STATUS AND DEVELOPMENT OF OPERATIONAL METEOSAT WIND PRODUCTS

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ABSTRACT

The Operational Meteosat Meteorological Products are produced by the MPEF, a facility in the Meteosat Ground Segment developed and operated by EUMETSAT under the Meteosat Transition Programme (MTP). The most important MPEF products are the wind products, derived from all three Meteosat channels.

The current operational wind products are the Cloud Motion Winds, derived from 5 km resolution imagery in all three Meteosat channels, the High Resolution Visible winds, derived from full (2.5km) resolution visible images and Clear Sky Water Vapour Winds, derived from 5 km WV imagery in cloud free areas. The current status and quality of these wind products is presented.

The planned development of the wind products from the current Meteosat MTP satellite is driven by the meteorological community requirements for higher spatial and temporal coverage, including winds in cloud-free areas. These needs will be satisfied by a number of developments: more frequent wind distribution, BUFR distribution of winds with quality information, increased HRV coverage through improved tracer selection techniques, high resolution winds from the Water Vapour channel. These developments and their relationship to the development towards the Meteosat Second Generation (MSG) products are described and discussed in detail.

1. INTRODUCTION

The EUMETSAT Meteosat Transition Programme (MTP) ground segment controls the Meteosat satellites and provides ground processing for all Meteosat missions. The MTP ground segment includes a Mission Control Centre (MCC) located in the EUMETSAT headquarters building in Darmstadt, Germany.

The MTP products are produced in the Meteorological Products Extraction Facility (MPEF), which is a facility in the MTP Mission Control Centre. The core products are the wind products, extracted from all three Meteosat channels in near-real time, and distributed on the GTS.

The operational Meteosat satellites are Meteosat-7 at 0°E and (in support of the INDOEX field experiment) Meteosat-5 at 63°E. The Meteosat Second Generation Ground Segment is under development, and the MSG MPEF will be the follow-on facility for extraction of meteorological products from the MSG satellites.

2. STATUS AND QUALITY OF MPEF WINDS

The current range of operational wind products consists of:

- Cloud Motion winds (CMW)
  - Combined wind product from Infrared, Water Vapor and low resolution Visible images
  - Distributed in SATOB at 00Z, 06Z, 12Z, 18Z
- Expanded Low Resolution winds (ELW)
  - Multi-channel cloud track wind product from Infrared, Water Vapor and low resolution Visible images
  - Distributed in unified BUFR format every 90 minutes
- Clear Sky WV winds (WVW)
  - Wind product from Water Vapor images in cloud-free areas
  - Distributed in unified BUFR format every 90 minutes
- High Resolution Visible Winds (HRV)
  - Produced from high resolution Visible images
  - Distributed in BUFR at 06Z, 09Z, 12Z, 15Z, 18Z (-3 hours for 63°E Mission)
  - Parallel distribution in unified BUFR format and in simplified BUFR format.

