Continuing Yoram Kaufman's Legacy: From $PM_{2.5}$ and Fires to Aerosol Emissions

Jun Wang

ARROMA group

Aerosol, Radiation, Remote-sensing, & Observation-based Modeling of Atmosphere

Univ. of Nebraska **Univ. of Iowa, starting Aug. 2016**

10th Anniversary Yoram Kaufman Memorial Symposium
NASA GSFC, 21-23 June 2016

My ties with Yoram

- One of graduate students growing up with reading Yoram's paper
  - "Knowing a person from reading his/her book"

- Had only one conversation with him during a AGU meeting break (something like this):
  - "Hi, Yoram, I read a lot of your papers"
  - "Oh, so you're also interested in aerosols?"
  - "yes …", "Is it important to consider aerosol hygroscopicity in satellite retrievals?"
  - "In some cases of course, but globally difficult …"

- First person to use Yoram's office for a year after he passed away
  - Read many of his papers on his desk

Satellite characterization of urban aerosols: Importance of including hygroscopicity and mixing state in the retrieval algorithms

Jun Wang[1] and Scot T. Martin[1]

Received 27 September 2006; revised 5 April 2007; accepted 2 May 2007; published 11 September 2007.

JGR 2007

What do I learn from reading Yoram's paper?

- Ground-break ideas & new concepts
- Clear and easy-to-understand description of physics
- Thorough analysis, but high-level presentation of results
- "big brushes", focus on key/major processes & variables
- Tackle complex problems with principals, simplicity and elegancy

This talk presents some of my (and my group's) work inspired Yoram's paper related to air pollution ($PM_{2.5}$) and fires.
Focus is put the concept

SATELLITE MEASUREMENTS OF AEROSOL MASS AND TRANSPORT

Atmospheric Environment, 1984.

ROBERT S. FRASER

Laboratory for Atmospheric Sciences, NASA/Goddard Space Flight Center, Greenbelt, MD 20771, U.S.A.

YORAM J. KAUFMAN

University of Maryland in collaboration with Goddard Laboratory for Atmospheric Sciences, NASA/Goddard Space Flight Center, Greenbelt, MD 20771, U.S.A.

and

R. L. MAHONEY

Science Systems and Applications, Inc. 10210 Greenbelt Road, Seabrook, MD 20706, U.S.A.

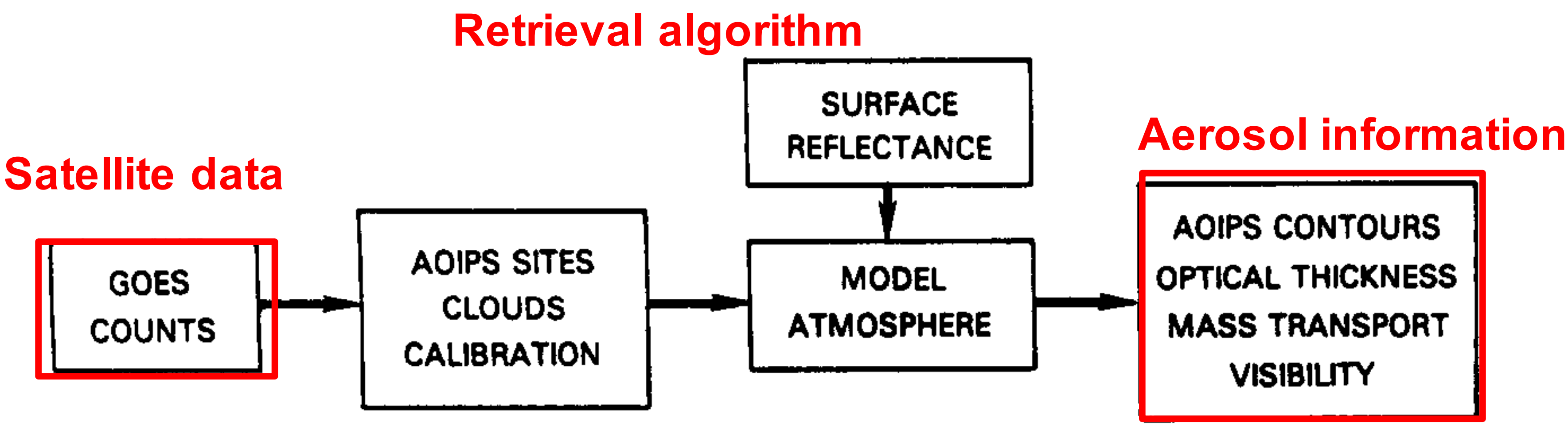
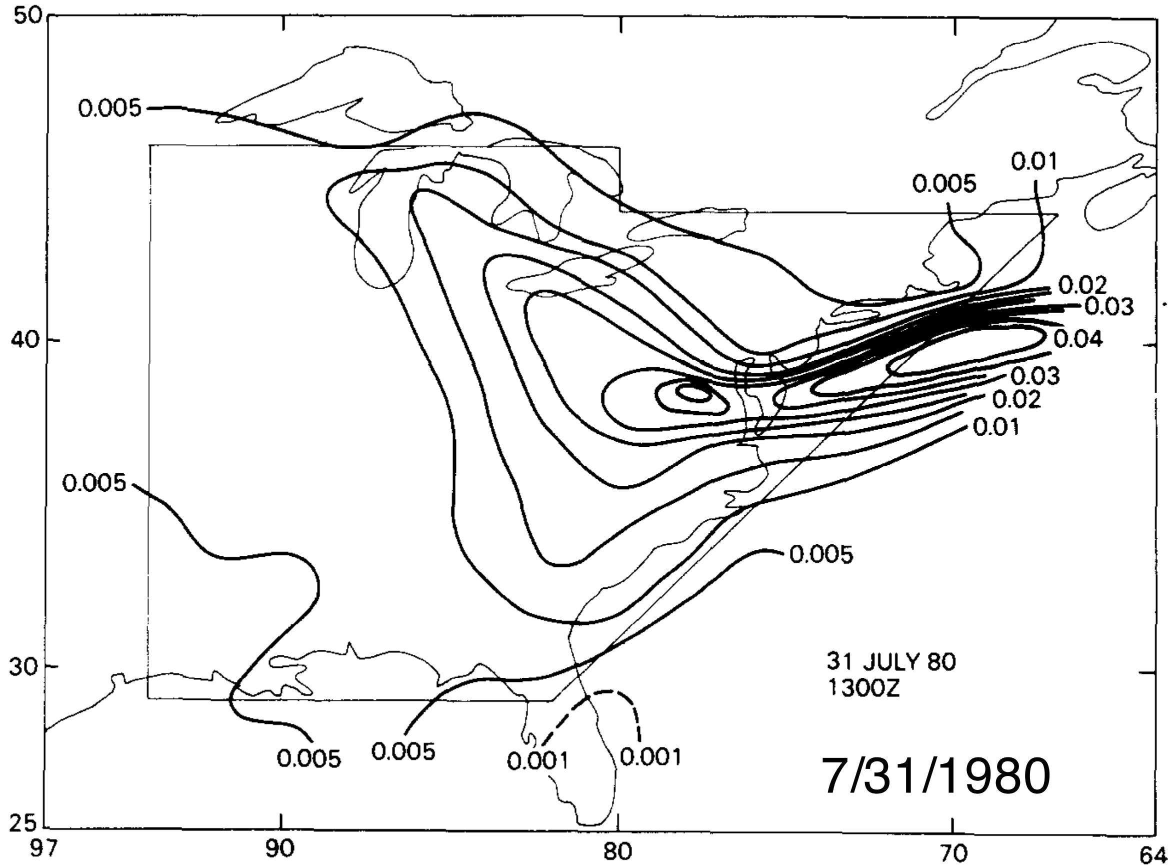


Fig. 3. Algorithm for deriving aerosol properties from satellite observations.



Atmospheric loading of particulate sulfur (gm^{-2}) on 31 July 1980.

Derived from GOES visible reflectance are

- **aerosol optical thickness (AOT)/depth (AOD)**

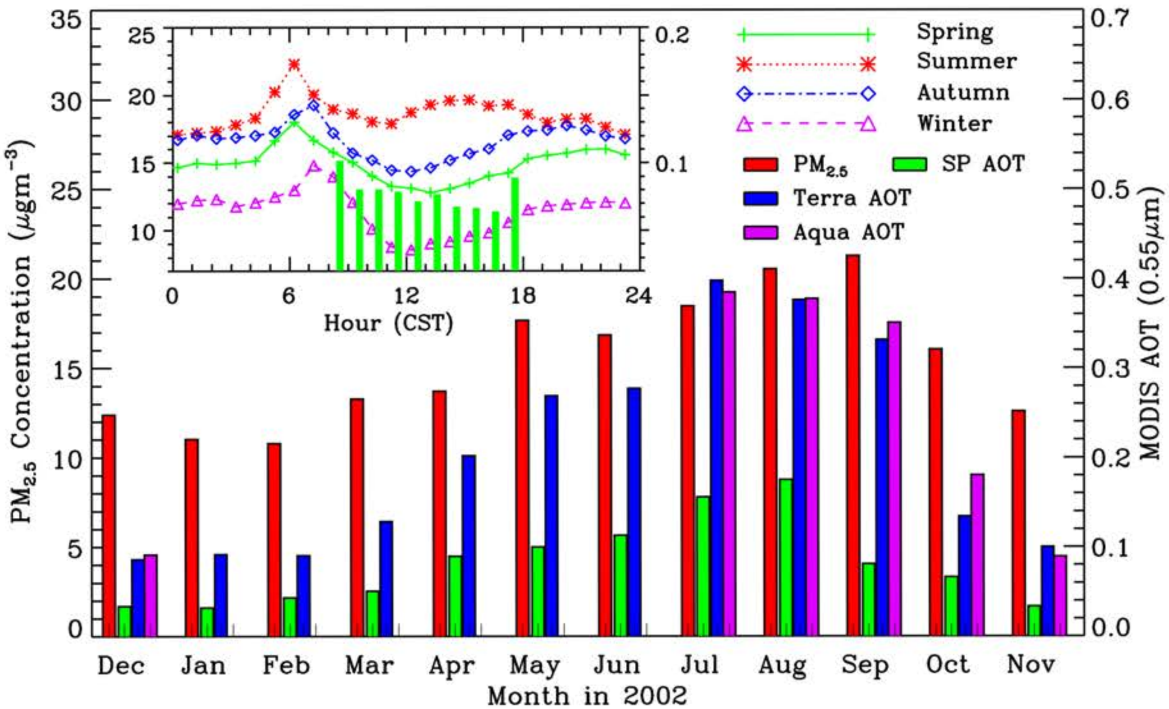
↓

- **Columnar amount of sulfur**

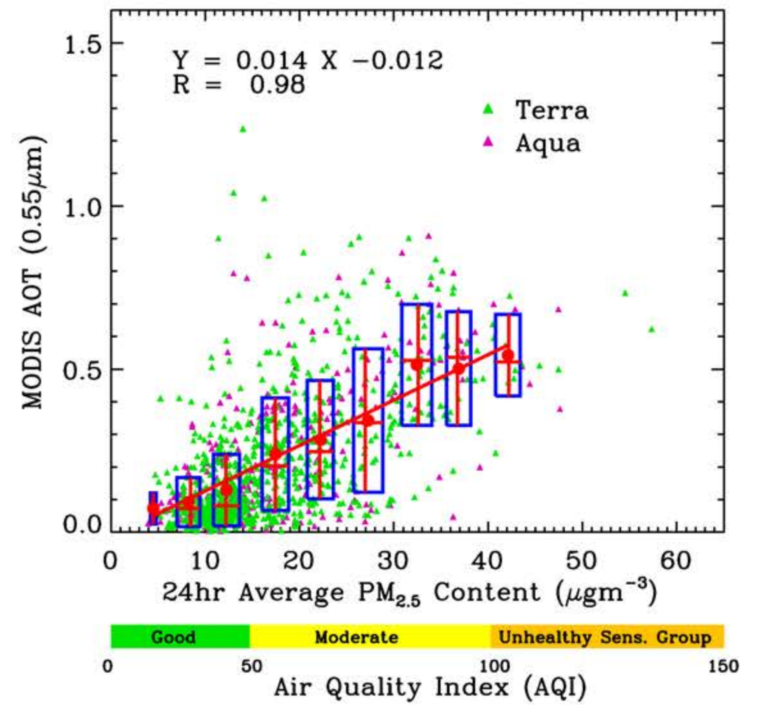
Table 1. Comparison of columnar masses of sulfur derived from ground-based and satellite observations. The satellite observations were made at 1300 GMT on 31 July 1980

1 Place	2 Latitude (deg. N)	3 Longitude (deg. W)	4 Particulate sulfate mass ($\mu g\ m^{-3}$)	5 Columnar sulfur mass ($g\ m^{-2}$)	6 Reference	7 Satellite sulfur mass ($g\ m^{-2}$)	8 Ratio columns 7 and 5
Virginia	38.7	78.3	38	0.018	Ferman *et al.* (1981)	0.040	2.3
Virginia	38.7	78.3	38	0.018	Stevens *et al.* (1984)	0.040	2.3
Near Baltimore	39.3	76.4	24	0.014	Tichler *et al.* (1981)	0.017	1.2

Mass loading to surface $PM_{2.5}$: first attempt



Jefferson County, AL



This example illustrates an advantage of using the MODIS AOT product to infer air quality categories over large spatial scales where ground point measurements are limited or unavailable.

