Analyzing the Diurnal Cycle of Precipitation in the NCEP Global Forecast System

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Key Points:

- Diurnal cycle is more pronounced in summer months
- Models seem to have a tendency to have maximum and minimum precipitation early and late at times
- Forecasting quantitative precipitation forecast (QPF) is a huge problem for the GFS/GFSX, especially the diurnal cycle

Abstract

Forecasting the diurnal cycle of precipitation over the continental United States (CONUS) is a problematic process for most global forecast systems. A majority tends to have a strong bias and they don't provide a skilled prediction of the intensity, coverage and frequency of the diurnal cycle. Accurately forecasting the diurnal precipitation cycle, is closely related to the overall quality of the global forecast itself. Also, the accuracy of representation of physical processes in the models is indicative to the forecast skill. Major implementations have been made for the National Center for Environmental Prediction (NCEP) operational Global Forecast System (GFS) throughout the years to make improvements to the diurnal cycle of precipitation. This study examines the diurnal cycle of precipitation over the CONUS during the winter and summer months of 2016-2017. The operational and experimental GFS will be analyzed and compared to the observed diurnal cycle of precipitation. To accomplish this, 3-hourly averaged accumulated precipitation vs. forecast hour plots, for the different models, were created. This allowed us to gain insight on how the skill of the models were performing, against the observations.

This study is expected to provide feedback to the model developers at NCEP's Environmental Modeling Center (EMC) to inform (for making further) priorities for improvements to the GFS model, especially with the newly selected Next Generation Global Prediction System (NGGPS) Finite Volume Cube Sphere (FV^3) modeling system. The NGGPS is a fully coupled system that will be designed to create useful forecast guidance out to 30 days, extend forecast skill beyond 8 to 10 days, and improve hurricane track/intensity forecast.

1 Introduction

In the continental United States (CONUS), the diurnal cycle of precipitation is a parameter of great importance. The diurnal cycle of precipitation plays a large role on surface hydrology, surface temperature and atmospheric moist convection and cloudiness [*Dai et al.,* 1999]. This diurnal cycle contributes to a vast majority of the precipitation in the CONUS, especially in the warm season. In fact, during the warm season, the diurnal cycle is much stronger than any other season. This is mainly due to the presence of more convective available potential energy (CAPE) over much on the CONUS [*Dai et al.,* 1999] during this time. Since the diurnal cycle is stronger in the warm season, it becomes an even greater challenge for forecast models. As a result, summer precipitation has the lowest forecast skill compared to any other season [*Olson et al.,* 1995]. Being able to understand the behavior and drivers of the diurnal cycle of rainfall is essential for advancing numerical weather prediction (NWP) models for more accurate representation of physical processes that lead to improved forecasts of the diurnal cycle of precipitation.

There are several known characteristics of the diurnal cycle over the CONUS. In the southeast United States and North American monsoon region, the diurnal phase of rainfall contains a maximum in local afternoon [*Lee et al.,* 2007]. In the central United States there is a propagating rainfall axis that accounts for approximately 60% of seasonal (JJA) rainfall [*Carbone and Tuttle*, 2008]. Carbone et al. [2002] discovered a large scale coherent regeneration of rainfall systems much larger than mesoscale convective complexes that they referred to as “episodes”. These “episodes” influenced the phase and amplitude of the diurnal cycle eastward of the Continental Divide. Also, the Great Plains and Midwest have a strong mid-night to early morning maximum of precipitation frequency [*Dai et al.,* 1999].

However, operational forecast models demonstrate low skill in predicting the diurnal cycle. Different explanations have been proposed to explain why this occurs. One contributing factor is the model's inability to capture the coherent propagating rainfall axis observed in the central United States, which can lead to a diurnal cycle that is completely opposite to the observed diurnal cycle [*Davis et al.,* 2003]. Fritsch and Carbone [2004] explained that most errors originate from shortcomings associated with convection parameterization schemes (CPSs) and are directly linked to the warm-season quantitative precipitation forecast (QPF) problems. These problems are said to be derived from crude convective trigger functions, as well as lack of representation of mesoscale organization of convection [*Liu et al.,* 2006]. Parameterization of sub-grid scale physical processes are necessary for NWP models, for now, because many are not fully understood, and computers are not powerful enough yet to explicitly resolve these processes because they are either too small or complex to be resolved. Resolution of the models also complicates the process of explicitly resolving physical processes due to coarse resolution (usually about 10-15 km for current generation global models).

