The SPoRT-WRF: Evaluating the Impact of NASA Datasets on Convective Forecasts

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1. Introduction

The Short-term Prediction Research and Transition Center (SPoRT) is a collaborative partnership between NASA and operational forecasting partners, including a number of National Weather Service (NWS) Weather Forecast Offices (WFO). SPoRT transitions real-time NASA products and capabilities to its partners to address specific operational forecast challenges related to short-term, regional-scale weather forecasts. SPoRT uses forecaster interaction and feedback as a primary tool for improving these transitioned products. Numerical weather prediction (NWP) is one focus area of the SPoRT program.

Accurate numerical prediction of the timing, intensity, mode, and location of convection is a forecast challenge for regional and local scale modeling. In 2011 alone, 1,688 tornadoes causing more than 5,000 injuries (more than 550 fatalities) and approximately $20-25 billion in estimated damages were attributed to convective thunderstorms. While many of these tornadoes had lengthy lead times, many WFOs cite convection as their main forecast challenge in local modeling efforts. In fact, NOAA's Hazardous Weather Testbed (HWT)—a collaboration between the Storm Prediction Center (SPC), the National Severe Storms Laboratory (NSSL), and the Norman, OK NWS WFO—have held a yearly Experimental Forecasting Program (EFP; e.g. Coniglio *et al.* 2009) where researchers and forecasters collaborate to address the challenges of convection in NWP. The goal of this program is to subjectively evaluate model performance and discuss strengths and limitations of regional models and their use in operations.

Numerous SPoRT NWP research efforts have shown the positive impacts of NASA datasets (*e.g.* LaCasse *et al.* 2008, Case *et al.* 2011a, Case et al. 2011b, Zavodsky *et al.* 2012). In 2011, SPoRT configured a real-time version of the Advanced Research Weather Research and Forecasting (WRF-ARW) model that incorporates four distinct NASA datasets and capabilities that specifically address aspects of convective forecasting in NWP: the Land Information System (LIS; Kumar *et al.* 2006; 2007), Greenness Vegetation Fraction (GVF) from the Moderate Resolution Imaging Spectroradiometer (MODIS), SPoRT sea surface temperature composites, and retrieved profiles from the Atmospheric Infrared Sounder (AIRS). This WRF configuration—hereafter referred to as the SPoRT-WRF—was evaluated at the HWT EFP during the 2011 Spring Experiment.

This paper focuses on a description of Version 1 of the SPoRT-WRF, sample results for high-impact cases of the super tornado outbreak of April 2011, and feedback from the EFP. Feedback from the EFP and the research assessment has led to changes in the SPoRT-WRF system. These

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system improvements for SPoRT-WRF Version 2 are presented as future work.

2. SPoRT-WRF Background

NSSL runs a real-time version of the WRF-ARW at a convection-allowing resolution, in which a convective parameterization is not used. The WRF-ARW is run at 4-km horizontal grid spacing on a CONUS domain (hereafter referred to as the NSSL-WRF) and is routinely used by forecasters at the SPC and select NWS WFOs (Kain et al. 2010). Currently, the NSSL-WRF uses WRFv3.1.1 with options tuned towards parameterization schemes that are most useful for forecasting convection (see Table 1). The NSSL-WRF model is initiated once daily at 0000 UTC and produces hourly forecasts out to 36 hours

The SPoRT-WRF was configured using the same domain, physics, and dynamics as the NSSL-WRF, but incorporated unique NASA products and capabilities to improve the initial and boundary conditions of the model. Output from a real-time version of the the NASA LIS running the Noah land surface model was generated every 3 hours using atmospheric forcing data from the Global Data Assimilation System and real-time SPoRT/MODIS GVF data to simulate soil characteristics that are important in partitioning energy fluxes within the boundary layer to enhance forecasting of weakly-forced convection. SPoRT-'s 1-km SST composite (Jedlovec *et al.* 2010) provided enhanced over-ocean heat fluxes to aid in seabreeze forecasting. SPoRT's real-time 1-km MODIS GVF composite (Case *et al.* 2011) was generated once daily and replaced the lower spatial resolution GVF monthly climatology an affects energy fluxes within the boundary layer for weakly-forced convection. Finally, retrieved temperature and moisture profiles from NASA's AIRS instrument aboard the EOS-Aqua satellite were assimilated to provide improved horizontal spatial resolution vertical soundings at asynoptic times to enhance upper-air moisture and stability (Zavodsky *et al.* 2012).

