Current System for Extracting Cloud Motion Vectors from Meteosat Multi-Channel Image data

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Abstract

Global observations of atmospheric wind fields are potentially the most important data in the analysis for numerical weather prediction (NWP), with the proviso that the accuracy of the wind observations are always adequate to the steadily improving performance of NWP models.

This paper reports on algorithm changes and improvements to the operational CMWs from METEOSAT that have been made over the last seven years. The improvements are shown by long-term comparisons with collocated radiosondes. In particular the height assignment of a wind vector and radiance filtering techniques preceding the cloud tracking have ameliorated the errors in METEOSAT winds. The slow speed bias of high level CMWs (< 400hPa) in comparison to radiosonde winds has been reduced from about 4 m/s in 1986 to about 1 m/s for a mean wind speed of 24 m/s.

More recently a water vapour (WV) wind retrieval became operational. The results are encouraging and it appears that the high level tracking in the WV channel is superior to the IR window tracking. Research on wind extraction from visible winds indicates another potential for improving the total yield and the quality of winds from motions in satellite images.

A future system could combine the data from all three channels. This will increase the product quality through the enhanced possibility of spatial consistency checks. Consistency checks in time would be possible with the advent of a CMW derivation system that extracts products as often as every 30 minutes.

1. Introduction

Global observations of atmospheric wind fields are potentially the most important data in the analysis for numerical weather prediction (NWP) (e.g. Baker, 1991; Kalnay et al., 1985). Direct wind observations are indispensable at low latitudes where winds cannot be inferred from the mass field. Wind observations from satellites also constitute the sole source of wind data over wide regions of the Southern hemisphere.

To date cloud motion winds (CMWs) are the only satellite-based direct wind retrievals in operational use for numerical weather prediction, although they will be complemented soon by surface wind estimates from passive and active microwave instruments aboard polar orbiting satellites. It is important to realise that CMWs are not a direct measurement of the wind field and, therefore, may possess properties that compromise their use as single level observations of the wind field. Firstly, clouds are not always passive tracers. Secondly, the location of cloud occurrence may be in areas that are not representative for the wind field. Cloud motion may also represent a layer-mean flow rather than a wind vector at a specific level. In spite of those reservations, it has to be accepted for the foreseeable future, that CMWs will be used as a single level vector in NWP. Consequently improvements should principally enhance the usefulness of CMWs as single level wind data.

During the past years all operational data centres producing cloud drift winds have put large efforts to improve the quality of CMWs. Merrill et al. (1991) demonstrated upgrades to the CMWs from the U.S. GOES. Hayden (1992) reports on new ways to improve the quality control of GOES winds with an automatic editing that is based on an objective analysis method (Hayden and Purser, 1988). Improved altitude assignment has considerably improved the winds from the Japanese Himawari satellite (Uchida, 1992). Noteworthy is also the potential of cloud motion winds for climatological studies (e.g. Desbois et al., 1984, Schmetz et al, 1994).

This paper provides a brief overview of the operational methods for extracting windfields from METEOSAT images at the European Space Operations Centre (ESOC). A complete description of the present method for deriving CMWs is given in Schmetz et al (1993) and the current water vapour wind vector (WVWV) extraction method is described in Holmlund (1994). The methods are fully automatic except for a final manual quality control of the CMWs. The main emphasis of this paper is on the quality of the derived vectors and on the impact of modifications to the derivation technique. Furthermore the use of quality indicators will be discussed.

2. Cloud motion winds from METEOSAT images

The geostationary METEOSAT satellites observe the Earth with an imaging radiometer in three channels: in the solar spectrum (VIS) between 0,4 and 1.1 *µm* , in the infrared window region (IR) between 10.5 and 12.5 *µm,* and in the water vapour (WV) absorption band between 5.7 and 7.1*µm*. Images are taken at half hourly intervals and the spatial sampling at the sub-satellite point corresponds to 2.5 km x 2.5 km for the VIS, and 5 km x 5 km in the IR and WV channels.

CMWs and WVWVs are derived four times per day from a triplet of successive images. The visible winds (VISW) are at present derived only once per day from a triplet of VIS imagery data, which has been sampled to the IR resolution. The utilisation of full resolution VIS data for wind extraction is currently under development. The height assignment for CMWs and VISWs is based on the infrared channel, which assigns a equivalent blackbody temperature (EBBT) to the identified cloud top. For semitransparent clouds a bispectral method, utilising the WV channel, is applied (Schmetz et al , 1993). For the WVWVs the infrared EBBT is used whenever high clouds are present. For other areas a scene dependant WV EBBT is computed. This latter derivation scheme takes into account the cloud configuration and uses only the fraction of water vapour pixels, which are colder than the mean cloud temperature. The details on the WV height assignment are presented in Holmlund (1994). Figure 1 presents a typical CMW field disseminated to the users.

