Opportunities & Challenges for Leveraging Non-NOAA Satellite Data in Support of NOAA User Needs

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Opportunities & Challenges for Leveraging Non-NOAA Satellite Data

- NOAA’s geostationary and polar satellite programs do not meet all existing and evolving NOAA user data and information needs.

- NOAA can close some of these observing system gaps by leveraging extensive investments that other space agencies have made in environmental satellites.

- This cost effective approach, leveraging non-NOAA resources at a fraction of a complete satellite mission life cycle cost, enhances NOAA’s ability to successfully execute its mission, with corresponding socio-economic benefits.

- However, no overarching institutional framework or infrastructure within NOAA systematically acquires, processes and distributes non-NOAA satellite data in support of user needs.

- Therefore, need to implement within NOAA the capabilities for timely, routine and sustained exploitation of high priority non-NOAA environmental satellite data from operational as well as research & development missions.

- Capabilities required include acquisition & (secure) ingest of data, development of algorithms, products, applications, and data assimilation demonstration, and the generation, calibration, validation, distribution, monitoring, transition to operations and utilization of these data.

- These can be provided through an enterprise satellite mission-services framework that employs consistent processes (scientific, technical, & programmatic) to exploit non-NOAA mission data.

- A mission agnostic, measurement-based approach will ensure highest priority key observables across the atmospheric, oceanic and terrestrial domains are generated on a routine and sustained basis.
Ex. Non-NOAA Satellite Fly Out
From the CEOS Database (1)
Non-NOAA Satellite Fly Out From the CEOS Database (2, et al.)

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Measurement-based approach in support of users: Ensuring continuity & coverage

**Observing System Highways:** Utilize satellite data from NOAA & non-NOAA missions. Leverages existing science, technical, programmatic et al. infrastructure in NESDIS.

- **Observations from NOAA missions**
  - S-NPP
  - GOES-R
  - JPSS-1
  - GOES-S
  - JPSS-2
  - GOES-T
  - POES

- **Observations only available from Non-NOAA missions**
  - Landsat-8
  - Sentinel-1A
  - ALOS-2
  - Sentinel-2A
  - ASCAT
  - Sentinel-1B
  - RapidScat
  - Sentinel-2B
  - ScatSat
  - RCM
  - Oceansat-3

- **Non-NOAA missions augment NOAA missions: Gap Filler (Time, Space, Spectral et al.)**
  - Sentinel-3A
  - GPM
  - etc

- **Regional Gaps**

- **Non-NOAA missions complement NOAA missions: Redundancy; Risk Reduction**
  - INSAT-3D
  - Himawari-8
  - MSG-4
  - FY3
  - HY-1 C/D
  - HY-1 E/F
  - SABIA-MAR

Scientific enterprise approach along observing system “highways”, Data Distribution: User Engagement

Cal/Val; Algorithm & Product Development; Application Development; User Engagement
Measurement-based approach in support of users: Ensuring continuity & coverage

Observing System Highways: Utilize satellite data from NOAA & non-NOAA missions

Leverages existing science, technical, programmatic et al. infrastructure in NESDIS

Scientific enterprise approach along observing system “highways”:
- Cal/Val; Algorithm & Product Development; Data Distribution
- Application Development; User Engagement

Observations only available from Non-NOAA missions
Non-NOAA missions augment NOAA missions: Gap Filler (Time, Space, Spectral et al.)
Non-NOAA missions complement NOAA missions: Redundancy; Risk Reduction

Regional Gaps
- Ocean Color
- Precip

Heritage Polar Product Continuity
- Non-NOAA Data


S-NPP
GOES-R
GOES-S
JPSS-1
JPSS-2
GOES-T

POES
SAR & High Res Imagery
OSVW
Ocean Color
PACE
Precip
Atm soundings, Aerosols, SST, Fire, Imagery, et al.
Example of mission-agnostic, measurement-based enterprise approach: SAROPS Processing Chain

Operational

Test products can be produced

Level 0 Level 1 Level 2 Level 3

TerraSAR-X
Tandem-X
COSMO
SkyMed
Radarsat-2
Sentinel-1
Future SAR satellites

SAR Ingestor

NRCS Info

IMS Ice Mask
Model Winds (GFS etc.)
Land Mask (GSHHS)

SAR Ice mask & class.

Wind Speed

Oil Mask

Wind Field in the Original Projection (netCDF)

Ocean Wave Spectra

Ship Detection

NCEI Archive

SAR Ingestor

Ice mask / class. in the Original projection (netCDF)

Oil Mask in the Original projection (netCDF)

Wind Field PNG, KMZ, GeoTIFF, netCDF, AWIPS II

Wind Field PNG, KMZ, GeoTIFF, netCDF, AWIPS II

Wind Field PNG, KMZ, GeoTIFF, netCDF, Shape files

Ocean Wave Spectra

Ship Detection (netCDF)

NCEI Archive

Ocean Wave Spectra (netCDF)

Wind Field PNG, KMZ, GeoTIFF, netCDF, AWIPS II

Wind Field PNG, KMZ, GeoTIFF, netCDF, Shape Files
Copernicus Missions: The Sentinel Series

- Flagship of the European Space Policy
- Led by the European Union
- Europe’s contribution to GEOSS
- European capacity for global, timely and easily accessible information about climate, environment & security

**S1A/B:** Radar Mission

**S2A/B:** High Resolution Optical Mission

**S3A/B:** Medium Resolution Imaging and Altimetry Mission

**S4A/B:** Geostationary Atmospheric Chemistry Mission

**S5P:** Low Earth Orbit Atmospheric Chemistry Precursor Mission

**S5A/B/C:** Low Earth Orbit Atmospheric Chemistry Mission

**Jason-CS/Sentinel-6 A/B:** Altimetry Mission
**Copernicus: European Sentinel Missions**

**Sentinel-1A/B**
(3 Apr 2014, 2016)

C-band synthetic aperture radar (SAR)

Applications:
- Sea Ice/Cryosphere
- Marine winds and waves
- Oil spills
- Ship detection
- Coastal monitoring, etc.

**Sentinel-2A/B**
(23 Jun 2015, 2017)

Optical imagery - 13 bands for land observation (MSI)

Applications:
- Land management
- Biomass
- Water management
- Urban Mapping

**Sentinel-3A/B**
(~31 Oct 2015, 2017)

Sea and Land Surface Temperature Radiometer (SLSTR), Ocean and Land Color Instrument (OLCI), Synthetic aperture radar altimeter (SRAL)

Applications:
- Ocean color and land reflectance
- Sea, land, and ice surface temperature
- Fire monitoring
- Sea surface topography, winds, significant wave height
High-Resolution SAR-Derived Wind Speed Products
Bill Pichel & Frank Monaldo

Operational RSAT2 wind speed
2015-02-04  04:05 UT

Pre-operational S1A wind speed
2015-01-08  02:46 UT
Interactive and Automated Techniques for Oil Spill Analysis Using (SAR) Imagery


Automated Texture Classifying Neural Network (TCNNA) oil spill map for the same day. This algorithm is being developed in a collaboration between NESDIS/STAR and Florida State Univ. for future use as an automated oil spill mapping tool.
MERIS Image of Cyanobacteria Bloom in Lake Erie: Worst bloom in decades, over 5000 sq km on this day 09 October 2011
Toledo-area water advisory expected to continue through Sunday as leaders await tests; water stations to remain open

Microcystin found in samples; boiling not recommended

BY TAYLOR DUNGEON AND DAVID PATCH
BLADE STAFF WRITERS

Toledo’s public water will remain under a do-not-drink advisory until at least 6 a.m. Sunday pending the return of results from test samples sent out to three different laboratories, Mayor D. Michael Collins said during an evening news conference.
Experimental Lake Erie Harmful Algal Bloom Bulletin

24 August, 2015, Bulletin 13

The Microcystis cyanobacteria bloom continues across a large part of the western basin along the Michigan and Ohio coasts and into the central basin. The recent southwesterly winds have pushed the bloom northward along the Michigan coast. Moderate to high concentrations extend eastward to midway between Cleveland and Rondeau, Ontario. Scum has been scattered in the last few days. Microcystin toxins are still present in the bloom, but the concentration has decreased in general. However, scum areas remain a significant risk.

Strong, westerly winds are expected through Tuesday, creating strong mixing. A possible shift to NW winds on Wed and Thursday may favor southward movement. Milder winds on Thursday may reduce mixing, giving greater potential for scum formation. The persistent bloom in Sandusky Bay continues. No other blooms are evident in the central and eastern basins.