The SPoRT-WRF was initialized each day using the 12-km North American Mesoscale (NAM) model as the initial and boundary conditions. The boundary conditions were updated every 3 hours using the same model forecast. The LIS, SPoRT SSTs, and MODIS GVFs were all incorporated into the initial conditions at model initialization. Due to the timing of the AIRS observations over CONUS, these profiles were assimilated at 0900 UTC using the WRF-Var data assimilation system (Barker et al. 2004) with the 9-hour SPoRT-WRF forecast as the background field.

3. Impact on April 25-27 Forecasts

For three days in late April, the Southeastern United States was ravaged by a historic tornado outbreak that spawned over 350 tornadoes, left over 300 people dead, and caused over $10 billion in damage. This event was used as a case study to evaluate the impact of NASA datasets and capabilities on convective forecasts by comparing NSSL- and SPoRT-WRF forecasts. Variables such as 2-m temperature, 2-m dew point, and total precipitable water are important for determining where a model will produce convection. These variables were compared both quantitatively and qualitatively to determine the impact of the NASA datasets.

First, the NSSL- and SPoRT-WRF were compared to METAR, SAO, and Mesonet observations using the National Center for Atmospheric Research (NCAR) Model Evaluation Tools (MET) software (Brown et al. 2009) over the southeastern quarter of the CONUS (see red box in Fig. 1). The mean forecast error (*i.e.* forecast minus observations) of 2-m temperature is shown in the left column of Figure 2; the verification of 2-m dew point temperature is shown in the right column of Figure 2. In this evaluation, the SPoRT-WRF (red lines) appeared to have a cool and dry bias for both variables compared to the NSSL-WRF (black lines) with the largest impact being from the assimilation of the AIRS profiles. The LIS/GVF data alone (No AIRS in green lines) only account for a slight change from the NSSL configuration, likely due to the strong forcing from this event masking the land-atmosphere interactions. There is also likely little impact from the SSTs for these strongly-forced, non-coastal storms.

Beyond the quantitative analysis, a qualitative analysis of selected variable was performed to track changes in the initial conditions to the differences in forecast 1-km above ground level (AGL) reflectivity. Figures 3 and 4 show 2-m temperature and total precipitable water differences (respectively) between the NSSL- and SPoRT-WRF for selected domains of interest on each of the three case study days. These forecasts were compared using the 13-km Rapid Update Cycle (RUC; Benjamin *et al.* 2004). Figure 5 shows differences in the 1-km AGL reflectivity between the NSSL- and SPoRT-WRF compared to NSSL's National Mosaic & Multi-Sensor QPE composite.

On April 25, a focus sub-region that covered Arkansas and southern Missouri was selected. After assimilation of the AIRS profile data at 0900 UTC, the SPoRT-WRF was slightly cooler than the NSSL-WRF. However, this cooling was more consistent with the RUC analysis than the NSSL-WRF (top row in Fig. 3). At the same time, the SPoRT-WRF was drier than both the NSSL-WRF and RUC analysis (top row in Fig. 4). The resulting simulated reflectivity showed a two separate lines of convection propagating through Arkansas and a large area of moderate/heavy precipitation in southern Missouri that was more consistent with the Q2 reflectivity than the NSSL-WRF (top row in Fig. 5).

