Analyzing the GFS 211 Model's Cyclogenesis Forecast (24-hour & 48-hour forecasts originating at 12Z on December 17th, 2009)

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Background

Model forecasting of the winter storm that formed on December 18, 2009 did provide forecasters with generally decent assistance in warning the public of an impending snowstorm. All aspects of the models' predictions included, meteorologists were able to rather accurately provide advance notice as far as 39 hours ahead of time that a winter storm was likely to occur anywhere from North Carolina to the New England states (Badgett et al.).

In retrospect, that is exactly what occurred. Snowfall totals exceeded a foot in many locations north and west of Raleigh and even reached two feet in some isolated spots. In Wake County, snowfall amounts barely made it to the half-inch mark in a few spots, with most areas seeing a trace. The eastern boundary of the flakes ran from just east of I-95 near the NC-VA state line, curving westward and running with the interstate in Johnston County, and then shooting quasi-laterally out west to Montgomery County before sloping south into South Carolina via Union County. Nearly all North Carolina counties as you head west had increasing amounts of snowfall, with the axis along the Appalachians Mountains *(Fig. 1)*.

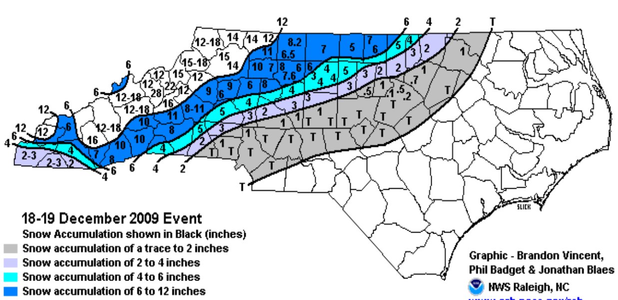


Fig. 1: Total snowfall accumulation over North Carolina for the December 2009 event. (Courtesy of the NWS-Raleigh office)

Outside of North Carolina, a heavy axis of snow also ran through the Blacksburg area of Virginia, and continued northeast into the nation's capital before tapering off farther north (December...). Otherwise, some rain was measured in the outer edges of the system, as there was only narrow boundaries of mixed precipitation, in accordance with a Miller Type A system (Badgett et al.).

All of this originated from a low pressure system which developed in the Gulf of Mexico on December 18, 2009. This low was helped in its strengthening in part due to an upper level trough that slid across from the west. This low eventually tracked to the north and east, and rode along the eastern coastline as it continued on to the northeast states. Preceding the low pressure system's arrival was an initially powerful high pressure system that moved across the Great Lakes region and subsequently weakened. According to the National Weather Service office in Raleigh, the high pressure system "was initially of sufficient strength (>1025 mb) and location (Great Lakes region) to deliver cold dry air into central North Carolina in advance" of the low pressure system (Badgett et al.). However, because this high moved off and weakened rather quickly, the cold air that would have been in place over the area filtered out quicker as well. Therefore, as the NWS office pointed out also (Badgett et al.), the snowfall that did fall in North Carolina mainly was a result of diabatic processes, which means that snow had to melt aloft in order to cool the air enough for it to reach the surface.

The objective from here on out is to determine how well the Global Forecasting System (GFS 211) model performed in forecasting and providing meteorologists with accurate data to warn the public of an impending winter storm. The focus here will further be limited to the model's performance in forecasting the cyclogenesis that helped develop the low pressure system and strengthen it as it moved toward the mid-Atlantic region. In addition, the model's 24-

hour forecast from 12Z on the 17th and the model's 48-hour forecast from 12Z on the 17th will be compared with each respective analysis from 12Z on the 18th and 19th of December 2009.

Data Collected & Methods Used

Most of the data gathered for this analysis was collected from the GEMPAK and GARP systems, in order to utilize the Global Forecasting System (GFS 211) model's archived forecast and analysis for the above-discussed event. As mentioned before, the focus lies primarily on cyclogenetic processes; in other words, did the model pick up on such items as upper-level troughs, jet streaks, general cyclogenesis, and proper height levels? The closer these answers are to “yes”, the better the model should have been able to forecast the mid-Atlantic winter storm. For most plots, the focus will not be strictly confined to a large-scale map. Instead, a broader area will be studied, in order to realize the full effects of upper-level system progressions as well as surface systems, and how they correlate with one another. Marginalizing the spatial zones too much may cause an important feature (present or not present) to be missed. In conjunction with the model, background knowledge and other analysis maps will be utilized from the online database sites of the National Weather Service offices in both Raleigh and Blacksburg.

