EXPERIMENTS WITH ATMOSPHERIC MOTION VECTORS AT ECMWF

M. Rohn, G. Kelly, R. Saunders

European Centre for Medium Range Weather Forecasts
Shinfield Park, Reading, RG2 9AX, UK

ABSTRACT

Two new developments in extracting wind information by tracking of clouds or water vapour features are increasing the spatial coverage and providing quality estimates for individual observations. The transition from low density to high density wind observations of both GOES satellites led to first experiences with increased spatial coverage in NWP centres. The relative impact of low density and high density wind observations on the ECMWF assimilation and forecast system was tested. The rms vector difference against the background of the high density data is increased by up to 20 % for high level winds where the number of observations has increased by one order of magnitude. An initial negative forecast impact in the Northern Hemisphere was removed by introducing a thinning step for SATOB data as part of the observation screening. High density winds from GMS and GOES 9 during the NORPEX field study reveal potential for forecast improvements but confirms the complications with increased coverage. Secondly the monitoring of experimental Meteosat 7 wind products indicates the usefulness of the MPEF Quality Indicator (QI). The observation screening of SATOB winds was extended using this quality indicator as an additional selection criterium. Application of this approach leads to improvement for the NORPEX study.

1. INTRODUCTION

During the Third International Winds Workshop in 1996 activities suggested by the CGMS Working Group on Cloud Motion Winds were discussed. Two items were:

1. *Generation of wind products with improved temporal and spatial resolution.*
2. *Developing methods to assign "quality flags" to individual winds.*

In March 1998 the GOES wind data was replaced by a high density data set. An overlap of time low and high density GOES winds simultaneously transmitted on the GTS allowed a comparison of both observation sets on the ECMWF assimilation and forecast system. The statistics of rms background departures reveal the high density observations are of good quality. The smaller processing segments in the wind extraction is capable of providing enhanced information. However, a degradation of the short and medium range forecast in the Northern Hemisphere was observed. The situation was improved by the introduction of a thinning of SATOB data. This implementation will be described and the effect on the data usage will be discussed. However, the question arises why the development of a data set towards enhanced information content while maintaining the quality can have a detrimental effect. Various aspects of the extraction scheme point to spatial correlated error of cloud and WV tracked winds.

Experimental wind products from Meteosat-7 are currently received at ECMWF for evaluation. The main differences between this data set and the Cloud Motion Winds (CMW) used operationally from Meteosat are the 90 minute sampling, the additional clear sky WV winds, and the transmission of winds including the MPEF quality indicator (QI) and the final decision of the automatic quality control scheme as an additional flag value. The monitoring of the distribution of background departures of different wind channels versus the assigned QI "confidence" reveals the value of the QI for screening decisions. The thinning step for SATOB has been extended using this quality estimate which allows the wind to be chosen with the highest QI value.

In a collaboration between CIMSS and EUMETSAT the high density winds from GMS and GOES-9 extracted during the NORPEX field study were reprocessed employing the quality control of the Meteorological Production Extraction Facility (MPEF) used at EUMETSAT prior to the GOES wind editor. The application of this approach on the NORPEX study together with screening decisions based on the MPEF quality indicator in the assimilation shows improvement compared to the original data set.

The operational use of SATOB products at ECMWF will be outlined in the paper by Lalaurette and Garcia during this workshop.

2. HIGH DENSITY GOES WINDS

The scheme used at NESDIS to derive vector information from sequences of GOES-8 and GOES-9 images was updated (Nieman *et al.*, 1997). The main difference is the smaller processing segment used in the tracer selection and height assignment steps leading to an increased resolution of the extraction process. The segment size currently in use for GOES wind extraction corresponds to ca. 60 km or 0.5° resolution. Over a limited period both the low and high density wind data from GOES were available on the GTS. During a two weeks period from 6 to 19 February 98 the relative impact of these observations were tested by assimilating the high density observations in an experiment and comparing to the operational suite. The low density GOES data were entirely blacklisted and replaced by the high density set. Note that the GOES winds on the GTS also include Picture Triplet winds at 900 hPa on a 2.5° grid which have not been changed. These observations were used in operations but not used in the experiment.

