Naval Research Lab Update:
Toward Improved Predictions of Extreme Fire Spread, Pyroconvection, and Smoke Plume Altitude

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TFRSAC Meeting, 30 April 2014, NASA-Ames
Current Limitations: Smoke Transport Modeling

NRL COAMPS—OS® Seac4rsT2c 15.0km
Valid Time: 00:00Z 17 AUG 2013  Analysis: 00:00
Base Time: 00:00Z 17 AUG 2013

1. Satellite fire data quality?
2. Short-term changes in fire size?
3. Smoke injection altitude?

Goal: Global prediction of smoke emissions!
The Rim Fire’s Extreme Fire Spread and PyroCbs

USFS Fire Progression Map: 8/17 (Ignition) – 8/31

http://inciweb.nwcg.gov/incident/maps/3660/

Arrow Color:
- Ignition/pyroCb period:
  - Light blue: 8/17-8/19
  - White: 8/20-8/21
- Extreme Spread:
  - Dark blue: 8/22-8/23
- SEAC⁴RS Flights:
  - Black dashed: 8/26-8/27

8/22-8/23
8/26/8/27
8/20-8/21
8/19 PyroCb
PyroCb late 8/21
8/17-8/19
SEAC⁴RS
8/26-8/27
Two periods of extreme spread!
Forecast smoke emissions were underestimated!

Should we use fire counts or fire radiative power (FRP)?
Many models are based on fire counts!

2013 Rim Fire

Many artifacts can be corrected!

- Fire growth has strong day-to-day variability
- Satellite time series reflect that variability, and also:
  - Orbital pattern
  - Cloud cover
  - Scan angle
  - Time(s) of observation (diurnal)
- These factors need to be considered when interpreting daily MODIS fire counts and FRP
- NRL is developing a process to correct for all of these effects
  - Substantial improvement in MODIS-vs-GOES correlation
  - Works best at broad scales
1. How can we use weather information to make automated short-term forecasts of emissions for AQ models?

2. Do fire observations contain information to identify potential for high smoke injection and extreme fire spread?

3. How can we use weather information to improve smoke emission estimates in near-real-time and retrospectively?

**Toward Building a Fire Prediction Model**

- **Green:** daily precipitation
- **Red:** MODIS FRP
- **Solid black:** mean
- **Dashed Black:** max or min

**Limitations of Fire Weather Indices**
- Extreme fire danger during majority of Rim Fire
- Representativeness error near small-scale precip
- Lack upper-level meteorology!

See Peterson et al., 2013, Atmos. Env.
Impacts from Upper-Level Disturbances

Can we use upper-air analyses to forecast extreme spread & pyroconvection?

NARR 500 hPa Heights & Wind Barbs, 22 August 2013, 00Z (5 PM PDT, 21 August)

Moving to the NE
Identifying Extreme Fire Spread: Rim Fire

- Spread events driven by upper-levels!
- Higher NWP accuracy at upper-levels?
- Strong surface wind speed overnight!
- Wind direction relative to topography?
- Effect of NWP resolution on surface wind information?

- RH remains low overnight
- NAVGEM (1/3 degree) captures this effect!
- Day/night & upper-level info not included in fire weather indices!
Pyroconvection During Extreme Fire Spread?

8/22/2013 (Extreme Spread)

• Extreme FRP, but atmospheric column was dry
• Only a few capping pyroCu were observed
• Unstable lower-atmosphere (Haines Index = 6)
• Produces a positive feedback loop for spread
• Enhanced by upper-level/nighttime conditions!
Rim Fire Smoke Plume Altitude: Extreme Fire Spread

- DIAL lidar sampled smoke emitted over 48-50 hrs (24-26 Aug.)
  - Mixing with Idaho smoke?
  - Idaho fires were decaying

- Despite extreme FRP and pyroCu, nearly all smoke is below 6 km!
- High enough for long distance transport.

Image from John Hair et al.
NASA DC-8 aircraft during SEAC4RS
**Toward the Prediction of PyroCbs**

**Pyrocumulonimbus (PyroCb) Development**

- How much FRP?
- Low-level instability (Haines Index = 6)
- Moisture/latent heat release is required!
- What is the primary moisture source?
  - Combustion
  - Ambient atmosphere
- Recent modeling studies disagree!

**Hypothesis:** pyroCb environment similar to traditional high-based dry thunderstorms?

- Ahead of approaching disturbance
- Mid-level moisture advection
- Upper-tropospheric lapse rate (UTLR) > 7.5 °C/km
- Divergence at 250 hPa
- What about CAPE?

