Application of DNB for air quality and fire monitoring

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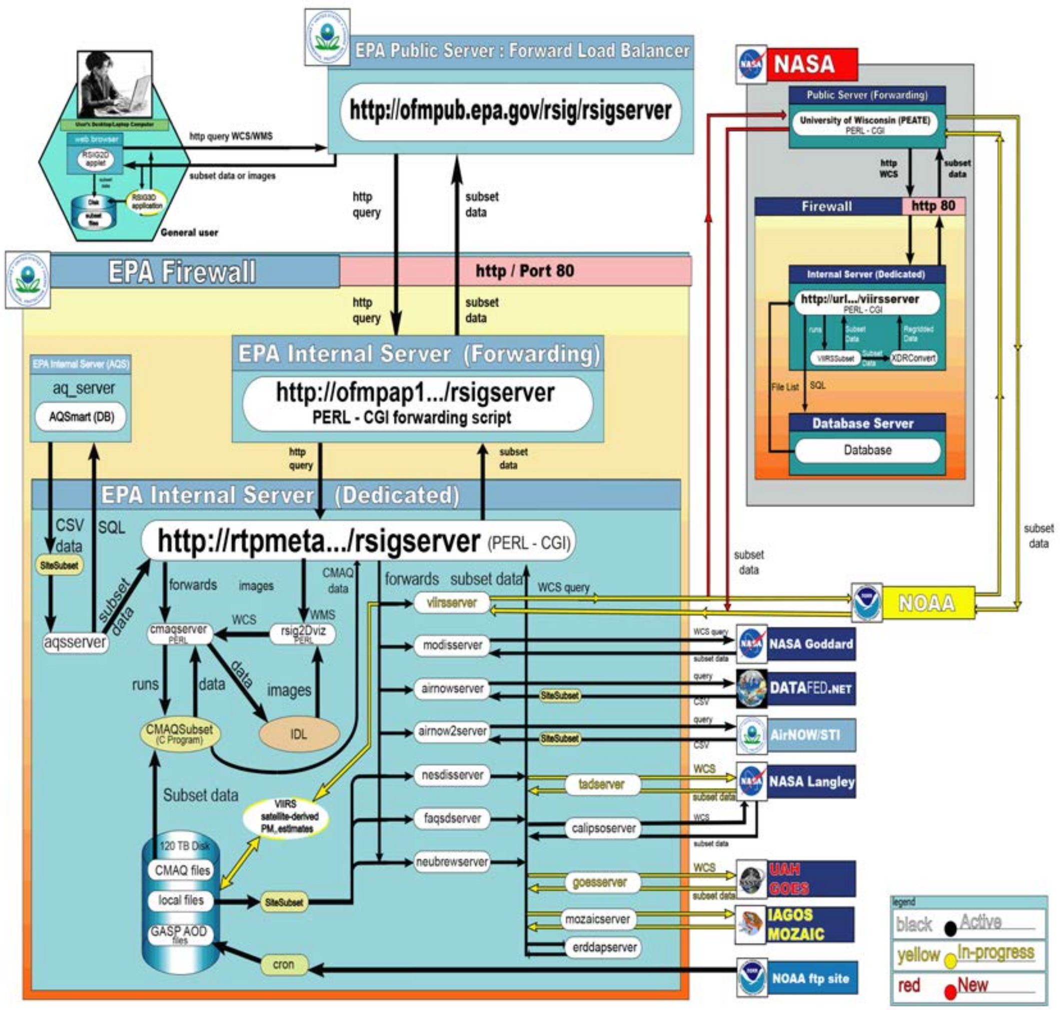
Use of EPA Remote Sensing Information Gateway to deliver VIIRS AOD/$PM_{2.5}$ data products

RSIG Data Flow Diagram



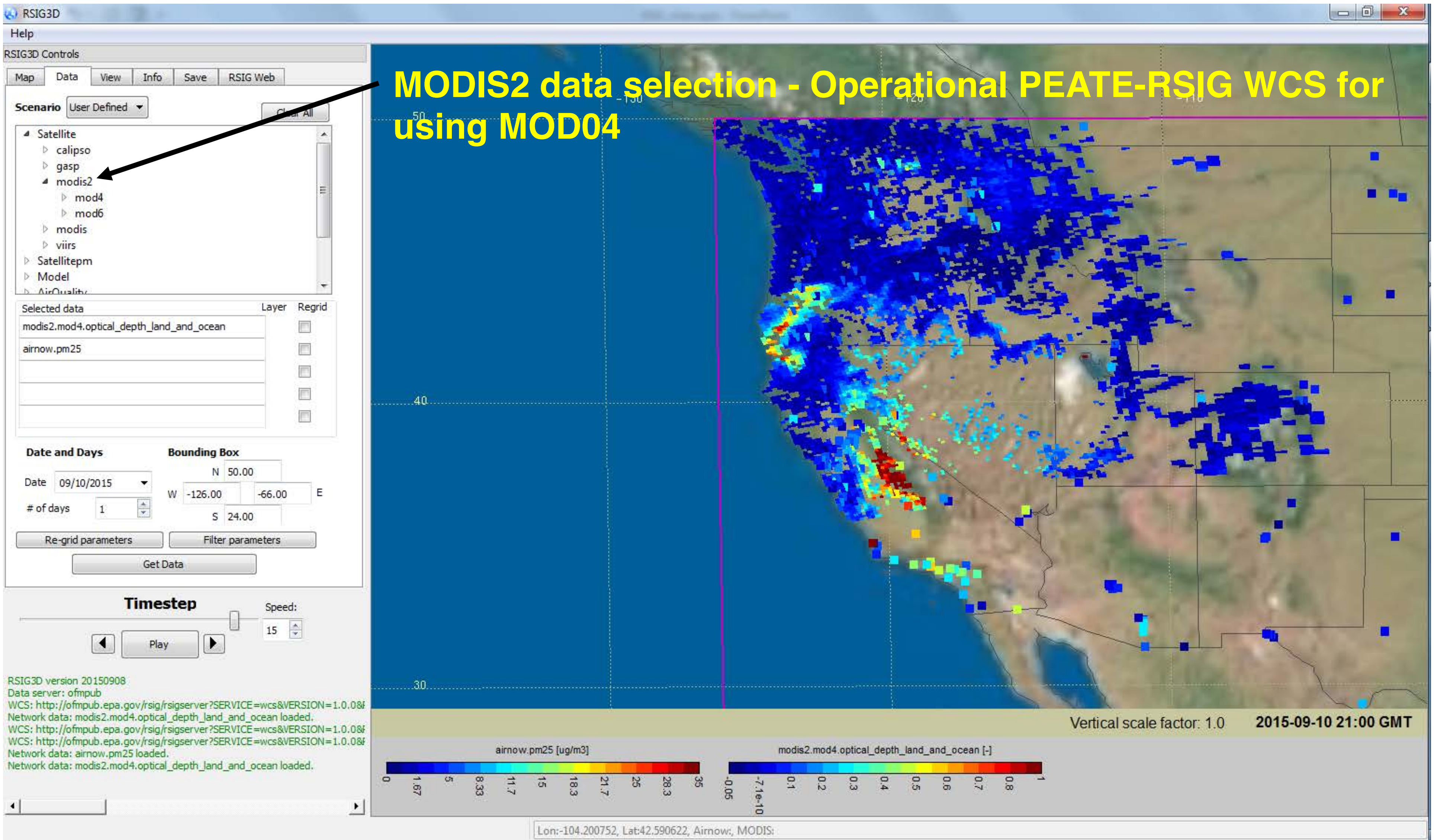
http://ofmpub.epa.gov/rsig/rsigserver?index.html

- Current satellite WCS:
  - MODIS C6 (10 km, 3 km, DB)
  - CALIOP, GASP (GOES AOD)
  - Prototype NOAA-VIIRS
- Establish OGC compliant Web Coverage Service (WCS) between PEATE and RSIG to add NASA- VIIRS data (This project). --- Done !!!
- GEOS-Chem scaling factors used to create a daily Look-Up-Table (LUT) of the spatial varying relation of AOD and $PM_{2.5}$ (van Donkelaar et. al., 2012, ES&T) .
- Prototype use of AOD-to-PM2.5 scaling factors via regional models (WRF-CMAQ & WRF-CHEM) and explore ensemble type approach (This project).

