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PRELIMINARY METEOROLOGICAL ANALYSES OF THE 2011 'TEXAS FIRESTORMS'

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1. INTRODUCTION

In recent years, episodic drought has contributed to the occurrence of wind-driven grassland wildfire outbreaks in the Southern Plains. Such extreme wildland fire events have emerged as a preeminent natural hazard in the region. Since 2005, at least 18 Southern Plains wildfire outbreaks have inflicted widespread damages and the loss of life across portions of eastern New Mexico, Texas, Oklahoma, and southern Kansas. Texas Forest Service (TFS) records (unpublished) indicate that an unprecedented 3.2 million acres (1.3 million ha) were destroyed by wildfire in Texas during the first half of 2011, and the state was impacted by at least eight regional wildfire outbreaks during the course of an historic fire season. Three such outbreaks were particularly intense.

TFS officials have stated that the most violent Southern Plains wildfire outbreaks are *"a perfect storm for extreme fire…natural disasters that are truly beyond our capability to do anything about"*, and have termed such events that impact the state 'Texas firestorms' (Mutch and Keller 2010). Past Southern Plains wildfire outbreaks that have been coined as 'firestorms' were individually characterized by the near-simultaneous onset and/or intense spread of dozens of wind-driven grassland fires that consume 100,000s to over a million acres (40,469 ha to > 404,686 ha).

This study provides preliminary meteorological analyses of 'Texas firestorms' that occurred on 27-28 February, 9-10 April, and 14-15 April, during initial stages of the exceptional 2011 drought. These analyses are compared to a previously documented meteorological composite that relates Southern Plains wildfire outbreaks to the passage of mid-latitude cyclones (Lindley et al. 2007). The evolution of the 27-28 February wildfire outbreak closely resembled the synoptic scale composite of similar past events when fire activity peaked during the diurnal passage of the parent weather system. The 9-10 April and 14-15 April 'firestorms', however, deviated from this conceptual model. During the April 2011 events, prolonged 'firestorm' conditions occurred not only in association with the cyclone passage, but also 1) with the initial infringement of strong wind fields upon low-level thermal ridging in advance of the approaching cyclone and 2) within the post-frontal environment immediately following the cyclone (Fig. 1). Through documentation of the later 'Texas firestorms', this study expands the conceptual model for Southern Plains wildfire outbreaks to include the potential for multi-day episodes prior to and in the wake of passing mid-latitude cyclones, especially during periods of unusually dense and dry fuels.

Figure 1: NOAA MODIS Aqua imagery of a 'Texas firestorm' in a post-frontal regime on 15 April 2011.

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2. SOUTHERN PLAINS WILDFIRE OUTBREAK CONCEPTUAL MODEL – 2007-2009

Lindley et al. 2007 documented a meteorological composite of the synoptic-scale pattern associated with the peak burn-period for six Southern Plains wildfire outbreaks that occurred during the unusually intense 2005/06 winter and spring fire season. The study utilized 2100 UTC initial-hour Rapid Update Cycle (Benjamin et al. 2004) analyses post-processed on a 20 km grid to generate GEneral Meteorological PAcKage (Unidata 2002) plots of average mean sea level pressure (mslp), 2 m relative humidity and temperature, 10 m wind, as well as geopotential heights, wind and isotachs for the 700 hPa, 500 hPa, and 300 hPa pressure levels (Fig. 2a-b). Pattern recognition forecast methods based on these composite charts helped fire weather meteorologists to improve forecasts and warnings for additional widespread and extreme fire weather events in the Southern Plains during 2008 and 2009.

In late 2009 the Southern Plains wildfire outbreak composite was updated to include four additional cases that occurred in 2008 and 2009. This expanded the dataset from six to ten outbreak cases that spanned various degrees of drought during four fire seasons from 2005 to 2009. The 2009 inclusion of additional Southern Plains wildfire outbreaks helped to increase the statistical and scientific integrity of the composite method as a conceptual model (Fig. 3) for these climatologically rare events. Even with the inclusion of additional cases, the composite synoptic pattern remained strikingly similar to the 2005-2006 cases. Each Southern Plains wildfire outbreak in the dataset occurred as multiple wildfires developed on spatial and temporal scales associated with: 1) the passage of progressive mid-latitude cyclones and accompanying wind maxima, 2) intense surface cyclogenesis, and 3) deep diurnal mixing of the planetary boundary layer coincident with favorably dry biofuels and antecedent drought within the cyclone's warm/dry sector west of a surface dryline and south of a cold front (Fig. 4).

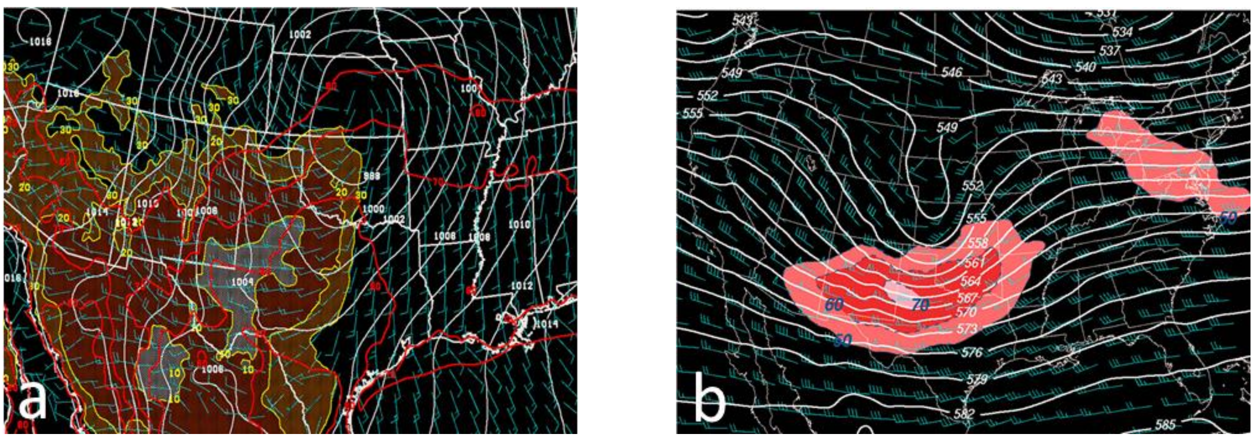


Figure 2a-b: *Example meteorological composite charts for Southern Plains wildfire outbreak showing a) 2 m temperature (red contours), 2 m relative humidity ≤ 30 percent (shaded), 10 m wind (cyan barbs), and mslp (white contours) and b) 500 hPa heights (white contours), wind (cyan barbs), and isotachs ≥ 50 kt (26 m/s) (shaded).*

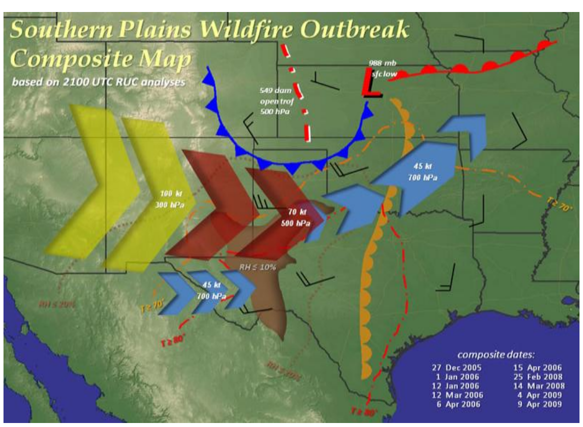


Figure 3: *Conceptual model of a Southern Plains wildfire outbreak from 2007-2009 composites.*

