Satellite-based Fire Data and Products: A NASA perspective

Photo courtesy of Brian Stocks

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with slides from:
Louis Giglio and Kelvin Brentzel
Under the control of weather and climate, fire is a driving force of change.
NASA Supports Fire Science

• Science Mission Directorate
• Earth Science Programs
  – Carbon Cycle and Ecosystems (e.g. Carbon Cycle, Land Cover Land Use Change, Terrestrial Ecology, Biodiversity, Climate and Biological Response, HyspIRI, Terra and Aqua, Ocean Biology Biogeochem.)
  – Climate Variability and Change
  – Water and Energy Cycle
  – Tropospheric Chemistry
  – Atmospheric Composition
  – Interdisciplinary Science
  – Weather

Funding through ROSES

http://nspires.nasaprs.com/external/
A-Train formation allows for simultaneous coordinated measurements.

Data used together to obtain comprehensive information about the atmosphere or processes.

Combining the information collected simultaneously from several sources provides a more complete understanding.
NASA Real-time Receiving Sites

- Number of Users of Fire Algorithms = 176
- Number of Countries Represented = 33
- Number of Users from Government Agencies = 67
Using the Langley Trajectory Model, MODIS fire detection data, samples taken from pits, and CALIOP space-based lidar data, we can tease apart feedbacks to climate.

July 04th, 2013

WorldView MODIS
Aqua and Terra

July 28th, 2013

CALIPSO track

Fires: red
Air parcels: green
IDS: Tyva, Siberia: Locals report forests are disappearing; Models predict this area should exhibit the initial signs of climate change; Field research results - severity of fire increasing and sapling growing conditions hotter and dryer.

This is a Forest Steppe ecosystem already on the margin.

Satellites show no change in forest fire frequency.

SiBCLiM Results

Tchebaková, Parfenova, et al. 2006
NASA model data are freely available

**GEOS-5** (Goddard Earth Observing System Data Assimilation System Version 5) data are a long-term data set of satellite-based meteorological and climate data.

**MERRA** (Modern Era-Retrospective Analysis for Research and Applications) are a reanalysis data set that uses GEOS-5 data and ground-based data to correct the data at a monthly time scale from 1979 through the present.

http://gmao.gsfc.nasa.gov/research/merra/
MODIS (Moderate Resolution Imaging Spectroradiometer)

* Key instrument aboard the Terra (morning overpass) and Aqua (afternoon) satellites.
  * Polar orbiter with 36 spectral bands, ranging in wavelength from 0.4 μm to 14.4 μm
  * Products
    * Atmospheric [~7 (cloud, aerosol, water)]
    * Land [~15 (Burned Area, Thermal Anomaly, NDV, EVI, GPP, NPP, Temp., reflectance)]
    * Cryosphere products [~3 (snow cover, Ice)]
    * Ocean products [~9 (Sea Surface Temperature, Chlorophyll, Carbon)]

FIRMS: Active Fire - txt, shape, maps, KML, WMS

https://earthdata.nasa.gov/earth-observation-data/near-real-time/rapid-response

https://worldview.earthdata.nasa.gov
Visualize NASA fire and other data

NASA Worldview

https://worldview.earthdata.nasa.gov
https://earthdata.nasa.gov/earth-observation-data/near-real-time/firms
Vegetation Indices
an indicator that describes greenness - the relative density and health - of vegetation for each pixel in a satellite image

AVHRR NDVI data are available in a consistently processed database from 1982-present at an 8-km re-sampling grid covering the entire planet, and from 1989-present at a 1-km resolution for the conterminous United States

Enhanced Vegetation Index (EVI) – similar to NDVI, corrects for some distortions in the reflected light caused by the particles in the air as well as the ground cover below the vegetation. Doesn’t become saturated as easily as NDVI when viewing areas of the Earth with large amounts of chlorophyll.

