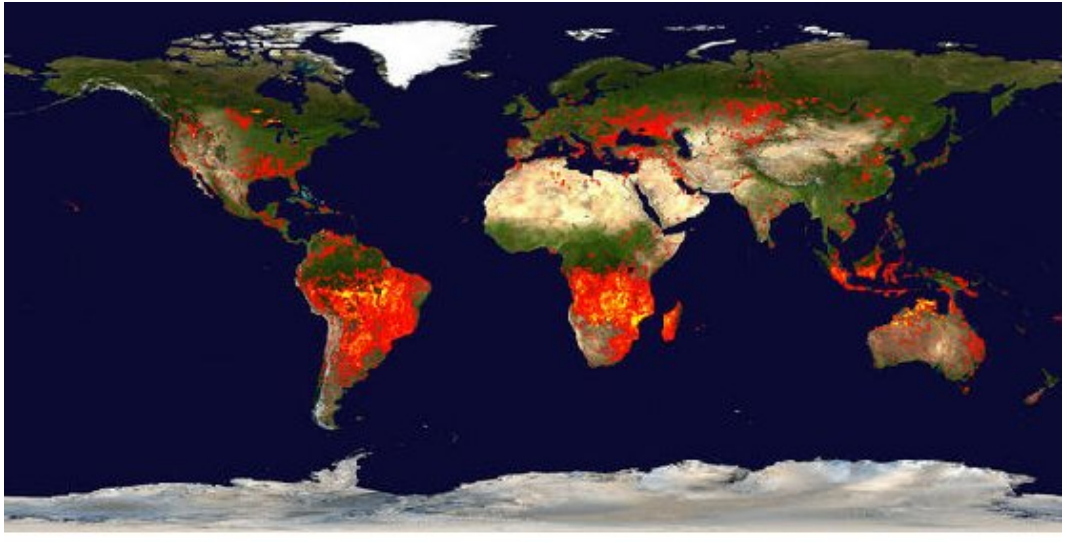
# Satellite remote sensing of fires: principals, datasets, and Python programming

**Jun Wang**

**Professor**

**University of Iowa**



**NCAR ACOM/ACCORD Workshop:**
**Analysis of existing biomass burning datasets**

# First fire detection from space was from visible light at night…

## Burning Waste Gas in Oil Fields

I WAS recently amazed by some night-time spacecraft photographs, exemplified by Fig. 1, that present graphic evidence of waste and pollution. These were obtained by the United States Air Force DAPP system which has sensors in the visible 0.4 to 1.1 μm band and an infrared imaging system in the 8 to

- T. A. Croft, *Nature*, 1973.

**Such agricultural "Fires, invisible by day, are seen ranging all around … at night (when) we were literally surrounded by them; some smouldering, … others fitfully bursting forth, whilst others again stalked along with a steadily increasing and enlarging flame…"**
**Hooker (in 1846), cited by Croft, 1973.**

# Nighttime Images of the Earth from Space

*An unusual aspect of the earth is revealed in pictures recorded at midnight by U.S. Air Force weather satellites. The brightest lights on the dark side of the planet are giant waste-gas flares*

by Thomas A. Croft

**THREE MAJOR LIGHT SOURCES associated with human activities are visible in this nighttime satellite image …**

**the upper third of this picture are the city lights of Europe.**

**The larger isolated lights near the middle and bottom arise from gas flares at oil fields in Algeria, Libya and Nigeria.**

**The uniform band of smaller lights scattered across Africa south of the Sahara appears to originate with agricultural and pastoral fires.**

***Scientific America, 1978.***

# One of the most-cited paper on remote sensing of fires

*REMOTE SENSING OF ENVIRONMENT* 11 221–229 (1981)

## A Method for Satellite Identification of Surface Temperature Fields of Subpixel Resolution

JEFF DOZIER*

*NOAA National Earth Satellite Service, World Weathe*

**Plank function**

$$\beta(\lambda, T) = \frac{c_1 \lambda^{-5}}{\exp(c_2/\lambda T) - 1} \qquad (2)$$

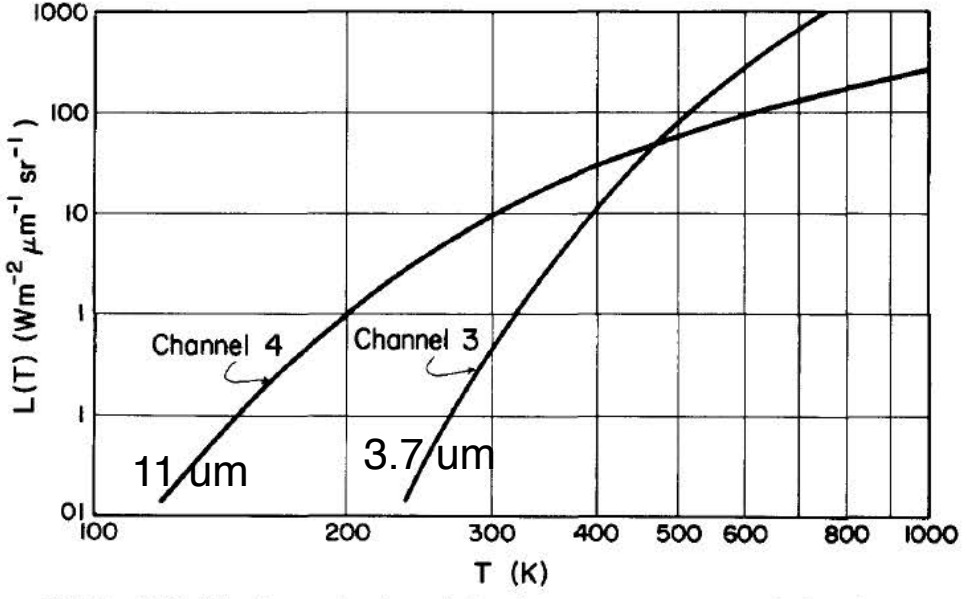



FIGURE 2 NOAA-6 radiances for channels 3 and 4 vs temperature, as calculated by Eq (1) with the spectral response functions in Fig 1

# Early detection of fires using AVHRR MWIR

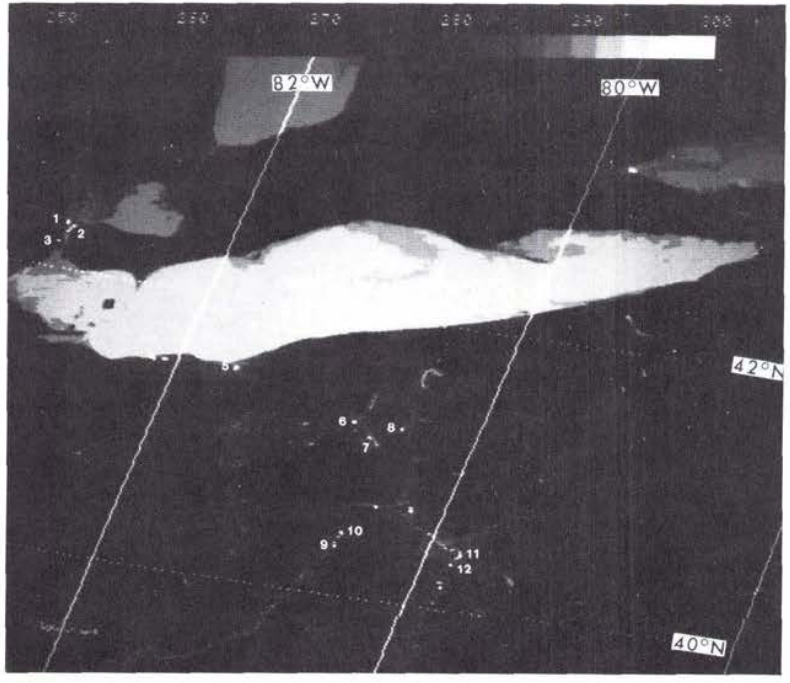


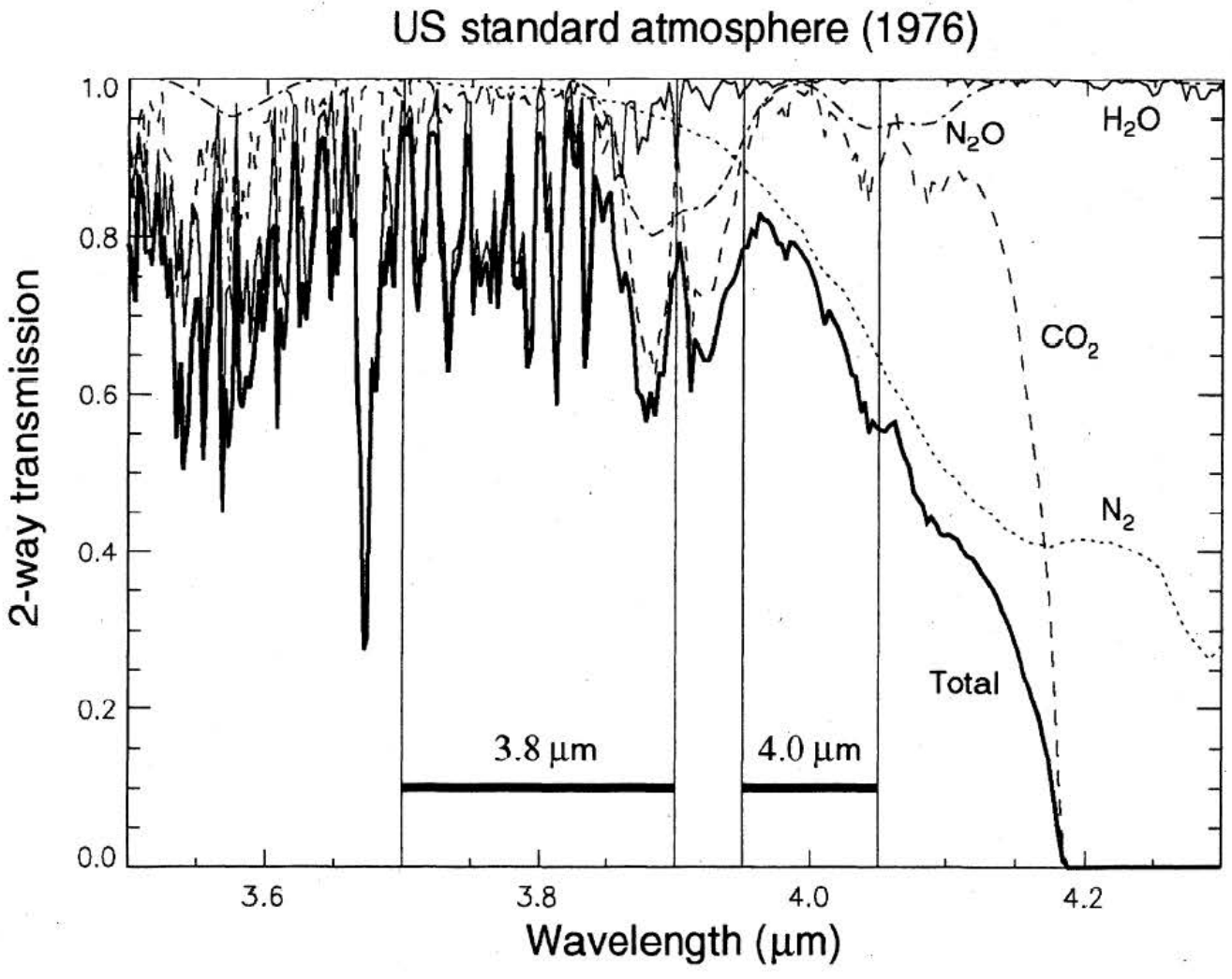

FIG. 1. NOAA-6 3.8-$\mu$m image of the midwestern United States taken on 24 September 1979 at 0015 GMT. The high temperature areas appear white and are identified in Table 2. Imagery processed by NASA/GSFC, Code 942.

MICHAEL MATSON
*NOAA National Earth Satellite Service*
*Washington, DC 20233*
JEFF DOZIER
*Department of Geography*
*University of California*
*Santa Barbara, CA 93106*

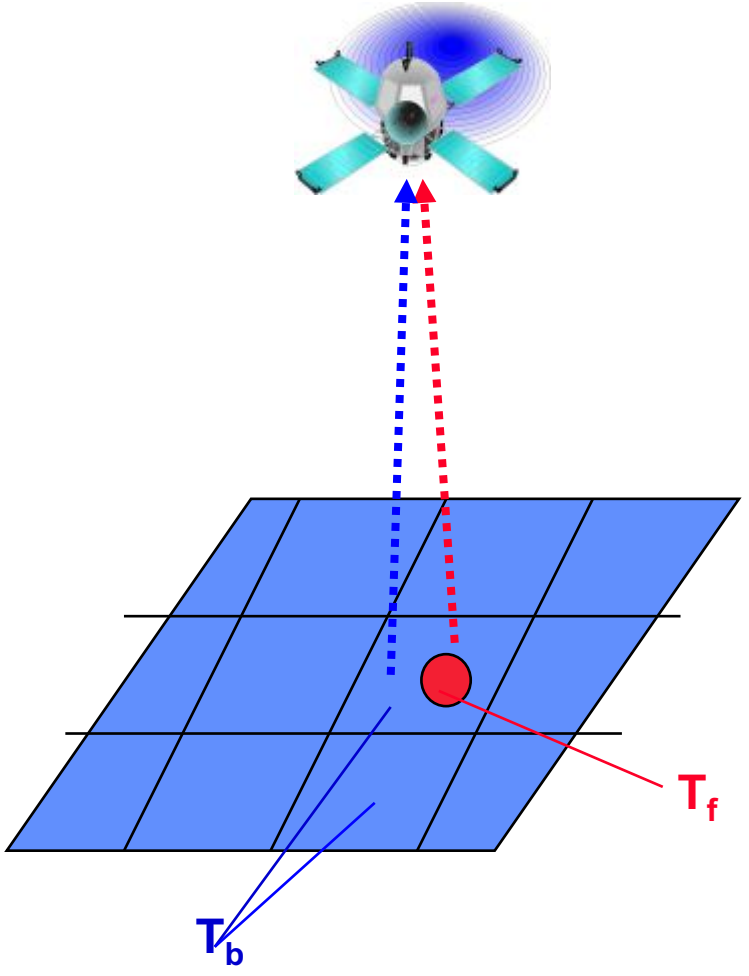
## Identification of Subresolution High Temperature Sources Using a Thermal IR Sensor

Steel mills, and gas flares from oil fields, were identified by using the 3.8-$\mu$m and 11-$\mu$m sensors on board the NOAA-6 satellite.

