# How to Use the NOAA Enterprise Cloud Mask (ECM)

**Andrew Heidinger, Tom Kopp, Denis Botambekov and William Straka**

*JPSS Cloud Team*

*August 29, 2015*

# Outline

- Describe ECM and its differences to VCM
- Describe the Cloud Probability
- Demonstrate using the Cloud Probability to optimize cloud detection.
- Visually compare ECM and VCM

# ECM

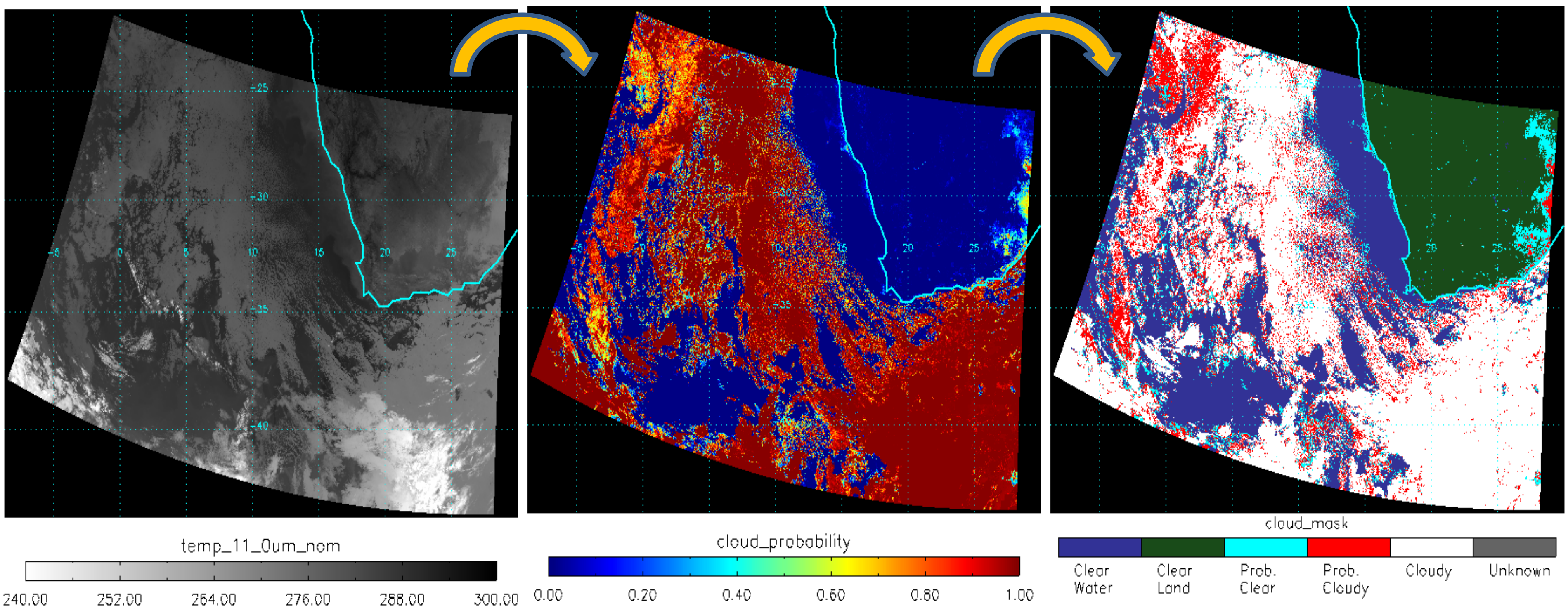
- ECM is the NOAA Enterprise Cloud Mask
- Uses the same tests as the GOES-R Cloud Mask.
- Naïve Bayesian methodology.
- Fundamental output is cloud probability.
- Supports GOES-Imager, AVHRR, VIIRS, MODIS, AHI, MTSAT, COMS, SEVIRI.

*Note there is a full Bayesian Cloud Mask used by the GOES SST team which is unrelated to this effort.*

# CLOUD PROBABILITY

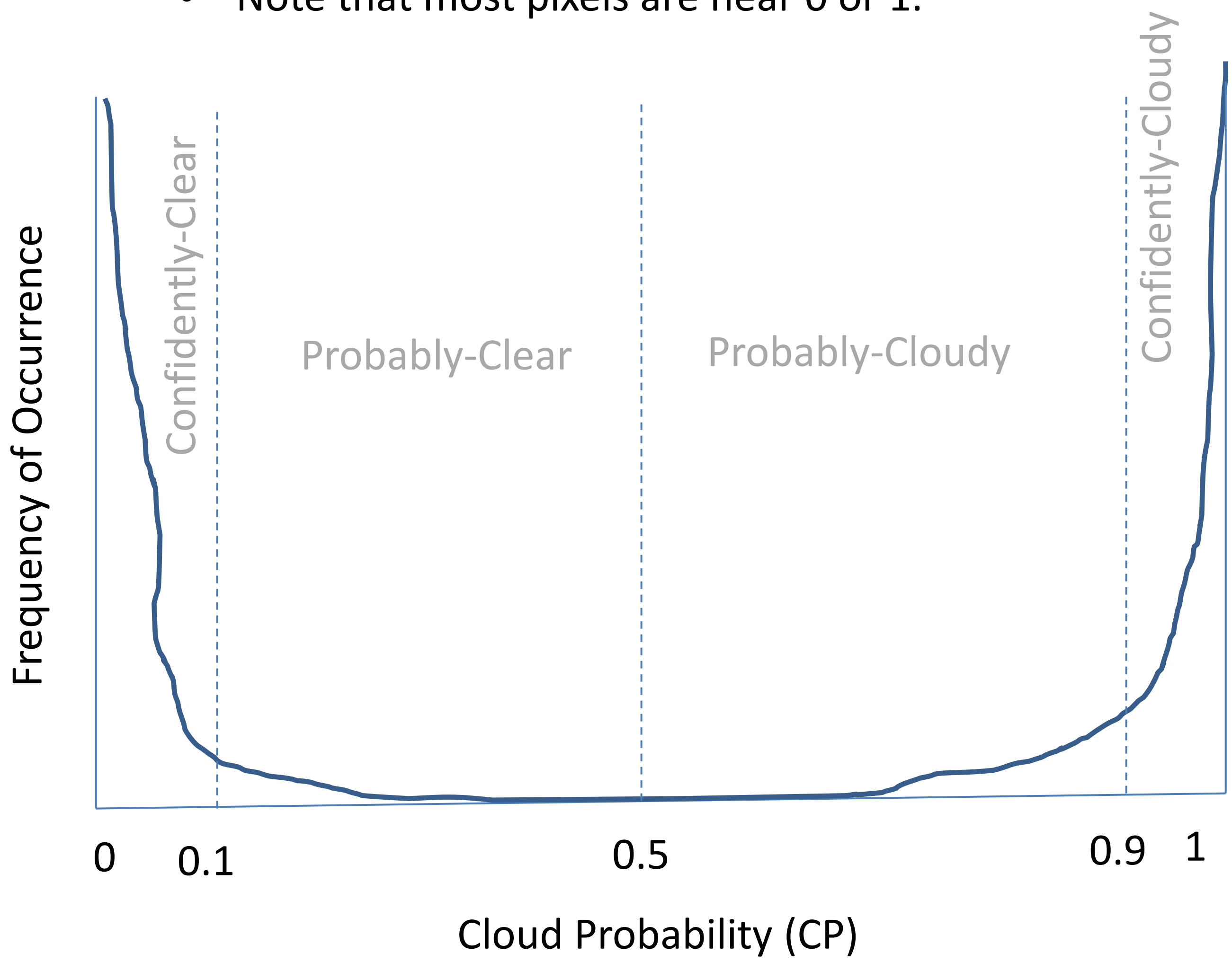
# Cloud Probability Example

- Cloud probability is defined as the probability (0-1) of a pixel being classified as cloudy and is the output of our Naïve Bayesian scheme.
- In our case, the definition of cloudy comes from the NASA CALIPSO/CALIOP (a space borne lidar).
- The 4-level mask comes directly from the cloud probability values.
- The example below shows results from nighttime data from the South Atlantic
- Very thin and warm cloudy at night often give probabilities less than 1.  These result in probably-cloudy classifications (red mask values).



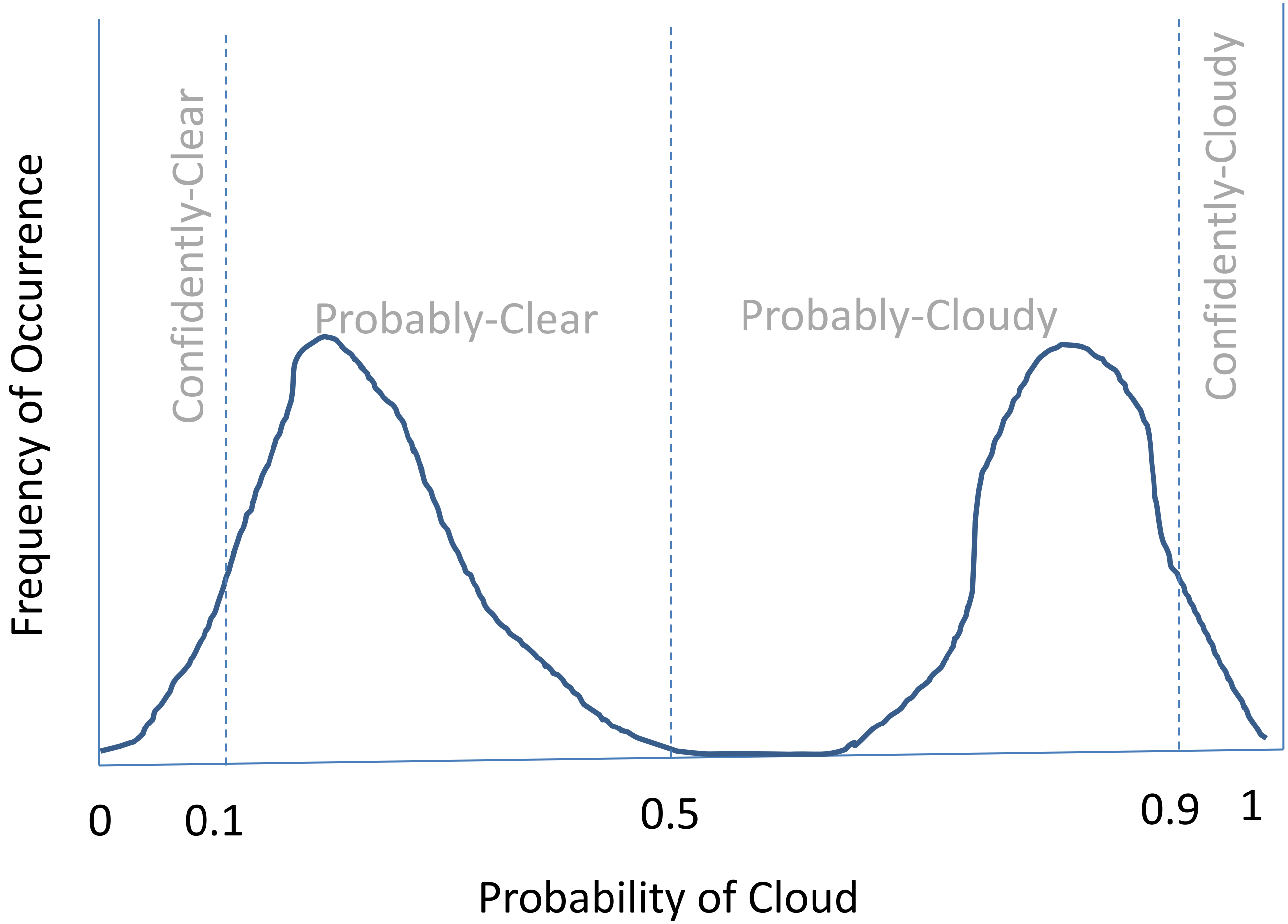
# Relationship Between Cloud Probability and 4-Level Cloud Mask

- This is the relationship for an ice-free ocean.
- Note that most pixels are near 0 or 1.



# Relationship Between Cloud Probability and 4-Level Cloud Mask

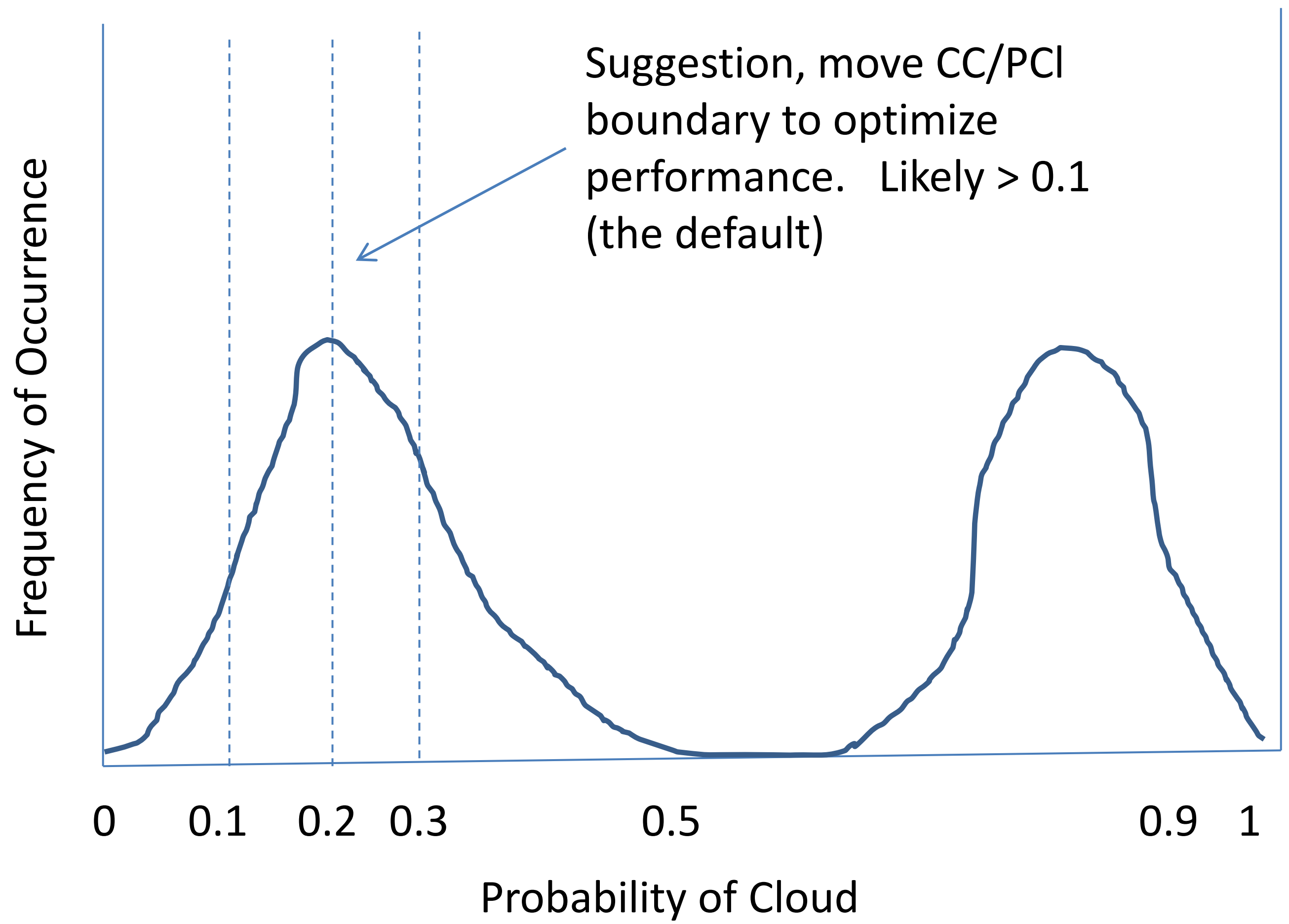
- This is the relationship for a snow/ice covered region.
- Note that most pixels are NOT near 0 or 1.
- ECM does not change boundaries for each surface type.



# OPTIMIZING CLOUD DETECTION

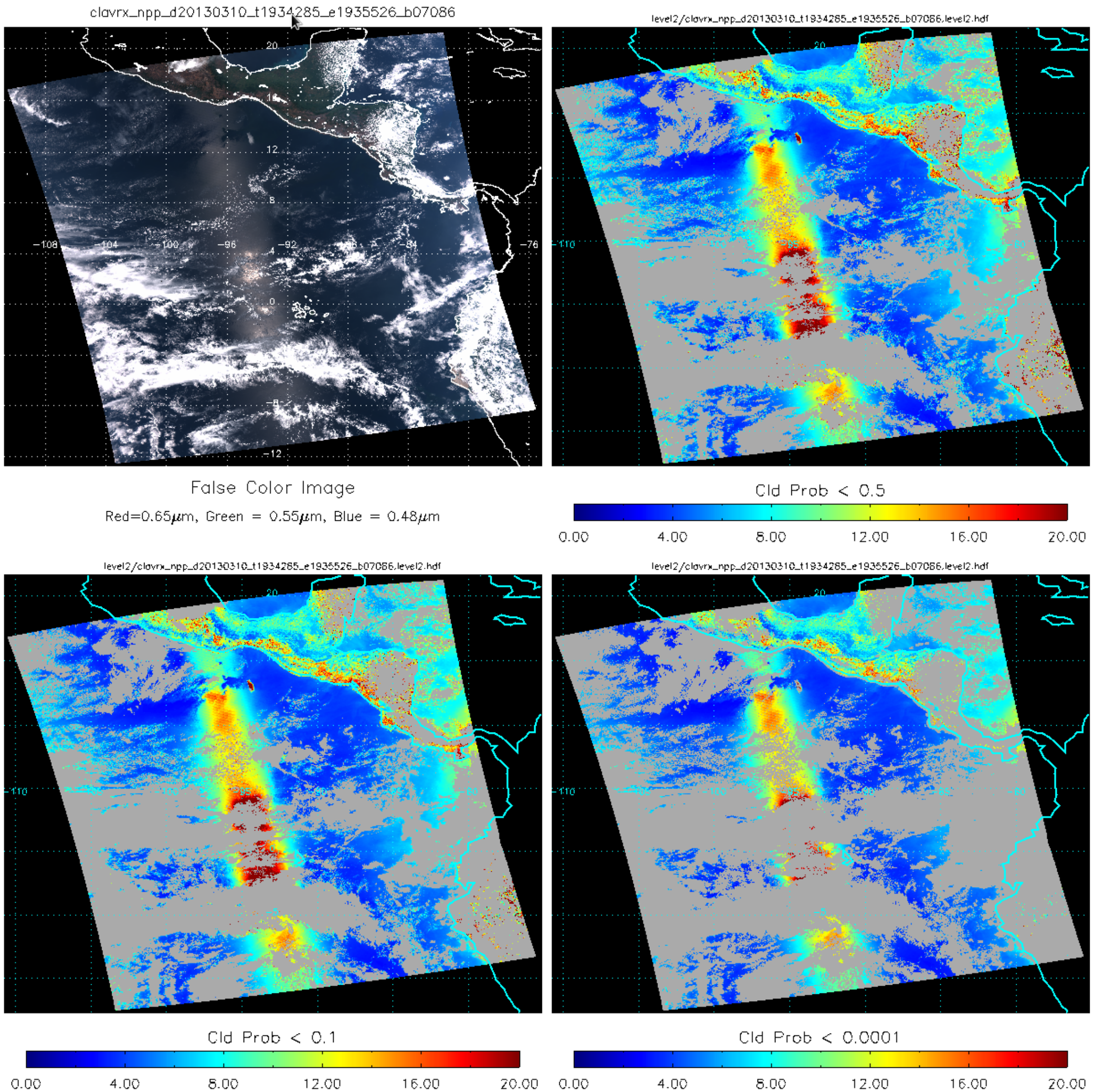
# Schematic Illustration of Tuning Cloud Probability for Optimally Clear Pixels

We have added different thresholds to illustrate moving the CP Threshold



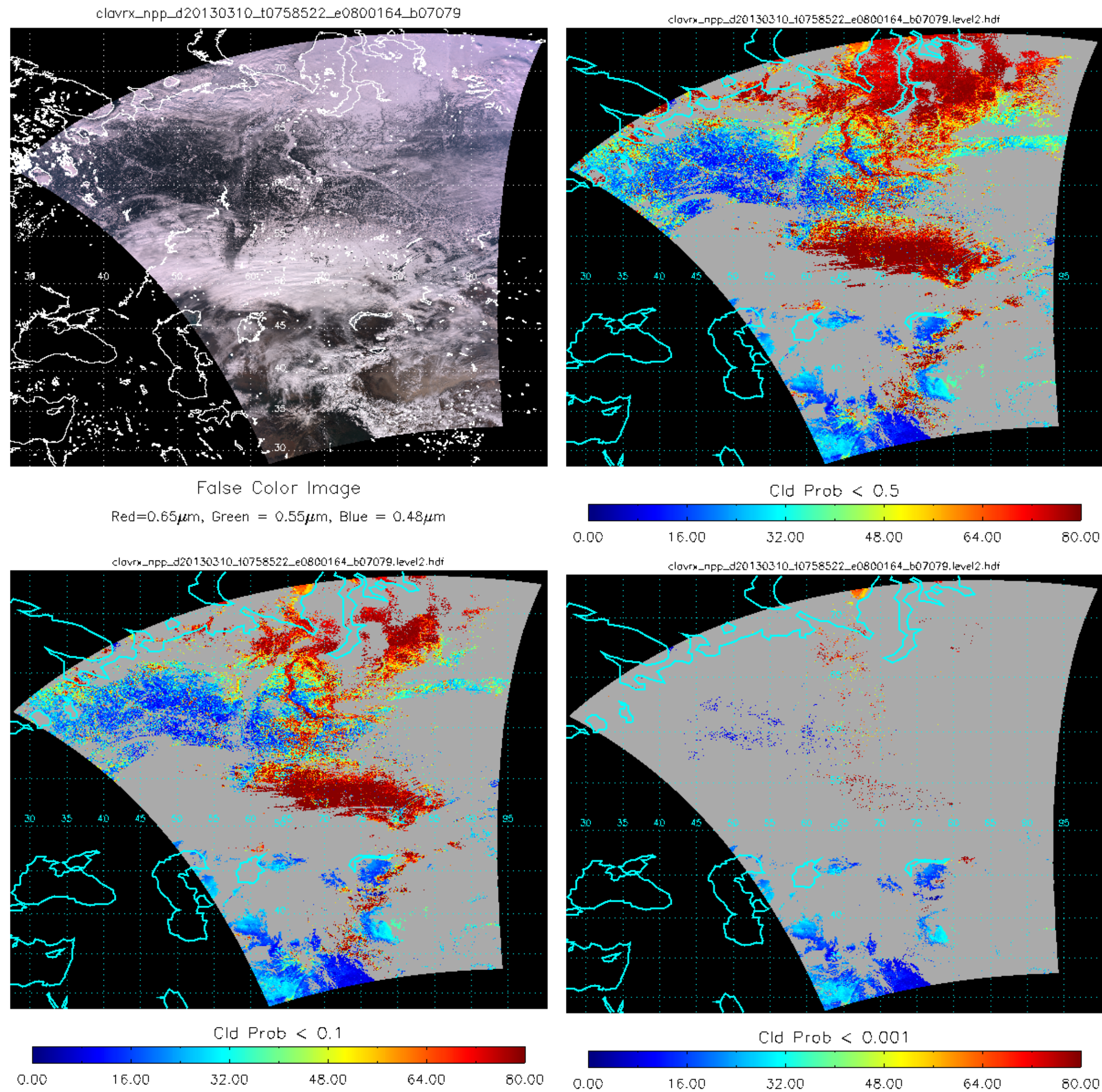
# Using the Cloud Probability (CP) to Optimize Clear Data

- The ECM provides the floating point cloud probability.
- In the 4-level mask, the confident clear is set for CP < 0.10.
- Maybe this value is not optimal?
- The images on the right show images of the 0.65 μm reflectance with masks overlaid. Each mask is a threshold of CP.
- Optimal CP value for clear ocean may be less than 0.1



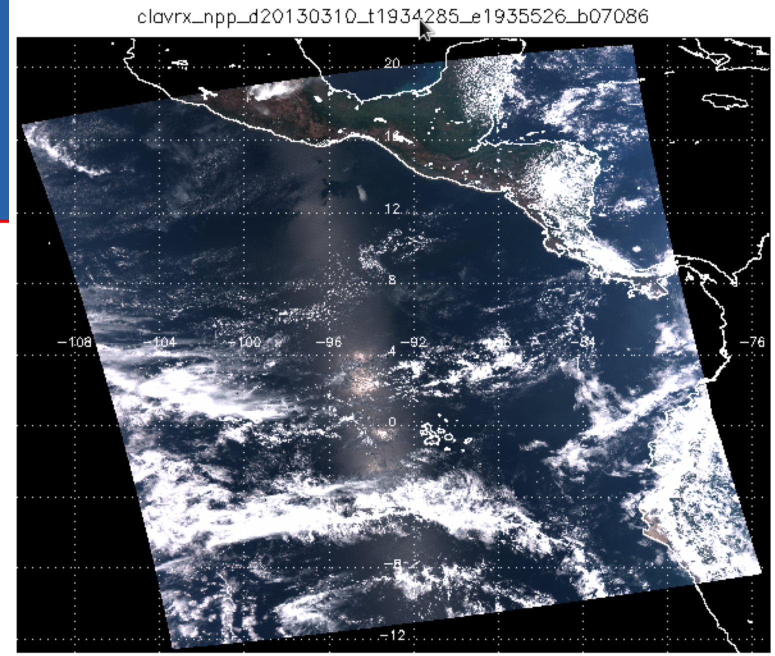
# Using the Cloud Probability (CP) to Optimize Clear Data

- Same analysis as before except applied to a Northern Europe/Asia.
- Note that presence of CP < 0.1 are rare.
- Optimal CP threshold is likely between 0.1 and 0.5.
- Unlike Ocean, very few pixels have CP << 0.1
- This behavior is expect since the ability to predict clear-sky drives how close to CP=0 we can get.



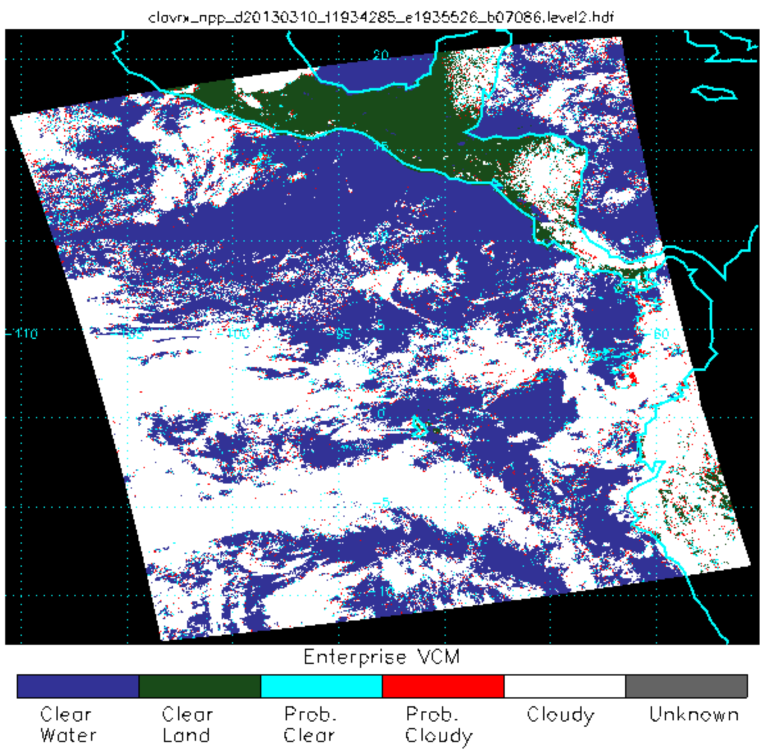
# VISUAL COMPARISON OF ECM WITH VCM

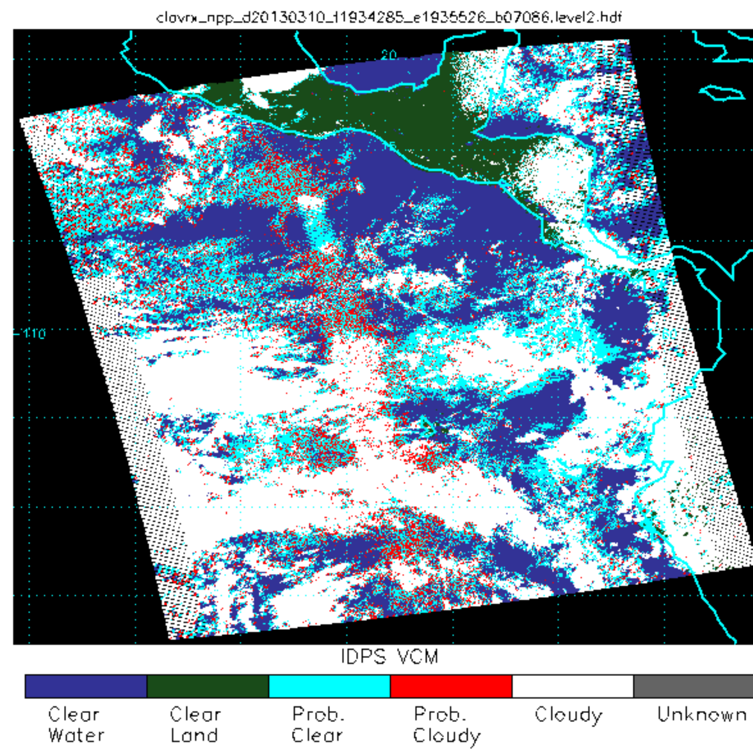
# Difference with VCM for an ocean scene




- This scene is from March 10, 2013 in Eastern Tropical Pacific.
- ECM on the bottom left. VCM on the bottom right.
- Differences in glint regions. (likely false Cloud in VCM)
- More probably clear in VCM. More Cloudy in ECM.

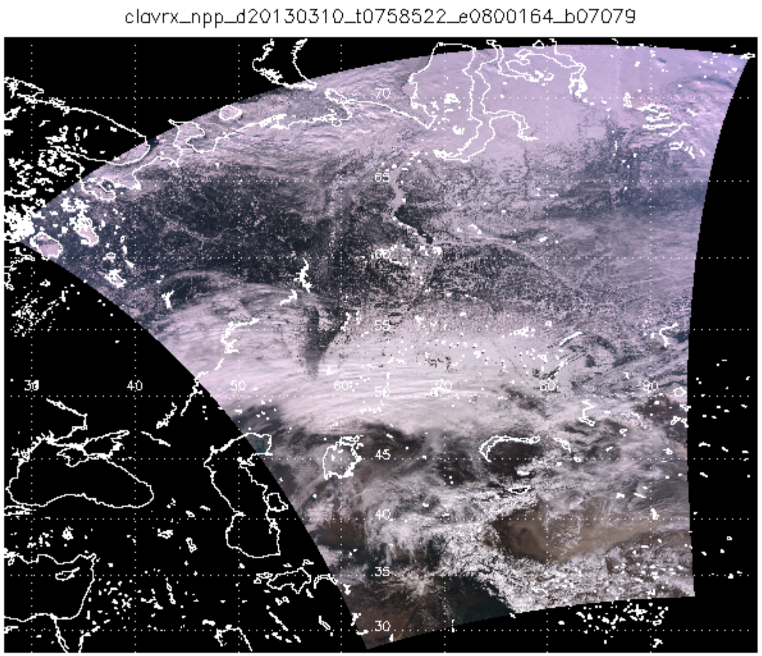
Note, SAPF and CLAVR-x use bow-tie gap filling.

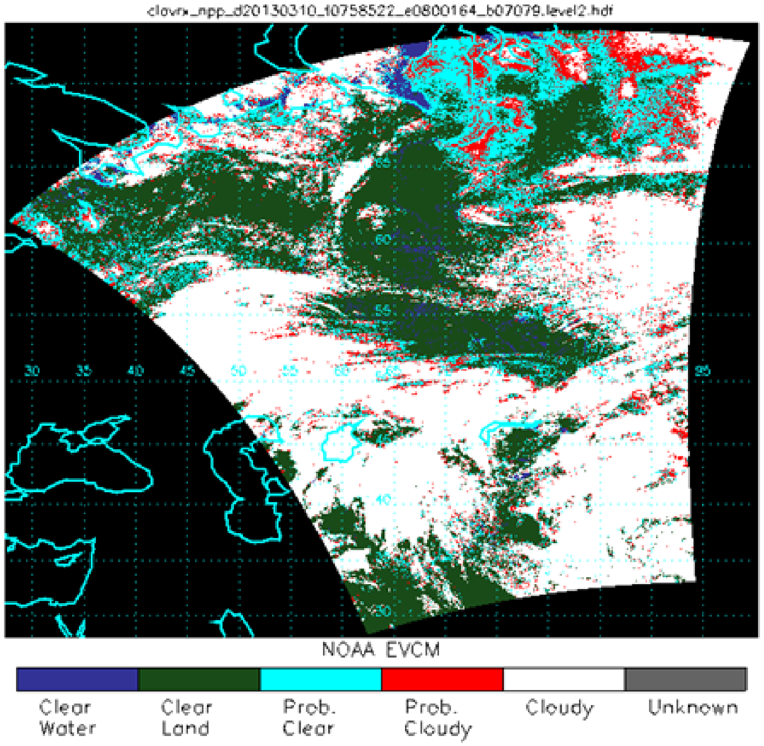


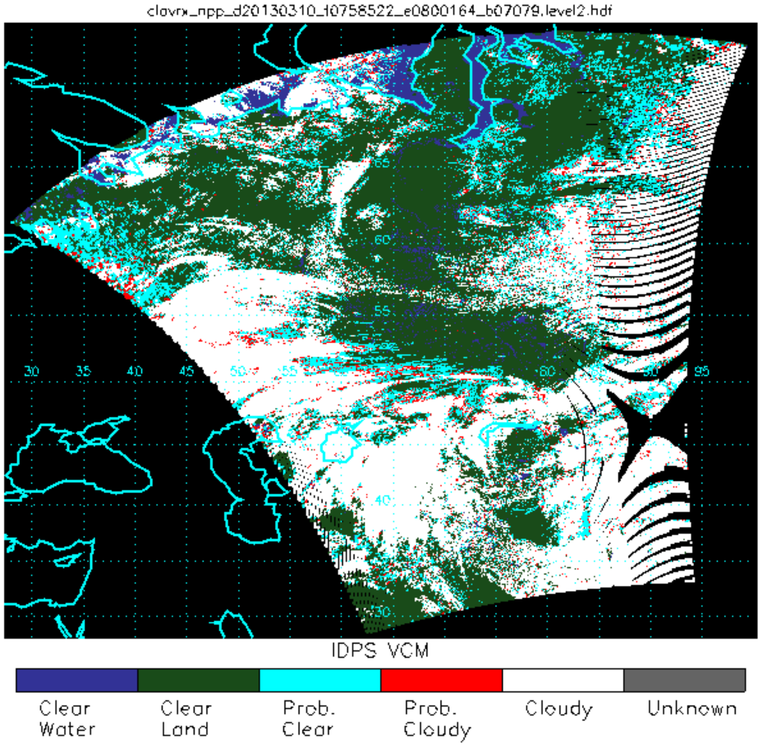



# Difference with VCM for an snow-covered land scene

- This scene is from March 10, 2013 over Russia / Kazakhstan.
- ECM on the bottom left. VCM on the bottom right.
- ECM now generates more Probably-Clear/Cloudy than VCM.



# Summary

- ECM and VCM are both mature but differ in some philosophical ways
- Users of the ECM for clear-sky applications are **strongly encouraged to use the cloud probability** and define their own threshold for clear-pixels.
- Alternatively or additionally, a full array of test bits are available.
- ECM works well globally but we still want and need feedback on our performance for specific applications.

Extra Material Follows

# THANK YOU

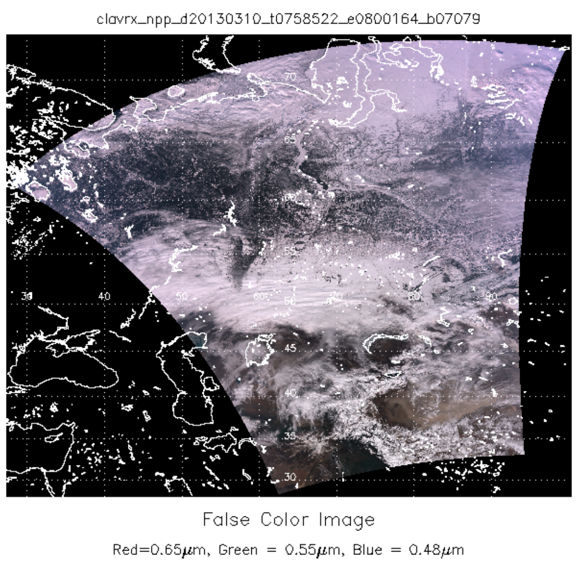
# Difference with VCM

- Both the VCM and ECM make 4-level masks
- Both provide many diagnostic bits (generally unused)
- ECM officially provides a binary mask (yes/no) which comes from the 4-level mask.
- **ECM provides a floating point probability**.
- This is the fundamental output of the ECM.
- It means “the probability that CALIPSO/CALIOP would have detected cloud”
- Both break-up the world into different regions.
  - The manual tuning of the VCM allows VCM to adjust its mask’s appearance in regions of low confidence.
  - In the ECM, some surface types generate less certain probabilities (expected) and this impacts the appearance of the mask.
- **Limited use of ancillary data and RTM. This is by design and also imposed by IDPS restrictions.**

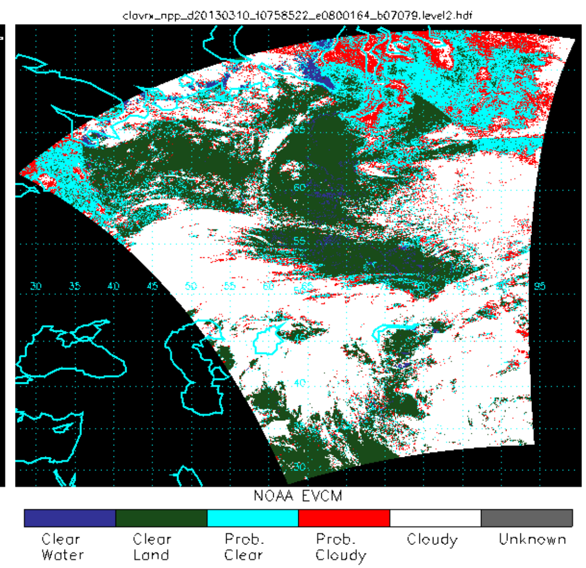
# ECM Issues

- Yes, there are still issues with ECM and the VCM.
- There are still traditional thresholds in the ECM that need to be optimized.
- One of these is the limit on the airmass.
- Reflectance tests are turned off when the airmass exceeds this threshold.
- Current limit of 5 may be too restrictive for VIIRS.

