Evaluation of Suomi NPP VIIRS Imagery

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VIIRS Imagery: SDRs and EDRs

- **VIIRS: Visible Infrared Imaging Radiometer Suite**

- **All 22 bands are available as Sensor Data Records (SDRs)**

- **Bands highlighted in red are available as Environmental Data Records (EDRs)**

- **Day/Night Band (DNB)** SDRs are converted to Near Constant Contrast (NCC) EDRs

### VIIRS Band Table

<table>
<thead>
<tr>
<th>VIIRS Band</th>
<th>Central Wavelength (μm)</th>
<th>Band Explanation</th>
<th>Spatial Resolution (m) @ nadir</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>0.412</td>
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<tr>
<td>M2</td>
<td>0.445</td>
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<tr>
<td>M3</td>
<td>0.488</td>
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<td>M4</td>
<td>0.555</td>
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<td>M5</td>
<td>0.672</td>
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<td>M6</td>
<td>0.746</td>
<td>Near IR</td>
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<tr>
<td>M7</td>
<td>0.865</td>
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<tr>
<td>M8</td>
<td>1.240</td>
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<tr>
<td>M9</td>
<td>1.378</td>
<td>Shortwave IR</td>
<td>750 m</td>
</tr>
<tr>
<td>M10</td>
<td>1.61</td>
<td></td>
<td></td>
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<tr>
<td>M11</td>
<td>2.25</td>
<td>Medium-wave IR</td>
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</tr>
<tr>
<td>M12</td>
<td>3.7</td>
<td></td>
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</tr>
<tr>
<td>M13</td>
<td>4.05</td>
<td>Longwave IR</td>
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<tr>
<td>M14</td>
<td>8.55</td>
<td></td>
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<tr>
<td>M15</td>
<td>10.76</td>
<td></td>
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</tr>
<tr>
<td>M16</td>
<td>12.01</td>
<td></td>
<td></td>
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<tr>
<td>DNB (NCC)</td>
<td>0.7</td>
<td>Visible / Reflective</td>
<td>750 m across full scan</td>
</tr>
<tr>
<td>I1</td>
<td>0.64</td>
<td>Visible / Reflective</td>
<td></td>
</tr>
<tr>
<td>I2</td>
<td>0.87</td>
<td>Near IR</td>
<td>375 m</td>
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<tr>
<td>I3</td>
<td>1.61</td>
<td>Shortwave IR</td>
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<td>I4</td>
<td>3.74</td>
<td>Medium-wave IR</td>
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<tr>
<td>I5</td>
<td>11.45</td>
<td>Longwave IR</td>
<td></td>
</tr>
</tbody>
</table>
SDRs and EDRs: What’s the difference?

I-2 SDR (SVI02)

I-2 EDR (VI2BO)

Unmapped SDR and EDR granules from 08:14 UTC 24 October 2013
Scan lines in SDR data are not orthogonal to the satellite ground track, due to the constant motion of the satellite. Mapping the data to the Ground Track Mercator (GTM) grid restores orthogonality. This is the cause of the apparent rotation between SDRs and EDRs.
The Case of the Missing Triangles

The brown outline shows where a SDR granule matches up with a given EDR granule. It takes three SDR granules to produce one EDR granule. If an SDR granule is missing when the EDR is created, you get a “missing triangle”...

17 January 2013

24 February 2012

FILL VALUE LEGEND ND

SOUB VDNE N/A MISS ERR ELINT PIXEL TRIM ONBOARD ONGROUND
The Case of the Sawtoothed Eye

I-5 SDR image of the eye of Typhoon Jelawat (25 September 2012) produced using McIDAS-v
The unmapped image of the typhoon eye (left) shows artifacts caused by the bowtie effect. These artifacts disappear when the same data was correctly mapped to the Earth’s surface using IDL.

The “sawtooth pattern” was caused by improper mapping. It is a display issue, not a problem with the data!

NOTE: McIDAS-v does have the ability to properly map VIIRS data to avoid this issue.
Geolocation Evaluation: I-band SDR
Geolocation Evaluation: I-band SDR
Geolocation Evaluation: I-band EDR
Geolocation Evaluation: I-band EDR
Terrain Correction Evaluation: SDR

SDR – I-1, I-2, I-3, displayed with GITCO geolocation

Mt. Logan (6050 m MSL)
Mt. St. Elias (5489 m MSL)

2014/01/25 21:13 UTC
EDRs are not Terrain Corrected!

EDR – I-1, I-2, I-3, displayed with GIGTO geolocation

Mt. Logan (6050 m MSL)

Mt. St. Elias (5489 m MSL)

2014/01/25 21:13 UTC
It is difficult to display DNB images near the day/night terminator, as radiance values vary by 7-8 orders of magnitude from day to night, and many displays only have 256 colors.

The NCC EDR converts DNB radiance to a “reflectance” to reduce the dynamic range of the data, improving the display across the terminator.
Stray light and striping were an issue with DNB and NCC imagery until 20 August 2013, when a correction was applied. Problem solved!
Bug? Or Feature?

DNB SDR

Nighttime DNB image of Alaska, 11:37 UTC 9 February 2014
Nighttime DNB images of Antarctica with aurora, 00:22 UTC 1 October 2012
Nighttime NCC images of Alaska, Spring 2014
Summary

• VIIRS Imagery is alive and well!
  – Geolocation has been accurate and stable since mid-2012
  – “Missing Triangle” problem eliminated (mid-2012)
  – Striping reduced or eliminated (August 2013 for DNB and NCC imagery)
  – Stray Light in DNB reduced or eliminated (August 2013)
  – NCC imagery available at night throughout the lunar cycle
  – All Imagery EDR products have achieved Validation Stage 3 (April 2014)

• Many “bugs” are actually features of the data
  – Moon glint
  – Aurora motions

• Others are attributed to “user error”
  – Incorrect mapping of SDR data by users, e.g.

• For the future:
  – Anomalously dark/light areas in NCC near terminator
  – Terrain correction for the EDR geolocation
  – Make EDRs from all 16 M-bands
  – Make M-band EDRs more readily available
Resources

Geolocation evaluation tests:

http://rammb.cira.colostate.edu/projects/npp/calval/

JPSS Imagery and Visualization Team blog:

http://rammb.cira.colostate.edu/projects/npp/blog/

High-latitude applications of VIIRS Imagery:

http://rammb.cira.colostate.edu/projects/alaska/blog/
Nightfire: Using the VIIRS Nighttime M-bands to Detect and Characterize Combustion Sources

May 14, 2014

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Gas Flaring

- A widely used practice to dispose of natural gas in oil production areas that lack infrastructure to make productive use of the gas.
- More common in remote locations and in impoverished countries.
- Reporting is poor since this is a waste disposal process.
- Satellite data sources have the potential for global systematic observation of flares and estimation of flared gas volume / CO₂ emissions.
What makes nighttime VIIRS data so great for detection of combustion sources?

The M7,8,10 spectral bands are well placed to record the peak radiant emissions from flares. During daylight hours the signal is overwhelmed by sunlight. At night combustion sources stand out clearly against the background.
Gas flares are readily detected in the VIIRS M10 spectral band.
VIIIRS Nighttime Imagery
Riau Indonesia
June 19, 2013
VIIRS Nightfire v2 has two independent hot pixel detection algorithms

High Temperature Detector
SWIR: M10 (1.6 um) detection threshold set based on background noise – mean plus four standard deviations. The detected pixels are then checked for detection in M7 & M8.

Low Temperature Detector
MWIR: M12-M13 (3.8 and 4 um) scattergram analysis identifies background. Hot pixels are the outliers.
M12 and M13 detection algorithm identifies pixels outside of scene background, which is in the form of a baseline. Local background not used.
Planck Curve Fitting

• Planck curve fitting uses an iterative simplex algorithm.
• Pixels with M10 detection and no M12-M13 detection are fit with a single hot Planck curve.
• Pixels with M10 plus M12-M13 detection are fit with dual Planck curves (one hot and one background) spanning all nine bands. Observed radiances used as constraints.
• Single curve fitting with insufficient detections
  – Fitting for pixels without M16 detection use zero radiance in M16 as a hot source constraint.
  – Fitting for pixels without M10 detection use zero radiance in M10 as a hot source constraint.
Planck Curve Calculations

• Peak radiance indicates temperature (K) using Wein’s Displacement Law.

• Subpixel sources appear as graybodies. The ratio of the observed curve versus the full pixel curve for that temperature is traditionally referred to as emissivity. We call it emission scaling factor (ESF) to distinguish it from full field of view graybodies. Source area is calculated by multiplying ESF by the size of the pixel footprint.

• Radiant heat (aka heat release) is calculated in MWs using the Stefan-Boltzmann Law.
Typical Gas Flare Detection

Combustion parameters:
ID: VNF_npp_d20140425_10800568_0806372_012924_x9622946w_y19604211_12716_s2045_v21
Lat=19.604264 Lon=-92.294624 deg.
Time=2014/04/26 08:08:32
Temperature source=1730 deg. K
Radiant heat intensity=16.63 W/m²
Source footprint=25.96 m²
Methane equivalent=0.356 m³/s
Cloud state=clear

CO₂ equivalent=951.983 g/s
Atmosphere corrected=no

IR source radiance

- no detection
- detection
- used as constraint
- dual curve model
- IR source
- background
Typical Biomass Burning Detection

Lower temperature than gas flaring. Often these have larger source size than gas flares.
Weak Detections

- Approximately 40% of all detections have M10 and DNB detection only.
- The Planck curve fitting fails.
- It is not possible to calculate temperature, radiative heat, and source footprint.