2.1 Data coverage, quality, and forecast impact

The mean bias and rms of background and analysis departures together with the vertical distribution of the active observations are given for both the experiment and the operational suite in Figure 1. The increase in number of observations is different depending on the tropospheric level. A careful comparison of these numbers requires further information:

- Initially the production/transmission of the 'new' winds was very unstable. This was partly due to technical problems in encoding the observations on the GTS. This means that the conventional data stream often provided data whereas the theoretical high density product was simply missing.
- Additionally, the Picture Triplet (PT) winds continued to be transmitted after the conventional data was switched off. The picture triplet winds were not used in the experiment.

Keeping in mind these complications in the GOES wind transmission the differences in coverage can be summarized as follows:

- Largest differences up to a factor ten occurred at high levels (100 - 300 hPa) where traditionally the most cloud tracked winds are produced.
- At mid level the number of observations is increased by a factor of two.
- At 700 hPa the coverage is increased by a factor of three.

- Coverage around 850 hPa is similar to the operational run. The lack of the PT winds in the experimental setup explains the small difference at 850 hPa where the operational setup is using the conventional IR winds including the separate PT winds.
- In the lowest layer below 925 hPa almost no winds are available. It is possible that a smaller processing segment reduces the averaging of cloud top temperature with partly cloudy or cloud free pixel surrounding the tracer. A lower brightness temperature consequently leads to the assignment of cloud motion to higher levels.