*Photogrammetric Engineering and Remote Sensing, 47,* 1311-1318.


US standard atmosphere (1976)
2-way transmission
1.0
0.8
0.6
0.4
0.2
0.0
3.6
3.8
4.0
4.2
Wavelength (μm)
$H_2O$
$N_2O$
$CO_2$
$N_2$
Total
3.8 μm
4.0 μm

# Dozier's method for fire detection
# fire size and temperature detection




**Fire pixels: the IR temperature anomalies.**
**Fire size and temperature are retrieved simultaneously.**

**4 μm:** $B_4(T) = P\,L_4(T_f) + (1-P)\,L_4(T_b)$

**11 μm:** $B_{11}(T) = P\,L_{11}(T_f) + (1-P)\,L_{11}(T_b)$

**L: IR radiative transfer function;**
**P: fire area fraction.**

**Derived Information:**

**Fire location**
**Fire size**
**Fire temperature**

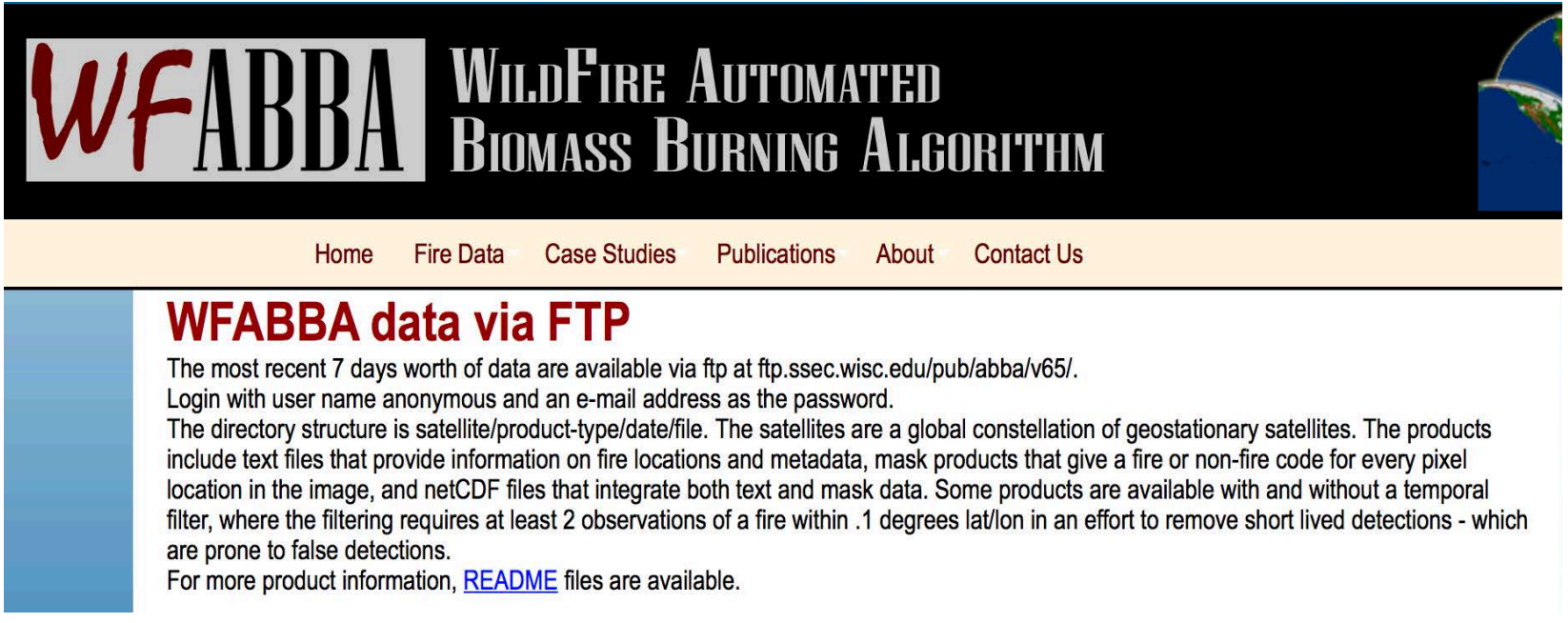
**Parameterization**

**(large uncertainties)**

**Smoke emission inventory**

# GOES-fire products

- http://wfabba.ssec.wisc.edu/ftp.html
- ftp://ftp.ssec.wisc.edu/pub/abba/v65/




Prins, E. M., News from fire research: The GOES-8 Automated Biomass Burning Algorithm (ABBA) introducing new capabilities for monitoring diurnal fire activity in the Western Hemisphere, *International Forest Fire News*, 49-52, 1996.

# ftp://ftp.ssec.wisc.edu/pub/abba/v65/goes-15/text/2017186/f20171860000.v65.g15

NOAA/NESDIS/ORA  University of Wisconsin-Madison/CIMSS
GOES-15 WF_ABBA (vs 6.5.008) Experimental Fire Product
Note: This product is preliminary and has not been quality controlled
Date: 2017186   Time: 0000 UTC

| Longitude | Latitude | Satzen(deg) | Pix Size(km2) | T4(K) | T11(K) | Fire Size(km2) | Temp(K) | FRP(MW) | Ecosystem | Fire Flag |
|---|---|---|---|---|---|---|---|---|---|---|
| -141.33 | 67.50 | 75.90 | 84.6693 | 302.3 | 284.4 | 0.5316 | 488. | 689. | 17 | 0 |
| -141.16 | 67.33 | 75.80 | 83.4612 | 301.7 | 280.1 | -9.0000 | -9. | -9. | 17 | 2 |
| -130.93 | 66.35 | 74.60 | 76.4866 | 298.4 | 285.9 | 0.0188 | 790. | 443. | 17 | 0 |
| -122.16 | 51.23 | 59.70 | 38.2548 | 306.4 | 297.9 | -9.0000 | -9. | -9. | 52 | 5 |
| -103.02 | 51.89 | 66.20 | 59.4047 | 314.4 | 292.8 | 0.0491 | 771. | 1033. | 30 | 0 |
| -120.97 | 50.76 | 59.40 | 38.1424 | 307.0 | 300.5 | -9.0000 | -9. | -9. | 40 | 5 |
| -87.86 | 48.80 | 71.50 | 101.7021 | 282.9 | 194.4 | -9.0000 | -9. | -9. | 21 | 5 |

# New concept and development

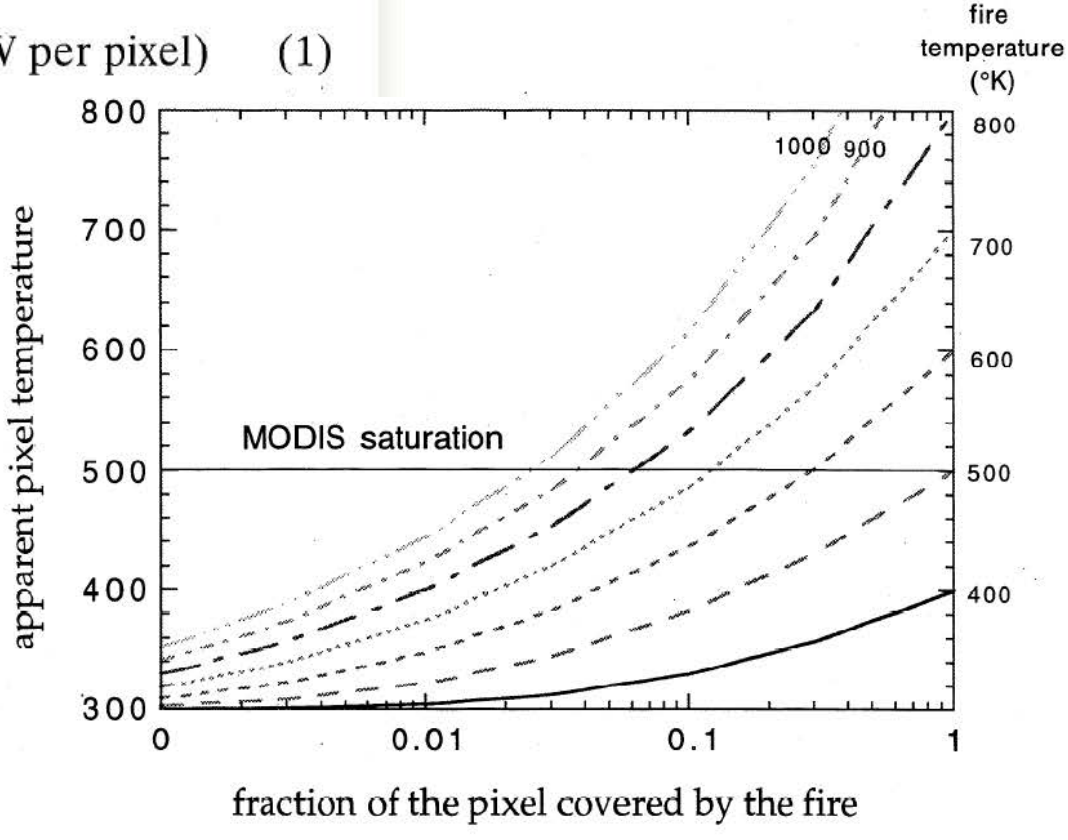
# Potential global fire monitoring from EOS-MODIS

JGR, 1998

Yoram J. Kaufman,[1] Christopher O. Justice,[2] Luke P. Flynn,[3] Jackie D. Kendall,[4] Elaine M. Prins,[5] Louis Giglio,[4] Darold E. Ward,[6] W. Paul Menzel,[7] and Alberto W. Setzer[8]

$$E_f = 4.34 \times 10^{-19}(T_4^8 - T_{4b}^8) \text{ (W/m}^2 \text{ or MW per pixel)} \quad (1)$$

- **Fire Radiative Power**
- **Fire location/time**
- **1 km resolution**
- **Much higher saturation temperature**

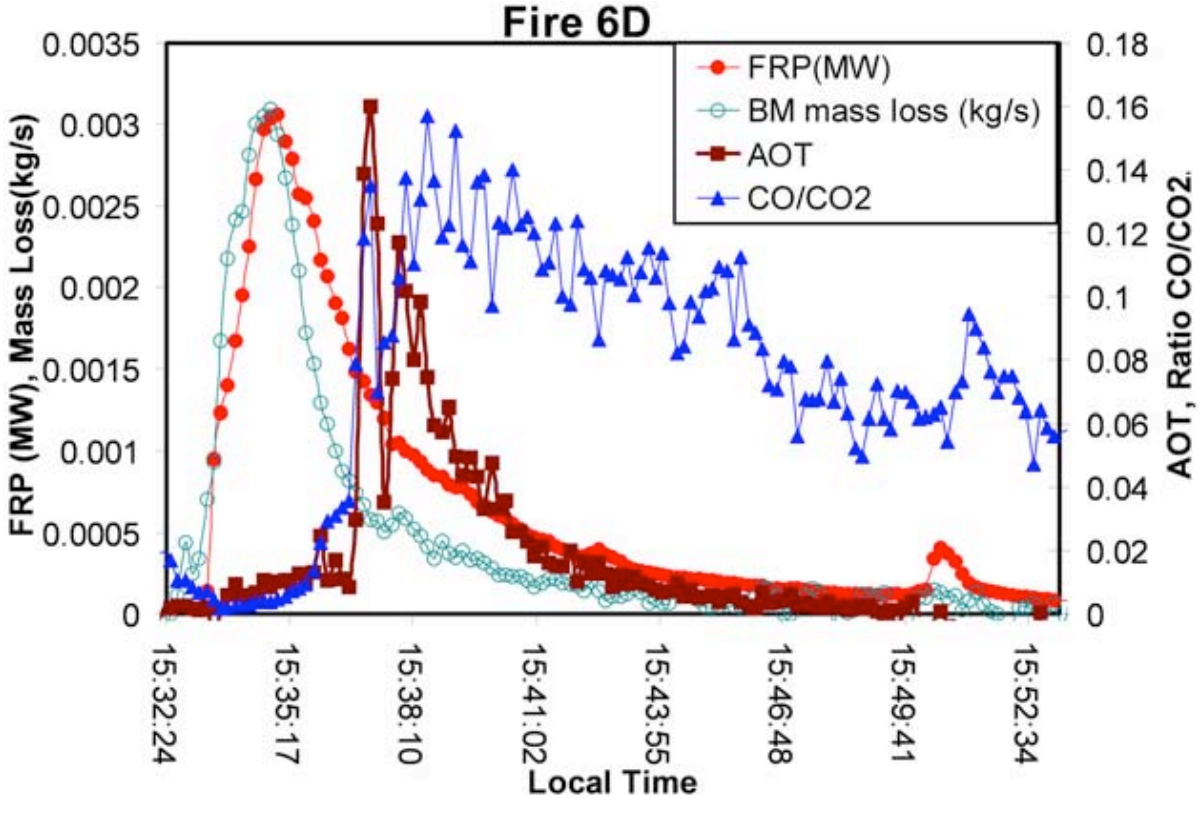


# Laboratory investigation of fire radiative energy and smoke aerosol emissions

JGR, 113, D14S09,
doi:10.1029/2007JD009659, 2008

Charles Ichoku,[1,2] J. Vanderlei Martins,[2,3] Yoram J. Kaufman,[4,5] Martin J. Wooster,[6]
Patrick H. Freeborn,[7,8] Wei Min Hao,[8] Stephen Baker,[8] Cecily A. Ryan,[8]
and Bryce L. Nordgren[8]