Please check for updates on Ohio State Parks at Ohio EPA’s site, http://epa.ohio.gov/habalgae.aspx. Keep your pets and yourself out of the water in areas where scum is forming.

-Stumpf, Tomlinson

Figure 1. Cyanobacterial Index from NASA’s MODIS-Aqua data collected 22 August, 2015 at 13:10 EST. Grey indicates clouds or missing data. Black represents no cyanobacteria detected. Colored pixels indicate the presence of cyanobacteria. Cooler colors (blue and purple) indicate low concentrations and warmer colors (red, orange, and yellow) indicate high concentrations. The estimated threshold for cyanobacteria detection is 20,000 cells/mL.

Figure 2. Nowcast position of bloom for 24 August, 2015 using GLCFS modeled currents to move the bloom from the 22 August, 2015 image.
NOAA Utilization of MERIS/OLCI Ocean Color Data: Harmful Algal Blooms, Ecological Forecasting & More!

• MERIS data declared operational by SPSRB in Jan 2009; however, Envisat failed in 2012.

• Chlorophyll-a/anomalies were generated from MERIS amongst other ocean color products, supporting NOS et al. users.

• Coastwatch/NOAA was a “Champion User” for the ESA Coast Colour Project, supporting coastal users internationally.

• STAR and others in NESDIS are now actively working to facilitate acquisition of the follow-on Sentinel-3 (OLCI et al.) data to support NOS HAB & other U.S. user needs.

• Sentinel-3/OLCI, like Envisat/MERIS, has improved spatial resolution (300 m), useful for coastal/inland waters, and especially has additional spectral bands – and as such is a vital complementary capability to VIIRS (especially as provides mid-morning orbit).

• STAR is supporting ESA/EUMETSAT as part of the Sentinel-3 Validation Team (3 projects).

http://coastwatch.noaa.gov

NESDIS efforts have resulted in the generation and flow of experimental and operational ocean color products to the NOAA & broader user communities.
Key Sentinel land data needs

- **SLSTR**: Active fire detection and fire radiative power
  - Provide MODIS/VIIRS compatible fire observations on mid-morning orbit to monitor diurnal cycle
- **SLSTR**: Land surface temperature
  - Additional LST observations combining with VIIRS compatible LST observations for gridded LST data that can be used for Weather model assimilation and evaluation
- **OLCI**: Vegetation indices
  - can be designed to provide continuity and potential gap filler with derived SNPP/JPSS VIIRS Vegetation Indices
- **SLSTR / OLCI / MSI**: Integration within Land Product Characterization System (LPCS)
  - intercomparison with NOAA land products
- **SLSTR / MSI**: surface type change detection
  - complimentary to VIIRS observations and for validation of VIIRS surface type products
Satellite Ocean Surface Vector Winds

ASCAT Daily Coverage Example

- OSVW data supports wind and wave warning and forecasting
- ASCAT data from EUMETSAT operational at NOAA
- OSCAT data from ISRO was in operational demonstration phase prior to its failure in 2014
- NOAA P-3 used to fly a profiling scatterometer system (IWRAP) for validation and improvement of satellite algorithms in tropical (hurricanes) and extratropical cyclone conditions

Goal: Provide the best possible product and training to end users

NOAA Satellite Ocean Surface Winds Science Team
http://manati.star.nesdis.noaa.gov/
NASA RapidScat on ISS
Available to NWS/NCEP Ocean Prediction Center and National Hurricane Center from STAR since 11/19/14
Importance of GPM from NOAA’s Perspective

• Strong connection to several NOAA mission goals
  – Weather Ready Nation, Climate Adaptation and Mitigation
  – Only agency responsible for operational “water” forecasts

• Continuity of “operations” for TRMM
  – GPM-core - higher inclination than TRMM (65 vs. 35 deg.)
    • Serves as calibration anchor for algorithm development/tuning
  – GPM has more advanced payloads (GMI vs. TMI; DPR vs. PR)

• Precipitation Constellation
  – DMSP, POES, MetOp, JPSS, GCOM, ... are all part of it
  – Synergy with our own satellite programs (POES/JPSS and GOES/GOES-R)
  – Enables new multi-sensor (+ in-situ) blended precipitation products that will lead to major improvements for
    • Operational monitoring/forecasting
    • Monitoring of seasonal to inter-annual variations, as well as long-term trends
  – Can improve our understanding of precipitation impact on other variables, e.g., soil moisture (SMAP, SMOS) and salinity (SMOS)

• We are leveraging off huge investment from NASA & JAXA
  – Sensors and launch vehicles.... ~ $1 Billion
  – NASA science team ~ $8 M/yr – state of the art science & processing system
    • NOAA “historical” investment about $500 K/year from a variety of programs
Benefits of GPM Precipitation Constellation to NOAA

• Achieve ≤ 3-hourly global coverage
  – Global monitoring of “storms”
  – Tuning of merged GEO/MW algorithms (<30 min)
    • GOES & GOES-R
  – NWP data assimilation (L1 data)
    • OSSE’s show improved TC track prediction
  – Climate monitoring and prediction
    • NOAA/CMORPH, GPM/IMERG

• Develop inter-satellite calibrated data sets for Climate Data Records
  – Need high precision GMI as anchor

• High latitude precipitation - Alaska
  – Beyond GOES capability
  – Sensitive to cold season precipitation

• Integrated precipitation products
  – Satellite + radar + gauge
  – Reduce number of NOAA product systems
Satellite Sea-surface Salinity (SSS)

- Salinity = fundamental ocean state parameter

- **Satellite SSS data availability:**
  - *Only non-NOAA sources*
  - **ESA** Soil Moisture – Ocean Salinity (SMOS) mission
  - **NASA** Soil Moisture Active-Passive (SMAP) mission

- **Application:**
  - Ocean/regional modeling/prediction
    - NOAA’s Real-Time Ocean Forecast System (RTOFS)
    - NOAA’s West Coast Operational Forecast System (WCOFS, under development)
  - Coupled modeling/prediction
    - NOAA’s seasonal-interannual Climate Forecast System (CFS) - Global Ocean Data Assimilation System (GODAS)
    - Coupled hurricane modeling
    - Coupled ocean-atmosphere-cryosphere modeling
  - **Hydrological cycle**
    - Climate Prediction Center operational salinity/evaporation/precipitation analyses and trends
  - **Ecological forecasting**
    - Ocean acidification
      - Fundamental for deriving acidification parameters and rates
    - Habitats
    - Density fronts
GOES-R ABI Aerosol Detection Product Algorithm on H-8 Data

• Himawari-8 L1B data obtained from AIT
• Himawari-8 Cloud Mask data obtained from UW-Madison
• Aerosol Detection Product algorithm applied to H-8 data collected on March 25, 2015
  – No dust of smoke detected for 1700 UTC (night) but false smoke detected for 0230 UTC (day).
  – Data artifacts (false smoke) in H-8 data due to striping. RGB images for every hour of the day were also generated. Significant striping especially in the twilight zone (movie available but not shown here).
  – JAXA working on a fix to the striping issue

GOES-R ABI algorithms ran successfully on H-8 data and results indicate that L1B radiances need to be accurate to minimize data artifacts in retrieved products
Aerosol Optical Depth from Himawari-8

- Aerosol optical depth (AOD) estimated from Advanced Himawari Imager (AHI) data at 2:30 UTC on March 25, 2015. The GOES-R ABI algorithm was used.
- NCEP reanalysis data for water vapor, wind speed/direction, model surface pressure/height were used.
- \(O_3\) is from climatology.
Arctic Sea Ice Thickness Maps

Arctic sea ice thickness processed at UCL from CryoSat’s SAR mode data:

- Latest from Near Real Time Data
- Final Precise Data

- 2-days
- 14-days
- 28-days
- Autumn
- 2014

22-May-15: NRT Service Stopped until September 2015. Sea ice thickness cannot be accurately measured from CryoSat during the Arctic summer period, due to the formation of melt ponds on the sea ice surface. These ponds interfere with the radar signal and measurement method.

Latest 28-day Grid: 22/4/15 - 19/5/15

Arctic Sea Ice Timeseries

Display the change over time in sea ice thickness or volume over the whole Arctic, an ocean basin, or thickness at a point location:

- Show: Volume
- Thickness

Select Location of Thickness Time Series or click on Map.

