Spacecraft Monitoring of Wildland Fire, Smoke Transport, and Applications to Fire Management and Air Quality

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Read slide
Overview & Objectives

- Climate-driven changes to wildland fire and smoke are expected to increase in the warmer and dryer conditions predicted for many fire-prone regions
- We review:
  - the use of satellite sensing technologies for mapping and monitoring wildland fire and smoke and
  - the value of these methods for fire and smoke management, particularly in characterizing air quality, which is relevant to human health

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Specifically:
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- Mary Ellen Miller, Michigan Tech
- Emily Gargulinski, NAI/NASA Langley
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Read slide
• Fire is common in the Earth system
• It interacts with the land, air, and water
• It influences the
  • functioning of ecosystems,
  • atmospheric processes
  • as well as surface hydrology and water quality
Next
• We focus in this talk on aspects of fire related the production of smoke and impacts on air quality and human health
Fire, Smoke and Health:
Tracking the modeling chain from flames to health and well-being

Tatiana Loboda, Nancy HF French, Robin Puett, Editors

The focus of this volume is on describing the observational and modeling approaches that are currently used in fire science, smoke characterization, and health assessment, some of which are operationally employed, while others are at the forefront of research.

Publication Expected Later This Year

• This year our book will be published by AGU books
• Title: Fire, Smoke and Health: Tracking the modeling chain from flames to health and well-being
• The book presents the science and techniques used at the intersection of fire, smoke and health
Biomass burning smoke and human health outcomes

• Limited but growing body of research specific to fire smoke exposures shows increased risks of:
  • pre-term birth, low birthweight
  • respiratory events among children & adults
  • all-cause mortality

• Research needs to fill gaps
  • Smoke (wood smoke) toxicology
  • Impacts of repeated exposures
  • Critical time windows of exposure (e.g. pregnancy)
  • Combined stressors (e.g. psychological stress and smoke exposure)

• Read slide

• The consequences of a future increase in fire are great when you consider smoke exposure

(BACKUP)

• In the U.S. nearly 40% of particulate matter pollution originates from wildland fire (Cascio 2018)

• Total global deaths from landscape fire smoke: ~260,000 to 600,000 annually (1997 – 2006) (Johnston et al. 2012)

• At peak fire fine particulate concentrations the odds of a person seeking emergency care is increased by approximately 50% compared to non-fire conditions (Model results from analysis of San Diego 2007 fires; Thelen et al 2007)
Magnitude of PM2.5 from Fire

San Diego, California, USA  Aug – Dec 2007

From Thelen et al. 2013

- Fire can introduce a large pulse of PM into the air
- These daily peaks can be far above levels that are considered unhealthy
- This example is from the Fall of 2007 in San Diego county showing fire particulates much higher than anthropogenic particulates
- Put on the same scale anthropogenic emissions look like this
Review of Satellite Sensing for Fuels, Fire, and Smoke

- Active fire, post-fire, fire danger & predication
- Fuels and fuel environmental mapping and monitoring
- Fire detection and active fire monitoring
- Smoke mapping & air quality modeling

NOTE:
- Examples shown are not exhaustive
- Examples are focused on US satellite sensing capabilities
- European & Asian satellites systems have many similar capabilities
- Some examples shown are operational, most are research-level activities

Satellite Systems:
- Landsat & Sentinel-2 – active fire & post-fire
- MODIS, VIIRS, GOES – Global fire detection
- SAR – Fuel moisture, mapping
- CALIOP – Sensing smoke in the atmosphere
- Hazard Mapping System – smoke plume mapping
- MODIS & VIIRS – Aerosol mapping

• Read slide
  (BACKUP INFO):
Fuel → Fire → Smoke → Exposure of Humans to Pollution

- Smoke originates from what is burning – fuel on the ground
- In the next slides I am showing examples of satellite sensing that cover all aspects of this process
Active Fire: Landsat & Sentinel-2
2022 Ft Stewart, SC, USA

Landsat and Sentinel 2B images taken one day apart of prescribed fires in South Carolina. Prescribed fires are commonly performed for ecosystem improvement and fuels reduction in Southeast United States.
In Russia, good fire statistics do not exist on a historical basis. Large fires occur in this region, and can be mapped using satellite imagery.
Daily-orbiting MODIS and VIIRS can find hot spots even at sub-daily sampling.

Satellite augmented progression improves fire location & perimeter mapping:

This capability is also available from newer geostationary systems which have rapid observations (every 5 mins)
Fuel Type: MODIS, Landsat USGS Landfire mapping

Vegetation type is mapped with remote sensing and translated to fuelbed type class.

