CGMS-XXXI USA-WP-28
Prepared by USA
Agenda Item: III.2

Cloud-Drift and Water Vapor Winds in the Polar Regions from MODIS

SUMMARY AND PURPOSE OF DOCUMENT

THIS PAPER SUMMARIZES THE NEW RESEARCH WIND PRODUCT DERIVED FROM THE MODIS IRW AND WATER VAPOR IMAGES. MODEL IMPACT ASSESSMENTS ARE ALSO DISCUSSED.

ACTION REQUESTED: NONE

ACTION REQUESTED: NONE

CLOUD-DRIFT AND WATER VAPOR WINDS IN THE POLAR REGIONS FROM MODIS

Jeffrey R. Key[1], David Santek[2], Christopher S. Velden[2], Sarah Levinson[2], Niels Bormann[3], Lüder von Bremen[3], Jean-Noël Thépaut[3], Lars Peter Riishojgaard[4], Yanqiu Zhu[4], and W. Paul Menzel[1]

[1]Office of Research and Applications, NOAA/NESDIS
1225 West Dayton Street, Madison, Wisconsin, 53706

[2]Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin-Madison
1225 West Dayton Street, Madison, Wisconsin

[3]European Centre for Medium Range Weather Forecast
Shinfield Park, Reading, Berkshire, U.K.

[4]Data Assimilation Office, NASA/Goddard Space Flight Center
Greenbelt, Maryland

Abstract

Wind products from geostationary satellites have been generated for over 20 years, and are used in numerical weather prediction systems. However, because geostationary satellites do not provide wind information poleward of the midlatitudes and the high-latitude rawinsonde network is sparse, the polar regions remain data poor in terms of wind observations. This paper reports on the status of a project for deriving tropospheric wind information at high latitudes from polar-orbiting satellites. The methodology employed is based on the algorithms currently used with geostationary satellites, modified for use with the Moderate Resolution Imaging Spectroradiometer (MODIS). The project presents some unique challenges, including the irregularity of temporal sampling, different viewing geometries in successive orbits, uncertainties in wind vector height assignment as a result of low atmospheric water vapor amounts and thin clouds typical of the Arctic and Antarctic, and the complexity of surface features. MODIS winds are now generated experimentally in near real-time from both Terra and Aqua satellites. Model impact studies have shown that when the MODIS winds are assimilated in the European Centre for Medium Range Weather Forecast (ECMWF) and the NASA Data Assimilation Office systems, forecasts of the geopotential height for the Arctic, Northern Hemisphere extratropics, and Antarctica are improved significantly. As a result, ECMWF now uses the MODIS winds in their operational forecast system.

1. Introduction

In the early 1960s, Tetsuya Fujita developed analysis techniques to use cloud pictures from the first TIROS polar orbiting satellite for estimating the velocity of tropospheric winds (Menzel, 2001). Throughout the 1970s and early 1980s, cloud motion winds were produced from geostationary satellite data using a combination of automated and manual techniques. In 1992, the National Oceanic and Atmospheric Administration (NOAA) began using an experimental automated winds software package developed at the University of Wisconsin-Madison's Space Science and Engineering Center that made it possible to produce a full-disk wind set without manual intervention. Fully automated cloud-drift and water vapor motion vector production from the Geostationary Operational Environmental Satellites (GOES) became operational in 1996, and now wind vectors are routinely used in operational numerical models of the National Centers for Environmental Prediction (NCEP) (Nieman et al., 1997).

In early 2001 a project was begun to derive tropospheric motion vectors (wind speed, direction, and height) using the Moderate Resolution Imaging Spectroradiometer (MODIS) on-board the National Aeronautics and Space Administration's (NASA) polar-orbiting Terra and Aqua satellites. This paper describes the status of the project, and summarizes the retrieval methodology, early case study results, real-time processing, and model impact studies.

2. Wind Retrieval Method

Cloud and water vapor tracking with MODIS data is based on the established procedure used for GOES, which is described in Merrill (1989), Nieman et al. (1997), and Velden et al. (1997, 1998). With MODIS, cloud features are tracked in the infrared (IR) window band at 11 μm and water vapor (WV) features are tracked in the 6.7 μm band. After remapping the orbital data to a polar stereographic projection, potential tracking features are identified. Water vapor targets are selected in both cloudy and cloud-free regions.

