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Analysis of Temperature and Dew Point Statistical Trends over Differing Situations in Tucson, Arizona and the Value of Bias-Corrected Grids Using BOIVerify

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1. Introduction

Digital forecasts are a relatively new concept within the United States National Weather Service (NWS). They provide a user-friendly way to view forecasts issued by NWS. With the emergence of digital forecasts, comes a desire for useful verification data. This paper focuses on three types of changes that can affect the accuracy of numerical weather prediction model output: a month-to-month change, a numerical weather prediction (NWP) model change, and a weather regime change. In this study, all changes focus on maximum temperature, minimum temperature and 00Z and 12Z dew point temperatures for the Tucson, Arizona, (TWC) county warning area (CWA) (**Fig. 1)**. The two-month comparison looks at the months of June and July (30 and 31 day periods, respectively) 2007. This period corresponds with the arrival of the summer monsoon in the desert southwest. With the onset of the monsoon, the area experiences rising dew point temperatures, slightly decreased air temperatures, increased relative humidity, and significant rainfall.

The model change studied is a recent amendment to the NCEP North American Mesoscale Model at 12-km grid spacing (NAM 12). Two small changes were made, including the surface exchange coefficient in stable conditions and a decrease in canopy resistance over evergreen and mixed–evergreen forests (Ferrier 2007). This paper examines the 30 day periods before and after the model change to determine the impact on NAM12 raw and bias-corrected model guidance. Finally, the weather regime change section looks at 30 day periods before and after the onset of the summer monsoon in southeast Arizona.

Weather-related regime changes can occur frequently. These changes are likely to affect NWP model performance by magnifying, diminishing, reversing or otherwise altering the inherent biases in the models. NWS offices in Western Region use NWP models and their bias-corrected (BC) counterparts in preparation of daily digital forecasts. Thus, forecasters need to be aware of model biases and how these biases change to help them to decide when to use the raw models versus their bias-corrected counterparts.

2. Methodology

2.1 Parameter Selection

The parameters for this project were chosen based upon the NWS Western Region 2007 summer verification project (http://ww2.wrh.noaa.gov/ssd/ digital_services). Dew point temperature was also chosen for this study because of its importance to the fire weather community in the southwestern United States. Elevated (higher) dew points that accompany the monsoon translate to higher humidity, which naturally aids in fire suppression and leads to changes in management strategies. This paper has objectives similar to the verification project, with a comparable methodology, but aims to expand upon it by applying its principles to specific changes in weather regime and model parameterization.

2.2 BOI Verify

The program used to generate the verification statistics is known as BOIVerify, version 1.0. This program was developed at the Boise, Idaho, NWS forecast office by Tim Barker and operates within the Graphical Forecast Editor (GFE) software.

One of the main objectives of this project is to determine the effectiveness of bias-corrected grids in the forecast process. BC grids were developed by Barker (2006), within BOIVerify, as a way to dynamically correct systematic model output biases. Barker performs "a linear regression of forecast errors on each grid point independently" and then applies the result to the "current model forecast to estimate what the forecast error will be. This process removes the expected forecast error at each grid point (Barker 2006)."

To calculate the bias from the linear regression method, a training period of 30 days is used. Because forecast errors occur every day, the training period needs to be sufficiently long to reflect the *consistent* biases inherent in a particular model. Barker chose 30 days for the training period because a period of less than 30 days could be too responsive (and flip-flop between random errors), while a period much longer than 30 days would be too slow to respond to changes. To be consistent, each period examined in this project was approximately 30 days.

3. Month-to-Month Comparison

Because of the training period for BOIVerify, a month-to-month comparison should reveal notable changes in model biases, provided a regime change has occurred. Tucson, Arizona is a prime location to study this phenomenon, because the monsoon onset typically occurs either in late June or early July. The month of June in southeast Arizona is typically a period of consistently hot and dry conditions, with little day-to-day variability in temperature or dew point. Thus, with a training period of 30 days, the bias-corrected grids should perform relatively well. As expected, across the entire CWA, the error of the BC grids [in terms of mean absolute error (MAE)] was approximately 1^{o}F less than the raw model output for maximum temperature (MaxT) (**Fig. 2**). This improvement was more pronounced in the mountains (TWC CWA above 5000 feet) (**Fig. 3**) where the MAE was approximately 2^{o}F lower than the raw model (**Fig. 4**). Minimum temperature (MinT) errors were slightly larger than those exhibited by MaxT. As one would expect, MAEs for both MaxT and MinT increased out to days 5-7. Due to the relatively steady regime during the month of June, the BC grids removed systematic biases within the raw models, even out to day 7 (**Table 1)**. For example, the bias-corrected NAM12 and ADJMAV improved upon their raw model counterparts by as much as 2^{o}F in terms of MAE, and greatly reduced the warm bias in both raw models.

