A VISUALIZATION OF THE IMPACT OF MODIS-DERIVED POLAR WINDS ON GLOBAL FORECASTS

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ABSTRACT

The use of Atmospheric Motion Vectors (AMVs) in NWP (Numerical Weather Prediction) models continues to be an important source of information in data sparse regions. These AMVs are derived from a time-sequence of images from geostationary and polar orbiting satellites. NWP centers have documented positive impact on model forecasts not only in regions where the AMVs are measured, but elsewhere as well. One example is the effect of the Moderate Resolution Imaging Spectroradiometer (MODIS) polar winds on forecasts in the middle and lower latitudes.

Using a pre-operational version of the National Centers for Environmental Prediction's (NCEP) Global Forecast System (GFS), an experiment was run during August and September 2004, with and without the MODIS polar winds. Several cases within this period have been analyzed to determine how winds poleward of 65 degrees latitude affect the height and wind fields in lower latitudes. Two possible mechanisms were considered: a) an adjustment in the mass field by the three-dimensional variational (3DVAR) assimilation system and b) dynamics in the vicinity of the polar jet stream. By using a combination of model analyses and forecasts, with sophisticated visualization techniques, impacts to global model fields due to these two effects are examined.

1. Introduction

The use of satellite-derived Atmospheric Motion Vectors (AMVs) in NWP (Numerical Weather Prediction) models continues to be an important source of information in data sparse regions. These AMVs are derived from a time-sequence of images from geostationary and polar orbiting satellites. NWP centers have documented positive impact on model forecasts not only in regions where the AMVs are measured, but elsewhere as well. One example is the effect of the Moderate Resolution Imaging Spectroradiometer (MODIS) polar winds on forecasts in the middle and subtropical latitudes (Key et al, 2003; Velden et al 2005). The improvements were noted especially in the three- to five-day forecasts and forecast bust situations (Bormann and Thépaut, 2004; Cress, 2004; LeMarshall et al, 2004).

The MODIS winds are only derived poleward of 65 degrees latitude. What are possible explanations for this global impact? Two basic possibilities are investigated: a) an adjustment in the mass field by the three-dimensional variational (3DVAR) assimilation system and b) dynamical considerations in the vicinity of the polar jet stream.

The output of two experiments was examined for possible mechanisms that propagate wind information into lower latitudes. These were side-by-side experiments, with and without the MODIS winds, run for several weeks.

- A pre-operational version of the National Centers for Environmental Prediction's (NCEP) Global Forecast System (GFS) was run for a six week period. This experiment began on 10 Aug 2004.
- The Navy Operational Global Atmospheric Prediction System (NOGAPS) model runs are for a similar season, but in 2005.

A third experiment was a GFS model run assimilating global Advanced Microwave Sounding Unit (AMSU) radiances for a similar season, but in 2003. This is used as a comparison to better understand the visualization techniques and to see how the fields are impacted with a different data type.

Since these three experiments are for different years, but for the same season, a direct comparison of the difference features (differences in model analyses and forecasts, with and without the MODIS winds or AMSU radiances) can not be done. Rather, the *patterns* of the difference features in the three experiments are examined.

2. 3DVAR Considerations

To determine the effect of the 3DVAR assimilation, analyses very early in the experiment are examined to see if adding data in the polar regions affects the model fields in other areas. This is only for the GFS MODIS winds experiment.

Figure 1 depicts the speed difference at 800 hPa between the model run with and without the MODIS winds. These are global images with the dateline in the middle. North and South America are regions on the right hand side showing little difference (relatively flat). The yellow color is close to a zero difference; brown to black is up to a +7 m s-1 difference; the transition from green to blue is from -1 to -6 m s-1 difference. A positive difference indicates the model run with MODIS winds has higher wind speeds at that location. The contour lines are 800 hPa geopotential heights.

