Operational Implications of Model Predicted Low-Level Moisture and Winds Prior to the New Year's Day 2006 Wildfire Outbreak in the Southern Plains

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Abstract

Intensifying drought conditions over much of the Southern Plains contributed to devastating wildfires in Oklahoma, Texas, and New Mexico during the winter of 2005/06. A particularly intense episode of widespread and damaging wind-driven wildfires across the region on New Year's Day was associated with the passage of a mid-latitude cyclone. The combination of damaging winds, blinding dust, smoke, and wildfires during the holiday weekend resulted in 2 deaths and at least 20 injuries. Two communities in Texas were virtually destroyed, and property losses exceeded $25 million. Prior to this high-impact event, numerical weather prediction models provided poor guidance for several meteorological fields critical to predicting fire behavior. Output from the National Centers for Environmental Prediction's Global Forecast System (GFS), and especially the North American Mesoscale (NAM) model, underestimated 10 m sustained wind speeds by up to 15 kt, overestimated 2 m relative humidity with absolute errors as high as 25%, and failed to predict a frontal passage that adversely affected firefighting operations at major wildfire burn sites. This paper will document these large model errors leading up to the New Year's Day wildfire outbreak, and will describe how forecasters in the affected region improved upon model guidance to enhance services prior to, and during, this dangerous event.

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1. Introduction and Event Summary

The winter of 2005/06 was characterized by intensifying long-term drought conditions (Fig. 1a-b) across the southern Great Plains (U.S. Drought Monitor 2005 and 2006). The drought was accentuated by an unprecedented lack of rainfall that began during the autumn months of 2005, particularly over west Texas, where new climatological records for consecutive days without measurable precipitation were established (Table 1). The unusually dry weather enhanced the curing of vegetation, led to adverse fire weather conditions, and eventually contributed to historic wildfires over Oklahoma, Texas, and eastern New Mexico (NOAA 2006a, NOAA 2006b, and Texas Forest Service 2006).

Table 1:

Longest Periods Without Measurable Precipitation at Lubbock, Texas (NOAA 2006c)

Rank	Total Days	Begin Date	End Date
1st	98	October 28, 2005	February 2, 2006
2nd	88	October 8, 1921	January 3, 1922
3rd	79	February 12, 1972	April 27, 1972
4th	76	November 8, 1955	January 22, 1956
5th	75	October 3, 1995	December 16, 1995

On New Year’ s Day 2006, westerly wind gusts up to 58 kt combined with single-digit relative humidity values over the drought-stricken Southern Plains to create widespread weather conditions favorable for extreme fire behavior (NOAA 2006a). Such behavior, as explained by the National Interagency Fire Center, precludes methods of direct suppression due to high rates of spread, prolific crowning and/or spotting, the presence of fire whirls, and strong convective columns. Predictability of such fires is difficult since they often exercise some degree of influence on their environment and behave erratically. These conditions, likely aggravated by increased outdoor human activity and fire-start potential during the holiday weekend, contributed to a regional wildfire outbreak (Fig. 2), defined by Milne (2004) as a fire weather event with a minimum of 35 new fire-starts.

By the early evening hours of 1 January, 73 new fire-starts of varying sizes and severity were reported in Texas alone (GADR 2006). Across the entire Southern Plains, at least 30 major wind-driven wildfires resulted in significant damage. These fires destroyed approximately 125 structures from southeastern New Mexico to central Oklahoma, and scorched more than 400,000 acres of the region’ s landscape. Two small Texas communities, Ringgold and Kokomo, were virtually destroyed by fire. Property losses across the region exceeded $25 million (NOAA 2006a), and the combined effects of the wildfires and related damaging winds resulted in 2 fatalities and at least 20 injuries (Fig. 3). The event generated immediate national interest, as television networks aired live images of neighborhoods ablaze in the Oklahoma City metropolitan area during prime time breaking news coverage.

In the days prior to the 1 January 2006 wildfire outbreak, numerical weather forecasts grossly overestimated near-surface moisture and underestimated low-level wind speeds over the impacted region. For example, model-generated forecasts predicted 10 m wind speeds between 12 and 25 kt at Lubbock, Texas, during the afternoon hours of New Year's Day. Sustained wind speeds, however, were observed between 23 and 35 kt with frequent severe gusts over 50 kt. Likewise, model-derived forecasts of 2 m relative humidity ranged between 14% and 31%, while observed relative humidities fell to 6% during the event. These model forecasted values for both wind speed and relative humidity were significant given that they were only marginally indicative of local National Weather Service Red Flag Warning criteria (sustained 6 m winds of 17 kt and 2 m relative humidity values of 15% or less), yet catastrophic fire weather conditions were ultimately observed.