In June, all of the models exhibited MAEs greater than 4^{o}F for dew point temperature, an indication of how difficult it is to forecast dew points when using only model output. The official forecast from the Tucson office outperformed all of the models, often by as much as 2^{o}F. Thus, even in a static regime, human forecasters were adding value over both the raw models and their bias-corrected counterparts. The BC grids did perform better than their raw counterparts, but not by an appreciable amount. The lone exception was the NAM12BC, whose errors were 1-2.5^{o}F lower than the NAM12. The NAM12 also contained a slight moist bias, while all other models were too dry. Finally, while the definite reasons are unknown, all of the models, including the TWC official forecast, performed notably better with 12Z dew point forecasts than 00Z.

Data from the month of July showed considerable differences compared to June. These differences were most likely due to the dramatic humidity increases and fluctuations that came with the onset of the monsoon during the second week of July. The monsoon arrival not only affected dew point verification, but also MaxT and MinT verification. Because the monsoon onset is a relatively sudden shift in regime, the bias-corrected grids did not have sufficient time to react, and therefore performed poorly during the vast majority of the month. In fact, it took the BC grids over three weeks to respond, with MAEs not dropping back to late June levels until around August 1 (**Fig. 5).** Another feature of interest is the large MAEs around July 3 or 4, previously highlighted as showing monsoon moisture days before the official onset of July 8. Dew points also varied greatly from day to day, due to intra-seasonal and daily variability within the monsoon itself. However, during the last few days of the month, the elevated dew points occupied the majority of the 30-day training period of BOIVerify, resulting in a BC MAE rebound as the regime became relatively steady once more.

In addition, very large biases showed up in both the onset period and during smaller scale, yet significant, weather events. One such event occurred on July 9th when a Gulf Surge, combined with outflow from convection over Sonora, Mexico, spread across most of southeast Arizona. This change drastically affected the BC grids; resulting in NAM12BC biases ranging from 15^{o}F too dry to 25^{o}F too wet (**Fig. 6**). This event is a prime example showing not only the lag of the BC grids, but also a time in which the raw model is likely to perform better (**Fig. 7**), provided it is capturing the ongoing weather situation. In this case, the raw NAM12 did perform better than its bias-corrected counterpart with biases ranging from 2-10^{o}F too dry over most of the CWA.

With an event as drastic and sudden as July 9th, the BC grids simply could not “react.” During events like this, the forecaster becomes an integral player in the forecast process. He or she can look at the meteorological conditions and amend model guidance to better reflect the situation at hand. Toward the end of the post-monsoon 30 days, the BC grids had time to adjust to the elevated dew points and rebound to perform better as illustrated in **Fig. 8**. This would also be true even in smaller scale fluctuations over a broader region like the North American Monsoon. As with June, July also showed better model performance with the 12Z dew point forecasts than with 00Z. MaxT and MinT MAEs, while not substantial, did increase slightly from their June levels.

4. NWP Model Change

Another significant change that can affect raw and BC model performance is a change to the model itself. In this case, two small, but important changes were applied to the NAM12 model on June 18, 2007. First, canopy resistance over evergreen and mixed-evergreen forests was decreased with the hope of reducing both latent heat (moisture) fluxes and high 2-meter dew point temperatures. A change was also made in surface exchange coefficients in stable conditions. This coefficient is a function of the bulk Richardson number and the change was implemented to reduce the overnight/early morning warm bias over the mountain west (Ferrier 2007). For this project, only the NAM12, NAM12BC and the official (TWC) forecast were analyzed due to the changes being applied only to this particular model. The NAM12BC was analyzed to see how the bias correction would handle the model change and the official forecast as a control feature.

For the NAM12, the canopy resistance decrease over evergreen and mixed-evergreen forest succeeded in reducing the high 2-meter dew point temperature bias. However, the reduction was not exceptionally large. This is most likely due to the fact that southeast Arizona’s evergreen forest is above 5000 feet in the mountains (**Fig. 9**) and the majority of the CWA is below the forested elevations. Therefore, the change had the desired effect for TWC above 5000 ft, but probably not as significantly as other CWAs with greater evergreen forest coverage. In cases where the wet bias was not as severe, the change was actually enough to reverse the bias from wet to slightly dry. The change in stable-condition surface exchange coefficients may also have succeeded in its goal to reduce the overnight/early morning (MinT) warm bias. In fact, the warm bias over the TWC CWA was reversed to a slight cool bias soon after the model upgrade was made (**Fig. 10)**.