North Dakota
VIIRS Cloud Mask Algorithm Identifies Flares as Cloud

There is likely spectral confusion between clouds and gas flares.
Comparison with MODIS

\[ y = 0.8223x \]

\[ R^2 = 0.996 \]
Initial Flared Gas Volume Calibration Based on Monthly Reported Data

Annual BCM = 0.08306 * Average M10 radiance

$R^2 = 0.90$

$N = 840$
JPSS Validation System

Robert Holz, Andy Heidinger Fred Nagle, Greg Quinn, Min Oo, and Ralph Kuehn

May 14th 2014
Outline

• An overview the processing and validation tools
• Products and data access (Atmospheric PEATE)
• Developing a near realtime monitoring system for cloud products
Ingested Products at UW SSEC

Ingested Products

• VIIRS RDR, SDR, and EDR (Clouds and Aerosols)
• MODIS Terra and Aqua L1a, L1b, MYD04 (aerosol), MYD06 (Cloud)
• AVHRR L1B
• ATMS RDR and SDR
• CALIPSO V3 L1b, L2 products (aerosol), and IIR
• CloudSat L1 and L2 products
• CrIS SDR and EDR
• Metop-A (IASI) and Metop-B (IASI)
Collocation and Evaluation

CALIPSO

VIIRS FOV
Collocation and Evaluation

CALIPSO

VIIRS FOV

1 km
## Collocation and Evaluation

### PEATE multi-satellite sensors collocation

<table>
<thead>
<tr>
<th>Master</th>
<th>AVHRR</th>
<th>CALIOP</th>
<th>CLOUDSAT</th>
<th>GOES</th>
<th>MODIS</th>
<th>POLDER</th>
<th>SEVIRI</th>
<th>VIIRS</th>
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<tbody>
<tr>
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<td>⭐️</td>
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The Flo Processing System

- Leverages UW Atmospheric PEATE processing system
- Supports forward stream and archival processing
- Geographical and multi-sensor processing via integrated orbital prediction
- An extensible catalog of scientific algorithms; algorithms specify sensor and ancillary input requirements; Flo chains algorithms together as needed to reach output products
- Provides the capability to processes the collocation and algorithms that require multiple instruments platforms (ie VIIRS and CrIS)
Collocation and Evaluation

Aqua/CALIPSO Intersections with NPP

May 1 - Aug 11 2012 Observations within 20 min
Collocation and Evaluation

Match Files Generation

CALIPSO_Feature_Classification_Flag_Phase_Fraction_5km: [2704x3 double]
CALIPSO_Feature_Classification_Flag_Phase_QA_5km: [2704x1 double]
CALIPSO_IR_Derived_Cloud_Height_5km: [2704x1 double]
Column_Optical_Depth_Aerosols_532: [2704x1 double]
Column_Optical_Depth_Aerosols_Uncertainty_532: [2704x1 double]
CALIPSO_Pressure: [33x2704 double]
Master_Vertical_Index: [2704x1 double]
Master_Horizontal_Index: [2704x1 double]
Slave_Index: [2704x3 double]
Parallax_Table: [677x32 double]
CALIOP_GDAS_Pressure: [2704x33 double]
CALIOP_GDAS_Altitude: [33x1 double]
IFF_L1b_BrightnessTemperatureBandCenters: [11x1 double]
IFF_L1b_BrightnessTemperatureBands: [2704x11 double]
IFF_L1b_EmissiveBandCenters: [11x1 double]
IFF_L1b_EmissiveBands: [2704x11 double]
IFF_L1b_LandSeaMask: [2704x1 double]
IFF_L1b_Latitude: [2704x1 double]
IFF_L1b_Longitude: [2704x1 double]
IFF_L1b_ReflectiveBandCenters: [11x1 double]
IFF_L1b_ReflectiveSolarBands: [2704x11 double]
IFF_CLX_Cloud_Mask: [2704x1 double]
IFF_CLX_surface_type: [2704x1 double]
IFF_CLX_cloud_phase: [2704x1 double]
IFF_CLX_cld_press_acha: [2704x1 double]
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IFF_CLX_cld_height_base_acha: [2704x1 double]
## Collocation and Evaluation

### Current available multi-satellite sensors

<table>
<thead>
<tr>
<th>Geo-stationary satellites sensors</th>
<th>Polar-orbiting satellites sensors</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEVIRI</td>
<td>MODIS (Aqua)</td>
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<tr>
<td>COMS</td>
<td>✔️</td>
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<tr>
<td>VIIRS</td>
<td>✔️</td>
</tr>
<tr>
<td>CALIOP</td>
<td>✔️</td>
</tr>
<tr>
<td>MODIS (Aqua)</td>
<td>✔️</td>
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</tbody>
</table>

- ✔️ Aerosol Products
- ✔️ Cloud Products

![SSEC Logo](NOAA_SSEC_Logo.png)
Cloud Height Validation

- 3 Months of data
- IDPS has significant low bias

<table>
<thead>
<tr>
<th></th>
<th>COT &lt; 1.0</th>
<th>COT &gt; 1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>12 %</td>
<td>63 %</td>
</tr>
<tr>
<td>% in spec</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precision</td>
<td>43 %</td>
<td>49 %</td>
</tr>
<tr>
<td>STD (km)</td>
<td></td>
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</tr>
</tbody>
</table>
Cloud Cloud Optical Thickness

- Number of sample = 234 mills
- Both Ice and water cloud
- Color bar shows number density in log scale (example: 3 = 1,000)
Aerosol AOD Validation Against MODIS

IDPS EDR Land

2013 Feb–Mar Aqua MODIS vs VIIRS AOT (# of sample = 179127 )

Aqua MODIS Land AOT (550nm) vs VIIRS (EDR) Land AOT (550nm)

Accuracy = -0.051199
Precision = 0.1544
Corrcoef = 0.85031
Uncertainty = 0.16266

Number Density in log scale (eg. 3 = 1,000)

IDPS EDR Ocean

Dec 2012 to Mar 2013 Aqua MODIS vs VIIRS AOT
Number of sample = 234543

Aqua MODIS Ocean AOT (550nm) vs VIIRS (EDR) Ocean AOT (550nm)

Accuracy = -0.0074981
Precision = 0.043267
Corrcoef = 0.93537
Uncertainty = 0.043912

Number Density in log scale (eg. 3 = 1,000)
JPSS Cloud Validation Interface
JPSS Cloud Validation Interface
JPSS Cloud Validation Interface
JPSS Cloud Validation Interface
Near Real Time Processing

- 97% of VIIRS RDR files are created at 118 minutes after observation
- PEATE could ingest VIIRS RDR files within 5 minutes after creation on the IDPS
- Process RDR - IP or EDR within 10 min after being ingested

VIIRS RDR 130 minutes (min)
Take away messages

• UW SSEC is actively supporting the JPSS cloud and aerosol validation
• Leveraging our processing and collocation expertise has allowed long term inter-comparisons of the JPSS products to active (CALIOP) and passive (MODIS) observations
• We are currently developing a near realtime validation interface which will provide monitoring the of the JPSS products
• The system will also have the capability to reprocess selected products (NDE Clouds and ADL Aerosols) for evaluating algorithm changes
Evaluation of the VIIRS Cloud Base Height (CBH) EDR Using CloudSat

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Daniel T. Lindsey, Andrew K. Heidinger
NOAA/NESDIS/Satellite Applications and Research

1st STAR JPSS Annual Science Team Meeting, College Park, MD, May 2014
Introduction

- Satellites have been viewing the tops of clouds for 50+ years
- Hutchison (2002) developed algorithm to determine cloud base height (CBH) from VIS/IR observations from MODIS
- VIIRS (CBH) EDR is the first operational algorithm to determine cloud base height
- CBH is important for aviation
- CBH is also important for closure of the Earth’s Radiation Budget
The cloud base height for liquid clouds is defined at right. Cloud base height definition for ice clouds is similar, except the average ice water content is temperature dependent.

CBH requires upstream retrievals of cloud top height (CTH), cloud optical depth ($\tau$), effective particle size ($r_e$) and cloud type, which is used to determine the LWC value to use.

Errors in CBH are directly proportional to errors in each of these values. Issues in upstream retrievals directly impact CBH retrieval.

CBH algorithm for liquid clouds:

$$CBH = CTH - \left(\frac{LWP}{LWC}\right)$$

$$LWP = \frac{2\tau \rho r_e}{3}$$

Red variables come from upstream retrievals

LWC is pre-defined average value based on cloud type; cloud type comes from upstream retrieval.
Matching VIIRS with CloudSat

- CloudSat has a cloud-profiling radar that is well suited to observe CBH for most clouds
  - Ground clutter and precipitation are issues
- Suomi-NPP and CloudSat are in the same orbital plane, but at different altitudes
- CloudSat and VIIRS overlap for ~4.5 hours every 2-3 days
  - 8-9 “matchup periods” per month
- Due to battery issues, CloudSat only operates on the daytime side of the Earth
- Use only the closest non-fill VIIRS pixels that overlap CloudSat and have CBH and CTH above 1 km AGL
- Use only CloudSat profiles where precipitation is not present
What VIIRS Sees

- Intermediate Products (IP) have the same resolution as M-band SDRs
- Parallax-corrected cloud products (IVPTP, IVPCP) are required to properly account for line-of-sight issues
- Parallax means some clouds are missed
- VIIRS does not see through optically thick clouds
- Only the top of the top-most layer
What CloudSat Sees

1 CloudSat Granule

0.742 km @nadir

VIIRS Pixels

Each “PROFILE” has 125 vertical “BINS” (~30km)

Each vertical Bin is 240 m thick

1.1 km along-track

95 GHz Cloud Profiling Radar (CPR)
CPR samples at 625 kHz = 0.16 sec / burst (called a profile)
PRF = 4300
(4300 pulses / sec) * (0.16 sec/burst) = 688 pulses/profile

Figures courtesy D. L. Reinke, CIRA
Matchup Example

VIIRS CBH granule @ 13:53 UTC 9/26/2013

CloudSat track

CloudSat 2B-GEOPROF reflectivity
CloudSat Reflectivity (L1B) [dBZ] 2013/09/26 13:53:52 UTC

CloudSat Cloud Mask with VIIRS overlayed

CloudSat Cloud Mask 2013/09/26 13:53:52 UTC

Legend:
-28  -20  -13   -6    1    8   15   22   30

N/A  Opaque Ice  Cirrus  Water  Mixed-phase  Overlap
Known issue with CTH retrieval: cirrus cloud tops too low due to CTT

Known issue with CBH retrieval: cirrus cloud too thick due to IWC parameterization

Inconsistent cloud type and CTH; thin clouds identified as “opaque ice”

Gray shading represents vertical extent of clouds from CloudSat cloud mask. Colored areas represent vertical extent of clouds from VIIRS CTH and CBH retrievals, sorted by VIIRS cloud type.
“All Clouds” vs. “Within Spec”