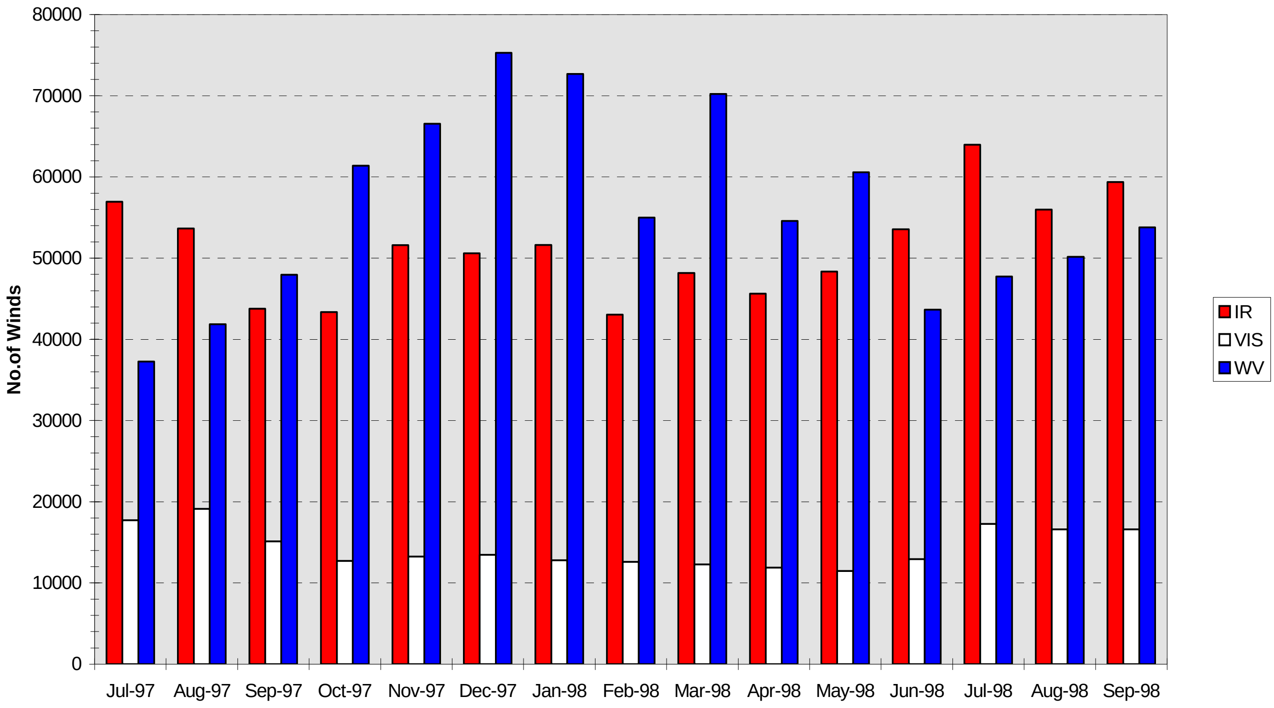
All wind products are produced fully automated, with no human intervention. The Manual Quality Control for all MPEF products was discontinued on Sep 7 1998. The unified BUFR format has been officially approved by the WMO CBS Working Group on Data Management and has entered into force as a standard WMO table in November 1998.

Major recent updates to the product extraction system have been:

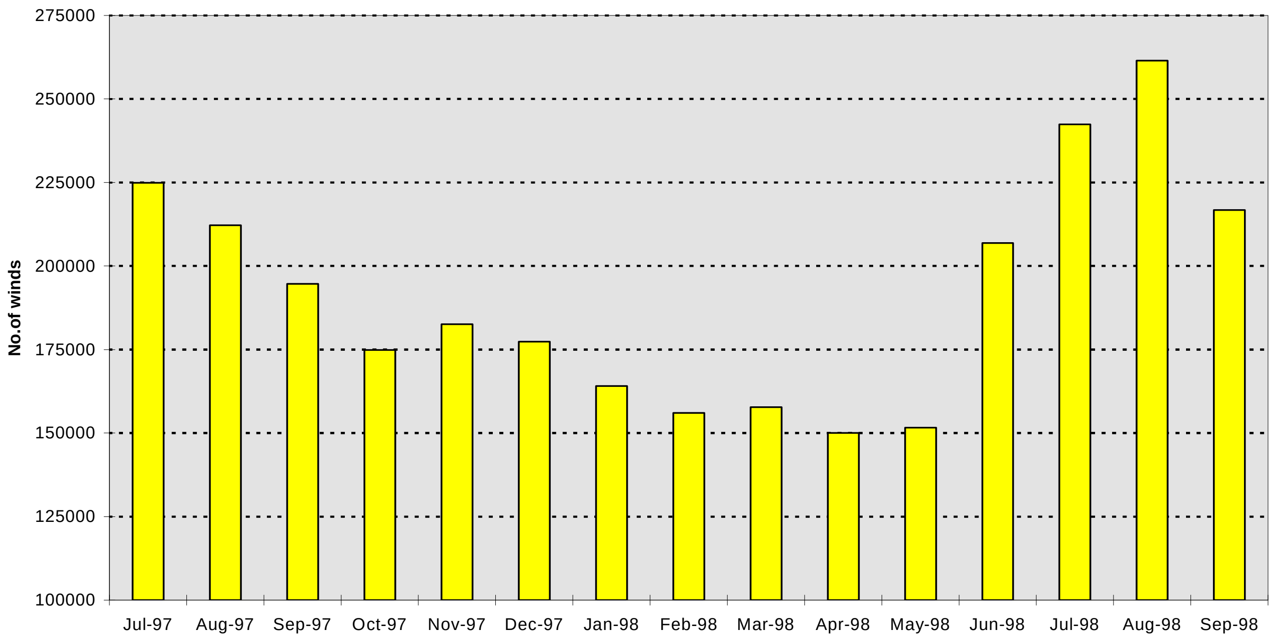
- ELW and WVW operational (Sep 8 1998)
- Start of Indian Ocean Mission at 73°E (July 1 1998)
- Introduction of inter-channel consistency check between WV and IR (Dec 12 1997).