As expected, the NAM12BC needed time to adjust to the model changes. The biases became cooler and drier, or reversed from wet to dry with the model change. Overall, the BC grid did not respond to the model change fast enough and thus overcorrected, leading to noticeable cold and dry biases on MinT and dew point respectively (**Fig. 11).** Because of this abrupt change to the raw NAM12 model output, the NAM12BC grids lost some value; but, knowing this, the forecaster can make corrections. During this period, TWC as an office tended to use a blend of the NAM12 and NAM12BC to mitigate the impacts of this model change. Other models, such as the ADJMAV and ADJMAVBC, were also occasionally blended in to aid in the mitigation of the model change effects.

5. Weather Regime Change

Due to the relatively long 30-day training period for the bias-corrected grids, a sharp weather regime change will likely affect the usefulness of these grids. The weather regime change studied in this project was the onset of the summer monsoon in the Tucson, Arizona area. Monsoon onset in 2007 fell on July 8. Pre-onset is considered the 30-day period ending on July 7 and post-onset is the 30-day period ending on August 7.

The verification results for this particular regime change were almost identical to those for the June-July comparison because the monsoon onset occurred so close to the transition from June to July. The BC grids made sizeable improvements over the raw models in the June and pre-onset periods, due to the relatively constant regime during those times. While the official onset fell on July 8, the monsoon pattern and dew point increase began as early as July 3 or 4. Dew point biases across the monsoon regime change were, on average, not more than a half to three quarters of a degree Fahrenheit different than those for the June-July comparison (**Table 2**). The initial intent was to examine a weather regime change as a separate phenomenon from the month-to-month comparison. However, upon further analysis, the regime change chosen coincided nearly identically to the June-July comparison, therefore a separate discussion is not provided here.

6. Summary and Conclusions

NWP models are not perfect. They have inherent biases that can become worse due to various changes, such as differences in weather regimes or model parameterization changes. While the BC grids were created to give the forecaster an easy way to view the raw models with the biases removed, the BC grids have trouble reacting to sudden pattern changes, or changes in the underlying raw models. Because the BC grids need time to adjust to these sudden changes, the human forecaster is still needed to apply his or her meteorological knowledge of the situation, notice these lags, and correct for them. In this example, the BC grids did not respond as quickly with reference to a regime change, such as the monsoon. After monsoon onset, the BC grids took more than three weeks to respond, with surface dew point MAEs not relaxing back to more typical values until around August 1.

On the other hand, the BC grids work well enough to be used frequently during regimes that have relatively constant weather, such as the month of June and the pre-monsoon periods in southeast Arizona. The take-home message with regard to BC grids is to know when it is appropriate and beneficial to use them. The forecaster must assess the current regime in place and make an informed decision about whether or not to employ the BC grids.

7. Acknowledgements

First and foremost, thanks go to Erik Pytlak, SOO at NWSFO in Tucson, Arizona, for review of this paper and assistance in learning and using the BOIVerify program. Thanks also go to David Kofron for his editing work on this project. Finally, thank you to David Myrick at NWS Western Region, for his helpful suggestions and editing work as well.

References

Barker, Tim. *BOIVerify, version 1.0: Smart Tools, Procedures and Scripts for maintaining a gridded verification database and displaying various statistics.* WFO Boise, ID. Fall 2006.

Ferrier, Brad S. *Two Changes to NAM*. PowerPoint presentation to NWS Science and Operations Officers, Spring 2007.

Western Region Summer 2007 Verification Assignments, June and July. http://ww2.wrh.noaa.gov/ssd/digital_services.

8. Tables and Figures

Table 1 – Max and MinT MAE for days 5 and 7, illustrating the good performance of the BC grids compared to the raw models for a steady regime.

	Day 5		Day 7	
	MaxT MAE	MinT MAE (98hr)	MaxT MAE	MinT MAE (146hr)
Official	3.81	4.06	4.28	4.44
MOSGuide	4.25	3.66	4.90	4.01
MOSGuideBC	2.29	3.08	6.46	3.71
GFS40	3.73	4.86	4.43	4.92
GFS40BC	2.73	3.13	4.62	3.76
ADJMEX	3.59	4.74	4.63	4.86
ADJMEXBC	3.05	3.20	6.34	4.23

Table 2 – A few highlighted examples showing the similarity between surface dew point MAEs for June/July and Pre/Post-Onset

	June				July			
	NAM12		NAM12 BC		NAM12		NAM12 BC	
	Average Error	MAE	Average Error	MAE	Average Error	MAE	Average Error	MAE
Day 1								
12z Td	5.21	7.21	0.24	4.81	2.55	4.10	-2.38	5.02
0z Td	2.82	5.49	-0.84	4.30	1.48	4.54	-1.00	4.61
Day 3								
12z Td	3.88	6.66	0.31	5.23	0.9	4.05	-3.89	6.11
0z Td	-0.10	5.93	-0.89	5.44	-1.62	4.26	-1.29	4.81

