Evaluation of QPF from a WRF Ensemble System during the Southwest Monsoon

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ABSTRACT

This study will examine the Weather Research and Forecast (WRF) physics parameterization ability to simulate and predict precipitation over Arizona during the Monsoon season. The sensitivity of the WRF model with respect to uncertainty of the model parameterization will be investigated by varying the planetary boundary layer (PBL), microphysical, and cumulus schemes. WRF ensemble members will be examined to see if they accurately predict the PBL and the convective inhibition to properly initiate convection over Arizona. Results should show that the MRF PBL scheme simulates the PBL reasonable well for the Southwest. However, the YSU PBL scheme will be examined and should be an improvement compared to the MRF PBL. Improvements to the Eta PBL scheme by varying the microphysics will also be examined. The quantitative precipitation forecasts will be examined for two events that produce widespread flash flooding across Southern Arizona. This study is the first step in the process to create a WRF ensemble system that will produce accurate QPF over the Southwest and be used as input into a hydrologic model to produce probabilistic streamflow.

1. INTRODUCTION

Flash floods are among the top three weather related killers in Arizona. Probabilistic streamflow would give forecasters an idea of where the potential flash flood threat exists. To give forecasters reliable probabilistic streamflow data, the precipitation input to the hydrologic model needs to be accurate. However, forecasting precipitation is extremely difficult over the desert Southwest during the North American Monsoon season (also known as the Mexican Monsoon, or Southwest Monsoon). The complex terrain (Fig. 1) and data void areas makes it difficult for numerical models to accurately predict precipitation (Bright and Mullen 2002a, b, McCollum et al., 1995). Other studies (Farfan et al., 2000; Dunn and Horel 1994; Janic 1994) have shown that numerical models demonstrate limited skill over Arizona with general location of precipitation over higher terrain and heavy rainfall amounts.

Recent studies have shown an improvement of skill in precipitation forecasts using ensemble systems (Du et al., 1997; Hamill and Colucci 1997 and 1998; Strensrud et al., 1999; Wandishin et al., 2001; Bright and Mullen 2002; and Jankov et al., 2004). Ensembles address the model uncertainty by varying the PBL, microphysical, and cumulus parameterizations. Not only are model physics sensitive to Midwest convective cases (Jankov et al., 2004), but Giorigi (1991) and Bright and Mullen (2002a, b) found summertime quantitative precipitation forecasts (QPFs) are extremely sensitive to model physics in the Southwest.

Bright and Mullen (2002a, b) used a 10 member ensemble system using the fifth generation of the Pennsylvania State University–National Center for Atmospheric Research Mesoscale Model (MM5) to evaluate short range probabilistic QPFs over Arizona during the monsoon season. They found that MRF PBL simulated the afternoon PBL better compared to the Eta PBL (Janic 1994). Other studies (Jankov et al., 2004; Janic 1994) have also shown that the Eta PBL scheme tends to be cool and moist, which will have large impacts the development of the convection. Bright and Mullen (2002) suggested that the Eta PBL may do better with varied microphysics. Although Jankov et al., (2004) study examined convective development in the Midwest, their findings indicated that the microphysics did not affect the lighter precipitation amounts, but there was a higher sensitivity at heavier precipitation amounts.

This study will expand and compare results with the findings by Bright and Mullen (2002a, b) by varying the model physics of the Weather Research and Forecast (WRF) model over Arizona for two heavy precipitation events during the Monsoon season. WRF ensemble members will be evaluated on how well they can simulate the PBL and accurately predict QPF. Section 2 will discuss the WRF model and the different ensemble members. A brief description of the flash flood events are in section 3. Due to the very preliminary results, section 4 will summarize what is expected to be found.

2. WRF ENSEMBLE SYSTEM

The WRF model being used is version 2.03 with 37 vertical layers and only 5 layers above 200 hPa. The model domain will have horizontal grid spacing of 12 km centered over Arizona (not shown). Future expectations are to include a 4km two way interactive nest. The boundary conditions are interpolated from the NCEP Eta Model from the NCEP grid 212 data at 3 hourly intervals and forecast start at 12 UTC. There was no additional mesoscale data used to refine model initialization.