[10] However, we emphasize that several factors including $f(rh)$, Q_{ext} and H_{eff}, affect the relationship between column AOT and $PM_{2.5}$. While the satellite-derived AOT is a measure of column AOT in ambient conditions, the $PM_{2.5}$ mass is indicative of the mass of dry particles near the surface.

Wang & Christopher (2003), GRL, Intercomparison between satellite-derived aerosol optical thickness and PM2.5 mass: Implication for air quality studies. 220 citation.

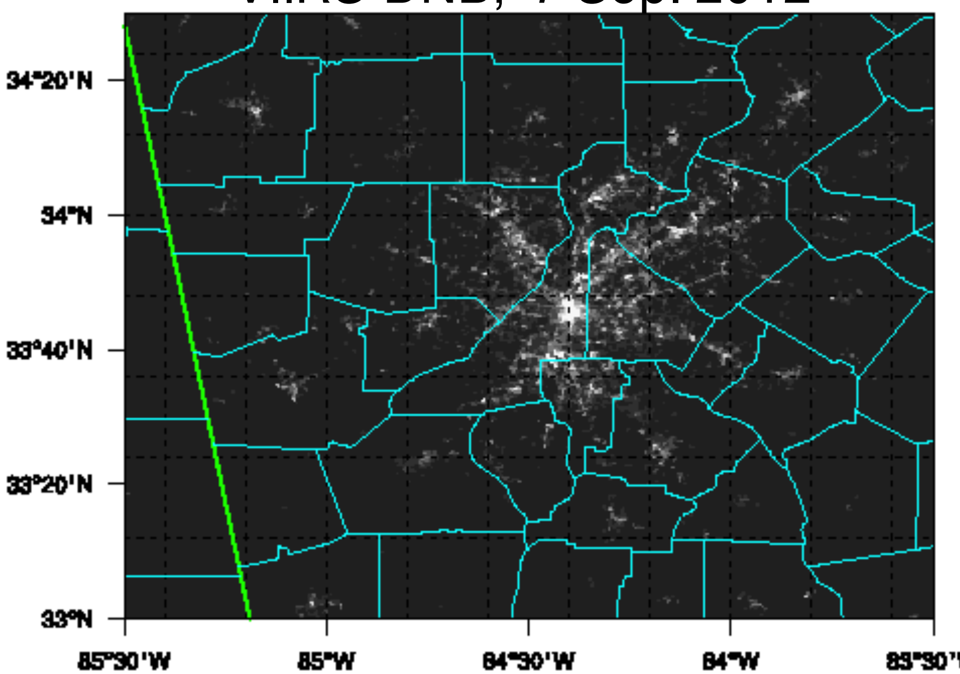
Air quality models may help …

NAAQS uses daily and annual averages of $PM_{2.5}$
Can we use DNB to estimate surface $PM_{2.5}$ at night?

- At night, aerosols are often mixed in a shallow nocturnal boundary layer.
- Retrieval of AOD from DNB is still in its infancy; preliminary work include Zhang et al. (2008) and Johnson et al. (2013) using isolated light sources.
- We like to make a first attempt to apply DNB for night time $PM_{2.5}$ air quality.
- Aug – Oct 2012. Focus area: Atlanta

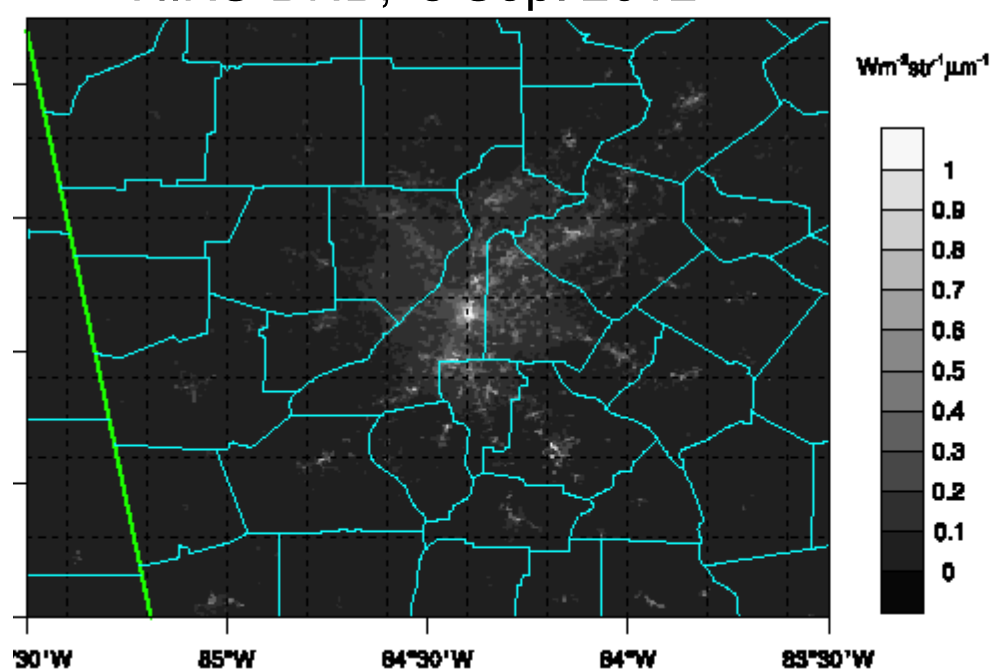
$PM_{2.5}$: 5 ug/m^3

VIIRS DNB, 7 Sep. 2012



$PM_{2.5}$: 13 ug/m^3

VIIRS DNB, 8 Sep. 2012



Potential application of VIIRS Day/Night Band for monitoring nighttime surface $PM_{2.5}$ air quality from space

Jun Wang [a,*], Clint Aegerter [a], Xiaoguang Xu [a], James J. Szykman [b]

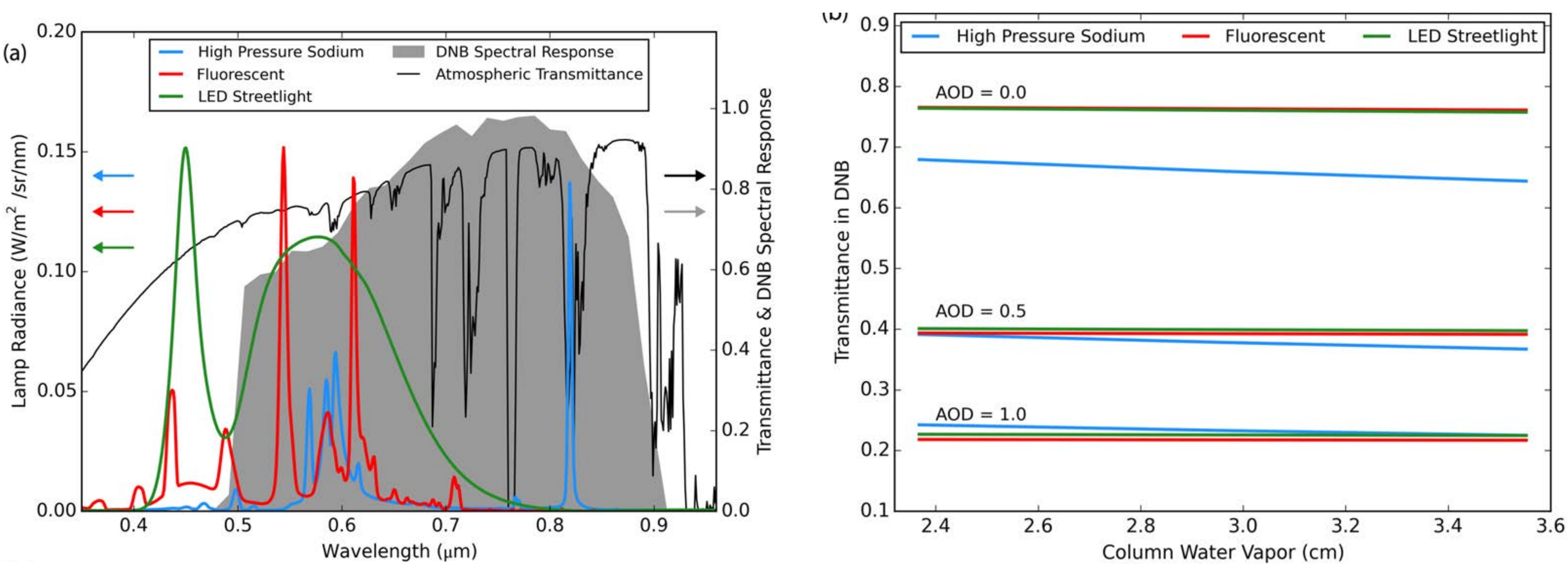
[a] *Department of Earth and Atmospheric Sciences, University of Nebraska, Lincoln, NE, USA*
[b] *National Exposure Research Laboratory, U.S. Environmental Protection Agency, RTP, NC, USA*

Atmospheric Environment, 2016

HIGHLIGHTS

- VIIRS Day/Night Band (DNB) is much more sensitive to aerosols than to water vapor
- Modeling of outdoor light transfer in nighttime atmosphere for VIIRS DNB
- DNB potential for estimating surface $PM_{2.5}$ is shown qualitatively and quantitatively
- $PM_{2.5}$ at VIIRS night overpass time is much closer to daily-mean $PM_{2.5}$ than at daytime
- Strategies for future DNB remote sensing of aerosols are elaborated

