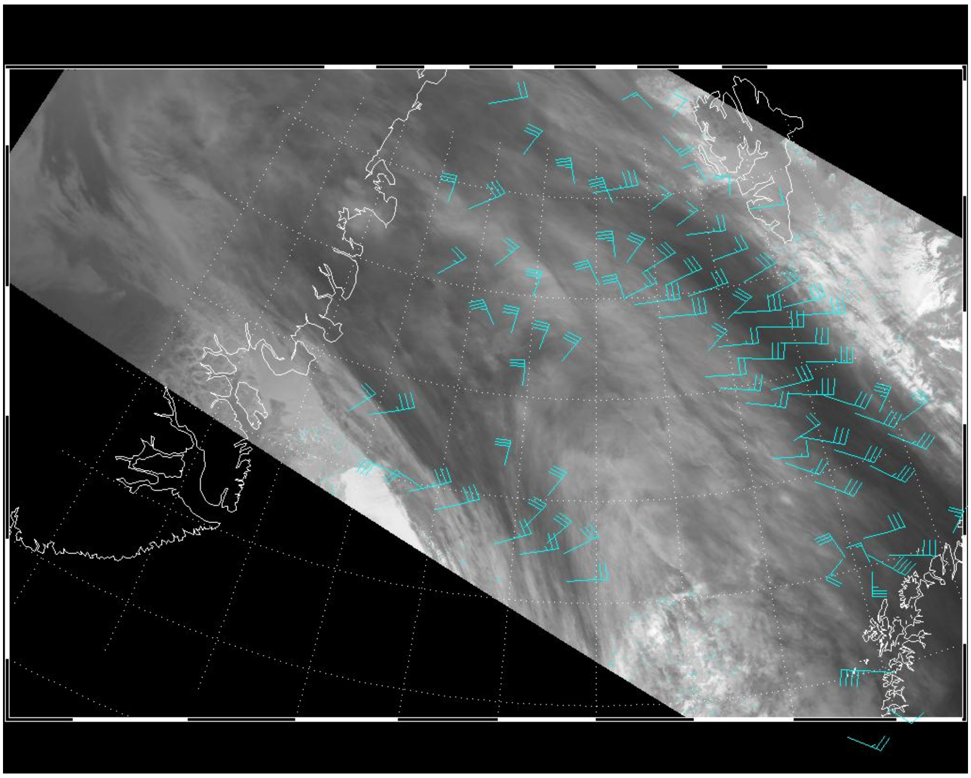

***Figure6*: Target Area 140 x 140**

In Figure 6, compared to Figure 5, for the larger target area the winds are of better quality and represent the general flow of the open-hoop cloud formation better.

3.5 Computational Efficiency

Using large target and search areas impacts on computational run-time. An orbit worth of AVHRR polar winds need to be processed within the time-frame of a single orbit. The cross-correlation (target tracking) part of this process is the most computationally intensive part. In the above example, the cross-correlation (spatial domain) computation time for a 140 x 140 target, 300 x 300 search area is typically about 300 times that compared to an MSG target of size 24 x 24, search area 80 x 80. However, use of the cross-correlation in the FFT domain significantly reduces the run time, and becomes relatively more advantageous for larger data sets - especially using a form of the FFT called Mixed-Radix FFT, instead of the more traditional Radix-2. This has been demonstrated by Dew and Holmlund (1998). The Mixed-Radix FFT is used in the EUMETSAT MSG Winds operational suite and will be used for the EUMETSAT AVHRR Winds Processor. As an example, the Mixed-Radix FFT computational run time for the target/search area 140 x 140, 300 x 300 pixel combination is estimated to be typically 3% that of the spatial domain computation.

3.6 Height Assignment

The absence of any absorption channels prohibits the use of semi-transparent correction and CO_2 absorption methods using AVHRR data. The IR window method will be used in conjunction with forecast data to extract the cloud top height brightness temperature and convert to a height. Temperature inversions will also be handled in the same effective way as in the EUMETSAT MSG operational suite, (ASD (2007)). The IR window method works well for opaque clouds but not for semi-transparent ones where the semi-transparent and CO_2 absorption methods would be expected to work better (Niemann et al (1993)).

