A Forecast Procedure for Dry Lightning Potential

Nick Nauslar, University of Nevada, Reno

Timothy J. Brown, DRI

Jim Wallmann, National Weather Service Reno WFO

Abstract

"Dry" thunderstorm (traditionally less than 2.5 mm or 0.1" of rainfall) forecasting has long been a forecast problem for the western United States. These dry thunderstorms are responsible for starting thousands of wildland fires every year. In the largest lightning outbreaks (or "busts" in the wildland fire community), hundreds of fires may be started in a 24 to 36 hour period. These extreme events put a huge strain on fire suppression efforts. Many of these fires may go unstaffed due to the lack of available fire personnel simply because of the large number of fire starts. Forecasting these events in advance, even just 24-48 hours, could help fire agencies plan resources in preparation of a large outbreak. Fires are much more likely to be controlled during the early stages, and therefore cost much less to fight.

Due to the seemingly innocuous conditions preceding dry thunderstorm development across the western United States (west of the Rocky Mountains), forecasting dry thunderstorm events can prove challenging and inconsistent. Jim Wallmann developed WA04, a conceptual model of dry thunderstorms that includes the pressure of the dynamic tropopause, jet streak dynamics, equivalent potential temperature, and upper level lapse rates in conjunction with the High Level Total Totals (Wallmann 2004). Isentropic analysis was added to WA04.

This procedure was applied to two case studies from the summer of 2009 including the dry lightning event in northwest Nevada, northern California, and south central Oregon on August 1, 2009 and the east central Washington dry lightning event of August 20-21, 2009. It proved useful in determining the potential for dry thunderstorm development in the preceding days and hours to the initiation of the event. This presentation summarizes these case studies, and describes the dry lightning forecast procedure.

1. Introduction

Dry lightning events or busts create numerous fire starts in the western United States (west of the Rocky Mountains), which stress local and regional initial attack resources. A lightning bust refers to a storm system producing thousands of lightning strikes over an area or region. During June 20-21, 2008 northern California received over 5,000 lightning strikes that ignited approximately 500 fires. This represented a top three lightning bust in that area throughout the history of the National Lightning Detection Network. Several of these busts occur annually mostly between June and September throughout the western United States. Many of these lightning busts occur with a trough approaching the western United States that phases with monsoonal moisture entrained from the south. Rorig and Ferguson 1999 and Crimmins 2005 show a short climatology of synoptic patterns for critical fire conditions in Pacific Northwest and the Southwest United States. However, it can be difficult to diagnose the location of high-based convection or to delineate dry and wet storm formations. These busts generate problems not only for fire managers, but to forecasters as well. Due to surface or lower tropospheric thunderstorm indices (Totals Totals (TT), Convective Available Potential Energy (CAPE), K Index, Lifted Index (LI), etc.) not revealing the true potential of most of these busts, many events go under forecasted. To better ascertain dry lightning potential, a collaborative effort developed a procedure incorporating some non-traditional thunderstorm parameters and analyses.

The procedure includes isentropic analysis, upper tropospheric level lapse rates (ULLR), high level total totals (HLTT), jet streak dynamics, and dynamic tropopause analysis. Isentropic analysis entails the inspection of vertical cross-sections with equivalent potential temperature and mixing ratio or potential temperature and relative humidity plotted to determine instability and moisture plumes. Upper level lapse rate values contoured illustrate the dry thunderstorm formation threshold of 7.5 C/km. HLTT values of 25 C or higher represent an environment conducive for high-based convection (Wallmann 2004. These thresholds are based on empirical evidence and can be explained physically. The influence and location of an upper level jet determine divergence aloft, which aides the vertical development of the storms. Finally, the analysis of the dynamic tropopause location and more importantly the transition or gradient of it in conjunction with the other parameters determines the potential for dry thunderstorm formation.

Other papers have aimed to predict dry thunderstorms by determining the importance of mid level instability and low level dewpoint depressions (Rorig and Ferguson 2002 and Rorig et al. 2006). Rorig et al. 2006 aimed to predict dry thunderstorms via an algorithm when convection was expected by implementing thresholds based on moisture and instability components.

