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SUMMARY OF THE FOURTH INTERNATIONAL WINDS WORKSHOP

The Fourth International Winds Workshops was held from 20 to 23 October 1998 in Saanenmöser, Switzerland.

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Summary of the Fourth International Winds Workshop

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ABSTRACT

The Fourth International Winds Workshop (IWW4) was held in Saanenmoeser, Switzerland, from 20 to 23 October 1998. The workshop was organized by the European Organisation for the Exploitation of Meteorological Satellites, and the World Meteorological Organization was the local host. IWW4 followed previous meetings convened in Washington, D.C., in September 199 1; Tokyo, Japan, in December 1993; and Ascona, Switzerland, in June 1996. The International Winds Workshop convenes the International Winds Working Group, which communicates with the Coordination Group for Meteorological Satellites on issues of importance regarding wind derivation from satellites. It provides a forum for data producers and users to share information on the characteristics of satellite-tracked winds and to optimize their use in several applications, especially numerical weather prediction. This report describes the proceedings of the Fourth International Winds Workshop and includes recommendations.

1. Introduction

The Fourth International Winds Workshop (IWW4) was held in Saanenmoeser, Switzerland, from 20 to 23 October 1998. The workshop was organized by EUMETSAT (the European Organisation for the Exploitation of Meteorological Satellites), and the WMO (World Meteorological Organization) organized the excellent workshop facilities.

Thirty-eight scientists attended IWW4. Fourteen countries and four international organizations were represented at the meeting: Australia, Austria, Brazil, China, France, Germany, India, Japan, Kenya, the Netherlands, New Zealand, Spain, Switzerland, the United Kingdom, the United States, ECMWF (European Centre for Medium-Range Weather Forecasts), WMO, ESA (European Space Agency), and EUMETSAT. It is noteworthy that most meteorological satellite operators, most numerical weather prediction (NWP) centers, and scientists in this field representing both the research and user communities from around the world participated in IWW4.

The International Winds Workshops provide a forum for data providers and users to share information on the characteristics of satellite-tracked winds and to optimize their use in NWP. At the first workshop in Washington, D.C., it was recognized that satellite-tracked winds were based initially on the simple process of identifying a feature (e.g., a cloud) in a satellite image, tracking that feature in a sequence of images, and estimating the height of that feature in the atmosphere. Such satellite-tracked winds were interpreted as a report of atmospheric motion at a single level. Correct height assignment was identified as crucial. At the second workshop in Tokyo, Japan, improvements in height assignment techniques were presented, grouping of water vapor winds into clear- and cloudy-sky conditions was encouraged, and motion estimation from more closely time-sequenced images was investigated. It was concluded that proper utilization of satellite-tracked winds to depict atmospheric motion must distinguish between single-level cloud motion and mean layer water vapor motion. At the third workshop in Ascona, Switzerland, a new standardized reporting method was recommended for evaluation of operational wind production quality and several algorithms for assessing wind vector quality were discussed.

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The Coordination Group for Meteorological Satellites (CGMS) at its meeting in July 1998 recommended that the Fourth International Winds Workshop make a record of their accomplishments in the context of CGMS priorities and review the scope of their future meetings. In addition, it was noted that utilization of the information contained in satellite-tracked wind fields by NWP remains a major challenge; IWW4 was encouraged to continue their discussions of this important issue. Some specific issues were suggested for discussion: 1) optimum scan intervals for tracking features; 2) consensus on wind vector quality indicators; 3) utilization of high density winds; 4) exchange of wind data in binary unified format records (BUFR); 5) water vapor winds in NWP versus direct assimilation of water vapor radiances; 6) climatological applications of reprocessed wind datasets; 7) nowcasting applications of real time wind datasets; 8) evolution of current geostationary systems; and 9) the role of satellite winds in the context of all motion observations (scatterometer, Doppler lidar, passive microwave surface winds, etc.). These items were taken up by the working groups and discussed in the plenary; results are presented in their reports.

