FINAL PROJECT REPORT **YEAR**: 2011
WTFRC Project Number: TR-10-110

Project Title: High resolution weather forecasting for freeze prediction in WA

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Total Project Request: **Year 1:** $95,000

Other funding sources

Indirect support through the existing infrastructure of the AgWeatherNet Program and its 137 weather stations

WTFRC Collaborative expenses: None

Budget

Organization Name: CAHNRS- WSU **Contract Administrator:** Mary Lou Bricker
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Item	**2011**		
Salaries	45,369		
Benefits	18,517		
Wages			
Benefits			
Equipment	25,000		
Supplies	5,114		
Travel	1,000		
Miscellaneous			
Total	**95,000**		

Footnotes:

Objectives
The overall goal of this project is to evaluate the potential for implementing the state-of-the-art Advanced Weather Research and Forecasting (WRF-ARW) model as a tool for AgWeatherNet for freeze predictions for Washington, specifically for the regions of the state where tree fruit crops are important.

Specific objectives of the original three year projected included the following:

- To explore the feasibility of running the WRF model for Washington.
- To evaluate the performance of the WRF model for local conditions using the data and observations collected by AgWeatherNet.
- To develop a protocol for implementing the WRF model as a freeze forecasting tool for AgWeatherNet.
- To develop freeze protection advisories for dissemination via the web, phone applications and other information technologies.

Progress
The start of this project was delayed due to personnel issues. A Postdoctoral Research Associate, Dr. Tes Ghidey, was hired late August, 2011 to start with the tasks associated with the first two objectives of this proposal. The progress of these activities are reported below.

As part of our analysis we evaluated the performance of the Advanced Weather Research and Forecasting Model for selected frost and freeze events that occurred during the 2010-2011 winter. Following discussions with members of the Washington Tree Fruit Research Commission we also evaluated performance of the model for high temperature events during 2011 summer.

Introduction
The weather dynamics modeling system that was used in this study is the regional *Advanced Research of the Weather Research and Forecasting* (*WRF-ARW, v. 3*) modeling system for the state of Washington. *WRF* has a flexible, state-of-the-art portable code and is supported by the *National Center for Atmospheric Research (NCAR)*. It is a 3-D, fully compressible, Euler non-hydrostatic model with several physics schemes and solver options (Skamarock *et al*. 2008). The University of Washington (UW) *WRF-ARW* configuration includes three nested horizontal domains of 36, 12, 4 km, and 38 vertical full sigma-levels with the innermost 4 km resolution encompassing Washington, Oregon and Idaho and adjacent parts of neighboring states (http://www.atmos.washington.edu/mm5rt/-info.html#sigma). Its physics options consist of Dudhia shortwave and RRTM long-wave radiation, Thompson microphysics with graupel, the Kain-Fritsch cumulus, the YSU Planetary Boundary Layer (PBL) and the five layer lower boundary thermal diffusion schemes (http://www.atmos.washington-.edu/mm5rt/info.html). The products of *WRF-ARW* model of UW and the downscaled Oregon State University (OSU) *WRF* model at 12 km resolution outputs (http://uspest.org/-AWN_FC/) were used to perform the model verification against the meteorological observations of AgWeatherNet (www.weather.wsu.edu).

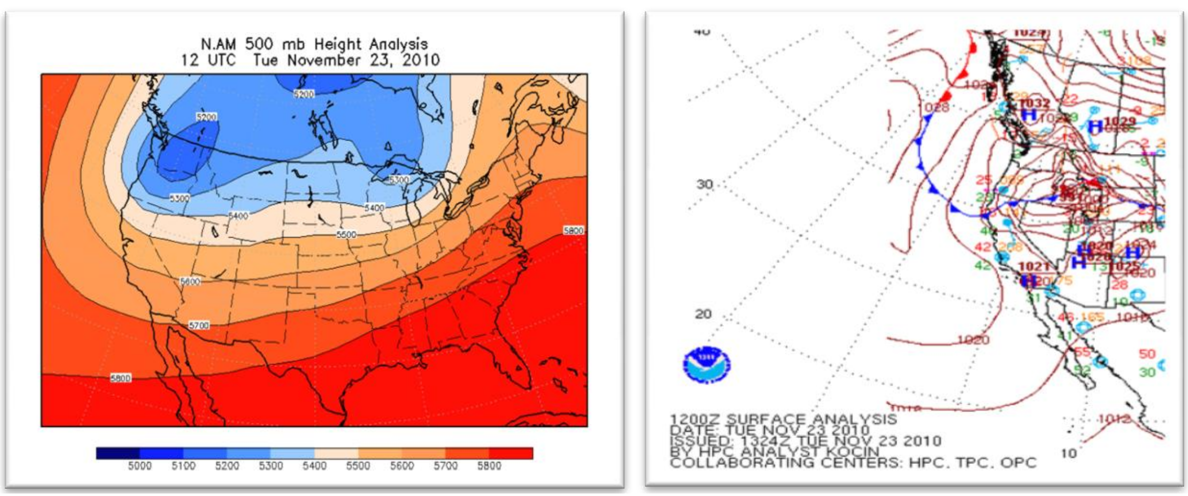
WRF Verification
The WRF model outputs of both UW and OSU were used to analyze and verify the model performance against ground stations and National Weather Service (NWS) weather analysis charts for both the extreme high and the frost/freeze temperature prediction over central eastern Washington during three seasonal events namely, the 23-24 November 2010 ("Thanksgiving") deep freeze, the 7 April 2011 freeze events, and the 26-28 August 2011 extreme temperature records. These events were used as verification periods to evaluate the forecasting capacity of WRF model over the complex topographic and agricultural areas of eastern Washington. A quantitative and qualitative weather

