Assessment of WRF ability in predicting extreme anomalies on sub-seasonal scales – preliminary results

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1. Introduction

One of the climate change signatures is that weather and climate become more extreme. The hundred-year floods now occur every 15 years and extensive droughts become more frequent and widespread. For example, July 2009 was a record cool for a large portion of the central and eastern U.S. Likewise, October 2009 was the wettest month on record in parts of the central U.S. These abnormal conditions on monthly scales have enormous effects on society, especially agriculture. Being able to predict anomalous weather patterns in extended advance would benefit the part of society affected, by allowing more time for preparedness and planning.

Sub-seasonal forecasting is very difficult, because the time-scale is longer than that of diagnostic weather predictions, and shorter than probabilistic climate predictions. These sub-seasonal scale forecasts provide a fundamental link between weather and short-term climate. Improving these time scales will improve weather and short term climate predictability and thus achieve a "seamless suite" of weather and climate forecast products. What makes intra-seasonal forecasts so difficult is the fact that the basic controlling and limiting factors on predictability are poorly understood. For weather forecasts, the memory of the initial conditions is the controlling factor on forecast skill. For seasonal forecast and longer averages, boundary forcing, such as sea surface temperatures (SSTs), are the dominant control (Schubert et al., 2002). Lead times for weather prediction is typically hours to days, while lead times for climate prediction is months to seasons. Sub-seasonal prediction is concerned with lead times on the order of weeks. At these longer lead times, the importance of initial condition information begins to give way to the importance of boundary condition information (Waliser et al., 2006). This is due to the fact that boundary conditions, such as SSTs, are slow changing and do not affect weather. They do, however, affect climate. As time scales increase from weather to short term climate, these slowly changing boundary conditions begin to have more and more of an impact.

This study is to examine the ability of WRF to forecast sub-seasonal extreme anomalies by inspecting how well WRF is able to capture extreme situations. For this study, weather prediction is not a concern, while monthly totals are the main focus of interest. Predicting weather on a monthly basis is not feasible due to extreme sensitivity on initial conditions and the chaotic state of the atmosphere. For example, whether or not it rains on a specific day does not matter, but the number of days it rains during the month is very important. Therefore, WRF's performance on a sub-seasonal scale is based on how well it captures the anomalous weather patterns.

2. Methodology

2.1 Extreme cases:

In this first step of the project, we test the extent to which the model can predict the abnormal cool July 2009 and wet October 2009. To contrast these two months, we selected from recent history two the opposite extreme months: July 1975 for the extreme hot and October 1980 for extreme dry.

July 2009 was characterized by a persistent and strong northwesterly flow over the central U.S. and brought anomalously low temperatures to much of the Midwest and Northeastern part of the country, breaking records in a large portion of the central U.S. Also, October 2009 was abnormal in the fact that a large portion of the U.S. received a surplus of rainfall. The eastern half of the country experienced anomalously low surface pressure, supported by a trough at 500 mb, which caused an environment favorable for copious amounts of precipitation. These months were chosen in the study as extreme events for WRF to model.

July 1980 was chosen for the anomalously warm temperatures, due to a strong ridge at 500 mb. October 1975 was also chosen and was characterized by dryer than normal conditions for the eastern half of the U.S, resulting from strong high pressure at the surface and abnormally low relative humidity. These various extreme cases chosen to model will further test WRF's ability to predict different anomalous situations.

2.2 Model configuration

The WRF used for this work is version 3.1 with default configurations for model physics and vertical resolution (Skamarock et al. 2008). The key physics parameter schemes include Kain-Fritsch (new Eta) for cumulus parameterization, SYU for boundary-layer physics, WSM 3-class simple ice for cloud microphysics, WSM 3-class simple ice, Dudhia (RRMT) for radiation, Monin-Obukhov for atmospheric surface layer, and thermal diffusivity for the land surface processes. The model atmosphere is 31 layers with finer resolution within the boundary layer and tropopause. The model was run using the Global version of WRF. There are three domains which correspond to the entire globe at $1.5^o x 1.5^o$, entire U.S. at $0.5^o x 0.5^o$, and the Central U.S. at $0.17^o x 0.17^o$, respectively. This presentation focuses on the U.S. domain.