Wind vector heights are currently assigned by one of two methods. The infrared window method assumes that the mean of the lowest (coldest) brightness temperature values in the target sample is the temperature at the cloud top. This temperature is compared to a numerical forecast of the vertical temperature profile to determine the cloud height. The method is reasonably accurate for opaque clouds, but inaccurate for semitransparent clouds. The H_2O-intercept method of height determination is also used for height assignment. This method examines the linear trend between clusters of clear and cloudy pixel values in water vapor-infrared window brightness temperature space, predicated on the fact that radiances from a single cloud deck for two spectral bands vary linearly with cloud fraction within a pixel. The line connecting the clusters is compared to theoretical calculations of the radiances for different cloud pressures. The intersection of the two gives the cloud height (Szjewach, 1982; Schmetz et al., 1993).

After wind vectors are determined and heights are assigned, the resulting data set is subjected to a rigorous post-processing, quality-control step. A 3-dimensional objective recursive filter is employed to re-evaluate the tropospheric level that best represents the motion vector being traced, to edit out vectors that are in obvious error, and to provide end users with vector quality information (Velden et al., 1998). Additional details of the retrieval methodology are given in Key et al. (2003).

3. Real-time Processing

Routine generation of MODIS winds with the Terra satellite began in May 2002. In November 2002, Aqua MODIS was added to the processing stream. At present, Terra and Aqua MODIS data are processed separately. Generally, the final winds product lags observing time (the time MODIS views an area) by about 3-5 hours. The lag is due to:

- 2+ hour delay before MODIS data is available
- 1/2 hour to transfer data from NASA Goddard via the Internet and process the winds
- 11/2 hour offset due to assigning vector to middle image time

An example of the delay frequencies for Terra MODIS over the Arctic is shown in Figure 1. The histogram represents all data runs, including image triplets that were reprocessed. While the delay is not trivial, ECMWF is still able to use about 80%[1] of the winds generated in their operational system.

The derived winds are routinely compared against collocated radiosonde observations at 00Z and 12Z for differences in height (temperature), wind speed, and wind direction. MODIS/AVHRR winds within 150 km of a raob station are used in the comparison. All MODIS/AVHRR winds that fall within 2 hours before and 1 hour after the raob time are used for the comparison. Figure 2 shows a recent time series of pressure and wind speed biases in satellite-derived winds relative to radiosonde winds for the Arctic with Terra MODIS data. The pressure bias is based on the difference between the satellite-derived pressure and pressure where the radiosonde and satellite-derived wind speeds match. Biases for cloud-track and water vapor winds are shown. The biases vary around zero, but are positive (MODIS winds too high in altitude and too slow) during part of the period. These results are undoubtedly influenced by the sparsity of radiosonde data in the polar regions.

Comparisons between water vapor and IR (cloud-drift) winds for each satellite, and winds from the different satellites are also being performed. For recent data, cloud-drift winds were, on average, slower

[1] Note that the ECMWF cut-off times are somewhat longer than for other operational NWP centers, i.e., 8:30 UTC for observations between 15 and 21 UTC the previous day, 9 UTC for 21-3 UTC observations, 19 UTC for 3-9 UTC, and 19:15 UTC for 9-15 UTC observations.

than water vapor winds by 1-2 m/s. These and other real-time plots and statistics are available at http://stratus.ssec.wisc.edu/products/rtpolarwinds.