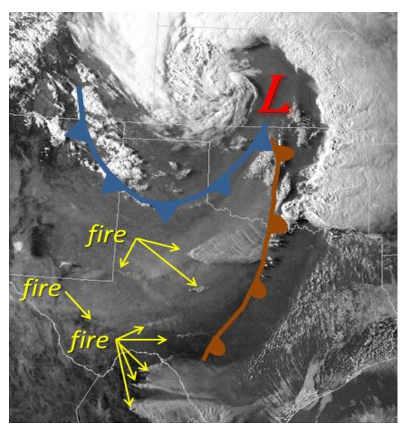
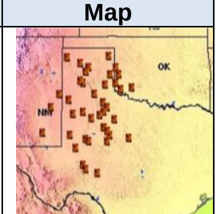
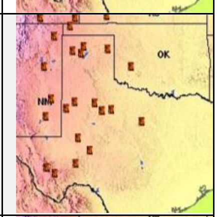
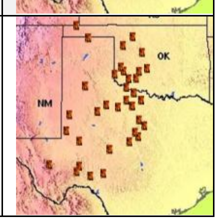


Figure 4: *Visible satellite imagery showing a typical Southern Plains wildfire outbreak impacting Texas.*

3. 2011 'TEXAS FIRESTORMS'

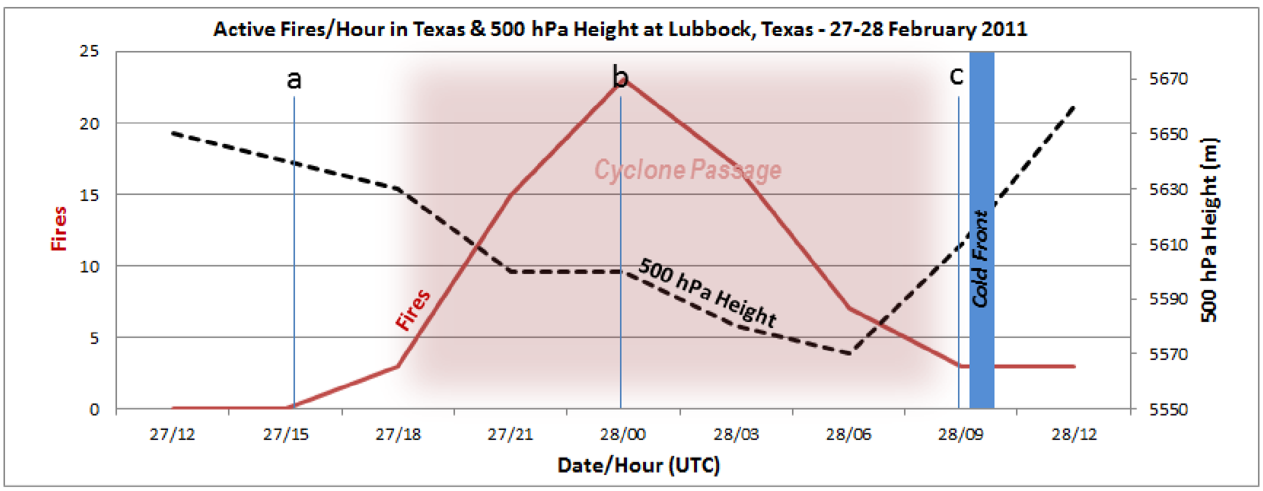
During the historic Texas drought and fire season of 2011, the occurrence and severity of wildland fires across the state peaked during eight Southern Plains wildfire outbreaks. Three such outbreak episodes were noted to be particularly violent and burned 100,000s of acres (>40,469 ha), causing widespread property loss and human casualties (Table 1).

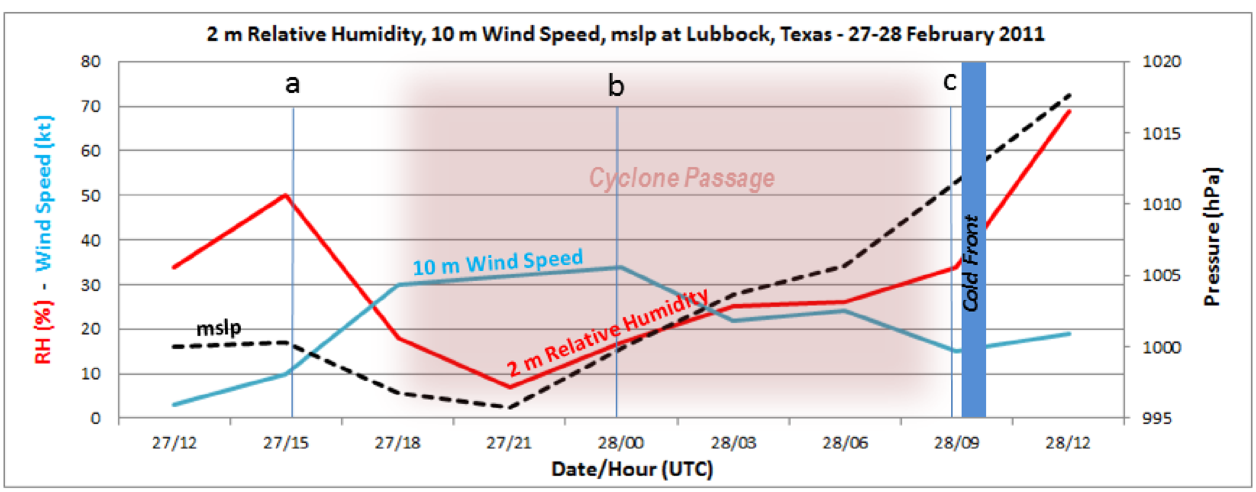
Preliminary meteorological analyses and comparisons to the pre-existing conceptual model of similar past outbreaks follow for 'firestorms' which occurred on 27-28 February, 9-10 April, and 14-15 April 2011. A synopsis for each 'firestorm' precedes a graphical presentation of meteorological data. The number of active fires is related to meteorological observations for a site near the geographic center of the outbreak (27-28 February at Lubbock, Texas, 9-10 April at Lubbock, Texas, and 14-15 April at Abilene, Texas). Meteogram format: top chart - 500 hPa height (black dash) derived from Rapid Update Cycle (RUC) (Benjamin et al. 2004) analyses and number of active fires (red line), bottom chart - mslp (black dash), 2 m relative humidity (red line), and 10 m wind speed (blue line). Each plot of active fires and weather is highlighted (light red shade) to indicate the passage of parent mid-latitude cyclones. This timeframe is defined by bracketing the relative mslp and 500 hPa minima associated with pressure and height troughs during each cyclone at the chosen observation site. A bold blue line denotes the passage of the system's cold front. Three times of interest are additionally demarked as "a", "b", and "c". These times represent various maxima and minima of fire weather and wildfire activity throughout the event. Corresponding satellite images and RUC derived 500 hPa height analyses (green lines) are provided for each time of interest. Locations of the observation site (red star), surface lows (red "L") and trough (black dash), cold fronts (blue barbed line), dryline (brown barbed line), 500 hPa trough axis (green dash) and closed lows (red "*low*") are denoted on the satellite images as applicable. Mesoscale plots that illustrate the proximity of wildfires (flame icons) to mid-tropospheric wind maxima (cyan shaded arrow) and low-tropospheric thermal ridges (bold amber dash) as described in the narratives are referenced to the appropriate time of interest and are formatted as: 2 m relative humidity (warm shade=dry, cool shade=moist), 10 m wind (kt, green barbs), 850 hPa isotherms (C, orange dash), 500 hPa isotachs (kt, cyan lines). Finally, graphs depicting the area burned per day in Texas for each episode are shown.

