THE IMPACT OF MODIS WINDS ON AMPS WRF FORECASTS

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1. INTRODUCTION

The Antarctic Mesoscale Prediction System (AMPS) (Powers et al. 2003) provides numerical forecasts over Antarctica in support of the flight operations and scientific activities of the United States Antarctic Program (USAP). While AMPS has historically used the MM5, it is now also running a version of the Weather Research and Forecasting (WRF) model called the Advanced Research WRF (ARW) (Skamarock et al. 2005). In addition to providing guidance to the USAP forecasters at McMurdo Station (see Fig. 2(c)), AMPS serves a broad range of international scientific and logistical activities across Antarctica.

A challenge to Antarctic NWP has been the lack of conventional (e.g., surface and radiosonde) data over the Southern Ocean and the continent. Satellite measurements can populate the data void, however, and a promising type is the MODIS (Moderate Resolution Imaging Spectroradiometer) wind retrievals (Key et al. 2003). Given the potential for these measurements to enhance polar forecasting (Key et al. 2003; Bormann and Thépaut 2004), this study investigates the impacts of the assimilation of MODIS winds on the ARW in AMPS. Specifically, we present the latest results from two lines of inquiry. The first looks at assimilation experiments involving forecasts of a high-impact weather event, the 15 May 2004 McMurdo windstorm (Powers 2005a; Steinhoff and Bromwich 2005). The second, which is preliminary, considers a month-long period (May 2004) of data assimilation simulations. In both, WRF-Var is employed to assimilate different MODIS datasets. Statistical evaluations reveal differences between the experiments and their significance. While previous work has demonstrated the ability of the ARW to capture the 15 May 2004 case (Powers et al. 2005), this study continues with a statistical examination of MODIS data's influence.

2. BACKGROUND AND EXPERIMENTS

The 15 May 2004 windstorm (Powers et al. 2005; Steinhoff and Bromwich 2005) battered the McMurdo Station area (see Fig. 2(c)) and forced Condition 1 status with sustained winds at over 44 m/s and gusts exceeding 52 m/s. The winds caused significant damage to structures and equipment in and out of town. Figure 1 presents time series of the wind speeds at sites in the McMurdo area. Arrival Heights and Crater Hill (near town) show winds to 50 m/s, while Black Is. recorded winds to 64 m/s. For the longer-term study also considered here, the month of May 2004 was chosen because of the overlap with this targeted case.

The ARW Version 2 (Skamarock et al. 2005) is used with a four-domain, nested-grid setup (Fig. 2). Although the current AMPS spacings are 60 km, 20 km, 6.7 km, and 2.2 km, because prior to November 2005 these were 90 km, 30 km, 10 km, and 3.3 km, the May 15 case experiments have this configuration. For the month-long investigation, a sole 60-km grid is run.

All nesting is two-way interactive. The vertical resolution reflects 32 levels between the ground and the model top at 50 hPa. For the case experiments, the model initialization is at 0000 UTC 15 May 2004. For the month period, initializations are at 0000 and 1200 UTC, for forecasts of 48 hrs.

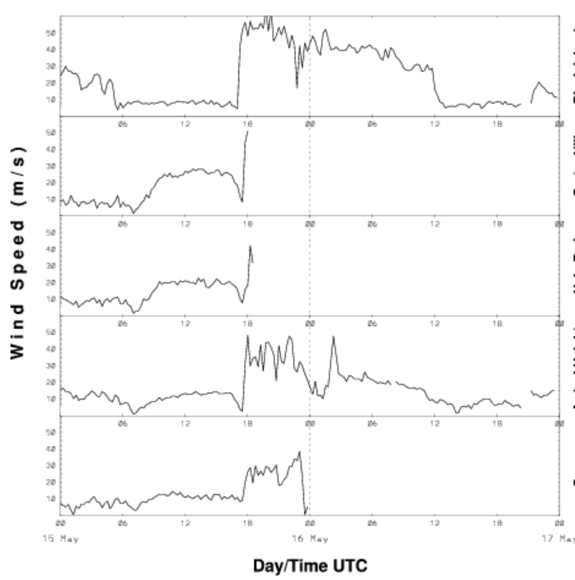

Fig. 1: Observed wind speeds at sites in the McMurdo area. Cosray, Arrival Heights, Helo Pad, and Crater Hill all in the immediate McMurdo vicinity; Black Is. about 34 km south of McMurdo. Scale increments every 10 m/s.