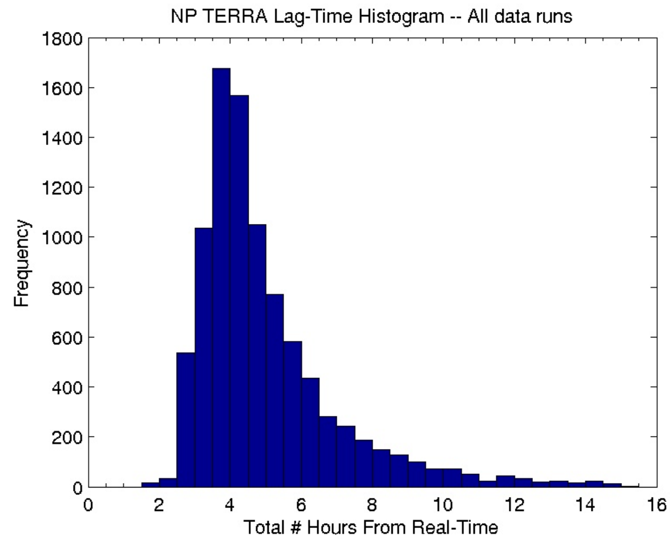

Fig. 1. Frequency of the delay between the time of MODIS data acquisition (observation time) and the completion of the polar winds processing, including reprocessed image triplets. The average delay is in the 3-5 hours. Data are from January through August 2003.

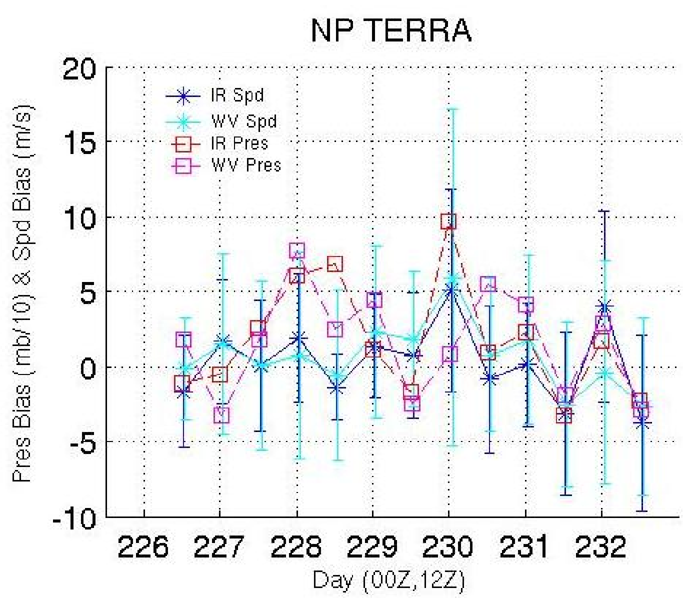

Fig. 2. Pressure and wind speed biases in satellite-derived winds relative to radiosonde winds for the Arctic using Terra MODIS data (radiosonde minus satellite). Biases for cloud-track ("IR") and water vapor ("WV") winds are shown. The symbols indicate the biases; vertical lines represent the root-mean-square difference. Results are from August 2003.

4. Impact on Numerical Weather Forecasts

Given the sparsity of wind observations in the polar regions, satellite-derived polar wind information has the potential to improve forecasts in polar and sub-polar areas. Model impact studies were performed at ECMWF and the NASA Data Assimilation Office (DAO). The goal was to determine if forecasts are improved when Terra-MODIS winds are assimilated.

For an initial trial period of 30 days in March/April 2001, both ECMWF and the DAO used a 3D variational analysis scheme. Although the two systems are different in a variety of ways, both showed that there is a significant positive impact on forecasts of the geopotential heights when MODIS winds are assimilated (Key et al., 2003). This was particularly true over the Arctic and the Northern Hemisphere extratropics, but also for the Antarctic region. Both studies recognized a somewhat poorer quality of lower level winds, particularly over Antarctica, and lower level winds were largely excluded from the assimilation in the ECMWF study.

Figure 3 gives an example of the results of the DAO experiments. The figure shows the 500 hPa forecast score (anomaly correlation) as a function of forecast day for the Arctic and Antarctic, defined as the areas poleward of 60^{o} latitude. Forecasts from the MODIS winds assimilation scored significantly higher than the control experiment (no MODIS winds) in the Arctic, and marginally higher in the Antarctic. Due to the lack of observations over Antarctica, the Southern Hemisphere result may be less meaningful than the Northern Hemisphere result.