2. Summary of the presentations

The workshop participants were welcomed by Dr. T. Mohr, director of EUMETSAT. His opening remarks mentioned the improvements in the space observing system since the last workshop in 1996; these include the launch of the *Meteosat-7* and the utilization of *Meteosat-5* over the Indian Ocean as well as the continuing good performance of the winds from the geostationary satellites of the NOAA-NESDIS (National Oceanic and Atmospheric Administration-National Environmental Satellite, Data and Information Service) Geostationary Operational Environmental Satellites (GOES) *GOES-8* through -10 and the Japanese Meteorological Agency QMA) Geostationary Meteorological Satellite (GMS) *GMS-5*. He noted that this workshop was widening the agenda to include surface winds from microwave sensors onboard polar satellites. He encouraged the workshop participants to focus on the important issues suggested by the CGMS.

The workshop proceeded with six plenary sessions. The first session on current systems to derive atmospheric motion vectors (AMVs) outlined the recent improvement and remaining deficiencies of the systems in operational use. NESDIS and the Cooperative Institute for Meteorological Satellite Studies (CIMSS) noted a 10-fold increase in their yield of AMVs with the March 1998 advent of fully automated production of high density winds every 3 h; positive impact of these winds was demonstrated in rnidlatitude field experiments and numerical model 72-h forecasts of hurricane trajectories. The People's Republic of China (PRC) showed results with Feng Yun-2 (FY-2) where improved discrimination of high and low cloud tracers produced more useful AMVs in regions of light cloudiness. EUMETSAT described the current production of AMVs using all three Meteosat spectral bands at full resolution; winds from the operation of *Meteosat-5* over the Indian Ocean since July 1998 were presented. JMA doubled the AMVs from cloud tracking in *GMS-5* images (quadrupled AMVs from water vapor tracking) using an improved infrared window and water vapor radiance height assignment algorithm. The improvements in dissemination of satellite-tracked winds through BUFR were described by EUMETSAT; it is the goal that all wind data and quality information will be transmitted in this unified wind template by the end of the year.

The second session on assimilation and impact of AMVs in NWP focused on recent evaluation studies using operational numerical forecasts. The United States presented results of a case study into the sensitivity of the Eta data assimilation system to radiosonde observations, Aircraft Communications Addressing and Reporting System wind estimates, GOES cloud drift (CD) winds, and GOES water vapor (WV), motions; while radiosonde information was very important, observations of water vapor winds were also found to have significant impact on the 48-h Eta forecast of 500-hPa geopotential height (Z500). Brazil outlined their NWP activities using winds and trajectories inferred from GOES; it was noted that Southern Hemisphere wind information is sparse and opportunities for nowcasting impact remain. Australia presented impressive results for tropical cyclone applications using hourly GMS-5 winds in their high-resolution (15 km) fourdimensional variational assimilation (4DVAR) system; in a case study, 72-h trajectory forecast errors were reduced to about 120 km (down from 360 km five years ago). Scatterometer data helped to properly locate the tropical storm in the numerical forecast model. A paper from the ECMWF presented results of the 15-yr reanalysis; quality of the AMVs increased considerably from 1979 to 1993. To expand the benefit of satellite data, it is proposed that available satellite data from archives be reprocessed with current AW algorithms (EUMETSAT is proceeding with plans to do this); reanalysis will use three-dimensional variational assimilation **(3DVAR)** approaches with 6-hourly cycling. Another ECMWF paper noted the difficulty of interpreting clear-sky water vapor winds; the volumetric nature of **this information** is being studied in 4DVAR simulations.

The third session focused on utilization of AMVs. ECMWF itemized some of the difficulties in using the high density winds in their model; case study investigations reveal that not all of the information is making it into the model (collaborations with satellite wind providers are continuing to resolve these issues). PRC presented several applications of diagnosing tropical cyclone development using high density AMVs (high tropospheric westerly jets appear to be likely precursors); gridded winds at 1.25° lat-long are proving to be a good forecasting discriminator along with cloud images (rainfall in northern China is characterized by divergent high-level flow while a high-level ridge is indicative in southern China). France showed results from mesoscale interpretations of water vapor wind field divergence persisting over broad layers in the upper troposphere; only partial agreement was found in a comparison with ECMWF analyses. A paper from Germany showed that water vapor displacement vectors represent a sum of motions averaged over an atmospheric layer. India presented correlations of low-level AMVs with surface wind measurements; large-scale surface features appear to emerge when cloud motion winds were used to resolve the direction ambiguity of scatterometer winds. France showed that monsoonal circulations were clearly evident in trajectories deduced from AMVs measured with *Meteosat-5* over the Indian Ocean. Kenya noted the need for more satellite-derived AMVs to assist nowcasting and forecasting activities in the regional offices; the Meteorological Data Distribution (MDD) system remains highly utilized and the information is found to be complementing the sparse radiosonde observations, but more remains to be done.