Summary

- Data flow from UW-SIPS (Science Investigator Processing System) to EPA's RSIG is implemented, tested, and successful. **ARL4->ARL-7**
- Evaluation of ensemble approach for surface PM2.5 estimates from VIIRS and other satellite projects is conducted for June 2012. This would provide insight on the selection and improvement of operation approach for remote sensing of surface $PM_{2.5}$. **ARL2->ARL3**
- Refinement of Hierarchical Autoregressive Model has started in EPA site. **ARL5->ARL7**

Developed and implemented operational PEATE-RSIG WCS using MOD04; to be switched to VIIRS data products when final file format implemented on PEATE



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

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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

National Ambient Air Quality Standards

Pollutant [final rule cite]		Primary/ Secondary	Averaging Time	Level
Carbon Monoxide [76 FR 54294, Aug 31, 2011]		primary	8-hour	9 ppm
			1-hour	35 ppm
Lead [73 FR 66964, Nov 12, 2008]		primary and secondary	Rolling 3 month average	0.15 $\mu g/m^3$ (1)
Nitrogen Dioxide [75 FR 6474, Feb 9, 2010] [61 FR 52852, Oct 8, 1996]		primary	1-hour	100 ppb
		primary and secondary	[illegible]	[illegible]b (2)
Ozone [73 FR 16436, Mar 27, 2008]		primary and secondary	8-hour	0.075 ppm (3)
Particle Pollution [71 FR 61144, Oct 17, 2006]	$PM_{2.5}$	primary and secondary	Annual	15 $\mu g/m^3$
			24-hour	35 $\mu g/m^3$
	PM_{10}	primary and secondary	24-hour	150 $\mu g/m^3$
Sulfur Dioxide [75 FR 35520, Jun 22, 2010] [38 FR 25678, Sept 14, 1973]		primary	1-hour	75 ppb (4)
		secondary	3-hour	0.5 ppm

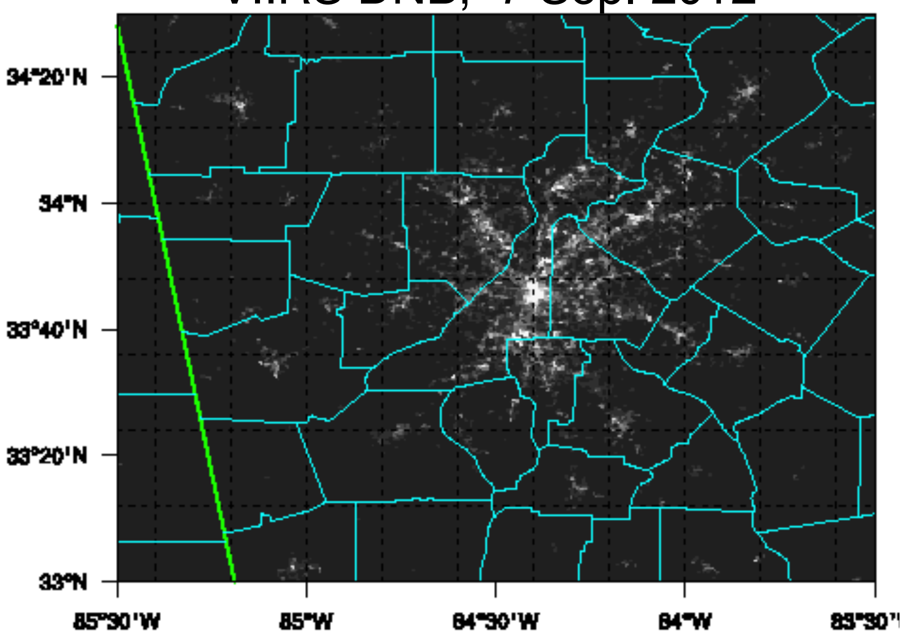
12 $\mu g/m^3$,
FR, 15 Jan. 2013

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).
- We like to make a first attempt to apply DNB for night time $PM_{2.5}$ air quality.
- Aug – Oct 2012. Focus area: Atlanta