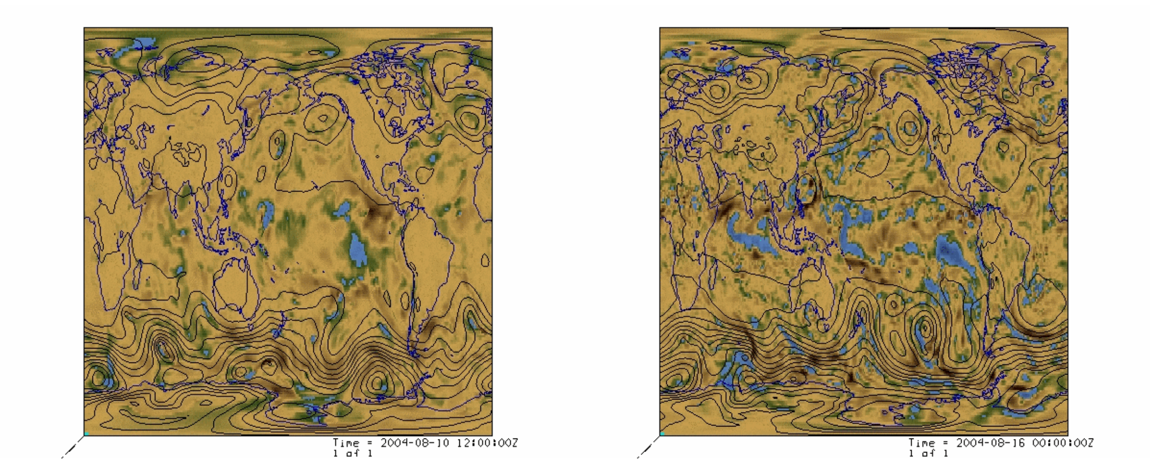

***Figure 1*: Speed difference (shaded) at 800 hPa with 800 hPa geopotential height contours. (a) 12 hours into the experiment. (b) 6 days into the experiment.**

Figure 1a is the speed difference in the analysis 12 hours into the experiment at 800 hPa. Even though this is only 12 hours into the model run, significant differences are found from the polar regions to the tropics. Because of the adjustments to observations in a 3DVAR, the effects of the MODIS winds can be found in regions away from the actual measurements and more immediate than typical wave propagation would suggest. The biggest effect is in regions where there are no observations, most notably the lack of radiosondes. Note that there is little difference over the land regions. Figure 1b is 6 days into the model run. There is finer-scale structure to the differences with the largest differences in the Roaring 40s (southern hemisphere mid-latitudes) and in the ITCZ across the Pacific and into the Indian Ocean.

3. Dynamical Effects

When winds are assimilated into a numerical model system, an adjustment to the mass field takes place. Basically, this is because of the relationship of the gradient of the geopotential height (or mass) to the geostrophic wind. Also, the change in the geopotential height requires an adjustment to the temperature structure for the thermal wind relationship to hold. To determine impact on the analyses and forecasts from assimilating MODIS winds, differences in the 1000-500 hPa thickness fields between the control and MODIS wind model runs are computed. Thickness was chosen instead of geopotential height because other comparisons were done with the impact due to AMSU radiances, which has a more direct effect on the temperature field.

GFS MODIS Winds Experiment

Figure 2 is an example of thickness difference field, with and without the MODIS winds, about one month into the GFS experiment. The largest differences are found poleward of the jet streams, especially in the southern hemisphere winter, and over data void regions, such as the oceans. The Global Data Assimilation System (GDAS), used as input into the GFS, results in adjustments to the mass field not only in the region where the observations are located (poleward of 65 degrees latitude for the MODIS winds) but also in other areas where other data is not present to constrain the change (over low-latitudes in the western Pacific Ocean, for example). This results in a global change to the analysis, due only to the MODIS winds.