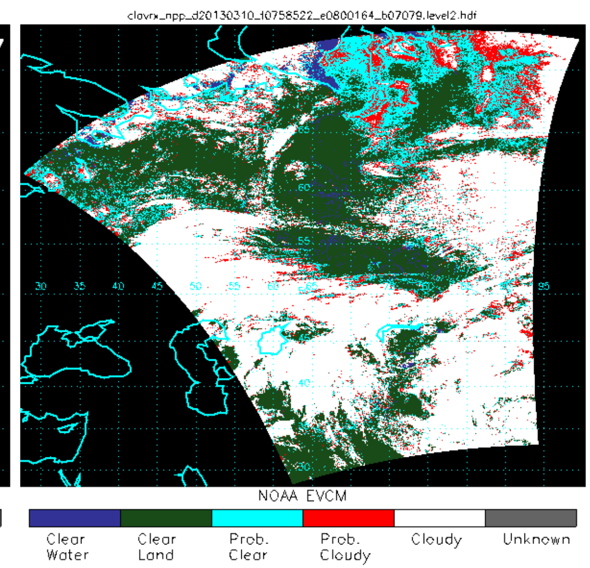
False Color




ECM with airmass threshold = 5




ECM with airmass threshold = 100

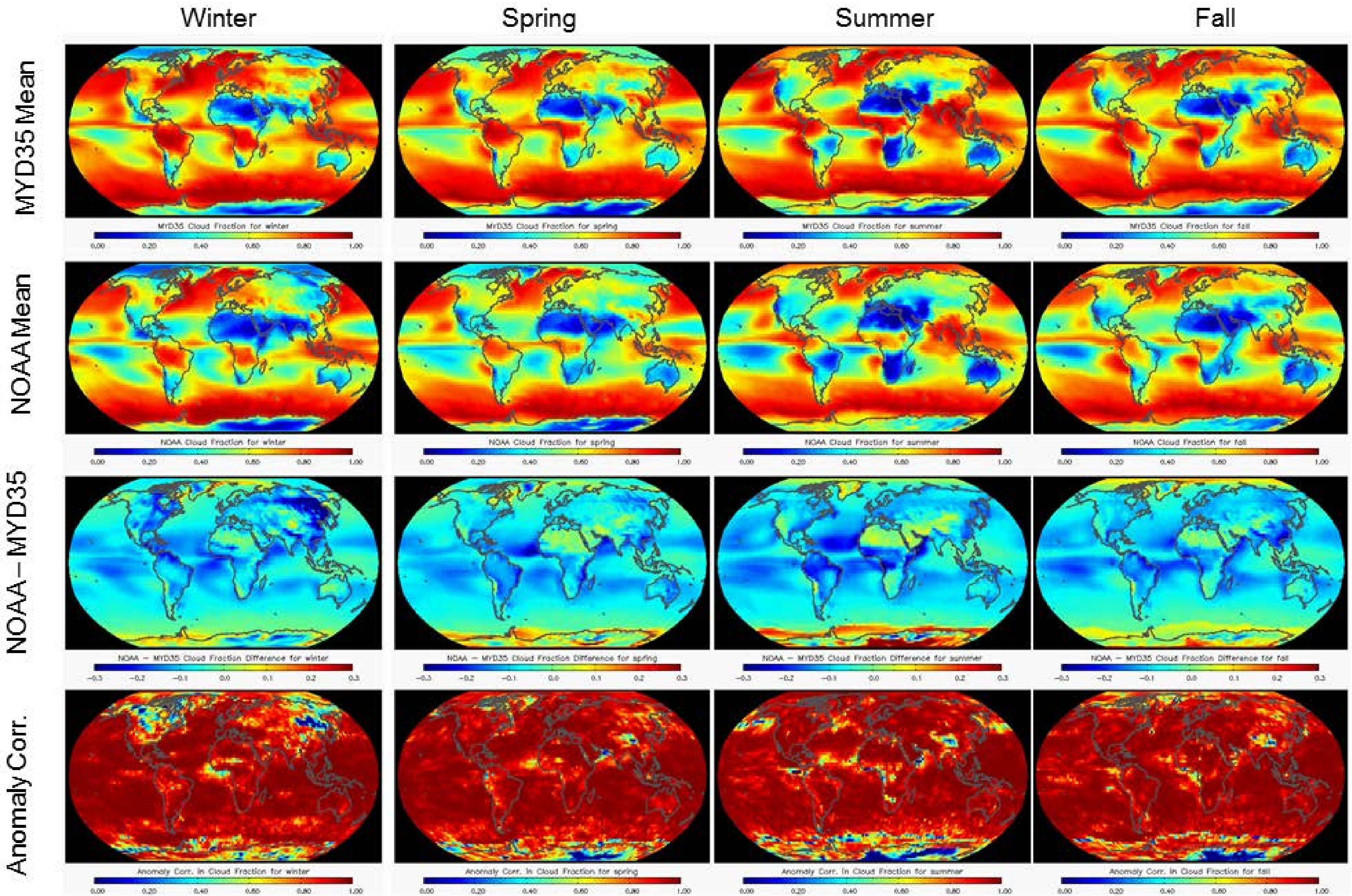



Note, coming up with one set of thresholds for all sensors is a challenge

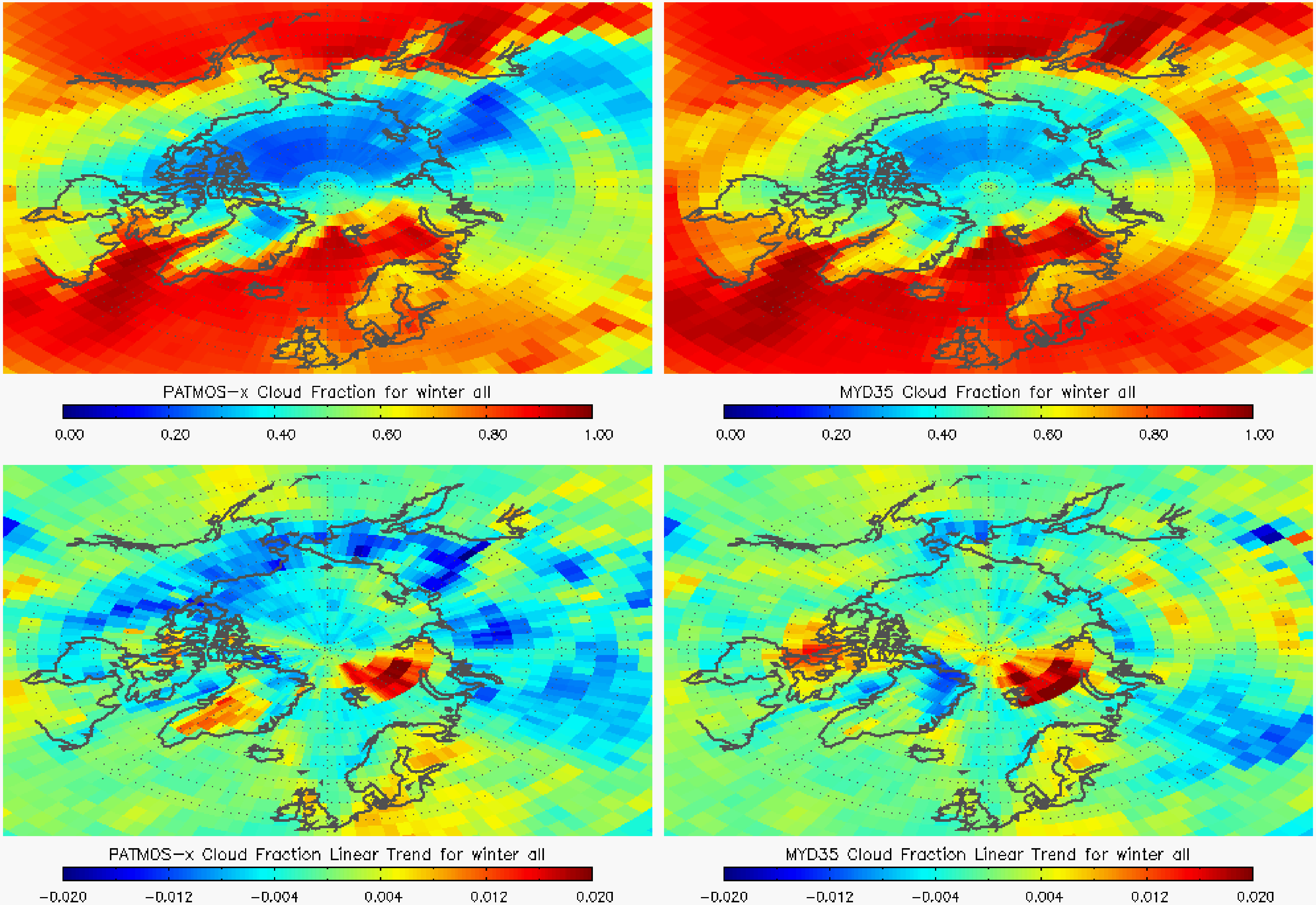
Comparisons to MYD35 provide an opportunity for a long-term global comparison of ECM to a well-established standard

# GLOBAL LOOK AT ECM

# ECM versus MYD35 over MODIS/AQUA (2003-2014)



# Arctic Winter Cloud Amount and Trend



# Enterprise Cloud Base

## VIIRS Cloud Base Height Algorithm Improvement and Evaluation Using CloudSat

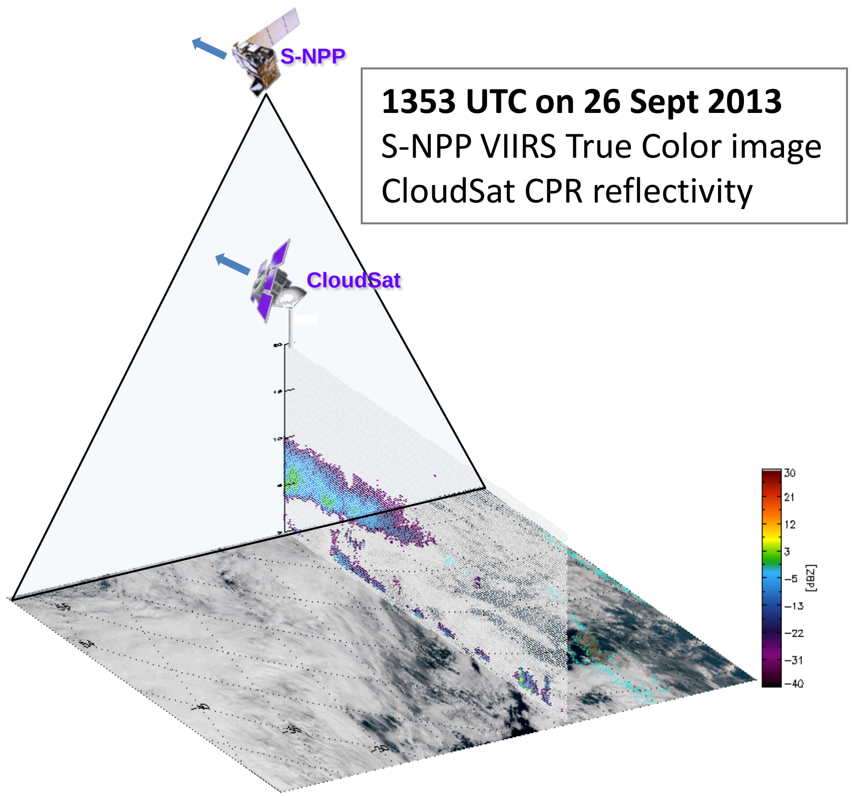
Yoo-Jeong Noh, John Forsythe, Curtis Seaman, Steve Miller, Matt Rogers
Colorado State University/CIRA

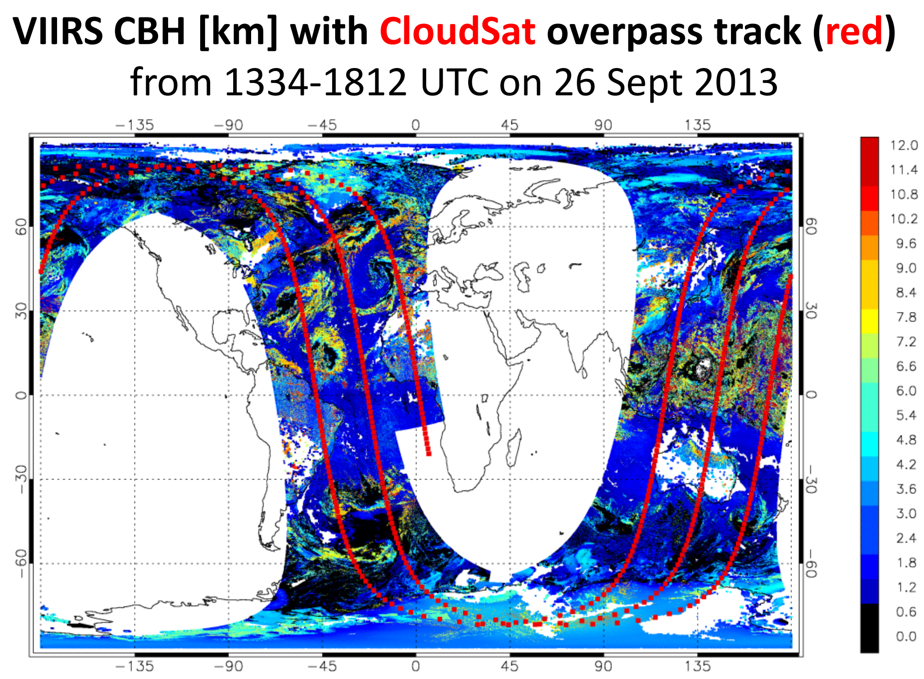
Dan Lindsey, Andy Heidinger
NOAA/NESDIS/Satellite Applications and Research

# Introduction

- **CBH (Cloud Base Height) is important for aviation.**
  - ✓ Cloud ceiling and visibility - critical to the general aviation community
- **CBH is also important for closure of the Earth's radiation budget in climate modeling.**
- **CBH helps improve Cloud Cover Layer products.**
- **A few attempts:**
  - ✓ Hutchison (2002) developed algorithm to determine cloud base height (CBH) from VIS/IR observations from MODIS.
  - ✓ Chakrapani *et al*. (2002) and Minnis *et al*. (2005) developed CBH empirical parameterizations from GOES and ARM data.
- **We have been working on VIIRS CBH CAL/VAL and improvement using CloudSat data.**

# Matching VIIRS with CloudSat




- Suomi-NPP and CloudSat are in the same orbital plane, but at different altitudes
- CloudSat and VIIRS overlap for ~4.5 hours every 2-3 days (8-9 matchups per month)
- Due to battery issues, CloudSat only operates on the **daytime** side of the Earth
- Use only the closest VIIRS pixels that overlap CloudSat and have CBH above 1 km
- Parallax-corrected

# VIIRS IDPS CBH Algorithm

VIIRS IDPS CBH algorithm for liquid clouds:

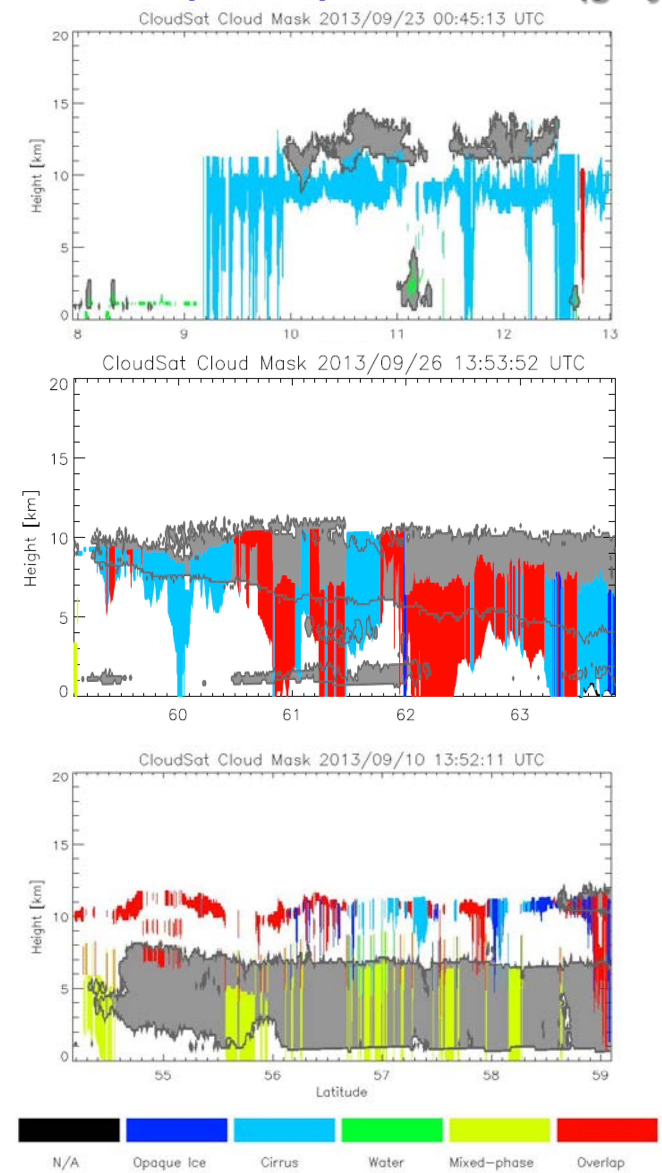
$$CBH = CTH - \left(\frac{LWP}{LWC}\right), \quad LWP = \frac{2\tau\rho r_e}{3}$$

- ✓ Red variables come from upstream retrievals.
- ✓ LWC is pre-defined average value based on the upstream cloud type retrieval.
- ✓ CBH for ice clouds is similar (T-dependent IWC).

- CBH requires upstream retrievals of cloud properties which issues directly impact CBH retrieval.
- As part of the JPSS Cloud Cal/Val efforts, our evaluation showed **the IDPS CBH algorithm provided only marginal skill.**

Sample comparison results are shown at right. CloudSat Cloud Mask (gray, from 2B-GEOPROF) with VIIRS overlaid (IDPS CTH/CBH colored by cloud type)

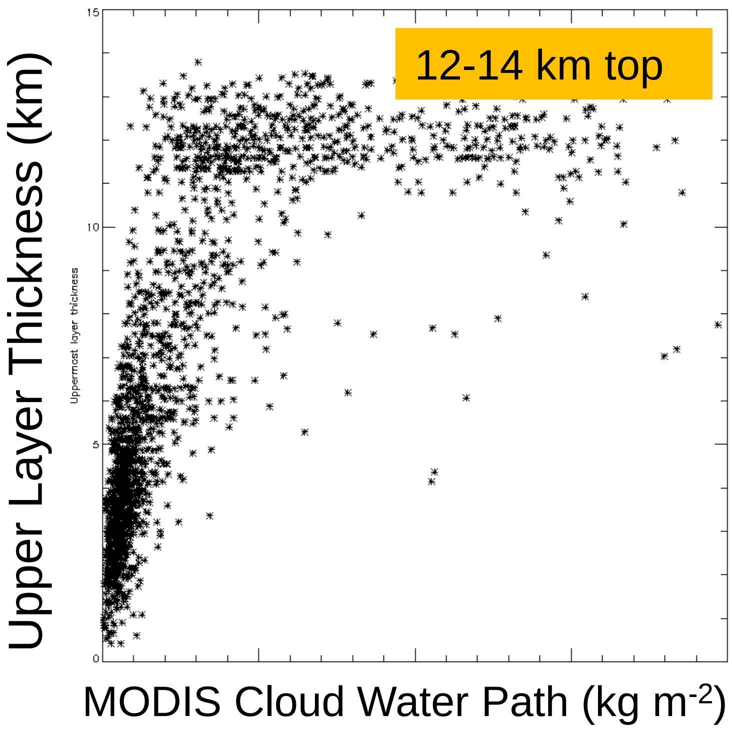
**VIIRS IDPS (colored)** vs. **CloudSat (gray)**



# Enterprise CBH Algorithm

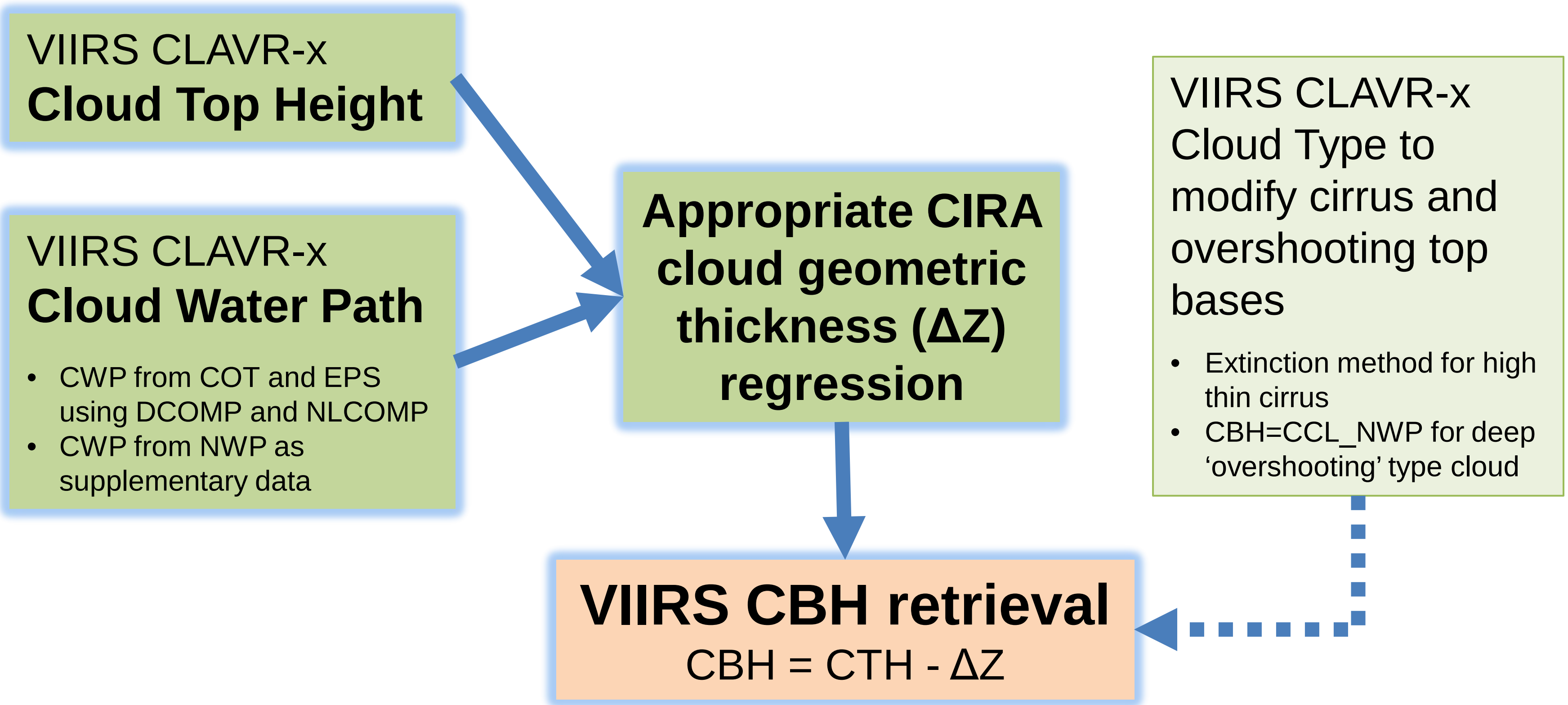
**CIRA's new statistical Cloud Base Height Algorithm using A-Train satellite data**

- Linear regression fits were performed between water path and geometric thickness for cloud top heights residing in 2 km vertical bins up to 20 km.
- The median CWP value in each 2 km CTH bin was determined, and a linear regression above and below this value was performed.
- An initial two-piece linear regression was performed for July daytime data from 2007-2010 (1743 CloudSat/CALIPSO granules).



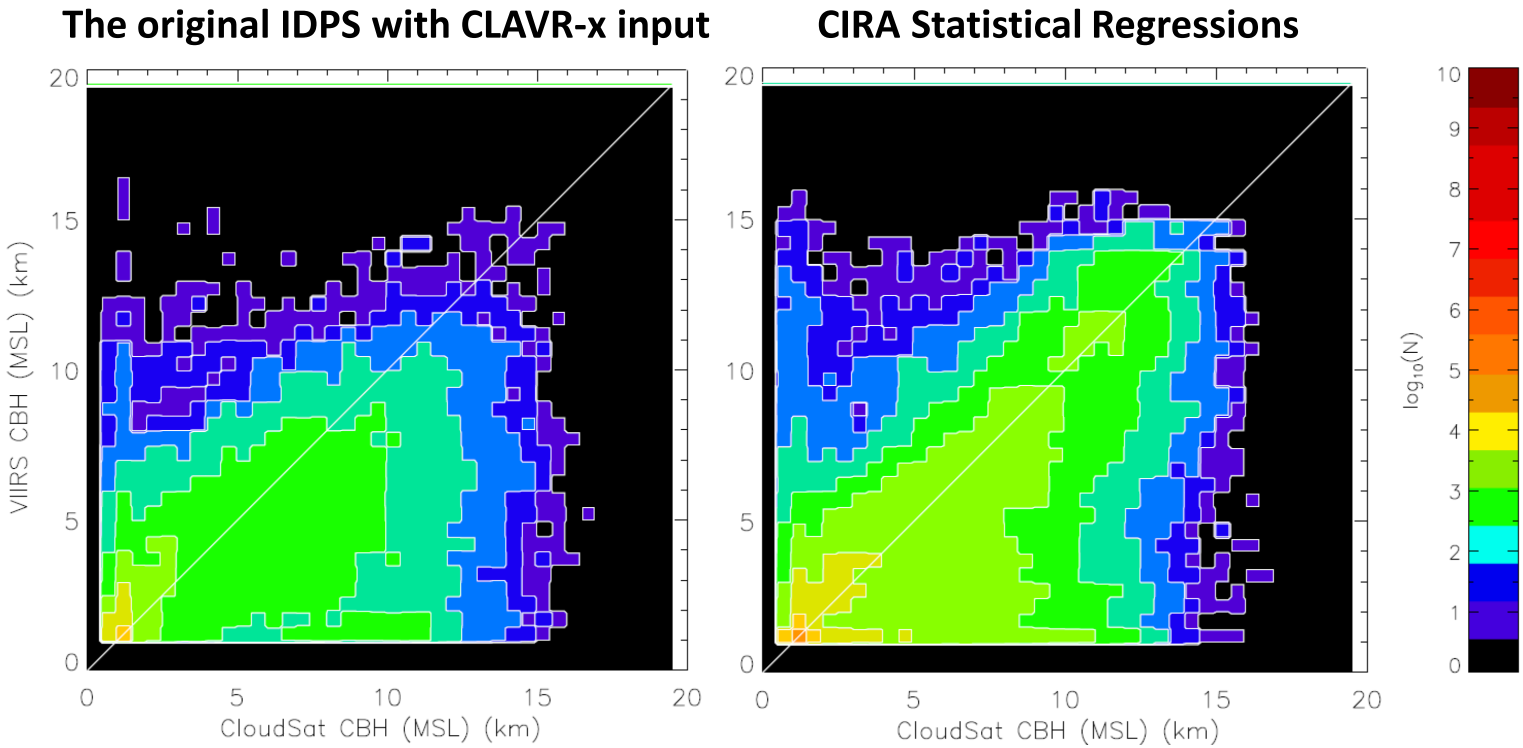

**Cloud geometric thickness** of the uppermost layer from the combined **CloudSat/CALIPSO** cloud profile product (2B-Geoprof-Lidar) and **MODIS Cloud Water Path** (MOD06)

# Enterprise (Uppermost Layer) Cloud Base Data Flow



# Investigating a Switch of Algorithms

## IDPS vs. Enterprise CBH: "All Clouds"



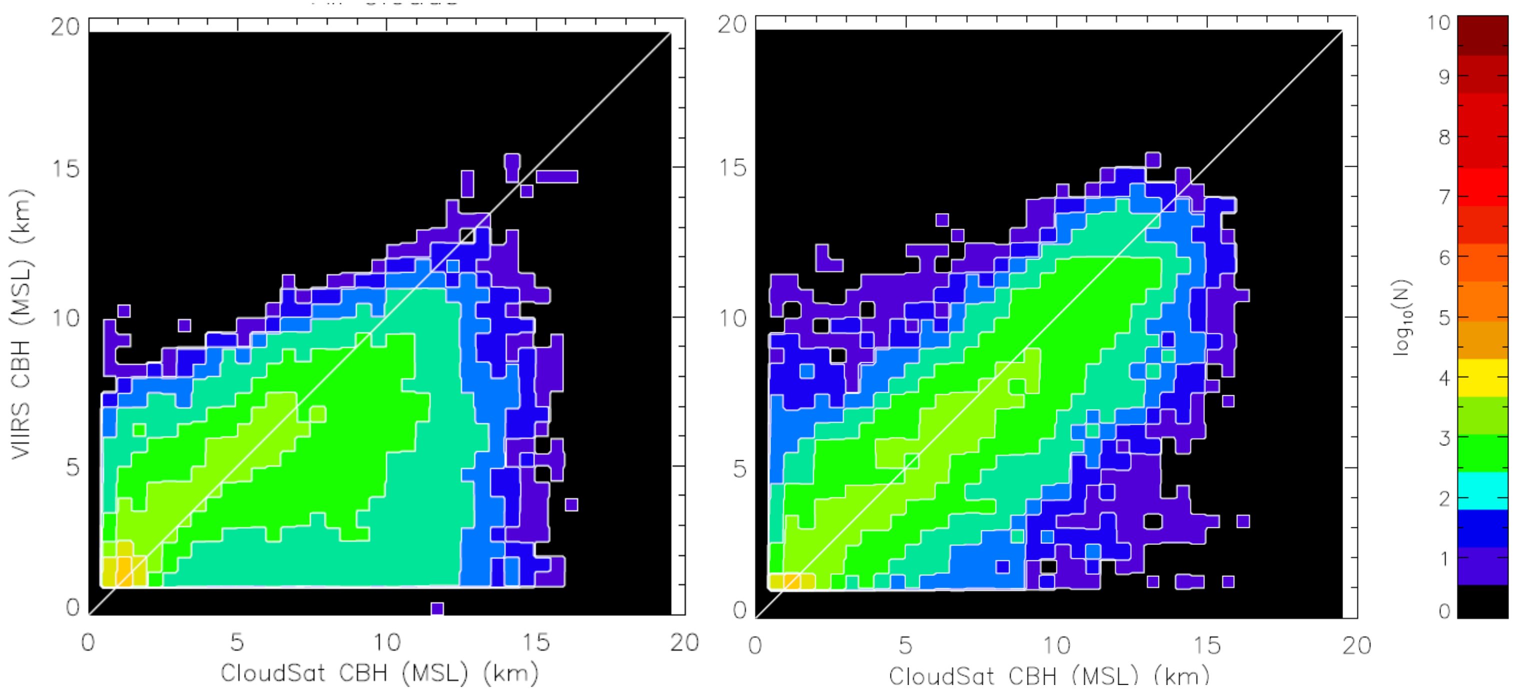

- "**All Clouds**" evaluation: all clouds observed by CloudSat and VIIRS for the general performance
- 1540 VIIRS granules and 202642 matchup points for Sept-Oct 2013 cases

| CBH [km] | Avg error (bias) | RMSE | Std of error | $r^2$ |
|---|---|---|---|---|
| **IDPS** | **1.0** | **3.3** | **3.1** | **0.286** |
| **Enterprise** | **1.0** | **3.0** | **2.8** | **0.427** |

✓ **Better**

# The enterprise CBH performs better!

## IDPS vs. Enterprise CBH: "Within Spec"




- "**Within Spec**" evaluation for only clouds where the VIIRS CTH retrieval is within the error specifications: CTH within 1 km of CloudSat CTH if COT ≥ 1, or within 2 km if COT < 1 (82599 matchup points for Sept-Oct 2013)

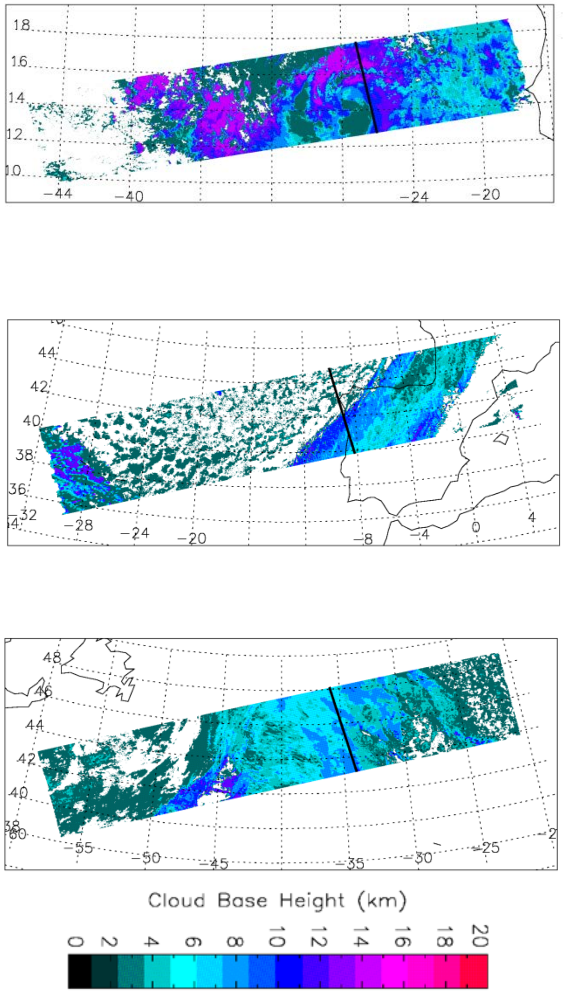
| CBH [km] | Avg error (bias) | RMSE | Std of error | $r^2$ |
|---|---|---|---|---|
| IDPS | 0.7 | 2.7 | 2.6 | 0.452 |
| Enterprise | 0.3 | 1.8 | 1.8 | 0.760 |

✓ Much better!

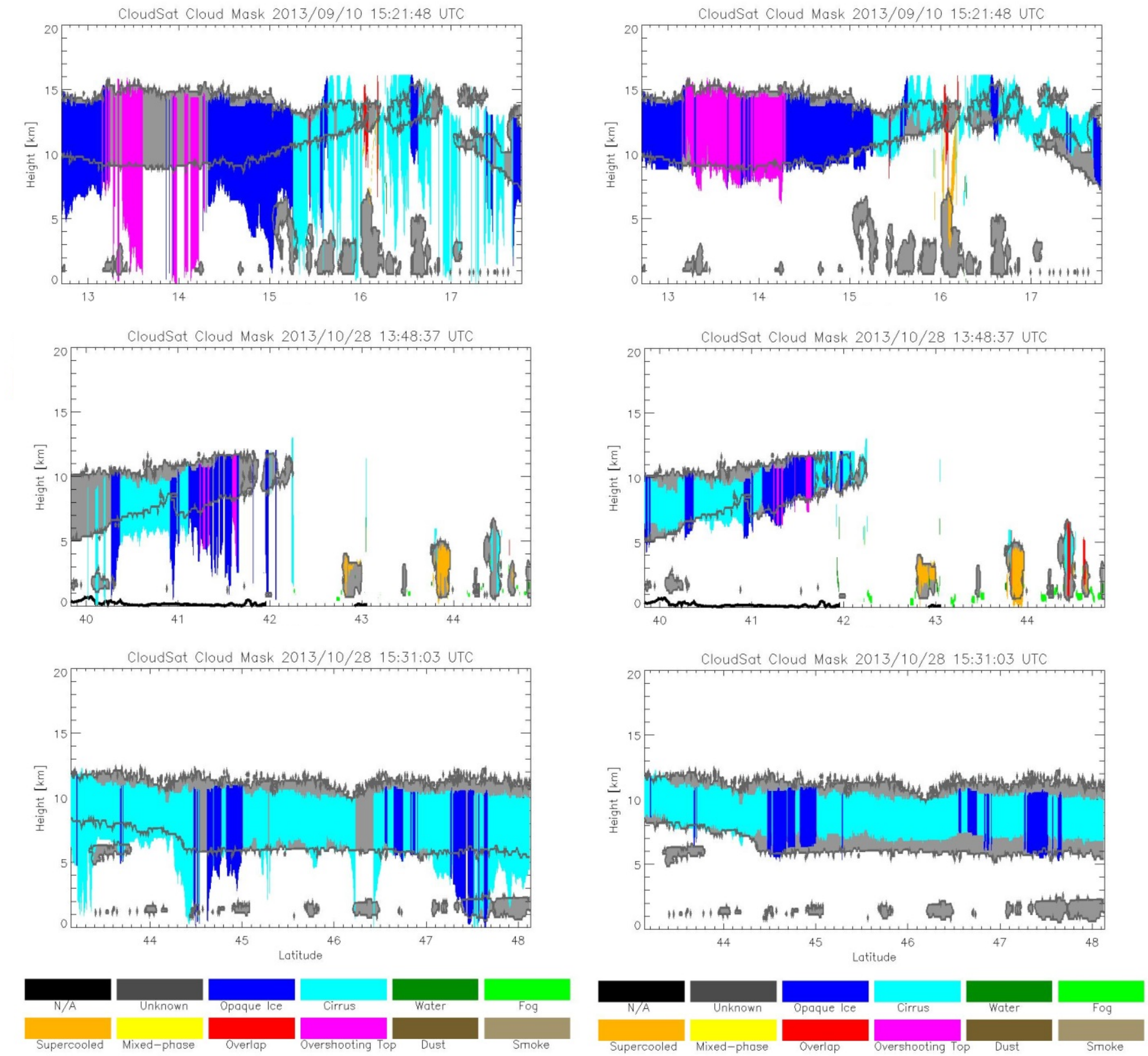
# Sample matchup comparisons

**The original IDPS with CLAVR-x input => Enterprise CBH**

**Horizontal CBH contours**



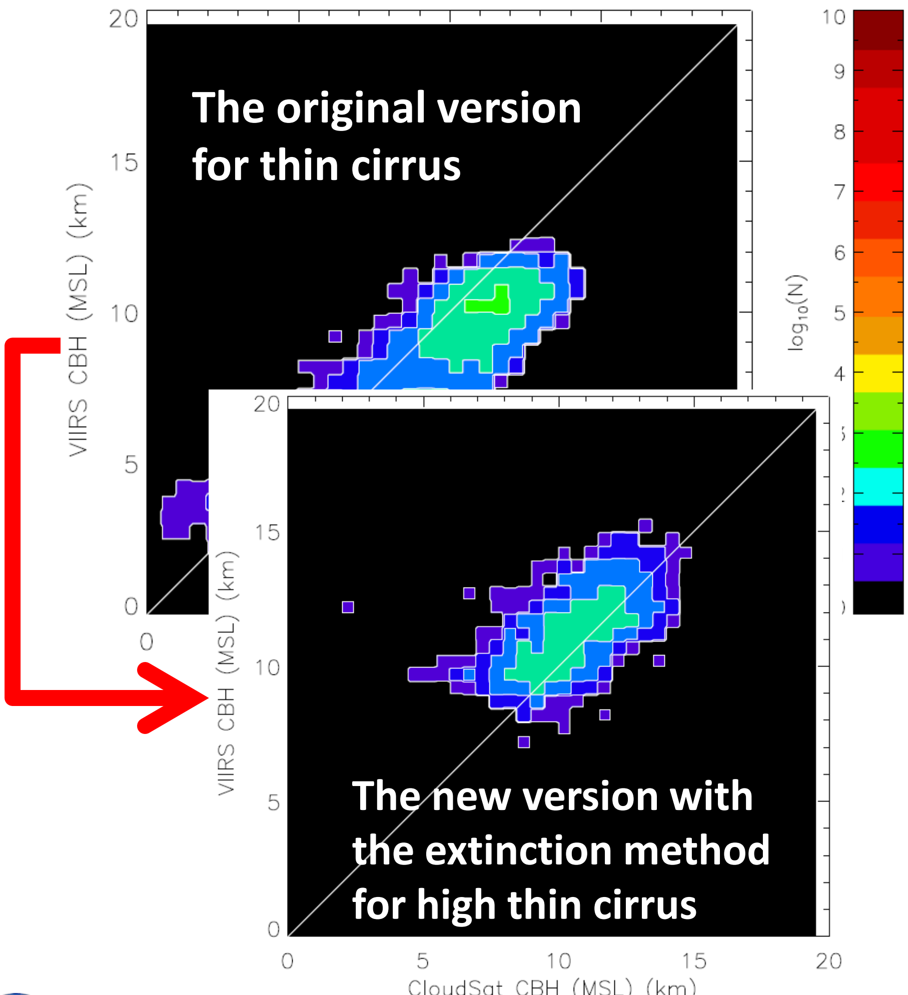

**Enterprise CBH [km]**



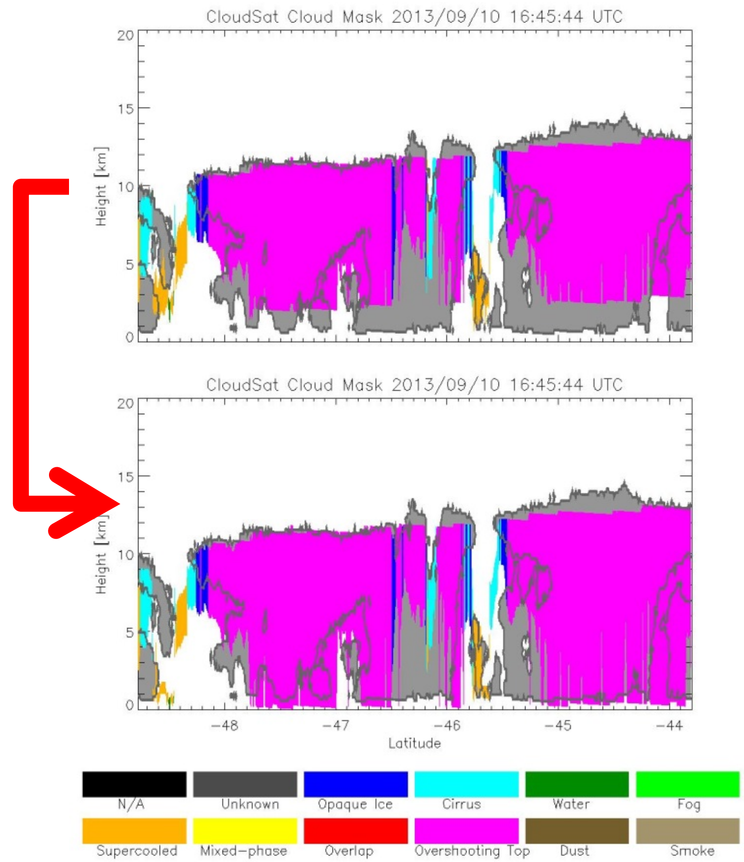

**CloudSat Cloud Mask (gray) and VIIRS CTH/CBH (colored by cloud type)**

# Ongoing work to provide an optimized CBH retrieval

For high thin Cirrus, CALIPSO-based extinction method by Yue Li (CIMSS) and Andy Heidinger (NOAA/STAR)