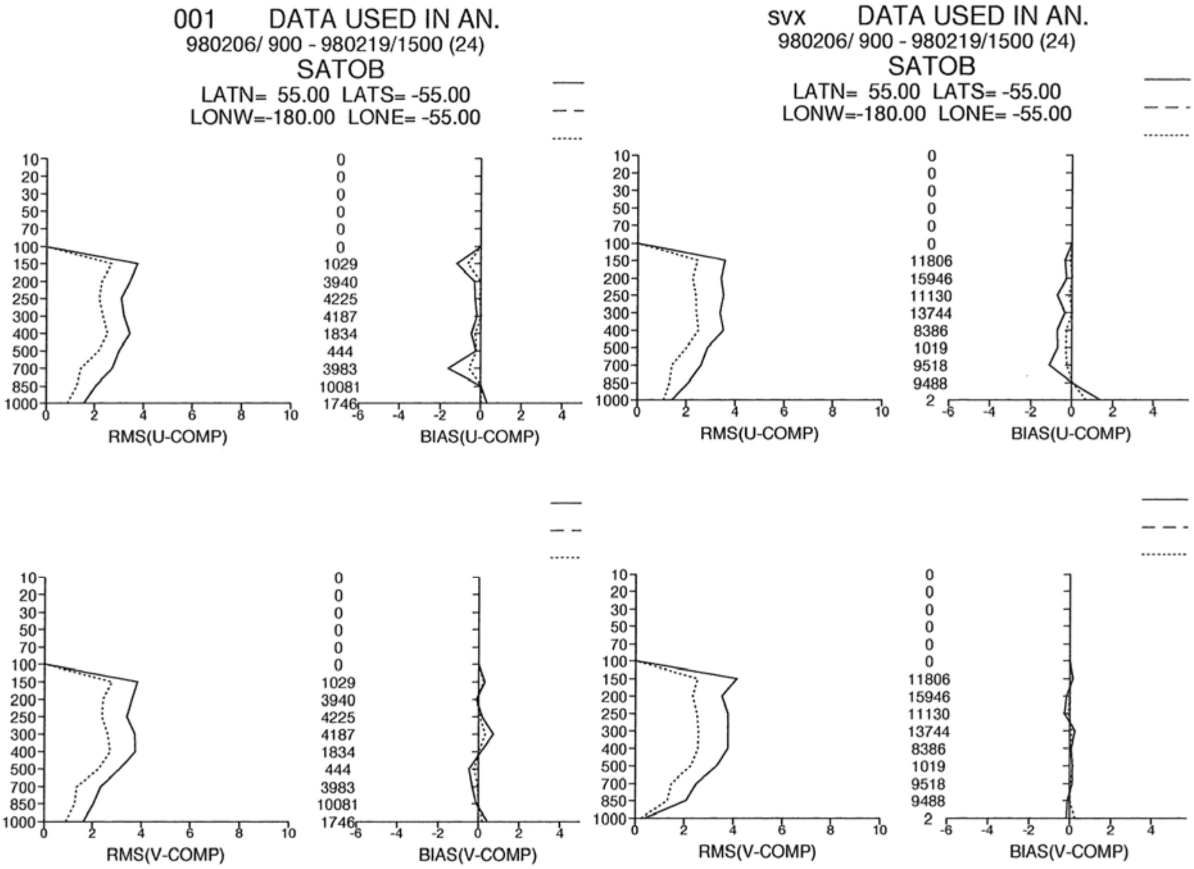

Figure 1: Comparison of the statistics of active SATOB data during the experiment using high density GOES winds (right column) and low density data in the operational suite (left column). The statistic is restricted to the area which is directly influenced by GOES observations. The solid line marks the fit to the background while dashed indicates the fit to the analysis.

The vertical distribution of rms departures from the background (solid) and analysis (dashed) show similar characteristics for operational and high density GOES winds. The vertical structure of rms differences are almost identical with an increase of 10 % between 275 and 225 hPa. This can be expected by a dataset representing more structure in the wind field. This increase is confirmed by comparing rms background departures before and after the transition to the high density data (ECMWF 1997 and 1998). Generally, the increased coverage is not equally distributed in the vertical and horizontal since it still relies on the same tracers (cloud or water vapour) to be tracked as before the transition. The number of observations are most increased in areas with high clouds where the coverage is also best in the old data set. In the data sparse vertical domain at mid tropospheric levels the number of observations is increased by a factor of 2-3.

The improved resolution is demonstrated in Figure 2. showing GOES winds between 250 hPa and 350 hPa for both the conventional (black) and high density (red) data set. The new observations are capable of providing a more complete representaton of the flow (over the East coast of South

America for instance) or even providing new information (e.g. the cyclonic pattern in the South Pacific).