• The VIIRS CBH algorithm has been evaluated for two groups:
  – All clouds observed by CloudSat and VIIRS
  – Only those clouds where the VIIRS CTH retrieval is within the error specifications (aka “Within Spec”)
    • Error specifications: CTH must be within 1 km if the COT is greater than 1, or within 2 km if the COT is less than 1
• Thus, “All Clouds” results show the general performance of the CBH retrieval, “Within Spec” results show the performance of the CBH retrieval when the CTH retrieval is accurate
  – CBH accuracy is very closely related to CTH accuracy
  – CBH is within the error specifications if CBH error is less than 2 km
# From a Month of Matchups

**Match-up locations (Sept. 2013)**

<table>
<thead>
<tr>
<th></th>
<th>September 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matchup periods examined</td>
<td>9</td>
</tr>
<tr>
<td>Total matchup profile-pixel pairs</td>
<td>363,499</td>
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<tr>
<td>Valid matchup points</td>
<td>56,655</td>
</tr>
<tr>
<td>Percentage of valid points where CTH is “within spec”</td>
<td>37.6%</td>
</tr>
<tr>
<td>Percentage of valid points where CBH error &lt; 2 km</td>
<td>44.6%</td>
</tr>
</tbody>
</table>
All “Valid Matchups”

Negative errors indicate CloudSat CBH was lower than VIIRS CBH (VIIRS biased high relative to CloudSat)
“Within Spec” Matchups

Negative errors indicate CloudSat CBH was lower than VIIRS CBH (VIIRS biased high relative to CloudSat)

Average error: 0.2 km
Standard deviation of error: 2.1 km
Median error value: -0.1 km
RMSE: 2.1 km

Percentage of pixels with CBH within 250 m of CloudSat: 22.9%
# Cloud-type Statistics

## All valid matchups

<table>
<thead>
<tr>
<th></th>
<th>All Clouds</th>
<th>Opaque Ice</th>
<th>Cirrus</th>
<th>Water</th>
<th>Mixed-phase</th>
<th>Overlap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of valid points (%)</td>
<td>100</td>
<td>5.5</td>
<td>36.6</td>
<td>18.9</td>
<td>14.4</td>
<td>24.6</td>
</tr>
<tr>
<td>Average Error (km)</td>
<td>0.8</td>
<td>-1.1</td>
<td><strong>1.7</strong></td>
<td>0.9</td>
<td>-0.2</td>
<td>0.6</td>
</tr>
<tr>
<td>Median Error (km)</td>
<td>0.6</td>
<td>-1.0</td>
<td><strong>2.2</strong></td>
<td>0.0</td>
<td>-0.3</td>
<td>1.2</td>
</tr>
<tr>
<td>Standard Deviation (km)</td>
<td>3.6</td>
<td>3.4</td>
<td>3.5</td>
<td>2.9</td>
<td><strong>2.5</strong></td>
<td><strong>4.2</strong></td>
</tr>
<tr>
<td>RMSE (km)</td>
<td>3.6</td>
<td>3.6</td>
<td>3.9</td>
<td>3.0</td>
<td><strong>2.5</strong></td>
<td><strong>4.3</strong></td>
</tr>
<tr>
<td>Percentage within 250 m (%)</td>
<td>1.6</td>
<td><strong>0.9</strong></td>
<td>1.6</td>
<td>4.3</td>
<td>1.9</td>
<td>1.4</td>
</tr>
<tr>
<td>R-squared correlation (-)</td>
<td>0.188</td>
<td>0.030</td>
<td>0.093</td>
<td><strong>0.124</strong></td>
<td>0.066</td>
<td><strong>0.000</strong></td>
</tr>
</tbody>
</table>

When the CTH retrieval is within the error specifications, the CBH retrieval performs better.

CBH retrieval performs best on clouds classified as **liquid water**. The retrieval performs the worst for cirrus and overlap clouds.

## Within Spec matchups

<table>
<thead>
<tr>
<th></th>
<th>All Clouds</th>
<th>Opaque Ice</th>
<th>Cirrus</th>
<th>Water</th>
<th>Mixed-phase</th>
<th>Overlap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of valid points (%)</td>
<td>100</td>
<td>4.2</td>
<td>28.6</td>
<td>31.1</td>
<td>19.3</td>
<td>16.6</td>
</tr>
<tr>
<td>Average Error (km)</td>
<td>0.2</td>
<td>0.5</td>
<td><strong>1.0</strong></td>
<td>-0.2</td>
<td>-0.7</td>
<td>0.8</td>
</tr>
<tr>
<td>Median Error (km)</td>
<td>-0.1</td>
<td>0.2</td>
<td>0.9</td>
<td>-0.2</td>
<td>-0.4</td>
<td>0.5</td>
</tr>
<tr>
<td>Standard Deviation (km)</td>
<td>2.1</td>
<td>2.4</td>
<td>2.7</td>
<td>0.6</td>
<td>1.5</td>
<td><strong>2.8</strong></td>
</tr>
<tr>
<td>RMSE (km)</td>
<td>2.1</td>
<td>2.4</td>
<td>2.8</td>
<td>0.7</td>
<td>1.6</td>
<td><strong>2.9</strong></td>
</tr>
<tr>
<td>Percentage within 250 m (%)</td>
<td>22.9</td>
<td><strong>10.9</strong></td>
<td><strong>7.3</strong></td>
<td><strong>44.4</strong></td>
<td>26.5</td>
<td><strong>8.1</strong></td>
</tr>
<tr>
<td>R-squared correlation (-)</td>
<td>0.595</td>
<td>0.190</td>
<td>0.208</td>
<td><strong>0.814</strong></td>
<td>0.224</td>
<td><strong>0.181</strong></td>
</tr>
</tbody>
</table>

**Green values** indicate best performer

**Red values** indicate worst performer
Investigating a Switch of Algorithms

<table>
<thead>
<tr>
<th>September 2013</th>
<th>IDPS</th>
<th>NOAA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matchup periods examined</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Valid matchup points</td>
<td>56,653</td>
<td>68,266</td>
</tr>
<tr>
<td>Percentage of valid points where CTH is “within spec”</td>
<td>37.6%</td>
<td>52.1%</td>
</tr>
<tr>
<td>Percentage of valid points where CBH error &lt; 2 km</td>
<td>44.6%</td>
<td>56.3%</td>
</tr>
</tbody>
</table>
### IDPS vs NOAA: All Valid Matchups

<table>
<thead>
<tr>
<th></th>
<th>Average error</th>
<th>$r^2$ value</th>
<th>Standard deviation of error</th>
<th>Median error value</th>
<th>RMSE</th>
<th>CBHs within 250 m of CloudSat</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDPS vs NOAA</td>
<td>0.8 km</td>
<td>0.188</td>
<td>3.6 km</td>
<td>0.6 km</td>
<td>3.6 km</td>
<td>1.6%</td>
</tr>
<tr>
<td>CBH with NOAA input</td>
<td>0.7 km</td>
<td>0.272</td>
<td>3.1 km</td>
<td>-0.0 km</td>
<td>3.1 km</td>
<td>2.6%</td>
</tr>
</tbody>
</table>

- **CloudSat - VIIRS All CBH histogram**
- **CBH with NOAA input**

**R²= 0.188, RMSE= 3.6 km, Avg error= 0.8 km**

CBHs within 250 m of CloudSat = 1.6%

- **R²= 0.272, RMSE= 3.1 km, Avg error= 0.7 km**

CBHs within 250 m of CloudSat = 2.6%

Negative errors indicate CloudSat CBH was lower than VIIRS CBH (VIIRS biased high relative to CloudSat)
IDPS vs. NOAA: “Within Spec”

CBH calculations with NOAA upstream input are ongoing.
IDPS vs. NOAA: “Within Spec”

Negative errors indicate CloudSat CBH was lower than VIIRS CBH (VIIRS biased high relative to CloudSat).

**IDPS CBH**

- Average error: 0.2 km
- Standard deviation of error: 2.1 km
- Median error value: -0.1 km
- RMSE: 2.1 km
- Percentage of pixels with CBH within 250 m of CloudSat: 22.9%

- $R^2=0.595$, RMSE= 2.1 km, Avg error= 0.2 km
- CBHs within 250 m of CloudSat = 22.9%

**CBH with NOAA input**

- Average error: 0.4 km
- Standard deviation of error: 2.5 km
- Median error value: -0.2 km
- RMSE: 2.5 km
- Percentage of pixels with CBH within 250 m of CloudSat: 20.2%

- $R^2=0.527$, RMSE= 2.5 km, Avg error= 0.4 km
- CBHs within 250 m of CloudSat = 20.2%
Mean CTH & CBH of Sept-Oct 2013 VIIRS-CloudSat matchups (1° x 1°) CLAVR-x Supercooled cloud type as water phase to CBH calculation
Mean COT and EPS of Sept-Oct 2013
VIIRS-CloudSat matchups (1° x 1°)

VIIRS IDPS COT
Mean COT_IDPS

NOAA COT
Mean COT_NOAA

Δ COT
Mean COT difference (IDPS–NOAA)

VIIRS IDPS EPS
Mean EPS_IDPS (µm)

NOAA EPS
Mean EPS_NOAA (µm)

Δ EPS
Mean EPS difference (IDPS–NOAA) (µm)
Summary

• Retrieving CBH from VIS/IR information is difficult
  – VIIRS CBH EDR is the first to attempt this on a large scale

• Errors in upstream retrievals all directly impact CBH
  – IWC parameterization results in very low CBH values for high clouds
  – Cloud type errors impact CBH
  – Very low effective particle size and optical depths observed
  – Difficult to retrieve CTH for optically thin ice clouds

• VIIRS and CloudSat do not always agree on where the upper-most cloud layer is
  – Results in large CBH errors

• CBH has some skill when CTH is “within spec”

• In general, the NOAA algorithms perform better than IDPS when compared to CloudSat for all valid matchups
  – Similar performance for “within spec” matchups

• CBH retrieval performs best for low, liquid water clouds; worst on thin cirrus and overlap

• Large differences in EPS and COT between IDPS and NOAA algorithms - This feeds back into CBH
For the Future

• Errors in CTH, COT and EPS need to be fixed

• Average LWC values used by CBH algorithm are constant across the globe
  – Use latitude/temperature dependent LWC

• Investigate fix for poor IWC parameterization
  – Eliminate cirrus CBH at ground level

• Different cloud types form under different dynamic conditions
  – Use lifted condensation level for convective cloud CBH, e.g.