MODIS August 1993
2002-2015 Mean Burned Area
Fraction of a grid cell that burns each year
Collection 6 MCD64A1  500 m product
Burned Area in Central African Republic and South Sudan
2004-2005 Fire Season

500 km (311 mi)
Aim is to Transition NASA Data, Models, Technologies to Operational Fire Management Support

The VIIRS 375 m active fire detection product enables early detection of small fires and improved mapping of large wildfires.

"These refined data further improve the situational awareness of fire managers and are also ingested into operational modeling, analysis and visualization applications that support fire management decision-making at a landscape scale." – Brad Quayle, F.S.

VIIRS fire algorithm complements temporally & spatially limited airborne & spaceborne (e.g., NIROPS, Landsat-8 & upcoming Sentinel-2) data to identify remote lightning strikes, support tactical firefighting, evacuation & strategic planning to mitigate ecological & flood impact.
SMAP (Soil Moisture Active Passive) Mission

Launched in January to map global soil moisture and detect whether soils are frozen or thawed

- Near-polar orbit
- 8-day repeat track (6 am/pm)
- Global land area 3-day
- Mission life expected ~3 years

SMAP's radar - soil moisture and freeze-thaw measurements
~5.6 miles (9 kilometers) for soil moisture;
~ 1.9 miles (3 kilometers) for freeze-thaw.

Without radar
~ 25 miles (40 kilometers) for soil moisture and freeze-thaw.

Sensor | Spatial Resolution was expected to be:
--- | ---
Radar (Synthetic Aperture) | 10 km Soil Moisture 1-3 km Freeze-Thaw
Radiometer | 40 km (IFOV 38km x 49 km)

July 7, 2015
SMAP's radar stopped transmitting
SMAP continues to meet its requirements for soil moisture accuracy and will produce global soil moisture maps every 2 to 3 days.

First-of-their-kind concept, design and measurements

Design
The radar enabled high-resolution measurements of up to 1.9 miles, but with lower accuracy for sensing surface soil moisture.
In contrast, the microwave radiometer is more accurate in its measurements, but has lower resolution of about 25 miles.
By combining the active and passive measurements, SMAP was designed to estimate soil moisture at a resolution of about 5.6 miles.

SMAP's radiometer Surface Soil Moisture composite
(3-day Aug. 2015). Dry areas: yellow/orange - Sahara Desert, western Australia, western U.S.
Blue: wet areas; White: snow, ice or frozen ground
Two instruments are capable of defining fire plume injection heights (if incorrect, transport incorrect as are Air Quality estimates and deposition (i.e. Black Carbon to Arctic).

CALIOP onboard Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) – underway.

Multi-angle Imaging SpectroRadiometer (MISR) - D. Diner, R. Kahn, J. Logan, et al. - used stereographic heights to derive plume height database (LaRC DAAC).

1 year after burn
Several wildfires have burned for days over central and southern Chile, killing at least 11 people. The fire and smoke have destroyed thousands of homes and consumed an area 3 times the size of New York City. On 28 Jan. 2017, the smoke plume was observed by MODIS (top left). The ISS passed over the plume (red line) around 11:25 UTC. The CATS backscatter image (bottom left) shows the elevated smoke plume between 2 and 4 km (red circle). The smoke and fire have displaced over 8,000 Chileans from their homes.

http://cats.gsfc.nasa.gov/
CALIPSO
* able to identify plume heights from extensive smoke fields;
* increased capability of detecting optically thin smoke layers at a finer vertical resolution;
* smoke plume identification with back trajectories are temporally random, representing the entire temporal range of fire plumes.

MISR
* needs abrupt well-defined columns - relies on multi-view angles to estimate the stereo height of distinct features;
* substantially larger swath width than CALIPSO which results in a greater opportunity to capture smoke plumes [Kahn et al., 2007]; &
* morning overpasses do not capture the natural temporal fire pattern.

