OPERATIONAL METEOSAT WIND PRODUCTS TOWARDS MSG

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ABSTRACT

The Operational Meteosat Meteorological Products are produced by the MPEF, a facility in the Meteosat Ground Segment operated by EUMETSAT. The most important MPEF products are the wind products, derived from all three Meteosat channels.

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

The planned development of the products from the current Meteosat satellite is driven by the meteorological community requirements for higher spatial and temporal coverage and for consistent reliability indicators. It is planned to satisfy these needs 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 and associated WV radiance information. 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 services. 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 Indian Ocean Service) 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 Meteosat products

The current range of operational products consists of:

- Cloud Motion winds (CMW)
    - Combined wind product from Infrared, Water Vapor and low resolution Visible images
    - Distributed on GTS 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 on GTS in standard BUFR format every 90 minutes
- Clear Sky WV winds (WVW)
    - Wind product from Water Vapor images in cloud-free areas
    - Distributed on GTS in standard BUFR format every 90 minutes
- High Resolution WV winds (HWW)
    - Wind product from Water Vapor images in cloudy areas
    - 16x16 Pixel target areas, giving higher spatial resolution
    - Distributed on GTS in standard BUFR format every 90 minutes
- High Resolution Visible Winds (HRV)
    - Produced from high resolution Visible images
    - Distributed in GTS in BUFR at 06Z, 09Z, 12Z, 15Z, 18Z (-3 hours for 63°E Service)
    - Parallel distribution in standard BUFR format and in simplified BUFR format.
- Clear Sky Radiances (CSR)
    - WV cloud-cleared radiances, scale 160 km
    - Distributed on GTS in BUFR format hourly
- Upper Tropospheric Humidity (UTH)
    - Distributed on GTS in BUFR at 06Z, 09Z, 12Z, 15Z, 18Z (-3 hours for 63°E Service)
- Sea Surface Temperatures (SST)
    - Distributed on GTS in SATOB at 00Z, 12Z
- Cloud Analysis (CLA)
    - Distributed on GTS in SATOB at 00Z, 06Z, 12Z and 18Z
- Climate Data Set (CDS)
    - Hourly, available from METEOSAT archive
- ISCCP Data Set (IDS)
    - Reduced resolution Image Data for ISCCP
    - 3-hourly, available from METEOSAT archive
- High-resolution Precipitation Index (HPI)
    - 3-hourly IR histograms for GPCP

All products are produced fully automated, with no human intervention. The Manual Quality Control for all METEOSAT products was discontinued on Sep 7 1998. The standard BUFR format contains definitions of quality control parameters and product derivation details and 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:

- Jan 27 1999
    - Introduction of new inversion height assignment scheme
        - Old scheme:
            - Direct temp -> pressure conversion based on IR EBBT
            - Problem: Multi-valued conversion in inversion areas, causing large height assignment errors
        - New scheme:
            - Temperature: unchanged, based on EBBT
            - Pressure: If inversion present at low levels, pressure is set to bottom of inversion layer from forecast profile
        - Impact:
            - Comparison with St. Helena radisondes shows decrease in RMS
            - ECMWF rejection rates in South Atlantic strongly reduced
- July 1 1999
    - Cloud base height re-assignment scheme parameters changed
        - Adjustment of sigma parameter
        - - Limit on downward correction
    - Multi-channel spatial consistency test
        - All channels are used for the spatial consistency, if within 50 hPa
    - Pre-operational distribution of High-Resolution Water Vapour Winds
        - 16x16 pixels target, BUFR, every 90 minutes, cloud-track only
        - Positive feedback from ECMWF regarding product quality
- March 16 2000
    - High Resolution WV Winds fully operational
        - Distributed every 90 minutes in WMO standard BUFR

More information about the MTP products, including schedules, GTS headers, full statistics and full description of the standard BUFR format, can be found on the MPEF WWW pages at www.eumetsat.de/en/area3/topic3.html. These pages will shortly also contain statistics on product volumes and product quality. 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 and is planning the operational assimilation of METEOSAT clear-sky 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 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 METEOSAT products.

An ongoing debate in the NWP community addresses the issue of 4-D assimilation of satellite geophysical products, e.g. winds, vs. direct assimilation of 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.

Other major NWP operators are planning operational implementation of 4-D Var.

4. Development plans

4.1 Pre-processing

Calibration
Based on data collected on the performance of the METEOSAT-7 black-body calibration a new calibration scheme is under development to be based on black-body measurements performed at least twice a day, as well as a simplified front-optics model. This scheme gives promising results, and the new calibration scheme will become operational in May 2000. For METEOSAT-5 a scheme for operational cross-calibration with METEOSAT-7, based on the overlap area, has been developed and will become operational in October 2000.

Improved spatial resolution of forecast data
On Mar 1 1999, the migration of ECMWF forecast data used in MPEF from GRID fields with very coarse horizontal and vertical resolution (3x3 deg, 10 pressure levels), to high-resolution GRIB data (1.5x1.5 deg, model hybrid-sigma levels (currently 50) was completed. The high-resolution forecast data provides very significant improvements in the description of deep low-level trade inversions and together with the new inversion height assignment scheme, this has significantly improved 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, if these become available operationally, 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 developed as part of MSG MPEF, and it is planned to integrate the complete MSG MPEF scenes analysis and semi-transparency correction in MTP MPEF later in 2000.