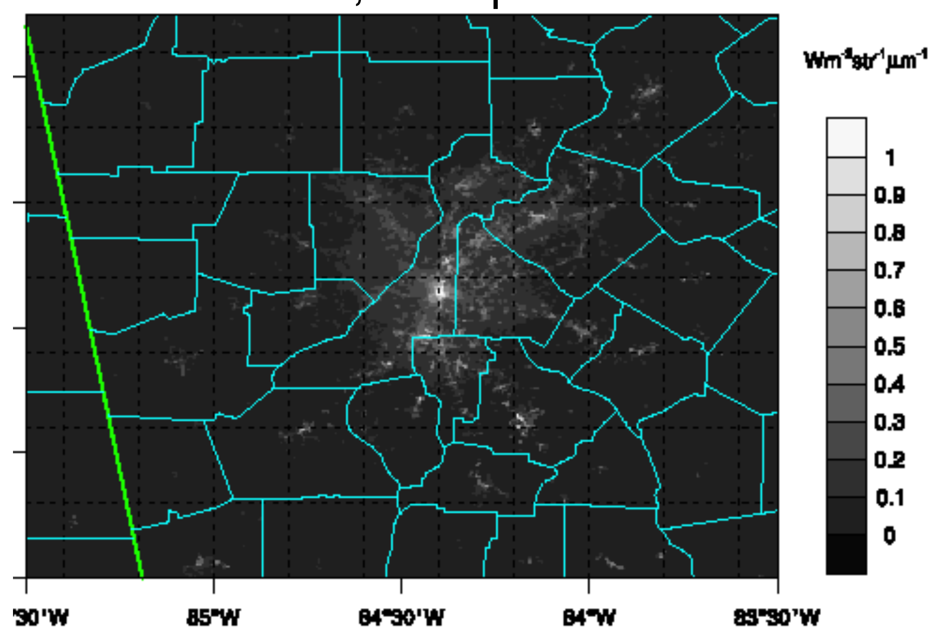
$PM_{2.5}$: 5 ug/m^3

VIIRS DNB, 7 Sep. 2012

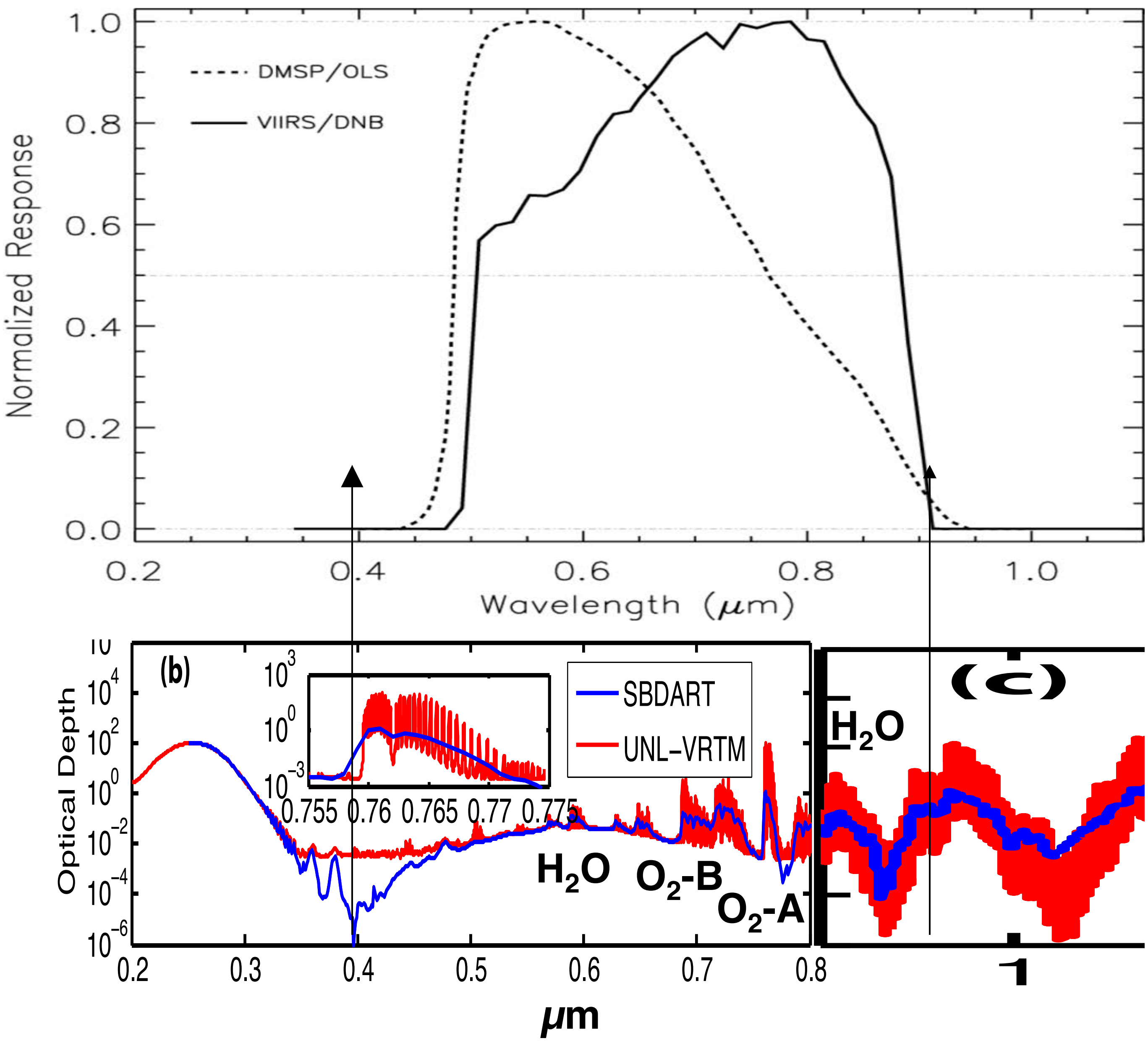


$PM_{2.5}$: 13 ug/m^3

VIIRS DNB, 8 Sep. 2012



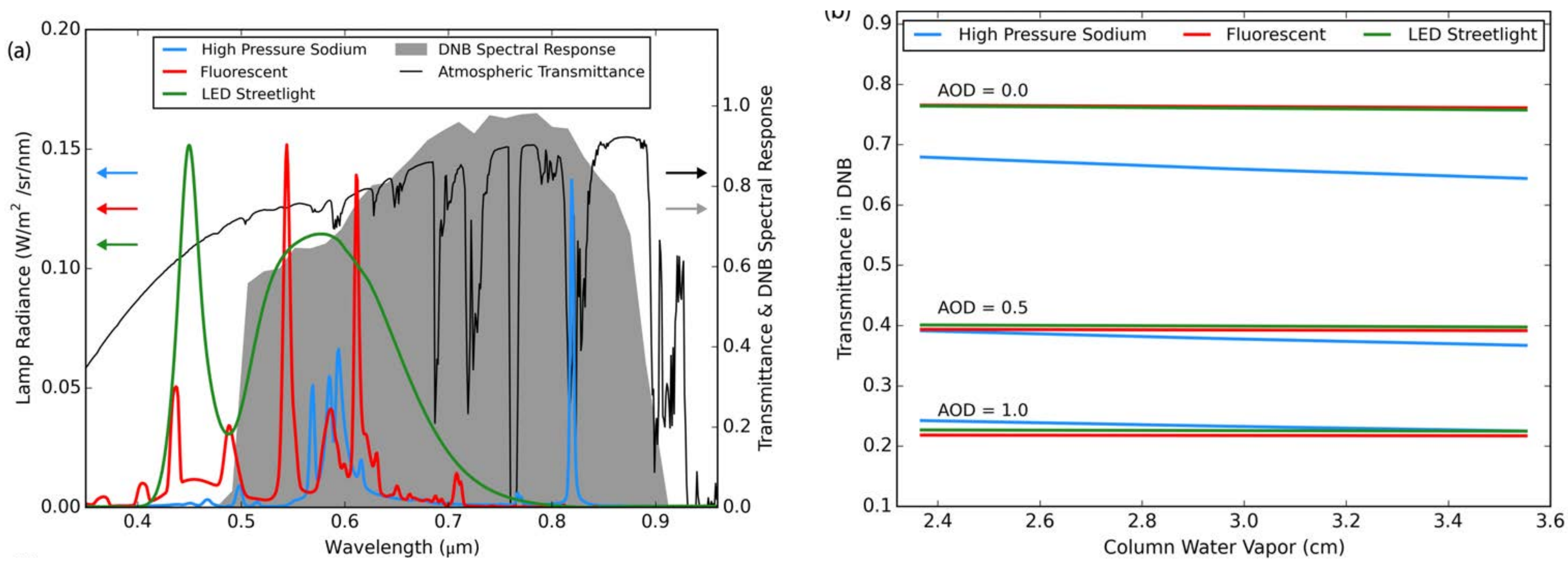
Is DNB sensitive to aerosol, water vapor, & O_2 absorption ?