The following two graphs show the evolution of the number of produced winds in the CMW and HRV products for the 0°E mission over the last 15 months. The numbers shown are average numbers of winds per month for the different channels.

PRIME Mission
Figure 1: Summary of IR, VIS & WV Winds after Manual Quality Control

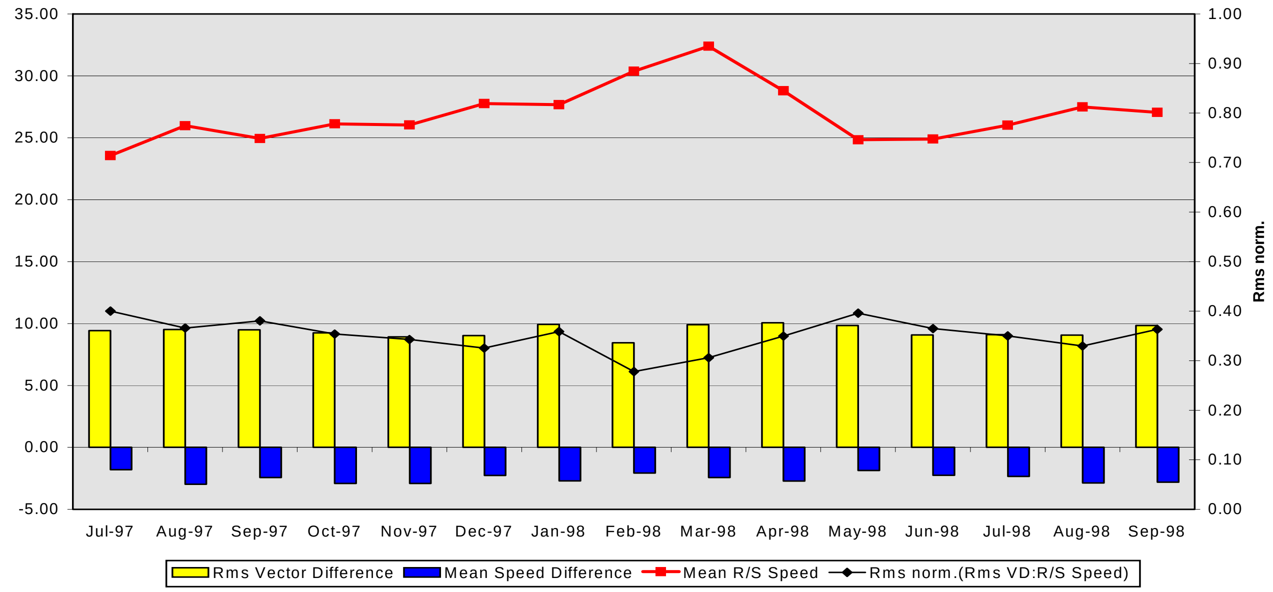


PRIME Mission
Figure 2 : Summary of High Resolution Visible Winds after Automatic Quality Control