• Use 5+ years of CloudSat statistics on cloud thickness to improve CBH
Backup Slides
September 2013 Matchups

Total number of CloudSat granules included in this matchup: 26
Total number of VIIRS granules included in this matchup: 716
Number of matchup profiles examined: 363499

Number of profiles with VIIRS N/A fill value: 3468 (1.0%)
Number of profiles with VIIRS missing fill value: 205 (0.1%)
Number of profiles with VIIRS pixel trim fill value: 12171 (3.3%)
Number of profiles with VIIRS error fill value: 101824 (28.0%)
Number of profiles with VIIRS VDNE fill value: 0 (0.0%)
Number of profiles with VIIRS flagged as out-of-range: 1 (0.0%)
Number of profiles with valid CBH retrieval and invalid CTH retrieval: 14849 (4.1%)

CloudSat profiles removed due to ground clutter: 120954 (33.3%)
CloudSat profiles removed due to precipitation: 31379 (8.6%)

Profiles where CloudSat detected cloud VIIRS did not: 18866 (5.2%)
Profiles where VIIRS detected cloud CloudSat did not: 53374 (14.7%)
Profiles where CloudSat and VIIRS both detected cloud: 56653 (15.6%)
Profiles where CloudSat and VIIRS did not detect cloud: 234606 (64.5%)

CTH Error specifications: CTH must be within 1 km if the COT is greater than 1, or within 2 km if the COT is less than 1

Profiles where VIIRS is within spec: (CTH) 21308 (5.9%)
Percentage of pixels where both detected cloud and VIIRS was within spec: 37.6%

CBH Error specifications: CBH must be within 2 km

Profiles where VIIRS is within spec: (CBH) 25266 (7.0%)
Percentage of pixels where both detected cloud and VIIRS was within spec: 44.6%
CBH performance – Opaque Ice

September 2013

All Clouds

Opaque Ice Clouds

Histogram of CloudSat CBH (MSL) and VIIRS CBH (MSL)

All Clouds

Within Spec

Opaque Ice Clouds

Histogram of CloudSat CBH (MSL) and VIIRS CBH (MSL)

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CBH performance – Cirrus

September 2013

Histogram of CloudSat CBH (MSL) and VIIRS CBH (MSL)

Cirrus Clouds

All Clouds

Within Spec

Histogram of CloudSat CBH (MSL) and VIIRS CBH (MSL)

Average error: 1.7 km
Standard deviation of error: 3.5 km
Median error value: 2.2 km
RMSE: 3.9 km
Percentage of pixels with CBH within 250 m of CloudSat: 1.6%

CloudSat – VIIRS Cirrus CBH histogram

All Clouds

Within Spec

VIIRS Cloud Optical Thickness

Average error: 1.0 km
Standard deviation of error: 2.7 km
Median error value: 0.9 km
RMSE: 2.8 km
Percentage of pixels with CBH within 250 m of CloudSat: 7.3%

CloudSat – VIIRS Cirrus CBH histogram

VIIRS Cloud Optical Thickness

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CBH performance – Water
September 2013

Average error: 0.9 km  \( r^2 \) value: 0.124
Standard deviation of error: 2.9 km  N: 16712
Median error value: -0.0 km
RMSE: 3.0 km
Percentage of pixels with CBH within 250 m of CloudSat: 4.3%

Histogram of CloudSat CBH (MSL) and VIIRS CBH (MSL)

Average error: -0.2 km  \( r^2 \) value: 0.814
Standard deviation of error: 0.6 km  N: 6636
Median error value: -0.2 km
RMSE: 0.7 km
Percentage of pixels with CBH within 250 m of CloudSat: 44.4%

Histogram of CloudSat CBH (MSL) and VIIRS CBH (MSL)
CBH performance – Mixed-phase

September 2013

Histogram of CloudSat CBH (MSL) and VIIRS CBH (MSL)

All Clouds

Within Spec

Average error: −0.2 km
Standard deviation of error: 2.5 km
Median error value: −0.3 km
RMSE: 2.5 km

Percentage of pixels with CBH within 250 m of CloudSat: 1.9%

CloudSat – VIIRS Mixed-phase CBH histogram

Average error: −0.7 km
Standard deviation of error: 1.5 km
Median error value: −0.4 km
RMSE: 1.6 km

Percentage of pixels with CBH within 250 m of CloudSat: 26.5%

CloudSat – VIIRS Mixed-phase CBH histogram
CBH performance – Overlap

September 2013

Overlap Clouds

All Clouds

Within Spec

CloudSat – VIIRS Overlap CBH histogram

Average error: 0.8 km
Standard deviation of error: 2.8 km
Median error value: 0.5 km
RMSE: 2.9 km
Percentage of pixels with CBH within 250 m of CloudSat: 8.1%

Within Spec

CloudSat – VIIRS Overlap CBH histogram

Average error: 0.6 km
Standard deviation of error: 4.2 km
Median error value: 1.2 km
RMSE: 4.3 km
Percentage of pixels with CBH within 250 m of CloudSat: 1.4%
Comparisons between IDPS and NOAA (%) over the globe

Sept-Oct 2013 matchup cases (daytime granules only)

- Some very high CTHs from NOAA over desert areas?
- Extremely small VIIRS IDPS EPS
- Different IWC value selection for some water cloud pixels?
  (Very low CBHs are not included in comparisons with CloudSat)
Differences between **IDPS** and **NOAA** mean cloud properties

- **Δ CTH**
  Mean CTH difference (IDPS−NOAA) (km)

- **Δ Geometric Thickness**
  Mean cloud thickness difference (IDPS−NOAA) (km)

- **Δ COT**
  Mean COT difference (IDPS−NOAA)

- **Δ CBH**
  Mean CBH difference (IDPS−NOAA) (km)

- **Δ Water Content**
  Mean Water Content difference (IDPS−NOAA) (g/m²)

- **Δ EPS**
  Mean EPS difference (IDPS−NOAA) (µm)
Summary of Comparisons Between SNPP VIIRS and Calipso/PATMOS-X Cloud Properties and Progress in Addressing the Discrepancies

NOAA STAR JPSS 2014 Annual Science Team Meeting, May 12-16, 2014
NCWCP, College Park, MD

Eric Wong
Outline Of the Presentation

• Description of the 2 major issues affecting performance of IDPS Cloud Properties Products

• Work completed in addressing the day COT/EPS retrieval discrepancies issue

• Progress in addressing the ice cloud low bias issue

• Concluding Remarks
Provisional Effective Particle Size Ice Phase – Discrepancy Issue Identified Below

Requirements:
- Precision & Accuracy: 28% for Ice (or 1 μm whichever larger)

58.6% of pixels meets the specs. (similar to Beta Analysis)

Distinctive disagreement features in scatterplot density plot:
- Pattern of very low EPS values
- Density gap between 5μm and 15μm
- High EPS values where DCOMP has values between 40 and 80μm. (belong to un-converged pixels)

• Issue remains: the wide scatter in comparison
• Hints: scatter points mainly land pixels; un-converged data mostly are land pixels
• Leading candidate for discrepancies – differences in land surface albedos used
Global CALIPSO/CALIOP Cloud Top Height Evaluation of the VIIRS IP CTH – Low Bias Issue Identified

Results at Provisional Presentation (before low cloud inversion logic)

- 4 months of collocated CALIOP (lidar) comparisons with the VIIRS IP CTH product
- 20 minute maximum time separation
- Poles (>60deg lat) excluded.
- Candidates for low bias:
  - Error in clear sky radiances
  - Error in land surface emissivities
  - Error in above cloud water vapor transmission correction
- Results show positive bias for water clouds has been largely removed.
- High cloud bias remains.
CBH Statistics When CTH Is “within spec”

Candidates for improvement:
- Improvement in CTH from upstream CTH will improve CBH performance
- A DR submitted to investigate performance due to LWC of different cloud types
Assessment Of The Impact Of Land Surface Albedo On COT/EPS Performance

**Diagnosis:**
- Current NPP COP algorithms use a static database for land surface albedos
- There are only 3 land surface type in database: desert, land and forest - one single value is used to represent each land type
- Land surface albedos are highly non-uniform

**Expected outcome**
- Constant land surface albedo introduces large error in COT/EPS for thin and semi-transparent clouds

**Method for assessing the land surface albedo effects on COT/EPS Retrievals**
- IDPS VIIRS Operational System generates Granulated Land Surface Albedo based on years of MCD43C1 white sky land surface albedo product (years of data since 2002)
- Replace Static Database with input of VIIRS Granulated Land Surface Albedo files
- Assess improvement by comparing with CLAVRX-PATMOS COT/EPS
Region selected for testing and assessing effect of land surface albedo on COT/EPS performance
Comparison of Land Surface Albedo Between COP Static Database and VIIRS Granulated Products – Scene Of Africa 08/20/13, 11:41-11:57

- Significant differences between static database and white sky albedo values
- Albedo values are highly non-uniform under the same land type
- Albedo value differences within the land type exceed 50%
- Albedo value differences within the desert type can also vary greatly
Comparison of M5 Surface Albedo Between VIIRS Granulated White sky Albedo And PATMOS-X Based On MODIS Moody Dataset

• Both white sky albedo images show big albedo transition region from desert high to land low values, while static database shows a jump
• While the 2 sources of white sky albedo look similar there are regions of significant difference
• Such differences will undoubtedly contribute to differences in COT/EPS retrievals
Comparison of M10 Surface Albedo Between VIIRS Granulated White sky Albedo And PATMOS-X Based On MODIS Moody Dataset

Similar behaviors as shown in the previous slide on M5 albedo comparison
Comparison of Cloud Optical Thickness Between Baseline, Updated VIIRS COP And CLAVRX – Scene Of Africa 08/20/13, 11:41-11:57