The fourth session featured three papers on spaceborne wind retrieval systems outside of AMVs derived from the geostationary satellite systems. The U.S. National Polar Operational Environmental Satellite System has firm plans for the development of a space-based polarimetric radiometer WINDSAT in the early years of the next century. ESA is preparing a mission to demonstrate the capabilities of wind profilers; a Doppler wind lidar called ALADIN is being developed as part of the Atmospheric Dynamics Mission currently being considered for the international space station. The positive impact of scatterometer-derived winds on the model-derived forecasts was presented by the Netherlands; European Remote Sensing Satellite (ERS) scatterometer data improve the prediction of tropical cyclones in the ECMWF 4DVAR analysis scheme and scatterometer winds contain considerable subsynoptic-scale information (but the smallest scales resolved are difficult to assimilate into an NWP model). The main conclusion of the session was to encourage the development of space-based wind retrieval systems in view of their importance to a number of users.

Session five covered verification and objective quality analysis of AMVs. The AMVs discussed were those determined using geostationary satellite imager data; exclusively visible and infrared data at about 10.7 and 6.7 µm. The first two presentations provided information on the two prevalent quality control schemes, the auto-editor (AE) technique of NESDIS and the quality indicator (Q1) scheme of EUMETSAT. Both schemes were automated and have advantages and drawbacks; the AE provides better quality control information with regard to tracer height, and the QI provides better quality information with respect to tracer speed and direction. Participants at the workshop were encouraged by the fact that NESDIS-CIMSS and EUMETSAT were working together to extract the attributes of each scheme into an optimized combined method that will provide complete vector information and reliable quality control estimates for users. It was also encouraging to see that preliminary results from ECMWF using the combined information were positive. A paper from EUMETSAT explored dependencies of thin cirrus cloud height assignment on accurate infrared calibration; a 5% deviation in the water vapor radiance calibration caused about a 1 -km height error. The sensitivity studies have also indicated that cirrus cloud vectors are best assigned to levels within the cloud. The United Kingdom Meteorological Office presented their AW monitoring results; difficulties with the GOES low-level wind vectors were noted but the causes were not understood. ECMWF monitoring results noted reduced numbers of GOES AMVs at 0600 UTC during the eclipse periods (a daily update of AMV coverage is available online at http://www.ecmwf.int). It also pointed out the current need to thin high density AMVs to about one-third of the vectors for use in the analysis. A paper from the National Aeronautics and Space Administration's Marshall Space Flight Center presented an approach for assessing AMVs using structure functions; the proper balance of spatial and temporal resolutions was explored (4-km resolution infrared window images at 10-min separation produce high quality cloud motion vectors if image registration is maintained to about 1 km). Finally, India presented improved infrared window height assignment approaches but noted that significant advances are expected when water vapor radiance measurements become available on future INSATs (Indian satellites).

The sixth and last session presented several papers on new developments and applications. Opportunities for using both polar and geostationary satellites to measure the earth-atmosphere were stressed; these include stereographic height assignments and polar microwave measurement of tropical cyclone intensity. Examples of asynchronous stereo height and motion analysis of slowly changing cirrus clouds were presented; several observations in time from several viewpoints are used to derive both height (to better than 1 km) and motion of clouds. Initial statistics of *Meteosat-5* winds over the Indian Ocean were presented and plans for experimental *Meteosat-6* rapid scan imagery in May 1999 in support of a mesoscale Alpine project were revealed. In addition, Spain reported on the development of a high-resolution wind product supporting nowcasting with Second Generation Meteosat. A cross-correlation tracking procedure in the Fourier domain was shown to produce reliable vectors with greatly enhanced computational efficiency; more refinement was suggested. Initial experiments demonstrated the potential of assimilating geostationary radiance data directly into the ECMWF 4DVAR, assimilation system; by taking advantage of the high temporal resolution of such datasets, there is the possibility to correct not only the model variables, but also the model motion fields. This paper created a very enthusiastic response; IWW4 encouraged more activity in this area. Finally, a commercial nowcasting package was presented that offers quality controlled cloud motion fields, forecasts of subsequent satellites images, and indications of areas of cloud growth.