- Lat: 60.0 96.0
- Lon E: 160.0 30.0

Select by Point

All Arctic

The plot below shows the timeseries of Monthly mean sea ice thickness calculated from CryoSat precise and near real time (NRT) data over the whole Arctic area of sea ice extent.

Whole Arctic Thickness

A timeseries at a single location and Arctic basin can also be displayed by clicking on the sea ice thickness maps on the left or by entering a latitude and longitude location and choosing Select by Point in the panel above.

CPOM Sea Ice Report

Report Date: 20-July-2015

Credit: University College London
So, the question is.......
So, the question is......

- How do we (NOAA) proceed with the acquisition, development and (operational) distribution et al. of non-NOAA data (foreign & domestic) in the JPSS (polar)/GOES-R (geo) era in support of user needs?
But don’t worry Mitch (and JPSS) - you are still beloved!!
Backup slides
Sample Sentinel-1A wind images:
2014-12-31 20:19:38 UTC

PNG Image

KMZ File
Sentinel-1A Wind Speed Retrieval Baltic Sea

July 6, 2015, 1652
Initial biogeochemical modeling at NOAA/NCEP: Using VIIRS ocean color data for validation and data assimilation

Lead PI: Avichal Mehra¹
Co-PI’s: Hae-Cheol Kim², Eric Bayler³, David Behringer¹
Collaborators: Sudhir Nadiga², Vladimir Krasnopolsky¹, Zulema Garraffo², Carlos Lozano¹, Watson Gregg⁴

¹: NOAA/NWS/NCEP/EMC; 2: IMSG at NOAA/NWS/NCEP/EMC
3: NOAA/NESDIS/STAR; 4: NASA/GMAO
Project Descriptions
(Background)

• The NOAA Ecological Forecasting Roadmap (EFR) for 2015-2019 states that its objective is “to provide dependable, higher quality forecast products, derived from the successful transition of research and development into useful applications....”

• In support of the NOAA-approved roadmap, this project proposes to evaluate approaches and develop a prototype foundational global biogeochemical modeling capability for NOAA’s operational Real-Time Ocean Forecast System (RTOFS) for reliably providing the global modeling fields required to support the ecological forecasts of the EFR technical teams
Project Descriptions
(Background)

• Specifically,
  ➢ to establish a component for the national modeling ‘backbone’ that will generate global predictions of the common physical and biogeochemical variables used by ecological forecasts

  ➢ to address key linkages and gaps within the EFR infrastructure framework via JPSS VIIRS ocean color data and physical-biogeochemical numerical modeling because ocean color data from VIIRS provides a unique path toward ecological forecasting through biogeochemical (BGC) analyses and forecasts, facilitating both real-time and scenario-based marine ecosystem applications
Project Descriptions
(Identification of Users)

• Targeted users within NOAA:
  ➢ Ecological Forecasting Roadmap technical teams (harmful algal blooms, hypoxia, habitats),
  ➢ Those explicitly involved with numerical modeling and prediction in conjunction with the NOAA Ecological Forecasting Infrastructure and Process team

• The external user community:
  ➢ Local, state, federal governments, non-governmental organizations (NGO's), and academic and industry entities using derivative analyses and predictions.
Scientific Objectives

• Employing coupled BGC-physical modeling to improve NWS forecasting skill at short-term and seasonal scales
  ➢ by including the effects of biological heating on upper-ocean thermal structure
  ➢ by exploring the direct assimilation of VIIRS products ($K_{d490}$) in conjunction with radiative transfer (RT) computations using existing validated algorithms (Lee, 2006; Gregg, 2002).
• Providing scenario-based forecasting
  ➢ to predict system responses to potential changes by drivers (natural or through ecosystem management decisions)
• Assessing the effects of carbon dynamics between the atmosphere and the ocean and subsequent changes in the acidity of the global ocean
• Exploring BGC model to support for upper-trophic-level modeling
Approaches
(Schematic Diagram)
Approaches
(Ocean Model: RTOFS-Global)

- RTOFS-Global
  - Hybrid Coordinate Ocean Model (HYCOM) based system with 1/12° and 41 layers
  - iso-pycnal (deep ocean), z-levels (surface), σ (coasts)
  - Tripole grid (1 at South Pole and 2 from Arctic bipole)
  - Recti-linear (<47°N) and curve-linear (>47°N)

- RTOFS-Global
  - NAVOCEANO daily initialization with MVOI (now 3DVAR) data assimilation from NCODA (Navy Coupled Ocean Data Assimilation)
  - KPP for vertical mixing
  - 2-day nowcast (GDAS) and 6-day forecast (GFS)
Approaches
(Ocean Model: RTOFS-Global)
Approaches
(NOBM: NASA Ocean Biogeochemical Model)

Biogeochemical Processes Model
Ecosystem Component

- Nutrients: Si, NO$_3$, NH$_4$, Fe
  - Iron Detritus
  - N/C Detritus
  - Herbivores
  - Silica Detritus
- Phytoplankton: Diatoms, Chlorophytes, Cyanobacteria, Coccolithophores

Biogeochemical Processes Model
Carbon Component

- pCO$_2$ (air)
- pCO$_2$ (water)
- Winds, Surface pressure
- Phytoplankton
- Herbivores
- Dissolved Organic Carbon
- N/C Detritus

Approaches
(Data Assimilation: 2DVAR)

• Step 1. Integrate model for a certain period with **no nudging** from t=0 (beginning of cycle) to t=T. Initial condition is \(X(t=0)\). End condition is \(X(t=T)\).

• Step 2. Carry out CHL analysis at 0-hr and at T-hr.

• Use CHL from \(X(t)\) as a background \(X_b\).

  \[ X_a = X_b + K(y_0 - H(X_b)) \]

  where \(X_a\): analysis; \(X_b\): background; \(K\): Kalman gain; \(y_0\): observations (VIIRS); \(H\): observation operator; \([y_0 - H(X_b)]\): innovation, distance between model and observation.

  • Data points will be assimilated (e.g., VIIRS) with a certain time window for data pooling.

• Step 3. Create linearly interpolated CHL field between the two consecutive CHL analyses \(X_a (t=0)\) and \(X_a (t=T)\).

• Step 4. Integrate model for T hours with **nudging** from t=0 (beginning of cycle) to t=Thrs. Initial condition is \(X(t=0)\). End condition is \(X(t=T)\).

• Next cycle: re-label end condition of integration with nudging as the initial condition if the next cycle.
Approaches
(Data Assimilation: NCODA)

Cummings (2011)
Milestones

• Year 1:
  ➢ Use VIIRS-derived $K_{d\text{PAR}}$ and $K_{d490}$ with a two-band scheme (Lee et al., 2006)

• Year 2:
  ➢ Implement coupling of the modified BGC model with online HYCOM/RTOFS-Global
  ➢ Modify NOBM (Gregg, 2002; 2003) biogeochemical module to include air-sea oxygen dynamics

• Year 3:
  ➢ Implement simple data assimilation techniques (2DVAR) to nudge model values to better represent VIIRS observations
  ➢ Validate model-derived Chl-a against independent in situ observations (e.g., BIO-Argo) and VIIRS data.
Thanks!
Robust VIIRS Reflective Solar Bands On-Orbit Calibration for Ocean Color Data Processing

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8/25/2015 4:00-4:15 PM
Outline

• Introduction
  – VIIRS Instrument Background
  – Reflective Solar Bands (RSB) On-Orbit Calibration
• SDSM Calibration
  – Algorithms, data analysis, and performance
• SD Calibration
  – Algorithms, data analysis, and performance
• Lunar Calibration
  – Algorithms, data analysis, and performance
• Hybrid Approach
  – Algorithms and hybrid calibration coefficients
• Improvements in Ocean Color Products
• Summary
VIIRS Background

- Separately Mounted Electronics Module
- Solar Diffuser
- Blackbody
- 3-Mirror Anastigmat All reflective Rotating telescope
- RTMA
- Solar Diffuser Stability Monitor
- 4-Mirror Anastigmat All Reflective Aft Optics Imager
- 4-Mirror Anastigmat All Reflective Aft Optics Imager
- Cryoradiator
- Half-angle Mirror
- Cold FPA Dewar Assembly
- FPIE
RSB On-Orbit Calibration

- VIIRS has 22 spectral bands covering a spectral range from 410 nm to 12.013 µm
- 14 Reflective Solar Bands (RSB): 3 image bands, I1-I3, and eleven moderate bands, M1-M11
- The VIIRS RSB are calibrated on orbit by SD/SDSM calibration
- VIIRS has also been scheduled to view the moon monthly through its space view (SV) since launch.
- For VIIRS, the angle of incidence (AOI) of the SV is exactly the same as that of the SD. Lunar observations should provide identical on-orbit gain change for VIIRS RSB as SD/SDSM calibration.