	Pre-Onset				Post-Onset			
	NAM12		NAM12 BC		NAM12		NAM12 BC	
	Average Error	MAE	Average Error	MAE	Average Error	MAE	Average Error	MAE
Day 1								
12z Td	3.98	6.25	-1.26	5.09	1.78	3.20	-1.90	4.19
0z Td	3.09	5.89	-0.53	5.07	-0.06	3.65	-1.65	4.08
Day 3								
12z Td	3.53	6.45	-1.13	5.94	0.49	3.33	-2.49	5.08
0z Td	-0.76	6.04	-0.96	5.78	-1.42	3.85	-1.12	4.20

Fig. 1 - TWC CWA in green shaded region

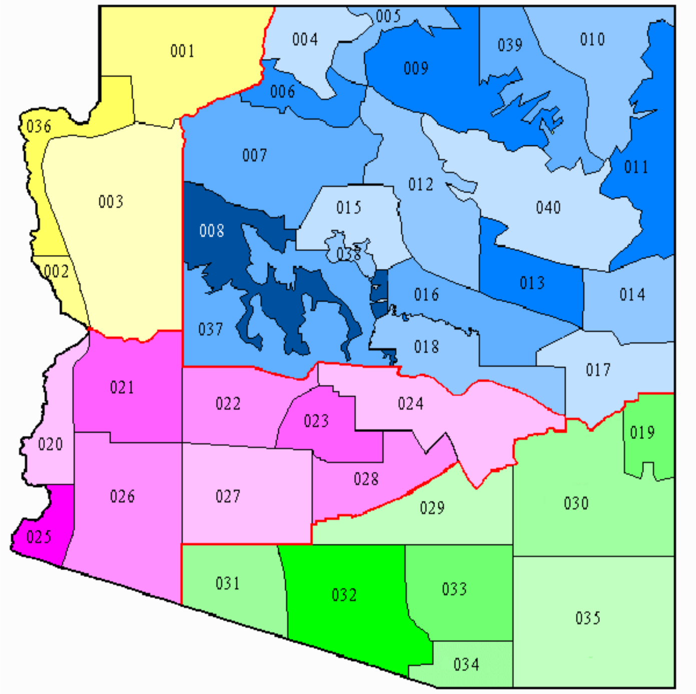


Fig. 2 – MaxT MAE for entire CWA, June 1-30, 2007 from BOIVerify (Barker 2006)

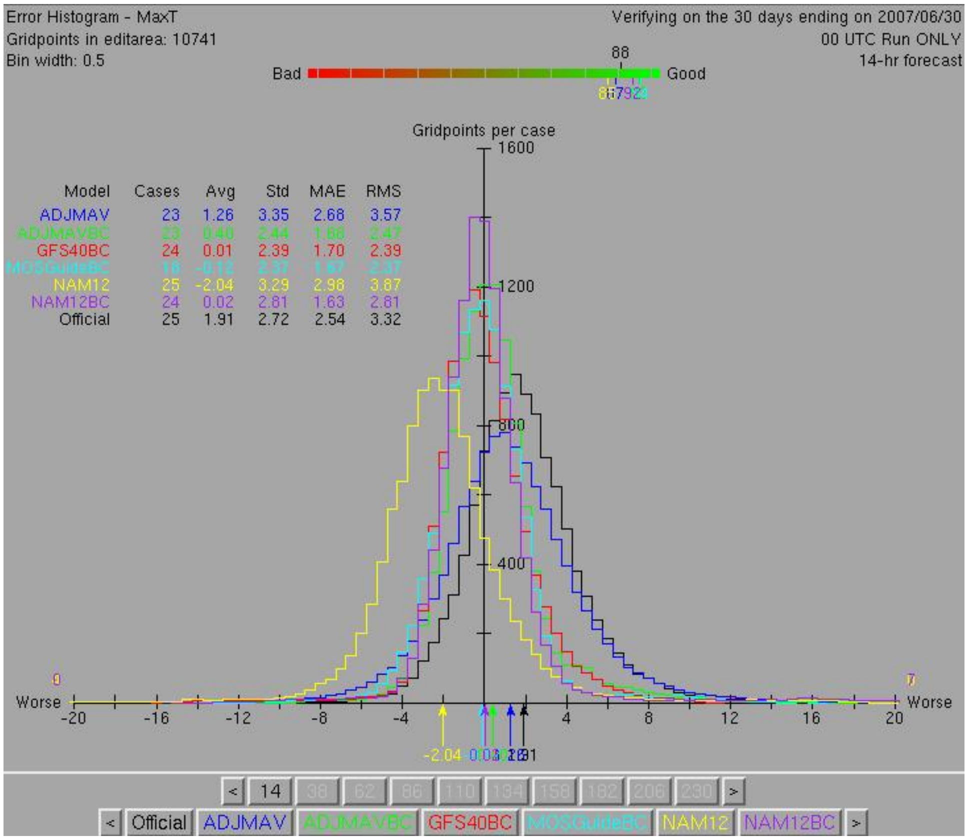


Fig. 3 – Map of CWA above 5000 feet (white hatched regions)

