CGMS-XXVIII EUM-WP-24
Prepared by EUMETSAT
Agenda Item: III.1

SUMMARY OF THE FIFTH INTERNATIONAL WINDS WORKSHOP

The International Winds Workshops interact with the Coordination Group for Meteorological Satellites (CGMS) with respect to important issues related to the derivation and utilization of wind information based on the imagery derived from geostationary satellites. It also provides a forum for data producers, data users and the science community to exchange information on the characteristics of satellite tracked winds and to optimize their use in several applications including Numerical Weather Prediction (NWP), nowcasting and climate applications. The sequence of meetings began in Washington DC, USA in September 1991. Since then, meetings have been held in Tokyo, Japan in December 1993, Ascona, Switzerland in June 1996 and in Saanenmöser, Switzerland in October 1998. This report describes the proceedings at the Fifth International Winds Workshop and includes the recommendations derived from the meeting.

SUMMARY OF THE FIFTH INTERNATIONAL WINDS WORKSHOP

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(for submission to the Bulletin of the American Meteorological Society)

ABSTRACT

The International Winds Workshops interact with the Coordination Group for Meteorological Satellites (CGMS) with respect to important issues related to the derivation and utilization of wind information based on the imagery derived from geostationary satellites. It also provides a forum for data producers, data users and the science community to exchange information on the characteristics of satellite tracked winds and to optimize their use in several applications including Numerical Weather Prediction (NWP), nowcasting and climate applications. The sequence of meetings began in Washington DC, USA in September 1991. Since then, meetings have been held in Tokyo, Japan in December 1993, Ascona, Switzerland in June 1996 and in Saanenmöser, Switzerland in October 1998. This report describes the proceedings at the Fifth International Winds Workshop and includes the recommendations derived from the meeting.

1. Introduction

The Fifth International Winds Workshop (IWW5) was held in Lorne, Australia from 28 February – 3 March 2000. The Workshop was organized jointly by the University of Wisconsin Co-operative Institute for Satellite Studies (UW-CIMSS), EUMETSAT and the Australian Bureau of Meteorology (BoM). The BoM was successful in providing excellent workshop facilities in Lorne. The IWW5 was attended by 40 scientists from thirteen countries (Australia, China, Denmark, France, Germany, India, Japan, The Netherlands, Spain, Switzerland, Taiwan, United Kingdom and United States of America) and four international organizations (ECMWF, WMO, ESA and EUMETSAT). It is noteworthy that all satellite operators producing Atmospheric Motion Vectors (AMVs) operationally, and most global NWP centers were present. Scientists from both the research and scientific community working in this field were also well represented.

The winds workshops provide an established forum for data providers, users and the science community to exchange experience and knowledge on the production, use and interpretation of AMVs derived from multi-spectral satellite imagery. They also provide an important way for these communities to improve the use of the satellite data in NWP. The fourth workshop (IWW4) held in 1998 maintained the high standard of the previous workshops and it was felt that the specific new achievements were; expansion of the winds user community, inauguration of high density winds, characterization of the strengths (and weaknesses) of different Automatic Quality Control (AQC) procedures, demonstration of applications in nowcasting, comparisons of impact from direct assimilation of radiances vs. AMVs, expansion of the NWP impact studies, realization of FGGE like data sets and the initiation of a dialogue with the community representing other kinds of space borne instruments providing wind information. In the view of the success and importance of the previous workshops the expectation for the IWW5 were again high.

The IWW5 plenary sessions were primarily devoted to contributed presentations from each of the participants. These are briefly summarized in section 2. The IWW5 also incorporated the recommendations given by the CGMS in the discussions that were held in three topical working groups. These issues are addressed specifically in section 3.

