1.6 IMPACT OF POLAR CLOUD TRACK WINDS FROM MODIS ON ECMWF ANALYSES AND FORECASTS

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1. Introduction

Polar wind analyses for numerical weather prediction (NWP) systems have long been hampered by a lack of wind observations in polar regions. Independent rawinsonde data from Arctic field experiments, for instance, indicate considerable biases in the polar wind fields of NCEP/NCAR and the ECMWF Reanalyses (e.g., Francis 2002).

This study investigates the impact of a new satellite-derived polar wind data set on ECMWF analyses and forecasts. These new observations provide unprecedented observational coverage over the polar regions (i.e., beyond 60N and S, respectively; e.g., Fig. 1). They are derived at the Cooperative Institute for Meteorological Satellite Studies (CIMSS) at the University of Wisconsin-Madison by tracking structures in subsequent swaths from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument flown on the Terra satellite. They complement similar Atmospheric Motion Vectors (AMVs) commonly derived by tracking features in geostationary satellite data within 60N and S.

2. Data and experiments

This study is based on an initial test dataset of MODIS AMVs, covering the 30 day period 5 March 2001—3 April 2001.

2.1 *MODIS polar winds*

Cloud and water vapor tracking with MODIS data is based on the established automated procedure used for geostationary satellites at CIMSS (e.g., Nieman et al. 1997, Velden et al. 1997). 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. MODIS swaths from the Terra satellite are available approximately every 100 min over the polar regions, allowing the use of about 12 image triplets for feature tracking per day.

The derivation of the wind vector is as follows. After remapping the orbital data, potential tracking features are identified through gradient-based methods. The tracking method then searches for the minimum of the sum of squared radiance differences between the target and predefined search boxes in two subsequent images. Displacement vectors are derived for each of the two subsequent images. They are then subject to consistency checks which eliminate spurious wind vectors.

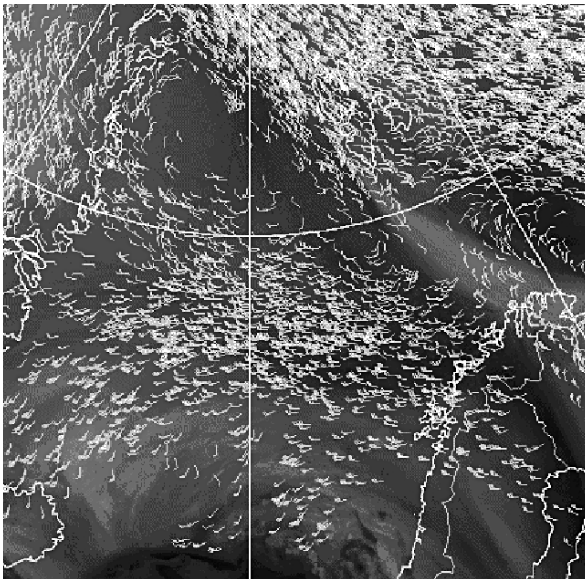

Figure 1: Sample of MODIS WV wind coverage over the North Polar Sea between Greenland and Norway for 5 March 2001, overlaid over MODIS WV imagery.

Wind vector heights are assigned by first determining a representative temperature of the feature using either the infrared window method or the H_2O – intercept method (e.g., Frey et al. 1999, Schmetz et al.1993, Menzel et al.1983). A height is assigned by comparing this temperature to a vertical profile from an NWP forecast, in the present study taken from the U.S. Navy Operational Global Atmospheric Prediction System (NOGAPS) model with 1.0º spatial resolution and 19 vertical levels.

The final data set is the product of a further rigorous postprocessing and quality-control step, based on a 3-dimensional objective recursive filter (e.g., Velden et al. 1997).

