A CLIMATE MODEL INVESTIGATION OF LOWER ATMOSPHERIC WIND SPEED BIASES OVER WIND FARM DEVELOPMENT REGIONS OF THE CONTINENTAL UNITED STATES

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1. INTRODUCTION

Variability of lower-atmospheric wind resource under climate change scenarios is a subject of interest within the wind farm development industry. General circulation models used for preparation of the IPCC 4th Assessment Report can be evaluated for their simulation of effects on wind from various emissions scenarios; predictions vary. In part, this may be explained by differences in physical parameterizations. It is well known that GCMs poorly represent lower atmospheric wind speed due in part to inadequacies of these schemes. It is necessary for biases to be measured and understood to facilitate robust use of the models for predictions of wind under climate change and more generally for understanding its interannual variability.

This study evaluates the fidelity of one such model in its simulation of lower atmospheric wind speed over the central United States, a primary wind farm development region and speculates on the possible causes of deficient simulation.

2. METHODOLOGY

The model used for evaluation is the Community Atmosphere Model ver. 3 (CAM3), developed at the National Center for Atmospheric Research (Collins, et al 2006). CAM is the atmospheric component of the coupled Community Climate System Model (CCSM). A 5-year period was chosen for simulation, to be consistent with boundary condition data (observed SST) and with reliably consistent wind measurement evaluation: 1996 - 2000. In order to measure the model's bias relative to its own internal variability, it was necessary to carry out multiple independent simulations, each forced by perturbed initial conditions.

Wind data was compiled from multiple sources, including towers from the Automated Surface Observing System (ASOS), as administered by the National Oceanic and Atmospheric Administration (NOAA) (NOAA 1998), the West Texas Mesonet (Schroeder, et al 2005), administered by Texas Tech University, the Oklahoma Mesonet (Brock, et al 1995) administered by the University of Oklahoma, and the North American Regional Reanalysis (NARR) (Mesinger, et al 2006). ASOS towers consist of rotating cup anemometers and simple wind vanes mounted at 10 m for speed and direction measurement respectively. Hourly values, as derived from 2-minute averages were used for this study. West Texas Mesonet towers consist of R.M. Young anemometers for equivalent measurements at 10 m from 40 towers distributed throughout western Texas and the Texas Panhandle. Analogous measurements from over 100 Oklahoma Mesonet stations provided high-density coverage of Oklahoma. NARR provides uniform 36-km resolution coverage of a large number of atmospheric variables at multiple levels in the atmosphere over the continental United States (CONUS), including winds at 10 m, partly derived from the Eta Model and its Data Assimilation System (DAS), developed at the National Center for Environmental Prediction (NCEP) and from surface-based measurements.

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3. RESULTS

3.1 Regionalization

For ease of comparison between the model output and measured fields, the Plains belt of the Central U.S. was sectioned into 6 regions. Tower and NARR-derived wind speeds from 11 years of measurement (1998 - 2008) were averaged onto the regions and then averaged in time for comparison of monthly means. Regional mean monthly mean wind speed at 10 m is shown for the 6 regions of the Plains Belt in Figure 1.

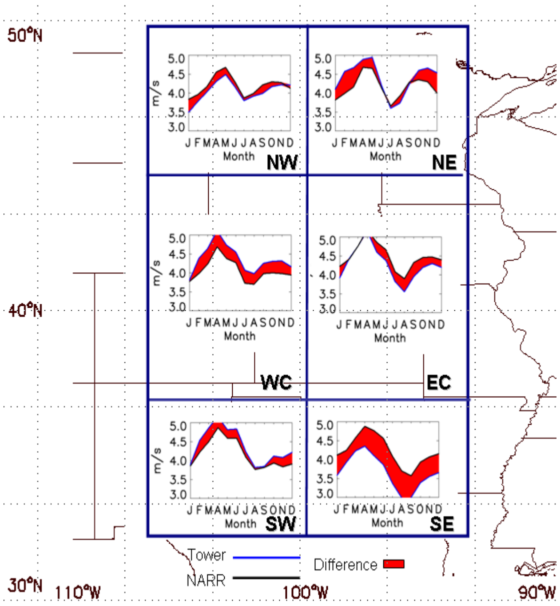

Figure 1. Monthly mean 10-m wind speed as measured by tower anemometers of the ASOS, West Texas Mesonet, and Oklahoma Mesonet (blue) and by the NARR (black) for six distinct regions of the Plains belt of the U.S. Difference is shown by the red shading.

While there are clear amplitude differences between the datasets (as high as 12-15%), both physical measurements and reanalysis show similar seasonal cycles. Amplitude differences are most pronounced over the lower resource southeast region (SE) and consistently smallest over the NW region.

3.2 Monthly mean and seasonal cycle

Amplitude disparities measured between the observations are relatively small compared to model bias on a monthly level. In Figures 2a-d, monthly wind speed at the 850-mb level is mapped for the NARR, the CAM, and for their difference, as averaged over the model simulation period of 1996 - 2000.

Note that while the model tends to simulate well the overall spatial distribution of wind across the belt, amplitude biases are considerable, on the order of 40-50% during the winter months over the western high plains (Fig. 2a). That bias is weakened in spring (Fig. 2b) but there is a strong bias during the summer over the central Plains, on the order of 50%, focused on eastern Nebraska and Kansas. The central Plains bias is maximized in July (Fig. 2c). Model overprediction is shifted back to the northwest during the fall months (Fig. 2d).

Zonal and meridional cross sections through the Plains belt highlight the seasonal and regional nature of the model's overprediction (Fig. 3). In the sectioning described in section 3.1, it is clear that winter bias characterizes the northwest (NW) region while summertime bias characterizes the east-central (EC) region.