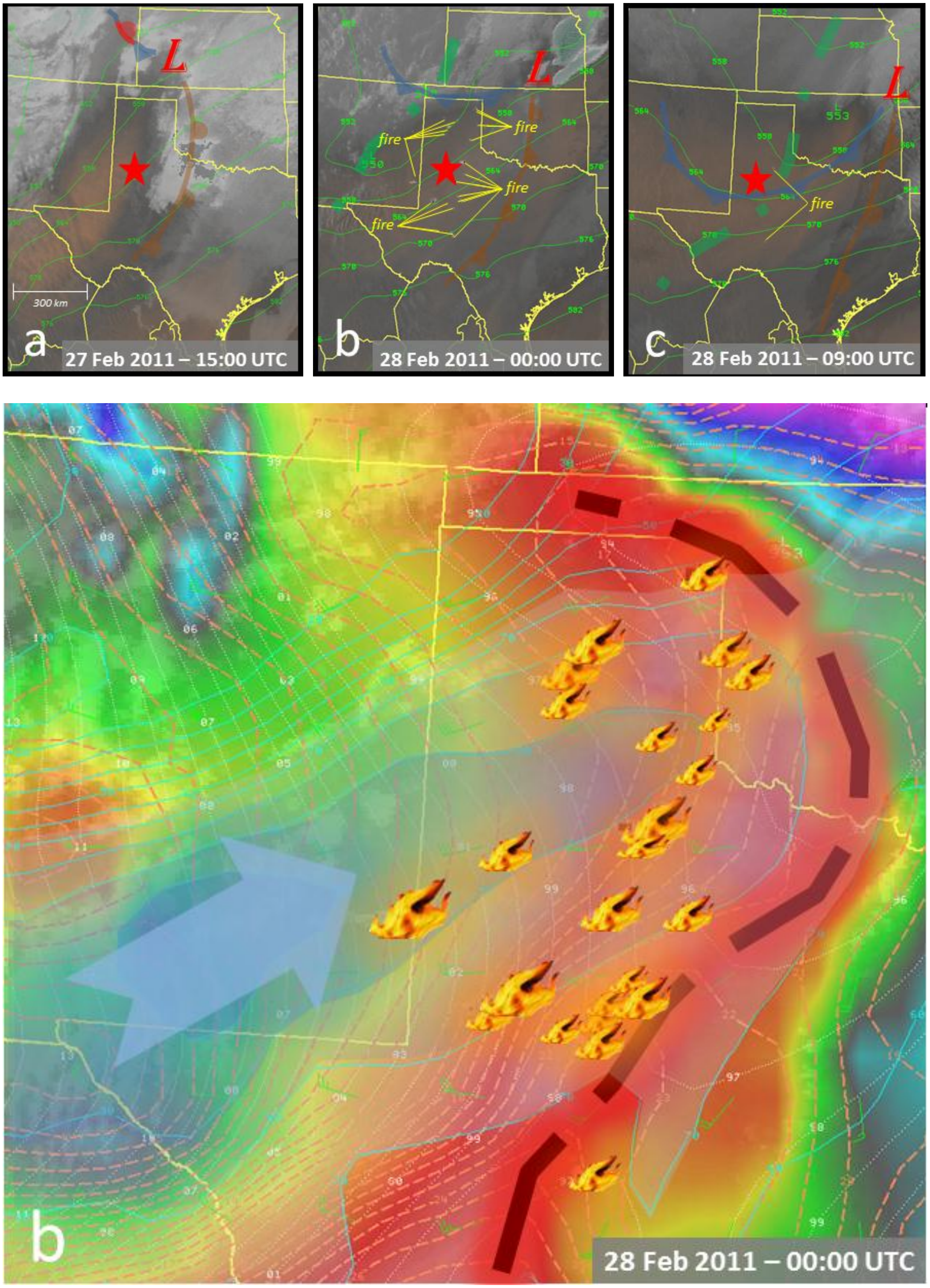
	Table 1: 2011 Southern Plains Wildfire Outbreaks Deemed 'Texas Firestorms'						
Event Date	**Major Wildfires**	**Acreage Burned**	**Economic Damages**	**Structures Destroyed**	**Reported Deaths**	**Reported Injuries**	**Outbreak Map**
27-28 Feb	39	284,911 (115,299 ha)	$19 M	210	1	4	
9-10 Apr	22	362,074 (146,526 ha)	$14 M	87	1	3	
14-15 Apr	36	325,726 (131,817 ha)	$10 M	70	1	10	

a. 27-28 February 2011

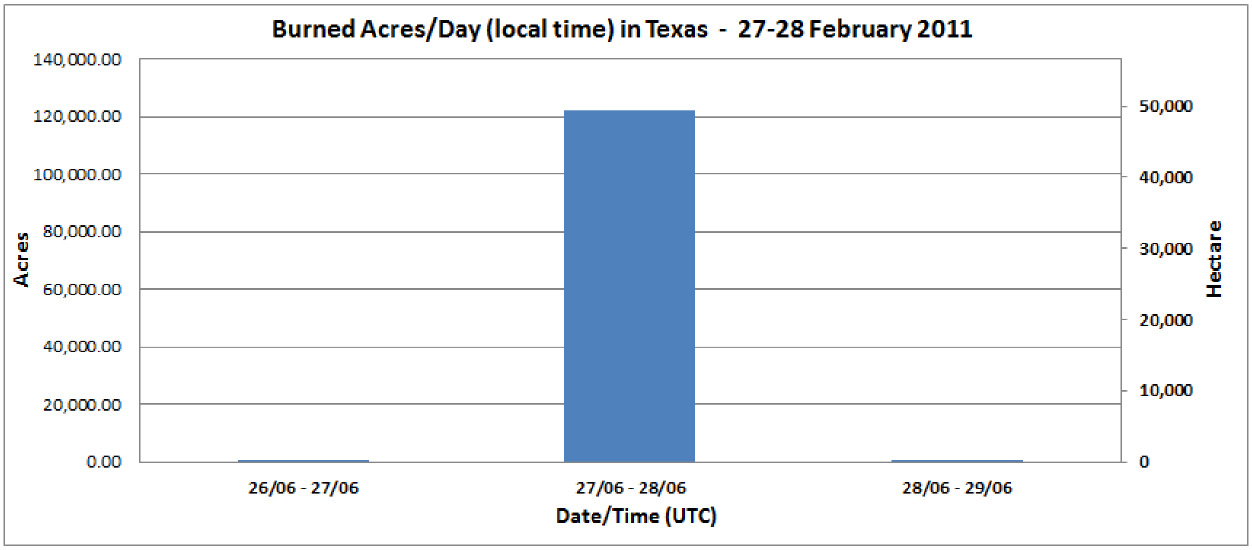
The first 2011 Southern Plains wildfire outbreak to impact Texas occurred on 27-28 February. The synoptic weather pattern associated with the 27-28 February 'firestorm' was very similar to the conceptual model for Southern Plains wildfire outbreaks, and the event was quantitatively identified as an analog to two of the region's wildfire outbreak episodes that occurred in 2006 (Vitale et al. 2011). This outbreak occurred as a deep but progressive mid-latitude cyclone characterized by a 5490 m height trough at 500 hPa ejected northeastward from the Southern Rockies over the Southern Plains between approximately 27/1800 UTC and 28/0900 UTC. As the cyclone translated west to east over the region, a period of extremely critical fire weather developed within the warm/dry sector with daytime relative humidity minima < 10 percent and sustained winds > 30 kt (15 m/s) and was accompanied by a pronounced increase in active wildfires across west Texas and adjacent areas of New Mexico and Oklahoma between 27/1800 UTC and 28/0000 UTC. The most intense fire weather and wildfire activity occurred in temporal and spatial proximity to the nose of a mid-tropospheric wind maximum as it overspread a low-tropospheric thermal ridge in the hours around 28/0000 UTC. Evidence of intense wildfire activity similarly focused in proximity to the juxtaposition of these low and mid-tropospheric features has been observed during past Southern Plains wildfire outbreaks (Smith 2009). Wildfire activity then decreased as fire weather conditions improved (increased relative humidity and decreased wind speeds) in the wake of the low and mid-level trough, and only a few very large fires persisted beyond the passage of the system's associated cold front. Thus, virtually all of the acreage burned occurred on 27 February (local time).