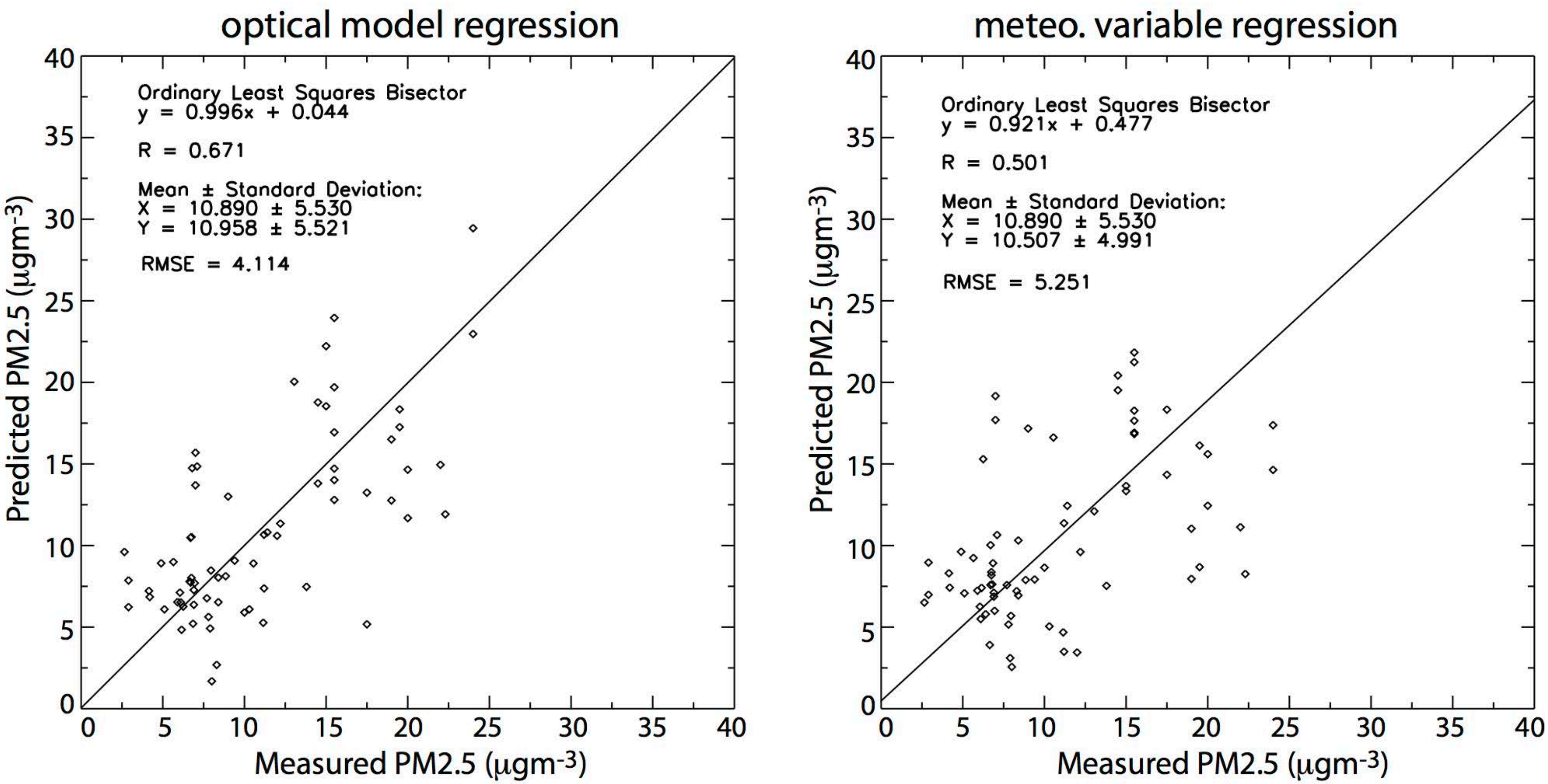
DNB is most sensitive to change of AOD but, water vapor effect is also not negligible



The database of spectral intensity emitted from HPS, fluorescent, and LED bulbs are from Elvidge et al., (2010).

In the U.S., high- pressure sodium lamps (HPS) are the most common type of light source used for outdoor applications (Rea et al., 2009)

Leave-one-out cross validation of regression model



$$\frac{PM_{2.5} f(rh)}{\mu} = a_0 - a_I ln(I) - a_r \times W - a_p \times P_s$$

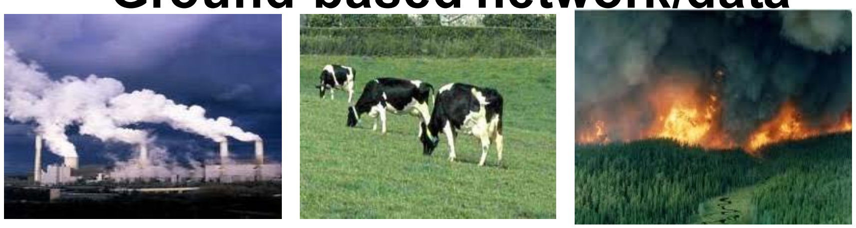
$$PM_{2.5} = \boldsymbol{f}(W, Ps, U, V)$$

VIIRS-based optical model gives better estimate of surface $PM_{2.5}$ than meteorology-based regression.

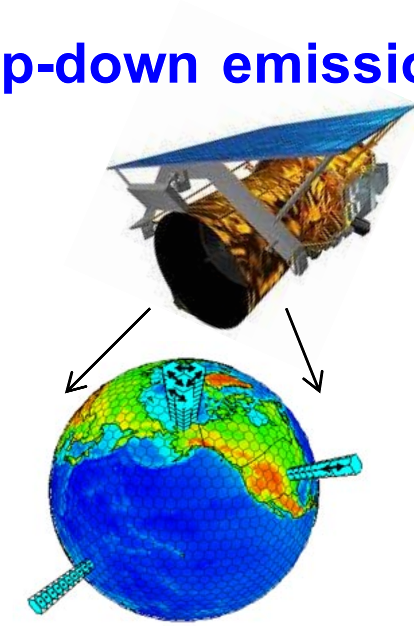
Top-Down vs. Bottom-Up estimate of aerosol emission

Bottom-up emission estimate

Ground-based network/data



Top-down emission estimate



- Usually has a 2~3 yr lag
- Often seasonal or annual
- Point or area average
- Chemically speciated
- lack of constraint on emission above the surface

- Has the potential for near real time
- Daily (polar-orbiting) or higher (geo..)
- Globally with high spatial resolution
- Trace gases, & optical thickness
- Reflecting the columnar mass, and thus 1st order of emission

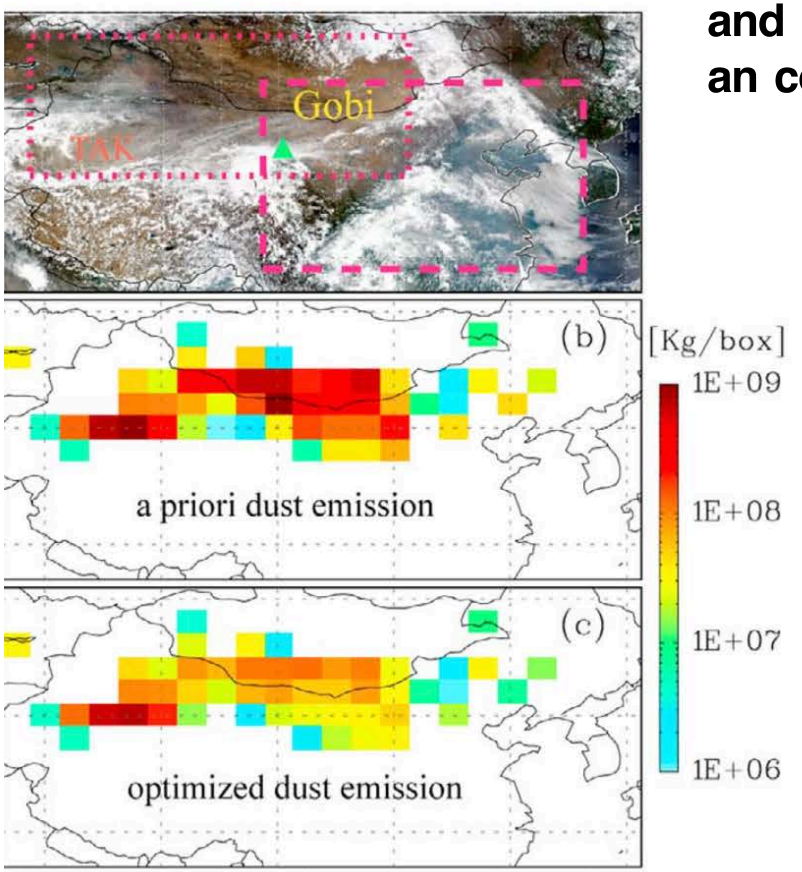
Mass Loading -> Emission

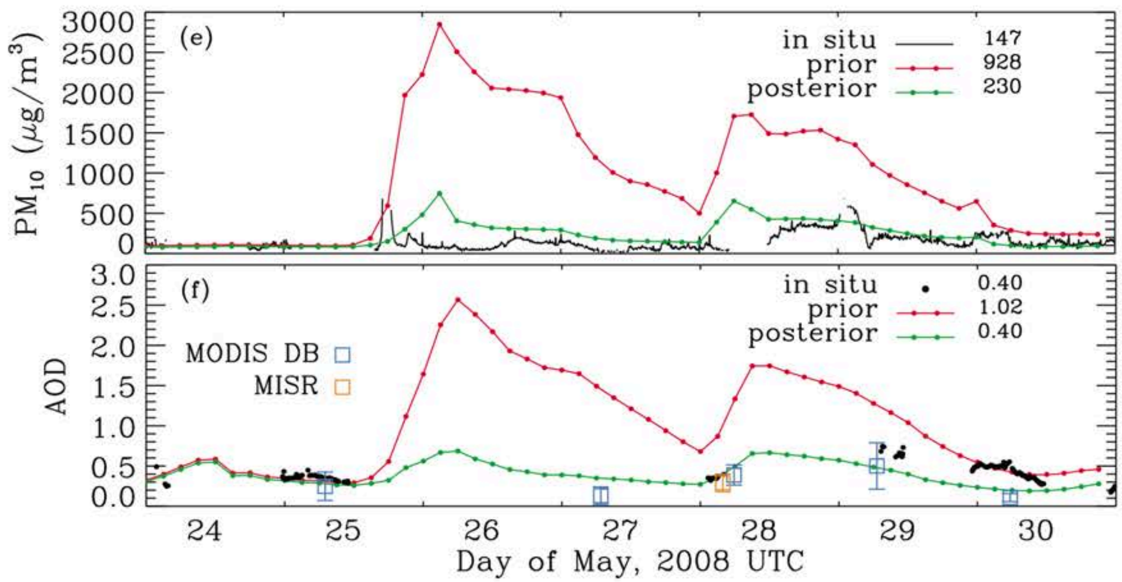
GRL, 2012

Top-down estimate of dust emissions through integration of MODIS and MISR aerosol retrievals with the GEOS-Chem adjoint model

Jun Wang,[1] Xiaoguang Xu,[1] Daven K. Henze,[2] Jing Zeng,[1] Qiang Ji,[3,4] Si-Chee Tsay,[4] and Jianping Huang[5]

To avoid difference of aerosol properties between model and satellite algorithm, MODIS radiance is directly used as an constraint.