## Fire Radiative Power vs. Emission



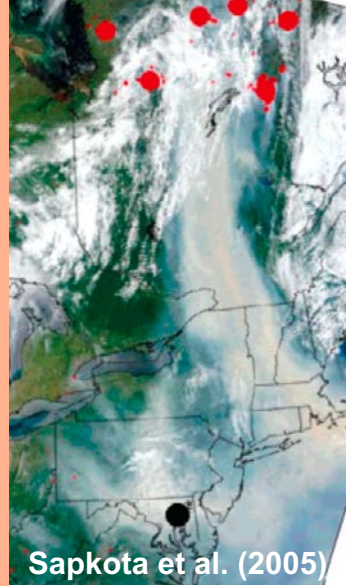
# MODIS Fire Radiative Power (FRP)

Slide from David Peterson, NRL

## Advantages

- Quantitative indicator of fire intensity (Ichoku et al, 2008)
- Proportional to amount of biomass consumed (Wooster et al., 2005)
- Proportional to amount of smoke released (Ichoku and Kaufman, 2005)
- Related to the smoke plume height (Val Martin et al., 2010)

**Current FRP Limitation (collection 5)**
**FRP per 1 km$^2$**

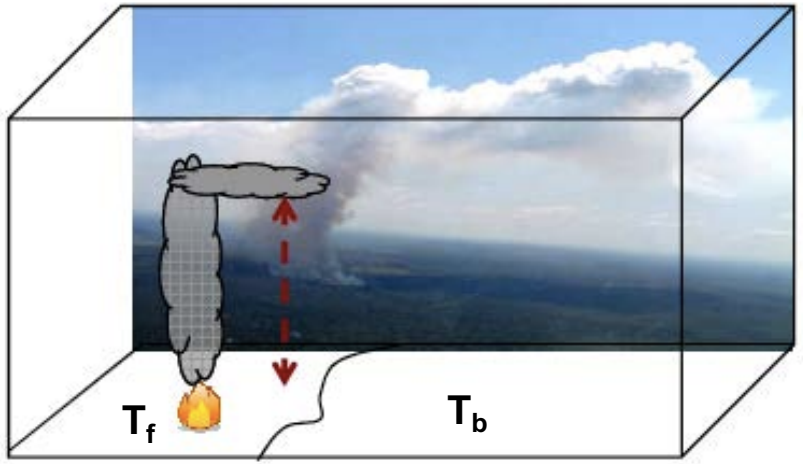



**These pixels have equal FRP?**

| MODIS Pixel #1 | MODIS Pixel #2 |
|---|---|
| High fire temp. | Cooler fire temp. |
| Small fire area | Large fire area |

**We need FRP per fire area!**

**FRP = $f(T_f - T_b)$** **Units: MW per pixel area**




Val Martin et al. (2010)

Contents lists available at SciVerse ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

# A sub-pixel-based calculation of fire radiative power from MODIS observations: 1 Algorithm development and initial assessment

David Peterson [a,*], Jun Wang [a], Charles Ichoku [b], Edward Hyer [c], Vincent Ambrosia [d]

[a] University of Nebraska, Lincoln, Lincoln, NE 68588, USA
[b] NASA Goddard Space Flight Center, 8800 Greenbelt Road, Greenbelt, MD 20771, USA
[c] Naval Research Laboratory, 7 Grace Hopper Avenue, Monterey, CA 93940, USA
[d] NASA-Ames Research Center, Mail Stop 245-4; Room 128, Moffett Field, CA 94035-0001, USA

# A sub-pixel-based calculation of fire radiative power from MODIS observations: 2. Sensitivity analysis and potential fire weather application

David Peterson *, Jun Wang

Department of Earth and Atmospheric Sciences, University of Nebraska—Lincoln, Lincoln, NE 68588, USA

The principal for sub-pixel fire area and temperature is based on Dozier (1981).

AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE

10.1002/2013JD021067

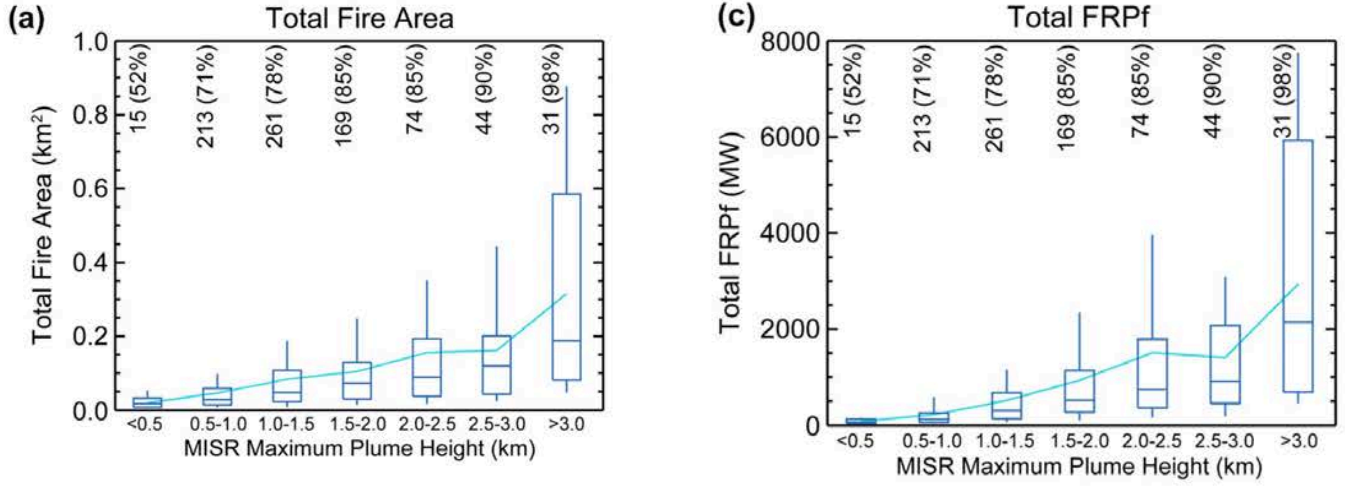
**Key Points:**

- Combining pixel and subpixel fire data improves plume height characterization
- Increasing subpixel fire area and temperature correspond to higher injections
- Filtering and clustering improve the information content of subpixel outputs

# Quantifying the potential for high-altitude smoke injection in the North American boreal forest using the standard MODIS fire products and subpixel-based methods

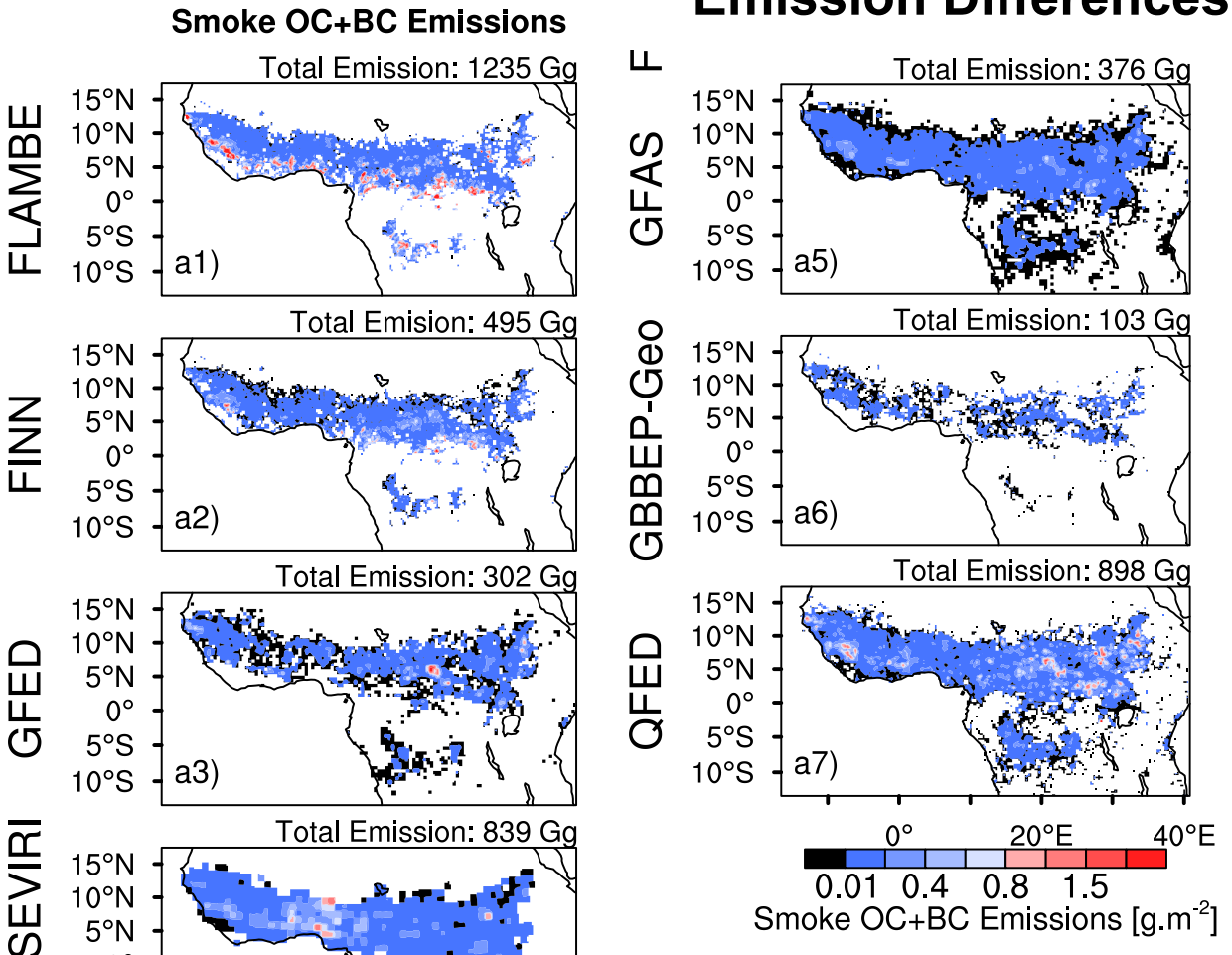
**David Peterson[1], Edward Hyer[2], and Jun Wang[3]**

[1]National Research Council, Monterey, California, USA, [2]Naval Research Laboratory, Monterey, California, USA, [3]Department of Earth and Atmospheric Sciences, University of Nebraska–Lincoln, Lincoln, Nebraska, USA




"The probability of injection above the BL reaches 50% when the subpixel radiant flux (FRP flux) exceeds 20 kW/m$^2$, highlighting its potential for estimating plume buoyancy".

# Emission Differences




**Feng ZHANG** et al., ERL, 2014.

**The large differences (a factor of 13) can be primarily attributed to the discrepancies in regions with high concentrations of fires.**

# VIIRS Fire Products

- **http://viirsfire.geog.umd.edu**

TABLE I
GENERAL SUOMI-NPP AND VIIRS SENSOR CHARACTERISTICS [1], [2], [10]

| | |
|---|---|
| Launch date | 28 October, 2011 |
| Orbit description | Near-circular, near-polar, sun-synchronous |
| Mean orbital altitude | 840 km |
| Inclination | 98.7° |
| Orbital period | 101.5 min. |
| Ascending equator local crossing time | 13:30 ± 10 min. |
| Swath width | ~3000 km |
| Number of bands | 5 I-bands, 16 M-bands, 1 DNB |
| Nominal spatial resolution | 375 m (I-bands), 750 m (M-bands, DNB) |
| Spectral range | 0.411−11.87 μm |
| Detectors per band | 32 (I-bands), 16 (M-bands), 672 (DNB) |
| Lines per scan | 32 (I-bands), 16 (M-bands, DNB) |