L
300 km
a
27 Feb 2011 – 15:00 UTC
fire
fire
fire
fire
b
28 Feb 2011 – 00:00 UTC
fire
c
28 Feb 2011 – 09:00 UTC
b
28 Feb 2011 – 00:00 UTC



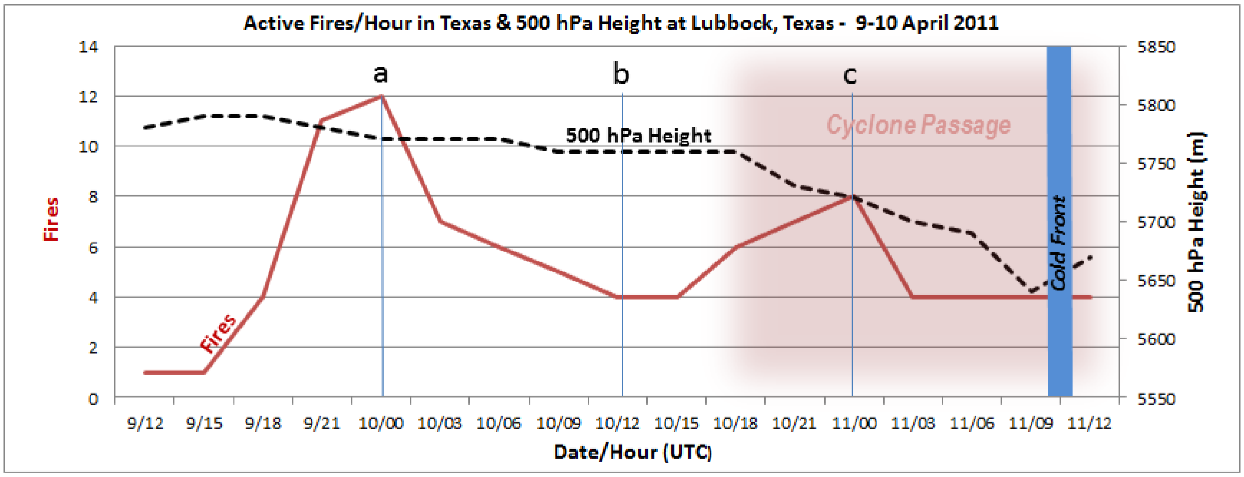
b. 9-10 April 2011

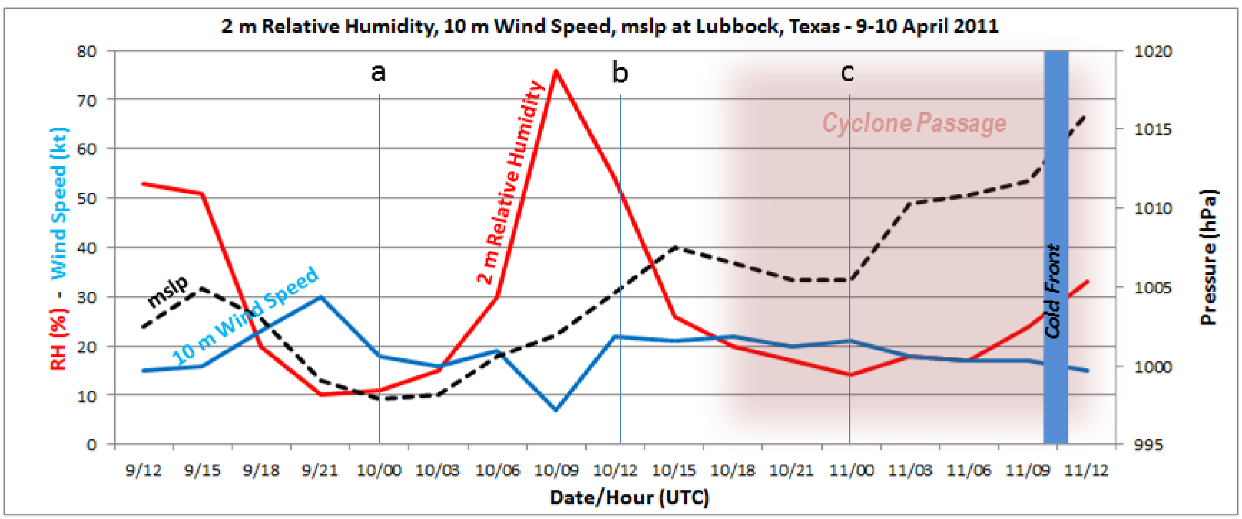
On 9-10 April 2011 another 'firestorm' erupted across the Southern Plains. A majority of these wildfires occurred in west Texas. The evolution of this outbreak, which featured a bi-modal multi-day peak of wildfire activity and maximum fire occurrence in advance of the parent mid-latitude cyclone, deviated from past extreme fire episodes in the region. Previous such outbreaks had only been observed to be characterized by a single and abrupt peak of activity during a parent cyclone passage.

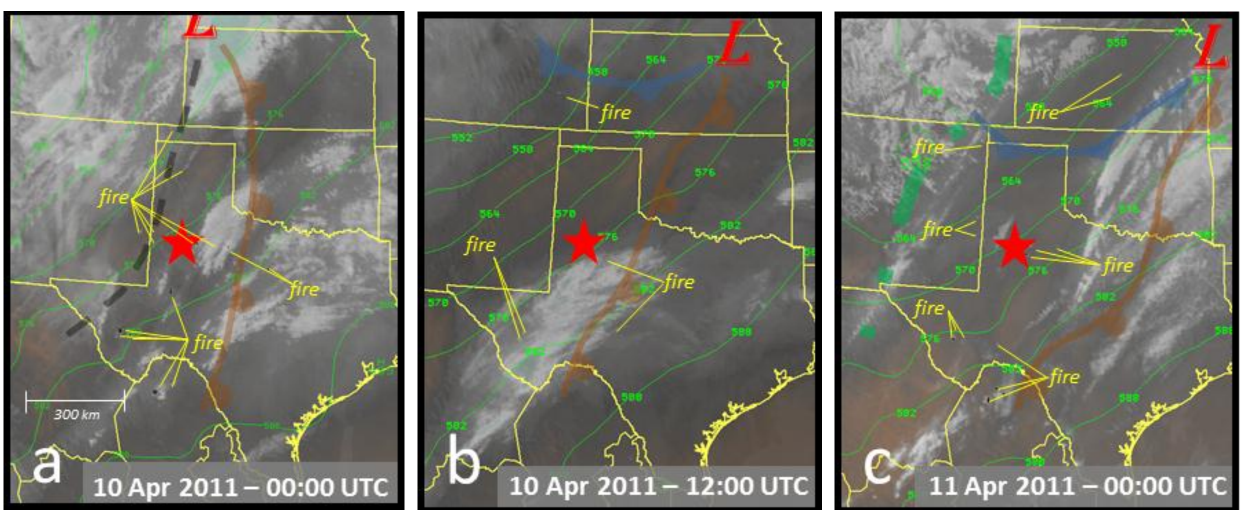
The onset of the 9-10 April 'firestorm' occurred as southwesterly wind fields increased in advance of an upper air trough over the Desert Southwest late on 9 April. This resulted in the deepening of a surface trough over eastern New Mexico and west Texas which further promoted downslope winds and associated warming and drying of the low-level atmosphere. A broad and pronounced low-tropospheric thermal ridge developed over west Texas late on the 9th. Pressure falls along the surface trough, deep diurnal mixing in proximity to the thermal ridge, and increasing winds aloft in advance of the parent upper air trough resulted in extremely critical fire weather characterized by 2 m relative humidities near 10 percent and sustained 10 m winds near 30 kt (15 m/s) between 9/1800 UTC and 10/0000 UTC. These conditions supported a peak in wildfire activity across the region by 10/0000 UTC, which included extreme growth of at least one pre-existing fire as well as the emergence of numerous wildfire starts.