Four independent (uniquely initialized) model simulations over five years were used to constitute 20 independent realizations of each month of the year; the spread of the realizations' simulations provides a measure of the model's internal variability. Similarly, the 5 years of NARR measurement were used to quantify year-to-year variability in the data. Comparison between the model and the data was carried out in relation to their independent variabilities, displayed in Figure 4. Disparities between regional wind speeds fall most outside the bounds of natural variability over the northwestern (NW) and east-central (EC) regions. Additionally, it is evident from this view that model biases exceed any observational uncertainties presented in Figure 1.

3.3 An Event-Oriented Perspective

Investigation of model bias was facilitated by comparing the distributions of daily mean wind speeds between the model and observations. Histograms of the regional daily-mean wind speeds are shown for the seasons of least favorable comparison (DJF and JJA) in Figure 5. Both CAM3 and NARR indicate an overwhelming percentage of "calm" days (less than 1 m/s daily mean)

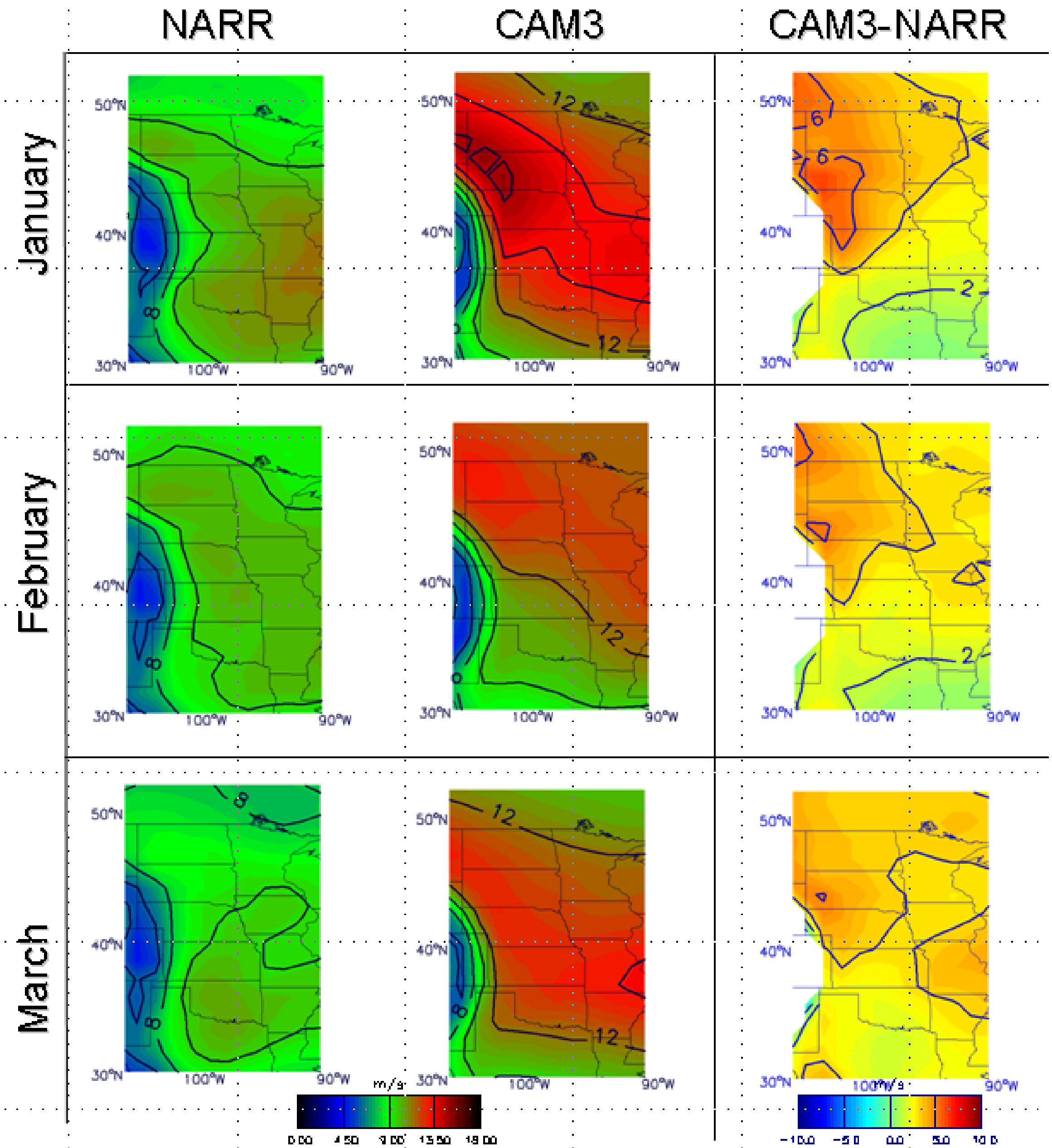

Figure 2a. Monthly mean wind speed (m/s) at the 850-mb level, as derived from the NARR (left) and CAM3 (middle) as averaged from the simulation period 1996 - 2000. The difference (CAM3 - NARR) is shown on the right.