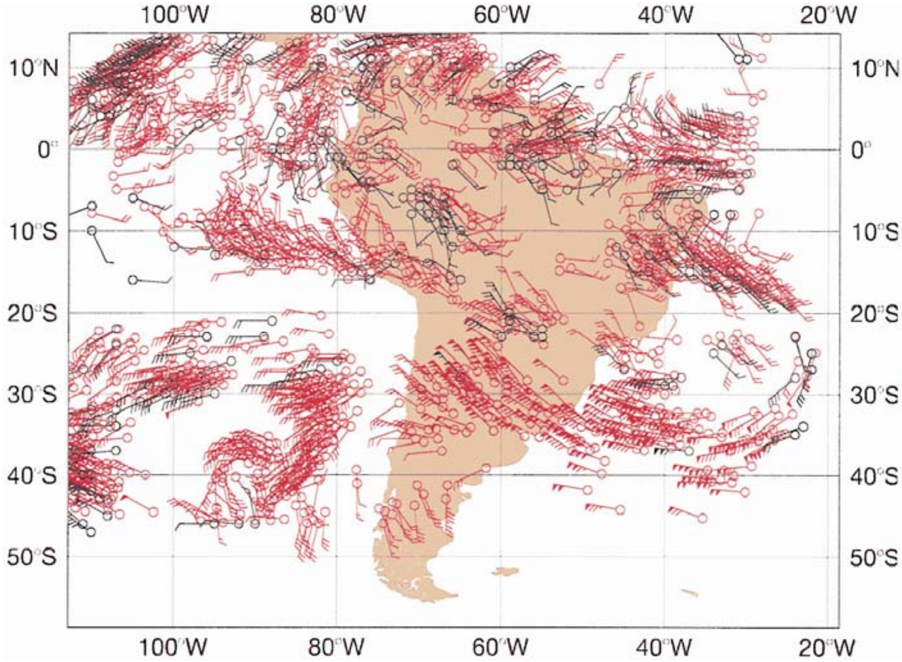

Figure 2: Example of GOES cloud and water vapour tracked winds at different resolutions for February 10, 1998 at 00z. The high density (red) and low density observations (black) are given between 200 and 400 hPa. It illustrates the large increase in areas with good conventional coverage. The finer resolution of the extraction scheme also provides new information around 30ºS - 40ºS.

The verification of 200 hPa vector wind forecast error showed slightly negative impact in the Northern Hemisphere, neutral in Tropics and positive in the Southern Hemisphere. The forecast error differences at 850 hPa lead to the same conclusion. Initially, with the replacement of the operational product by the high density winds on March 2nd 1998 the decision was taken not to use the GOES winds north of 20° North.

2.2 Discussion of complications

Generally, increasing the spatial coverage of satellite winds does not change the basic approach. Cloud features of imagery taken in the IR window channel (IR) or patterns observed in the strong water vapour absorption band (WV) are tracked using a pixel matching. Possible error sources in the extraction are:

1. Aperture problem: The extraction of cloud and WV tracked winds is based on the assumption that the displaced features are conserved within the image sequence. This can be expressed by an advection equation for the pixel grey values g(x,y,t) representing the received radiation by the radiometer.

$$\frac{d}{dt}g(x,y,t) = \frac{\partial}{\partial t}g(x,y,t) + \underline{u}\nabla g(x,y,t) = 0$$

The time sequence of images allows only to determine the flow parallel to the image gradient or perpendicular to any structures within the image.

$$\underline{u}_{\perp} = -\left(\frac{\partial g}{\partial t}\right)/(\nabla g).\frac{\nabla g}{|\nabla g|}$$

This is known as aperture problem in image processing (Jaehne, 1989) which leads most likely to uncertainty along 'edges' within the image. This can be expected to be of particular importance for the processing of meteorological imagery in the case of tracking along elongated cloud or WV features in Jet stream areas.

2. Height assignment: The comparison of the equivalent blackbody temperature of the tracer to a 12 or 24 hour forecast temperature profile leads to an initial height assignment. A bias in the FC profile can be expected to affect the height assignment of neighbouring vectors in a systematic way. The semitransparency correction also involves the radiative transfer calculations of expected radiances for opaque clouds at different levels using a 12 or 24 hour forecast profile.
3. GOES wind autoeditor: In the case of GOES winds, pressure and speed (only if p < 400 hPa) are adjusted according to the 12 hour forecast field from the NCEP Aviation model (Velden *et al.,* 1998). Possible differences between different models come into play when assimilating these winds into the ECMWF system.

All these error sources can be expected to produce spatially correlated observation errors. This issue appears to be of crucial importance in the case of increased spatial resolution.

3. SATOB THINNING

Possible solutions in the case of spatial correlated errors are:

- “Super-obbing”: Averaging neighbouring observations and accounting for the higher number of observations by decreasing the observation error.
- The explicit consideration of spatial correlation which requires knowledge about the nature of the correlation.
- Thinning

Since the case of the high density winds required an immediate reaction was the option of thinning was accepted.

3.1 Implementation

A thinning scheme has been adopted which is used in the ECMWF system also for AIREP, SYNOP, TOYS, and SSMI data. A difference in the thinning for SATOBs compared to other observation types is that several SATOB observations can coincide at a particular location at similar levels. Possible reasons are the tracking of winds using different radiometric channels like IR and WY at high levels or IR and VIS at low levels. Also the viewing angles of different geostationary platforms are overlapping in some areas, for example Meteosat and GOES-8 over the Atlantic and GOES-9 and GMS over the Pacific. Since July 2nd 1998, Meteosat-7 and Meteosat-5 also cover a common area between 8° and 55° East.

