Aerosol Measurements from the VIIRS Instrument During NPOESS

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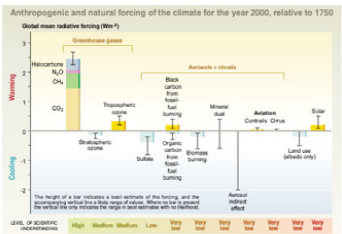
Why Measure Aerosols?

- Aerosol affect light propagation through the atmosphere, so will impact the operation of Precision Guided Munitions (PGM) and other Electro-Optical (EO) Sensors
- Volcanic Ash & Wind Blown Dust Impact Aircraft Operations
- Aerosols have a significant role in Climate Change and currently represent the largest uncertainties in IPCC assessments of global change



From IPCC 2001

Aerosol Impacts on Climate

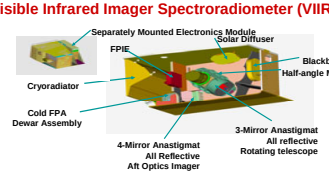
- Aerosols directly impact the earth's radiation balance by reflecting and absorbing the incident solar radiation.
  - This cools the earth's surface and atmosphere below the aerosols by reducing the incident sunlight, and locally heats the atmosphere surrounding the aerosols
- Aerosols indirectly affect the climate by altering clouds.
  - Aerosols act as Cloud condensation Nuclei (CCN)
  - They can increase the cloud albedo by distributing the cloud liquid water among more smaller droplets
  - They can increase the cloud lifetime because the smaller droplets reduce the rainfall

VIIRS at a Glance

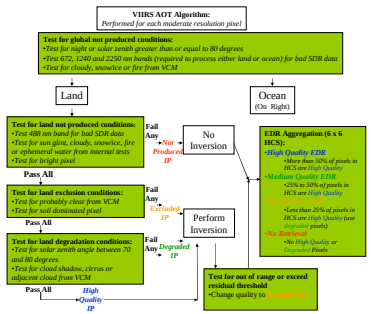
VIIRS: Visible Infrared Imager Radiometer Suite will provide the primary aerosol measurements from NPOESS

- VIIRS will continue the observational program of:
  - OLS: Optical Line Scanner
  - AVHRR: Advanced Very High Resolution Radiometer
  - SeaWiFS: Sea viewing Wide Field-of-view Sensor
  - MODIS: Moderate Resolution Imaging Spectroradiometer
- VIIRS will provide operational and research users with:
  - Spectral coverage from 412 nm to 12 microns in 22 bands
  - Imagery at 371 m nadir resolution in 5 bands
  - Moderate resolution (~742 m at nadir) radiometric quality data
  - Complete global daily coverage with a single sensor
  - 4 Measurements per day from the 2 NPOESS Satellites
  - Aerosols (& other EDRs) which require backscattered sunlight only get 1/day in winter & 2/day in summer hemisphere
- VIIRS also will provide Environmental Data Records (EDR) of:
  - Imagery (including nighttime visible imagery)
  - Cloud cover, cloud layers
  - Cloud and aerosol physical properties
  - Land & ocean biosphere properties, snow & ice
  - Sea Surface Temperature, Land & Ice Temperatures

Visible Infrared Imager Spectroradiometer (VIIRS)



Summary of VIIRS AOT Retrieval over Land



Core Inversion Equations

•Following the MODIS approach for retrieval of aerosol over Land, the surface reflectance in the red (672 nm) and blue (488 nm) bands is estimated from the TOA reflectance in the 2.25 µm band, enabling retrieval of the AOT and aerosol model retrieval.