On April 26, a focus sub-region centered on northeastern Mississippi and northwestern Alabama was selected. In this region, there were very subtle differences between the NSSL- and SPoRT-WRF, but both were slightly warmer than the RUC analysis (middle row in Fig. 3). The SPoRT-WRF was drier than the NSSL-WRF over this domain at the SPoRT-WRF re-initialization time, but both were drier than the RUC analysis over northern Mississippi and western Tennessee (the RUC analysis was drier than both forecasts over eastern Kentucky and Tennessee; middle row in Fig. 4). The resulting observed reflectivity in the 15h forecast showed some light to moderate precipitation over Western Alabama but very little in the way of convective precipitation. The NSSL-WRF produced an intense squall line across Alabama; whereas, the SPoRT-WRF produced no precipitation across Alabama. While the SPoRT-WRF indicated little to no precipitation, it did not over-forecast the convection as in the NSSL-WRF (middle row in Fig. 5).

On April 27, a focus sub-region centered on central and northern Alabama was selected. Both runs were too warm relative to the RUC analysis, with the SPoRT-WRF being slightly warmer than the NSSL-WRF (bottom row of Fig. 3). The SPoRT-WRF was slightly drier than the NSSL-WRF, but both were too dry compared to the RUC analysis (bottom row of Fig. 4). The forecasted reflectivity evaluated for this date was for the 24h forecast valid at 0000 UTC on 28 April). This was around the time of some of the strongest tornadic supercells across northern and central Alabama. The SPoRT-WRF simulated more of a squall line feature with the main front out ahead of the observed front. The NSSL-WRF produced a similar squall line, but did simulate a few distinct supercells ahead of and embedded within the line. The main front was more consistent with the observed front in the NSSL-WRF; however, the supercell features in Central Alabama were completely missed.

Overall, the SPoRT-WRF exhibited a cool and dry bias in these qualitative analyses which led to 2 of the 3 case study dates producing less convective storms when convection did occur. This was consistent with the quantitative assessment performed using MET.

4. Feedback from HWT Spring Experiment EFP

As mentioned above, the SPoRT-WRF was evaluated at NOAA's HWT EFP. The SPoRT-WRF was evaluated as a deterministic model alongside the NSSL-WRF and a configuration of WRF generated by NCAR (hereafter referred to as NCAR-WRF). The 2011 EFP took place from 9 May to 10 June, and the SPoRT-WRF was evaluated for 12 days during that span. Figure 6 shows a sample of the feedback from the EFP. Overall, the SPoRT-WRF evaluated as "fair", "good", or "very good" in 33% of the forecasts when compared to observed 1-km AGL reflectivity, with a majority of the forecasts rating "poor". However, both the NSSL- and NCAR-WRF also had 50% or less "fair", "good", or "very good" ratings, meaning that most of the models struggled with the convection during this time period (Fig. 6a). When compared directly to the NSSL-WRF, the SPoRT-WRF performed the same or better 25% of the time for 1-km AGL reflectivity, 17% of the time for 2-m temperature, and 50% of the time for 2-m dew point (Figs. 6b and 6c). Overall, the EFP determined that the SPoRT-WRF was too cool and dry and suppressed convection. In some instances, this suppressed convection improved the forecast (when the other models overforecasted convection), but more often reduced convection too much compared to observations. These results are consistent with the quantitative and qualitative assessments from the 25-27 April case study presented above.

5. Conclusions and Future Work

The NASA SPoRT Center seeks to improve short-term convection forecasts by adding unique NASA datasets and capabilities to NWP models. To this end, SPoRT has developed a real-time version of the WRF-ARW called the SPoRT-WRF that incorporates real-time data from the NASA LIS, SPoRT MODIS GVF composites, SPoRT SST composites, and NASA AIRS thermodynamic profiles. Evaluation of the SPoRT-WRF revealed that the system had a cool, dry bias that tended to suppress large convection events during the period of study. Much of this cool, dry bias appears to be introduced during the assimilation procedure whereby the AIRS profiles are brought into the system. It is hypothesized that these biases are be caused more by imbalances created by stopping and restarting the system than attributed to the quality of the AIRS profiles themselves.