analysis is provided for the ‘Thanksgiving’ deep freeze of 2010, and general numerical comparisons between model results and observational data are provided for the other two events.

November 23-24, 2010 Freeze Event

The 500mb NWS weather chart for 21 November 2010 at 1200 UTC (4 a.m. PST) shows a low pressure system (central value of 5280 m) that was stationed offshore of coastal Oregon. Wind direction was thus mostly south-southeasterly at about 5 m s^{-1} (10 knots) over most of Washington. The low was later weakened and moved southeastward, causing the mostly continental cold air to move northerly-northwesterly towards eastern Washington. By 23 November at 1200 UTC (4 a.m. PST), another low from British Colombia moved and centered over central Washington significantly dropping the temperature from the previous day (Fig. 1a). As the low moved southeastward, northerly winds persisted over Washington bringing cold, mostly continental air to the region that contributed to the deep freeze during the 23 – 24 November period (See Fig. 2). By 25 November at 1200 UTC (4 a,m. PST), however, winds had shifted westerly-northwesterly ending the cold air advection to the region (not shown).

Concurrently, the NWS surface chart on 21 November 2010 at 1200 UTC (4 a.m. PST) shows the reflection of the upper-level low-pressure system centered over southern Oregon with a stationary front over central Washington. Winds are northerly at about 2.5 m s^{-1} at the coastal regions to calm inland with air temperature ranging from 19^{o}F inland to 36^{o}F at the coast. The following day, as the stationary front and northerly winds persisted, temperatures dropped over most of the state (e.g. by 9^{o}F over coastal stations). On 23 November at 1200 UTC (4 a.m. PST), temperatures further dropped as reflection of the upper-air low pressure system stationed over central Idaho, and north-northeast winds dominated over inland Washington (Fig. 1b). As the surface low further progressed southeastward, a high pressure system developed over British Columbia replacing clear weather conditions over inland Washington for the following couple of days.



(a) (b)

Figure 1. NWS weather charts over western U.S. on 23 November 2010 at 1200 UTC (4 a.m. PST) at 500mb depicting low-pressure system stationed over central Washington (a) and at the surface continental dry and cold north-northeasterly winds flow towards Washington (b).

In summary, the surface and upper-air NWS weather charts show that areas of Washington east of the Cascade ranges were mainly under cold advection system that originated from the north. This condition dropped surface temperatures significantly over eastern Washington (Fig. 2), as the wind peaked starting on 22 November 2010 (Fig. 3)

