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On the Performance of the AFWA version of the PSU/NCAR MM5 model for short-range forecasting in Alaska, the Western Arctic and North Pacific

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1. Introduction

The Air Force Weather Agency (AFWA) has adopted the Penn State/NCAR MM5 modeling system for regional numerical weather prediction over a large number of regions, or theatres, where there are either military actions in progress or important bases where exercises are conducted on a routine basis. One of these theatres of interest includes Alaska and adjacent areas of the Arctic Ocean, the North Pacific Ocean, Canada and Siberia. As of this writing, forecasts are conducted four times daily on a 45 km grid encompassing these areas, with a twice daily 15 km nested grid forecast for most of mainland Alaska.

At the University of Alaska-Fairbanks(UAF), we have been receiving AFWA Alaska theatre MM5 forecast output routinely since April 2000 and have also been using the AFWA output as an input to two model-based in-flight icing diagnostic algorithms. During this period we have been monitoring the performance of the model forecasts through a series of standard skill scores, including root mean square (RMS) error, the average absolute error, average bias and the Teweles and Wobus (1954) S1 skill score, verified against the MM5 grid analysis produced at AFWA using the GTWAPS implementation (e.g.,Starr et. al 1999) of the Local Analysis and Prediction System (LAPS; e.g.,Albers et. al, 1996). Further, we are using pilot reports in tandem with contingency table-based statistics to evaluate the performance of the in-flight icing algorithms.

In the remainder of this paper we present an overview of the performance of the AFWA MM5 from a domain based perspective during the period April-December 2000. Further details and results from a specific case will be presented in the future.

2. Model Configuration, Data and Methods

For the period under consideration here, AFWA has been utilizing versions of MM5v3 (e.g, Chen and Dudhia 2000) that are fundamentally the same as the standard NCAR versions save the use of LAPS for the initialization procedure. The principal differences between the various versions of MM5v3 utilized during the period are the inclusion of some additional physical parameterization options (which were not utilized by AFWA; Moore, pers. comm) and some minor bug fixes. As such, the fundamentals of the MM5 model configuration and physical parameterizations used by AFWA during this period did not change. For all their simulations, the Dudhia (1989) 2-stream radiation, MRF planetary boundary layer (Hong and Pan 1996), Grell (1993) cumulus and Reisner et al (1988) microphysical schemes are used on both domains. For specification of initial and boundary conditions for the soil, AFWA uses the MM5 five-layer soil model (Dudhia 1996) so that there is consideration of soil thermal diffusion processes but not an explicit soil moisture treatment.

The model simulations discussed here utilize a nested grid structure as shown in Figure 1. The coarse grid has a 45 km resolution and covers the North Pacific and Western Arctic regions to approximately 77^{o} N latitude; the nested grid has a 15 km resolution and encompasses most of mainland Alaska, as well as parts of the southeast Alaska Panhandle and Alaska Peninsula.

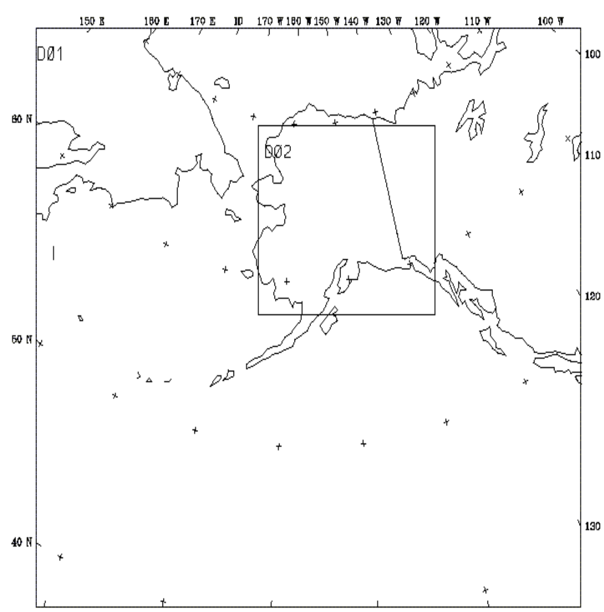

Figure 1. Domain configuration for the MM5 ensemble experiments. Grid resolution for domains 1 and 2 are 45 and 15 km, respectively

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Both domains include 41 computational vertical levels in the MM5's native sigma coordinate system. Unfortunately, as the configuration of the nested grid was changed in mid February 2001, we cannot provide comparable performance statistics for a complete annual cycle. For that reason, in this paper we restrict out attention to the period from April - December 2000.

