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REAL-TIME DERIVATION OF CLOUD DRIFT AND WATER VAPOR WINDS IN THE POLAR REGIONS FROM MODIS DATA

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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 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 this paper we present a fully automated methodology for estimating 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. The retrieval methodology is discussed and case study results are presented. The case study dataset is used in numerical weather prediction (NWP) model impact studies, where the effect of the MODIS winds on forecasts is assessed. Also, the status of the real-time production of MODIS winds is presented. Additional details are provided in Key et al. (2002).

2. WIND RETRIEVAL METHODS

Cloud and water vapor tracking with MODIS data is based on the established procedure used for the GOES, which is essentially that 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. The lowest (coldest) brightness temperature in the infrared window band, generally indicating cloud, within a target box is isolated and local gradients are computed. Gradients that exceed a specified threshold are classified as targets for tracking. For water vapor target selection, local gradients are computed for the area surrounding every pixel rather than the single pixel with the minimum brightness temperature in a box. 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 semi-

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transparent clouds. In our case study, the U.S. Navy Operational Global Atmospheric Prediction System (NOGAPS) model with 1.0 degree spatial resolution and 13 vertical levels was used.

The H_2O-intercept method of height determination can be used as an additional metric. 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).

3. APPLICATION

A 30-day case study has been completed. The study period is 05 March - 03 April 2001. MODIS Level 1B data from the Terra satellite were acquired from NASA's Goddard Distributed Active Archive Center (DAAC). The 1 km image data were normalized and de-striped to reduce the effect of detector noise and variability. Two to four 5-minute granules from each orbit were remapped into a polar stereographic projection at 2 km resolution and composited with the Man computer Interactive Data Access System (McIDAS). The resulting images are 2800 x 2800 pixels in size. Winds were derived from successive image triplets of the water vapor (band 27) and IR window (band 31) channels. Approximately 25,000 quality-controlled vectors, on average, were produced per day at each pole for the 30-day study period.

There are two approaches to quantitatively assessing the quality of the wind vectors: comparing the satellite-derived winds with collocated rawinsonde observations, and evaluating their impact on numerical weather prediction. NWP studies are described in the next section. Statistics from comparisons with rawinsondes can provide a measure of product quality over time and can aid in the determination of observation weights used in objective data assimilation. In the 30-day case study, the root-mean-square (RMS) difference between the satellite winds and rawinsonde observations, averaged over all vertical levels, is 8.11 m/s with a speed bias of –0.58 m/s (satellite wind speed less than rawinsonde). The RMS differences include errors in rawinsonde measurement and reporting, which are on the order of 3 m/s (Hoehne, 1980). The RMS and bias values are similar to, but slightly larger than, those for geostationary satellite winds. This is expected from the larger temporal sampling intervals. The best results are obtained for the middle and upper troposphere. Low-level RMS differences are larger relative to the mean wind speed. The verifying observational network is sparse in the polar regions so that these statistics do not necessarily apply uniformly to the entire Arctic and Antarctic. The approximately 27,000 collocations of satellite winds with rawinsonde represent less than 2% of the 1.5 million vectors in the dataset.

4. IMPACT OF MODIS WINDS ON NWP FORECASTS

Given the sparse rawinsonde observation network in the polar regions and the relative importance of high-latitude wind observations in NWP forecasts noted by Francis (2002), satellite-derived polar wind information has the potential to improve forecasts in polar and sub-polar areas. Model impact studies using the 30-day case study dataset were performed at ECMWF and the NASA Data Assimilation Office (DAO). Both groups reported significant improvements in forecast skill not only in the Arctic region, but also over the Northern Hemisphere. The impact was also positive over the Antarctic, but not as strong. More details on these results can be found in Key et al. (2002), Zhu and Riishojgaard (2003), and Thépaut and Bormann (2003).

5. REAL-TIME PROCESSING

On 2 July 2002 we began routinely generating MODIS-derived winds from Terra in near real-time. The delay from real-time is usually 5 to 8 hours (Fig. 1). This lag is due to:

- 2 to 5 hour delay before MODIS data is available
- 1/2 hour to transfer data from NASA Goddard

- 1 hour to process winds
- 1-1/2 hour offset due to assigning vector to middle image time

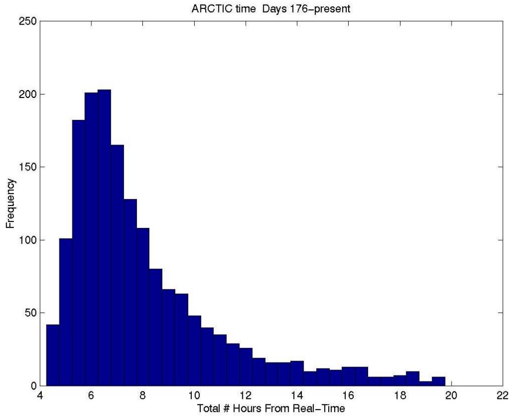

Fig. 1 Histogram of the time delay from real-time that the Arctic MODIS winds are available. Time period covers three months beginning in June 2002.

With recent changes in the data files from the GSFC (now compressed) and more computing power at SSEC for deriving the winds, we anticipate a reduction of about an hour for the overall process. Even with an 8-hour delay, the ECMWF is able to use approximately 70% of the total winds generated.

The ECMWF, NASA/DAO, Navy, and the Canadian Meteorological Centre are retrieving the MODIS-derived winds in real-time. Results of their use of the data will be presented at the conference.

6. CONCLUSIONS

This study has demonstrated the feasibility of deriving tropospheric wind information at high latitudes from polar-orbiting satellites. The cloud and water vapor feature tracking methodology is based on the algorithms currently used with geostationary satellites, modified for use with the polar-orbiting MODIS instrument on the Terra and Aqua 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.

Nevertheless, model impact studies with the MODIS polar winds conducted at ECMWF and the NASA Data Assimilation Office are very encouraging. A 30-day case study dataset was produced and assimilated in the ECMWF model and the DAO assimilation system to assess forecast impact. 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).

Improvements in height assignment, parallax corrections, 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. The impact of these wind data sets should be further enhanced with the use of 4D variational data assimilation techniques. Near real-time processing of MODIS data has begun and with the addition of Aqua MODIS data expected soon, we will have even better coverage of the polar regions on a daily basis.

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