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Spatial products available for identifying areas of likely wildfire ignitions using lightning location data-Wildland Fire Assessment System (WFAS)

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Abstract-- **The Wildland Fire Assessment System (WFAS, www.wfas.net) is a one-stop-shop giving wildland fire managers the ability to assess fire potential ranging in scale from national to regional and temporally from 1 to 5 days. Each day, broad-area maps are produced from fire weather station and lightning location networks. Three products are created using 24 hour lightning location data: Dry Lightning/Dryness, Dry Lightning/Estimated Rain and Potential Lightning Ignition. The Dry Lightning/Estimated Rain map is also available in a Google Earth KMZ format along with regional subset maps based on Geographic Area Coordination Centers (GACCS).**

The Potential Lightning Ignition map spatially integrates the Lightning Ignition Efficiency map (http://www.wfas.net/index.php/potential-lightning-ignition-experimental-products-95) with 24-hour cloud-to-ground (CG) lightning strike data. Pixel values are the number of potential fires. Since pixel values of less-then-one fire are possible, the map legend converts the potential fire values to adjective classes similar to the familiar fire danger rating system.

INTRODUCTION

Wildland fire is an important disturbance mechanism in US forests especially in the western US. The frequency, duration and acres burned has been increasing since the mid-1980's with a concurrent increase in fire-fighting expenditures for US land management agencies. (Westerling, et al. 2006). Lightning is the primary natural wildland fire ignition source with an average of 10,600 lightning-caused fires reported in the US each year. (NIFC 2015). Lightning is also the primary ignition source in the western US, accounting for over one half of all wildland fires and up to 70% of the fires in the Desert Southwest (Pyne, 2001) (Nauslar, 2014). Lightning fire occurrence can be especially problematic for managers given that summer thunderstorms can produce enormous numbers of cloud-to-ground (CG) lightning strikes starting numerous fires in a short time. These outbreaks can quickly overwhelm an agency's suppression resources leading to increased acreage burned and other human-based impacts.

The Wildland Fire Assessment System (WFAS,www.wfas.net), in existence since 1996 gives land managers the ability to spatially assess fire potential on a national or regional basis with time scales ranging from 1 to 5 days (Burgan, et al. 1997). This paper describes the spatial lightning products provided by WFAS and available to help wildland land managers assess when and where fires are expected to occur using lightning location, weather and fuels data.

WFAS DRY LIGHTNING

Dry lightning occurrence is of critical importance to land management agencies since it is most likely to cause wildland fires. Dry lightning is CG lightning without any accompanying rainfall nearby. It is produced by "dry" thunderstorms which are particularly common in the western US during the summer months. These type of storms occur when rain produced by convective cells falls through a layer of very dry air evaporating the precipitation before it reaches the ground. Such storms can produce large amounts of CG lightning, have relatively high cloud bases and can produce strong gusty winds at the surface which exacerbate fire behavior. A storm does not have to be completely lacking in precipitation to be considered dry; in the western US, one tenth of an inch of precipitation is the threshold between a dry and wet storm. Recent dry lightning research has concentrated on using upper air measurements--atmospheric stability and moisture content to predict dry lightning episodes in advance of storm arrival (Rorig and Ferguson 1999). The Storm Prediction Center (SPC) has an experimental Dry Thunderstorm forecasting product (www.spc.noaa.gov/exper/dryt/) which combines weather model output and derived equations to predict potential dry lightning episodes up to 180 hours in advance. Given that predictive tools are in existence pre-event, spatial products are needed to give managers an idea of where dry lightning has occurred immediately after the storms have passed.

Two associated maps are produced daily in WFAS. One shows grid cells that contain dry lighting overlying the 24 hour estimated rainfall while the second displays the dry lightning grid cells overlying current fuel "dryness" levels (http://www.predictiveservices.nifc.gov/outlooks/7-Day_Product_Description.pdf).

Dry lightning grids are created by merging daily estimated rainfall grids, produced by the National Weather Services (NWS) Advanced Hydrologic Prediction Service (AHPS), with two polarity segregated lightning density grids, produced from daily cloud to ground lightning strike data furnished by Weather Services International (WSI). A lightning fuel type grid converted from a cover map (Schmidt et al., 2002) is used in the dry lightning cell calculation. The lightning strike and estimated rainfall data are adjusted for the 24-hour hydrologic day (ending at 1200GMT) used by AHPS.