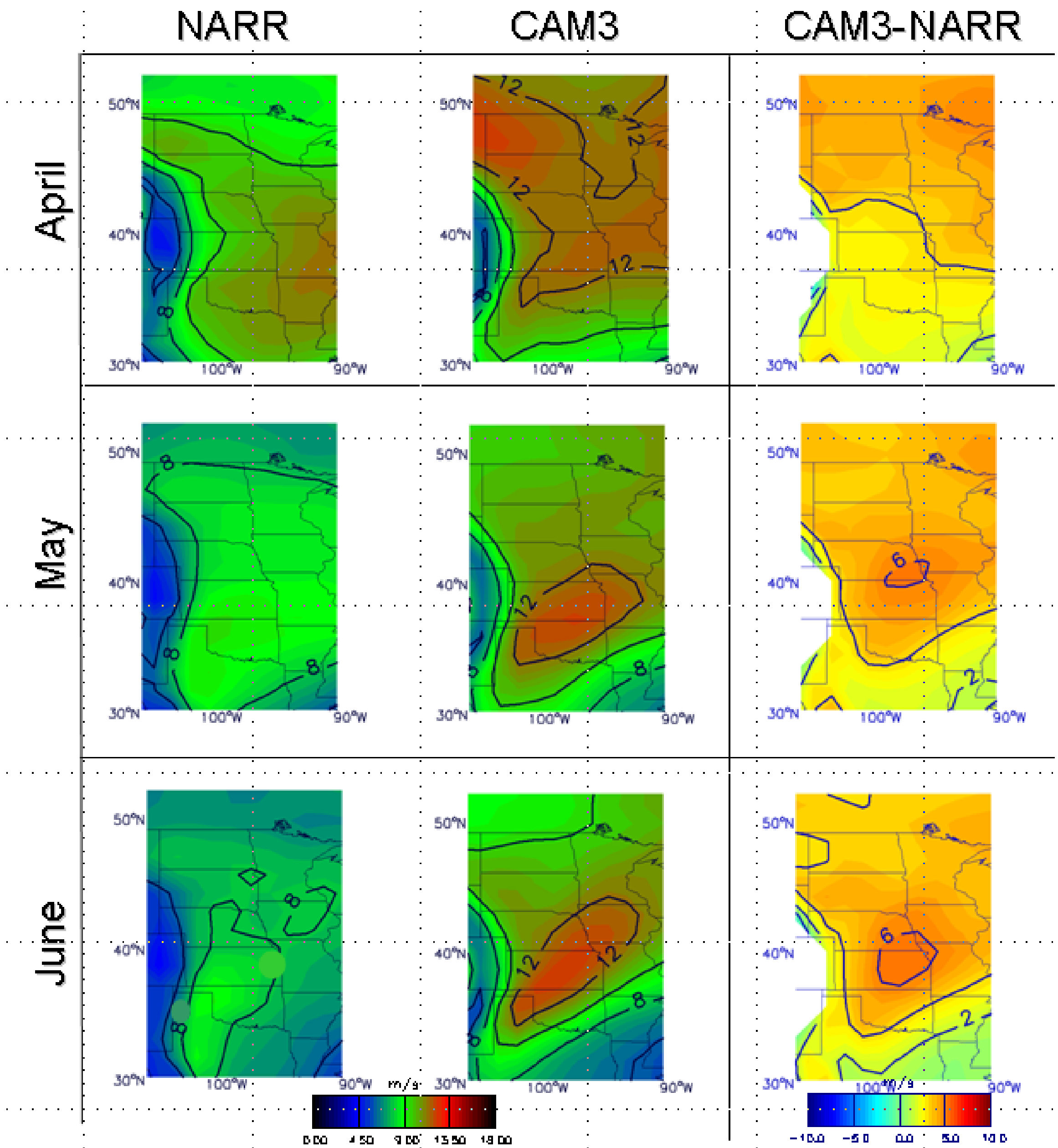

Figure 2b. Same as in Figure 2a except for March - June.