<table>
<thead>
<tr>
<th>Sensor (spacecraft)</th>
<th>Product</th>
<th>Spatial Resolution</th>
<th>Satellite Overpass</th>
<th>Temporal Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>MISR (Terra)</td>
<td>AOD, aerosol plume height</td>
<td>1.1 km horizontal x 500 m vertical</td>
<td>10:30 a.m.</td>
<td>~Once every 7 days</td>
</tr>
<tr>
<td>CALIOP (CALIPSO)</td>
<td>extinction profile</td>
<td>100 m diameter x 30 m vertical</td>
<td>1:40 p.m.</td>
<td>Once every 16 days</td>
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</table>
MISR uses cameras pointed in 9 different directions to view the amount of sunlight scattered in different directions.

https://www-misr.jpl.nasa.gov/getData/accessData/MisrMinxPlumes/
Coincident NOAA HMS smoke plume, and CALIPSO overpass.

Focus on this CALIPSO swath and coincident smoke plume.
CALIPSO overpass
Swath from south to north
20:07 to 20:20

532 nm Total Attenuated Backscatter
1064 nm Attenuated Backscatter
Vertical Feature Mask
Orange - aerosol
Aerosol Subtype
Brown – polluted dust
30m Vertical Resolution
Using multiple CALIPSO overpasses (w/ LaTM), the evolution of a smoke plume can be defined. This is unique and a new application.

Mean Altitude for the Tripod, WA
August 04, 2006

Multiple CALIPSO overpasses

- 20060805
- 20060805b
- 20060806
- 20060806b
- 20060807
- 20060807b
- 20060807c
- 20060807d
- 20060808
- 20060808b
Quantifying Cropland Burning and Related Emissions Using NASA Sensors
Jessica L. McCarty, PhD

Informing U.S. Emissions Inventories:
- McCarty refined MODIS based cropland burned algorithm to produce county, state, and lat/long specific emission estimates for contiguous U.S. (CONUS) for 25 atmospheric species and 21 crop types (Figure 1).
- Include as the official source of cropland burning emissions for 2011EPA’s National Emissions Inventory.
- Provided detailed uncertainty analyses upon request from state environmental agencies.
- NASA Applications contract # NNX12AQ90G; PI: Soja.

Cropland burning affects local and regional air quality, is a consistent source of emissions, and, as source of GHG/short-lived climate forcers, its impact on climate is not well understood (photo by J. McCarty).
NASA EO Supports Rapid Assessment / Recovery Operations on Ft. McMurray Wildfire

**Situation:** Ft. McMurray (Horse River) Fire in Alberta burned 1 May to 5 July 2016, and consumed 1.5M acres. *It was the costliest disaster in Canadian history* ($3.58B)!

**Approach:** Use MODIS and Landsat measurements, coupled with soils and terrain information to model burn severity and create inputs to hydrological forecast models in near-real-time.

**Results / Implications:**
- Supported managers with real-time tools to pinpoint active fire, develop post-fire burn severity and model hydrologic processes for rapid remediation remediation actions;
- Helped prioritize watersheds to concentrate post-fire treatment areas and save resources and significant mitigation costs.
FIRECAST: A Near-Real-Time Monitoring System
Improving Forest Management in the Tropics

Karyn Tabor and team

FIRECAST uses satellite data to deliver daily email alerts of fire activity and daily forest flammability alerts that are used to warn communities and authorities of dangerous fire conditions.

Targets areas of high biodiversity and specific communities.

Currently the system operates in Brazil, Peru, Madagascar, Indonesia, and Bolivia.
Satellites Improve Tropical Forest Management

Firecast empowers localities and regional managers with NRT weather and fire information derived from NASA products to enable sustainable landscape management for the protection of biodiversity and ecosystems that provide critical services for human well-being.

FIRECAST is used in Colombia, Indonesia, Peru, Bolivia and Madagascar.