2.2 *Assimilation experiments*

Assimilation impact experiments with the MODIS winds test data have been performed using ECMWF's 3-dimensional variational (3DVAR) assimilation system with 6-hourly analyses based on

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the First Guess (FG) at the appropriate observation time. The model and analysis resolution was T159 (approx. 125 km), with 60 levels in the vertical. 10-day forecasts were run from each 12 UTC analysis. The experiments cover the 30 day period 5 March 2001 12 UTC – 3 April 2001 12 UTC. The following experiments were performed:

CTL: Control experiment with passive monitoring of MODIS winds. All other observational data were used as in operations.

MODIS: Experiment with assimilation of MODIS winds (everything else as CTL). Over land we used MODIS IR and WV winds above 400 hPa only. Over sea, we used IR winds above 700 hPa and WV winds above 550 hPa. The restrictions for lower level winds were chosen after earlier trial experiments indicated poorer quality of the lower level winds, most likely a result of height assignment problems over high orography and ice. All other settings for the MODIS winds were as for operational AMVs from geostationary satellites (e.g., Rohn et al. 2001): the winds were thinned to 1.25° resolution, and quality control was based on an asymmetric check against the FG. This check rejects more of the slower winds to address the slow bias common in extra-tropical AMVs (e.g., Bormann et al. 2001).

3. Results

Tables 1 and 2 give the monitoring statistics from a passive comparison of the MODIS IR and WV cloud winds, respectively, against the FG used in the assimilation. The normalized RMS vector difference (NRMSVD) shown is defined as the RMS vector difference divided by the mean wind speed. For most levels and regions the NRMSVD and the speed bias are similar or slightly poorer than for other extra-tropical satellite-derived winds currently assimilated by ECMWF. This highlights the acceptable quality of the MODIS winds. The current exception is at lower levels in the Antarctic region where the monitoring statistics reveal large RMS vector errors and relatively strong, fast speed biases (reaching 1.3 m/s). These poorer statistics motivated the cautious use of the MODIS winds at lower levels.

Globally, the fit of other observations against the FG or the analysis is not significantly altered when MODIS winds are assimilated. This is also true locally for wind observations from rawinsondes, pilot reports, or aircraft observations for the Arctic region (not shown). This lack of change of the FG fit to other observations suggests that the MODIS winds do not disagree with the rest of the observing network in the Arctic and is thus a positive aspect. Over the Antarctic region, a degradation of the FG fit against rawinsondes suggests some disagreement between the MODIS winds and rawinsonde winds (not shown), at least in the coastal areas where most of the rawinsonde observations are made. The vertical and horizontal resolution of the forecast fields used in the height assignment for MODIS winds, particularly in temperature inversion regimes, are likely a contributing factor. Future winds derivation will employ the full resolution ECMWF fields in the data processing, allowing an evaluation of the impact of forecast data on the winds derivation.

Table 1: First Guess statistics for all IR MODIS AMVs from experiment CTL.

Level	*South. Hem.*	*North. Hem.*
Low (below 700 hPa)		
NRMSVD	0.64	0.41
Speed bias (OBS-FG) [m/s]	1.36	0.54
Mean model speed [m/s]	9.66	12.80
N	15,319	62,088
Mid (400—700 hPa)		
NRMSVD	0.49	0.38
Speed bias (OBS-FG) [m/s]	0.56	0.30
Mean model speed [m/s]	14.43	14.70
N	90,462	78,892
High (above 400 hPa)		
NRMSVD	0.40	0.37
Speed bias (OBS-FG) [m/s]	-1.38	0.31
Mean model speed [m/s]	21.47	19.49
N	19,037	3,490

Table 2: First Guess statistics for all WV cloud MODIS AMVs from experiment CTL.

	South. Hem.	*North. Hem.*
Mid level (400—700 hPa)		
NRMSVD	0.60	0.37
Speed bias (OBS-FG) [m/s]	1.39	-0.36
Mean model speed [m/s]	12.55	15.06
N	282,527	207,324
High level (above 400 hPa)		
NRMSVD	0.41	0.34
Speed bias (OBS-FG) [m/s]	-0.51	0.70
Mean model speed [m/s]	21.29	20.86
N	80,083	23,196

The mean polar wind analysis is considerably altered in the experiment with MODIS winds. The differences for the Arctic are largest over the sea ice, with differences up to 3 m/s at all levels. Here, the MODIS winds act to strengthen the circulation at upper levels (e.g., Fig. 2), whereas at lower levels the difference field suggests a weakening of the local circulation. There are some indications that MODIS winds correct deficiencies in the mean Arctic flow field in the model: the u-component bias between the Canadian Arctic profiler data and the FG is slightly improved (not shown).