VIIRS RSB uncertainty specification is 2%; For ocean color EDR products, the ocean bands (M1-M7) are required to be calibrated with an uncertainty of ~0.1-0.3%.
SD/SDSM Calibration Overview

- **SD and SDSM sun view screens:**
  - Prevent RSB and SDSM saturation
  - Vignetting functions (VF$s$)
  - VF$s$ measured prelaunch and validated by yaw measurements
  - SD bidirectional reflectance factors (BRFs)

- **BRFs measured prelaunch and validated by yaw measurements**
  - SD on-orbit degradation is tracked by the SDSM measurements at 8 wavelength from 412 nm to 935 nm

- **Key assumption:** SD degrades uniformly with respect to both incident and outgoing directions

  Fist step: Carefully derive BRFs and VF$s$ from the yaw measurements

SDSM calibration algorithm

- SDSM is a ratio radiometer, which views SD, Sun, and an internal dark scene successively in three-scan cycles.

- SD BRF for SDSM view direction

\[ BRF_{SD,SDSM}(\lambda) = \rho_{SD,SDSM}(\lambda)H(\lambda) \]

- \( \rho_{SD,SDSM}(\lambda) \): Prelaunch BRF for SDSM view direction
- \( H(\lambda) \) is solar diffuser degradation since launch

- SD degradation, H factors, for SDSM view direction at the wavelength of the SDSM detector D

\[
H(\lambda_{D}) = \left( \frac{dc_{SD,D}}{\rho_{SD,SDSM}(\lambda_{D})\tau_{SDS}\cos(\theta_{SD})} \right)_{Scan} \frac{dc_{SV,D}}{\tau_{SVS}}_{Scan}
\]

- **Improvements**
  - Carefully derived the VFs and BRFs from yaw measurements
  - Ratio of the averages
  - Sweet spots selection

**SDSM operations:** Every orbit first few months, then once per day for about two years, and once per two days since May, 2014.

SDSM Calibration Results

SD Degradation (H-Factors)

Sweet spots

Sun view response trending

SD view response trending

Sun view response trending

SD degradation

Unexpected but real degradation (Nov., 2014)

SDSM can accurately track the SD degradation for SDSM direction
SD Calibration Algorithm

- SD is made of Spectralon®, near Lambertian property
- Solar radinace reflected by the SD
  \[ L_{SD}(\lambda) = I_{Sun}(\lambda) \cdot \tau_{SD} \cdot \cos(\theta_{SD}) \cdot \rho_{SD,RTA}(\lambda) \cdot h(\lambda) / d_{VS}^2 \]
  - \( \rho_{RSD,RTA}(\lambda) \): Prelaunch BRF for RTA view direction
  - \( h(\lambda) \): SD degradation for SDSM view direction is used as the SD degradation for the RTA direction
- RSB calibration coefficients, F factors
  \[ F(B, D, M, G) = \frac{RVS_{B,SD} \cdot \int RSR_B(\lambda) \cdot L_{SD}(\lambda) \cdot d\lambda}{\sum_i c_i(B, D, M, G) \cdot dn^i \cdot \int RSR_B(\lambda) \cdot d\lambda} \]
  - \( B, D, M, G \): Band, Detector, HAM side, and gain status

SD Calibration: Every orbit

- Improvements
  - Carefully derived the VFs and BRFs from yaw measurements
  - Improved H factors
  - Sweet spot selection
  - Time-dependent RSR

SD Calibration Results

RSB Calibration Coefficients (SD F-Factors)

SD can accurately track the RSB gain change as long as SD degradation for the RTA view can be approximated as that for the SDSM view.
Lunar Calibration Algorithm

- Moon is very stable in its reflectance
- RSB calibration coefficients, F factors, from lunar observations

\[ F(B, M) = \frac{g(B)N_{t,M}}{\sum_{D,S,N} L_{pl}(B, D, S, N)\delta(M, M_N)}, \]

- \( g(B) \): View geometric effect correction (ROLO lunar model and extra correction)

SNPP VIIRS is scheduled to view the Moon approximately monthly (about nine months every year)

**Advantages**
- Lunar surface reflectance has no observable degradation
- Can be used for inter-comparison

Lunar Calibration Results

RSB Calibration Coefficients (Lunar F-Factors)

Lunar image (M6 in April, 2012)

Lunar and SD F factors

- The differences between the SD F-factors and lunar F-factors increase with time, especially for short wavelength RSB
- Which is correct?
Non-Uniformity of the SD Degradation

- SD degrades non-uniformly with respect to the incident angle for SDSM view direction.
- SD degrades non-uniformly with respect to the incident angle for rotating telescope assembly (RTA, RSB) view direction.
- According to optical reciprocity, then SD also degrades non-uniformly with respect to the outgoing direction.
- The different signs of the variation slopes of the H-Factors and F-Factors with respect to incident direction confirm that SD degrades non-uniformly with respect to outgoing direction.

Slopes of H-factors and F-factors in each individual event with respect to solar declination.

- 0.1% per degree; 1% per 10 degrees for 412 nm (D1 and M1).
- Angle between SDSM view direction and RTA view direction is larger than 100 degree?
- SD calibration is not accurate enough for ocean color data processing.
Hybrid Approach

- **SD Calibration**
  - SD degrades non-uniformly, resulting long-term drifts
  - Results are stable and smooth
  - Observation in every orbit

- **Lunar Calibration**
  - No degradation issue
  - Infrequent and no observation in three months every year

- **Hybrid Approach**
  
  \[ F(B,D,M,G) = R(B,t) \cdot F(B,D,M,G) \]

  \[
  R(B,t) = \left( f(B,M,t) \right)_M / \left( F(B,D,M,0,t) \right)_{D,t-15<t_i<t+15,M}
  \]

  - Lunar calibration provides long-term baseline
  - SD calibration provides smoothness and frequency

Improvements in Ocean Color Products

- VIIRS data were reprocessed using MSL12 with SDR generated with updated hybrid calibration coefficients.
- NOAA ocean color products produced with the hybrid calibration coefficients have met validated maturity in March 2015.
- Hybrid results agree with MOBY in situ!

Green: VIIRS IDPS; Red: VIIRS Hybrid; Blue: Moby in Situ

Summary

• It is shown that SD/SDSM calibration can provide stable and clean calibration coefficients with all carefully derived input components.
• The “degradation uniformity condition”, a key assumption in SD/SDSM calibration methodology, has recently proved to be untrue, which results in a long-term bias into the calibration coefficients.
• Lunar observations provide stable and clean calibration coefficients without surface degradation issue even but are infrequent.
• An hybrid approach properly combining the SD and lunar calibration coefficients restores the accuracy of the calibration coefficients from the non-uniformity issue and other various effects.
• The hybrid coefficients significantly reduce the long-term drifts in the ocean color EDR products and improves the VIIRS ocean products to high quality, capable to support of the science research and various operational applications.
• “Degradation uniformity condition” will be a key issue for all instruments such as VIIRS J1, VIIRS J2, etc, that use SD/SDSM for reflective solar bands calibration.
• Lunar calibration is a necessary component of an accurate calibration for reflective solar bands for SNPP VIIRS, J1 VIIRS, J2 VIIRS, etc.
• With good calibration, SNPP VIIRS is showing to be a beautiful instrument.

More detail technique discussions will be presented in Thursday ocean color breakout session.
Table 1. Specification for SNPP VIIRS RSBs and SDSM detectors.

<table>
<thead>
<tr>
<th>VIIRS Band</th>
<th>CW* (nm)</th>
<th>Band Gain</th>
<th>Detectors</th>
<th>Resolution*</th>
<th>SDSD Detector</th>
<th>CW* (nm)</th>
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</table>

*CW: Center Wavelength; DG: Dual Gain; SG: Single Gain; Resolution: Track x Scan at Nadir after aggregation
VIIRS Marine Isoprene: Linking Ocean Phytoplankton to Air Quality and Climate

Daniel Tong, Hang Lei, Li Pan, Pius Lee
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Menghua Wang
*NOAA Center for Satellite Applications and Research (STAR), College Park, MD*

**Acknowledge:** NOAA JPSS Program for funding support;
What is isoprene

Isoprene (CH₂=CH-C(CH₃)=CH₂) is a biogenic hydrocarbon emitted by trees, grasses and ocean phytoplankton.