3. Preliminary Results: 45 km Domain

Other than several periods of missing data near Julian dates 146, 280 and 308, we have received at least one cycle of 45 km AFWA MM5 output and analyses per day (and most of the time four cycles/day) since Julian date 95 (4 April) 2000. We have chosen in this paper to focus on the 00 and 12 UTC cycle data on the assumption that these two runs are most likely to be initialized at AFWA with the greatest amount of high quality data via LAPS. This assumption is based upon several years of experience with observation availability and quality in the Western Arctic as well as consultation with local NWS forecasters in Fairbanks. For brevity, we further restrict our attention to the 12 and 24 hour forecasts from each cycle.

Figures 2a and 2b depict the RMS error of the surface temperature (Fig. 2a) and surface mixing ratio (Fig. 2b) for the 45 km domain. Recall that these statistics are verified against the appropriate LAPS-generated analysis and not station observations. As such, by "surface" we are referring to the lowest model level temperature and mixing ratio fields. Except in one or two rare instances, values of zero RMS error correspond to missing data times, especially for the temperature field.

Figure 2a indicates a steady drop in temperature RMS error from spring (extreme left of figure) extending into mid-summer (e.g., Julian date 180) for both the 12 and 24 hour forecasts. After mid-summer, the RMS error for the 12 hour forecasts remains, with some modest variability, approximately constant while the 24 hour forecast RMS error rises slightly into the fall and winter. The decline of error in summer is not entirely unexpected. Climatologically, the diurnal and intraseasonal ranges in temperature over both the North Pacific Ocean and the high latitude land areas (due in large part to the long length of the solar day) are relatively small compared to the potential variability during the cold season. And while mesoscale features tend to dominate the significant weather during this period, they are generally not accompanied by strong temperature gradients other than those associated with the cloud cover attendant to such a system. Thus, unless the overall long wave and synoptic scale patterns are very poorly forecast, the 12 hour forecast temperature errors will be somewhat constrained by the small overall temperature range during the season.

a)

b)

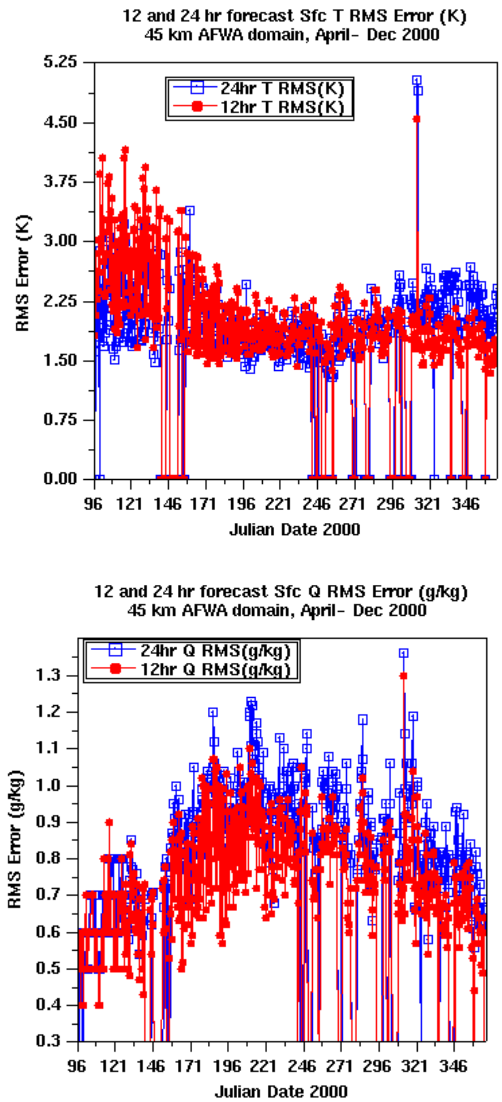
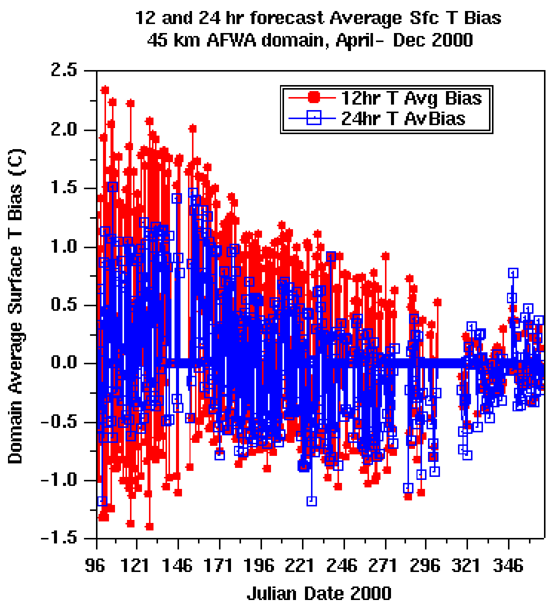