For deep convective clouds, CBH = Convective Condensation Level from NWP

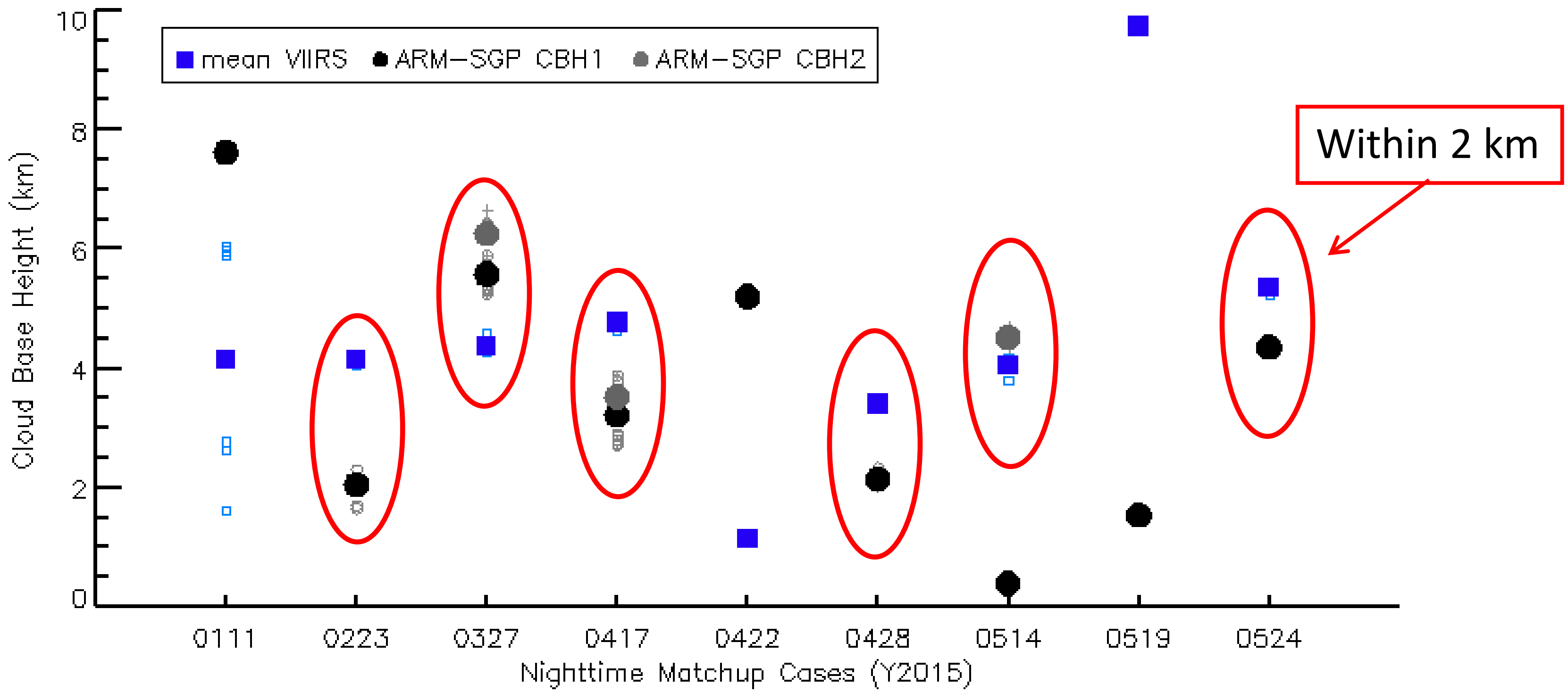



*Combined with the statistical method in the current CLAVR-x CBH routine*

*New work in progress*

# Nighttime CBH algorithm performance

**Preliminary results for the enterprise CBH and ARM SGP-C1 ceilometer data**
(9 valid cases within a 1-km and 3-min matchup window in Jan-May 2015)

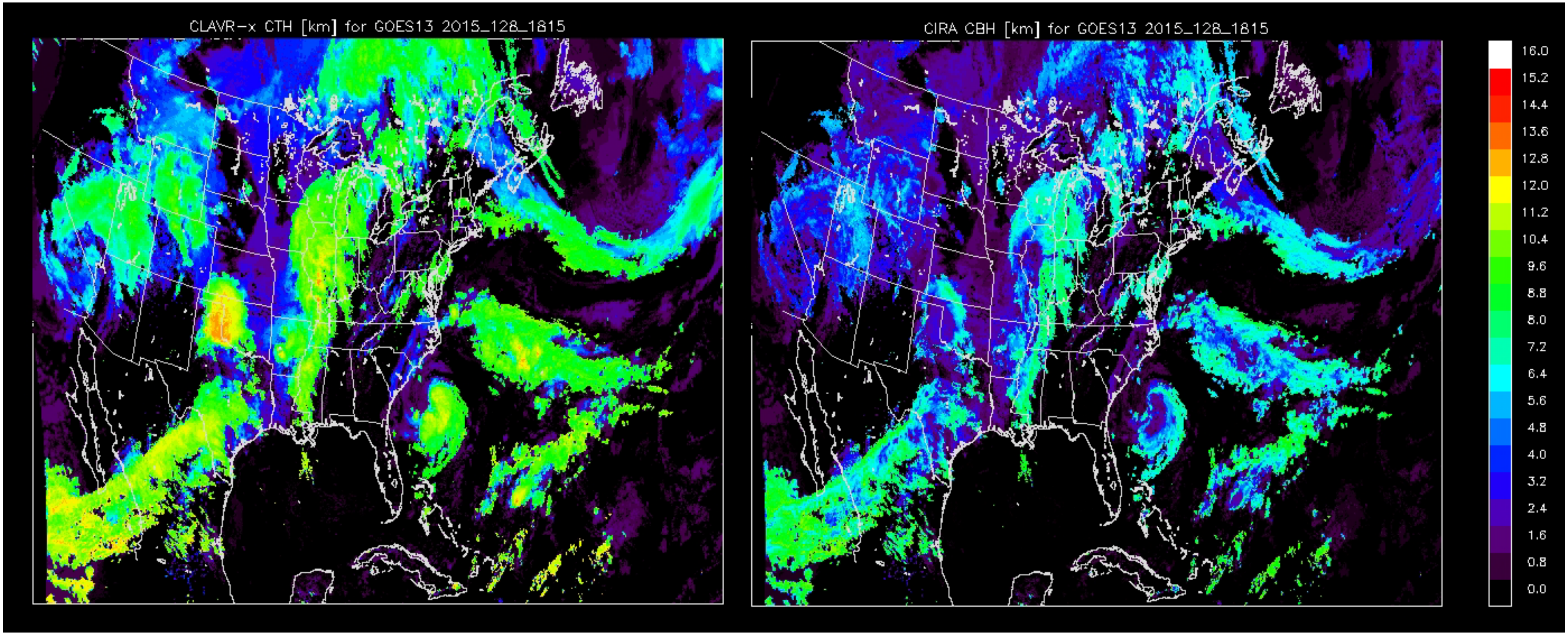



- ✓ *NLCOMP or NWP products used for nighttime CWP*
- ✓ *Ongoing work using ARM NAS (Barrow, Alaska) ceilometer data*

# Apply to geostationary satellites (I)

## GOES-W and GOES-E

### Sample CTH and CBH from GOES-13 on 8 May 2015 (1815 UTC)

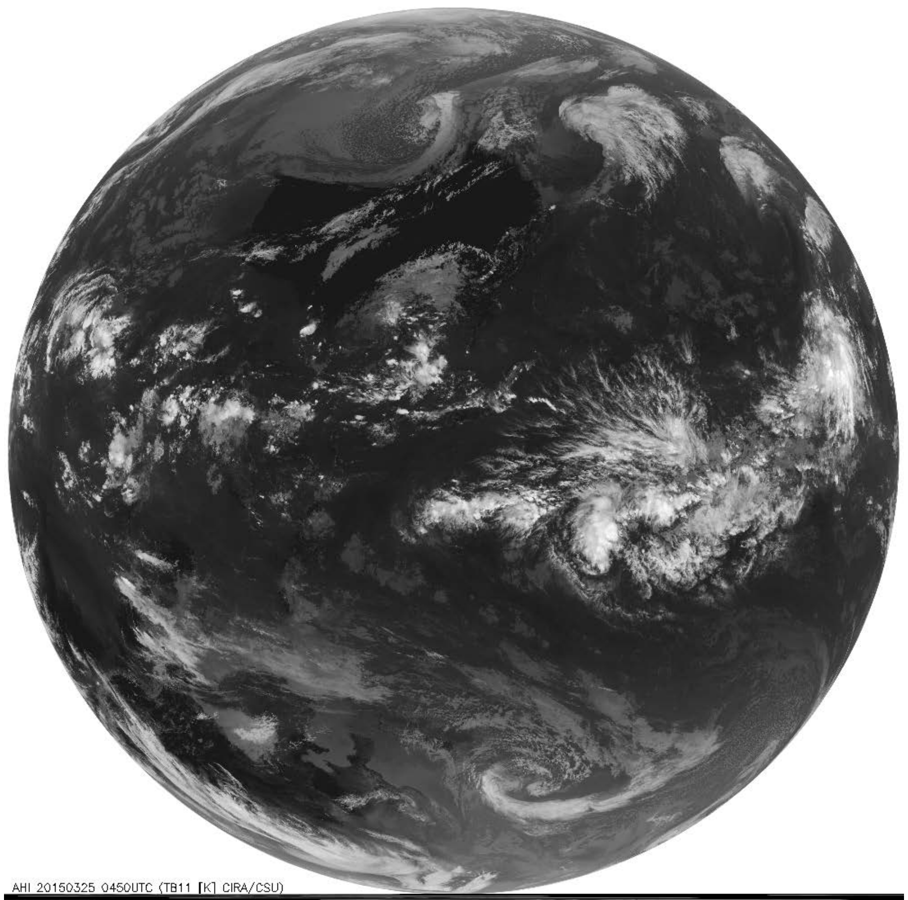



**CTH [km]** **CBH [km]**

*Similar CBH data (lower layer CBH) being produced from the NASA Langley Center*

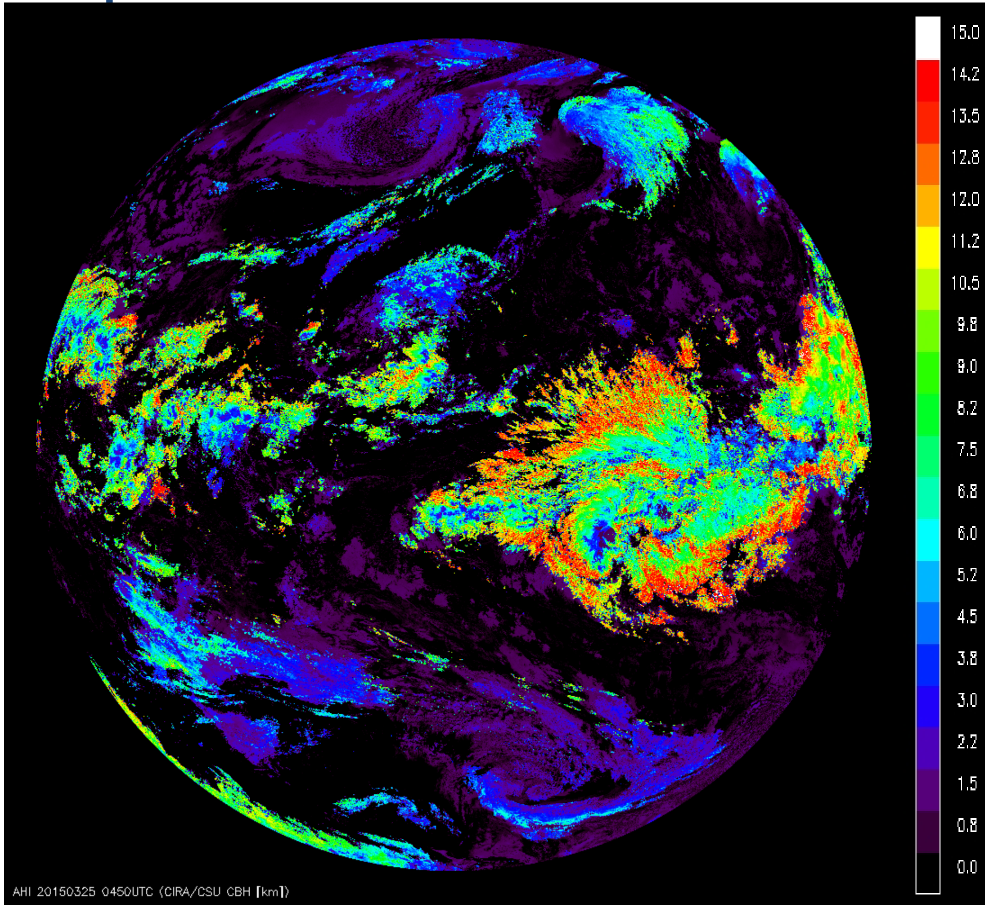
# Apply to geostationary satellites (II)

## **Himawari-8 AHI** -> *for the future GOES-R ABI*




AHI 11µm TBs (190-300 K)

Sample CBHs at 0450 UTC on 25 March 2015

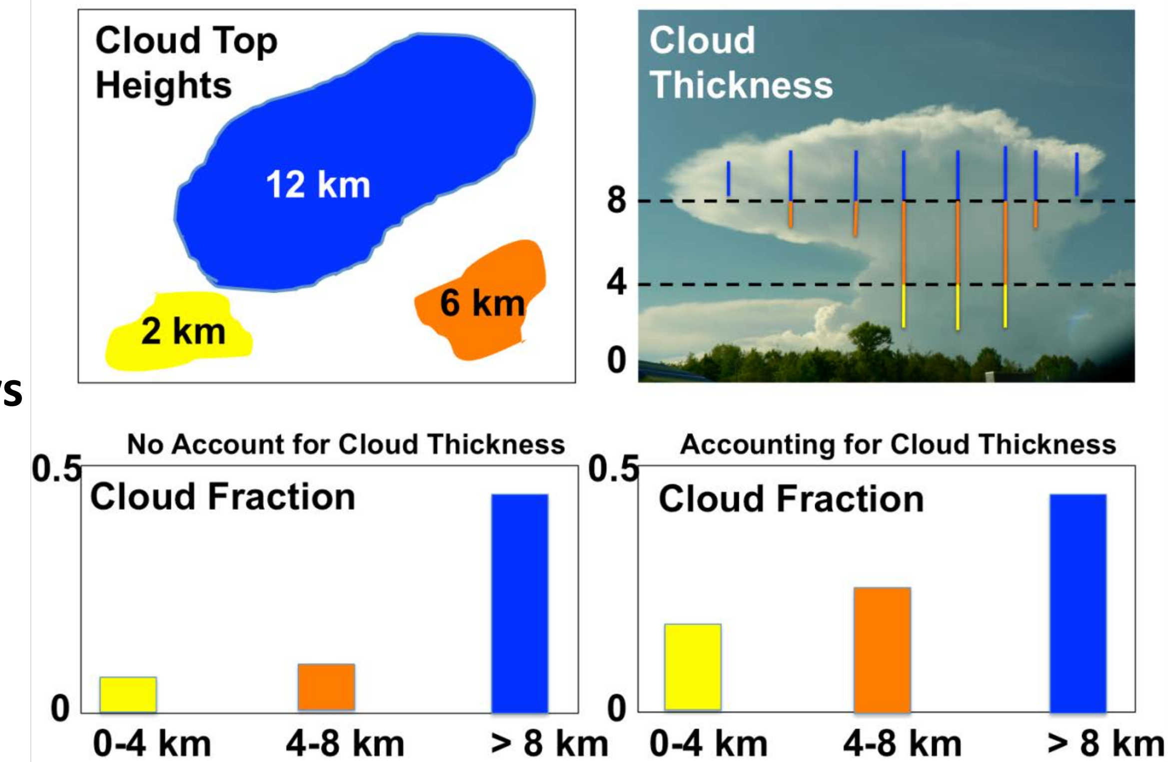



CIRA CBH (km)

***Cut the edge***

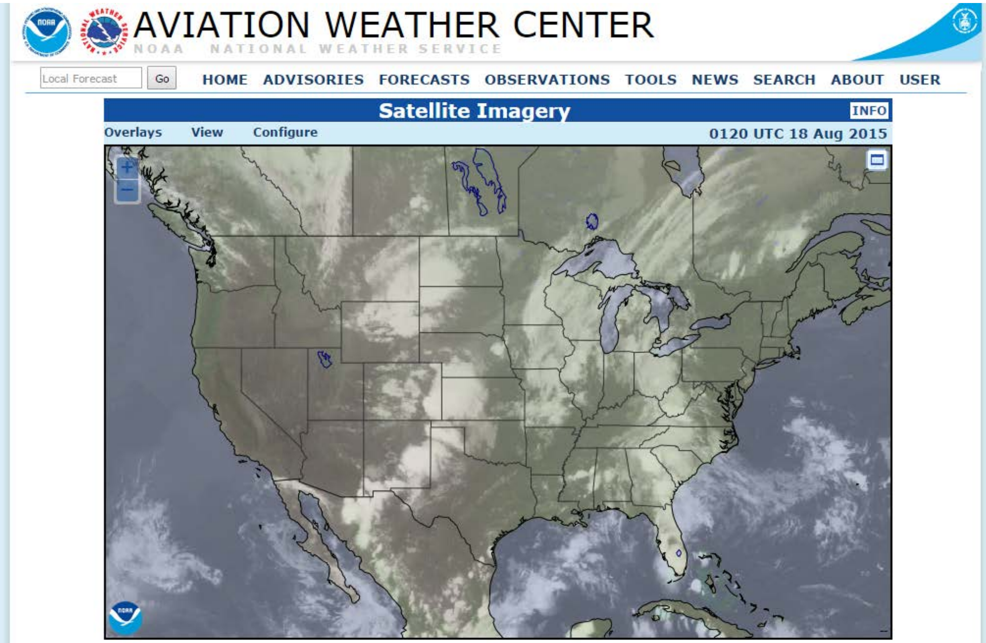
# For Cloud Cover Layer improvement

- Once the optimized cloud base height estimate has been established and validated, we can use it for improved CCL products.
- **The cloud geometric thickness information allows for a pseudo-three-dimensional cloud field which can be used to estimate cloud fractions at lower levels below CTH.**
- Coupling the information with cloud classification and NWP temperature profiles would assist in providing useful parameters with regard to CCL retrievals.

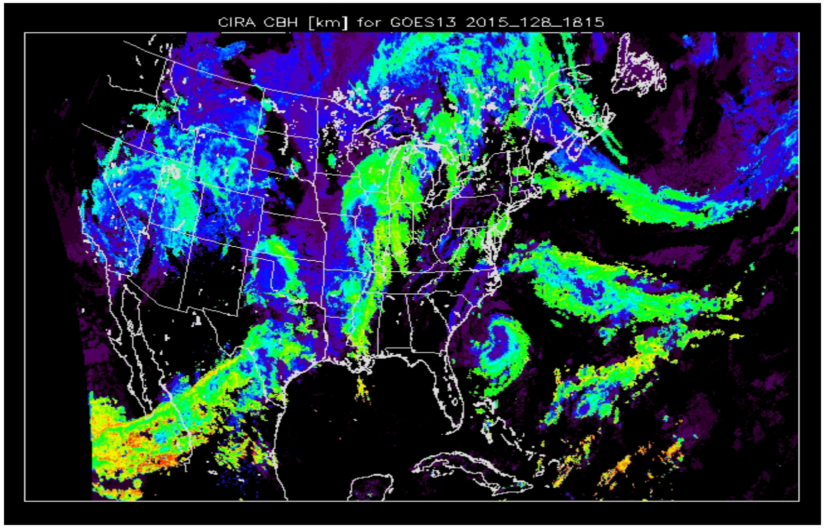



**Conceptual illustration of how cloud geometric thickness information can be used to modulate the layered cloud fraction (high/mid/low) by introducing additional cloud coverage at lower (unobserved via satellite) levels of the profile.**

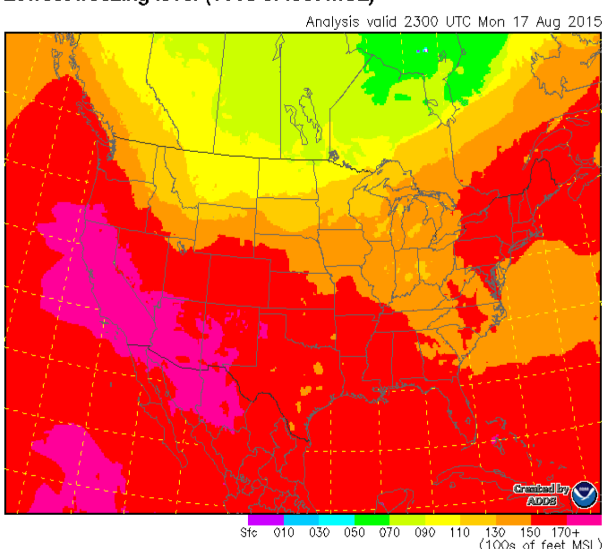
# For potential users …



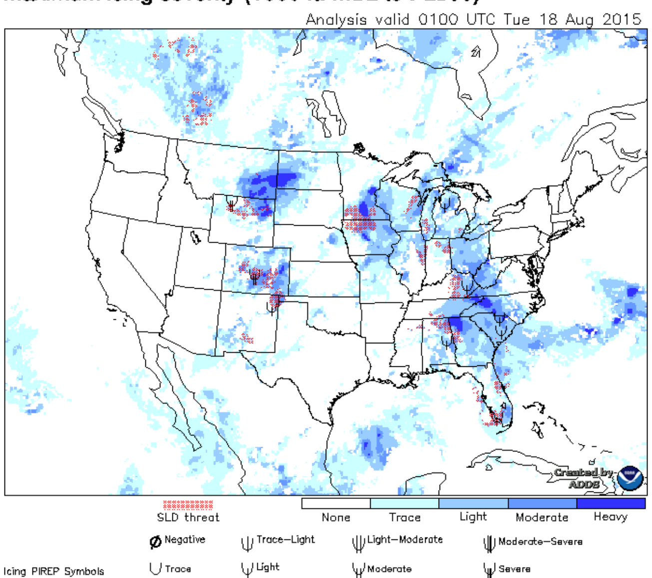

***Satellite CBH of the upper-most layer and CCL***
*(as supplementary info)*




Lowest freezing level (100s of feet MSL)

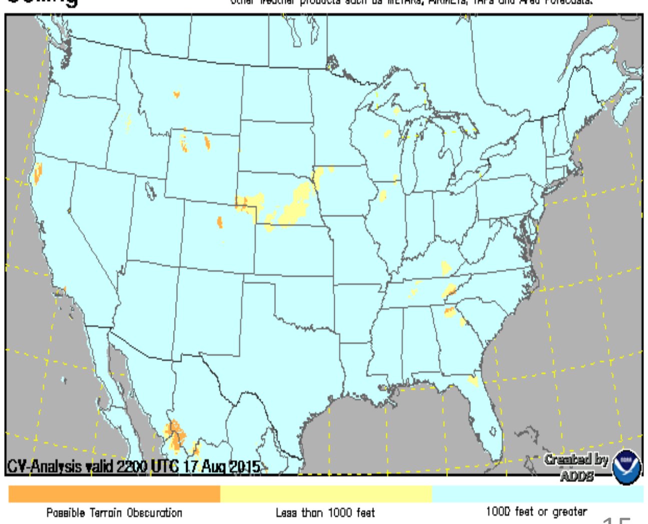



Maximum icing severity (1000 ft. MSL to FL300)




Ceiling

Caution: This product is intended to aid flight planning and is best used along with other weather products such as METARs, AIRMETs, TAFs and Area Forecasts.



# Summary

- Retrieving CBH is difficult. Our evaluation showed the IDPS CBH environmental data record provided only marginal skill.
  - Cloud Top Height and Cloud type errors significantly impact CBH.
- **CIRA developed a new statistical CBH algorithm constrained by CTH and CWP using CloudSat/CAIPSO and Aqua MODIS data.** (*Now part of the CLAVR-x system*)
- **The enterprise CBH algorithm outperforms** the other algorithms particularly when CTH is "within spec".
  - Work in progress is exploring alternative fits for the optimized CBH retrievals such as a higher order polynomials to improve thick cloud base.
  - Validation efforts are ongoing for an extended CloudSat matchup period (Jan-May 2015) including nighttime CBH performance test and comparisons with CALIPSO for thin cirrus.
- Once the optimized cloud base height estimate has been established and validated, we can leverage it to address forecaster needs for improved Cloud Cover Layer products.

***Thank you!***

# Cloud Properties using Lunar Reflectance from S-NPP VIIRS

Andi Walther[1], Steven Miller[3], Denis Botambekov[1], Yue Li[1], Andrew Heidinger[2]

[1]University of Wisconsin, Madison, WI
[2]NOAA/NESDIS/Center for Satellite Applications and Research, Madison
[3]CIRA, Fort Collins CO

# Motivation

- Nighttime cloud properties for optically thick clouds are not commonly available though clouds are known to have large diurnal cycles
- With the added capability we can
  - Provide improved ceiling and icing products to the aviation community.
  - Provide cloud microphysics for precipitation retrievals
  - Provide day/night consistent products for NWP verification.
  - Study day/night biases and variations for climate studies.
- The DNB band from VIIRS provides an unprecedented opportunity to study nighttime clouds, specifically we are exploring the impact of the DNB Lunar reflectance on …
  - ➢ Cloud Detection
  - ➢ Cloud Overlap Detection
  - ➢ Cloud Optical and Microphysical Properties
  - ➢ Dust Remote Sensing

# DNB Radiance → Lunar Reflectance

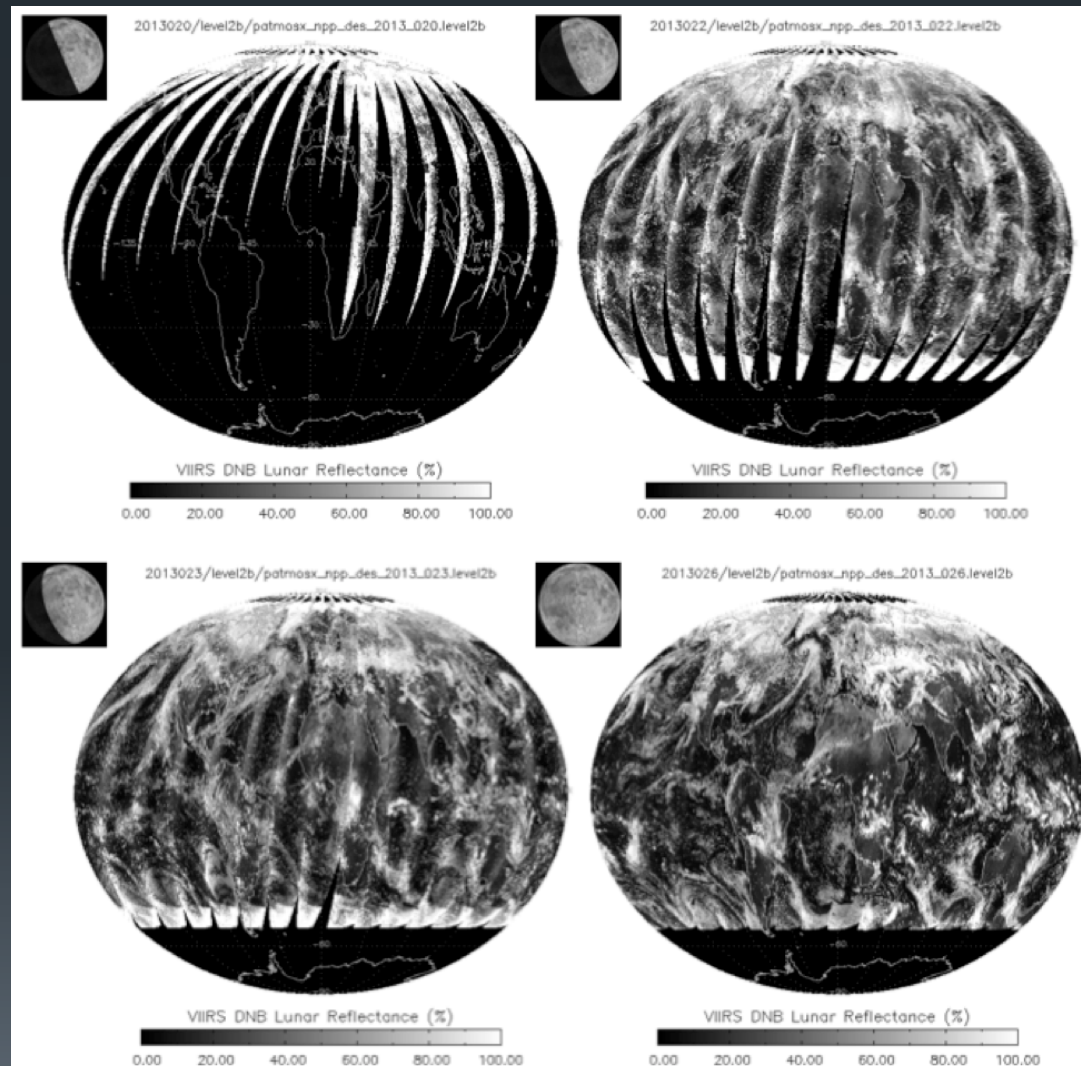


- The radiance to reflection retrieval was developed by Steven Miller (CIRA)
- In contrast to solar irradiance the computation of down-welling lunar irradiance is a complex task due to many components which have to be considered:
  - Lunar phase
  - Lunar spectral surface albedo
  - Moon-Earth-Sun orbital geometry
  - Lunar zenith angle
- We expect an overall uncertainty in lunar reflection of 5% with recent corrections for lunar phase-dependent albedo variations.
- Remaining errors are primarily related to libration and phase-dependent **spectral** albedo changes.
- Implemented in CLAVR-x and plans for SAPF but time-line unknown. DNB pixels mapped to M-bands

# Global Coverage of Calibrated Lunar Reflectance



- Lunar cycle is about 29.5 days
- Lunar reflectance requires filtering of solar zenith (19 below the horizon)
- Sufficient global lunar reflectance coverage is ~70% of nighttime
- Winter poles have coverage most of the time



# Cloud Detection

# Using VIIRS DNB Lunar Reflectance for Cloud Detection

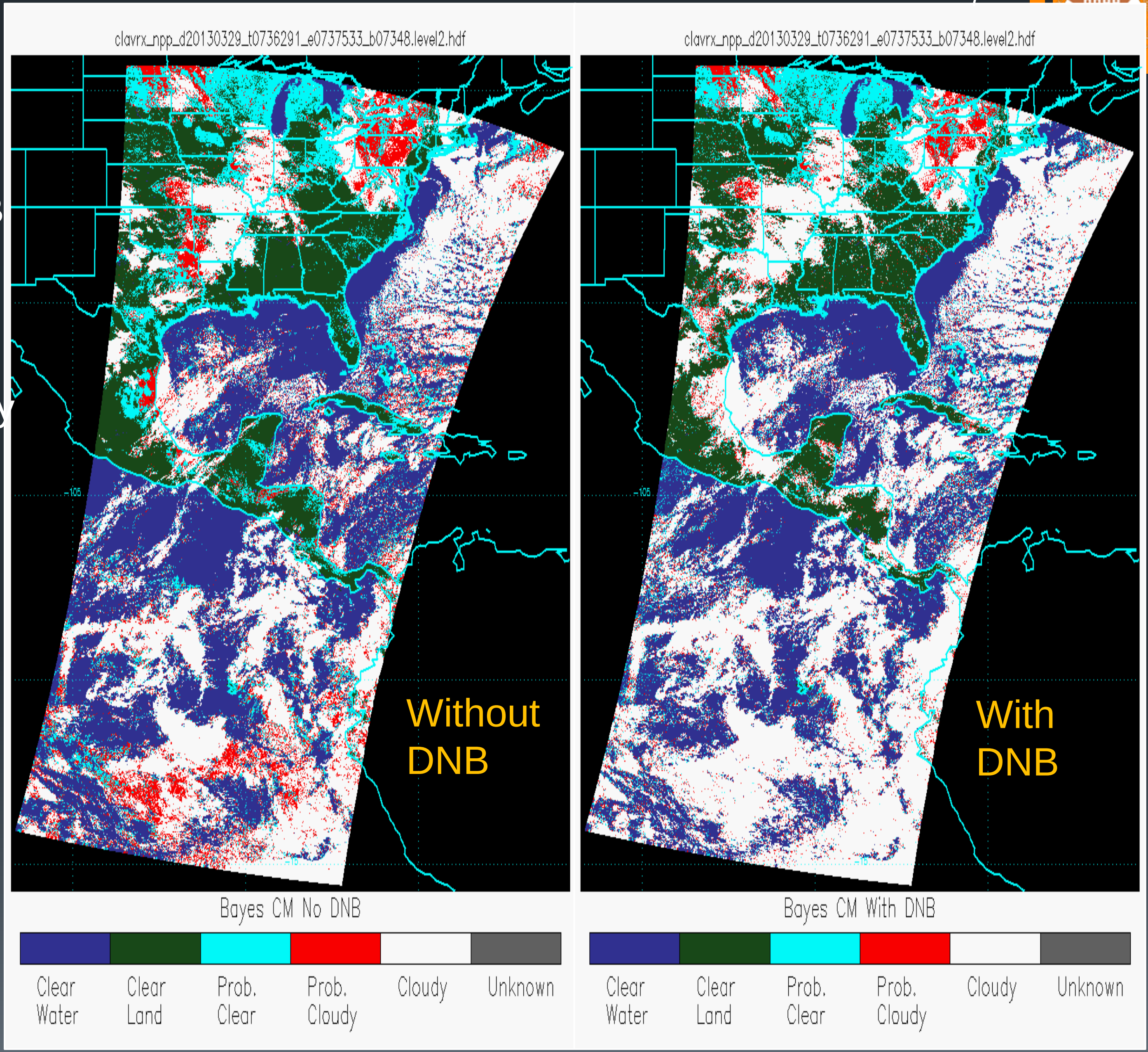


- NOAA Enterprise Cloud Mask (CLAVR-x) has been modified to use the lunar reflectance in its naïve Bayesian Cloud Detection Algorithm.
- We do this to try and improve day/night consistency.
- Clear-sky estimate computed using a combination of 0.63 and 0.86 μm MODIS surface reflectance.
- Cities detected using DNB radiance threshold. Gas Flare detection still being developed.
- No explicit treatment for Auroras.

# Impact of Lunar Reflectance on Cloud Mask Detection



- Less uncertainty to cloud mask when DNB is used
- Originally probably cloudy scenes are identified as confidently cloudy
- Global Stats:
  - POD values increase from 90% to 93%. (relative to CALIPSO)
  - cloud fraction increases by 3%
  - Probably cloudy amount drops in half.



# Cloud Overlap Detection

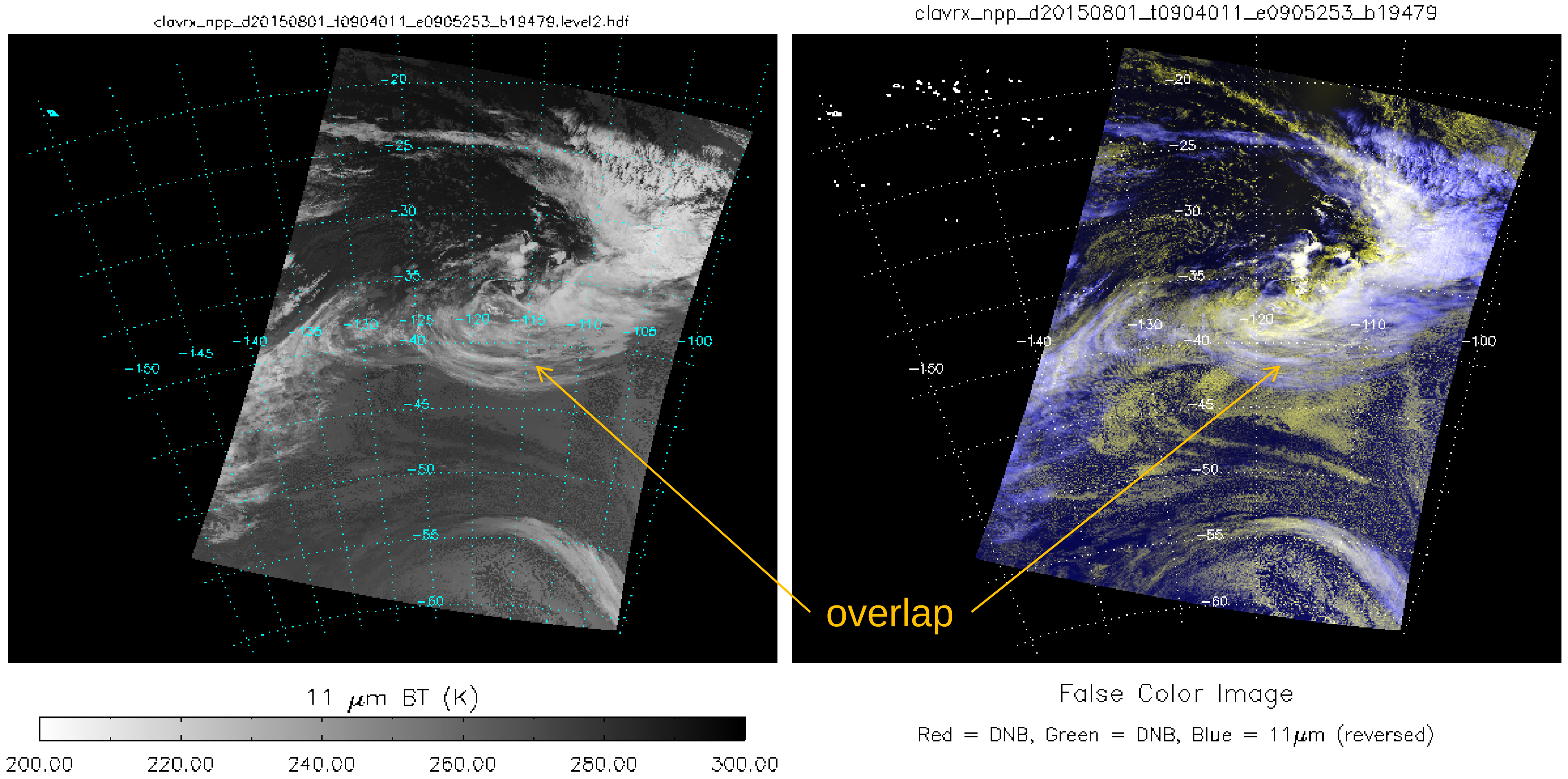
# Motivation for Overlap Detection

- Knowledge of cloud overlap is important since our retrievals often fail when this occurs and we don't handle it.
- Ability to detect depends on spectral information.
- GOES-R AWG  (Pavolonis et al) approach utilizes IR absorption channels which are missing on VIIRS.
- Visible + IR methods are applicable to VIIRS but not at night.
- We are exploring DNB based augmentation to improve cloud overlap detection.
- Important for height retrievals and these impact VIIRS Winds.

# Example Of Overlap Detection with Lunar Reflectance



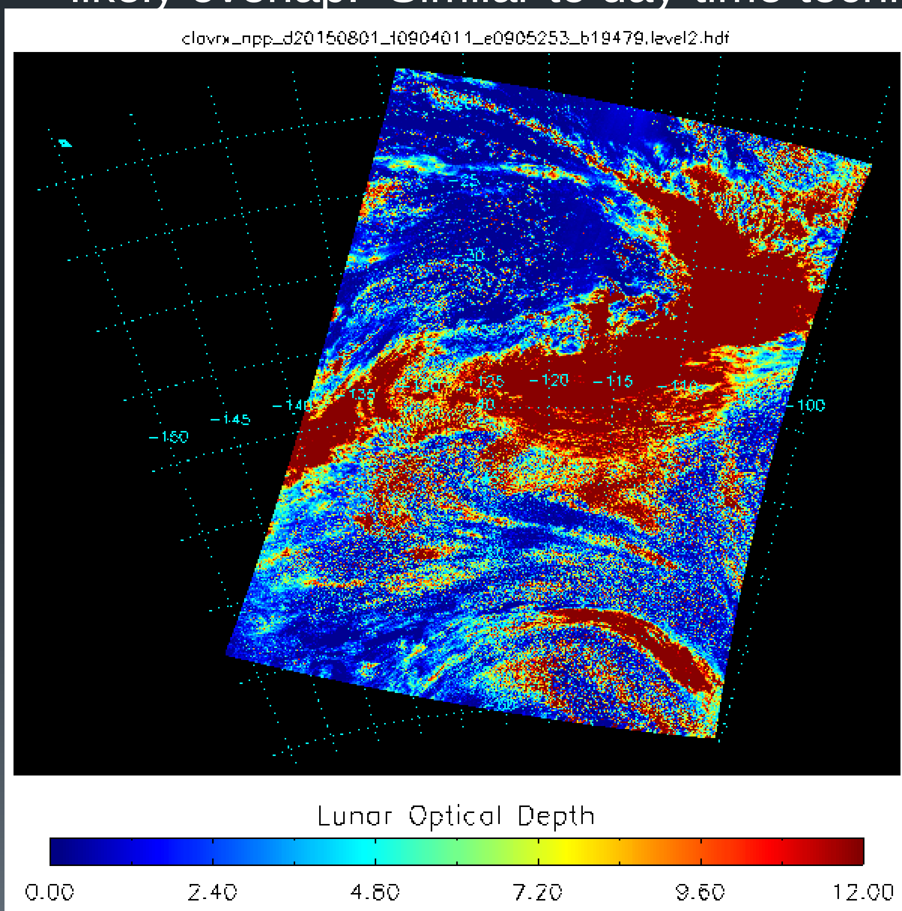
- S-NPP VIIRS August 1, 2015 (Nearly Full Moon)
- Window thermal bands are inconclusive on presence of overlap.
- Addition of Lunar Ref to a false color image shows overlap clearly.