The procedure detailed in this paper seeks to determine if dry thunderstorms will form and to some extent, the intensity of the event. Two cases chosen for this paper occurred 1-2 August 2009 over northwestern Nevada, northern California, and south central Oregon and 20-21 August 2009 over central and eastern Washington. The first case started in the late afternoon and persisted through the evening hours and yielded over 6500 lightning strikes and approximately 200 fires throughout the next week. The second case transpired overnight with nearly 3000 lightning strikes that included deployment of incident management teams. These two cases show the variability in the timing and the formation of these events, but with the implementation of the procedure both could be forecasted. The flexibility and inclusiveness of the procedure for different types of dry lightning events remains one of its strongest assets.

2. Procedure

Isentropic analysis has long been used to ascertain winter precipitation east of the Rocky Mountains. Meteorologists also implemented it to a lesser extent for thunderstorm forecasts. Isentropic analysis displays vertical motion in the atmosphere in the absence of strong evidence at a constant pressure level. It also identifies moisture transport in a more complete manner. For these reasons, isentropic analysis provides a competent tool for distinguishing high-based thunderstorms, which occur frequently within the intermountain west.

Two sets of isentropic maps developed included contours of equivalent potential temperature (Θ_e) with mixing ratio and contours of potential temperature with relative humidity (RH). By creating this type of plot, one needs only to find the moisture plumes and instability ($d\Theta_e/dz$). When higher values of Θ_e are below lower values of Θ_e, this implies instability. If a plume or an increase of moisture coincides with the instability, this becomes a focus for thunderstorm development. To ascertain its dryness, becomes more complicated. One can look for lower RH or mixing ratio values below this focus, and this can provide some support in deciding whether the storms will be dry or wet.

The presence of an upper level jet streak plays a vital role in the development of thunderstorms including dry thunderstorms. One main difference from severe weather and dry thunderstorms is the jet divergent region(s) do not have to be over the development of dry thunderstorms. The influence of an approaching jet streak can create enough mass momentum adjustments to allow for upper level divergence to couple with the other procedural entities. An approaching jet in the 1 August northern Sierras and southern Cascades case altered the upper level wind speeds and direction enough to induce divergence aloft and rising motion below it. The jet does not have to particularly strong either. On 20-21 June 2008 Northern California lightning bust, the polar and subtropical jets were not located over that region, but a smaller jet or jetlet existed between the two jets created in part by offshore convection. This jetlet aided the upper level lift throughout the event.

The dynamic tropopause is used to help assess the upper level forcing in two ways. First, weak short wave troughs can be difficult to see at times on 500mb vorticity charts and therefore forecasters may miss the weak forcing. Using the dynamic tropopause on a potential vorticity surface, these weak short wave troughs can be easier for a forecaster to locate as the trough will be represented by a tropopause undulation (Wallmann 2004, and Hirschberg and Fritsch 1991a) from which upper level vorticity advection and upward vertical motion can be inferred. Second, the undulation is often associated with atmospheric warm air advection at that level which can induce near-surface pressure falls with resulting low-level convergence and upward vertical motion (Hirschberg and Fristch 1991a-b). A large tropopause undulation existed off the Oregon Coast 20 June 2008 northern California case, but a weak fall in the tropopause moved onto the California Coast at 18 UTC 21 June. Significant lightning was associated with the trough as it moved onshore with numerous new fire starts.

With cloud bases often high during dry thunderstorm outbreaks, sometimes above 5 km above sea level, commonly used instability parameters such as surface-based lapse rates and the Total Totals index should be adjusted upward

(Wallmann 2004 and Milne 2004). The high level total totals (HLTT – Milne 2004) index and upper level lapse rates (ULR, 500-300mb) are useful with values most conducive to extensive dry thunderstorm development 30 C and 7.5 C/km, respectively. For dry thunderstorms, HLTT can be as low as 20 C, but is most often found with values above 25 C (Wallmann 2004). It is important to note that while increasing values of HLTT and ULLR above the thresholds would suggest much better potential for thunderstorms the increase does not necessarily portend an increase in the storms being dry. In fact, for HLTT it is often the opposite as an increase in the HLTT could be the result of higher dewpoints at 700mb, which would result in wetter storms.

