CERES Science Team Meeting, NASA LaRC, April 22-24, 2014

Aerosol retrieval from S-NPP/VIIRS: Analysis of data quality

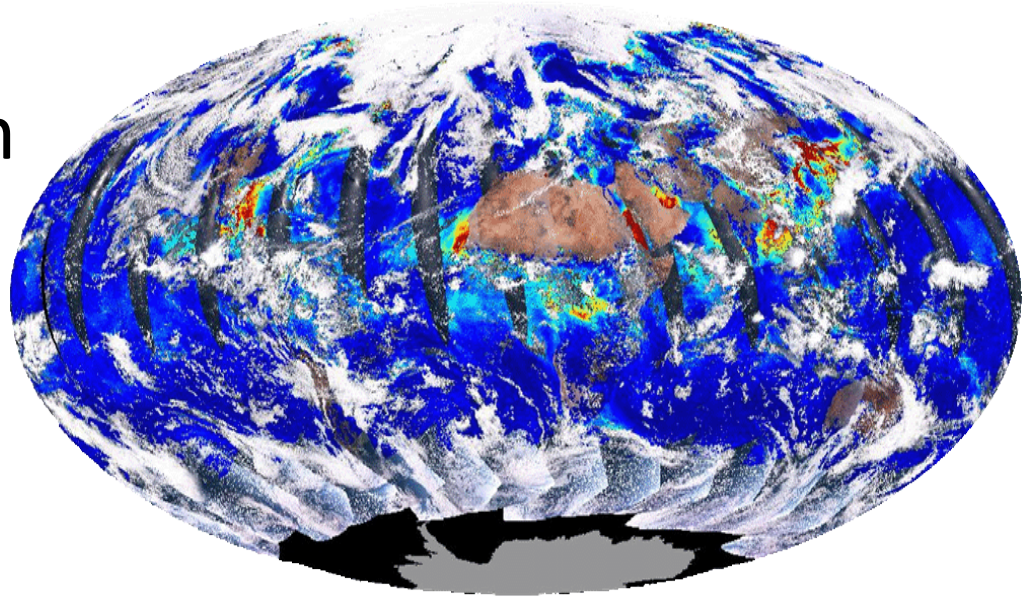
The S-NPP Aerosol Cal/Val Team
presented by
Istvan Laszlo
NOAA & UMD

VIIRS Aerosol Cal/Val Team

Name	Organization	Major Task
Kurt F. Brueske	IIS/Raytheon	Code testing support within IDPS
Ashley N. Griffin	PRAXIS, INC/NASA	JAM
Brent Holben	NASA/GSFC	AERONET observations for validation work
Robert Holz	UW/CIMSS	Product validation and science team support
Ho-Chun Huang	UMD/CICS	SM algorithm development and validation
Jingfeng Huang	UMD/CICS	AOT Algorithm development and product validation
Edward J. Hyer	NRL	Product validation, assimilation activities
John M. Jackson	NGAS	VIIRS cal/val activities, liaison to SDR team
Shobha Kondragunta	NOAA/NESDIS	Co-lead
Istvan Laszlo	NOAA/NESDIS	Co-lead
Hongqing Liu	IMSG/NOAA	Visualization, algorithm development, validation
Min M. Oo	UW/CIMSS	Cal/Val with collocated MODIS data
Lorraine A. Remer	UMBC	Algorithm development, ATBD, liason to VCM team
Hai Zhang	IMSG/NOAA	Algorithm coding, validation within IDEA
Stephen Superczynski	IMSG/NOAA	Product evaluation, data management

Outline

- VIIRS instrument
- Aerosol algorithm
- VIIRS aerosol products
- Data quality



High quality AOT (EDR) at 550 nm on 22 May 2013

VIIRS

Visible Infrared Imaging Radiometer Suite (VIIRS)

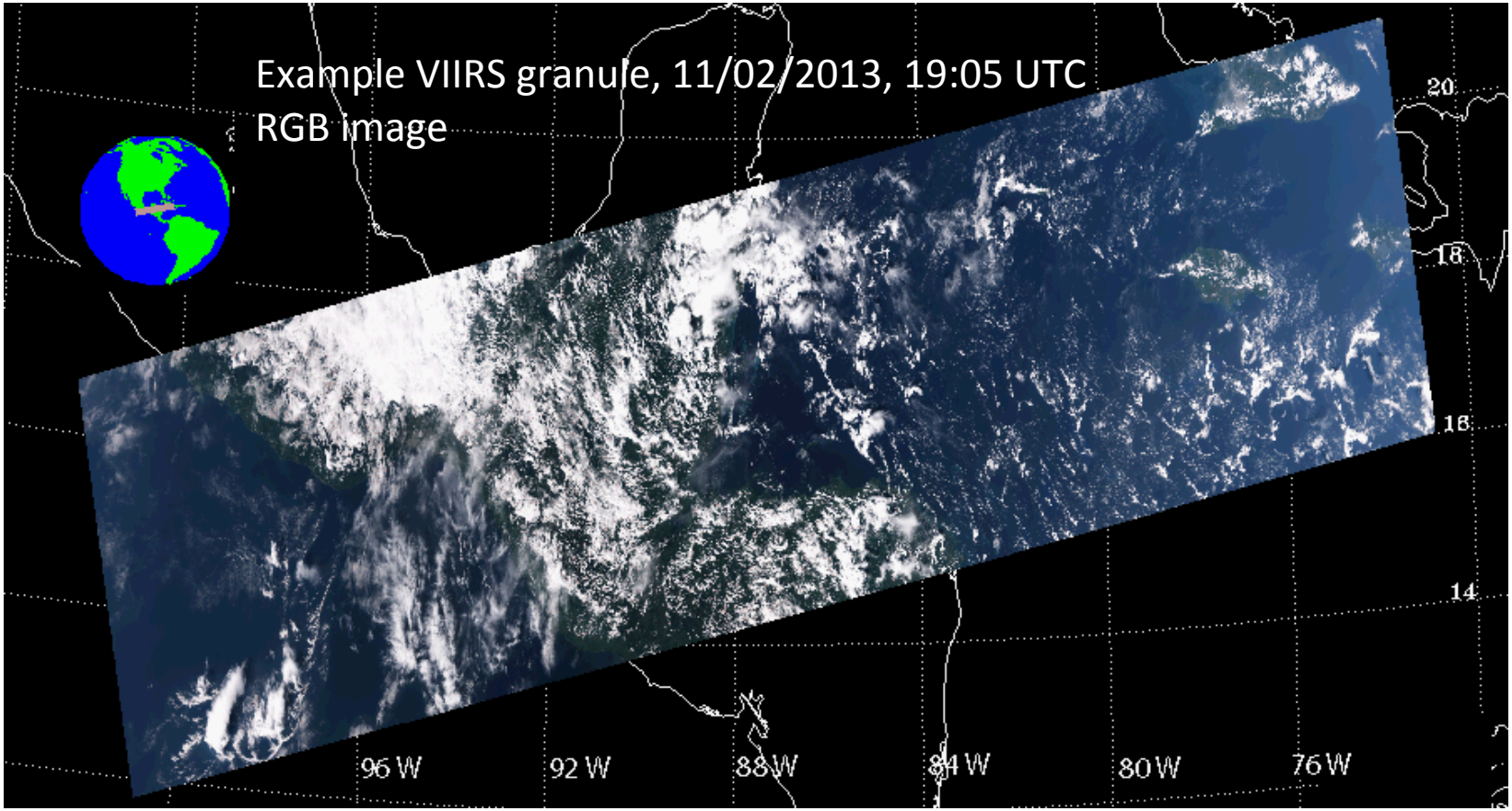
- cross-track scanning radiometer with ~3000 km swath – full daily sampling
- 7 years lifetime
- 22 channels (412-12,016 nm)
  - 16 of these are M bands with 0.742 x 0.776 km nadir resolution
  - **aerosol retrieval is from M bands** ➡
- high signal-to-noise ratio (SNR):
  - M1-M7: ~200-400
  - M8-M11: ~10-300
- 2% absolute radiometric accuracy
- single look
- no polarization

Band name	Wavelength (nm)	Bandwidth (nm)	Use in algorithm
M1*	412	20	L
M2*	445	14	L
M3*	488	19	L, TL, TO
M4*	555	21	TO
M5*	672	20	L, O, TO
M6	746	15	O
M7*	865	39	O, TL
M8	1,240	27	O, TL, TO
M9	1,378	15	TL
M10	1,610	59	O, TL, TO
M11	2,250	47	L, O, TL, TO
M12	3,700	191	TL
M13	4,050	163	none
M14	8,550	323	none
M15	10,763	989	TL, TO
M16	12,016	864	TT, TO

*dual gain, L: land, O: ocean; T: internal test

VIIRS (cont)

- Sensor Data Records (SDRs), converted from raw VIIRS data (RDR), are used in the VIIRS aerosol algorithm
- **Processing is on a granule by granule basis**
  - VIIRS granule typically consists of 768 x 3200 (along-track by cross-track) 0.75-km pixels