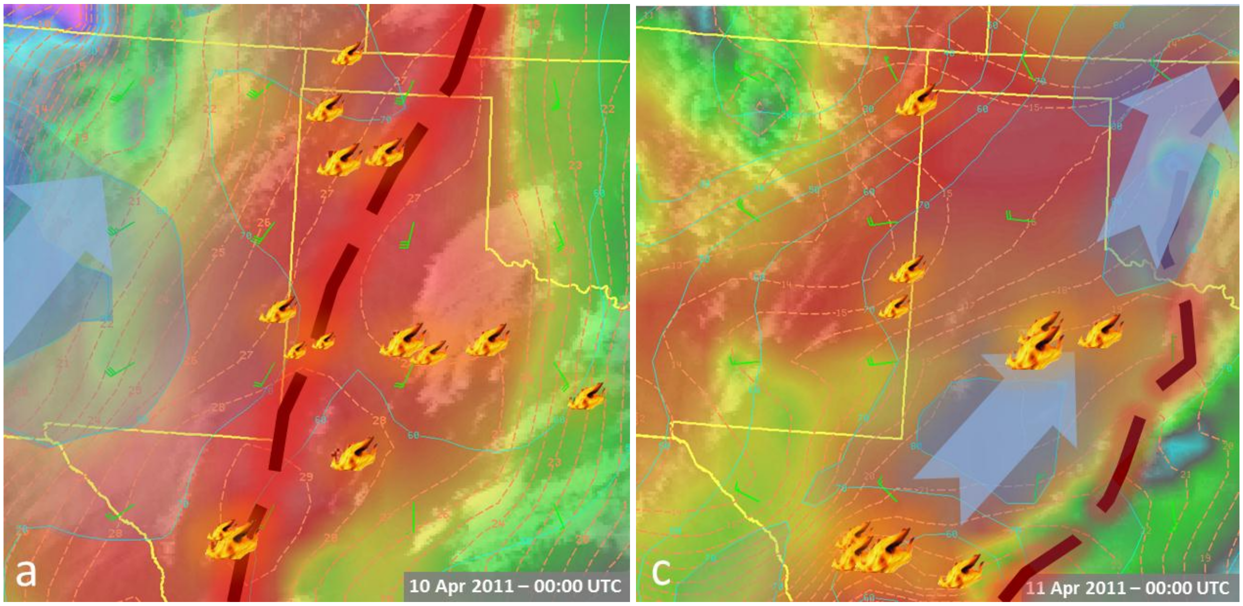
With the parent mid-latitude cyclone located west of the Southern Rockies, continued and gradual height falls throughout the night supported a westward retreat of the surface dryline and brought overnight relative humidity recoveries of 70 to 80 percent to portions of the outbreak area by 10/1200 UTC. Such nocturnal relative humidity recoveries typically limit the following diurnal burn period and lessen the likelihood of new wildfire starts due to pre-conditioning and moistening of fine grassland fuels (Lindley et al. 2011). Despite these recoveries, however, renewed critical fire weather with 2 m relative humidity values ≤ 15 percent and sustained 10 m winds ≥ 20 kt (11 m/s) associated with the ejection of the mid-latitude cyclone over the Southern Rockies and Plains resulted in a secondary peak in wildfire occurrence between approximately 10/1800 UTC and 11/0300 UTC.

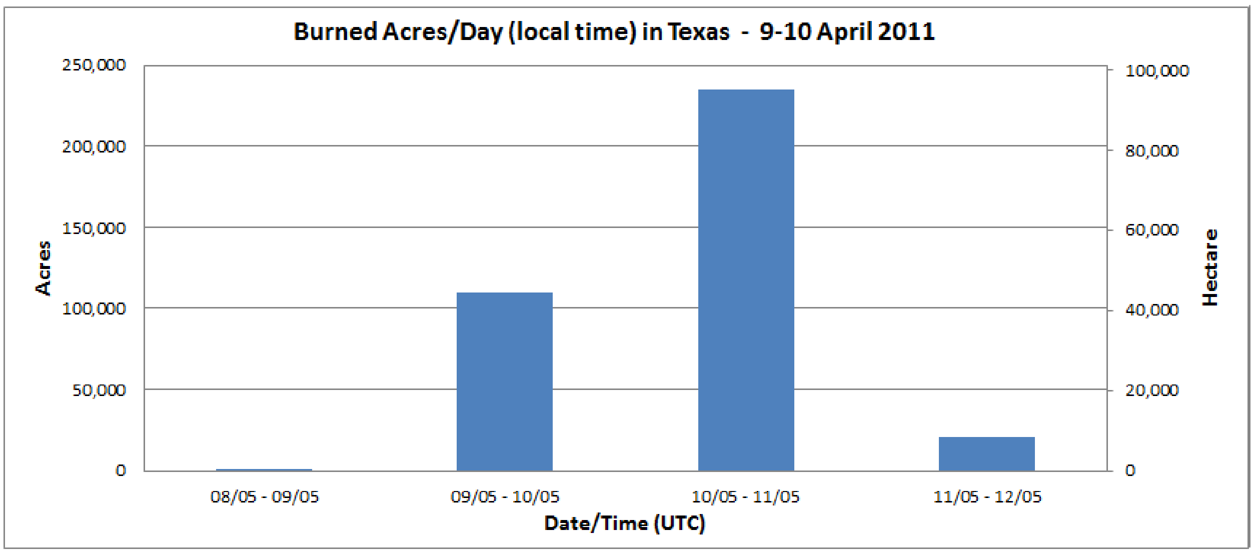
Although the number of wildfires during the diurnal burning period of 9 April exceeded that observed on 10 April, the burned area in Texas on 9 April was less than on 10 April (110,226 acres or 44,607 ha as compared to 234,690 acres or 94,976 ha). It appears that the effects of a renewed onset of critical fire weather conditions late on 10 April was sufficient to support extreme growth of four ongoing very large fire complexes, some of which were carry-overs from the previous day. The spread of these fires combined with the relatively fewer, yet still significant number of new wildfires to contribute to the high burn area observed on the 10 April. It is also noted that the peak in area burned occurred in the warm/dry sector of an approaching mid-latitude cyclone during its imminent passage as mid-level wind maxima overspread a low-level thermal axis, and correlated to a large scale weather pattern that approximated the Southern Plains wildfire outbreak composite.