There is a significant positive impact on forecasts of the geopotential heights when MODIS winds are assimilated, particularly over the Northern Hemisphere. Figure 3 shows the improvement in forecasts of the 1000 and 500 hPa geopotential heights over the Arctic (north of 65^{o} latitude) when the MODIS winds are assimilated. The figure shows the correlation between the forecast geopotential height anomaly and the verifying analysis with the forecasts from the MODIS and the control experiments each validated against their own verifying analyses. The forecast improvements are significant at the 98% confidence level or better (t-test) at most vertical levels for a forecast range of 2-5 days.

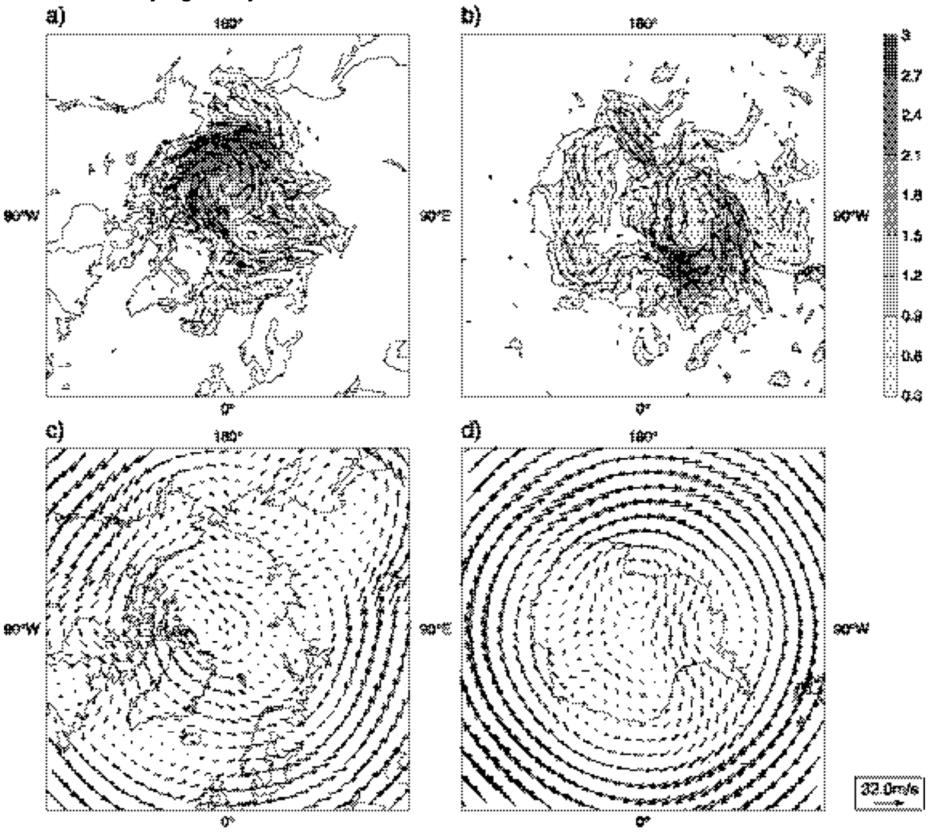

Figure 2: a) Difference between the mean wind analyses from MODIS and CTL at 400 hPa over the Arctic region. Grey shading indicates the length of the difference vector. b) As a), but for the Antarctic region. c) Mean wind analysis at 400 hPa for the CTL experiment over the Arctic region. d) As c), but for the Antarctic region.