The ensemble members are shown in Table 1. All model physics descriptions can be found on the WRF Users web site (www.wrf-model.org). The two PBL schemes that will be used are the MRF and YSU. The

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cumulus parameterization will include the Kain-Fritsch (Kain and Fritsch 1993) and the Betts-Miller (Bett 1986; Betts and Miller, 1986; Janic 1994). Model runs with no convection will also be examined. Finally, the Lin et al. (1983) and the WSM class 5 will be examined for the microphysic parameterization. All of the ensemble members employed the NOAH land surface model, Dudhia shortwave radiation, and RRTM longwave radiation.

No.	Exp. name	CU	PBL	Microphysics
1	KMRFMP2	KF	MRF	Lin
2	KMRFMP4	KF	MRF	WSM class 5
3	KYSUMP2	KF	YSU	Lin
4	KYSUMP4	KF	YSU	WSM class 5
5	KETAMP2	KF	Eta	Lin
6	KETAMP4	KF	Eta	WSM class 5
7	BMRFMP2	BMJ	MRF	Lin
8	BMRFMP2	BMJ	MRF	WSM class 5
9	BYSUMP2	BMJ	YSU	Lin
10	BYSUMP4	BMJ	YSU	WSM class 5
11	BETAMP2	BMJ	Eta	Lin
12	BETAMP4	BMJ	Eta	WSM class 5
13	NMRFMP2	None	MRF	Lin e
14	NMRFMP4	None	MRF	WSM class 5
15	NYSUMP2	None	YSU	Lin
16	NYSUMP4	None	YSU	WSM class 5
17	NETAMP2	None	Eta	Lin
18	NETAMP4	None	Eta	WSM class 5

Table 1: The experiment name identifies the cumulus (CU) parameterization (K, new Kain-Fritsch; B, Betts-Miller; N, no convection), the PBL parameterization (MRF, YSU, Eta), and the microphysics parameterization (MP2, Lin; MP4, WSM class 5).

3. CASE STUDIES

Two significant flash flood events that occurred in the Tucson WFO area of responsibility (Fig. 1) will be examined. Both events had widespread showers and thunderstorms develop in the afternoon with flash flood events occurring through the late evening. At this time results are very preliminary; however, a comparison of WRF members PBL to the 12 and 18 UTC soundings will be performed. Also, a comparison of the QPF to the NCEP/EMC Stage IV precipitation data will be shown.

3.1. July 29, 2003

Severe thunderstorms developed in the afternoon through the early evening producing flash floods for many portions of southern Arizona. East and west portions of Pima County and Cochise County received the worst damage due to the heavy precipitation. Moisture was already abundant over the area as an inverted trough moved toward southern Arizona on the morning of the 29th (Fig. 2). The 12Z KTUS sounding showed a very moist and unstable atmosphere (Fig. 3), with a lifted index of -6 degree Celsius and unmodified convective available potential energy (CAPE) of 1200 J/kg.

Thunderstorms initially developed over the higher terrain around 19 UTC and then developed into a line of thunderstorms by 00 UTC on the 30th. The line moved west across southern Arizona through midnight. Precipitation gages across Tucson ranged from 13 to 38 mm (0.50 to 1.5 inches) with Tucson International Airport recording 38 mm (1.49 inches).

3.2. August 13, 2004

Another event of heavy precipitation and severe thunderstorms erupted on the afternoon of August 13, 2004, producing flash flooding across Santa Cruz and eastern Pima counties. Several disturbances moving around an upper level low off the coast of California helped trigger the afternoon thunderstorms (not shown).