Fire management officials have long recognized that atmospheric conditions are the primary variable factors to influence wildfire behavior and severity (Heilman 1995 and Anderson 1998). Relative humidity and winds, along with atmospheric instability, are the most critical meteorological parameters used to predict fire behavior and spread (U.S. Dept. of Commerce 1998). With large guidance errors in relative humidity and wind speeds, forecasts based soley upon numerical weather predictions prior to the New Year' s Day winds and wildfires would not have indicated the potential for a significant event. Furthermore, within 24 hours of the event, model generated forecasts failed to depict a cold front that pushed south over the Texas Panhandle and western Oklahoma. The abrupt northerly wind shift associated with the front altered the spread and propagation of several wildfires and created dangerous conditions that threatened equipment, structures, and injured at least one firefighter.

This paper will evaluate the North American Mesoscale (NAM) model and the Global Forecast System (GFS) gridded solutions prior to the New Year' s Day 2006 Southern Plains wildfire outbreak relative to observed surface conditions over west Texas. The large errors observed in model predicted low-level relative humidity and wind fields will be documented. A discussion of the meteorological logic and local expertise used by forecasters in the affected region to enhance services and improve upon the numerical guidance will be included.

2. Meteorological Overview

In the days prior to the event, poor overnight relative humidity recoveries were observed over much of west Texas, New Mexico, and Oklahoma, with maximum relative humidity values generally between 30% and 50%. This short-term drying, coupled with the intensifying drought conditions, acted to cure fuels in the region and allowed ambient fire dangers to reach critical levels. Experimental shrub moisture data suggested that satellite-derived relative greenness measurements, adjusted according to the Normalized Difference Vegetation Index (NDVI), were less than 80% of normal over much of the Southern Plains, with particularly low values of only 61% to 70% relative greenness over parts of eastern New Mexico and west Texas (Fig. 4).

A deep mid-latitude cyclone and associated dry slot were evident in water vapor imagery approaching the Southern Plains during the morning hours of 1 January (Fig. 5). As these features moved eastward, surface pressure gradients tightened over the Southern Plains as cyclogenesis initiated along a surface front over southeastern Colorado and southwestern Kansas. This helped to sharpen a dryline across central Oklahoma and Texas (Fig. 6a-f).

Strong westerly winds were evident throughout the atmospheric column, as indicated by area 1200 UTC soundings and upper air analyses. Of particular note was a very dry boundary layer over the region, with surface dewpoint depressions that ranged from 14 to 22 degrees C (18 to 40 degrees F) over west Texas (Fig. 7a-d), and the presence of 65 to 75 kt mid-level winds upstream at El Paso, Texas, and Albuquerque, New Mexico, respectively at the 500 hPa level (Fig. 8). The synoptic pattern was an example of the " Chinook-Type" Southern Plains critical fire weather pattern documented by Schroeder et al. (1964).

By late morning, 20 kt westerly winds at the surface had enhanced downslope trajectories over the higher terrain. This allowed surface temperatures to warm rapidly, eventually to record-breaking levels for the day with readings across the Southern Plains that ranged from 20 to 25 degrees C (upper 60s to near 80 degrees F). The abnormally warm low-level air contributed to the erosion of a weak inversion, and allowed for deep mixing of the boundary layer over the region. Consequently, very dry air and strong winds aloft were easily mixed to the surface, and enhanced the fire weather threat.

3. Evaluation Methodology of Numerical Weather Prediction Guidance For 2 m Relative Humidity and 10 m Wind Speed

Five operational model solutions initialized within 72 hours of the event were investigated, three from the ETA configured NAM and two from the GFS solutions. These gridded solutions were available for operational use in the Advanced Weather Interactive Processing System (AWIPS) environment at the following spatial and temporal resolutions; the "40NAM" post-processed at 40 km grid spacing in three hour forecast intervals available for forecast hours 3-60, the "80NAM" post-processed at 80 km grid spacing in six hour forecast intervals available for forecast hours 6-84, and the "80GFS" post-processed using 80 km grid spacing at six hour forecast intervals available for forecast hours 6-240. It is noteworthy that both the NAM and GFS solutions generally provided small errors in low-level temperature fields despite observed record values, and that the observed errors in predicted relative humidity were largely due to overestimates of model-forecasted near-surface dewpoints.