Latham and Williams (2001) theorized that positive CG strikes are most likely to ignite wildfires. Therefore the lightning density grids are segregated into two grids: one for positive and one for negative CG strikes. All grids have a 4 km pixel size. The lightning fuel type grid is static while the lightning density, estimated rainfall and dryness grids are recalculated daily. A dry lightning grid cell exists when three criteria are present: rainfall less than 0.10 inch (0.25 inch for the Southern and Eastern GACC maps), fuel (not classified as barren, urban or water), and a positive or negative CG lightning strike. Dry lightning grid cells are displayed based on strike polarity. If both positive and negative strikes occur in a cell, the cell is classified as "positive."

Figures 1 and 2 show typical Dry Lightning/Estimated Rain maps during early and late fire season.

The 24 hour estimated rainfall is compiled by AHPS using area River Forecast Center (RFC) data. The fuel dryness levels are determined on a daily basis by the National Weather Service (NWS) Office in Missoula, Montana using data from the regional Geographic Area Coordination Centers (GACC) (gacc.nifc.gov). Dryness level is a combination of one or two fuel dryness and/or fire weather indices which correlate well to large fire occurrence. These dryness levels are:

- Moist (Green): Indicates a burn environment which has historically resulted in a very low or no probability of new large fires or significant growth on existing fires, even when accompanied by critical weather events.
- Dry (Yellow): Indicates a transitional burn environment that typically results in low probabilities of new large fires or significant growth on existing fires unless accompanied by a critical weather or ignition trigger event.
- Very Dry (Brown): Indicates a very dry burn environment which has historically resulted in a higher than normal probability of significant fire growth and new fires, especially when accompanied by a critical weather or ignition trigger event.

Areas that SPC delineated as having a significant threat of wildfires where pre-existing fuel conditions combined with weather conditions such as wind or relative humidity create a “Critical” or ‘Extreme” Fire Weather Area are also shown as polygons. Critical Fire Weather Areas for wind and relative humidity (RH) are defined when strong winds and low RH are expected to occur where dry fuels exist. Extremely Critical Fire Weather Areas for wind and relative humidity are delineated when very strong winds and very low RH are expected to occur with very dry fuels. Dry lightning grid cells within these areas should provoke close scrutiny since they have a much higher likelihood of igniting a wildfire.

Figure 3 shows a typical Dry Lightning/Dryness map for the US during the early summer. Notice that the majority of the dry lightning cells fall into burn environments considered to be “Moist.” This is common for areas that are not experiencing drought conditions. It illustrates the fact that dry thunderstorms producing CG strikes with little or no rain occur but unless they take place in areas of dry fuels/burn environments, the likelihood of an ignition or large fire is low. The blank area in eastern Montana and North Dakota indicates that no report was filed for that particular day and therefore the area is designated as “No Dryness Data.”

There are regional differences in the definition of a dry lightning strike. Dry lightning maps are available based on GACC boundaries. The Eastern and Southern area maps have a rainfall threshold for a dry lightning event of 0.25 inch or less. All other regions use an estimated rainfall threshold of 0.10 inch. The Dry Lightning/Estimated Rain map is also available in a Google Earth KMZ format.

Figure 4 shows an example of a Dry Lightning/Estimated Rain map based on data from the Southwest Geographic Area Coordination Center.

WFAS POTENTIAL LIGHTNING IGNITIONS

The WFAS Potential Lightning Ignition map spatially integrates the WFAS Lightning Ignition Efficiency map http://www.wfas.net/index.php/lightning-efficiency-fire-potential--danger-33 with daily cloud-to-ground (CG) lightning strike data. The 24 hour "day" runs from 0000 to 2400Z (1800 MDT).

