HyspIRI Measurement of Fire Parameters for Climate Change and Carbon Budgets: Fuel, Occurrence, Intensity and Recovery

Louis Giglio (University of Maryland)
*Ivan Csiszar (NOAA/NESDIS)
Wilfrid Schroeder (University of Maryland)
Many others (noted on slides)
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*presenter
Need for improved global and regional fire monitoring – in plain language

• Societal issues
  – long-term or permanent land cover changes
  – significant contribution to greenhouse gas and particulate emissions
  – smoke from fires is a major health hazard
  – human-fire-climate interactions

• Scientific Issues
  – need to be able to monitor fires and their impacts
  – what vegetation burned
  – how intense and severe was the burning was
  – how much material was emitted into the atmosphere
  – process of vegetation recovery over the burned areas
  – carbon exchange between the land surface and the atmosphere
Early warning system products

Current fire danger - data inputs

Local/regional information links

Ground-based Weather Products
- Current and forecast fire weather using ensemble models

Fire Danger
- Integrated mapping of weather, fuels, fire behaviour, active fire locations

Fire Mgt Tools
- Early warning action plans: prevention, resource-sharing, detection, mobilization

Remote Sensing Products
- Active fire monitoring, veg/fuels/biomass, spatial weather, fire radiative energy

Global Early Warning System for Wildland Fire

EWS-Fire Information and Data Coordination
- Global compilation of current national Fire Danger Rating Systems (FDRS)
- Forecast global FDR, weather data and EWS-Fire products

Global Early Warning System for Wildland Fire

CFS, GFMC, NOAA/NESDIS, JRC, UMD (FIRMS), WMO

Sub-national and/or Local
- Capable of operating FDRS locally, or as part of larger Network

National Fire Organizations
- Nations with FDRS
- Nations w/out FDRS

Regional Wildland Fire Networks
- UNISDR and GOFC-GOLD

UNISDR, FAO, UNEP, WHO
- Early Warning of Fire Disaster - safety; Resource-Sharing coordination; Fire emission health warnings

Early warning system products

Current fire danger - data inputs

Local/regional information links
“To date, research suggests a general increase in area burned and fire occurrence but there is a lot of spatial variability, with some areas of no change or even decreases in area burned and occurrence. Fire seasons are lengthening for temperate and boreal regions and this trend should continue in a warmer world. Future trends of fire severity and intensity are difficult to determine owing to the complex and non-linear interactions between weather, vegetation and people. Improved fire data are required along with continued global studies that dynamically include weather, vegetation, people, and other disturbances. Lastly, we need more research on the role of policy, practices and human behavior because most of the global fire activity is directly attributable to people.”
Changing fire regimes – complex interactions between climate and society

- Climate change
  - Fuel Type/Amount
  - Fire Season
  - Fire Weather
  - Land use transformation
  - Pasture improvement
  - Fire suppression
  - Land abandonment

- Developing Country Policy Issues
  - Land use transformation
  - Pasture improvement
  - Fire suppression
  - Land abandonment

- Developed Country Policy Issues
  - Land use transformation
  - Pasture improvement
  - Fire suppression
  - Land abandonment

- Land Use Policy and Management
  - Land use transformation
  - Pasture improvement
  - Fire suppression
  - Land abandonment

- Demographics/Socio Economics
TQ2. Wildfires

• How are global fire regimes changing in response to, and driven by, changing climate, vegetation, and land use practices? [DS 198]

• Is regional and local scale fire frequency changing? [DS 196]

• What is the role of fire in global biogeochemical cycling, particularly trace gas emissions? [DS 195]