In order to quantify the errors in model guidance that forecasters observed prior to the New Year' s Day wildfire outbreak, subjectively-observed values of 2 m relative humidity and sustained 10 m wind speed were sampled from gridded model output for a single point near the Lubbock International Airport (33.59° N, 101.89° W). These model-predicted values were compared to the observed conditions measured by the Automated Surface Observing System (ASOS) located at the Lubbock International Airport (KLBB). The comparisons of these data are seen below in Table 2. The point values were deemed to be centrally located and largely representative of the model error across the geographical outbreak area in west Texas; the southern Texas Panhandle, the South Plains, and the Permian Basin (Fig. 9). Line graphs were used to graphically compare the model-forecasted values of 2 m relative humidity and 10 m wind speed versus the ASOS observed conditions for corresponding forecast hours.

Also, to provide a visualized comparison between the graphical model forecasts and the approximate-observed conditions, plan-view images of gridded model output for 2 m relative humidity and 10 meter winds were compared to displays of the same meteorological fields generated by the Local Analysis and Prediction System (LAPS) (Ablers et al. 1995 and 1996) at 1200 UTC, 1800 UTC, and 2400 UTC. The LAPS analyses were used only as an approximation of observed conditions, and were primarily helpful in obtaining color imagery depicting the large errors in model-derived 2 m relative humidity fields. Links to both of the graphical comparisons described, line graphs and non-quantified plan-view images, are contained within Table 2 as Fig. 10 through Fig. 24.

Table 2:

Model-Derived Values of 2 m Relative Humidity, 10 m Wind Speed, and KLBB Observed Values						
Model Run	**Values**	**Model Forecast and Observation Times For 1 January 2006**				
		1200 UTC	**1500 UTC**	**1800 UTC**	**2100 UTC**	**2400 UTC**
80NAM 0000 UTC 30 December 2005: Forecast Hours 60-72	RH	20%		31%		23%
	Wind Speed	10 kt		20 kt		15 kt
	Link to Figure	Fig. 10		Fig. 11		Fig. 12
40NAM 0000 UTC 31 December 2005: Forecast Hours 36-48	RH	36%	37%	27%	25%	29%
	Wind Speed	15 kt	18 kt	23 kt	20 kt	12 kt
	Link to Figure	Fig. 13	n/a	Fig. 14	n/a	Fig. 15
40NAM 0000 UTC 1 January 2006: Forecast Hours 12-24	RH	33%	34%	28%	25%	27%
	Wind Speed	15 kt	18 kt	20 kt	23 kt	15 kt
	Link to Figure	Fig. 16		Fig. 17		Fig. 18
80GFS 0000 UTC 30 December 2005: Forecast Hours 60-72	RH	30%		23%		18%
	Wind Speed	12 kt		20 kt		15 kt
	Link to Figure	Fig. 19		Fig. 20		Fig. 21
80GFS 0000 UTC 1 January 2006: Forecast Hours 12-24	RH	27%		19%		14%
	Wind Speed	15 kt		25 kt		12 kt
	Link to Figure	Fig. 22		Fig. 23		Fig. 24
KLBB Surface Observations	RH	26%	16%	6%	6%	7%
	Wind Speed	13 kt	20 kt	35 kt	35 kt	23 kt

4. Failure to Resolve Cold Frontal Passage and Impacts on Firefighting

Operations

Between 2200 UTC and 2400 UTC 1 January a cold front advanced south over active wildfires in the Texas Panhandle and southwestern Oklahoma. The northerly wind shift associated with the frontal passage altered fire propagation. Fire crews battling large blazes in severe westerly winds (gusts greater than 50 kt) near the Texas Panhandle communities of Howardwick and Shamrock were adversely impacted by the wind shift after enacting attack strategies based on forecasts for continued west winds and eastward fire propagation. The shifting wildfires threatened 10 structures near Shamrock, and required the emergency evacuation of 100 residents and patrons of a local motel. In addition, a firefighter received burn injuries near Howardwick when that fire shifted and threatened heavy equipment and 70 homes (NOAA 2006a).

The failure of numerical weather prediction to forecast a significant wind shift (Fig. 25a-c) and frontal passage over the Southern Plains on New Year' s Day was a critical element that contributed to a loss of situational awareness for both forecasters and fire managers. A complicating factor was a mesoscale enhancement of the synoptic scale frontal boundary by evaporatively cooled air that originated from post frontal virga showers (Fig. 26). The hazards realized by this frontal passage underscore the importance of maintaining a continuous flow of accurate observational and forecast information between meteorologists in the operational setting and local decision makers at the scene of major wildfires.

