Application of DNB for air quality and fire monitoring

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In collaboration with

Suomi-NPP launch
28 Oct. 2011

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

- 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.
Potential application of VIIRS Day/Night Band for monitoring nighttime surface PM\textsubscript{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\textsubscript{2.5} is shown qualitatively and quantitatively
- PM\textsubscript{2.5} at VIIRS night overpass time is much closer to daily-mean PM\textsubscript{2.5} than at daytime
- Strategies for future DNB remote sensing of aerosols are elaborated
# National Ambient Air Quality Standards

<table>
<thead>
<tr>
<th>Pollutant [final rule cite]</th>
<th>Primary/Secondary</th>
<th>Averaging Time</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Monoxide [76 FR 54294, Aug 31, 2011]</td>
<td>primary</td>
<td>8-hour</td>
<td>9 ppm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1-hour</td>
<td>35 ppm</td>
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<tr>
<td>Lead [73 FR 66964, Nov 12, 2008]</td>
<td>primary and secondary</td>
<td>Rolling 3 month average</td>
<td>0.15 μg/m³ (1)</td>
</tr>
<tr>
<td>Nitrogen Dioxide [75 FR 6474, Feb 9, 2010]  [61 FR 52852, Oct 8, 1996]</td>
<td>primary</td>
<td>1-hour</td>
<td>100 ppb</td>
</tr>
<tr>
<td></td>
<td>primary and secondary</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ozone [73 FR 16436, Mar 27, 2008]</td>
<td>primary and secondary</td>
<td>8-hour</td>
<td>0.075 ppm (3)</td>
</tr>
<tr>
<td>Particle Pollution [71 FR 61144, Oct 17, 2006]</td>
<td>PM₂.₅</td>
<td>primary and secondary</td>
<td>Annual</td>
</tr>
<tr>
<td></td>
<td>PM₁₀</td>
<td></td>
<td>24-hour</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulfur Dioxide [75 FR 35520, Jun 22, 2010] [38 FR 25678, Sept 14, 1973]</td>
<td>primary</td>
<td>1-hour</td>
<td>75 ppb (4)</td>
</tr>
<tr>
<td></td>
<td>secondary</td>
<td>3-hour</td>
<td>0.5 ppm</td>
</tr>
</tbody>
</table>

12 μg/m³, 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$_{2.5}$×f(rh)/µ and different variables at 6 ground sites (A-F as described in Table 1 and marked in Figure 2)$^1$.

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

$^1$At each site, the largest value is in bold and second largest value is in the italic bold
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


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 unpreced-
First fire detection from space was from visible light at night...

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.
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 shortwave IR (1.6 um) for night fire detection


Correction of pixel overlaps

(a)

(b)

(c)

(d)
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

(a) (b)
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

(a) Scatter plot showing the relationship between $\ln(DNB\text{ radiance})$ and $\ln((4\ \mu m\ BT)^4)$ for flaming and smoldering. The data points are color-coded, with flaming in blue and smoldering in red. The correlation coefficient $R = 0.69$.

(b) Line graph illustrating the change in DNB radiance over time from 8/18/2013 to 9/23/2013. The graph shows two lines: one in black and another in red, with the correlation coefficient $R = 0.69$. The x-axis represents the date, and the y-axis represents the DNB radiance in nW cm$^{-2}$ sr$^{-1}$.
Potential to detect fires through clouds
Acknowledgement:
NASA Suomi-NPP program & NASA Applied Science program.


Case Analysis

Moon Nights

Low PM$_{2.5}$
Large VZA →

High PM$_{2.5}$
Nadir view →

Moonless Nights
City lights enhance the signal for detecting PM$_{2.5}$ changes.

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