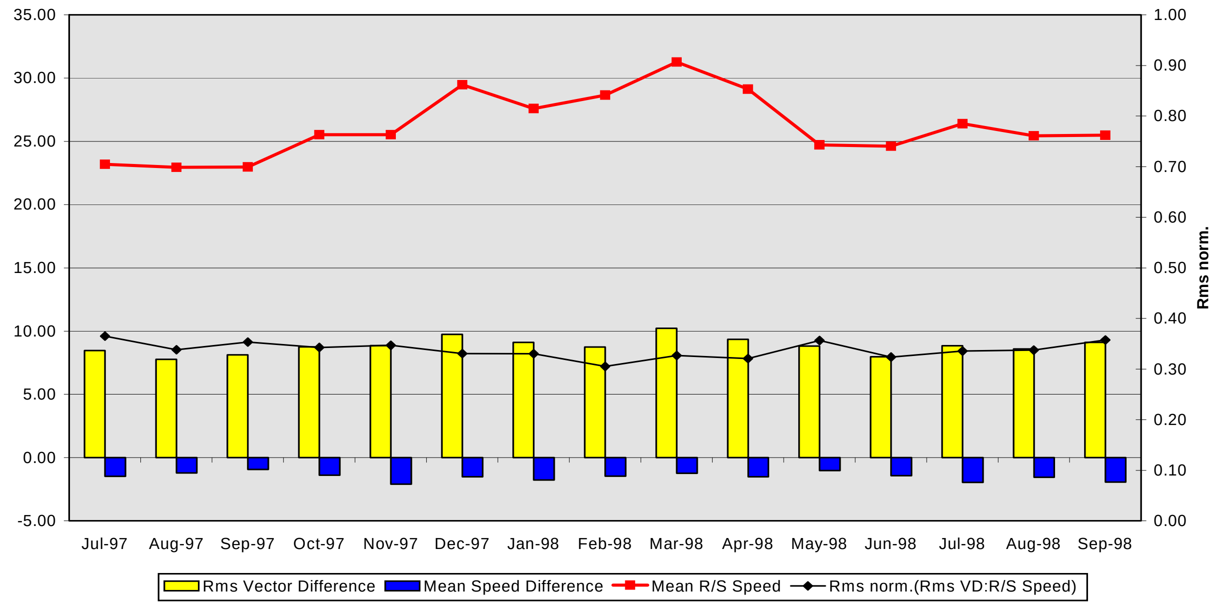


The following graphs show the evolution of the RMS and BIAS of the CMW Product as measured against radiosondes for high-level IR and WV winds, full disk. The criteria for collocation are: 150km horizontal threshold, 25 hPa vertical threshold and 1.5 hours temporal threshold.

PRIME Mission
Figure 3: Meteosat Infrared High Level Winds Verification



PRIME Mission
Figure 4: Meteosat Water Vapour High Level Winds Verification



More information about the MTP products, including schedules, GTS headers, full statistics and full description of the unified BUFR format, can be found on the MPEF WWW pages at www.eumetsat.de/en/area3/topic3.html. More information about operational radiosonde collocation statistics from all satellite wind producers can be found at www.wmo.ch/hinsman/CGMShome.html.

3. USER REQUIREMENTS

The key driving forces for the development of the Meteosat products have been the support to the global NWP operators, the support to the synoptic forecasters and the support to the WMO climate programs. By and large this will remain so in the coming years. The following key developments in the user community are foreseen in the coming years and should be supported by the MPEF.

Variational data assimilation

The migration of the optimum interpolation analysis schemes to variational methods has already started. ECMWF has for several years employed variational schemes for assimilation of TOVS radiances. The variational methods make possible the assimilation of data containing non-model variables by the use of so-called observation operators, which define a relation between model variables and observed data. An example of an observation operator is a forward radiative transfer model, defining a relationship between a profile of temperature and humidity and observed radiances in specific channels. The variational methods then makes it possible to assimilate satellite radiances, even if they cannot be directly converted into a real profile.

The variational technique can also be used to assimilate bulk data like deep-layer mean winds. Such a procedure could be employed for MPEF clear-sky WV winds, but no significant development work in this area has yet been done in the user community.