Specifically, the following fields were analyzed for model forecast accuracy for both the 24-hour and 48-hour forecast: 500 mb height field differences, 850 mb absolute vorticity differences, sea level pressure differences, and 300 mb height field/wind speed differences.

The 500 mb height field plots were chosen to determine if there were any significant differences in upper-level trough or ridge progression. For example, the upper-level trough discussed earlier was an important feature to helping the low pressure system develop while in the Gulf of Mexico. If the model did not indicate well the timing or intensity of this trough, it most likely would not have forecasted the low pressure's intensity or track well. However, even if it were to have done well with the low but not the upper-level trough, then there must be another process involved that needs to be identified.

The next plots to be analyzed are the 850 mb absolute vorticity fields. The 850 mb level was chosen as it is expected to be the most active in terms of important weather development from the absolute vorticity parameter. From there, we can get an overall view of the model's prediction of cyclogenetic intensity across the region of interest.

Sea-level pressure forecasts will allow us to see how the model projected the high and low pressure system to progress in time, along with their physical placement. We can predict how air parcels near the surface would be affected by the sea-level pressure gradients, and how that corresponds to dynamical processes at both the 850 mb and 500 mb levels.

One other important level is at 300 mb and its relevant height field and wind speed overlay. Locating where any jet streaks were forecast to be and the resulting analysis can play a major part in discovering why the model did or did not forecast well this winter event.

Results & Consequences

500 mb Height Field

First of all, we take a look at the 500 mb height field differences for the two aforementioned forecasts and their respective analyses. Below *(Fig. 2)* is the GFS 211 model's 12Z 24-hour forecast from

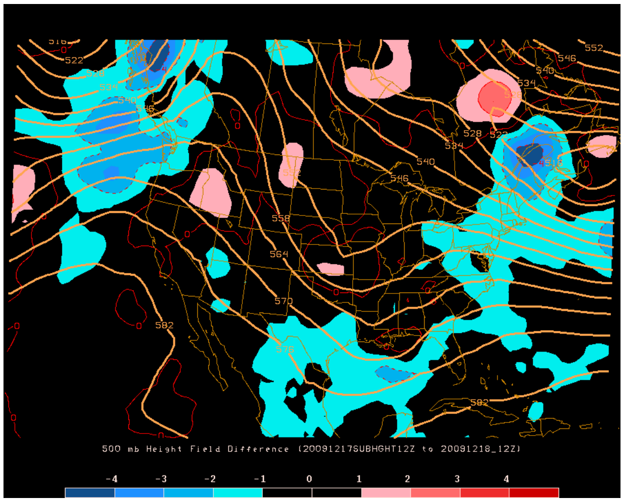


Fig. 2: 24-hr. forecast 500 mb height field difference with analysis from 12Z on the 18th overlayed

the 17th for the 18th of December 2009.

As you can immediately notice, there is a significant amount of "blue" shading stretching from the Gulf of Mexico and along the East Coast until reaching a maximum difference in southeastern Canada. The implications from this would appear that the model forecasted heights that were too low when compared to the resulting analysis, which is seen overlayed. Specifically, for the timing of the low development over the Gulf of Mexico, the GFS 211 model seems to have predicted the upper-level trough to be ever so slightly deeper than what resulted. The isoheights over the central U.S. appear to have been accurately measured a day ahead of time, so the "dip" to the south should have meant the model expected a little deeper of a trough. From this, it would appear that the model should expect enough cyclogenesis, seeing as the trough's intensity was somewhat overpredicted.