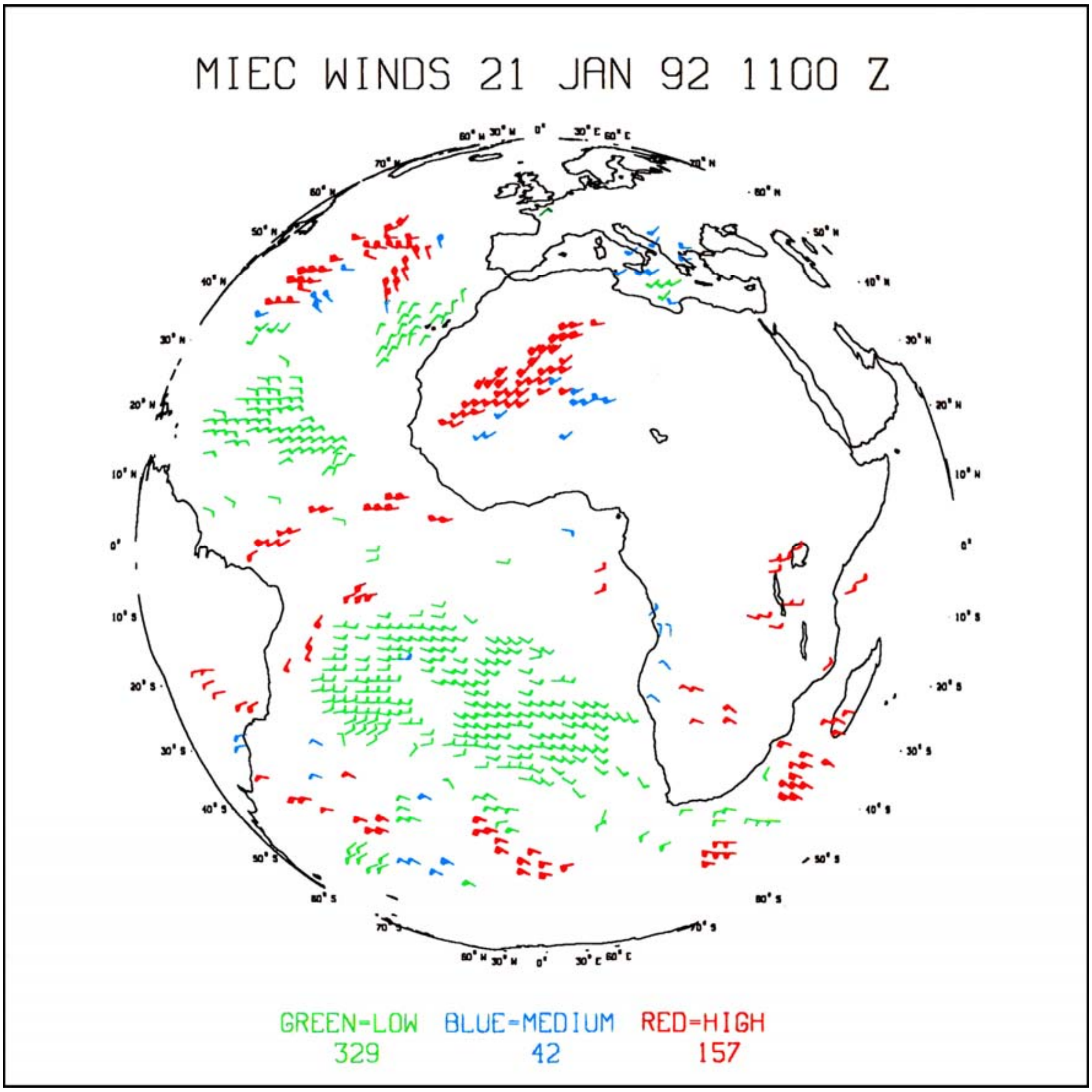

Figure 1. Disseminated CMW field 21 January 1992 11 utc.

More than 500 wind vectors were disseminated on the particular time of Figure 1. Even though many large scale phenomenons can still be detected (e.g. the low level flow in the South Atlantic or the subtropical Jet extending out over the Sahara), large data void areas can also be seen.