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e.g. Rorig and Ferguson, 1999; Nauslar et al., 2013
Presence of Mid-Level Moisture: 2013 Rim Fire

Primary Burning Period (17-31 August) Relative Humidity

Cutoff Low | Major Spread | SEAC4RS

Ambient mid-upper level moisture seems necessary!

http://nomads.ncdc.noaa.gov/#narr_datasets
Favorable Meteorology for PyroCb Development

8/19/2013 8/21/2013

- Located well ahead of approaching cutoff low
- Unstable/moist mid-upper troposphere
- In the vicinity of traditional dry T-storms
- Divergence at 250 hPa

GOES West
Aqua MODIS

8/19: 250 hPa Heights, Wind Barbs, & Divergence

Cutoff Low
Ambient moisture
PyroCb Observed!

UTLR = 9.7 C/km
Haines Index = 6

5 PM PDT 8/19/2013

1x10^-5 s^-1
PyroCb Impact on Smoke Altitude

- Most efficient avenue for lofting smoke
  - Aided by latent heat release
- Less important for extreme fire spread
- Upper-level meteorology is key!

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<th>Spread</th>
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J. Campbell, NRL - Monterey
**Characterizing Smoke Plume Altitude using MOD14**

**Peterson et al. (in press, JGR)**

### Low FRPp, Low-Altitude Injection

- **BL\(_{500}\) Injection Probability:** 50%
- **Total FRPp:** 954 MW
- **FRPf Flux:** 8.8 kW/m\(^2\)
- **Mean Fire Temp:** 647 K
- **Total Fire Area:** 0.09 km\(^2\)

### High FRPp, High-Altitude Injection

- **BL\(_{500}\) Injection Probability:** 90%
- **Total FRPp:** 5793 MW
- **FRPf Flux:** 11.4 kW/m\(^2\)
- **Mean Fire Temp:** 643 K
- **Total Fire Area:** 0.54 km\(^2\)
Characterizing Smoke Plume Altitude using MOD14

**Peterson et al. (in press, JGR)**

Low FRPp, High-Altitude Injection

- BL$_{500}$ Injection Probability: 60%
- Total FRPp: 2424 MW
- FRPf Flux: 14.6 kW/m²
- Mean Fire Temp: 663 K
- Total Fire Area: 0.17 km²

High FRPp, Low-Altitude Injection

- BL$_{500}$ Injection Probability: 65%
- Total FRPp: 3517 MW
- FRPf Flux: 14.4 kW/m²
- Mean Fire Temp: 702 K
- Total Fire Area: 0.25 km²

Meteorology must be considered!

Kahn et al. (2007)
Val Martin et al. (2010, 2012)
Conclusions and Future Work

Extreme Fire Spread
- Initiated by the passage of an upper-level disturbance (e.g. cutoff/shortwave)
- Effect on nighttime wind speed and relative humidity is key!
- Likely corresponds to highest FRP

PyroCb Hypotheses
- Meteorological environment is similar to high-based dry thunderstorms
- More important for lofting of smoke particles, less important for fire spread

Signal of Plume Height in MODIS Fire Observations
- All retrieved fire properties (pixel and sub-pixel) correlate with plume height
- Combining pixel and sub-pixel fire data may improve plume height characterization for lower FRPp events!

Improving fire time series with MODIS and GEO satellite data
- Systematic production of MODIS observation quality data and graphics to interpret MODIS fire observations
- Construction of corrected smoke release time series from MODIS and GEO.

Future Goal: Produce a global fire and smoke altitude prediction tool that can be used for operational smoke emissions modeling (e.g. NRL’s FLAMBE).
Thank You!

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Acknowledgements and Related Publications

National Research Council Postdoctoral Fellowship
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Naval Research Enterprise Intern Program


Upper-Level Impacts: SEAC$^4$RS

Periods of extreme fire spread initiated by an upper-level disturbance. SEAC$^4$RS flights preceded by a shortwave trough...

NARR 500 hPa Heights & Wind Barbs, 25 August 2013, 21Z (2 PM PDT)

[Map and satellite image showing the Rim Fire, TS Iva, Short Wave, Convection, and Tropical Moisture Plume]
No PyroCb on 25 August?