To solve these imbalances, SPoRT-WRF Version 2 has been developed to continuously assimilate profiles from both AIRS and the Infrared Atmospheric Sounding Interferometer (IASI) in a cycling methodology using the Gridpoint Statistical Interpolation (GSI) data assimilation system. Additionally, the SPoRT-WRF has evolved into a truly real-time NASA forecast as the NASA-Unified WRF (NU-WRF)—including use of Goddard microphysics and radiation schemes—has been implemented. Other improvements include the use of the Climate Prediction Center Morphing satellite precipitation product to force the

LIS soil moisture and expansion of the SPoRT MODIS GVF domain to cover the entire SPoRT-WRF domain. Experiments with the real-time SPoRT-WRF Version 2 will seek to evaluate the impacts of NASA datasets and model options on convective forecasts, assess how well the SPoRT-WRF performs (both qualitatively and quantitatively) against other operational models, and determine which individual components of the SPoRT-WRF have the largest impact on the performance in select case studies.

Acknowledgments

This research was funded by the NASA Earth Science Division in support of the SPoRT program at Marshall Space Flight Center. The authors would like to thank Tsengdar Lee of NASA HQ for providing the "Weather in a Box" computer systems on which the real-time SPoRT-WRF is run. The authors would also like to thank Jack Kain (NSSL) and Steven Weiss (SPC) for the opportunity to participate in the 2011 HWT Spring Experiment and for condensing the EFP results and feedback for our evaluation.

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Table 1. Model configuration for real-time NSSL WRF available to the SPC and select NWS offices.

Version	3.1.1
Dynamic	Advanced Research WRF (ARW)
Horizontal Grid Size	908 x 750
Vertical Levels	35
Horizontal Grid Resolution	4 km
Initial and Lateral Boundary Conditions	NCEP Eta 212 grid
Computational Platform	SGI Altix 4700 (64 processors)
Simulation Length	36 hours
Time Step	24 seconds
Cloud Microphysics	WSM6 Scheme
Shortwave Radiation	Dudhia Scheme
Longwave Radiation	RRTM Scheme
Land Surface Physics	Noah Land-Surface Model
PBL Physics	MYJ Scheme
Scalar Advection	Positive Definite

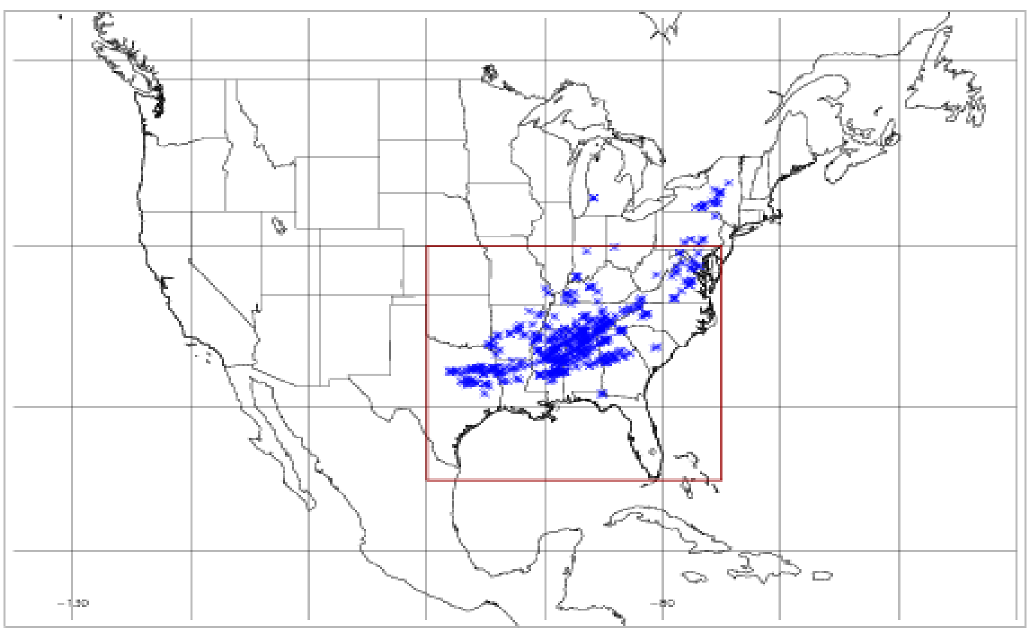

Figure 1. Verification region (red box) for MET evaluation with locations of tornado storm reports from SPC in blue.