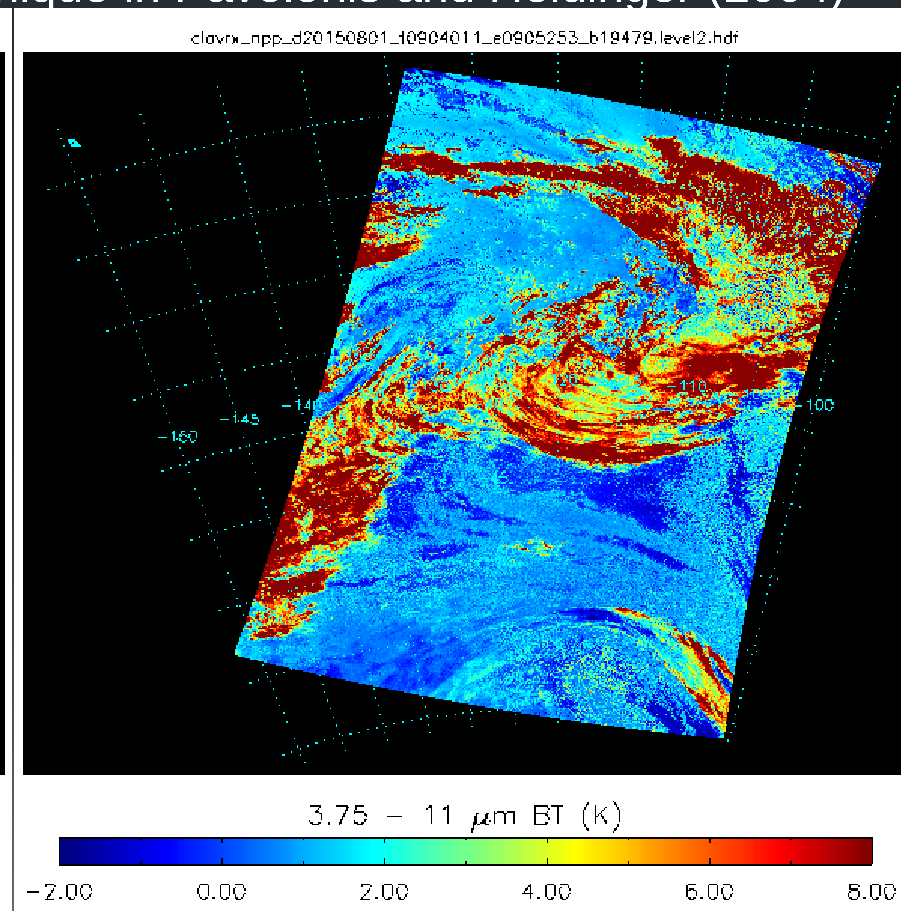


# Method



- Overlap detection is often accomplished by detecting spectral inconsistencies.
- We know cirrus clouds are semi-transparent and should exhibit large 3.75-11 μm BT and small values of reflectance or optical depth.
- Overlapped clouds (high over low) can give both high optical depths and high values of 3.75-11 μm BT.
- Below we show these two quantities. Pixels that are red in both images, are likely overlap. Similar to day-time technique in Pavolonis and Heidinger (2004)

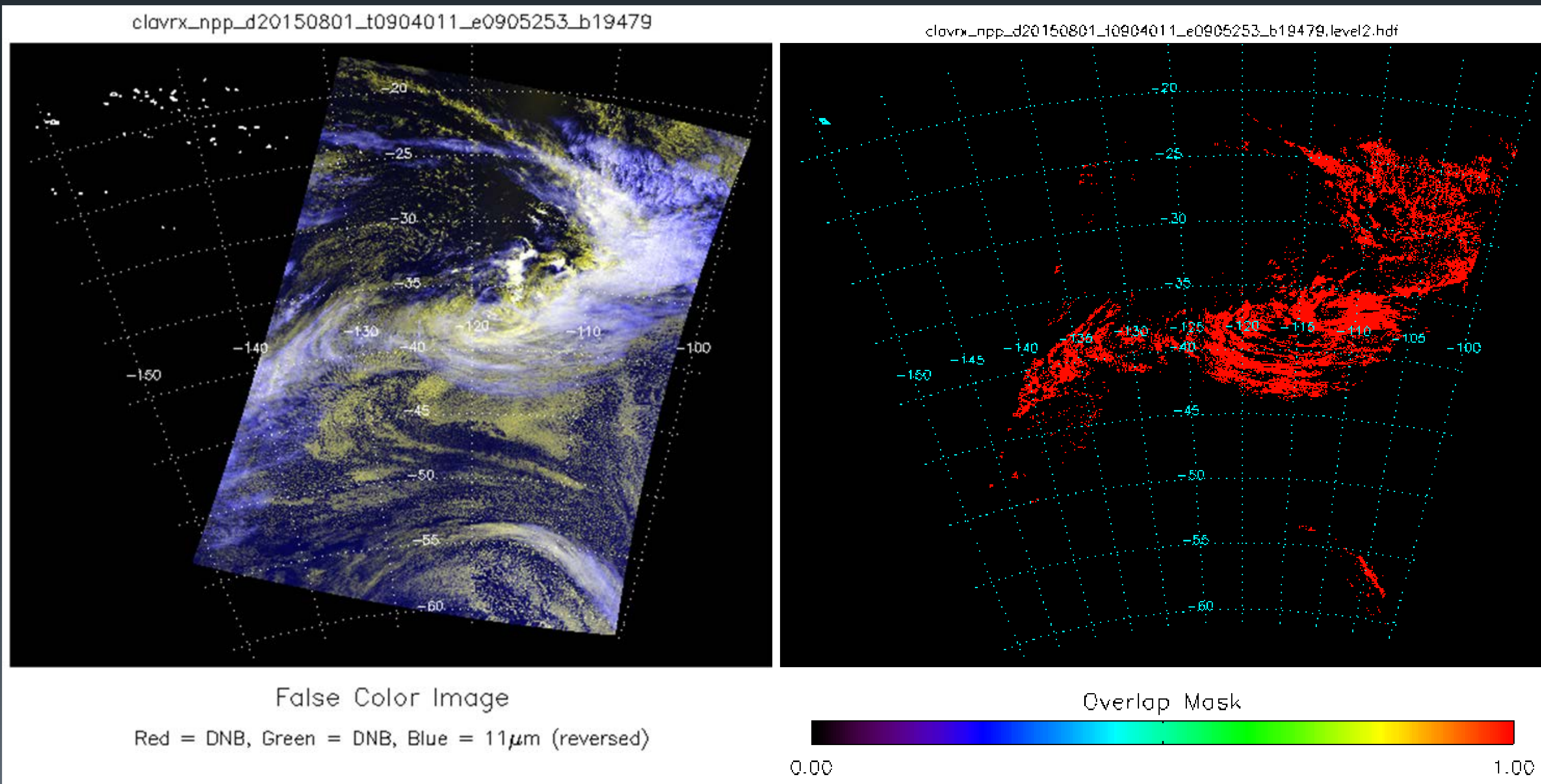


# Results



- Here is the resulting overlap detection for this scene.
- Goal is to finalize this and test impact to the official NOAA Enterprise Cloud Typing Algorithm.
- In a similar effort for CCL, we are using CrIS radiances with a similar goal.



# Cloud Micro and Optical Properties (NLCOMP)

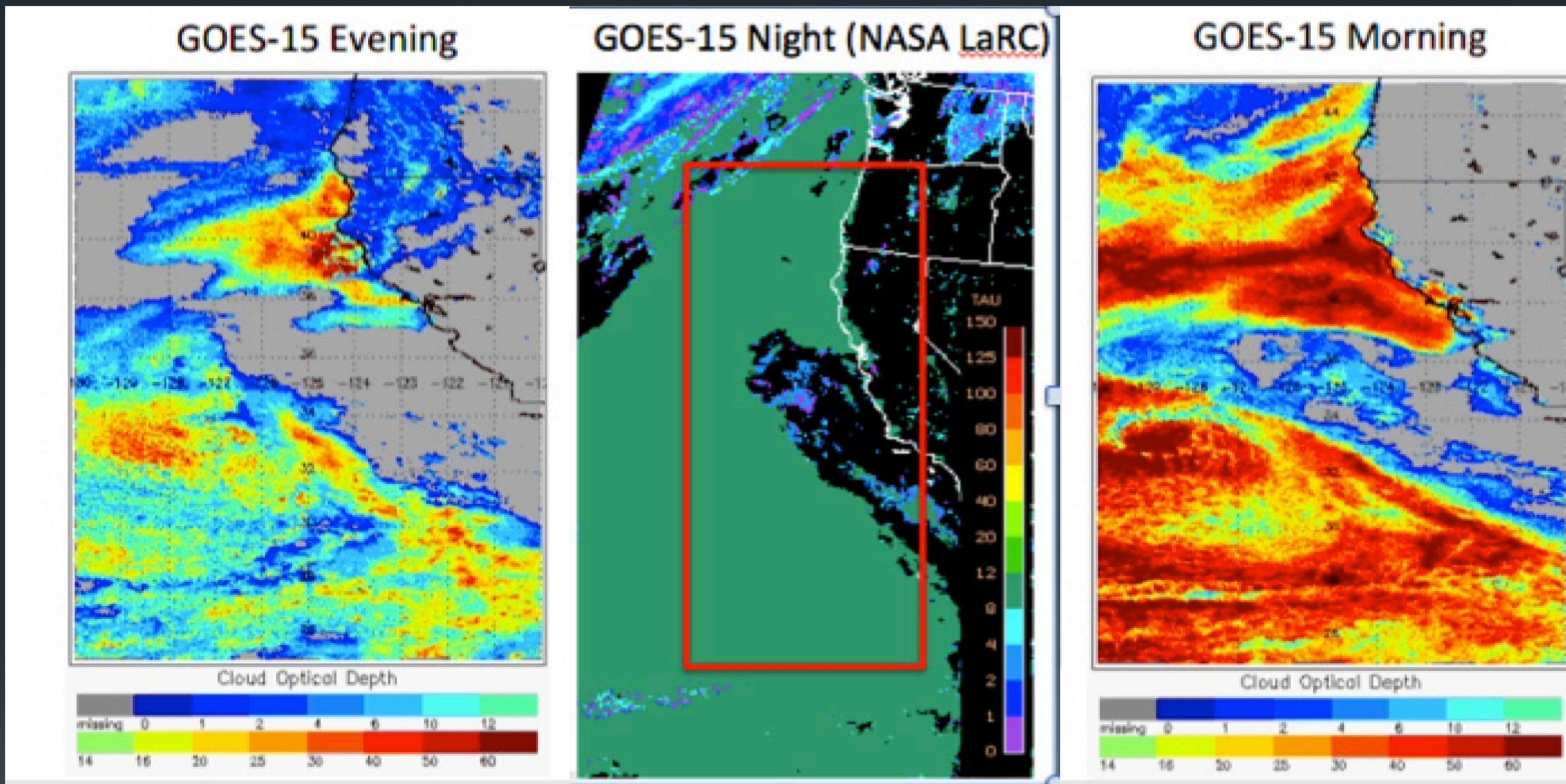
# The Nighttime Lunar Cloud Optical and Microphysical Properties (NLCOMP) retrieval



- Is the nighttime adaption of the daytime equivalent DCOMP ( Daytime-COMP)
- Retrieves Cloud Optical Thickness and Effective Radius, those can be used to derive cloud water path.
- Input parameter: DNB visible lunar reflectance  and M-12 (3.75um) brightness temperature
- NLCOMP products has higher uncertainty than DCOMP due to higher uncertainty of lunar reflectance in contrast to solar reflectance.
- Limitations: City lights, ships, diffuse lights, etc..

# NLCOMP: Filling the nighttime gap: Cloud Optical Thickness






DCOMP
06:30PM

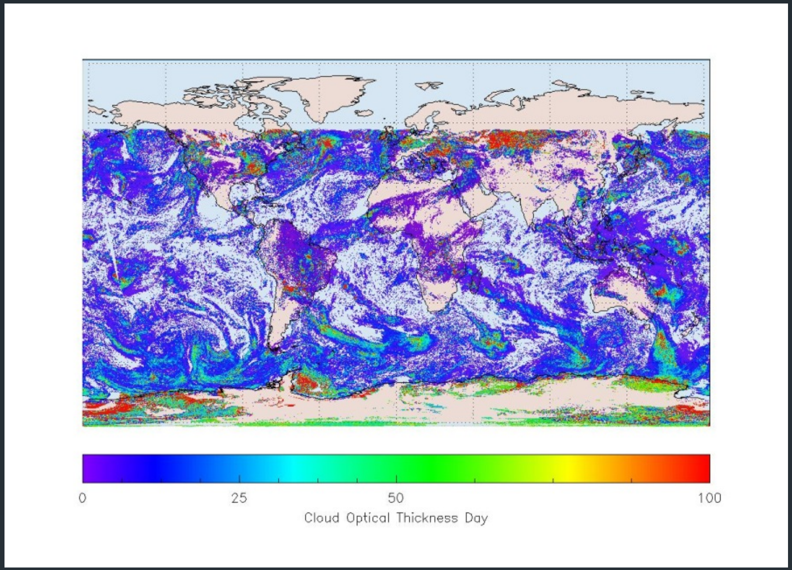
IR-based
01:30AM

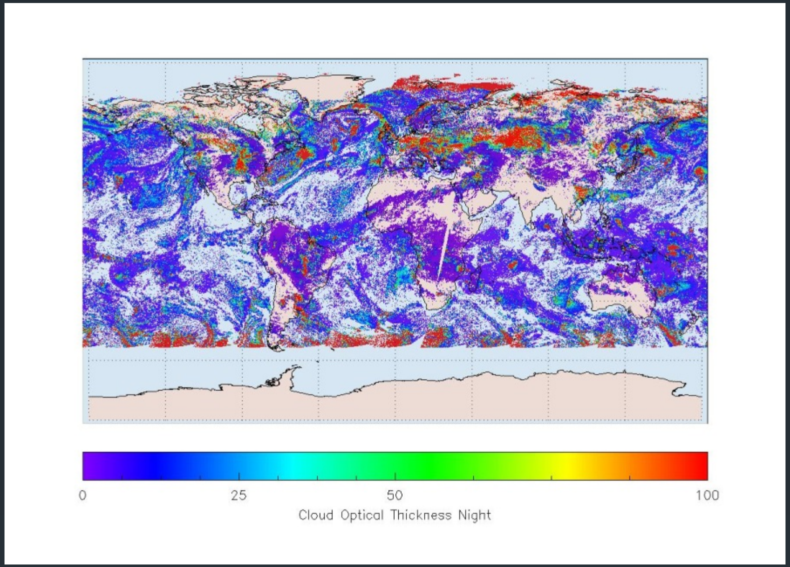
LARC Shortwave Infrared Infrared Split Window Technique (SIST) algorithm (Minnis et al., 1998).

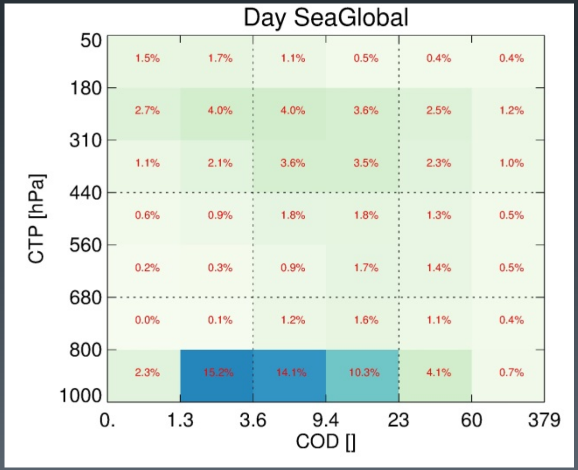
DCOMP
09:30AM

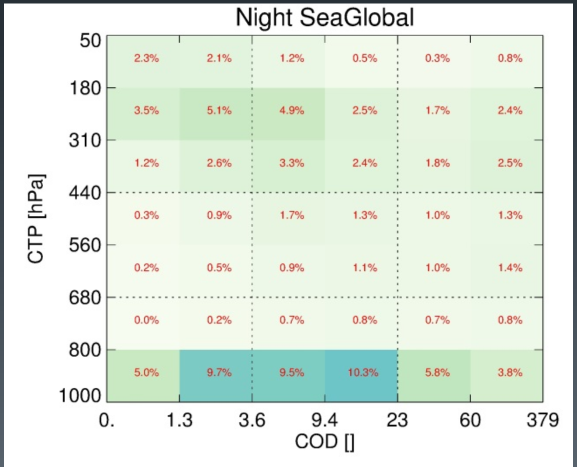
# Global daily composite:  27 Jan 2013





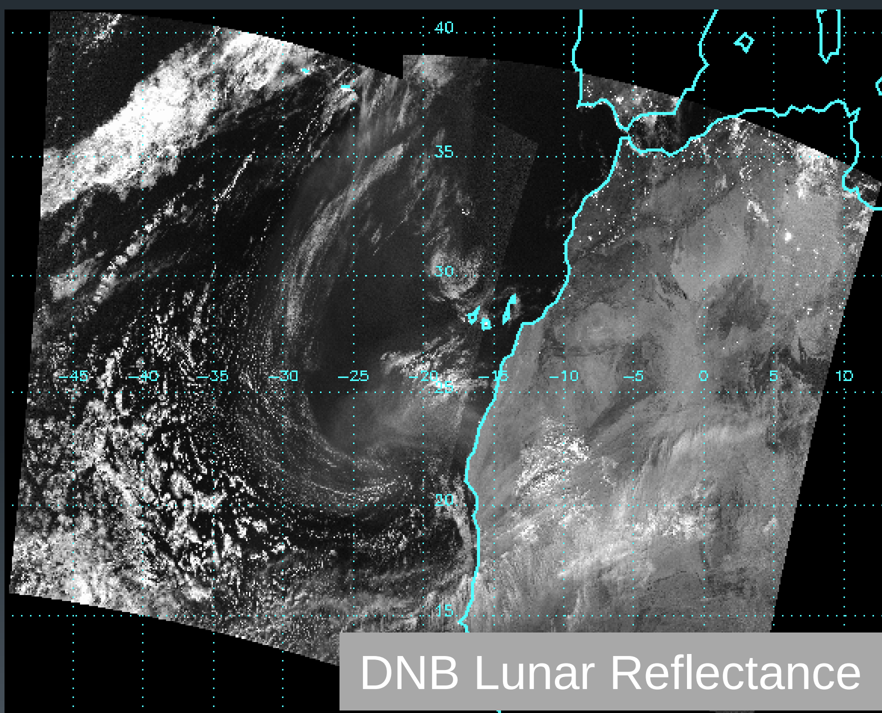
# Aerosol Remote Sensing Potential

# Lunar Reflectance of Aerosol

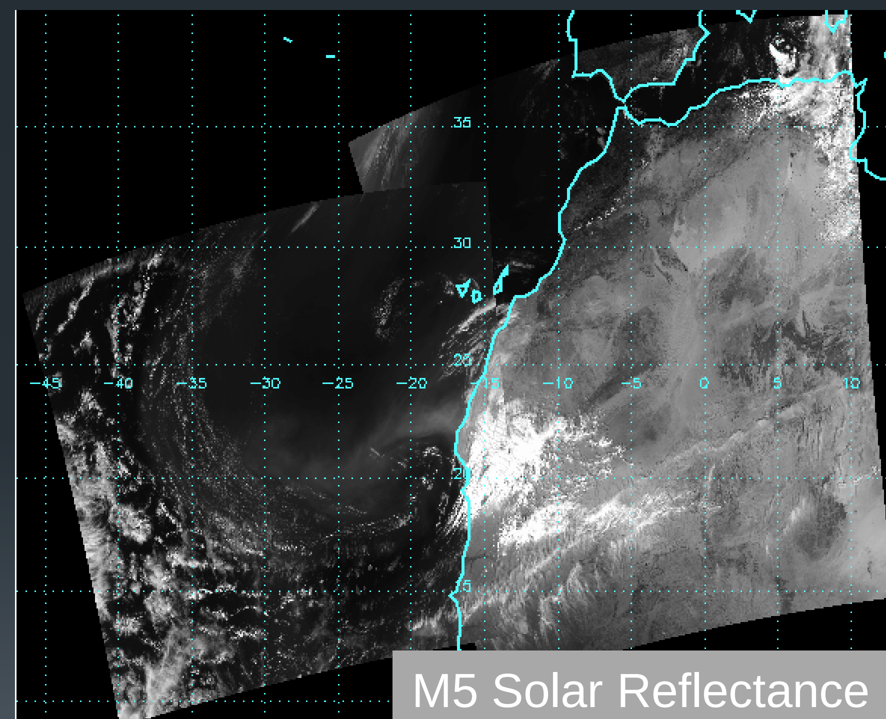


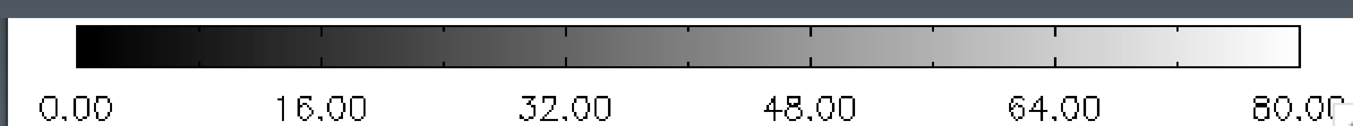
- Thick Aerosol (Dust) is well observed in Lunar Reflectance
- On nights with sufficient illumination, noise appears to be low.

March 9, 2015 Night




March 9, 2015 Day



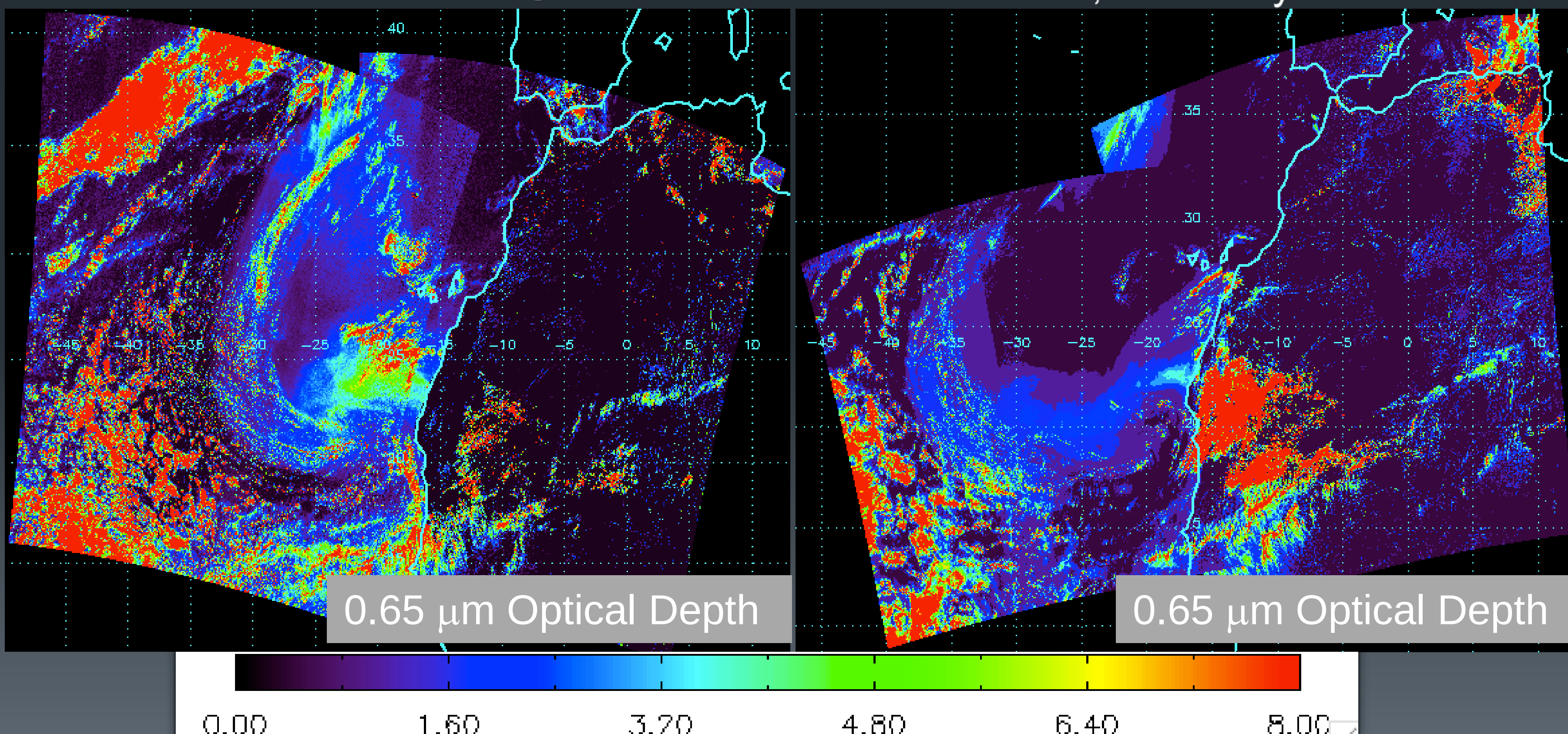
# “Dust” Optical Depths From Lunar Ref.



- In the next version of the cloud mask, we will make optical depths everywhere assuming a liquid phase cloud with $R_{eff}$ = 10 microns. Optical depths will replace our reflectance tests.
- Images below show these optical depths for the dust scene.
- Noise also does not appear to be an issue.

March 9, 2015 Night

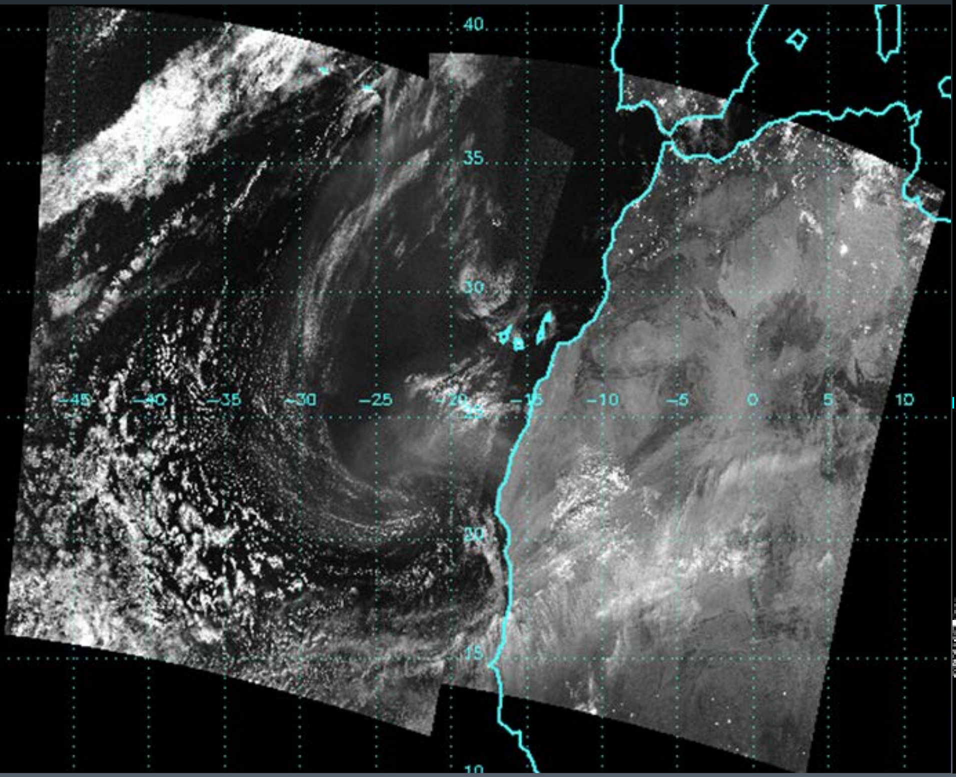
March 9, 2015 Day

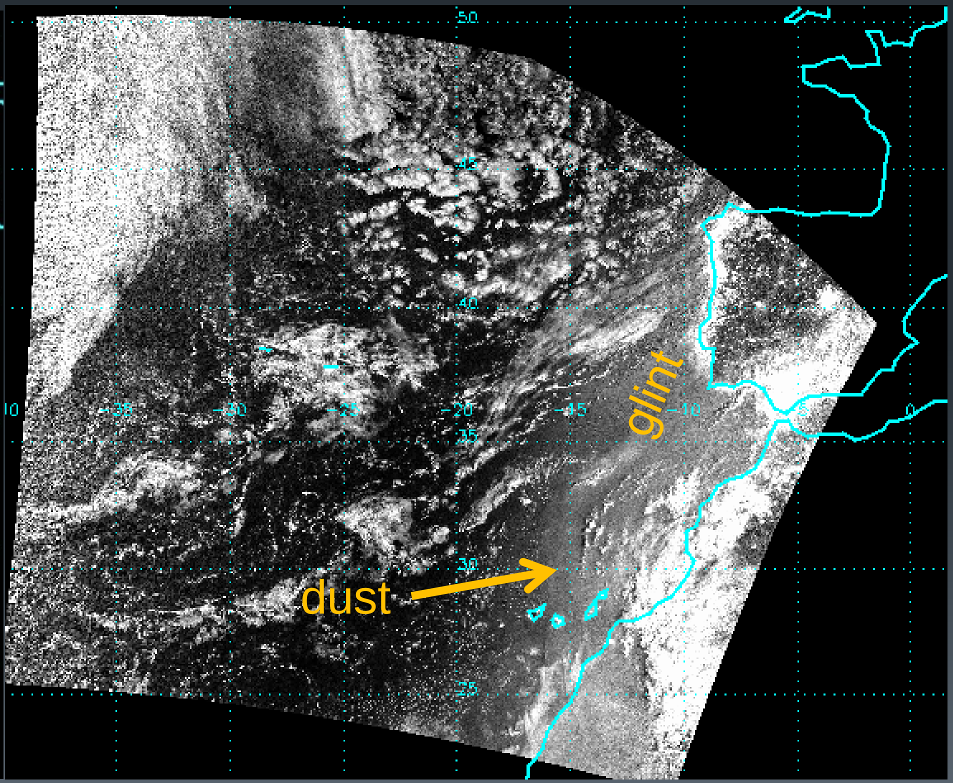


# Viewing Dust at Different Moon Phases



Noise may be an issue at the limit of illumination (quarter moon) for dust retrievals





# Summary

- Lunar reflectance is being used in several ways by the cloud team
  - Improvement nighttime detection in the NOAA Enterprise Mask of low-level cloud (making it more consistent with the daytime).
  - Improving detection of overlapped (multi-layer) cloud with VIIRS at night.
  - Extending retrievals of cloud micro and optical properties to night – where had no similar capability before.
- Aerosol/Dust remote sensing at night is one where area where the Cloud and Aerosol Teams can collaborate. Cloud team plans on using Lunar Ref and needs to detect Dust.
- We plan on serving these in the OCONUS PG and in the Alaska Cloud Products project.
- Thank you JPSS RR for support!

# Extra Material

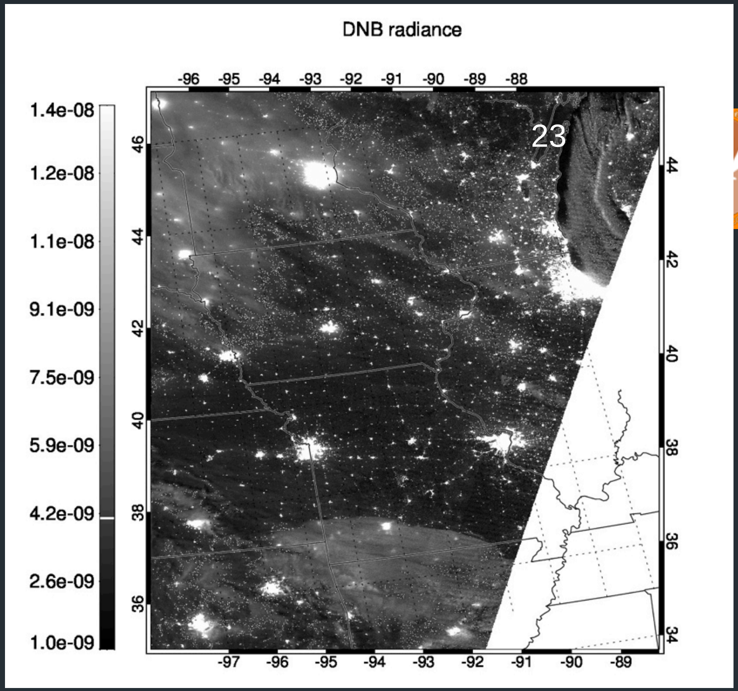
# From DNB radiance to Lunar Reflectance

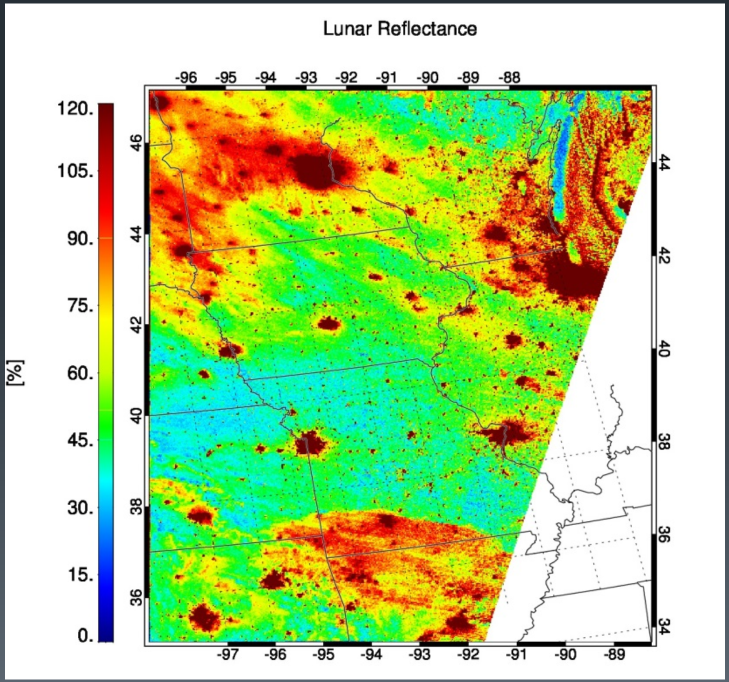
- The radiance to reflection retrieval was developed by Steven Miller (CIRA)

- In contrast to solar irradiance the computation of down-welling lunar irradiance is a complex task due to many components which have to be considered:
  - Lunar phase
  - Lunar spectral surface albedo
  - Moon-Earth-Sun orbital geometry
  - Lunar zenith angle

- Implemented in CLAVR-x and plans for SAPF but time-line unknown.

- DNB pixels mapped to M-bands.

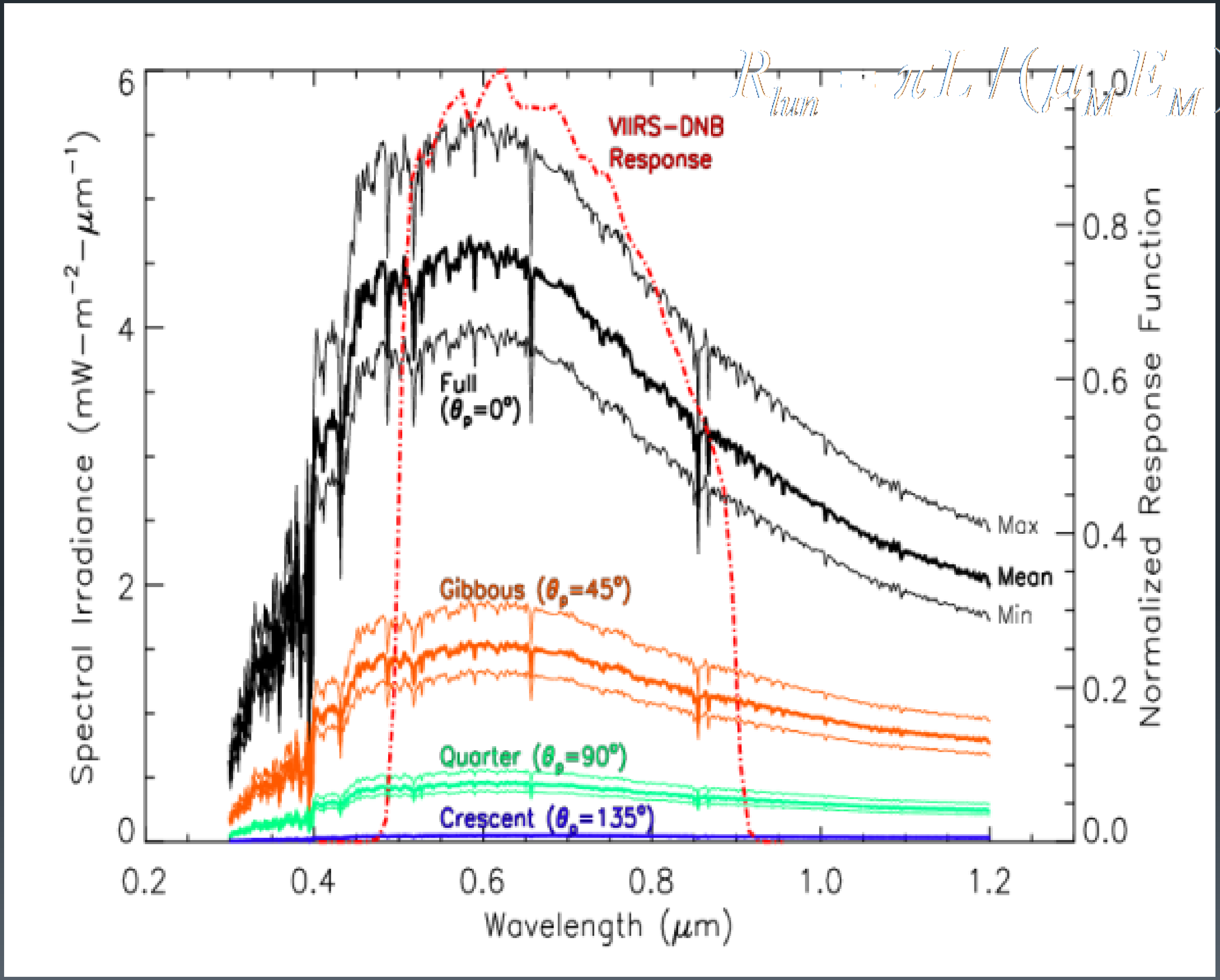


# Variations of lunar irradiance with lunar phase



$$R_{lun} = \pi L / (\mu_M E_M)$$

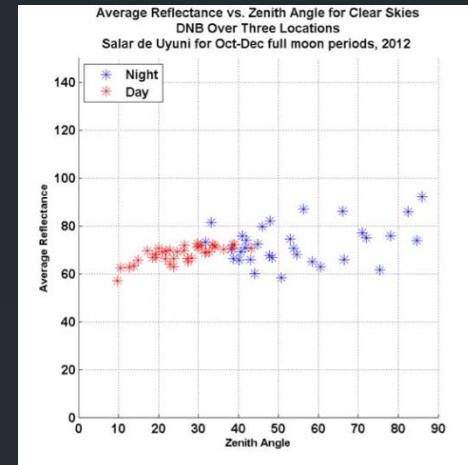



From Miller and Turner 2009

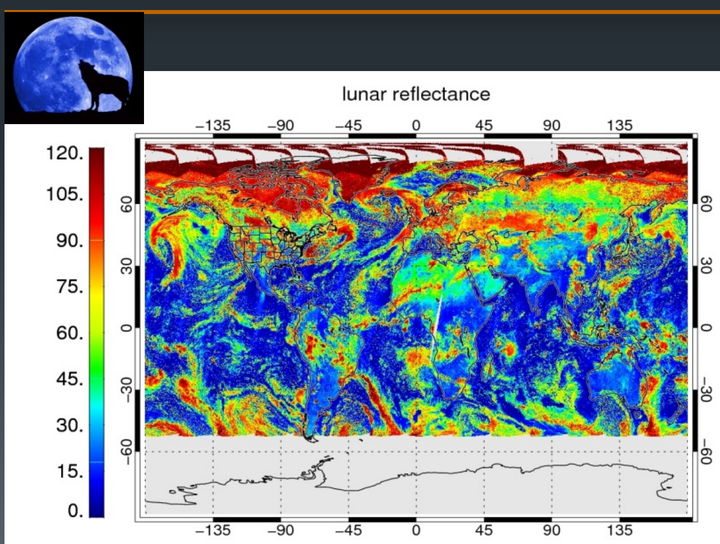
# Consistency of lunar and solar reflectance

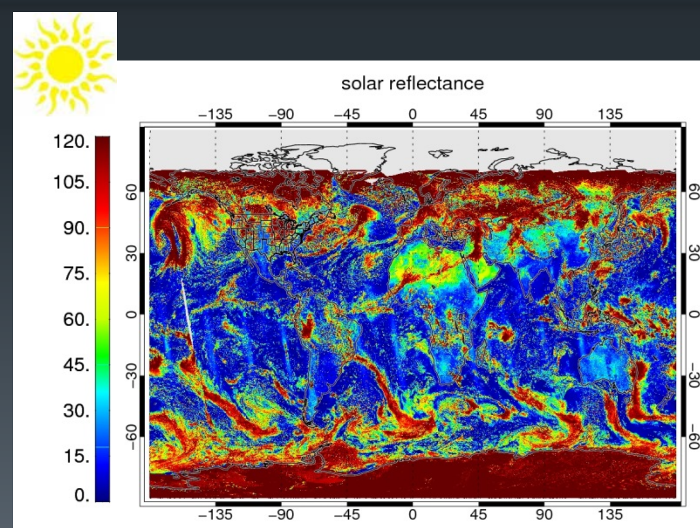


Lunar and solar reflection results for cloud-free scenes at the Salar de Uyuni salt flat ("Salzpfanne") in Bolivia.




Results show agreement which is consistent with assumed uncertainties of the lunar model.