Miller et al., 2013

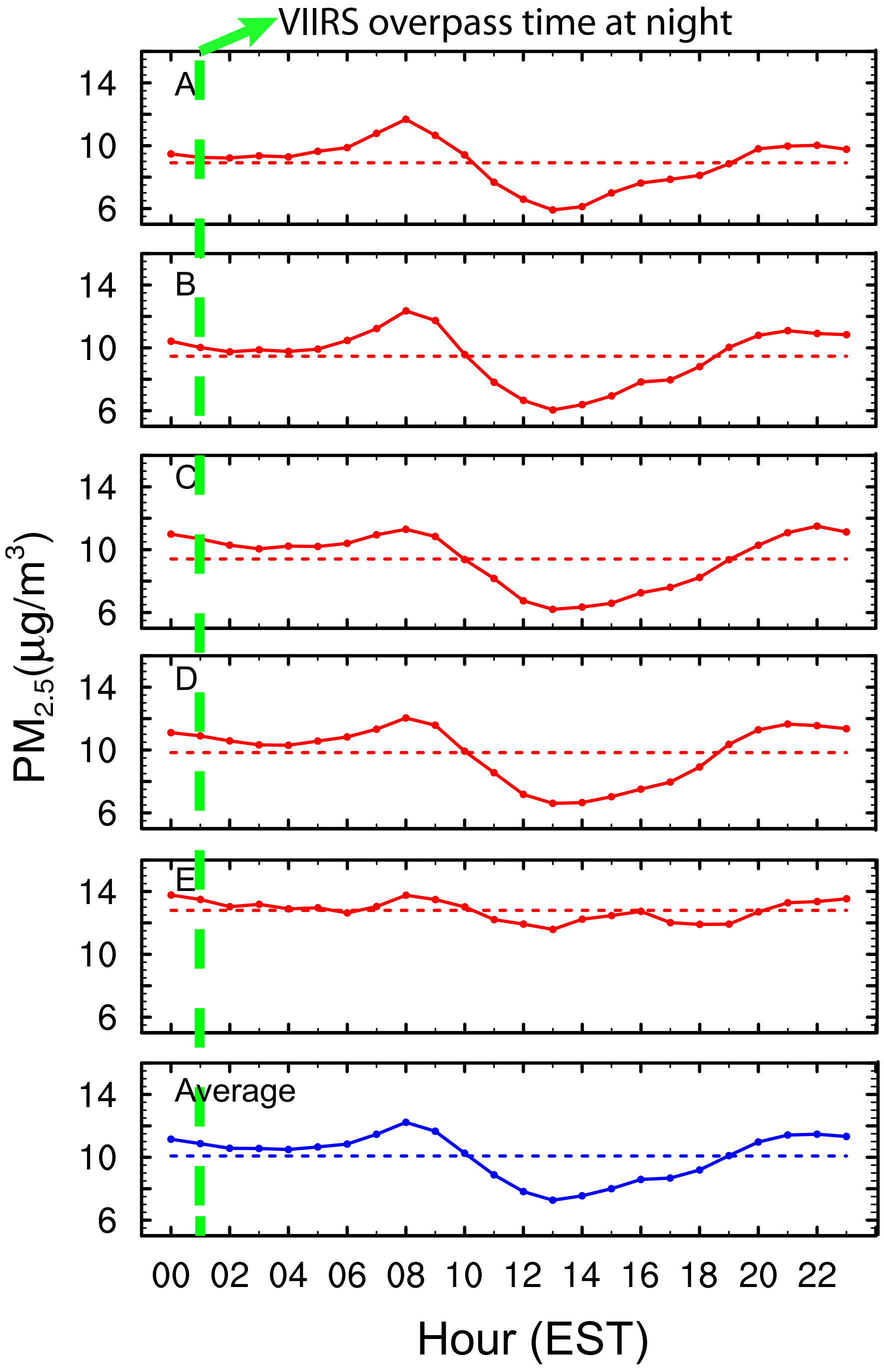
Wang et al., 2014

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

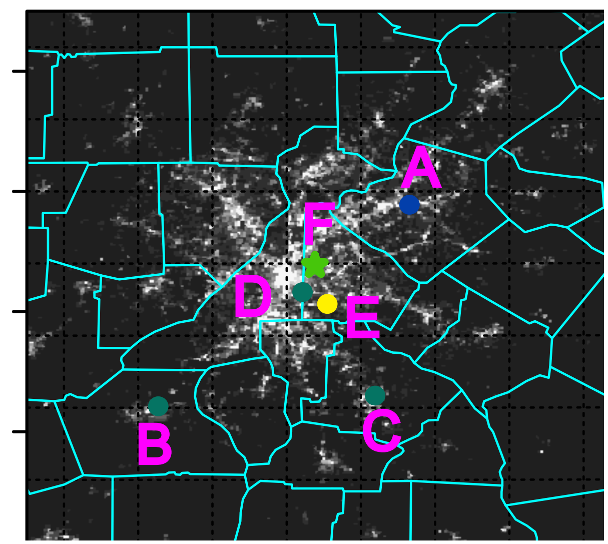


The database of spectral intensity emitted from HPS, fluorescent, and LED bulbs are from Elvidge et al., (2010).

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)



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



Regression analysis

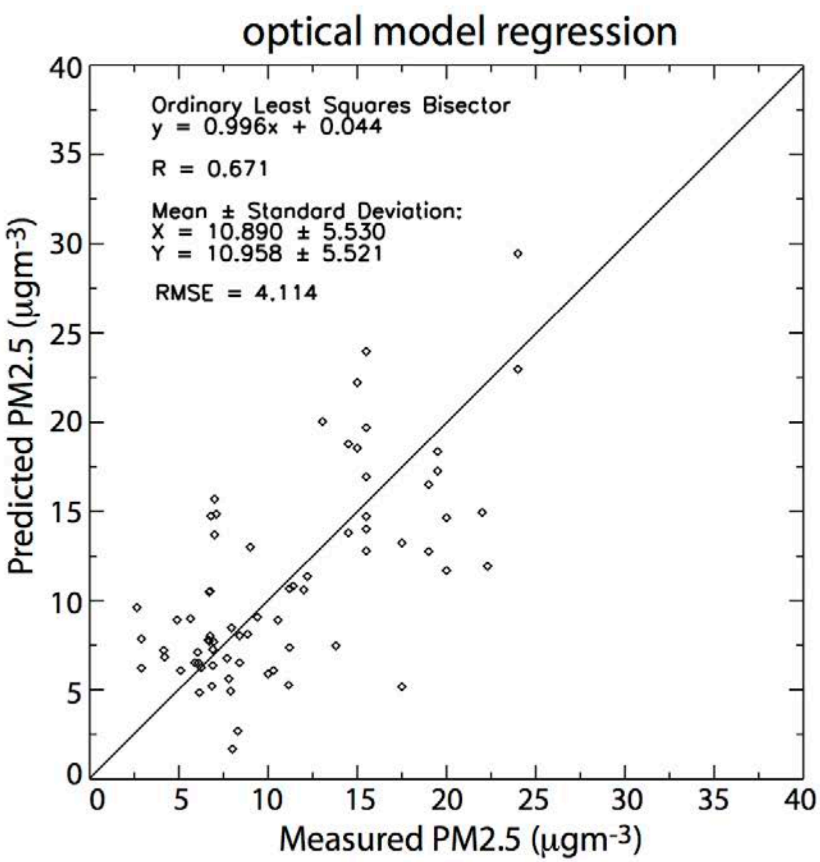
Among surface wind speed, surface pressure, and columnar water vapor amount) that are routinely measured at the surface, the DNB light intensity is the only variable that shows either the largest or second largest correlation with surface $PM_{2.5}$.

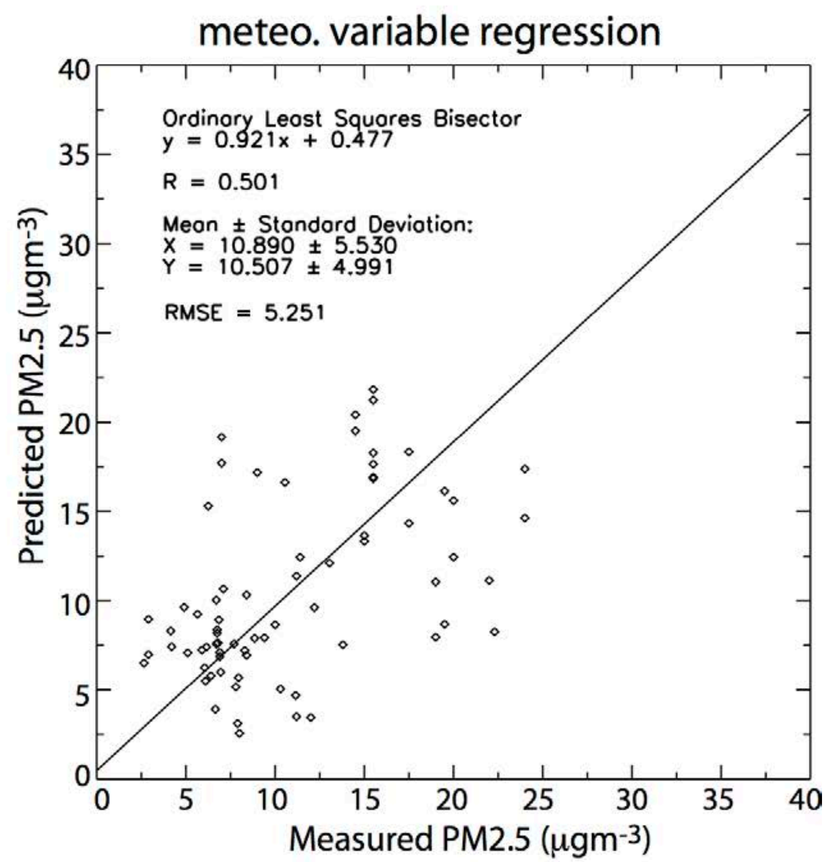
Table 2. Correlation coefficients (R) between $PM_{2.5} \times f(rh)/\mu$ and different variables at 6 ground sites (A-F as described in Table 1 and marked in Figure 2)[1].

	A	B	C	D	E	F(CTR)
Variables\R						
lnI	**-0.78**	**-0.56**	***-0.53***	***-0.39***	**-0.71**	**-0.73**
ΔPs	0.05	0.21	0.08	0.14	0.10	0.10
W	0.49	0.38	**0.85**	0.17	0.00	0.10
U×f(rh)/μ	-0.21	-0.08	-0.21	-0.30	***-0.60***	***-0.66***
V×f(rh)/μ	***0.59***	***0.49***	0.48	**0.53**	0.54	0.52

[1]At each site, the largest value is in bold and second largest value is in the italic bold

Leave-one-out cross validation of regression model





$5\ f(rh)/\mu = a\downarrow 0 - a\downarrow I\ ln(I) - a\downarrow r \times W - a\downarrow p \times P\downarrow s$