- Updated COT image looks much closer to that of PATMOS-X
- Updated COT has more converged retrievals than that of Baseline
Comparison of Cloud Effective Particle Size Between Baseline, Updated VIIRS COP and CLAVRX – Scene of Africa 08/20/13, 11:41-11:57

- Updated EPS shows noticeable improvement in these 2 regions
- Updated VIIRS EPS are smoother at cloud edge than in PATMOS-X
Updated COT shows better performance than Baseline
Updated COT has significantly less number of optically thin clouds predicted than in the Baseline
Discrepancies between Updated and PATMOS-X are unavoidable due to differences in surface albedo values, particularly for optically thin clouds
Statistics On The Comparison of Water Cloud EPS Between Baseline, Updated VIIRS COP and CLAVRX – Scene of Africa 08/20/13, 11:41-11:57

• Updated EPS shows better performance
• Large number of off diagonal pixels are no longer in the Updated retrievals
Updated COT shows better performance than Baseline
Updated COT has significantly less number of optically thin clouds predicted than in the Baseline
Discrepancies between Updated and PATMOS-X are unavoidable due to differences in surface albedo values, particularly for usually optically thin ice clouds
Updated EPS shows better performance
Large number of off diagonal pixels are no longer in the Updated retrievals
Statistics Of VIIRS Granulated And PATMOS-X Land Surface Albedo

• Precision error dominates the overall uncertainty
• This albedo precision error will translate into precision errors in COT/EPS performance statistics
Statistics of IDPS COT/EPS Performance Relative To PATMOS-X, Due To Differences In Land Surface Albedo

- Precision error dominates the overall uncertainty in COT/EPS performance
- These COT/EPS precision errors are direct results of precision errors in albedo noted above
Focus Areas Contributing To The Low Bias In Ice Cloud Top Height

• Error in clear sky radiances due to Non-VIIRS RSR used in Pfaast RTM – DR to be submitted to correct for the discrepancies

• Error in land surface emissivities – to be investigated along with the above

• Error in the above cloud water vapor transmission effect – Correcting an error in transmission effect for ice clouds, preliminary results were obtained and presented here
• After code update ice cloud CTT is noticeably colder thus raising CTH
• Removing the error in transmission correction will reduce the low CTH bias seen in Calipso data comparisons
Correcting the transmission error raised the CTH, therefore reducing the low bias.
Summary
- 2 major issues derived from the Provisional Cloud Properties Review are discussed here: (1) Discrepancies in COT/EPS comparisons; (2) low bias in ice cloud CTH
- Approached are identified to address these 2 major issues affecting the performance of the cloud properties products
- From preliminary results it was found that the discrepancies in COT/EPS are caused by the differences in land surface albedo used between the VIIRS and PATMOS-X code
- The COT/EPS issue can be completely resolved once the VIIRS COP code is updated with the Granulated surface albedo
- For the reduction of the low bias in ice cloud CTH 3 candidates: errors in clear sky radiance derived from MODIS Pfaast RTM, surface emissivities and above cloud transmission were identified
- With preliminary testing results it was demonstrated that correction to the above cloud transmission error reduces the low bias
- With updates to Pfaast and perhaps including surface emissivities the ice cloud CTH low bias issue will be completely resolved

Conclusion
- With completion of these 2 DR updates to COP it is expected all IDPS cloud properties products will meet the JPSS L1RD requirements, thus advancing the products to Validated stage1 Maturity
THE VALUE OF PERFORMANCE.

NORTHROP GRUMMAN
Preparation for assimilation of aerosol optical depth data from NPP VIIRS in a global aerosol model

Edward J. Hyer¹
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Douglas L. Westphal¹

1. NRL, Monterey, CA
2. Computer Science Corporation

And the JPSS Aerosol Cal/Val Team
In This Talk

- Data Requirements for Aerosol Assimilation
- Preparation of NPP VIIRS products for assimilation
- Observations of processed VIIRS data
- Conclusions / Prospects
Navy Global Aerosol Forecasting

- Navy Aerosol Analysis and Prediction System (NAAPS) operational since 2005
- Navy Variational Data Assimilation System for AOD (NAVDAS-AOD) Operational at FNMOC from September 2009 (MODIS over ocean)
- Global MODIS is assimilated operationally as of February 2012

Level 2 MOD04 (NASA) or VAOOO EDR (JPSS) data is generated by upstream data centers – spatial resolutions of a few km
Preparation of Satellite Data for Assimilation

AOD data process developed by NRL and UND, includes:
- Aggressive cloud filtering
- Ocean wind speed correction
- Land albedo correction
- Land surface and snow filters
- Microphysical AOD bias correction
0.5 degree product distributed to public via NASA LANCE (MxDAODHD)

This is the process developed for MODIS Collection 4&5

How much pre-processing will be required for Suomi NPP VIIRS?
NPP VIIRS pre-processor

• 1-degree, 6-hour
  – Operational NAAPS now 1/3°, 1° used for testing
• “fullQA” uses information packaged with EDR granules
  – QA = ‘High’ (highest EDR QA value)
  – Cloud mask, cloud proximity, snow flags, glint flags
  – No textural filtering (this is a cal/val experiment, not an operational candidate)
• Results shown using 12 months of data
  – 2013.01.24.00 to 2014.01.12.00
VIIRS ‘fullQA’ coverage vs NRL-UND Level 3 MODIS-- Land

- NRL/UND Level 3 MODIS is stringently filtered
- VIIRS potentially delivers much more data vs 1 MODIS
  - Almost as much as 2 MODIS
VIIRS ‘fullQA’ AOD vs NRL-UND Level 3 MODIS-- Ocean

Global patterns match very well
VIIRS has smaller excluded area, greater coverage
VIIRS ‘fullQA’ AOD vs NRL-UND Level 3 MODIS-- Ocean

VIIRS is higher in low-AOD areas (land and ocean)

NPP VIIRS  MODIS AQUA

Aerosol Optical Depth

0.0  0.2  0.4  0.6  0.8  1.0
VIIRS ‘fullQA’ AOD vs NRL-UND Level 3 MODIS-- Ocean

- VIIRS shows elevated AOD in this region
- Very few retrievals pass QA
- 4 days in August, 23 1-degree grid cells, 500+ EDR retrievals with QA=‘High’ have means ~= 1.0
We are testing a heavily filtered VIIRS aerosol dataset based on IDPS products.

All data:
- Best QA
- All granule ancillary data used to filter
  - (cloud adjacency, etc.)
- Textural filtering for clouds (limit on local variability of AOD)

Over-land:
- MCD43 snow filter used
  - (adapted from NRL/UND MODIS processing)

Over-ocean
- Excluded above 65N

Products have been generated at UW PEATE, assimilation testing is now underway at NRL.
Attempt at DA-ready VIIRS AOD

NPP VIIRS Aerosol Product Status

- We are testing a heavily filtered VIIRS aerosol dataset based on IDPS products

  - All data:
    - Best QA
    - All granule ancillary data used to filter
      - (cloud adjacency, etc.)
    - Textural filtering for clouds
      - (limit on local variability of AOD)
    - Over-land:
      - MCD43 snow filter used
      - (adapted from NRL/UND MODIS processing)
    - Over-ocean
      - Excluded above 65N

- Products have been generated at UW PEATE, assimilation testing is now underway at NRL

VIIRS with JPSS QA only

VIIRS with NRL filters
We are testing a heavily filtered VIIRS aerosol dataset based on IDPS products.

All data:
- Best QA
- All granule ancillary data used to filter (cloud adjacency, etc.)
- Textural filtering for clouds
- (limit on local variability of AOD)

Over-land:
- MCD43 snow filter used
- (adapted from NRL/UND MODIS processing)

Over-ocean
- Excluded above 65N

Products have been generated at UW PEATE, assimilation testing is now underway at NRL
Attempt at DA-ready VIIRS AOD

- We are testing a heavily filtered VIIRS aerosol dataset based on IDPS products
  - All data:
    - Best QA
    - All granule ancillary data used to filter
      - (cloud adjacency, etc.)
    - Textural filtering for clouds
    - (limit on local variability of AOD)
  - Over-land:
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    - Excluded above 65N
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VIIRS with JPSS QA only

VIIRS with NRL filters
1-degree products vs AERONET

(left) White bar indicates % of data within 0.05+/-20%, gray bars indicate % above or below. At low AOD, positive errors dominate.

VIIRS product from JPSS has truncation problem at low AOD
- AOD retrieval is uncertain: MODIS permits negative AOD values
- When aggregated, zero truncation results in positive bias
- We’ll get to high optical depths momentarily
- This is not a problem that can be fixed with filtering
Comparison for high-AOD case

- Massive midsummer Siberian fires
- Episodic, intense plumes
- Signal in VIIRS is much lower than MODIS
Comparison for high-AOD case

- IDPS VIIRS Aerosol algorithm does not retrieval optical depths above 2
- This results in a truncation effect on averaged data

Data in region shown from 2013.07.23 to 2013.08.23
- Suomi NPP VIIRS ‘fullqa’ vs MODIS-Aqua C5 NRL/UND L3

JPSS Cal/Val team is discussing a fix that would extend valid range of AOD to match MODIS (-0.05 to 5.0). This would mitigate this problem.
Results and Next Steps

- NPP VIIRS AOD requires additional filtering of EDR to improve analysis and forecast
- Cal/Val Team has further improvements to over-land AOD data underway
- Additional analysis of over-ocean VIIRS AOD data is needed
- Assimilation testing of candidate DA-ready VIIRS AOD products is underway
- Thank you to sponsors: JPSS, NASA AQAST, NRL
The JPSS Risk Reduction
Aerosol Algorithm

Hongqing Liu and Istvan Laszlo
May 14, 2014
Objectives

- Cross-platform consistency
  - Apply a single algorithm on JPSS and GOES-R
- Extensive internal tests
  - Minimize the dependence on external cloud mask
- Extending the range of aerosol optical thickness
  - Extend the retrievals for episodic aerosol events
- Address known issues in IDPS algorithm
  - Snow/ice contamination
  - Positive bias of Ångström Exponent over water
  - Globally constant land spectral reflectance ratios
  - Degraded or no retrievals over soil-dominated area
  - Negative bias for high AOT over land
## Algorithm Comparison (Over Water)