3. Monitoring the quality of CMWs and WVWVs

The quality of the disseminated vectorfields is monitored routinely by comparisons with collocated radiosondes where the collocation area extends over 2°x2° and is within a time interval of one hour. Poleward of 20 ° the longitude interval of a collocation box is increased to 3 °. The comparison is conducted on a daily basis with the sonde data received through the Global Telecommunication System. Monthly mean statistics are routinely computed. It is the purpose of this section to, firstly, describe how the CMWs are monitored at ESOC and, secondly, how the accuracy of a CMW can be estimated. The methods discussed will be used for quantifying the improvements to the CMWs due to various changes over recent years. Two quantities are directly derived from a comparison with radiosondes (R/S). The average speed difference is defined as:

$$BIAS \ = <\,!\vec{v}_{CMW}!\,> \ - <\,!\vec{v}_{R/S}!\,> \qquad [1]$$

where < . > denotes a monthly mean and ! . ! is the norm of a wind vector. The second quantity considered for quality monitoring is the monthly mean of RMS vector difference:

$$\sigma_{CMW,R/S} \ = < [(\Delta u)^2 + (\Delta v)^2] >^{1/2} \qquad [2]$$

where:

$$(\Delta u)^2 = \sum_{i=1}^{N}(u_i^{CMW} - u_i^{R/S})^2 \quad , \quad (\Delta v)^2 = \sum_{i=1}^{N}(v_i^{CMW} - v_i^{R/S})^2$$

N is the number of collocations in a month, *u* and *v* are the zonal and meridional wind components of a wind vector.

Figure 2 presents the monthly mean statistics for the CMWs and WVWVs.

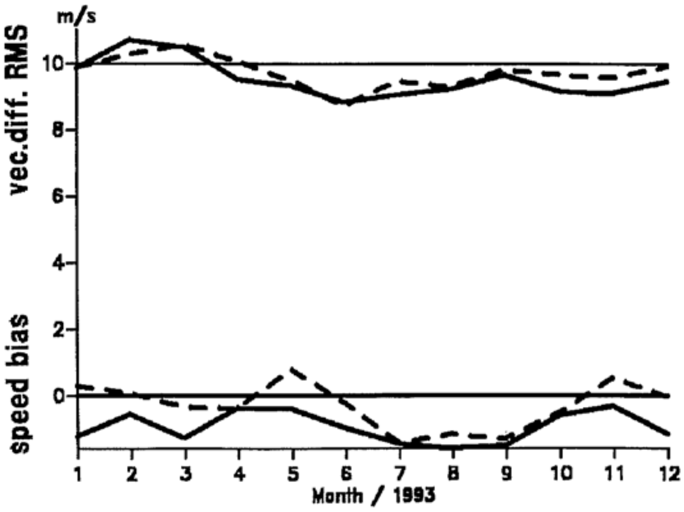

Figure 2. Monthly mean speed bias and vector difference RMS as derived from comparisons against radiosondes for high level CMWs (solid line) and WVWVs (dotted line) during 1993.

Assuming that a radiosonde provides an unbiased measure of wind velocity, Equation 1 defines the mean velocity bias inherent in CMWs. $\sigma_{CMW,R/S}$ in Equation 2 is only a relative measure of the CMW error, because it encompasses the error of the radiosonde measurement and the differences due to separation in both time and space. The representativeness error due to the different nature of both wind measurements, i.e. CMWs rather being a volume average, will be considered as part of the CMW error. This appears justified since CMWs are simply used as single level wind for NWP, although it is recognised that the representativeness error in some cases may dominate the total CMW error.

The CMW 'true' RMS error (σ_{CMW}) was estimated by Schmetz et al (1993) with

$$\sigma_{CMW}{}^2 = \sigma_{CMW,RS}{}^2 - \sigma_t{}^2 - \sigma_d{}^2 \quad [3]$$

where $\sigma_{CMW,RS}$ is the RMS vector difference between radiosonde and CMW, σ_t and σ_d are the vector differences associated with the separation in both horizontal space and time, respectively. σ_t and σ_d were estimated according to table 1.

Table 1: Root mean square differences between measurements of vector wind separated by about 100 km distance and 1 hour time interval, respectively (estimated from Kitchen, 1989). The values are used for estimating the RMS error of the CMWs from the RMS differences versus collocated radiosondes.

Cloud level	RMS difference due to distance separation	RMS difference due to time separation
High	6 - 7 m/s	4 m/s
Medium	5 m/s	3 m/s
Low	4 m/s	2 m/s

In order to compare different time periods with each other one has to normalise the data. Schmetz et al (1993) noted a clear linear relationship between the vector RMS difference and the R/S speed. As the quality of the CMWs are improving this linear dependance is not as pronounced as before. This could indicate that the differences in scales and nature, the R/S being a point and CMWs a time averaged volume measurement, are becoming increasingly important. Furthermore it can be expected that the CMW quality varies with the weather situation and hence the linear regression could be different for different weather types. For the purpose of this paper the assumption of a linear relationship between the RMS error and the R/S speed has been kept, but the above considerations have to be kept in mind when interpreting the results. The regression was computed for the different periods between significant modifications of the code.

Figure 3-5 presents the evolution of the quality of the CMWs for different time periods and different levels. The values in the figure are derived using the regression derived for the different time periods. The estimations are based on a mean radiosonde speed of 24 m/s.