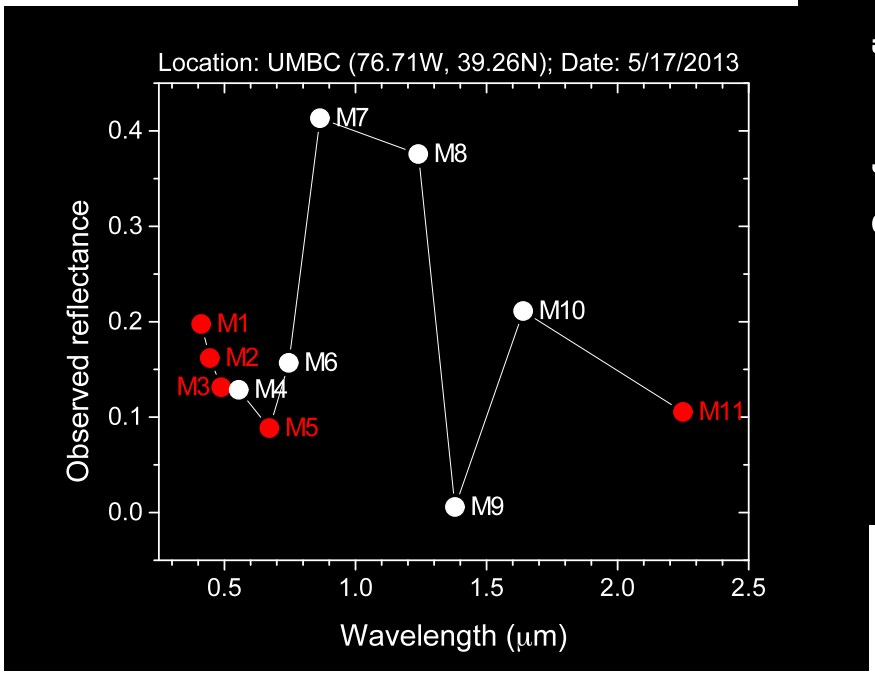


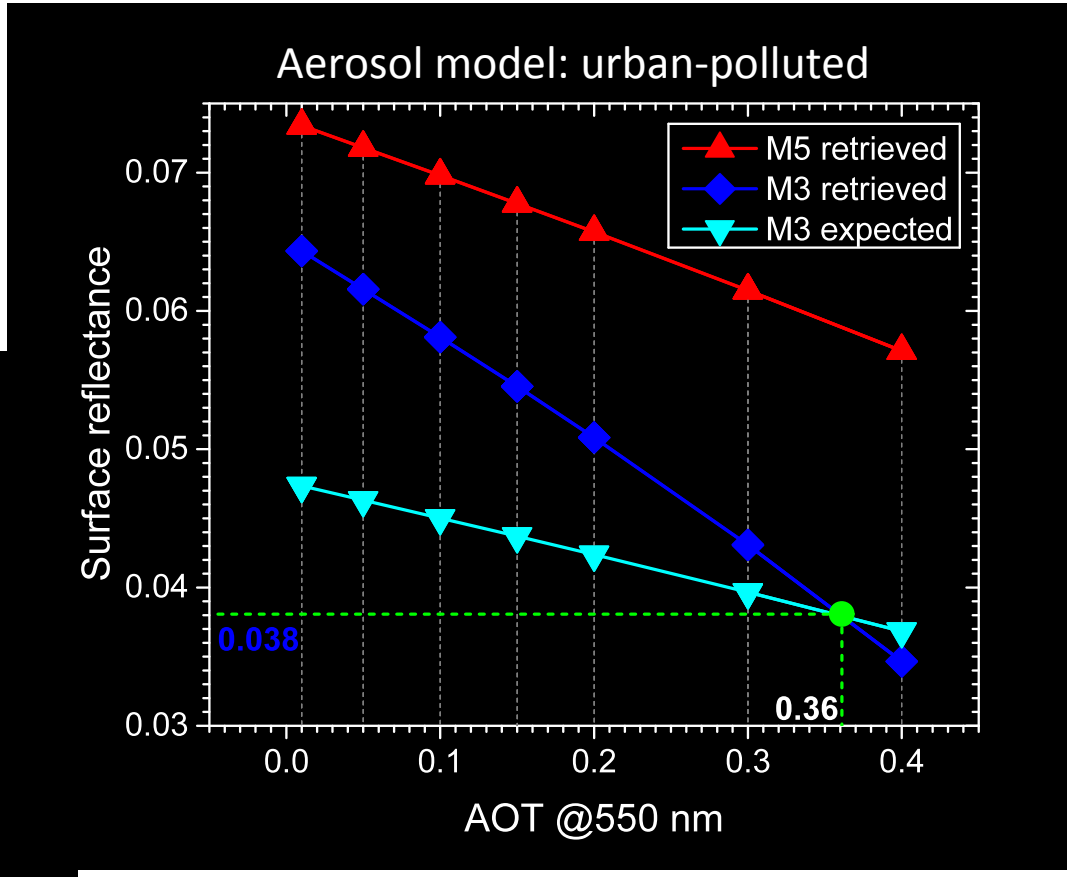
Over Land Retrieval (1)

- Atmospheric correction of reflectances [*Vermote and Kotchenova*, 2008]
  - AOT and aerosol model are by-products of surface reflectance retrieval
- Basis: aerosols change the ratios of spectral reflectances (spectral contrast) from those of the surface values.
- AOT and aerosol model are the ones that provide the best match between ratios of surface reflectances retrieved in multiple channels and their expected values.
  - Expected ratios are derived empirically by atmospherically correcting VIIRS TOA M-band reflectances using AERONET AOT (99 sites, ~60,000 matchups).
- Lambertian reflection ρ_{surf} is assumed.
- 5 aerosol models [*Dubovik et al*. 2002]:
  - dust
  - smoke (*high and low absorption*)
  - urban (*clean & polluted*)
  - bimodal lognormal size distribution, function of AOT, spherical particles

Over Land Retrieval (2)

- AOT is retrieved by marching through AOTs in LUT until the retrieved M3 surface reflectance is close to the one expected from the retrieved M5 value.





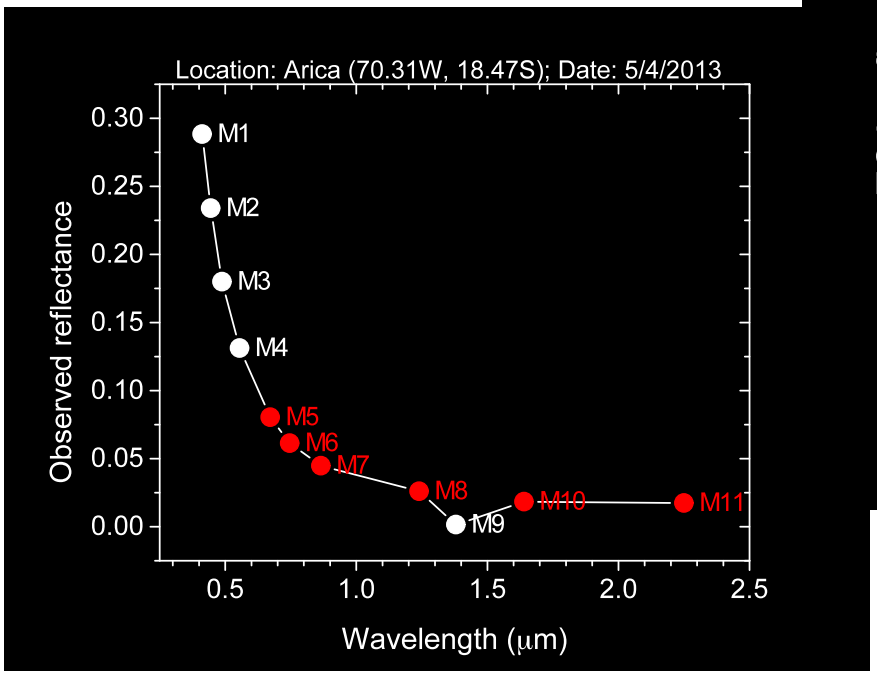
Repeated for all models; residuals of surface reflectances are calculated. **Solution is AOT and model with smallest residual.**

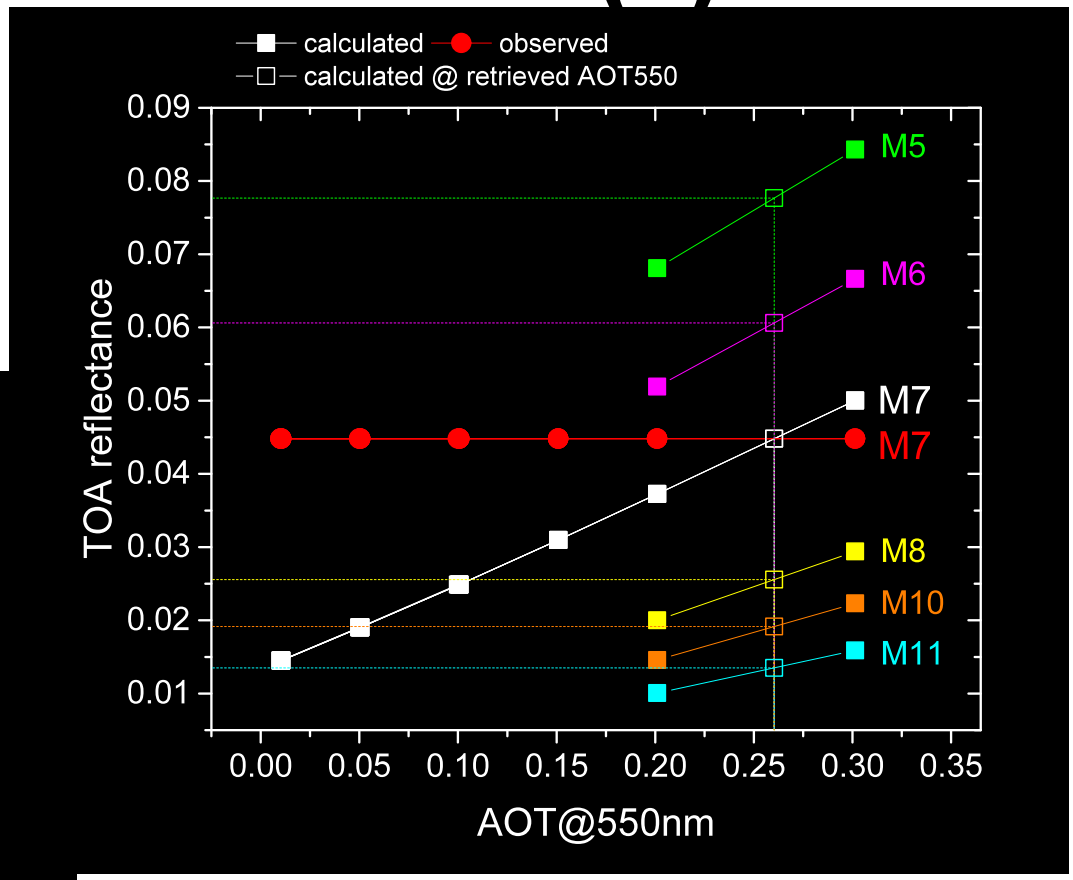
Over Ocean Retrieval (1)