<table>
<thead>
<tr>
<th>Internal Tests</th>
<th>IDPS</th>
<th>NOAA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbid water; Sun glint; Sea ice</td>
<td>Bright cloud; Cirrus; Sea ice; Spatial homogeneity; Turbid/shallow water; Heavy aerosol</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Aerosol Models</th>
<th>MODIS C4</th>
<th>MODIS C5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Reflectance</td>
<td>$R_f+R_u+R_s$</td>
<td>$R_f+(1-R_f)R_u+(1-W)R_s$ [Koepke, 1984]</td>
</tr>
<tr>
<td>AOT Range</td>
<td>[0.0, 2.0]</td>
<td>[-0.05, 5.0]</td>
</tr>
<tr>
<td>Channel Used</td>
<td>0.67, 0.74(saturation), 0.86, 1.24, 1.61, 2.25 µm</td>
<td><strong>0.55, 0.67, 0.74(saturation), 0.86, 1.24, 1.61, 2.25 µm</strong></td>
</tr>
</tbody>
</table>

| Residual                | $\sum_{\lambda=1}^{n} (\rho^m_{\lambda} - \rho^{LUT}_{\lambda})^2$ | $\sqrt{\frac{\sum_{\lambda=1}^{n} (\rho^m_{\lambda} - \rho^{LUT}_{\lambda})^2}{n}}$ |
| Ångström Exponent       | 0.86 vs. 1.61 µm          | 0.55 vs. 0.86 µm        |
| Inland Lakes            | No retrievals             | Included                |

### Equations

\[
\sum_{\lambda=1}^{n} (\rho^m_{\lambda} - \rho^{LUT}_{\lambda})^2
\]

\[
\sqrt{\frac{\sum_{\lambda=1}^{n} (\rho^m_{\lambda} - \rho^{LUT}_{\lambda})^2}{n}}
\]
## Algorithm Comparison (Over Land)

<table>
<thead>
<tr>
<th></th>
<th>IDPS</th>
<th>NOAA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Internal Tests</strong></td>
<td>Cirrus; Sunglint; Fire; Snow; Ephemeral water</td>
<td>Cloud; Cirrus; Snow; Spatial homogeneity; Ephemeral water; Heavy aerosol</td>
</tr>
<tr>
<td><strong>Aerosol Models</strong></td>
<td>AERONET</td>
<td>MODIS C5</td>
</tr>
<tr>
<td><strong>Surface Reflectance</strong></td>
<td>Constant ratios</td>
<td>Linear relationship as functions of NDVI&lt;sub&gt;SWIR&lt;/sub&gt; and scene redness</td>
</tr>
<tr>
<td><strong>Spectral Relationship</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>AOT Range</strong></td>
<td>[0.0, 2.0]</td>
<td>[-0.05, 5.0]</td>
</tr>
<tr>
<td><strong>Reference Channels</strong></td>
<td>0.48 and 0.67 µm</td>
<td>0.48 and 0.67 µm (SW scheme)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.48 and 2.25 µm (SWIR scheme)</td>
</tr>
<tr>
<td><strong>Residual</strong></td>
<td>$\sum_{\lambda=1}^{n}(\alpha^{corr}<em>{\lambda} - \alpha^{est}</em>{\lambda})^2$</td>
<td>$\sqrt{\frac{\sum_{\lambda=1}^{n}\left(\frac{\rho^{m}<em>{\lambda} - \rho^{LUT}</em>{\lambda}}{\rho^{m}<em>{\lambda} - \rho^{Ray}</em>{\lambda} + 0.01}\right)^2}{n}}$</td>
</tr>
<tr>
<td><strong>Ångström Exponent</strong></td>
<td>Dictated by selected aerosol model</td>
<td>Independent channel retrieval</td>
</tr>
</tbody>
</table>
Land Aerosol Algorithm

- **IDPS VIIRS (SW scheme)**
  - Surface reflectance at 0.48µm is estimated from 0.67µm
  - Pros: robust spectral surface reflectance relationship
  - Cons: strong atmospheric effect
  - Better performance at low AOTs

- **MODIS/ABI (SWIR scheme)**
  - Surface reflectance at 0.48µm is estimated from 2.25µm
  - Pros: transparent atmosphere at 2.25µm
  - Cons: uncertain spectral surface reflectance relationship
  - Better performance at high AOTs

- **JPSS Risk Reduction Aerosol Algorithm (NOAA VIIRS)**
  - SW scheme as the first choice
  - Apply SWIR algorithm if
    - Invalid retrievals from SW scheme
    - Surface reflectance at 0.48µm is out of uncertainty range
  - Surface spectral reflectance relationship are linear functions of redness ratio (TOA M5/M4 reflectance ratio) and NDVI_{SWIR} (TOA M8-M11/M8+M11)
    \[ Y = (c_1+c_2 \cdot \text{Redness}+c_3 \cdot \text{NDVI}_{SWIR}) + (c_4+c_5 \cdot \text{Redness}+c_6 \cdot \text{NDVI}_{SWIR}) \cdot X \]
Land Aerosol Algorithm (Cont.)

- **Measurement**
  - AERONET station: Taihu (China)
  - June 9, 2012
  - $\tau_{550} = 1.71$

- **Retrieval**
  - Urban aerosol model
  - $\tau_{550} = 1.71$ from both SW and SWIR schemes
Land Aerosol Algorithm (Cont.)

- **Measurement**
  - AERONET station: Karachi (Pakistan)
  - June 6, 2012
  - $\tau_{550} = 2.70$

- **Retrieval**
  - Generic aerosol model
  - $\tau_{550} = 1.33$ from SW scheme
  - $\tau_{550} = 2.70$ from SWIR scheme
Land Aerosol Algorithm (Example)
Local Retrievals

- Local retrievals with JPSS Risk Reduction Aerosol Algorithm
  - Global retrievals (74 days)
    - 03/01/2013 – 03/01/2014; every 5 days
    - Wider spatial coverage from RR algorithm

<table>
<thead>
<tr>
<th>Spatial Coverage</th>
<th>$N_{NOAA}/N_{IDPS}$</th>
<th>$N_{NOAA}/N_{MODIS}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Over Land</td>
<td>1.62±0.13</td>
<td>4.79±0.49</td>
</tr>
<tr>
<td>Over Ocean</td>
<td>1.04±0.08</td>
<td>2.73±0.17</td>
</tr>
</tbody>
</table>

Spatial coverage is evaluated by counting the number of 0.1° grids containing retrievals

- Retrievals over AERONET match-ups
  - 05/02/2012 – 03/31/2014
  - Satellite retrievals within 20km-radius circle (centered on stations)
  - AERONET measurements within one-hour window (centered on satellite overpass time)
Global 1° Gridded
Validation Over Land

**NOAA VIIRS**

\[ Y = 0.835X + 0.061 \]

**IDPS VIIRS**

\[ Y = 0.763X + 0.080 \]
## Statistics

<table>
<thead>
<tr>
<th></th>
<th>LAND</th>
<th>NOAA-VIIRS</th>
<th>IDPS-VIIRS</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>&lt;0.1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accuracy</td>
<td>0.05</td>
<td>0.05</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>Precision</td>
<td>0.12</td>
<td>0.11</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>Number</td>
<td>27,174</td>
<td>21,107</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>[0.1, 0.8]</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accuracy</td>
<td>0.03</td>
<td>0.04</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>Precision</td>
<td>0.17</td>
<td>0.15</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>Number</td>
<td>26,079</td>
<td>21,861</td>
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</tr>
<tr>
<td><strong>&gt;0.8</strong></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Accuracy</td>
<td>-0.12</td>
<td>-0.22</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>Precision</td>
<td>0.49</td>
<td>0.46</td>
<td>0.45</td>
<td></td>
</tr>
<tr>
<td>Number</td>
<td>887</td>
<td>666</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>All</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accuracy</td>
<td>0.04</td>
<td>0.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precision</td>
<td>0.16</td>
<td>0.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number</td>
<td>54,140</td>
<td>43,634</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Sampling Issue in Validation

- As many as ~2100 pixels within the 20km-radius-circle matching domain.
- Validation requires at least 15 satellite retrievals (<1%).
- Statistics improve as the required minimum number of retrieval increases.
- RR algorithm outperforms the IDPS if minimum number of retrievals is higher than 200.
**Time Series**

**Accuracy**

- AOT550 Retrieval Accuracy
- Land (Globe)
- VIIRS-NOAA
- VIIRS-IDPS
- MODIS-C51

**Number of Match-ups**

- Land (Globe)
- VIIRS-NOAA
- VIIRS-IDPS
- MODIS-C51

**Mean Aerosol Optical Thickness at 550 nm**

- Land (Globe)
- VIIRS-NOAA
- VIIRS-IDPS
- MODIS-C51
- MODIS-C6

**Mean Aerosol Angstrom Exponent (0.47 vs 0.67 μm)**

- Land (Globe)
- VIIRS-NOAA
- VIIRS-IDPS
- MODIS-C51

STAR JPSS Science Team Meeting, 12-16 May, 2014
VIIRS pixel level retrievals are filtered before averaging in order to be comparable with MODIS products:

- Requiring at least 100 pixel retrievals within 20km-radius-circle matching domain.
- Discarding the highest 40% and lowest 20% AOTs in spatial averaging.
- Number of match-ups:
  
<table>
<thead>
<tr>
<th>Dataset</th>
<th>Match-Ups</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIIRS-NOAA</td>
<td>45,855</td>
</tr>
<tr>
<td>VIIRS-IDPS</td>
<td>31,889</td>
</tr>
<tr>
<td>MODIS-C51</td>
<td>20,422</td>
</tr>
</tbody>
</table>
Validation Over Ocean

NOAA VIIRS

\[ Y = 0.901X + 0.058 \]

IDPS VIIRS

\[ Y = 0.948X + 0.048 \]
Statistics

<table>
<thead>
<tr>
<th>Ocean</th>
<th>NOAA-VIIRS</th>
<th>IDPS-VIIRS</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.3</td>
<td>Accuracy</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>Precision</td>
<td>0.08</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>Number</td>
<td>14,851</td>
<td>14,939</td>
</tr>
<tr>
<td>&gt;=0.3</td>
<td>Accuracy</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>Precision</td>
<td>0.18</td>
<td>0.16</td>
</tr>
<tr>
<td></td>
<td>Number</td>
<td>1,603</td>
<td>1,722</td>
</tr>
<tr>
<td>All</td>
<td>Accuracy</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>Precision</td>
<td>0.09</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>Number</td>
<td>16,454</td>
<td>16,661</td>
</tr>
</tbody>
</table>