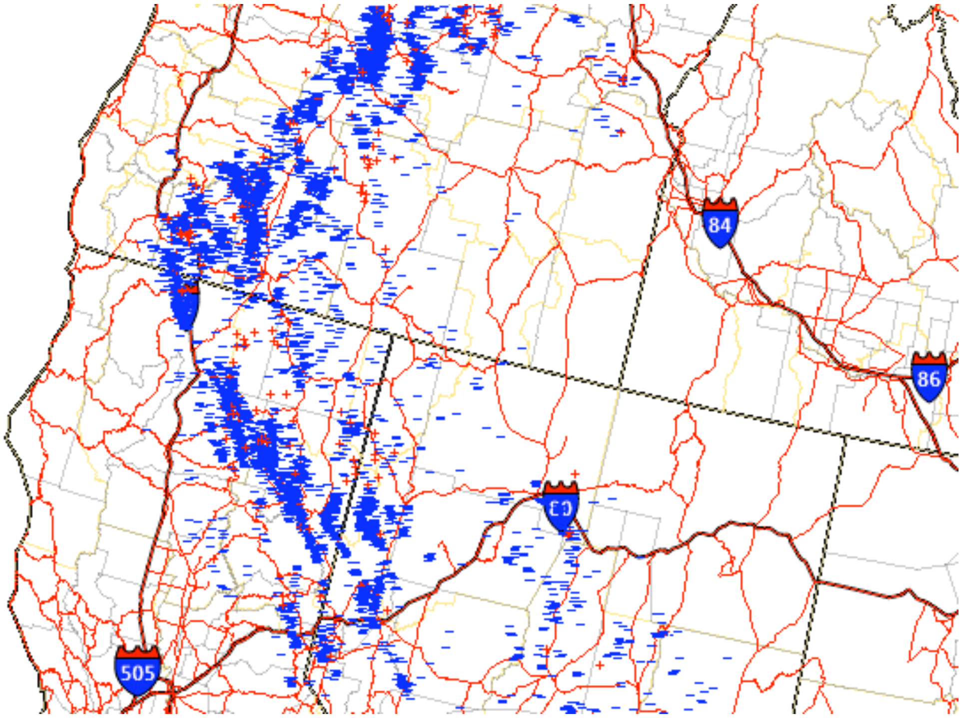
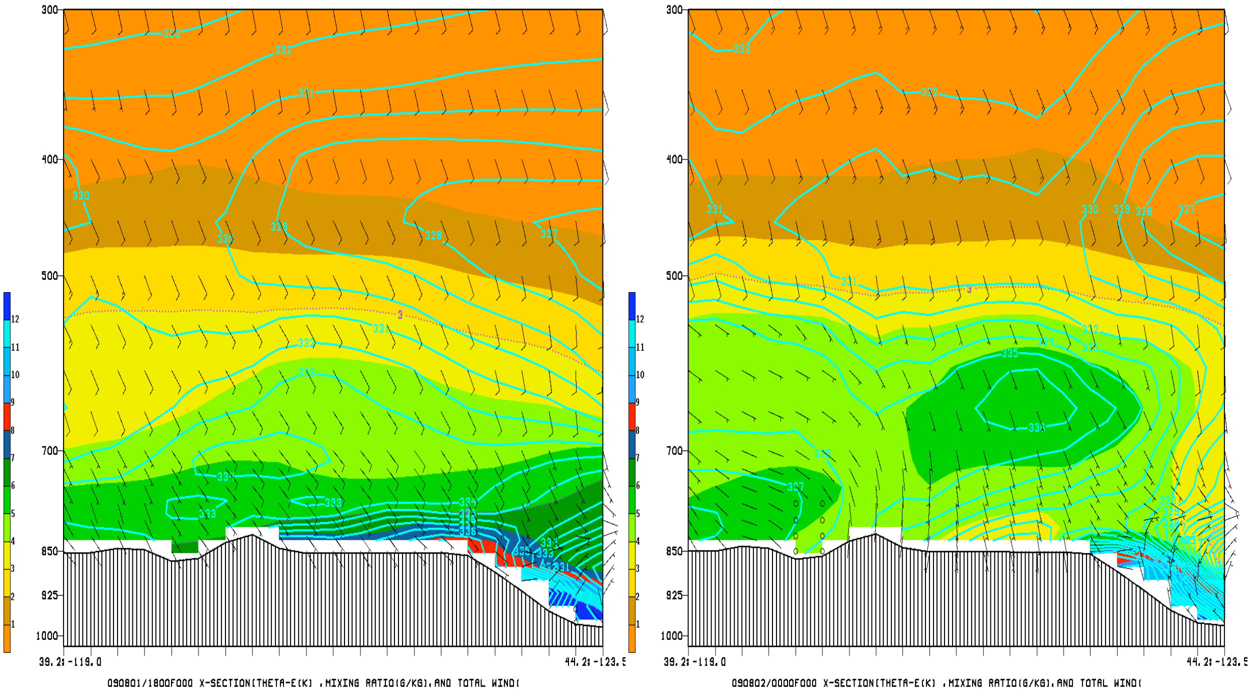