- Close adaptation of the MODIS approach [*Tanré et al.*, 1997]
  - search for AOT and aerosol model that most closely reproduces the VIIRS-measured TOA reflectance in multiple bands.
  - wind-dependent (speed and direction) ocean surface reflectance is calculated analytically.
    - Accounts for water-leaving radiance (Lambertian, fixed pigment concentration), whitecap (Lambertian, wind-speed dependent) and specular reflection (dependent on wind speed and direction).
  - Combines 4 fine mode and 5 coarse mode models with 0.01 increments in fine mode fraction (2020 models)
  - TOA reflectances in selected M bands are calculated and compared to observed ones to retrieve AOT aerosol models and their weights simultaneously.

Over Ocean Retrieval (2)

- AOT for a given aerosol model is from matching calculated and observed **M7 TOA reflectances**.
- Retrieved AOT is used to calculate TOA reflectances in other channels.





Repeated for all combination of fine and coarse mode models; residuals of TOA reflectances are calculated. **Solution is AOT, fine and coarse mode models and their weights giving the smallest residual.**

Pixel Selection & Quality Flags

Condition	Quality Flag			Applies to		Detected by	
	Not Produced	Excluded	Degraded	Land	Ocean	VCM	Internal Tests
Invalid SDR data	X			X	X		X
Cloud Contamination	X			X	X	X	
Sun Glint	X			X	X	X	X
Snow/Ice	X			X	X	X	X
Fire	X			X		X	X
Bright Surface	X			X			X
Coastal or Inland Water	X					X	
Turbid Water	X				X		X
Ephemeral Water	X			X			X
SolZA ≥ 80°	X			X	X		X
Out of Spec Range		X		X	X		X
Cloud Adjacency			X	X	X		X
Cloud Shadow			X	X	X	X	
Cirrus			X	X	X	X	X
Soil Dominated			X	X			X
65° ≤ SolZA < 80°			X	X	X		X
Large Retrieval Residual			X	X	X		X

Sensor and Other Inputs

- VIIRS M-band SDRs (reflectances)
  - M1-M12, M15, M16, and quality flags
- Solar and view geometry
  - zenith and azimuth angles
- VIIRS Cloud Mask (VCM)
  - pixel cloud flag (clear/cloudy, probably clear/cloudy), cloud shadow, land/water, snow/ice, fire, sunglint, heavy aerosol, volcanic ash
- NCEP GFS data (backup:FNMOC/NAVGEM)
  - Water vapor, ozone, surface pressure, winds (speed and direction)
- Navy Aerosol Analysis and Prediction System (NAAPS) aerosol data
  - used for filling in missing VIIRS IP retrievals

VIIRS Aerosol Products (1)

- **Aerosol Optical Thickness (AOT)**
  - for 11 wavelengths (10 M bands + 550 nm); valid range: 0-2
- **APSP (Aerosol Particle Size Parameter)**
  - Ångström Exponent derived from AOTs at M2 (445 nm) and M5 (672 nm) over land, and M7 (865 nm) and M10 (1610 nm) over ocean
  - qualitative measure of particle size
  - **over-land product is not recommended!**
- **Suspended Matter (SM)**
  - classification of aerosol type (dust, smoke, sea salt, volcanic ash) and smoke concentration
  - currently, derived from VIIRS Cloud Mask (volcanic ash); aerosol model identified by the aerosol algorithm over land; and fine mode weight and AOT over ocean
- Only day time and over dark land and non-sunglint ocean

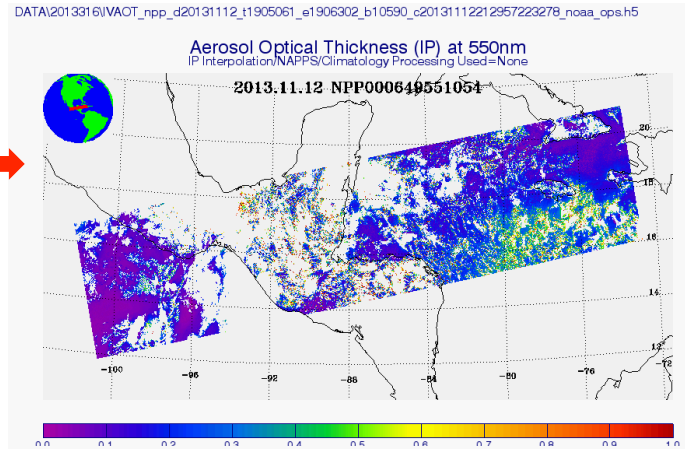
VIIRS Aerosol Products (2)

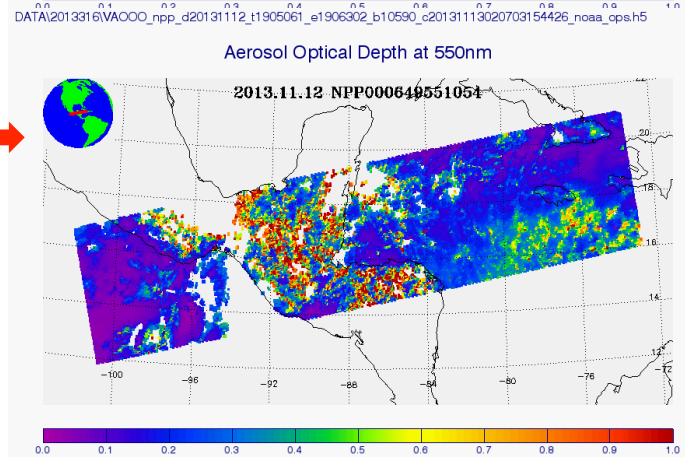
At NOAA Comprehensive Large Array-data Stewardship System (CLASS):

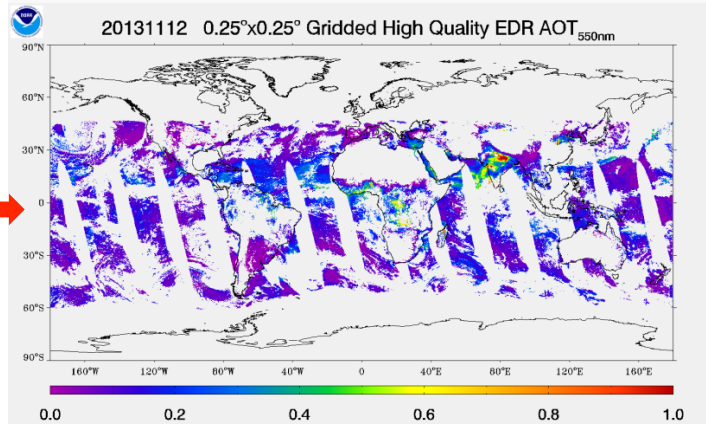
- **Intermediate Product (IP)**
  - 0.75-km pixel
    - AOT
    - APSP
    - AMI (Aerosol Model Information)
      - land: single aerosol model
      - ocean: indexes of fine and coarse modes and fine mode fraction
    - quality flags
- **Environmental Data Record (EDR)**
  - 6 km aggregated from 8x8 IPs filtered by quality flags
    - granule with 96 x 400 EDR cells
    - AOT
    - APSP
    - quality flags
  - 0.75 km
    - SM