Land management agencies recognize weather as the primary variable to impact fire behavior. They are aware that keeping abreast of potential meteorological changes is of utmost importance for safe and effective fire fighting (National Wildfire Coordinating Group 2002). Changes in wind speed or direction are a reoccurring element common to many wildfire-related fatalities (National Wildfire Coordinating Group 1997). Wind shifts, or increases in wind speeds, can have disastrous consequences for fire crews. Therefore, it is of great importance for fire weather forecasters to understand the basic role that wind has in determining fire fighting strategies.

Wind affects wildfire propagation, and a wildland fire' s structure is largely the result of local wind fields. The leading edge of a fire, called the head, is the hottest and fastest moving part of a fire. The sides of the fire, or flanks, tend to parallel the wind and they are wider, slower, and less intense than the head. Flame lengths determine the type of attack strategy that firefighters use. Flame lengths of 1.2 m (4 ft) or less can generally be fought by " direct attack" hand crews. Flame lengths of 1.2 m to 3.7 m (4 to 12 ft) can be fought more safely with direct attack using heavy equipment such as dozers, tractors, or engines. Therefore, ground crews typically work a direct attack on the less intense flanks if flame lengths are 1.2 m (4 ft) or less (National Wildfire Coordinating Group 2002). When an abrupt wind shift moves through a wildland fire, the orientation of the fire changes with the flank becoming the fire' s head. This change rapidly increases the size of the fire as the broader flank spreads with the shifting wind, and can potentially drive the fire into crews working the flanks of the fire.

Fire weather forecasters provide an important service to those fighting wildfires. It is therefore important that they maintain situational awareness before and during wildfire events. The information communicated to fire planners and personnel can dramatically influence their decision-making process at the scene, and can be vitally important in maintaining the safety of fire crews. Fire weather forecasters should always discuss anticipated wind shifts and changes in wind speed in all fire weather products, and should relay short-term wind forecasts through collaboration with local emergency and fire fighting officials during wildfire activity (Lindley et al. 2006).

5. Forecast Logic and Manipulation of Model Guidance in Operational Forecasts

Prior to New Year's Day 2006, forecasters at the Storm Prediction Center (SPC) in Norman, Oklahoma, and in forecast offices across the Southern Plains, recognized discrepancies between the model-forecasted low-level dewpoints and wind fields compared to conceptual models for the passage of an intense mid-latitude cyclone over the region. The NAM and GFS solutions, and the associated MOS guidance, depicted westerly downslope winds over the New Mexico plains and much of west Texas following the passage of the mid-level trough, while conversely indicating constant or increasing surface dewpoints over much of west Texas. Forecasters believed that these model errors were producing overestimates of low-level relative humidity. In addition, surface wind speeds indicated by both models also appeared to be too low given the magnitude of mid-level height falls and surface pressure gradients forecasted over the region.

These discrepancies were consistent with an observed tendency, particularly by the NAM model, to overestimate low-level dewpoints during the winter of 2005/06 over the Southern Plains. This resulted in forecasts of afternoon minimum relative humidities that were higher than observed values. Furthermore, model wind speeds tended to be stronger than those forecast by the deterministic numerical models and MOS guidance. Both errors were due to a greater depth of boundary layer mixing than forecast, and were evident in post-event comparisons of NAM model forecast soundings with observed radiosonde data (Fig. 27). Another contribution to the errors was likely a documented high bias in 2 m dewpoints generated by the operational NAM model. This bias was attributed to code in the land-surface physics that led to excessive modeled evapotransporation over vegetated landscapes during warm and dry weather (EMC 2006).

Model errors and discrepancies became apparent as the drought intensified over the Southern Plains in late 2005, when periodic mid-latitude cyclones induced periods of heightened fire danger. Following a significant fire weather event on 27 December, forecasters anticipated that the trough passage on New Year's Day would again result in a scenario for high impact fire weather conditions given a combination of strong to severe winds, record warm temperatures, and critically low relative humidities. Given the known model-observational discrepancies and model biases, a downward adjustment of relative humidities and an increase in afternoon wind speeds were applied in fire weather forecasts. These forecast adjustments were not only made prior to the New Year's Day event, but also for a number of subsequently significant fire weather events in the Southern Plains during the remaining winter and early spring of 2006.