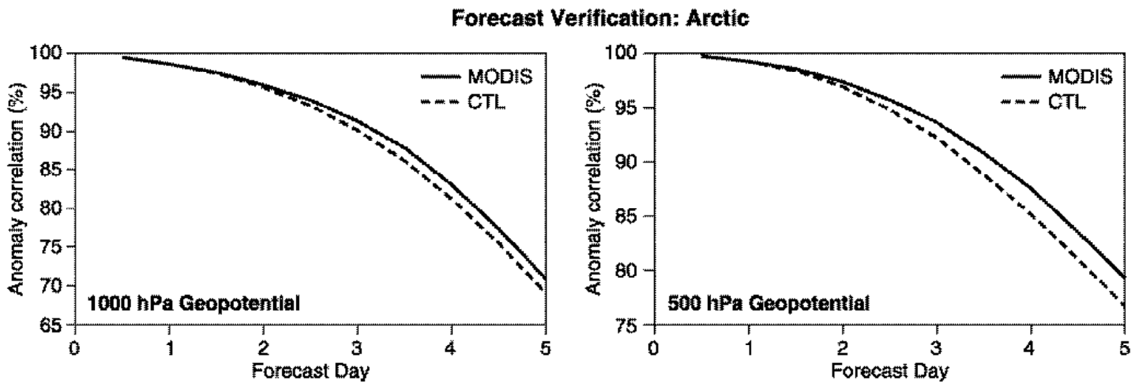

Figure 3. Anomaly correlation as a function of forecast range for the 1000 hPa (left) and 500 hPa (right) geopotential height forecast in the Arctic region for the ECMWF MODIS winds impact experiment (25 cases). The MODIS experiment (solid) and the CTL experiment (dashed) were each verified against their own analyses.

The geopotential height forecast over Antarctica is also improved (not shown) by the inclusion of the MODIS winds, though the impact for the Southern Hemisphere is neutral overall. On the one hand, the less positive impact over the Southern Hemisphere may be related to increased difficulties in the height assignment for the MODIS winds over high and steep orography of the Antarctic continent. On the other hand, verification of forecasts in the Southern Hemisphere is hampered by fewer observations and thus smoother verifying analyses. The addition of MODIS winds is likely to increase the variability of these analyses over the Southern Hemisphere, making an interpretation of forecast scores more difficult. Further investigations and the use of other verification strategies are required in this respect.

4. Discussion and Conclusions

This study investigated the impact of a 30 day test data set of new satellite-derived polar wind observations on ECMWF analyses and forecasts. The new wind observations are derived by tracking structures in subsequent swaths of the MODIS polar-orbiting instrument. Our main findings are:

- The assimilation of the new MODIS winds has a substantial positive impact on ECMWF forecasts over the Northern Hemisphere, particularly the Arctic region. The impact on Southern Hemisphere forecast scores appears mainly neutral. However, some care has to be taken when interpreting forecast scores from data impact studies over the Southern Hemisphere, as the verifying analyses are less controlled by other observations.
- The MODIS winds have a considerable impact on the mean polar wind analysis in the ECMWF system.
- First Guess statistics for lower level winds suggest that height assignment for lower level MODIS AMVs needs further attention, particularly over the Antarctic region.

The results of our first evaluation of the use of MODIS polar winds in a data assimilation system are very encouraging. The new wind observations are indeed capable of correcting deficiencies in the model fields otherwise undetected by the rest of the observing network. The study suggests considerable benefits from a routine derivation and assimilation of MODIS polar winds.

There is scope for further improvements, both in the winds derivation as well as the data assimilation. Improvements in height assignment, parallax corrections, and the use of additional spectral channels in the winds derivation are under investigation. Progress in any of these areas is thought to aid the impact of the MODIS polar winds on model forecasts. The impact of MODIS wind data should be enhanced further with the use of 4D variational data assimilation techniques. Near real-time processing of MODIS data will begin in the near future, providing a robust data set for impact studies and meteorological applications. The addition of Aqua MODIS data to Terra MODIS data will allow for even better coverage of the polar regions on a daily basis.

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