Global daily composites show also good agreement

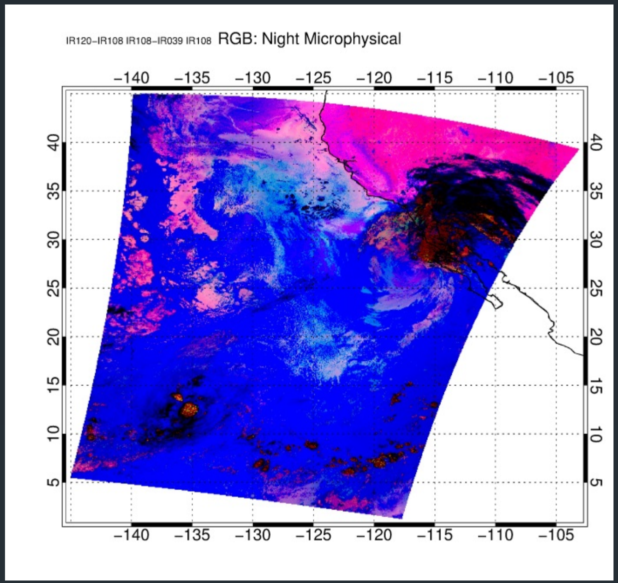
# DNB and moon light for quantitative cloud retrievals in CLAVR-x

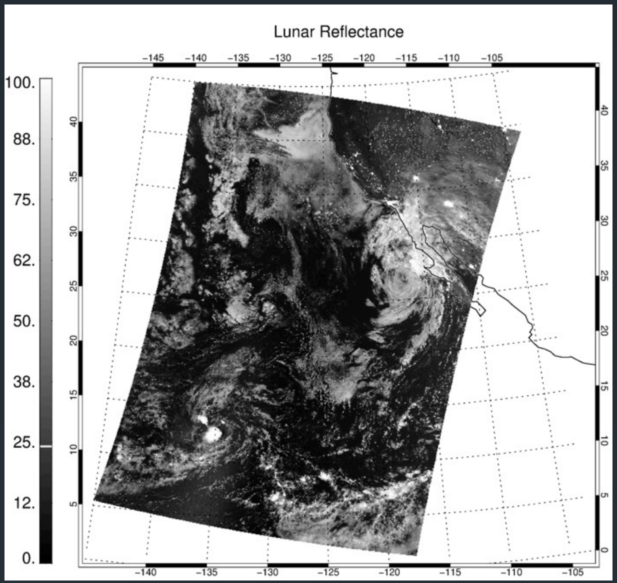


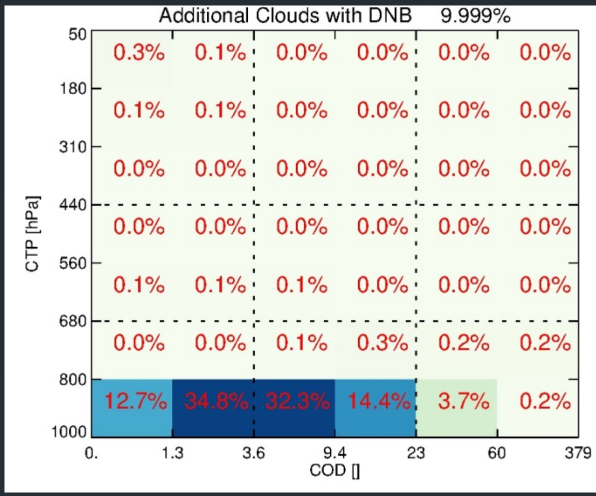
- Moon light is about 250 000 dimmer than sun (~$10^{-5}$ W $m^{-2}$ $sr^{-1}$ $\mu m^{-1}$ at full moon)
- Current sensors (MODIS, AVHRR, etc..) in visible spectrum are only able to detect signals from around $10^{0}$-$10^{2}$ W $m^{-2}$ $sr^{-1}$ $\mu m^{-1}$
- DMSP-OLS offered low-light images, but the data were not calibrated, with low information depth (6-bit) and low spatial resolution.
- DNB VIIRS onboard NPP-Soumi is the first channel which is both, highly sensitive to low-light in visible spectrum and providing a sufficient data depth (down to $10^{-5}$W $m^{2}$ $sr^{-1}$ as a band average with a 14-bit resolution)
- DNB spatial resolution is uniformly 740m along and across the swath from nadir to the edge of the swath.
- DNB has to be collocated with VIIRS M-band channels those pixels grow from nadir to the edge (up to 5 times larger pixels) for retrievals.

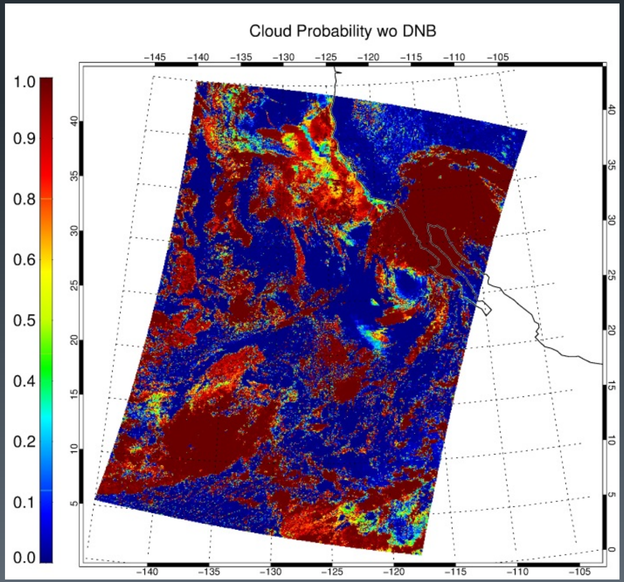
# Cloud Mask improvement with DNB

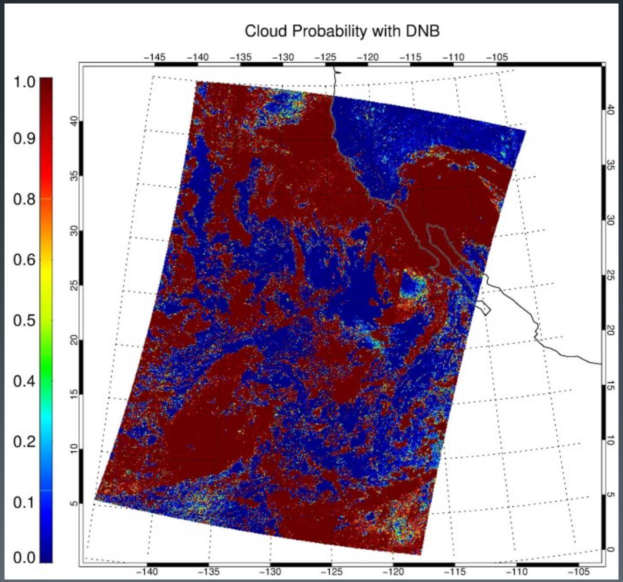


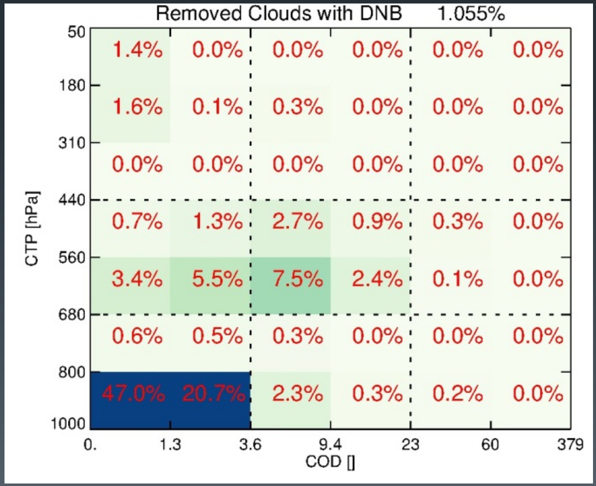


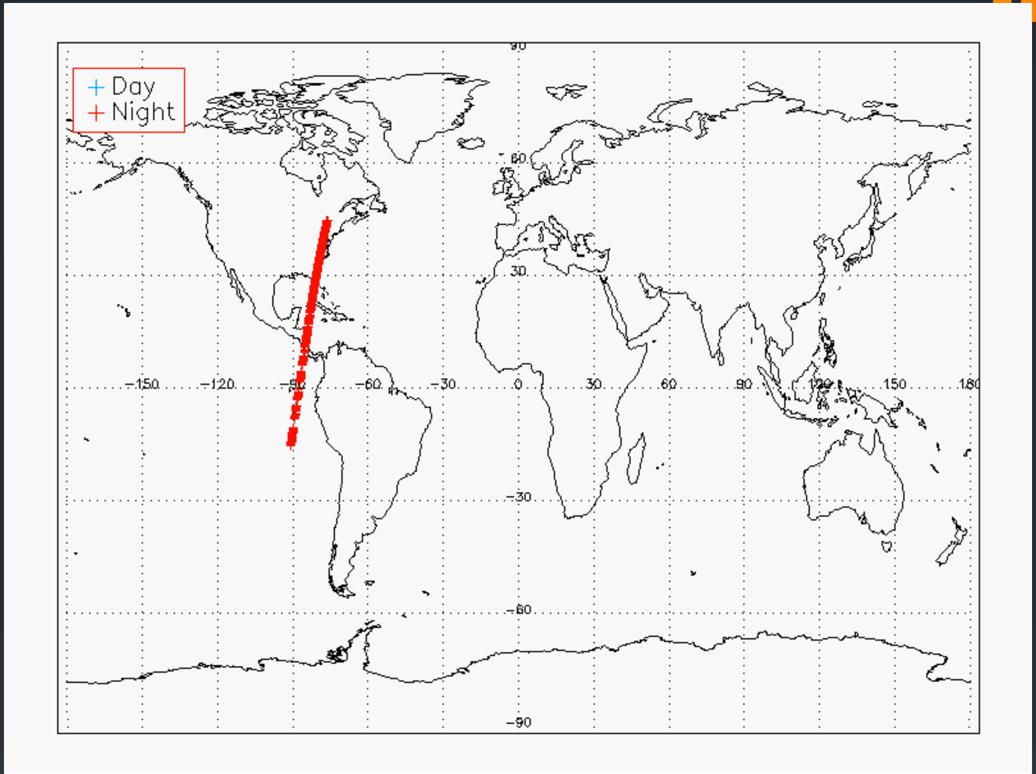



# Cloud Mask Validation



CALIOP - VIIRS Matchup
Pixels with Maximum
± 0.2 Hour (± 12 Minutes)
Time Difference;
03/29/2013



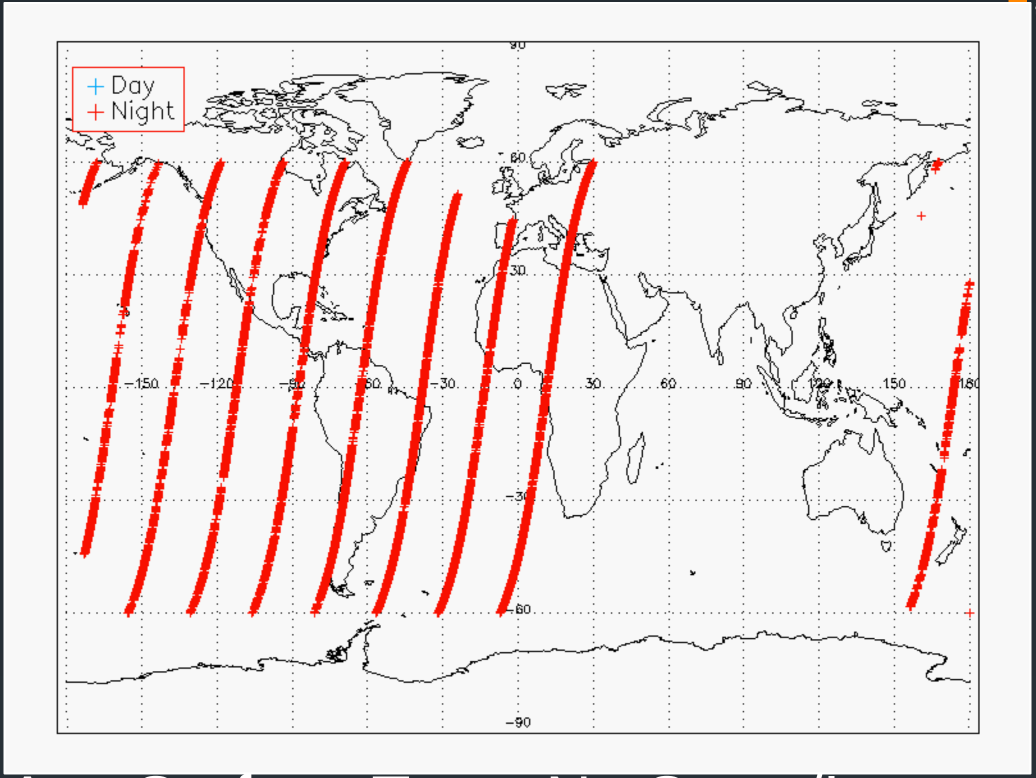

## 90N – 90S, Day/Night, Any Surface and Any Condition

| Cloud Mask Algorithm | Sample Size | Cloud fraction | | | | Probability of | | |
|---|---|---|---|---|---|---|---|---|
| | | Active | Passive | Pr. Clear | Pr. Cloudy | Detection | False D. | Leakage |
| CLAVR-x No DNB | 6213 | 0.565 | 0.452 | 0.099 | 0.168 | 0.883 | 0.002 | 0.115 |
| CLAVR-x DNB | 6213 | 0.565 | 0.515 | 0.040 | 0.080 | 0.921 | 0.014 | 0.065 |
| VCM | 5911 | 0.574 | 0.470 | 0.072 | 0.046 | 0.892 | 0.002 | 0.106 |

# Cloud Mask Validation – a more global view



CALIOP - VIIRS Matchup Pixels with Maximum ± 0.2 Hour (± 12 Minutes) Time Difference; 03/29/2013

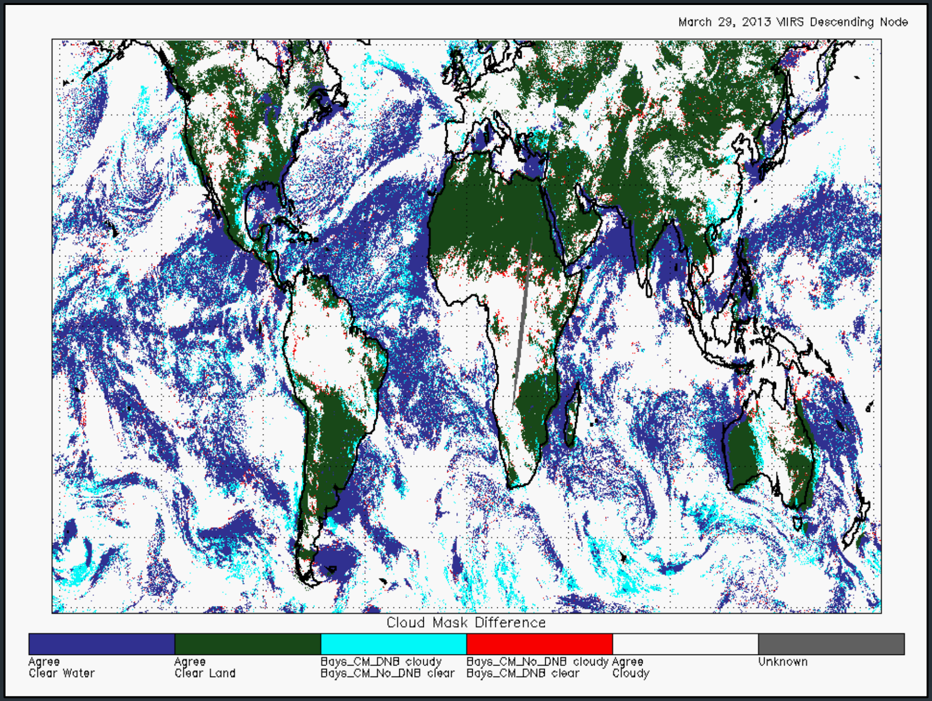


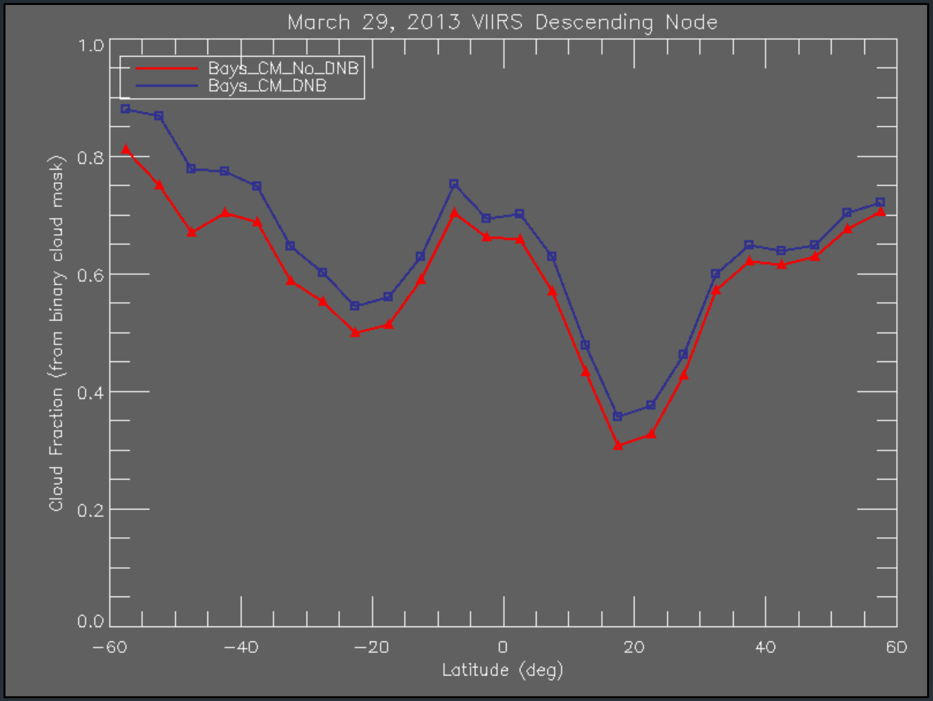

60N – 60S, Night, Any Surface Type, No Snow/Ice

| Cloud Mask Algorithm | Sample Size | Cloud fraction | | | | Probability of | | |
|---|---|---|---|---|---|---|---|---|
| | | Active | Passive | Pr. Clear | Pr. Cloudy | Detection | False D. | Leakage |
| CLAVR-x No DNB | 96688 | 0.713 | 0.641 | 0.080 | 0.117 | 0.903 | 0.013 | 0.084 |
| CLAVR-x DNB | 96688 | 0.713 | 0.674 | 0.056 | 0.052 | 0.932 | 0.015 | 0.053 |

# Cloud Mask Validation – A Global view





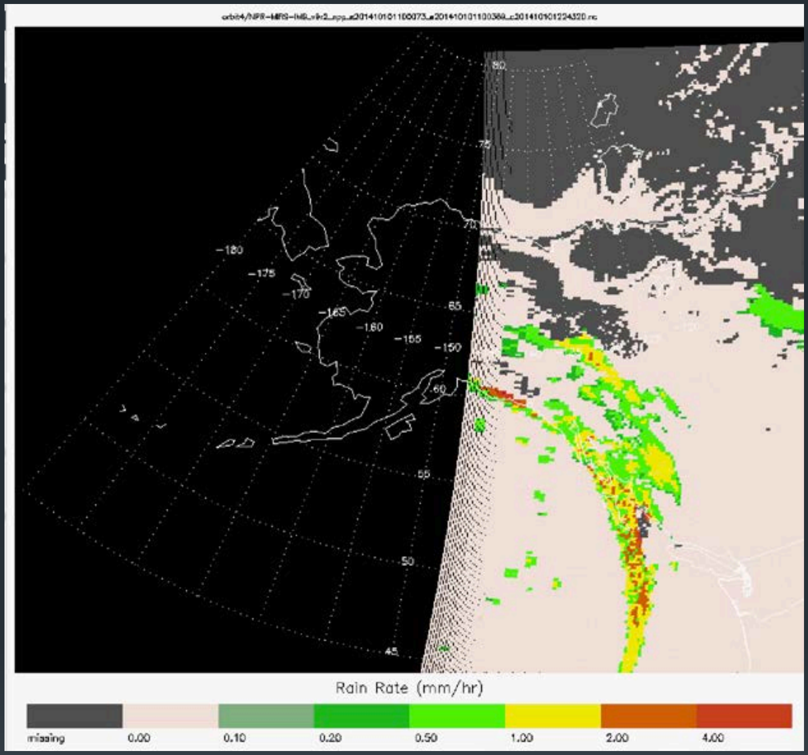




Bayesian CM Difference
No DNB – With DNB

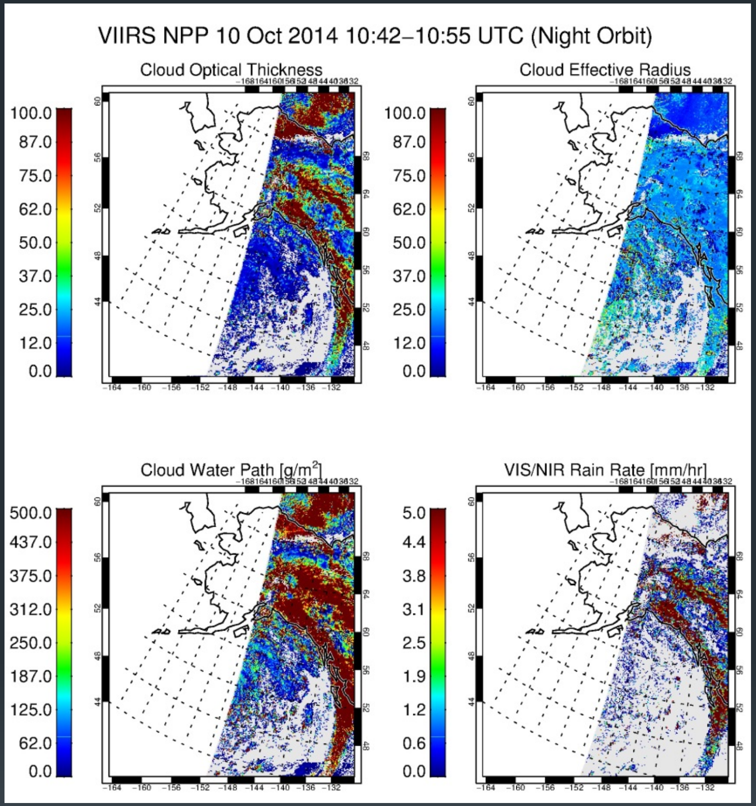
Bayesian CM Zonal Fraction

# NLCOMP: Filling the Arctic winter gap: Precipitation






ATMS sensor on NPP provides MW–based rain rate




NLCOMP cloud products and rain rate estimates using (Roebeling 2009)

# VCM Status

**Thomas Kopp, Andrew Heidinger, Richard Frey,**
**Denis Botambekov and William Thomas**
*JPSS Cloud Mask Team*
*August 27, 2015*

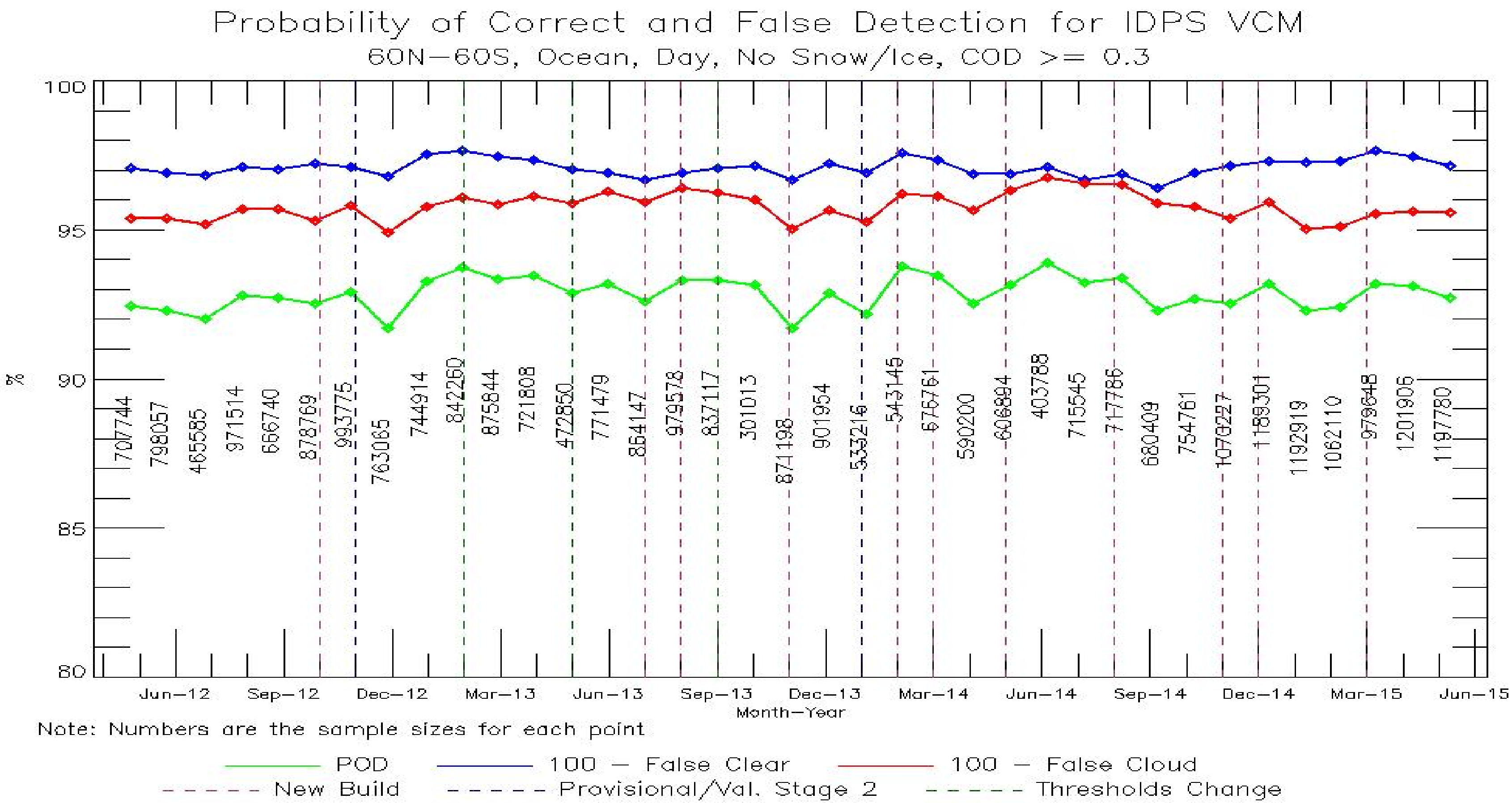
# Overall Status

- The VCM continues to meet or exceed its requirements
- The core team has lost 30% of its personnel over the last year
- The focus of work has transitioned to corrections as requested by downstream users and written as DRs
  - This is consistent with the program memo from 2014 limiting work to corrections only, and no “improvements”
- Software updates over the past year have corrected issues with the cloud shadow and ephemeral water Quality Flags
- Tuning is decreasing in frequency, as expected
  - Adjustments were made in early 2015 to reduce false alarms over deserts and improve the probability of correct typing at night
  - One more tuning event is planned in the fall, before Block 2.0
- Noticeable improvement is seen with the implementation of a daily snow/ice (GMASI) update starting 1 December 2014

# Overall Performance

Global, non-polar statistics as of June 2015, Ocean Day, No snow

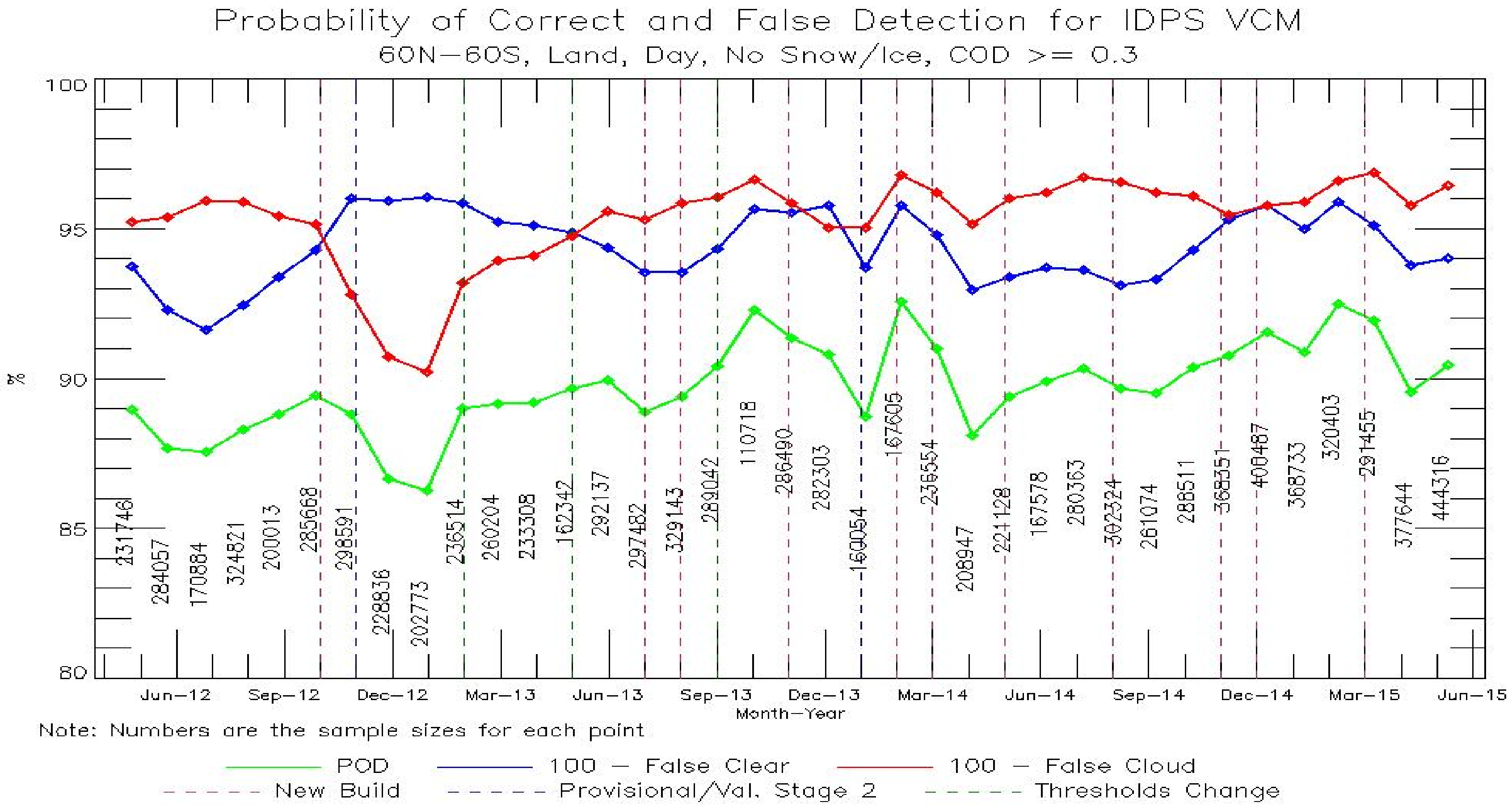
Values are for COD > 0.3 but requirement is for COD > 1.0



# Overall Performance

Global, non-polar statistics as of June 2015, Land Day, No snow

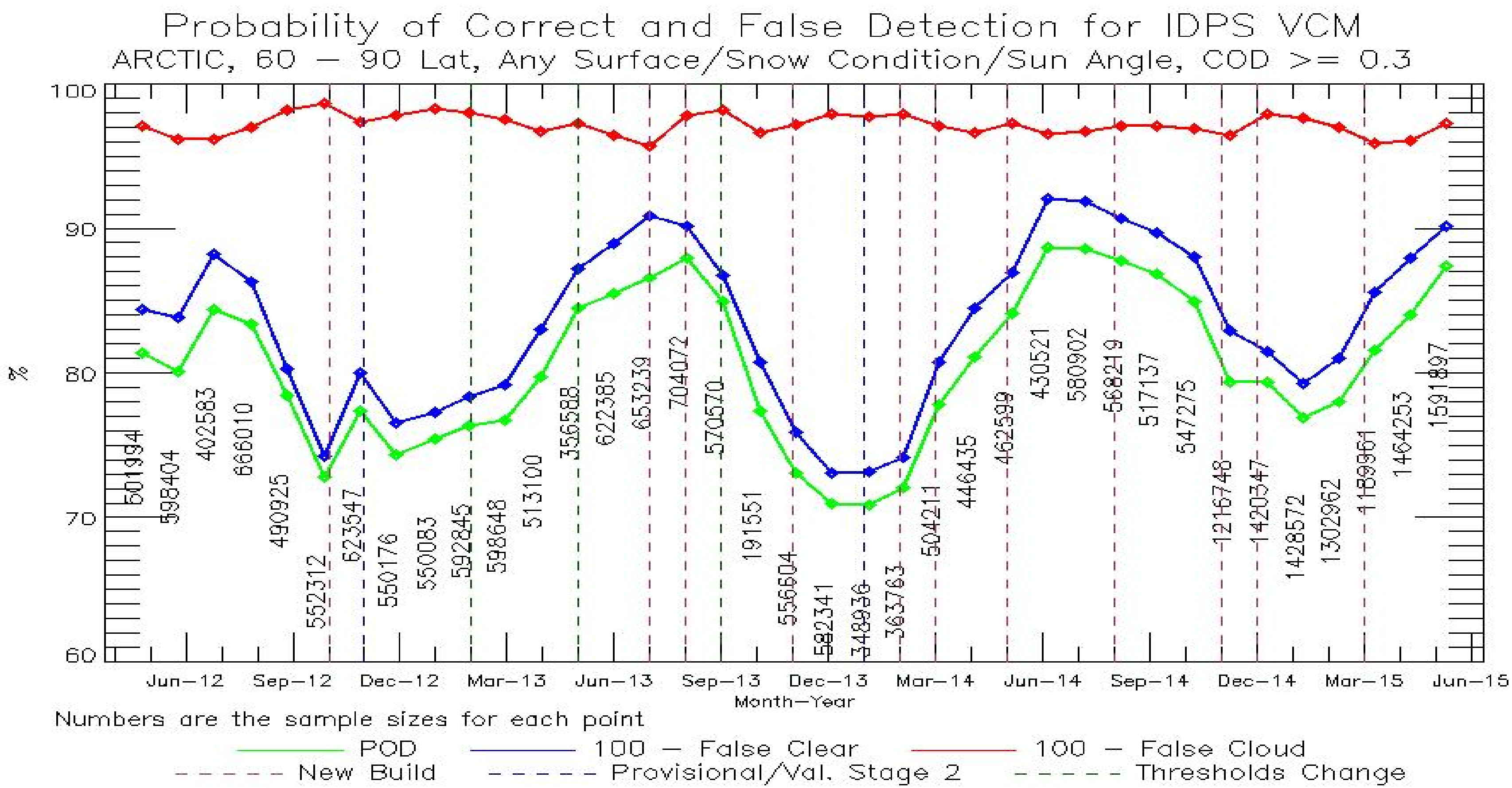
Values are for COD > 0.3 but requirement is for COD > 1.0



# Overall Performance

Global statistics as of June 2015, Snow Day, Polar Regions

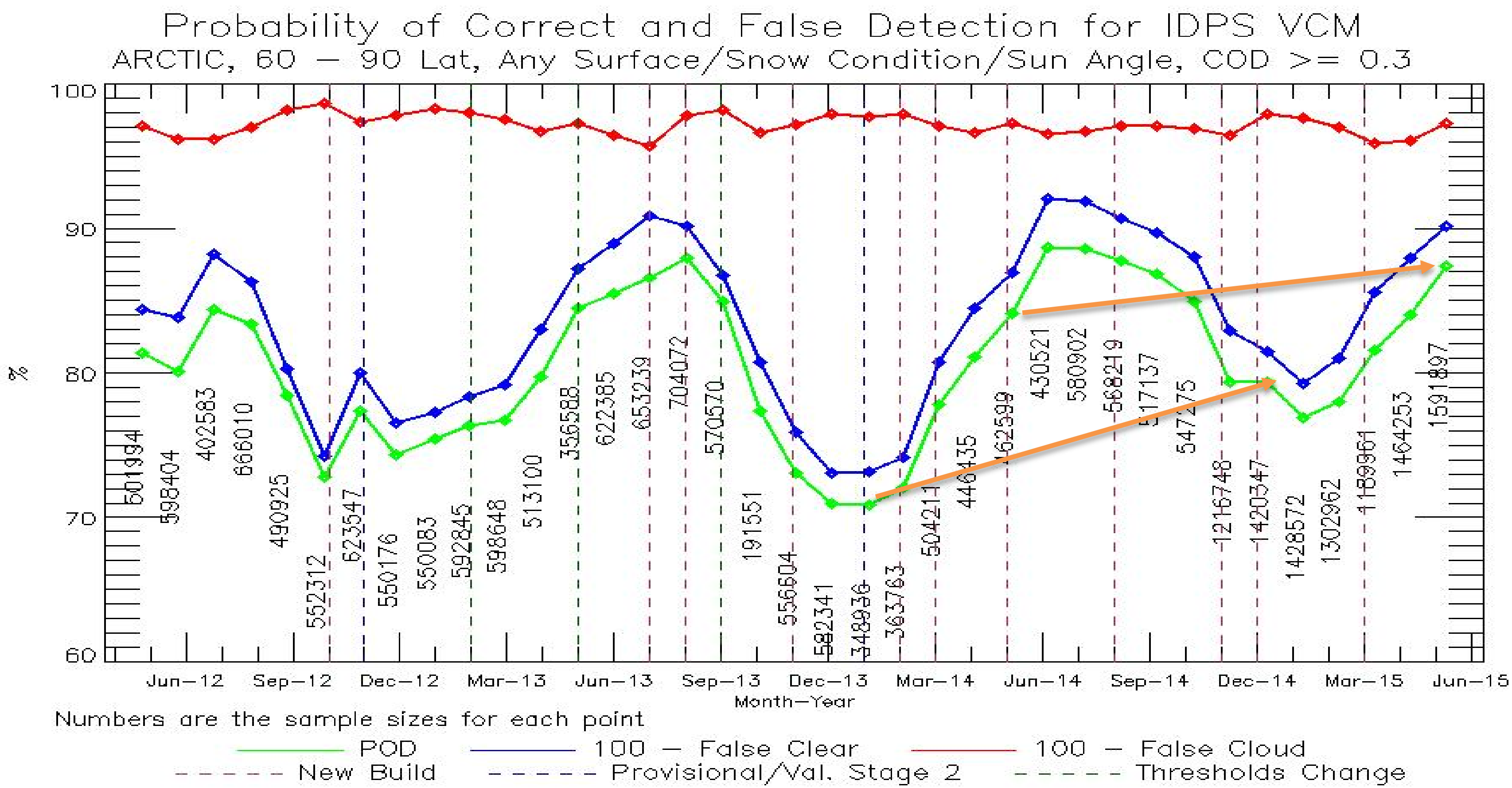
Impact of GMASI not obvious unless you compare similar months



# Overall Performance

Global statistics as of June 2015, Snow Day, Polar Regions

Lines show improvement from monthly updates to daily updates

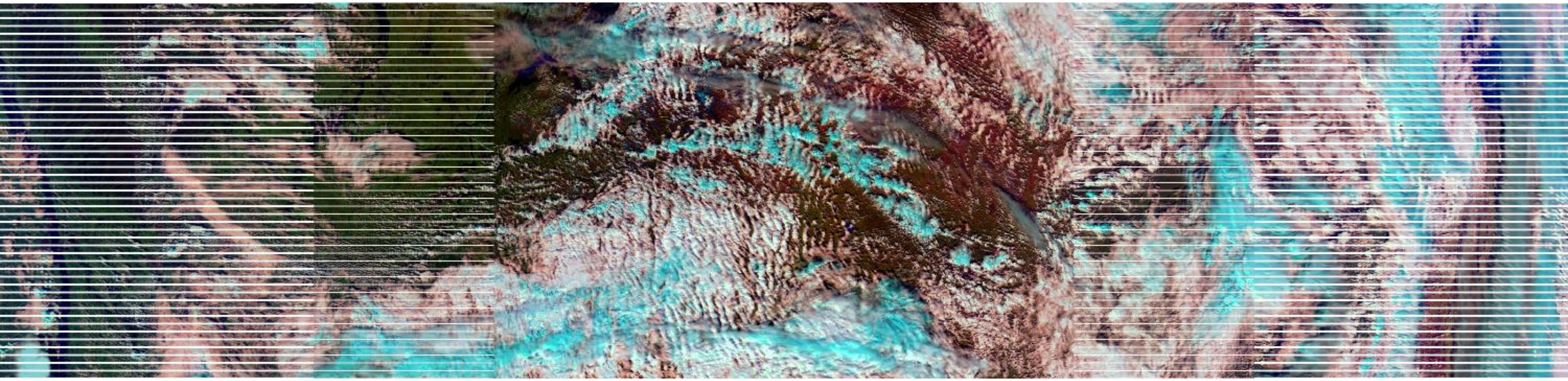


# Near term efforts

- There are three active efforts with the VCM at present
  - Software update currently under review at the AERB mitigates the clouds over fires DR
    - Update addresses land backgrounds only, though that is where the majority of the error occurs
  - Tuning updates to address leakage (ice clouds) over cold backgrounds and over deserts at large viewing angles, possibly other items in late September/early October
    - Goal is to have these updates implemented before the Northern Hemisphere winter season
  - Software update in testing to sharply reduce leakage over cold bare ground, recent DR as requested from the cryosphere team with missed ice clouds
    - Example of the issue on the following slides