Figure 1: Map of all lightning strikes throughout duration of 1-2 August 2009 event

3. Case Study Analysis

a) 1-2 August 2009

On 1 August 2009 a vigorous trough approached the Pacific coast of California and Oregon. Ahead of this trough, monsoonal moisture advected northwestward from the southwestern United States in the mid levels of the atmosphere. This set up resulted in over 6500 lightning strikes and approximately 200 fires from central Nevada to central Oregon (Figure 1). As with many of the dry lightning busts, the event became wetter with time. However, south central Oregon, northern California, and northwestern Nevada received several thousand lightning strikes with minimal precipitation.

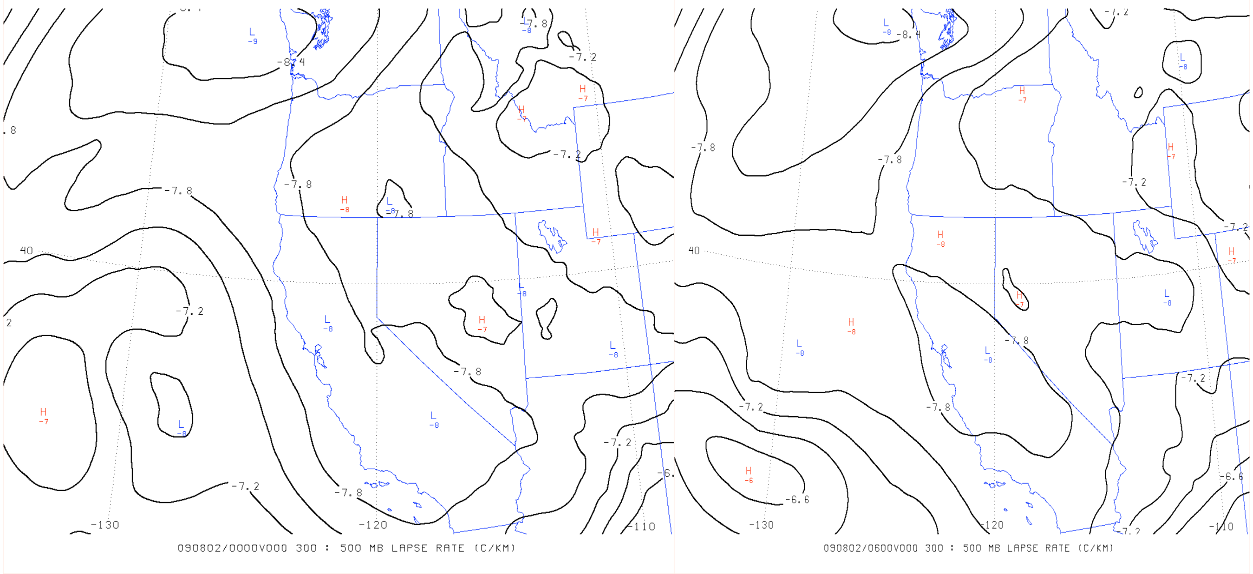


Figures 2&3: 18 UTC 1 August 2009 and 00 UTC 2 August 2009 Θ_e (Kelvin, blue contours), mixing ratio (g/kg, colored filled with scale on left), and wind barbs (black) NARR cross-sections. Approximate location from southeast of Reno, NV to west central Oregon.

Examining the 18 UTC and 00 UTC 2 August 2009 (Figures 2&3) North American Regional Reanalysis (NARR) cross sections that stretch from northwestern Nevada to western Oregon, a plume of higher mixing ratios and RH exist in the 00 UTC cross section that did not exist in the 18 UTC cross section. Additionally, the plumes of moisture collocate with potential/convective instability. The 336 K closed contour with the lower values above it indicates this instability. This occurs to a lesser extent further to the southwest where the 338 K contour resides below lower values.

The lowest lower level mixing ratio values reside below the greatest instability and moisture at mid levels showing a prototypical dry thunderstorm event. This is in part due to afternoon mixing and the lower level moisture increases again at 06 UTC (not shown). The moisture plumes indicate a monsoonal push while the increase in lower level moisture demonstrate the effects of diurnal boundary layer dynamics, and the storms' precipitation adding moisture below cloud base securing the fact that this event became wetter with time.