The WFAS Lightning Ignition Efficiency map is based on the concept that lightning fires are started by CG strikes that have a continuing current. All positive discharges have a continuing current, and about 20% of negative discharges have one (Fuquay, 1982). Ignition depends on the duration of the current and the kind of fuel the lightning hits. Ignition in fuels with long and medium length needle cast, such as Ponderosa pine and Lodgepole pine, depend on fuel moisture. Ignitions in short-needled species, such as Douglas-fir depend far more on the depth of the duff layer than on the moisture (Latham and Schlieter, 1989). Spread of the fire after ignition usually depends on fuel moisture and other topographic and weather factors. The ignition efficiency on a 1 km pixel is given on a per discharge basis. That is, if the efficiency is high, then about nine discharges will result in one ignition; if the efficiency is extreme, about five or fewer discharges will result in an ignition. The ratio of positive and negative discharges is built into the calculation. Latham and Schlieter, (1989) document the efficiency algorithms. The fuel type and depth are conversions of the 1 km resolution current cover type (Schmidt, et al, 2002) for this specific calculation. The moisture input is the 100-hr dead fuel moisture calculated in the afternoon and obtained from the National Fire Danger Rating System (NFDRS).

The Potential Lightning Ignition map splits the CG strike data and Lightning Efficiency calculations into separate datasets for positive and negative discharges. Potential ignition values are simply the cell's efficiency value multiplied by the number of lightning strikes in the cell. Sopko, et al. (2007) described the general process. Separate polarity-based potential ignition values are calculated and then recombined to provide the total potential ignitions per 1km pixel. Positive discharges yield higher efficiency values and increase the likelihood of an ignition. Under extreme conditions, two positive discharges (per pixel) would result in one ignition. Regardless of polarity, more CG strikes per 1km pixel increase the likelihood of a potential ignition. Pixel values are the number of potential fires. Values of less-than-one fire are possible and happen when a discharge(s) occurs in combination with pixels having low efficiency values or when a single discharge occurs in a pixel. Therefore, the map legend converts potential fire values to adjective classes similar to the familiar fire danger rating system.

Presently, rainfall that occurs in conjunction with the lightning-producing storm cell is not part of the efficiency calculation. In general, higher rainfall amounts correspond with higher CG strike rates and clustered potential ignition pixels. Dry fuels in addition to numerous CG strikes are needed to produce an ignition. Presently, the calculation favors large numbers of clustered CG strikes (where there is generally a large amount of rain) over dry fuels (low 100 hr fuel moisture values) creating false high pixel values in areas that experience large thunderstorm complexes such as the US Midwest. Pixels which are isolated and possess a high potential ignition value, signify areas that have a higher likelihood of a "dry" lightning strike.

Figure 5 shows a typical Potential Lightning Ignition map for the US during the late summer. Figure 6 shows a magnified cutout of an area of the south-central US detailing areas where high CG rates in summer mesoscale complexes can lead to pixels with Moderate-High designations or more potential ignitions.

LIMITATIONS

A. Dry Lightning maps

There are several limitations for dry lightning maps. Dry lightning maps can only identify areas where a CG strike occurred in conjunction with little or no rain. The Dryness overlay gives a sense of the general fuel condition over a large area but it does not account for variables such as site-specific fuel condition, weather and topography, which have important influences on ignition potential and fire spread.

Pixel size is large (4 km) in relationship to the scale at which lightning ignitions occur. The actual size of the lightning strike's core is measured in centimeters while the variability of fine fuel and duff moistures can be measured in meters due to sheltering provided by individual trees and other natural factors.

Wotton and Martell (2005) have shown that the time of day of a storm's occurrence can have a significant influence on the probability of ignition in Ontario. These lightning strike data and maps are not segregated by time of day.

Errors in reported lightning position and detection efficiency can skew the lightning activity reported for each pixel. Spatial accuracy of the lightning detection network is 1-2 km and strike detection efficiency is 80-90%.

B. Potential Lightning Ignition maps

There are also limitations in the Potential Lightning Ignition maps. Large, wet thunderstorms, especially Midwestern mesoscale complexes, put out copious amounts of CG strikes within their cores coinciding with high rainfall rates. The coincidental large number of strikes per pixel leads to high value potential ignitions. The user is instructed to look for isolated cells with high potential ignition values since these probably occur in an area with dry fuels/numerous "dry" strikes.

The moisture content of forest fuels, especially fine fuels can vary considerably within small distances. The current method of estimating the 100- hour fuel moisture using weather station observations and interpolating between them can lead to misrepresentations, especially in areas of low spatial station density.