- **Purpose of emission:** combat abiotic stresses;

- **Ozone formation:**

- **Aerosol formation:**

\[ \text{VOC} + \text{OX} \rightarrow \sum_{i=1}^{N} \alpha_i \times P_i \rightarrow \text{SOA} \]

- **Cloud formation:** Cloud Condensation Nuclei (CCN);

**Ozone, Aerosol, cloudiness all at the central stage of climate change debate**

A suite of reactive gases and aerosols emitted from the Ocean:

- Isoprene;
- Dimethyl Sulfide (DMS);
- Organic Aerosols;
Algae Bloom and Ocean Cloudiness

(Meskhidze and Nenes, Science, 2006)
A Review of Approaches for Marine Isoprene Emissions

- **Shaw et al. (2003):**
  \[ E_{iso} = [Chl - a]*V*EF \]

- **Palmer & Shaw (2005):**
  \[ E_{iso} = K_{AS}*(C_W - H*C_A) \]
  \[ P - C_W(k_i*C_{Xi} + k_{bio} + k_{AS}/Z_{ML}) - L_{MIX} = 0 \]
  \[ k_i \] – chemical reaction rate for oxidant i;
  \[ k_{bio} \] – bacterial loss rate;
  \[ L_{MIX} \] – loss due to downward mixing;

- **Gantt et al. (2009):**
  \[ E_{iso} = SA*H_{max}*[Chl - a]*F_{iso} \int_0^{H_{max}} Pdh \]

- **Symbols:**
  \[ E_{iso} \] - Isoprene emission;
  \[ [Chl-a] \] - Isoprene emission;
  \[ V \] – euphotic water volume;
  \[ EF \] – Emission factor;
  \[ k_{AS} \] – exchange coeff.;
  \[ C_W \] – isop. conc. in water
  \[ C_A \] – isop. conc. in the air
  \[ H \] – Henry’s law constant;
  \[ P \] – isoprene production;
  \[ H_{max} \] – euphotic zone height;
  \[ Z_{ML} \] – mixing layer height;
JPSS marine Isoprene algorithm (V1.0)

- Built upon several pioneering works:

\[ F = a \times [Chl] \times \sum_{i=1}^{N} (EF_i \times f_i) \times H_{\text{max}} \times \gamma \]

Euphotic zone height (Gantt et al., 2009)

\[ H_{\text{max}} = (-\ln\left(\frac{2.5}{I_0}\right)) / K_{490} \]

- \( I_0 \) – ground radiation; \( K_{490} \) – defuse attenuation coefficient in water

Phytoplankton Functional Types (PFTs) (Arnold et al., 2009)

Determine emission factor (EF) and abundance (f);
No data available from JPSS, using SeaWiFS climatological data

JPSS Products Used:
- [Chl-a]
- \( K_{d490} \)
- PAR
Chlorophyll-a and $K_d(490)$

- **Sensor/Satellite**: Visible Infrared Imaging Radiometer Suite (VIIRS) on SNPP

- **Ocean Color Data Processing**:
  - Multi-Sensor Level-1 to Level-2 (MSL12) is used for VIIRS ocean color data processing
  - Routine ocean color data production from SDR (Level-1B) to ocean color EDR (Level-2), and to global Level-3 data, including $nL_w$, chlorophyll-a, and $K_d(490)$.
  - Level 3: Products are mapped to the CoastWatch geographic regions

- **Algorithms (Ocean Color EDR Team)**:
  - Chlorophyll-a concentration: VIIRS OC3 algorithm
  - Diffuse attenuation coefficient at 490 nm $K_d(490)$: *Wang et al.* (2009) algorithm
Global Distribution of Marine Isoprene

JAN

APR

JUL

OCT

Marine Isoprene Emissions (molecules/cm²/s)

0.0E+00  1.0E+05  2.0E+05  3.0E+05

Marine Isoprene Emissions (molecules/cm²/s)

0.0E+00  1.0E+05  2.0E+05  3.0E+05
Isoprene Observations and Reprocessing

**Issue:** Some data cannot be directly used for product validation.

**Reprocessing Approach:** Air-sea mass transfer.

Convert seawater concentration into flux:

\[ E_{iso} = K_{AS} \times (C_W - H \times C_A) \]

- \( k_{AS} \) – exchange coefficient;
- \( C_W \) – isoprene concentration in water
- \( C_A \) – isoprene concentration in the air
- \( H \) – Henry’s law constant;

Calculate exchange coefficient based on wind speed:

\[ K_{AS} = 0.31 \times U^2 \times \left( \frac{(3913.15 - 162.13T + 2.67T^2 - 0.012T^3)}{660} \right)^{-0.5} \]

- \( U \) – surface wind speed;
- \( T \) – Sea surface temperature

(Wanninkhof et al., 2004)
Isoprene Product Validation (Cont.)

![Graph showing observed vs. satellite isoprene flux](image-url)
NOAA National Air Quality Forecast Capability (NAQFC)

- Developed by OAR/Air Resources Laboratory; Operated by National Weather Service (NWS) (PM: I. Stajner).
- Provides national numeric air quality guidance for ozone (operational product) and PM$_{2.5}$ (particulate matter with diameter < 2.5 µm);

NAQFC is one of the major gateways to disseminate NOAA satellite observations and model prediction of air quality to the public.
Isoprene applications:
National and regional air quality forecasting

Global Isoprene (April 2014)

Isoprene into model domains
Terrestrial vs. marine isoprene emissions

(Preliminary Results)

Land Emission

Marine Emission

JPSS Isoprene product fills the gap of missing ocean emissions in air quality and climate models

JPSS Isoprene User Workshop: September 2, 2015 in College Park, MD
Contact: Daniel.Tong@noaa.gov for details
Operational Monitoring and Forecasting of Land Surface Phenology from JPSS VIIRS Observations and its Applications

Xiaoyang Zhang, Yunyue Yu, Lingling Liu, Yihua Wu, and Michael Ek
August 25, 2015
Objectives

- **Goal(s):**
  - To establish a system for monitoring in real-time and forecasting in short term temporal development of vegetation growth in North America and across the globe from JPSS VIIRS.

- **Targeted users:**
  - Numerical Weather Prediction Systems at NOAA Environmental Modeling Center
  - Agriculture and forest management
  - Climate monitoring
Metrics of Land Surface Phenology/Dynamics

1. Onset of greenness increase
2. Onset of greenness maximum
3. Onset of greenness decrease
4. Onset of greenness minimum
5. Growing season VI minimum
6. Growing season VI maximum
7. Summation of VI for growing season length
8. Rate of change in greenness increase;
9. Rate of change in greenness decrease
10. Onset of fall foliage low coloration
11. Onset of fall foliage moderate coloration
12. Onset of fall foliage near peak coloration
13. Onset of fall foliage peak coloration
14. Onset of fall foliage post peak coloration
Climate data record of phenology is detected from annual time series of satellite data with a latency longer than half year.

Real Time phenology is detected from currently available time series of satellite data without any latency.
A set of potential VI trajectories in a senescent phase are modeled in near-real time for a pixel from the available observations (dots) and climatology.
Prediction of Temporal Greenness Trajectory in Spring

Simulating the potential temporal trajectory from available daily VI data (circles) and monitoring and forecasting phenological events in spring green-up phase.
Biophysically Understanding Temporal Trajectory of Satellite Vegetation Index (VI)
Calibration of Climatological Phenology Trajectory (from MODIS) to be comparable with VIIRS Data

- MODIS EVI and VIIRS EVI are not exactly the same
- Climatological EVI from MODIS needs to be calibrated to be comparable to VIIRS EVI
Climatology of Dormancy Onset and Standard Variation

Climatology from MODIS data from 2001-2012

Standard variation of dormancy onset (2001-2012)

Red: 0-3
Green: 3-6
Blue: 6-9
Yellow: 9-12
Cyan: 12-15
Magenta: 15-18
Real-time Monitoring and Short-term Forecasting of Fall Foliage from JPSS VIIRS
Uncertainty of Color Foliage Monitoring

preceeding 3day NPC

preceeding 9day NPC

>10
5-10
<5 days

>10
5-10
<5 days
Monitoring and Forecasting of Spring Vegetation Progress
VIIRS Monitoring Across North America
STAR developed new Foliage Phase Prediction system

Two scientists of the Center for satellite Applications and Research (STAR), the scientific arm of the NOAA Satellite and Information Service (NESDIS), have elaborated a new method to observe and forecast short-term fall foliage coloration.