- Statistics can be a function of minimum number of retrievals (MN) required for matching.
- RR algorithm has a slightly higher precision if MN>200.
• Requiring at least 100 pixel retrievals with 20km-radius-circle matching domain.
• Discarding the highest 40% and lowest 20% AOTs in spatial averaging.
• Number of match-ups:
  VIIRS-NOAA: 13496
  VIIRS-IDPS: 13905
  MODIS-C51: 4745
Aerosol Ångström Exponent

- Independent channel retrieval
  - Spectral AOTs are retrieved from corresponding channels
  - Assign aerosol model as the one selected from the AOT550 retrieval

- Output the spectral AOTs at VIIRS channels calculated from the retrieved AOT550 and selected aerosol model
  - Can be used to calculate Ångström Exponent
Retrieval over Bright Surface

- Attempting to retrieve aerosol over bright surface with deep-blue channels (M1 and M2)
- Establish spectral surface reflectance relationship between M1 and M2
- Assign aerosol model (generic or dust/smoke)

AOT550 over North Africa and Middle East (06/24/2013)
Summary

- JPSS Risk Reduction Aerosol Algorithm was developed.
  - Single algorithm applied to both VIIRS and ABI
  - More functionalities with less number of line of code than the IDPS algorithm (~3500 vs. ~5600)
- RR algorithm is tested with global retrievals
  - Wider spatial coverage than IDPS
  - More retrievals over significant aerosol events
  - Wider AOT range [-0.05, 5.0]
- Evaluation with AERONET shows slight improvement over IDPS for cases dominated by clear-sky.
- Evaluation with MODIS shows better consistency of retrievals over water.
Summary (Cont.)

- Some IDPS retrieval issues have been addressed:
  - Snow/ice contamination in the Spring season is reduced
  - Ångström Exponent over water is decreased
  - Land spectral reflectance relationship depends on NDVI_{SWIR} and redness
  - More retrievals over arid area
  - Alternative scheme is available for high AOT cases
- Experiment with independent-channel AE retrieval and retrieval over bright land surface using deep-blue channels.
- Future plans
  - Evaluate and improve internal tests
  - Deep-dive evaluation
  - Improve the surface reflectance estimation
Application of DAI-based smoke/dust detection algorithm to VIIRS observations

Pubu Ciren$^{1,2}$ and Shobha Kondragunta$^1$

$^1$NOAA/NESDIS
$^2$IMSG
JPSS Risk Reduction Algorithm for VIIRS Dust and Smoke Detection

• Adapt GOES-R Advanced Baseline Imager (ABI) aerosol (dust and smoke) detection algorithm
  – For dust, take advantage of deep-blue channels on VIIRS and adapt MODIS dust detection algorithm developed by STAR*
• Simple, fast, and easy to be implemented operationally
• Detects most plumes with good accuracy

*Dust Aerosol Index (DAI) Algorithm for MODIS
Pubu Ciren and Shobha Kondragunta
Journal of Geophysical Research: Atmospheres
03/2014 DOI:10.1002/2013JD020855

• Spectral dependence of three processes allows the dust detection
  ➢ Surface reflectance
  ➢ Rayleigh scattering
  ➢ Dust absorption
6S Radiative Transfer Simulations

6S Simulations:
1. MODIS C5 dust aerosol model used
2. Desert, vegetation, ocean BRDF with easterly wind speed of 6 m/s are used to represent surfaces in 6S

DUST reduces the contrast between 412nm and 440 nm as a result of increasing absorption by dust with decreasing wavelength
MODIS Observations: Dust vs. Clear Sky
Smoke and dust vs. Clear Sky

Smoke:
- Has the same effect as dust in terms of reduction of the contrast between 412nm to 440nm.
- Difference in particle size enables us to pick-out the smoke by introducing short-wave IR channel (2.13 µm).

![Graph showing the comparison between clear, smoke, and dust conditions.

Ref(412nm)/Ref(440nm) vs. Ref(412nm) for clear, smoke, and dust conditions.

The graphs illustrate the relationship between the reflectance at 412nm and 440nm for clear, smoke, and dust conditions, with distinct regions indicating the differences in particle size and effect on reflectance.](image-url)
**Dust Aerosol Index**

\[
DAI = 100 \times \left[ \log_{10}(R'_{412\text{nm}}/R'_{445\text{nm}}) - \log_{10}(R'_{412\text{nm}}/R'_{445\text{nm}}) \right]
\]

\[
NDAI = -10 \times \left[ \log_{10}(R_{412\text{nm}}/R_{2.25\text{um}}) \right]
\]

- **DAI** and **NDAI** are computed for pixels that pass these tests:
  - *Water*: \( DAI \geq 4 \) and \( NDAI \geq -10 \)
  - *Land*: \( DAI \geq 11.5 \) and \( NDAI \geq 0 \)

- **Clouds** are first screened by using \( R_{0.42\text{um}} \).
- **Residual Clouds** over water are screened using a 0.86 \( \mu \text{m} \) spatial variability test. Over land, residual clouds are screened by a 412 nm spatial variability test. Cirrus clouds are screened using a 1.38 \( \mu \text{m} \) test.
- **Bright desert surfaces** are screened for by a bright pixel index (normalized difference of 1.24 \( \mu \text{m} \) and 2.25 \( \mu \text{m} \)).
- **Turbid water** test based on Shi and Wang, 2007 uses 0.746 \( \mu \text{m} \) and 1.24 \( \mu \text{m} \) measurements.
- **Sunglint**, snow/ice, fire hot spots are also screened based on different tests (geometry, spectral etc.)

\( R' \) -- reflectance from Rayleigh scattering
JPSS RR dust/Smoke Detection

DAI after cloud screening

NDAI after cloud screening

Dust flag

Sunglint flag

Final dust flag
• The NDAI in the dust algorithm can also indicate the presence of smoke and/or haze mixed in with smoke

<table>
<thead>
<tr>
<th>Surface</th>
<th>Condition</th>
<th>Smoke Detection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land</td>
<td>DAI ≥ 5.0 and NDAI ≤ -2.0</td>
<td>Thin Smoke</td>
</tr>
<tr>
<td></td>
<td>DAI ≥ 9.0 and NDAI ≤ -2.0</td>
<td>Thick Smoke</td>
</tr>
<tr>
<td>Water</td>
<td>DAI ≥ 4.0 and NDAI ≤ -10.0 and R_{410} &lt; 0.1</td>
<td>Thin Smoke</td>
</tr>
<tr>
<td></td>
<td>DAI ≥ 9.0 and NDAI ≤ -4.0</td>
<td>Thick Smoke</td>
</tr>
</tbody>
</table>
Spectral (wavelength dependent) thresholds can separate thick smoke, light smoke, and clear sky conditions.
Smoke over West Coast of United States on September 22, 2012
JPSS RR Dust and Smoke Detection Examples

VIIRS fire hot spots and visible smoke in the RGB image on July 8, 2012

JPSS RR smoke detection algorithm identifies the smoke plumes including the one removed from fire hot spots
VIIRS true color image of blowing dust from different sources in Alaska on April 28, 2013
Validation

- JPSS RR dust detection algorithm run on VIIRS observation for the entire year of 2013.
  - VIIRS smoke/dust frequency vs. CALIPSO and MISR
  - VIIRS smoke and dust detection matchups with CALIPSO and AERONET

- Derive performance metrics
  - Accuracy
  - Probability of Correct Detection (POCD)
  - Probability of False Detection (POFD)

<table>
<thead>
<tr>
<th>VIIRS</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>No</td>
<td>C</td>
<td>D</td>
</tr>
</tbody>
</table>

POCD = \( \frac{A}{A+C} \)
POFD = \( \frac{B}{A+B} \)
Accuracy* = \( \frac{A+D}{A+B+C+D} \)
January 31, 2013

VIIRS vs. CALIPSO

SM DAI

Accuracy 83%
POCD 85%
+DUST+

**July**

*2013.07 VIIRS "Dust" Type Frequency*

**September**

*2013.09 VIIRS "Dust" Type Frequency*

---

**2013.07** CALISPO VFM "Dust" Type Frequency (High Quality)

**2013.09** CALISPO VFM "Dust" Type Frequency (High Quality)
# JPSS RR Dust Detection Over Land: VIIRS vs. CALIPSO

<table>
<thead>
<tr>
<th></th>
<th>Month (2013)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td><strong>Accuracy</strong></td>
<td>100.0</td>
</tr>
<tr>
<td><strong>POCD</strong></td>
<td>N/A</td>
</tr>
<tr>
<td><strong>POFD</strong></td>
<td>N/A</td>
</tr>
</tbody>
</table>

* CALIPSO data not available
# JPSS RR Dust Detection Over Water: VIIRS vs. CALIPSO

<table>
<thead>
<tr>
<th></th>
<th>Month (2013)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td><strong>Accuracy</strong></td>
<td>99.8</td>
</tr>
<tr>
<td><strong>POCD</strong></td>
<td>54.2</td>
</tr>
<tr>
<td><strong>POFD</strong></td>
<td>56.6</td>
</tr>
</tbody>
</table>