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

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

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

***Abstract*—Building on existing techniques for remotely sensing fires via satellite, this paper takes advantage of the day–night band (DNB) aboard the Visible Infrared Imaging Radiometer Suite (VIIRS) to develop the Firelight Detection Algorithm (FILDA), which characterizes fire pixels based on both visible-light and infrared (IR) signatures at night. By adjusting fire pixel selection criteria to include visible-light signatures, FILDA allows for significantly improved detection of pixels with smaller and/or cooler subpixel hotspots than the operational Interface Data Processing System (IDPS) algorithm. VIIRS scenes with near-coincident Advanced Spaceborne Thermal Emission and Reflection (ASTER) overpasses are examined after applying the operational VIIRS fire product algorithm and including a modified "candidate fire pixel selection" approach from FILDA that lowers the 4-μm brightness temperature (BT) threshold but includes a minimum DNB radiance. FILDA is shown to be effective in detecting gas flares and characterizing fire lines during large forest fires (such as the Rim Fire in California and High Park fire in Colorado). Compared with the operational VIIRS fire algorithm for the study period, FILDA shows a large increase (up to 90%) in the number of detected fire pixels that can be verified with the finer resolution ASTER data (90 m). Part (30%) of this increase is likely due to a combined use of DNB and lower 4-μm BT thresholds for fire detection in FILDA. Although further studies are needed, quantitative use of the DNB to improve fire detection could lead to reduced response times to wildfires and better estimate of fire characteristics (smoldering and flaming) at night.**

that, despite improving warning systems [1], [2], have exacted greater costs in recent years [3], [4]. In addition, they impact global atmospheric chemistry by releasing potent trace gases such as carbon monoxide, carbon dioxide, methane, and ethene [5], as well as aerosols and black carbon [6]. These by-products of combustion are capable of traveling great distances and impacting health and meteorological processes in remote locations [7], [8], and in addition to creating local pollution hazards, these can affect Earth's climate [9]. Fire-spawned smoke aerosols have complex interactions with the atmosphere by causing a reduction in surface illumination [10]–[12] and simultaneously warming the atmosphere, thereby decreasing vertical temperature gradients and increasing atmospheric stability [13] due to their relatively low single-scattering albedo [14]. As a consequence of wildfire lethality and potential for property damage, earlier detection of wildfires via remote sensing is paramount to proper allocation of fire management resources [15], [16]. Effective response to all of these phenomena requires accurately detecting and characterizing fires as well as accurately quantifying emissions from biomass burning.

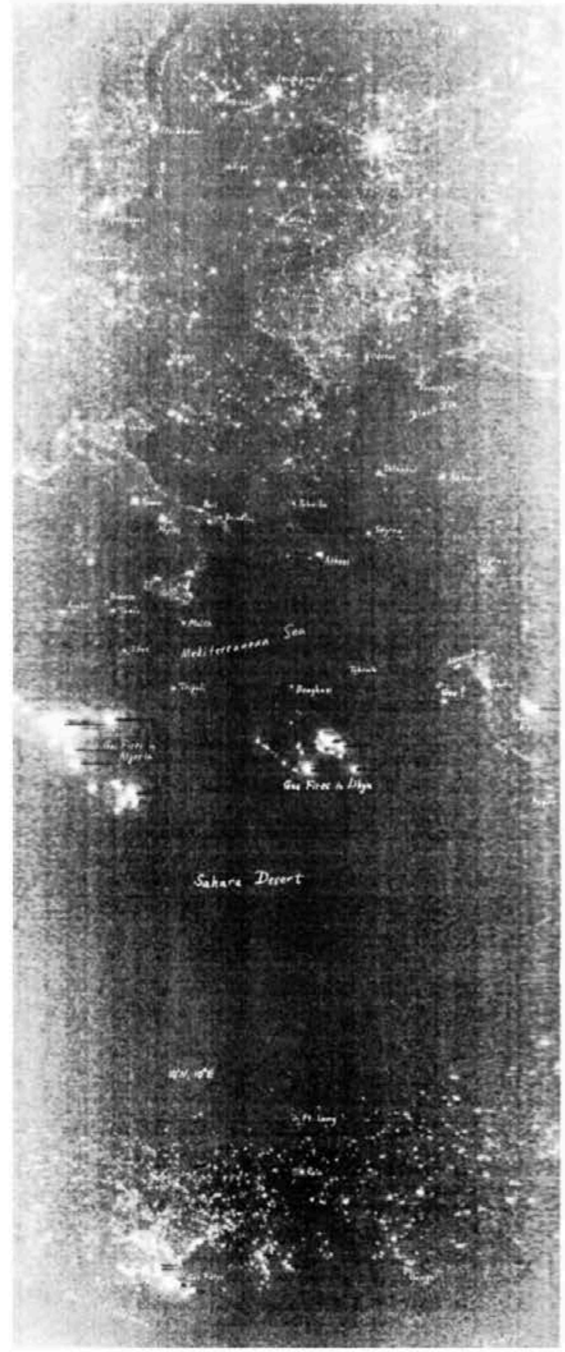
The launch of the Suomi National Polar-orbiting Partnership (S-NPP) satellite on 28 October 2011 has opened up unprece-

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 associ-ated 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 bot-tom arise from gas flares at oil fields in Al-geria, Libya and Nigeria.

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

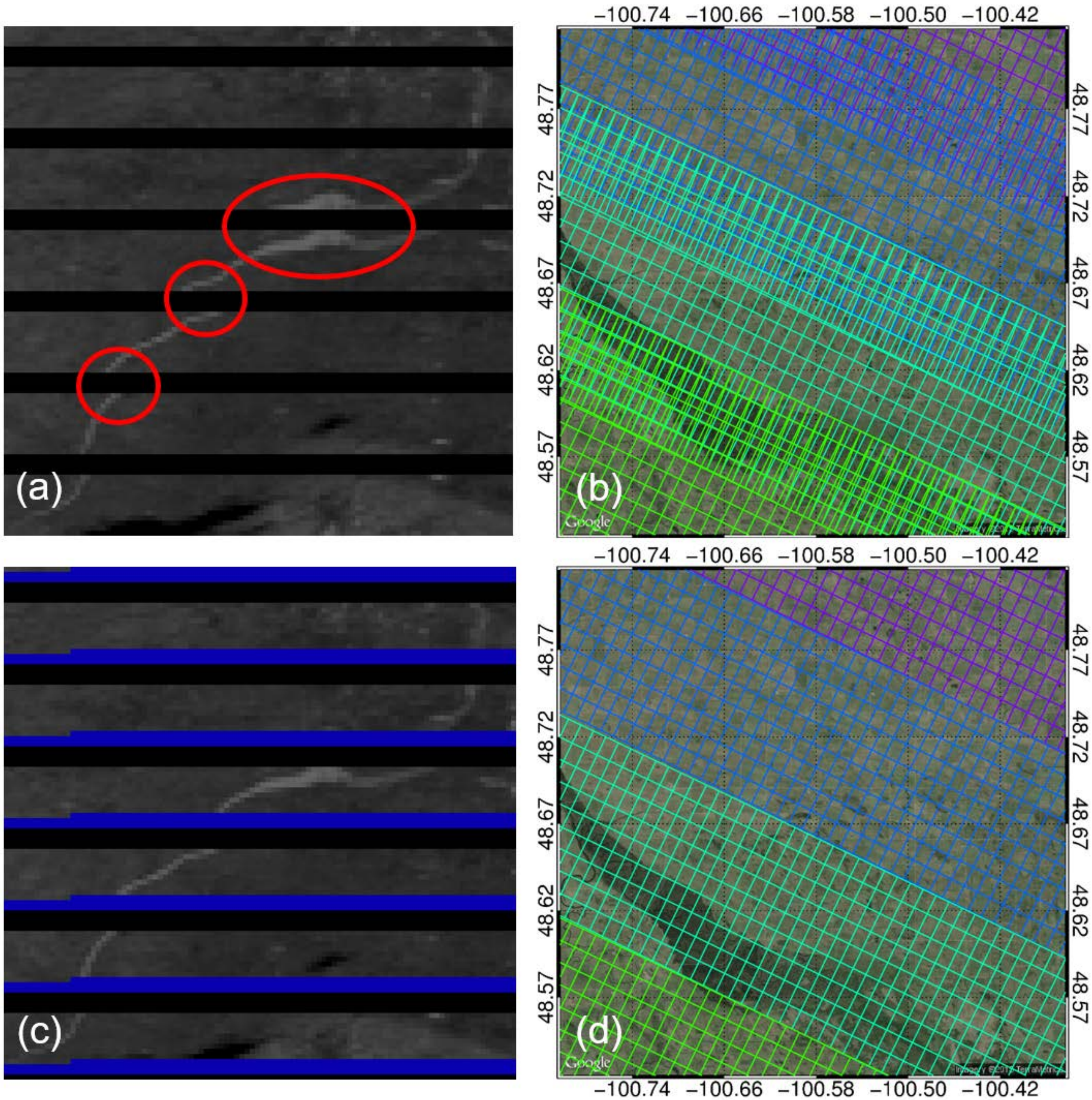
Scientific America, 1978.