New and Unique:
- Mobile Firecast application launched; includes offline map functionality in English, Spanish and French;
- Enhanced Fire Flammability Risk expanded to Indonesia: host Global Forest Watch;
- Partnered with USAID to expand Firecast alerts to Colombia;
- Partnered with Logi Analytics to develop of a new Firecast visualization Dashboard – requested by the data users – puts data in perspective for the decision makers;
Ozone DIAL & Aerosol/Cloud HSRL – DC-8
Johnathan Hair - PI NASA LaRC

- Measured O3 and aerosols profiles on all SEAC4RS flights
- Provided real-time O_3 & aerosol data for in-flight guidance
- Provided O3 and aerosol curtains data for comparison to CTMs
- Made UTLS O3 & aerosol measurements for NAM assessments
- Made HSRL multi-wavelength lidar observations of fire emissions
- Provided HSRL measurements relevant to CALIOP assessments
- Provided data for comparison and assessment of remote sensors retrievals on ER-2 (extinction, AOT)
- Coordinated with DISCOVER-AQ to provide O_3 curtains over Houston

Profile Measurements:
- Ozone Concentrations
- Aerosol Extinction (532nm)
- Layer AOD at 532nm
- Aerosol/Cloud Backscatter (355,532,1064nm)
- Aerosol/Cloud Depolarization (355,532,1064nm)

26 Aug. 2013: Curtain of aerosol concentration along plume axis of RIM fire in Yosemite National Park

http://science.larc.nasa.gov/lidar/
August 2013 Rim Fire (Sierra Nevada, CA)
- Burned for 38 days over 257,314 acres
- Sampled by the NASA DC-8 during the SEAC4RS airborne project
  - Directly at the fire (top)
  - Several days downwind (bottom)

Atmospheric Effects
- Downwind smoke affects ground-level air quality & alters Earth’s radiative budget
- Changes in smoke properties were measured as it is transported and ages
  - Aerosols uptake more water (increasing visibility degradation)
  - Albedo of the smoke increases (less absorption of sunlight)
Aerosols Travel Far!

Siberian Fire Smoke

May 12th, 2012

The Science Directorate at NASA's Langley Research Center
Aerosols Travel Far!

Siberian Fire Smoke

May 12th, 2012

CALIPSO ground track
(approximate)

Backscatter (green wavelength)

Color Ratio (red/green)

Depolarization Ratio

Horizontal Distance (South to North)

The Science Directorate at NASA’s Langley Research Center
Aerosols Travel Far!
2 days later
Smoke from Siberia over United States
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<tr>
<td>MODIS (Terra and Aqua)</td>
<td>Thermal anomaly (fire detection), area burn, and Aerosol Optical Depth (AOD)</td>
<td>500 m area burned, Fire detection 1 km², and AOD 10 x 10 km² product</td>
<td>10:30 a.m. 1:30 p.m. 6:30 p.m.</td>
<td>Active fire and AOD 4 times per day (1 day, 1 night overpass per sensor x 2 sensors), 8-day area burned</td>
</tr>
<tr>
<td>MISR (Terra)</td>
<td>AOD, aerosol plume height</td>
<td>17.6 x 17.6 km²</td>
<td>10:30 a.m.</td>
<td>~Once every 7 days</td>
</tr>
<tr>
<td>MOPITT (Terra)</td>
<td>Columnar CO (combustion tracer)</td>
<td>22 x 22 km²</td>
<td>10:30 a.m. 10:30 p.m.</td>
<td>Twice every 3 days</td>
</tr>
<tr>
<td>ASTER (Terra)</td>
<td>Level 3 AST14OTH Orthorectified</td>
<td>15 m</td>
<td>10:30 a.m. 6:30 p.m.</td>
<td>Twice per day</td>
</tr>
<tr>
<td>AWiFS</td>
<td>Georeferenced visible, NIR, and SWIR data</td>
<td>56 m</td>
<td>variable</td>
<td>Tasked data every ~5 days; orbiting every 14 days</td>
</tr>
<tr>
<td>Landsat</td>
<td>L1-L3 L4-L8</td>
<td>Typically 30 m</td>
<td>variable</td>
<td>Every 16 days</td>
</tr>
<tr>
<td>AIRS (Aqua)</td>
<td>CH₄, Columnar CO (combustion tracer)</td>
<td>45 km diameter</td>
<td>1:30 a.m 1:30 p.m.</td>
<td>Twice every day</td>
</tr>
<tr>
<td>OMI (Aura)</td>
<td>AOD, SSA</td>
<td>13 x 24 km²</td>
<td>1:45 p.m.</td>
<td>Every day</td>
</tr>
<tr>
<td>CALIOP (CALIPSO)</td>
<td>extinction profile, aerosol plume height</td>
<td>100 m diameter x 30 m vertical</td>
<td>1:40 p.m.</td>
<td>Once every 16 days</td>
</tr>
<tr>
<td>GOES (east and west)</td>
<td>ABBA instantaneous area</td>
<td>16 km²</td>
<td>Geostationary Orbit</td>
<td>30 minute data (2 sensors, 15 minute data)</td>
</tr>
</tbody>
</table>
Thank-you for listening!