The National Centers for Environmental Prediction (NCEP) Global Forecast System (GFS) is a NWP model that operational forecasters, governments, researchers and civilians rely on for weather forecasts out to 16 days using a sophisticated suite of physical parameterization schemes and data assimilation techniques. This study will examine forecasts of the diurnal cycle of precipitation for the CONUS region in the summer and winter months of 2016-2017. Two sets of precipitation forecast data collected from the current operational GFS and the experimental GFS (implemented July 19, 2017) will be compared to relevant observations. The observation dataset that the models used for model verification is the Climatology-Calibrated Precipitation Analysis (CCPA).

The goal of this project is to obtain a better understanding of how the GFS forecasts are departing from observations and how the skill of the models performs. This is accomplished by creating average precipitation amount vs. forecast hour plots for the operational/experimental GFS and for the CCPA observations. Performing different types of verification analysis helps determine what aspects of the model need to be carefully examined and improved. Verification is an important process for measuring forecast quality and skill. Results from this study are expected to provide useful feedback to the model developers at the Environmental Modeling Center (EMC) and forecasters from the field.

2 Data and Methodology

3-hourly accumulate precipitation model forecasts from the operational Global Forecast System (GFS, http://www.emc.ncep.noaa.gov/GFS/doc.php) and experimental GFS (GFSX), both with a resolution of 1°, were used to study the diurnal cycle of precipitation in the models. The model forecasts were verified against the 0.125° resolution data from the Climatology-Calibrated Precipitation Analysis (CCPA; http://journals.ametsoc.org/doi/abs/10.1175/JHM-D-11-0140.1). The time periods that were investigated were May 1 – August 31, 2016, December 1, 2016- February 28, 2017, and May 1 – June 30, 2017. With the exception of the GFSX dataset which was only available from July 12 - August 31, 2016 and May 1 –June 30, 2017. All model runs were initialized at 00z, which include forecast hours 3-168 every 3 hours (3 hour accumulations). Confingency tables and partial sums were calculated using the Model Evalutaion Tools (MET, Developmental Testbed Center, 2017: MET: Version 6.1 Model Evaluation Tools Users Guide. Available at http://www.dtcenter.org/met/users/docs/overview.php) at various thresholds greater than or equal to 0.0mm, 0.1mm, 0.2mm, 1mm, 5mm, 10mm, 15mm, 25mm, 35mm, 50mm, 75mm and 0.0mm, 0.1mm, 0.2mm, 1mm, 5mm, 10mm, 15mm, 25mm, 35mm, 50mm, 75mm, respectivley. Prior to the calculations, the model and CCPA grids were regridded to the National Centers for Environmental Prediction (NCEP)'s G218 grid (see Figure 2) using bilinear interpolation. The region of particular interest for this study was CONUS. In order to partition out the diurnal cycle better, sub-regions were created to take in consideration of time changes between the East and West coasts. The definitions for what makes up the East and West regions are in Figure 1. Graphics were created using METviewer version 2.1, a webpage used to create graphics from the MET output.

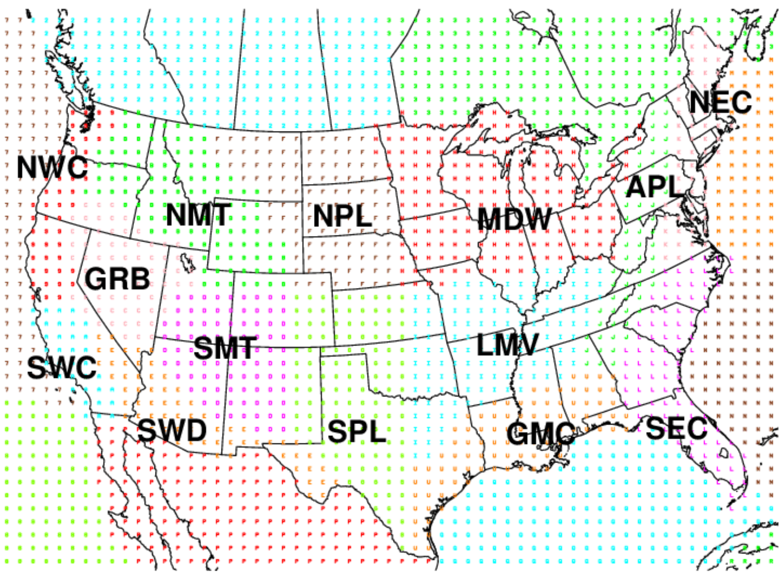

Figure 1:

West: NWC, SWC, GRB, NMT, SMT, SWD, NPL, SPL

East: MDW, APL, LMV, GMC, SEC, NEC

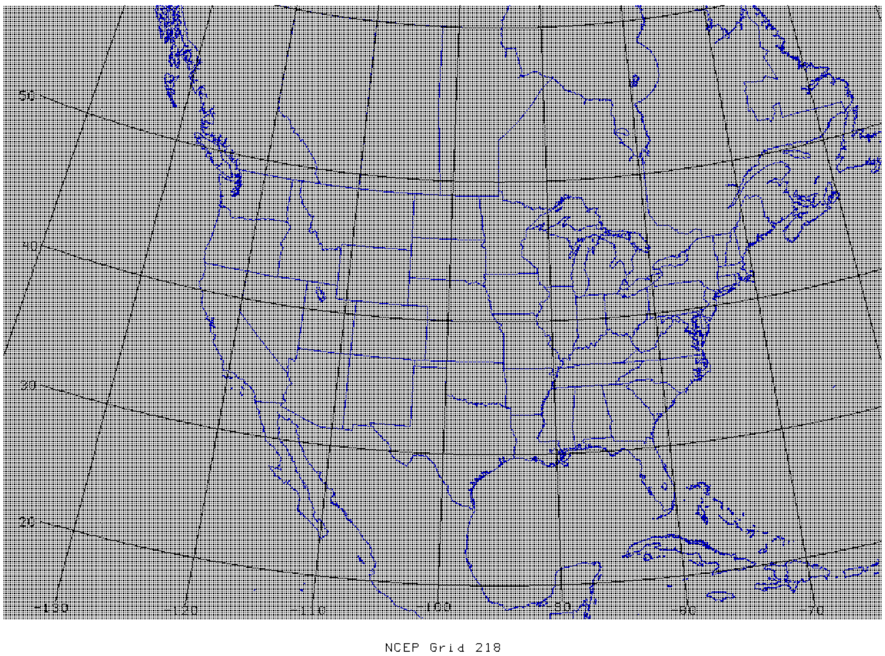

Figure 2: Grid used for region of study

3 Results

3.1 Diurnal Cycle of Precipitation for CONUS Region

Examining the diurnal cycle of precipitation from a continental viewpoint can help give a general idea of how the diurnal cycle behaves. The following plots are displaying the diurnal cycle of precipitation for the CONUS region for the different time periods analyzed in this study. By examining the different time periods, one can obtain a sense of how the different seasons play a role in the diurnal cycle. By examining figure 3, you can see that there is a significant diurnal cycle for the July 12 - August 31, 2016, time period. The GFSX also has a better magnitude than the GFS. However, both the models don't accurately time the maximum and minimum precipitation. The GFS has the maximum precipitation earlier than the CCPA, where as the GFSX has the maximum precipitation later than the CCPA.

Observing the winter time frame in figure 4 for December 1, 2016- February 28, 2017, there is no significant diurnal cycle. The GFS also departs greatly from the CCPA towards the end of the forecast. In figure 5, May 1 – June 30, 2017, you can see that there is a clear diurnal cycle. The GFSX is significantly over predicting and the GFS seems to have a better forecast. Both the models capture the maximum precipitation but are early with the minimum precipitation.

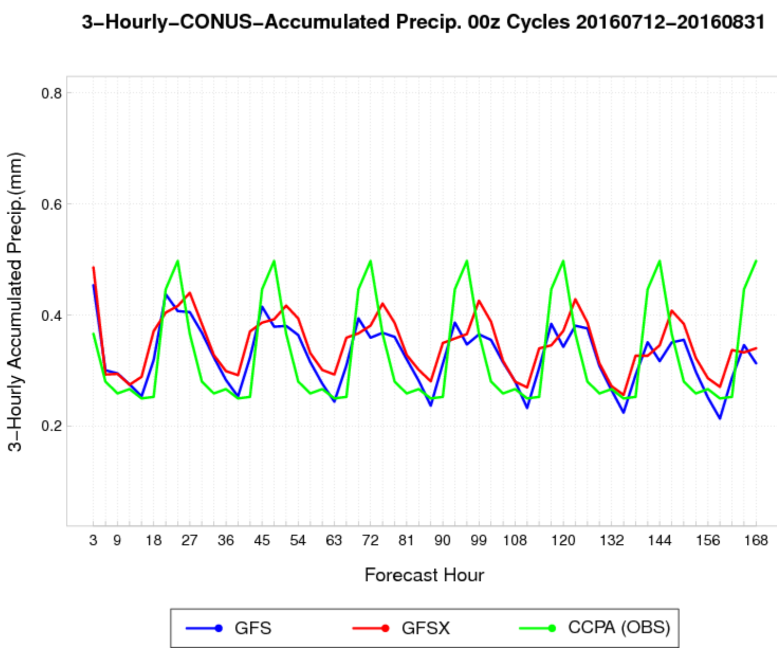

Figure 3: 3-hourly accumulated precipitation vs. forecast hour for CONUS region comparing GFS, GFSX, and CCPA for 00z cycles July 12, 2016- August 31, 2016