Model integrations start from the first day of each month and last for 31 days. The GFS (Global Forecast System) analysis is used for 2009 case and NCEP reanalysis is for the earlier cases. These initial conditions include both land and sea surface temperatures. Since our main goal is determine the *atmospheric* predictability and thus weather/climate on a monthly scale using the global version of WRF, which is not coupled with the ocean, we used fixed sea surface temperature (SST) during the course of 31-day integration. The fixed SST helps to indentify the predictability and WRF skill in the pure uncoupled model. Nevertheless, we expected that the SST varies unsubstantially within a month.

2.3 Validation data

The main output variables to be analyzed are monthly average temperature and accumulated precipitation. The observed temperature for these months was obtained using monthly composites from NCEP reanalysis data and data from NOAA's National Weather Service. Rainfall data for July and October 2009 were collected from NOAA's National Weather Service and are high resolution data (http://water.weather.gov). For October 1975 and July 1980, this high resolution data were not available, so lower resolution data were used, where each grid point is 2.5 degrees latitude and longitude. For both air temperature and rainfall data, observed data were compared to the WRF output for each of the four month-long cases, using qualitative comparisons.

3. Results

As a sub-seasonal forecast, we are only interested in averages properties, mainly temperature and precipitation with a focus on the heavily cultivated central U.S.

3.1 Temperature

Figure 1 compares the predicted and observed monthly surface air temperature. WRF was able to predict the anomalous patterns of temperature rather accurately, including location and magnitude of the anomalous areas. For July 2009, WRF correctly identifies the areas of abnormal cold temperatures, and predicts similar temperature values to the observed values, undershooting temperatures about 3-6 °C. WRF did not handle the colder temperatures over the Rocky Mountains, Northwestern U.S., and the Northeastern U.S. well, by predicting much lower temperatures than what was observed.

For the abnormally high temperatures which occurred in July 1980, WRF was able to predict the location of the higher than average temperatures in the Southeastern area of the country. The difference in observed and WRF temperatures were about 3-6 °C, with observed temperatures once again being greater than what WRF predicted. WRF, however, did not perform well over the northern U.S., by predicting way too cold of temperatures for much of the area, with WRF predicting temperatures in the range of 0-9°C over most of the area, while observed temperatures were in the range of 18-24°C.

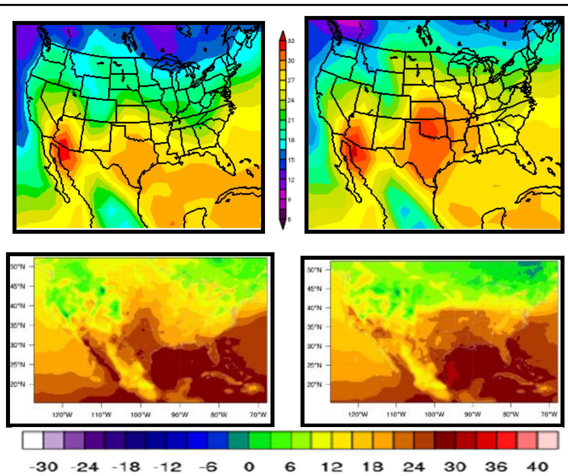

Fig. 1. Observed temperatures for July 2009 (top left), WRF temperatures for July 2009 (bottom left), observed temperature for July 1980 (top right), and WRF temperatures for July 1980 (bottom right). (http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl)