• Are there regional feedbacks between fire and climate change?
CQ2. Wildfires

- How does the timing, temperature and frequency of fires affect long-term ecosystem health?
- How does vegetation composition and fire temperature impact trace gas emissions?
- How do fires in coastal biomes affect terrestrial biogeochemical fluxes into estuarine and coastal waters and what is the subsequent biological response? [DS 198]
- What are the feedbacks between fire temperature and frequency and vegetation composition and recovery?
- How does vegetation composition influence wildfire severity?
- On a watershed scale, what is the relationship of vegetation cover, soil type, and slope to frequency of debris flows?
- How does invasive vegetation cope with fire in comparison to native species?
HyspIRI and fire – unprecedented measurement capabilities

- Pre-fire fuel properties, fire weather
  - fuel types, fuel loads
  - live fuel moisture, vegetation stress etc.
  - surface temperature, ET

- Detection/characterization of the combustion process
  - improved fire characterization
  - improved characterization of smoke emission

- Post-fire impacts
  - fire affected area
  - burn severity
  - amount of material burned
  - hydrophobicity
  - types of ash
  - land cover change
  - nutrient transport

A prime example for the complementarities between HyspIRI and DESDynI!
TIR (600 km)

VSWNIR Swath (151 km)

Ground Track

Active fire detection and characterization

Pre- and post-fire characterization

Improved active fire detection and characterization using data fusion

Comprehensive characterization of pre- and post-fire and burning processes
Fire Disturbance is an Essential Climate Variable (ECV) of the Global Climate Observing System (GCOS)

For climate-related science questions:

- coarse resolution fire observations (MODIS, VIIRS, etc.)
- high resolution fire & fuel observations

start of a new, improved data record?

HyspIRI
Current and expected capabilities from medium and coarse resolution sensors

• Long-term monitoring of large-scale fire dynamics from medium and coarse resolution sensors
  – fire occurrence
  – Fire Radiative Power and Energy
  – burned areas

• Gradual improvement, but no quantum leap is expected from operational systems
Global fire dynamics from MODIS

(a) Corrected Fire Pixel Density (km² yr⁻¹)
(b) Peak Month

(d) Autocorrelation (12-month lag)
(e) Mean FRP (MW)
### Continuity of Polar Operational Satellite Programs

| CY | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 |
|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| AM Orbit | DMSP 17 | DMSP 19 | DOD Evaluating AM orbit Requirements |
| Mid Morning Orbit | DMSP F16 | DMSP 18 | MetOp-A | MetOp-B | MetOp-C | DMSP 20 |
| | TERRA | PEPS |
| PM Orbit | NOAA-19 | NPP | *Climate and User Services | Launch Ready | JPSS 1 | Launch Ready | JPSS 2 |

**Legend:**
- **DMSP:** Defense Meteorological Satellite Program
- **MetOp:** Meteorological Operational satellite for EUMETSAT (European Organisation for the Exploitation of Meteorological Satellites)
- **PEPS:** Post EUMETSAT Polar System
- **Terra & Aqua:** NASA’s Earth Observing Satellites
- **NOAA-19:** NOAA’s Polar-orbiting Operational Satellite
- **NPP:** NPOESS Preparatory Project
- **JPSS:** Joint Polar Satellite System
- *Details to be defined during the transition period*
Fire occurrence in South America from GOES data (JAS)