All SATOB observations that have passed background quality control are assigned with an index referring to equally sized geographical boxes (1.25° x 1.25°) with vertical extent confined between the standard pressure levels (50-175 hPa). After sorting with respect to a quality indicator all but one observation within a box are rejected. This indicator takes into account the time difference between observation and analysis and chooses the data closest to the analysis time. The entire thinning is performed in two steps using increasing box sizes.

3.2 Influence on SATOB screening and forecast impact

Based on the observed problems described above the additional thinning step for SATOB data was tested simultaneously with the replacement of the GOES satellite winds on the GTS. The influence of the SATOB thinning is discussed based on the average statistics for the 12 UTC cycle over the entire period. High levels (l00 - 350 hPa) are mostly affected (reduction between 50 to 75 %) due to the high number of suitable tracers for cloud tracking along the jet streams. Between 350 and 600 hPa the number of active data is decreased by 20 - 35 %. At low levels 50 % of the observations are used. Note that at low levels very dense cloud tracked winds are also provided

from the Meteosat VIS images.
The verification showed a positive impact by reduced vector wind forecast errors in the Northern Hemisphere. The Tropical and Southern Hemispheric verification was neutral. With the operational implementation of the SATOB thinning step the usage of GOES winds was extended again to the Northern Hemisphere. This is of particular importance since periods of poor forecast performance over Europe in 1998 could be traced back to the lack of GOES data over the North Pacific (Rohn and Grazzini, 1998).

4. MPEF QUALITY INDICATOR

An essential feature of new wind products from Meteosat are quality indicators appended to each single wind. The MPEF automatic quality control scheme computes a quality indicator (QI) based on the consistency of the resulting vector fields with their neighbours and against the 12 or 24 ECMWF forecast (Holmlund, 1997). The operational MPEF wind product contains only winds passing the AQC threshold of currently QI > 0.8. Experimental MPEF winds are currently assessed at ECMWF which includes all observations down to an estimated quality of QI = 0.3.

4.1 Information content

The performance of the MPEF quality indicator (QI) for Meteosat is evaluated according to the verification of the MPEF QI at EUMETSAT. Winds are sorted in bins of assigned quality. For each bin rms vector departure and bias compared to the ECMWF analysis or background wind field are computed. Additionally the mean speed for each quality interval is computed separately. The distribution of rms wind vector departure and bias against ECMWF analyses is shown in Figure 3.