The contributing pixels to be selected in the calculation of the height can be determined by a number of different ways. Methods such as selecting a certain percentage of coldest pixels, or use of a dynamic clustering method to select a suitable scene have been previously investigated in the MSG winds production suite, as a means to try and select the most critical pixels. These methods can also be investigated for the AVHRR winds production.

The use of the Recursive Filter Function (RFF) can be investigated as an option to improve the height assignment estimate. The RFF was developed at CIMSS (Hayden and Purser (1995)). It is an objective 3D recursive filter analysis of the derived AMVs, successively modifying a 3D background field defined at fixed grid locations, based on appropriately weighted contributions from the forecast field and the AMV observations. The fit of each AMV to the modified background field yields an adjusted AMV height. This has been implemented operationally at both NOAA and, more recently, for the EUMETSAT MSG winds (Dew (2006)).

However, perhaps a very promising method of improving the height assignment estimate is to make use of other Metop-A instrument height assignment data (see Section 3.7).

3.7 Use of Other Instrument Data

The IASI instrument on board Metop-A provides an opportunity to improve the height assignment accuracy of the AVHRR winds. IASI has a wide spectral range of channels and produces pixel based (resolution 12 km at nadir) cloud top height information, for which it can use the CO_2 absorption height method.

AVHRR data is already used to support geo-location of IASI products, so co-registration information is readily available. A potential issue is the discrepancy in pixel resolutions between the two instruments, however quality tests can be carried out to assess the suitability of the co-located IASI cloud top heights, eg by comparing brightness temperatures from the two instruments.

The CO_2 absorption method, however, does not work if the surface – cloudy radiance difference is very small, and particularly in cases where there are clouds warmer than the surface (which happens fairly frequently in the polar regions) (Key, Santek and Velden (2004)). The use of IASI data will be investigated but will not appear in the initial operational version.

The Metop-B satellite is planned to be launched in 2011. So there is the potential to combine images from the Metop-A and B satellites to provide better quality winds, eg through smaller repeat cycles and more frequent coverage.

3.8 Parallax

Parallax is the apparent position displacement of a feature above the ground that results from non-nadir viewing angles. It can be calculated as a shift in terms of distance and direction of wind over the geoid. It is a more important consideration for winds generated from successive orbits as the viewing geometry changes from orbit to orbit. Santek, Velden and Key (2004) have previously reported on cloud location errors associated with parallax. The implementation of a parallax correction in operational polar winds is being tested by NOAA. The addition of a parallax correction will add a not-insignificant component to the processing load, hence, before the assessment of the likely errors, initial versions at least of the AVHRR Wind Processor will not correct for parallax.

3.9 Quality Control

One of the most important aspects of the EUMETSAT AVHRR winds production is to assign a reliable quality indicator to each wind. For AVHRR winds, the quality checks used in the EUMETSAT MSG winds can be considered. These are based on the EUMETSAT AQC scheme as originally described by Holmlund (1998). Forecast wind profiles can be used to calculate forecast consistency checks, and spatial consistency checks can also be carried out. However, a calculation of temporal consistency is more difficult as there is just a single component of the wind.

One possibility to investigate is to forward track the target from its matched position as found in the search orbit (n-1) back to the target orbit (n). The new position compared to the original target

location provides an indication of the quality of the tracking, eg if they are identical the quality is excellent.
A quality indication for the height assignment could be provided by calculating the height assignment for the target position in both orbits and comparing the results. Similar heights would indicate a high quality.

The implementation of the RFF (see also Section 3.6), to provide an RFF quality flag for each AMV based on the quality of the neighbouring analysis and the fit of the AMV to the background field, may be another indicator of quality to adopt.

3.10 Validation

To validate the EUMETSAT AVHRR winds, the following activities will be carried out:

- Compare the CIMSS code generated winds and the EUMETSAT AVHRR winds
- Compare with radiosondes – however there are a limited number of radiosonde co-locations in the polar regions
- Use Numerical Weather Predictor (NWP) assimilation experiments, eg at ECMWF, to assess the impact on forecast models

4. FUTURE DEVELOPMENTS

The goal of EUMETSAT is to provide the best quality AVHRR polar wind product, investigating the techniques summarised in this talk and the techniques established in the CIMMS polar wind production software.
The target date for the AVHRR polar winds to become an operational Day-2 product is end 2008.
Over the next two years the aim will be to fine tune and investigate the techniques previously discussed.

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