2. Summary of the presentations

IWW5 was opened by Dr. M. Manton, Bureau of Meteorology (BoM, Australia) whom pointed out the importance of the IWWs and encouraged the participants to use the opportunity of this workshop to further advance not only the extraction methodologies but also the application of the data. The

welcoming address from Dr. T. Mohr (EUMETSAT, Germany) presented by Dr. J. Schmetz underlined the importance of these meetings to the satellite community and the relevance of the participation of the satellite data users. The recent work on quality indicators associated with the wind vectors and the use of rapid scan imagery to derive improved vector fields were further items that were emphasized. In this address, the importance of the workshops as a forum to interact with the Co-ordination Group for Meteorological Satellites was also emphasized. Finally, in his opening address, Dr. J. Le Marshall (BoM, Australia), re-iterated the importance of the derivation of AMVs from satellite imagery with a special focus on local weather prediction and the development of new assimilation techniques and new instruments.

a. Session I on "Current Systems to Derive AMVs"

The workshop proceeded with six plenary sessions. The first session gave an overview of the current status at the operational satellite data extraction centers; Japanese Meteorological Agency (JMA), National Oceanographic and Atmospheric Administration/National Environmental Satellite Data and Information Service (NOAA/NESDIS), European organisation for the exploitation of METeorological SATellites (EUMETSAT), Australian BoM and Chinese Meteorological Association/Satellite Meteorological Centre (CMA/SMC). JMA noted that AMVs were now being produced on a regular schedule four times per day, and demonstrated the importance of high-density wind fields that JMA produces once per day in the vicinity of typhoons. NOAA/NESDIS described new operational strategies that have resulted in improved wind products and associated increased utility in numerous applications. EUMETSAT described the current AMV retrieval scheme for Meteosat. This scheme has continuously been improved in order to make the transition to the new products derived with the new Meteosat Second Generation (MSG) scheduled for launch in 2002. BoM reviewed recent advances related to the generation and assimilation of high spatial and temporal winds from GMS-5. CMA/SMC showed the results from a comparison of the quality of AMVs produced with both the EUMETSAT and CMA/SMC processing systems using the same data set.

b. Session II on "Verification and Objective Quality Analysis"

The second session covered studies on vector accuracies and objective quality control. In addition, obtaining winds from QuickScat and the Atmospheric Dynamics Mission was also discussed. The first presentation described the integrated satellite wind monitoring report of the EUMETSAT Numerical Weather Prediction Satellite Application Facility (NWP SAF). The goal of these reports is to enable the improvement of both derived satellite winds and their treatment within NWP models. Most signatures from different sets of AMVs (from various data producers) were found to be consistent when the comparison is made with respect to both the ECMWF and the United Kingdom Meteorological Office (UKMO) NWP models. The main signatures are the stronger low level winds in stratus areas and weaker high level winds in the jet stream observed by the AMVs as compared to the models. In a joint paper by EUMETSAT and UW-CIMSS a new combined Automatic Quality Control (AQC) procedure based on the Quality Indicator scheme of EUMETSAT and the auto-editor/recursive filter analysis of UW-CIMSS was presented. The impact of the combined scheme during NORPEX-98 (NORth Pacific EXperiment) on the impact of high-density wind fields derived with both GOES and GMS imagery data on the ECMWF 3-5 day forecast was better than of either scheme alone. Further development of the EUMETSAT AQC scheme was discussed in the following paper describing an alternative approach with no involvement of NWP model data. The results showed that the forecast-independent system works well and now both sets of quality indicators (with and without the use of forecast wind field) are disseminated via GTS BUFR code. ECMWF presented their monitoring of GOES, METEOSAT-7 and GMS-5 AMVs against model first guess and co-located platforms (Aircraft and Rawinsonde). A general slight underestimation of satellite wind speeds was confirmed both with reference to the model and other in situ data. They showed that the

GOES error signature differs from that of the other satellites and that the most likely reason is the impact of the applied auto editor processing, i.e. the implicit use of the first guess field.