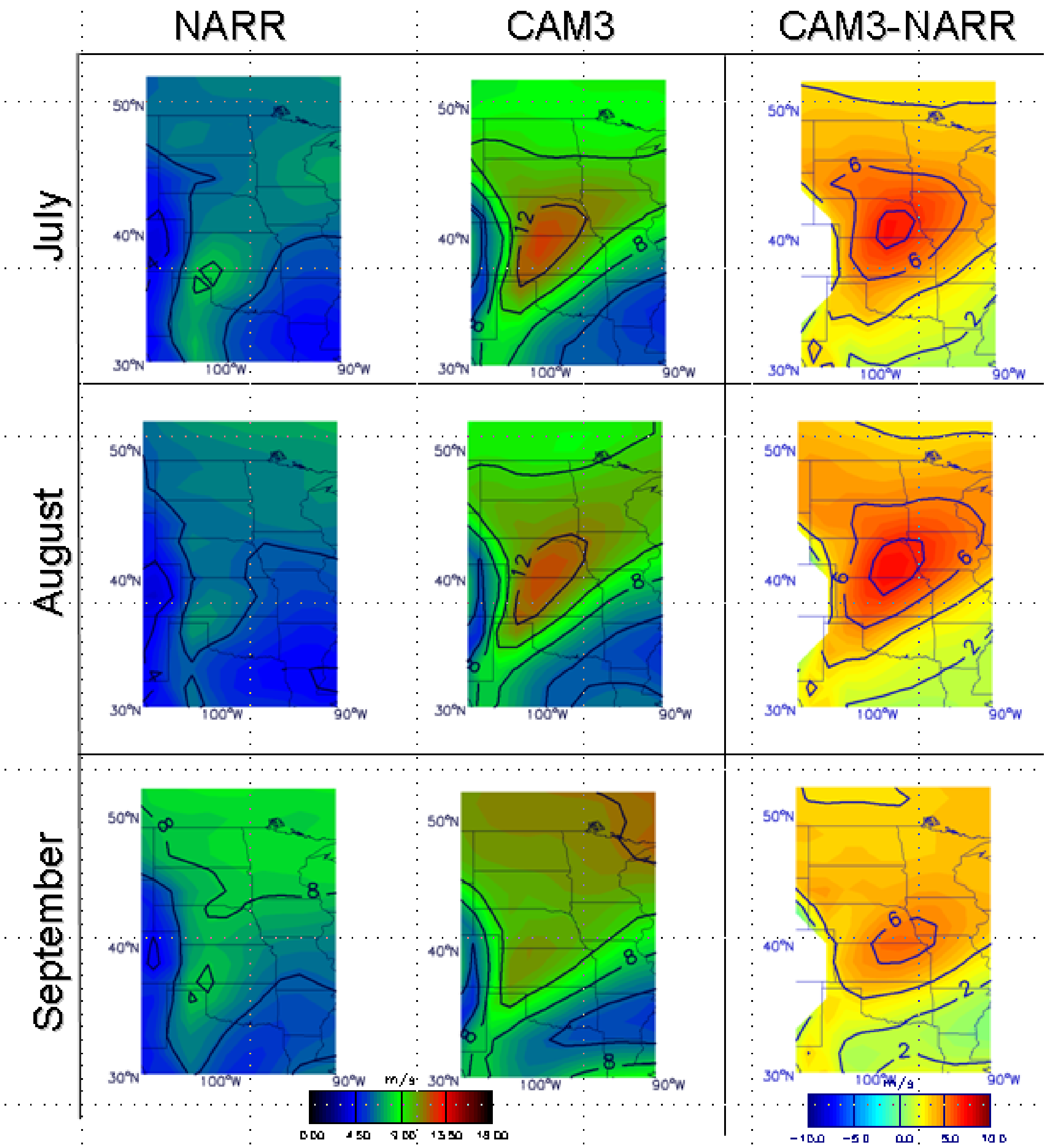

Figure 2c. Same as in Figure 2a except for July - September.

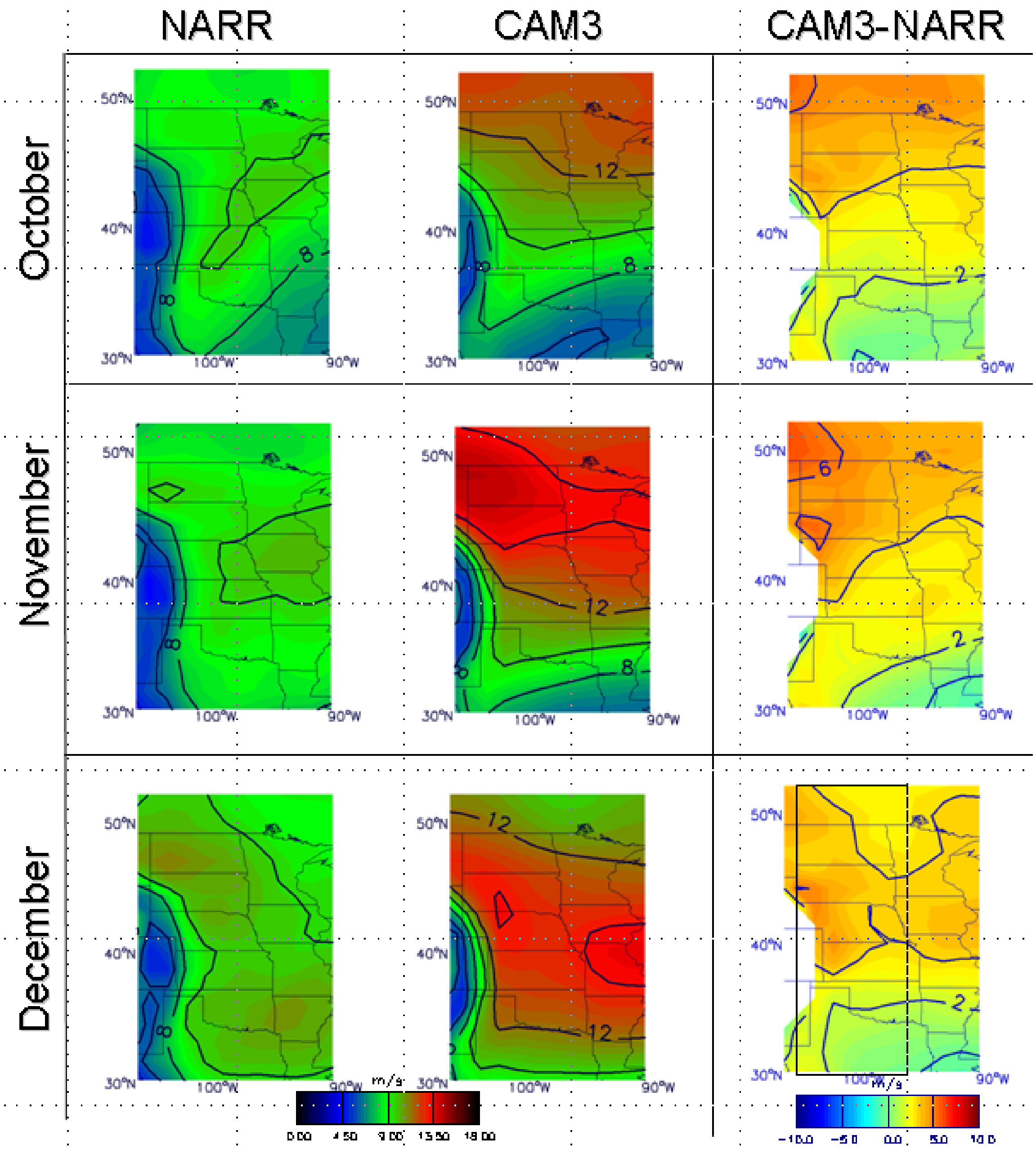

Figure 2d. Same as in Figure 2a except for October - December.