Recent work of using shortwave IR (1.6 um) 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.

Correction of pixel overlaps

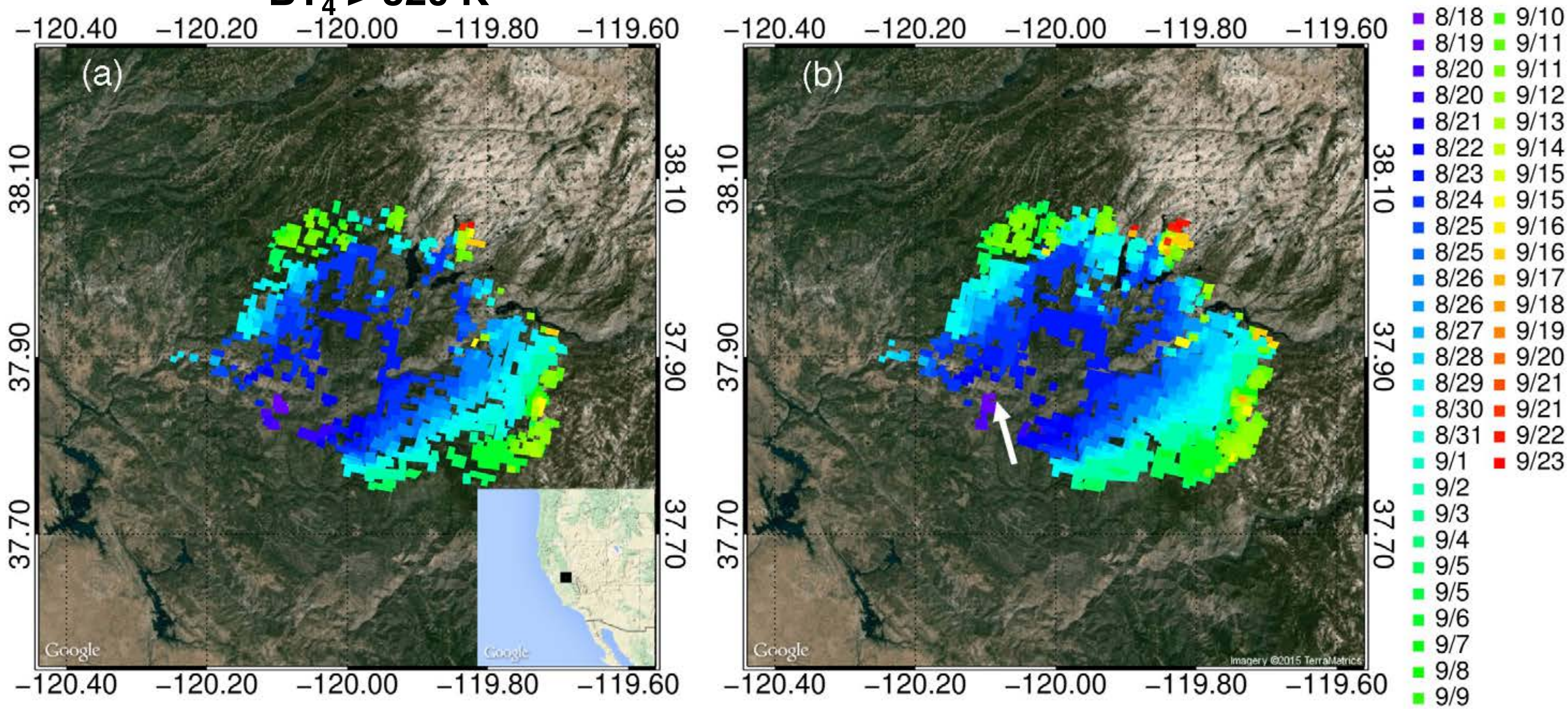


M13

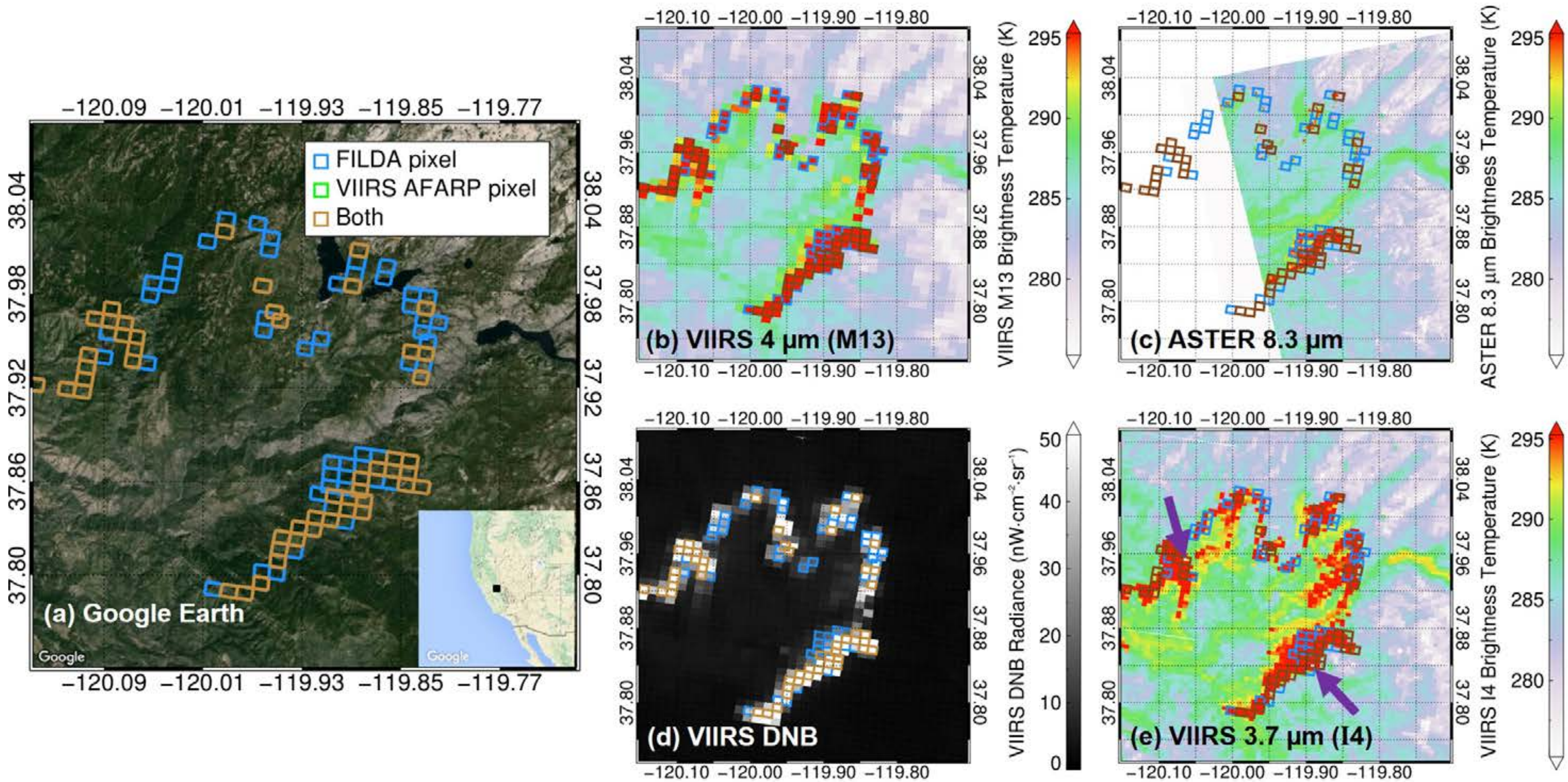
Firelight Detection Algorithm (FILDA)
Combined use of Vis + NIR + IR to detect fires