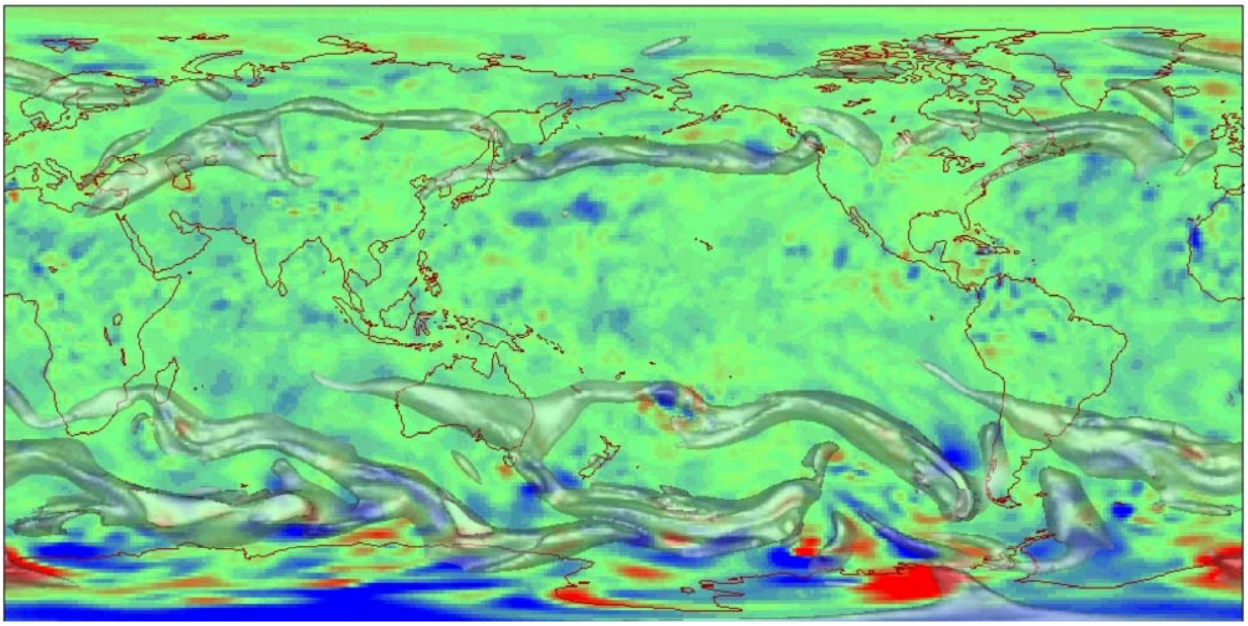

***Figure 2*: Thickness difference, with and without MODIS winds for the GFS 0000 UTC analysis on 11 Sep 2004. This is about one month into the experiment. The color range from blue to red denotes a range of -30 to +30 gpm difference. Red indicates that the MODIS winds increase the thickness (warm the layer). Near zero difference is in green. The 30 m/s wind speed, representing the jet stream, is in transparent white.**

Although the differences in the analysis in the north are much less than those in the southern hemisphere, Figure 3 illustrates how the thickness difference increases in the forecast. The magnitude of the differences in the thickness fields increased over the 5 days, primarily in and around the jet. The alternating red and blue regions represent a changing phase in the waves between the control and the forecast containing the MODIS winds: the red over the north central US is the region where the MODIS winds have slowed the advance of the ridge, the blue over the plains is where the trough is also slowed. The alternating pattern along the jet suggests the MODIS winds have slowed the progression of all waves in the jet stream region. These effects are felt into mid-latitudes as the trough digs into the Great Plains. Occasionally, the timing of a trough can affect when and where a Gulf of Mexico hurricane will make a turn more northward. The small cyclone over the southeast US coast is a forecast position of Hurricane Ivan, which actually tracked further west and hit Gulf Shores, Alabama. In this case, the separate red and blue circular regions in the Carolinas represent the difference in the forecast position of Ivan. The slowing of the overall wave pattern in the MODIS winds run allows the track of the hurricane to stay further west, represented by the red region.