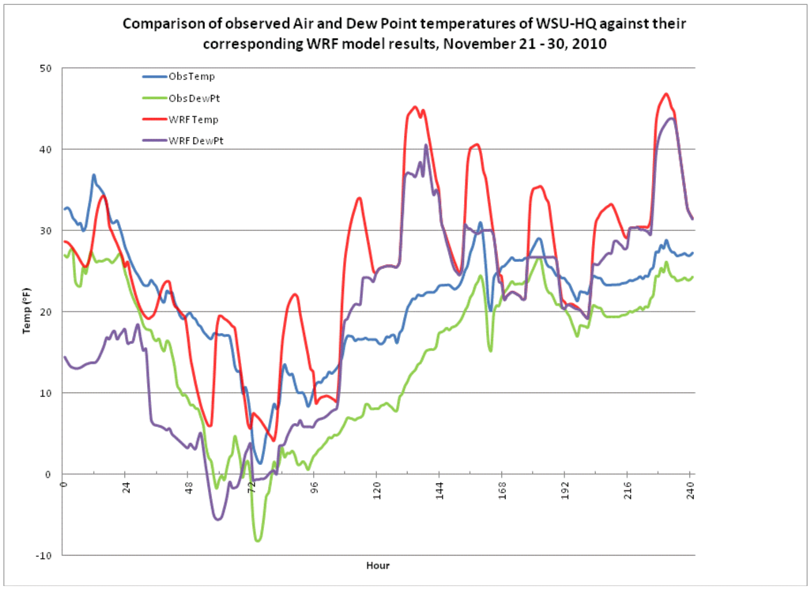


Figure 2. Comparison of observed and WRF modeled air and dew point temperatures at Prosser (WSU-HQ) for November 21 – 30, 2010.

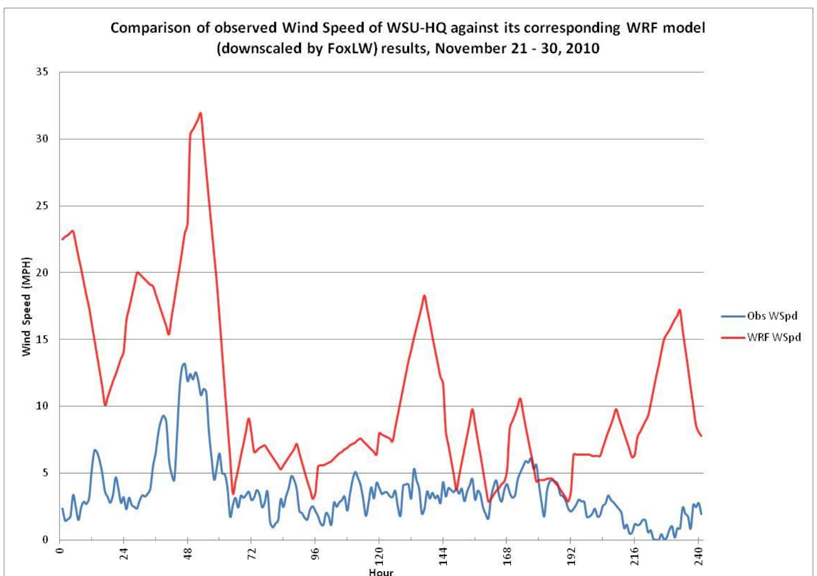


Figure 3. Comparison of observed and WRF modeled wind speed at Prosser (WSU-HQ) for November 21 – 30, 2010.

Figures 2 and 3 show that the temperature over Prosser (WSU-HQ) started to drop when the mostly northerly wind speed increased by 22 November, bringing cold and dry continental air by advection. Similar conditions were observed over most of the stations over the eastern half of Washington. Moreover, both the observed and WRF model outputs show the temperature drop over the station to its lowest, as the wind became strongest. The model, however, underestimated the average daily temperature by 3°F on 23 November and overestimated by 4.5°F on 24 November. While the model generally reproduced the observed diurnal variations of temperatures and winds, it overestimated both temperatures and wind speeds over most of the eastern Washington stations that were evaluated.

The OSU WRF model at 12 km output has forecast for a time length of five days. Therefore, different forecast times were taken into account to examine the model performance for the extreme high and low (deep freeze) temperature events. For example, figure 4 shows observed and six forecast temperature results initialized at different days encompassing the 'Thanksgiving' 2010 freeze event over Prosser (WSU-HQ) at an elevation of 843ft. The observed temperature shows a decreasing trend until the night of 24 November, when the last freeze period occurred. The six model forecasts were initialized at 1200 UTC (4 a.m. PST) each day from 19 – 24 November 2010. While the cooling trend was predicted during the multiple simulation periods, most model results overestimated daytime and significantly underestimated the nighttime temperatures. But during the nights of 23 and 24 November, the model predicted warmer temperatures when compared to the observed data as wind speeds became very low (data not shown). Average daily temperature biases for the 23 and 24 November were -2.0 and 4.5^{o}F for the 48-hour and -3.0 and 3.3^{o}F for the 24-hour forecasts respectively. The daytime model bias, (defined by 8 a.m. – 5 p.m.) of the 48-hr forecast on 23/24 November over the station was 1.3/-2.0^{o}F and the nighttime (0 – 7 a.m. and 6 – 11 p.m.) was -4.4/-3.0^{o}F. Similarly, the 24-hr forecast biases were at 0.1/4.1^{o}F for the daytime and -5.2/2.8^{o}F for the nighttime respectively. In general, the model significantly underestimated nighttime observed temperatures. Overall, the forecast accuracy for the freeze event was predicted much better when the model was initialized either on 21 or 22 November, 48- or 24-hours ahead of the beginning of the freeze event (Fig. 5).