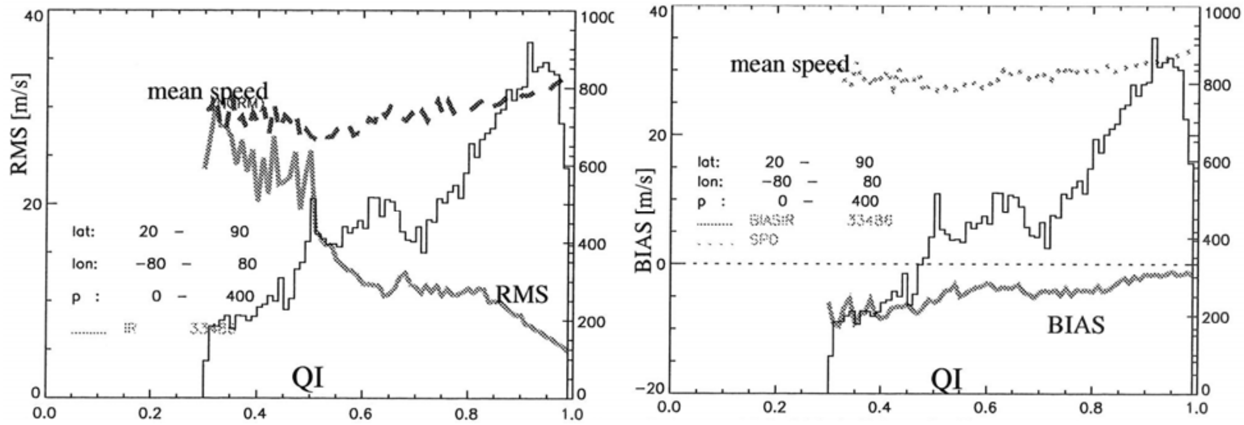

Figure 3: Monitoring of MPEF QI for high level (p < 400 hPa) IR winds over the Northern Hemisphere from Meteosat 6 between 1 to 14 March 98. The left panel shows the rms analysis departures while the right panel gives the bias against the analysis wind field. Also plotted are the mean analysis wind speed in each QI class. The number of observations within QI bins is given by the histogram.

The MPEF QI is capable of providing an indication of the quality of wind observations. The rms departure and bias are decreasing with increasing QI while the mean wind speed increases. Hence, the usage of the MPEF quality indicator appears to be useful for screening decisions in an assimilation system.
The first attempt to use the quality information is to lower the acceptance level winds below the operational value of 0.8 currently used within the MPEF quality control. Additionally the QI values can be used for the selection of active winds as part of the SATOB thinning described earlier. Suitable thresholds for Meteosat -5 and -7 data depending on channel, tropospheric layer, and geographical area are currently under investigation.

4.2 Application to NORPEX data set

During the NORPEX campaign satellite winds from both GMS and GOES-9 were extracted by the Cooperative Institute of Meteorological Satellite Studies (CIMSS). In contrast to the operationally available GOES winds these were also derived from 1 km GOES VIS imagery. GOES-9 winds were provided in 3 hour intervals. The data was assimilated within a 4DVar experiment at ECMWF. The positive impact for North America seen in the assimilation of NORPEX winds in the NRL NOGAPS model (personal communication by C. Velden, 1998) could be confirmed. However, Tropical verification as well as the verification for Europe showed a negative impact. The results are not fully understood but the detrimental effect could be caused by incorrectly represented observation error characteristics as discussed earlier. For the NORPEX dataset the very dense observations from VIS imagery could be particularly sensitive to correlated errors. A systematic pattern of wind speed differences between the control and NORPEX run over the North Pacific appears to confirm this problem. However, selected synoptic cases show the potential for forecast improvement by increased coverage.

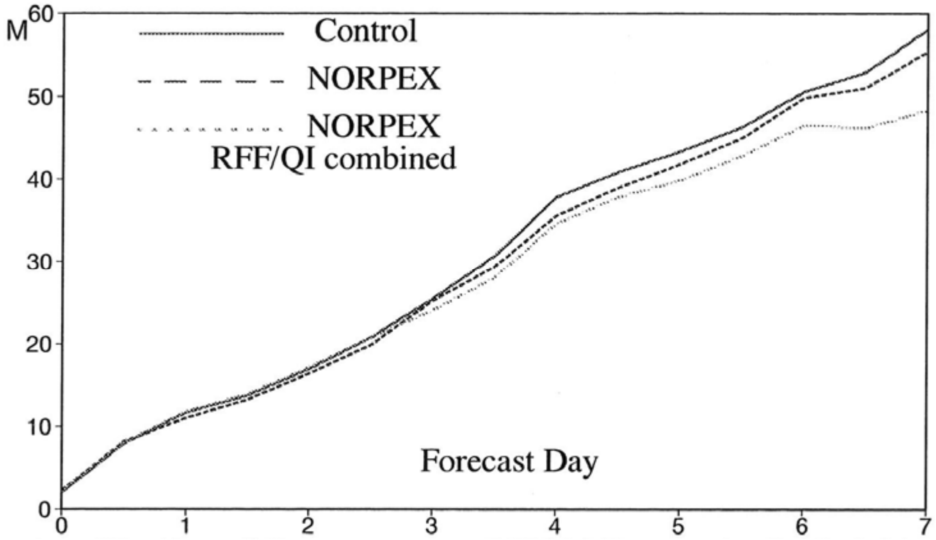

Figure 4: Forecast verification of the rms error of 1000 hPa geopotential height over the North America for the period from 25 January to 7 February 98.

