The Northwest California Lightning Event of June 20-21, 2008

Mark A. Burger
WFO Eureka, California
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Introduction

A highly anomalous outbreak of thunderstorms, notable both for its magnitude as well as for its unseasonable character, brought over 6,000 lightning strikes to California over a two-day period. Antecedent conditions were highly receptive for fire starts and subsequent growth: an unusually dry spring resulted in early curing of finer vegetation while larger fuels were already moisture-deficient due to chronic drought across most of the state. By the conclusion of the second day following the event, 602 separate fire starts attributable to lightning were detected or located in the U.S. Forest Service's northern California Geographic Area Coordination Center (GACC) region. However, a wholly accurate assessment is impossible due to numerous small fires combining into larger ones and initially undetected fires eventually becoming identified in the following days and weeks. In extreme northwest California, the counties of Del Norte, Humboldt, Trinity, and Mendocino, which comprise the Eureka forecast office County Warning and Forecast Area (CWFA), recorded most of their lightning during the late afternoon of June 20 through the morning hours of June 21, with approximately 1,500 strikes. This event has been called "one of the most severe wild land fire situations ever experienced in California's history," quite a remarkable feat given the state's propensity for fire (Overview). Over 25,000 firefighting personnel were stationed in northern California at the height of fire activity, with resource commitments totaling many hundreds of millions of dollars (an estimated $294 million in the Eureka CWFA alone), not including timber and structure losses. 12 firefighters also lost their lives in the Eureka CWFA in connection with the suppression of these fires. The following manuscript is not an attempt to rigorously define this event, but rather to provide forecasters with points of consideration for subsequent events to enhance situational awareness and decision-making.

Meteorology Primer

a. **Moisture.** Broad southwest flow aloft prevailed over northern California the morning preceding the lightning event as indicated in Figure 1. This synoptic regime is typically associated with dry and stable weather, especially during the late spring and early summer when mid-level moisture in association with the Southwest United States monsoon is absent. However, inspection of water vapor imagery in Figure 2 reveals embedded tropical moisture already in place across northern California extending southwest to Hawaii at 1215 UTC. In fact, satellite observations confirm that some of this moisture originated from a complex of convection near the International Dateline several days earlier.

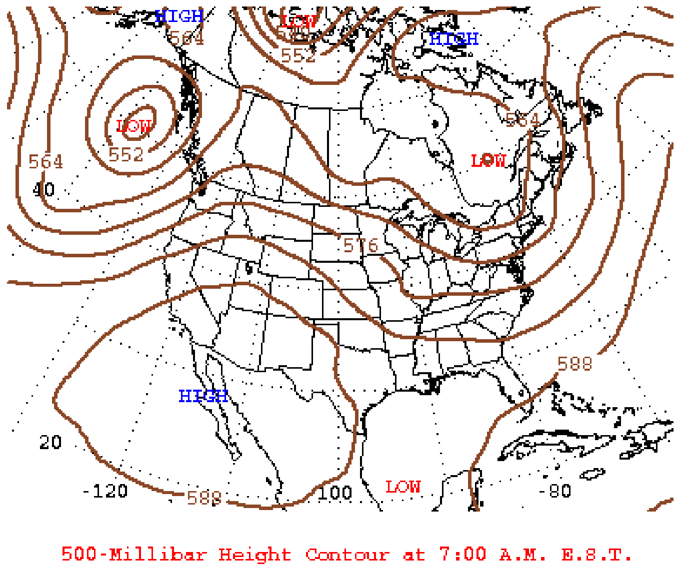

Figure 1. 500 mb height analysis for the morning of June 20. Courtesy NCEP.

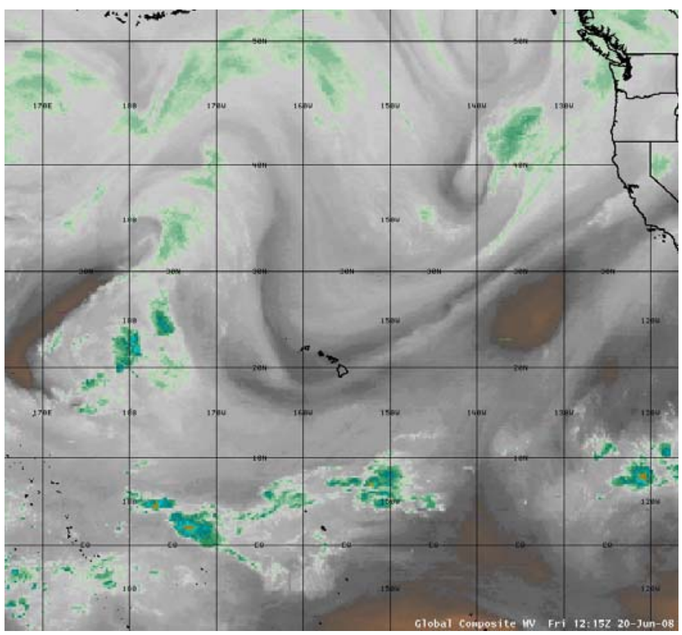

Figure 2. Water vapor imagery from 1215 UTC June 20.