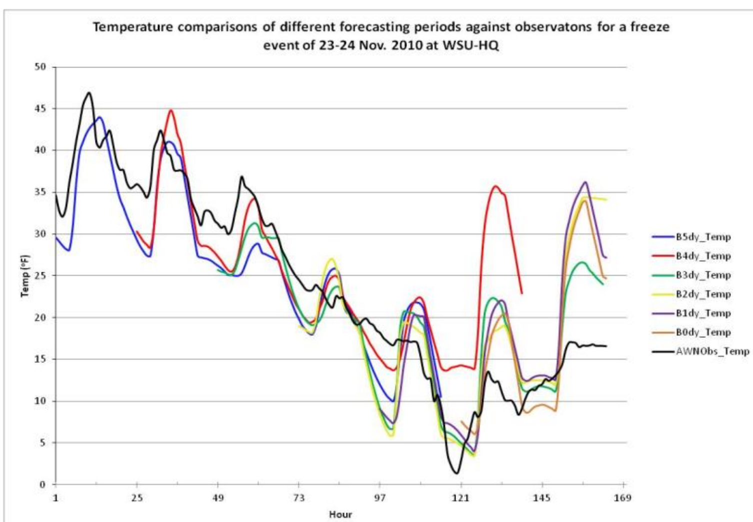


Figure 4. Comparison of observed and six different WRF model temperature predictions at Prosser (WSU-HQ) during the 23-24 November, 2010 deep freeze event. The five-day forecast (blue color) is initialized at 4 a.m. (12 UTC) on 19 November 2010.

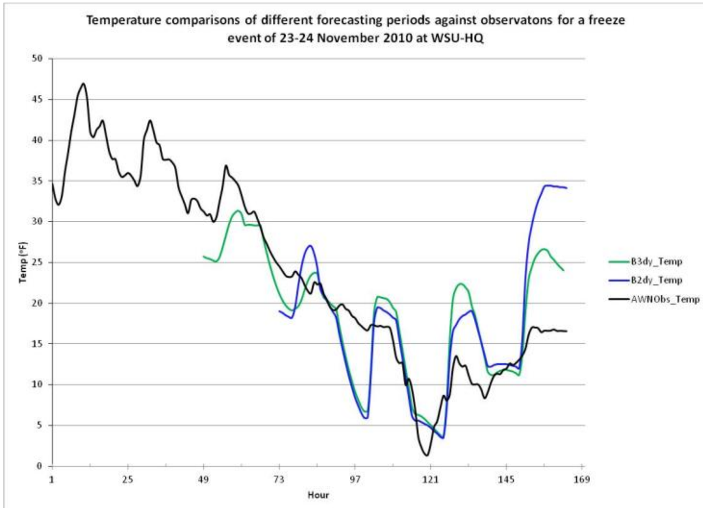


Figure 5. Comparison of observed and the 48-hr (initialized on 21) and 24-hr (initialized on 22) WRF model temperature predictions at Prosser (WSU-HQ) during the 23-24 November, 2010 deep freeze event.

Figure 6 shows observed and six forecast temperature results initialized at different days during the 'Thanksgiving' freeze event over Wenatchee Heights at an elevation of 2988ft. In general, most model results underestimated both day- and night-time temperatures. Average daily temperature biases for the 23/24 November were -4.0/2.5^{o}F for the 48-hr and -6.0/2.8^{o}F for the 24-hr forecasts, respectively. The daytime model bias of the 48-hr forecast on 23/24 November over the station was -1.8/0.6^{o}F and the nighttime was -7.8/0.8^{o}F. Similarly, the 24 hr forecast biases were at -3.5/3.2^{o}F for the daytime and -5.2/2.8^{o}F for the nighttime, respectively. Although, the forecast accuracy for the freeze event was better predicted when the model was initialized on 21 and 22 November, 48- and 24-hours ahead of the beginning of the freeze event, the model had significantly underestimated both daytime and nighttime observed temperatures (Fig. 7).