At NOAA/NESDIS/STAR

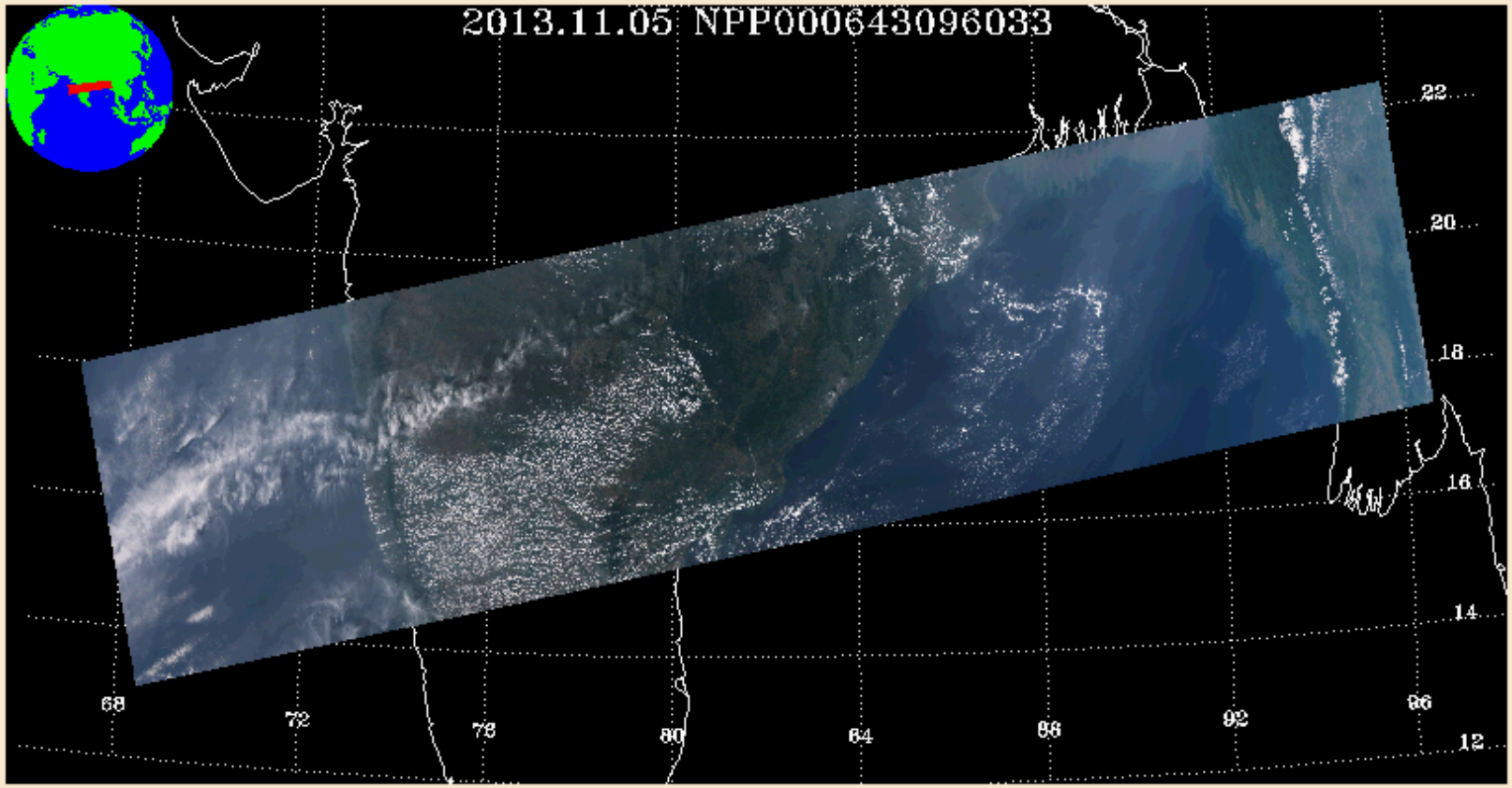
- **Gridded 550-nm AOT EDR**
  - regular equal angle grid: 0.25°x0.25° (~28x28 km)
  - only high quality AOT EDR is used



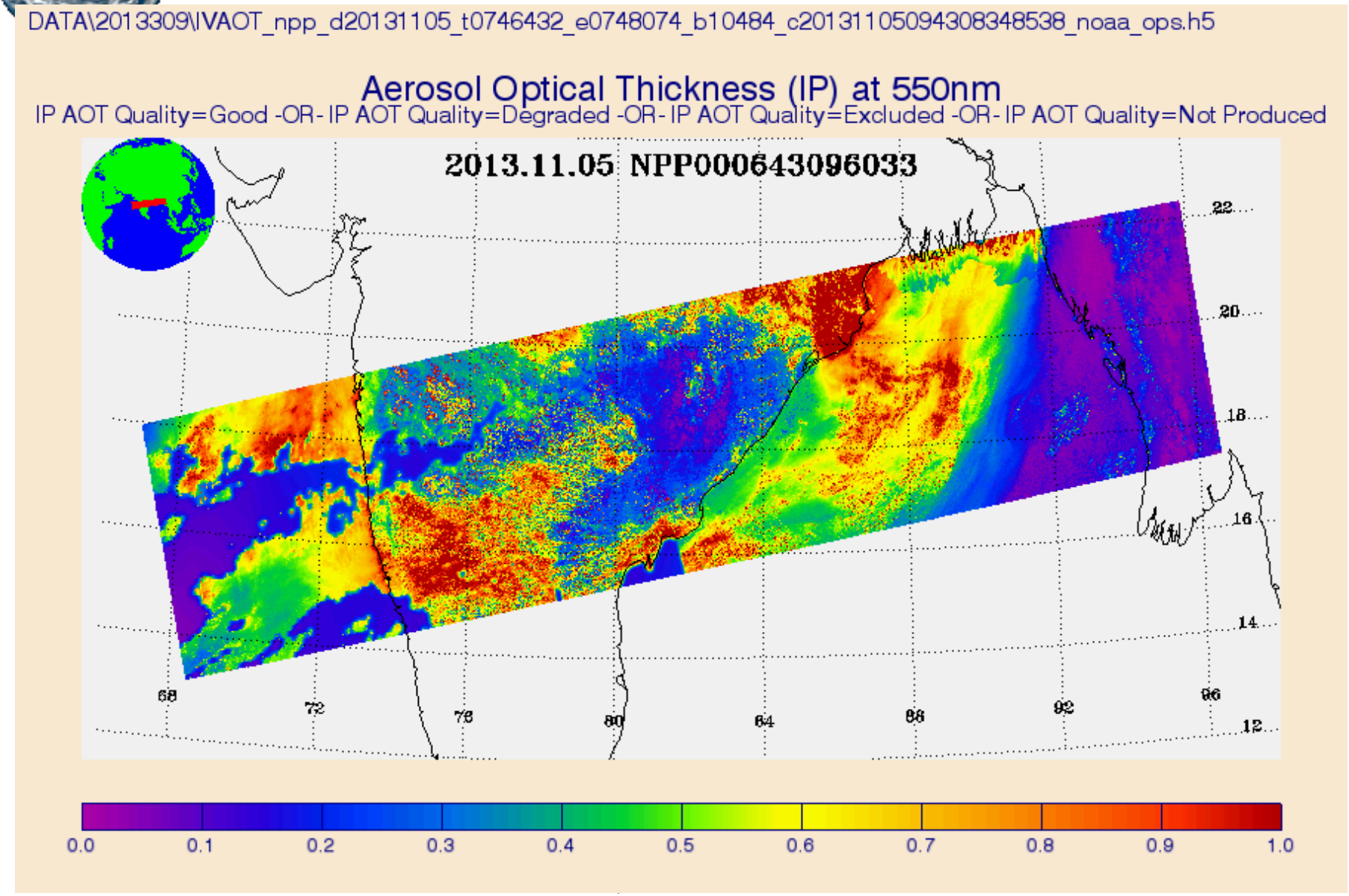




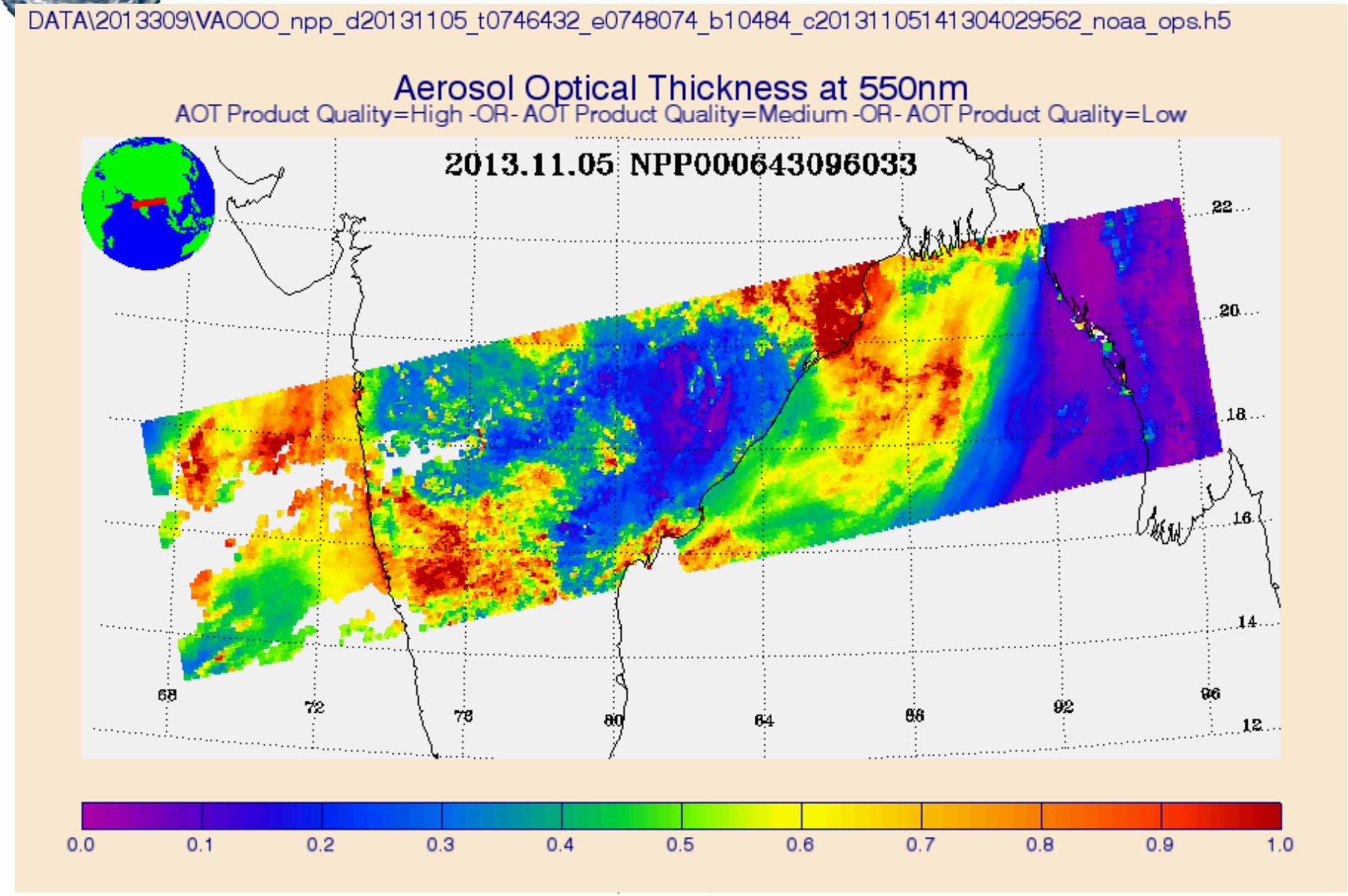
RGB Image [R=M5 (672 nm), G=M4 (555 nm), B=M3 (488 nm)]