1998 1999 2000 2001 2002
2003 2004 2005 2006 2007

0 0.05%
# Global Geostationary Active Fire Monitoring Capabilities

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Active Fire Spectral Bands</th>
<th>Resolution IGFOV (km)</th>
<th>SSR (km)</th>
<th>Full Disk Coverage</th>
<th>3.9 µm Saturation Temperature (K)</th>
<th>Minimum Fire Size at Equator (at 750 K) (hectares)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GOES-E/W Imager (75ºW / 135ºW)</td>
<td>1 visible 3.9 and 10.7 µm</td>
<td>1.0</td>
<td>0.57</td>
<td>3 hours (30 min NHE and SHE)</td>
<td>&gt;335 K (G-11)</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.0</td>
<td>2.3</td>
<td></td>
<td>&gt;335 K (G-12)</td>
<td></td>
</tr>
<tr>
<td>GOES-10 Imager (60ºW) (Ceased operation December 2009, replaced with GOES-12 in May 2010)</td>
<td>1 visible 3.9 and 10.7 µm</td>
<td>1.0</td>
<td>0.57</td>
<td>3 hours (Full Disk) 15 min (SA)</td>
<td>~322 K (G-10)</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.0</td>
<td>2.5</td>
<td></td>
<td>&gt;335 K (G-12)</td>
<td></td>
</tr>
<tr>
<td>Met-8/-9 SEVIRI (9.5 ºE, 0º)</td>
<td>1 HRV 1.6, 3.9 and 10.8 µm</td>
<td>1.6</td>
<td>1.0</td>
<td>15 minutes</td>
<td>~335 K</td>
<td>0.22</td>
</tr>
<tr>
<td></td>
<td>2 visible 4.8</td>
<td>3.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.8</td>
<td>3.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FY-2C/2D SVISSR (105 ºE / 86.5ºE)</td>
<td>1 visible, 3.75 and 10.8 µm</td>
<td>1.25</td>
<td>1.0</td>
<td>1 hour</td>
<td>~320 K (MTSAT-1R)</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.0</td>
<td></td>
<td></td>
<td>~320 K (MTSAT-2)</td>
<td></td>
</tr>
<tr>
<td>MTSAT-1R JAMI (140ºE) MTSAT-2 (HRIT) (145ºE) Operational 2010</td>
<td>1 visible 3.7 and 10.8 µm</td>
<td>1.0</td>
<td>0.57</td>
<td>30 minutes</td>
<td>~320 K (MTSAT-1R)</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.0</td>
<td>2.3</td>
<td></td>
<td>~320 K (MTSAT-2)</td>
<td></td>
</tr>
<tr>
<td>INSAT-3D (83 ºE ?, TBD) (Launch 2010)</td>
<td>1 vis, 1.6 µm 3.9 and 10.7 µm</td>
<td>1.0</td>
<td>0.57</td>
<td>30 minutes</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td>GOMS Elektro-L N1 (76 ºE) (2010) GOMS Elektro-L N2 (14.5 ºE) (2011?)</td>
<td>3 visible 1.6, 3.75 and 10.7 µm</td>
<td>1.0 km</td>
<td>1.0</td>
<td>30 minutes</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.0 km</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COMS (128 ºE ) (Launch 2010)</td>
<td>1 visible 3.9 and 10.7 µm</td>
<td>1.0 km</td>
<td></td>
<td>30 minutes</td>
<td>~350 K</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.0 km</td>
<td></td>
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</tbody>
</table>
Evolving MIR/TIR fire detection capability

MODIS-class (+geo)
- ~1km
- Optimal band configuration
- Daily or better revisit

BIRD-class
- ~300m
- Optimal band configuration
- Several-day revisit

ASTER-class
- ~30m
- Sub-optimal band configuration
- 16-day revisit

VIIRS, SLST, SEVIRI, ABI etc.

HyspIRI
- Moderate resolution (60m)
- Optimal band configuration
- 5-day revisit

LDCM etc.
Detection envelopes

90% probability of detection; boreal forest; nadir view

L. Giglio
Detection envelopes

90% probability of detection; boreal forest; nadir view

L. Giglio
Detection envelopes

90% probability of detection; boreal forest; nadir view

L. Giglio
HyspIRI: a changing paradigm

• MODIS-class: multiple sub-pixel fires within footprint, systematic, global observations
  – “fire” often means a fire pixel

• ASTER: detect (but characterize only over a limited range) individual fires on an opportunistic basis
  – cluster size, spatial variability

• HyspIRI: detect and characterize individual fires on a more routine basis
  – cluster size, fire temperature, spatial and temporal variability, size distribution, flaming/smoldering
  – helps us understand what is within the coarse or moderate resolution fire pixel
Global fire emission estimate: 2004

Biomass burning and fossil fuel emissions release $\sim 10^{15}$ g of carbon (C) to the atmosphere each year. Biomass burning constitutes $\sim 36\%$ of all global C emissions.