Solve Lambertian surface reflectance equation for AOT using TOA reflectance in 488 nm band

$$\rho_{toa}(\tau_A) = Tg_{sg}Tg_{O_3}\left[\begin{array}{l}(\rho_{B-A}(\tau_A) - \rho_R(P_s))Tg_{H_2O}(U_{H_2O}/2) + \rho_R(P) \\ + Tg_{H_2O}(U_{H_2O})T_{B-A}(\tau_A,\theta_v)T_{B-A}(\tau_A,\theta_s)\dfrac{\rho_{surf}}{1 - S_{B-A}\rho_{surf}}\end{array}\right]$$

Variables computed internally: $Tg_{sg}, Tg_{O_3}, Tg_{H_2O}, \rho_R$

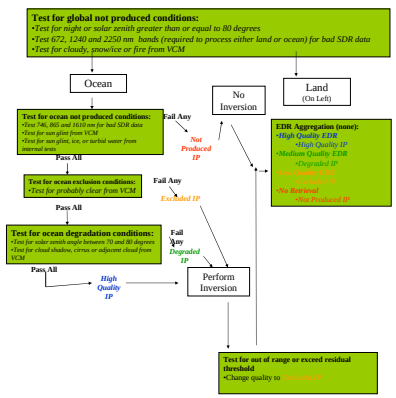
Variables derived from Look-up Tables: $\rho_{B-A}, T_{B-A}, S_{B-A}$

- For each model, solve for TOA reflectance at 672 nm using AOT derived from 488 nm band
  - Select model with best match to observe TOA 672 nm reflectance

Aerosol LUT Descriptions

- Computed with 6SV1.1 RTM
- Variables stored in LUTs:
  - Downward transmittance: T_{B-A}
  - Spherical albedo: S_{B-A}
  - Atmospheric reflectance: ρ_{B-A}
  - Ratio of τ_A to τ_{500}
  - Normalized integral of the downward irradiance with the ocean directional reflectance: $\overline{\rho_C}$
- Dimensions of LUTs:
  - Aerosol models (5 land, 9 ocean)
  - Bands (10)
  - AOT (15)
  - Scattering Geometry:
    - Solar Zenith, Sensor Zenith and Scattering Angle (5309)

Summary of VIIRS AOT Retrieval over Ocean



Core Inversion Equations

- Following the MODIS Approach, TOA reflectance is modeled as the sum of the TOA reflectances from the fine mode and coarse mode aerosols:

$$\rho_{toa}^{\eta}(\tau_a) = \eta\rho_{toa}^{f}(\tau_a) + (1-\eta)\rho_{toa}^{c}(\tau_a)$$

- Solve bi-directional surface reflectance equation for AOT using TOA reflectance in band

$$\rho_{toa} = Tg_{sg}Tg_{O_3}\left[\begin{array}{l}(\rho_{B-A} - \rho_R(P_s))Tg_{H_2O}(U_{H_2O}/2) + \rho_R(P) \\ + Tg_{H_2O}(U_{H_2O})\left[\begin{array}{l}T_{B-A}(\theta_s)T_{B-A}(\theta_v)\dfrac{\rho_{surf}}{1 - S_{B-A}\rho_{surf}} + e^{-\tau_{B-A}/m}\rho_C \\ + t_{B-A}^{d}(\theta_s)e^{-\tau_{B-A}/\cos(\theta_s)}\overline{\rho_C} + t_{B-A}^{d}(\theta_v)e^{-\tau_{B-A}/\cos(\theta_v)}\overline{\rho_C} \\ + t_{B-A}^{d}(\theta_s)t_{B-A}^{d}(\theta_v)\overline{\overline{\rho_C}} + \dfrac{T_{B-A}(\theta_v)T_{B-A}(\theta_s)S_{B-A}\overline{\overline{\rho_C}}}{1 - S_{B-A}\overline{\overline{\rho_C}}}\end{array}\right]\end{array}\right]$$

Variables computed internally: $Tg_{sg}, Tg_{O_3}, Tg_{H_2O}, \rho_R, \rho_{surf}, \rho_C, \overline{\rho_C}, \overline{\overline{\rho_C}}$

Variables derived from Look-up tables: $\rho_{B-A}, T_{B-A}, S_{B-A}, \overline{\rho_C}, \overline{\overline{\rho_C}}$