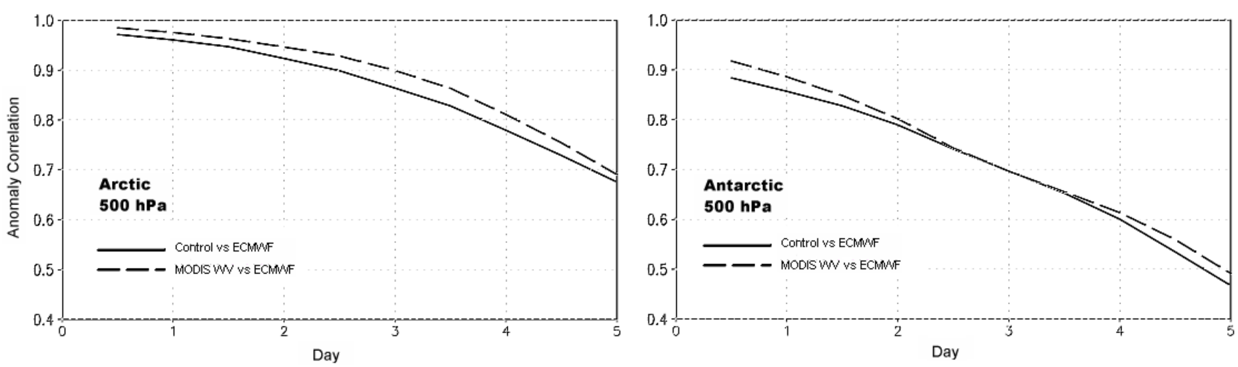

Fig. 3. Anomaly correlation as a function of forecast range for the 500 hPa geopotential height forecast over the Arctic (left) and Antarctic (right) from the DAO model impact study. The MODIS experiment (dashed) and the control experiment (solid) have each been verified against ECMWF analyses for the study period of 5-29 March 2001. Arctic and Antarctic are defined as poleward of 60^{o} latitude.

More recently, ECMWF performed impact trials with Terra MODIS winds in the operational 4DVAR configuration over an extended period (5 March - 3 April 2001 and 13 July - 29 August 2002 (Bormann and Thépaut, 2003). Figure 4 gives an example of the impact of the MODIS winds on the forecast of the 500 hPa geopotential height over the Northern Hemisphere. There is a positive impact on the forecast beyond day 5. Similar to the 3DVAR results, the 4DVAR experiments indicate that the MODIS winds have a positive impact on medium-range global weather forecasts, particularly over the polar regions and Europe, but also elsewhere over the Northern Hemisphere. The MODIS winds were found to considerably alter the mean polar wind analysis for some periods. As a result of the positive forecast impact, Terra MODIS winds have been assimilated operationally at ECMWF since January 2003.

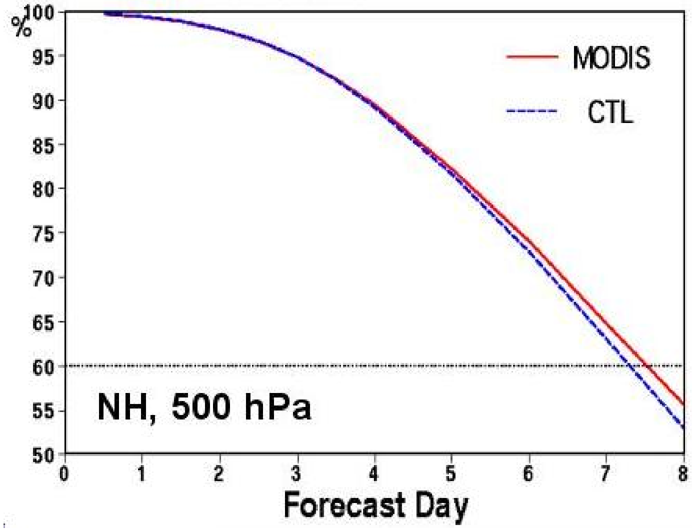

Fig. 4. Anomaly correlation (%) as a function of forecast range for the 500 hPa geopotential height forecast over the Northern Hemisphere in the ECMWF 4DVAR MODIS winds impact experiments. The MODIS experiment (solid) and the control experiment (dashed) have each been verified against their own analysis, resulting in a total of 58 cases over the two study periods.