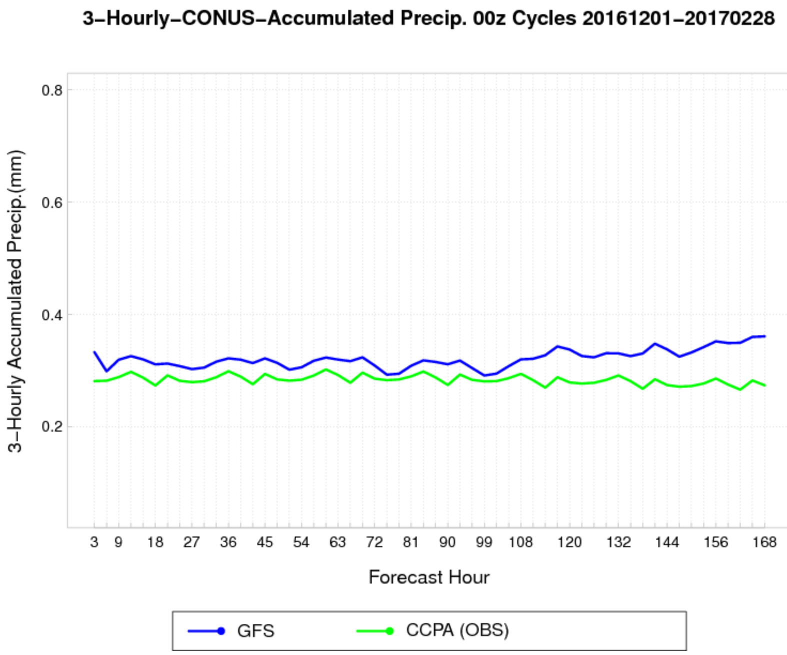

Figure 4: 3-hourly accumulated precipitation vs. forecast hour for CONUS region comparing GFS, GFSX, and CCPA for 00z cycles December 1, 2016 – February 28, 2017

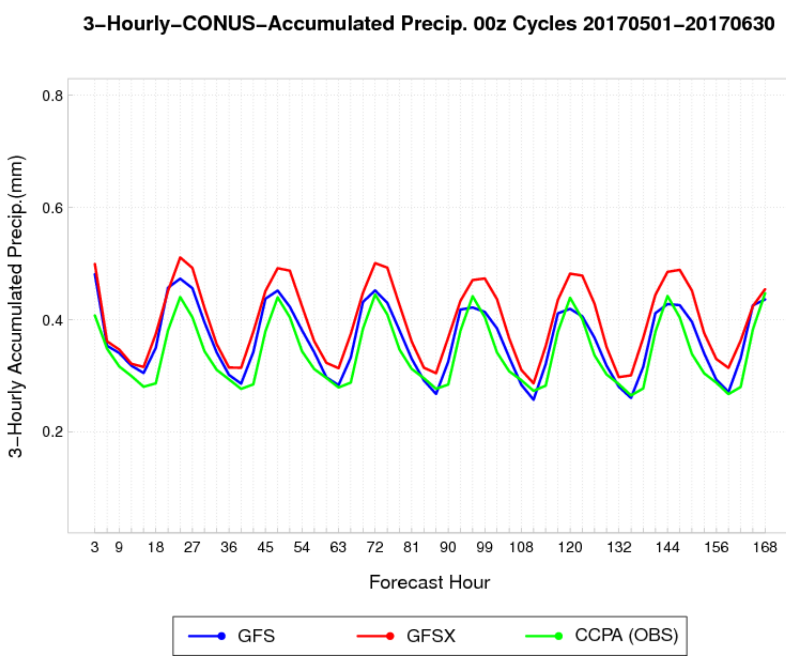

Figure 5: 3-hourly accumulated precipitation vs. forecast hour for CONUS region comparing GFS, GFSX, and CCPA for 00z cycles May 1, 2017- June 30, 2017

3.2 Diurnal Cycle of Precipitation for West US Region

The following graphs are displaying the diurnal cycle of precipitation for the West US region, for the different time periods in the study. Figure 6 shows July 12, 2016 – August 31, 2016 where the GFS seems to have a better forecast, while the GFSX is significantly over predicting. However, both the models capture the maximum precipitation but are early in the minimum precipitation.

The winter time period of December 1, 2016 – February 28, 2017 shows a greater defined diurnal cycle than for the same time period in the CONUS region. Both the models capture the maximum precipitation but are early in the minimum precipitation. This can be seen in figure 7.