# VIIRS pixel size is preserved across the scan

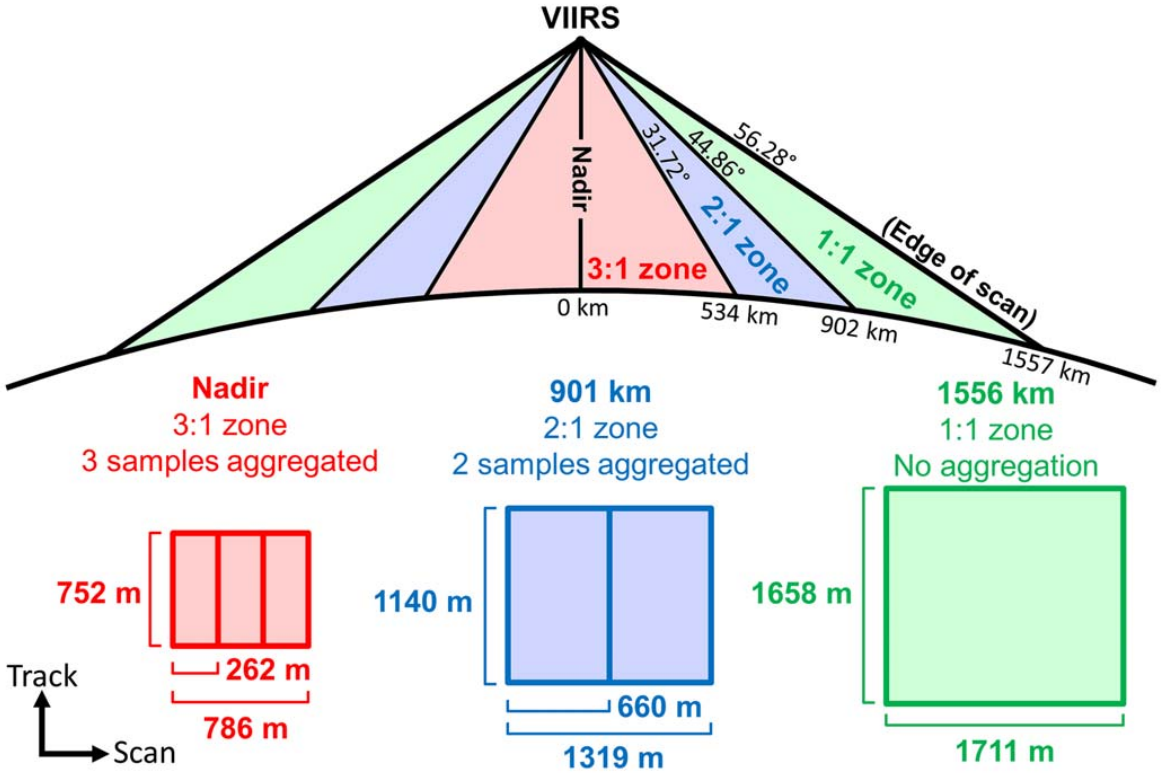
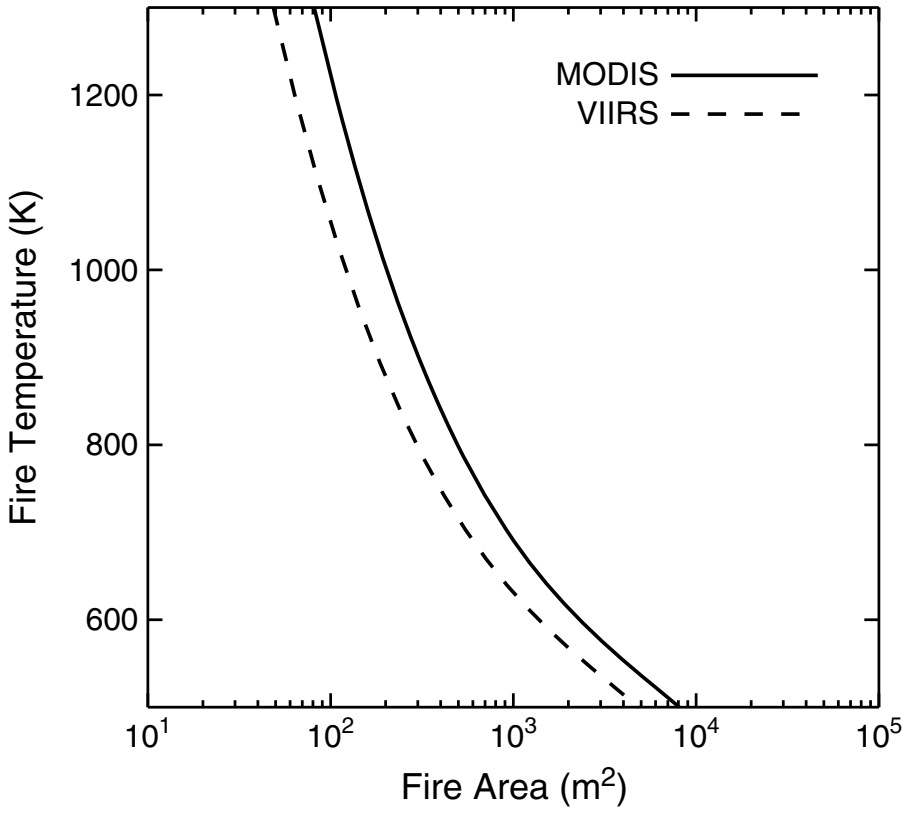



Fig. 1. VIIRS aggregation scheme (not to scale) and sample dimensions over the equator with an orbital altitude of 830 km [2]. The individual rectangles represent samples from an M-band detector, shaded by aggregation zone.

# VIIRS is better suited for detecting small fires



# Recent work of using 1.6 $\mu$m band for night fire detection

- C. D. Elvidge, M. Zhizhin, F.-C. Hsu, and K. E. Baugh, "VIIRS nightfire: 1333 Satellite pyrometry at night," *Remote Sens.*, vol. 5, no. 9, pp. 4423–4449, 1334 Sep. 2013, doi: 10.3390/rs5094423.
- W. Schroeder, P. Oliva, L. Giglio, and I. A. Csiszar, "The new VIIRS 375 m active fire detection data product: Algorithm description and initial assessment," *Remote Sens. Environ.*, vol. 143, pp. 85–96, Mar. 5, 2014, doi: 10.1016/j.rse.2013.12.008.

**How about using visible + IR to detect night fire?**

**Hot & Light: Flaming; hot & dim: smoldering**



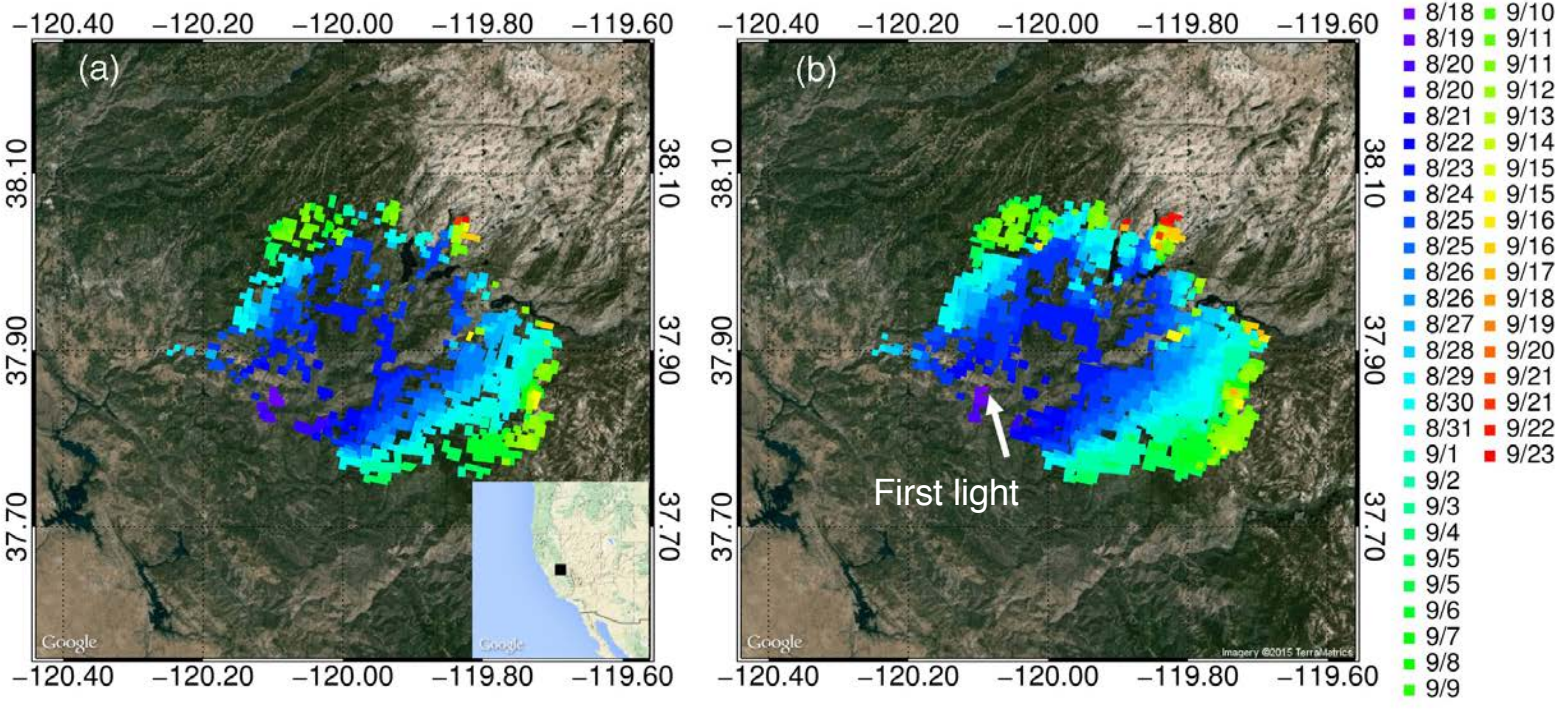
Improving Nocturnal Fire Detection With the VIIRS Day–Night Band

Thomas N. Polivka, Jun Wang, Luke T. Ellison, Edward J. Hyer, and Charles M. Ichoku

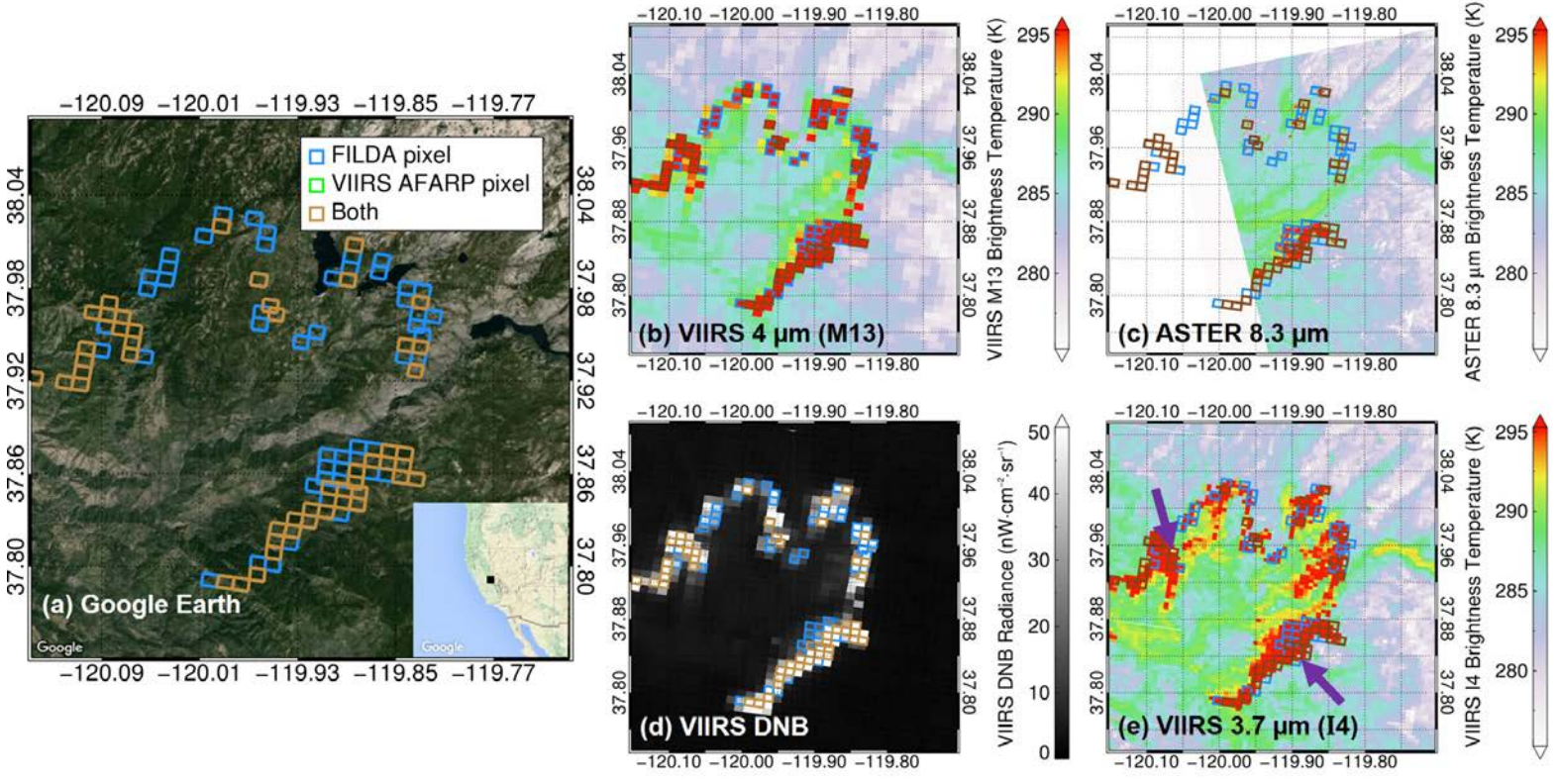
# Firelight Detection Algorithm (FILDA)
# Combined use of Vis + NIR + IR to detect fires