and a special thanks for conversations with individuals and communities: NASA Applied Sciences programs Wildland Fire and Disasters; FASMEE; FIREX; FIREChem; WE-Can; USDA Forest Service; Environmental Protection Agency; the CALIPSO Science Team; LARGE Team; NOAA HMS team; Wilfrid Schroeder, Brian Stocks, Charles Ichoku, Ralph Kahn, Mark Ruminski, Nancy French, Keith Weber, Christine Wiedinmyer, Bob Yokelson, Karyn Tabor, Mary Ellen Miller and many others.

Questions?
Additionally, there are other Distributed Active Achieve Centers (DAAC)

Oakridge DAAC
http://daac.ornl.gov/

NOAA Comprehensive Large Array-Data Stewardship System (CLASS)
www.class.ngdc.noaa.gov/saa/products/welcome

NASA Goddard Earth Sciences Data and Information Services Center
http://daac.gsfc.nasa.gov/

1 year after fire
The Wildfire Automated Biomass Burning Algorithm (WFABBA) processing system uses geostationary satellite data to detect and characterize biomass burning.

Two geostationary NOAA weather satellites GOES-East (GOES-13) and GOES-W (GOES-15)

http://wfabba.ssec.wisc.edu/
NOAA Hazard Mapping System (HMS)

Fire and Smoke Product

Combines information from GOES-ABBA, FIMMA-AVHRR, MODIS and generates unique products

http://www.ssd.noaa.gov/PS/FIRE/hms.html
Remote Sensing Applications Center (RSAC) Active Fire Mapping (AFM) Program

USFS operational use of NASA MODIS and NASA/NOAA VIIRS for wildfire activity in CONUS, Alaska, Hawaii & Canada

Facilitates decision support for strategic planning and response for U.S. and Canadian fire agencies

http://activefiremaps.fs.fed.us/index.php
NASA AMS Sensor to USFS Fire Operations

- NASA airborne Autonomous Modular Sensor (AMS) transferred to the USFS National Infrared Operations (NIROPS) and USFS Remote Sensing Applications Center (RSAC) for operations supporting fire and other research/applications needs.
  » Joint press announcement (NASA and USFS) released on 16 April 2013.
- AMS installed on a USFS Cessna Citation jet (FY2013); Flew a series of missions in support of data collection for partners in USDA Ag Research and the USGS Water Quality.
- AMS has NOT been used in 2013 to support US wildfire events
  » USFS felt their staff training was too short for adaptation into immediate operations.
- USFS funded $100K to NASA-ARC to support FY13-15 training, sensor calibration, and enhancements, to ready staff for AMS operations in FY2014 (and further support)

http://nirops.fs.fed.us/ams/
Satellite Data and Models Inform the Science and Management that then Inform the Data and Science.

Bastrop County Fire

November 11, 2011
Texas counties with burn bans: 206 of 254

MODIS Fire Detection
Landsat Fire Scar data

Endangered Canebrake

Mom and baby black bear