The latest STAR system was created with the support of the JPSS Proving Ground and Risk Reduction Program and it employs the VIIRS daily vegetation index to monitor foliage indicators across the United States with a time-pace of 3 days and to generate predictions of 10 days.

The STAR product represents the first instrument that can evaluate and forecast the fall foliage coloration phenomenon from a satellite data time series. The information will be useful for a wide variety of purposes, such as monitoring drought and crops germination, individuating hurricane destruction, forest pests, disease outbreaks, and species invasion.

Read full story: NOAA
Processed on Nov 6th 2014

Add new comment

changes in visible light and in infrared. The forecast is updated every three days.
VIIRS real time monitoring of fall foliage coloration can serve the prediction from weather data in NOAA National Weather Service.
Real Time Phenology for Land Modeling (in NOAA EMC)

Metrics of phenology – the seasonal vegetation dynamics
- Estimate surface energy balance,
- Determine the partition of surface sensible and latent heat fluxes
- Predict boundary layer structures in the global and regional numerical weather prediction models

Climatology greenness currently used in Land Model in EMC
Real Time VIIRS data from phenological detection
Assistance in USA National Phenology Network

- 2,001 - 5,000 records
- 5,001 - 10,000 records
- 10,000 - 85,000 records

1.5 M
Phenology records

People and Partners

4,451
Total active participants since 2009

41%
Proportion of participants registered since 2009 that submitted observations in 2014

3,975
Participants registered in 2014

23%
Increase in active participants over 2013

Of Special Interest: Maples, Oaks, and Poplars

Track the “Green Wave” across the country as trees progress through seasonal changes

Spring has finally sprung! Across the country, trees are responding. Are the trees in your yard putting on their leaves?

Since our last email, more of you have submitted observations for the Great Plains North Green Wave Campaign - thank you!

This spring, we have a new way for you to know when to expect leaves on your maples, oaks and poplars. A team of scientists including Drs. Xiaoyang Zhang and Lingling Liu (South Dakota State University) and Dr Yunyue Yu (NOAA/NEON/STAR/SMCD/EMB) have created predictions of green-up across the country, based on historical and current satellite information and temperature. Click the links below to see a larger version of these maps.

Does the Estimated Leaf-out map match what you see on your trees?

If you are not yet seeing leaf-out on your trees, the Predicted Leaf-out map will show you if you can expect to see leaves on your trees in the next week. Don’t forget to log your observations in Nature’s Notebook to help verify whether these models are correct!

Thank you for helping out on this important project! Through this effort, you are contributing directly to scientific discovery and your participation is truly appreciated.

Erin Posthumus
Outreach Associate
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bio
Serving Crop Progress Monitoring

Legend for shaded area:
- Turning green period
- Ear emergence period
- Boot stage period
- Heading period
- Flowering period
- Ripening period
- Milk ripen period
- Mental ripen period
- Kernel hard period
- Harvest ready

South Dakota 2015
- VIIRS greenness
- Corn Progress
- Oats Progress

Ohio 2015
- VIIRS greenness
- Corn Progress
- Oats Progress
Real time monitoring shows a earlier spring in the western region than eastern area in 2015

Comparison of the spring event in 2015 with climatology (2000-2011) shows the spring was advanced in western region while it was delayed in eastern area.
Summary and Issues

1. Near real time VIIRS observations make it possible to reconstruct the potential trajectories of daily vegetation dynamics timely.

2. The preliminary results indicate VIIRS real-time monitoring of phenology has wide applications.

3. This project has been very successful with the support from JPSS Risk Reduction during the past two years.

4. How to continue this effort is a major issue because the funding support will end before next summer.
Nowcasting Applications

Jordan Gerth
University of Wisconsin
STAR JPSS Science Team Meeting
25 August 2015
Challenges

• What NPP and JPSS spectral bands and science products have a direct application to operational responsibilities of NWS meteorologists?

• How do we deliver polar satellite information so that it is timely enough for nowcasting?

• How do we present that information in the field?
NPP and JPSS

- What instruments/capabilities of NPP and JPSS provide added value over geostationary satellites for nowcasting applications?
  - VIIRS Day/Night Band
  - Higher spatial resolution for imaging (VIIRS), especially in polar regions
  - Microwave products (ATMS)
  - Additional spectral information (CrIS) for characterizing clear scenes
Deliver and Display

• Timely delivery is facilitated by:
  ▫ A network of L/X-band antennas across the United States to capture and produce imagery and products with the Community Satellite Processing Package (CSPP)
  ▫ Improved bandwidth, especially in OCONUS, to reach NWS forecast offices

• Imagery and science products arriving at NWS offices are displayable within the Advanced Weather Interactive Processing System (AWIPS)
The Early Days: Valley Fog
The Early Days: Flossie

29 July 2013
The Early Days: Flossie

TROPICAL STORM FLOSSIE DISCUSSION NUMBER 19
NWS CENTRAL PACIFIC HURRICANE CENTER HONOLULU HI EP062013
500 AM HST MON JUL 29 2013

THE CENTER OF FLOSSIE WAS HIDDEN BY HIGH CLOUDS MOST OF THE NIGHT BEFORE VIRS NIGHTTIME VISUAL SATELLITE IMAGERY REVEALED AN EXPOSED LOW LEVEL CIRCULATION CENTER FARther NORTH THAN EXPECTED. WE RE-BESTED THE 0600 UTC POSITION BASED ON THE VISIBLE DATA. SUBJECTIVE DVORAK ANALYSES CONTINUED SHOW CURRENT INTENSITIES OF 3.0 BUT SATELLITE LOOPS SUGGEST A RAPID WEAKENING TREND WITH THE LOW LEVEL CENTER PULLING AWAY FROM A SMALL AREA OF CONVECTION SOUTHEAST OF THE CENTER. IT IS LIKELY THAT CONTINUED NORTHWEST SHEAR WILL MAINTAIN THIS WEAKENING TREND.

THE TRACK HAS BEEN SHIFTED NORTH TO REFLECT THE RE-LOCATED CENTER. THE TRACK GUIDANCE SHIFTED FOLLOWING THE TRACK CHANGE AND WAS CONSISTENT WITH A NEW TRACK FARTHER TO THE NORTH.

...
Recent Application: Fronts

10 February 2015
Frontal Passages in Hawaii

PHNL Aloha Front at 02/10/15 01:50 LT

Temperature (Blue) and Dew Point (Green) in °F

Time (Local)

NWS Collaborator: Eric Lau
New Activities

• Products for coastal forecasting applications
  ▫ ASCPO Sea Surface Temperature
  ▫ MIRS 90 GHz and Rain Rate

• Full-resolution VIIRS imagery in AWIPS II

• Enhancing AWIPS II and providing corrected reflectances for select VIIRS bands to support RGB multi-spectral applications
Example of NPP-ATMS Rain Rate and 11.0 μm IR Window in AWIPS II
VIIRS True Color RGB in AWIPS II
(Full Bit Depth)

Composites with corrected reflectances enhance quality of meteorological features

Smoke on 20 August 2015
VIIRS False Color RGB in AWIPS II
(Full Bit Depth)

Benefit: Easy to visually discriminate between fires, smoke, and burn scars

* False Color RGB (RGB): VIIRS Band M11 2.3 um Corrected Reflectance/VIIRS Band M17 0.86 um Corrected Reflectance/VIIRS Band M11 0.86 um Corrected Reflectance Thu 20:39Z 20-Aug-15
Other Applications

- Phenomena-based products:
  - Aerosols
  - Active fires
  - Land surface properties
  - River ice and flooding
  - Sea ice characterization and movement
  - Snow and ice cover
  - Volcanic ash detection
- Comparing to short-term numerical weather prediction forecasts
- Feature discrimination

Source: CIMSS Satellite Blog

23 April 2012

0.64 µm vs. 1.61 µm
The Future

• What can we assimilate into models, integrate into products, and combine with other observations while maintaining the integrity of the disparate sources?