The wind data from GMS and GOES9 during the NORPEX field study were reprocessed by a collaboration between CIMSS and EUMETSAT. The tracked winds passed the MPEF quality control scheme prior to the operational GOES wind post processing. Only observations with assigned quality above QI = 0.6 were accepted and further processed by the GOES wind editor (Velden *et al.*, 1998). The resulting wind data were assimilated over a two week period between 25 February and 7 March 98. Additionally, the assigned MPEF quality value was used as a selection criterium within the thinning process. Generally, the acceptance threshold was more strict in the Tropics (QI = 0.85) and relaxed in the Northern Hemisphere between QI=0.60 to 0.70 depending on channel (IR,VIS,WV) and tropospheric layer. This combination of the MPEF quality control and prescreening according to the QI gives the best results:

- The rms forecast error of the 100 hPa and 500 hPa geopotential height were further decreased (Figure 4.).
- The Tropical verification of 850 hPa wind vector error indicated problems with the original NORPEX data. This problem appears to be removed by the combined RFF/QI approach and using a strict QI threshold in the Tropics.
- The verification over Europe also indicates problems with the NORPEX data which could be corrected but not entirely removed by the QI screening.
- The potential for forecast improvement in selected synoptic situation could be seen.

These results are preliminary but encouraging for the combination of the enhanced GOES observations with the MPEF quality control which enables the selection of observations within the assimilation system according to assigned confidence. However, the problems with inappropriate representation of observation errors have to be corrected within the assimilation system.

5. CONCLUSION

The transition at NESDIS from a low density to high density SATOB data set from both GOES satellites intially led to complications in the ECMWF forecast system especially in the Northern Hemisphere. An additional thinning step as part of the observation screening improved the situation and allowed the new GOES winds to be assimilated in the Northern Hemisphere. This is of particular importance over the North Pacific where other data sources are sparse.

Generally, SATOB observations provide a spatially inhomogeneous data set according to the distribution of suitable cloud tracers. Different geostationary platforms with similar radiometers have overlapping viewing geometry and hence provide redundant information from similar radiometric channels. Different radiometric channels provide similar wind information, e.g. by tracking high level clouds in IR and WV or low level clouds in IR and VIS images. Based on the nature of this data type the thinning of SATOB's is a very appropriate means of adjusting the data use to the resolution of the assimilation, to reduce the differences between data rich and poor areas, and to remove redundant observations.

The MPEF quality control scheme appears to be a useful start in assigning quality indicators to single observations. The usage of this QI value for screening purposes within the NORPEX study has a positive impact on the forecast compared to the usage of the original full NORPEX dataset.

The experiences with increased density of observations indicates the need to address the characteristics of observations errors for satellite winds in more detail.

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REFERENCES

ECMWF, 1997/1998: ECMWF SATOB Data Monitoring Report, June – August 1997/1998.

Holmlund, K., 1997: The Utilization of Statistical Properties of Atmospheric Motion Vectors to Derive Quality Indicators. *submitted to Weather and Forecasting,* November 1997.

Jaehne, B., 1989: Digitale Bildverarbeitung, Springer, 1989.

Robn, M. and F. Grazzini, 1998: Operational performance and GOES 10 winds in early August 98, *ECMWF Research Department Memorandum,* R43.8178/MR.

Nieman, S.J., W.P.Menzel,C.M.Hayden,D.Gray,S.T.Wanzong,C.S. Velden, J.Daniels, 1997: Fully Automated Cloud-Drift Winds in NESDIS Operations,*Bull.Amer.Met.Soc.,* 78, 1121-1133, 1997.

Velden, C. S., T. L. Olander and S. Wanzong, 1998: The Impact of Multispectral GOES-8 Wind Information on Atlantic Tropical Cyclone Track Forecasts in 1995. Part I: Dataset Methodology, Description, and Case Analysis. Monthly Weather Review, 126, 1202-1217.