4-D data assimilation

The analysis schemes of at least the major NWP centres will over the next decade be migrated to the next generation 4-D variational methods and this will considerably change the data requirements. Whereas the NWP analysis schemes now depend almost solely on synoptic data, they will evolve into continuous data-assimilation systems with no special dependency on synoptic hours. As the geostationary satellites are the main continuous source of asynoptic data this will become a very important driving force for the MPEF products.

An ongoing debate in the NWP community addresses the issue of 4-D assimilation of satellite winds vs. satellite radiances. Theoretical arguments would suggest that 4-D assimilation of cloud-cleared radiances would generate a wind field consistent with the wind field derived directly from the images. This would indicate no need to assimilate clear-sky winds directly. This is however a theoretical argument, as direct assimilation of the radiances at instrument resolution in space and time is quite out of reach with current assimilation systems. Therefore a more pragmatic approach seems to prevail, namely the concurrent assimilation of radiances and winds at an appropriate resolution in space and time.

The major technical challenge in the 4-DVAR scheme is the correct handling of physics, especially in the tropics, but these issues have been satisfactorily resolved for the ECMWF model. ECMWF introduced 4-DVAR operationally in November 1997.

Other major NWP operators are monitoring the ECMWF progress with 4-D Var, but are currently not committed to operational implementation schedules.

4. DEVELOPMENT PLANS

General

The wind products are computed by identifying and localising the same pattern ("tracer") in consecutive METEOSAT images (Buhler and Holmlund, 1993). This tracking is done in all 3 spectral channels independently. Using the knowledge of the tracer displacement, combined with the measurement of its temperature, the following values are extracted which constitute the wind product : wind location, wind speed, wind direction, temperature and pressure level.

The first operation performed is the selection of the structures that will be used as the tracers, based on the information provided by the Histogram Analysis. This tracer selection is done in a channel-specific way, including cluster merging or rejection when necessary. When a useful tracer has been identified, height assignment is performed and the corresponding wind component can be extracted. The wind-component extraction process comprises the definition of the Target and Search areas taken from the current and previous image, their enhancement, followed by their cross-correlation.

For CMW and ELW the tracers are clouds identified from 5 km imagery from all channels, for HRV clouds clouds identified from 2.5 km visible imagery and for WVW the tracers are cloud-free tracers identified from 5km WV imagery.

The extracted wind components are thereafter subject to automatic quality control (AQC) (Holmlund, 1996). The AQC process calculates a number (currently 5) of consistency indicators for the extracted wind, and combines these as a weighted mean into an overall reliability indicator. The intermediate wind products contain all extracted winds and associated reliability indicators. No manual quality control is applied.

The intermediate wind products are encoded into GTS formats. For the CMW product the <u>best wind</u> per geographical location, as determined by the value of the overall reliability indicator, is selected from this intermediate product, and encoded into SATOB, if the reliability indicator exceeds a certain threshold value (currently 0.8). For the ELW, HRV and WVW products, the winds are encoded in BUFR, together with the reliability indicators themselves. All winds down to a very low reliability are included, but for each product, a suggested reliability indicator threshold is provided in the BUFR format. The BUFR and SATOB products are distributed on the GTS. The original intermediate products are archived in the Meteosat archive facility (MARF) and are thus available for historical retrievals.

Further details about the wind extraction process are provided in (Rattenborg and Holmlund 1996) and (Schmetz et.al.).

The following areas can be identified, where further improvement of the current MPEF wind are desired:

- Low level coverage around developing tropical systems. The lack of cloud motion-wind coverage in the vicinity of developing and developed tropical disturbances is an important issue for hurricane forecasting.
- Low-level height assignment in trade wind inversion areas. In the inversion areas, the Temperature-to-Pressure transformation is multi-valued. This results in low-level IR height assignment problems.

- Medium-level coverage. Although this area presents fundamental meteorological problems, the MPEF wind coverage at medium levels seems to be too low.
- High-level height assignment for cloud tracked winds. Significant scope for improvements to the semi-transparency correction.
- Provision of reliability indicators for speed, direction, pressure and temperature
- Decrease the required amount of detailed manual quality control

The needs of the user community will be addressed partly through improvements to the existing operational wind products (CMW and HRV) and partly through the introduction of new wind products.