4.2 Wind products

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 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 best wind 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 80%). For the ELW, HRV, HWW and WVW products, the winds are encoded in BUFR, together with the reliability indicators themselves. All winds down to a low reliability (30%) 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 products are desired:

- Low level coverage around developing tropical systems. The deficient cloud motion-wind coverage in the vicinity of developing and developed tropical disturbances is an important issue for hurricane forecasting.
- 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.
- Clear-sky tracking using cross-correlation is not performing satisfactorily
- Provision of reliability indicators independent of first-guess fields
- Provision of reliability indicators for speed, direction, pressure and temperature

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

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.

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, and an alternative height assignment is also included in the BUFR message, 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 is being 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.

Clear Sky WV tracking
Investigations have shown that tracking in cloud-free areas with the cross-correlation tracking algorithm produces high numbers of spurious fast winds. Investigations are ongoing to assess the impact of using Minimum Euclidean Distance tracking.

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. Initial results are encouraging and this change will be introduced operationally in 2000.

Increased time-frequency of winds distribution
The MPEF distributes winds in BUFR format every 1.5 hours. A further reduction of the wind extraction cycle to 1 hour, made possible by more powerful workstations, will bring the schedule inline with the MSG baseline and is planned for 2000.

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 2000.

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. A very important aim is also to provide quality indicators which are independent of the forecast wind fields. 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. A main goal is to introduce a quality indicator, independent of the first-guess field.

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, as well as quality indicators with and without forecast information. It could 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.

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.

4.3 Other products

80 km clear sky radiances (CSR)
These data are derived on a scale of 16x16 pixels (80 km), i.e. half the scale of the current UTH product, and provide clear-sky equivalent blackbody temperatures and radiances from both WV and IR channels, for 4D-VAR assimilation in NWP models. The product also includes upper tropospheric humidity, the standard deviation of the temperatures within the clear parts of the 80km quadrant, and

the fraction of the quadrant clear and cloudy for every quadrant in the processing area. The method employed is essentially the same as in the current 160km UTH product.

There is quality control information included (percentage confidence) which is currently simply based on a threshold amount of cloud cover for temperature and radiance data, and on a threshold amount of cloud cover and a threshold humidity limit for the upper tropospheric humidity. This scheme has scope for future enhancement by also using the standard deviation of the temperatures to give an indication of cloud contamination, and hence of reduced confidence in the data.

The CSR product has been distributed to ECMWF for testing since Jan 20 1999 and it is planned to introduce the product as fully operational when the new calibration procedures (see above) are operational.

5. Reprocessing

Recognising the increasing interest in the processing of historical image data, EUMETSAT has established a reprocessing environment, directly connected to the METEOSAT archive MARF. During the summer of 1999, 1 year (1996) of visible image data from METEOSAT-5 have been reprocessed to produce a pixel-level surface albedo product, using an algorithm developed at the Space Applications Institute (SAI) at the EU Joint Research Centre, Ispra. The surface albedo product is currently undergoing initial validation and will be presented to beta-testers later in 1999, after which it is planned to make the product generally available.

Starting spring 2000, reprocessing of METEOSAT-2 data (1981-1988) will start to reconstruct the record of cloud motion winds in support of the ECMWF 40 year re-analysis.

6. 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 standard 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 later this year, 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.

Meteosat-5 continues the 63°E service.
An extension of the 63°E service till at least the end of 2001 was approved at the June EUMETSAT Council, and this means that for considerable amount of time there will be an operational MTP spacecraft operating over the Indian Ocean. This in turn means, that the MTP MPEF products and algorithms will have to be operated and maintained in parallel to MSG, and it is therefore envisaged to cross-exploit certain key areas like scenes analysis.

7. 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.

REFERENCES

Buhler, Y. and Holmlund, K., 1994: The CMW Extraction Algorithm for MTP/MPEF, *Proceedings of the Second International Winds Workshop*, Tokyo, 13 -15 Dec 1993. EUM P14, Published by EUMETSAT, D-64294 Darmstadt, 205-217

Elliott, S. S., 1998: The Generation, Quality Control and Distribution of High Resolution Water Vapour Winds from Meteosat Data, *Proceedings of the Ninth Conference on Satellite Meteorology and Oceanography*, Paris, 25-29 May 1998, EUM P 22, Published by EUMETSAT, D-64294 Darmstadt, 353-355

EUMETSAT Seviri Science Plan, , www.eumetsat.de/en/area2/publications/severi_sp270398.pdf , Issue 1 March 98

Holmlund, K, 1996: Normalised Quality Indicators for EUMETSAT Cloud Motion Winds, *Proceedings of the Third International Winds Workshop*, Ascona, 10 –12 June 1996. EUM P18, Published by EUMETSAT, D-64294 Darmstadt, 155-165

Rattenborg , M. and Holmlund, K., 1996: Operational wind products from new Meteosat Ground Segment, *Proceedings of the Third International Winds Workshop*, Ascona, 10 –12 June 1996. EUM P18, Published by EUMETSAT, D-64294 Darmstadt, 53-59

Schmetz, J., Holmlund, K., Hoffman, J., Strauss, B., Mason, B., Gärtner, V., Koch, A. and L. van de Berg, 1993: Operational Cloud-Motion Winds from METEOSAT infrared images; *J. Appl. Meteor.*, **32,** 1206-122