Figure 2 Domain-averaged root mean square errors for the 45 km AFWA MM5 a) surface layer temperature (K); and b) surface layer mixing ratio (g/kg) over the period 5 April-31 December 2000. Data are plotted for the 00 and 12 UTC cycles only.

The results shown for surface layer mixing ratio in Figure 2b also have some consistency with climatological expectations, with a general trend towards maximum errors in mid-summer with lower errors in the other seasons. This trend is consistent with both a) the overall trend for mean mixing ratios in high latitudes as well as b) the fact that the magnitude of the range in mixing ratio, particularly over the high latitude land areas, follows the same cycle as the mean mixing ratio. The combination of the above trends allows for a situation in the summer season that maximizes the potential error in mixing ratio. In high latitudes this effect tends to be somewhat amplified compared to mid latitudes since the mixing ratio has such a strong variation over the annual cycle.

Figures 3a and 3b depict the bias errors of the surface temperature and surface mixing ratio fields. These statistics are not as easily explained in terms of climatological patterns, particularly the surface temperature bias 12 hour forecast results which show a steady decline in not only the range of bias values but also in the variability of the bias itself throughout the entire April-December period. By contrast, the 24 hour



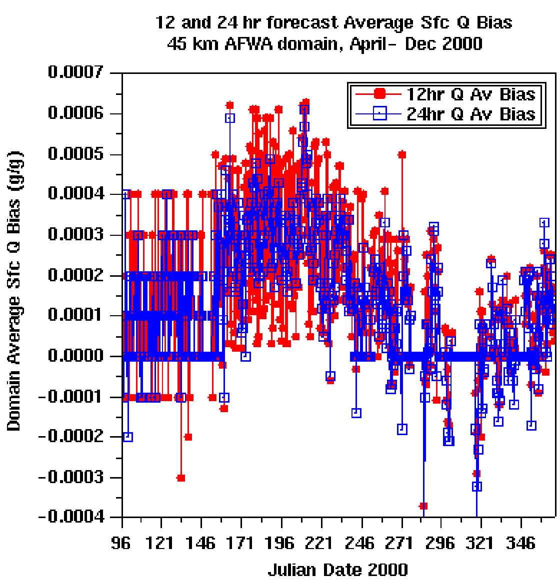


Figure 3 Domain-averaged bias errors for the 45 km AFWA MM5 a) surface layer temperature (K); and b) surface layer mixing ratio (g/g) over the period 5 April-31 December 2000. Data are plotted for the 00 and 12 UTC cycles only.

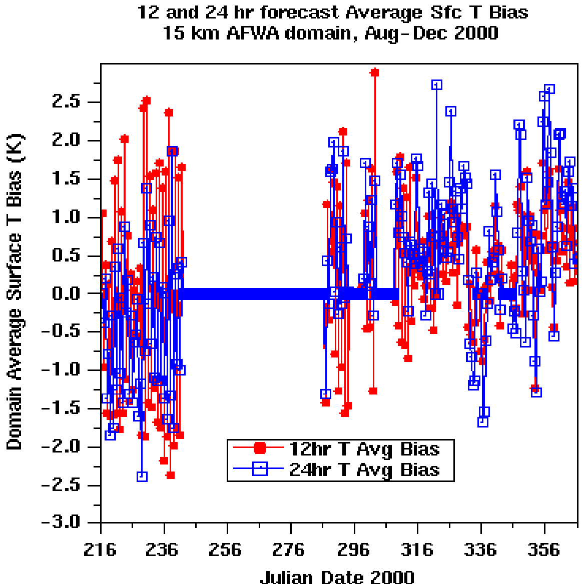
forecast biases show a more consistent range of biases between +/- 1C over the whole annual cycle, though there does appear to be a semi-annual wave of sorts describing the mean bias. This wave has a maximum positive amplitude (warm bias) during the spring transition and a maximum negative amplitude (cold bias) during the fall transition, both of which could be tied to the AFWA MM5's ability to properly treat the development/ melt of snow cover as well as dynamic-thermodynamic interactions between the troposphere and the underlying sea ice cover. Further investigation is expected to shed light on this mechanism as well as the steady decay of the 12 hour forecast temperature bias. We speculate that the latter problem may be tied to diurnally-related inconsistencies in the AFWA analysis, but again, further investigation is needed before any conclusions can be drawn.