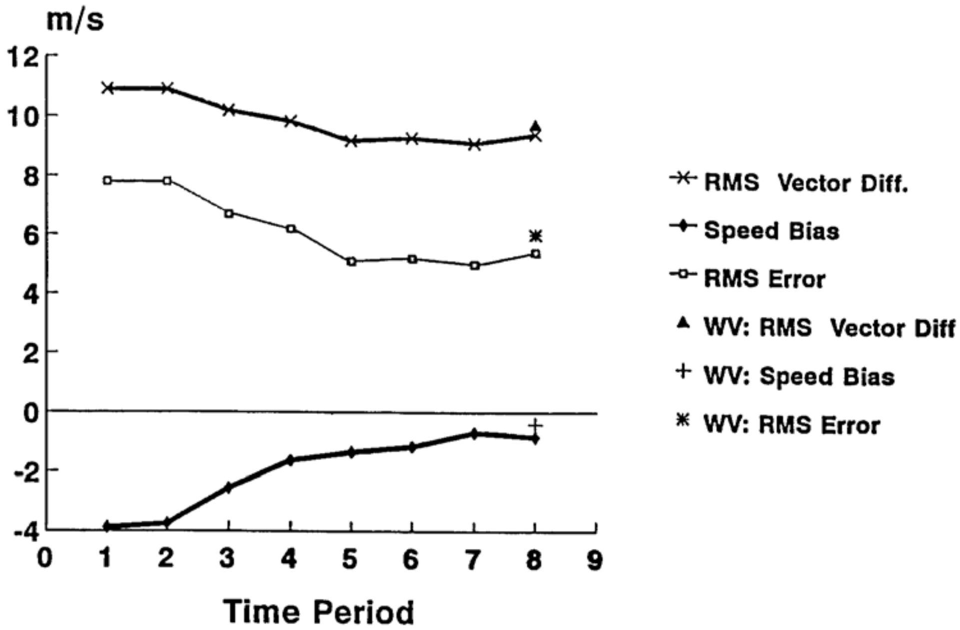

Figure 3. The high level CMW quality for different time periods separated by major modifications to the derivation scheme. The reference R/S speed is 24 m/s. The high level WVWV quality is also indicated.

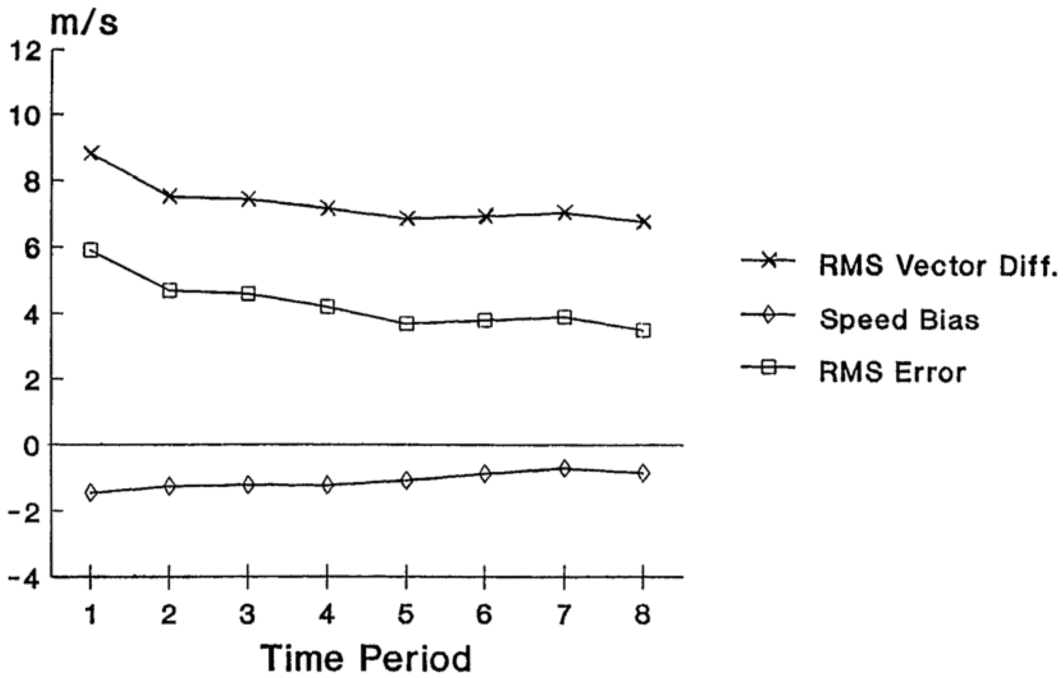

Figure 4. Same as figure 3, but for medium level CMWs.