AOT IP (“all” quality)



AOT EDR (“all” quality)



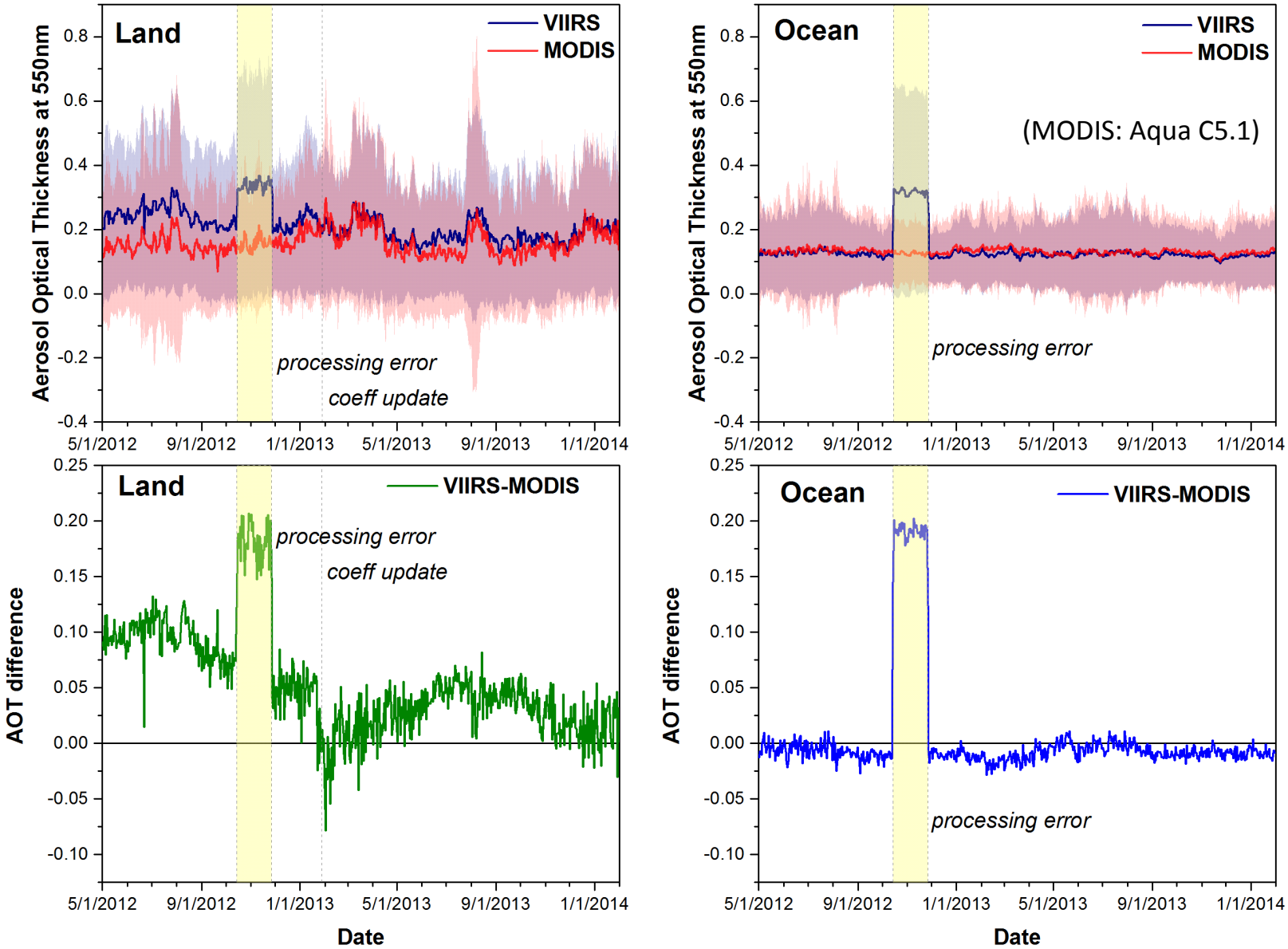
AOT Product Timeline

Products go trough various levels of maturity:

Red period:	Product is not available to public, or product should not be used.
Blue period: (Beta)	Product is available to public, but it should be used with caution, known problems, frequent changes.
Green period: (Provisional)	Product is available to public; users are encouraged to evaluate.

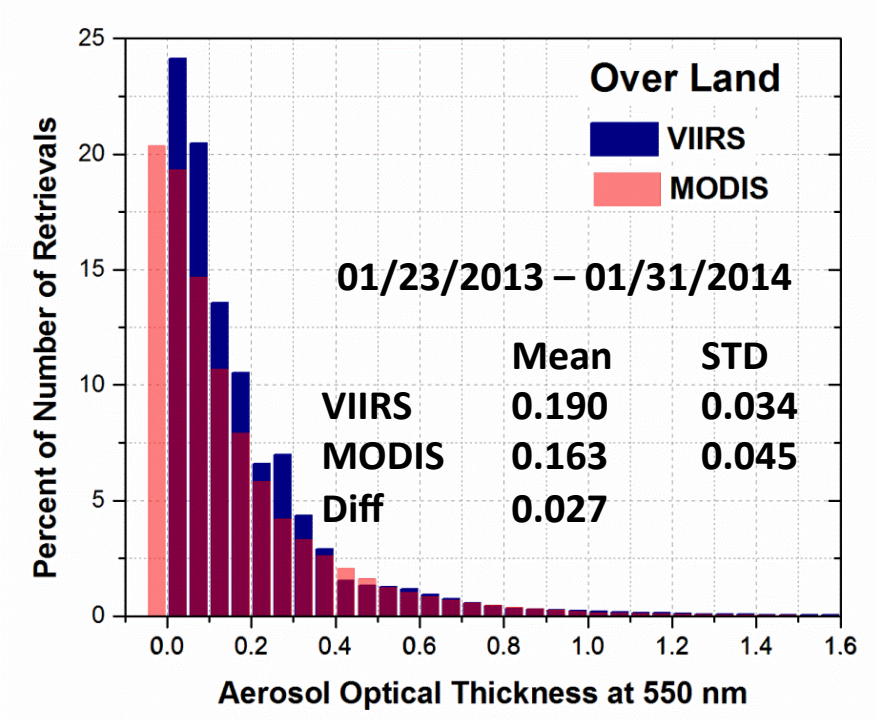
Time Series of Daily Mean Aerosol Products

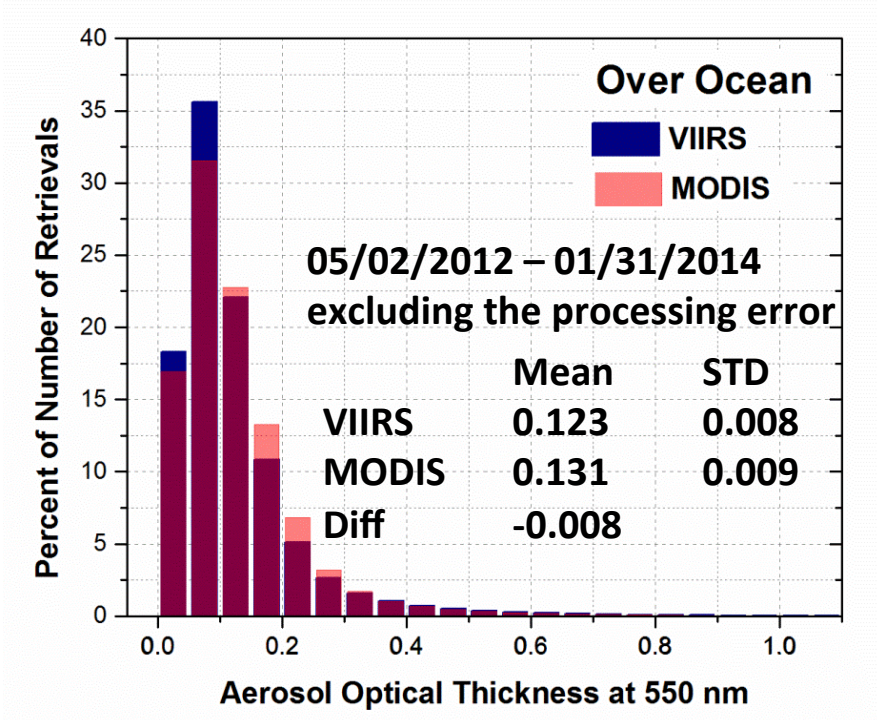
(non-collocated) (05/02/2012 – 01/31/2014)