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Initial and boundary conditions are derived from the NCEP Global Forecast System (GFS) model output. The 3-dimensional variational (3DVAR) WRF-Var data assimilation system is used for reanalysis. The observations referred to as “standard” data are the conventional GTS synoptic surface reports, soundings, geostationary winds, ship and buoy observations, pilot and automatic aircraft reports, and AWS observations. The MODIS observations are from CIMSS (Cooperative Institute for Meteorological Satellite Studies of the University of Wisconsin).

For some of the experiments, the MODIS data have been filtered. The filtering follows the suggestion of Key et al. (2003), later applied by Bormann and Thépaut (2004), in which retrieval height, surface type, and source MODIS channel (infrared/IR or water vapor/WV) are considered in accepting a measurement. This suggestion reflects lower confidence in the retrievals in certain regimes. The filtering used here retains the following MODIS observations: over the ocean— IR above 700 hPa and WV above 550 hPa; over land— IR and WV above 400 hPa. Observations outside of these bins are rejected.

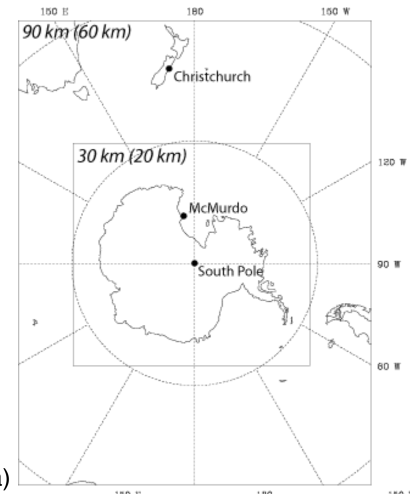
The windstorm case tests employ the WSM-5 microphysics, the Eta PBL scheme, and the Noah LSM. The 90/30/10/3.3-km setup is used, except as noted. The experiments are as follows.

CTRL— No data assimilation
STD— Standard data only
ALL— Standard data plus all MODIS
MOD1— Standard data plus filtered MODIS
MOD1_60— As in MOD1, but with the 60/20/6.7/2.2-km setup

For the May 2004 forecasts the ARW employs Lin microphysics and the YSU PBL scheme. The experiments are as follows.

EXP7— Standard data only
EXP8— Standard data + all MODIS
EXP9— Standard data + filtered MODIS

For both studies, on all grids coarser than 3.3 km/2.2 km the Kain-Fritsch cumulus parameterization is used. Sea ice is assumed at water points where the skin temperature is less than 271.4K.



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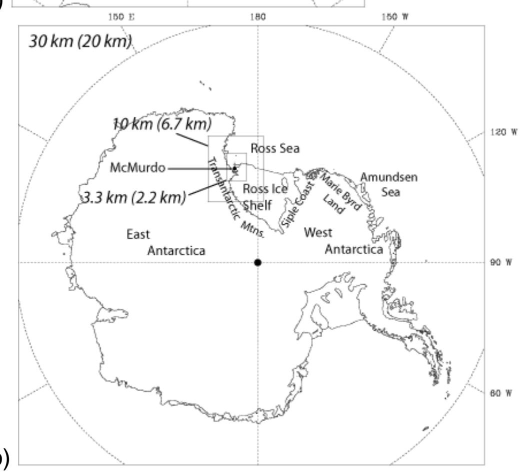

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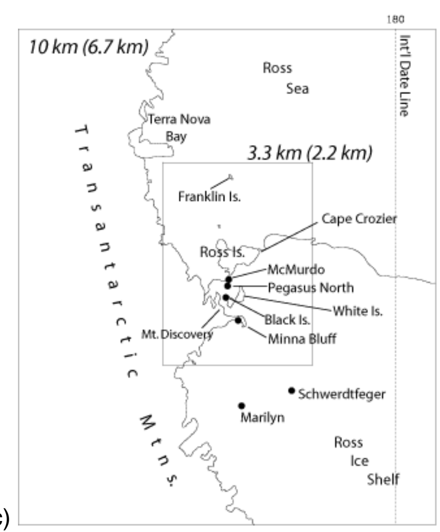