3. Summary of the working group discussions

Three working groups were convened to address topics raised by the CGMS. They were 1) the Working Group on Methods, 2) the Working Group on Utilization, and 3) the Working Group on Verification and Quality Indicators.

a. Working Group on Methods

The Working Group on Methods was cochaired by G. Jedlovec and X. Jianmin. The working group reviewed the tracking algorithm used by various members of the working group and then discussed several topics: 1) trade-offs between spatial and temporal resolution, 2) need for commonality in quality indicators, 3) improved winds in thin cloud situations, and 4) BUFR tables for exchange of wind products.

1) TRADE-OFFS BETWEEN SPATIAL AND TEMPORAL RESOLUTION

The trade-offs between image spatial resolution, temporal sampling, and wind errors were discussed. Since wind accuracy is limited by spatial resolution, sampling interval, and image-to-image registration, a balance of these three needs to be achieved. Preliminary empirical results suggest that 4-km resolution infrared images at 10- 15-min separation could be utilized to produce high quality winds if image registration is maintained to about 1 km. One-kilometer visible imagery warrants production of winds with image separations of 3-5 min. Unique datasets exist for verification of these preliminary findings (notably the 5-min datasets accomplished during *GOES-10* checkout). The working group encouraged continued work in this area.

2) NEED FOR COMMONALITY IN QUALITY INDICATORS

The activities toward commonality in quality indicators among the major wind producers were strongly supported. While commonality in tracking algorithms is also desirable, satellite-specific methodologies often prohibit this; however, a standard algorithm for cloud height assignment with various "tuning" schemes is close to becoming a reality. The working group encouraged continued efforts in this direction.

3) IMPROVED WINDS IN THIN CLOUD SITUATIONS

Recent work with FY-2 and GMS data has shown significant progress in developing an enhanced method to distinguish low cloud from thin cirrus. The procedure examines the correlation of suspect areas with water vapor and infrared imagery to better separate contributions from each and to improve height assignment. Additionally, emissivity differences between high and low clouds can be used in a similar way by examining the split window channel difference field; the reflective characteristics of ice versus water clouds at 3.8 μm can also be used in a similar way. Thus the height assignments of thin cloud tracers are becoming more reliable. The working group recommends additional research in this area.

4) BUFR TABLES FOR EXCHANGE OF WINDPRODUCTS

There was general support for the use of BUFR encoding for delivery of satellite wind products. Use of BUFR format is appropriate for AMV data dissemination as it enables the inclusion of extra information about the wind and quality for the NWP analysis; **NESDIS and EUMETSAT** are prepared to use BUFR for winds. Users are encouraged to switch to it; software and support for BUFR are available from ECMWF and the National Centers for Environmental Prediction. In the initial part of the changeover, parallel BUFR and satellite observation use is encouraged. In addition, a notice board should be established to pass on information about the availability and formats of AMV datasets through the WMO Satellite Activities World Wide Web site.

5) ADDITIONAL WORKING GROUP COMMENTS

The working group had several additional comments on various issues. 1) There is a need to produce "targeted" high density winds in certain situations; it is felt that operational wind producers are prepared to accommodate this. 2) There is a desire to eliminate the dependence of quality indicators on first-guess information so that these indicators can be better used in science applications; however, the continued use of guess information in tracking procedures is less problematic. 3) The feasibility of using new (additional) channels to produce winds in data-void regions has been demonstrated; a continued investigation of the utility of winds derived from additional channels is encouraged. 4) Some existing methods could provide improved target selection and feature tracking under certain conditions; it is difficult to implement many of these techniques operationally at this time but the working group recognized the need to continue to refine such methods for case studies and individual situations.

b. Working Group on Utilization

The Working Group on Utilization was cochaired by J. LeMarshall and G. Kelly. The record of steady expansion in the application of AMVs was noted by the working group; significant improvement was noted in forecasting tropical cyclones using high density winds and continuous assimilation techniques. It has been shown that analysis of the development of convective clusters is assisted by using upper-level high-density cloud and water vapor drift winds. Impact on large-scale NWP is now firmly established. The working group then focused on five areas of discussion: 1) climatological applications and reanalysis, 2) ap-plication to NWP, 3) nowcasting applications, 4) re-search on AMVs, and 5) education and training.