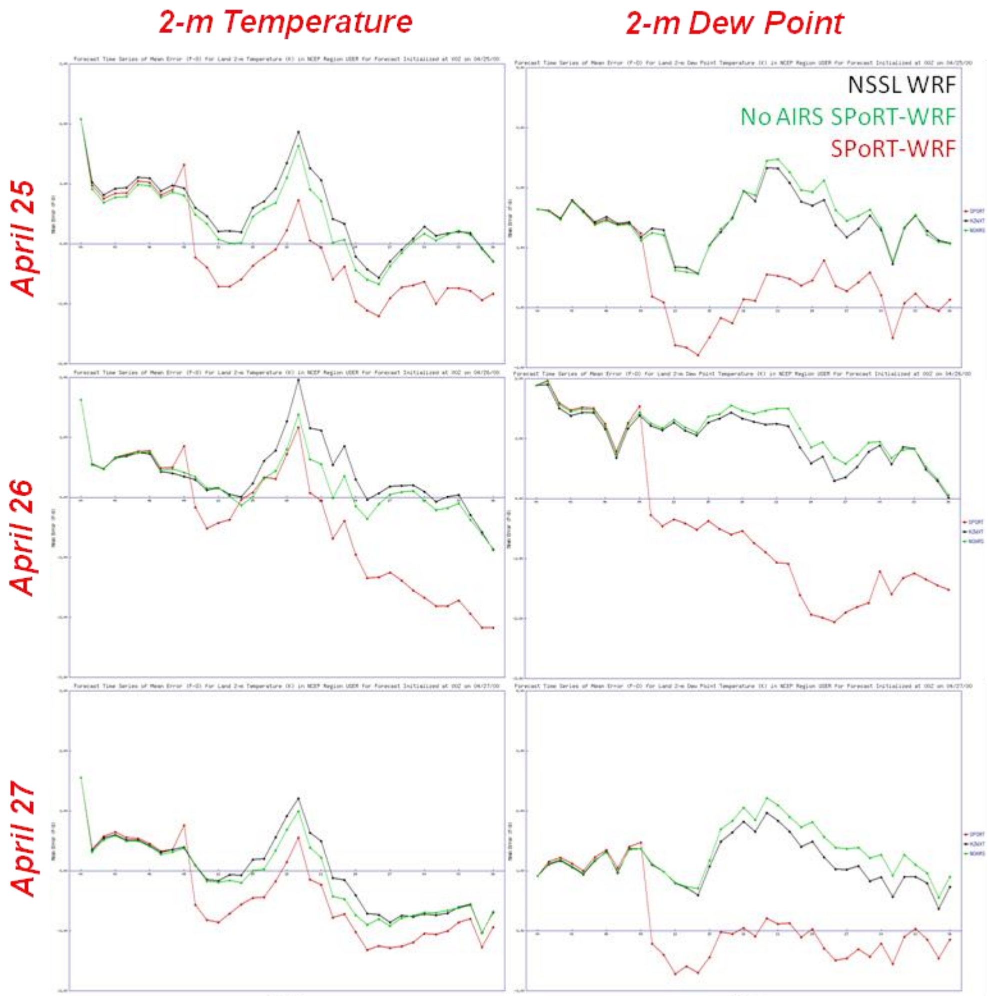

Figure 2. WRF model and observed reflectivity from 21-h forecast valid at 2100 UTC on 25 April 2011.