Looking ahead twice as far, the 48-hour 12Z forecast for 12Z on the 19th is next up (*Fig. 3*). First take in the overall picture compared to the 24-hour image. It is what we would expect from a forecast farther ahead in time; there is much more widespread disagreement between the forecast and resulting analysis. In addition,

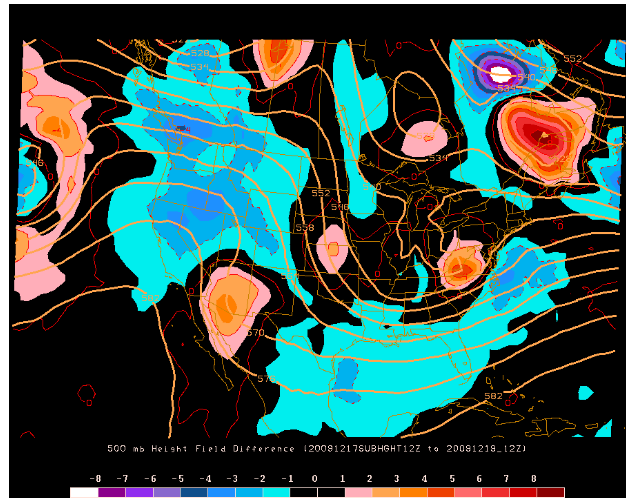


Fig. 3: 48-hr. forecast 500 mb height field difference with analysis from 12Z on the 19th overlayed

the intensity of such disagreement is stronger, especially over the North Carolina region and even up into southeastern Canada. It is important to note that the analysis shows an upper-level trough axis off to the west of the resulting surface low, giving what would be some upper-level divergence in support of the surface low. As for the forecast, you can see that the model actually predicted a greater spread of the isoheights in the vicinity of the surface low. Heigher heights were forecast over the Appalachians in NC, VA, and WV, and lower heights were forecast just to the east off the coast of NC and VA. It would seem that this would result in the model forecasting a weaker surface low than was present, due to the forecast of a weaker gradient. In this case, I would assume that proper cyclogenesis was underforecast from 48-hours ahead of time.

850 mb Absolute Vorticity

Vorticity is usually defined as a measure of local spin in the atmosphere. Furthermore, absolute vorticity simply includes both vorticity that is relative to the air mass we are examining, plus the vorticity resulting from the rotation of the planet. Knowing this, we can assume that by studying absolute vorticity plots, we will be able to see more specifically where the model would predict the greatest chances of cyclogenesis, when combined with other factors discussed. Therefore, we again examine the 24-hour absolute vorticity forecast difference from 12Z on the 17th for 12Z on the 18th *(Fig. 4)*.

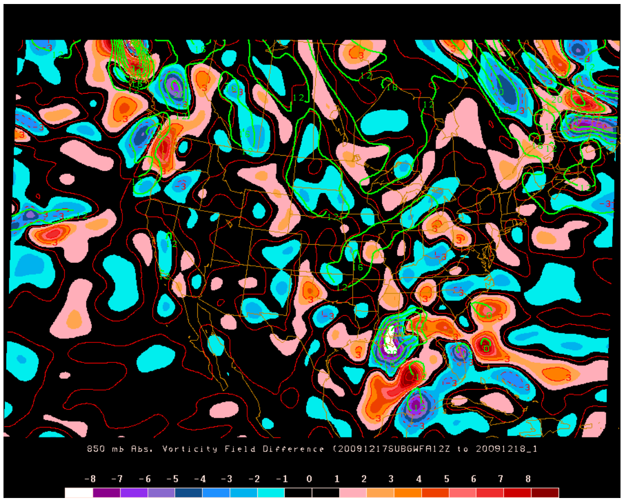


Fig. 4: 24-hour forecast 850 mb absolute vorticity field difference with analysis from 12Z on the 18th overlayed

There is an obvious amount of model miscalculation for just a day out. This is especially true across the Gulf of Mexico region and near Florida, where the low pressure system actually existed at 12Z on the 18th. You can see a large amount of difference near the coasts of Louisiana and Mississippi, near to the center of the low at that time. On the north and west side of the center, the model vastly underpredicted the amount of absolute vorticity , but overpredicted greatly just southeast of that point, and again projected too little southeast of there. This may be an indication that the model misjudged the exact location of the low's center, which we will look into shortly with the sea-level pressure analysis. So at this point we can assume that the model may have predicted the amount of vorticity present for cyclogenesis correctly, but it may have been forecast over the wrong area.

The second absolute vorticity plot looks ahead 48-hours from 12Z on the 17th of December *(Fig. 5)*. At this time, the center of low pressure was just slightly east of the North Carolina Outer Banks.