Histogram of VIIRS and MODIS AOT

(non-collocated)



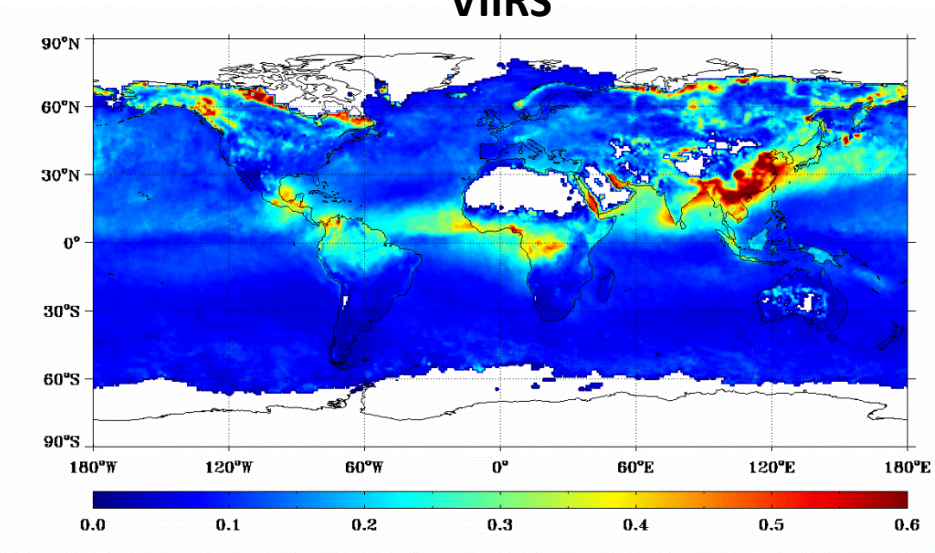


- Similar distributions
- Larger fraction of VIIRS retrievals at low AOT
- VIIRS does not report negative values

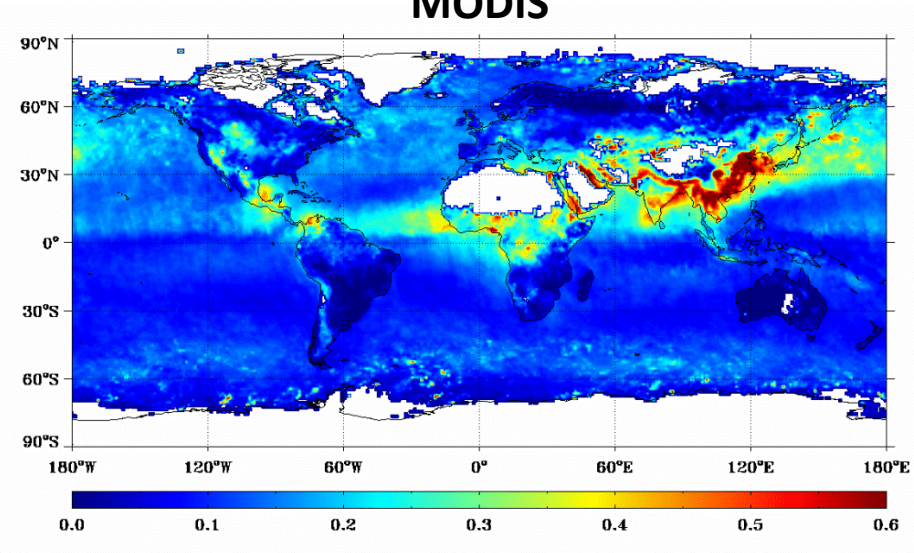
VIIRS and MODIS AOT (1° grid)