**IDPS AFARP**
**Active Fire Application Related Product**
**$BT_4$ > 320 K**

**FILDA**
**Dynamic threshold of $BT_4$**
**& DNB threshold**

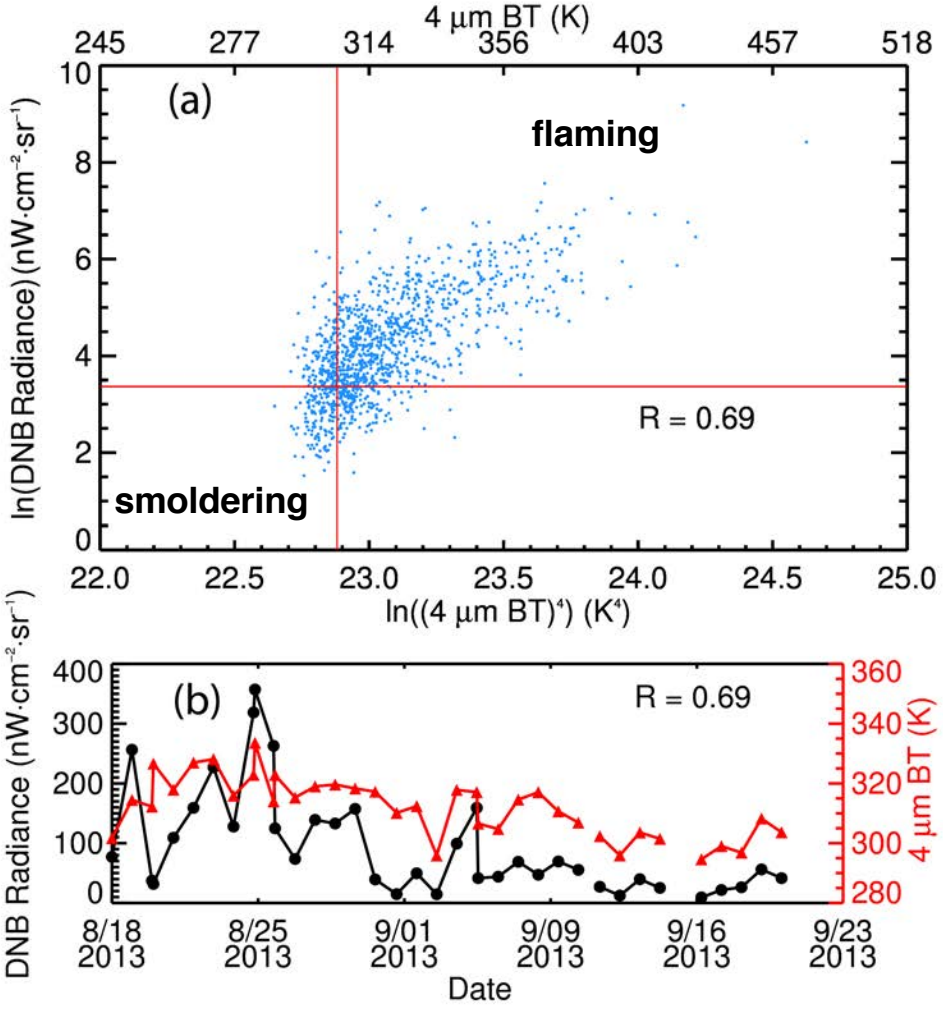


# Evaluation with ASTER

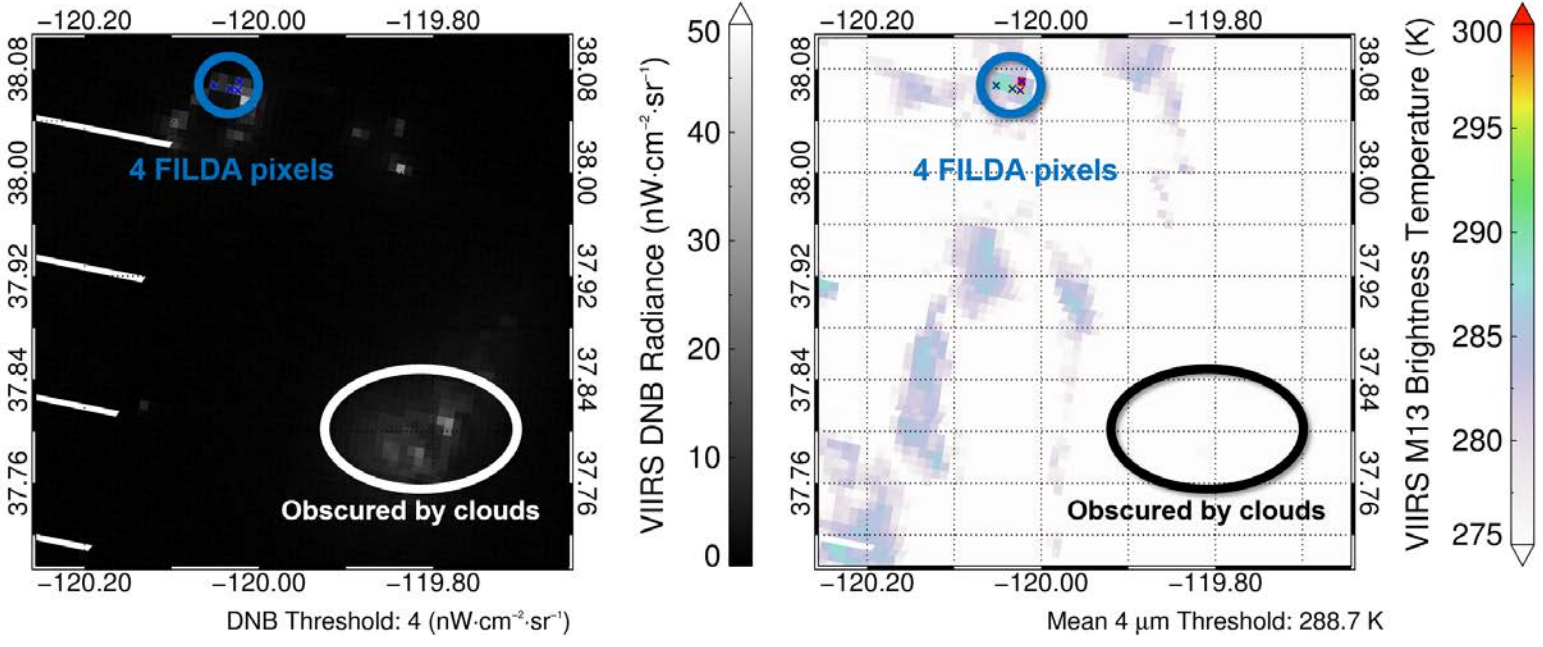



**Multiband/sensor view of the Rim Fire taken at 2:29 AM PDT, 24 August 2013**

# Potential characterization of smoldering vs. flaming



# Potential to detect fires through clouds



# Access and Analysis of MODIS and VIIRS operational products for fires with Python

**With help from Dr. Lorena Castro García**

# MODIS Operational Products for FIRE

**Active fire products**
The MODIS active fire product detects fires in 1km pixels that are burning at the time of overpass under relatively cloud-free conditions using a contextual algorithm, where thresholds are first applied to the observed middle–infrared and thermal infrared brightness temperature and then false detections are rejected by examining the brightness temperature relative to neighboring pixels (Giglio, L. et al. 2003).

**Burn area products**
Burned areas are characterized by deposits of charcoal and ash, removal of vegetation, and alteration of the vegetation structure (Pereira et al. 1997, Roy et al. 1999). The MODIS algorithm used to map burned areas takes advantage of these spectral, temporal, and structural changes (Roy et al. 2005a). It detects the approximate date of burning at 500 m by locating the occurrence of rapid changes in daily surface reflectance time series data. The algorithm maps the spatial extent of recent fires and not of fires that occurred in previous seasons or years.

**http://modis-fire.umd.edu/index.php**

# Name convention of MODIS products

- **LEVEL**
  - **Level-1, sensor-level data**
  - **Level-2, algorithm-level data, often instantaneous**
  - **Level-3, temporal-averaging data from level-2**

- **COLLECTION**
  - **After major updates/refinement of algorithms, all data products will be re-processed. The number of collections reflect the times that have been taken to conduct major re-processing.**
  - **Collection-6 means that the data is the result of $6^{th}$ major updates.**

# Level-2 MODIS file name convention

MOD06_L2.AYYYYDDD.HHMM.VVV.YYYYDDDHHMMSS.hdf

MYD06_L2. AYYYYDDD.HHMM.VVV.YYYYDDDHHMMSS.hdf

Definitions:
MOD06_L2 = Earth Science Data Type Name
A = Data Date (A = Acquisition)
YYYYDDD = Data Year and Julian Date
HHMM = Data Hour & Minute Start Time
VVV = Collection Version
YYYYDDDHHMMSS = Production Date (& Time)
hdf = Suffix denoting HDF file

- all times are UTC time, not local timet
- MOD06_L2 prefix is only an example (MYD04_L2, MOD05_L2, MYD05_L2, MYD06_L2, etc. could be substituted).

- MOD14: active fire product. 14 is the MODIS product #.
  - Example: MOD14.A2017001.1655.006.2017004111822.hdf
- MOD03: burn area products
  - Example: MOD03.A2017001.1655.006.2017003202340.hdf

# Example of MODIS level-2 active fire products

- **Where to get data?**
- **See step-by-step description from**

**https://esmc.uiowa.edu/fires_workshop**

**User's guide:**

**http://modis-fire.umd.edu/files/MODIS_C6_Fire_User_Guide_A.pdf**

### 5.1.1 Fire Mask

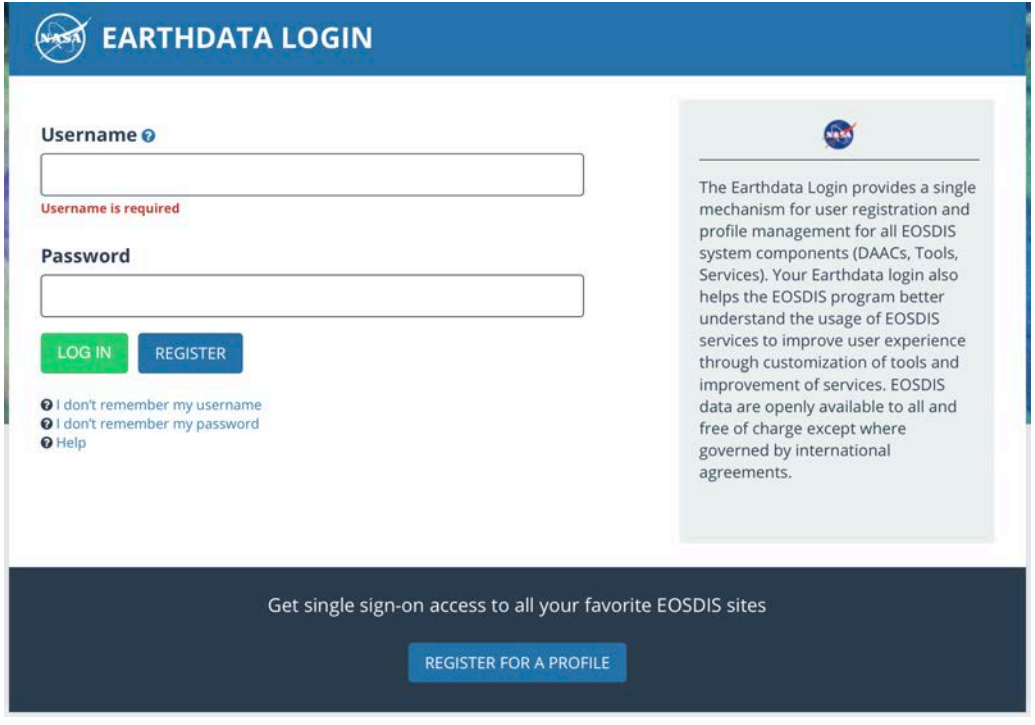
The fire mask is the principle component of the Level 2 MODIS fire product, and is stored as an 8-bit unsigned integer Scientific Data Set (SDS) named "fire mask". In it, individual 1-km pixels are assigned one of nine classes. The meaning of each class is listed in Table 2.

Table 2: MOD14/MYD14 fire mask pixel classes.

| Class | Meaning |
|---|---|
| 0 | not processed (missing input data) |
| 1 | not processed (obsolete; not used since Collection 1) |
| 2 | not processed (other reason) |
| 3 | non-fire water pixel |
| 4 | cloud (land or water) |
| 5 | non-fire land pixel |
| 6 | unknown (land or water) |
| 7 | fire (low confidence, land or water) |
| 8 | fire (nominal confidence, land or water) |
| 9 | fire (high confidence, land or water) |

# User account

1. **Create a user account at LAADS DAAC website**
   https://urs.earthdata.nasa.gov

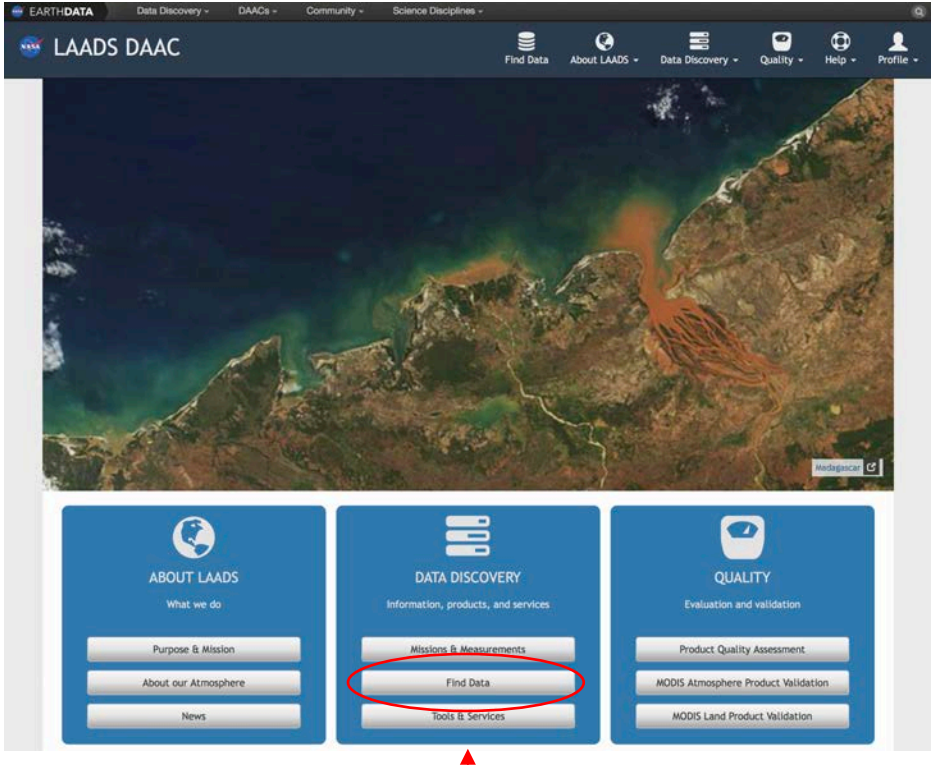


# Discovery data

**2. Visit the website of LAADS DAAC**

https://ladsweb.modaps.eosdis.nasa.gov

and select "**Find data**"