3.2 Precipitation

WRF's rainfall predictions appear to be less reliable than its temperature predictions (Fig. 2). WRF was able to capture the general trends in rainfall, however the locations of the anomalous rainfall patterns were not always accurate. For the October 2009 case, where a large portion of the country had large amounts of rainfall, WRF was only able to predict certain locations. Observed data shows that a large portion of the south central U.S. received at least 10-15 inches (250-320 mm) of rainfall, with a small area in Northern Louisiana/Southern Arkansas receiving more than 20 inches (500 mm) of rainfall. WRF does not capture either of these rainfall patterns entirely, only predicting very isolated locations with a range of 200-300 mm (about 8-12 in) of rainfall. For the majority of the area that received this surplus of rain, WRF predicts anywhere from 50-200 mm (about 2-8 in), which is a very large range. For the north central U.S., WRF performs better with predicting the general magnitude in rainfall amounts, however the locations are not necessarily accurate.

For the October 1975 case, WRF predicts less rainfall than observed for southern part of the Midwest, while predicting the correct range for much of the northern Midwest area, excluding a portion of the Norther, U.S. (Minnesota and Great Lakes region), where WRF overpredicts rainfall. WRF captures a rain maximum in the Northwestern corner of the domain, however it places the maximum over the Northwest U.S., when it was actually observed further North in Canada, not affecting the U.S. at all. WRF also shows increased rainfall over the Gulf of Mexico, when a rain maximum actually occurred further north, in the states bordering the Gulf of Mexico.

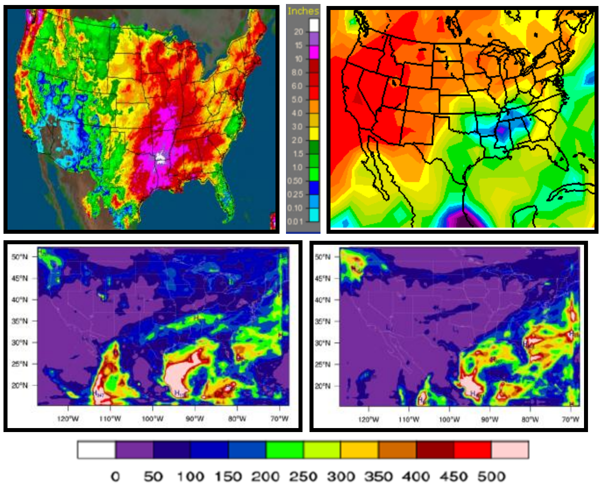

Fig. 2: Observed rainfall for October 2009 (top left), WRF rainfall for October 2009 (bottom left), obseved precipitation for October 1975 (top right), and WRF precipitation for October 1975 (bottom right). (http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl), (http://water.weather.gov/precip/download.php)

4. Discussion and future work

Upon qualitative comparisons, rainfall amount is a difficult parameter to predict on a sub-seasonal scale because of its wide variability over short spatial spans. General trends are catured by WRF, however, the location and/or magnitude is not always accurate. For air temperature, WRF's ability to capture extreme events is greater than that for precipitation. For the two cases in which air temperature was examined (July 2009 and July 1980), WRF predicts the general heating and cooling trends, but did not capture the full amplitude of the trends. In both cases, the model has a cold bias, performing worse in the Northern U.S. In the southern part of the U.S., the observed and predicted range of temperatures are more comparable.

Sub-seasonal forecasts propose a unique challenge due to the fact that they are neither strictly an initial condition or a boundary condition problem. Nonetheless, these intra-seasonal forecasts have a great importance because they provide a link between weather predicition and short-term climate prediction in which they are a dominant factor in modulating weather predictablility and limiting predictability on seasonal time scales (Waliser et al., 2006). Sub-seasonal forecasts are primarily a probabilistic problem and the uncertainties of the prediction problem need to be indentified, quantified, and reduced in order to naturally bridge the gap between weather and seasonal predictions, thus reiterating the importance of researching predictive capabilities on these time scales.

A more comprehensive evaluation of WRF's skill in predicting month-long mean temperature and precipitation requres mulitiple single-month integrations, including months termed as "normal". More vigorous analysis on rainfall variation and distribution such as thread scores and spatial correlations are also needed.

References

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