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<tr>
<th>Region</th>
<th>Fire emissions 1997-2001 average $(10^{15} \text{g C yr}^{-1})$</th>
</tr>
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<tbody>
<tr>
<td>Central and northern South America</td>
<td>0.27</td>
</tr>
<tr>
<td>Southern South America</td>
<td>0.80</td>
</tr>
<tr>
<td>Northern Africa</td>
<td>0.80</td>
</tr>
<tr>
<td>Southern Africa</td>
<td>1.02</td>
</tr>
<tr>
<td>Southeast Asia</td>
<td>0.37</td>
</tr>
<tr>
<td>Boreal (north of 38°N)</td>
<td>0.14</td>
</tr>
<tr>
<td>Other</td>
<td>0.13</td>
</tr>
<tr>
<td>Global</td>
<td>3.53</td>
</tr>
</tbody>
</table>

Van der Werf et al., 2004
Biomass burning and fossil fuel emissions release $\sim 10^{15}$ g of carbon (C) to the atmosphere each year. Biomass burning constitutes $\sim 25\%$ of all global C emissions.

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<th>Fire emissions 1997-2009 average ($10^{15}$ g C yr$^{-1}$)</th>
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<tr>
<td>Central and northern South America</td>
<td>0.04</td>
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<td>Southern South America</td>
<td>0.27</td>
</tr>
<tr>
<td>Northern Africa</td>
<td>0.48</td>
</tr>
<tr>
<td>Southern Africa</td>
<td>0.27</td>
</tr>
<tr>
<td>Southeast Asia</td>
<td>0.04</td>
</tr>
<tr>
<td>Boreal (north of 38$^\circ$N)</td>
<td>0.18</td>
</tr>
<tr>
<td>Other</td>
<td>0.73</td>
</tr>
<tr>
<td>Global</td>
<td>2.01</td>
</tr>
</tbody>
</table>

Van der Werf et al., 2010
Where does the difference in emission estimates come from?

- Longer time period (El Niño/La Niña in 1997/98)
- Updated fuel loads – HyspIRI can help further refine this!
  - Peat is important, but difficult!
- Updated burned area estimates
  - HyspIRI can help only where signal is persistent
  - HyspIRI can help over small scale, fragmented burned areas
- HyspIRI can also help better characterize the combustion, consumption and recovery processes
HyspIRI Burn Mapping Product

• Level 3
• Derived from VSWIR observations
  – Potentially use active-fire observations from TIR sensor to improve fidelity
• Generally requires coincident image pair
  – Large number (but small fraction) of global fires
• Sub-pixel area burned, combustion completeness
  – Mixture modeling (heavily underdetermined system for multi-spectral sensors)
  – Important for pyrogenic emissions estimation
Fire Radiative Energy

Ellicott et al. 2009
HysPIRI Active Fire Product

• Level 2
• Fire mask + fire radiative power (FRP)
  – Produced across 600-km TIR swath
• Improved fire mask + detailed fire characterization
  • Produced within 151-km hyperspectral swath
  • Sub-pixel temperature(s) and area
    – Minimum of flaming + smoldering + background
Example Fire Mask from ASTER

ASTER Bands 8 (2.33 µm), 3N (0.82 µm), 1 (0.56 µm)

Active Fire Mask

ASTER saturates for many fires – HyspIRI will allow the “coloring” of the fire mask
HyspIRI MWIR Saturation

• Select TIR MWIR dynamic range so that saturation is extremely rare when observing fires
  – valid radiance measurement essential for fire characterization
    • FRP, sub-pixel temperature and area estimates
  – detailed characterization using hyperspectral sensor possible for only 25% of fires detectable with TIR sensor
MWIR Dynamic Range Comparison