Elevated moisture was noted per the 12 UTC Oakland, California rawinsonde launch, with a precipitable water value of 0.84 inch. Given the time of year, this level is slightly above the 75th percentile of their historical (1948-2006) record. The concurrent sounding at Medford, Oregon registered only 0.64 inch of precipitable water, which falls just under the 50th percentile of the their historical record. It is apparent that neither of these values is particularly remarkable, at least in the hours well before convection initiated over land.

b. Instability and Capping. Satellite and National Lightning Detection Network (NLDN) observations showed areas of convection accompanied by occasional lightning strikes several hundred miles off the central California coast during the evening preceding the northwest California lightning event, thus indicative of significant air mass instability. The Storm Prediction Center (SPC) also noted the presence of offshore lightning in their 0611 UTC (2311 PDT June 19) Day 1 Fire Weather Outlook. Six hours later, the 12 UTC soundings across the region supported a destabilizing air mass. Comparing the two soundings, instability was superficially more pronounced at Medford, shown in Figure 3, mainly owing to the absence of the Oakland's marine layer. A surface-based lifted index of -2.5 C was observed at Medford, accompanied by CAPE of 458 J/kg and only 54 J/kg of CIN; a shallow mid-layer cap was also evident at around 675 mb. Although Oakland's sounding revealed a surface-based lifted index of -0.6 C, CAPE of 52 J/kg was completely offset by 139 J/kg of CIN. However, there was no cap aloft at Oakland, and recall column moisture was greater and above average for the time of year. Thus, three preconditions for thunderstorm development: moisture, instability, and little or no capping, were present to varying degrees across the region early on the morning of June 20.

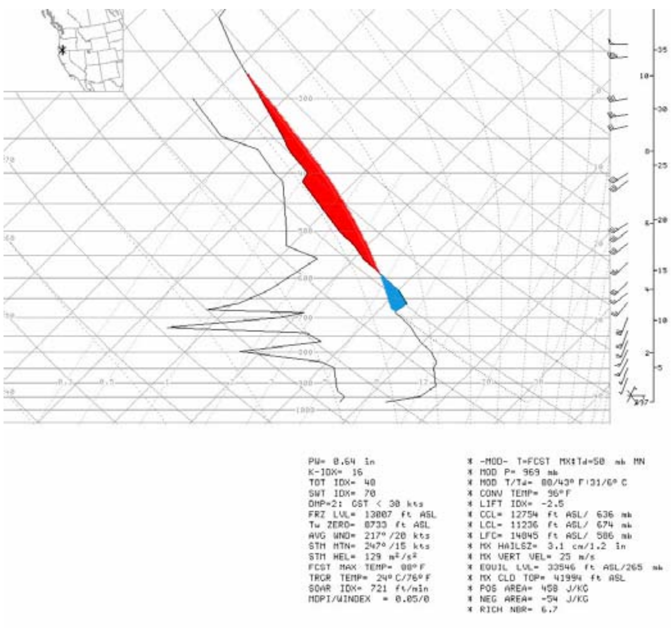

Figure 3. Medford sounding from 12 UTC June 20. The red area represents CAPE while the blue area represents CIN.

c. Lift. Several embedded impulses along with the particularly obvious shortwave can be seen on early morning water vapor imagery (Figure 2) either rotating around the base of the offshore trough or being ejected eastward. As SPC noted in their previously referenced Outlook, "these waves should move onshore at peak heating" and "lightning strikes will be capable of starting additional fires." Also evident on satellite imagery is the broad area of upper level diffluence developing offshore east of the lead shortwave, which is often a factor in convective outbreaks across northwest California during more typical monsoon events later in the summer.

In summation, all ingredients required for thunderstorm development were present to some extent the morning preceding the lightning event.

d. **Synoptic Discussion and Surface Parameters.** Strong upper level ridging which had been present over California earlier in the week was beginning to break down in response to the encroaching offshore trough. However, surface high temperatures were still 5 to 10 F above normal for most inland locations across northwest California and southern Oregon during the afternoon of June 20, with readings of 99 F at Ukiah and 92 F at Medford. Low level offshore flow resulted in coastal temperatures well above normal, with both Oakland and San Francisco International Airport reaching 97 F; a high of 71 F was achieved at the Arcata/Eureka airport. Downtown San Francisco even set a record maximum low temperature of 61 F the morning of June 20. Some increase in surface dew points were noted over the previous 24 hours, but overall, afternoon relative humidity remained seasonally dry.

Event Description

a. **June 20 through Onset.** Altocumulus castellanus (ACCAS) was noted by the author shortly after sunrise while on location some 135 miles southeast of Eureka; this field expanded north through the morning and early afternoon. In fact, some ACCAS was also noted over the state as early as the afternoon of June 19. Although such observations are often a harbinger of convective weather in most parts of the country, the presence of ACCAS in California is extremely rare, owing to the typically stable atmospheric mid-levels. By 21 UTC, visible satellite imagery over northwest California indicated that high-based cumulus were becoming more extensive and beginning to tower as shown in Figure 4. Two and a half hours later, estimated cloud tops were approaching 30,000 feet MSL (Figure 5), with the first recorded lightning strike occurring at 2322 UTC. The Eureka WSR-88D (KBHX) base and composite reflectivity from this approximate time are shown in Figures 6 and 7, respectively. Both images were presented to underscore the differences in interpreting these data.