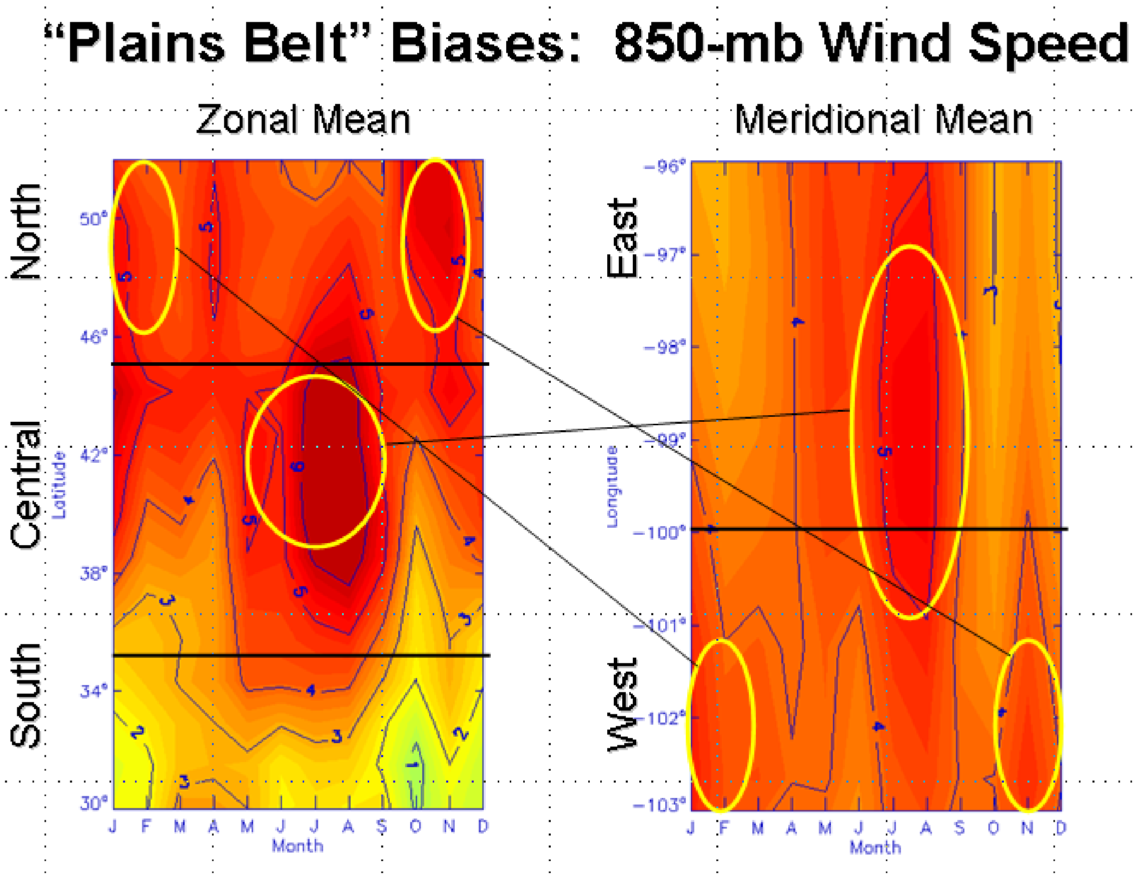

Figure 3. Zonal and meridional cross sections of monthly mean wind speed model bias over the Plains belt of evaluation.

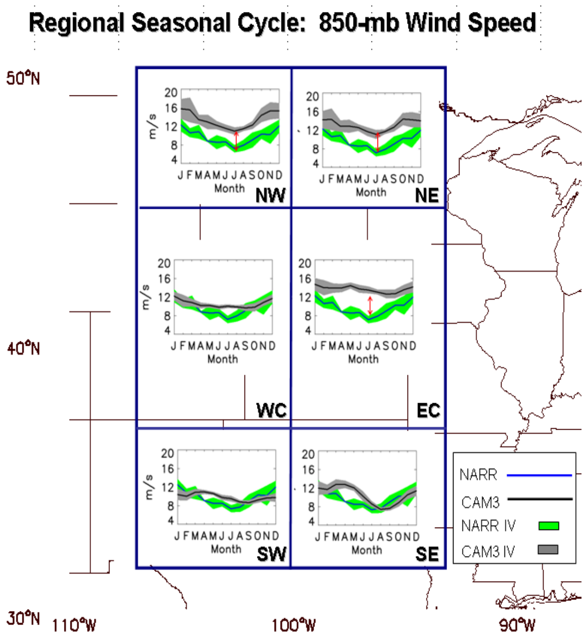

Figure 4. Regional mean monthly mean 850-mb wind speed from the CAM3 (black), NARR (blue) for the period 1996 - 2000. NARR interannual variability is shown in green while CAM3 internal variability is shown in gray.

on the order of 30-35%, but the distributions of the remaining 65-70% of days are distinctly different, with the model showing 30-40% fewer low-to-moderate wind days and relatively higher extreme wind days, i.e., with daily means greater than 12 m/s.

In order to better understand the dynamics and physics involved in the model's simulation of excessive wind, the simulated wind hourly time series was discretized into distinct wind "events" over the two most poorly simulated regions: NW and EC during DJF and JJA respectively. For NW, events whose mean amplitude wind speed measured below 18 m/s, were filtered out such that the remaining set were considered "High" wind events. The composite anomalies concurrent with these events for NW are shown for six variables describing the atmospheric state in Figure 6.

Note that high wind events over NW in winter are associated with strong northwesterly wind outbreaks, enhanced downward flux of horizontal momentum,

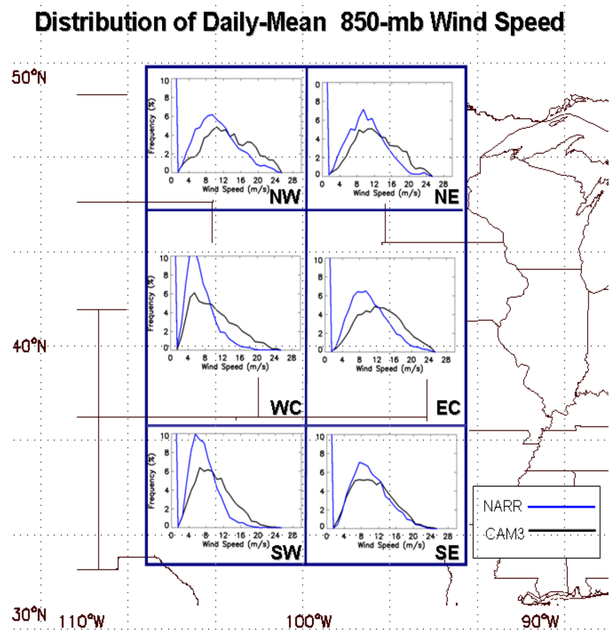

Figure 5a. Distribution of daily-mean 850-mb wind speed from the NARR (blue) and the CAM3 (black) for DJF.