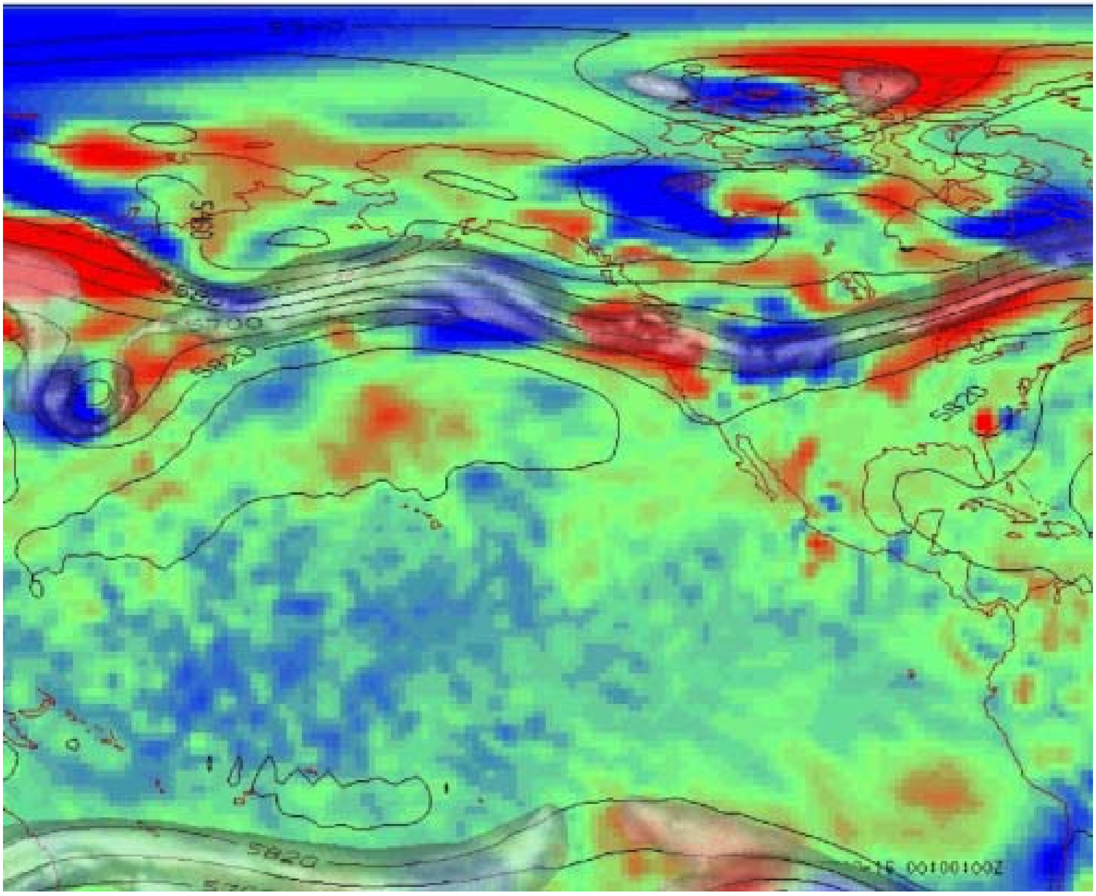

***Figure 3*: 120 hour GFS forecast differences of the 1000-500 hPa field, with and without the MODIS winds. This forecast is valid at 0000 UTC on 16 Sept. 2004. Same color scheme as Figure 2. The black contours are 500 hPa geopotential heights from the run including the MODIS winds.**

<u>GFS AMSU Radiance Experiment</u>

Figure 4 is a similar depiction of the 1000-500 hPa thickness difference shown in Figure 2, except for the AMSU radiance experiment. While the MODIS winds are only observed in the polar regions, the AMSU radiances are global. It is interesting to note that the primary differences in both experiments are in the polar jet regions. But as expected, the AMSU radiances have a larger impact over the oceanic region (where the majority of the observations are) than the MODIS winds.