1) CLIMATOLOGICAL APPLICATIONS AND REANALYSIS

Because of the importance of reanalysis to climate studies and seasonal forecasting, and the clear benefits from the reexamination of the attributes of the winds in this activity, there is a requirement to reprocess **AMV data using current methodologies.** Furthermore, it was universally agreed that archived satellite data ought to be readily available to the scientific community to support activities such as a wind reanalysis project. This activity would be a major undertaking because it requires significant resources both to restore the archived data and to reprocess wind datasets. There was disagreement as to which component posed the biggest challenge; however, the working group strongly recommends that archived data be restored. It was noted that this is already under way for Meteosat data.

2) APPLICATION To NWP

Extensive use of AMVs is currently undertaken in most NWP centers and has been summarized in a document to be placed on the Web (http://sat.wmo.ch). NWP is ready to benefit from provision of consistent AMV datasets, regular in time and space. To achieve this, full disk wind data need to be available at least every 6 h, and how to best utilize suitable tracers (clouds) over land (e.g., in terms of scanning frequency and appropriate channels) needs to be studied to improve coverage over land. Currently the winds from the scatterometer onboard *ERS-2* have proved to be one of the best data sources for positioning tropical cy-clones for NWP. These data need to be available in a timely fashion on the Global Telecommunications System; furthermore, data from the soon-to-be-launched Quickscat also need to be made available. Data from these research satellites will be required at least until operational satellites become available beginning with the Meteorological Operational Platform. These data should be made available to all WMO members. Because of the advantages of full wind profiles, research related to the provision of space-based wind profiles (lidar work) is encouraged.

Thus the working group had several recommendations regarding NWP applications. 1) Full disk high-resolution wind datasets should be available at least every 6 **h. 2) Research should be undertaken to enhance and optimize the estimation of AMVs over land.** 3) Research scatterometer data should be made available to operational NWP centers on a routine and timely basis. 4) Research related to the provision of space-based wind profiles (lidar work) is encouraged.

3) NOWCASTING APPLICATIONS

Mesoscale systems generally produce good upper-level traces and monitoring their evolution is important for nowcasting. It is important to produce winds as frequently as possible. This may depend on the satellite operator but should be less than 30 min. The resolution should be improved (spatial/temporal) over NWP requirements and winds of possibly lower quality should be included along with quality information. Dissemination needs to be timely and in a format useful to the nowcasting community (e.g., as derived product imagery). If nothing appropriate can be found in the short term using media such as the **GTS or MDD,** for example, then Web pages may offer a solution. Development of dedicated software for the on-site real-time derivation of nowcasting products is also encouraged.

4) RESEARCH ON AMVs

Regarding cloud studies, tracking with data from new channels such as the 3.9-pm channel may be an important source of new information. Technology development work in the area of hyperspectral data needs to be encouraged; the associated high vertical resolution may foster progress toward vertical wind profiles in clear skies. In addition, work is required on understanding both the horizontal and vertical scale of what the AMV represents. Activities currently providing high spatial and temporal resolution AMVs in support of field experiments are commended; further study is required to optimize use of these AMVs.

5) EDUCATION AND TRAINING

Effective utilization of AMVs requires an effective education and training program. Information dissemination related to applications should be accessible via the Web. The use of a "virtual laboratory" concept for training and distributing training material is encouraged; it would be very useful for developing nations. In the longer term, establishment of virtual laboratories at various regional meteorological training centers may be appropriate for the education and training program.

c. Working Group on Verification and Quality

Indicators

The Working Group on Verification and Quality Indicators was cochaired by C. Velden and K. Holmlund. They addressed the following two key issues: 1) validation of AMVs against collocated radiosonde data and 2) quality indicators of AMVs.