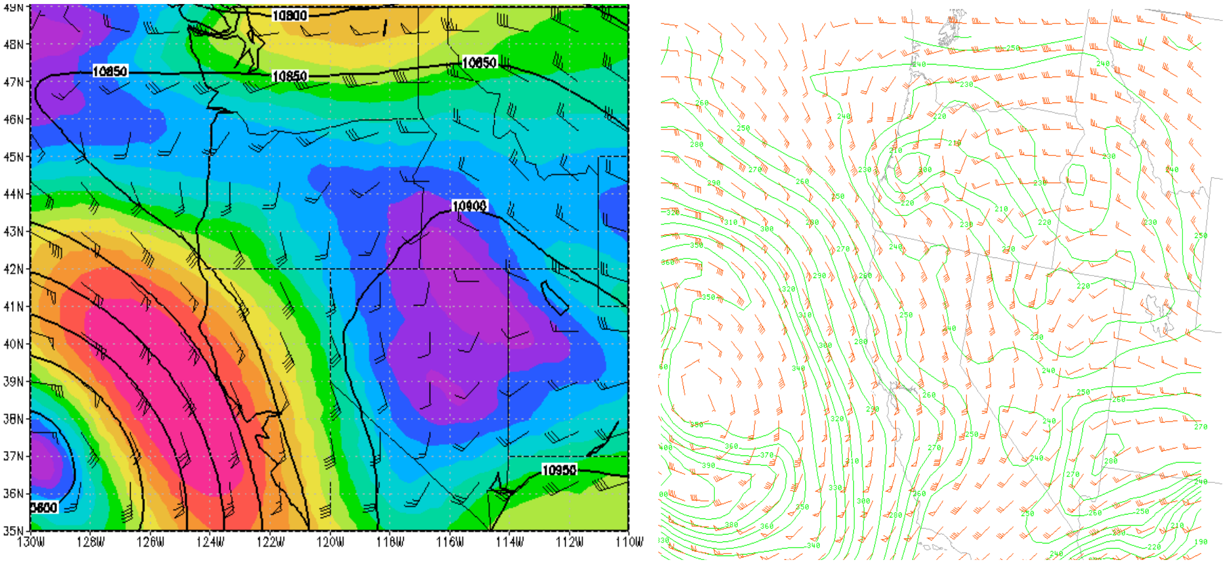
The moisture advected into this region remains confined to below the midlevel of the atmosphere, and the plumes that aid in the convective development exist 700-500mb region (Figure 3). The atmosphere becomes very dry with height above these plumes. At about 550mb the mixing ratio goes from 4 g/kg to 1 g/kg at 425mb. This drier air aloft can be cooled easier and thus helping to increase the ULLR.



Figures 4&5: Contours of ULLR at 00 UTC and 06 UTC 2 August 2009. H's and L's represent the highs and lows of ULLR in the region.

At 00 UTC, the ULLR surpasses the threshold of 7.5 C/km in along the path of the cross section where most of the lightning strikes occurred (Figure 4). At 06 UTC, the ULLR ranges from 7.8 C/km to 8 C/km in the region of interest (Figure 5). The collocation of the moisture, isentropic instability, and sufficient ULLR reside along the path of highest density of lightning strikes. The HLTT values near 30 C at Medford and Reno at 00 UTC supported the case for upward development.

The approaching polar jet from the eastern Pacific aided the development of the lightning bust. At 21 UTC and 00 UTC the jet streak within the larger 2-cell jet is oriented in a general southerly to northerly direction. While the area where the storms formed were not in the divergent region of this jet streak, and it dwelled on the fringe of the 2-cell jet's divergent region. The approaching jet provided a turning of the winds near the edge of the jet to southeasterly while the winds in central Nevada and Oregon still remained southerly. It also increased the wind the speed resulting in directional and speed divergence. While it seems minimal on a synoptic scale, it is sufficient to provide enough divergence aloft to aid lifting over this region. While the best dynamics exist west of the Sierras, the best moisture resides east of them. Therefore, where the dynamics remain just sufficient enough and moisture exists, the storms form and produced the lightning bust during the evening of August 1st. The isentropic analysis distinguished greater atmospheric instability and moisture plumes that otherwise might have looked more innocuous. The ULLR confirm that the upper levels support vertically developed thunderstorms, while the jet streak analysis demonstrated mediocre but sufficient divergence aloft. Finally, the dynamic tropopause analysis indicated a sharp gradient showing the transition from a higher to lower pressure of the tropopause thus conveying cooler and drier air aloft approaching.