2(c)

Fig. 2: Experiment domains. (a) 90-km/60-km and 30-km/20-km grids. (b) 30-km/20-km grid (outer frame) with 10-km/6.7-km McMurdo/Ross Sea grid and 3.3-km/2.2-km Ross Island grids (c) 3.3-km/2.2-km Ross Is. grids. Dots mark observation/AWS sites.

3. RESULTS

3.1 2004 McMurdo Windstorm Experiments

The 15 May 2004 windstorm was motivated by the passage of a deep synoptic low through the Ross

Island region. This track is shown in Fig. 3. All of the ARW experiments simulate the transit of this low from Marie Byrd Land across the Ross Ice Shelf, but differences in the track and evolution on the mesoscale around Ross Island have a significant impact on the model wind event.

The forecast experiment differences are reflected in Figs. 4(a)–(e), showing observed and model wind speeds for Pegasus North (Fig. 2(c)). The maximum winds at Pegasus occurred from 2000–2300 UTC, with a peak of 39.6 ms^{-1}. The ARW with no data assimilation (CTRL) (Fig. 4(a)) underforecasts and delays the event. The maximum simulated wind speed is 24.6 ms^{-1} (cf. 39.6 ms^{-1}). In contrast to CTRL, STD produces a significantly stronger event at Pegasus (Fig. 4(b)). ALL (Fig. 4(c)) yields a weaker, slightly more delayed episode.

MOD1 (Fig. 4(d)) produces a wind event of timing and magnitude that compares very well with the observations. The strong winds begin after hour 19, and peak at 36.6 ms^{-1} (cf. 39.6 ms^{-1} obsv'd). MOD1 also displays an increase in flow seen in the pre-event period of approximately 1000–1800 UTC. MOD1_60 (Fig. 4(e)) is similar to MOD1, but improved— its peak velocity is slightly higher (37.2 ms^{-1}), and the profile through the event period is overall more faithful to that observed.

The types of results reflected in these wind comparisons have been statistically analyzed. Wind speed verification has been performed at six locations across the Ross Island region: Arrival Heights, Pegasus North, Black Island, Minna Bluff, Marilyn, and Schwerdtfeger (Fig. 2(c)). Wind speed bias (or mean error, ME), mean absolute error (MAE), and root mean square error (RMSE) have been calculated for the six sites for two periods: 0000 UTC 15 May–0000 UTC 17 May and 1200 UTC 15 May–0600 16 May 2004. The former is the whole period of simulation (forecast hrs 0–48), while the latter represents the subperiod centered on the event, from six hours prior through six hours afterward (forecast hrs 12–30).

Table 1 presents average error statistics. Irrespective of the period, experiments STD, MOD1, and MOD1_60 display lower biases, MAEs, and RMSEs. The results suggest that the use of MODIS data without the filter (ALL) degrades the forecast with respect to using conventional data only and that the net performance is comparable to that from assimilating no data at all (CTRL). The negative biases indicate that the ARW experiments all underpredict the wind speeds. This confirms the picture from the results in Fig. 4.

To evaluate the statistical significance of inter-experiment variations, we test on the differences of their mean errors. A one-tailed test is applied. The null hypothesis is that the difference in error means is zero, while the alternate hypothesis is that the error mean of one experiment is less than that of the other. In Tab. 2 the experiment found to have a lower mean error at the 95% level (i.e., null hypothesis rejected and alternate accepted) is shown under the error type (bias, MAE) column. If the null hypothesis cannot be rejected at either the 95% or 90% level, an entry of "I" is given. If the tests indicate that the alternate hypothesis may be accepted for experiment 1 or 2 at the 90% level, then the entry given is $E1_{90}$ or $E2_{90}$ (i.e., for Expt. 1 or Expt. 2 having the lower mean error).