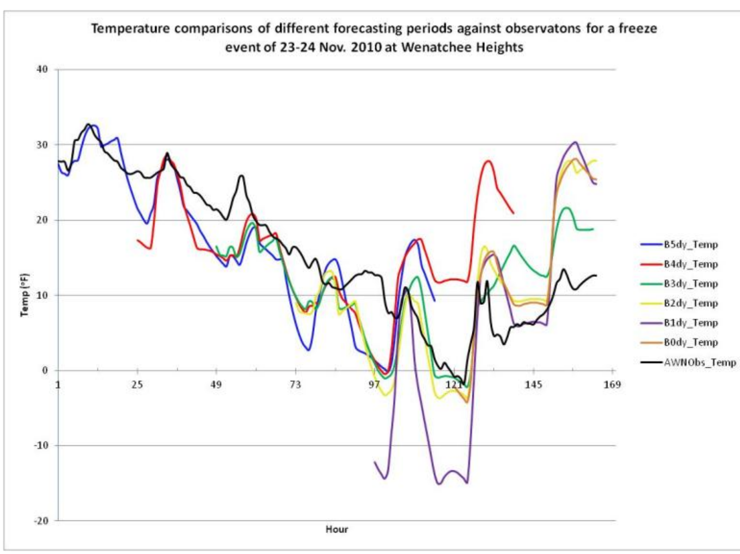


Figure 6. Comparison of observed and six different WRF model temperature predictions at Wenatchee Heights during the 23-24 November, 2010 deep freeze event. The five-day forecast (blue color) is initialized at 4 a.m. (12 UTC) on 19 November 2010.

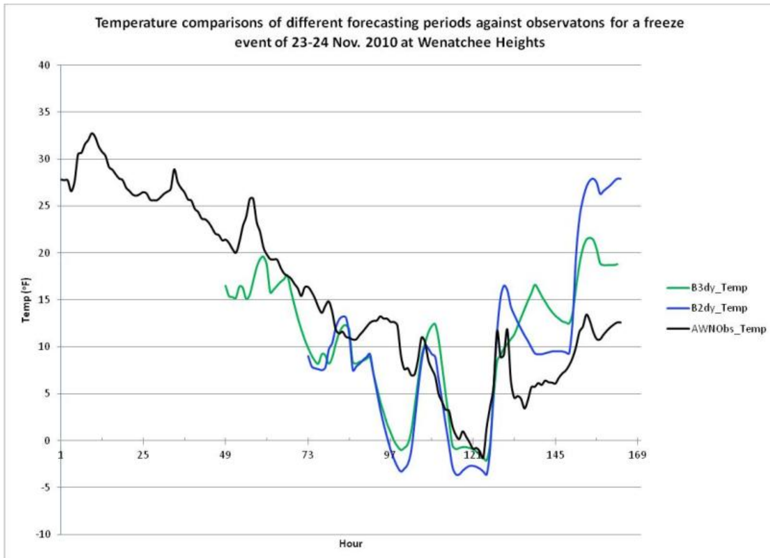


Figure 7. Comparison of observed and the 48-hr (initialized on 21) and 24-hr (initialized on 22) WRF model temperature predictions at Wenatchee Heights during the 23-24 November, 2010 deep freeze event.

Finally, Figure 8 shows observed and six forecast temperature results initialized at different days for the ‘Thanksgiving’ freeze event over Royal City East at an elevation of 1145ft. While the cooling trend was predicted during the multiple simulation periods, all model results overestimated both day- and night-time temperatures. Similar to the predictions for the other two stations discussed previously, the forecast for the freeze event was better predicted when the model was initialized on 21 and 22 November (Fig. 9). Average daily temperature biases for the 23/24 November were 5.0/10.2°F for the 48-hr and 3.8/10.4°F for the 24-hr forecasts. The daytime model biases of the 48-hr forecast on 23/24 November were 7.0/8.4°F and the nighttime biases were 3.6/11.5°F. Similarly, the 24-hr forecast biases were at -4.9/8.8°F for the daytime and 3.0/11.5°F for the nighttime, respectively. Generally, the model significantly overestimated the temperature when compared with the observed values.