Again, we see a wide difference in the amont of vorticity predicted in the area of

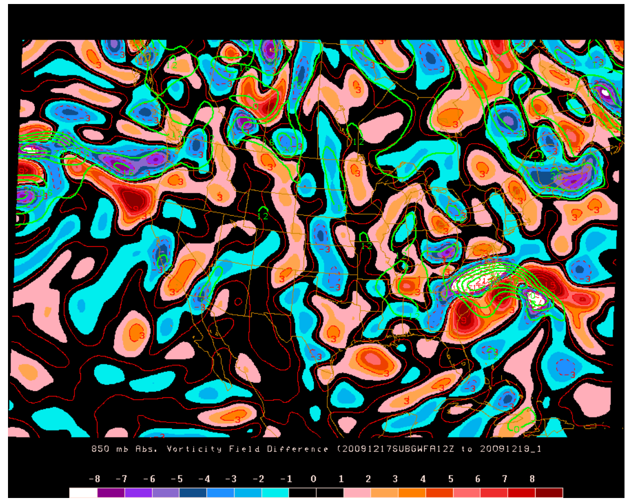


Fig. 5: 48-hour forecast 850 mb absolute vorticity field difference with analysis from 12Z on the 19th overlayed

the center of low pressure. Across the state of North Carolina and southern Virginia, the GFS 211 model forecasted much less absolute vorticity that what resulted. In contrast, the model projected too much vorticity across a wide swath of area, from eastern South Carolina and into the Atlantic, all along the coastlines of these three states. Again, this may be the result of the model incorrectly placing the low pressure system elsewhere. Regardless, the model would not have predicted as much cyclogenesis across the affected region when it was predicting much lower vorticity from two days ahead of time.

Sea-Level Pressure

Now, let's see where the GFS model projected the low pressure system of interest to develop and move. First, from one day out, the the 18th 12Z forecast from the same time on the 17th is shown below *(Fig. 6)*.

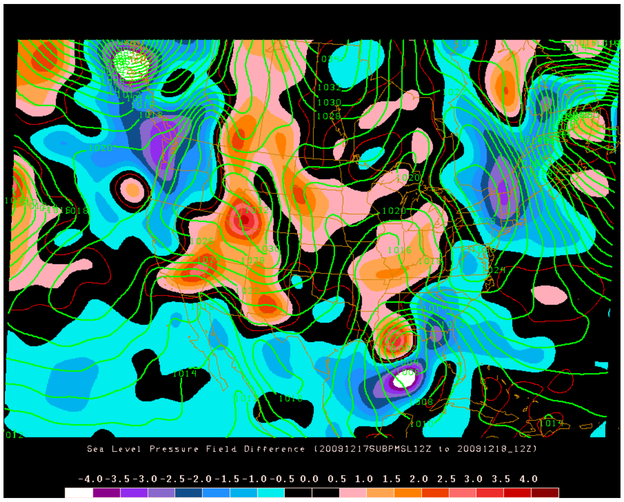


Fig. 6: 24-hour forecast sea-level pressure difference with analysis from 12Z on the 18th overlayed

We can verify from our discussion earlier that it is true that the GFS 211 model incorrectly placed the center of low pressure slightly too far south. Instead, the low was actually centered just off the coasts of Mississippi and Alabama. It does not appear, however, that the model incorrectly predicted the intensity of the low pressure system. For the location where it thought the center of low would be, the model projected a pressure of 1002 mb. The actual pressure is analyzed as 1002 mb. This is actually in line with what we have seen so far for the 24-hour forecasts. Stepping back for a moment, we can remember that the upper-level trough from the 500 mb height field was actually forecasted to be slightly deeper than what occurred, but its location was generally accurate. The 850 mb vorticity placement was inaccurate, but it still lines up with where the model thought the low would be. Also, similarly to the intensity forecast of the low pressure system, the vorticity intensity was correctly predicted, just for the wrong precise location. Therefore, this all adds up to be consistent with the 24-hour forecast for the sea-level pressure.