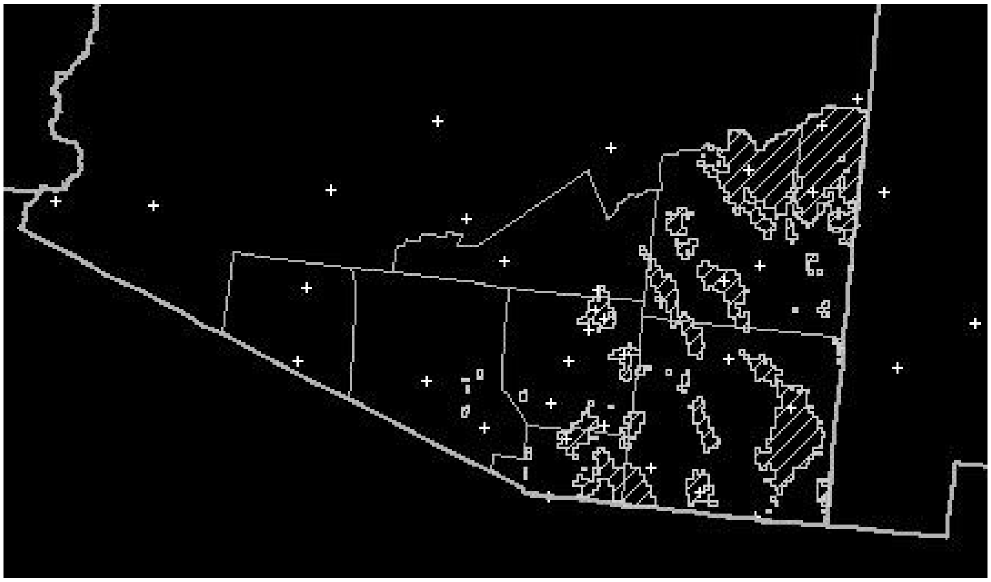


Fig. 4 – MaxT MAE for CWA above 5000 feet, June 1-30, 2007 from BOIVerify

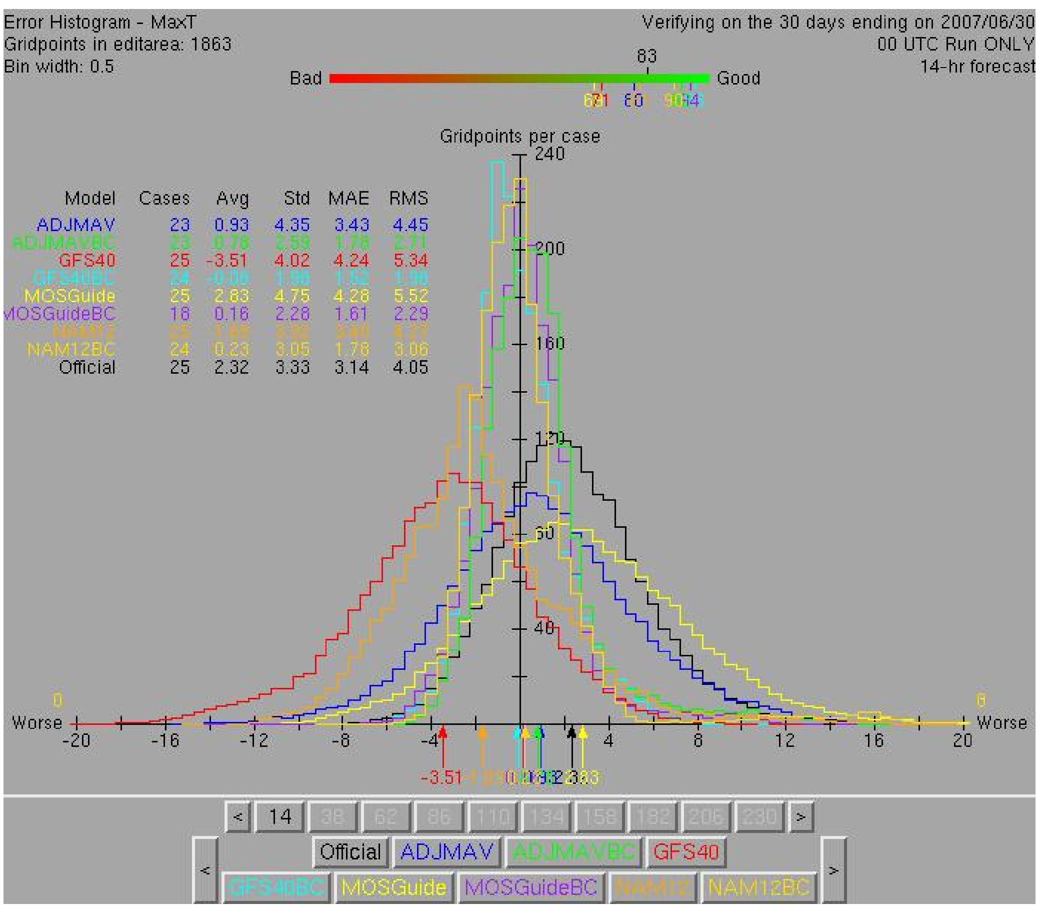
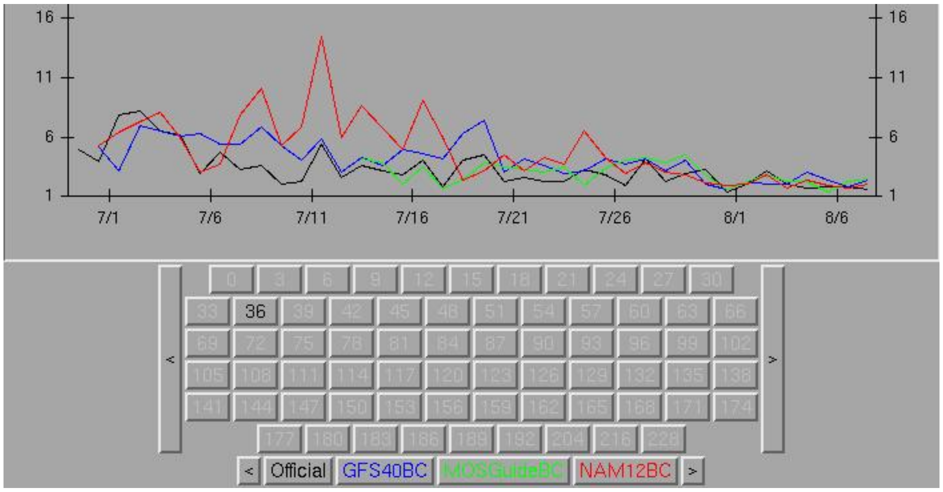