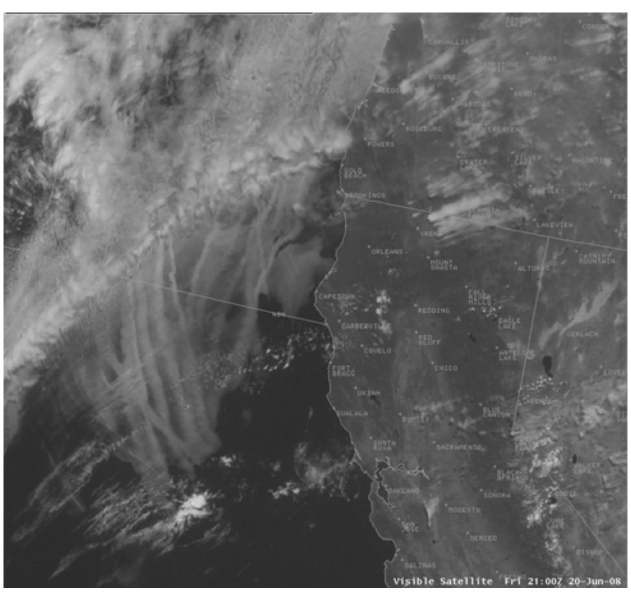

Figure 4. Visible satellite imagery at 2100 UTC.

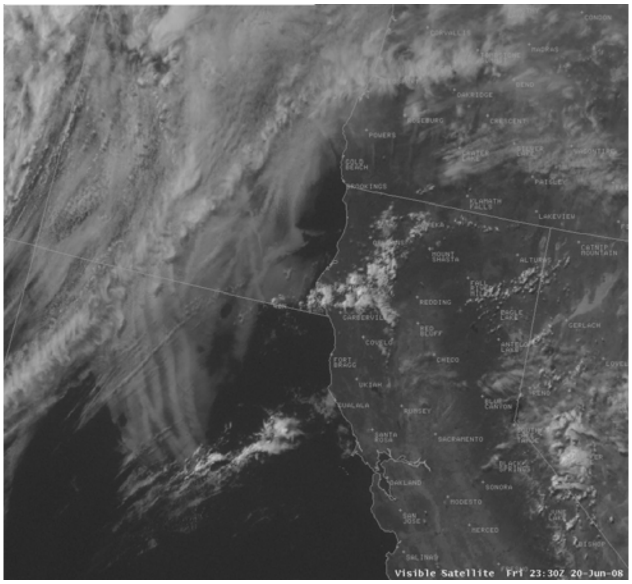

Figure 5. Visible satellite imagery at 2330 UTC.

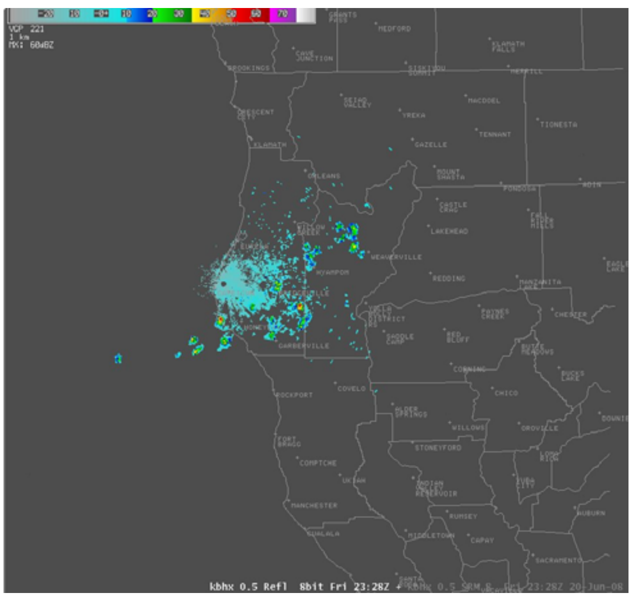

Figure 6. KBHX base reflectivity at 2328 UTC.

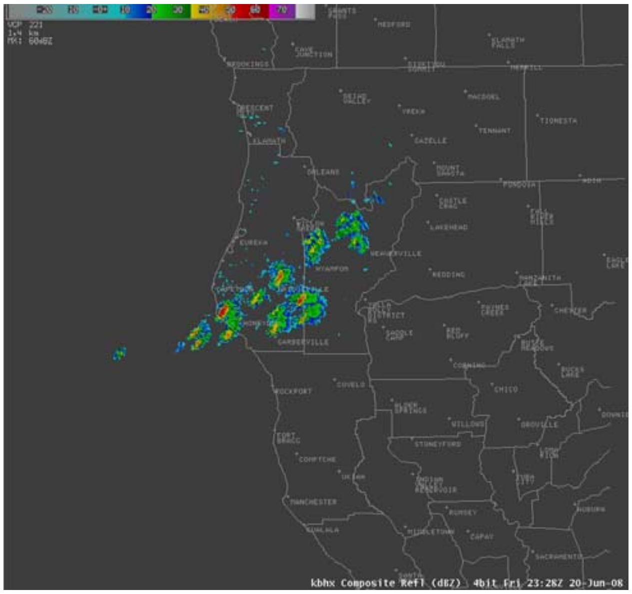

Figure 7. KBHX composite reflectivity at 2328 UTC.