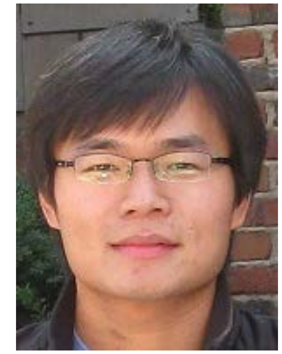


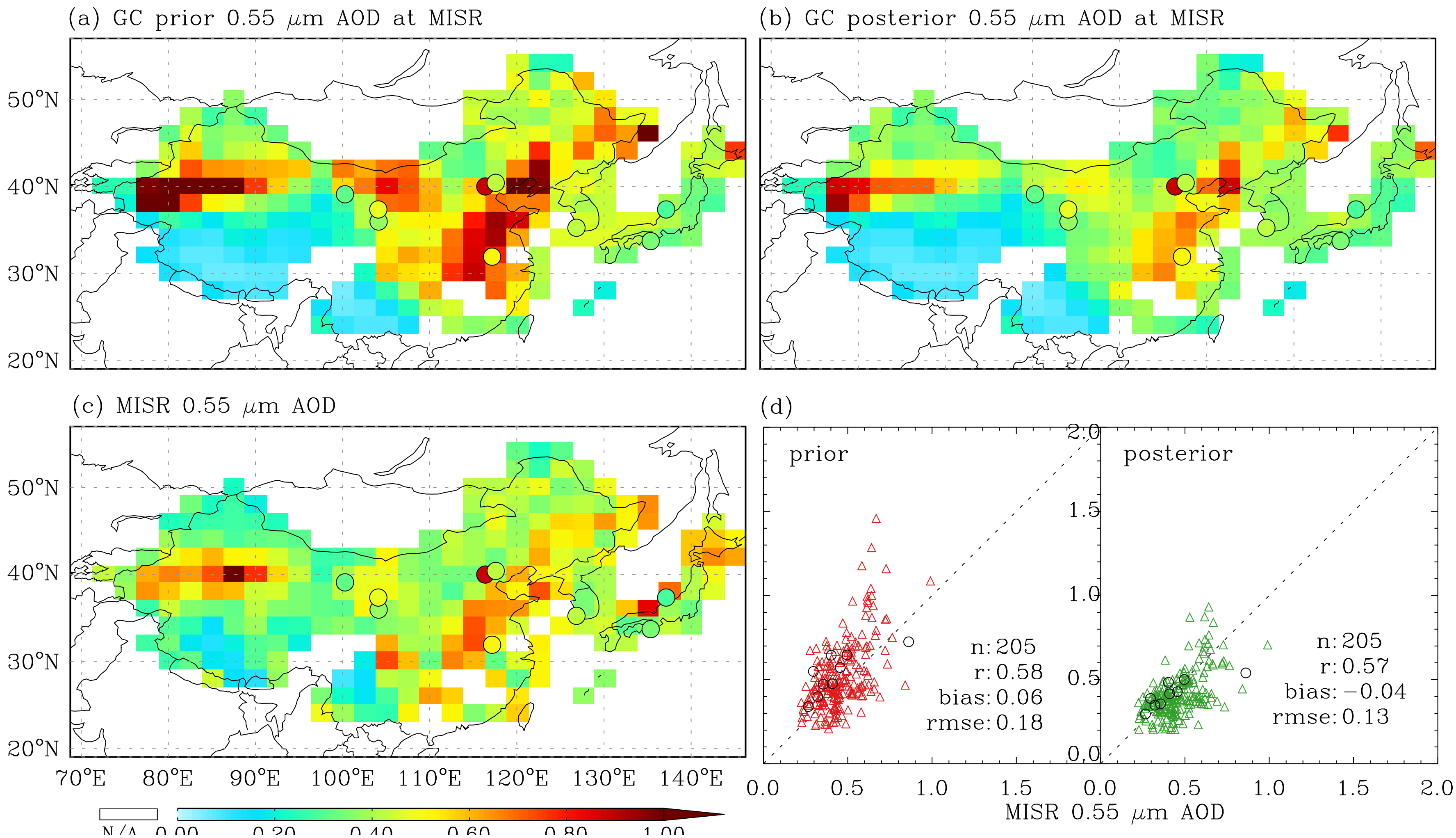


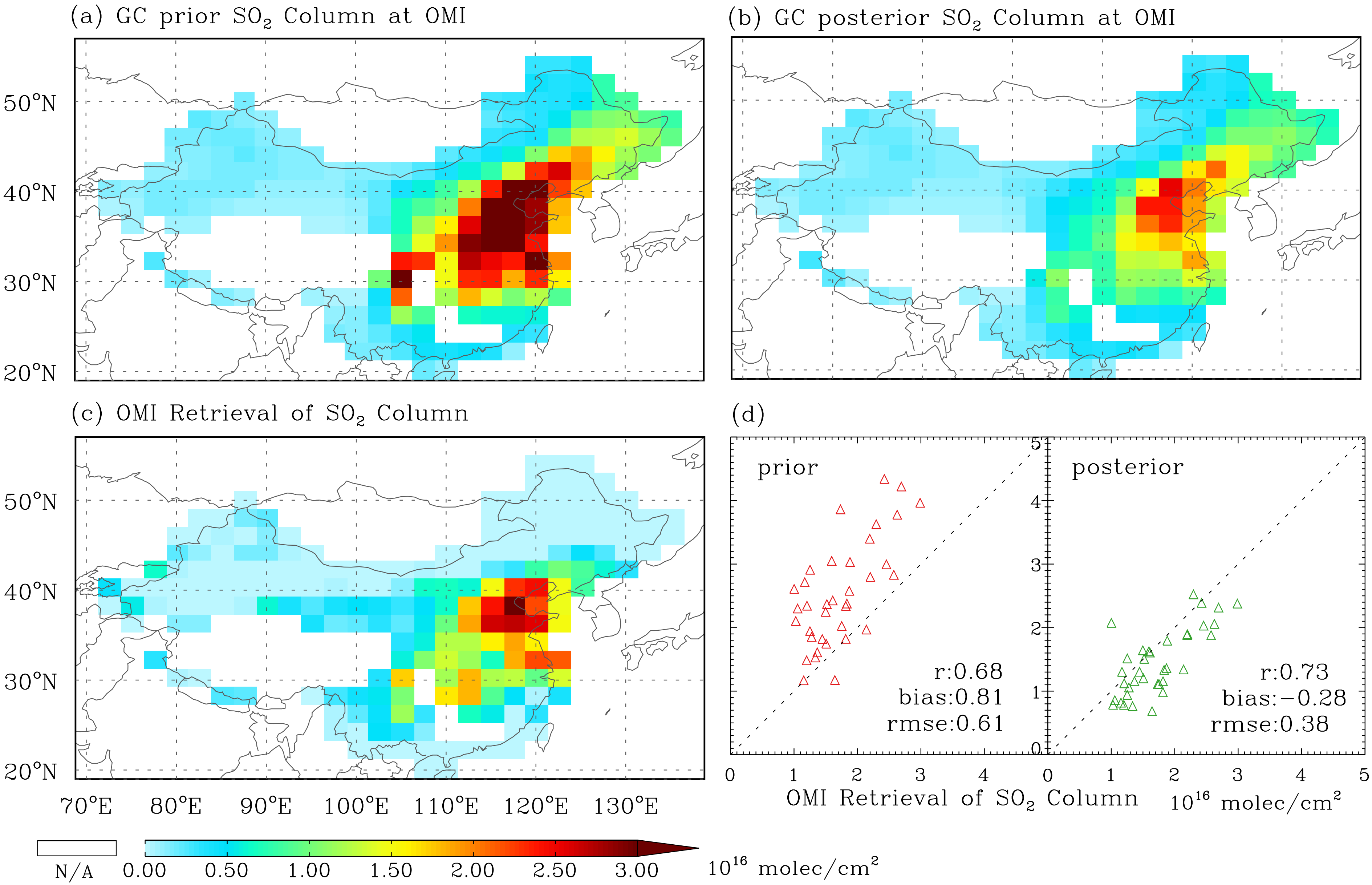
Constraints on aerosol sources using GEOS-Chem adjoint and MODIS radiances, and evaluation with multisensor (OMI, MISR) data

JGR 2013

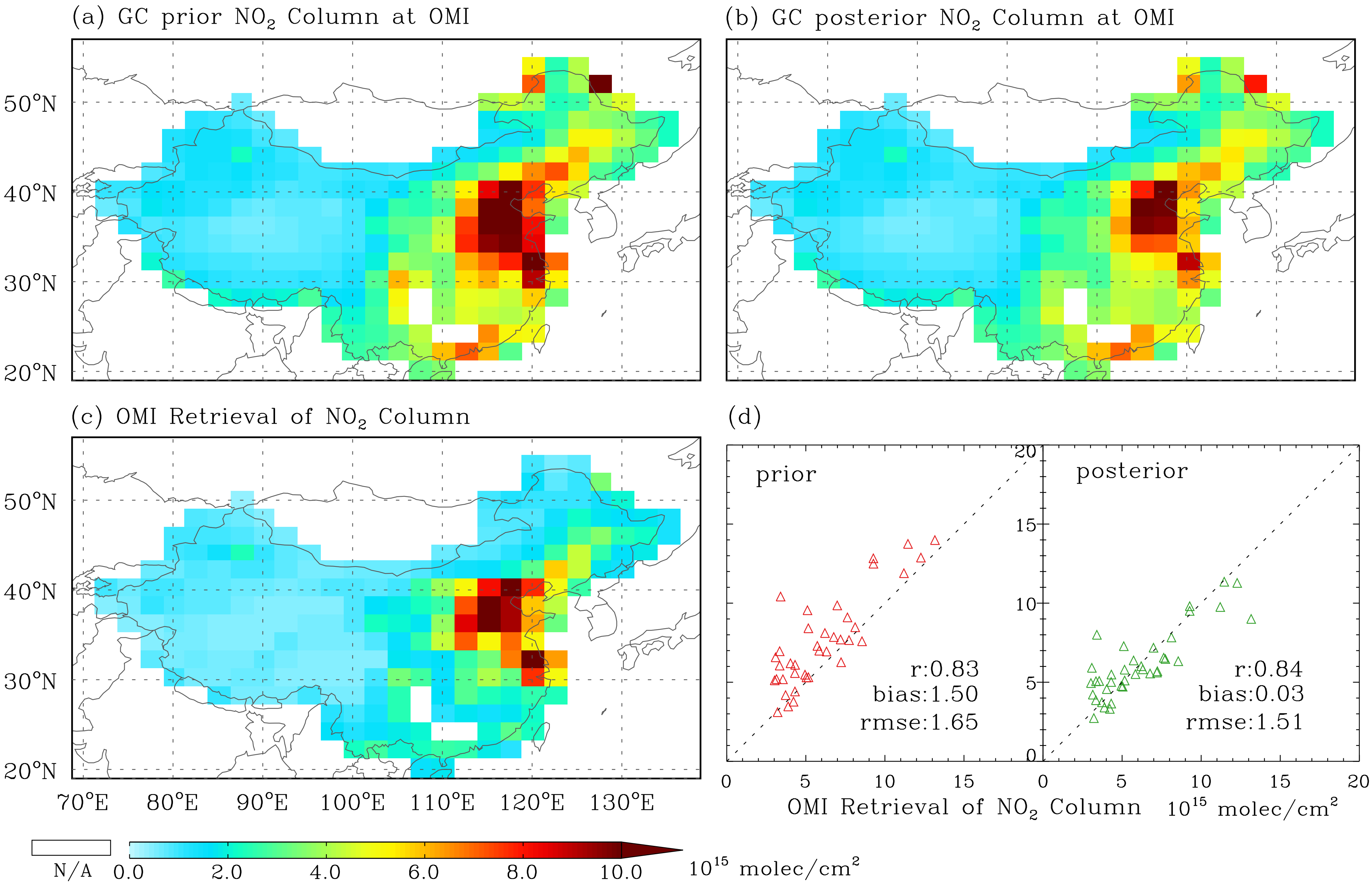
Xiaoguang Xu,[1] Jun Wang,[1] Daven K. Henze,[2] Wenjun Qu,[3] and Monika Kopacz[4]







(a) GC prior SO2 Column at OMI
(b) GC posterior SO2 Column at OMI
(c) OMI Retrieval of SO2 Column
(d)
50°N
40°N
30°N
20°N
70°E
80°E
90°E
100°E
110°E
120°E
130°E
prior
posterior
r:0.68
bias:0.81
rmse:0.61
r:0.73
bias:−0.28
rmse:0.38
OMI Retrieval of SO2 Column
10^16 molec/cm^2
N/A
0.00
0.50
1.00
1.50
2.00
2.50
3.00
10^16 molec/cm^2