Figures 6&7: 00 UTC 2 August 2009 250mb Geopotential heights (black contours) and wind barbs (black with color gradient for speed). 00 UTC 2 August 2009 RUC analysis of 1.5 PV surface showing pressure of dynamic tropopause (green contours) and wind barbs (brown).

b) 20-21 August 2009

On 20-21 August 2009, a strong trough and jet stream moved through Oregon and Washington during the evening hours. This trough triggered a nocturnal dry thunderstorm event over Central Washington that started several new fires. The first thunderstorms formed around 0430 UTC 21 Aug and continued through 12 UTC before moving out of Eastern Washington (Figure 8). The initial thunderstorms were driest, before 08 UTC, and resulted in the greatest number of problem fires with two incident management teams activated to coordinate the fight of the largest fires.

For the event, the dynamic tropopause was quite low west of the Oregon and Washington Cascades at 06 UTC, as low as 350mb, and sloped sharply upward to the east. Strong upward forcing would be expected in the area to the east of the center of the trough at this time with the strongest forcing east over Central Washington. By 09 UTC (Figure 9), the upper trough had progressed east into Central Washington with the expected forcing over Eastern Washington and the Idaho Panhandle.

The jet streaks associated with the upper trough were also quite strong for a mid-summer trough with peak winds in the core of the jets over 40 m/s. However, the locations of the individual jet streaks in this case were not favorable for ageostrophic upward vertical motion. At 06 UTC (Figure 10), the leading anti-cyclonically curved jet streak was over the Idaho Panhandle leaving Central Washington in the left entrance region, which would result in downward vertical motion.

Likewise, with the jet streak moving onshore, the right exit region of this jet was over Central Washington, also supportive of downward vertical motion due to the ageostrophic circulation.