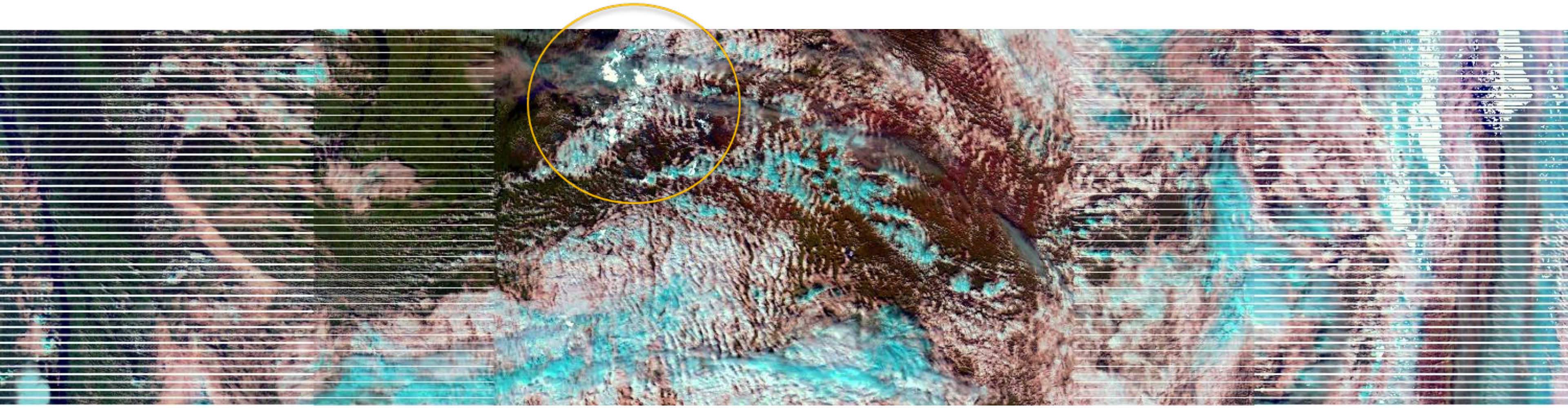
# Siberia

June 18, 2015, Red = M10, Green = M7, Blue = M1
White is lower cloud, blue shading is ice topped clouds
Darker shades of blue is surface snow, but the only location in this image where it exists and can be seen is on the right



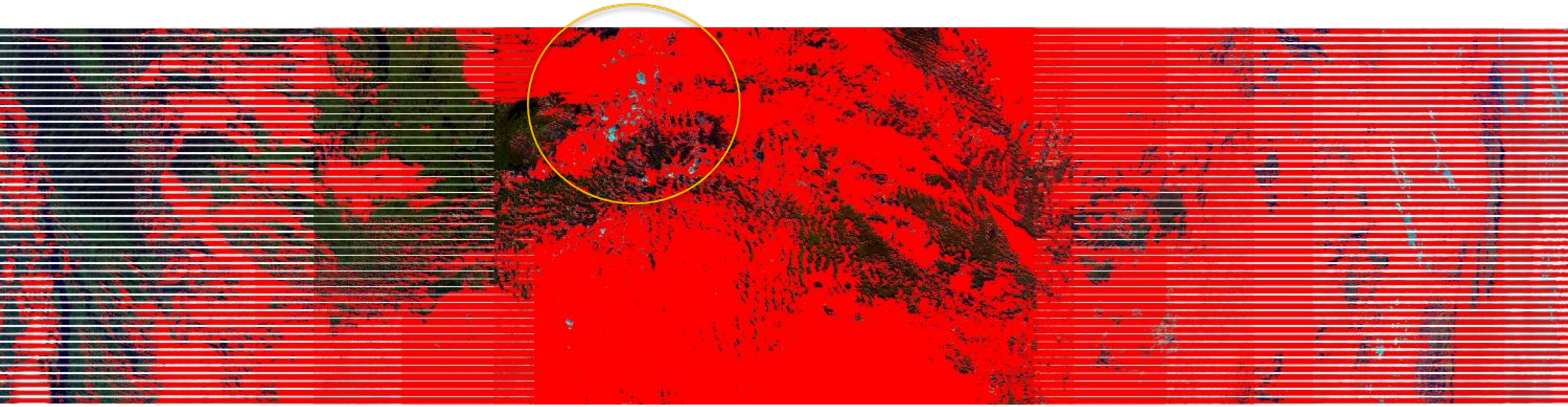
# Siberia

June 18, 2015, Red = M10, Green = M7, Blue = M1
White is lower cloud, blue shading is ice topped clouds
Snow, which is a combination of the daily GMASI ancillary data set and the VCM snow test, is bright white below.
The areas of snow in the middle are clouds



# Siberia

June 18, 2015, Red = M10, Green = M7, Blue = M1
White is lower cloud, blue shading is ice topped clouds
Red is confidently cloudy, note the missed clouds in the middle of the granule
Most of that cloud is missed even under the probably condition (not shown)



# Ice cloud fix

- Feedback from the cryosphere team in May 2015 reported missed ice clouds over cold bare ground was leading to spurious snow in the cryosphere products
  - Cryosphere products are impacted most where the ground is bare, hence missed ice clouds are interpreted as ground snow, issue occurs only if surface is cold enough that snow/ice is possible
- Extensive evaluation has led to a promising fix to the problem
  - In testing is use of M10 as a stand alone screen to identify pixels difficult to clearly identify as ground snow/ice or ice clouds
  - In this case VCM will default to GMASI, and the brightness of the pixel will flag these cases as clouds when GMASI does not contain snow/ice for that pixel
  - Essentially the daily update allows the VCM to increase dependence on the ancillary snow/ice field, something not possible until 1 December 2014

# Post Block 2.0

- Ice cloud fix is targeted for the first Block 2.0 implementation (highest priority)
- Three potential software updates exist in the VCM “queue”
  - Use of an ancillary Sea Surface Temperature field instead of the GFS for determining surface temperatures as part of cloud detection over oceans process
  - Develop a module for Antarctica
  - Extend the correction of clouds over fires to other backgrounds than land, and for night (gas flares)
- Any feedback and/or new DRs that may be addressed via tuning, these are not tied to builds

# JPSS-1 Preparation

- No major software changes are necessary for the VCM to support JPSS-1
- The tools needed to validate either the VCM or the Enterprise cloud mask are in place
- Quantitative validation may be slowed if CALIPSO is no longer available
- Similar to S-NPP, a 30-day spin up is planned to insure the VCM is at least at beta, if not provisional, level early in the EDR validation process
- There is every reason to believe the VCM will meet its requirements for JPSS-1, including any altered by the program by launch

# Summary

- The VCM continues to make progress and address downstream concerns from dependent users
- The VCM continues to at least meet all of its requirements
- The daily snow update clearly benefited the VCM, and now allows us to make adjustments as the VCM no longer has to concern itself with severely dated snow/ice backgrounds
- The clouds over fires mitigation is scheduled for Build 8.12
- The ice cloud fix is being worked to make the first post Block 2.0 build
- The cloud mask team has the tools available to support the validation of JPSS-1 for either or both cloud masks in play
- Feedback from the users is always encouraged, remember tuning is not tied to a build

Extra Material Follows

# THANK YOU

# Statistical Results, Clouds over Fires

Results are from 6 consecutive daytime granules over Africa on 15 June 2015

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| FIRE: | | | | | | Mx8.10 | Mx8.12 | | | Mx 8.12 (fire fix) has: |
| LAND | ConfCldy | HiQual | DAY | FIRE | | 3776 | 2108 | | -1668 | 2294 fewer Conf Cldy |
| LAND | ConfCldy | MedQual | DAY | FIRE | | 2075 | 1449 | | -626 | |
| LAND | ConfClr | HiQual | DAY | FIRE | | 9 | 1201 | | 1192 | 1818 more Conf Clr |
| LAND | ConfClr | MedQual | DAY | FIRE | | 13 | 639 | | 626 | |
| LAND | ProbCldy | HiQual | DAY | FIRE | | 2 | 15 | | 13 | 13 more Prob Cldy |
| LAND | ProbCldy | MedQual | DAY | FIRE | | 2 | 2 | | 0 | |
| LAND | ProbClr | HiQual | DAY | FIRE | | 8 | 471 | | 463 | 463 more Prob Clr |
| LAND | ProbClr | MedQual | DAY | FIRE | | 9 | 9 | | 0 | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| NO FIRE: | | | | | | Mx8.10 | Mx8.12 | | | Mx 8.12 (fire fix) has: |
| LAND | ConfCldy | HiQual | DAY | NOFIRE | | 1092946 | 1092885 | | -61 | 75 fewer Conf Cldy |
| LAND | ConfCldy | MedQual | DAY | NOFIRE | | 4112 | 4098 | | -14 | |
| LAND | ConfClr | HiQual | DAY | NOFIRE | | 2243966 | 2243996 | | 30 | 44 more Conf Clear |
| LAND | ConfClr | MedQual | DAY | NOFIRE | | 2439528 | 2439542 | | 14 | |
| LAND | ConfClr | LowQual | DAY | NOFIRE | | 251 | 251 | | 0 | |
| LAND | ProbCldy | HiQual | DAY | NOFIRE | | 36220 | 36223 | | 3 | 3 more Prob Cldy |
| LAND | ProbCldy | MedQual | DAY | NOFIRE | | 715 | 715 | | 0 | |
| LAND | ProbClr | HiQual | DAY | NOFIRE | | 874705 | 874733 | | 28 | 28 fewer Prob Clr |
| LAND | ProbClr | MedQual | DAY | NOFIRE | | 14399 | 14399 | | 0 | |

# Validation of Suomi NPP VIIRS Aerosol Optical Thickness and Particle Size Parameter with AERONET

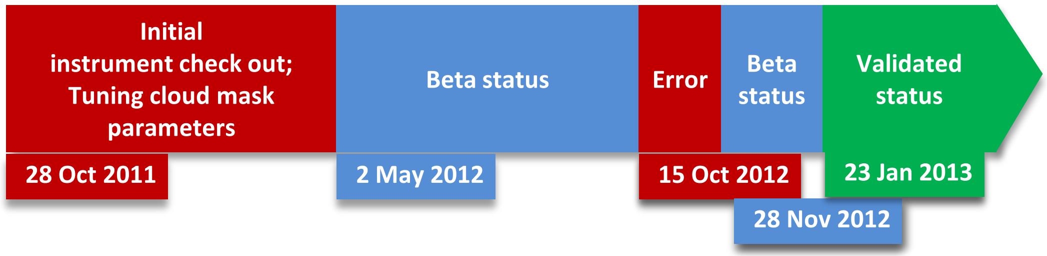
Jingfeng Huang and Istvan Laszlo

August 27, 2015

# Introduction

- VIIRS aerosol products, AOT and APSP (AE), are derived from 412 - 2,250 nm VIIRS M bands.
- Preliminary evaluation of AOT for May 2, 2012/Jan 23, 2013 - Sep 1,2013 aerosol data is in Liu et al. (2014):
  - Global biases: 0.01 over ocean and -0.01 over land
  - 64% (land) and 71% (ocean) of retrievals fall within the expected uncertainty range established by **MODIS** (!) [ocean: ±(0.03 + 0.05AOT); land: ±(0.05 + 0.15AOT)]
- This presentation extends the period to Dec 31, 2014 and establishes expected error range from VIIRS AOT & APSP.
- **Outline**
  - Aerosol data used
  - Matchup protocol
  - Results

# Aerosol Data




- **VIIRS:**
  - *Aerosol Optical Thickness (AOT)* Environmental Data Record (EDR) (6 km): <u>best quality AOT at 550 nm</u>;
  - *Aerosol Particle Size Parameter (APSP)* EDR <u>over ocean</u> (6 km) reported as the Ångström Exponent (AE) : calculated from AOTs at 865 nm and 1610 nm;
  - *Time period:* Jan 23, 2013 to Dec 31, 2014 (<u>land</u>) and May 2, 2012 to Dec 31, 2014 (except Oct 15, 2012 to Nov 27, 2012) (<u>ocean</u>).
- **AERONET:**
  - Level 2.0 AERONET Direct Sun Algorithm AOT wavelengths 380-870 nm, and at 1640 nm (Holben et al., 1998; Smirnov et al., 2000)
  - AERONET AOTs are interpolated to VIIRS wavelengths using a 2$^{nd}$ order polynomial fit in logarithmic coordinates. (Eck et al., 1999; Remer et al., 2005; Levy et al., 2010, Kahn et al., 2010)

# VIIRS-AERONET AOT Matchup

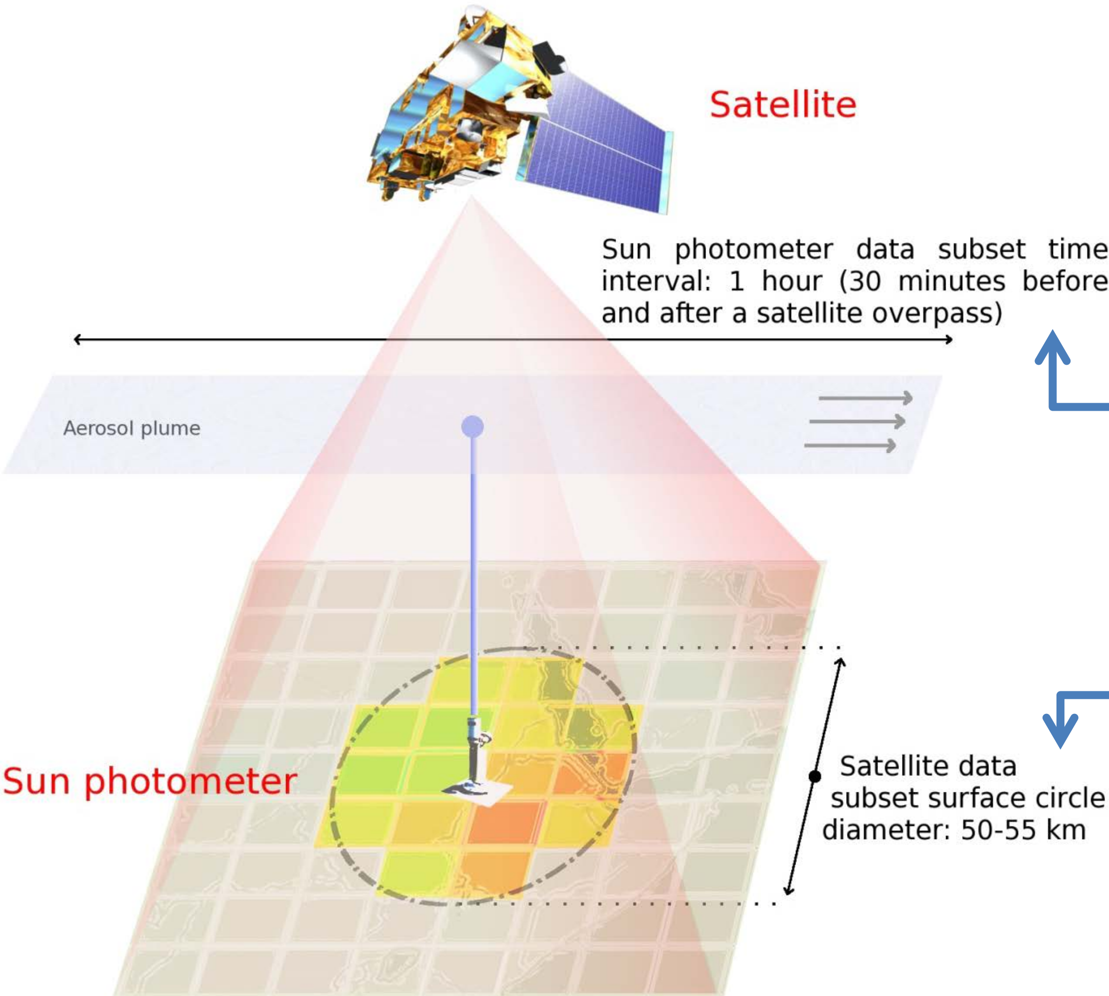



Figure credit of NASA GSFC MAPSS Group, P. Maksym & C. Ichoku (http://disc.sci.gsfc.nasa.gov/aerosols/services/mapss/)

**Matchup Protocol:**

Follows Multi-sensor Aerosol Products Sampling System (MAPSS)

**Matchup Criteria:**

- At least 2 AERONET L2.0 measurements are available within time window;
- At least 20% of VIIRS best quality AOT retrievals are available within spatial domain.

**Averages of AOTs are saved in matchup.**

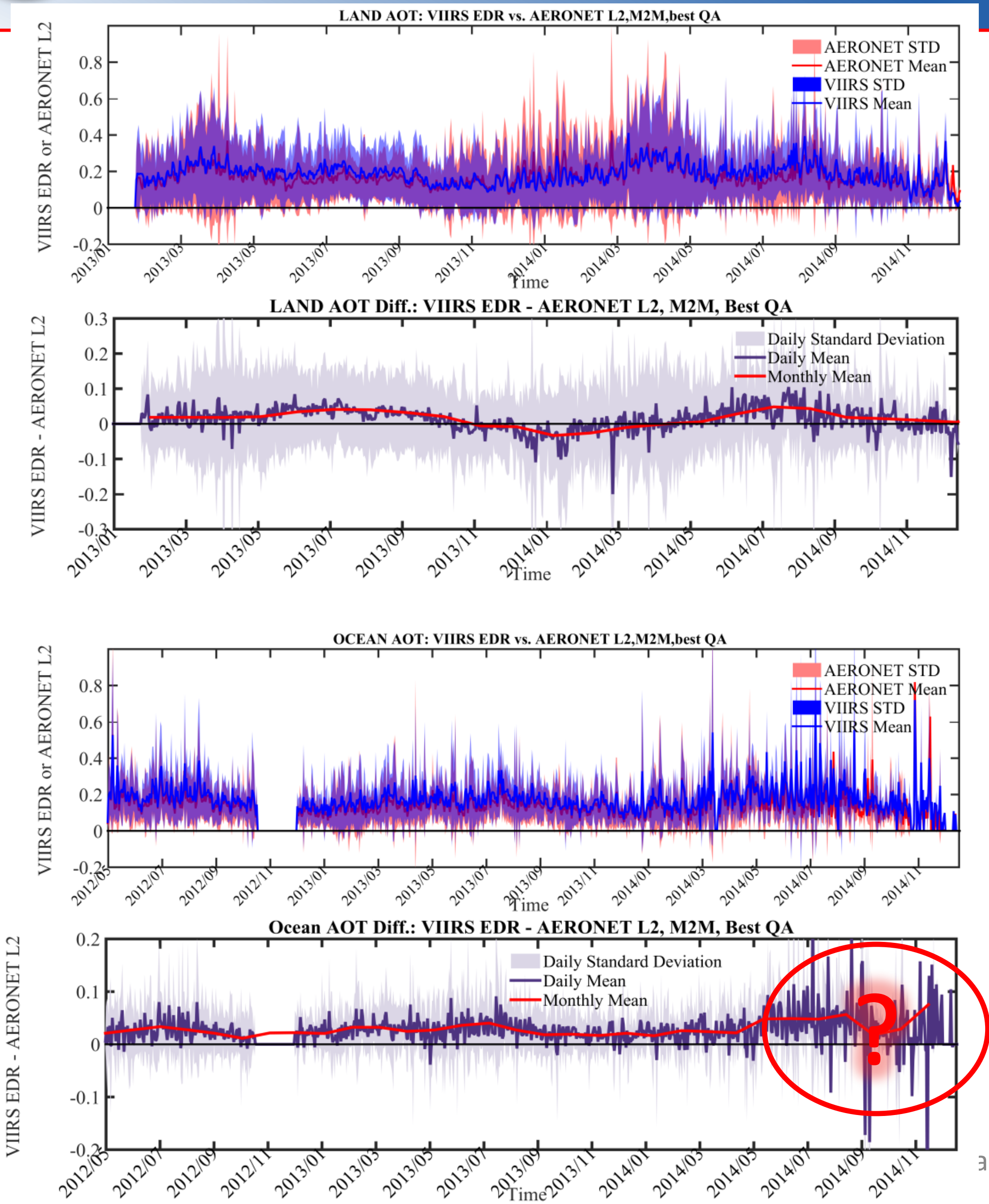
# VIIRS vs. AERONET Time Series

(a)

(b)

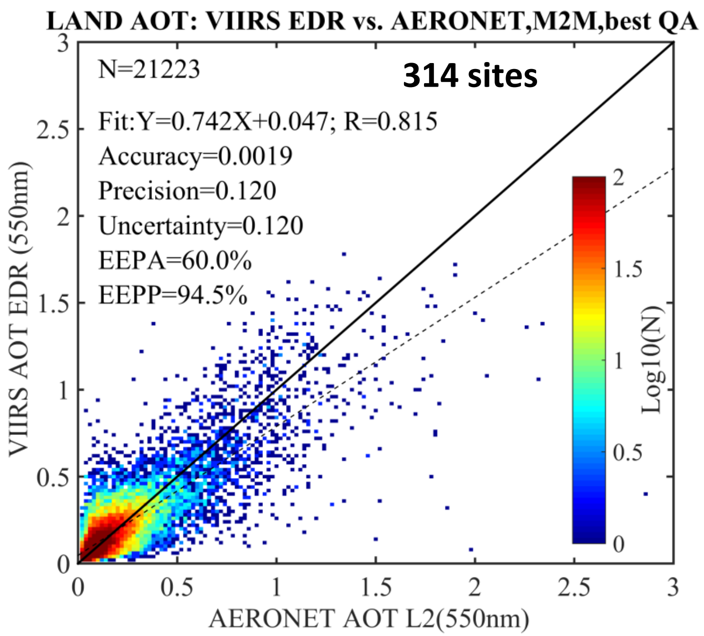
(c)

(d)



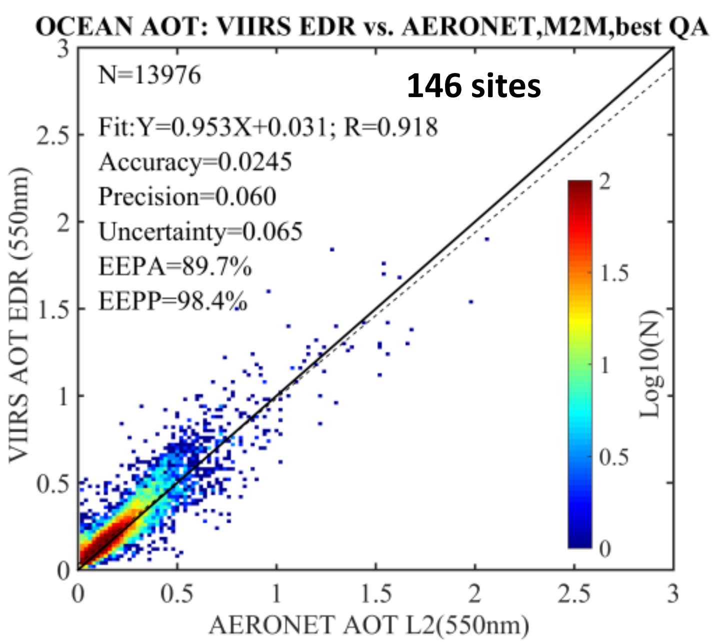

- Daily AOTs (**a, c**), daily and monthly mean AOT differences (**b, d**) over land and ocean.
- Day-to-day variability (**a, c**) is similar.
- Large seasonal dependence of bias <u>over land </u>(**b**); >0 during NH summer, <0 NH winter. (Because of constant surface reflectance ratios ?)
- No significant seasonal variability of bias <u>over ocean</u>, but persistent positive bias is present (**d**).

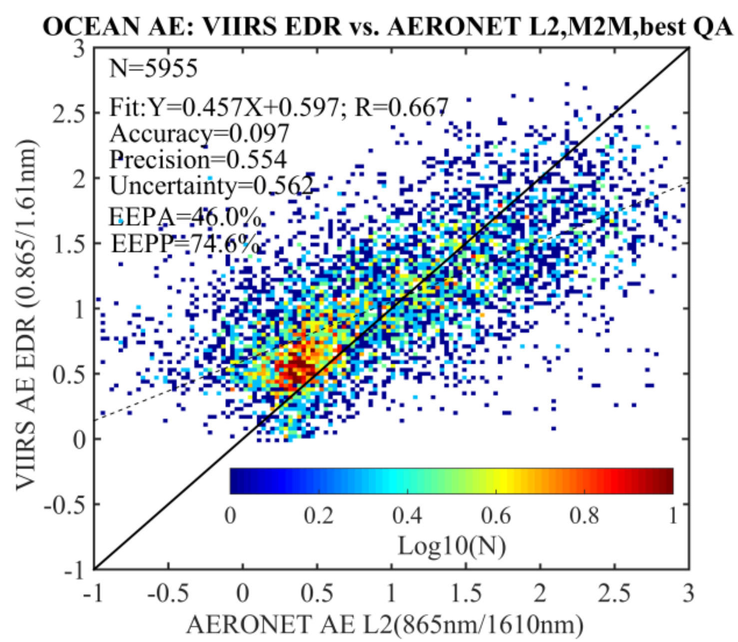
# Scatter Plots




**Land:** Large scatter, but small overall bias (due to cancellation of errors). High AOT is underestimated.

**Ocean:** Smaller scatter, but overall positive bias (doubled wrt. Liu at al., 2014). Smaller/larger particles from VIIRS when AERONET suggest larger/smaller particles



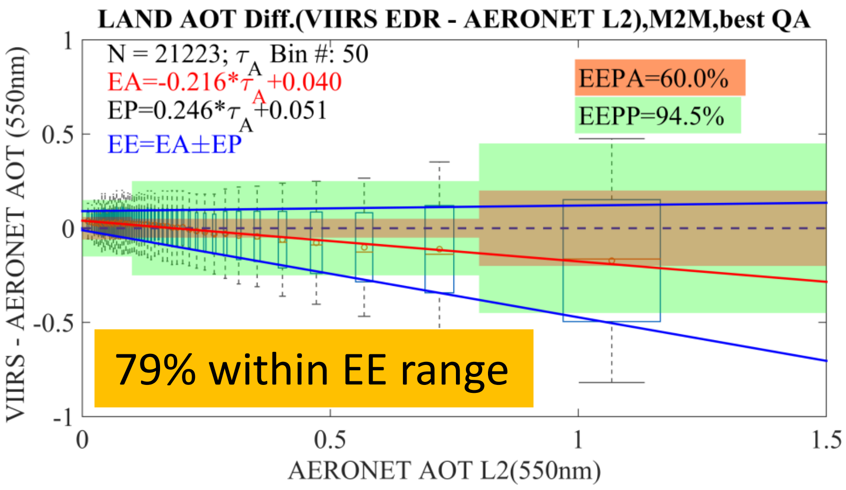
# EDR vs. JPSS L1RD Requirements

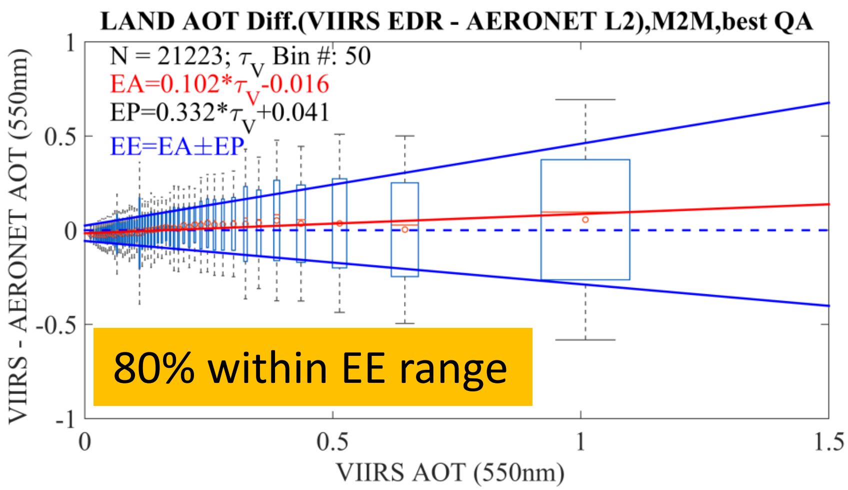
| AOT range | Accuracy | | Precision | |
| --- | --- | --- | --- | --- |
| | Specs | VIIRS | Specs | VIIRS |
| **LAND AOT (01/23/2013-12/31/2014)** | | | | |
| AOT < 0.1 | 0.06 | **0.03** | 0.15 | **0.07** |
| 0.1 ≤ AOT ≤ 0.8 | 0.05 | **-0.01** | 0.25 | **0.12** |
| 0.8 < AOT≤ 2.0 | 0.20 | **-0.19** | 0.45 | **0.34** |
| **OCEAN AOT (05/02/2012-12/31/2014, excluding 10/15/2012-11/27/2012)** | | | | |
| AOT < 0.3 | 0.08 | **0.03** | 0.15 | **0.04** |
| 0.3 ≤ AOT ≤ 2.0 | 0.15 | **0.02** | 0.35 | **0.13** |
| **OCEAN AE (05/02/2012-12/31/2014, excluding 10/15/2012-11/27/2012)** | | | | |
| 865nm/1610nm | 0.30 | **0.10** | 0.60 | **0.55** |

**Meeting JPPS requirements**

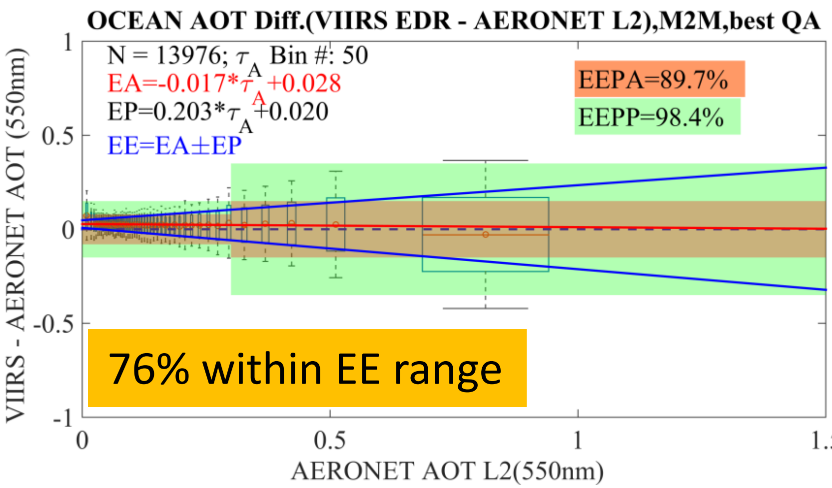
# Expected Error Estimates

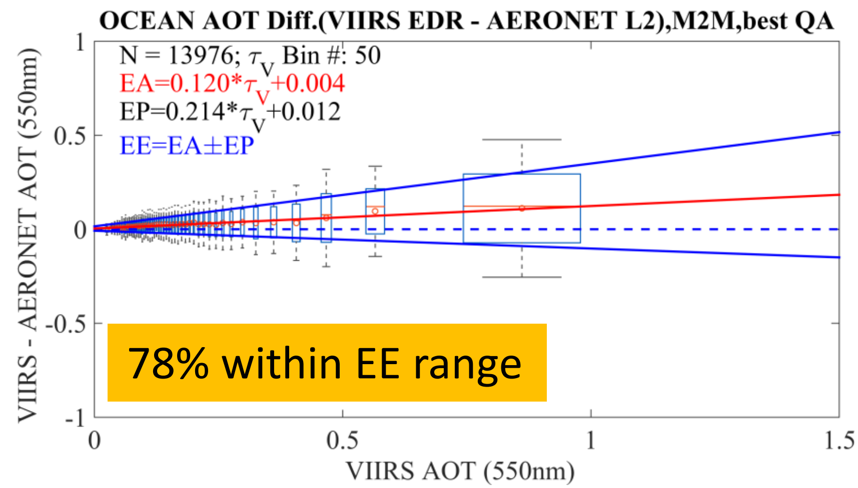
- Bin VIIRS-AERONET differences according to AERONET (VIIRS) AOT
- Calculate mean bias (circle) and (1 σ) standard deviation (box) for each bin.
- Linearly fit bin values of mean bias (**EA**) and standard deviation (**EP**) as function of AERONET (VIIRS) AOT.
- **Expected Error: EE = EA ± EP**

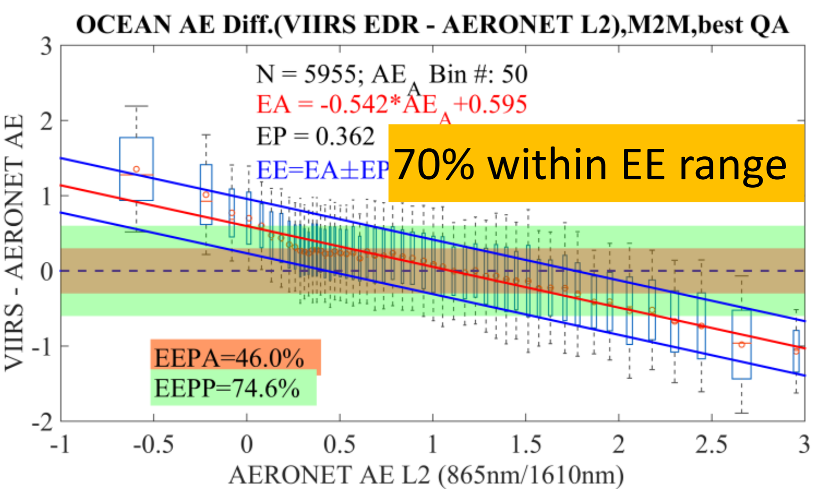


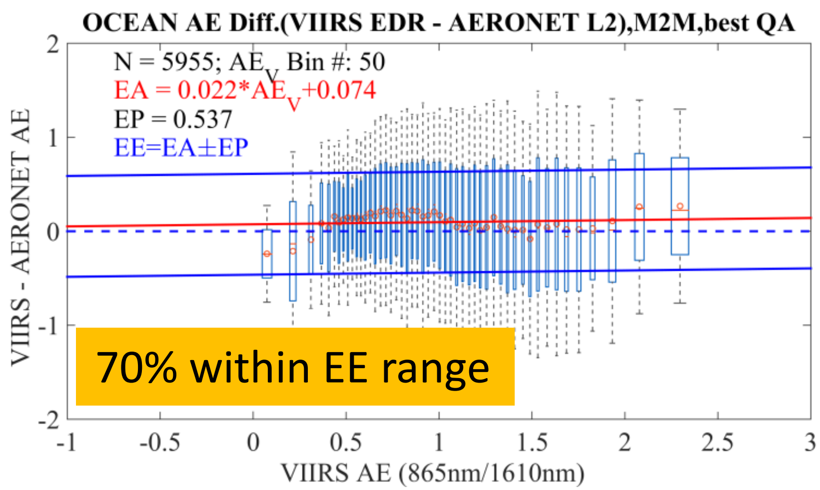



# Expected Error Estimates

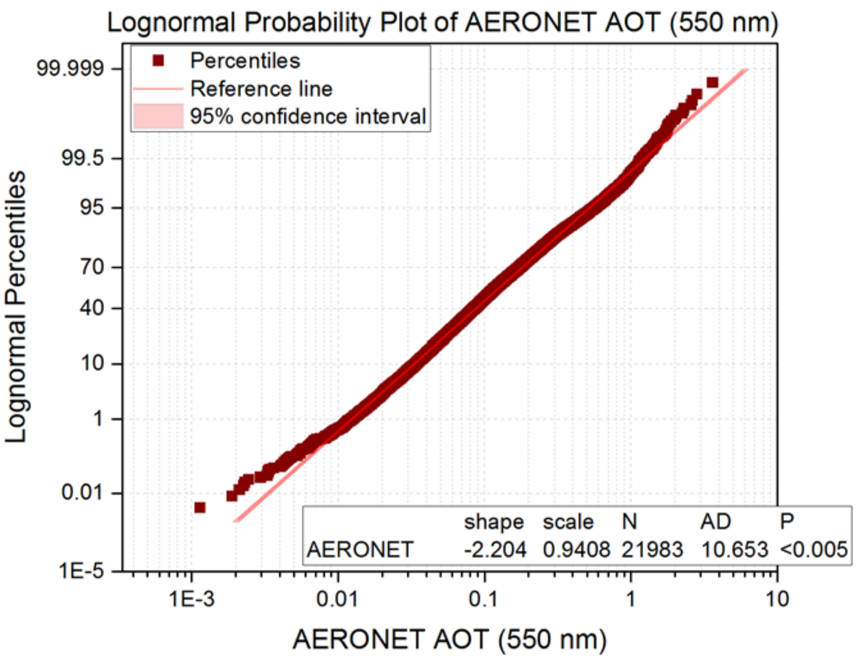


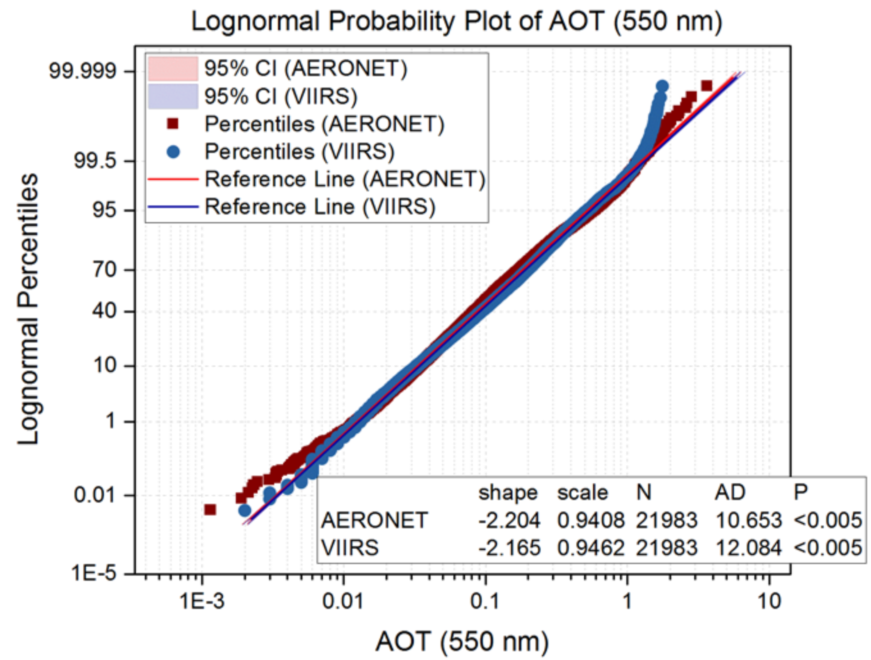



# A different look




**Motivation:** AERONET and VIIRS AOTs are samples of the AOT "population"; should have similar PDFs

- Assume the samples follow a *lognormal distribution* [O'Neill et al., 2000] and display them on a Probability plot (CDF; Benard median score was used)
  - VIIRS **empirical** CDF can be compared to AERONET CDF **fit**.
  - (If true the fit could be used to (objectively) detect outliers.)
- Actually, they do **not**! But still can be used for comparison.
  - VIIRS and AERONET fit parameters (shape and scale) are similar

# Summary

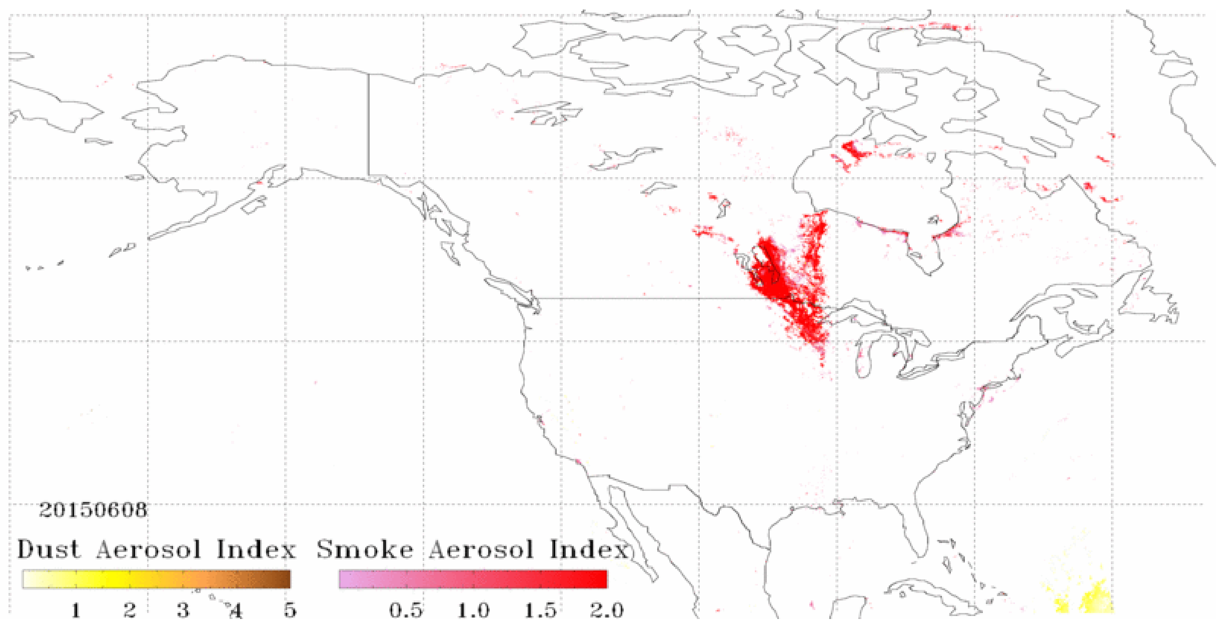
- Accuracy, Precision and Expected Errors of VIIRS AOT and APSP EDRs are estimated from a 2+ year record of VIIRS retrievals and AERONET L2 data.
- Bias over land/ocean is smaller/larger than that in the shorter time period in Liu et al. (2014), but still within JPSS specs.