Spring: March-April-May, 2013

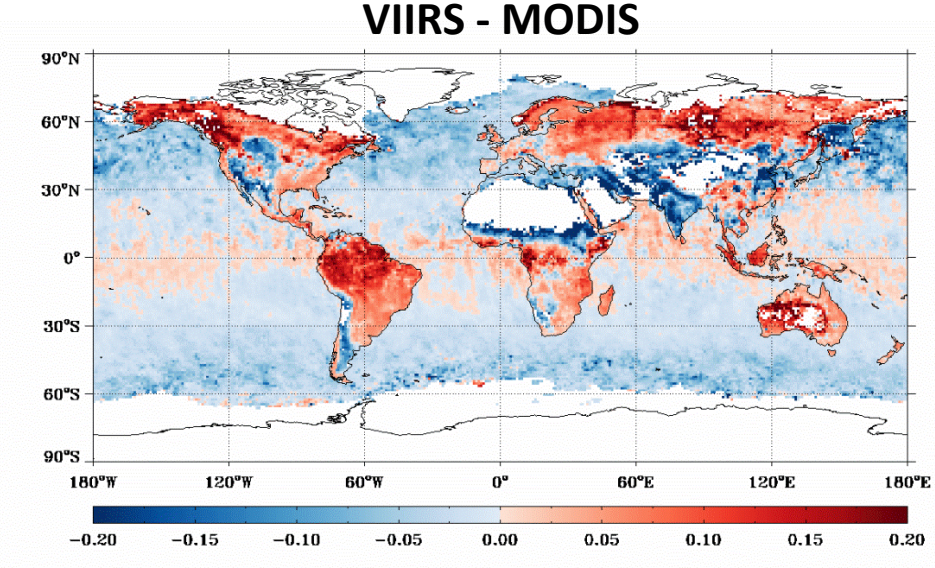
VIIRS



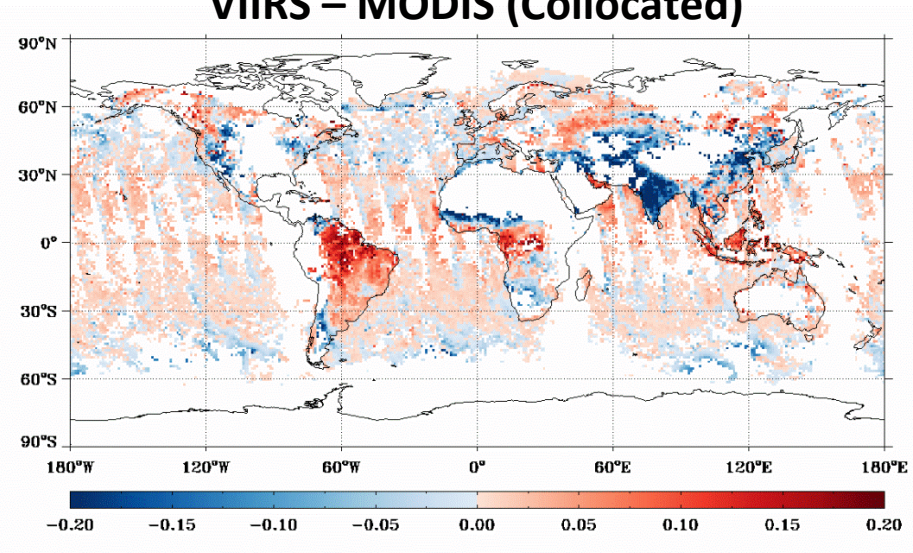
MODIS



VIIRS - MODIS

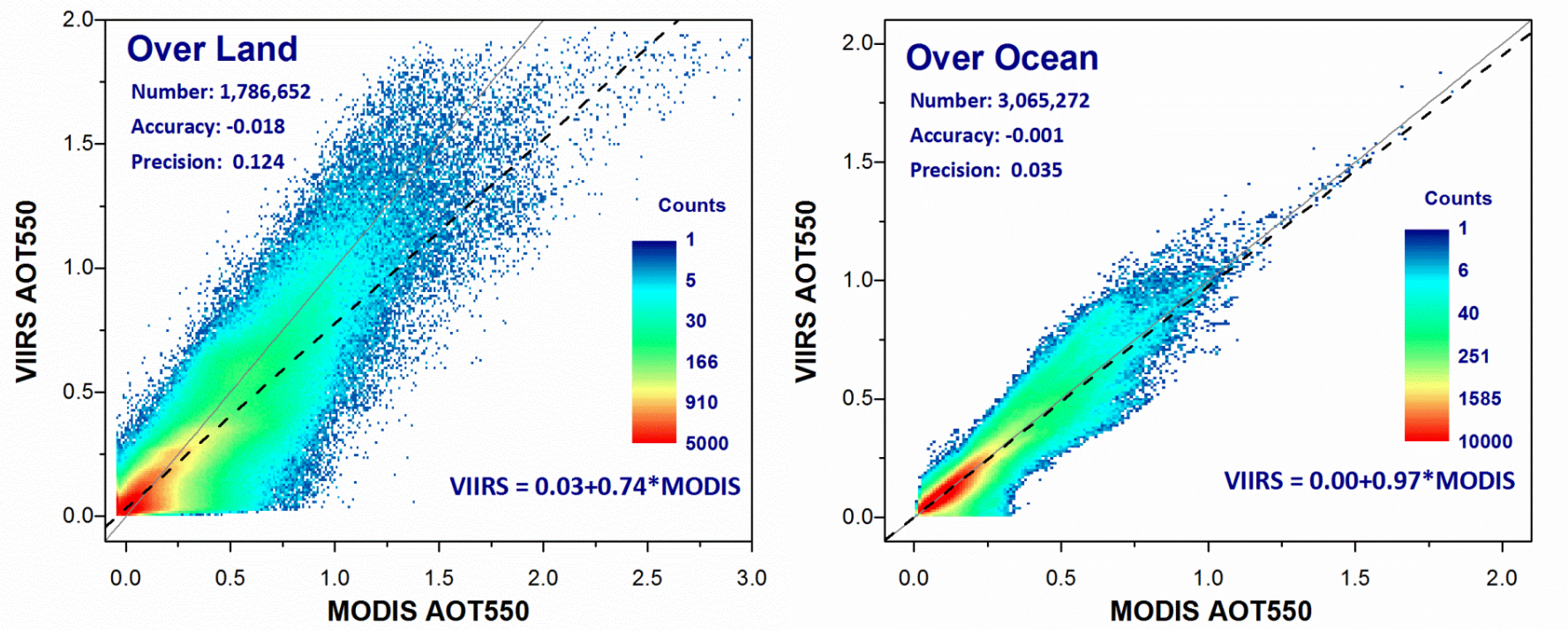


VIIRS – MODIS (Collocated)



Collocated VIIRS and MODIS AOT

Scatter Plots



- Over land: 01/23/2013 – 01/31/2014
- Over ocean: 05/02/2012 – 01/31/2014 excluding the processing error period (10/15/2012-11/27/2012)

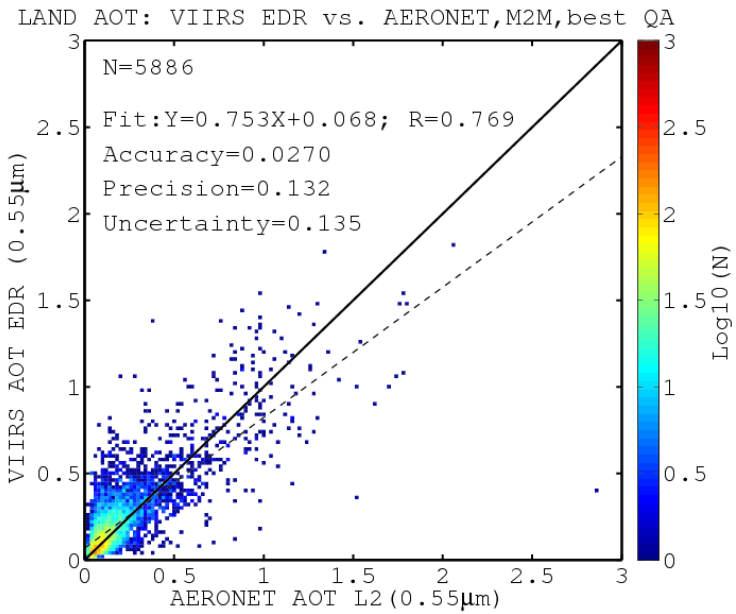
Evaluation with AERONET

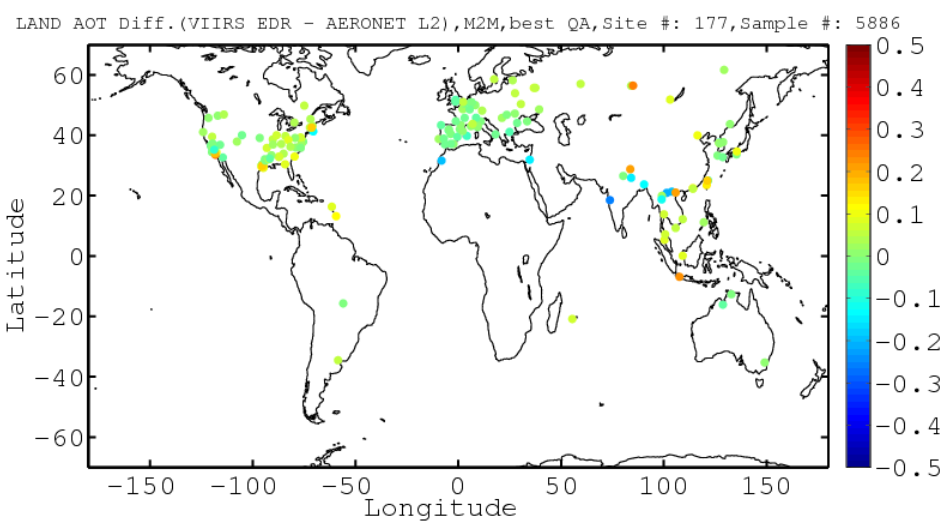
- **Matchup criteria (MAPSS* protocol):**
  - AERONET L2.0 **Direct Sun retrievals** (up to 536 sites) averaged within **±30 minutes** of VIIRS overpass time.
    - minimum **two AERONET AOT**
    - AERONET AOT data interpolated to 550 nm using a 2nd order polynomial fit of spectral AERONET AOT (if needed).
  - Best quality VIIRS AOTs (QF=0 for IP; QF=3 for EDR) averaged within a radius of **27.5 km** from the AERONET site.
    - minimum **five best quality VIIRS AOT**.

(*Multi-sensor Aerosol Products Sampling System)

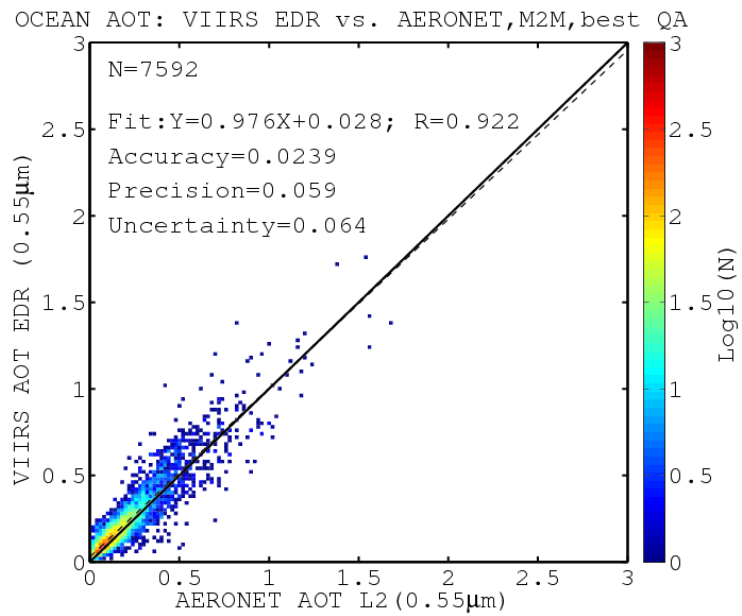
VIIRS AOT EDR vs. AERONET L2 AOT

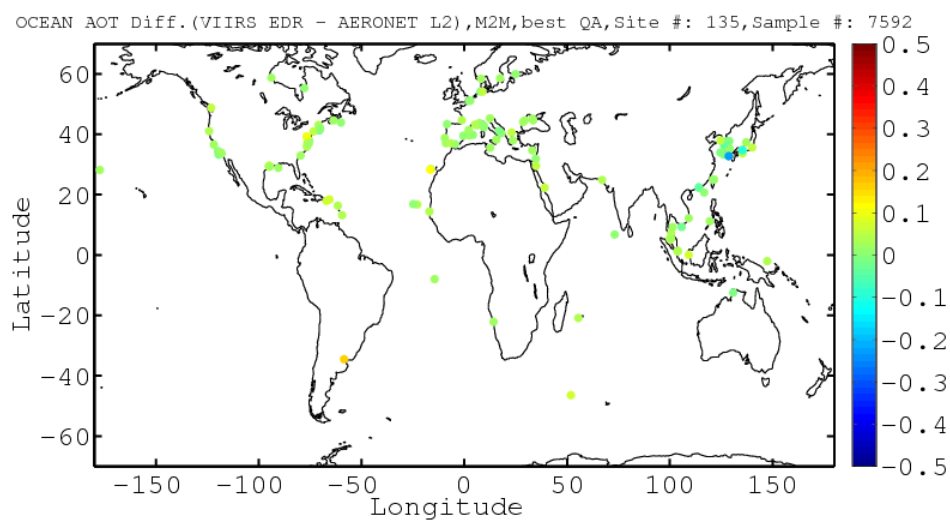
Land (01/23/2013-01/31/2014)





Ocean (05/02/2012-01/31/2014)





Satellite-derived AOT vs. AERONET L2 AOT

AOT (550 nm)	LAND				OCEAN			
	VIIRS EDR	VIIRS IP	MYD04	MISR	VIIRS EDR	VIIRS IP	MYD04	MISR
Sample Size	**5,886**	8,768	**2,189**	311	**7,592**	10,716	**2,606**	128
Mean difference	**0.027**	0.080	**0.003**	0.006	**0.024**	0.049	**0.007**	0.034
Std Deviation	**0.132**	0.170	**0.101**	0.123	**0.059**	0.088	**0.059**	0.050
RMS difference	**0.135**	0.188	**0.101**	0.123	**0.064**	0.100	**0.060**	0.060
Correlation	**0.769**	0.643	**0.904**	0.863	**0.922**	0.870	**0.913**	0.958

- *VIIRS and MODIS retrievals do NOT necessarily occur at the same station and date.*

- Land: 01/23/2013-01/31/2014
  - VIIRS bias and std dev are larger than those of MODIS
- Ocean: 05/02/2012-01/31/2014
  - VIIRS bias is larger than that of MODIS, but std dev and correlation are very similar

Satellite-derived AOT vs. AERONET L1.5 AOT

	Ocean		Land	
	VIIRS	MODIS	VIIRS	MODIS
Sample Size	1,652	1,281	4,647	3,624
Accuracy	0.007	-0.001	-0.028	-0.014
Precision	0.047	0.053	0.098	0.099
Uncertainty	0.048	0.053	0.102	0.100
Correlation	0.919	0.907	0.866	0.892
Percent within expected MODIS uncertainty range*	72.8%	66.6%	77.2%	67.2%

- Shorter period from earlier analysis(!):
  - Ocean: May 2, 2012 – September 1, 2013
  - Land: January 23, 2013 – September 1, 2013
- *Match-ups are limited to collocations in which VIIRS and MODIS retrievals occur at same station and date.*
- Over ocean, VIIRS performance is slightly better than that of MODIS.
- Over land, while VIIRS bias is larger, std dev and correlation are comparable.
- VIIRS performance re expected MODIS uncertainty is actually better.