KNMI (Het Koninklijk Nederlands Meteorologisch Instituut) presented the methodology of assimilating QuickScat inverted winds in numerical weather prediction. They showed that the presented methodology is better than using radar cross-section although significant advances are still required. Indian Meteorological Department (IMD) presented recent improvements in their extraction scheme. Combined with an improved data assimilation of AMVs in the operational IMD Limited Area they demonstrated a positive impact on the model forecast. The joint paper by Co-operative Institute for Research in the Atmosphere/Colorado State University (CIRA/CSU) and EUMETSAT presented the results of combing existing stereo-height software from CIRA/CSU with the fully automated target extraction methodology developed at EUMETSAT. The paper showed that the results from the 5 km resolution IR observations are just as useful as the results obtained with the analysis of 2.5 km visible data and demonstrated the value of the stereo height assignment as an independent approach to estimate the cloud tops and as a tool to verify other height assignment schemes.

c. Session III on “Assimilation and Impact of AMVs in NWP”

Session three provided new evidence on the importance and usefulness of AMVs and other wind data derived with space borne instruments for different kinds of weather events and different seasons. As in previous IWWs, this session gave considerable insight into the large range of activities associated with the use of AMVs and solid evidence of their utility in NWP. NOAA/NESDIS discussed in detail the seasonal impact of AMV on the ETA Data Assimilation/forecast System (EDAS). A modest positive impact on the model forecasts was shown for all seasons, with the maximum impact in winter. NOAA/GFDL discussed the use of GOES AMVs for numerical hurricane prediction and climate studies. Cloudy and clear sky multispectral water vapor observations were used in a series of parallel forecasts to determine the impact of the GOES winds on tropical cyclone track forecasts. Over 100 cases from 10 different storms in 3 seasons were examined. On average, the assimilation of satellite winds significantly reduced track errors at all forecast periods. Relative reductions of track error were 5% and 12% at 12 and 36 hours respectively. Also in this presentation, the application of hourly GOES 6.7-micron water vapor observations to an examination of the processes regulating the distribution of upper tropospheric water vapor was discussed. Use was made of an objective pattern-tracking algorithm to trace upper tropospheric water vapor features from sequential images. IMD presented a case study describing the use of METEOSAT-5 winds in an analysis of a tropical cyclone. This study indicated the utility of the winds in the analysis and subsequent prediction of a tropical cyclone affecting the Gujarat coast in May 1999. The paper by Pennsylvania State University described the development of the Community HUrricane Modeling System (CHUMS), based on the Pennsylvania State University/NCAR non-hydrostatic mesoscale model (MM5). The detailed physics of the MM5, down to the resolution of non-hydrostatic effects and cloud scale, and the availability of a 4-dimensional data assimilation cycle based on nudging were the reasons for the choice of this numerical system for tropical cyclone studies. An initial case study of Tropical Cyclone Floyd in 1999 was presented at the meeting, demonstrating the potential of this system for further studies. The UKMO described recent developments in the use of satellite winds. Changes to the operational NWP model as a result of impact tests with METEOSAT-5, GMS and GOES high-density infrared and METEOSAT high resolution visible winds were noted as was the introduction of 3D-VAR in place of the previous optimal interpolation method of assimilation. Some initial work, looking at the impact of METEOSAT winds over the Indian Ocean and Australian Region was also presented. In a second paper by IMD, the assimilation of conventional and satellite wind observations in the global data assimilation system at NCMRWF was given. This paper addressed research efforts at NCMRWF in assimilating various types of wind observations, conventional and satellite, in an operational global

data assimilation system (GDAS). It was reported that conventional winds from INSAT, GMS, GOES and METEOSAT at low resolution have been used and, recently, high resolution METEOSAT-5 and ERS-2 winds have been incorporated into the operational GDAS. The procedures adopted to overcome problems in assimilating these later data and their impact at NCMRWF were noted. A technique for assimilating surface wind speeds from the recently launched Indian IRSP4 OceanSat was also presented. The NOAA National Environmental Modeling Center, Washington DC, reported on their work toward improved assimilation of GOES satellite-derived winds paying particular attention to the use of quality indicators. The final paper of the session by JMA reported on a preliminary impact study using QuikScat/ SeaWinds ocean surface winds in the JMA spectral model using an improved assimilation system. The new system contains a wind retrieval system of higher accuracy, a new quality control scheme to reject erroneous wind data, a retrieval scheme for ocean surface pressure based on surface wind observations and a system to assimilate the pressure data into the NWP model. Using this assimilation system, JMA successfully showed positive impact from the use of the scatterometer data in the global model. JMA began the operational use of ERS scatterometer data in 1998. In addition to the ERS scatterometer study, a preliminary impact study demonstrating the capability to assimilate QuikScat/SeaWinds in the JMA spectral model was also presented. Overall, the session recorded recent advances in the assimilation of high-resolution winds from satellite observations and provided evidence of gains still to be made at many NWP centers.