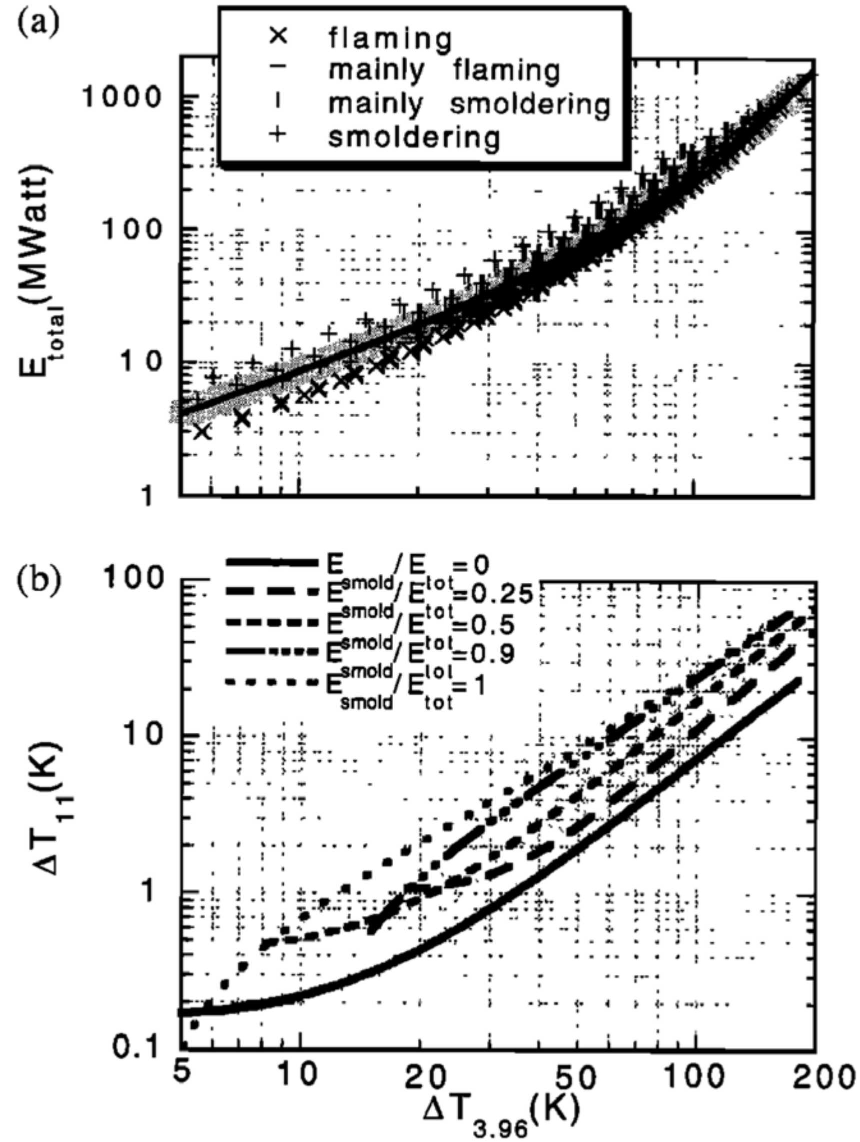


(a) GC prior NO2 Column at OMI
(b) GC posterior NO2 Column at OMI
(c) OMI Retrieval of NO2 Column
(d)
50°N
40°N
30°N
20°N
70°E
80°E
90°E
100°E
110°E
120°E
130°E
prior
posterior
r:0.83
bias:1.50
rmse:1.65
r:0.84
bias:0.03
rmse:1.51
OMI Retrieval of NO2 Column 10^15 molec/cm^2
N/A
0.0
2.0
4.0
6.0
8.0
10.0
10^15 molec/cm^2

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]

- Fire Radiative Power
- Flaming vs. smoldering ratio
- Fire location/time



Charles Ichoku's talk:
application of FRP for fire emission estimate by Charles Ichoku

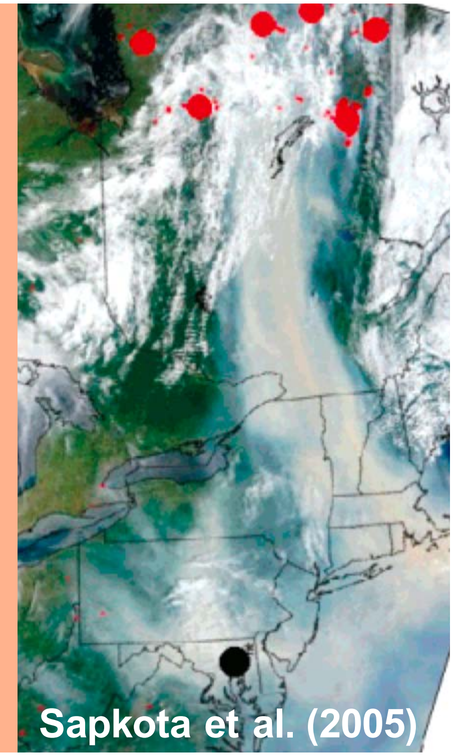
MODIS Fire Radiative Power (FRP)

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

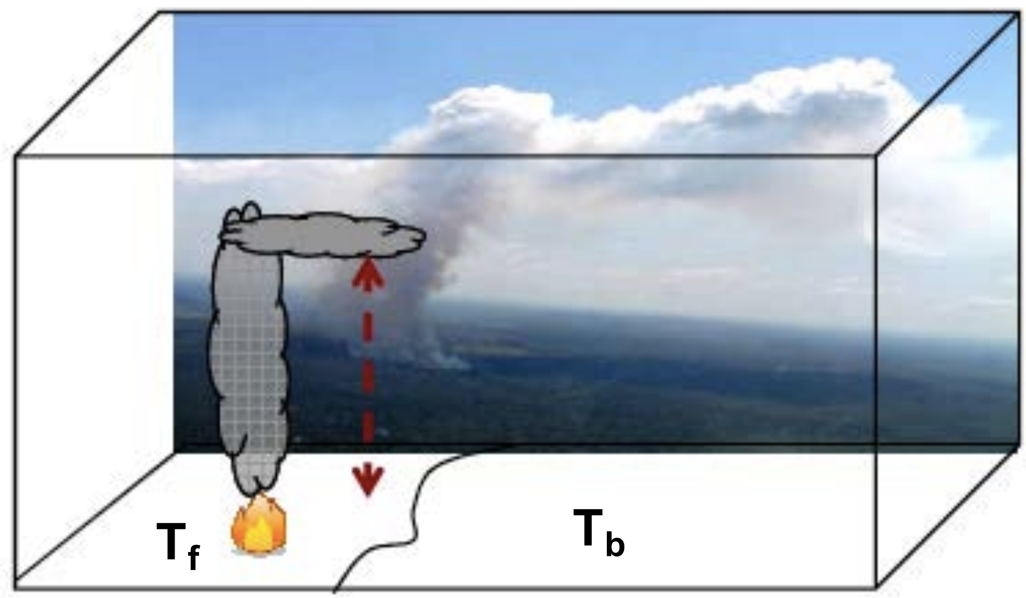


These pixels have equal FRP?

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

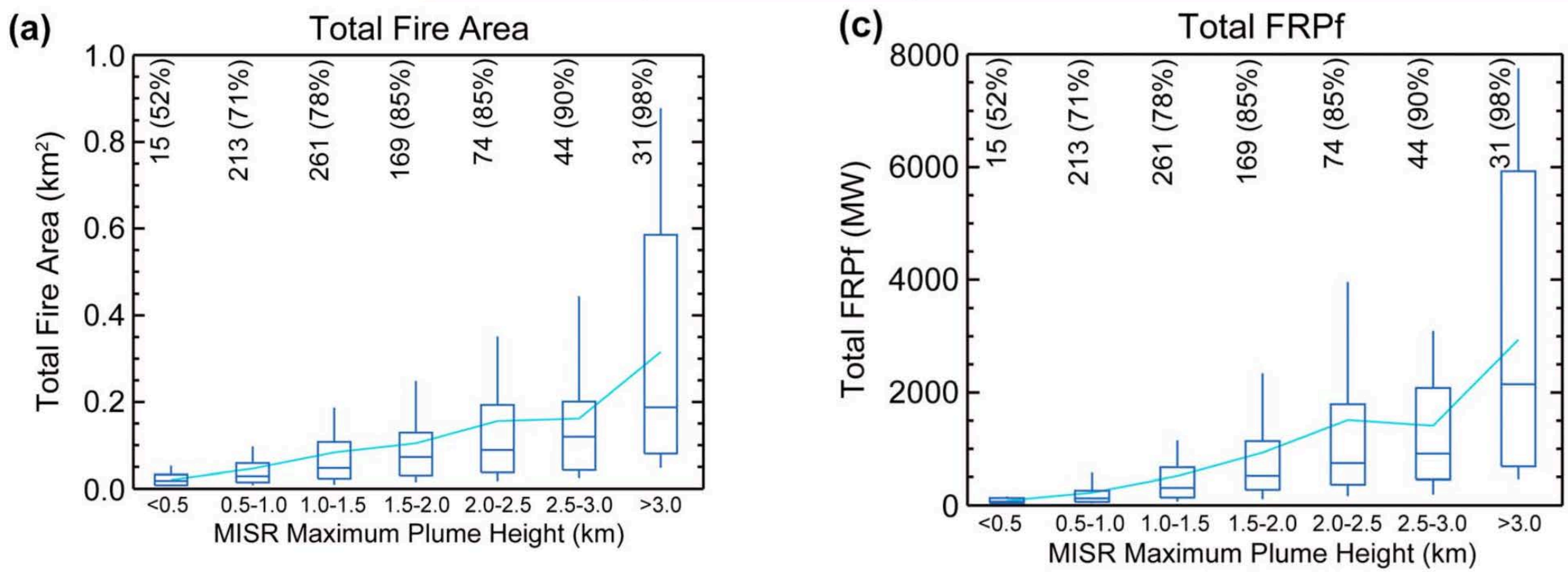
RESEARCH ARTICLE
10.1002/2013JD021067

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

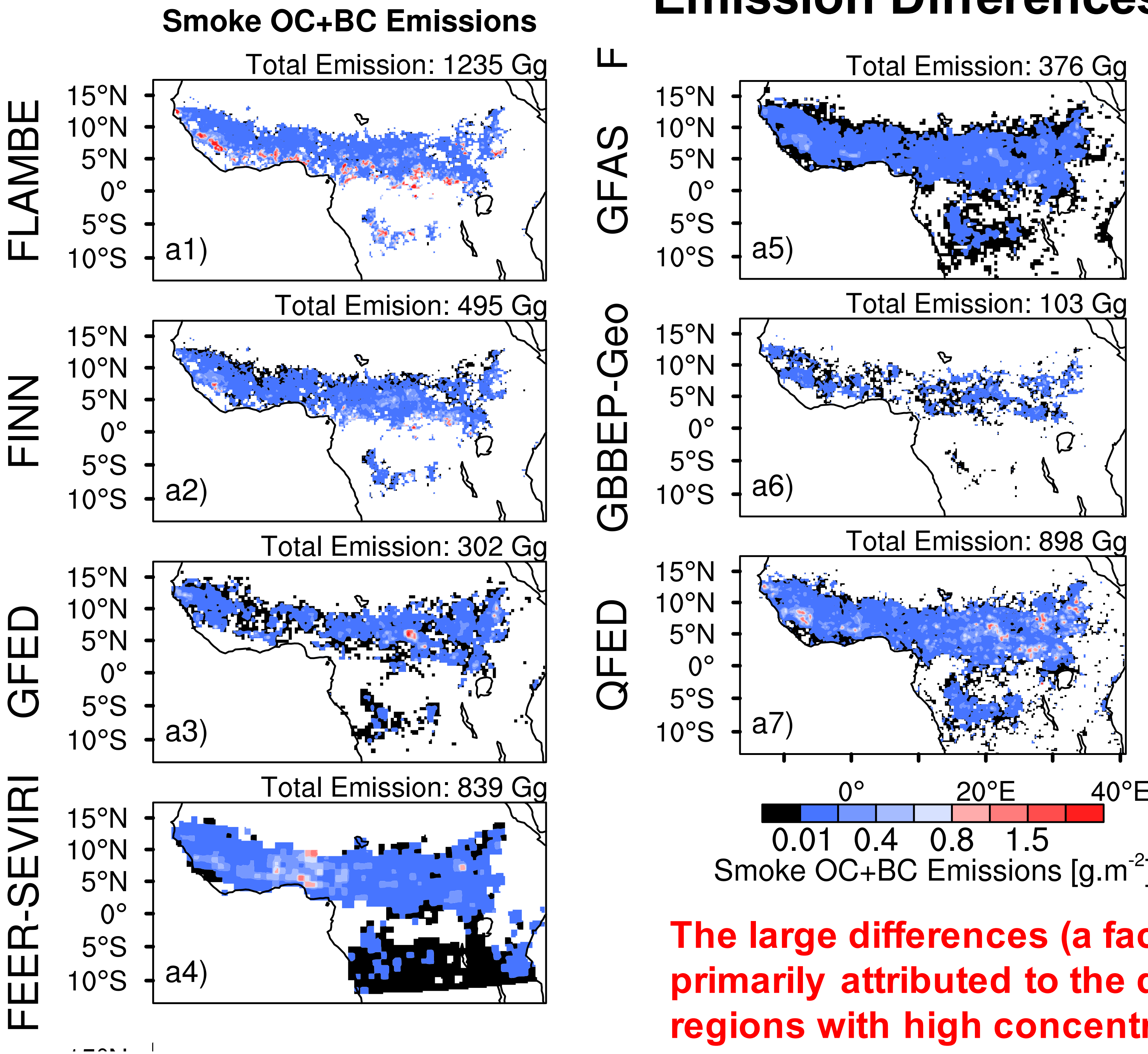
David Peterson[1], Edward Hyer[2], and Jun Wang[3]

[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.

