Wildfire Smoke Spectra and Long-Distance Atmospheric Transport

Murtadee Hughes, John E. Sohl; Dept. of Physics & Astronomy, Weber State University, Ogden, UT

Introduction & Background

Wildfire smoke in the Western United States is an increasing concern for air quality. Smoke aerosols are often transported several thousand kilometers. Satellite images provide large scale information, but direct measurement could fill-in more details. One solution for direct observation is ground-based spectrometers measuring an atmospheric column between the ground and the Sun.

We used two spectrometers to investigate measuring an air column and looking for a smoke signature. Due to instrument availability most of these exploratory measurements are with an Ocean Insight HR4000 spectrometer.

Preliminary Tests

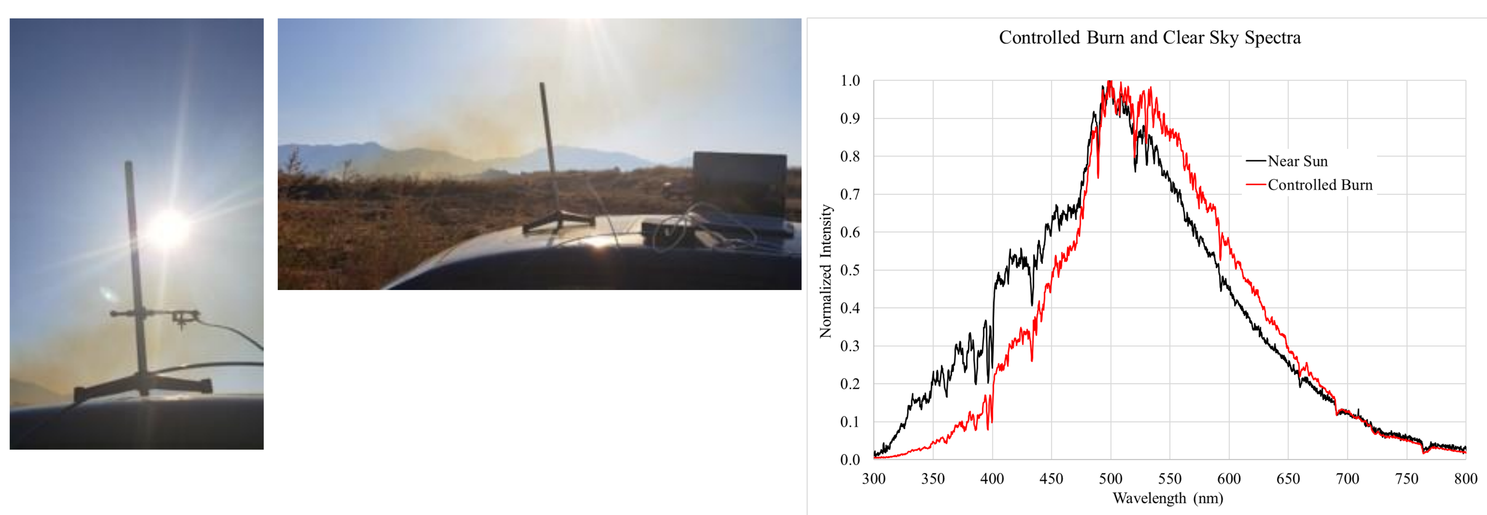


Figure 1. Smoke being measured from a controlled burn with a sample spectrum from those initial measurements. Brown colors are stronger and the shorter wavelengths are either absorbed or scattered.

Preliminary measurements were made at a controlled burn. It can be seen with the naked eye that the smoke has a range of colors from grey to brown. The spectrometer quantifies the colors in the resulting scattered light. About 40 spectra were collected in 2019 at a controlled burn with a clear signal showing the colors that combine to create brown. The spectra varied as the smoke evolved making it clear that further research would be valuable in the detection of long-distance transport from wildfires.

Exploratory measurements were made during the wildfire seasons of 2020 and 2021. Approximately 60 spectra were collected.

A range of conditions were explored including different smoke quantities and transport distance along with how the data were collected. Two spectrometers were used for data collection, an OceanOptics (now Ocean Insight) HR4000 UV-NIR (200 nm - 1100 nm, with 0.75 nm resolution) and a custom spectrometer built by a member of the HARBOR Team using a Hamamatsu model C12666MA Sensor (340 nm - 780 nm, with 15 nm resolution). Both spectrometers were pointed in three locations: directly at the Sun, ≈3-5° from the Sun ("near-Sun"), and ≈20° from the Sun ("blue sky"). Our best results (strong signal, high repeatability) were from the "near-Sun" measurements. The direct Sun measurements often saturated the detector and were more difficult to get the correct alignment. The "blue sky" measurements did not have a sufficient amount of light in the background to provide scattering in our desired wavelength range of interest (500 nm - 800 nm).

