

Hiroshi Hayasaka* and Carl N. Skinner**

* Hokkaido University, Sapporo, Hokkaido, Japan

** U.S. Forest Service, Pacific Southwest Research Station, Redding, California

1. INTRODUCTION

An unusually large outbreak of fires for northern California occurred in June 2008. Unprecedented dry thunderstorms with severe lightning occurred under very dry conditions due to the rainless weather since March. More than 8,000 lightning flashes were observed mainly in northern California and western Nevada. After the historical dry thunderstorms, more than 800 forest and wildland fires started and many lasted more than a month under dry and hot summer conditions. The peak number of fires totaled 2,696 and total burned area reached about 4,580 km². 511 houses were burned. Unfortunately, 15 firefighters lost their lives (2008 Lightning Siege Overview, International CNN.com).

One of the authors from Japan could have a chance to survey forest fire situation in northern California and visited the U.S. Forest Service's Pacific Southwest Research Station, Redding, California. Survey period was the week of July 9, 2008 that coincided with the largest peak in burned area. In this preliminary report, lightning data of these historical dry thunderstorms, weather data measured at Redding, fire (hotspot) data, weather maps, emagrams, and various satellite images were analyzed to explain occurrence of the severe lightning and the following fires.

There are two reports at least about this event as far as the authors knew. One is "Sacramento Fire Weather annual summary- 2008" and another one is a draft paper written by M. Burger. Two papers mainly described mechanism of historical dry thunderstorm only from meteorological point of view.

2. SURVEY OVERVIEW

Fig.1 is a map of northern California and a part of Nevada showing the distribution of lightning (dots) and fire (gray rectangles) is shown in Fig.1. Our focused research areas were shown in this Fig.1 by using rectangles numbered from 1 to 5. Both authors visited the Motion fire (area 1) and the lead author visited areas 2 to 5 alone.

Picture 1 showed the situation of "Motion" fire on July 11, 2008. This picture was taken from the center of Redding looking west. "Motion" fire was very active quickly covering a large area so it appeared that each mountain had its own fires. So many fires in adjacent mountains imply both dense lightning and rapid fire expansion by spot fire.

* Corresponding author address: Hiroshi Hayasaka, Graduate School of Engng., Hokkaido Univ., Sapporo, 060-8628, JAPAN; e-mail: hhaya@eng.hokudai.ac.jp

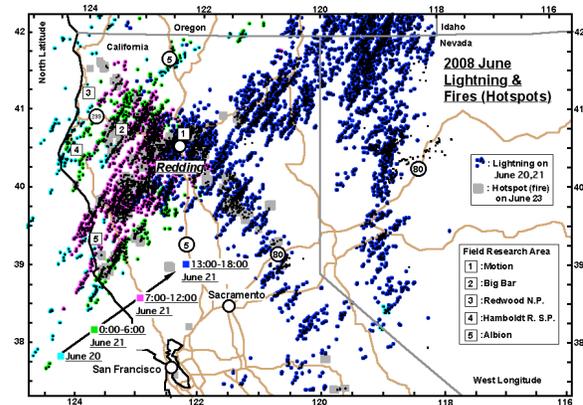


Fig.1 Distribution of Lightning and Fires (Hotspots)



Picture.1 "Motion" Fire Near Redding (July 11, 2008)

3. BACKGROUND OF LARGE FOREST FIRES DUE TO DRY THUNDERSTORM

3.1 Special features of climate and region in northern California

Northern California has a pronounced Mediterranean type climate influenced by strong high pressure in the adjacent Pacific that blocks frontal systems from northern California in summer. The center of high pressure is usually located at the neighborhood of about 50 degrees north latitude about and 150 degrees west longitude. This contributes to a prevailing northerly wind in the area along the Californian seashore. These winds cause upwelling off the California coast. Due to upwelling, sea surface temperatures near Californian are kept low even in mid summer. The center of upwelling is located offshore from San Francisco to Mendocino. Thus, mean sea surface temperature in August is only 11.1 °C.

This low summer sea temperature helps create stable atmospheric conditions under 300m height. Summer fog near the California coast is often a result of the cool California Current offshore. Lightning is not

common under such atmospheric stability or subsidence inversion.