Next, let's look at the 48-hour sea-level pressure forecast and verifying

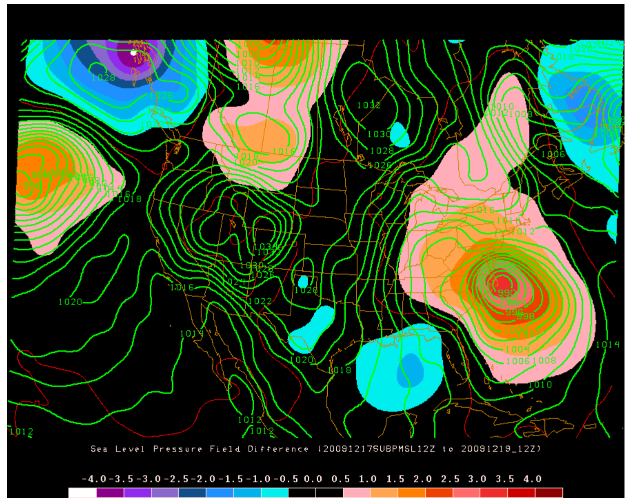


Fig. 7: 48-hour forecast sea-level pressure difference with analysis from 12Z on the 19th overlayed

analysis *(Fig. 7)*. There is a large area of difference sticking out off the coast of North Carolina, which, again, is exactly where the low pressure's center was analyzed to be located. In fact, the model difference shows that somewhat slightly higher pressure was forecast for this area, meaning that the GFS 211 model did not necessarily miss the location of the low, but it appears that what happened is it misjudged the intensity of it. Actually, the difference shows that the model predicted the lowest pressure to be about 994 mb, which would be about 4 mb higher. This is certainly not a huge difference, especially from two days ahead of time. Again, the model does seem to have predicted the location rather accurately. There are two areas, one to the southwest and one to the northeast, that the model forecasted lower pressure for, but only by a millibar or two.

300 mb Height Field & Isotachs

The last few plots all have their origination from GARP, so the two forecast plots will be separate from their respective analyses.

The first two images are the 24-hour forecast for 12Z on the 18th from 12Z on the 17th *(Fig. 8)*, and the resulting analysis *(Fig. 9)*, respectively.

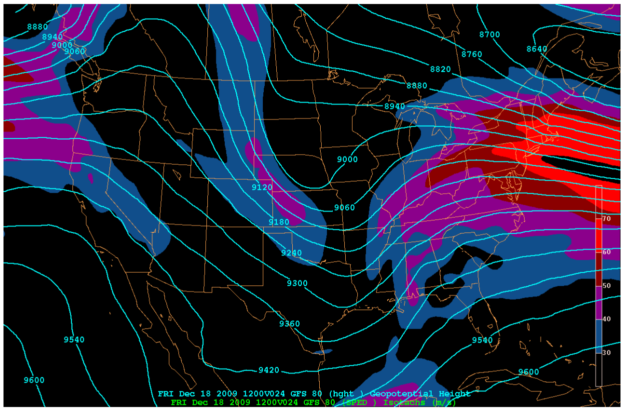
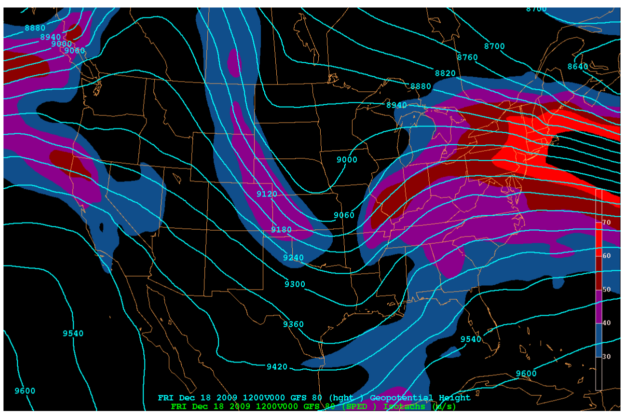


Fig. 8 (above): 24-hour forecast 300 mb height field and isotachs originating from 12Z on the 17th

Fig. 9 (below): 300 mb height field and isotachs analysis for 12Z on the 18th



Overall, the difference between the two plots doesn't seem to be too great. However, there is generally greater wind speeds at this level in most locations across this domain. Looking at the location where the low pressure system was at, just south of Mississippi and Alabama, we can see that the GFS 211 model was not predicting as great a wind speed aloft. There is not much of a jet streak anyway at this point, and the model did do well forecasting the location of the generally higher wind speeds and heights, so this should not have been a major implicating factor, which is not expected.

For the last two plots, we will examine the 48-hour forecast for 12Z on the 19th from the 17th *(Fig. 10)* and also its analysis *(Fig. 11)*.