b. **Onset through 0500 UTC June 21.** Over the course of the next couple of hours, isolated thunderstorms became scattered to numerous and also increased in intensity, with maximum cell reflectivity at KBHX reaching 62 dBZ. KBHX-derived echo tops were consistently between 35,000 and 40,000 feet MSL, with radar data indicating the highest tops at around 43,000 feet MSL. This clearly breached the equilibrium and cap levels on the 12Z Medford sounding. Figure 8 illustrates the relative peak in convective activity, which occurred between 0300 and 0400 UTC. Over the course of the next couple of hours, storm intensity and activity gradually waned.

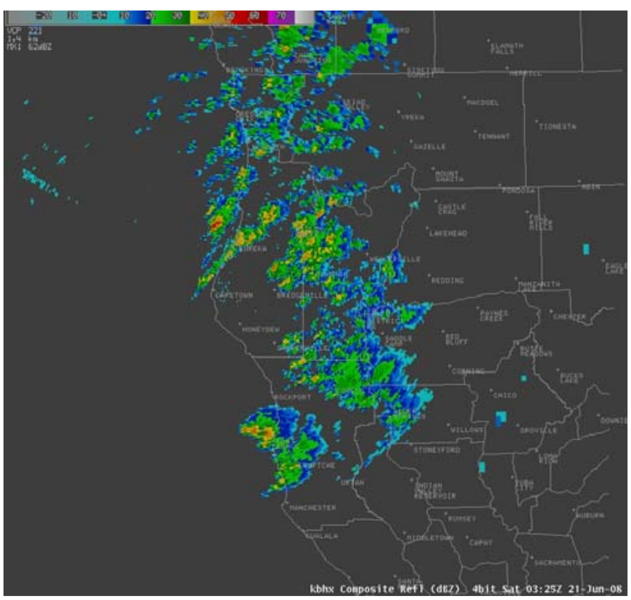

Figure 8. KBHX composite reflectivity at 0325 UTC June 21.

c. **0500 UTC through Daybreak.** Showers and thunderstorms regenerated as the night progressed, with a noticeable increase in initial development along the coast shortly before 0600 UTC as a secondary shortwave approached the area. These broken lines of thunderstorms moved northeast and expanded (see Figure 9) while new convective development occurred over inland areas through the night. Most thunderstorm activity shifted east out of the CWFA within a few hours after sunrise.

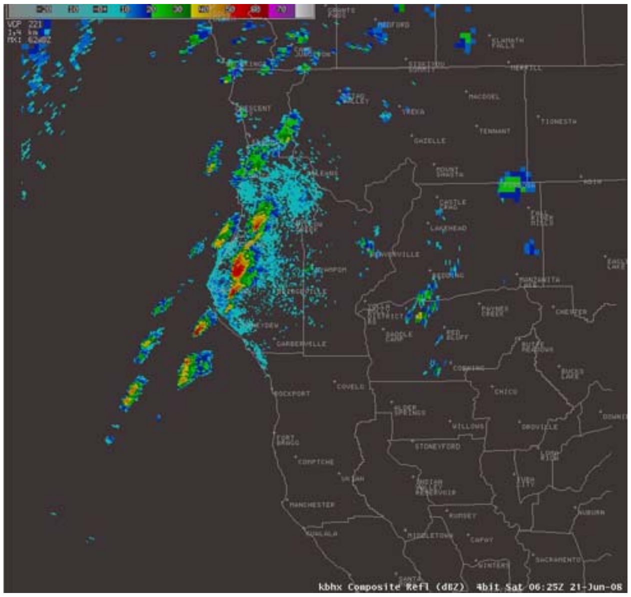

Figure 9. KBHX composite reflectivity at 0625 UTC June 21.

Forecasting Considerations

a. **Observational Precursors.** Aside from the normal preconditions for thunderstorms discussed earlier, what mechanisms turned what may have been an ordinary event into an extraordinary one? A review of the data and consultation with the SPC regarding this specific event strongly suggest that the numerical forecast models greatly understated atmospheric instability. However, it appears mid and upper level moisture fields were more accurately depicted among the models. There were, however, a number of observational cues to suggest in advance that an unorthodox event was a possibility:

1. *Lightning offshore many hours before commencing over land*
2. *Widespread ACCAS cloud field observed the morning of the event*
3. *Two moisture sources…Hawaii and offshore Baja California*
4. *Strong upper level diffluence and unseasonably strong jet*

The latter two points have only been partially illustrated thus far through the brief description in the Meteorology Primer. However, the presentation of Figure 10 adds further insight to the synoptic pattern with respect to moisture availability.