• How do we further improve the implementation of satellite imagery and products in our weather visualization tools (e.g., AWIPS II)?
Thank You

- If you are interested in learning more about how NWS conducts operations in the OCONUS and have a science product with an application to demonstrate, consider the NWS Pacific Region Visiting Scientist Program.

- Questions? Comments?
  - Jordan.Gerth@noaa.gov
Nighttime VIIRS products: Fires, Flares, Lights, and Boats

Christopher D. Elvidge, Ph.D.
Earth Observation Group
NOAA National Geophysical Data Center
Boulder, Colorado USA
chris.elvidge@noaa.gov

Kimberly Baugh, Feng-Chi Hsu, Mikhail Zhizhin, Tilottama Ghosh
Cooperative Institute for Research in the Environmental Sciences
University of Colorado

August 25, 2015
Cities and human settlements
Industrial Sites
Boats
Gas Flares
Fires
UN Initiative to end routine flaring by 2030

How will progress be tracked? VIIRS!

Zero Routine Flaring by 2030

The Zero Routine Flaring Initiative
May 22, 2015 — The initiative was launched by UNSG Ban Ki-moon and WBG President Jim Yong Kim with governments, oil
Read More »

During oil production, associated gas is produced from the reservoir together with the oil.
Gas flares are readily detected in the VIIRS M10 spectral band.
VIIRS Nightfire (VNF): A global multispectral fire product
Nine channels of data are collected at night

Nighttime collection of channel 11 is expected to start in 2015
Why Multispectral?

To get at the Planck curves!

Daily files are in csv and kmz formats.
Typical Biomass Burning Detection

Lower temperature than gas flaring. Often these have larger source size than gas flares.
Detection Limits

At 1800 K flares as small as 0.25 m² are detectable.

Temperature VS Detectable Area

- M10
- M13
- Biomass Burning
- Gas Flares
Daily VNF data are available at: http://ngdc.noaa.gov/eog/viirs/download_viiirs_fire.html

Current processing typically runs with a four hour delay
Temperatures are bimodal

![Histogram showing bimodal distribution of temperatures with peaks labeled 'Fires' and 'Flares'.]
Calibration for estimating BCM from radiant heat

\[ y = 0.0031x \]

\[ R^2 = 0.84 \]
Gas flaring volumes estimated at 7438 sites worldwide

929 flare sites in North Dakota

Rank 4310
Country: USA
Combustion parameters:
Lat=47.747852, Lon=-102.244143 deg.
Freq. detect.=19.95 %
BCM=0.00325

Flare ID: vnfdib_2012_02226
Tavg=1900.97 K, RHsum=1.04976 MW
Area=0.13 m2
Type: flare

Directions: To here - From here
Upstream gas flaring by country in billions of cubic meters (BCM)

Global total: 145 BCM
Downstream flaring by country in billions of cubic meters (BCM)

Total = 15.1 BCM
Flare site numbers by country
30% of flare sites are in the USA
Gas flaring site numbers by country.

Half of the flaring is at the top 397 flares.

90% of the flaring is at the top 2285 flares.
Discrimination of flaming and smoldering combustion

- There are two distinct combustion phases
- Flaming: higher temperature 700-1200 K, good oxidation, low smoke
- Smoldering about half as hot as flaming 350-450 K, poor oxidation, high smoke production
- Discriminating between flaming and smoldering could improve emission modeling
- There is a 400-500 K temperature differential
- Is the temperature differential sufficient to discriminate flaming and smoldering with VIIRS data?
Approach

• Prototype method developed with nighttime Landsat 8 data
• Model the flaming phase by Planck curve fitting the M10 & M11 radiances, producing flaming phase radiance estimates in long wave bands
• Subtract the flaming phase radiance and background radiance in bands M12,13,14,15,16
• Residual thermal anomalies suggest smoldering
Sumatra Peat Fire Study
With M11 – September 26, 2014
Temperature and source area from M10 & M11 Planck curve fitting
Residuals
After subtracting flaming phase and average background radiances

M12

M13

M14

M15

M16
Temperatures from M10 & M11 Planck curve fit – Sumatra September 26, 2014
Source areas from M10 & M11 Planck curve fit – Sumatra September 26, 2014
Summary on Flaming vs Smoldering with VIIRS

• M10 & M11 radiances can be used to extract flaming phase temperatures and source areas.
• The presence of residual hotspot radiances in mid-long wave infrared channels after subtracting flaming phase and background radiances suggests the presence of smoldering in Sumatra peat fires.
• Can smoldering phase temperatures and source areas be estimated?
• The method needs to be tested more widely.
VIIRS detects lights from boats at night

Near real time service running for Indonesia. Expansion to other regions begins later this year.

http://www.ngdc.noaa.gov/eog/viirs/download_indo_boat.html
Applications for VIIRS boat detections

- Supply alerts for boats detected in “no-take” and Marine Protected Areas
- Cross correlate with GPS beacon data to ID potentially illegal fishing
- Monitor for transboundary foreign vessels
- Assess the impacts of new regulations and enforcement regimes
Boat Detections Running for Indonesia
Documenting effectiveness of regulations
Aru Island, Arafura Sea

Ban on foreign fishing vessels
VIIRS Nighttime Lights Algorithm Development

- Algorithms developed to remove lighting and fires.
- The DNB based fire removal algorithm should work well for removing South Atlantic Anomaly (SAA) detector hits and may also remove aurora.
- Last major hurdle is removal of background.
South Asia DNB cloud-free composite
Background
Background with infrequent light
Minor urban area
Brighter urban area
Daytime DNB Cloud-free Composite

Ten brightness classes
Summary

• There are four unique types of nighttime VIIRS products:

• VIIRS Nightfire (VNF) produced globally on 24 hour increments. Gas flaring observations used to estimate flared gas volumes worldwide. Research is ongoing on discrimination of subpixel flaming and smoldering.

• VIIRS boat detections (VBD) currently running for Indonesia. Will begin the expand to other areas this year.

• VIIRS nighttime lights (VNL) last hurdle is the background removal algorithm.
EOG Publications

• Long-wave infrared identification of smoldering peat fires in Indonesia with nighttime Landsat data http://iopscience.iop.org/1748-9326/10/6/065002/

• Automatic Boat Identification System for VIIRS Low Light Imaging Data http://www.mdpi.com/2072-4292/7/3/3020

• VIIRS Nightfire: Satellite pyrometry at night http://www.mdpi.com/2072-4292/5/9/4423

• What is so great about nighttime VIIRS data for the detection and characterization of combustion sources? http://dx.doi.org/10.7125/APAN.35.5

• Using the short-wave infrared for nocturnal detection of combustion sources in VIIRS data http://dx.doi.org/10.7125/APAN.35.6

• Why VIIRS data are superior to DMSP for mapping nighttime lights http://dx.doi.org/10.7125/APAN.35.7

• Nighttime lights compositing using the VIIRS day-night band: Preliminary results http://dx.doi.org/10.7125/APAN.35.8
The Development of JPSS Volcanic Cloud Applications

Michael Pavolonis
(NOAA/NESDIS/STAR)
Justin Sieglaff, and John Cintineo
(UW-CIMSS)
Development of a Multi-sensor System

1). Unrest Alerts

False Color Imagery (12–11\(\mu\)m, 11–3.9\(\mu\)m, 11\(\mu\)m)

SNPP VIIRS (11/30/2014 – 20:29 UTC)

Annotation Key
(annexation colors are not related to colors in underlying image)
Ash/Pyroclastic Cloud  Volcanic De  Thermal Anomaly
Development of a Multi-sensor System

1). Unrest Alerts

2). Eruption Alerts
Development of a Multi-sensor System

1). Unrest Alerts

2). Eruption Alerts

3). Volcanic Cloud Tracking
Development of a Multi-sensor System

1). Unrest Alerts

2). Eruption Alerts

3). Volcanic Cloud Tracking

4). Volcanic Cloud Characterization
Development of a Multi-sensor System

1). Unrest Alerts

2). Eruption Alerts

3). Volcanic Cloud Tracking

4). Volcanic Cloud Characterization

5). Dispersion Forecasting
http://volcano.ssec.wisc.edu
1). **Ash dominated volcanic plumes** – Semi-transparent clouds dominated by volcanic ash. Lightning is usually not present in these clouds.

2). **Ice topped umbrella clouds** – These cloud are mostly observed during a major eruption. A spectral based volcanic ash signal is usually initially absent because the ash is encased in ice and/or the cloud is opaque. Lightning is often present in these clouds.