On the other hand, weather in inland California is greatly different from the coast. Fog and cool wet air of the Pacific Ocean do not move inland more than a few km. Instead, the inland area of northern California is usually hot and dry in summer. As a result, a big temperature difference exists between foggy coast with air temperature of 10 °C and inland basin with 40 °C in summer.

In addition to the above-mentioned climatic features, northern California occasionally experiences tropical maritime air masses. These later conditions are often referred to as “pineapple express” and provide northern California with large amounts of rain such as in the winter of 1997. These events clearly showed that the largest amounts of rain occurred where wet air flowing from the Pacific Ocean hit the western slopes of northern California mountains.

Thus, we suggest that the dry thunderstorms (Rorig, M.L. et al. 2006) of June 2008 may have been the result of tropical maritime air masses from near Hawaii islands. In other words, if wind direction changed from northerly to westerly or southerly, then the influx of moist, unstable air would help create conditions for thunderstorms because westerly or southerly winds are usually moist.

3.2 Recent Precipitation Trend

Mean and monthly precipitation in 2008 in Redding (California Weather Data) are shown in Fig.2. Annual mean precipitation in Redding is 999mm. But annual mean precipitation in 2007 and 2008 was 551 and 550mm respectively. This limited precipitation condition started from around May 2006 and lasted until May 2009.

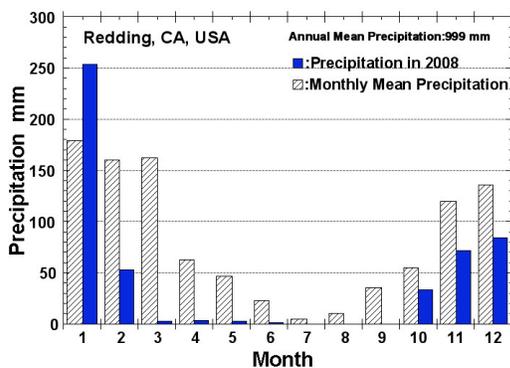


Fig.2 Precipitation in Redding

2008 monthly precipitation in Redding is shown in Fig.2 along with mean monthly precipitation. Bars with solid color are for 2008. From Fig.2, you will find rainless months started in March. Actually, the last rainfall of 8 mm was observed on 24 February 2008. After that, no significant amount of rain was observed until the end of September.

4. CONDITIONS FOR THE OCCURENCE OF THESE DRY THUNDER STORMS

4.1 Time series of lighting occurrence

Lightning position on June 20 and 21, 2008 are shown with small dots in Fig.1. Lightning started over the sea on the evening of June 20. Lightning position moved from the southwest to the northeast. Much lightning, more than 8,000 flashes, occurred on June 21. This thunderstorm is called “historical” dry thunderstorm because the great number of lightning flashes and damages due to forest fires were unusual.

Fig.3 shows hourly lightning strikes from 16:00 of June 20 to 14:00 of June 21. Fig.3 covers only a part of the northern California area (North latitude: 39-42°, West longitude: 122.5-125°) for discussion of forest and wildland fires in the northern California. As a result, total number of lightning flashes (2,334) is less than previously stated. Fig.3 clearly shows lightning occurrence peaked at 7:00 of June 21. This implied lightning was not a so-called thermal lightning that tend to peak in the middle of the day to early evening.

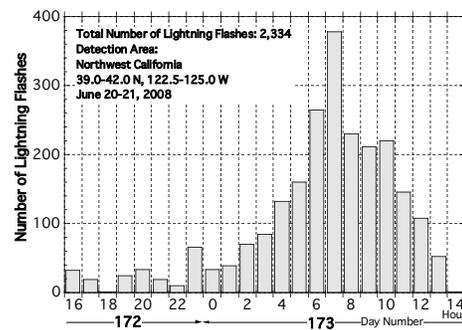


Fig.3 Lightning occurrence tendency in northern California

4.2 Weather Map, Clouds and Jet Stream

Surface weather map (NCEP/NCAR Reanalysis 1) at 12:00 on June 21, 2008 is shown in Fig.4. From Fig.4, two high-pressure zones were found north of Hawaii and in the Colorado Plateau. Four low pressure zones located south of Alaska Peninsular, in the east of Gulf of Alaska, west of California, and in northern Baja California.