The custom spectrometer is promising and compared well with the commercial unit but was not used extensively because our primary energies were put towards interpreting and understanding the collected data first. Though preliminary results indicate that it should be possible to build a system to detect the smoke spectra for a cost near $500 that is also highly portable.

Data & Analysis

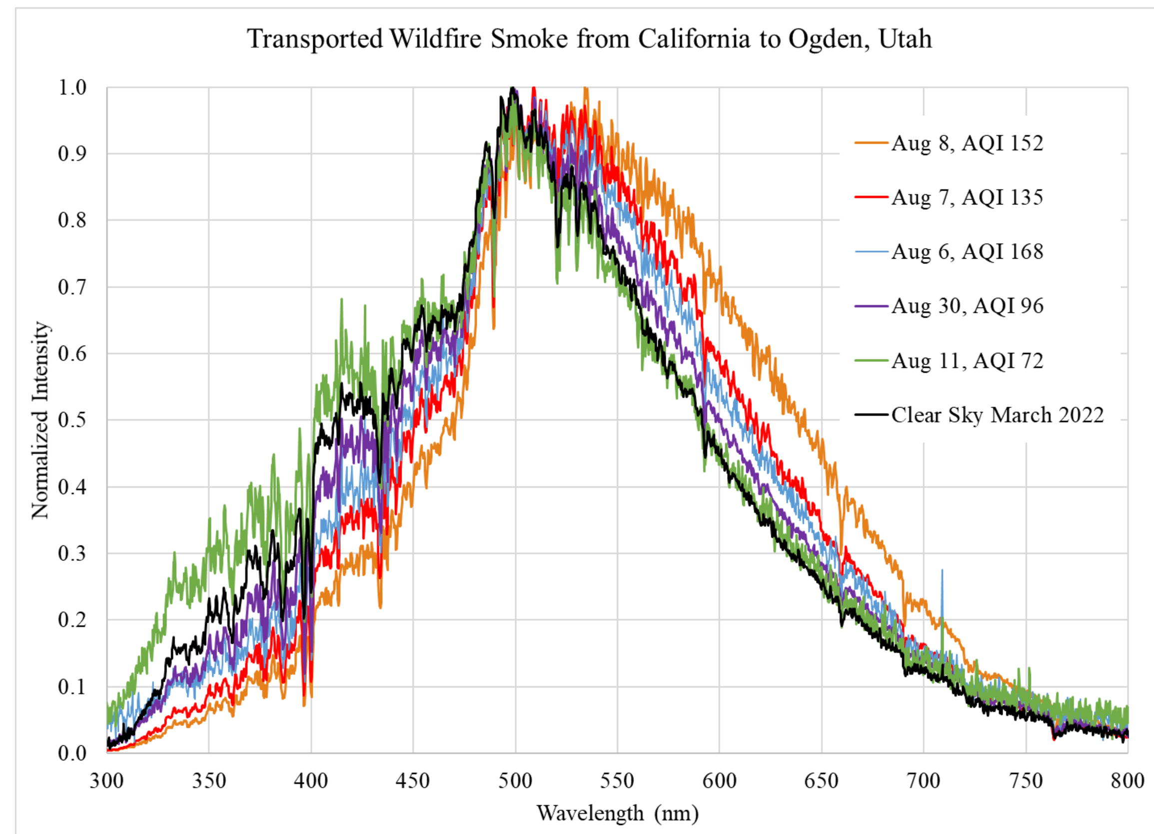


Figure 2. Spectra of smoke transported primarily from California as measured from Ogden, UT. Spectral intensity differences below 300 nm and above 800 nm were minimal. The AQI values are from a ground level PurpleAir monitor close to where the measurements were made. These data were collected at approximately 1400 hours on the dates listed.