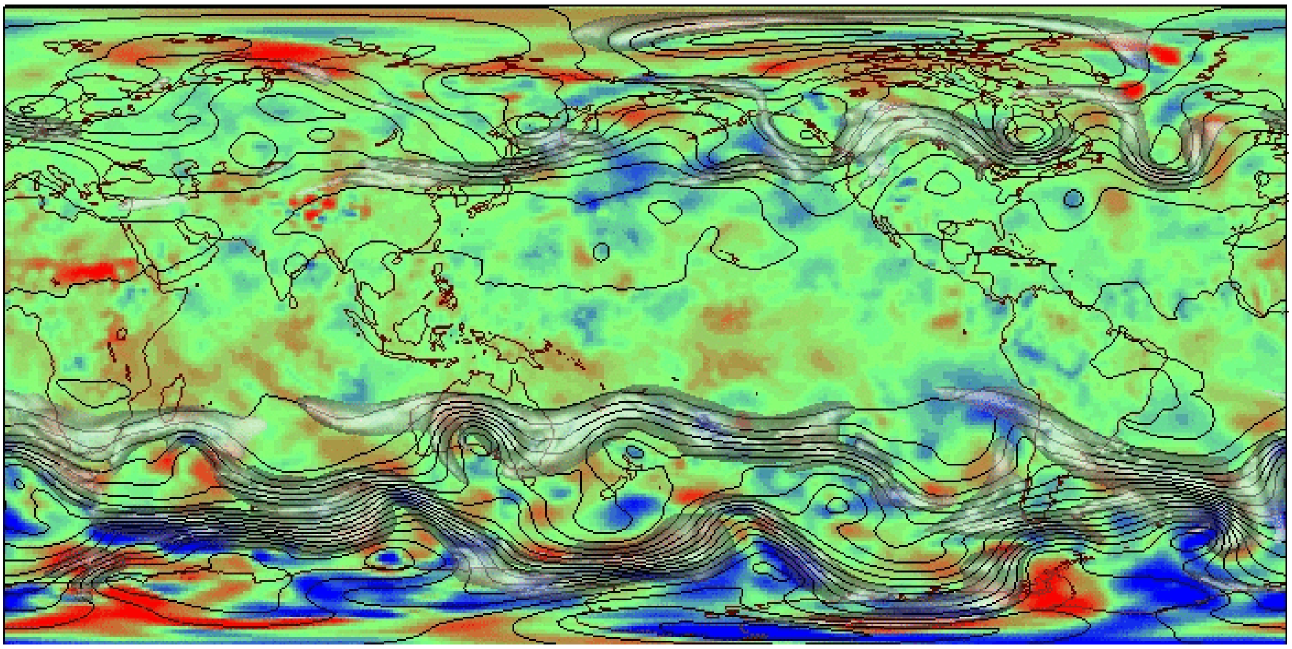

***Figure 4*: 0000 UTC on 23 Aug 2003. This is an analysis about two weeks into an AMSU denial experiment. The color scheme is the same as Figure 2, with 500 hPa geopotential heights as black contours.**

NOGAPS MODIS Winds Experiment

Figure 5 is similar to Figure 2, but for the NOGAPS MODIS winds experiment. This is a typical difference field at a few weeks into this experiment, which was run in August 2005. Like Figure 2, the differences are global. But, unlike the GFS experiment, the NOGAPS differences in the southern hemisphere are not as large throughout the jet stream region. Also, differences in the mid- and lower-latitudes are not as large as those in the GFS experiment. Other cases are being looked into to determine if this due to different synoptic situations and/or if it's a characteristic of the assimilation system.