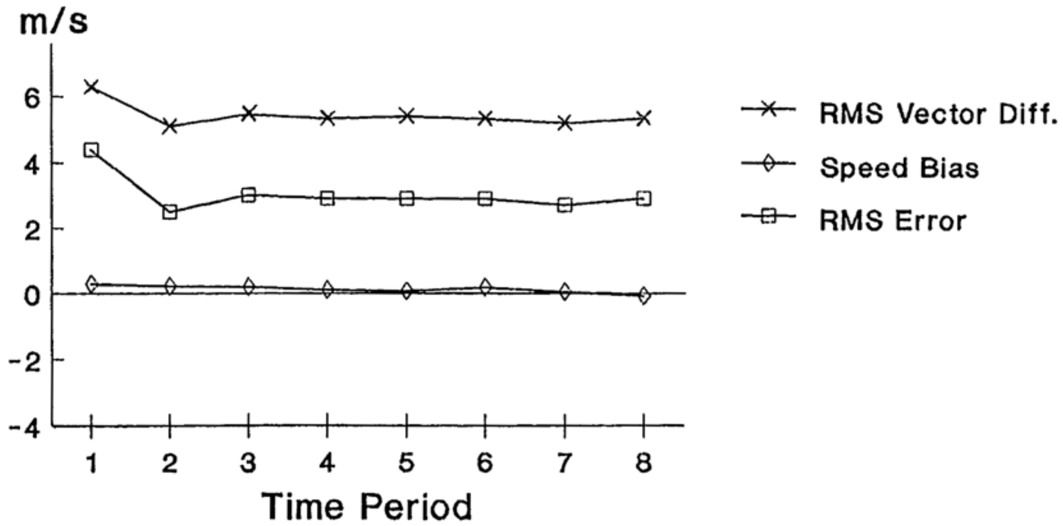

Figure 5. Same as figure 3, but for low level CMWs.

A intensive discussion related to the modifications is presented in Schmetz et al (1993). The largest impacts on high level winds came from a new method for calibrating the WV channel (September 1987) and from using a guided cross correlation method (March 1989). The medium level winds have experienced small but constant improvements, whereas the low level winds only improved through the decoupling of tracking and height assignment (March 1987). It is also interesting to note that the last modifications to the retrieval scheme have not brought any significant changes to the statistics. These modifications have been related to various areas of the retrieval scheme (automatic quality control, tracer identification and image filtering) and have mainly affected some extreme outlayers and hence the small impact in the overall statistics. It has also to be noted, that the present CMW derivation scheme is highly tuned, i.e. there are several feedback mechanisms which can compensate for errors created in other areas of the retrieval scheme. As an example one can mention the height assignment. The present height assignment method attempts to derive the EBBT of the cloud top. Through some artifacts in the retrieval method the height tends to be too low. On the average this is acceptable as the high level winds tend to travel more with a speed related to the mean cloud height than the top. An improvement in the height assignment scheme does therefore not automatically bring an improvement in the

CMW statistics. This implies that any modifications to the CMW method have to be thoroughly assessed before implementation.

The quality of the present WVWVs can be assessed with figure 3, where the WVWV quality has been included. It can be noted that the RMS error is slighly larger than the present CMW RMS error, but the bias is simultaneously better. The WVWV quality control does not include comparisons against forecast fields and there is also no manual intervention. It can be concluded that the WVWVs are of an equivalent quality as the CMWs.

4. Quality indicators

The large data void areas as well as the relatively small number of high level winds presented in Figure 1 are related to the present quality control method. Each vector has to pass several test (including manual quality control for CMWs), before acceptance. The original wind fields contain an extremely large amount of data which at large is useful. Figures 6-8 presents for the same situation as in figure 1, the complete vectorfields derived in the three spectral bands (IR, WV and VIS).