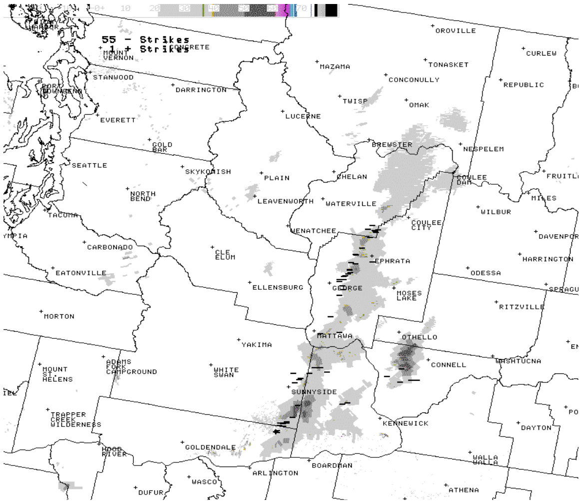
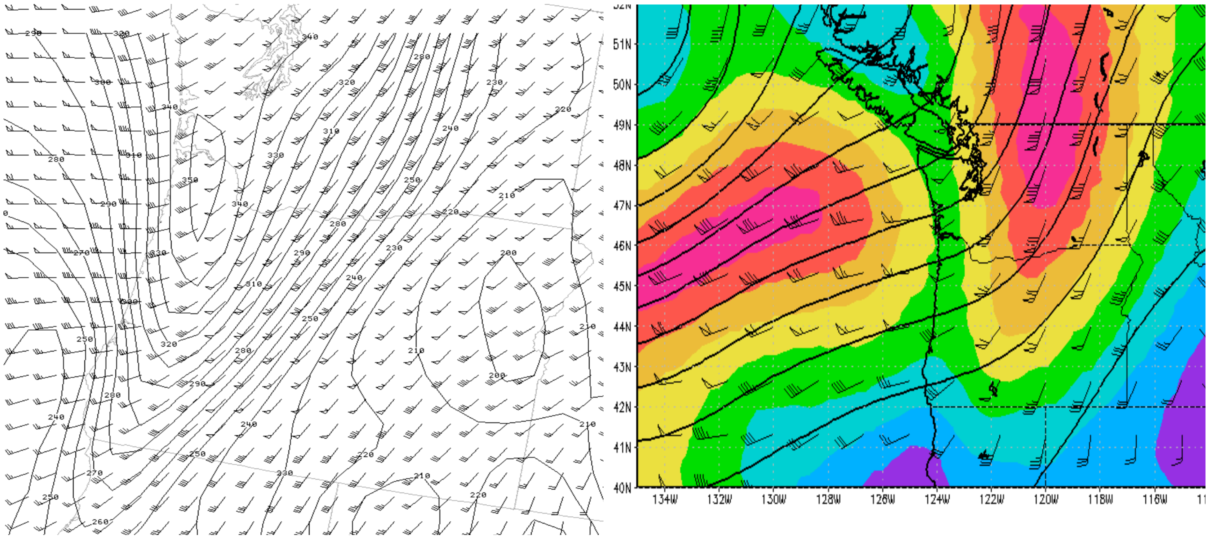
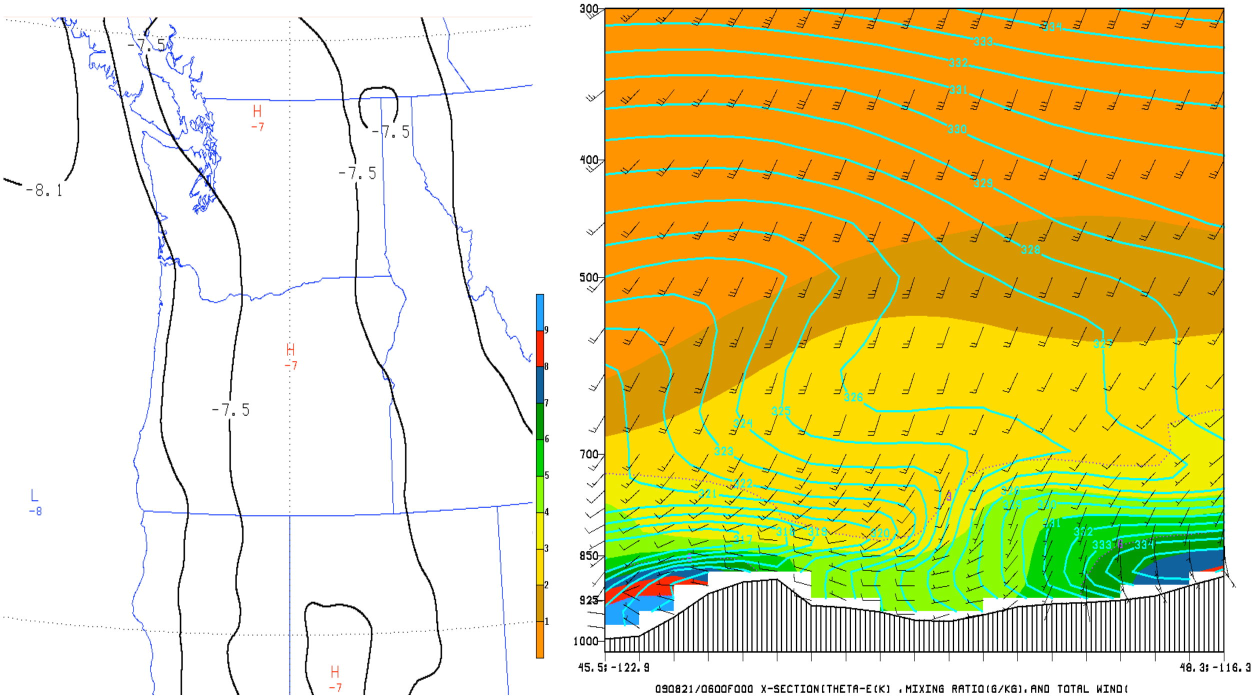


Figure 8: 15 Minute Lightning Plot of east central Washington 0530 UTC 21 August 2009

While the upper level forecasting diagnostics were opposed, the measures used to assess instability, favored convection. ULLR at 06 UTC (Figure 11) were near 7.5 C/km, which is at the threshold of supporting dry convection while HLTT were above 30 C over Central Washington (not shown). Isentropic analysis along a cross-section from Portland, Oregon to northern Idaho also shows the instability present east of the Washington Cascades. Over the east slopes of the Cascades, Θ_e values were maximized near 325 K above 700 mb with the isentropes decreasing slightly with height indicating and area of potential instability through at least 500 mb (Figure 12). In addition, the mixing ratio showed the largest amount of mid-level moisture in this region as the 4 g/kg values reached near 700 mb with the 3 g/kg values near 600 mb with lower values to the east and west. Higher RH was also present near the base of the potentially unstable layer, which would be released with the forcing from the strong short wave trough.