Recognizing these model biases, the SPC Day 2 Fire Weather Outlook issued on 31 December (valid for 1 January) featured a Critical fire weather outlook for eastern New Mexico, all of Oklahoma, and northern/central Texas. Within the Critical area, an Extremely Critical fire weather area was highlighted for central and eastern Oklahoma and north central Texas. While SPC Critical fire outlook areas are issued occasionally, Extremely Critical outlooks are issued very infrequently and are reserved for the most serious of anticipated fire weather conditions. During the morning hours of 1 January, the SPC Day 1 Fire Weather Outlook's Extremely Critical fire weather area was expanded to include eastern New Mexico, the southern two-thirds of Oklahoma, and a large portion of northwest and north central Texas. A Critical fire weather area also was issued for the remainder of the Southern Plains. This outlook included strong wording that stated:

" A POTENTIALLY DANGEROUS SITUATION WITH EXTREME FIRE DANGER IS EXPECTED THIS AFTERNOON AND TONIGHT ACROSS A LARGE PORTION OF OK...NORTH/NORTHWEST TX...AND FAR EASTERN NM."

The SPC Fire Weather Outlook graphics for 1 January 2006 can be viewed in Fig. 28a-b.

Upon a thorough review of operational model guidance, meteorologists at forecast offices in Albuquerque, Amarillo, Lubbock, Midland, Norman, and San Angelo collaborated using the 12Planet chat software (NOAA/SRH 2003) and agreed that model-derived dewpoint temperatures were too high; hence model-derived relative humidities were too high, and progged surface winds were too low. After applying the forecast adjustments discussed above, it was determined that a significant fire weather event was likely over a large portion of the Southern Plains. Local forecasters, utilizing the fire weather guidance products issued by SPC, were able to express the likelihood of a rare wildfire outbreak to both the public and emergency management officials with a high degree of confidence.

Products that addressed the anticipated critical fire weather threat were issued at many Southern Plains forecast offices as early as 30 December. These products not only included Red Flag Warnings that highlighted the potential for " rapid and explosive fire growth and spread" for fire weather planning customers, but also Special Weather Statements that increased public awareness of the extreme fire hazard. Texas emergency management officials also requested that several forecast offices issue specialized Public Information Statements to highlight the extreme fire danger and to discourage citizens from using open flames during outdoor holiday activities. Despite these enhanced services, the misleading model guidance did contribute to brief lapses in forecaster awareness. This led to the temporary cancellation of a Fire Weather Watch for a small portion of the outbreak area during the evening of 31 December. Through proactive coordination, however, forecasters were generally able to issue excellent fire weather forecasts.

6. Conclusions

This evaluation of the NAM and GFS model solutions prior to the New Year's Day Southern Plains wildfire outbreak documented errors in model-forecast low-level relative humidities and winds. These errors were found to be as high as 15 kt for sustained 10 m wind speeds and 25% for 2 m relative humidity as compared to the observed conditions at Lubbock, Texas, per official ASOS observations. Since these meteorological parameters are the primary critical variables in predicting wildland fire behavior, official National Weather Service fire weather planning and public hazard forecasts based solely upon the numerical weather prediction model guidance would have likely been unrepresentative of a regional high-impact and significant wildfire outbreak. Numerical model forecasts also failed to predict a cold front that swept through ongoing wildfires and resulted in a dangerous wind shift.

The misleading guidance produced by the NAM and GFS solutions created collaboration challenges for operational meteorologists in the affected forecast offices. In addition, errors in model guidance likely contributed to a loss of situational awareness among forecasters and fire planners resulting in the brief cancellation of a Fire Weather Watch over a small portion of the outbreak area within 24 hours of the event, and the adverse effects on ill-prepared fire crews following the unforecasted wind shift. Nonetheless, forecast services were enhanced through the recognition of model biases and inconsistencies relative to conceptual models by forecasters at both the SPC and the local forecast offices, and through inter- and intra-agency coordination. Through such coordination, a multi-agency effort allowed forecasters and state officials to convey predictions of a significant event despite numerical guidance that depicted a lesser wildfire threat.

The multiple wildfire outbreaks experienced across the Southern Plains during the winter and spring of 2005/06 were of historical significance. Lyster and Murdoch (2001) stated that fire weather concerns have traditionally not been a high priority for National Weather Service forecasters across the region, particularly in west Texas, and that local meteorological studies regarding critical fire weather patterns and wildfire behavior have been lacking. It is the hope of the authors that additional research and documentation of the unprecedented 2005/06 fire weather events in the Southern Plains, combined with an educational initiative to train local volunteer fire departments on the use and availability of National Weather Service fire weather products and services, be implemented by local forecast offices to improve the collaboration and services provided to local and regional customers.

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