4.2 **ASSIMILATION OF POLAR MODIS ATMOSPHERIC MOTION VECTORS AT ECMWF**

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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.

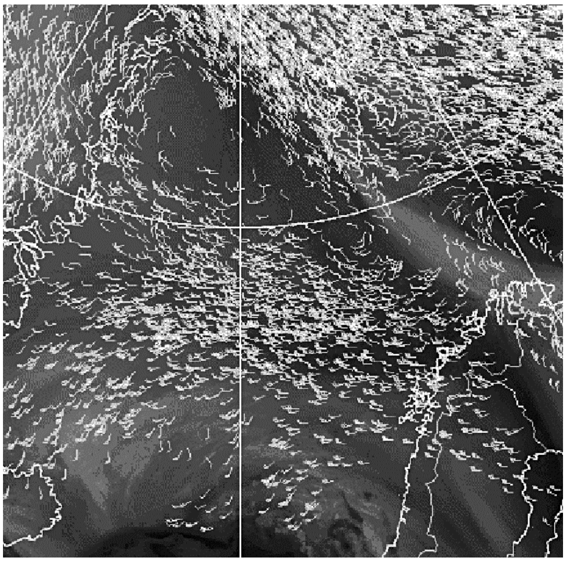

Figure 1: Sample of MODIS WV wind coverage over the North Polar Sea between Greenland and Norway for 5 March 2001, overlaid over MODIS WV imagery.

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2. Data and experiments

2.1 *MODIS polar winds*

Cloud and water vapour 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 (e.g., Fig. 1). A more comprehensive description of the winds derivation can be found in Santek et al. (2003).

2.2 *Assimilation experiments*

Initial assimilation impact experiments with MODIS winds test data had been performed using ECMWF's 3-dimensional variational (3DVAR) assimilation system with 6-hourly analyses based on the First Guess (FG) at the appropriate observation time (see Bormann et al. 2002). More recently, the same period (5 March 2001 12 UTC – 3 April 2001 12 UTC) is being reanalysed using the currently operational ECMWF 4DVAR system (Rabier et al. 2000). A second period in July/August 2002 is currently running at the time of writing. The model resolution is T511 (approx. 40km) while the increments are calculated at T159 (approx. 125 km), with 60 levels in the vertical. 10-day forecasts were run from each 12 UTC analysis. Overall, 52 cases were accumulated for the following experiments:

CTL: Control experiment with passive monitoring of MODIS winds. All other observational data are 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 140 km 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

3.1 *4DVAR forecast impact*

Overall, the first-guess statistics of the MODIS 4DVAR assimilation are very comparable to that of the 3DVAR experiments presented in Bormann et al. (2002). In terms of forecast scores, the impact of MODIS winds that was originally detected in the 3DVAR experiments is confirmed to a somewhat less extent. Fig. 2 shows the improvement in forecasts of the 500 hPa geopotential heights over Europe (Fig. 2a) and Northern Hemisphere (Fig. 2b) when 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. The forecast improvements are significant at the 90-95% confidence level (t-test) at a forecast range of 8 days.

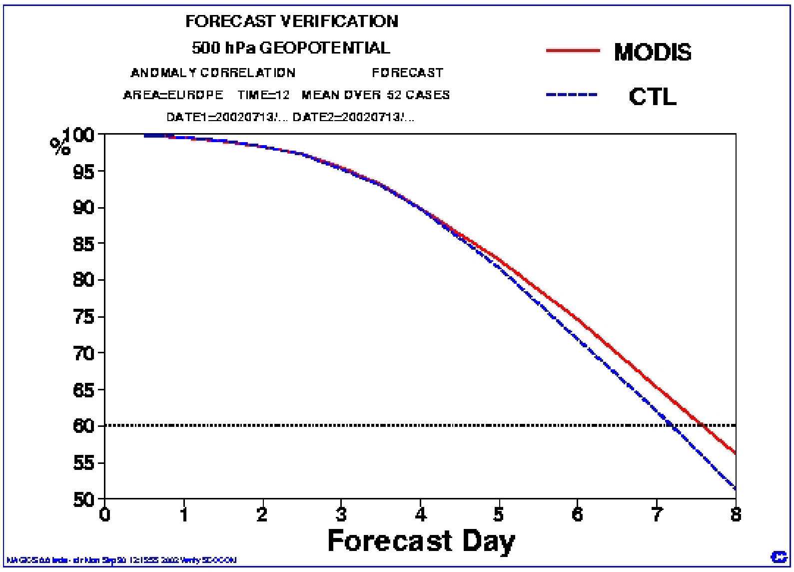

Figure 2: a) Anomaly correlation as a function of forecast range for the 500 hPa geopotential height forecast in the European region for the ECMWF MODIS (solid red) and CTL (dashed blue) experiment (52 cases).