For STD and CTRL the mean wind speed biases (both negative) are statistically significantly different. Furthermore, one can conclude that the bias for experiment STD is significantly less than that of experiment CTRL. In terms of MAEs, however, the errors in STD and CTRL are not distinguishable.

For MOD1 and CTRL, MOD1 is concluded to have significantly lower mean biases and MAEs. The same is true for MOD1_60 compared to CTRL. In contrast, in considering the approach of assimilating all of the available MODIS data without filtering (ALL) through a comparison with either no (CTRL) or standard data only (STD) assimilation, the results argue against the no-filter approach. STD exhibits significantly lower biases and MAEs than ALL for both periods, while CTRL is superior for the 18-hr subperiod.

The addition of filtered MODIS data to the standard data (MOD1 v. STD) yields an improvement over the entire simulation, resulting in significantly lower biases and MAEs. Compared to using all of the available MODIS data (MOD1 v. ALL), filtering the MODIS data results in better model performance.

It is seen that the increase in resolution from a 90/30/10/3.3-km to a 60/02/6.7/2.2-km configuration does improve scores somewhat. MOD1_60 exhibits a lower wind speed bias than MOD1 for the episode at the 95% level, while at lower 90% confidence level it is better in terms of MAE for both periods.

Among the 90/30 forecasts, MOD1 overall shows the lowest mean errors. It is followed by STD, then CTRL. The results for ALL are statistically the poorest. One can compute a measure of the performance for each of the runs by formulating a relative score. This is done here through summing the number of other experiments a given one is statistically better than, worse than, or equal to. The results for hours 0–48 are as follows, with the better experiments near the top. Experiments sharing a line have the same relative score.

Bias	MAE
MOD1, MOD1_60	MOD1, MOD1_60
STD	STD
CTRL, ALL	CTRL
	ALL

MOD1_60 and MOD1 lead in lowest bias and MAE comparisons. Of the 90/30 forecasts, MOD1 enjoys the highest favorable comparison score. MODIS data can significantly improve the ARW simulations for this extreme polar event, but under the conditions of the application of a filter.

3.2 May 2004 Period

To explore the impact of MODIS data on AMPS ARW forecasts over the longer term, statistics for the month of May 2004 have been calculated for the experiments described in Sec. 2. Preliminary results from analyses of the experiment errors and the significance of their differences are presented here.

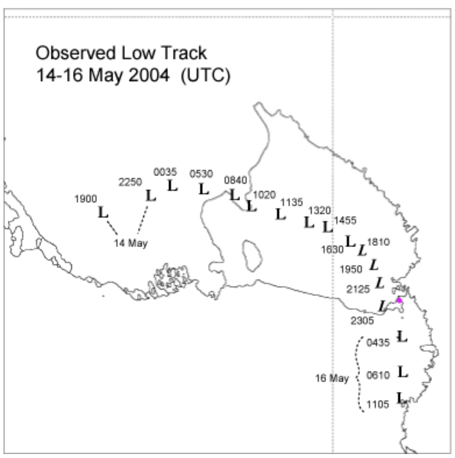
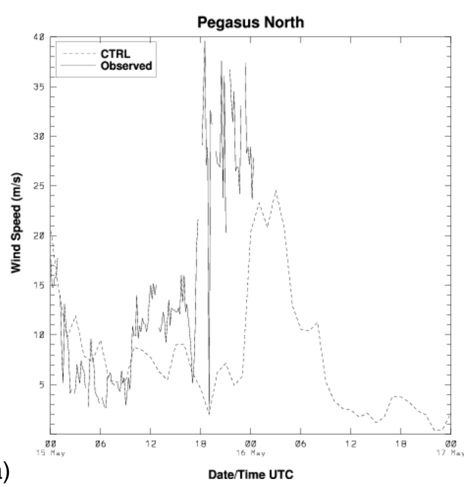
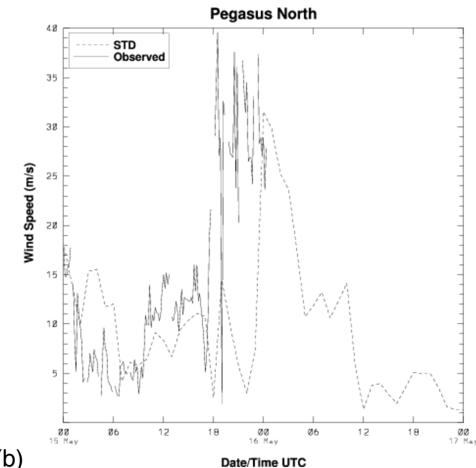


Fig. 3: Track of low forcing the May windstorm. Times (UTC) of central position of low (marked "**L**") indicated. "*L*" reflects period of the wind event at McMurdo.