• MODIS (1 km pixels): 500 K
  – based on theoretical worst case

• VIIRS (247 m pre.-agg.): 634 K
  – based on theoretical worst case

• BIRD (370 m): 600 K

• GOES-R ABI (2 km): 400 K

• HyspIRI (60 m): TBD
Defining HyspIRI MWIR saturation level - need for regional analysis

- Gao et al. (2007) MODIS Study – statistical analysis
  - Only 0.4% of fire pixels have $T_{MWIR} > 450$ K
  - Only 1.7% of fire pixels have $T_{MWIR} > 400$ K
  - For 1-km pixels saturation “…should be specified at about 450 K or even lower to 400 K in order to make the channels more useful for quantitative remote sensing of fires.”

- Our own independent analysis shows that from 2003-2009 only 0.02% of all fire pixels saturated MODIS MWIR band 21 (~500K saturation)
Percentage of saturated fire pixels: the Land Surface Temperature analogy

• LST retrieval not possible for saturated land pixels
  – Fire characterization not possible for saturated fire pixels

• Depict Gao et al. (2007) suggested fire-pixel saturation rates as equivalent saturated land surface area confounding hypothetical LST retrieval
Saturation issues

• What is the expected uncertainty in emission estimates?
• What is the frequency of saturated pixels on a regional basis?
• What are the realistic “extreme” fire characteristics?
  – Up to ~1800K flaming temperature possible for forest (Ward et al., 1992, Lobert et al., 1993)
    • 1200 is a realistic upper end
  – Crown fires on a slope can cover the entire HyspIRI pixel
Fire characteristics in Roraima, Brazil

Maintenance

Conversion

Temperature (°C) vs. Minutes

- Forest Conversion
- Piled Debris
- Grassland
- Secondary Forest
Retrieved Temperature Endmembers

Dennison et al., 2006
Simulated MWIR brightness temperatures

Up to 1200K, up to 100% fractional area within the HyspIRI pixel

Up to 1200K, up to 20% fractional area within the HyspIRI pixel
Global dataset of ASTER fire masks

- Use of equidistant grid (circular - 900km diameter)
  - 642 cells
  - ~370 over land
  - ~210 in areas with some fire activity (deserts and poles automatically excluded in the process)

- Six years of data represented
  - ASTER SWIR data quality issues beginning May 2007

- ~2500 ASTER scenes selected
  - 4 scenes for each grid cell - 2 year period
  - up to 3 scenes representing highest number of MOD14 fire pixels
  - at least one random scene per cell/period containing fire, no fire, water, clouds, etc.
  - 140 nighttime scenes

⇒ 16K daytime MOD14 fire pixels sampled
⇒ 700 nighttime MOD14 fire pixels sampled

~30% of fire clusters consist of more than 10 ASTER fire pixels
The Case of Central Mato Grosso State in Brazilian Amazonia

Example of piled debri burning

> 90% of the areas with active fires did not produce a distinguishable burn scar for the time period and area analyzed.
Percentage of MODIS fire pixels with MWIR brightness temperature above the indicated value
Percentage of MODIS fire pixels with MWIR brightness temperature above the indicated value
Percentage of MODIS fire pixels with MWIR brightness temperature above the indicated value
Percentage of MODIS fire pixels with MWIR brightness temperature above the indicated value.
Major benefits of HyspIRI for fire

• Unprecedented capability of global fuel mapping and characterization of the recovery process
• Unprecedented sensitivity to active flaming and smoldering fires
  – can easily detect small agricultural fires (difficult with coarser resolution sensors)
  – fewer false alarms in fire detection
  – straightforward retrieval of fire radiative power
    • single band vs. three or more bands with existing sensors
• Greatly expanded spatial and temporal coverage
  – large samples of detailed fire characteristics useful for statistically modeling fires and their behavior
• Interpretation, calibration and validation of fire observations derived from coarser resolution data