Figure 3b also shows a suggestion of a semi-annual wave in the surface mixing ratio biases at both forecast times, though lagging in phase from the similar feature in the 24 hour forecast temperature bias field. The patterns in the mixing ratio field are more consistent with the annual high latitude thermal wave and large scale moisture transport patterns but are skewed towards an overall positive bias in surface mixing ratio. Two possible contributing factors towards such a bias are poor large scale moisture transport (excessive net convergence at low levels into the domain) and inadequate specification of topographic effects over the land masses due to relatively coarse spatial resolution (insufficient condensation and rain-out of water vapor). Further study will be needed to ascertain if either of these effects contribute to this overall positive bias.

4. Preliminary Results: 15 km Domain

At UAF, we have been receiving AFWA 15 km MM5 data only since August 2000. Further, since that time there have been several periods of data loss due to transmission problems in our data pathway from AFWA, which includes routing through Elmendorf Air Force Base and the Alaska Region of the National Weather Service. As a result the statistical results are associated with a substantially smaller population of forecasts than is the case for the 45 km domain. Nonetheless, we believe that even with a sample of approximately 200 forecasts that our results contain useful information in assessing forecast performance.

Figures 4a and 4b show the bias errors for the surface temperature and surface mixing ratio on the AFWA 15 km domain. As was the case for the coarser domain, zero values depict, for the most part, periods of missing data. Comparing Figure 4a with Figure 3a, we see that the biases in the temperature field tend to be slightly larger than those for the 45 km domain, which is



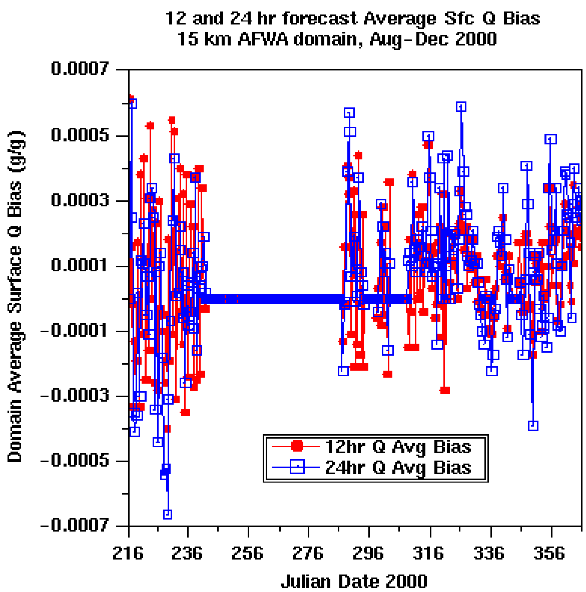


Figure 4 Domain-averaged bias errors for the 15 km AFWA MM5 a) surface layer temperature (K); and b) surface layer mixing ratio (g/g) over the period 5 April-31 December 2000. Data are plotted for the 00 and 12 UTC cycles only.

to be expected given the greater influence of topographic and other meso-β scale effects on the forecast fields over time as compared to an analysis field that is interpolated from a coarser resolution field. The long missing data period breaks the statistics into two periods with different behavior: (1) an early period with no overall trend or skewness, and which further shows no sign of the overall decreasing trend seen in the 45 km temperature biases, and (2) a late period with an overall positive bias but without a readily discernible trend other than the 24 hour forecast biases showing greater variability than the corresponding 12 hour forecasts.

The 15 km surface mixing ratio biases (Figure 4b) also do not reflect the pattern seen at 45 km (Figure 3b). An overall positive bias exists during the latter part of the year, with greater overall bias and greater variability shown in the 24 hour forecasts as compared to the 12 hr forecasts. However, the values of the 15 km biases are of the same order as those for the coarser resolution domain. These facts suggest that there is only a modest contribution to the fine domain moisture bias from meso-β scale processes, since such contributions would be expected more at the 12 hour forecast time than at the 24 hour forecast time (where one would expect more of an influence from the larger scale synoptic moisture transport). Further work is needed to substantiate this hypothesis.

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