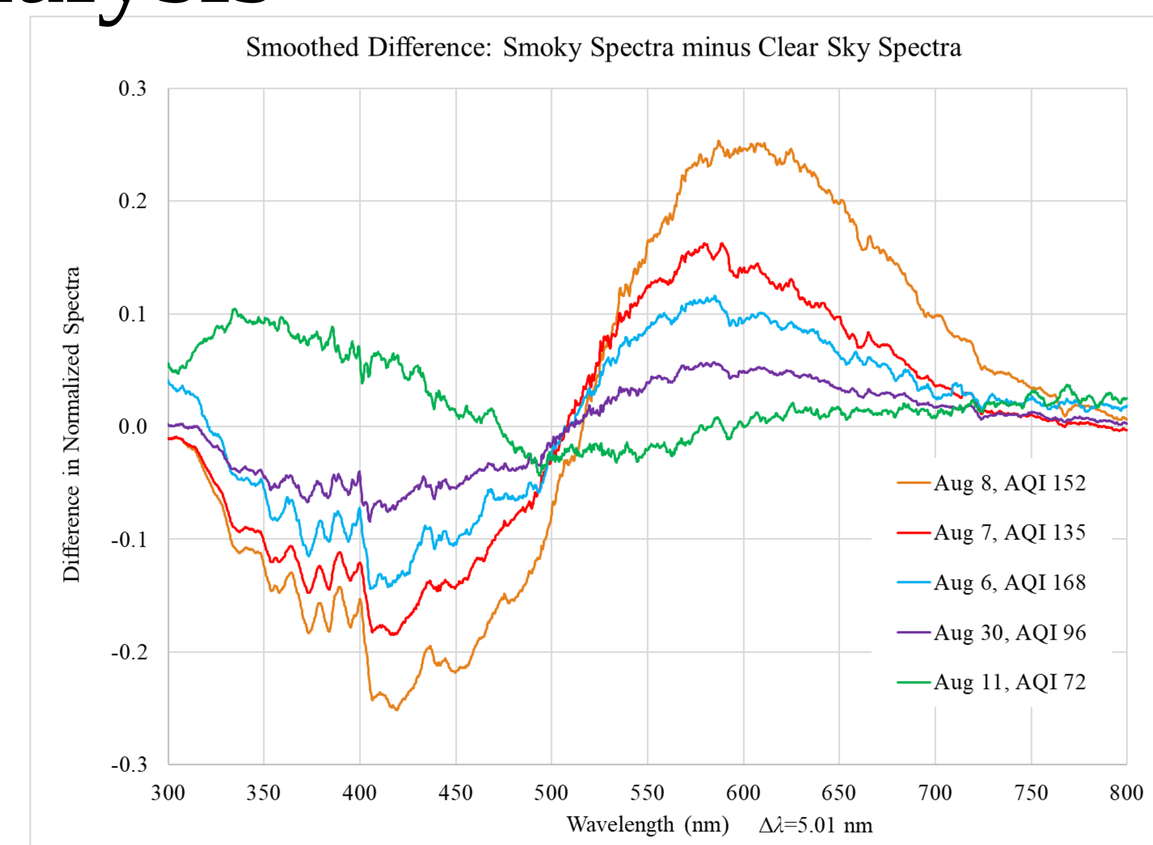
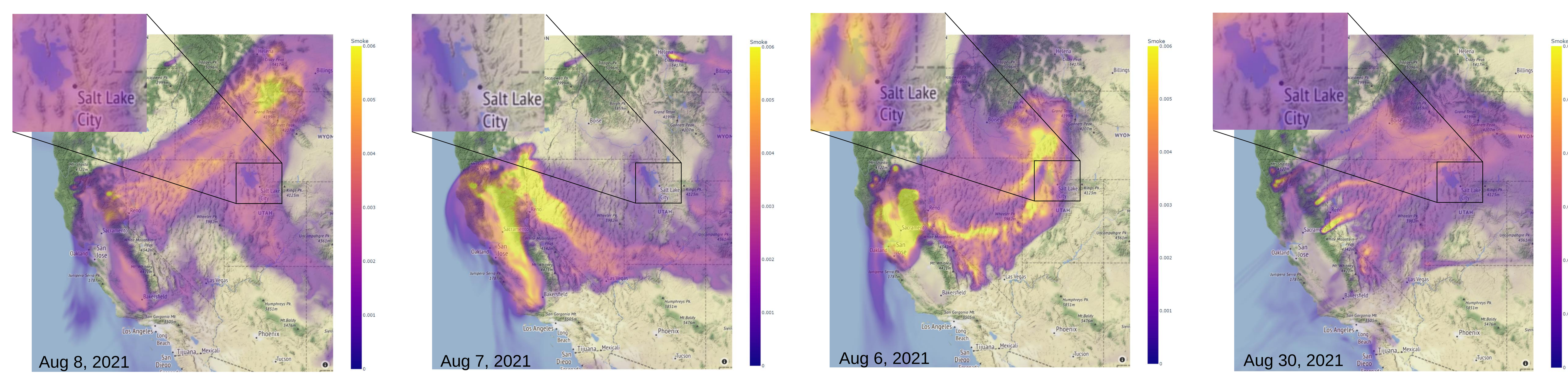
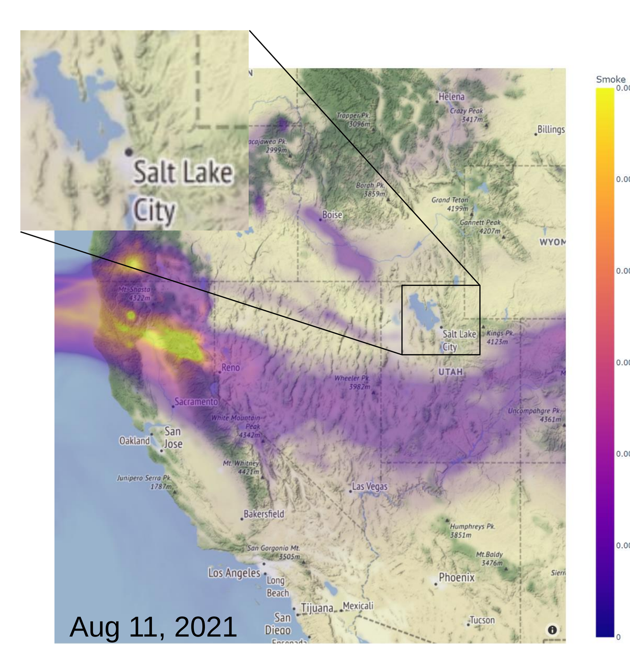


