Smoke Properties as a Function of Fire Type, Age & Altitude

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CO data from G. Diskin & J. DiGangi, NASA Langley Research Center; AMS data from J. Jimenez, UC Boulder
SO_2 data from G. Huey, Georgia Institute of Technology; NO_x (NO + NO2) data from T. Ryerson, NOAA ESRL
HNO_3 data from P. Wennberg, California Institute of Technology

Motivation

Smoke emitted from biomass burning can not only affect local air quality but also have detrimental affects on regions downwind and perturb the Earth's radiative balance. Laboratory studies have shown that aerosol emissions from fires are highly heterogeneous with dependence on the fuel type and fire conditions. In addition, aerosol properties change as the smoke ages due to depositional loss, photochemical processing, coagulation, bidirectional adsorption/desorption of gas-phase species, and dilution.

Measurements during SEAC⁴RS allow for an analysis of smoke properties. These include wildfires in the western United States and agricultural fires in the southeast. Future work will compare these measurements to sampling during other recent NASA campaigns:

- DISCOVER-AQ-Texas: Fresh and Aged Agricultural Fires
- ARCTAS: Fresh Boreal Fires in Canada and Grassland Fires in California

Aerosol Optical Properties

Single Scattering Albedo (SSA)
- Aerosol Scattering / Extinction
- As absorption increases, SSA decreases

Aerosol Hygroscopicity: f(RH)
- Scattering at 80% RH / Scattering at 20% RH
- Water-uptake potential of aerosol; dependent on composition

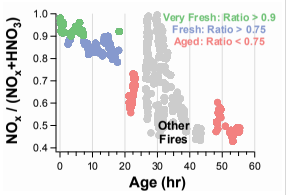
Angstrom Exponent of Scattering (SAE)
- Wavelength dependence of scattering
- As aerosols get larger, SAE decreases (dust ~ 0)

Angstrom Exponent of Absorption (AAE)
- Wavelength dependence of absorption
- Black Carbon (BC) ~ 1; light-absorbing organics (brown carbon, BrC) > 1

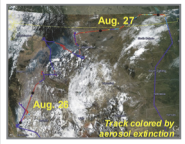
Methods

Composition:
- BC mass (SP2) & sub-micron composition (AMS)
- Filter measurement of water-soluble organic carbon (WSOC) and brown carbon (BrC) absorption

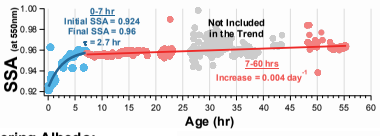
Smoke Identification:
- CO above a threshold – typically 160 ppbv
- Source based on back trajectories & flight notes
- Age:
  - definite source – based on distance from fire and wind measured at the aircraft
  - other – $NO_x/(HNO_3+NO_x)$ decreases with age
    - Rim Fire at right



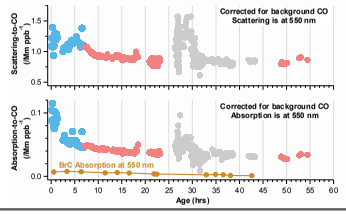
Aging of Rim Fire Smoke

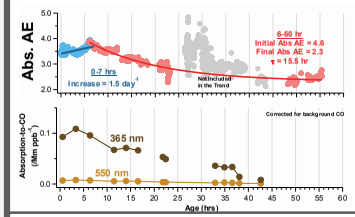


Sampled August 26th & 27th
- Wildfire: brush, oaks, and pine
- Aug. 26: also sampled Little Queen Fire (removed)
- Aug. 27: mixed with smoke from Elk Creek Complex Fire (Idaho) making age less certain



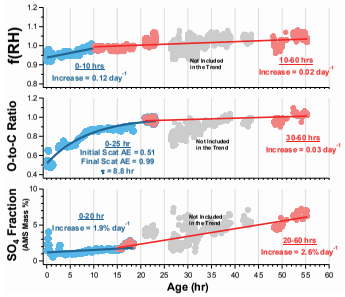
Single Scattering Albedo:
- Increase from 0.92 to 0.96 in 7 hr
  - Scattering increases (relative to CO) due to secondary aerosol formation
  - Absorption-to-CO decreases
- Slight increase after 7 hrs
  - Scattering and absorption decrease at similar rates
  - Possible decrease in abs. due to brown carbon (BrC) bleaching