- Located in vicinity of approaching short wave
- Unstable/moist mid-upper troposphere
- Devoid of traditional dry T-storms
- Convergence at 250 hPa

Aqua MODIS: 2 PM PDT

GOES 14: 5 PM PDT

- Located in vicinity of approaching short wave
- Unstable/moist mid-upper troposphere
- Devoid of traditional dry T-storms
- Convergence at 250 hPa

UTLR = 10.4 C/km

Shortwave

Ambient moisture

NO PyroCb!

Haines Index = 6

250 hPa Heights, Wind Barbs, & Divergence

UTLR = 10.4 C/km
Additional PyroCbs & High-Altitude Smoke During SEAC4RS

HYSPLIT Backward Trajectories

From Mike Fromm, NRL - DC

<table>
<thead>
<tr>
<th>Date (2013)</th>
<th>Fire</th>
<th>State</th>
</tr>
</thead>
<tbody>
<tr>
<td>8/8</td>
<td>Beaver Creek</td>
<td>Idaho</td>
</tr>
<tr>
<td>8/8</td>
<td>McCan</td>
<td>Idaho</td>
</tr>
<tr>
<td>8/9</td>
<td>Pony, Elk?</td>
<td>Idaho</td>
</tr>
<tr>
<td>8/10</td>
<td>Elk</td>
<td>Idaho</td>
</tr>
<tr>
<td>8/10</td>
<td>NA</td>
<td>Canada?</td>
</tr>
<tr>
<td>8/12</td>
<td>Pony</td>
<td>Idaho</td>
</tr>
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<td>Pony</td>
<td>Idaho</td>
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Selected PyroCbs

- ★ 8/16 Gold Pan
- ★ 8/16 Beaver Creek

PyroCb impact on smoke properties?

http://hsrl.ssec.wisc.edu/by_site/
Map contains smoke emitted over 4-5 days (23-27 August) SEAC4RS likely sampled 2-3 days of smoke (~24-26 August)
Low-Level Impacts (850 hPa)

5 PM PDT, 8/18
SE, 5 Kts

5 PM PDT, 8/19
NNE, 5 Kts

5 PM PDT, 8/20
S, 5-10 Kts

5 PM PDT, 8/21
S, 15-20 Kts

5 PM PDT, 8/22
SSW, 15 Kts

5 PM PDT, 8/23
SW, 10 Kts

24-hr Spread: > 40,000 Acres

24-hr Spread: > 40,000 Acres

Pyro Cb

Pyro Cb

24-hr Spread: > 40,000 Acres

24-hr Spread: > 40,000 Acres
Wind Direction Relative to Topography

- **Direction of spread after 8/19**: 8/17-8/19
- **Direction of spread after 8/19**: 5 PM PDT, 8/22 (SSW, 15 Kts)
- **24-hr Spread**: > 40,000 Acres
PyroCb Impact on Smoke Altitude

- Prediction of pyroCbs important for plume height!
- Less important for extreme fire spread
- Upper-level meteorology is key!

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CALIPSO Vertical Feature Mask: 8/20/13
Nighttime, soon after local midnight

Mix of smoke and clouds
High injections generally correspond to the largest and most intense fire events!
Similar results have been shown in earlier studies (e.g. Val Martin et al., 2010).
Signal of Plume Height in MODIS Sub-Pixel Outputs

There is signal in the filtered sub-pixel data! Filtering primarily removes low injection cases!

\[ \sum_{i=1}^{n} FRP_{f_i} = \sigma(T_f^A - T_{4b}^A)A_f \]

\[ \sum_{i=1}^{n} A_{f_i} \]

\[ FRP_f = \sigma(T_f^A - T_{4b}^A)A_f \]

• Using a bi-spectral (4 and 11 µm) retrieval of sub-pixel fire area and temp. (Peterson et al., 2013; Peterson & Wang, 2013, RSE)

• **FRP\(_f\) flux**: closer approximation to fire line intensity!
  – Related to plume buoyancy!

Peterson et al., in press, JGR
Diagnosing MODIS time series: Coverage for one day

Over most of 50S-50N, we get 4 scenes/day: nominal MODIS coverage

MODIS bowtie gives us extra looks, complicates the spatial pattern

2013.08.13.00.-2013.08.14.00. MODIS Views w/ overlap
Diagnosing MODIS time series: Fire observability

Over most of 50S-50N, we get 4 scenes/day: nominal MODIS coverage.

MODIS bowtie gives us extra looks, complicates the spatial pattern.

2013.08.13.00.-2013.08.14.00. MODIS Fire Observability

Observability (""Hours"")