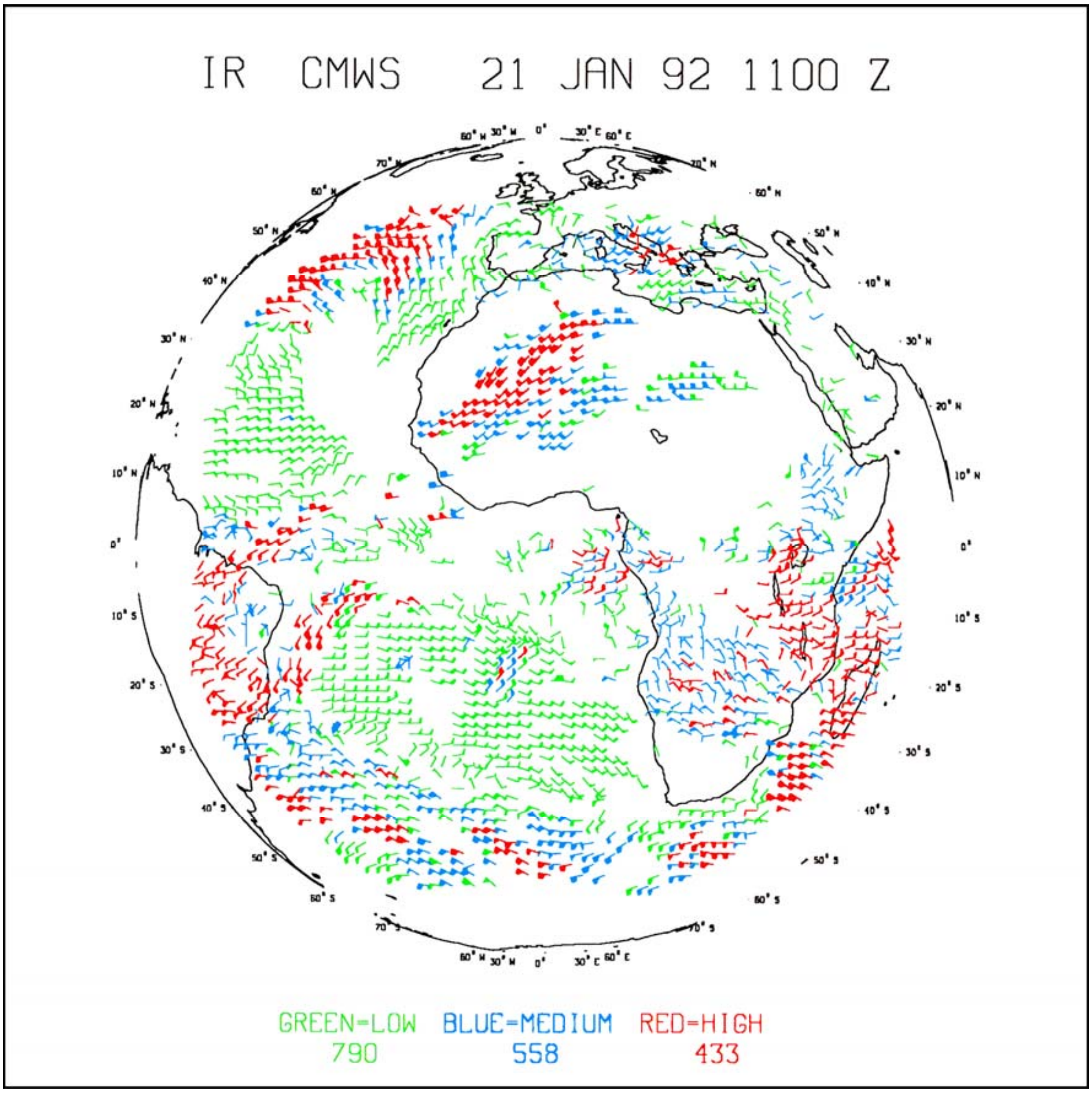

Figure 6. The complete CMW field before any quality control.

A comparison of the three different fields reveal that each of the fields have advantages. The WVWV gives the best high level coverage, whereas the VISW gives a good description of the low level flow over the oceans during day time. The mid troposhperic flow is best depicted by the CMWS. The different methods are also limited by their height assignment. The WVWV height assignment is at present reliable only for high level winds, whereas for VISWs the use of IR EBBT works fine mainly for low level clouds. With the wealth of information provided by these fields the