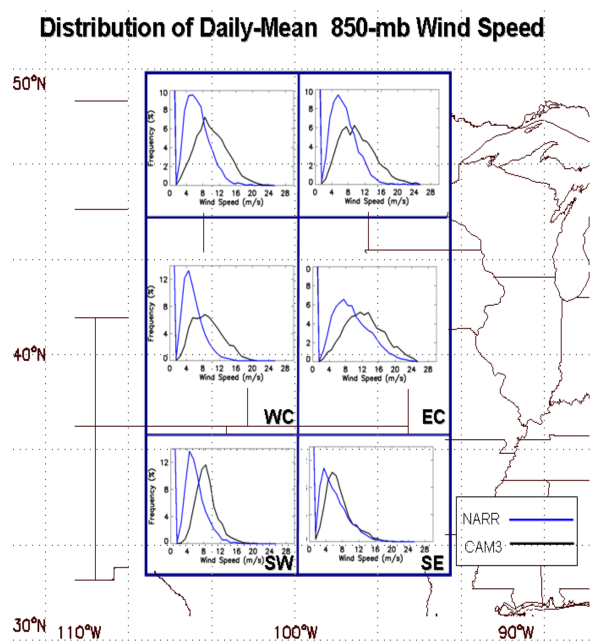

Figure 5b. Same as in Figure 5a except for JJA.

warming of the underlying atmosphere, enhanced instability (through enhanced Convective Available Potential Energy (CAPE) and potentially enhanced cooling aloft), and reduced sea level pressure to the east. This combination is typical of strong mid-latitude westerly jets wherein upper-level geopotential contours are mostly flat with no blocking patterns and upper-level flow is nearly zonal, which in part, explains the atmospheric warming at low levels. Sea level pressure anomalies to the east act to enhance the strong westerly flow events.

Ambient conditions were observed to change at the onset of these high wind events. Generally speaking, the majority of extreme wind events were concomitant with increases in lower atmospheric temperature throughout the 925 - 850 mb layer and drops in sea level pressure, typical of purely zonal flow (Figure 7). High wind events concomitant with temperature falls and/or pressure rises were comparatively less probable. There appears to be little dependence in the amplitude of the wind event on the change in ambient conditions. However, note that stratifying by duration of event reveals that longer events tend to be associated with smaller temperature change. Short events (of one day or less)

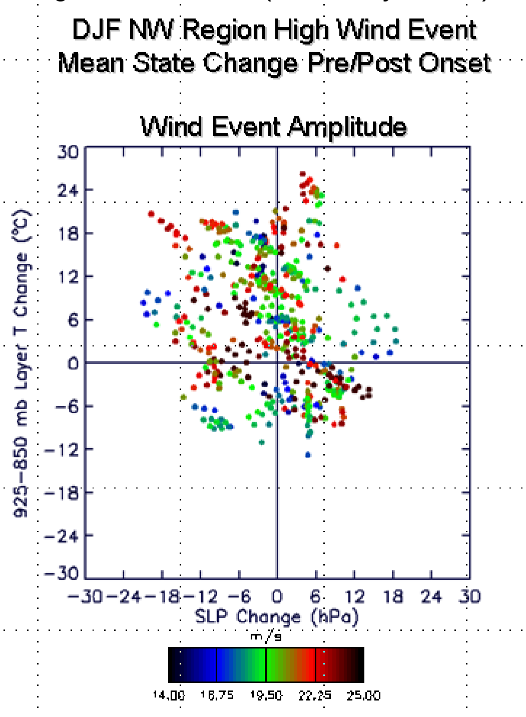

Figure 7a. Change in 925-850 mb layer temperature and change in SLP following onset of high wind event over NW region in DJF as a function of wind event amplitude.

were associated with large temperature and pressure fluctuations.

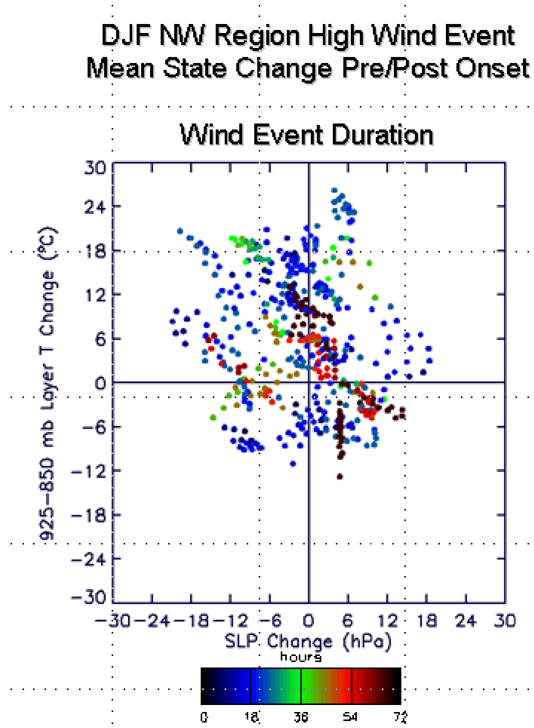

Figure 7b. Change in 925-850 mb layer temperature and change in SLP following onset of high wind event over NW region in DJF as a function of wind event duration.

The composite anomalies for the summertime high wind events over the EC region are very different from those to the north during winter (Figure 8). Much of the momentum appears to be described by enhanced southerlies, with little forcing of high-energy zonal wind aloft. Temperature change is minimal but CAPE change during the wind events is dramatic, as is the drop in sea level pressure. The combination of events likely is related to anomalously strong convection (and storminess) over the southern Dakotas. Increased CAPE induces reduced sea level pressure, and the geostrophic circulation around the SLP anomaly pushes enhanced southerly winds across the east-central Plains. This bias is a good example of the sensitivity of climate model wind speed bias to physics parameterization.