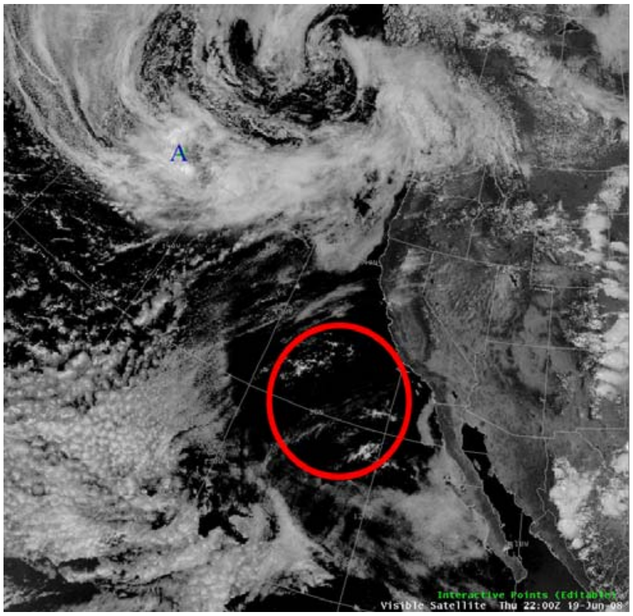

Figure 10. Visible satellite imagery from 22 UTC June 19.

Over 24 hours before the eruption of thunderstorms across northwest California, visible satellite imagery confirms the presence of developing convection near point A as indicated in Figure 10. This area represents an early look at the consequences of the moisture tap from Hawaii presented in Figure 2. Additionally, the cloudiness within the circled area offshore the California-Baja California coast suggests lower mid-level stability. The moisture associated with this cloudiness not only originated from the southwest flow but also involved recycled moisture from the southeast. With visual indicators of copious moisture and conditional stability, it is foremost to question why the forecast models fell short in their portrayal of this event from the outset; the area near point A seems an appropriate place to begin this analysis given the highly unusual development of convection over the open ocean. Figure 11 indicates that the area near point A was, at the time, experiencing highly anomalous sea surface temperatures between 3 and 5 C above the seasonal normal. This pattern persisted for several weeks before and after the event.

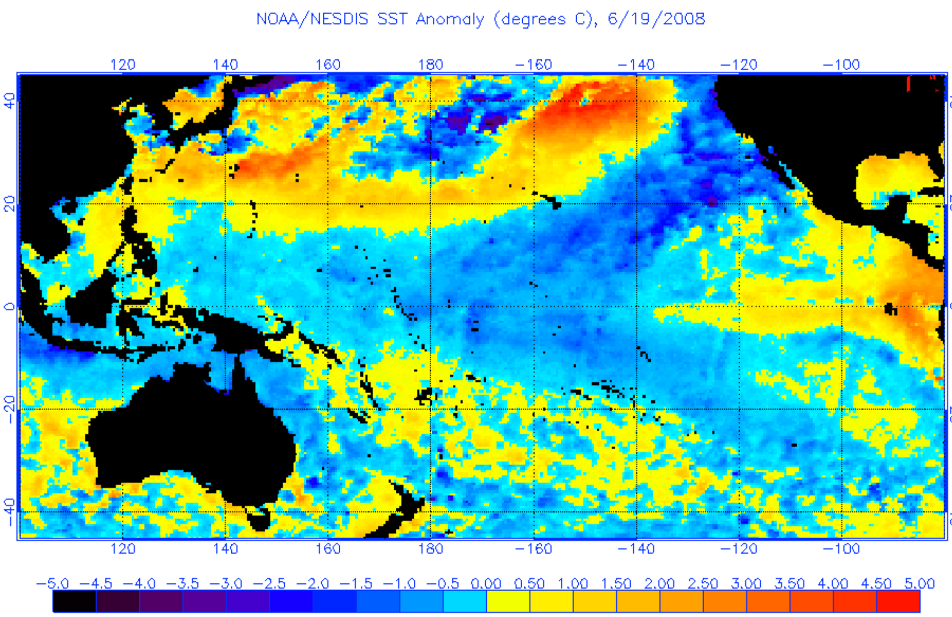

Figure 11. Sea surface temperature anomaly (C) on June 19.

With such a strong surface temperature anomaly, and the obvious impacts it would have on the temperature and moisture profile of the lower atmosphere, did the models accurately initialize these conditions? Ship reports confirm surface atmospheric temperatures in the middle to upper 60s F in this area during the afternoon of June 19. Using point A from Figure 10 as a proxy for GFS model rendition of modeled atmospheric variables, it appears surface temperatures were initialized around 6 F too cool compared to observations. Despite this, the cooler, unmodified sounding, shown in Figure 12, still sported 116 J/kg of CAPE offset by 4 J/kg CIN. By raising the surface temperature to 66 F, a reading backed by observations, and modifying only the temperature sounding for the lowest 75 mb to ensure reasonable representation of low level lapse rates, CAPE climbed to 535 J/kg with no CIN. Surface-based lifted index fell from 0.3 C in the unmodified sounding to -1.4 C once modified.