Lightning ignitions can smolder for weeks before either dying or becoming a detectable fire. These "holdover fire" events can present problems that are outside the scope of the maps since there is scant data available detailing development between a lightning ignition and a detected fire.

CONCLUSIONS

WFAS provides three daily products that use lightning location combined with weather and fuels data: Dry Lightning/Estimated Rain, Dry Lightning/Dryness and Potential Lightning Ignition. The Dry Lightning/Estimated Rain map shows where CG lightning occurred in conjunction with little or no rainfall ("dry" lightning) under-laid by the 24-hour estimated rainfall. The Dry Lightning/Dryness map also shows where dry lightning has occurred but it is under-laid by a map showing general fuel "dryness." The processes used to create these maps are described and examples are provided in this paper. Assumptions and limitations of the model can be attributed to input data or lack thereof and are described. Currently there are predictive tools available that help identify dry lightning episodes up to 180 hours in advance. The WFAS maps provide guidance as to where potential ignitions have occurred the day after the storms have passed. These tools can be used by fire management to help direct resources, especially aerial detection, to areas where ignitions are most likely to have occurred.

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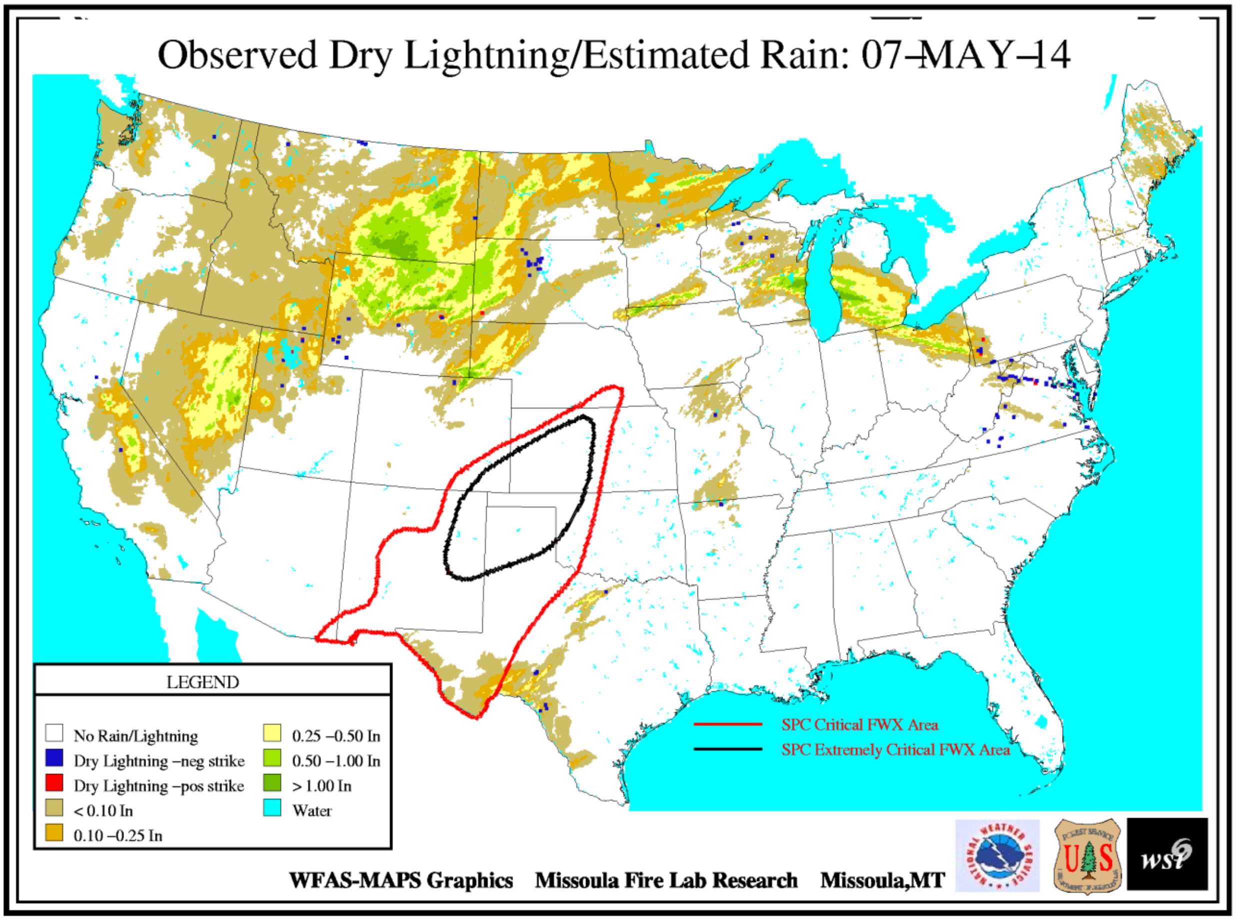