1) VALIDATION OF AMVS AGAINST COLLOCATED RADIOSONDE DATA

The advantages and disadvantages of elliptical collocation areas were discussed. Since the differences in the statistics provided by elliptical versus circular collocation areas were found to be quite small in the study performed by Japan, it was agreed that the best approach for deriving the collocation statistics should be based on the already common and simple approach of a circular collocation area.

The guidelines for reporting the comparisons of AMVs and radiosonde observations have been outlined in a revised annex 9 to the CGMS consolidated report. The working group found the criteria presented in the revised annex 9 to be good for present reporting, but they identified some further enhancements for future consideration. Currently the collocation area must be circular with a radius of 150 km, with a maximum height difference of 25 hPa and a time difference limited to 90 min. It was suggested that the radiosonde ascent time and displacement should be taken into account when applying the above criteria; more and better collocations are obtained by producing high density AMVs at nominal synoptic times when radiosondes are launched. An extension to the criteria in annex 9 will be needed when dealing with a multitude of possible collocations. In this case a valid collocation should be selected according to

$$\text{Minimum} = (dx/xl)^2 + (dp/p1)^2 + (dt/t1)^2,$$

with more stringent parameters $x1$ = 80 km, $p1$ = 20 hPa, and $t1$ = 60 min that will also define a new maximum difference; dx, dp and dt are the compu-ted differences between the actual radiosonde time, height, and location, and those for the AMV in question. This new reporting procedure will be considered in the future after demonstrations in parallel with the old reporting procedure; the new procedure will foster more accurate statistical comparisons that are mandatory for proper error analysis for NWP and the development of quality control procedures. Further discussion is needed addressing the quality indicator thresholds for collocation statistics. Also in the future, the statistical tables for quarterly wind performance should include the total number of winds produced.

2) QUALITY INDICATORS OF AMVs

There are presently two approaches for estimating the quality of AMVs: the AE used by NOAA-NESDIS and the QI used by EUMETSAT. After some discussion, several conclusions emerged. 1) Both methods have some advantages and disadvantages. 2) The simplicity of the QI approach lends itself more easily for implementation into different data production centers. 3) The current set of tests in the QI could form an adequate baseline for a common approach to provide quality information. 4) The QI test functions require further tuning and improvement; an optimum set of tests must still be researched. 5) The centers utilizing the AE procedure should continue this approach but provide the QI values as additional information. 6) The combined use of and development related to the AE and the QI is encouraged. 7) The data production centers should provide all their derived vectors in the BUFR format, including all available quality information.

4. Concluding remarks

In plenary discussion, IWW4 assessed their ac-complishments in the context of CGMS priorities and reviewed the scope of their future meetings,

Since 1991, the IWWG has 1) made height assignments more uniform with an IR-WV intercept approach, 2) increased successful use of water vapor and visible winds, 3) standardized reporting of AMV versus radiosonde observation differences, 4) introduced common quality indicators for AMVs, 5) initiated BUFR dissemination of AMVs with additional quality information, 6) demonstrated positive impact of high density winds in field programs and case studies (notably in tropical cyclone trajectory forecasts), 7) studied global First GARP Global

Experiment (FGGE)-like wind datasets (for the first time since 1979), and 8) demonstrated improvement in AMV derivation with more frequent observations (implications for revised satellite operation schedules are being explored).

The specific accomplishments of IWWG-4 were felt to be 1) expansion of the winds users community resulting from enhanced education and training efforts as well as improved data communications; 2) inauguration of high density winds and identification of user problems with the high data volume; 3) characterization of the strengths of automatic quality flags (Q1 and AE); 4) demonstration of applications in nowcasting as well as forecasting; 5) completion of initial study of additional benefit from direct assimilation of radiances in time sequences in NWP models; 6) ex-pansion of NWP impact studies to a more diverse community; 7) realization of FGGE-like datasets with *Meteosat-5* over the Indian Ocean; and 8) initiation of dialog with the scatterometer, passive microwave, and Doppler wind lidar community.

There was general agreement that operational applications should continue to be the guiding theme for future workshops. The next workshop will be organized by C. Velden (CIMSS) and K. Holmlund (EUMETSAT) and will occur in 2000. The proceedings of the Fourth International Winds Workshop can be ordered from EUMETSAT, Information Division, Am Kavalleriesand 31, 64295 Darmstadt, Germany.