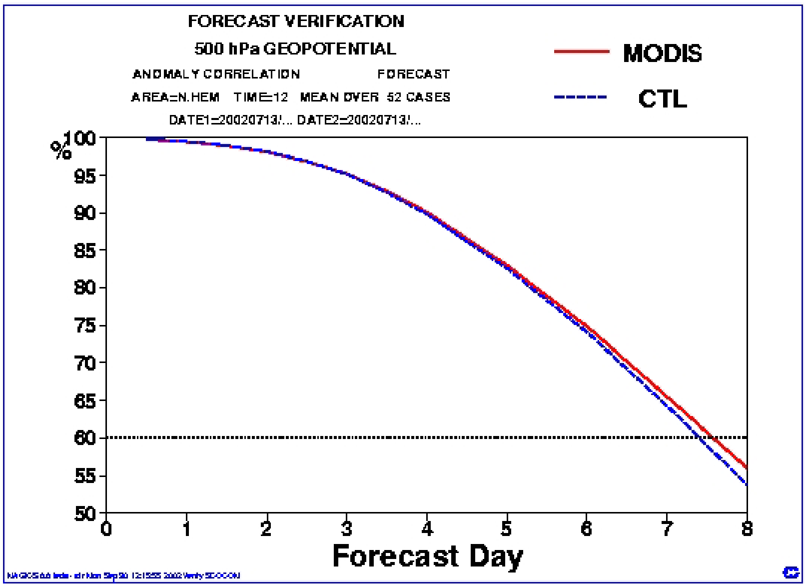

Figure 2: b) Idem as 2:a) but for the Northern Hemisphere.

The geopotential height forecast over the poles is also slightly improved (not shown) by the inclusion of the MODIS winds, though the impact is not as spectacular as for the early 3DVAR experiments. One possible explanation is that 4DVAR is doing a better job at assimilating other data (such as ATOVS) in a dynamically consistent way and therefore already constrains reasonably well the wind field. In that sense, MODIS winds lose the "uniqueness" they had in the 3DVAR context. However, the overall impact of MODIS winds in the ECMWF 4DVAR system is very encouraging.

3.2 *3DVAR forecast case study*

To further highlight the forecast impact of the MODIS polar winds we will now discuss a sample forecast from our 3DVAR experiment. This forecast was initialized 15 March 2002 12 UTC. The 5 day forecast of the 500 hPa geopotential for the MODIS and the CTL experiment can be seen in Fig. 3, together with the verifying analysis.