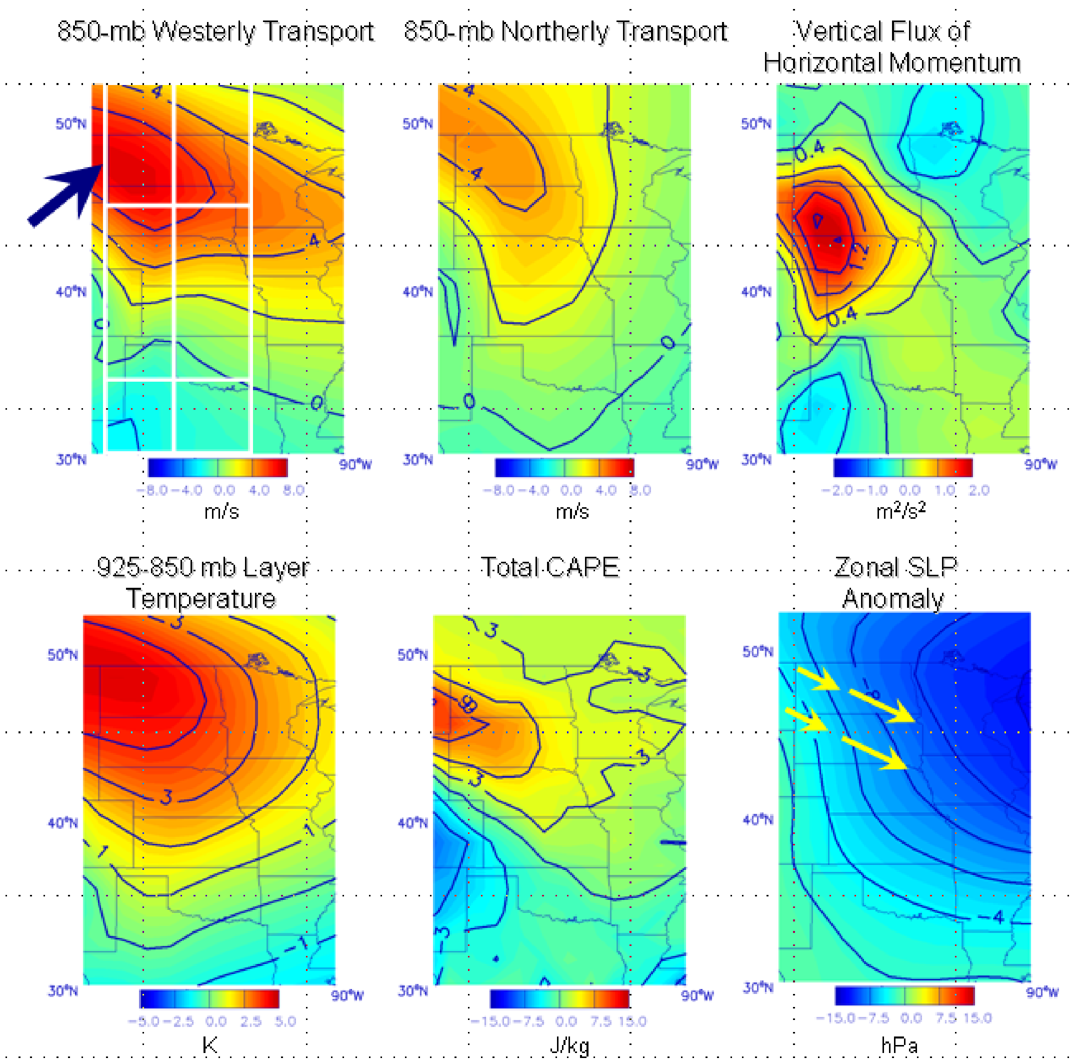

Figure 6. CAM3 anomalies associated with DJF NW region high wind events (daily mean greater than 18 m/s).