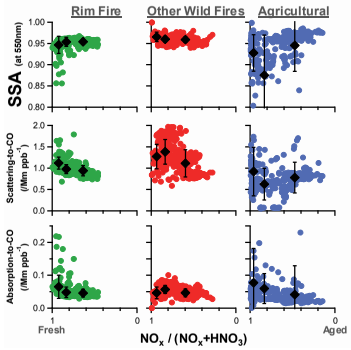


Absorption Angstrom Exponent:
- Increase during the first 7 hours
  - Driven by production of brown carbon (from filter samples)
  - BrC increases absorption preferentially for UV (365nm) over visible (550nm)
- Decay in AAE after
  - Lifetime of 15.5 hrs
  - Coincides with decrease in BrC

f(RH) – Aerosol Hygroscopicity:
- First 10 Hours:
  - f(RH)<1 signifies soot restructuring
  - Increasing f(RH) coincides with increase in organic aerosol oxidation state (O-to-C) ratio and sulfate aerosol formation
- 10-60 Hours:
  - Reduced rate of increase in f(RH)
  - Maximum f(RH) of 1.1
    - very hydrophilic
  - Slower oxidation rate of organics
  - Maximum sulfate fraction of 7%

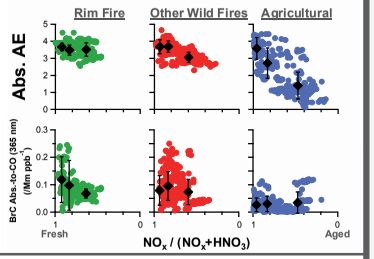


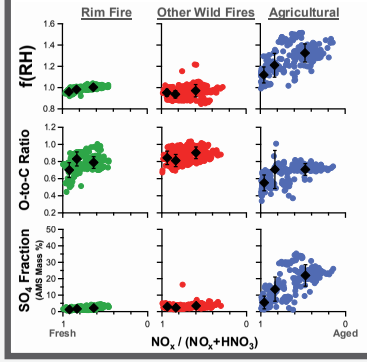
Wild vs. Agricultural Fires



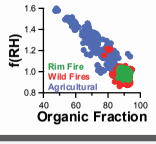
Single Scattering Albedo:
- Large variability
  - Using nitrogen speciation does not provide a good comparison between differing fires
  - Especially for agricultural fires
    - Conditions are more variable
- Agricultural fires have lower SSAs
  - Due to reduced scattering in comparison to wildfires (relative to CO)
  - Absorption-to-CO is comparable amongst fire types

Absorption Ang. Exponent:
- Fresh Smoke
  - AAE ~ 3-4 regardless of fire type
- Decreases with age
  - Possibly due to BrC bleaching
- Aged Smoke
  - Wildfires still have AAEs ~ 3
  - Agricultural Fire AAEs ~ 1
    - Due to lower levels of BrC absorption



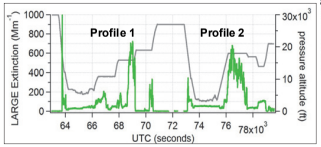


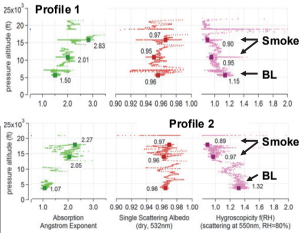
f(RH):
- Increases with age
- Increases with increasing sulfate fraction (measured by the AMS)
  - Or decreasing organics
- Agricultural fires are only ones with increased f(RH) due to high sulfate fractions
- **SO_2-to-dCO (ppt/ppb)**
  - **Wildfires: 0.75**
  - **Agricultural: 7.0**

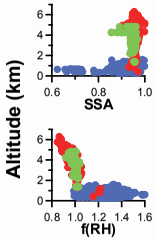


Dependence on Altitude

August 19th: Transported Smoke
- Idaho (Profile 1)
  - 10 hr old smoke at 7 km
  - 1 day old smoke at 4 km
- Wyoming & New Mexico (Profile 2)
  - 3 days old
- Variable aerosol properties with altitude







Single Scattering Albedo:
- Increase with altitude

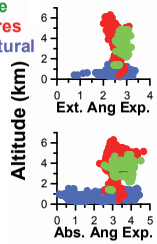
f(RH):
- Decrease with altitude

Extinction Ang. Exponent:
- Variable with Altitude

Absorption Ang. Exponent:
- Increase with altitude

Most variability is due to changes in aerosol type and age with altitude
- Agricultural fires predominantly measured at low altitude
- Freshest wildfire plumes at highest altitudes

Rim Fire
Wild Fires
Agricultural



Conclusions

The Rim Fire allowed for an analysis of smoke properties during the first 2 days after emission
- SSA increases rapidly during the first 7 hours due to secondary aerosol formation
- Slower increases in SSA are possibly due to brown carbon bleaching
  - which also changes the absorption angstrom exponent
- f(RH) increased slowly throughout the two days

Wildfires versus agricultural fires
- Lower SSAs and absorption angstrom exponents for agricultural fires
- Aerosol hygroscopicity controlled by differing sulfur dioxide emissions
  - Wildfire SO_2 emissions are 10 times higher than those for wildfires

Altitudinal dependence of aerosol properties are largely due to differences in aerosol type and age with altitude
- Agricultural fires predominantly measured at low altitude
- Freshest wildfire plumes at higher altitude

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