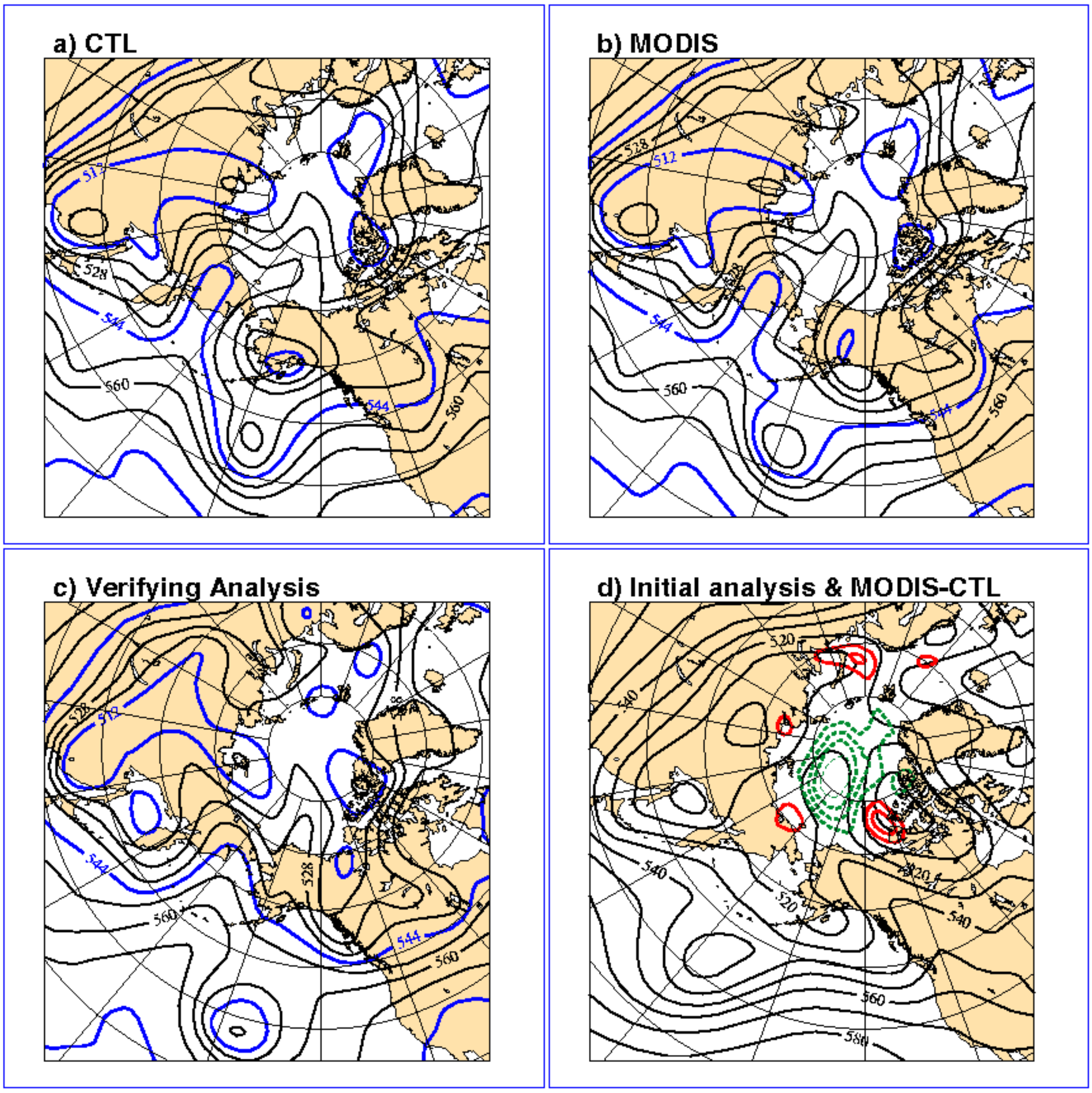

Figure 3: a) Sample 5-day forecast of the 500 hPa geopotential height [gdm] from the CTL experiment, initialised 15 March 2001 12 UTC. b) As a), but for the MODIS experiment. c) Verifying analysis for a) and b) (from the MODIS experiment). d) Initial analysis of the 500 hPa geopotential height [gdm] for 15 March 2001 12 UTC from the MODIS experiment (black contours). Also shown are the differences between the MODIS and the CTL analysis, with positive differences in red and negative differences in green (8 gdm contour interval).

The two forecasts show considerable differences in the Alaskan region, while changes over other areas appear small. The CTL experiment develops a deeper trough over south-west Alaska, whereas the MODIS experiment indicates a northerly flow in this region, in much better agreement with the verifying analysis. These forecast differences are associated with large differences in snowfall forecasts over Southern Alaska (not shown).

The forecast differences over these higher mid-latitudes can be traced back to differences in the MODIS and the CTL analyses over the Arctic region (Fig. 3d). The CTL analysis positions the trough over Northern Canada and the Beaufort Sea slightly more westward and indicates somewhat higher geopotential height values over extended areas around the pole and the Beaufort Sea. These analysis differences propagate south-westward during the forecast and subsequently lead to the large differences over Alaska for the day 5 forecast. Further investigations reveal that the analysis differences are associated with a strong tropopause fold which appears overdeveloped in the CTL analysis (not shown).

4. Discussion and Conclusions

This study investigated the impact 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 significant positive impact on ECMWF forecasts over the Northern Hemisphere.
- 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 results of our 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 an operational assimilation of MODIS polar winds. It is worth mentioning that CIMSS is now routinely producing MODIS winds that can be accessed by NWP centres.

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 by an improved quality control that has been designed so far in a very conservative way. The addition of Aqua MODIS data to Terra MODIS data should allow for even better coverage of the polar regions on a daily basis.

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