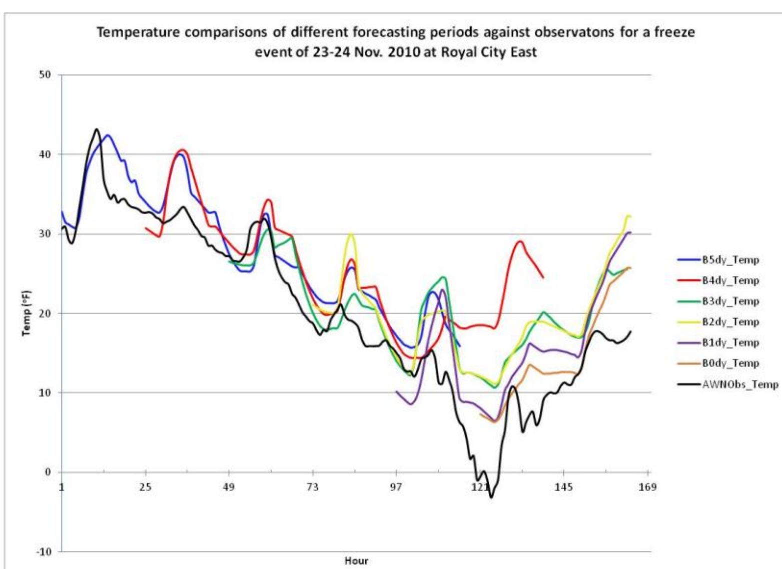


Figure 8. Comparison of observed and six different WRF model temperature predictions at Royal City East during the 23-24 November, 2010 deep freeze event. The five-day forecast (blue color) is initialized at 4 a.m. (12 UTC) on 19 November 2010.

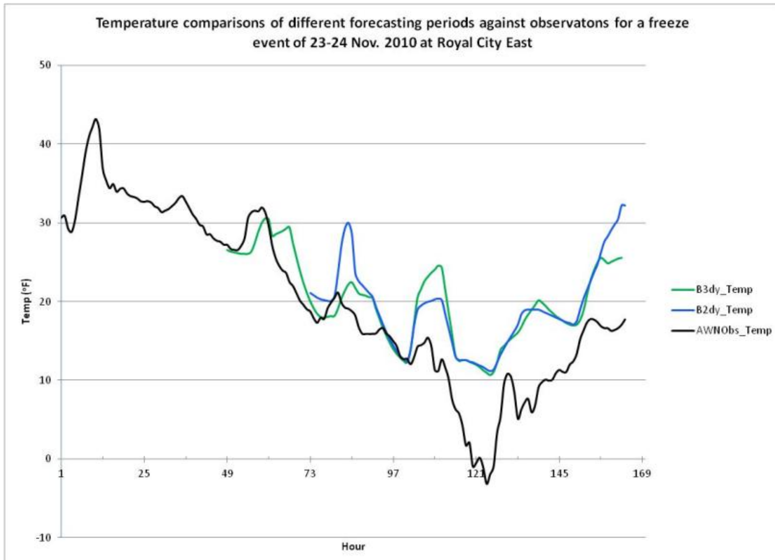


Figure 9. Comparison of observed and the 48-hr (initialized on 21) and 24-hr (initialized on 22) WRF model temperature predictions at Royal City East during 23-24 November, 2010 deep freeze event.

April 7, 2011 Freeze Event

In the following, we briefly report the analysis conducted for the extreme temperature event of April 7, 2011 for Prosser (WSU-HQ). In figure 10, several simulated model outputs for different initialization days are compared against observations for the freeze event of the late spring of April 7, 2011 for Prosser (WSU-HQ). While the 3 April simulation initialized with better values, the rest of the simulations still show poor initializations. Average daily temperature model bias on 7 April, for example, was 1.7^{o}F, while the daytime model bias was -1.1^{o}F and the nighttime bias was at 3.8^{o}F for the 48-hr forecasts (Fig. 11). The model, therefore, overestimated nighttime temperature when compared with the observed values.

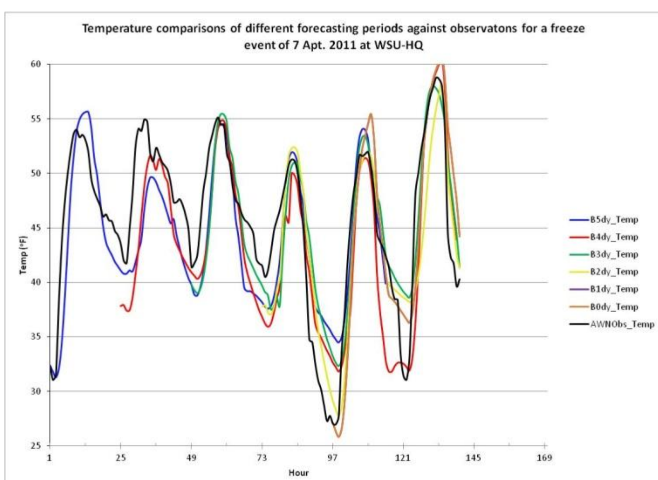


Figure 10. Comparison of observed and six different WRF model temperature predictions at Prosser (WSU-HQ) during the 7 April, 2011 freeze event. The five-day forecast (blue color) is initialized at 4 a.m. (12 UTC) on 3 April 2011.