Figure 1. Dry Lightning/Estimated Rain map for the Continental US during mid-spring

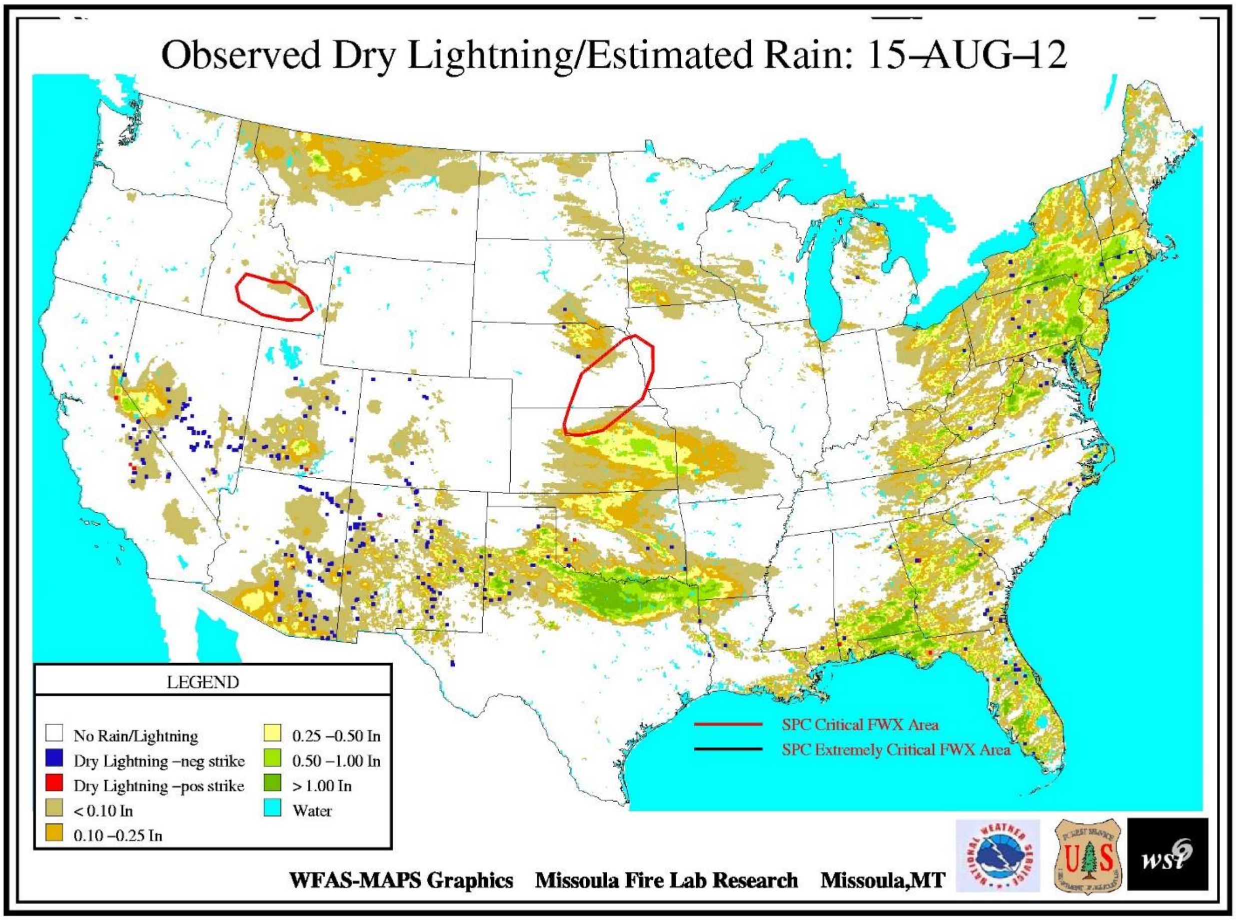

Figure 2. Dry Lightning/Estimated Rain for the Continental US during the late summer