d. Session IV on “New Retrieval Systems”

The five papers in the fourth session gave an overview of the potential future capabilities of AMV retrieval schemes, which will depend on improved satellite data methodologies. The main focus was on new techniques being developed for derivation of AMV. The first presentation brought out results of several advances in winds processing and assimilation being explored at UW-CIMSS. These include winds derived from rapid scan imaging, the use of 3.9 μm imagery for night-time wind retrievals, water vapor wind characterization and assimilation into NWP, and derivation of vector fields from simulated data of potential future instruments. In the following paper, also presented by UW-CIMSS, the results of work being done at UW-CIMSS to produce a platform independent version of their processing algorithm was described. The new software is currently under evaluation and will soon be made available to the interested data processing centers and research institutes. It includes the latest post-processing QC module incorporating techniques of UW-CIMSS and EUMETSAT. The next paper by EUMETSAT presented details of the new MSG AMV retrieval scheme highlighting changes with respect to the current METEOSAT AMV scheme and the expected areas of improvements. Validation results showed that the new retrieval scheme will provide improved AMVs with MSG. Further work in preparation for MSG and in support of nowcasting were presented by the Spanish Meteorological Institute. The last presentation showed the results of new work done at National Satellite Meteorological Center, China for development of analysis tools that are used in their AMV derivation scheme. Using these diagnostic tools, image animations, parameters, scatter diagrams, etc. can be visualized thereby providing a way to monitor the calculation process of individual vectors. These tools can be very useful to diagnose and further investigate specific data processing problems.

e. Session V on “New Techniques”

The presentations in session five focussed on ways to improve the derivation techniques for the future, the importance of rapid scans for nowcasting, as well as methodologies useful for limited areas. In a second paper by CIRA/CSU the stereo height assignment technique presented earlier was taken further utilizing data from polar orbiting satellites. The presented approach employs simultaneous use of several platforms to estimate not only heights but also motions of the observed clouds. This was demonstrated with data from POLDER and GOES. However the 6-km resolution of POLDER limits the accuracy. In the following paper, EUMETSAT provided a summary of work with

rapid scan data, including preliminary results from Meteosat-6 rapid scans and the perspectives for Meteosat Second Generation (MSG). MSG will have a full disk repeat cycle of 15 minutes and a twelve-channel imager, which provide new opportunities to observe the fast component of the hydrological cycle (cloud formation, convection, water vapor outflow). Results from other papers were confirmed; the rapid scans from Meteosat-6 provided more coherent wind fields and more numerous wind vectors. The computation of divergence fields from these wind fields is feasible. The following paper presented results of a comparison of both spatial and Fourier pattern matching techniques undertaken during the development of the MSG Meteorological Products Extraction Facility. Significant performance benefits were achieved by computing the Fourier domain cross-correlation using Mixed Radix Fast Fourier Transform (FFT) with specific optimal data sizes. The paper also compared the displacement vectors derived by spatial and Fourier techniques. It was indicated that in low contrast regions maximum discrepancy was observed between the two techniques. The final paper of the session described a low-level cloud motion wind-tracking scheme developed specially for land areas. It was concluded that a limited number of low level cloud motion winds could be computed over land with standard time interval of 30 min. The selection can be improved with the use of climatological thresholds. An important increase of the number of AMVs is observed over land in the tropics when the time interval between images is reduced to 15 min. The use of the IR/WV correlation and the IR brightness temperature of the coldest pixels lead to similar selection of low level AMVs. AMV fields computed with a solar correction are very close to those computed without it. An alternative method based on optical flow techniques gives a realistic motion in some areas.

f. Session VI on “New Space Borne Systems”