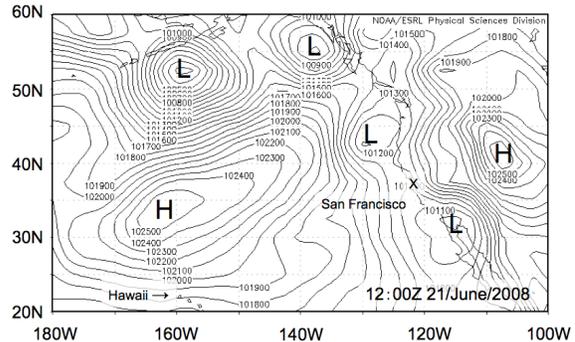


Fig.4 Surface Weather Map at 12 UTC June 21

Satellite image take by GOES (California Regional Weather Server, San Francisco State University) at 18:00 UTC on June 21 is shown in Fig.5. Four vertical and horizontal dotted lines in Fig. 5 show west longitude of 120 and 135 degrees, and north latitude of 45 and 60 degrees respectively. Vortex clouds named C1 and C2 are seen in Fig. 5 and they were formed corresponding to low-pressure zones in Fig.4. The size of the vortex clouds of C2 is about 1,400 km from around 140 degrees west longitude to west coast of United States and about 2,000 km from about north latitude of 30 to 50 degrees. This size is not so small as middle-latitude storm.

In addition to C1 and C2, C3 was found in northern California. C3 clouds made historical dry thunderstorms and C3 appears to have been independent from C2 clouds. According to GFS Model analysis, the jet stream was approaching from the northwest coast of United States. C3 clouds may have formed with the help of tropical moisture flows from near Hawaii and near the Gulf of California. When they entered into northern California, the jet steam may have helped the formation of C3 clouds.

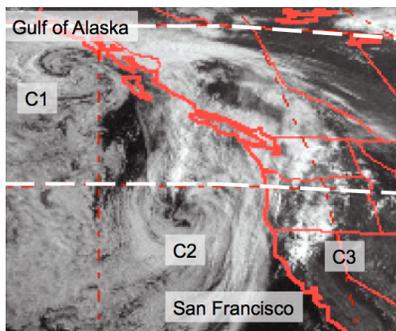


Fig.5 Surface Weather Map at 12 UTC June 21

4.3 Emagrams

To study the mechanism of these historical dry thunderstorms, emagrams (Atmospheric Science, University of Wyoming) were made. Fig.6, shows emagrams from the Oakland Airport near San Francisco.

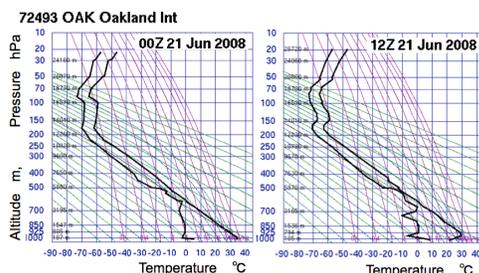


Fig.6 Emagrams in Oakland

Emagram at 00:00 on June 21 is shown in the left panel in Fig.6. The right side panel in Fig.6 is for 12:00 on June 21. It is apparent there was a big difference between their air temperatures up to 800m. Air

temperature at height 6m from ground changed from 34.2 °C (relative humidity, RH, 16%) to 22.2 °C (RH, 41%). From right-hand side figure of Fig. 6, large environmental lapse rate (15.5~18.2 °C/1000m) was observed up to a height of about 400m.

Table 1 shows more detail in temperature conditions up to a height of 2,000m at 12:00 UTC on June 21 in 2008. Table 1 also shows temperatures in recent years from 2004 to 2007 for comparison. From Table 1, you will see that temperatures in 2008 at any height were higher than those of other recent years. Especially, the temperature of 29.1 °C at a height of 500m was very high. There was also a large lapse rate of 7.4 °C/1,000m ($\Delta T_2 = T_{2000} - T_{500}$). This lapse rate was larger than in the other four years. Thus, the atmosphere in 2008 was "conditionally unstable".

Table 1. Comparison of Temperatures (12:00 UTC on June 21) at Various Heights in Recent Years

Height (m)	2004	2005	2006	2007	Mean '04-'07	2008	ΔT_1
6	13.0	13.4	14.0	12.4	13.2	22.2	9.0
500	9.2	10.3	20.9	9.1	12.4	29.1	16.7
1,000	20.5	10.2	25.1	19.9	18.9	27.0	8.1
2,000	16.0	9.9	17.3	14.6	14.5	18.0	3.6
ΔT_2	6.8	-0.4	-3.6	5.5	2.1	-11.1	-13.2

4.4 Observation Clouds Using Satellite Images

A satellite image take by Terra at about 10:00 LST on June 21 was shown in Fig.7.