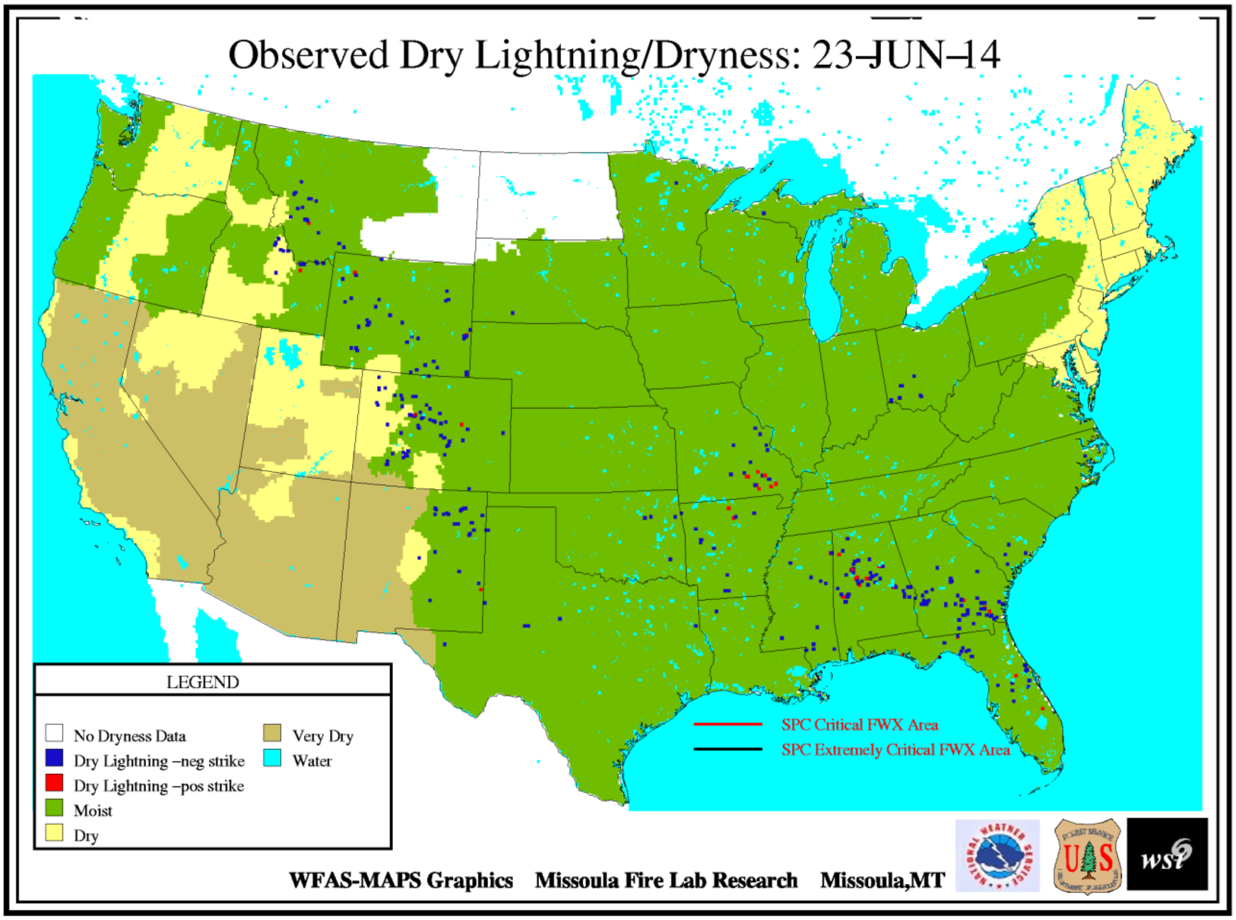

Figure 3. Dry Lightning/Dryness for the Continental US during the early summer