* CALIPSO data not available
<table>
<thead>
<tr>
<th>Stations</th>
<th>True positive</th>
<th>False positive</th>
<th>True negative</th>
<th>False negative</th>
<th>Accuracy</th>
<th>POCD</th>
<th>POFD</th>
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<tr>
<td>Banizoumbou</td>
<td>10</td>
<td>1</td>
<td>65</td>
<td>12</td>
<td>85.2</td>
<td>45.4</td>
<td>9.0</td>
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<td>Darkar</td>
<td>1</td>
<td>0</td>
<td>25</td>
<td>1</td>
<td>96.3</td>
<td>50.0</td>
<td>0.0</td>
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<tr>
<td>IER_Cinzana</td>
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<td>0</td>
<td>23</td>
<td>1</td>
<td>96.2</td>
<td>66.6</td>
<td>0.0</td>
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<td>Solar_Village</td>
<td>6</td>
<td>5</td>
<td>29</td>
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<td>45.4</td>
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<td>Capo_Verde</td>
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<td>1</td>
<td>9</td>
<td>0</td>
<td>91.6</td>
<td>100.0</td>
<td>33.3</td>
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<tr>
<td>Cape_San_Juan</td>
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<td>2</td>
<td>18</td>
<td>0</td>
<td>90.4</td>
<td>100.0</td>
<td>66.6</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Over 401 AERONET stations</th>
<th>Accuracy</th>
<th>POCD</th>
<th>POFD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year of 2013</td>
<td>99.8</td>
<td>86.9</td>
<td>39.3</td>
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</tbody>
</table>
Summary

• An algorithm based on observations from deep-blue and shortwave-IR developed for MODIS has been adapted for VIIRS.
  – Algorithm is simple, fast, and easy to be implemented operationally.
• Dust and smoke detections meet L1RD requirements
• Additional validation on smoke detection is needed
• Additional investigation of data artifacts (false detections) is required to enhance product accuracy
Toward Improving NCEP Global Aerosol Forecasting System using VIIRS Aerosol Observations

Sarah Lu (NOAA/NWS/NCEP/EMC; IMSG)
Shobha Kondragunta (NESDIS/STAR)
Arlindo da Silva (NASA/GSFC)
Xiaoyang Zhang (South Dakota State University)

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Why Include Aerosols in the Predictive Systems?

- Improve weather forecasts and climate predictions by taking into account of aerosol effects on radiation and clouds
- Improve the handling of satellite observations by properly accounting for aerosol effects during the assimilation procedure
- Provide aerosol (lateral and upper) boundary conditions for regional air quality predictions
- Account for the aerosol impact on climate, human health, ecosystem, and visibility.
- Meet NWS and WMO global dust forecasting goals
Presentation Outline

➢ Current Operational Configuration

➢ Future operational requirements and applications
Current State

- Near-real-time operational system. implemented into NCEP Production Suite in Sept 2012
- The first global in-line aerosol forecast system at NWS
- Model Configuration:
  - Resolution: T126 (~ 1°x1°) L64
  - AGCM: NCEP’s NEMS GFS
  - Aerosol: GSFC’s GOCART
- 120-hr dust-only forecast once per day (00Z), output every 3-hr
- ICs: Aerosols from previous day forecast and meteorology from operational GDAS
- Leverages the expertise in GSFC, NESDIS, the ICAP working group (NRL, ECMWF, JMA, UKMO, GMAO, BSC), and WMO SDS-WAS program.

In-line chemistry advantage

- Consistency: no spatial-temporal interpolation, same physics parameterization
- Efficiency: lower overall CPU costs and easier data management
- Interaction: Allows for feedback to meteorology

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Near-Real-Time Global Aerosol Forecasting

- NGAC forecasts are routinely evaluated using AOD observations from AERONET and MODIS as well as aerosol analysis from other models.
- Results of 1-year operational NGAC forecast (09/2012-09/2013) are shown here.
- NCEP is yet to extend forecast verification system to include VIIRS aerosol products.
Near-Real-Time Global Aerosol Forecasting

MODIS AOD | NGAC dust AOD | GEOS-5 dust AOD

Oct 2012

Jan 2013

Apr 2013

Jul 2013

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Saharan Dust Transport by NGAC forecasts

VIIRS Dust Aerosol Index: MODIS dust mask algorithm applied to VIIRS globally

Pubu Ciren and Shobha Kondragunta (NESDIS/STAR)

5th ICAP WG Meeting, 5-8 Nov 2013
• NGAC dust products contribute global multi-model ensemble (by International Cooperative for Aerosol Prediction, ICAP) and regional multi-model ensemble (by WMO Sand and Dust Storm Warning Advisory and Assessment System, SDS-WAS)

• NGAC forecasts are independently evaluated by the ICAP and SDS-WAS programs
Near-Real-Time Global Aerosol Forecasting

- SDS-WAS Africa node, conducts daily inter comparison for dust AOD and dust surface concentration
- Regional multi-model ensemble, including 5 global models (NCEP, ECMWF, GMAO, UKMO, BSC)
Presentation Outline

- Current Operational Configuration
- Future operational requirements and applications
NGAC aerosol forecasts

- NGAC has the capability to simulate dust, sulfate, sea salt, and carbonaceous aerosols.
- NGAC using NESDIS’s NRT smoke emissions is slated for operation implementation in FY15.
- An example is given here where NGAC experiments for 2011 are conducted.
Flowchart of Blending QFED and GBBEP-Geo

**QFEDv2**
- Terra+Aqua MODIS fire detections
- MODIS fire FRP with cloud adjustment
- MODIS fire emissions calibrated with GFEDv2 and MODIS AOD

**QFED**: Quick Fire Emission Dataset from MODIS fire data

**GBBEP-Geo**
- Geostationary satellite fire detections
- Simulating diurnal FRP
- Fire emissions
- Adjusting Fire emissions to QFEDv2

**GBBEP-Geo**: Global Biomass Burning Emissions Product from Multiple Geostationary Satellites

- Blended global biomass burning emission
- **NEMS-GFS**
  - Scaling fire emissions
  - **MODIS AOD**
  - Tuning blended fire emissions
- **NEMS-GFS-GOCART** forecast

Xiaoyang Zhang (SDSU)
FY15 Planned Implementation

- Extend the dust-only system to include sulfate, sea salt, and carbonaceous aerosols
  - NESDIS - GSFC - NCEP collaboration to develop and test near-real-time biomass burning emissions (GBBEPx)

- Link low-resolution NGAC with high-resolution GDAS Hybrid EnKF and GFS
NGAC Product Suite and Applications

NGAC provides 1x1 degree products in GRIB2 format once per day. Product files and their contents include:

- **ngac.t00z.aod$_CH$, CH=340nm, 440nm, 550nm, 660nm, 860nm, 1p63um, 11p1um**
  - Aerosol Optical Depth (AOD) at specified wavelength from 0 to 120 hour

- **ngac.t00z.a2df$FH$, FH=00, 03, 06, ….120**
  - AOD at 0.55 micron
  - Dust emission, sedimentation, dry deposition, and wet deposition fluxes
  - Dust fine mode and coarse mode surface mass concentration
  - Dust fine mode and coarse mode column mass density

- **ngac.t00z.a3df$FH$, FH=00, 03, 06, ….120**
  - Pressure, temperature, relative humidity at model levels
  - Mixing ratios for 5 dust bins (0.1-1, 1-1.8, 1.8-3, 3-6, 6-10 micron) at model levels

Potential applications for NGAC products are highlighted in red.

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Priority System Enhancements

- **Long-term goal**
  - Allow aerosol impacts on weather forecasts and climate predictions to be considered
  - Enable NCEP to provide **quality atmospheric constituent products** serving wide-range of stakeholders, such as health professionals, aviation authorities, policy makers, climate scientists, and solar energy plant managers

- **Phased implementation**
  - **Phase 1**: Dust-only forecasts (operational)
  - **Phase 2**: Forecasts for dust, sulfate, sea salt, and carbonaceous aerosols using NESDIS’s GBBPEx smoke emissions (planned FY15 implementation)
  - **Phase 3**: Aerosol analysis using VIIRS AOD (well-defined R2O building upon existing NCEP-NESDIS-GSFC collaboration)
Why VIIRS AOD Data Assimilation?

• While development work remains, ground work has been laid for building a global aerosol data assimilation capability within NGAC and Hybrid EnKF-GSI
• Prognostic aerosol capability has been established
• Infrastructure development (CRTM supports GOCART, GSI code development for AOD DA*)
• Near-real-time smoke emissions have been developed, slated for operational in FY15
• Community aerosol modeling/assimilation efforts (ICAP, GSI)

• Other centers (e.g., NRL, ECMWF, GMAO) are assimilating MODIS AOD, and are currently assessing the VIIRS aerosol products. NCEP is yet to develop the AOD data assimilation capability and will be focused on VIIRS products (instead of the “MODIS then VIIRS” approach).

* GSI AOD data assimilation: (1) Development work at NCEP is temporarily suspended due to budgetary constraint (2) Extensive development work conducted by other centers (NCAR, ESRL)
<table>
<thead>
<tr>
<th>Future Operational Benefits Associated with NEMS GFS Aerosol Component</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provides a first step toward an operational <strong>aerosol data assimilation</strong> capability at NOAA</td>
<td>VIIRS AOD data assimilation (pending support)</td>
</tr>
<tr>
<td>Allows <strong>aerosol impacts</strong> on medium range weather forecasts (GFS/GDAS) to be considered</td>
<td>Ongoing work at EMC</td>
</tr>
<tr>
<td>Allows NOAA to explore <strong>aerosol-chemistry-climate interaction</strong> in the Climate Forecast System (CFS) as GFS is the atmospheric model of CFS</td>
<td>CPO MAPP-CTB funded project</td>
</tr>
<tr>
<td>Provides global aerosol information for various applications (e.g., satellite radiance data assimilation, satellite retrievals, SST analysis, UV-index forecasts, solar electricity production)</td>
<td>Ongoing NCEP-NESDIS-Howard collaboration on aerosol-SST</td>
</tr>
<tr>
<td>Provides <strong>lateral aerosol boundary conditions</strong> for regional aerosol forecast system</td>
<td>Benchmark study completed</td>
</tr>
</tbody>
</table>

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Conclusions

NCEP is developing global aerosol forecasting/assimilation capability

• The aerosol project builds upon extensive collaboration with NOAA labs/centers (NESDIS) and external research community (GSFC, the ICAP working group, WMO SDS-WAS program)

• Phased implementation
  • Phase 1: Dust-only forecasts (operational)
  • Phase 2: Forecasts for dust, sulfate, sea salt, and carbonaceous aerosols using NESDIS’s GBBPEx smoke emissions (planned FY15 implementation)
  • Phase 3: Aerosol analysis using VIIRS AOD (well-defined R2O building upon existing NCEP-NESDIS-GSFC collaboration)
Thanks.

Questions and Comments?