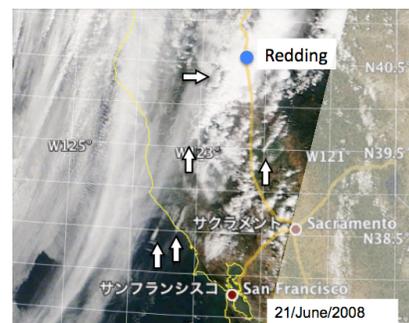


Fig.7 Terra Imagery at about 10:00 LST on June 21

Redding is located near the top center of Fig.7. In this image Redding was under relatively large white cloud that was part of the historical thunderstorms. The inland clouds are considerably different in shape compared to the clouds over the Pacific Ocean. Many of the inland clouds tend to have an origin. Arrows in Fig.7 show such origins. These clouds may form due to such as islands at sea, a cape near the coast, or hill and mountain on land. Such prongs will create atmospheric disturbances. Three clouds in Fig.7 shown with arrows may have been formed by topographical prongs, but the other two clouds with arrows may have been created by the effect of a forest fire. Actually, Terra MODIS detected hotspot (forest fire) on June 20 near right-pointing arrow in Fig.7.

5. ANALYSIS OF FIRE AND WEATHER CONDITION

5.1 Forest Fires (Hotspots) and Fire Occurrence Rate

In Fig.1, fire locations were shown with gray rectangles and lightning locations were shown with dots. Both symbols exaggerated size in the image. Also hotspots were detected two days after the historical lightning event. This is due to MODIS not being able to detect a forest fire until it could become relatively large.

To calculate the fire occurrence rate, hotspot will not be suitable data because MODIS could not detect a small forest fire. For this, two figures from fire fighter teams and news are used. The total number of lightning flashes was 5,064 for the region of northern California (North Latitude: 37.5-42 degrees, West Longitude: 120-124.4 degrees). Formula for fire occurrence rate is show below.

$$\text{FOR (Fire occurrence rate)} = \frac{\text{(Number of fires)}}{\text{(Number of lightning flashes)} \times 100 (\%)}$$

Fire occurrence rate is also called the "ignition rate". Here I used fire occurrence rate.

The number of fires was 2,096 according to fire fighter teams and 800 from news. Their fire occurrence rates were 41.4 % and 10% respectively. There is a big difference. This is simply because fire fighter teams could include small fires and new fires caused by spotting fire. But we should pay more attention on high fire occurrence rate. Some explanation is needed for future fire fighting.

5.2 Time Series of Forest Fires (Hotspots)

Fig.8 shows the number of hotspots become 731 just two days after ignition. This number is similar to the fire number from news. This is the number of fire areas that grew large enough to be detected.

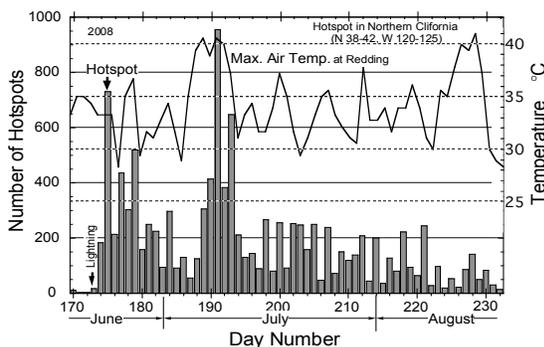


Fig.8 Fire (hotspot) and Air Temperature after Ignition (North Latitude: 38-42 degrees, West Longitude: 120-125 degrees)

After this first hotspot peak in Fig.8, the number of hotspots decreased. But a second peak started in early July when maximum air temperature reached around

40 °C. Maximum hotspot number occurred in this second peak and it was 955. After the second peak, the number of hotspots decreased but more than 200 hotspots were observed until the top of August.

5.3 Lightning and Forest Fires near Redding

To learn more about the relationship between the historical thunderstorms and the resulting lightning-caused fires, the distribution of lightning and fire locations were plotted in Fig.9. Here, the total number of lightning flashes was 426. Lightning locations are shown by cross marks with three different colors. Different colors were used to distinguish lightning occurrence time.