| | Land AOT | Ocean AOT | Ocean AE |
|---|---|---|---|
| Sample Size | 21223 | 13976 | 5955 |
| Accuracy | 0.002 | 0.025 | 0.097 |
| Precision | 0.120 | 0.060 | 0.554 |
| Uncertainty | 0.120 | 0.065 | 0.562 |
| Corr. Coef. | 0.815 | 0.918 | 0.667 |
| Slope | 0.742 | 0.953 | 0.457 |
| Intercept | 0.047 | 0.031 | 0.597 |
| EEPA | 60.0% | 89.7% | 46.0% |
| EEPP | 94.5% | 98.4% | 74.6% |

# JPSS Proving Ground Project
# "Fire and Smoke Initiative"

**Shobha Kondragunta and Ivan Csiszar**
NOAA/NESDIS

August 27, 2015

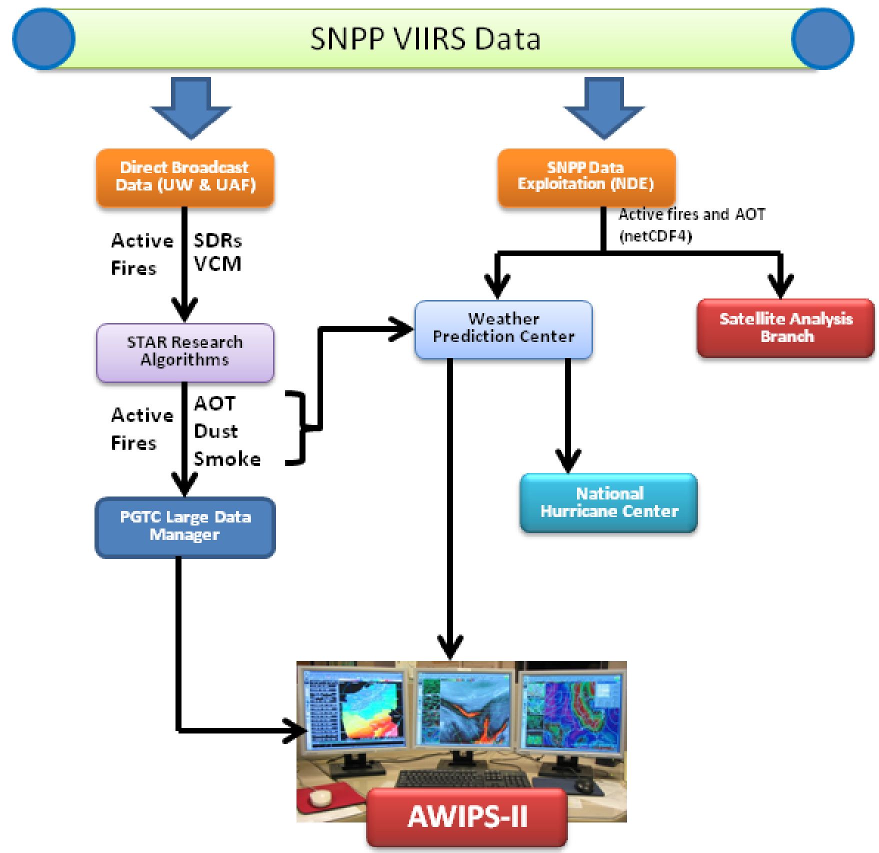


# Objective

- **To quantify key socio-economic impacts of fires and smoke using SNPP VIIRS products.**

- **To enhance product distribution generated from SNPP VIIRS direct broadcast (DB) data for CONUS and Alaska for targeted regions to end users.**

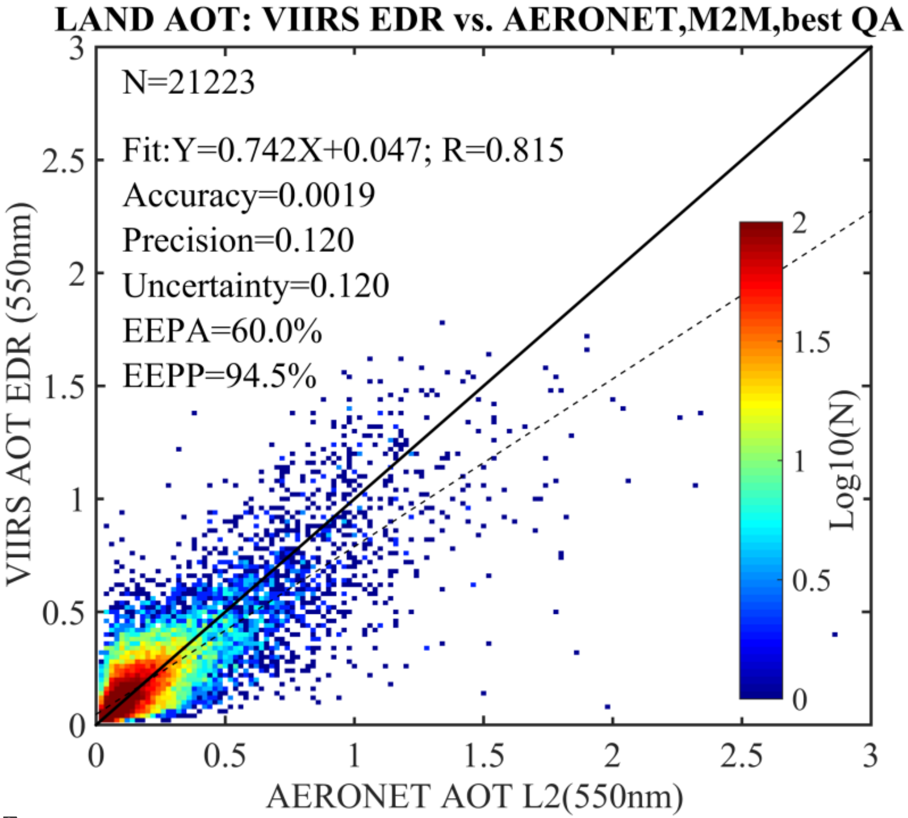
- **To port SNPP VIIRS fire and aerosol products into AWIPS-II in collaboration with University of Maryland Proving Ground and Training Center (PGTC).**

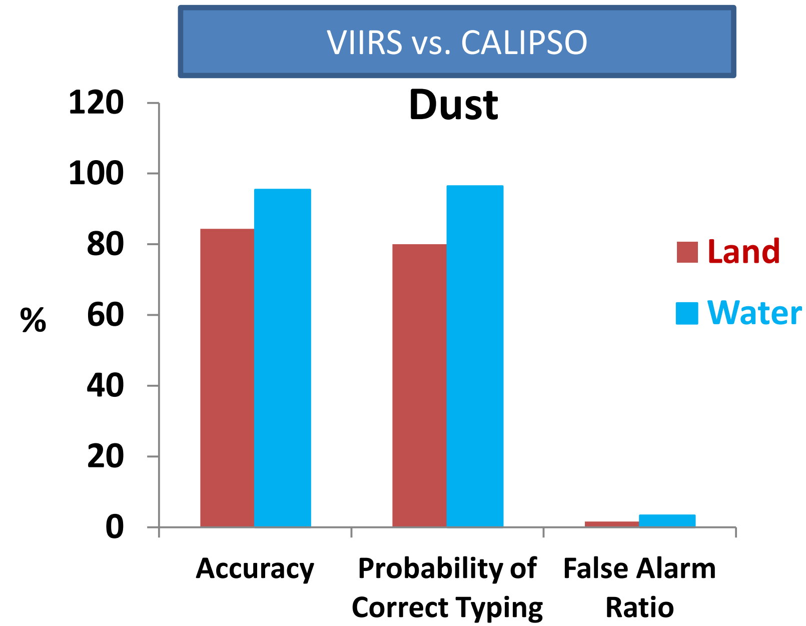


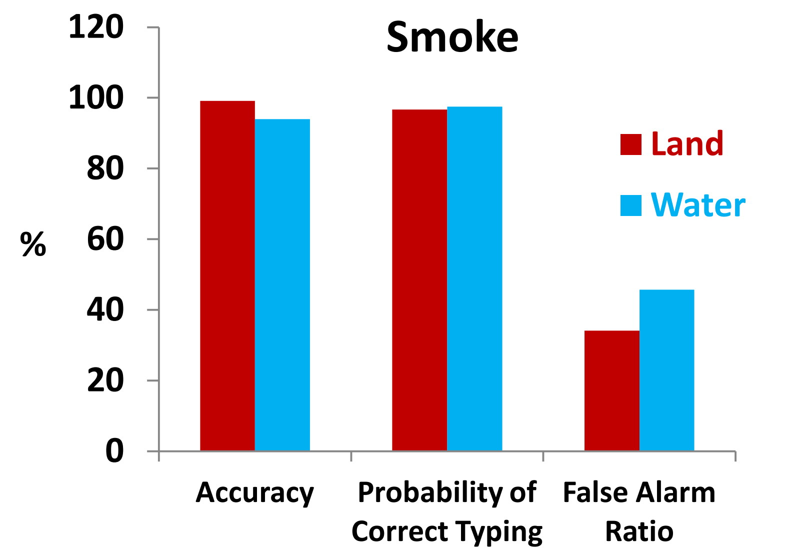

*PGTC lead is Scott Rudlosky*

**AOT (within IDPS) and smoke/dust mask (Direct Broadcast data and within NDE by January 2016) are well validated and at a mature stage.**

*Courtesy of VIIRS aerosol cal/val team*



# Wildfires have detrimental effect on human health and economy: May 2014 San Diego Fires as a specific example

Smoke can be seen rising from the 8,000-acre Pulgas Fire on Camp Pendleton on May 16, 2014. San Diego-area fires prompted a smoke advisory in areas to the north. (Credit: KSWB)

Estimated Cost to Local Governments of Responding to Fires

| Agency | Estimated Cost* (millions) |
|---|---|
| County of San Diego | $3.9 |
| City of Carlsbad | $12.5 |
| City of San Marcos | $10.4 |
| City of San Diego | $1.3 |
| Other Agencies | $0.4 |
| Total | **$28.5** |

*Estimated costs represent revised estimates submitted to the State of California Office of Emergency Services. Initial cost estimates of $27.9 million were later revised to include the County's cost of debris removal.

*http://www.readysandiego.org/aar/may-2014-san-diego-county-wildfires/May-2014-San-Diego-County-Wildfires.pdf*

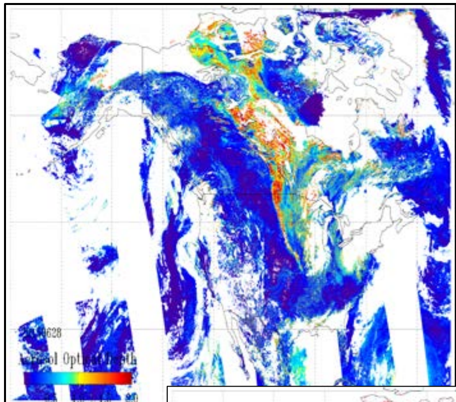
14 fires
26,000 acres burned
149,000 evacuation orders
65 structures damaged
$29.8 million loss to private property owners

## SNPP VIIRS Products in Near Real Time

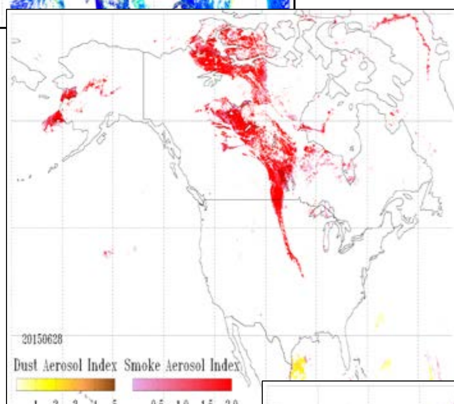
1. Fire hot spots
2. Area burned
3. Smoke aerosols
4. Air Quality Index

Operational decision making process by multiple federal, state, and local agencies : is there a significant smoke associated with a fire, where is the smoke now and where is it headed, how bad is the air, should hospitals be evacuated, should roads be closed etc.

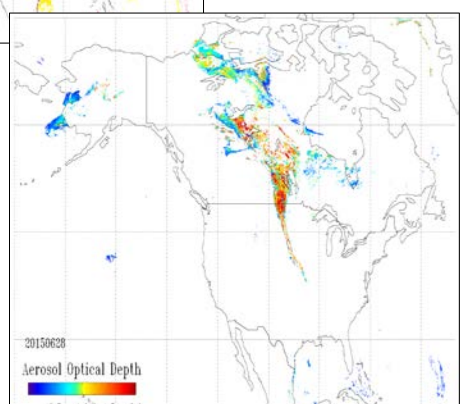
# Value Added SNPP VIIRS Aerosol Products



Quantitative Retrieval of "Aerosol Optical Thickness"
*Jackson et al., JGR, 2014*



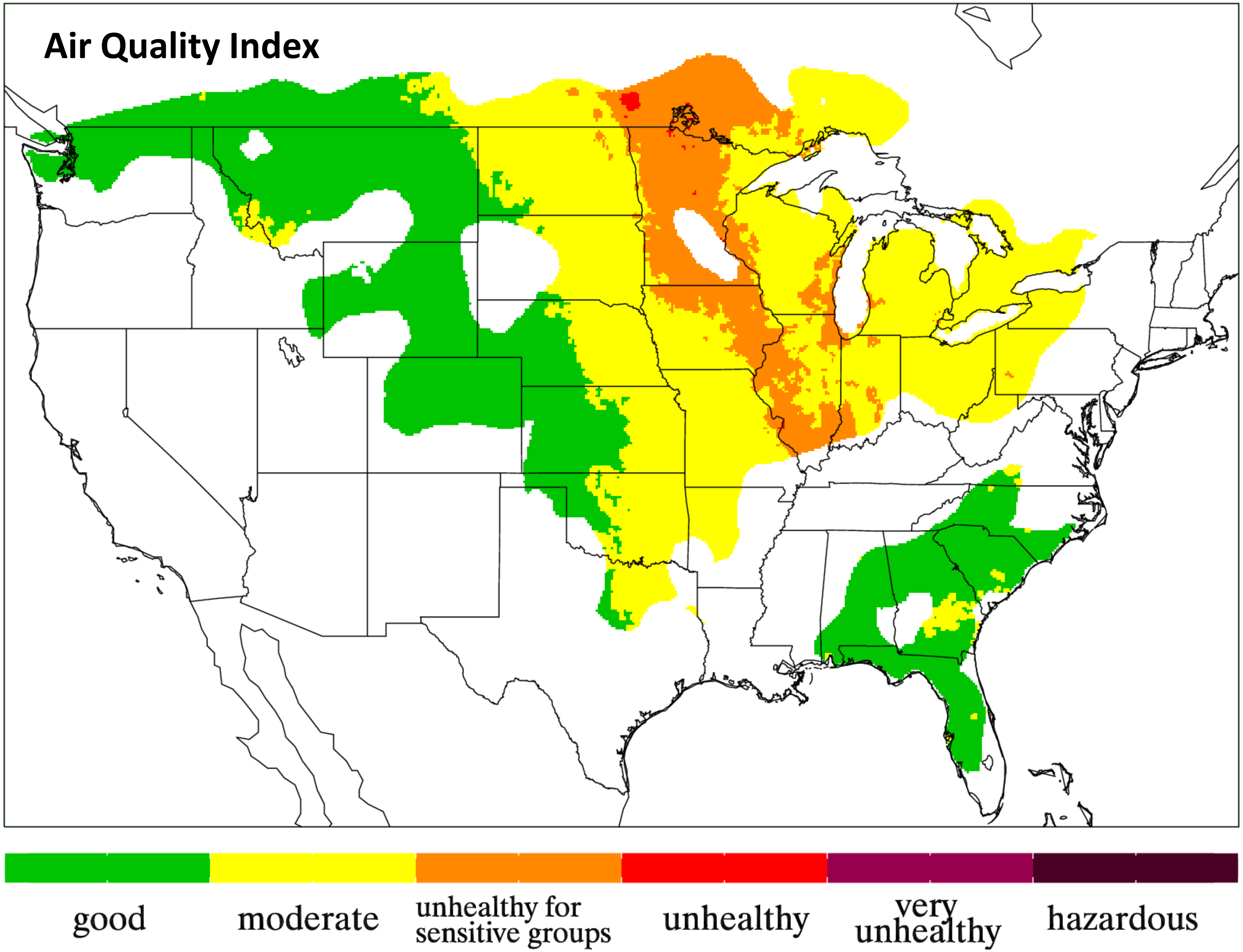

Qualitative Retrieval of "Smoke Mask"
*Ciren and Kondragunta, JGR, 2014*




Quantitative Information of "Smoke Aerosol Optical Thickness"

- Forecast: NWS WFOs via AWIPS-II
- Mitigation: NWS IMETs via web
- Forecast guidance: NWS NCEP and other models
- Monitoring: Local, State, Federal environmental agencies

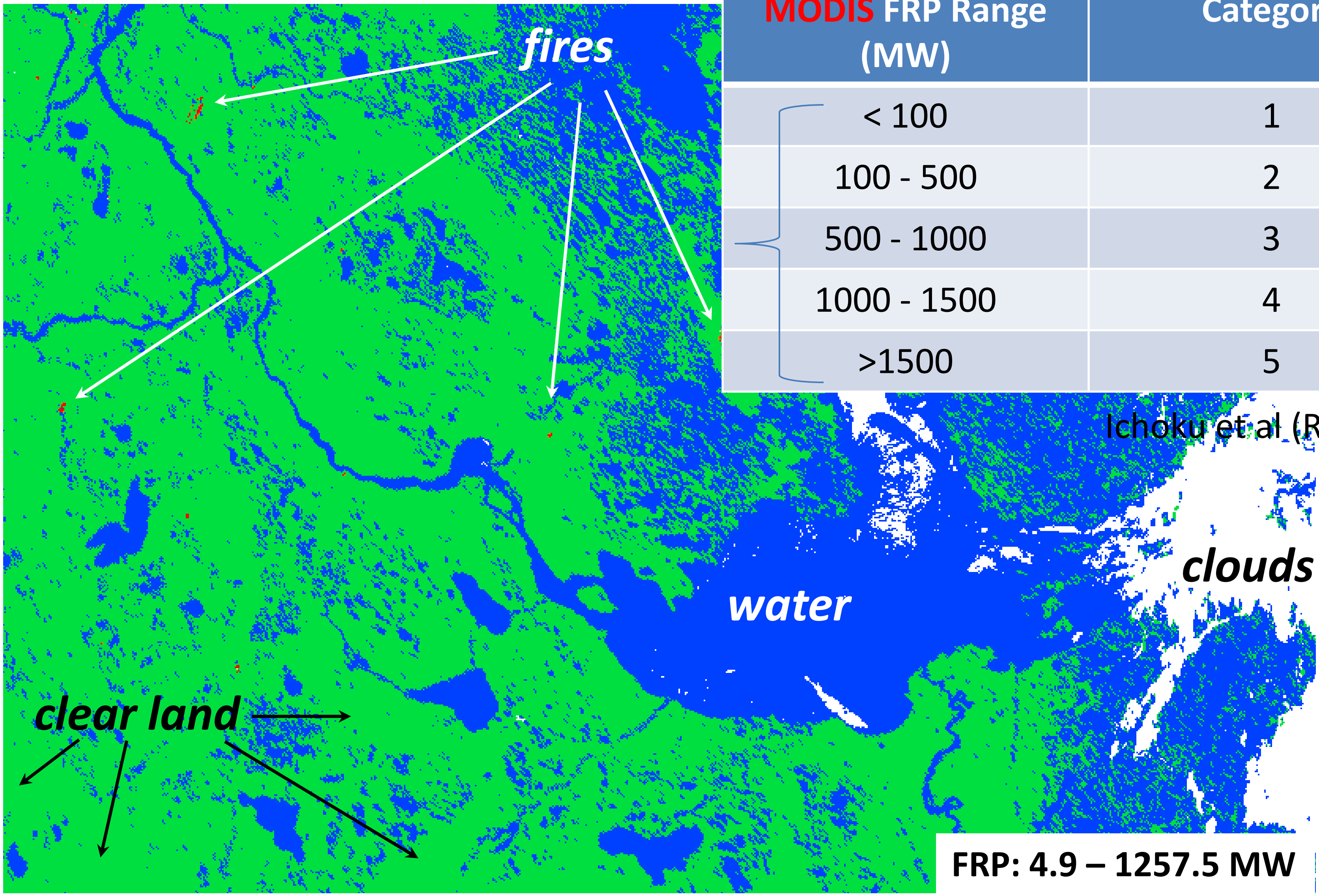
# Value Added SNPP VIIRS Aerosol Products



# Value Added SNPP VIIRS Fire Products

| MODIS FRP Range (MW) | Category |
|---|---|
| < 100 | 1 |
| 100 - 500 | 2 |
| 500 - 1000 | 3 |
| 1000 - 1500 | 4 |
| >1500 | 5 |

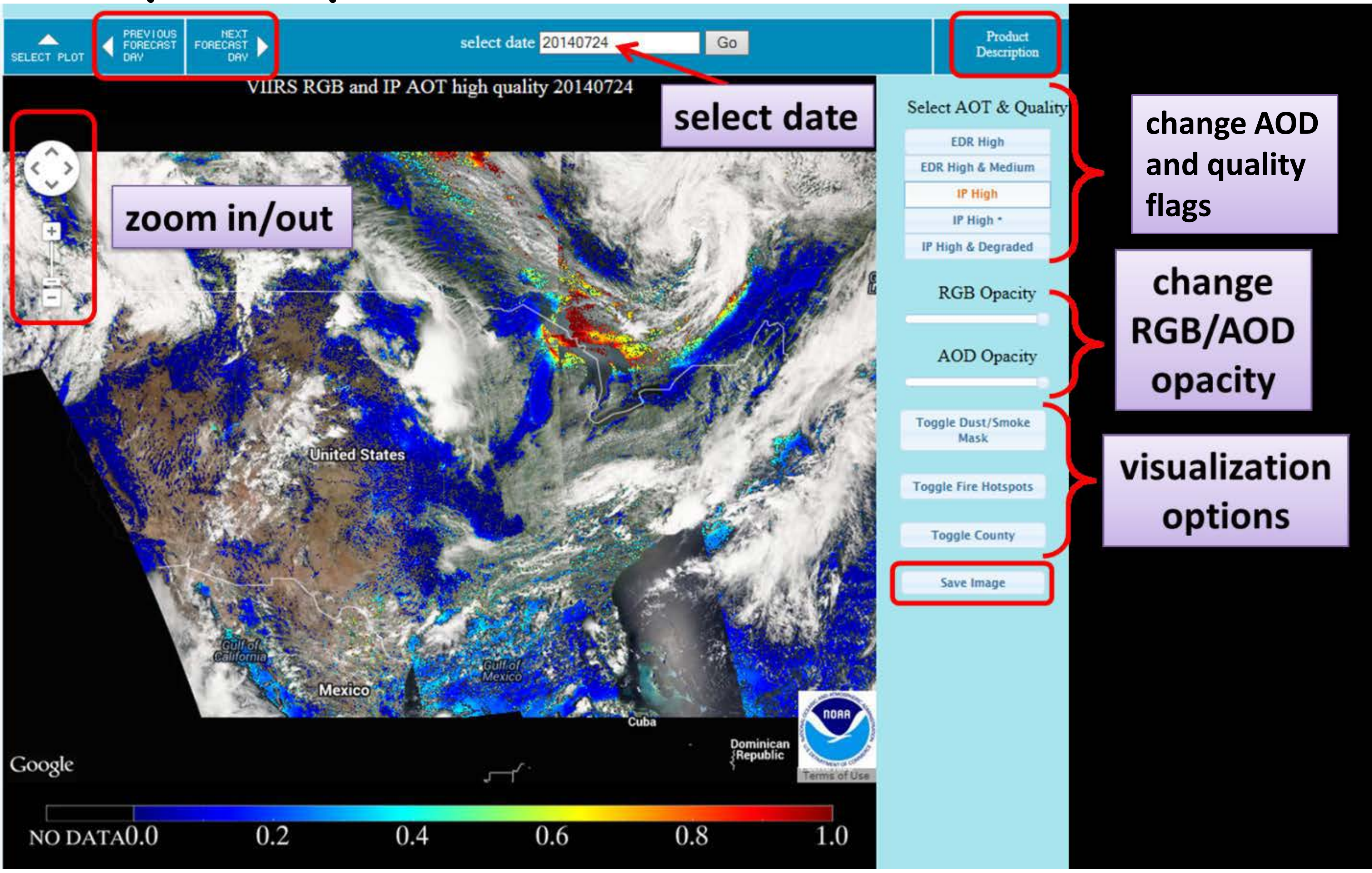
Ichoku et al (RSE, 2008)




*VIIRS fire mask over NW Canada 5/29/2015 20:06 UTC*

# VIIRS fire and aerosol products are validated and ready for operational use

www.star.nesdis.noaa.gov/smcd/spb/aq



# What has been done so far…

- Coordination with NWS Western Region, WFOs, IMETs, NWS Alaska (through GINA) to develop a roadmap in line with objectives/VIIRS products highlighted here.

- While many smoke forecast models exist, HRRR (High Resolution Rapid Refresh) model and an enhanced IDEA tool will be the focus for this Proving Ground (PG) fire and smoke initiative project.

- Ongoing discussions with PGTC to develop plug-in tools that can display VIIRS fire and aerosol products in AWIPS-II

- Ongoing discussions with IMETs to enhance IDEA tool to display smoke extent and transport without specifying which satellite is providing the information
  - Highest resolution possible
  - Clickable layers
  - Zoom capabilities

# VIIRS AOT retrieval for bright surfaces

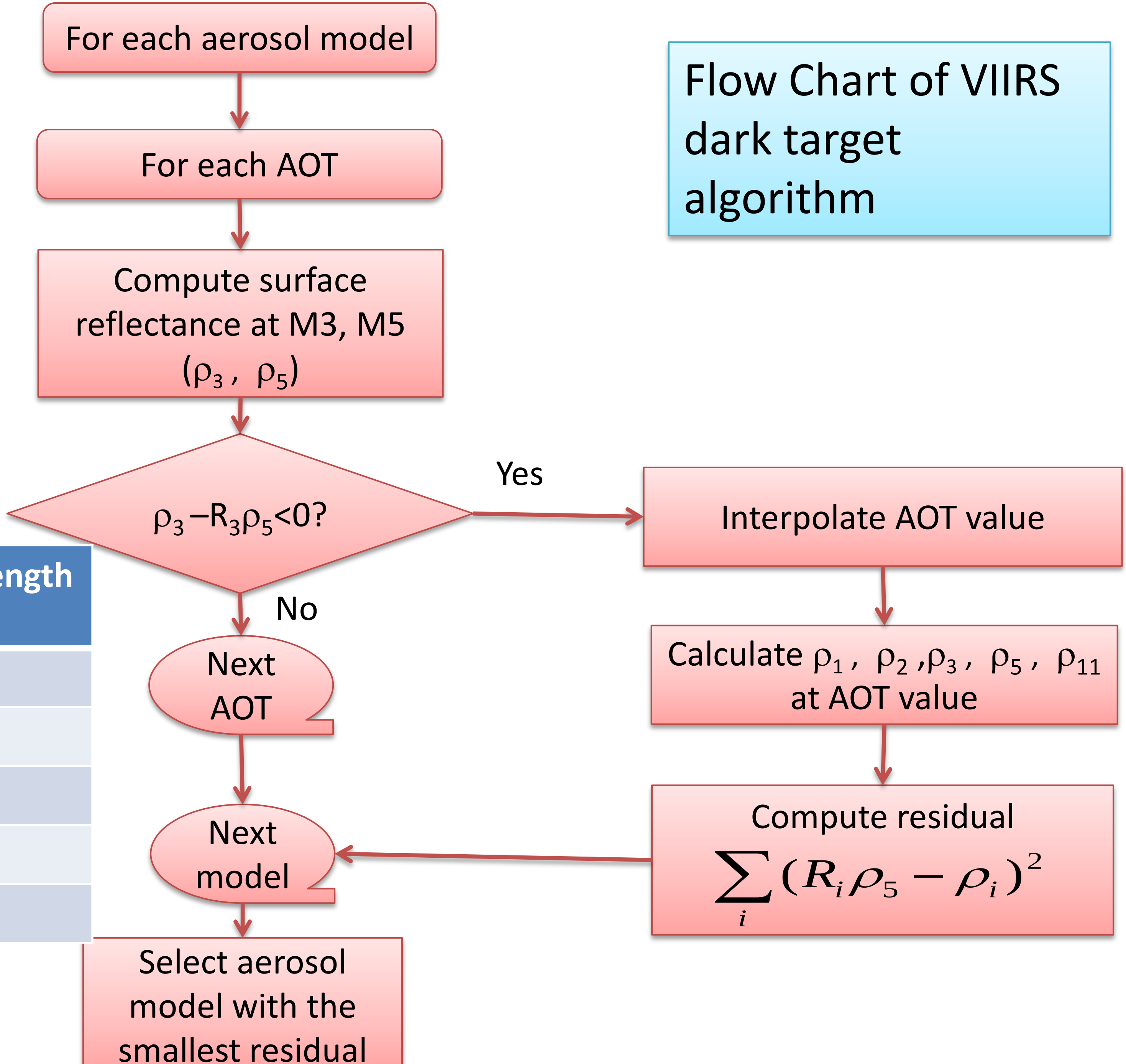
Hai Zhang, Hongqing Liu,
Shobha Kondragunta, Istvan Laszlo,
Lorraine Remer, Jingfeng Huang,
Stephen Superczynski

STAR JPSS 2015 Annual Science Team Meeting
8/27/2015

# Introduction

- Current operational VIIRS AOT retrieval only works over dark surfaces
- We developed a new algorithm to retrieve VIIRS AOT over bright surfaces
  - The algorithm is a modified version of the VIIRS dark target algorithm.
  - **The algorithm uses surface reflectance ratios, instead of absolute surface reflectance as in deep blue algorithm, to retrieve AOT over bright surfaces**
  - The surface reflectance ratios are dependent on location and geometry.

# Flow Chart of VIIRS dark target algorithm




| Bands | Wavelength (µm) |
|---|---|
| M1 | 0.412 |
| M2 | 0.445 |
| M3 | 0.488 |
| M5 | 0.672 |
| M11 | 2.25 |

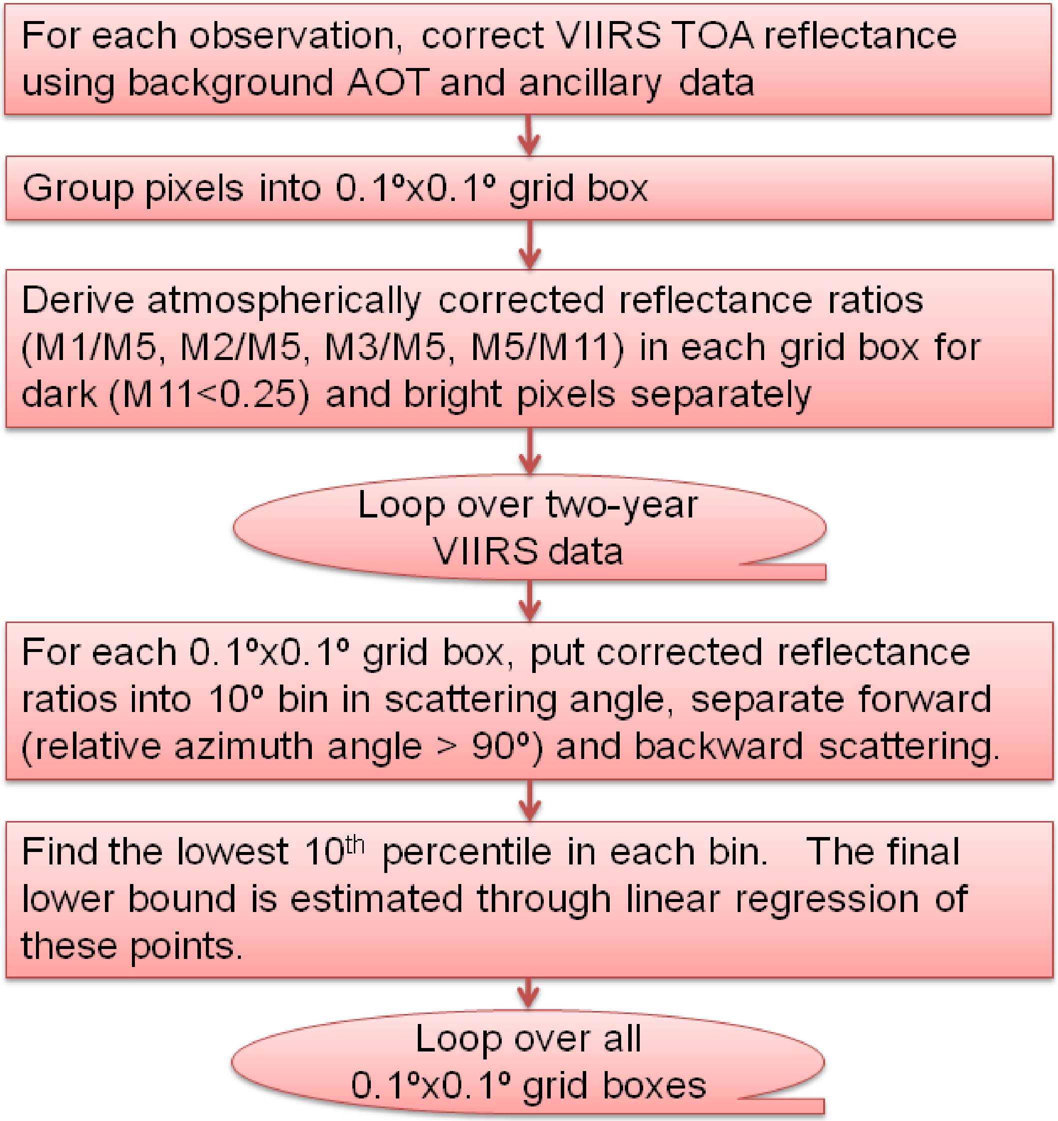
# Modifications of the algorithm over bright surfaces

| | Dark target algorithm | Bright surface algorithm |
|---|---|---|
| Bands used | M1,M2,M3,M5,M11 | M1,M2,M3,M5 |
| Surface reflectance ratios | Global fixed ratios | Global reflectance ratio database |
| Bands used for AOT retrieval | M3, M5 | M3,M5 for North Africa/Arabian Peninsula<br>M1,M5 for the other regions |
| Aerosol model selection | Select aerosol model using residuals | Fixed dust model for North Africa/Arabian Peninsula<br>Select aerosol model over the other regions |

# Surface reflectance ratio database

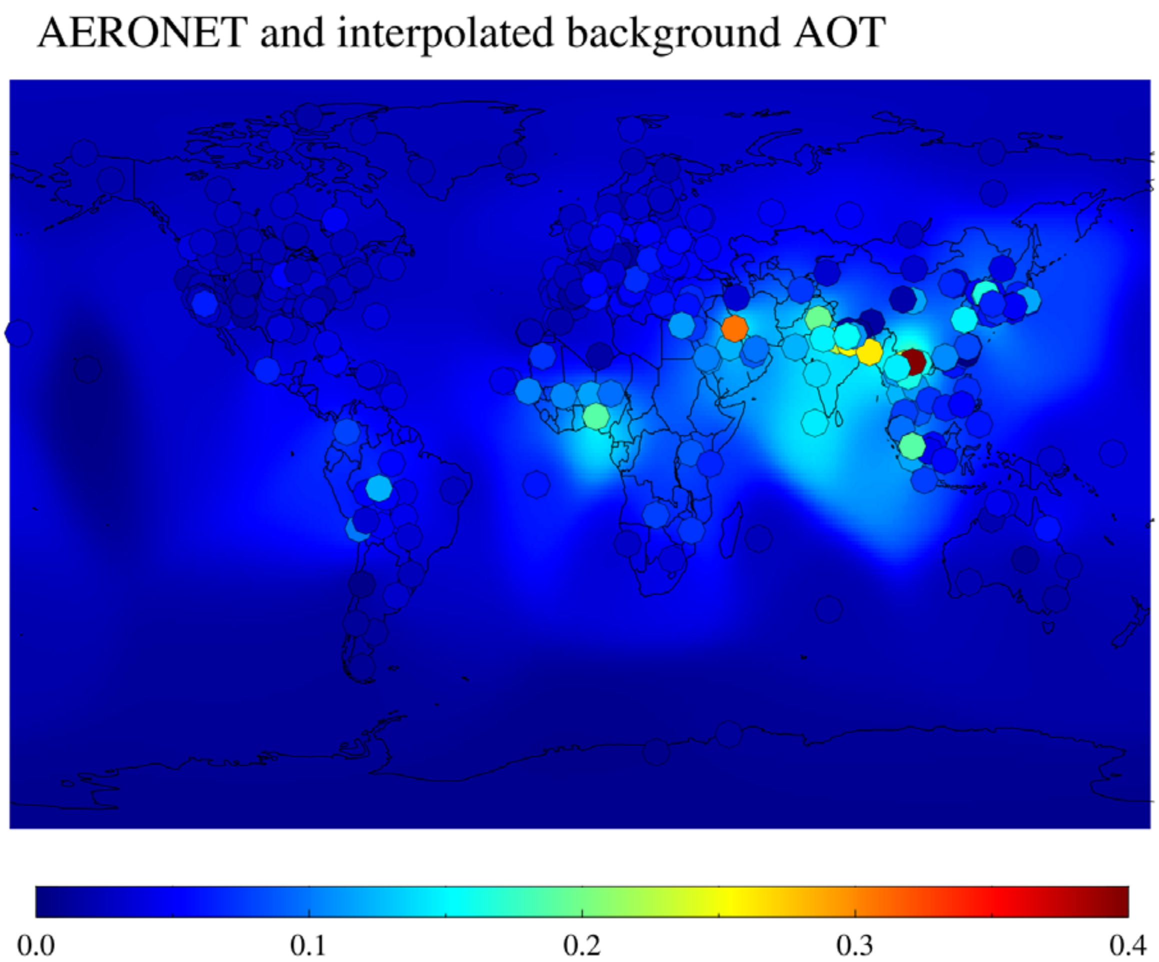
- Derived from two-year VIIRS SDR data (May,2012-Apr, 2014)
- $0.1^o x 0.1^o$ spatial resolution
- Background AOT at AERONET sites and interpolated globally for atmospheric correction
- Lower bounds of the two year atmospheric corrected reflectance ratios

# Surface reflectance ratio database derivation flow chart

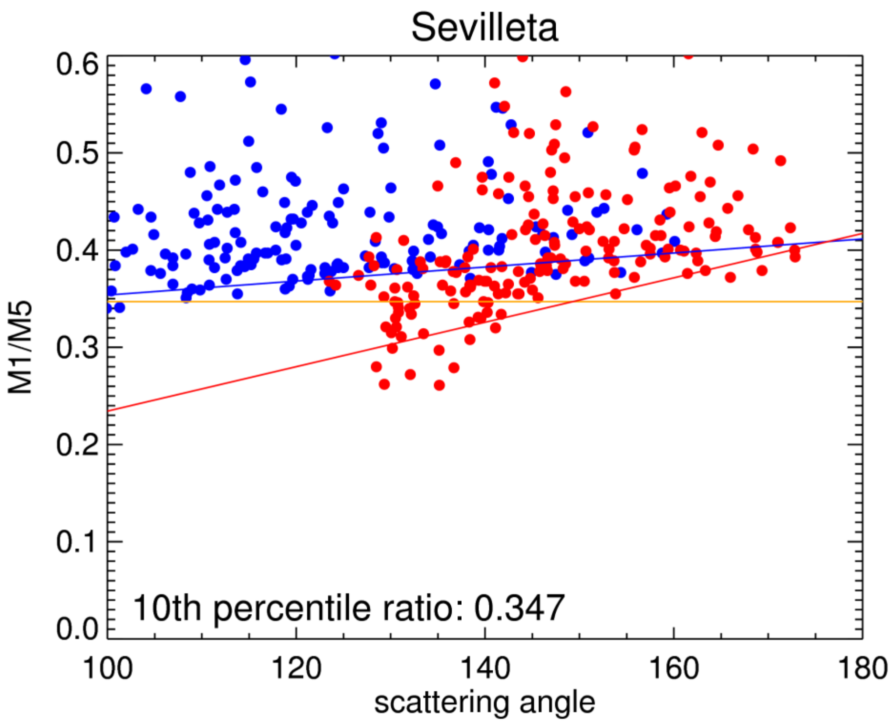


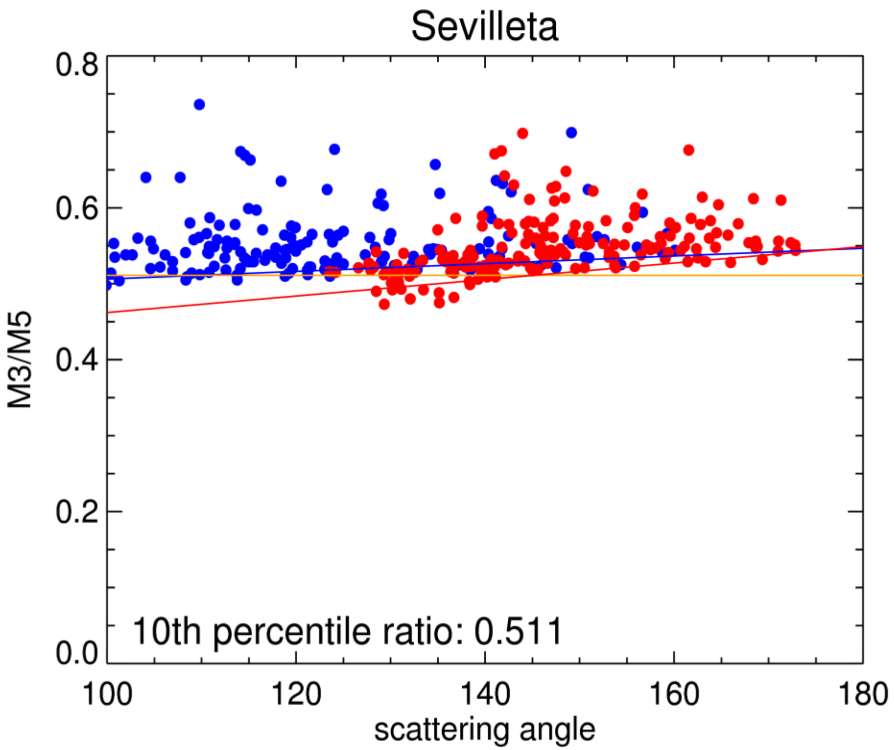
# Background AOT for deriving surface reflectance ratios