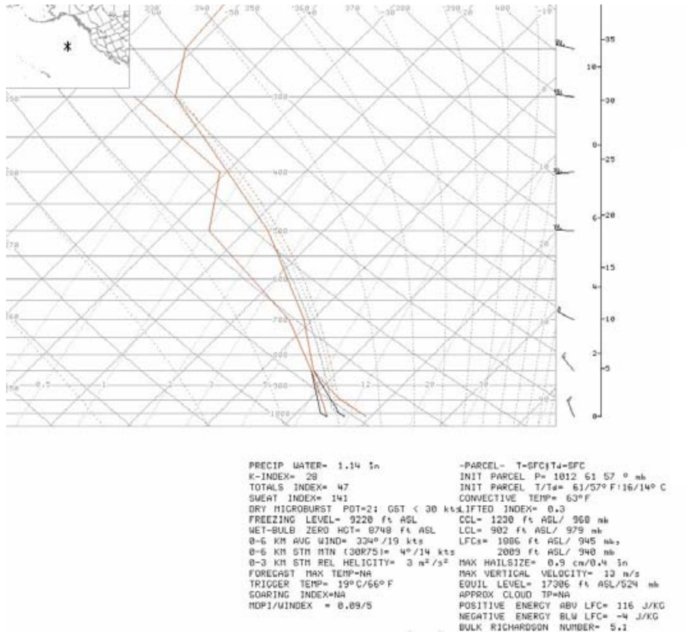

Figure 12. GFS model sounding for 00 UTC June 20 at point A from Figure 10. Lines colored black represent original data that were subsequently modified (red colored) to reflect surface observations.

Thus, it seems likely that at least some of the poor model performance with this event can be attributed to underestimation of sea surface temperature and the subsequent impacts on destabilization of the overlying air mass in the developing area of the surface cyclone. Additionally, moisture and instability sources aloft were more varied and mature than were likely accounted for in the modeled guidance.

In consideration of item 4 referenced earlier in this section, Figure 13 shows the water vapor imagery around the time convection was beginning to develop across northwest California. While the plume of mid and upper-level moisture present to the south and southwest is obvious, as is the upper level diffluence across northwest California, brightening associated with enhanced lift from the left front quadrant of a jet streak can also be seen nosing into the region (represented by the upper portion of A). This jet was well initialized by the GFS model and corroborated by GOES high density winds. Although this secondary jet was not nearly as strong as the upper level jet in association with the primary shortwave well to the west, maximum speeds at 200 mb were still around 75 knots, which is quite high given the time of year. Convection rapidly developed across northwest California as this jet streak impinged on the coast during the late afternoon hours of June 20.

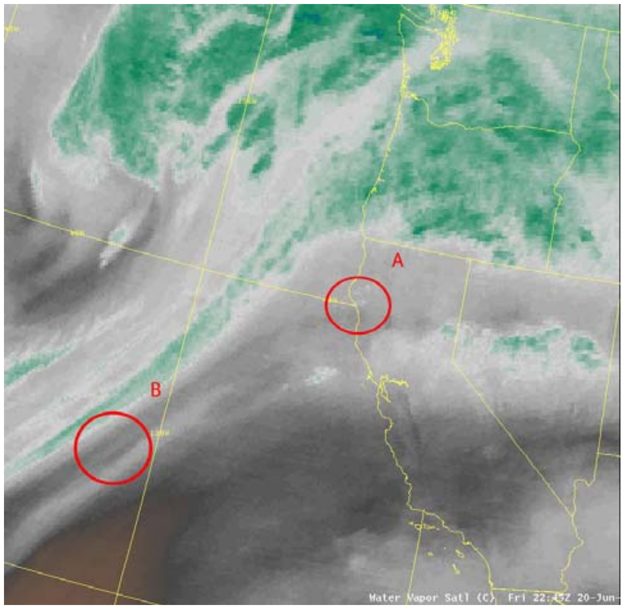

Figure 13. Water vapor imagery at 2245 UTC showing upper level jet and circulations.

Closer inspection of Figure 13 also reveals a weak shortwave downstream (represented by B). The arrival of this feature appeared significant in regenerating convection after 0500 UTC June 21 across northwest California. It appears plausible that cooling of the mid-levels due to cloud evaporative processes from the afternoon convection helped to steepen mid-layer lapse rates further during the evening. As shortwave B approached the coast later during the night, the associated ageostrophic circulations provided the trigger to induce additional convection. Although during a rapidly evolving situation the shortwave at B may have been overlooked and/or its potential impacts miscalculated, the identification and understanding of probable impacts of such subtle waves in an environment already primed for convection is key to nowcasting the event and issuing updates and/or warnings to land management agencies.

b. Model Data. As discussed earlier, model performance was less than optimal in the presentation of convective parameters associated with this lightning event. However, just as the case with observational data, there were a few indications in the forecast data that suggested the potential for a significant convective event. The model data from the images that follow were all from the 18 UTC GFS suite, although analysis of the 06 and 12 UTC runs from earlier in the day were quite similar.