Improved spatial resolution of forecast data
The forecast data used up to now in MPEF has been ECMWF products in GRID code with very coarse horizontal and vertical resolution (3x3 deg, 10 pressure levels), but migration to high-resolution GRIB data (1.5x1.5 deg, model hybrid-sigma levels (currently 31)) is in progress and will be completed in Nov 1998. The higher resolution will improve both the results of the radiative transfer calculations and many other processes, such as CMW height assignment. The high-resolution forecast data provides very significant improvements in the description of deep low-level trade inversions and this will significantly improve the quality of the low-level wind products in the subtropics.

Improved resolution of diurnal cycle
Improving the resolution of the diurnal cycle in surface temperature is important for the prediction of IR radiances for surface scenes. Because of the 6-hour resolution in time, the diurnal cycle variation has to be simulated in a separate step. The present scheme will be improved by the use of 3 hourly forecast fields, to provide a better resolution of the diurnal cycle.

Improved Semi-Transparency correction
Studies indicate that the height assignment of IR and WV winds in many cases fail because of failure to apply a correct semi-transparency correction to the cloud clusters. Several factors can contribute to an improvement in this area:

- The Semi-Transparency correction can be calculated by using a linear regression on the individual pixels. This eliminates the requirement for background scene identification.
- The quality of the humidity forecast is crucial in determining the radiance curve, and with the rapidly improving humidity fields supplied from the NWP centres an improvement will be expected.
- A posteriori adjustment of the radiance curve to fit the observed background clusters could be investigated.
- The Semi-Transparency model could be refined to more truly represent semi-transparent clouds
- Improvements of the stability of the WV vicarious calibration will have a significant effect on the semi-transparency correction.

An improved semi-transparency correction scheme, primarily based on the linear regression technique, is being development as part of MSG MPEF prototyping, and will, after completion of an extensive validation, be tested for at least partial integration into MTP MPEF.

HRV tracer selection improvements

The tracer selection and height assignment for HRV will be based on averaging pixel counts over the target area in the pixel-classified image instead of using the segment-based cluster information. This will provide more HRV winds in mixed cloud segments and better coverage in areas with developing systems. Planned for 1st quarter of 1999.

Height assignment in inversion areas

The problem of multiple pressure points per given temperature in the trade winds area will be addressed. With the usage of ECMWF GRIB forecast data on model levels (currently 31, but planned to increase to around 50 in the course of 1998), the resolution of the inversion will obviously be better, but the height assignment scheme still requires minor changes to correctly handle the inversion case.

Automatic Quality Control

A core issue to be addressed for the MPEF CMW product is the definition of the AQC processes and parameters. The process is essential to ensure a maximum yield of high-quality winds for all channels and all levels and to ensure the availability of stable reliability indicators for the user community. Optimisation of AQC is also a pre-requisite for providing fully automated products with higher time-resolution. The AQC tuning is based on the continuously growing data set of collocated radiosondes and MPEF satellite winds, as well as on comparisons with ECMWF first-guess fields. The AQC definition process is ongoing with continuous improvements over the next year. From then onwards it is expected, that no major modifications will be performed to the AQC scheme. Extensions to the AQC scheme, e.g. cross-channel AQC between WV and IR, will be applied.

With an optimal AQC the size and coverage of the SATOB encoded product can be increased and meaningful reliability indicators for the BUFR product, including individual reliability indicators for speed, direction and height, can be provided. It will also be investigated whether estimates for the error distribution functions can be produced, which could be used in the NWP data assimilation schemes.

The optimised AQC system will be used as a basis for tuning the MSG MPEF, as the MSG system will employ the same AQC system as MTP.

Medium-level IR winds

The quality and coverage of the medium level IR winds is relatively poor. This is mainly a reflection of the complex physics and dynamics of the mid-level atmosphere, especially over the continents, and no single internal problems causing this have been identified, but the medium-level winds issue will continue to be investigated.