Highest number of lightning flashes was 82 observed at 11:00 LST on June 21. Three dense lightning groups were found in Fig.9. They were named 1, 2, and 3. They were highlighted by ovals. Direction of each group was from the southwest to the northeast. This direction was same as in Fig.1. Three groups of lightning follow the shape of the land, in other words, along or above mountains.

Lightning began around 5:00 LST on June 21. Until 11:00 LST, 245 lightning flashes were observed mainly in zones of 1 and 2 in Fig.9. From 11:00 to 14:00 LST, the number of lightning flashes was 160 and they hit mainly in zone 3.

Further investigation is needed to explain fires occurrence in zone 2 because there was a big difference in the fire (hotspot) occurrence rate among the three zones. Understanding the reason for many hotspots in zone 2 would be helpful for future fire fighting.

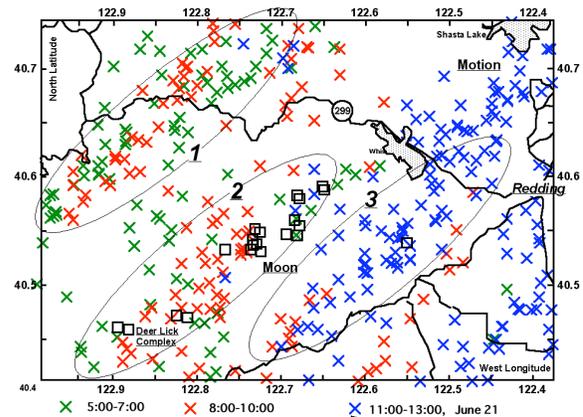


Fig.9 Distribution of Lightning and Fire Near Redding

6. CONCLUSIONS

1. Clouds of the historical thunderstorm were identified on various satellite images such as Terra and GOES. The mechanism leading to formation of the historical thunderstorm was not so clear. This may suggest that there was complex cause. A detailed study of the historical thunderstorm should be undertaken.

2. High fire occurrence rate of around 10% (more than 800 forest and wildland fires ignited by 8,000 lightning flashes) is likely due to highly dried vegetation under strong drought condition and the lack of significant moisture with these storms.

3. The activity of these fires appeared to be associated with air temperature and wind speed and direction. Highest peak of hotspot (fire) was observed when air temperature exceeded 40 °C.

REFERENCES

M.L. RORIG, S.J. MCKAY, S.A. FERGUSON and P. Werth, 2006 : "Model-Generated Predictions of Dry Thunderstorm Potential", J. Applied Meteorology and Climatology, Vol. 46, pp. 605-614. and etc.

2008 Lightning Siege Overview, California Department of Forestry and Fire Protection, http://www.fire.ca.gov/index_incidents_overview.php

International CNN.com/US, Hundreds of post-lightning fires burn in California - CNN.com, 08/06/25 9:06. and etc.

California Weather Data, Agriculture and Natural Resources, University of California. <http://169.237.>

140.1/WEATHER/ wxretrieve.html

NCEP/NCAR Reanalysis 1: Surface, Earth System Research Laboratory, Physical Sciences Division, NOAA Research, U.S. Department of Commerce. http://www.cdc.noaa.gov/data/gridded/data.ncep_reanalysis.surface.html

Satellite images, California Regional Weather Server, San Francisco State University. [http://squall.sfsu.edu/Department_of_Atmospheric_Science,_College_of_Engineering,_University_of_Wyoming.](http://squall.sfsu.edu/Department_of_Atmospheric_Science,_College_of_Engineering,_University_of_Wyoming._http://weather.uwyo.edu/upperair/sounding.html?region=seasia) <http://weather.uwyo.edu/upperair/sounding.html?region=seasia>
Unknown Author, Sacramento Fire Weather annual summary - 2008, http://www.wrh.noaa.gov/sto/fire_wx_verification_2008.pdf

M. Burger : "The northern California lightning event of June 20-21, 2008", 23rd Conference on Weather Analysis and Forecasting/19th Conference on Numerical Weather Prediction, June, 2009.

P. J. Bartlein, S. W. Hostetler, S. L. Shafer, J. O. Holman and A. M. Solomon, 2008, Temporal and spatial structure in a daily wildfire-start data set from the western United States (1986–96), Int. J. of Wildland Fire, 17, 8–17.