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

FILDA
Dynamic threshold of BT_4
& DNB threshold

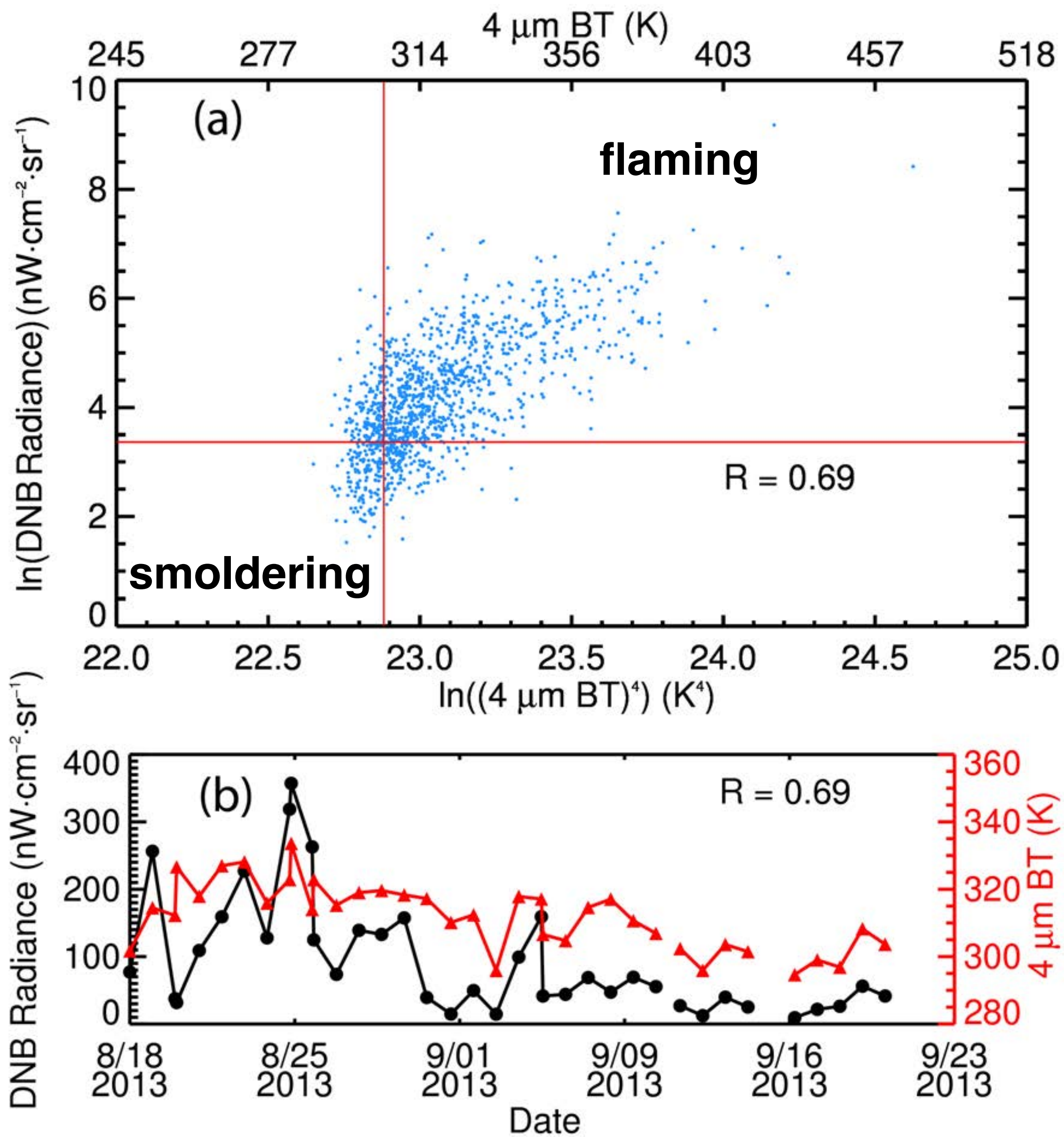


Evaluation with ASTER

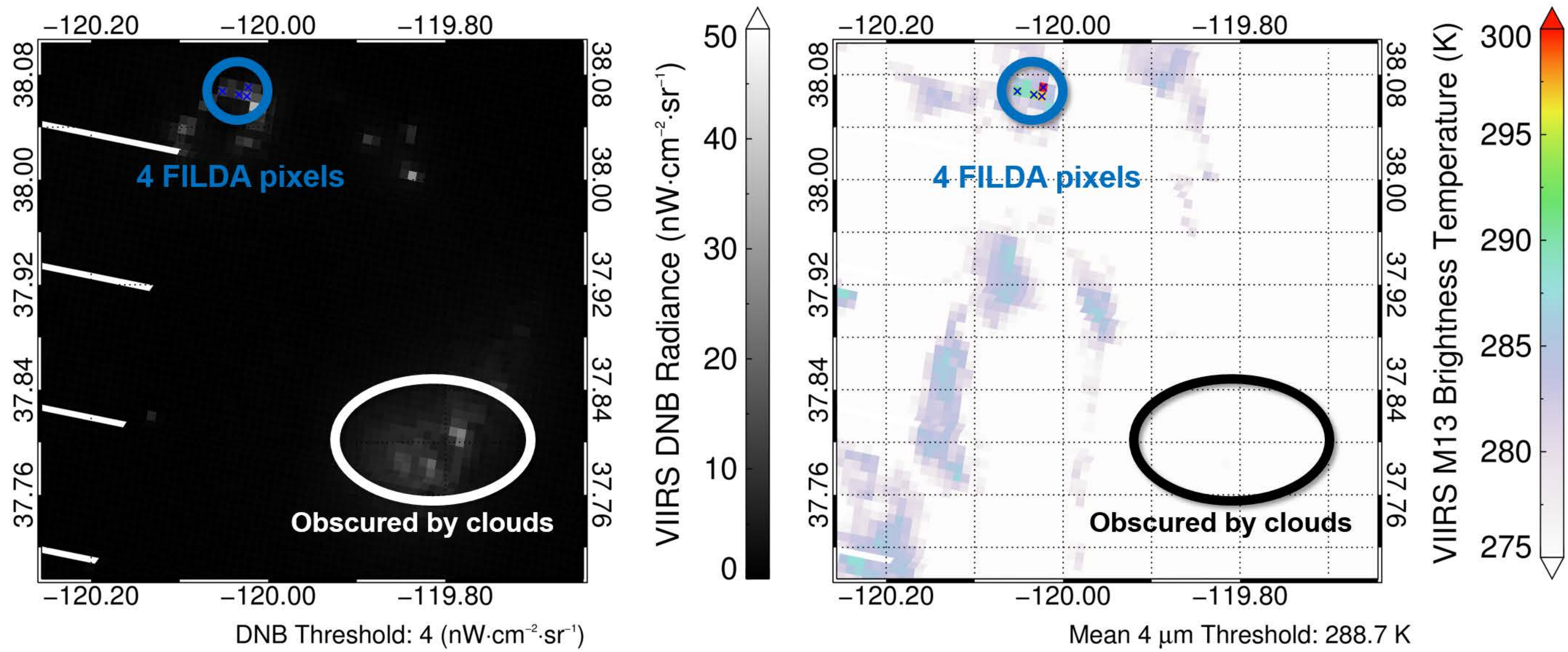


Multiband/sensor view of the Rim Fire taken at 2:29 AM PDT, 24 August 2013

Potential characterization of smoldering vs. flaming



Potential to detect fires through clouds



Thank you !

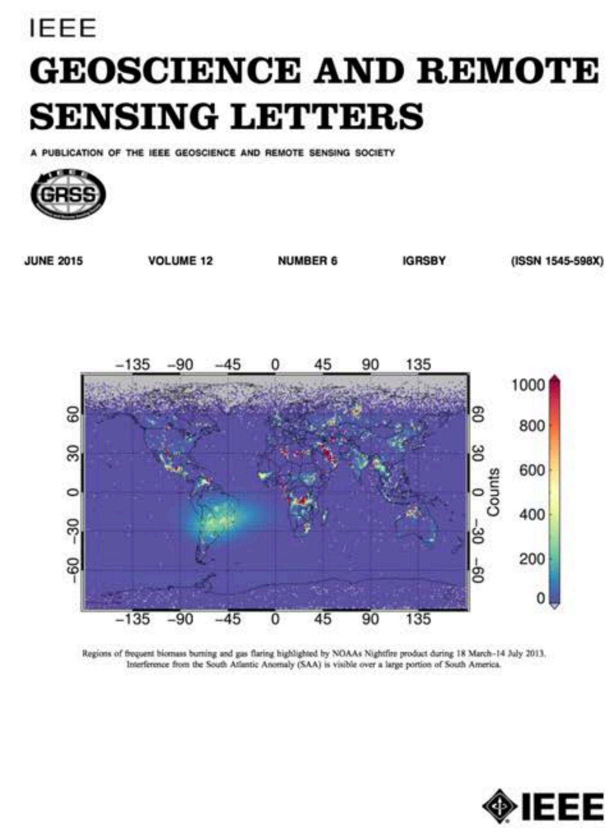
Acknowledgement:

NASA Suomi-NPP program & NASA Applied Science program.

