Regional Likelihood of Very Large Wildfires Over the 21St Century Across the Western United States: Motivation to Study Individual Events Like the Rim Fire, a Unique Opportunity With Unprecedented Remote Sensing Data

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Studies project that a warming climate will likely increase wildfire activity in many areas (Westerling and others 2002; Flannigan and others 2005, 2009; Littell and others 2009). These analyses are often of aggregate statistics like annual area burned, which are insufficient for analyzing changes in seasonality of fire events, the temporal resolution useful for fire management and understanding what drives individual events. Stavros and others (in press, a) show that very large wildfires (VLWFs >20,234 ha ~50,000 ac) may account for only the top two percent of all fires burned in the western contiguous United States, but they constitute a substantial fraction (approximately 33 percent) of aggregate area burned from 1984 to 2010, thus providing strong motivation for understanding what drives them. Using composite records of mean and 95% confidence interval of climate indices for individual fires within a region vs. these same indices the weeks leading up to, including, and post ignition, Stavros and others (in press, a) investigate the spatial and temporal variability of the VLWF climate space. The VLWF climate space was used to define explanatory variables for logistic regression models of the probability of VLWF occurrence with high accuracy of area under the curve (AUC) > 0.80. Assessments of this climate space show that relationships between climate and aggregate area burned may be driven by how VLWFs respond to climate, and that climate and weather both before and after ignition determine fire growth to VLWF size.

Using these models, Stavros and others (in press, b) project the likelihood of VLWF across the western United States using two representative concentration pathways (RCPs): 4.5 and 8.5. Results show a significant ($\alpha \leq 0.05$) difference between the historical modeled ensemble mean probability of a VLWF occurrence from 1979 to 2010 and both RCP 4.5 and 8.5 means during 2031 to 2060. Assessing the likelihood of VLWF exceeding a classification threshold allows analysis of how occurrence may change in the future. For example, with a classification threshold of 0.5, any week with a probability exceeding 0.5 is classified a week when a VLWF occurs. Generally, VLWFs will occur more frequently, and over longer season under both future scenarios RCP 4.5 and 8.5, with more pronounced patterns under RCP 8.5. The biggest changes in likelihood of VLWF occurence depend on whether system's fire regime is flammability-limited, fuel-limited, or mixed. Flammability-limited areas have abundant fuel and require specific conditions for ignition, whereas fuel-limited areas often have conditions suitable for ignition, but not enough fuel. General changes in probability of VLWF occurrence are more pronounced in flammability-limited areas and mixed fire regimes. Results provide a quantitative foundation for management to mitigate the effects of a changing wildfire environment across the western contiguous US, one marked by longer fire seasons with more VLWFs (Stavros and others in press, b). Furthermore, results suggest that understanding what drives VLWFs as individual events is crucial to preparing for the future.

There are a number of techniques for understanding what drives individual VLWFs, many of which include spatially comprehensive, remotely sensed satellite data, but the level of detail from this information can be a limiting factor (Kokaly and others 2007). Often studies relate fire severity, or the magnitude of environmental change caused by fire, to fire behavior, e.g. how much energy is released or flame length. A commonly used remote sensing metric of fire severity, derived from Landsat, is differenced Normalized Burn Ratio (dNBR) (Key and Benson 2006; French and others 2008). The dNBR is a normalized spectral index derived from the differences between pre- and post-fire red (0.615-0.680 µm) and shortwave infrared (SWIR: 1.750-2.400 µm) (Key

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and Benson 2006). Although dNBR is used as a fire-severity metric, it requires ecosystem-specific calibration with field data to derive biophysically meaningful quantitative estimates (French and others 2008). As an alternative to assess fire severity other studies have used spectral mixture analysis (SMA) to estimate fractional char cover (e.g., Lentile and others 2009; Veraverbeke and Hook 2013). SMA and dNBR are currently used with broadband satellite remote sensors, like Landsat, but newer technologies with finer spectral information and more complete coverage of the IR spectrum may improve data quality (Kokaly and others 2007). Technologically advanced imagers are difficult to apply, however, because they are often first heavily tested on airborne platforms before being launched into orbit. Consequently, studies have mostly focused on post-fire data alone with these advanced data sets because access to pre-fire data has been limited as a result of the unpredictable nature of wildfires.

August 2013, however, presented a unique opportunity to study unprecedented amounts of pre and post-fire remotely sensed data at particularly fine spatial (~1-40 m) and spectral resolution with bands from visible to thermal infrared. A VLWF, known as the Rim Fire, burned 104,131 hectares (257,314 acres) in Yosemite National Park and the Stanislaus National Forest before extinction on October 24th, 2013. Raw data provided by flight line came from three airborne sources: (1) the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS); (2) MODIS/ASTER Airborne Simulator (MASTER); and (3) high-resoultion, discrete-return LiDAR. These data cover 100% of the Rim Fire with a 2-km buffer after the fire, and approximately 5%, 50% and 95% before the fire for LiDAR, AVIRIS, and MASTER respectively. AVIRIS and MASTER are part of the HyspIRI airborne campaign to provide a testbed for what will be possible with these kind of datasets once these technologies are launched into orbit. Considering future applications, these data are being processed for the fire perimeter, with a 2-km buffer, into atmospherically and topographically corrected surface reflectance, surface metrics (for example, canopy surface and digital elevation model), and indices widely used by researchers and decision makers (available for download: RimFire.jpl.nasa.gov). These airborne data at high spectral and spatial resolution, unparalleled by any satellite data, provide a unique opportunity to cross-reference remote measurements collected from different technologies to assess VLWF characteristics specifically related to fire behavior and fuel dynamics.

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