Fig. 5 – Time series of surface dew point MAE for bias-corrected grids from just before monsoon onset through the first week of August



GFS40BC = blue; MOSGuideBC = green; NAM12BC = red

Fig. 6 – NAM 12 BC surface dew point bias for July 9th at 00Z. Orange down to pink indicates 2-20 degrees F too dry. Blue up to light pink indicates 2-25 degrees F too wet.

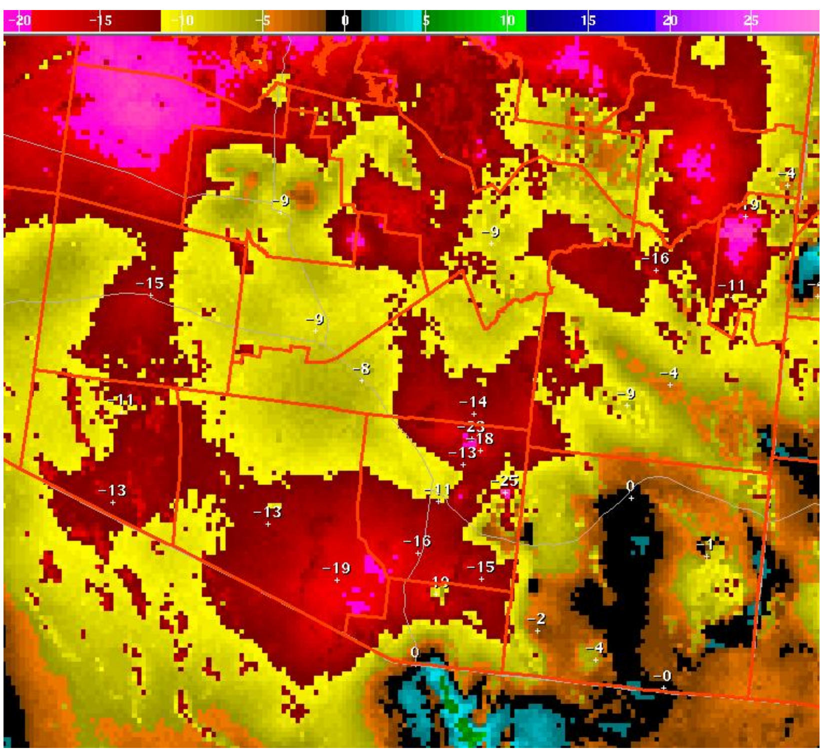


Fig. 7 – NAM12 surface dew point bias for July 9th at 00Z. Color scale is same as Fig. 6.