- Fore each model solve for TOA reflectances in the 672, 865, 1610 and 2250 nm bands using AOT derived from 1240 nm and compute residual:

$$\mathrm{Residual}^{\eta} = \sum_{i=4}^{N}\left(\rho_{toa}^{i}(\tau_a^{240})^{\eta} - \rho_{obs}^{i}\right)$$

- Select model with the lowest residual

Aerosol Model Descriptions

Land Aerosol Models

Dust
$r_v^{fine} = 0.12, \sigma = 0.49 + 0.10r, r_v^{coarse} = 1.9, \sigma = 0.63 - 0.10r, n = 1.48 - 2.5\times10^{-3}i$

Smoke (High)
$r_v^{fine} = 0.12 + 0.025r, \sigma = 0.4, r_v^{coarse} = 3.22 + 0.71r, \sigma = 0.73, n = 1.51 - 2.1\times10^{-3}i$

Smoke (Low)
$r_v^{fine} = 0.13 + 0.04r, \sigma = 0.4, r_v^{coarse} = 3.27 + 0.58r, \sigma = 0.79, n = 1.47 - 9.3\times10^{-3}i$

Urban (Low)
$r_v^{fine} = 0.12 + 0.11r, \sigma = 0.38, r_v^{coarse} = 3.03 + 0.49r, \sigma = 0.75, n = 1.41 - 3\times10^{-3}i$

Urban (High)
$r_v^{fine} = 0.12 + 0.04r, \sigma = 0.43, r_v^{coarse} = 2.72 + 0.6r, \sigma = 0.63, n = 1.47 - 1.4\times10^{-2}i$

Ocean Aerosol Models

Fine Mode 1 (Water Soluble)
$r_v = 0.07, \sigma = 0.4, n = 1.45 - 3.5\times10^{-3}i$

Fine Mode 2 (Water Soluble)
$r_v = 0.06, \sigma = 0.6, n = 1.45 - 3.5\times10^{-3}i$

Fine Mode 3 (Water Soluble)
$r_v = 0.08, \sigma = 0.6, n = 1.4 - 2\times10^{-3}i$

Fine Mode 4 (Water Soluble)
$r_v = 0.1, \sigma = 0.6, n = 1.4 - 2\times10^{-3}i$

Coarse Mode 1 (Sea Salt)
$r_v = 0.4, \sigma = 0.6, n = 1.45 - 3.5\times10^{-3}i$

Coarse Mode 2 (Sea Salt)
$r_v = 0.6, \sigma = 0.6, n = 1.45 - 3.5\times10^{-3}i$

Coarse Mode 3 (Sea Salt)
$r_v = 0.8, \sigma = 0.6, n = 1.45 - 3.5\times10^{-3}i$

Coarse Mode 4 (Dust Like)
$r_v = 0.6, \sigma = 0.6, n = 1.53 - 1\times10^{-3}i$

Coarse Mode 5 (Dust Like)
$r_v = 0.5, \sigma = 0.8, n = 1.53 - 1\times10^{-3}i$

VIIRS Validation

AERONET and several other sunphotometer networks measure Aerosol Optical Thickness (AOT) and sky radiance and downwelling solar irradiances.

These will allow retrieval of the aerosol particle size parameter (either Ångström exponent or effective radius) in addition to the AOT.

At least for NPP there will be some other satellite aerosol measurements.

The Aerosol Polarimetry Sensor (APS) on NASA's Glory Mission (scheduled for launch in December 2008)

Hopefully one of the MODIS instruments on Terra or Aqua will still be operational.