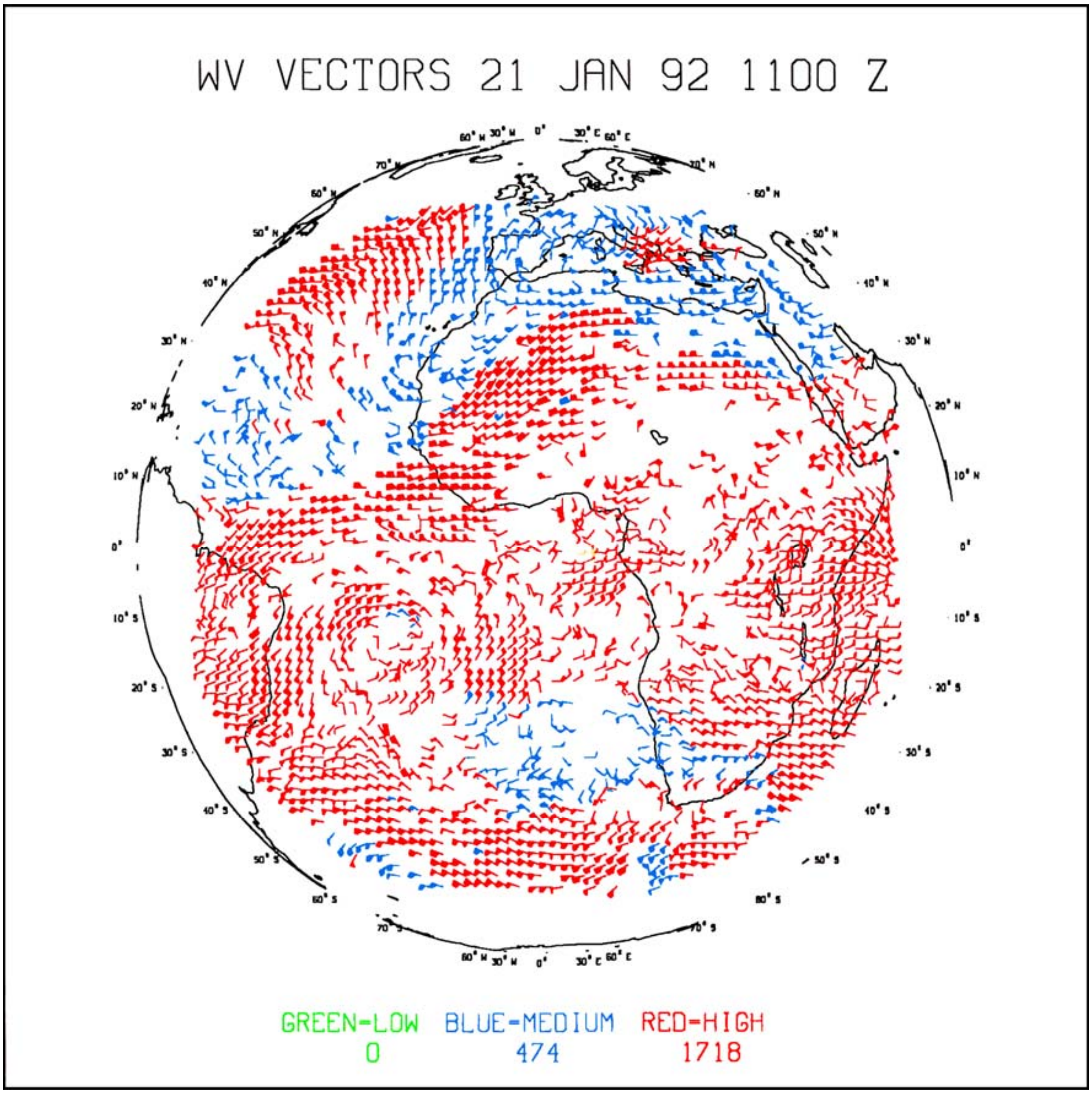

Figure 7. The complete WVWV field before any quality control.

importance of quality control is enhanced. As the capabilities of the new assimilation schemes of NWP is increasing, the possibility to use data at a high spatial and temporal frequency is also increasing. Simultaneously the present quality control does not seem to be adequate, as a large amount of useful information is removed. At present a new QC concept is being developed at ESOC. This QC scheme will assign for each vector a quality indicator, which will be a combination several separate test results. This indicator could then be used to assimilate the vector in the NWP with an appropriate weight. In order to validate this concept ESOC is performing together with ECMWF a validation campaign where WVWVs are disseminated with a related quality indicator (Holmlund, 1994).

Another further expansion to the present derivation technique is the utilisation of high resolution VIS data for tracking. The first results show that it is possible to extract good displacement vectors at a higher horizontal resolution. The main problem at present is the height assignment, which at ESOC is generally related to the segments. As the high resolution data can produce results on a finer scale than a segment the use of the segment information for the height assignment can in certain unhomogeneous areas cause problems. It is however foreseen that most of these problems can be solved with appropriate quality control and therefore the high resolution data will potentially be the main source for day time low level winds.