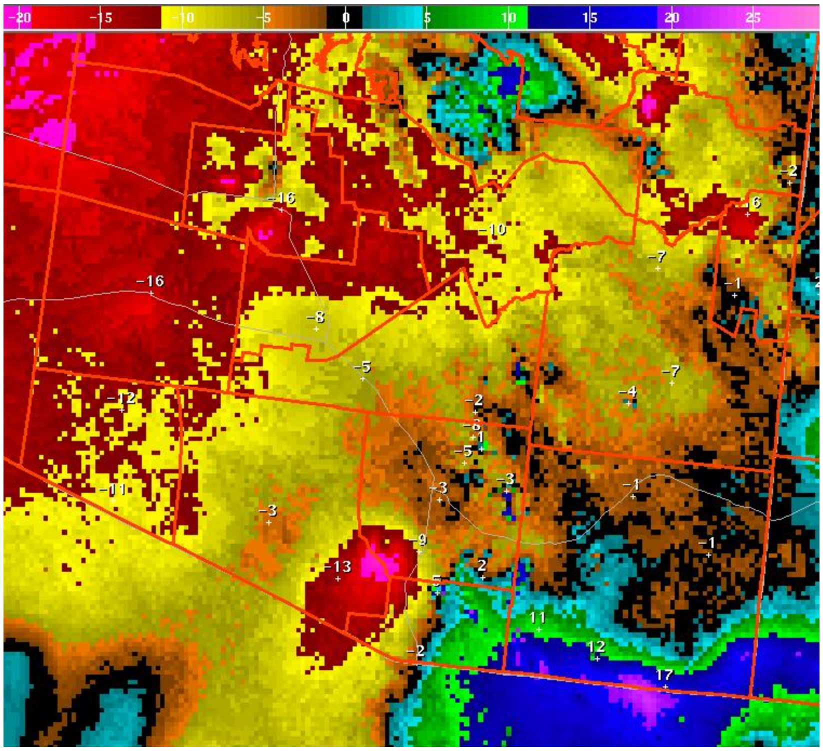


Fig. 8 – NAM12 BC surface dew point map showing the late July (27th) bias improvement of the BC grid after it had time to adjust to the new weather regime.

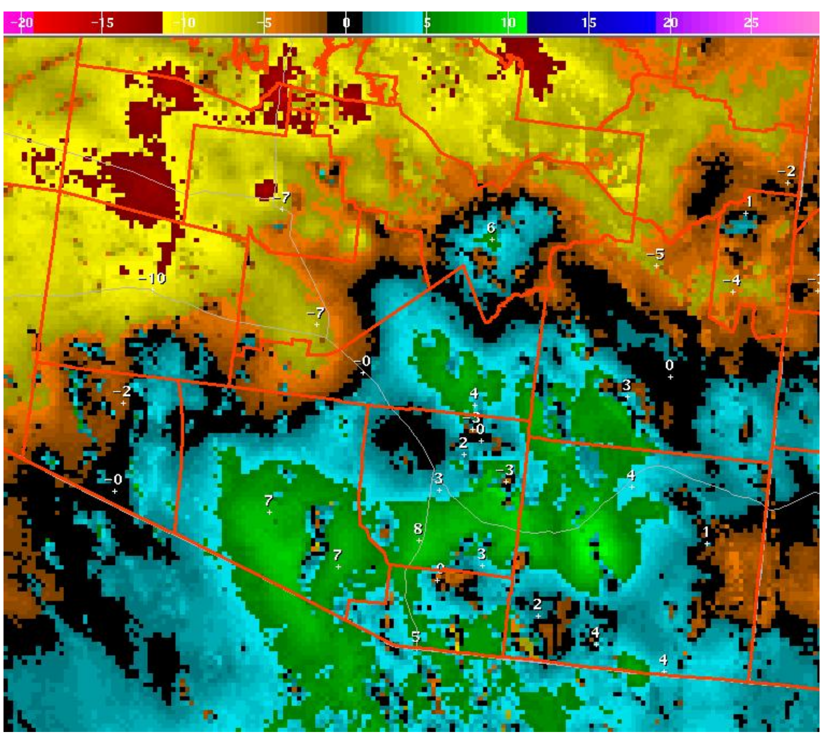


Fig. 9 –Vegetation Type Map Categories 14 (green) and 15 (yellow) encompass the evergreen and mixed evergreen forest affected by the NAM changes. Note that the green areas in the Tucson CWA are limited to the mountainous areas.