Figure 8 shows the time period of May 1- June 30, 2017. Once again the GFSX significantly over predicts and the GFS seems to have a better forecast. Both the models capture the maximum precipitation but are early in the minimum precipitation. In all, the West US region shows the GFSX over predicting and a pronounced diurnal cycle for the summer months but not for the winter months.

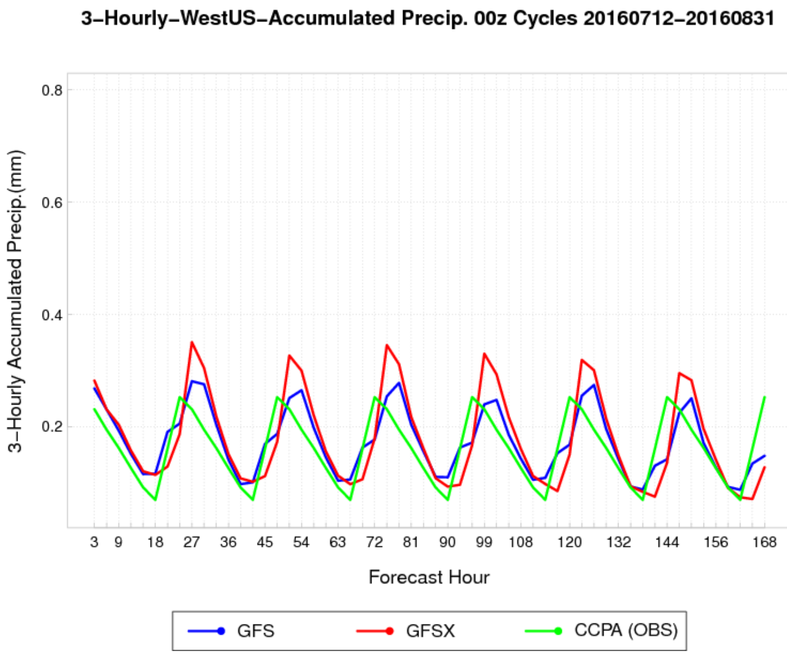

Figure 6: 3-hourly accumulated precipitation vs. forecast hour for West US region comparing GFS, GFSX, and CCPA for 00z cycles July 12, 2016- August 31, 2016

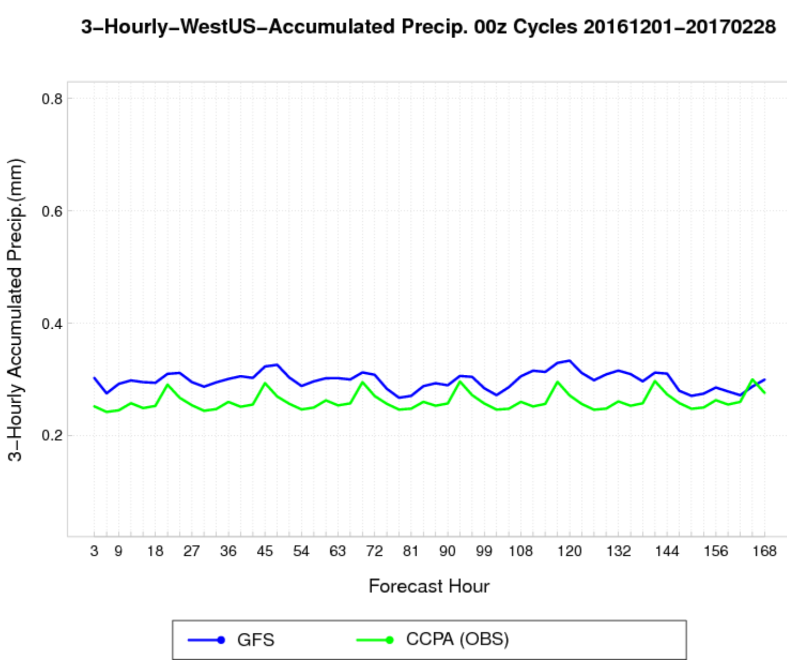

Figure 7: 3-hourly accumulated precipitation vs. forecast hour for West US region comparing GFS, GFSX, and CCPA for 00z cycles December 1, 2016- February 28, 2017