Figures 9&10: 06 UTC 21 August 2009 1.5 PV surface showing pressure of dynamic tropopause (black contours) and wind barbs (brown). 06 UTC 22 August 2009 250mb Geopotential heights (black contours) and wind barbs (black with color gradient for speed)



Figures 11&12: 06 UTC 21 August 2009 Upper Level Lapse Rate Contours. 06 UTC 21 August 2009 Θ_e (Kelvin, blue contours), mixing ratio (g/kg, colored filled with scale on left), and wind barbs (black) NARR cross-section. Approximate location from west of Portland, OR to north of Coeur d'Alene, ID.

4. Conclusion

Monsoonal moisture along with Pacific trough dynamics represents a common occurrence for dry lightning in the western United States. This procedure allows forecasters to diagnose lightning busts ahead of time in the absence of strong synoptic or traditional evidence of thunderstorm development. Dry thunderstorm development usually occurs at the edges of the best dynamics and moisture, which makes it somewhat of a difficult forecast. Using traditional methods and indices can leave a forecaster unsure of the potential for thunderstorm development. And with many of these events having narrow gradients of lightning and/or thunderstorm development, the potential for missing or busting a forecast remains high.

Isentropic analysis represents most comprehensive tool within the procedure while the ULLR might be the most important. Looking at other events that did or more importantly did not materialize, the ULLR threshold of 7.5 C/km holds true. This may be due it encompassing the other three tools effects into one value. However, this does not mean that this should be the only step one should consider. It does not resolve the issue of moisture in the atmosphere, which remains equally important. Jet streak and dynamic tropopause analyses with HLTT provide support to the top two steps and more confidence in the forecast of dry thunderstorms. The procedural works best as sum of all its parts and not individually. The collocation of each step along with the magnitude of each determine if an event will happen and if it does, the scale of it.

When there are less significant features of each procedural step, the chance of not having dry thunderstorms does not necessarily go down, but the magnitude of the event will be less. Smaller events can be fueled by local or mesoscale processes, which are not discussed in this procedure. However, the focus of this procedure is to detail a forecast for dry thunderstorms especially events that will stress local fire initial attack capabilities.

Some limitations and possible additions to this procedure could better distinguish the relationship between storm speed, motion and precipitable water. This would better exhibit the potential for dry versus wet thunderstorms. Storm movement and development along with the amount of precipitable water would greatly impact how much rainfall occurs over an area. This affects the potential for ignition and could negate the effects of lightning strikes collocated with the rainfall. Additionally, surface RH and fuel conditions could be added to provide a more comprehensive dry thunderstorm forecast tailored to fire managers, who feel the most impact of these events.

Acknowledgements. Dr. Mike Kaplan, Hauss Reinbold, Bo Tan, and NWS WFO Reno.

REFERENCES

Crimmins, Michael A., 2006. Synoptic Climatology of Extreme Fire-Weather Conditions Across the Southwest United States. *International Journal of Climatology, 26*, 1001-1016.

Hirschberg, P. and J. M. Fristch, 1991. Tropopause Undulations and the Development of Extratropical Cyclones. Part I: Overview and Observations of a Cyclone Event. *MWR,* **119,** 496-517.

Hirschberg, P. and J. M. Fristch, 1991. Tropopause Undulations and the Development of Extratropical Cyclones. Part II: Diagnostic Analysis and Conceptual Model. *MWR,* **119,** 518-550.

Milne, R. M., 2004. A Modified Total Totals Index for Thunderstorm Potential over the Intermountain West. *WR Technical Attachment No. 04-04.*

Rorig, Miriam L. and Sue Ferguson, 1999. Characteristics of Lightning and Wildland Fire Ignition in the Pacific Northwest. *Journal of Applied Meteorology*, **38**, 1565-1575.

Rorg, Miriam L. and Sue A. Ferguson. The 2000 Fire Season: Lightning-Caused Fires. *Journal of Applied Meteorology*, **41,** 786-791.

Rorig, Miriam L., Mckay, Steven L., Ferguson, Sue A., and Paul Werth. Model-Generated Predictions of Dry Thunderstorm Potential. *Journal of Applied Meteorology and Climatology*, **46**, 605-614.

Wallmann, J., 2004. A Procedure for Forecasting Dry Thunderstorms in the Great Basin using the Dynamic Tropopause and Alternate Tools for Assessing Instability. *WR Technical Attachment No. 04-04. August 3, 2004.*