*ocean: ±(0.03+0.05AOT); land: ±(0.05+0.15AOT)

Publications

- Jackson, J., H. Liu, I. Laszlo, S. Kondragunta, L. A. Remer, J. Huang, H-C. Huang, 2013: **Suomi-NPP VIIRS Aerosol Algorithms and Data Products**, *J. Geophys. Res.* doi: 10.1002/2013JD020449
- Liu, H., L. A. Remer, J. Huang, H-C. Huang, S. Kondragunta, I. Laszlo, M. Oo, J. M. Jackson, 2013: **Preliminary Evaluation of Suomi-NPP VIIRS Aerosol Optical Thickness**, *J. Geophys. Res.* doi:10.1002/2013JD020360

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STAR / SMCD / VIIRS Aerosol Calibration...
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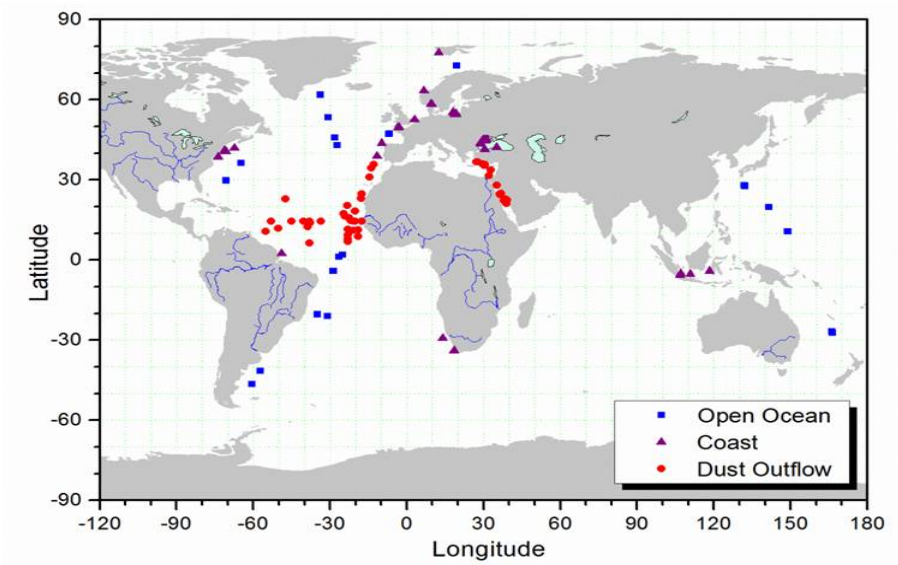
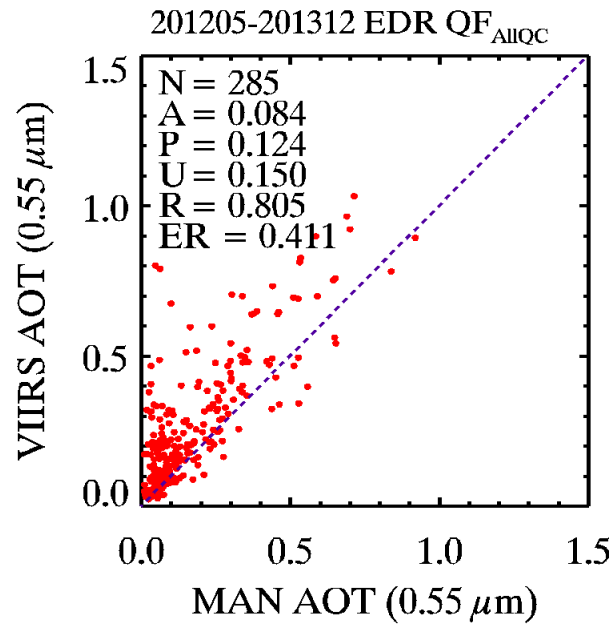
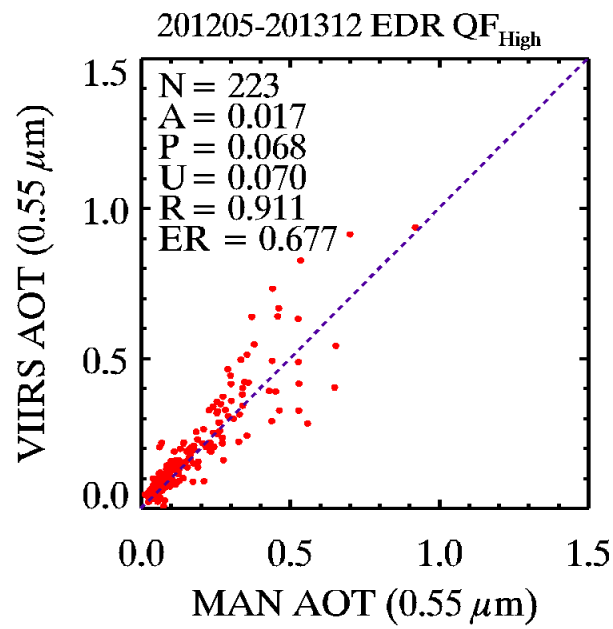
JUMP TO:
VIIRS AEROSOL
GRIDDED DATA
AOT VIDEO
Aerosol from SNPP/VIIRS
The Visible Infrared Imaging Radiometer Suite (VIIRS) sensor onboard the Suomi National Polar-orbiting Partnership (SNPP) satellite provides a key set of aerosol Environmental Data Records (EDRs) based on daily global observations from space. These products are:
Aerosol Optical Thickness (AOT), providing a measure of the aerosol content of the atmospheric column,
Aerosol Particle Size Parameter (APSP), given as the Ångström Exponent (AE), a qualitative measure of particle size with larger AE corresponding to smaller particles, and vice-versa,
Suspended Matter (SM), indicating the presence of dust, smoke, sea salt, volcanic ash above a threshold amount.
Global high quality AOT EDR at 550 nm on May 22, 2013. True color (RGB) image is provided as background to show the absence of retrievals due to cloud, sunglint and bright surface.
More information on these products is available from the Products page. Detailed instructions on how to access the data from their official archive location at the NOAA Comprehensive Large Array-data Stewardship System (CLASS) are provided in the subpages of the Products page.
Global gridded aerosol optical thickness
The operational VIIRS 550-nm AOT EDRs at nominal 6-km resolution, and collected during a 24-h period, are gridded at STAR on a
Secure Search
McAfee

Summary

- Compared to MODIS:
  - Performance of VIIRS AOT (550nm) retrieval is comparable with that of Aqua MODIS
  - global VIIRS EDR AOT-MODIS AOT difference
    - for uncollocated data
      - over ocean: -0.008 (~6%)
      - over land: 0.027 (~17%)
    - for collocated data:
      - over ocean: -0.001
      - over land: -0.018
- Compared to AERONET:
  - VIIRS can provide a quantitative measure of AOT with an uncertainty similar to that of MODIS
  - over land, VIIRS AOT EDR is biased higher and has larger standard deviation than MODIS
  - over ocean, VIIRS and MODIS standard deviations and correlations are very similar.

Planned Enhancements

- Replace current fixed surface reflectance relationships with NDVI-dependent relationships.
- Extend AOT reporting range to [-0.05, 5.0]
- Update ocean aerosol models with those from MODIS algorithm.
- Improve cloud/heavy-aerosol discrimination, snow/ice detection; add spatial variability internal test.
- Add Deep-Blue module to extend retrievals over bright surfaces.
- Provide aerosol files that are similar in format and content to those produced by the EOS MODIS aerosol algorithm.

Comparison with MAN data

- **Maritime Aerosol Network (MAN)**
  - Ship-borne measurements of AOT with Microtops II sun photometers (uncertainty < 0.02) [Smirnov et al., 2009]
  - Level 2 MAN: consecutive measurements within two minutes are averaged.
  - VIIRS-MAN match-up: VIIRS retrievals averaged within 0.5° lat/lon and one hour centered on the MAN observation.
    - At least 12 (about 20%) VIIRS EDRs.
    - Multiple collocations within one-hour time window are averaged to a single match-up.
  - 5/2/2012-12/31/2013 (excluding proc error)