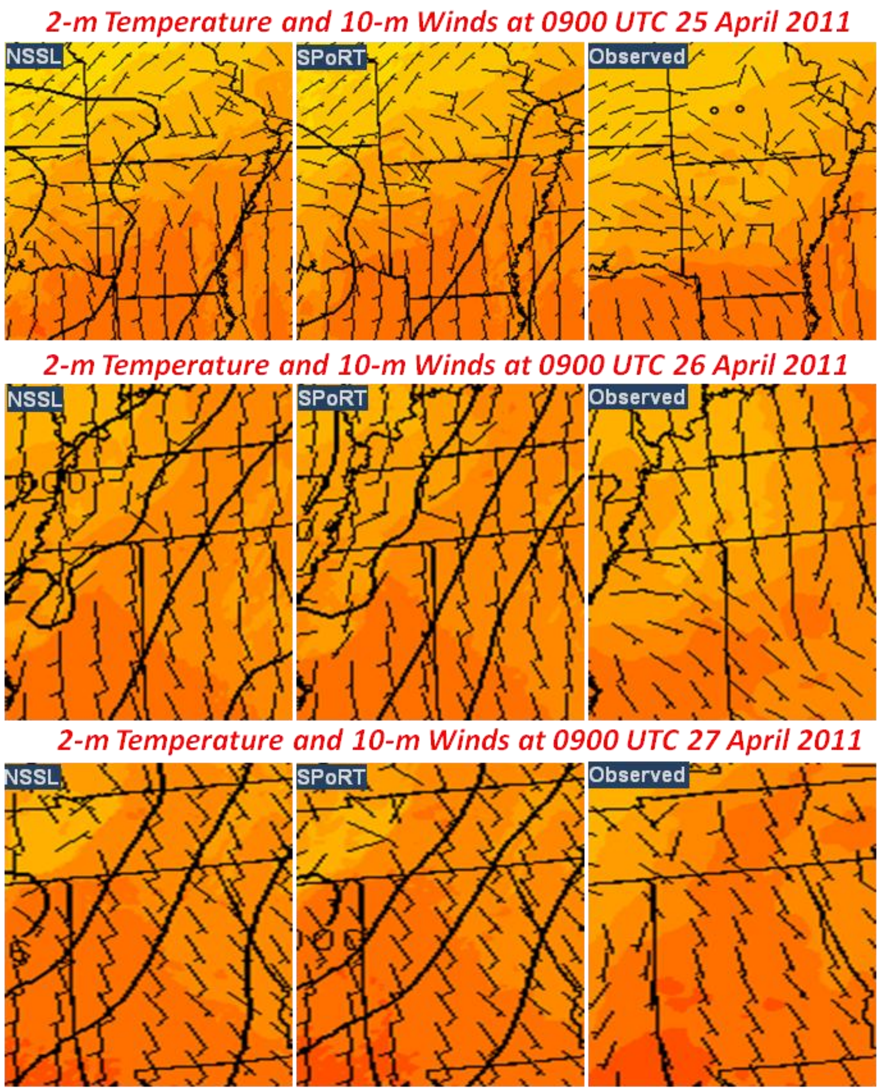

Figure 4. 2-m temperature at the 9h forecast in the NSSL-WRF (left column), 0900 UTC re-initialization of the SPoRT-WRF (left column), and 0900 UTC RUC analysis (right column).