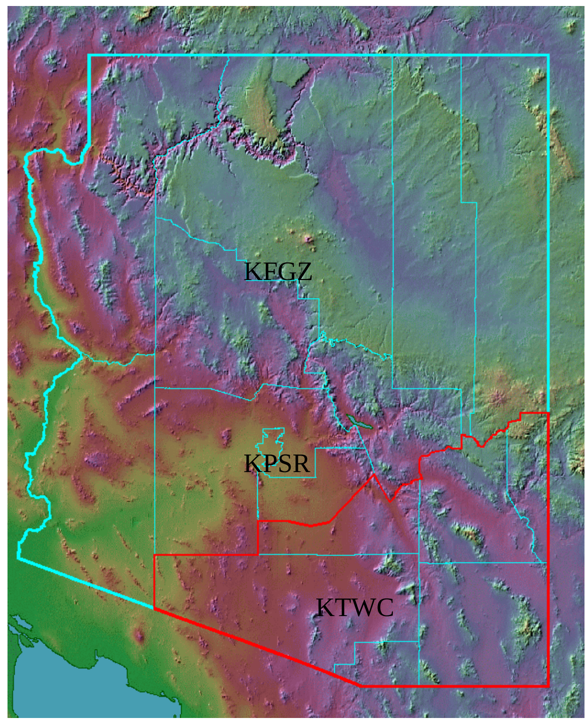

Figure 2: Topographic map of Arizona and the complex terrain. The National Weather Service Tucson (KTWC), Phoenix (KPSR), and Flagstaff (KFGZ) weather forecast office (WFO) indicated in black. The Tucson WFO area of responsibility is outlined in red.

The 12 UTC KTUS sounding (Fig. 4) was also very moist, with a lifted index of -5 degrees Celsius and unmodified CAPE of 1250 J/kg. The GOES estimated PW (not shown) ranged from 36 to 41 mm (1.4 to 1.6 inches) across southern Arizona. Thunderstorms initially developed over the higher terrain with thunderstorms covering much of Arizona by 22 UTC. Stronger storms were seen across eastern portions of Arizona indicated by the colder cloud tops in the infrared imagery seen in Figure 5.

Although there were several road closures in Tucson, the heaviest precipitation fell near the town of

Rio Rico (a town south of Tucson in Santa Cruz County). Seven homes were flooded and many roads were impassable due to the high water.

4. SUMMARY

This study will examine the WRF ability to simulate and predict precipitation over the desert Southwest during the Monsoon season on July 29, 2003 and August 13, 2004. The sensitivity to the WRF model with respect to the uncertainty of the model parameterization will be investigated by varying the PBL, microphysical, and cumulus schemes. Theoretically the YSU PBL scheme should do better than the MRF PBL since it incorporates explicit treatment of entrainment and the depth of the PBL is determined by the thermal profile.

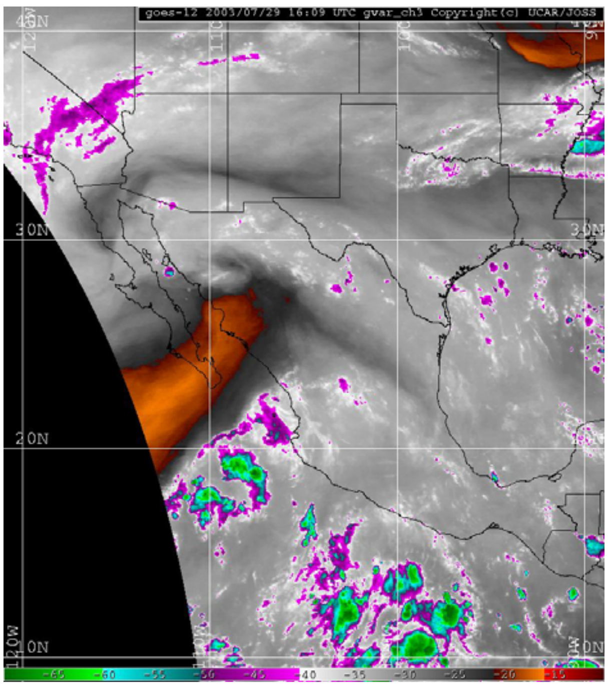

Figure 2: Water Vapor imagery of inverted trough moving across Arizona at 16 UTC on July 29, 2003.

The study will also be varying the microphysics parameterization. Jankov et al. (2004) used a 19 ensemble member WRF system with convection over the Midwest. They found that the sensitivities to the PBL and microphysical schemes for lighter precipitation are comparable, while the heavier precipitation indicated a higher sensitivity to the microphysics. Due to the very preliminary stages of the study, results will be shown later.