3). **SO₂ clouds** – Sulfur dioxide clouds (SO₂ gas is invisible to the eye) that may or may not contain volcanic ash. Some eruptions produce large amounts of SO₂ and very little ash and vice-versa.
1). **Ash dominated volcanic plumes** – Semi-transparent clouds dominated by volcanic ash. Lightning is usually not present in these clouds.

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3). **SO₂ clouds** – Sulfur dioxide clouds (SO₂ gas is invisible to the eye) that may or may not contain volcanic ash. Some eruptions produce large amounts of SO₂ and very little ash and vice-versa.
Difficult to detect features are automatically detected using a multi-spectral cloud object based approach.
Even with the new GEO’s, VIIRS is still critical!
Detect and Alert

Within our automated alerting system, VIIRS identifies the most volcanic ash clouds due to its enhanced sensitivity to small-scale features (even at large viewing angles).

Volcanic Cloud Alert Report

**DATE:** 2015-06-30
**TIME:** 17:59:52
**Production Date and Time:** 2015-06-30 21:29:46 UTC
**PRIMARY INSTRUMENT:** NPP VIIRS

UBINAS (Peru): June 30, 2015

Possible Volcanic Ash Cloud

Basic Information

- **Volcanic Region(s):** South America
- **Country/Countries:** Peru
- **Volcanic Subregion(s):** Peru
- **VAAC Region(s) of Nearby Volcanoes:** Buenos Aires
- **Mean Object Date/Time:** 2015-06-30 17:59:52 UTC
- **Radiative Center (Lat, Lon):** -16.350°, -70.900°

- **Nearby Volcanoes (meeting alert criteria):**
  - Ubinas (9.00 km)
  - Huaynaputina (28.70 km)
  - Misti, El (54.50 km)
  - Tocanci (56.80 km)
  - Chachani, Nevado (69.40 km)

- **Maximum Height [AMSL]:** 9.30 km; 30512 ft
- **90th Percentile Height [AMSL]:** 5.60 km; 18373 ft
- **Mean Tropopause Height [AMSL]:** 16.50 km; 54134 ft

Show More ▲  ▼ View all event imagery
Detect and characterize

Ubinas (Peru):
June 30, 2015
Raung (Indonesia)  
July 23, 2015 

False Color Imagery (12–11µm, 11–8.5µm, 11µm)  

**VIIRS** 

**Aqua MODIS** (07/23/2015 – 17:40:00 UTC) 

Annotation Key 
(annotation colors are not related to colors in underlying image) 

Ash/Dust Cloud  Volcanic Cb  Thermal Anomaly 

Annotation Key 
(annotation colors are not related to colors in underlying image) 

Ash/Dust Cloud  Volcanic Cb  Thermal Anomaly
Raung (Indonesia)
July 23, 2015
Ash Mass Loading

IR Window Imagery and Ash/Dust Loading
SNPP VIIRS (07/23/2015 - 18:22:40 UTC)

VIIRS

IR Window Imagery and Ash/Dust Loading
Aqua MODIS (07/23/2015 - 17:40:00 UTC)

MODIS
Absorption channels are needed to gain sensitivity to cloud height - VIIRS + CrIS can be used to obtain high quality IR-based cloud property retrievals.
1). Ash dominated volcanic plumes – Semi-transparent clouds dominated by volcanic ash. Lightning is usually not present in these clouds.

2). Ice topped umbrella clouds – These cloud are mostly observed during a major eruption. A spectral based volcanic ash signal is usually initially absent because the ash is encased in ice and/or the cloud is opaque. Lightning is often present in these clouds.

3). SO₂ clouds – Sulfur dioxide clouds (SO₂ gas is invisible to the eye) that may or may not contain volcanic ash. Some eruptions produce large amounts of SO₂ and very little ash and vice-versa.
Geostationary satellites are needed for timely detection of explosive eruptions, but JPSS adds significant value – benefit of a multi-sensor/multi-orbit approach.
At 4+ km resolution, the minimum 11 μm brightness temperature is -66°C.
At 375 m resolution, the minimum 11 μm brightness temperature is -101°C

April 23, 2015 (05:09 UTC)
NASA’s CALIOP lidar later verified that ash was present at least up to 20 km!
1). Ash dominated volcanic plumes – Semi-transparent clouds dominated by volcanic ash. Lightning is usually not present in these clouds.

2). Ice topped umbrella clouds – These cloud are mostly observed during a major eruption. A spectral based volcanic ash signal is usually initially absent because the ash is encased in ice and/or the cloud is opaque. Lightning is often present in these clouds.

3). SO$_2$ clouds – Sulfur dioxide clouds (SO$_2$ gas is invisible to the eye) that may or may not contain volcanic ash. Some eruptions produce large amounts of SO$_2$ and very little ash and vice-versa.
False Color Imagery (12–11μm, 11–8.5μm, 11μm)

SNPP VIIRS (07/16/2015 – 11:30:19 UTC)

SO₂ plume

Annotation Key
(abbreviation colors are not related to colors in underlying image)
Ash/Dust Cloud  Volcanic Cb  Thermal Anomaly
A multi-sensor SO$_2$ analysis is needed.
False Color Imagery (12–11μm, 11–8.5μm, 11μm)

SNPP VIIRS (09/03/2014 – 13:46 UTC)

SO₂ Plume

Dispersed SO₂

Annotation Key
(annotation colors are not related to colors in underlying image)
Ash/Dust Cloud  Volcanic Cb  SO₂  Thermal Anomaly
WMO Intercomparison of Satellite-based Volcanic Ash Retrieval Algorithms Workshop

29 June - 2 July 2015
The Pyle Center
University of Wisconsin-Madison
Particularly good agreement for MODIS_NOAA, SEVIRI NOAA, SEVIRI MO
Aircraft-based Ash Mass Loading Validation

1. AATSR_FMI vs. FAANLM0
2. AVHRR_MO vs. FAANLM0
3. IASI_OXFORD vs. FAANLM0
4. IASI_ULB vs. FAANLM0
5. MODIS_LUT vs. FAANLM0
6. MODIS_NOAA vs. FAANLM0
7. MODIS_ORAC vs. FAANLM0
8. MODIS_VPR vs. FAANLM0
9. SEMIRLEUMOP vs. FAANLM0
10. SEVIRI_NOAA vs. FAANLM0

Sample sizes:
- AATSR_FMI: 4
- AVHRR_MO: 13
- IASI_OXFORD: 5
- IASI_ULB: 2
- MODIS_LUT: 17
- MODIS_NOAA: 15
- MODIS_ORAC: 16
- MODIS_VPR: 25
- SEMIRLEUMOP: 53
- SEVIRI_NOAA: 117
- SEVIRI_NQAA: 238
Application to desert dust

Day and night, Land and water
Application to desert dust

Day and night, Land and water
Application to desert dust

Day and night, Land and water
Summary

• In the era of “Big Data” automation is critical for generating environmental intelligence for mitigating natural hazards

• Low latency (< 20 minutes) data are critical (need to utilize DB sites to the fullest extent)

• The IDPS aerosol and VCM products are not well suited for volcanic cloud applications across the full spectrum of cloud types. The JPSS Risk Reduction projects are a significant improvement, but the multi-sensor VOLCAT system is the long-term solution.
References


False Color Imagery (12–11µm, 11–8.5µm, 11µm)

SNPP VIIRS (07/09/2014 – 02:43 UTC)

Ash cloud

Jet contrail

Annotation Key
(annocation colors are not related to colors in underlying image)
Ash/Dust Cloud  Volcanic Cb  SO₂  Thermal Anomaly
False Color Imagery (12–11μm, 11–8.5μm, 11μm)

SNPP VIIRS (09/07/2014 – 14:12 UTC)

Annotation Key
(Annotation colors are not related to colors in underlying image)
Ash/Dust Cloud  Volcanic Cb  SO₂  Thermal Anomaly
Kelut Eruption (February 13, 2014)

Martin Setvak
Baseline AWG approach: Medium to high confidence of detection
Improved approach
A multi-sensor SO$_2$ analysis is needed
More consistent ash detection capabilities are needed across the spectrum of optical depth (down to detection limit) and height.
- Single channel IR window
- 11/13.3 µm retrieval
- 11/12 µm retrieval
- 11/12/13.3 µm retrieval

Ash cloud

Total Attenuated Backscatter (km^-1sr^-1)