The sixth and final session continued the dialog between the community representing the AMV derivation and the community representing wind derivation with other space borne active and passive instruments. The importance of exchanging ideas between the different communities was noted in order to derive a homogeneous picture of the atmospheric flow. The first paper presented by NASA gave an enlightening talk on the Geostationary Imaging Fourier Transform Spectrometer (GIFTS) which will constitute a breakthrough in measurements from geostationary orbit. With a large focal plane array the instrument can provide full disk images at 4 km resolution with a repeat rate of five minutes. The imagery will consist of thousands of channels with very high spectral resolution thus enabling soundings with high vertical resolution and, hence the tracking of water vapor features at different levels in the atmosphere. DMI (Danish Meteorological Institute) gave a paper on wind energy mapping using Synthetic Aperture Radar (SAR) data. The SAR data will be very useful in preparation of the plans to deploy offshore wind energy turbines in the seas around Denmark. It was noted that this paper presented new aspects to the workshop that had not been addressed at any previous workshop. ESA introduced their Atmospheric Dynamics Mission (ADM) that will measure the global wind fields in the stratosphere up to about 26 km and in the cloud-free troposphere with an active UV Doppler Wind Lidar (DWL). It gives profiles with consistent errors throughout the troposphere and will also provide ancillary information on cloud top height, vertical distribution of cloud, aerosol properties, and wind variability as by-products. The expected performance of the Atmospheric Dynamics Mission was further examined in a presentation by KNMI. They demonstrated a sufficiently large coverage of measurements on the basis of a statistical analysis of cloud cover. An Observation System Simulation Experiment (OSSE) has been conducted which showed the expected overall positive impact of the new DWL wind data on numerical weather forecasts. The final presentation of the workshop by NOAA/NESDIS on the combined capabilities of active and passive space borne systems highlighted outstanding previous research on the tracking of atmospheric motion. It also recalled the need for a good understanding of the physics of the observations that may be often forgotten in statistical presentations of problems. Clearly this calls for research on case studies. Convincing examples were presented on recent achievements ranging from

SAR image data to rapid scans from geostationary satellites. A lively discussion on the utilization of satellite observations in NWP and mesoscale models emerged after the final presentation emphasizing the need for early preparation for new space borne systems in order to have the relevant science ready for applications of the new data.

3. Summary of the working group discussions

Three working groups convened during the meeting. These were 1) Working Group on Methods (WG I), 2) Working Group on Utilization (WG II) and 3) Working Group on Verification and Quality Indicators (WG III). The working groups continued the work from the previous workshop (IWW4) to improve the derivation and utilization of AMVs. They also incorporated the requests from the CGMS for analysis and recommendations.

a. Working group on methods

The working group on satellite-derived wind tracking methods that was chaired by Chris Velden discussed a wide range of topics. Some of these topics were new, while others were re-emphasized from the IWW4 recommendations. The "top ten" list of issues or research areas is presented below. The group felt that an overarching issue was that with a growing AMV producer and user community, communication of new ideas and methods to extract wind data from satellites is increasingly essential to maintain uniform vector field quality and understanding of the data properties.

1) Standardization of processing methods

The standardization of processing methods by the global operational satellite wind producing community include tracking and height assignment methodology as well as unified quality control indicators. Promising new techniques from proven research studies should be introduced at IWWs for consideration of implementation by all of the operational wind producing centers. In order to make standardization easier, code exchange was highly encouraged. The distribution of the wind extraction software from UW-CIMSS and quality control software from EUMETSAT serve as good examples.

2) Convergence of observing systems

The group also recommended convergence of the geostationary satellite observing system in regards to common imaging channels/frequencies for global winds production.

3) Rapid scan capabilities

The group endorsed the recommendation to satellite agencies to create scanning strategies that allow Rapid Scan (RS) scheduling on a more routine basis. Preliminary studies have shown the increased vector yield and quality from more frequent imaging, and the positive impact on the applications (e.g., tropical storms, mesoscale analyses). Further studies were encouraged to solidify the relationship between optimal scan frequency vs. spectral band and resolution, and to explore the value of multiple RS image tracking (more than three images in the tracking loop).