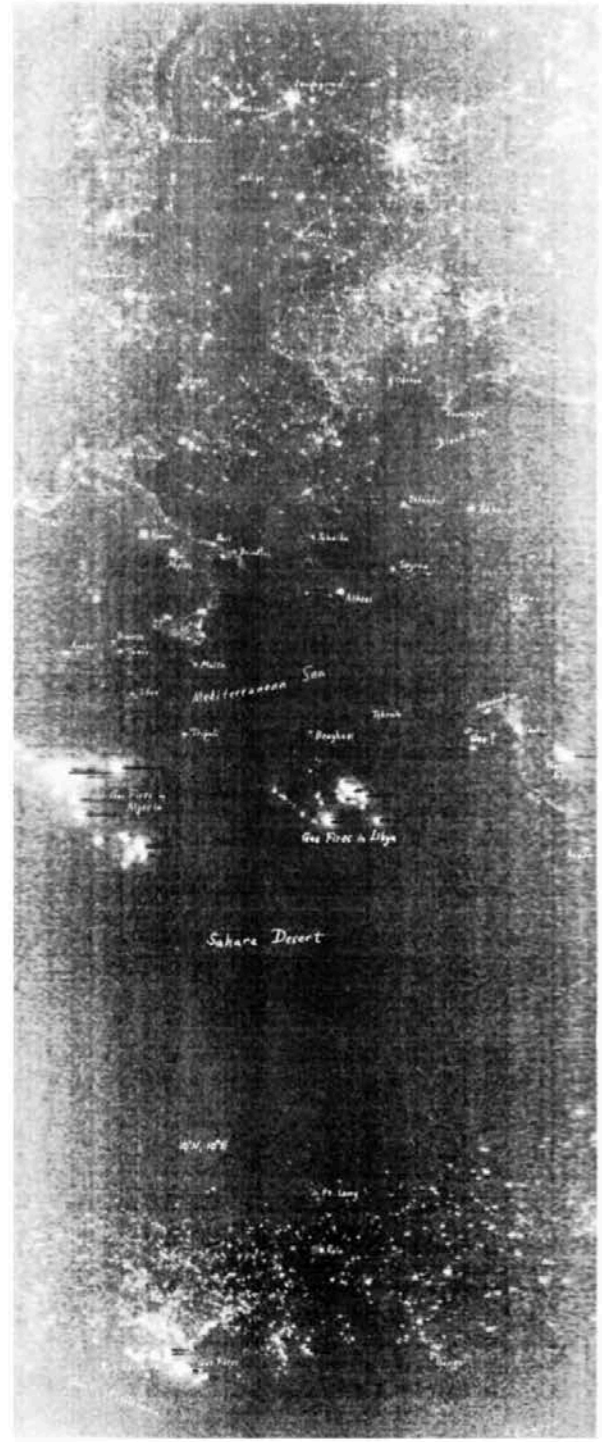
First fire detection from space was from visible light at night…

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.

Recent work of using 1.6 μm 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

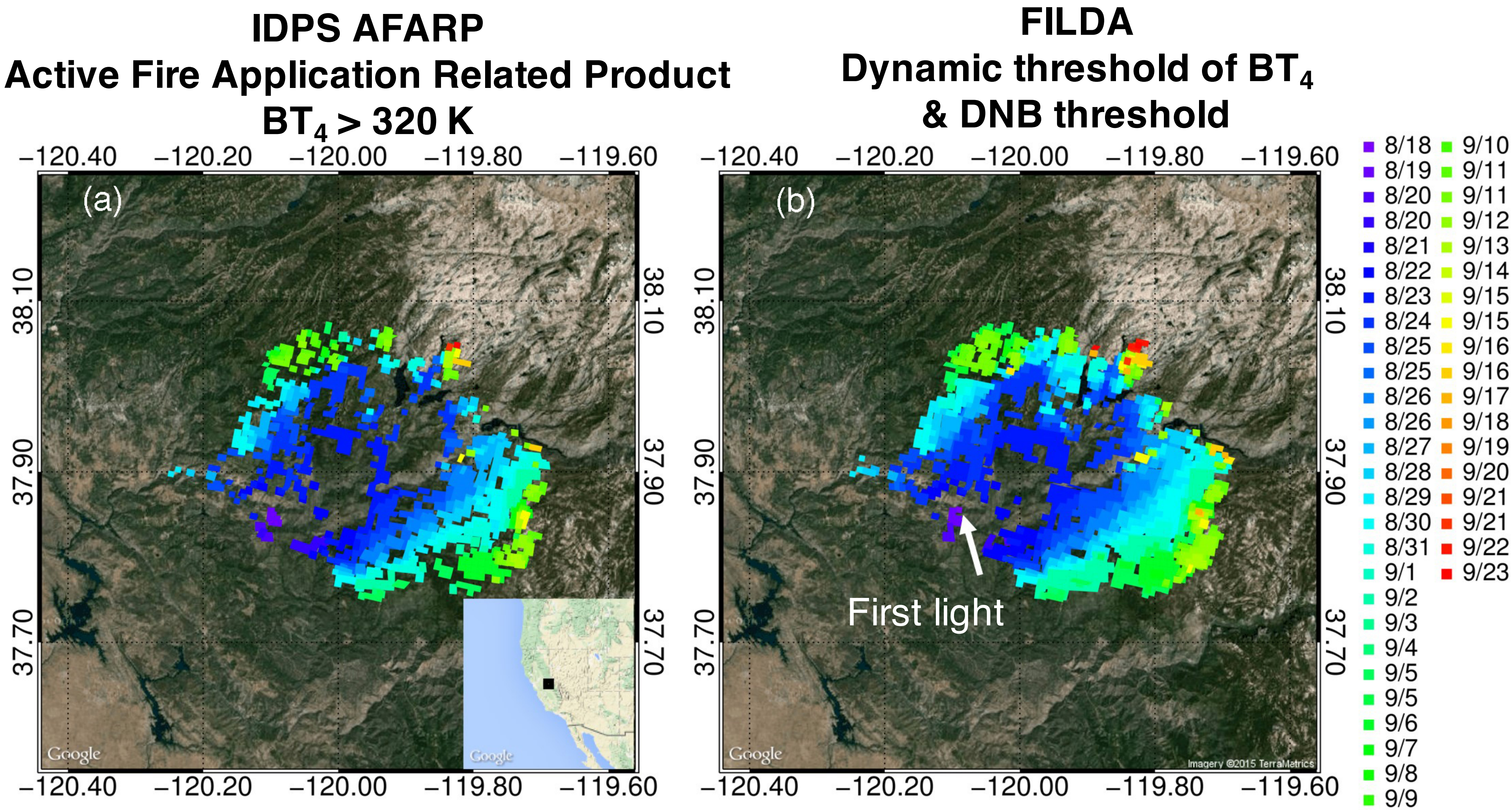
IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING

Improving Nocturnal Fire Detection With the VIIRS Day–Night Band

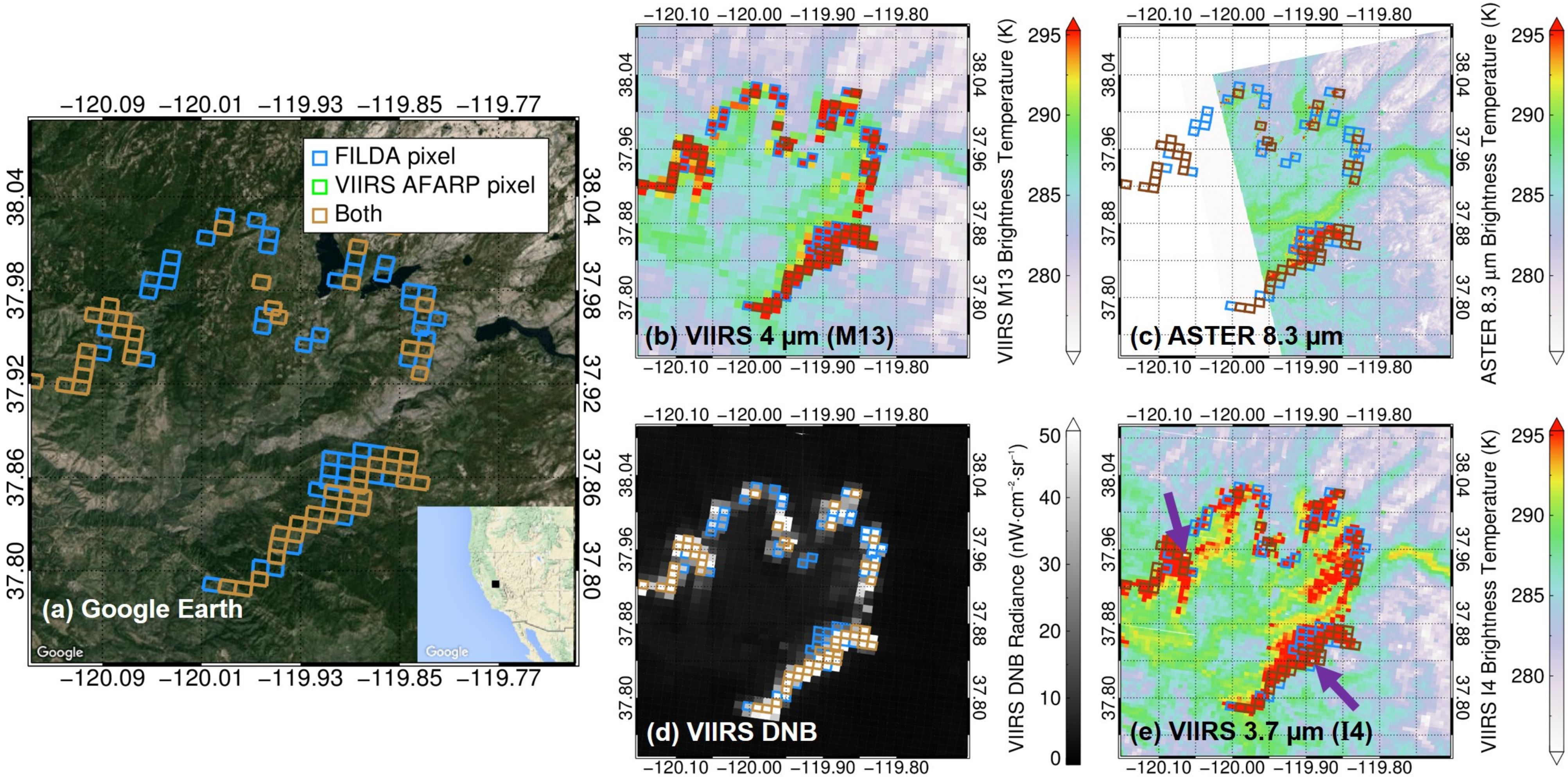
Thomas N. Polivka, Jun Wang, Luke T. Ellison, Edward J. Hyer, and Charles M. Ichoku