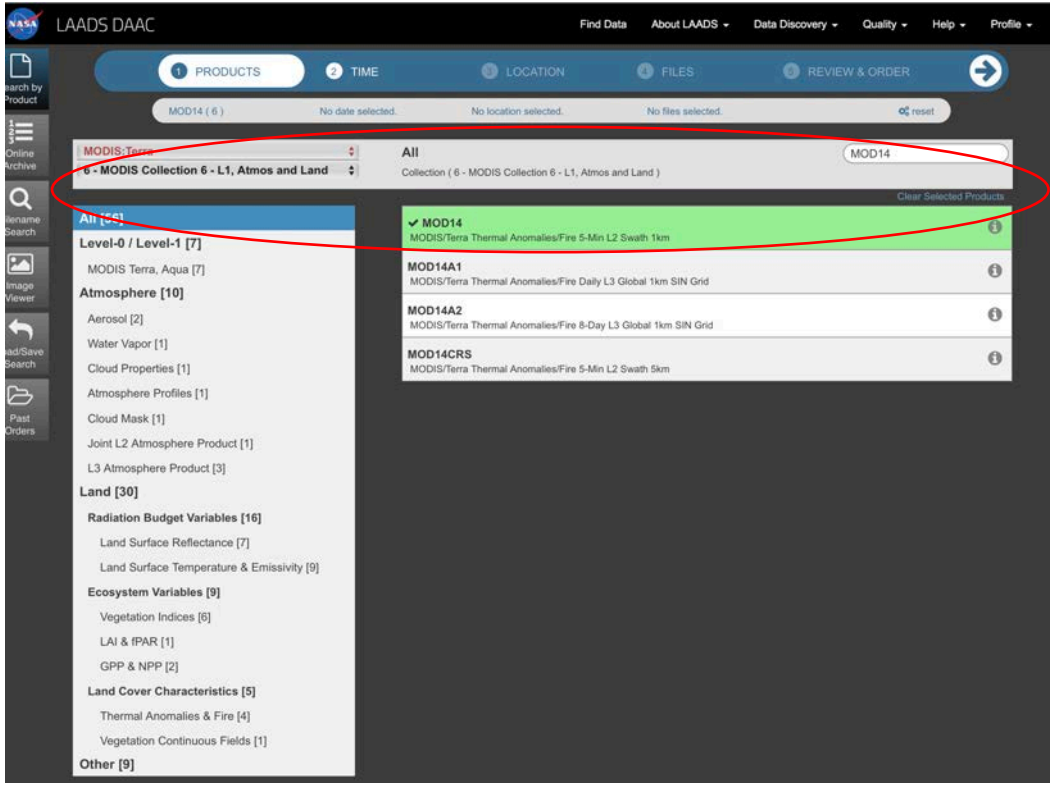
# Products

**3. Select interest product**

**sensor**: MODIS terra

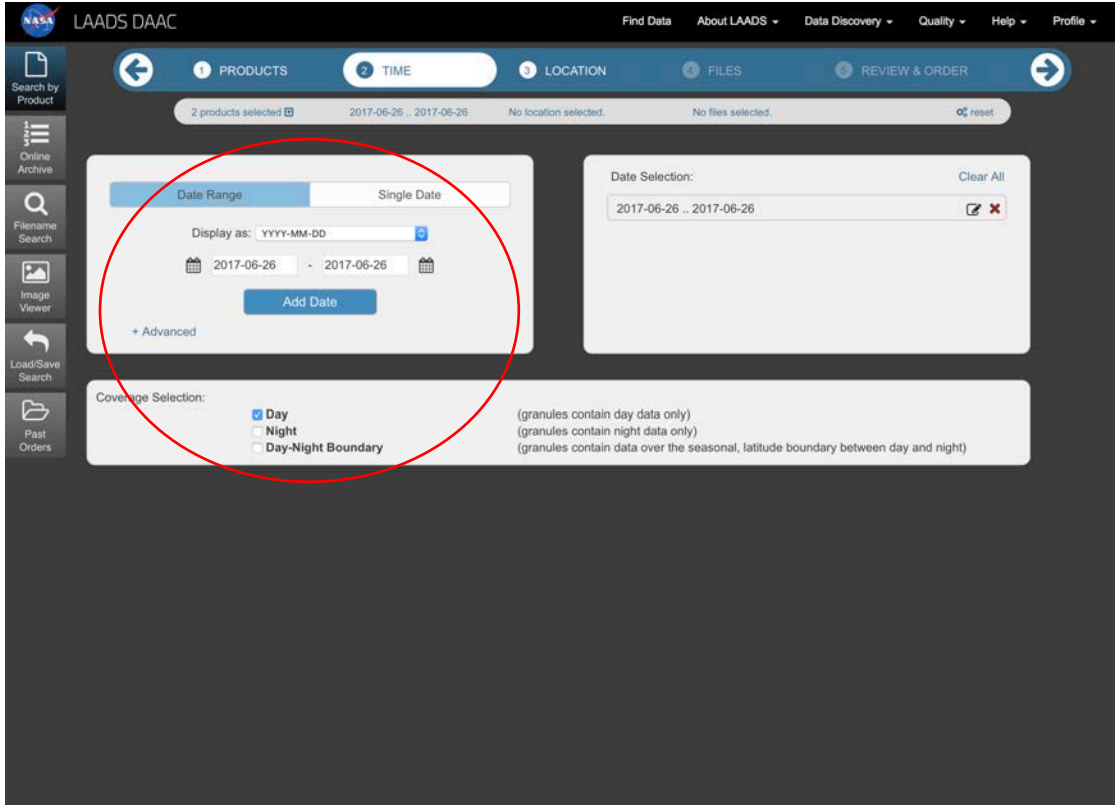
**collection**: Modis Collection6

**product**: MOD14 and MOD03



# Time

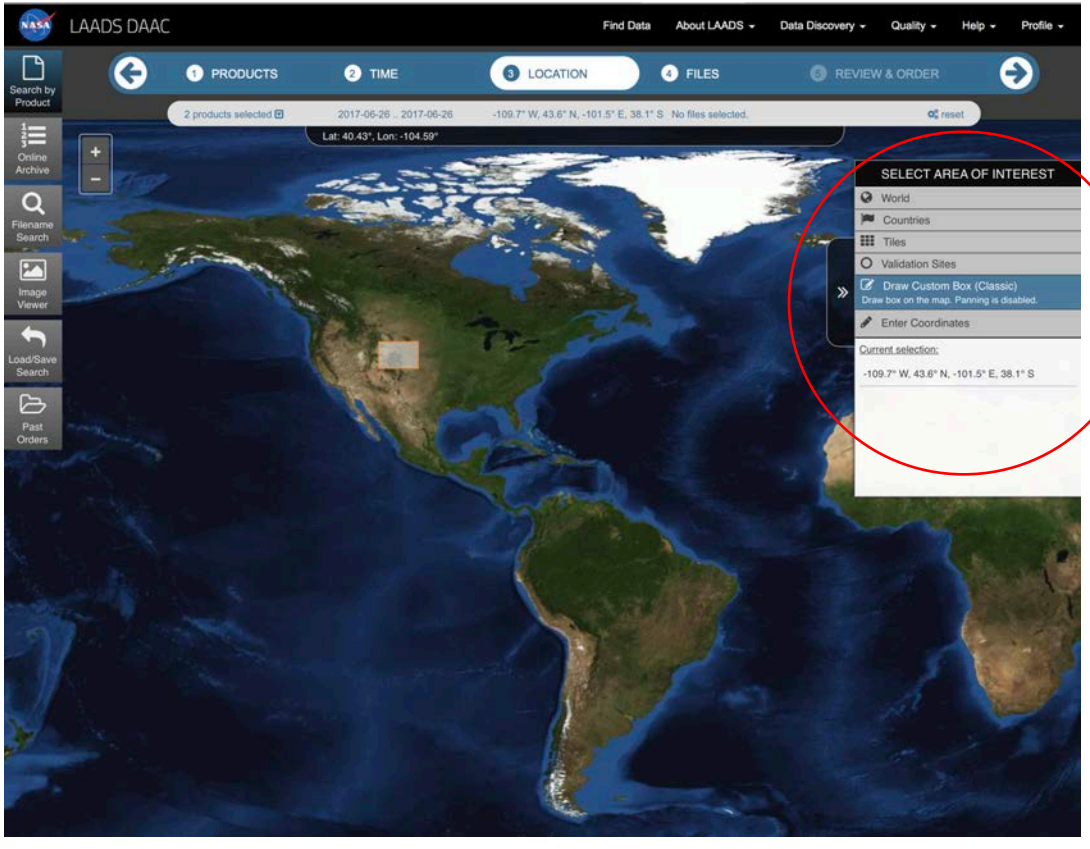
4. **Select period of time and coverage**



# Location

**5. Select Area of interest**

In this case, we opted by using the Draw Custom Box tool for selecting our area of interest

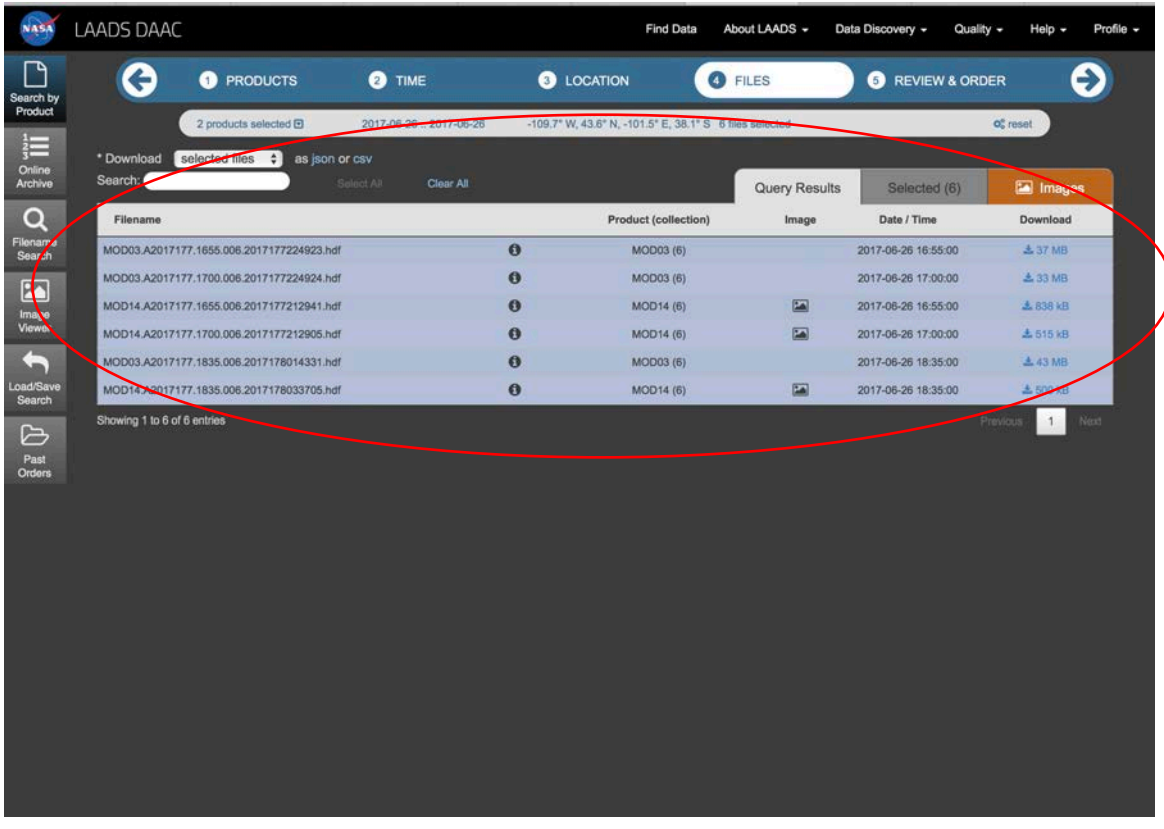


# Files

**6. Select files to download**

At this point, you can download each file by separately , or you can order all the selected files to download them via FTP.

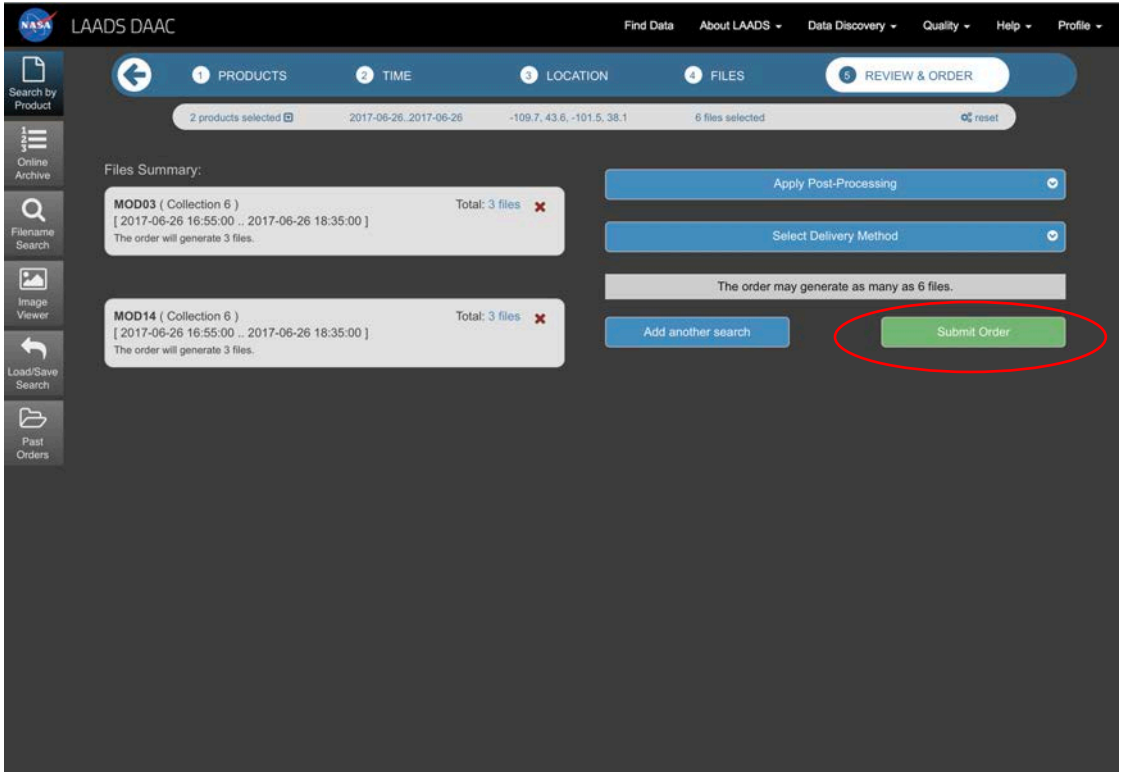
*Note that in the result appears files for MOD14 and MOD03, this is because MOD03 product contains geolocation data for MOD14 .*



# Order

**7. Order files**

You will receive an email with the information and instructions for retrieving the files using the command line.



