Analyzing Extreme Behavior of the North Star Fire
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Introduction
The North Star Fire began on August 13, 2015 and burned over 218,000 acres. It is the largest of the Washington State 2015 fire season and 4th largest in recent state history (Inciweb). Current fire prediction models such as the Haines Index provide only broad forecasts for fire behavior. Pyrocumulus (PyroCu) and Pyrocumulonimbus (PyroCb) clouds have been observed in large wildfires and can inject smoke high into the atmosphere where it persists for much longer and with lasting effects on human health and global warming. Often the upper index of these predictive models is encoded in many extreme fire events. Updated models such as the Continuous Haines Index (C-Haines) attempt to extend the upper limit in order to include the most extreme fire behavior (Mills et al., 2010). The goal of this project is to identify and quantify fire growth, potential PyroCu/PyroCb development, and compare these to atmospheric events at the time using a combination of ground, airborne and spaceborne instruments.

PyroCu/PyroCb and FRP
MODIS Aqua true color imagery is used to ocularly identify PyroCu/PyroCb clouds above the North Star Fire perimeter. The MODIS satellite also has thermal sensors that can measure the radiative power (FRP) of fire, which can be used as an estimate for burning intensity. FRP will be summed each hour of the date-time signature and then divided by the number of available observations during each hour interval to achieve normalized values. (Peterson et al., 2015)

Atmospheric Anomalies
North American Regional Reanalysis (NARR) archives for Geopotential Height contours and wind speed/directional vectors for 3-hour composites at 250, 500, and 850 mb are retrieved and analyzed to identify atmospheric conditions before/during/after potential PyroCu development, high FRP events, and large growth days.

Smoke and Aerosol injection
Aerosols injected into the atmosphere by the North Star Fire are detected via multiple sensors including NASA Worldview Optical Depth (ACD) layer (via Aqua MODIS), verified using NOAA HYSPLIT archived trajectory model, and identified in a vertical profile for presence at specific atmospheric levels using CALIPSO Satellite day and night observations in the direction of suspected smoke and aerosol transport (Sienko, 2015).

Haines environment and Vertical Atmospheric Stability
Wind speed and relative humidity data are collected at the Omak weather station (OMAW) and are available at 15-minute intervals. The Spokane weather station (OTX) utilizes weather balloon sounding to collect temperature, dew point temperature, and wind speed/direction at 850 and 700 mb in order to calculate normalized values. (Peterson et al., 2015)

Haines Index (2-6) = Stability Score (CA) + Moisture Score (CB)

Haines Index Values

<table>
<thead>
<tr>
<th>Value</th>
<th>Score</th>
<th>C-Haines</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 or Less</td>
<td>1</td>
<td>5 or Less</td>
</tr>
<tr>
<td>6 to 10</td>
<td>2</td>
<td>6 to 12</td>
</tr>
<tr>
<td>11 or more</td>
<td>3</td>
<td>13 or More</td>
</tr>
</tbody>
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CA = (T850-T700)/2-2

Calculated C-Haines and traditional Haines index values compared to total fire acreage from 14 AUG - 06 SEP.

Discussion
PyroCu event #1 coincided with largest FRP hour from 1400-1435 LT of 689 MW. Officials successfully predicted extreme behavior for 08/19. C-Haines values calculated for afternoons on 8/17 and 8/18 reveal increasing risk for extreme fire behavior with C-Haines scores increasing above 11. Upper atmospheric (240 MB) composite from 0200-0900LT shows fire location near the center of high pressure ridge from S->N but also at the crux of a weak pressure gradient going SW->NE. Skew-T plot extremely high deep point depression (DPD) from 1300-1600W at 1400M. Event #2 occurred after a cutoff low rejoined an incoming low pressure system, displacing a longwave ridge of higher pressure. A high normalized FRP value from 1200-1500LT of 46 MW was observed at the time of PyroCu development. Eastern WA again was near the crux of a long-wave GPH axis going SW->NE and was directly under a high pressure block, observed from 0700 (LT) 22 AUG to 0700 (LT) 24 AUG. The Skew-T plot showed a far lower DPD from 1400-1500W at 1500M. C-Haines value of 92. The climatic conditions during each event are discrete, although they share some characteristics such as location along a troposphere. Aqua MODIS satellite can only capture early afternoon true color imagery and at a resolution of 250 m/pixel, while PyroCb are most mature in the late afternoon/evening and occur because of intense, even at the finest resolution. PyroCu development in past large wildfires is not consistently documented and performing more individual studies will improve understanding of weather patterns that preclude PyroCs.