This examination is the first step in the process to create a WRF ensemble system that will produce accurate QPF over the Southwest and be used as input into a hydrologic model to produce probabilistic streamflow.

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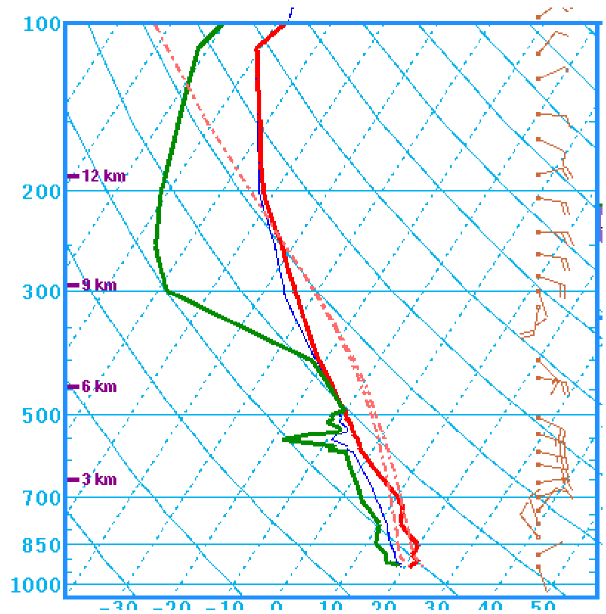

Figure 3: Skew T-logp plot at 12 UTC sounding on July 29, 2003. The temperature profile is shown in red solid line and dew point temperature profile is shown in green solid line.

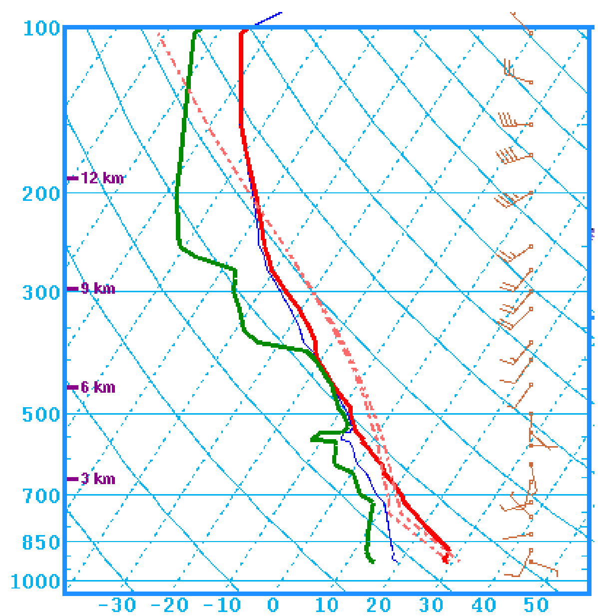

Figure 4: Same as in Figure 6, except for August 13, 2004.

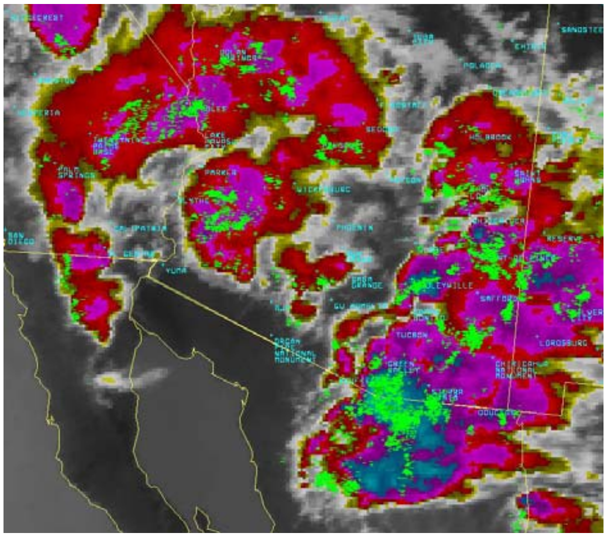

Figure 5: Infrared satellite imagery thunderstorms over Arizona at 2221 UTC on August 13, 2004. The one hour lightning data is shown in green at 2200 UTC.

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