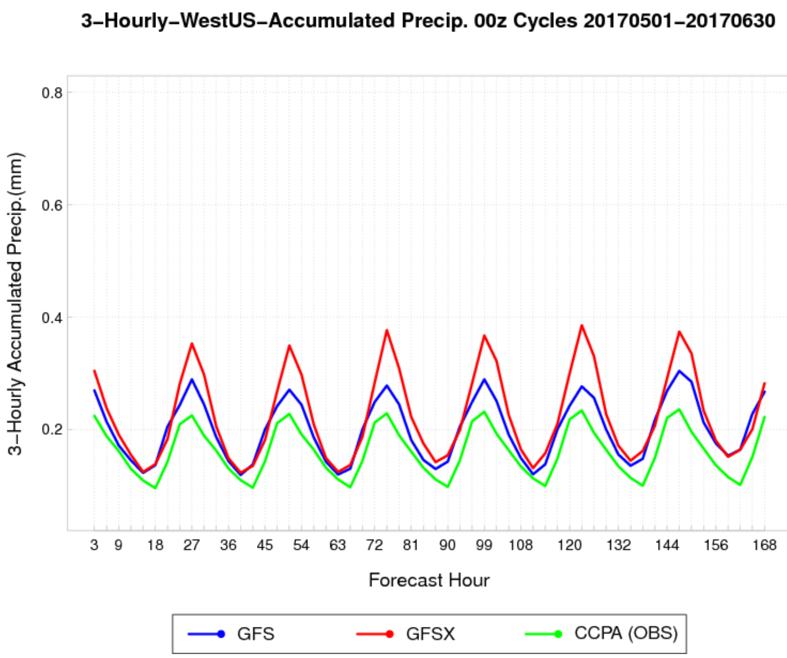

Figure 8: 3-hourly accumulated precipitation vs. forecast hour for West US region comparing GFS, GFSX, and CCPA for 00z cycles May 1 – June 30, 2017

3.3 Diurnal Cycle of Precipitation for East US Region

The graphs for the East US region are shown below for the different time periods. In figure 9, you can see both the models under predict and get worse as the forecast hour increases. Also, throughout the entire forecast both the models are early with the maximum precipitation, late with the minimum precipitation, and both are similar in magnitude.

Figure 10 is very similar to figure 4, in that, both regions show the GFS departing from the observations towards the end of the forecast. In the east US region, the diurnal cycle can be seen greater than the CONUS region however. In figure 11, both the models do well at predicting the precipitation amount. Once again both the models are off with the timing. The GFS is early with the maximum precipitation but is early with the minimum precipitation. The GFSX is early at times with the maximum and minimum precipitation.

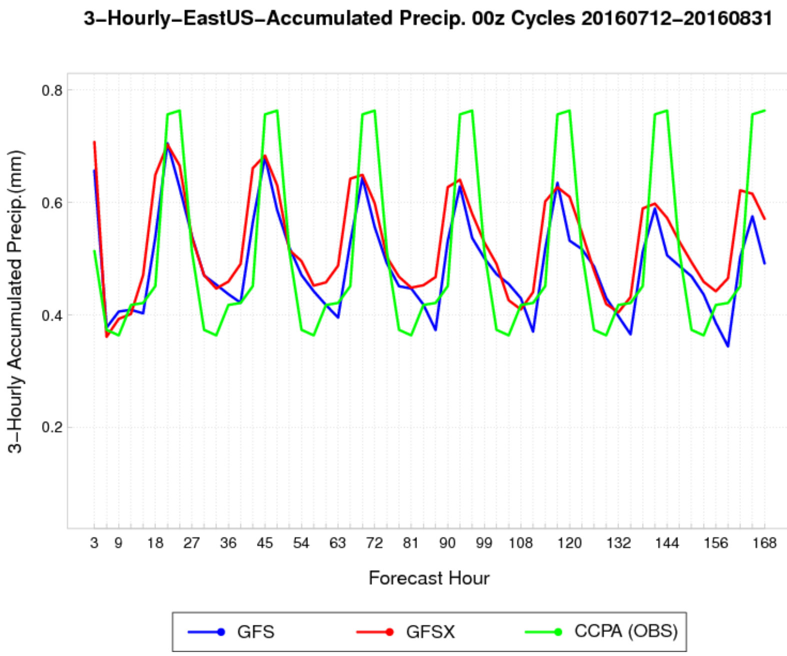

Figure 9: 3-hourly accumulated precipitation vs. forecast hour for East US region comparing GFS, GFSX, and CCPA for 00z cycles July 12, 2016- August 31, 2016