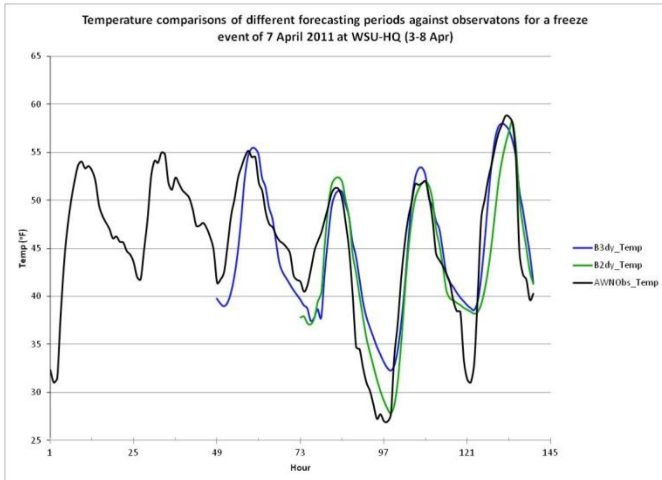


Figure 11. Comparison of observed and the 48-hr (initialized on 5) and 24-hr (initialized on 6) WRF model temperature predictions at Prosser (WSU-HQ) during the 7 April, 2011 freeze event.

August 26-28, 2011 High Temperature Event

In figure 12, a simulated model output for different initialization days is compared against observations for the extreme high temperature event of the 26-28 August 2011 for Prosser (WSU-HQ). Although the model's overall forecast for the high summertime temperature was satisfactory, the forecast date of 25 August (48 hr before the 27 August) performed better temperature prediction. Average daily temperature bias for the 27 August thus was -1.3^{o}F, and the daytime model bias over the station was -4.0^{o}F and the nighttime was 0.6^{o}F (Fig. 13). While WRF provided a better forecast during the summertime, the model still underestimated the daytime temperature when compared with observed values

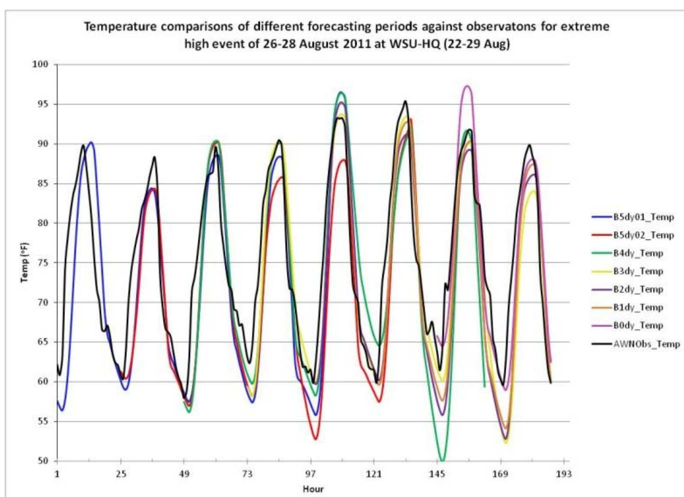


Figure 12. Comparison between observed and six different WRF model temperature predictions at Prosser (WSU-HQ) during the 26 – 28 April, 2011 extreme high temperature event. The five-day forecast (blue color) is initialized at 4 a.m. (12 UTC) on 22 August 2011.

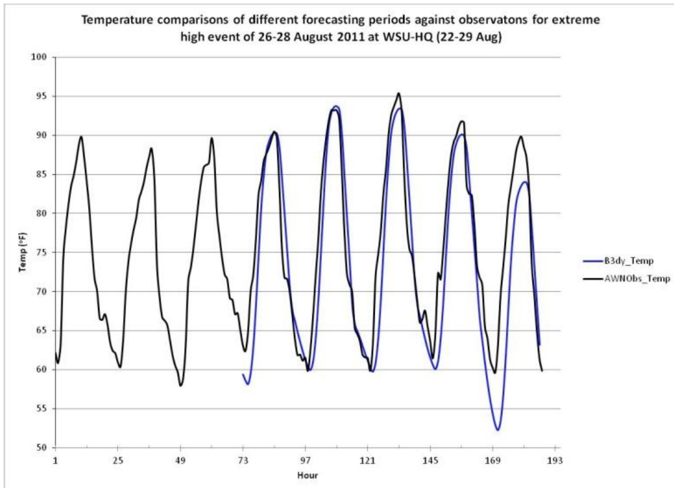


Figure 13. Comparison between observed and the 48-hr (initialized on 25) WRF model temperature prediction at Prosser (WSU-HQ) during the 26-28 August, 2011 extreme high temperature event.