4) Image navigation and registration

The production of RS winds at high resolution and the use of sophisticated geometric height assignment techniques demand higher accuracy in image navigation and registration. The group re-emphasized the recommendation from the Working Group II of IWW4 for registration and navigation accuracy to be better than 1 km for accurate AMV wind determinations.

5) Speed bias

The slow bias in satellite-derived cloud-tracked vectors in the upper levels still exists, and is being treated by quality control or statistically based increments. Clear sky water vapor winds at mid levels are also showing a slow bias, especially with GOES. The WG encouraged further research into these

problems and/or their solutions.

6) Vector derivation over land areas.
Cloud-tracked winds over land areas offer increased difficulties. The WG endorses research into the scanning strategies and processing/QC adjustments necessary to create vector fields over land with accuracy equal to marine regions.

7) Limit dependency on model first-guess
This is a follow-up from IWW4. Methods are desired to derive displacement vectors, assign heights and QC with minimal influence of model-dependent fields.

8) Expand research
The working group discussed several areas that the current extraction techniques do not handle well and where further research to identify the problems and to develop solutions is required. The WG especially recommends research in the following areas:

- The GOES 3.9-micron channel has demonstrated promise for nighttime low-level vector determinations. Other planned satellite launches will contain this channel and new channels will have the same capability. Exploitation of these spectral bands for winds is encouraged.
- The success of scatterometer winds and their use has been documented. Similar advances have been made in derivation of winds from SSM/I, SAR and AMSU. The WG endorses the continued efforts to extract winds from polar-orbiter microwave information and to improve the algorithms.
- Exploration into new methods to improve the height assignment accuracy should be continued, as well as data characterization studies (i.e. the representativeness of clear sky WV winds).
- Investigation of tracking methodologies. Preliminary work suggests correlation tracking is optimal in some cases, and the Euclidean distance method in others. New, more sophisticated methods (model-free) may lead to increased tracking accuracy.

b. Working group on utilization
The working group on utilization (WG II) was chaired by Brian Soden and considered the application of satellite wind information in climatological analyses, numerical weather prediction, and nowcasting. It also discussed the importance of data formatting and access, and noted the role of education and training in promoting the effective use of AMVs. A discussion of the key achievements since the last workshop and recommendations for future efforts in five areas are outlined below.

1) Climatological analyses
The potential of wind information from geostationary satellites to substantially enhance our understanding of the atmospheric circulation for climate diagnostics and model evaluation was clearly established. In light of this potential, the reprocessing of the existing geostationary archive using a consistent set of wind algorithms (to the extent feasible) was recognized as a high priority. Such an undertaking should provide near-global coverage and be designed for use by both the NWP-reanalysis and the climate diagnostics community. To facilitate the use of the wind data by this broader community, the reprocessing of the satellite archive should also offer a set of gridded, model-independent wind products. The working group further recommends that the wind retrievals be performed in conjunction with the retrieval of other quantities from the geostationary archive, such as precipitation, cloud cover, and water vapor, so that the relationship between these variables and the atmospheric dynamics can be studied.

2) Numerical weather prediction

The presentations during the meeting clearly demonstrated that the production and use of AMVs for NWP has greatly expanded since the previous workshop. Presentations at this workshop offered further demonstration of the utility of cloud and water vapor motion vectors, and scatterometer data for tropical cyclone forecasting in a variety of numerical models (GFDL, NOGAPS, NCMRWF, BMRC) using both intermittent and continuous assimilation techniques. Positive impacts were also demonstrated for model forecasts on both regional (UW-Eta) and global (ECMWF) scales. In particular, several studies highlighted the importance of assimilating AMV fields in combination with other satellite products (e.g., radiances or temperature/moisture retrievals) to achieve optimal impact of the satellite AMV data. It was also noted as a highlight that the assimilation of satellite data improved forecasts in both the northern and southern hemispheres, with impacts comparable to that obtained from the global rawinsonde network. However, achieving these improvements required considerable effort in the development and tuning of the assimilation methods specifically for the satellite data. Furthermore, as the assimilation algorithms become more sophisticated (e.g., 4DVAR), the quality of the analysis becomes more vulnerable to the quality of the ingested data. Fortunately, data providers have made considerable progress in developing consistent and meaningful Quality Indicators (QIs) for AMVs. However, the WG recommends that the data providers continue to make improvements in the quality of the data itself, in addition to the quality of the QIs. In particular, a better understanding of the nature of the speed and altitude biases in AMVs and their possible correlation with each other was noted to be a high priority.