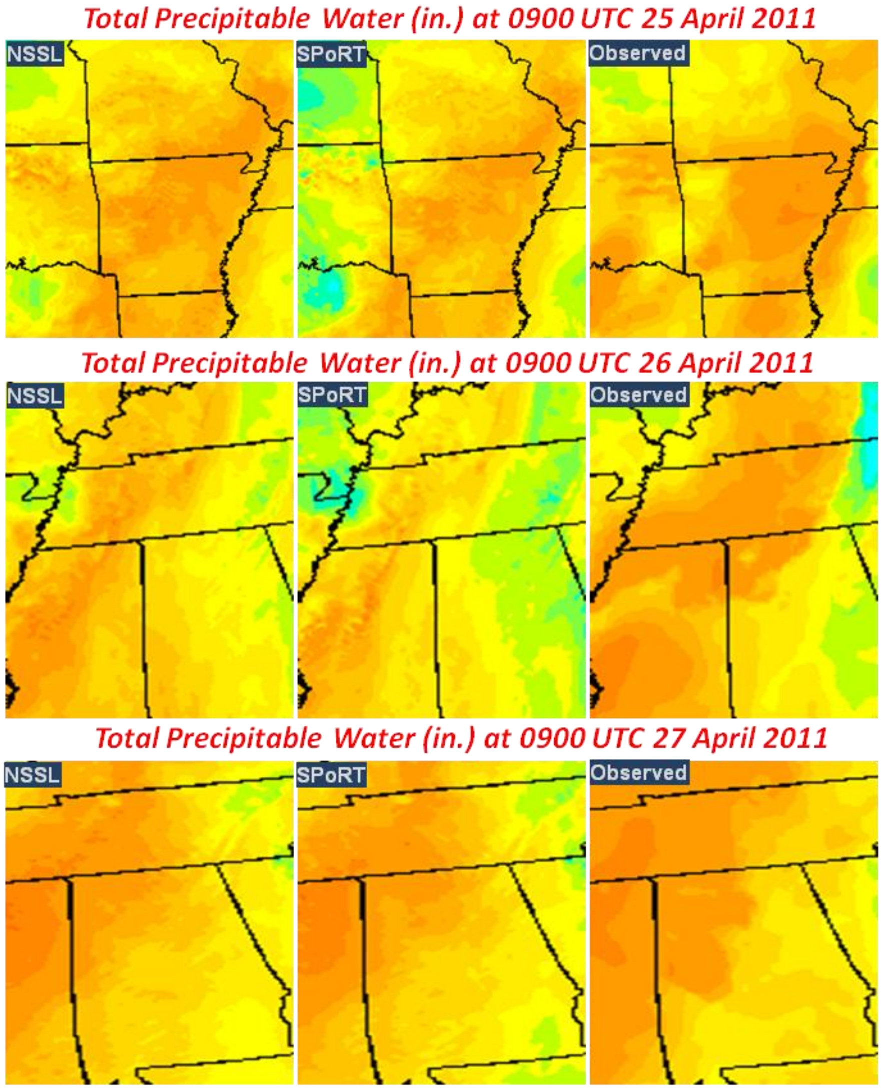

Figure 4. Total precipitable water at the 9h forecast in the NSSL-WRF (left column), 0900 UTC re-initialization of the SPoRT-WRF (left column), and 0900 UTC RUC analysis (right column).