# Email instructions

**8. Retrieve files**

**apache user for nonltp servers**
To: Lorena Castro Garcia
LAADS Web Order Notification

Your Order ID is: 501158967

The data you ordered will be staged (in about 10 minutes), and you can retrieve the data through anonymous FTP using:

ftp ladsweb.modaps.eosdis.nasa.gov
username: anonymous
password: lorena-castrogarcia@uiowa.edu

cd /orders/501158967
binary
prompt
mget *

Order 501158967 contains 3 file

- if your submission required additional post-processing you will be notified when these files become available

*NOTE: The files will be deleted after 5 days, please download the files before they get deleted.

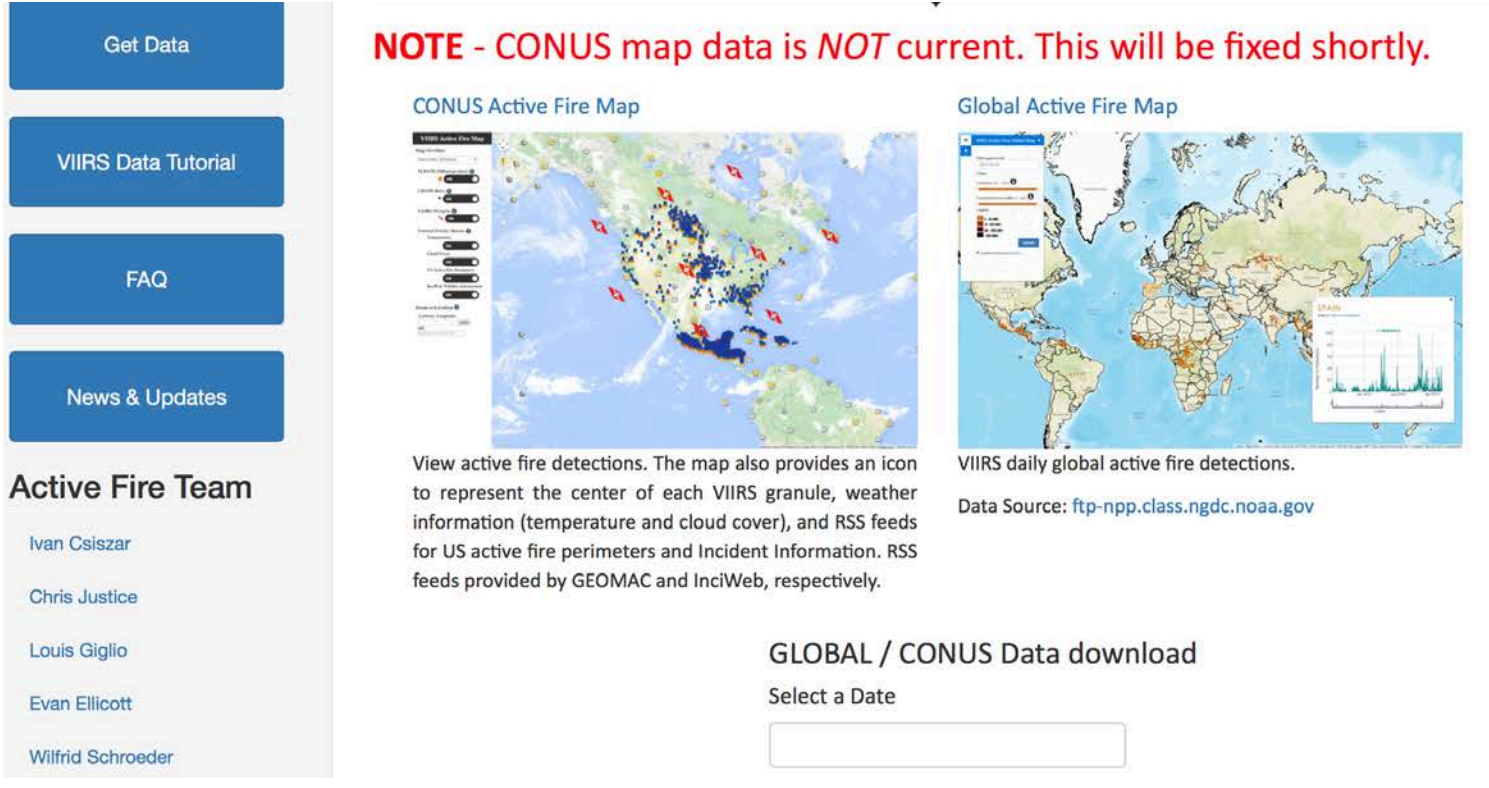
For help, please contact us at modapsuso@lists.nasa.gov

Thank you,

The LAADS Support Team

# VIIRS fire products

- **http://viirsfire.geog.umd.edu**
  - **M-band product, 750 m resolution**
  - **I-band product, 375 m resolution**



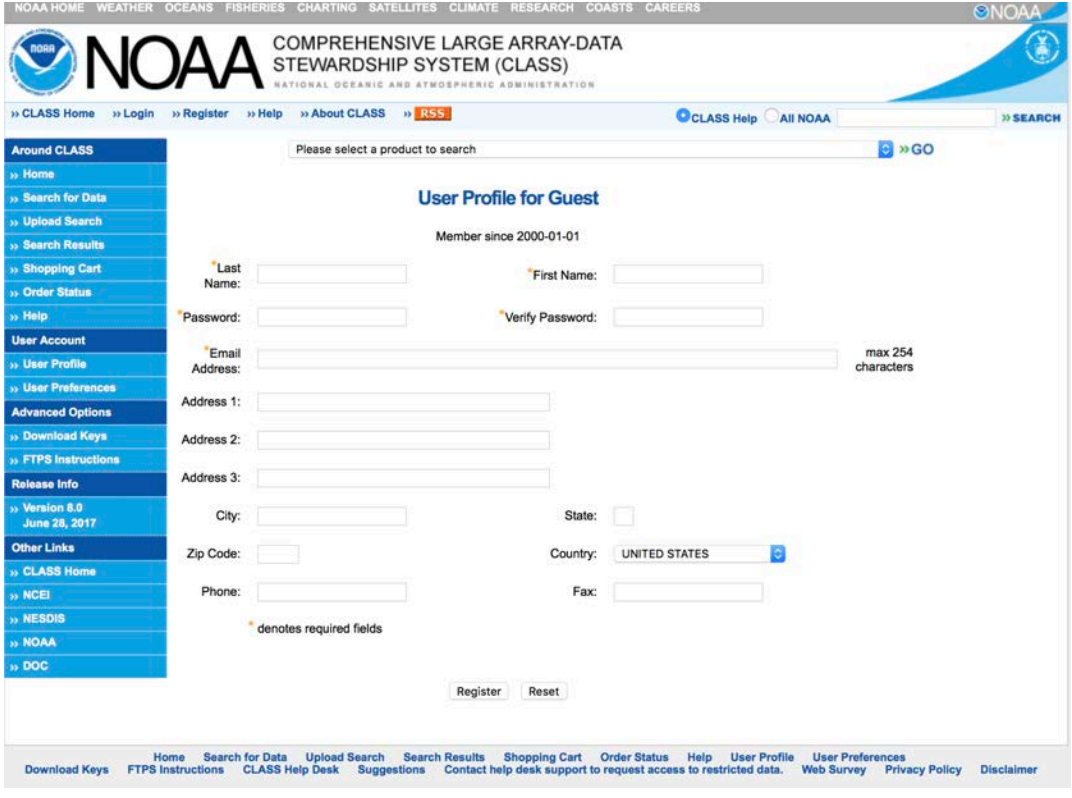
# Where/How to get VIIRS M-band fire product?

- **For M-band, hdf5 format**
- **https://esmc.uiowa.edu/fires_workshop/ppts/**

# User account

1. **Create a user account at NOOA CLASS website and login it.**

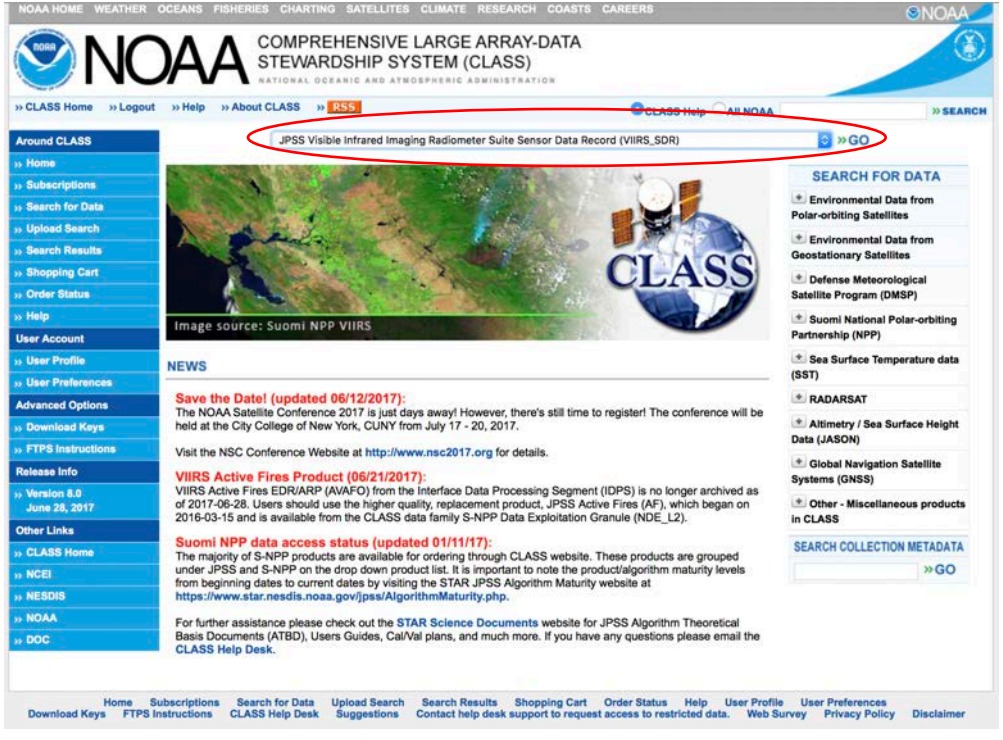
https://www.class.ngdc.noaa.gov/saa/products/user_profile



# Discovery data

**2. Select a product for search**

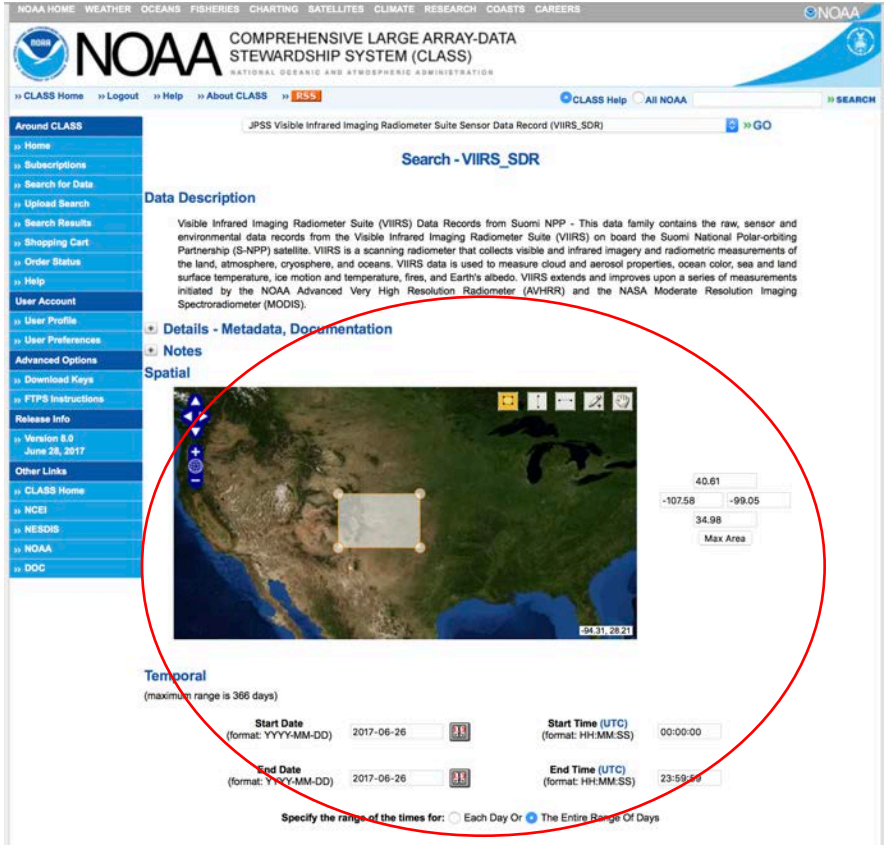
For this case, let's go to select **VIIRS_SDR**