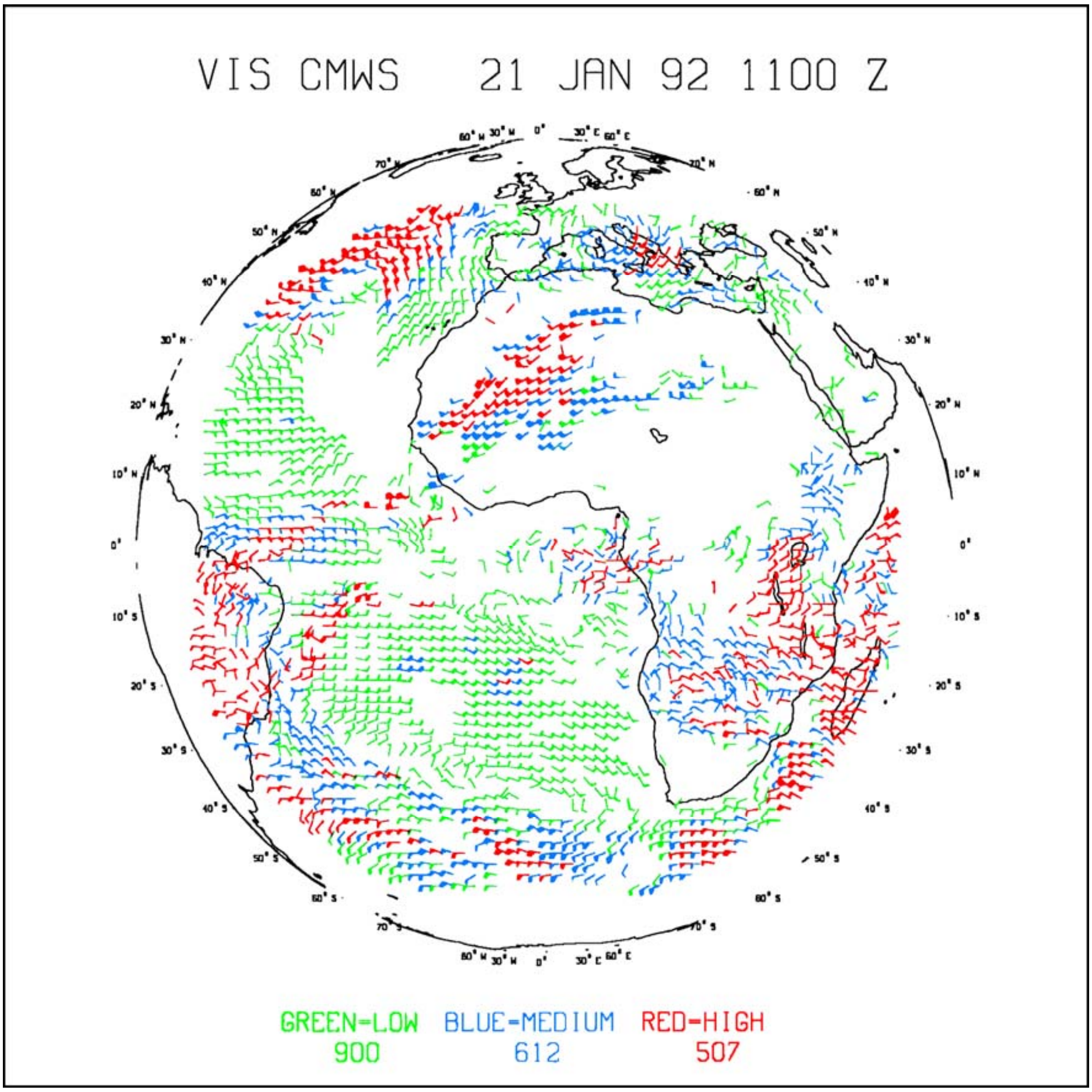

Figure 8. The complete VISW field before any quality control.

5. Discussion and conclusions

Winds estimated from the tracking of clouds in successive satellite images have been used for the global analysis of numerical weather prediction (NWP) models for more than a decade. The recent research and development of the CMW product has reversed a trend where the CMWs had been found less beneficial for Northern hemisphere forecasts (Thoss, 1992). In particular the operational winds from METEOSAT are considered as a very useful data source at all latitudes. An important general conclusion is that research and development work on satellite products should be a continuous effort in order to keep abreast with the advances on the user side.

This paper has summarised the advances of the operational CMW retrieval from METEOSAT IR images at ESOC. Between August 1987 and March 1990 the speed bias of high level CMWs (< 400 hPa) versus radiosondes within a 2 ° by 2 ° collocation box has been diminished from about 4 m/s to 1.3 m/s for a mean radiosonde speed of 24 m/s. At the same time the vector error decreased from 7.8 m/s to about 5 m/s. Improvements for the medium level CMW vector error were from 6.0 m/s to 3.6 m/s at a wind speed of 15 m/s. Low level CMW errors decreased from 4.1 m/s to 2.7 m/s at a reference speed of 10 m/s.

The improvements have been achieved through different changes to the CMW algorithm. Specifically, two changes improved screening the highest cloud level for the tracking which in turn improved the height allocation of the cloud tracer. The use of a forecast for the tracking by automatic cross-correlation reduced the slow speed bias of CMWs, since the previous tracking invariably stopped at the first local correlation maximum obtained in a strategy search that started at zero-displacement. A new calibration of the METEOSAT 6.3 *μm* channel also improved the height assignment of displacement vectors through the altitude correction for semi-transparent and broken clouds.

The work on CMWs was particularly successful in improving the height assignment either directly through the semi-transparency/ broken cloud correction or indirectly through a better definition of the height range of a tracer. Consequently future work will also focus on an improved concept for height assignment. Current research work at ESOC also addresses the definition of quality flags for individual cloud motion vectors and better quality control (Holmlund, 1992). The use of quality flags would enhance the information content of the product for NWP analyses as lower error characteristics could be given to the high quality CMWs, thus increasing their impact in the analyses.

The use of quality indicator will become increasingly important when tracking is performed in several spectral channels simultaneously and at a high temporal frequency. This indicators could be used not only to select the most representative vector for a certain area, but could also be disseminated with each vector for further use in NWP assimilation schemes.

It also has to recognised that the windfields derived from geostationary satellite data are not only used for NWP. It is therefore increasingly important to make all the data, again with appropriate quality indicators, available for users within the climatological or synoptical community.

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