WV winds from cloud-free areas

The tracking of water vapour in cloud-free areas provides a wind product with extensive coverage. This product (WVW) at a resolution of 160 km is now available as an operational product, using the single-level height assignment based on the cluster EBBT. With the new unified BUFR template, is it possible to provide the user with alternative height assignments, and it is planned to include height assignment information based on the WV contribution function calculated in the Radiative Transfer Model.

Low-level tracking over land
The tracking of low-level clouds over land presents significant problems because of the short lifetime of low-level clouds over land, the impact of surface features on the tracking and of flow deformation/curvature effects. The feasibility of advanced techniques to address these issues using the MSG spacecraft will be addressed in a EUMETSAT study, and if the results of this study are promising and applicable an implementation in the MTP system will be considered.

High Resolution WV winds
Prototyping has shown the feasibility of a WV winds product at half-segment size resolution, i.e. 80km, for both cloudy and non-cloudy areas (S.S. Elliott, 1998). This product will be provided as an operational product in BUFR 16 times per day and is planned for 2nd quarter of 1999.

Increased time-frequency of winds distribution
The MPEF derives winds every 1.5 hours, but only products from the main synoptic times (00Z, 06Z, 12Z and 18Z) are currently disseminated in SATOB after manual quality control. The 1.5 hourly wind products have since March 1997 been disseminated in BUFR on a bilateral basis to ECMWF for testing. The ECMWF experience with this product is so positive, that it is planned to turn this product into an operational product. A further reduction of the wind extraction cycle to 1-hour, bringing the schedule inline with MSG baseline, is planned for 1999.

Move winds derivation to synoptic times
To leave enough time for manual quality control, the derivation of the wind products has historically been performed 1 hour before the main synoptic hours, e.g. 12Z products were derived from the three images ending at 10:30Z, 11:00Z and 11:30Z. As all procedures are now fully automated, this is no longer required, and the wind extraction times will be moved to match the synoptic hours. Planned for 1st quarter of 1999.

Better geographical positioning
Presently the extracted winds are positioned at the segment centres, introducing an inaccuracy of up to half a segment size. A better positioning can be obtained by explicit tracer location in the image, and will be investigated.

Better distribution accuracy for wind position information
The SATOB dissemination accuracy is only 1°, which is inadequate for the high-resolution wind products. The accuracy is improved with the BUFR encoding, which indicates the true accuracy of the wind positioning information.

Verification improvements
The verification of the CMW product is currently based exclusively on radiosondes and forecast fields. Use of other data (e.g. AIREP/ASDAR/ACARS) for verification is foreseen.

5. TRANSITION FROM MTP TO MSG

The first MSG spacecraft MSG-1 will be launched in October 2000. The development of the MSG system is very advanced, and the MSG MPEF algorithms are well defined (EUMETSAT, 1998). The MTP wind products development strategy, as detailed above, takes the following issues into account:

The User community requirements will continue to evolve before the start of MSG operations.
The capabilities of the NWP systems to assimilate wind and radiance products asynoptically at increased spatial resolution will continue to grow.

The User community transition to the MSG products baseline should be as smooth as possible.
The unified BUFR template for the wind products, developed for the MTP products, will also be employed in the MSG MPEF system, thus securing minimum user community effort required for the transition to MSG. Also at the end 1999, the MTP system will produce wind products hourly, equivalent to the MSG system.

MSG will benefit from early operational exploitation in MTP of new developments.
There is a significant synergy effect from early implementation of MSG product developments in the MTP system. This applies to areas like the semi-transparency correction, higher resolution WV winds, usage of pixel-level classification in tracer selection and the automatic quality control.

Meteosat-7 has an estimated end-of-life of 2004.
The mission concept for the approved continuation of the MTP programme until the end of 2003 has not been finalised, but a continued derivation of wind and radiance products from Meteosat-7 for the meteorological user community could be envisaged.

6. CONCLUSIONS

The MTP MPEF system will continue to develop the wind products to provide the user community with higher quality wind products, and a clear continuity of service towards the MSG MPEF system will be achieved.

7. REFERENCES

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