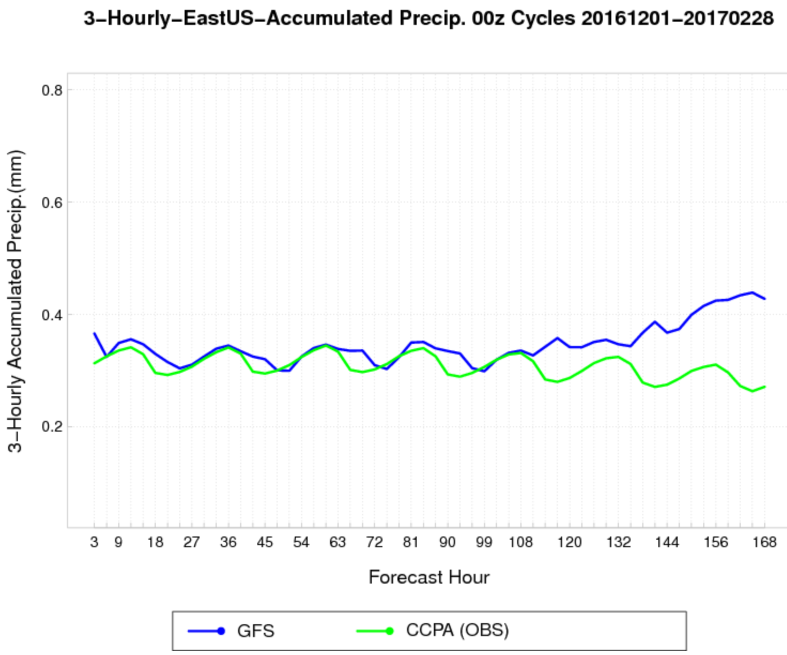

Figure 10: 3-hourly accumulated precipitation vs. forecast hour for East US region comparing GFS, GFSX, and CCPA for 00z cycles January 1, 2016 – February 28, 2017

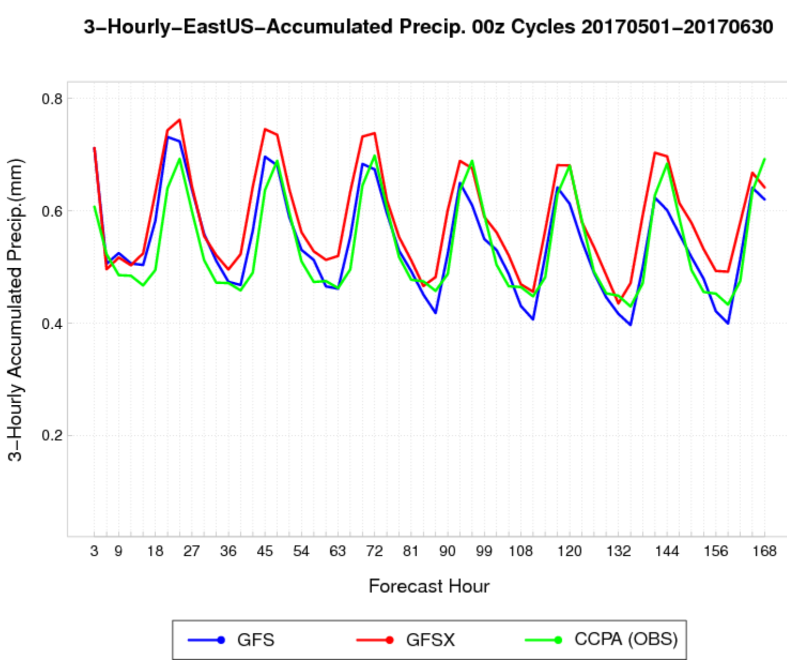

Figure 11: 3-hourly accumulated precipitation vs. forecast hour for East US region comparing GFS, GFSX, and CCPA for 00z cycles May 1, 2017 – June 30, 2017

3.4 July 10, 2017 Case

On July 10, 2017 there were numerous cases of severe weather events across the midwestern United States. There were two specific cases that stood out the most to us. These two cases can give you an idea on how the models can be accurate and inaccurate at different times. The first case was at Chicago O' Hare International Airport , where the models did a fairly well job of capturing the precipitation event. This can be seen in Figure 12, by carefully analyzing the plot, you can see that the models initiated early. Even with the models initiating early, they still did a fairly good job of capturing the event. By looking at figure 13, this is a severe weather event that occurred at Findlay Airport, Ohio where the models didn't do well capturing the intensity of the event. By comparing the observations to the GFS and ensemble members, you can see that none of them came close to capturing the heavy precipitation at 06z/13. This could have been due to the models having the event start later than the observations. These two events were shown to give a closer look at the diurnal cycle of precipitation, instead of from just a very broad region point of view.