ITGRS, in press

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

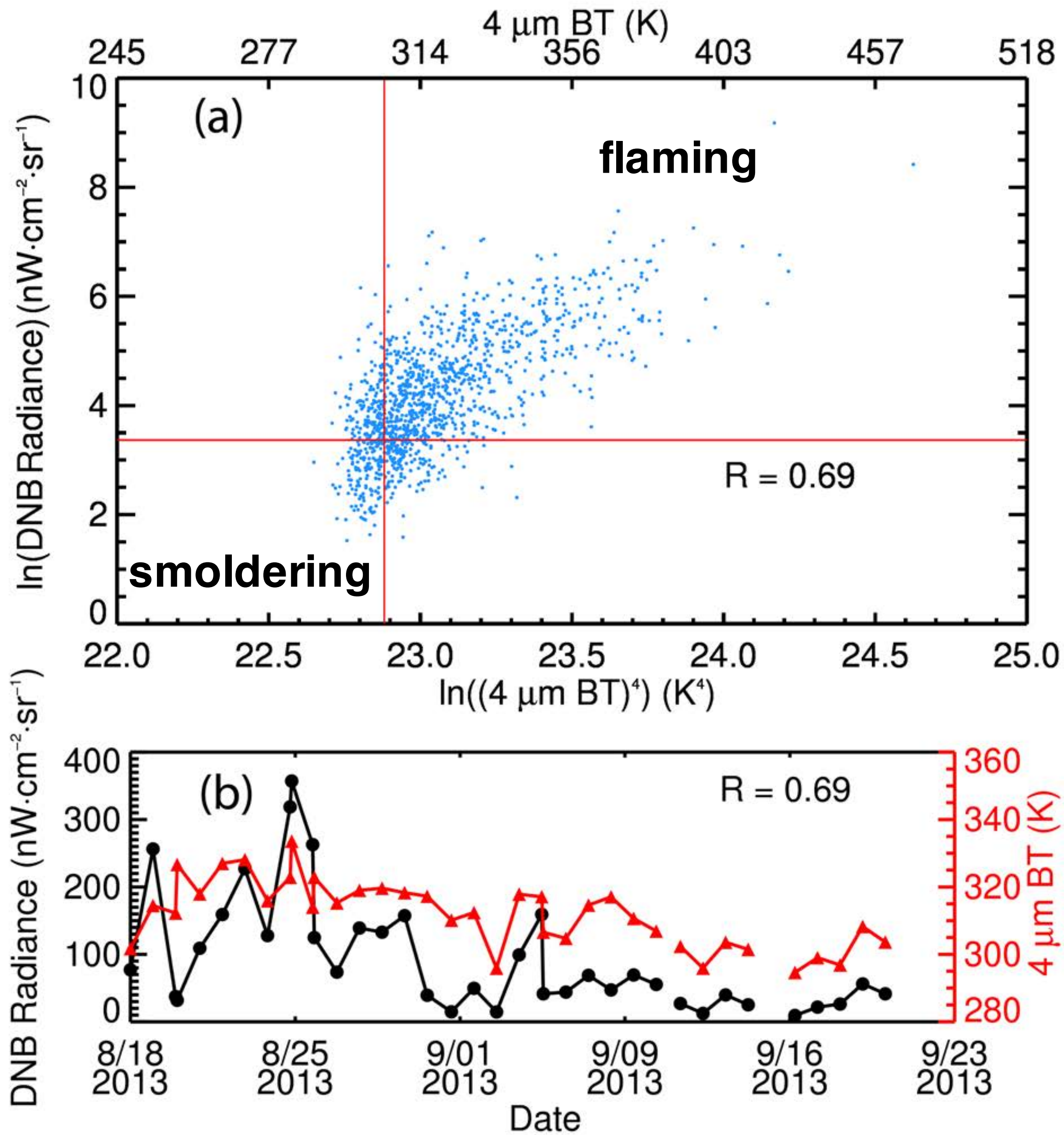


Evaluation with ASTER

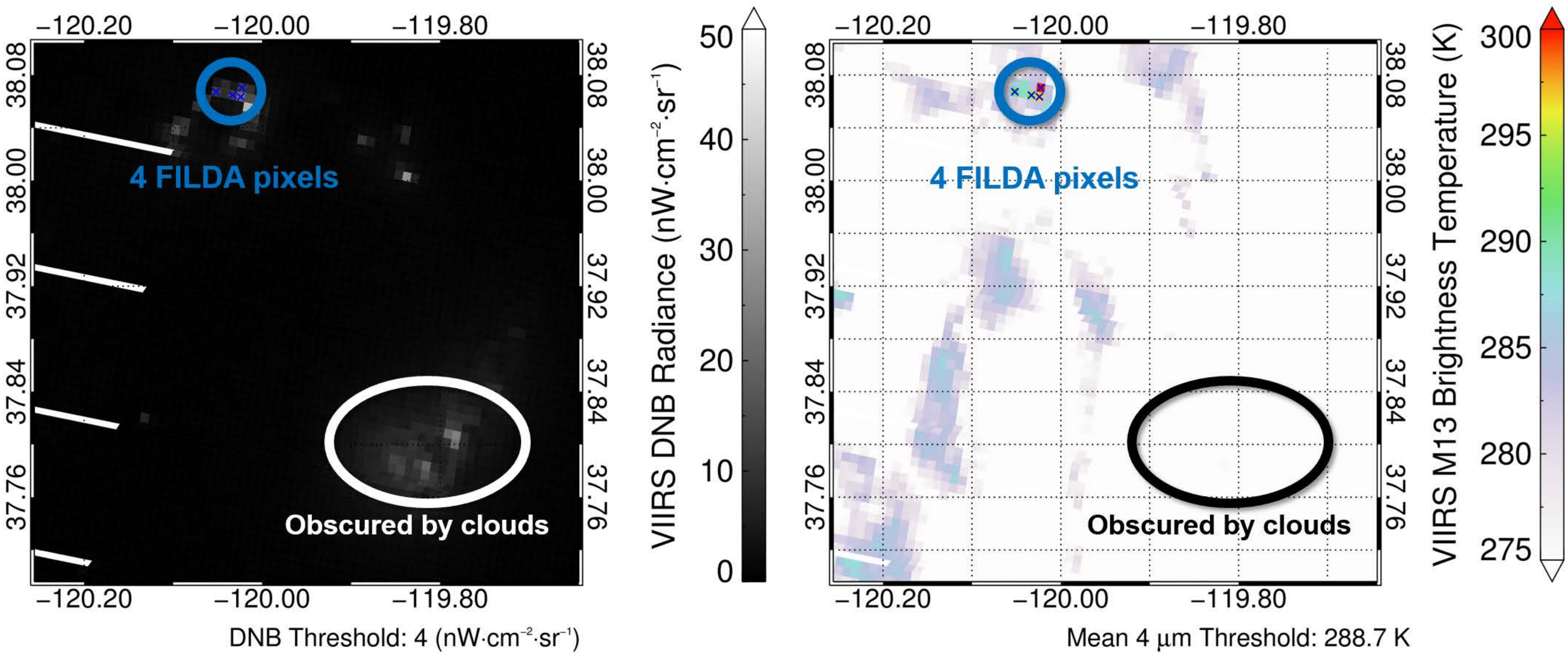


Multiband/sensor view of the Rim Fire taken at 2:29 AM PDT, 24 August 2013

Potential characterization of smoldering vs. flaming



Potential to detect fires through clouds



Summary

- The concept of AOD map for studying air quality and pollution meteorology has advanced the use of satellite data for estimating surface $PM_{2.5}$ and aerosol primary and precursor emissions.

- The concept of FRP when combined with sub-pixel retrievals add another dimension to characterize fires.

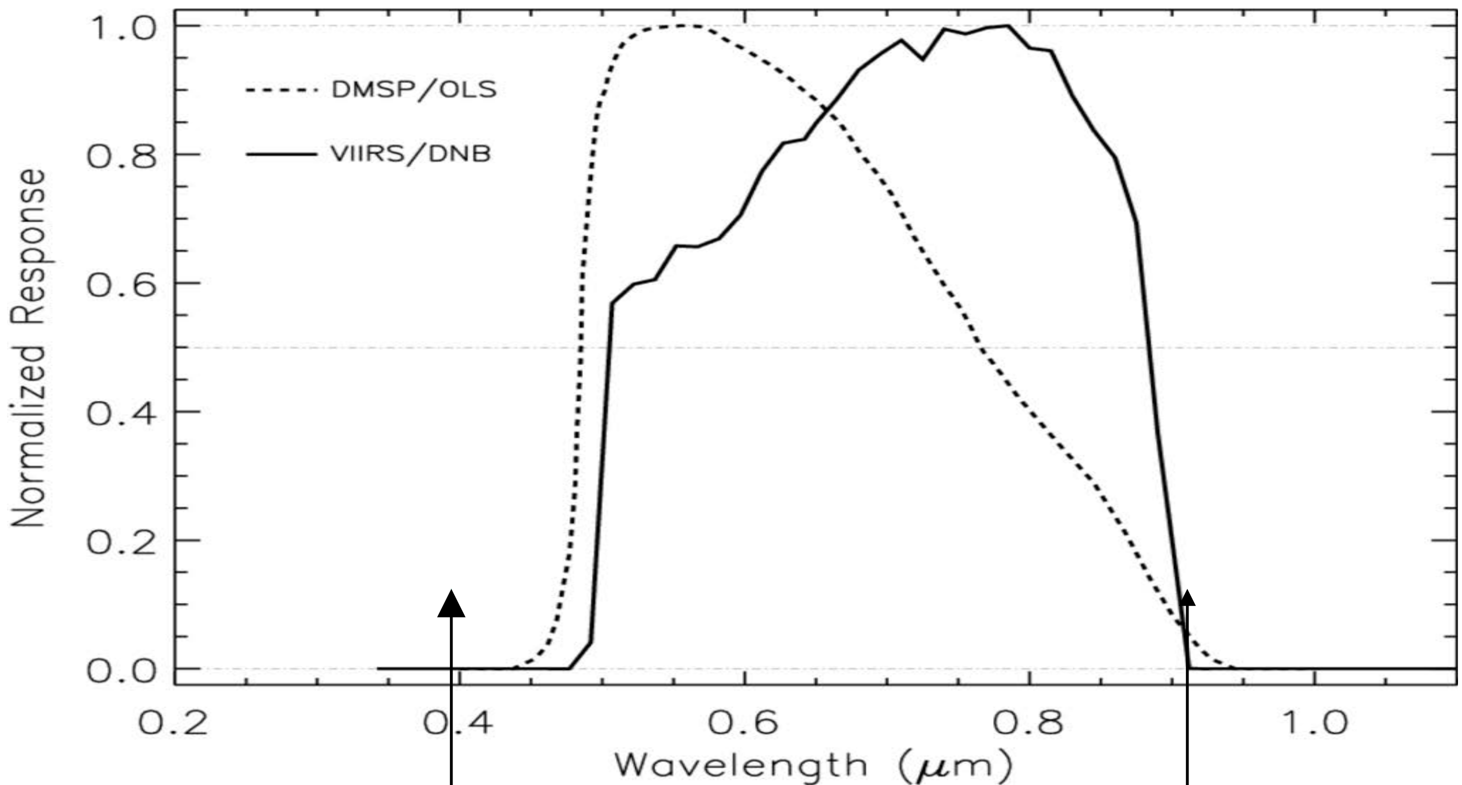
- Visible light at night is shown to be valuable for better characterizing surface $PM_{2.5}$ and smoldering/flaming fires.

- Yoram’s papers continue to inspire me and my students to
  - stick to the principals to avoid getting lost in big data and numbers.
  - think new concepts and ideas

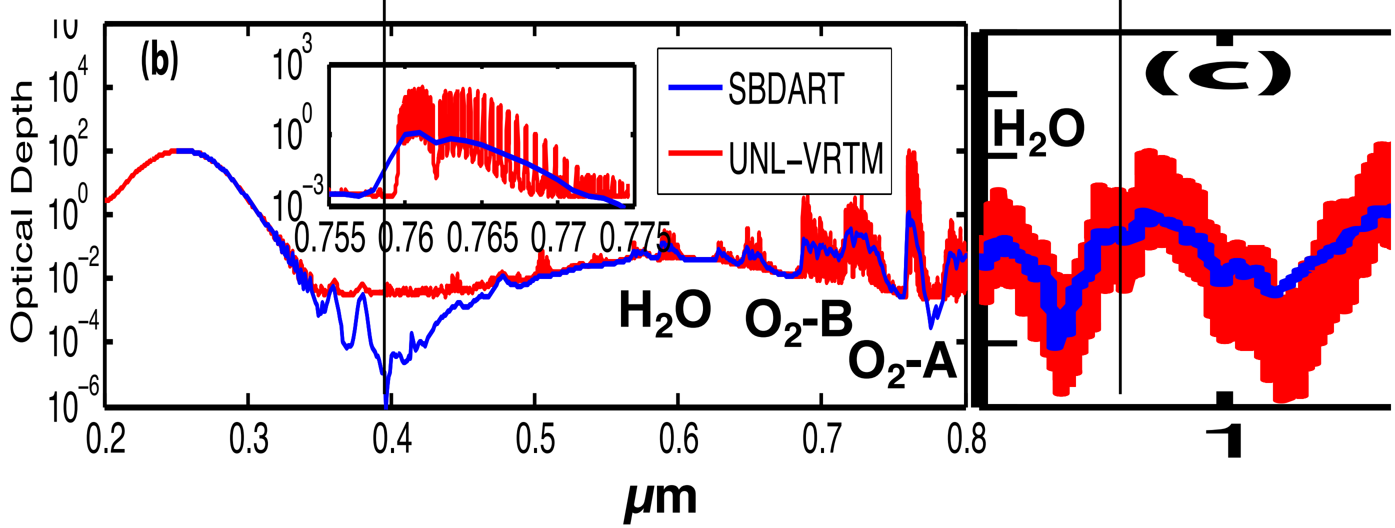
- Challengings: what shall we present in 20th Anniversary Yoram Kaufman Memorial Symposium?