(a)



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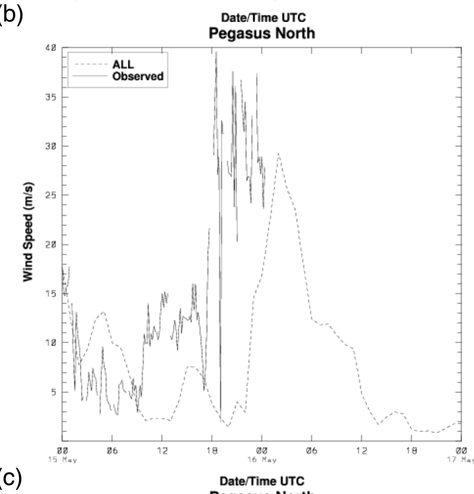

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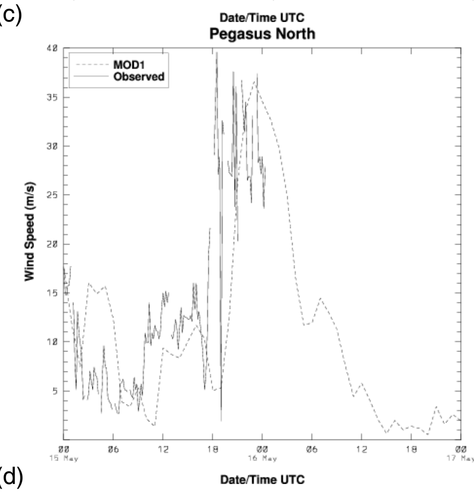

(d)

(e)

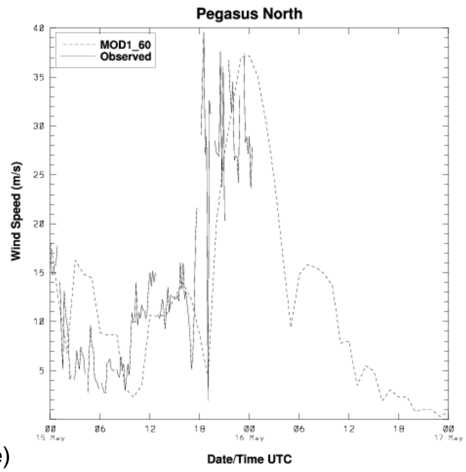

Fig. 4: Observed (solid) and ARW (dashed) wind speed (m/s) at Pegasus North. Abscissa shows time in hours from 0000 UTC 15 May. (a) CTRL. (b) STD. (c) ALL. (d) MOD1. (e) MOD1_60.

Figure 5 presents vertical profiles of the wind speed MAEs for hour 24 of the May 2004 forecasts. In these plots statistically significant differences at the 95% level are indicated by circles around the mean error values. In Fig. 5(a) the results for Expt. 7 (blue) and Expt. 8 (red) show significantly lower errors for the standard data forecasts than for the unfiltered MODIS runs at almost all levels. This is consistent for the findings for the case study wind speed MAEs.

For the filtered MODIS (Expt. 9) and all MODIS (Expt. 8) (Fig. 5(b)) experiments, the results are similar. The filtered MODIS MAEs (green) are consistently lower through the column that the unfiltered MAEs (red).