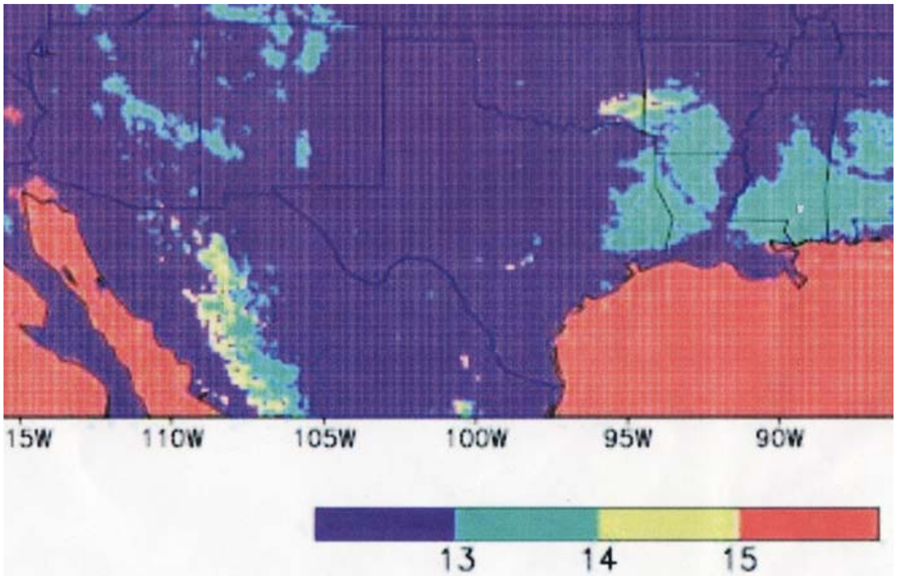


Fig. 10

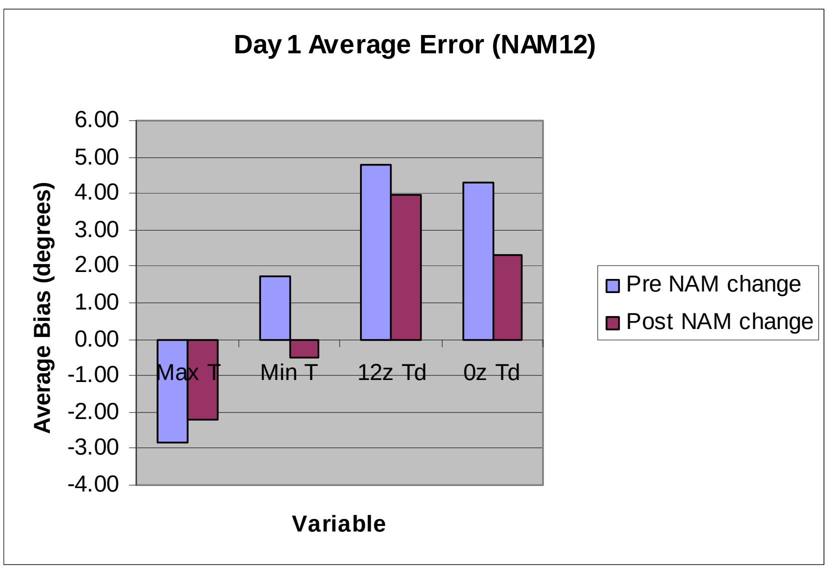
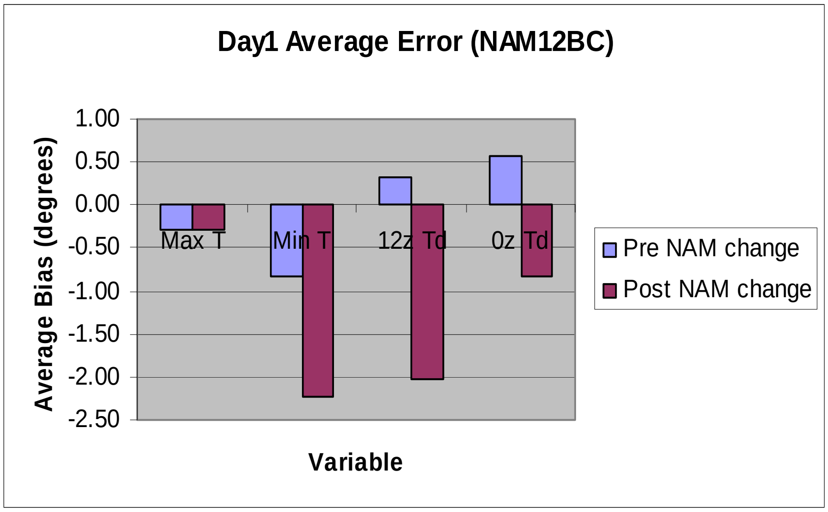


Fig. 11



Day1 Average Error (NAM12BC)
Average Bias (degrees)
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
-2.50
Max T
Min T
12z Td
0z Td
Variable
Pre NAM change
Post NAM change