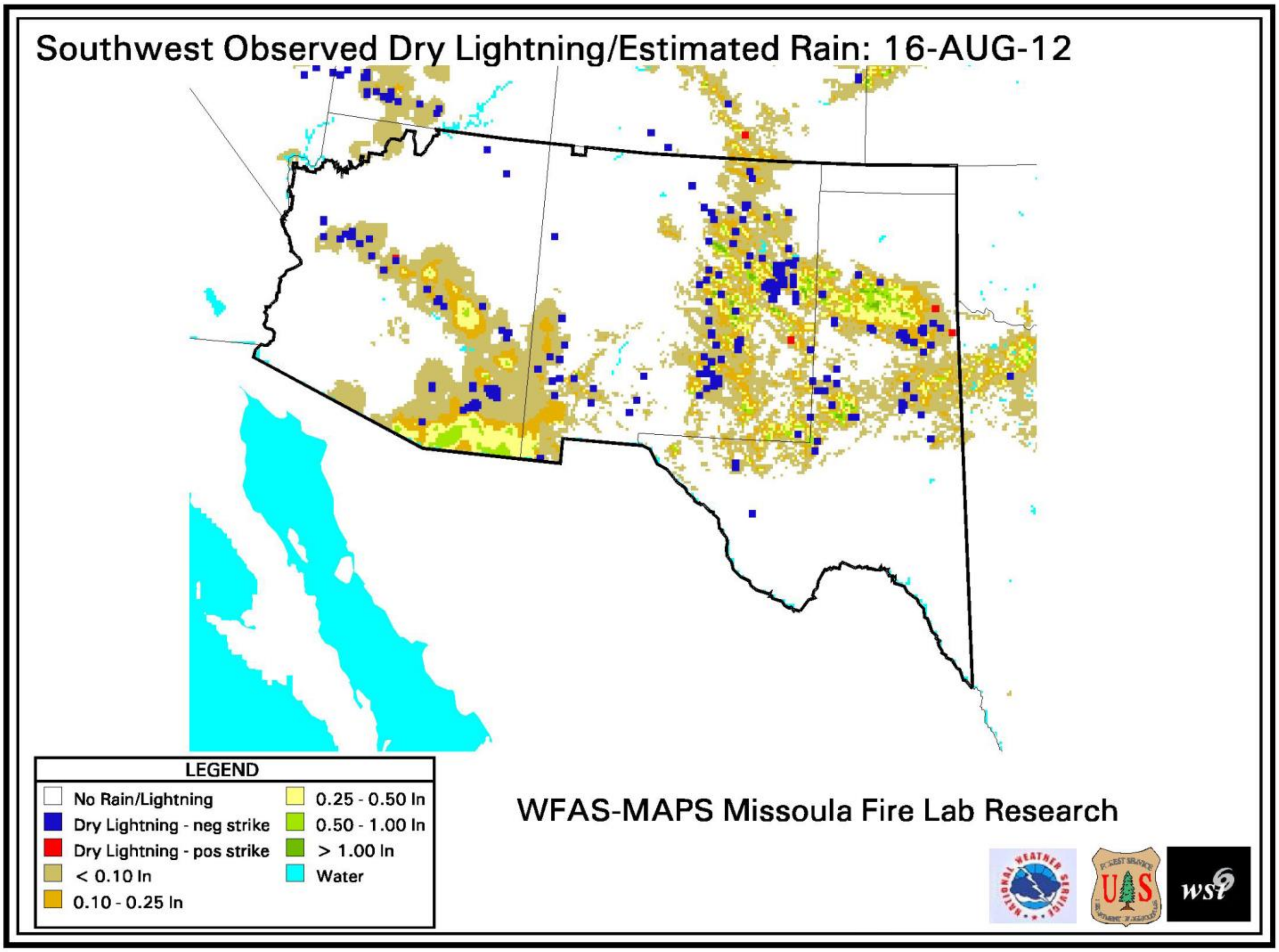

Figure 4. Dry Lightning/Estimated Rain for August 16 2012 for the Southwest Geographic Area Coordination Center.