Figure 5(c) compares the standard data (Expt. 7; blue) and filtered MODIS (Expt. 9; green) errors. In this setting, the former experiment in general displays statistically significantly lower wind speed MAEs. In the lower troposphere, however, the advantage is less than that seen in the comparison of Expt. 7 with 8. Furthermore, the mean errors in Expts. 7 and 9 are indistinct at the 850 hPa and 1000 hPa levels, contrary to what is seen in Fig. 5(a) for Expt. 7 v. Expt. 8. Overall the analyses so far show Expt. 9's performance with respect to Expt. 7 to be mixed, with some parameters occasionally being forecast better than in Expt. 7. However, that the unfiltered MODIS errors (Expt. 8) are greater than the standard data or filtered MODIS errors (Expts. 7, 9) is a consistent signal in these preliminary results.

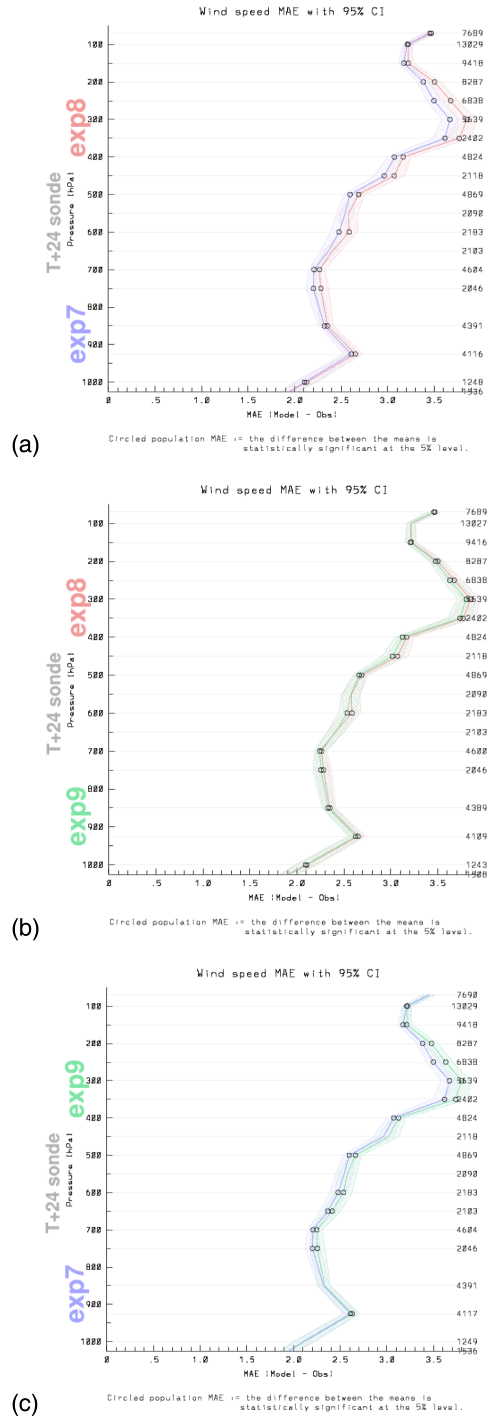

Fig. 5: Surface wind speed MAEs for initial May 2004 forecast investigation. Ordinate shows height in hPa; abscissa shows MAE in m/s. Curves as follows: Expt 7=blue; Expt 8= red; Expt 9= green. (a) Expt 7 v. Expt 8. (b) Expt 8 v. Expt 9. (c) Expt 7 v. Expt 9.

Figure 6 offers the comparison of the temperature biases for Expts. 7 and 9. Most of the mean biases at the various levels do not differ significantly. However, Expt. 9 exhibits a lower bias at the 300 and 250 hPa levels, while Expt. 7 prevails at 500 hPa. This illustrates the varying results for the filtered MODIS.

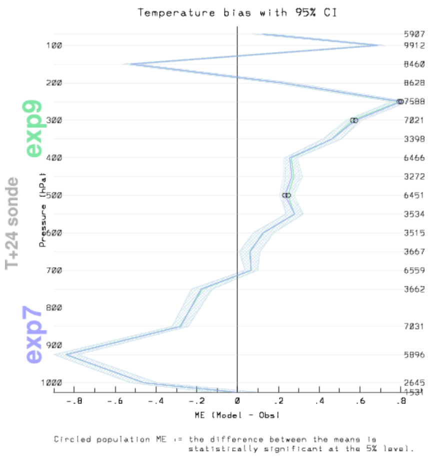

Fig. 6: Temperature biases for initial May 2004 forecast investigation. Ordinate shows height in hPa; abscissa shows bias in C. Expt 7=blue; Expt 9= green.