There should be at least a couple of AVHRR/3 instruments on the NOAA polar orbiters and METOP

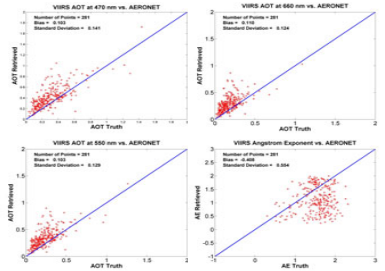
Pre-Launch Validation Methodology

- MODIS / AERONET match-up data and analysis methodology used
  - See Remer et. al., [*J. Atmos. Sci.*, **62**, 947-973, 2005]
  - Quality controlled AERONET retrievals are averaged from ± 30 minutes from MODIS overpass
  - AERONET retrievals at 440 nm and 870 nm are interpolated linearly in log space to the MODIS band wavelengths
- MODIS Level 1B data processed through VIIRS algorithm (modified for MODIS band pass definitions)
  - High quality VIIRS pixel level AOT retrievals are aggregated to the MODIS 5 cell x 5 cell area used for comparison to AERONET
  - 20 granules of MODIS data processed through VIIRS algorithm
    - Approximately 300 match-up data points used (land only)

AERONET Locations

Preliminary Pre-Launch Validation Results

Validation results versus AERONET match-up Data shown below



Summary

To date, validation of the VIIRS AOT and Particle Size algorithm using MODIS Level 1B data as input and match-up AERONET data as truth has been limited to approximately 300 data points over land. Initial results are promising, and the algorithms provide comparable quality to the heritage MODIS Aerosol algorithm (Collection 4) while performing the retrieval at a higher spatial resolution. Pre-launch validation work will continue and be extended to ocean retrievals over the next several years prior to deployment of the first VIIRS sensor on the NPP satellite.

Aerosol Optical Thickness Requirements

Measure Range	0.0 to 2.0 units of τ
Measurement Accuracy	
Over Ocean, τ < 0.5	0.02
Over Ocean, τ > 0.5	0.07*τ - 0.015
Over Land, τ < 1.0	0.1
Over Land, τ > 1.0	0.15
Measurement Precision	
Over Ocean, τ ≤ 0.6	0.02
Over Ocean, τ > 0.6	0.03
Over Land	0.1
Long Term Stability	0.01
Measurement Uncertainty over Land	
τ < 0.45	0.05 + 0.2* τ
0.45 < τ < 1.0	0.14
τ > 1.0	0.18
For 70º < Solar Zenith Angle < 80º Degraded Accuracy, Precision, & Uncertainty	
Excluded Measurement Conditions	
Solar Zenith Angle < 80°	
Over Oceans with Sun Glint < 36°	
Over land Without Dark Vegetation i.e. without Dark Pixel in 2.25 µm Band	

Aerosol Particle Size Parameter Requirements

Measurement Range (Ångström Exponent, α)	**-1 < α < +3**
Measurement Accuracy	
Over Ocean, τ < 0.04	0.3 α units
Over Ocean, τ > 0.04	0.1 α units
Over Land	0.6 α units
Measurement Precision	
Over Ocean, τ < 0.04	0.3 α units
Over Ocean, τ > 0.04	0.1 α units
Over Land	0.6 α units
For 70º < Solar Zenith Angle < 80º Degraded Accuracy & Precision	
Excluded Measurement Conditions	
Solar Zenith Angle < 80°	
Over Oceans with Sun Glint < 36°	
Over land Without Dark Vegetation i.e. without Dark Pixel in 2.25 µm Band	

Suspended Matter Requirements

Measurement Range	
Detection	Flag cells where atmosphere contains suspended matter
Identify the Type of Suspended Matter for: (All from VIIRS except SO_2 from OMPS)	Dust, Sand, Volcanic Ash, Sea Salt, Smoke, & SO_2
Concentration (for smoke only)	0-1000 µgm / m³
Probability of Correct Type Identification	
Suspended Matter	90 %
Dust/Sand	85 %
Smoke	85 %
Volcanic Ash	85 %
Sea Salt	85 %
SO_2 (from OMPS with Index ≥ 3 Dobson Units)	85 %
Measurement Uncertainty for Smoke Concentration	50 %
Excluded Measurement Conditions	
Solar Zenith Angle < 80°	
Over Oceans with Sun Glint < 36°	
Over land Without Dark Vegetation i.e. without Dark Pixel in 2.25 µm Band	