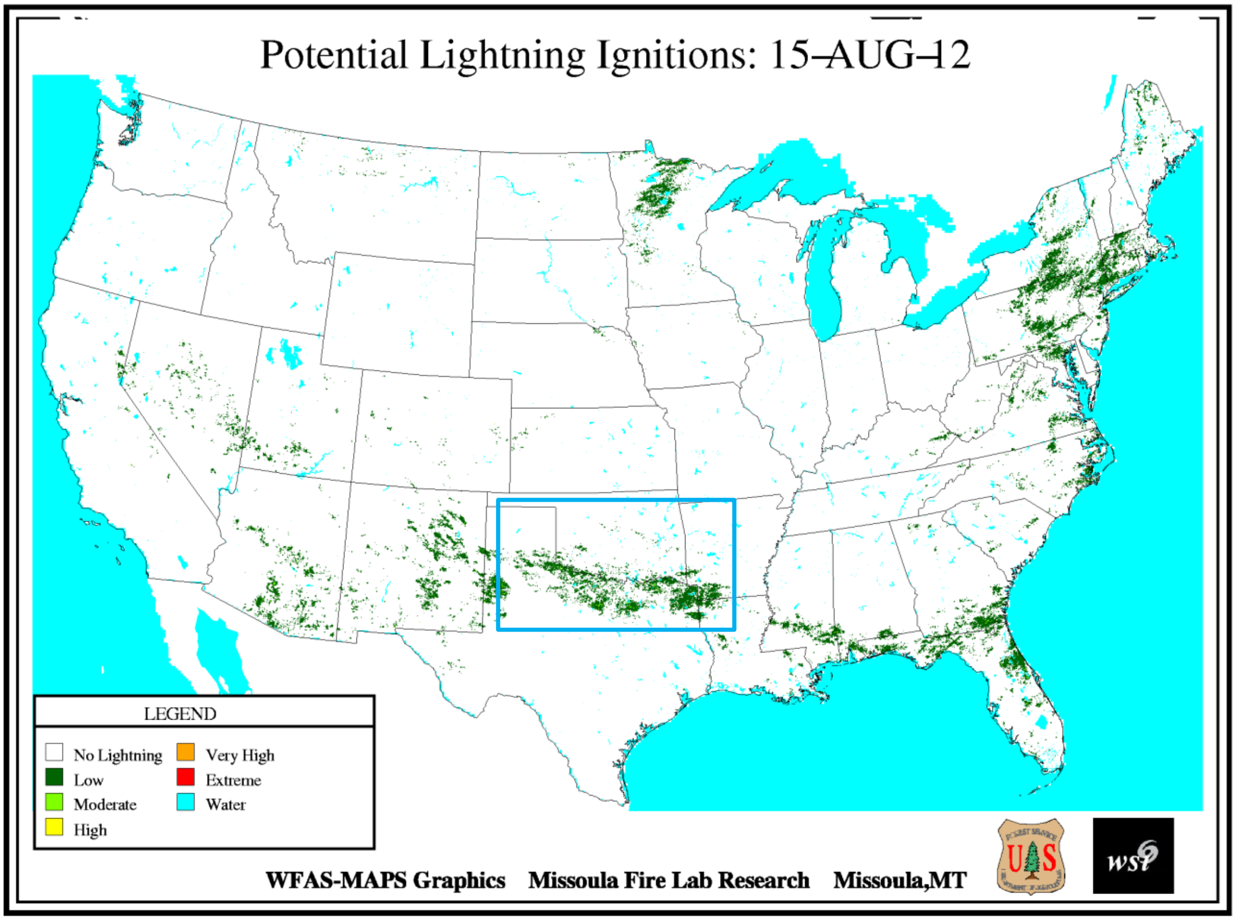

Figure 5. Potential Lightning Ignitions Continental US- late summer

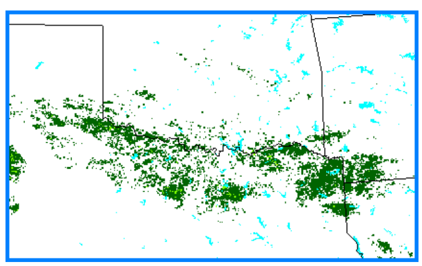

Figure 6. Cutout detail of Figure 5 showing Potential Lightning Ignitions for northern Texas and southern Oklahoma