Thank you !

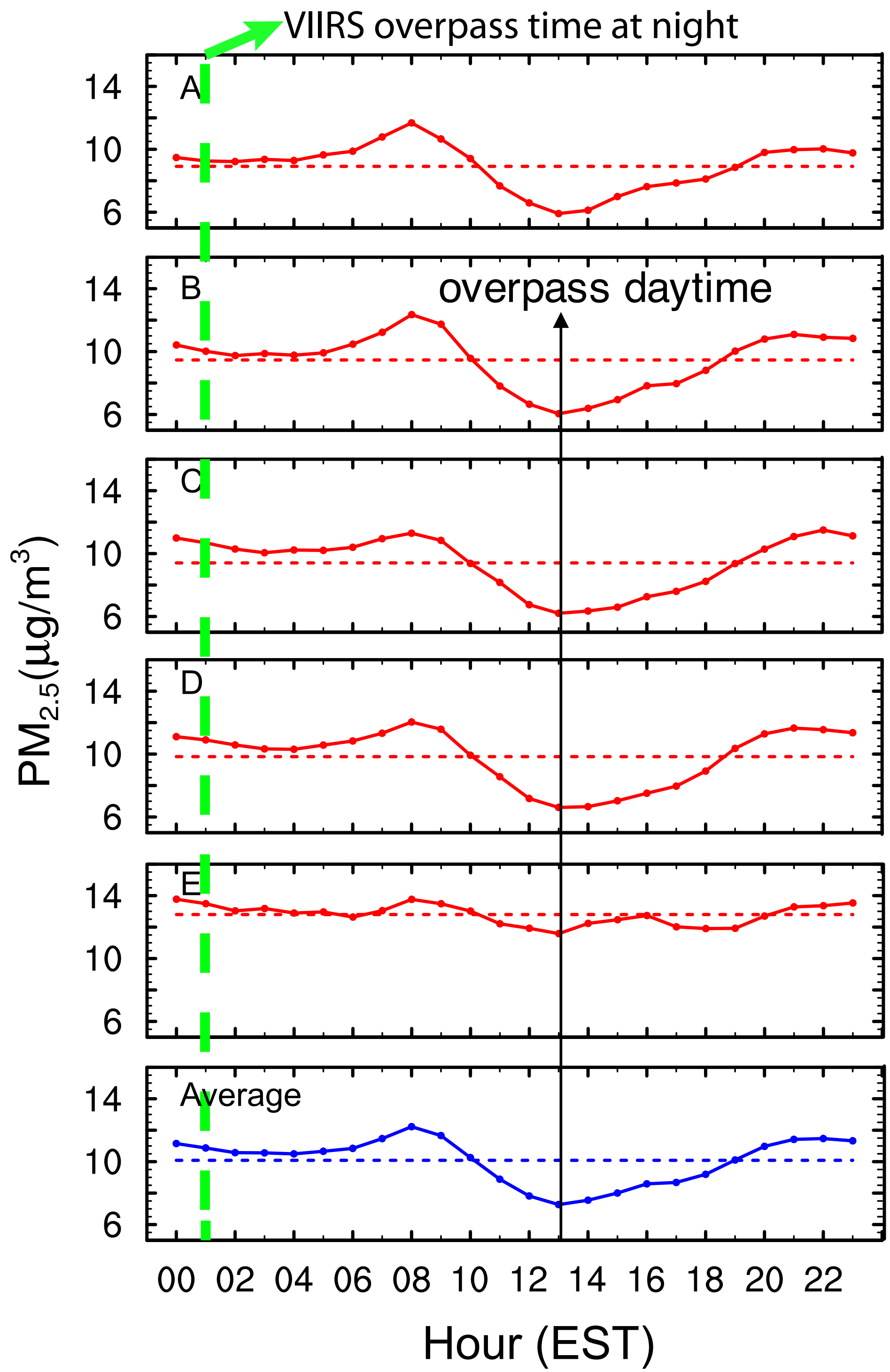
Is DNB sensitive to aerosol, water vapor, & O_2 absorption ?



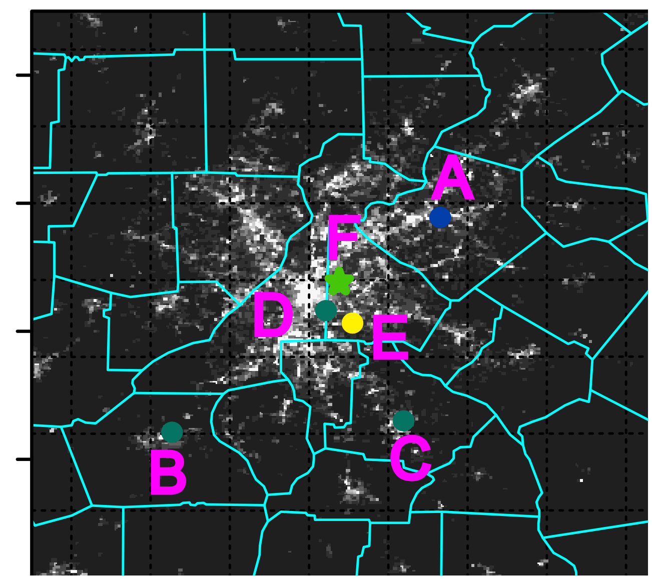
Miller et al., 2013



Wang et al., 2014



$PM_{2.5}$ at VIIRS night overpass time is more representative daily-mean $PM_{2.5}$ than at noon time (VIIRS daytime overpass)



Different types of research

- Ground-breaking & seminal
- Development, increment, refinement

equally important for answering science questions.

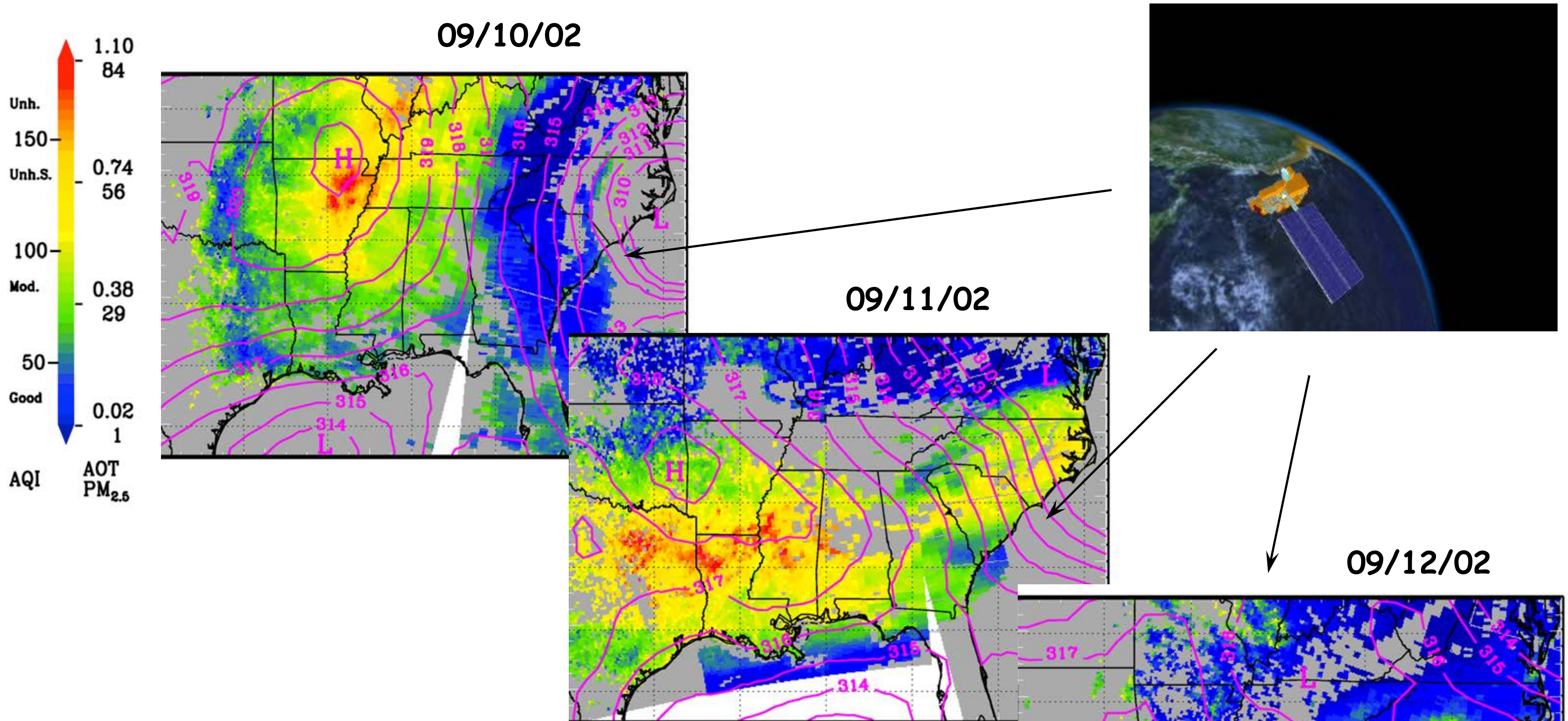
- New physics
- New technique
- New concept/idea…

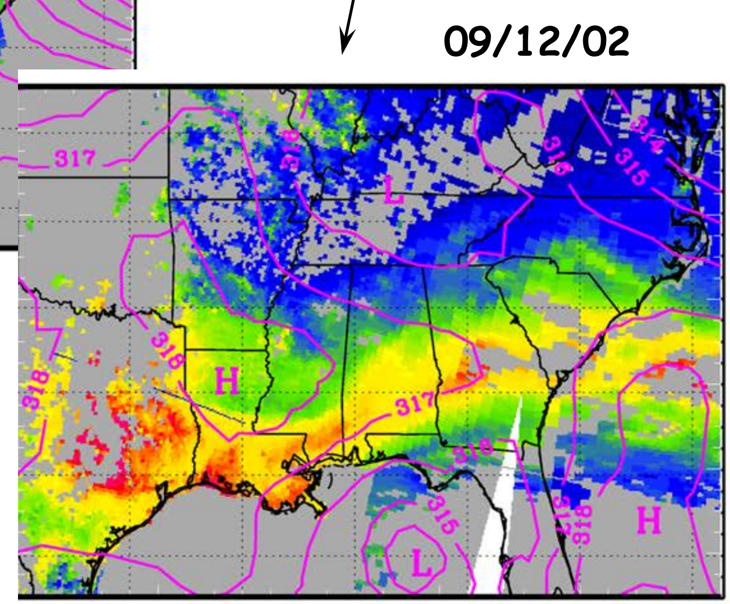
From nothing to have something

- Clean up
- Analysis
- Quantification

From having something to make things better and complete

Satellite Remote Sensing of Aerosol Transport





MODIS Aerosol Optical Thickness &
700mb Geopotential Height

Wang & Christopher (2003), GRL, Intercomparison between satellite-derived aerosol optical thickness and PM2.5 mass: Implication for air quality studies.
220 citation.