5. Conclusions

This project has continued to demonstrate the feasibility of deriving tropospheric wind information at high latitudes from polar-orbiting satellites. Orbital characteristics, low water vapor amounts, a relatively high frequency of thin, low clouds, and complex surface features create some unique challenges for the retrieval of high-latitude winds.

Model impact studies with the MODIS polar winds conducted at ECMWF and the NASA Data Assimilation Office are very encouraging. When the MODIS winds are assimilated, forecasts of the geopotential height for the Arctic and Northern Hemisphere extratropics are improved significantly in both impact studies. The impact is also positive for the Antarctic.

The vast majority of the MODIS polar wind vectors come from tracking features in the water vapor imagery. This fact reduces the utility of imagers without water vapor channels for wind retrieval, such as the current operational NOAA polar-orbiting satellite AVHRR instrument. It also provides strong support for a water vapor channel on the Visible Infrared Imager/Radiometer Suite (VIIRS) that will be flown on the National Polar-Orbiting Operational Environmental Satellite System (NPOESS).

Over the past year Aqua MODIS data has been added to the real-time processing system at CIMSS, and ECMWF began assimilating the near real-time Terra MODIS winds in their operational forecast system (January 2003). Additionally, winds are now generated with the NOAA-17 AVHRR along with NOAA-15 and -16.

Improvements in height assignment, parallax corrections, spatial scale, and the use of additional spectral channels are under investigation. Progress in any of these areas can be expected to increase the impact of the MODIS polar winds on model forecasts. At present Terra and Aqua MODIS data streams are processed separately. However, after a correction for parallax has been implemented, it will be possible to combine both Terra and Aqua data for an improved temporal sampling frequency.

Acknowledgments. This work was supported by NOAA grant NA07EC0676 and NASA grant NAS5-31367.

References

Francis, J.A., 2002, Validation of reanalysis upper-level winds in the Arctic with independent rawinsonde data, *Geophysical Research Letters*, 29(9).

Bormann, N., J.-N. Thépaut, 2003, Impact of MODIS polar winds in ECMWF's 4DVAR data assimilation system. EUMETSAT/ECMWF Fellowship Research Report 13, ECMWF, Reading, U.K., 13pp., submitted to *Mon. Wea. Rev.*

Key, J., D. Santek, C.S. Velden, N. Bormann, J.-N. Thepaut, L.P. Riishojgaard, Y. Zhu, and W.P. Menzel, 2003, Cloud-drift and Water Vapor Winds in the Polar Regions from MODIS, *IEEE Trans. Geosci. Remote Sensing*, 41(2), 482-492.

Menzel, W.P., 2001, Cloud tracking with satellite imagery: From the pioneering work of Ted Fujita to the present. *Bull. Amer. Meteorol. Soc.*, 82(1), 33-47.

Merrill, R., 1989, Advances in the automated production of wind estimates from geostationary satellite imageing. *Proc. Fourth Conf. Satellite Meteorol.*, San Diego, CA, Amer. Meteorol. Soc., 246-249.

Nieman, S.J., W.P. Menzel, C.M. Hayden, D. Gray, S.T. Wanzong, C.S. Velden, and J. Daniels, 1997, Fully automated cloud-drift winds in NESDIS operations. *Bull. Amer. Meteorol. Soc.*, 78(6), 1121-1133.

Schmetz, J., K. Holmlund, J. Hoffman, B. Strauss, B. Mason, V. Gaertner, A. Koch, and L. van de Berg, 1993, Operational cloud motion winds from METEOSAT infrared images. *J. Appl. Meteorol.*, 32, 1206-1225.

Velden, C.S., C.M. Hayden, S.J. Nieman, W.P. Menzel, S. Wanzong, and J.S. Goerss, 1997, Upper-tropospheric winds derived from geostationary satellite water vapor observations. *Bull. Amer. Meteorol. Soc.*, 78(2), 173-196.

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 1: Dataset methodology, description and case analysis. *Mon. Wea. Rev.*, 126, 1202-1218.