Fuelbed type provides information on the characteristics of what is burning:

- Helps with fire behavior and smoke modeling
- Fire emissions mapping
Landsat is used to map the prefire site and can show change from the fire in a post fire image.
Landsat is used to map the prefire site and can show change from the fire in a post fire image.
Fire extent: Synthetic Aperture Radar (SAR)
Alaska, USA

- Fire extent
- Fuel moisture
- Fire danger
  can be mapped with Synthetic Aperture Radar (SAR) backscatter images

Synthetic Aperture Radar is sensitive the changes in soil moisture
It can be used to
- Map fire extent (shown here)
- For fuel moisture monitoring
- Fire danger assessment
My colleague Dr Laura Bourgeau-Chavez has developed methods to map soil and fuel moisture status by establishing relationships between fuel moisture in the soil (shown here as Drought Code (DC) and SAR backscatter

SAR penetrates into the surface to sense moisture conditions relevant to fire danger
- Useful for fire danger monitoring
Fuel Moisture: Polarimetric SAR
1987 & 1999 Ft Greely Fires, Alaska, USA

Polarimetric SAR improves mapping of soil moisture
• Polarimetric variables: strongly correlated to the structural complexity
• Backscatter variables: strongly related to soil moisture

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ECOSTRESS is a thermal radiometer instrument on the International Space Station
My colleague Dr Mary Ellen Miller has been exploring the value of ECOSTRESS Evaporative Stress Index for pre-fire fuel condition

On the right: shows the Evaporative Stress Index for a site before burning on the top and on the day of the fire on the bottom, when ESI shows the vegetation to be very stressed/water limited
On the left:
• Middle graph shows ECOSTRESS Evaporative Stress Index
• Lower graph shows that ESI tracks standard fuel moisture metrics
Smoke Mapping: (CALIOP) Cloud-Aerosol Lidar with Orthogonal Polarization

2013 Rim Fire, California, USA

*CALIOP is a lidar that provides high-resolution vertical profiles of aerosols and clouds.*

The CALIPSO Satellite carries CALIOP: detects low-level Smoke, Dust, and Polluted Dust

CALIOP is a lidar that provides high-resolution vertical profiles of aerosols and clouds on the CALIPSO Satellite Platform
Detects smoke dust and other aerosols

The 2013 Rim Fire can be seen in red with the smoke plume visible
Fire smoke is shown in black in the CALIOP track
Smoke Mapping: (CALIOP) Cloud-Aerosol Lidar with Orthogonal Polarization*

Smoke is Expansive

CALIOP does not need to be over a fire to determine smoke height

Smoke primarily at 4 - 7 km and some at the surface

So CALIOP does not need to be over a fire to determine smoke height

In this example smoke is primarily at 4 to 7 km altitude, and some at the surface
Aerosol Subtypes: CALIOP*

Flint Hills, Kansas, USA

- Aerosol type can be sensed
- Vertical profile of aerosols
- Dust is common in this area
- Smoke and dust vary from year to year

*a lidar that provides high-resolution vertical profiles of aerosols and clouds

CALIOP can distinguish different types of aerosols
Center: we see the vertical distribution of smoke over the Flint Hills of Kansas
Right: we see that smoke and dust vary from year to year in this region
The Hazard Mapping System (HMS) smoke plume maps are derived from visual detection of smoke using a variety of weather satellites operated by the National Oceanographic and Atmospheric Administration. The lines in left image and colors in lower right show smoke plume extent and density.
MODIS Aerosol Optical Depth (AOD) MODIS
2019 Alaska, USA

MODIS MCD19A2 Optical Depth
7/1/2019 - 7/15/2019
over Alaska (center of image)

MODIS Aerosol Optical Depth provides maps of smoke density
In this study the satellite-based maps were compared with surface sensors
To assess air quality in Alaska during the 2019 fire season
Fire Mapping: MODIS, VIIRS, Landsat, other:
Arctic and Boreal North America

Fire is common and widespread in many biomes
Satellite sensing provides ability to map fires everywhere.
This shows a map of fires across the boreal regions of North America built from fire records, many derived from satellite observations.
Modeling smoke PM
Alaska, USA

Where and when fires occur can be combined into a modeling framework to map emissions, model transport, and make maps of PM concentrations, which are used in smoke exposure studies.
This is an example of modeled particulate matter dispersion in 2015 for fires from Alaska. Smoke covers much of northern North America, sometimes densely.
In this example, Alaska smoke was unhealth across a wide swath of boreal North America in 2004.

This type of modeling can provide critical information for citizens and communities to take steps to avoid exposure.
Large fires export PM pollution

These large fires can export particulate pollution to far distances
Smoke Particulates (PM2.5) are harmful to human health

Lungs

Growth & development

Medical Emergency

Heart

Brain

Pregnancy and birth

Read slide
Summary: Satellite Sensing for Air Quality and Fire Operations Support

- Fire and smoke forecasting
- Improved smoke emissions and smoke plume mapping
- Provide information content for decision support
- Improve predictions and response time regarding smoke exposure to alleviate the health burden of fire smoke

The vision is to produce added value for support of fire and smoke management and fire operations in order to improve air quality and reduce human exposure to air pollution

- Read bullets
Thank-You

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