3) Nowcasting

Presentations at the meeting also highlighted the continued importance of AMVs for tropical cyclone nowcasting. In addition to the AMVs themselves, products derived from AMVs, such as the UW/CIMSS vertical wind shear index, have been particularly useful for real-time monitoring and prediction of cyclone intensification. Currently, the real-time wind products are operationally distributed via the Global Telecommunication System (GTS) and some products are also available via the World Wide Web (WWW). However, UW/CIMSS has recently rewritten their software to allow users to run the wind retrievals locally, rather than relying upon the WWW to obtain the real-time data.

4) Data format and accessibility

The WG recognized the need for a standardized BUFR format to encode satellite wind data. Specifically, the WG recommends that CGMS require:

- Wherever possible, the use of local BUFR table entries is to be avoided; and
- Where no existing table entry exists, the data provider should instigate the introduction of such an entry through the standardized WMO procedure.

Furthermore, despite the widespread availability and reliability of the core BUFR encoding/ decoding software provided by ECMWF, the WG noted that some data providers and users still have difficulty encoding and decoding the satellite data. To help resolve the issue, the WG recommends that CGMS:

- Request the centers with existing BUFR software to make their software available. This software would be provided as it is, and would form an example of the necessary procedure for other data providers.

Finally, the WG noted that the current difficulties in obtaining high-resolution satellite radiance data, from both historical and real-time archives, was a substantial impediment and prevents a significant portion of the research community from using the data. Such limitations clearly hinder the effective utilization of the data and the WG therefore recommends that efforts be taken to facilitate the free and open access to the satellite archives. This is important in the view of a better understanding of the

benefits and drawbacks between assimilation of wind data vs. radiance data.

5) Education and training
The WG noted the recent enhancement to the WMO strategy for education and training in satellite matters through the development of a virtual laboratory to improve satellite data utilization, education and training. The virtual laboratory has at its core a global network of specialized centers of excellence for education and training. The virtual laboratory, with the group of centers having access to the Internet, would provide a global forum for the exchange of expertise, knowledge, and education and training with specialized focus groups such as found at the International Winds Workshops. The WG requests that the IWW use the CGMS Winds list-servers and the virtual laboratory to assist in education and training for interested participants.

c. Working Group on Verification and Quality
The working group on Verification and Quality Indices, chaired by K. Holmlund, considered three major areas: Recommendations from IWW4, CGMS actions and recommendations, and issues raised at the current workshop. The following items were discussed:

- Vector accuracy statistics against other data sources (IWW4)
- Combined use, research and development of QI/RFF (IWW4)
- NWP monitoring statistics on the Internet (CGMS)
- Convergence toward one set of quality control flags (CGMS)
- Expanded use of geometric approaches (e.g. stereo) for height validation purposes (CGMS)
- Model-to-model statistics (IWW5)
- Statistics from other monitoring centers (IWW5)
- QI/RFF as observation errors (IWW5)
- Table of error characteristics assigned to AMVs at different NWP centers (IWW5)
- CGMS statistics (IWW5)

After a lively and constructive discussion on the above-mentioned topics the working group (III) decided to divide the recommendations into two groups, namely monitoring/verification and quality indices. The monitoring and verification of the AMV is currently performed at all major operational data production and NWP centers. The results are publicly distributed and a multitude of significant information is available over the Internet. The trend towards unified reporting, e.g. the work performed by the EUMETSAT Numerical Weather Prediction Satellite Application Facility (NWP SAF), was seen as a positive development and was generally encouraged. To increase the usefulness and availability of the monitoring and verification results, the working group concluded with the following recommendations:

1) WMO maintained CGMS statistics
   Recognizing the value of the WMO-maintained CGMS statistics, WGII recommends WMO to facilitate an easy input of the statistical tables on the WEB-site. The current content of the table gives only a general overview of the performance. Further separation of the statistics into e.g. height bands would increase the use of the tables. EUMETSAT was therefore encouraged to provide a paper to CGMS on modified contents of the CGMS statistics including e.g. stratification of the data in speed classes. The table of observation errors assigned to AMVs at different NWP Centers is currently accessible via the CGMS home page. The table should be maintained and furthermore be completed with the errors assigned to other types of upper air observation. Finally all major NWP centers were encouraged to include their data in the table.
2) NWP SAF monitoring results

The monitoring results on the WEB maintained by the NWP SAF were found to be valuable and should be completed with statistics for all operational satellite tracked winds. This data should be complemented with information on background errors and the NWP SAF is encouraged to propose a way to present information on background errors on the WEB for the next IWW. The monitoring results of other NWP centers, not currently contributing to the NWPSAF monitoring, were encouraged to publish their own monitoring statistics on the WEB and provide a link to the NWPSAF monitoring page. Furthermore, the monitoring pages of WMO and CGMS should be linked to the NWP SAF WEB page.

The research in the past few years with respect to work related to the EUMETSAT Quality Indicator (QI) scheme and the UW/CIMSS Recursive Filter Function (RFF) scheme and the efforts to combine the two schemes was noted as an important development. The new information provided by the combined scheme will enable a better use of the AMVs, tailored towards each user. An internationally unified automatic quality scheme was seen as an important goal for the future winds community. In order to achieve this goal the working group came to the following conclusions and recommendations:

3) Derivation of quality indices

All data providers should strive to implement quality control procedures equivalent to the combined UW-CIMSS RFF and EUMETSAT QI scheme. In order to enable an easy merging towards similar schemes to derive quality indices, EUMETSAT and UW-CIMSS were encouraged to continue to make their schemes readily available to all operational data providers as stand alone s/w packages. All data providers should continue the development of new and improved quality control schemes that do not make assumptions on atmospheric balance, e.g. current schemes are tuned towards large scale synoptic flow and are therefore not optimal for mesoscale features or extreme weather conditions (e.g. hurricanes). In parallel, the NWP centers should work on methods to utilize the information given by the RFF and QI schemes and therefore move to the use of AMVs distributed in the BUFR format.

4) Height assignment

Height assignment is still the major contributor to the total error of the AMVs. The data providers are therefore encouraged to produce information on height assignment methods and their accuracy, and to develop methods to provide statistics on height assignment accuracy, e.g.:

- inter-comparisons on methods
- alternative methods
- alternative observations (e.g. R/S, Lidar)

Eventually this kind of information could be used in improved quality control schemes to provide reliability information on the heights attributed to the vectors, enabling a better assimilation of the data.

4. Concluding remarks

IWW5 concluded with a plenary session reflecting on the achievements of the workshop. The main achievements were found to be the increased utilization of AMVs including the quality indicators in global NWP. For the first time an NWP center (ECMWF) reported that AMVs have a positive impact not only in the Southern but also in the Northern Hemisphere. Of note is that the positive impact is comparable to that of the conventional rawinsonde network. Also, the large number of impact studies using different types of limited area and climate models was found to be encouraging, showing the huge potential of the AMVs in the future. The efforts to unify wind extraction and quality control procedures were also found to be a positive development as well as the flexibility of the new systems to adapt themselves to various kinds of observations. Especially the potential of rapid scans and new

channels should be thoroughly evaluated. Also the extended potential of current and near future satellite platforms was encouraging. Finally the synergy between different wind observation types (e.g., AMV vs. scatterometer) was a development that was noted to be important.

The IWW5 incorporated the recommendations given by the CGMS in the discussions that were held in three working groups and were addressed specifically.

It was felt that the high expectations of the workshop were met and that the workshops should be continued in their present form. The excellent local arrangements were attributed with gratitude to D. Jasper and J. Le Marshall from BoM. The same scientific committee will again organize the next IWW and it is planned for early 2002 in Madison, Wisconsin, USA. The proceedings of the Fifth International Winds Workshop can be ordered from EUMETSAT, Information Division, Am Kavalleriesand 31, 64295 Darmstadt, Germany.