Active Fires/Hour in Texas & 500 hPa Height at Lubbock, Texas - 9-10 April 2011
Fires
500 hPa Height (m)
500 hPa Height
Cyclone Passage
Cold Front
a
b
c
Date/Hour (UTC)
9/12 9/15 9/18 9/21 10/00 10/03 10/06 10/09 10/12 10/15 10/18 10/21 11/00 11/03 11/06 11/09 11/12


2 m Relative Humidity, 10 m Wind Speed, mslp at Lubbock, Texas - 9-10 April 2011
RH (%) - Wind Speed (kt)
Pressure (hPa)
mslp
10 m Wind Speed
2 m Relative Humidity
Cyclone Passage
Cold Front
a
b
c
Date/Hour (UTC)
9/12 9/15 9/18 9/21 10/00 10/03 10/06 10/09 10/12 10/15 10/18 10/21 11/00 11/03 11/06 11/09 11/12

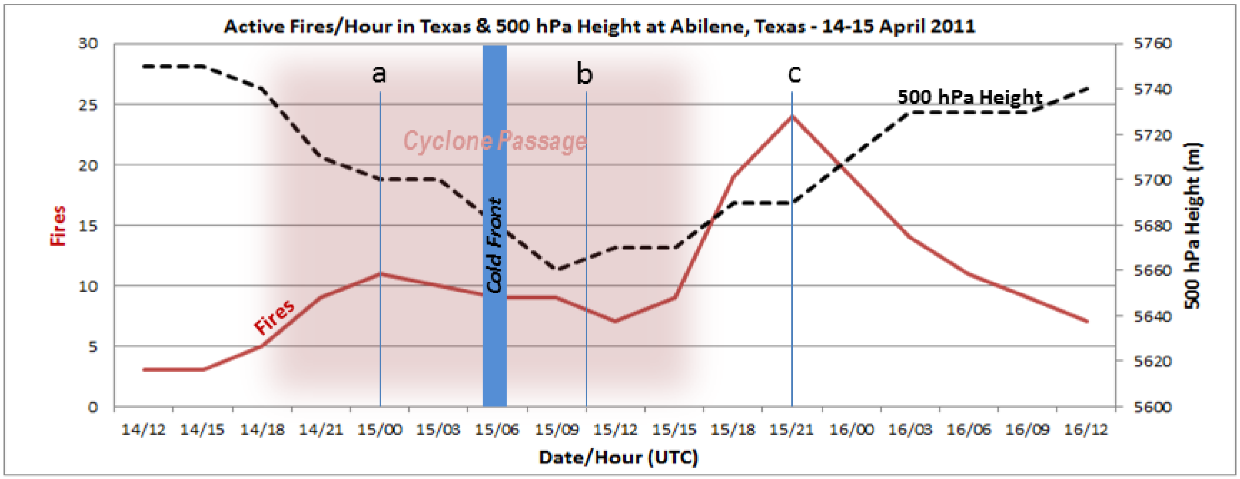

a
10 Apr 2011 – 00:00 UTC
300 km
fire
b
10 Apr 2011 – 12:00 UTC
c
11 Apr 2011 – 00:00 UTC