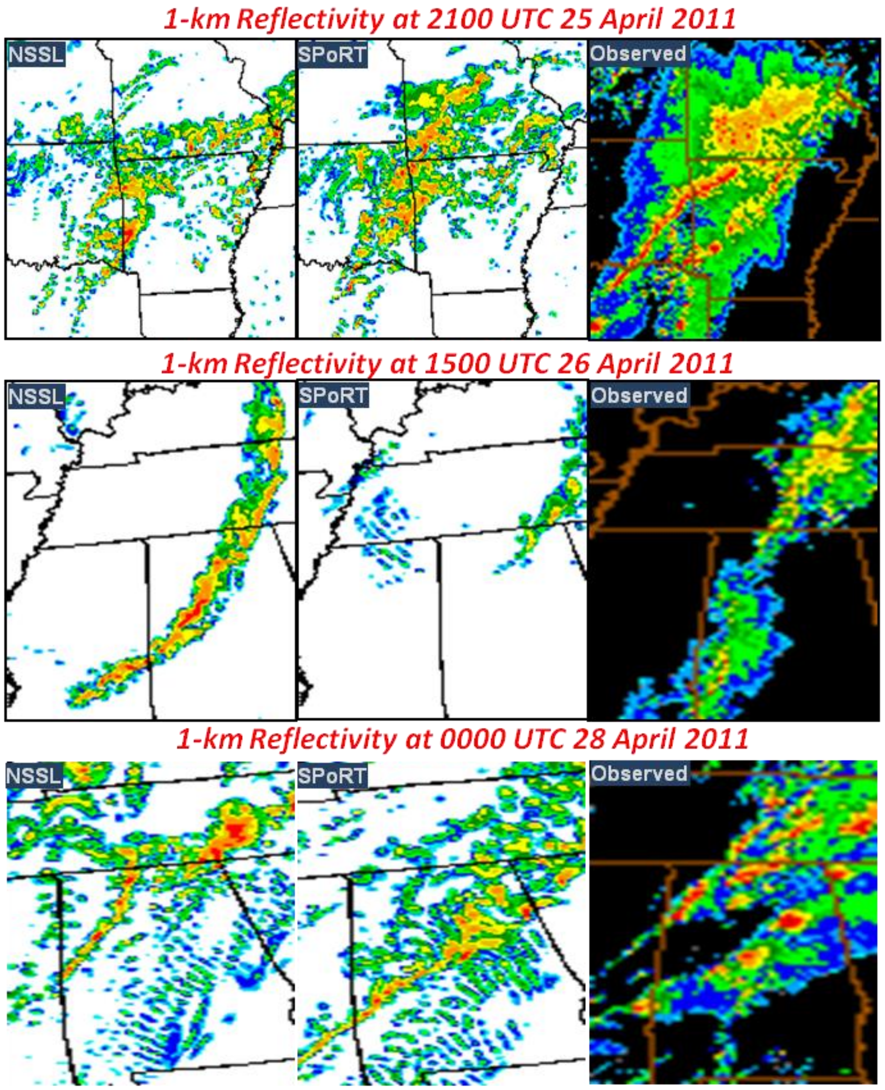

Figure 5. 1-km AGL simulated reflecitivty at each of the times indicated in the figure for NSSL-WRF (left column), SPoRT-WRF (left column), and NSSL Q2 analysis (right column).

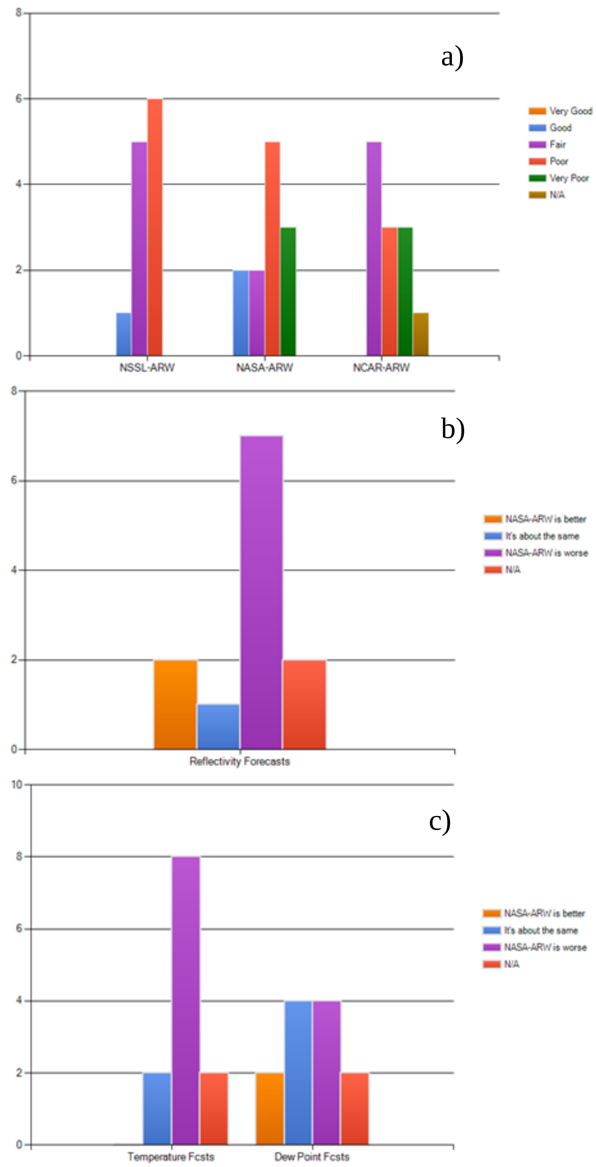

Figure 6. Feedback from NOAA's HWT EFP for a) subjective rating of 18-06Z forecasts of 1-km AGL reflectivity, b) subjective comparison of NSSL- and SPoRT-WRF for 1-km AGL reflectivity, and c) subjective comparison of NSSL- and SPoRT-WRF for temperature and dew point.