4. SUMMARY AND CONCLUSIONS

In the setting of the Antarctic Mesoscale Prediction System (AMPS), the ARW has been applied to investigate the impact of the assimilation of MODIS AMV datasets. Their influence on forecasts of a severe weather event and on simulations over a month-long period has been examined.

For the case study it is found that the assimilation of MODIS polar winds can improve the high-impact event forecast in statistically significant terms. However, application of a filter accounting for instrument channel, observation height, and surface type is necessary, as the assimilation of unfiltered measurements degrades model performance for the case. In fact, it is preferable to not use MODIS data than to assimilate unfiltered MODIS.

A preliminary analysis of the experiments for the May 2004 period indicates the assimilation of unfiltered MODIS observations to be associated with higher wind speed errors compared to the assimilation of conventional data only. While the assimilation of filtered MODIS data yields improvements over the unfiltered data runs, the assimilation of the former in this coarse-grid setup is not yet seen to yield consistently lower error scores than that of the standard data alone. This is an early analysis, however, and higher-resolution experiments and a focus on the errors over Antarctica are planned.

ACKNOWLEDGMENTS

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Mean Errors— Surface Wind Speed
(values in m/s)

Hours 0–48   (0000 UTC 15 May–0000 UTC 17 May)

Expt	Bias	MAE	RMSE
CTRL	-9.9	10.8	13.9
STD	-6.7	9.1	11.8
ALL	-11.4	12.4	15.5
MOD1	-5.8	8.2	10.5
MOD1_60	-5.0	7.8	10.2
MM5	-5.5	8.5	10.7

Hours 12–30   (1200 UTC 15 May–0600 UTC 17 May)

Expt	Bias	MAE	RMSE
CTRL	-6.2	7.5	10.6
STD	-4.4	6.9	9.4
ALL	-5.9	7.8	11.1
MOD1	-2.9	6.1	8.3
MOD1_60	-2.4	5.8	7.9
MM5	-3.1	6.9	8.9

Tab.1: Model average wind speed errors (ms^{-1}) for hours 0–48 and 12–30. MAE= mean absolute error; RMSE= root mean square error. Error means are averages over sites of Arrival Heights, Pegasus North, Black Island, Minna Bluff, Marilyn, and Schwerdtfeger.

Significance of Differences of Experiment Mean Errors

H_0: $\mu_1 - \mu_2 = 0$ Population (error) means of two experiments= 0
H_1: $\mu_1 - \mu_2 \neq 0$ Population (error) means of two experiments≠ 0
α= .05, one-tailed test
EXPT= Reject null hypothesis H_0 (that means are the same) at 95% level.
"EXPT" error mean lower than compared experiment at 95% level
I= Inconclusive at 95% or 90% level I_{95}= Inconclusive at 95% level
$EXPT_{90}$= EXPT error mean lower at 90% level   M1_60= MOD1_60

		Hours 12–30		Hours 0–48	
Expt 1	Expt 2	Bias	MAE	Bias	MAE
STD	CTRL	STD	I	STD	I
ALL	CTRL	CTRL	CTRL	I	I
MOD1	CTRL	MOD1	MOD1	MOD1	MOD1
M1_60	CTRL	M1_60	M1_60	M1_60	M1_60
ALL	STD	STD	STD	STD	STD
MOD1	STD	I	I	MOD1	MOD1
M1_60	STD	I_{95}/M1_60_{90}	I_{95}/M1_60_{90}	M1_60	M1_60
ALL	MOD1	MOD1	MOD1	MOD1	MOD1
MOD2	MOD1	MOD1	MOD1	MOD1	MOD1
M1_60	MOD1	M1_60	I_{95}/M1_60_{90}	I	I_{95}/M1_60_{90}
M1_60	ALL	M1_60	M1_60	M1_60	M1_60

Tab. 2: Statistical comparison of experiments.