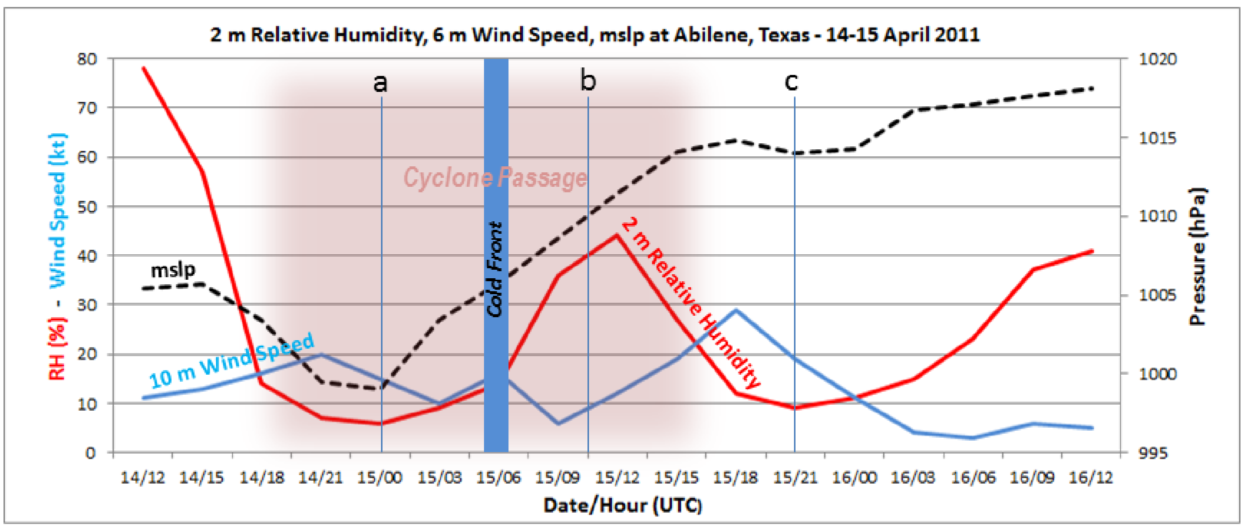


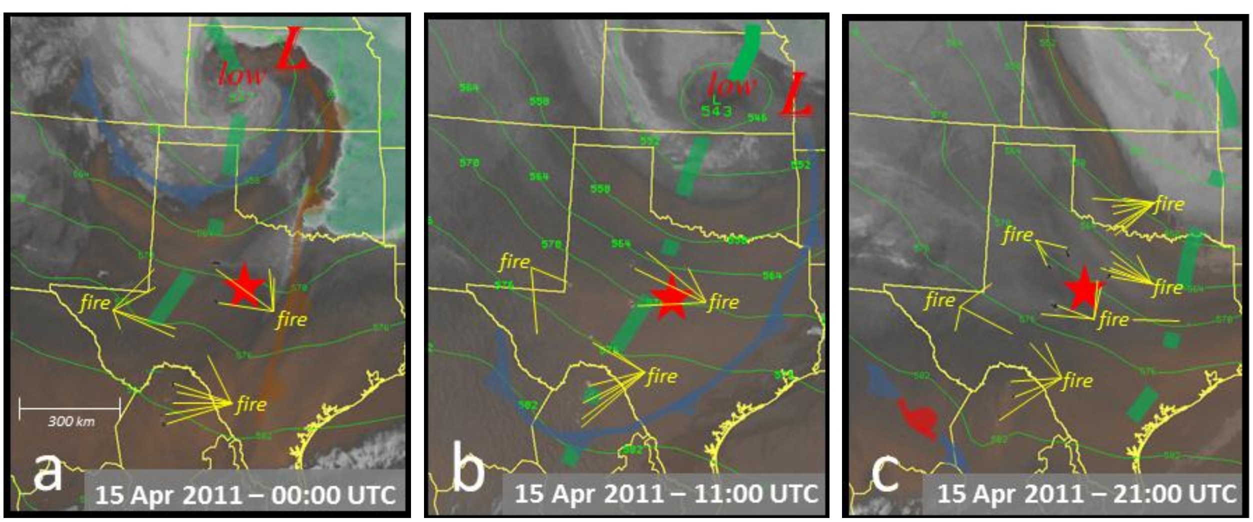


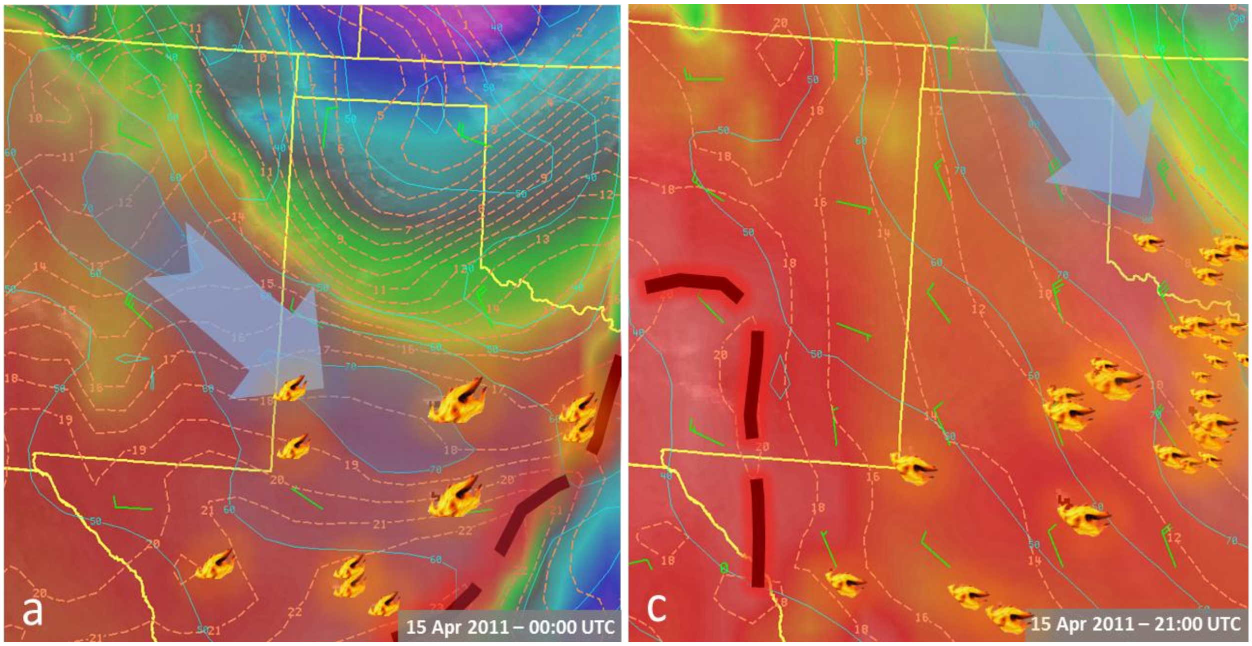
c. 14-15 April 2011

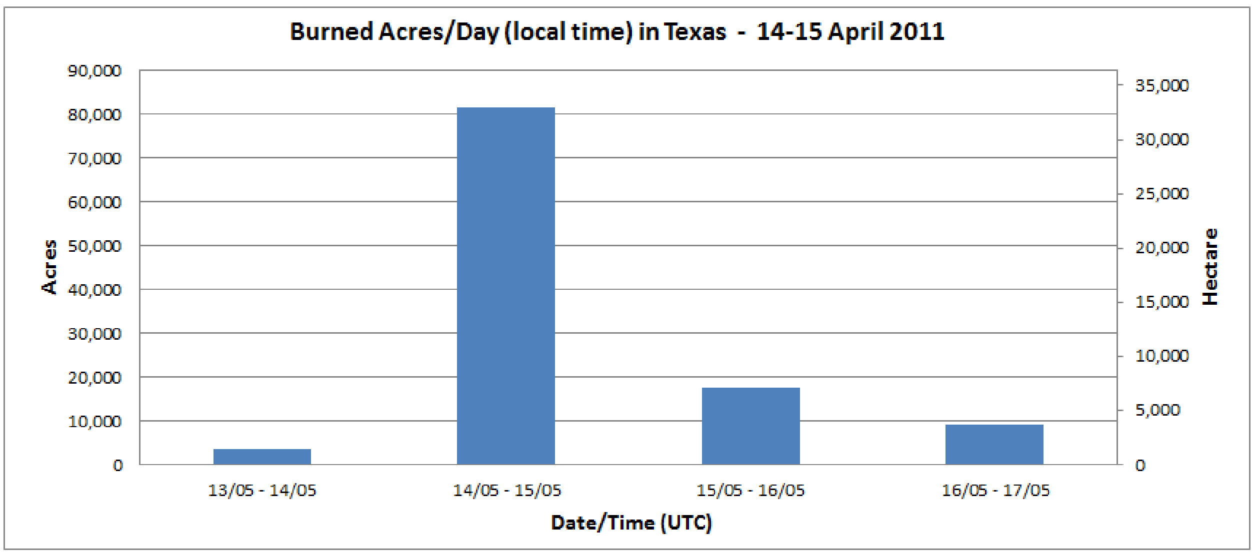
The 14-15 April 2011 Texas 'firestorm' also deviated from the conceptual model for Southern Plains wildfire outbreaks. A bi-modal peak in fire activity was again observed, but the number of fires was maximized in the wake of the parent mid-latitude cyclone. A deeply cutoff mid-latitude cyclone (closed 5470 m height low at 500 hPa) ejected over the Southern Plains between approximately 14/1900 UTC and 15/1500 UTC. The synoptic pattern during the local afternoon and evening hours of 14 April closely resembled the Southern Plains wildfire outbreak composite. Numerous wildfires developed and pre-existing long-lived fires exhibited extreme rates of spread as diurnal relative humidity minima below 10 percent combined with sustained winds over 20 kt (11 m/s) in association with the cyclone passage late on 14 April and early on 15 April. The mid-latitude cyclone was slow to eject well east of the Southern Plains, however, and 500 hPa heights deepened to 5430 m within the center of the cutoff mid-level low over Kansas by 15/1100 UTC. The proximity of the parent cyclone and its associated wind fields resulted in a secondary peak in wildfire occurrence over west-central and western-north Texas as daytime relative humidities dropped to near 10 percent and winds increased to between 20 kt (11 m/s) and 30 kt (15 m/s) in the post-frontal environment from 15/1600 UTC to 16/0000 UTC. Although the number of active fires in Texas peaked during the secondary period of post-frontal critical fire weather behind the slowly departing cyclone, the area burned by fire once again peaked during the composite-like pattern on 14 April when a mid-tropospheric wind max overspread a pronounced low-tropospheric thermal ridge.











4. VEGETATIVE FUELS

A high degree of precipitation variability with excessive rainfall during the summer growing season of 2010 followed by the onset of a strong La Nińa episode and associated deepening Southern Plains drought in late 2010/early 2011, primed vegetative fuel conditions for an increased wildfire risk across the region (Van Speybroeck et al. 2011). In order to examine the state of biofuels at the time of the 2011 Texas 'firestorms', the Energy Release Component (ERC) is utilized.

ERC is a quantity directly related to the total energy (BTU) per unit area of biofuel, or potential "heat release" available for burning in the flaming zone of a head fire for a specific fuel model (Bradshaw et al. 1983). Variables of ERC include fuel loading as well as a composite of live and dead large fuel moistures. The ERC is a cumulative index, and applies values from each of the previous seven days to successive calculations. Thus, the effects of day-to-day weather and fuel loading build over time as live fuels cure and as dead fuels dry. Therefore, ERC has low variability and is an excellent indicator of intermediate to long-term drying and potential fire behavior.