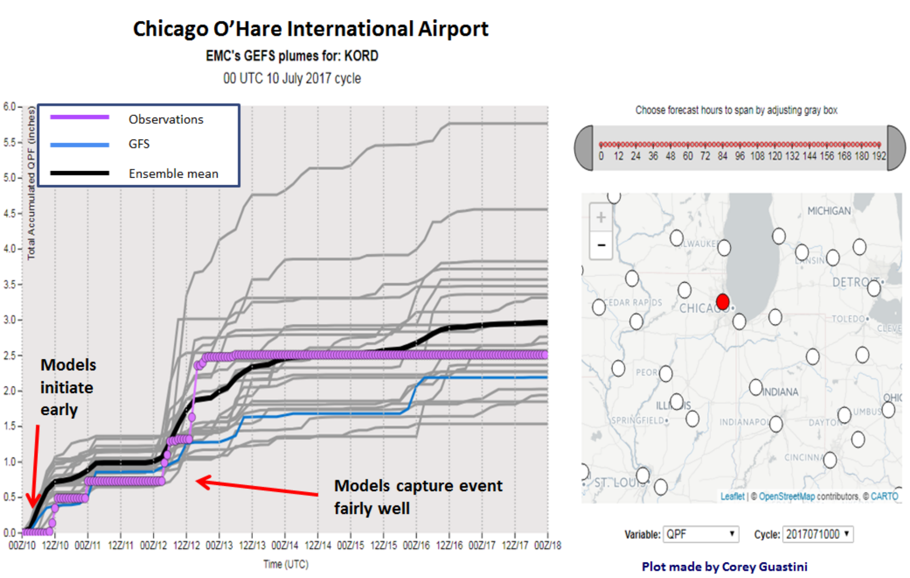

Figure 12: Plot showing the July 10, 2017 case at Chicago O'Hare airport where the GFS and ensemble members captured the precipitation event fairly well

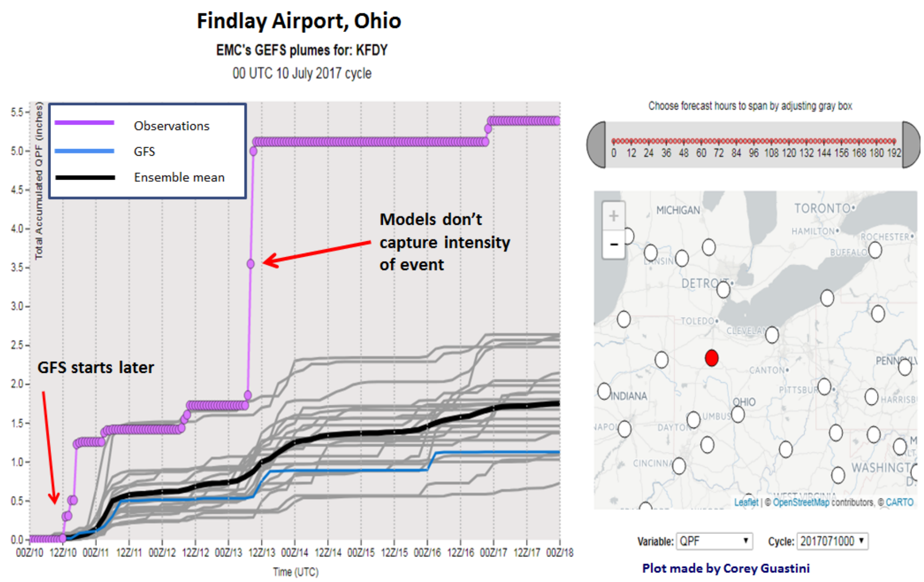

Figure 13: Plot showing the July 10, 2017 case at Findlay airport, Ohio where the models didn't capture the intensity of the precipitation event.

4 Summary and Future Work

This study examined the diurnal cycle of precipitation in both the operational GFS and the experimental GFS (implemented on July 19, 2017). The models were verified with the CCPA dataset, to analyze how the models captured the diurnal cycle, when compared to the observations. The overall focus of the research was to determine how the two models departed from the observations and if different regions and seasons within the CONUS played a role on the aspect of the departure.

After carefully analyzing all the plots, the winter months had a higher skill when compared to the summer months. This is expected because there is more lift in the atmosphere in the summer, which leads to a more pronounced diurnal cycle. For a majority of the months, both the models seemed to have a tendency to have the maximum and minimum precipitation early and late at times. The GFSX had a consistent overestimation throughout a majority of the time periods we analyzed. In all, the quantitative precipitation forecast (QPF), is a problem for the GFS and GFSX, especially the diurnal cycle.

In the future, we plan to examine more specific regions in the CONUS, instead of just the west and east. This would allow us to gain a better perspective of how the models perform in different parts of the CONUS. Also, we will take a quantitative approach and perform different statistical analyses to understand the skill of the models. Verification will be continued with the GFS and necessary implementations will be brought forward.

Acknowledgments

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