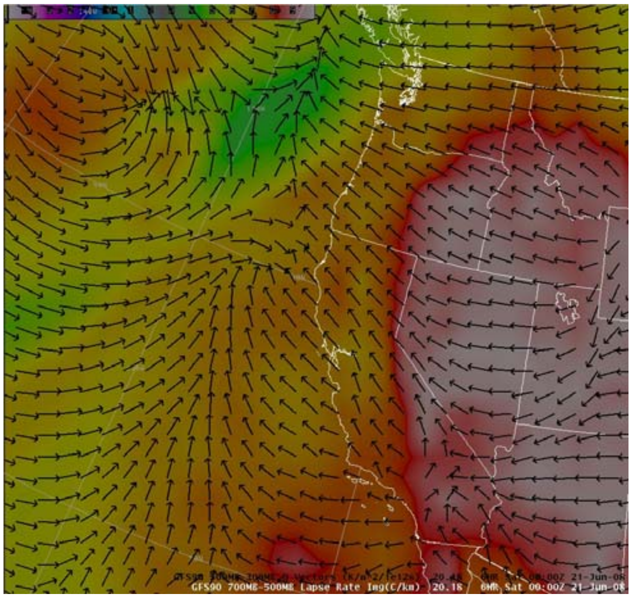

Figure 14. GFS 700-500 mb lapse rates (image) and 500-300 mb Q-vectors for 00 UTC June 21.

Figure 14 confirms the GFS was indicating large scale mid-layer lapse rates around 7.5 C/km, implying conditionally unstable atmospheric conditions. Although the steepest mid-layer lapse rates lie to the east of northwest California, strong upper level Q-vector convergence is noted just to the west. Thus, although the Eureka CWFA is not in the greatest concern area for either one of these parameters, it is in the overlap area that takes advantage of large values of each parameter. Even though modeled surface-based and elevated CAPE seemed low, conditional mid-layer instability and synoptic upper level forcing were suggested more indirectly by the models.

Of course, such mid-layer lapse rates are not particularly unusual across California in the summer, although the Q-vector convergence is certainly more atypical. Even with these ingredients, thunderstorms would be absent if not for an abundant supply of moisture. Figure 15 illustrates that the GFS model did indicate an increase in moisture from the southwest, and in general, models performed better with moisture representation than instability diagnosis per se. In particular, the “warmer” colors nosing towards California show a pronounced theta-e ridge, the axis of which is often a favored environment for convective development.

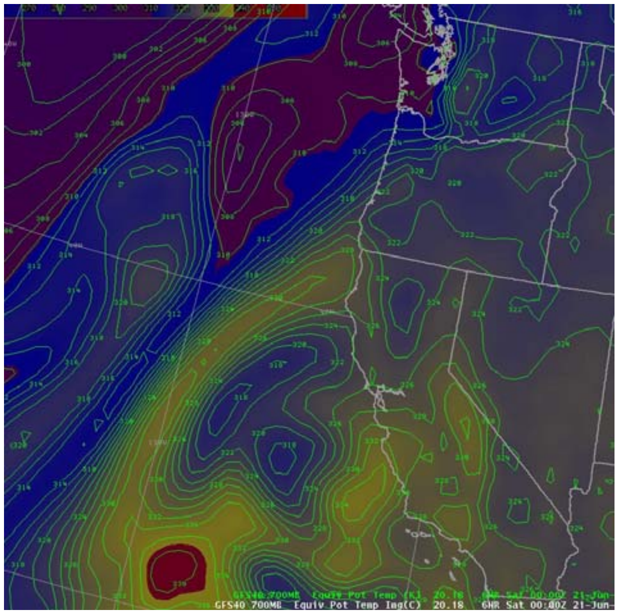

Figure 15. GFS 700 mb theta-e image and values for 00 UTC June 21.

A look at isentropic surfaces may also help in visualizing the combination of broad scale lift and moisture abundance. Both the 310 K and 315 K surfaces from the GFS model showed mid-level upglide accompanied by substantial moisture over northwest California around the time that convection began. The 315 K surface is presented in Figure 16.

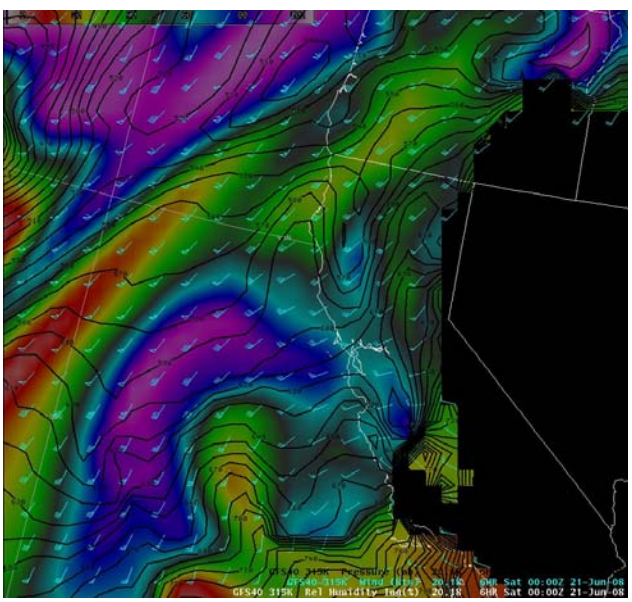

Figure 16. GFS 315 K isentropic surface overlaid with relative humidity image for 00 UTC June 21.