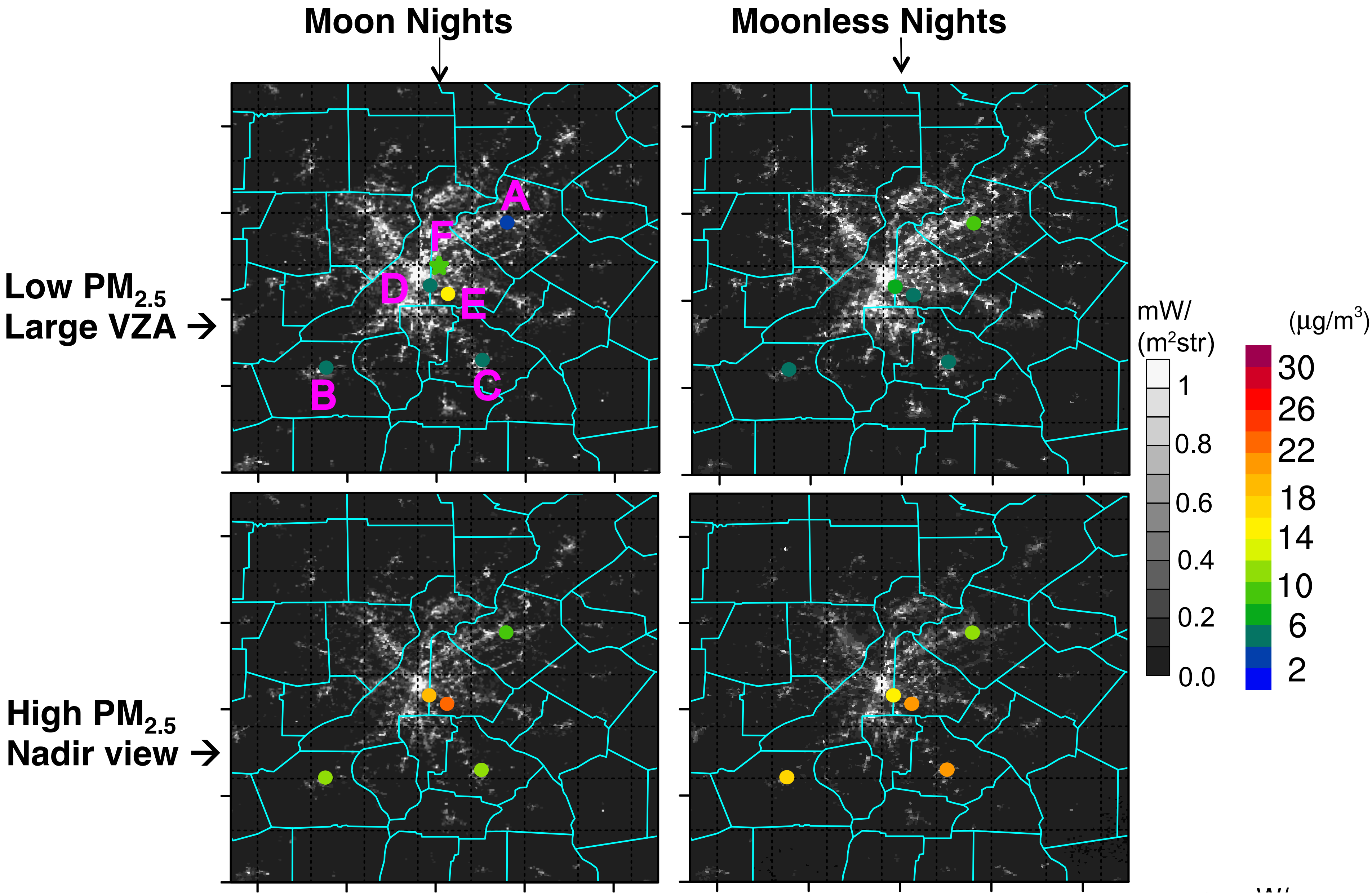
Polivka, T., J. Wang, L. Ellison, E. Hyer, and C. Ichoku, Improving Nocturnal Fire Detection with the VIIRS Day-Night Band, *IEEE Transactions on Geoscience & Remote Sensing*, in press, 2016.

Wang, J., Clint Aegerter, Xiaoguang Xu, and J. J. Szykman, Potential application of VIIRS Day/Night Band for monitoring nighttime surface PM2.5 air quality from space, *Atmospheric Environment*, 124, 55–63, doi:10.1016/j.atmosenv.2015.11.013, 2016.

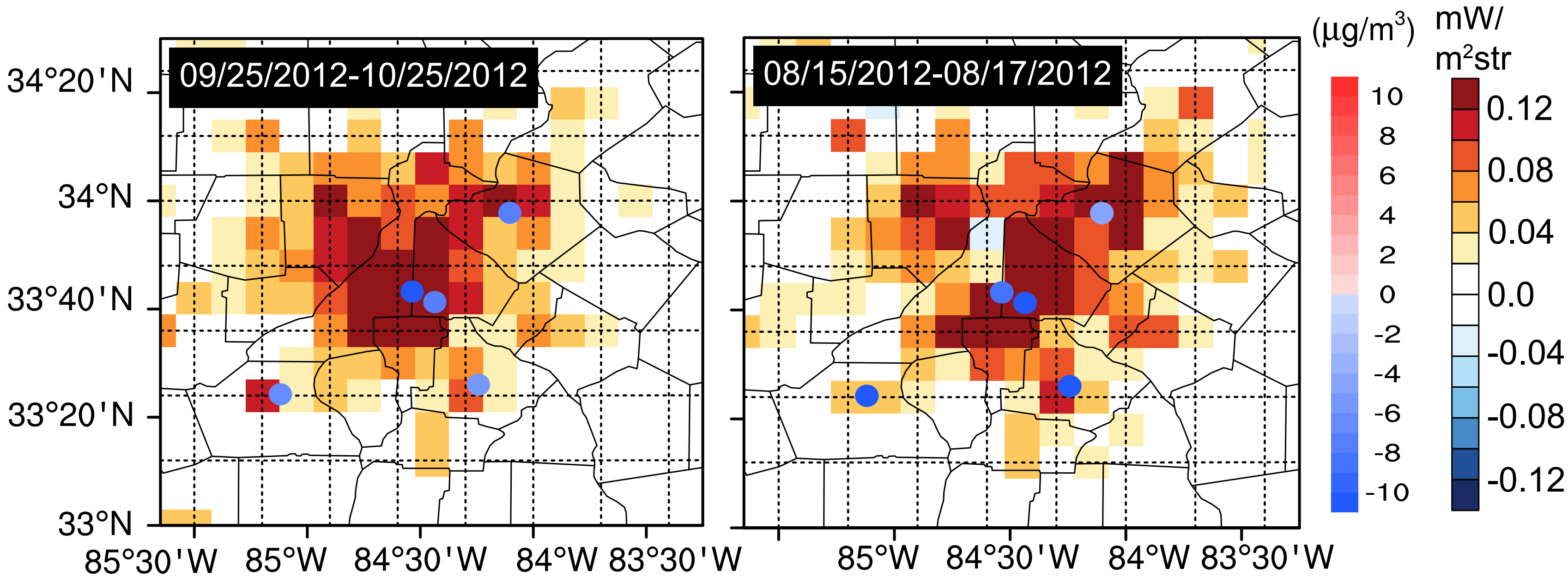
Polivka, T., E. Hyer, J. Wang , and D. Peterson, First global analysis of saturation artifacts in the VIIRS infrared channels and the effects of sample aggregation, *IEEE Geoscience and Remote Sensing Letters*, 1262-1266, 2015, (journal cover article).



Case Analysis



City lights enhance the signal for detecting $PM_{2.5}$ changes.



Using moonlight alone to detect PM2.5 appears very challenging.