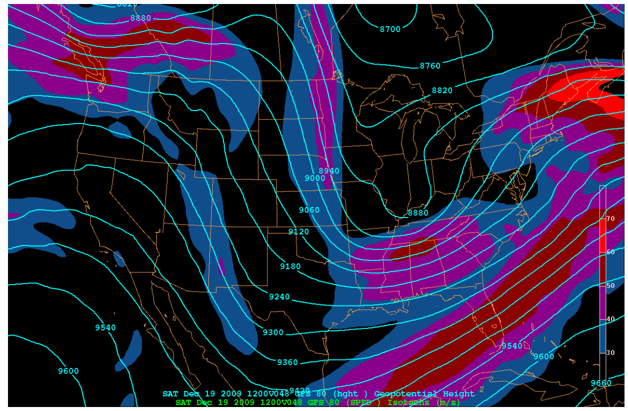
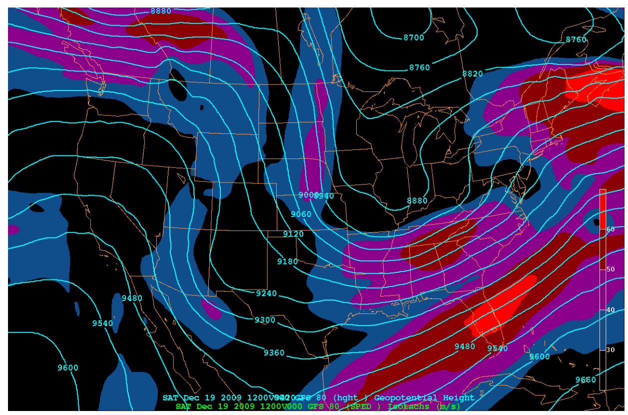


Fig. 10 (above): 48-hour forecast 300 mb height field and isotachs originating from 12Z on the 17th

Fig. 11 (below): 300 mb height field and isotachs analysis for 12Z on the 19th



Again, for most of the map, the model's forecast predicted weaker winds than what resulted, especially across the eastern U.S. Specifically, in the area of the low pressure system (off the N.C. Coast), the model did not predict a strong enough jet streak. The center of low is actually situated here in the left exit of the jet streak, and both the forecast and analysis show this. However, as we saw earlier, the model most likely predicted a weaker low in part due to this forecast of a weaker jet streak. Once again, this goes hand-in-hand with what we have seen from earlier discussions.

Summary

In general, it appears that the GFS 211 model 24-hour and 48-hour forecasts (from 12Z on the 17th of December 2009) did not miscalculate neither intensity nor location greatly. As we have seen in the last section, there were instances of model misplacement, such as the 24-hour forecast for the center of low. However, the model did not really miss the intensity of the storm at that point. For the two day forecast, the model actually predicted the location rather nicely, but missed the intensity forecast.

From the previous examinations of 500 mb height field, 850 mb absolute vorticity, sea-level pressure, and 300 mb height field and isotachs, we have realized some details that the model did not pick up on, which may very well be the reason for its misses. Overall, the cyclogenesis associated with this system should not have been greatly miscalculated, as both location and intensity forecasts did fairly well for both the one and two day forecasts, from the 17th. To better understand the model's progression, it would be appropriate to study similar results closer in time to the event occurrence. For example, it would be helpful to compare these results with the 24-hour forecast from 12Z on December 18th.

For the forecaster, it would appear that these results from this model would be pretty helpful in designing an accurate forecast, in terms of associated cyclogenesis and tracking and development of the low pressure system. Is there room for any improvement? Absolutely, and the best way to proceed is to go back and analyze why the model did miss those smaller features, which played into the larger ones. Why did the model not forecast greater wind speeds at the 300 mb level? Why did it miss the precise location of the low 24-hours ahead of time? Going further back to answer these question will certainly lead to a better understanding of the model's workings and will be helpful in improving and designing a better model for future forecasts.

References

Badgett, Phillip, Gail Hartfield, Russ Henes, Brandon Locklear, Jeff Orrock, Scott Sharp, Barrett Smith, Brandon Vincent, and Jonathan Blaes. "December 18-19, 2009 Winter Storm." *Event Summary*. National Weather Service & North Carolina State University, 15 June 2010. Web. 20 Nov. 2012. <http://www4.ncsu.edu/~nwsfo/storage/cases/20091218/>.

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