Figure 3. Smoothed difference spectra showing the smoky day spectra with the clear sky spectra subtracted. As expected, "brown" (a mixture of red through green) shows up strongly, even when it is not visually obvious. Blue light is either scattered and/or suffers strong extinction. We don't yet understand the August 11 data.





Figures 4. HRRR-smoke vertically integrated smoke data. These models are the 1-hour prediction for 1800 hours on the dates shown. The heat map scale is 0 to 0.006 μg/m³. for the total column-integrated mass density (COLMD). The "blue sky" (no smoke) spectrum that we use as a comparison is from a day (March 12, 2022) with COLMD values less than ten thousand times smaller than these smoky days.

The sequence of these images is based on the strength of the spectral signals in figures 2 and 3.

Discussion

The agreement between the spectral signal and the HRRR-smoke data is excellent. At first glance, the August 6 (AQI 168) appears out of sequence, however the smoke plume was moving across northern Utah at the time. The HRRR-smoke data are for 1900 hours (1800 hours, 1-hr prediction). When the August 6 spectrum was taken ground-level smoke was building but total column smoke had not yet risen.

The August 30 data are surprising. Visually the sky looked "clear", but the smoke signal is strong in the spectrum which is consistent with the HRRR-smoke data.

Future work will include comparisons to the 2-D aerosol optical depth (AOD) predictions contained in the HRRR-smoke data.

Conclusions

1. These initial results are promising and worth further investigation.
2. Smoke shows up in the spectral data even when your eyes cannot see any obvious smoke in the sky.
3. Spectra taken 3-5° from the Sun were more repeatable day-to-day than spectra of the direct Sun or of "blue sky" (≈ 20° from Sun).
4. Thin clouds gave predictable results in the green to blue spectral region but are not yet understood in the red to green region. For now, we are avoiding days with any cloud cover.
5. Taking spectra through window glass results in a predictable shift. For best comparison, all spectra should be either "outdoors" or through the same window glass.
6. No obvious spectral lines were detected that we could unambiguously attribute to the smoke. The solar Fraunhofer lines clearly show up.
7. Adding in situ drone data of particulates from controlled burns while also measuring the spectrum is worth the effort.

Acknowledgments

HRRR-smoke vertically integrated smoke data provided by Eric James (CU CIRES / NOAA GSL)
Controlled burn data and images taken by WSU HARBOR student Jeff Kindall.
Funded by a generous grant from an anonymous donor, thank you IAS.