Despite the presence of ingredients favoring convection, and certainly some hints of it both in observational and modeled data, other factors undoubtedly turned what may have been an innocuous convective event into a historic one. These factors are subject to much speculation and deliberation at the present time. However, the magnitude of convection observed over the ocean in the days before the event was certainly much less than what occurred in northwest

California during the late afternoon of June 20 through the morning of June 21. Although diabatic processes may explain some of this, as well as the correct combination of convective parameters coming together at the right time and place, there are other possible explanations for the numerous thunderstorms that occurred late on the afternoon of June 20. As discussed earlier, observational and modeled data both indicated an unusually strong upper level jet streak moving into the area. However, mid-level winds were increasing rapidly during the afternoon hours.

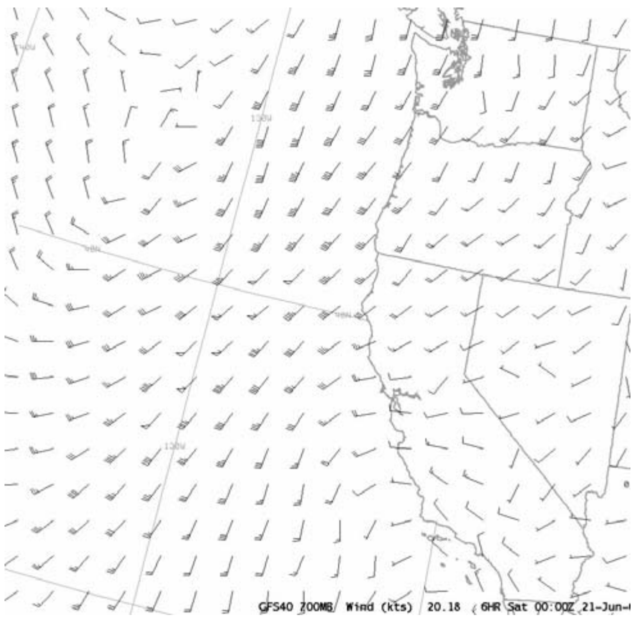

Figure 17. GFS 700 mb wind at 00 UTC June 21.

In fact, at 700 mb, GFS data indicated winds increasing from around 20 knots to over 50 knots as the day progressed. These modeled winds at this level are well corroborated with GOES high density wind data. As can be seen in Figure 17, this regime sets up a very pronounced area of speed convergence over northwest California. Daytime thermal lifting from the surface combined with strong speed convergence, especially as this flow was forced to rise against the mountainous terrain, was sufficient to break weak capping observed earlier in the day. High lapse rates through the mid-levels augmented by unseasonably strong forcing aloft were favorable to allow moist parcels to continue to rise, leading to the afternoon and early evening convection. As proposed earlier, this early convection likely laid the foundation for the nocturnal convection that was to follow through cooling of the mid layers and additional lift being generated by the approaching shortwave trough. Although this is but one explanation for the magnitude of convection witnessed across northwest California, it does provide forecasters a more comprehensive mechanism for assessing convective threat in situations where “off-the-shelf” convective parameters are unimpressive. Thus, in addition to the observational cues suggested earlier in this section, forecasters should also be mindful of a few modeled parameters that may help increase confidence in a potential thunderstorm event:

1. *Confirm that models have an accurate handle on moisture and instability by looking at the totality of observational data; if model guidance does not agree with observations, modify the environment and thought process accordingly*
2. *When utilizing models, also consider synoptic mid-level lapse rates and upper level forcing rather than simply relying on computed surface-based or elevated CAPE/LI*
3. *Look for theta-e ridges and axes as being probable sites for convective initiation*
4. *Isentropic analyses can help tie together the larger scale lift and moisture characteristics in synoptic-scale convection episodes*

A Final Word About Impacts

In addition to the financial and human costs detailed earlier, other, less quantifiable impacts also occurred in connection with the fires. Three months of smoke, often dense and sufficient to cause health advisories, was experienced from the source of the fires to areas hundreds of miles away, including the coast. Many recreational outfits and related businesses, whose livelihood depends on capturing tourist dollars during the vital summer months, experienced sharp revenue declines due to the corresponding drop in vacationers who stayed away due to forest closures and smoke. Timber losses, while difficult to ascertain, were undoubtedly high, and burn scars will leave a changed landscape more vulnerable to erosion and flash floods. The aggregate area burned within the Eureka CWFA as a result of these fires reached some 432,000 acres, or 6% of the total land area.

Conclusion

This lightning event was among the most significant in California's history. It remains ambiguous as to the degree to which initial attack firefighting resources could have contained these fires if better advance warning had been given concerning lightning risk. However, it is highly probable that advance warning communicated effectively in the days leading up to the event would have provided for improved resource commitment and deployment. Despite modeled parameters that, taken at "face value," were largely unimpressive, there were still indications that a convective event was a significant possibility. Additionally, observational data in the hours and days before the event strongly suggested that the normally stable regime across northern California was about to undergo substantial change. It seems doubtful that even with consideration of these data that the magnitude of this particular event could have been understood in advance. However, this event reminds forecasters that situational awareness and critical interpretation of observational data and thorough analysis of modeled parameters remain exceedingly important to correctly estimating and responding to thunderstorm risk.

Acknowledgments

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References

State of California. California Department of Forestry and Fire Protection. 2008 Lightning Siege Overview. 11 Aug. 2008 <http://www.fire.ca.gov/index_incidents_overview.php>.