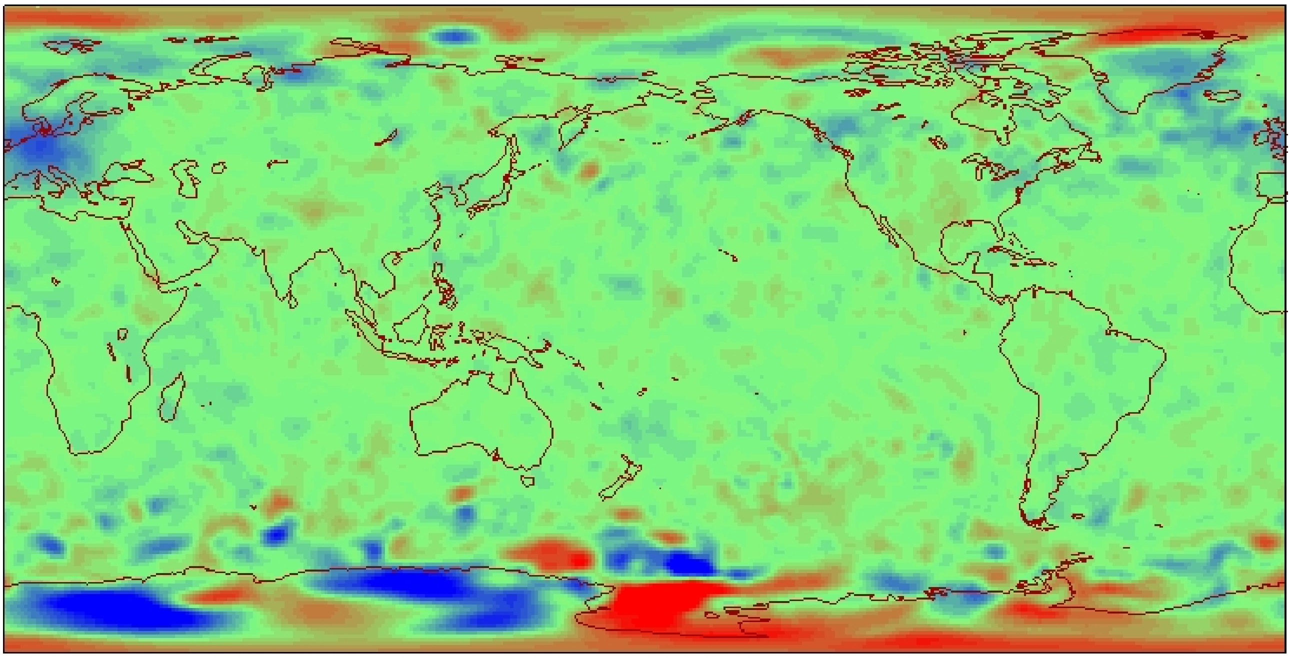

***Figure 5*: NOGAPS analysis on 0000 UTC on 17 Aug 2005. This is one week into the MODIS winds assimilation.**

4. Summary

The following points summarize the results to date:

- The specific example for 11 September 2004 shows that the addition of polar winds has an effect on the analysis of the waves in the jet stream, even though the data is not directly assimilated in those regions. The resulting forecasts slow the overall wave propagation, which in turn permits Hurricane Ivan to track further west. Other cases are being investigated.

- The MODIS winds experiments may be the first case of assimilating high-resolution tropospheric data that is *only* available in the polar regions. It highlights the importance of polar observations for improving global forecasts.

- The geographic extent of the MODIS AMV forecast impact may be dependent on the assimilation system, as evidenced in the differences between the GFS and NOGAPS experiments. More work is needed to substantiate this.

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5. References

Bormann, N., and J-N. Thépaut, 2004. Impact of MODIS Polar Winds in ECMWF's 4DVAR Data Assimilation System*. Mon. Wea. Rev.*, 132, 929-940.

Cress, A., 2004. Impact of MODIS winds on the global NWP system of the German weather Service. Proc. Of the Seventh Int. Winds Workshop, Helsinki, Finland, WMO [Available online at www.eumetsat.int/].

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.

LeMarshall, J., R. Seecamp, A. Rea, M. Dunn, J. Jung, J. Daniels and C. Velden, 2004. Error characterization and application of atmospheric motion vectors over Australia and high latitudes, Proc. Of the Seventh Int. Winds Workshop, Helsinki, Finland, WMO [Available online at www.eumetsat.int/].

Palmén, E., and C. W. Newton, 1969: Atmospheric Circulation Systems: Their Structure and Physical Interpretation. Academic Press, 603 pp.

Velden, C., and many co-authors, 2005: Recent innovations in deriving tropospheric winds from satellites. *Bull. Amer. Meteor. Soc.*, 86, 205-223.