In summary, one problem that is apparent was the poor initial conditions (IC) used to start the model simulations, which is one of the many reasons of poor model performance. From the station analyses performed, WRF provided a better forecast when it was initialized one to two days ahead of the start of the freeze event. In particular, the model provided better temperature forecasting over lower elevations, but did poorly over medium and higher elevations of eastern Washington, east of the Cascade Mountain ranges.

Conclusion

The WRF model at a 12 km resolution provided a good performance over the lower regions of eastern Washington when it simulated temperature for 48-hr and/or 24-hr durations. While the results obtained from WRF model are encouraging, improved model output accuracy can be obtained at higher horizontal resolutions (down to a resolution of 3 km or less), with better initial and boundary conditions, and by implementing a combination of physics schemes convenient to the complex topographic structures of Washington, east of the Cascade ranges (e.g., Probha et al. 2007). From the pool of different physics, model configurations and large scale 'first guess' model initializations, therefore, the best combination should be studied to achieve the most accurate WRF model temperature predictions for the agricultural region of eastern Washington (Table 1).

Table 1. Different physics options and WRF model configurations.

	Microphysics schemes	Cumulus Parameterizations schemes	Planetary Boundary Layer (PBL)	Atmospheric Radiation	4-D Data Assimilation (FDDA)	Initialization 'First guess' data
1.	Kessler	Kain-Fritsch	MRF	RRTM	Grid nudging	NAM
2.	Purdue Lin	BMJ	YSU	GFDL longwave	Station nudging	GFS
3.	WSM(3,5or 6)	GD ensemble	MYJ	CAM longwave		NARR
4.	Eta GCP	Grell-3	ACM2	GFDL shortwave		GDAS
5.	Thompson			MM5 shortwave		NNRP
6.	GCEM			Goddard shortwave		
7.	Morrison			CAM shortwave		

Recommendations

Further research is needed to improve the weather predictions for eastern Washington using higher resolution simulations, different initialization and boundary conditions, and different physics parameterization schemes. One a more accurate prediction scheme has been established the outputs can be linked to the data currently provided on the AgWeatherNet web site in order to improve the decision aids.

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USPEST.ORG for Agricultural, Pest Management, and Plant Biosecurity Decision Support in the US (last cited 09/30/2011). [Also available at http://uspest.org/]

Executive Summary

The overall goal of this project was to conduct a preliminary evaluation of the potential for implementing the state-of-the-art *Advanced Research Weather Research and Forecasting* (*WRF-ARW*) model as a tool for AgWeatherNet freeze prediction for the state of Washington, specifically over the regions of the state where tree fruit crops are important.

Specific objectives of this project included the following:

- To explore the feasibility of running the WRF model for the state of Washington.
- To evaluate the performance of the WRF model for local conditions using the data and observations collected by AgWeatherNet.

As part of our analysis, therefore, we evaluated the performance of the WRF-ARW model for selected frost and freeze events that occurred during the 2010-2011winter, and for extreme high temperature events during 2011 summer. The *WRF-ARW* modeling system is a 3-D, fully compressible, Euler non-hydrostatic model with several physics schemes and solver options. The products of *WRF-ARW* model outputs of the University of Washington and the Oregon State University were used to perform model verification against the meteorological observations of AgWeatherNet (www.weather.wsu.edu) and National Weather Service weather analysis charts.

Based on the individual weather station analyses, WRF provided a better forecast when it was initialized one to two days ahead of the start of the freeze event. In particular, the model provided relatively good temperature predictions for the stations located at lower elevations, but did poorly over medium and higher elevations of eastern Washington, east of the Cascade Mountain ranges. The model, however, performed better for summertime temperature forecasting over the tested elevations. While the results obtained from WRF model are encouraging, improved model output accuracy can be obtained at higher horizontal resolutions (down to a resolution of 3 km or less), with better initial and boundary conditions, and by implementing a combination of physics schemes convenient to the complex topographic structures of eastern Washington. Once a more accurate prediction scheme has been established, the outputs can be linked to the data currently provided on the AgWeatherNet website to improve the decision aids.