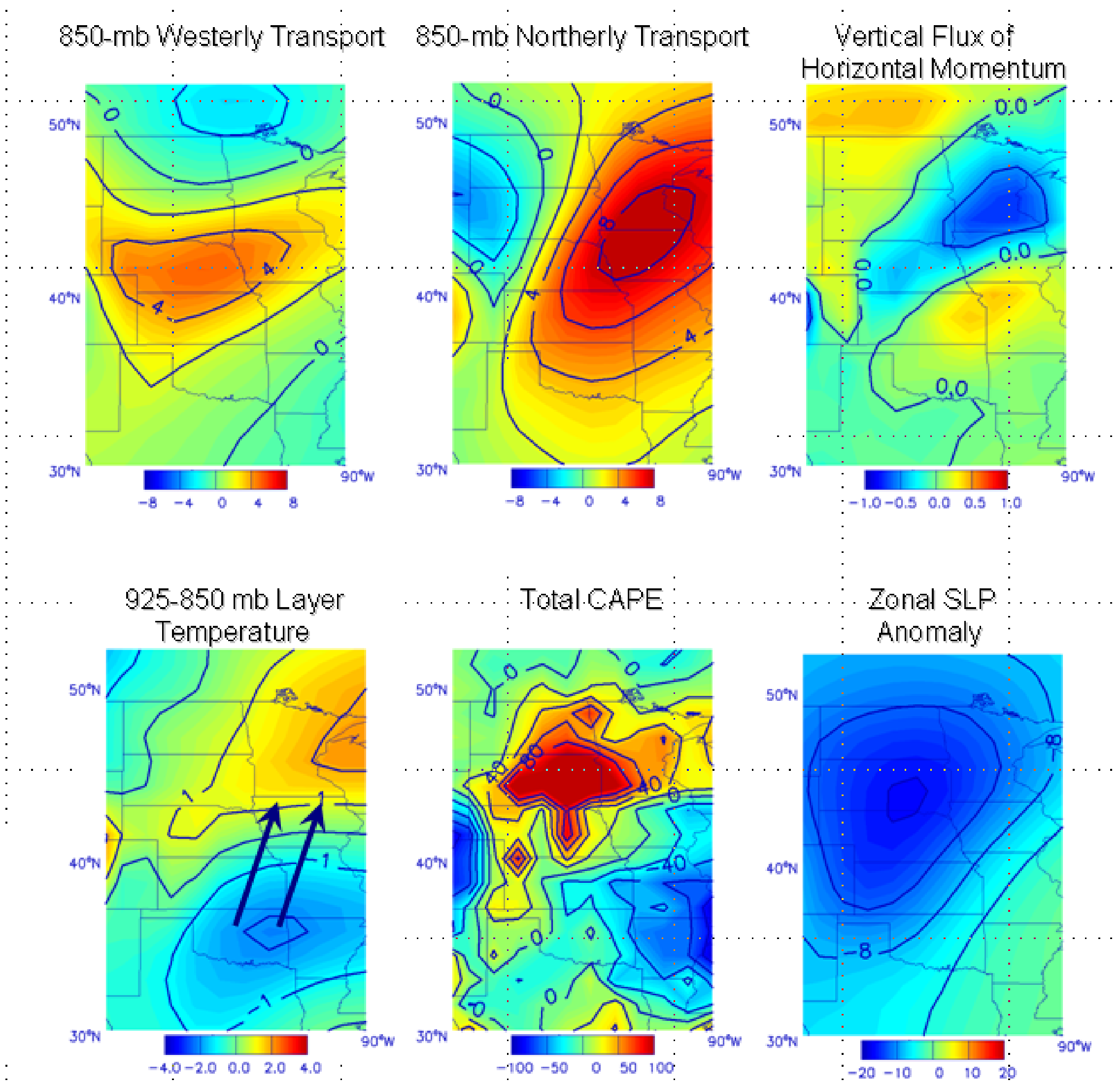

Figure 8. CAM3 anomalies associated with JJA EC region high wind events (daily mean greater than 15 m/s).

High wind events as defined for the EC region (with amplitudes greater than 15 m/s) tend to be of short duration (1 day or less), associated with pressure falls (possibly due to increased convective heating), and mostly negative temperature trend due to northward advection of cold air from the negative temperature anomaly over eastern Oklahoma. Amplitude of event appears insensitive to the changes in ambient conditions before and after event onset.

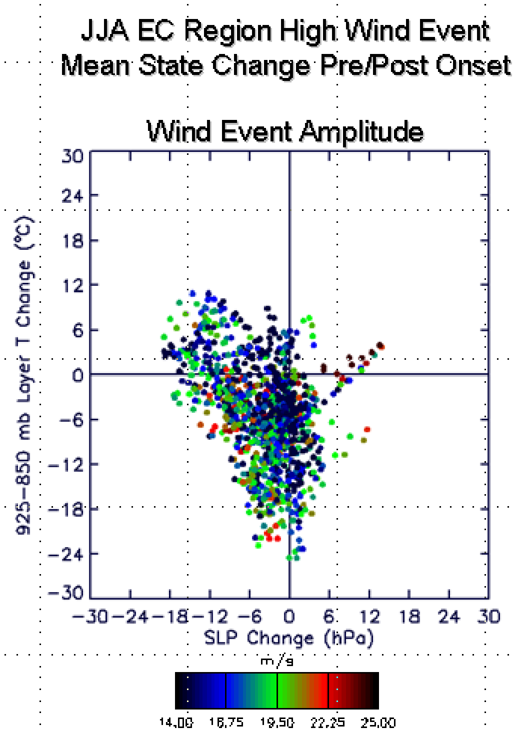

Figure 7a. Change in 925-850 mb layer temperature and change in SLP following onset of high wind event over EC region during JJA as a function of event amplitude.

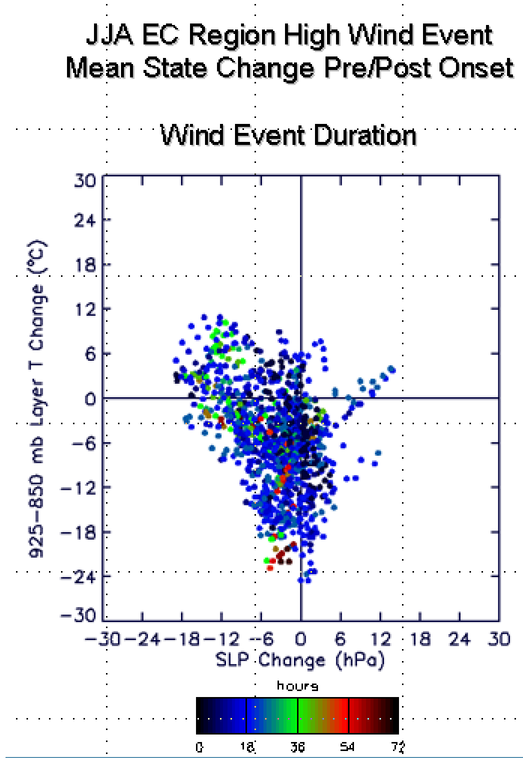

Figure 7b. Change in 925-850 mb layer temperature and change in SLP following onset of high wind event over EC region during JJA as a function of event duration.

4. CONCLUSIONS

This study highlights deficiencies in one model's low-level wind simulation over the Great Plains wind belt. The model for evaluation, the NCAR Community Atmosphere Model, ver. 3 (CAM3), shows large biases in lower atmospheric wind simulation over the northwestern and east central portions of the Plains belt. Biases are larger than observational uncertainties and model internal variability. DJF positive wind biases are linked to strong upper-level zonal jet activity over the northwestern Plains, enhanced by unexplained sea level pressure anomalies to the east. JJA positive wind bias likely is caused by excessive convection in the Dakotas.

Climate model biases for present day wind climate limit utility of future wind resource under climate change scenarios. Sensitivity studies of various emissions scenarios on future wind resource must be considered in the context of these biases, and the role of underlying physics deficiencies in climate warming response should be fully evaluated.

5. REFERENCES

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