The daily ERC value (fuel model G) averaged from observations in proximity to five west Texas cities (Abilene, Amarillo, Childress, Lubbock and Midland) is plotted relative to climatological maxima, minima, and mean values for a period spanning January 2000 through July 2011 in Figure 5. Occurrences of Southern Plains wildfire outbreaks are additionally shown in relation to ERC, as is the typical growing season. The data show that the observed ERC was near climatological record maximum values across west Texas by late spring and early summer 2011. This suggests that prolonged curing and drying of extreme fuel loads was widespread. At the time of the 27-28 February wildfire outbreak, the average observed ERC across west Texas was 54. This compares to the region's lowest observed ERC associated with a Southern Plains wildfire outbreak of 51 on 6 April 2006. By the time of the April 2011 'firestorms', however, ERC values across west Texas had increased to an average of 68 on 10 April and 73 on 15 April. These values matched or exceeded the highest observed ERC across west Texas associated with past Southern Plains wildfire outbreaks (since 2005) which was 68 on 12 January 2006. It is hypothesized that the volatile state of vegetative fuels enhanced the ambient fire danger and thus magnified the relative severity of fire weather within the pre- and post-cyclone environments sufficiently to prolong 'firestorm' conditions during the 9-10 April and 14-15 April events in a manner not previously observed.

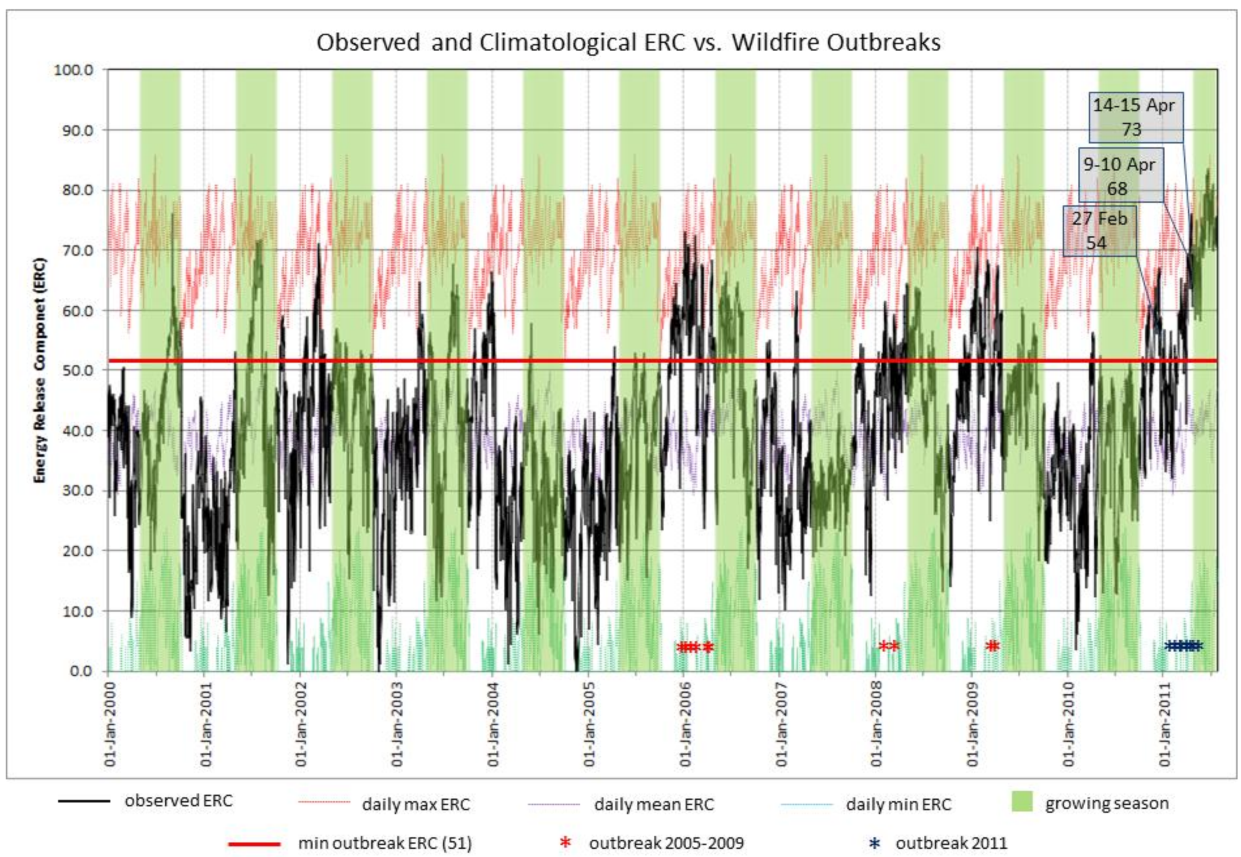


Figure 5: *Daily average observed ERC in west Texas January 2000-June 2011 with reference to past Southern Plains wildfire outbreaks and the 2011 Texas 'firestorms' highlighted.*

5. CONCLUSIONS

During the historic 2011 Texas drought and fire season, the state was the epicenter of three particularly destructive Southern Plains wildfire outbreaks coined by TFS officials as 'Texas firestorms'. These wildfire outbreaks, which occurred on 27-28 February, 9-10 April, and 14-15 April, were characterized by dozens of wind-driven grassland wildfires that engulfed 100,000s of acres (> 40,469 ha) and caused extensive property damage and the loss of human life. The evolution of the 27-28 February Texas 'firestorm' resembled that of ten previous Southern Plains wildfire outbreaks observed between 2005 and 2009 and generally matched a meteorological composite of mean atmospheric fields derived from the past outbreak events. Both the 27-28 February outbreak and all of the later fire episodes occurred within a strikingly similar synoptic-scale weather pattern that supported an abrupt diurnal peak in wildfire activity associated with the warm/dry sector of passing mid-latitude cyclones and accompanying wind maxima atop drought-stricken biofuels west of a surface dryline and south of an advancing cold front. The most intense fire activity during the 27-28 February outbreak occurred as strong mid-tropospheric winds overspread a low-level thermal ridge.

The April 2011 'Texas firestorms', however, differed from this conceptual model. During the 9-10 and 14-15 April outbreaks, wildfire activity peaked during 1) the initial infringement of strong wind fields upon low-level thermal ridging in advance of an approaching cyclone and 2) within the post-frontal environment immediately following the passage of a mid-latitude cyclone respectively. In addition, extreme wildland fire conditions were prolonged throughout a multi-day period of 36 h to 42 h when the influence of the parent cyclone remained sufficient to support favorable combinations of relative humidity and wind atop extremely critical fuels prior to, during, and following its passage. It is hypothesized that the extreme dryness of vegetative fuels during the April 'firestorms', characterized by near climatological record high observed ERC values of 68 and 73 for the respective events, contributed to each weather system's effectiveness in driving protracted extreme fire conditions. Although the evolution of these 'firestorms' deviated temporally from the existing conceptual model provided by the Southern Plains wildfire outbreak composite with maxima in wildfire occurrence in advance of the 10 April cyclone and in the wake of the 14 April cyclone passage, peaks in the total area burned per day throughout the 'firestorms' suggests that more intense fire growth and spread indeed occurred in association with the actual cyclone passages over the Southern Plains.

These preliminary meteorological analyses of the 2011 'Texas firestorms' indicate that the previously documented Southern Plains wildfire outbreak composite serves as a valid tool for pattern-recognition of synoptic scale weather systems that pose an enhanced fire weather threat and in identifying the peak burn periods associated with such features. It is recommended, however, that fire weather forecasters additionally utilize ingredient-based forecast methods to further determine the fire threat both prior to and immediately following the passage of mid-latitude cyclones, especially during periods of unusually dense and dry vegetation.

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