# Location and Time

**3. Select area of interest and period of time**

In this case, we opted by using the Draw Custom Box tool

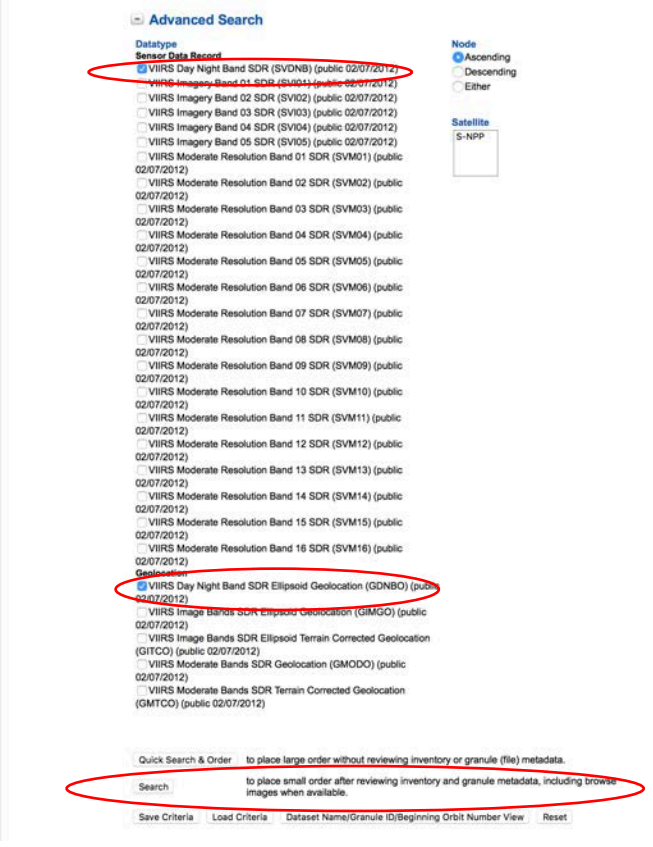


# Products and search

**4. Select interest product (s)**

**sensor**: SVDNB and GDNBO

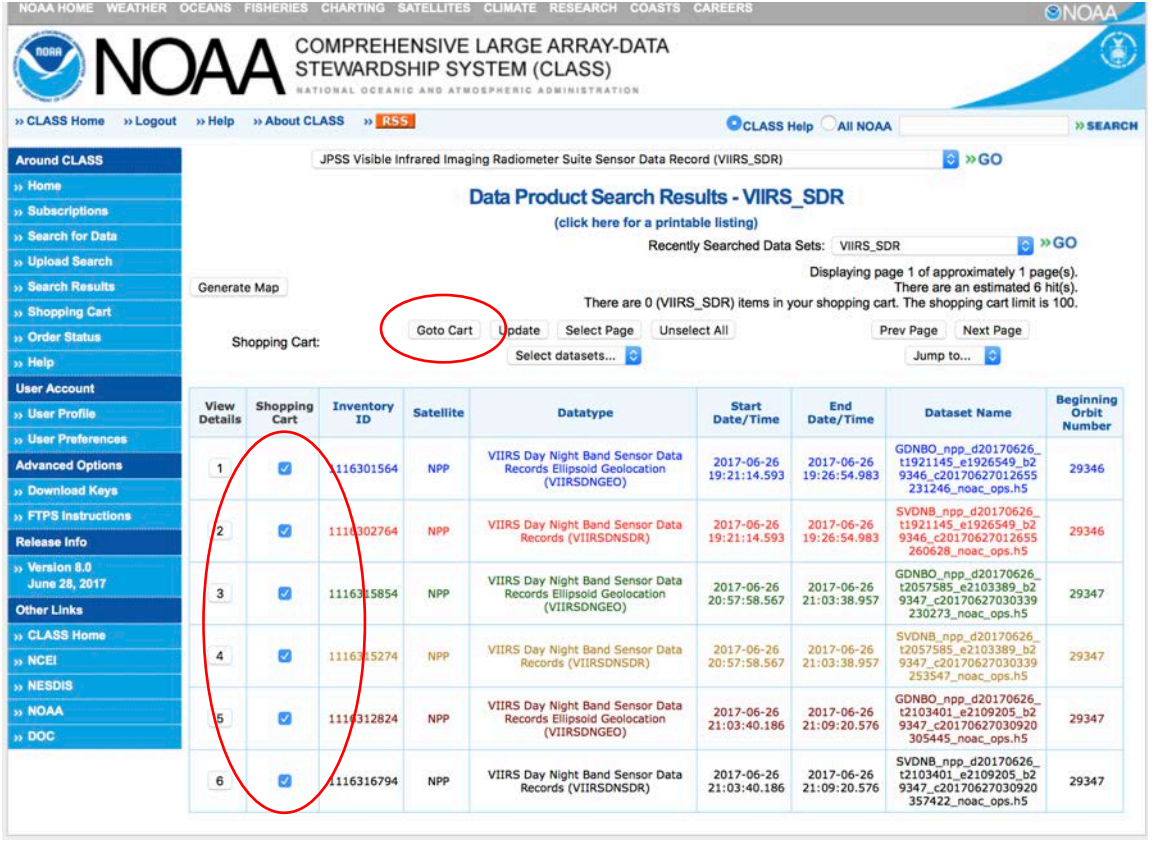
**5. Select the type of search**



# Files

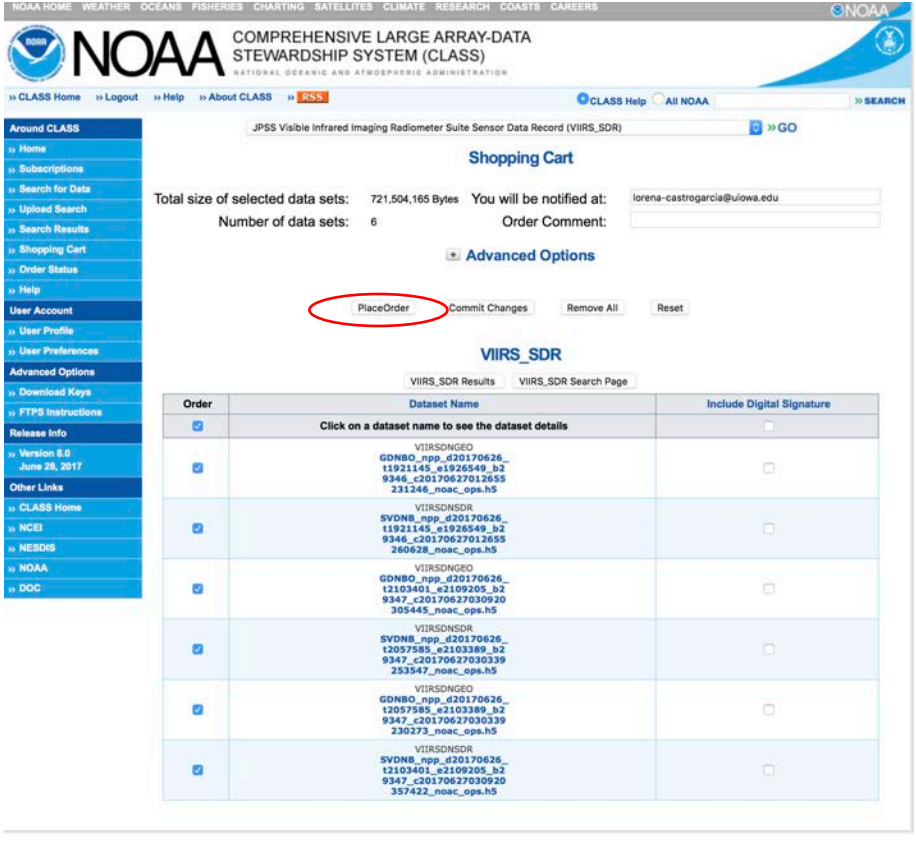
**6. Select files to order**

At this point, we have **selected** the files that we want to retrieve, now we need to press "**Goto Cart**" option



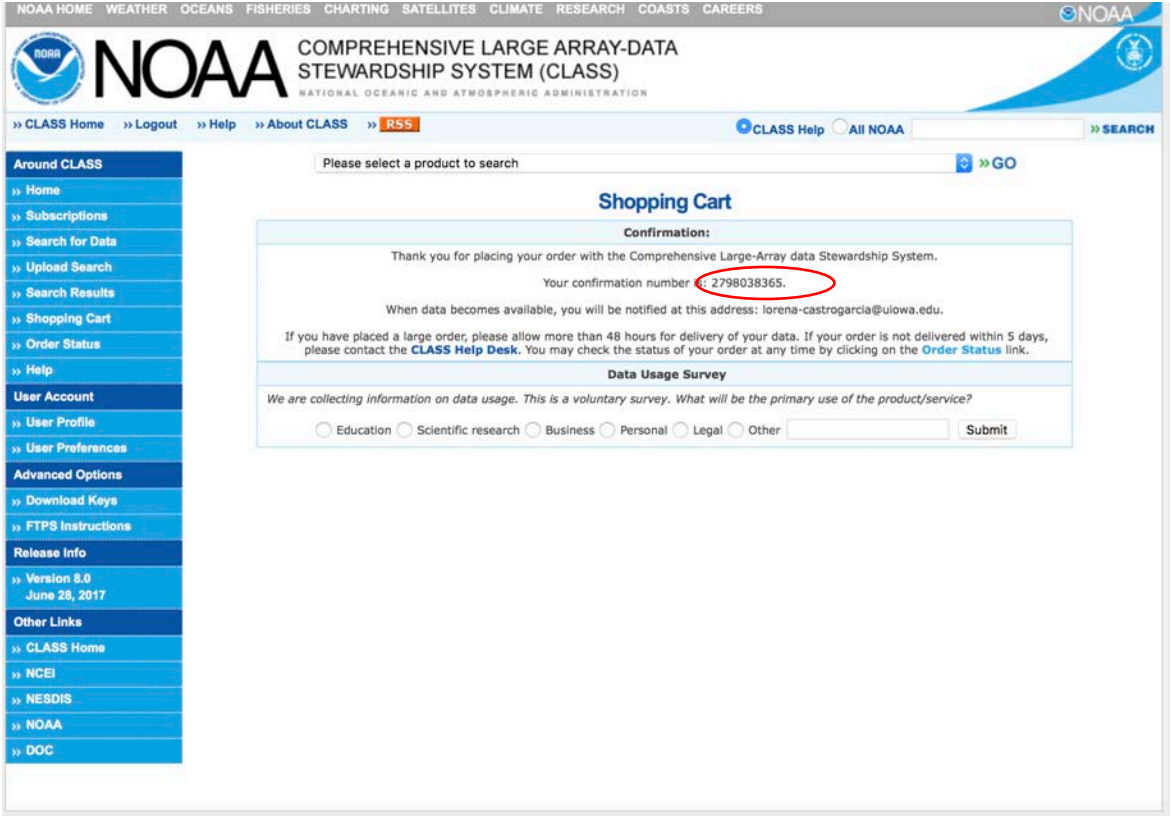
# Order

7. **Order files**



# Order confirmation

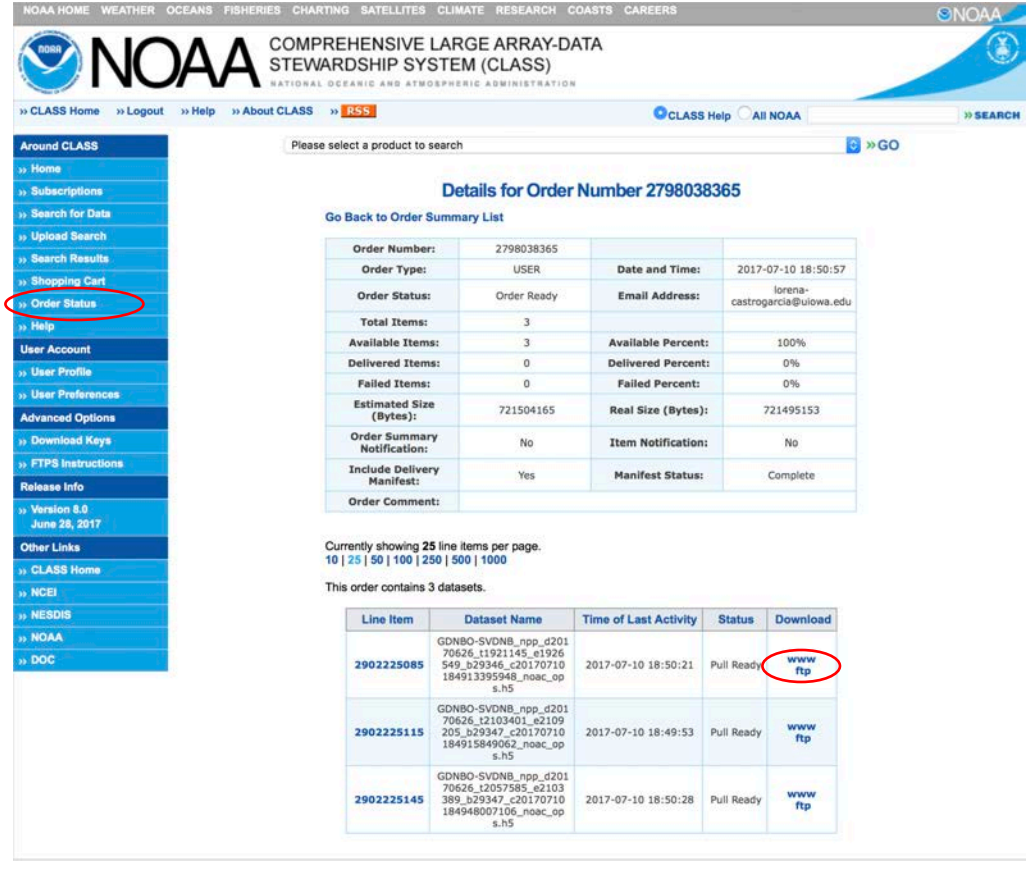
We will receive a conformation number which we can use for checking the order status



# Order status and get files

**8. Check the order status**

When the order is ready, we have the options ”**www** or **ftp**” for downloading the files.



# Where/How to get VIIRS I-band fire product?

- **For I-band, netcdf format.**
- **https://earthdata.nasa.gov/earth-observation-data/near-real-time**
- **ftp://nrt3.modaps.eosdis.nasa.gov/allData/5000/VNP14IMG_NRT/**

# Codes & Scripts

- https://esmc.uiowa.edu/fires_workshop/requisites.pdf


Thank you !