- Two-year AERONET data
- Bottom 5th percentile at each AERONET site
- Spatially interpolated to other areas



# Example of atmospheric corrected reflectance ratios

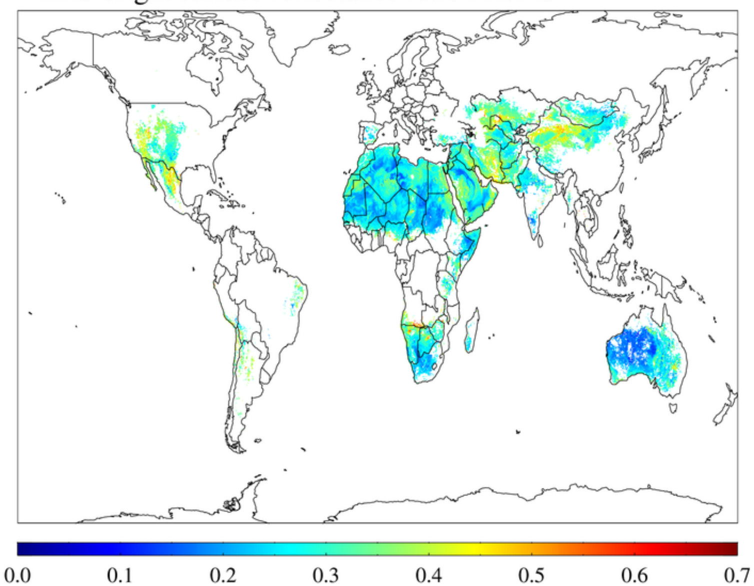


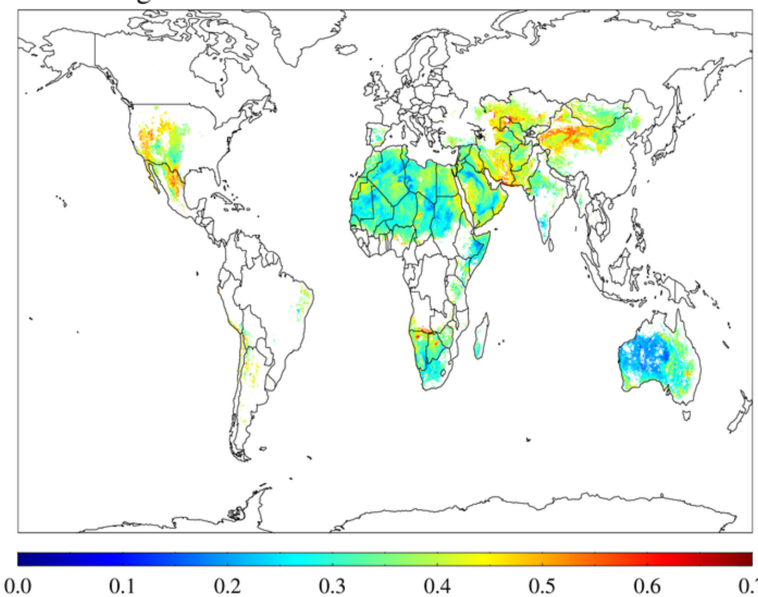

- Two-year corrected reflectance ratios at Sevilleta (a western US site)
- Blue: forward reflectance; Red: backward reflectance
- Linear model for the lower bounds (10th percentile)

# Surface reflectance ratio database over bright surfaces

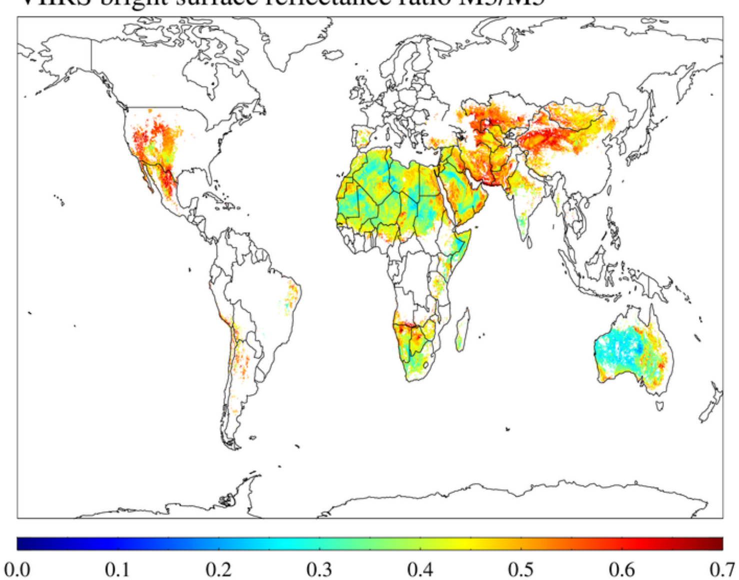
VIIRS bright surface reflectance ratio M1/M5




VIIRS bright surface reflectance ratio M2/M5

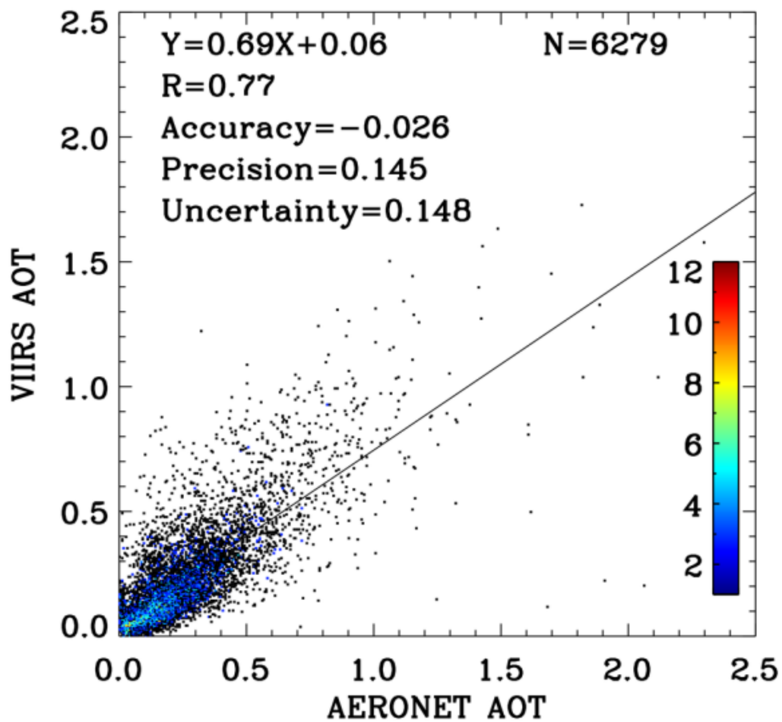



VIIRS bright surface reflectance ratio M3/M5

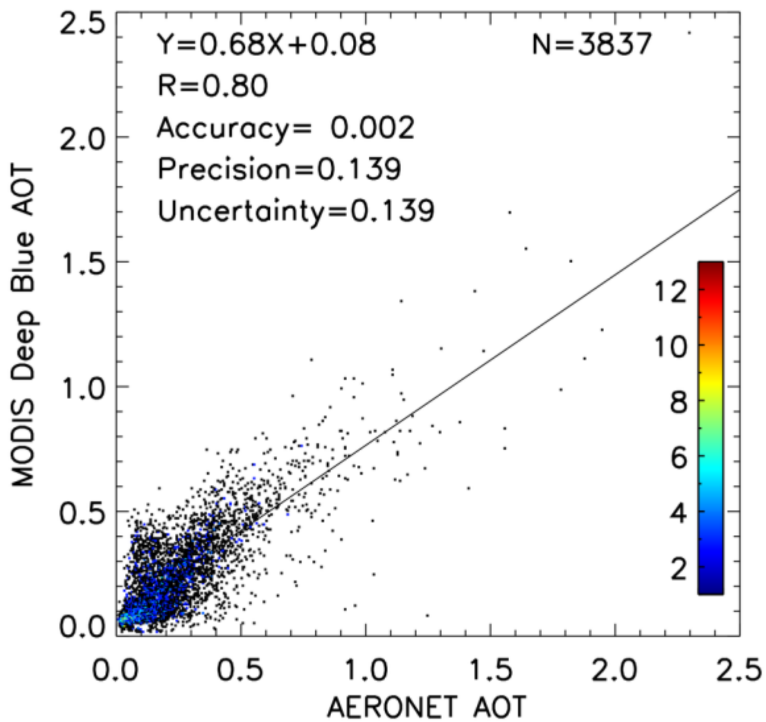



- M1/M5, M2/M5, M3/M5
- Linear dependence on scattering angle
- Separate forward and backward reflectance geometry
- The plots are in backward reflectance geometry with scattering angle 140º

# VIIRS AOT retrievals over bright surfaces at AERONET sites




VIIRS

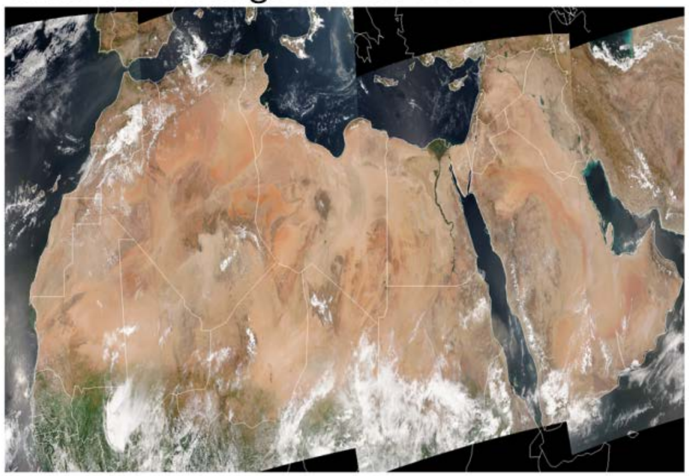



MODIS deep blue

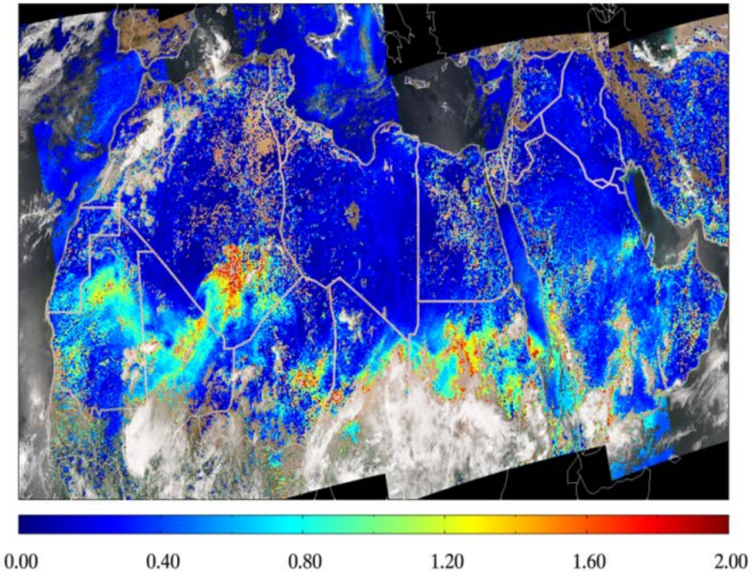
- Two-year AOT retrievals (May 2012- Apr 2014)
- Most of the sites are located in North Africa, Arabian Peninsula, and western CONUS

# An example of AOT retrieval over north Africa and Arabian Peninsula

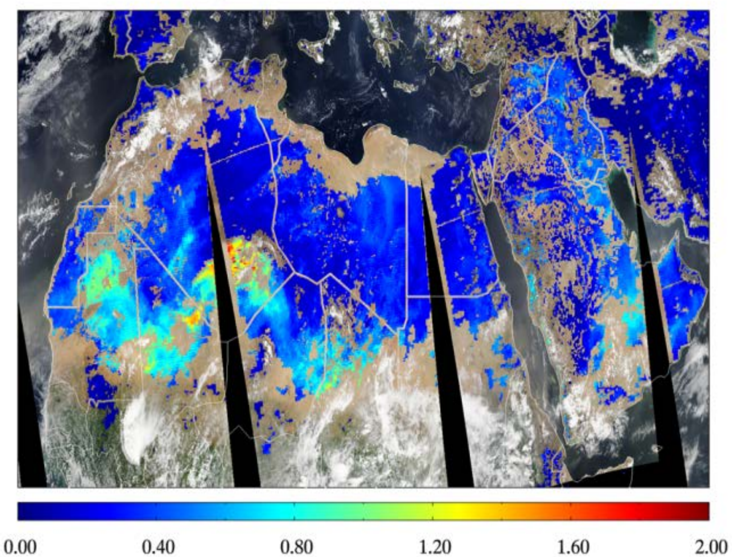
VIIRS RGB image 20130823



VIIRS AOT 20130823




MODIS deep blue AOT 20130823

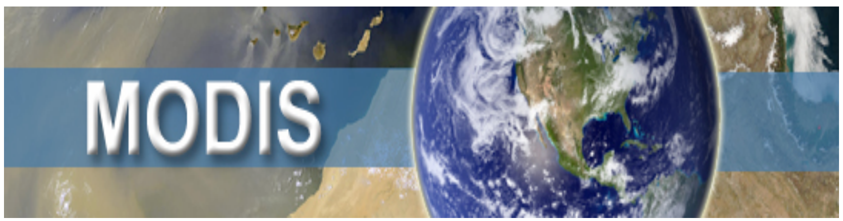



- VIIRS AOT retrievals are in agreement with MODIS deep blue AOT retrievals in most areas:
  - Both show dust storm in the west
  - Low AOT regions agree mostly
- Differences:
  - Some high AOT regions in VIIRS are not seen in MODIS deep blue
  - Less coverage in MODIS deep blue

# Conclusions

- We developed an AOT retrieval algorithm for bright surface using global surface reflectance ratio database
- The AOT retrievals compare well with AERONET and MODIS deep blue AOT
- The algorithm will be implemented in the NDE system

# Creating a global aerosol data time series from MODIS, Suomi-NPP VIIRS and beyond: Applying the MODIS Dark Target algorithm





Robert C. Levy (NASA-GSFC)
robert.c.levy@nasa.gov

And the Dark-target aerosol retrieval team:

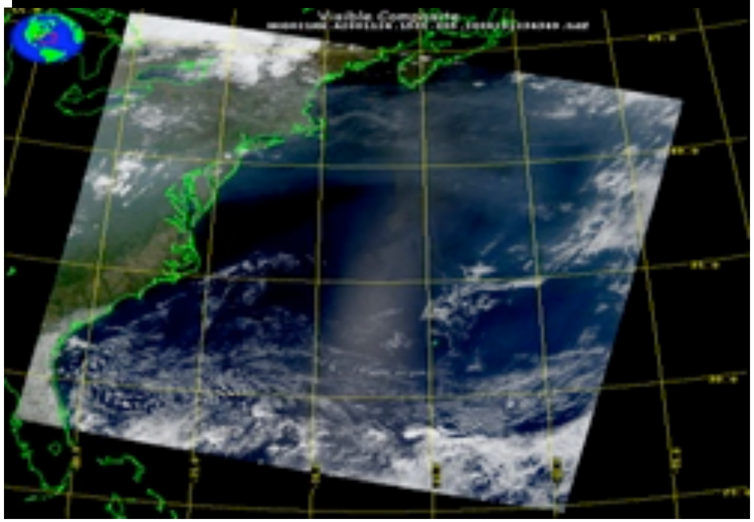
Shana Mattoo, Leigh Munchak and Richard Kleidman (SSAI/GSFC)
Lorraine Remer (UMBC/JCET), Falguni Patadia (MSU/GSFC),
Pawan Gupta (USRA/GSFC), Robert Holz (SSEC/UWisc), and others

JPSS meeting, College Park, 27 Aug 2015

# Aerosol retrieval from MODIS

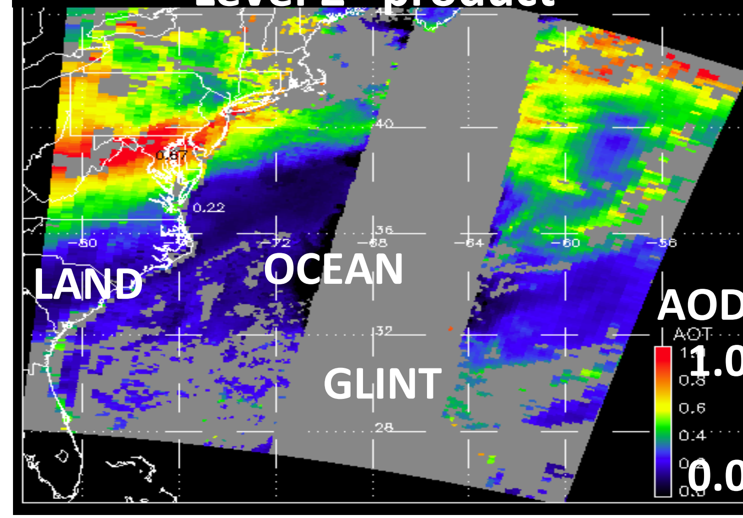
What MODIS observes

**May 4, 2001; 13:25 UTC**
**Level 1 “reflectance”**



Attributed to aerosol (AOD)

**May 4, 2001; 13:25 UTC**
**Level 2 “product”**




There are many different “algorithms” to retrieve aerosol from MODIS

1. Dark Target (“DT” ocean and land; Levy, Mattoo, Munchak, Remer, Tanré, Kaufman)
2. Deep Blue (“DB” desert and beyond; Hsu, Bettenhousen, Sayer,.. ): Previous talk!!!
3. MAIAC (coupled with land surface everywhere; Lyapustin, Wang, Korkin,…)
4. Land/Atmospheric correction (Vermote, …)
5. Ocean color/atmospheric correction (McClain, Ahmad, …)
5. Etc (neural net, model assimilation, statistical, … )
6. Your own algorithm (many groups around the world)

# Outline

1. MODIS Dark-target (DT) for Collection 6
2. Terra vs Aqua (and calibration and trends)
3. Onward to S-NPP VIIRS (and calibration and trends)
4. Summary, challenges, etc

# MODIS Collection 6 updates (Dark target)

- Specifically, the 10 km standard product (MxD04_L2)
- There is also a higher resolution product (3km: MxD04_3K), aimed at air quality applications.
- There is also a new Deep Blue/ Dark-target "merge" product
- and Deep Blue is improved greatly everywhere

# The Dark Target family consists of two separate aerosol optical depth (AOD) retrieval algorithms

**Dark land**

Spectral surface reflectance relationship, which is function of angle and NDVI_SWIR.

aerosol types are prescribed for location/season

Multispectral inversion using 3 wavelengths (0.47, 0.55 and 2.1 μm) and compared to lookup tables

**Water**

Surface BRDF including glint, foam, underlight (function of wind speed)

Aerosol types are not prescribed for season/location

Multispectral inversion using 6 wavelengths (0.55 – 2.1 μm) and compared to lookup tables

Both report the AOD at 550 nm,
Along spectral AOD and/or fine-mode fraction

Slide stolen and modified from A Sayer – ICAP 2015

# MODIS (MxD04) Collection 6!


- Levy, R. C., Mattoo, S., Munchak, L. A., Remer, L. A., Sayer, A. M., Patadia, F. and Hsu, N. C.: The Collection 6 MODIS aerosol products over land and ocean, *Atmos Meas Tech,* 6(1), doi:10.5194/amt-6-2989-2013, 2013.
- Sayer, A. M., Munchak, L. A., Hsu, N. C., Levy, R. C., Bettenhausen, C. and Jeong, M. J.: MODIS Collection 6 aerosol products: Comparison between Aqua's e-Deep Blue, Dark Target, and 'merged' data sets, and usage recommendations, *J Geophys Res-Atmos,* doi: 10.1002/2014JD022453, 2014.
- Munchak, L. A., Levy, R. C., Mattoo, S., Remer, L. A., Holben, B. N., Schafer, J. S., Hostetler, C. A. and Ferrare, R. A.: MODIS 3 km aerosol product: applications over land in an urban/suburban region, *Atmos Meas Tech,* 6(1), doi: 10.5194/amt-6-1747-2013,2014.
- Remer, L. A., Mattoo, S., Levy, R. C. and Munchak, L. A.: MODIS 3 km aerosol product: algorithm and global perspective*, Atmos Meas Tech,* 6(7), doi:10.5194/amt-6-1829-2013, 2013.

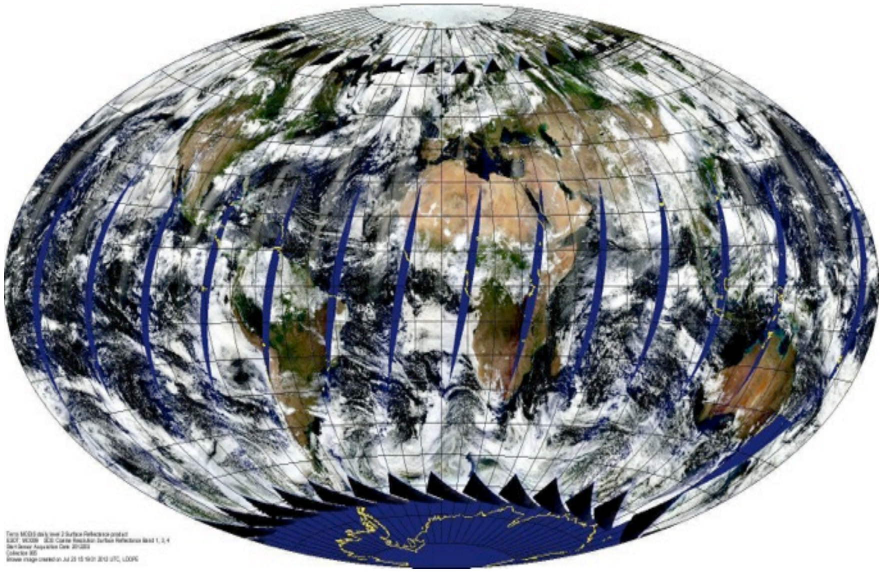

Collection 6 "Webinars": http://aerocenter.gsfc.nasa.gov/ext/registration/

New "dark-target" website: http://darktarget.gsfc.nasa.gov

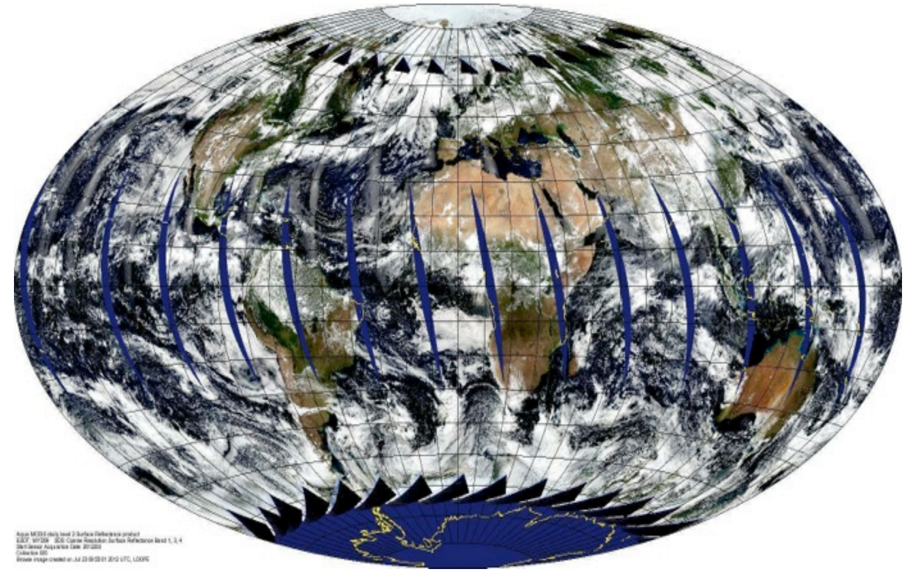
MODIS product website: http://modis-atmos.gsfc.nasa.gov

# Terra vs Aqua: Focus on Trends/Calibration

Terra (since spring 2000)



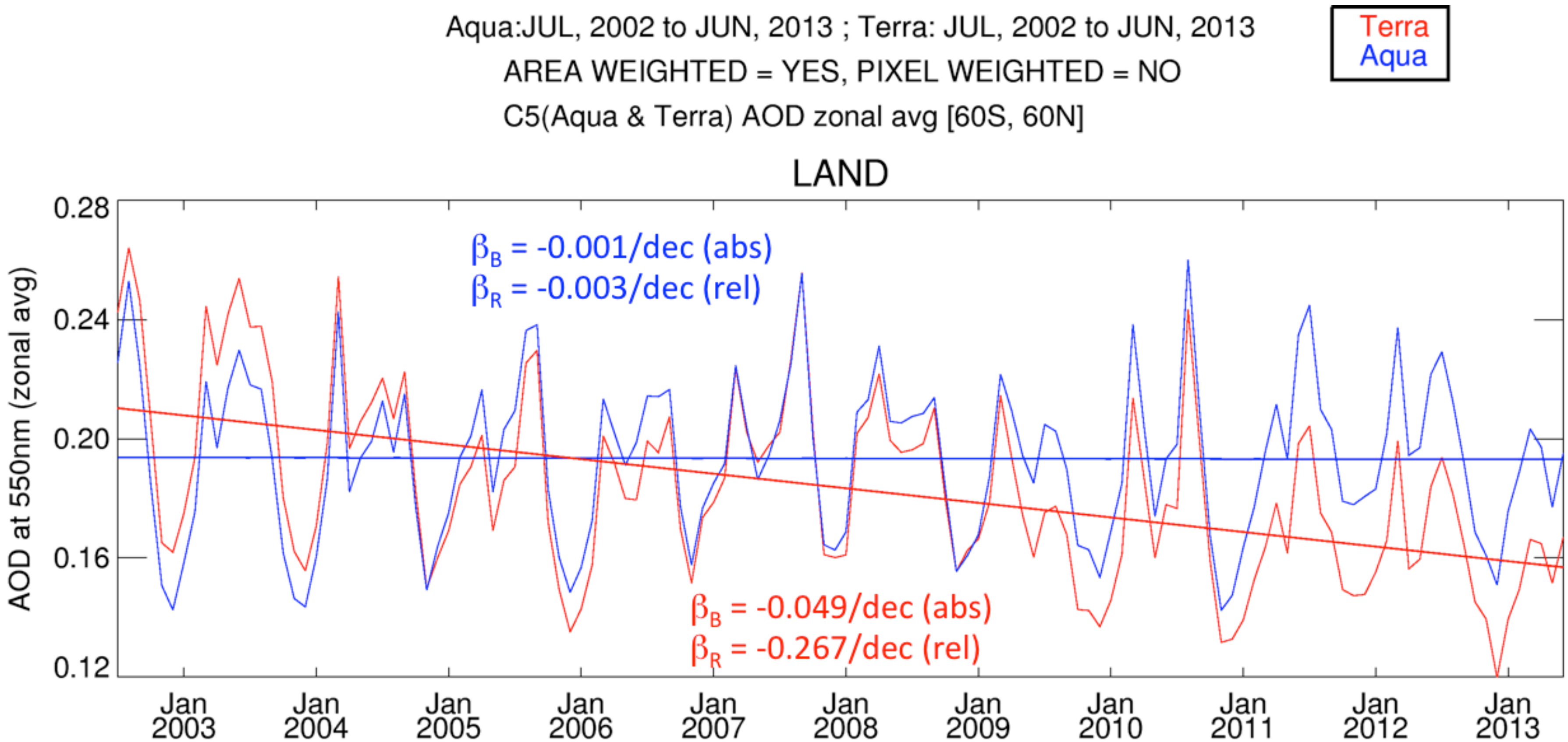
Aqua (since summer 2002)



- Same instrument hardware (optical design)
- Same spatial and temporal sampling resolution
- Same calibration/processing teams
- Same aerosol retrieval algorithms
- The two MODIS instruments are Identical twins!

How do they behave?

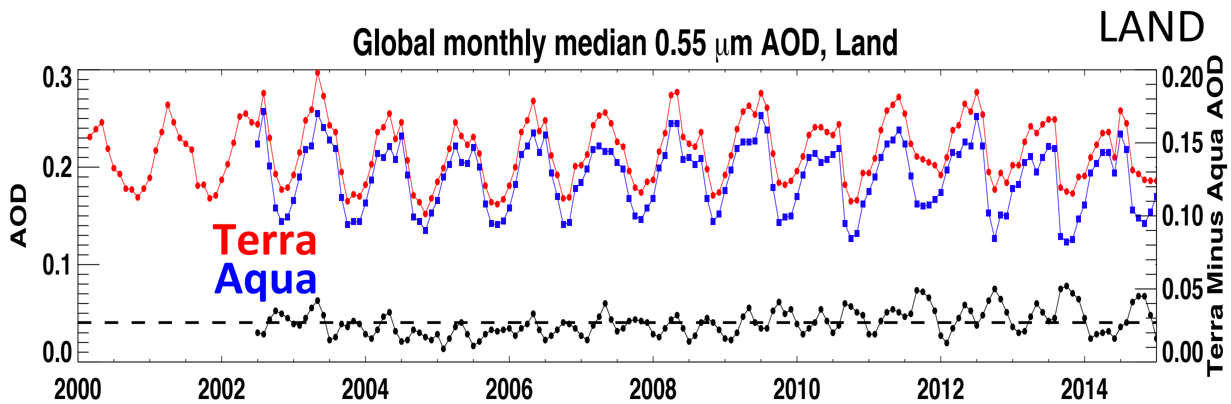
# Aerosol Trends: If based on Collection 5

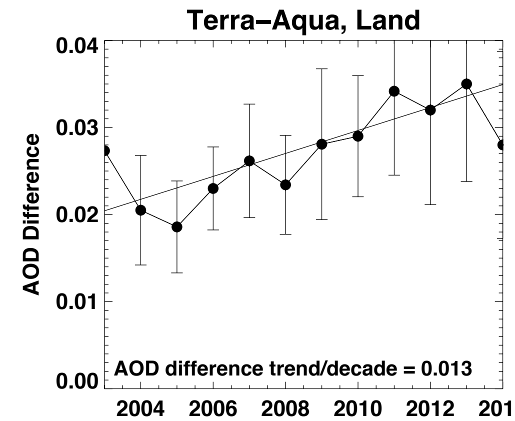


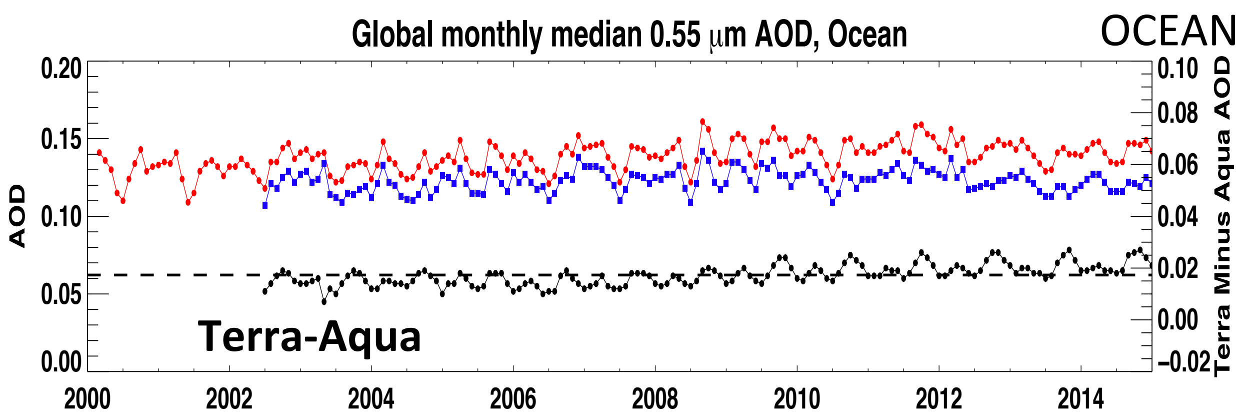

- Over land, Terra *decreased* (-0.05/decade), Aqua *constant*
- Terra / Aqua divergence was similar everywhere on the globe!

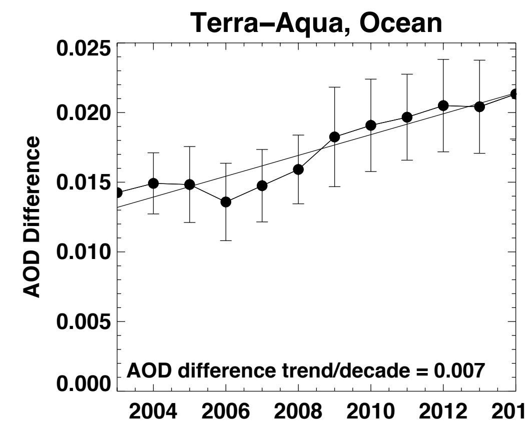
- Like identical human twins, the twin MODIS sensors aged differently.
- New calibration approach for Collection 6, using desert targets

# C6 differences AOD: Terra-Aqua



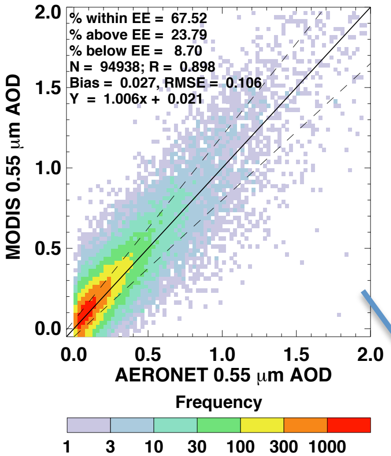




- Terra/Aqua divergence “mostly” removed for C6
- Terra offset by 0.027 land/0.017 ocean), THIS IS >13% of AOD!
- There is still residual trending (Terra-Aqua increasing by ~0.01/decade)
- Bigger-amplitude seasonal cycle to Terra-Aqua after 2011.

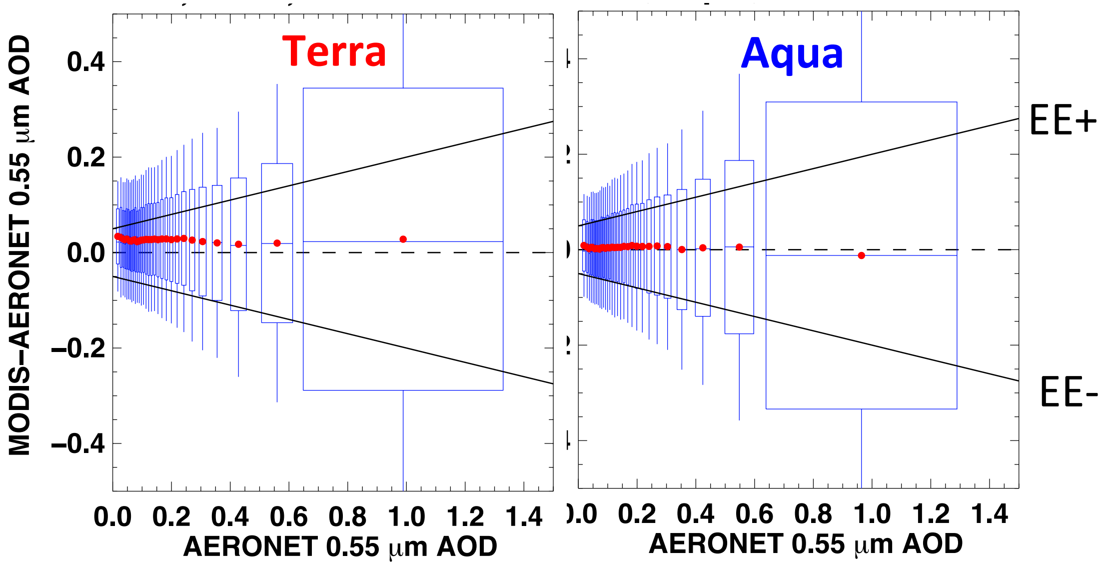
scatterplots




# "Validation": 2003-2013, Land

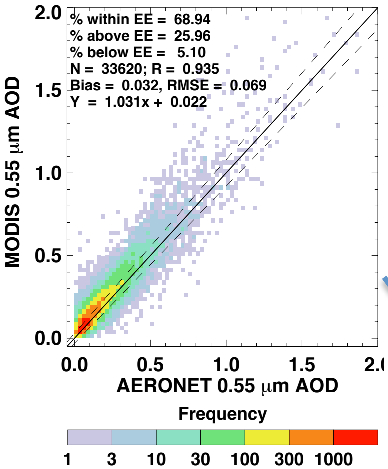
| Sat | N | Slope | Int | R | RMSE | Bias |
|---|---|---|---|---|---|---|
| Terra | 94.9K | 1.01 | 0.02 | 0.892 | 0.106 | 0.027 |
| Aqua | 80.5K | 1.01 | 0.00 | 0.890 | 0.104 | 0.004 |

MODIS vs AERONET: Mar 2003-Feb 2013




- EE% > 68%: Both Terra and Aqua meet "expected error (EE) " of ±(0.05 + 15%)
- Some metrics nearly identical: Corr = R=0.89, Slope=M=1.01, RMSE=0.10
- Terra is biased high for all AOD (due to **y-intercept of 0.02**)
- $N_{Terra}$ = 95K versus $N_{Aqua}$=81K. Why? Calibration? Sampling? AM/PM Clouds? Other?

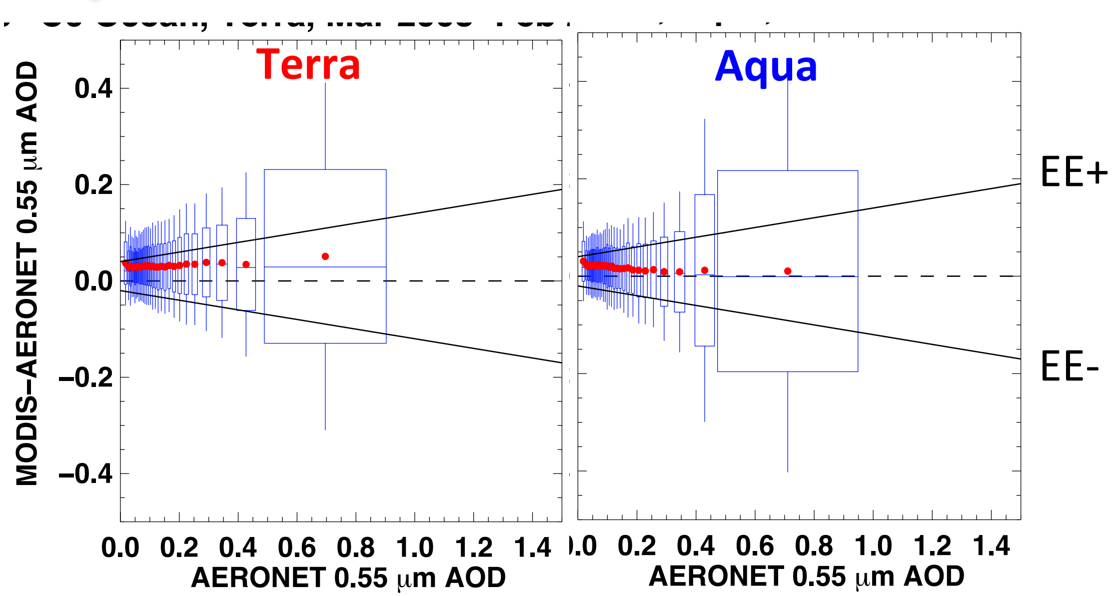
scatterplots




# "Validation": 2003-2013, Ocean

| Sat | N | slope | Y-int | R | RMSE | Bias |
|---|---|---|---|---|---|---|
| Terra | 33.6K | 1.04 | 0.02 | 0.935 | 0.069 | 0.032 |
| Aqua | 29.9K | 0.98 | 0.02 | 0.929 | 0.066 | 0.016 |

MODIS vs AERONET: Mar 2003-Feb 2013




- EE% > 68%: Both Terra and Aqua meet "expected error (EE) " of ±(0.03 + 10%)
- Some metrics nearly identical: Corr = R=0.93, Y-int=0.02, RMSE=0.07
- Terra is biased high, but due to **slope = 1.04 versus 0.98**.
- $N_{Terra}$ = 34K versus $N_{Aqua}$=30K. Why? Calibration? Sampling? AM/PM Clouds? Other?

# Summary (MODIS C6)

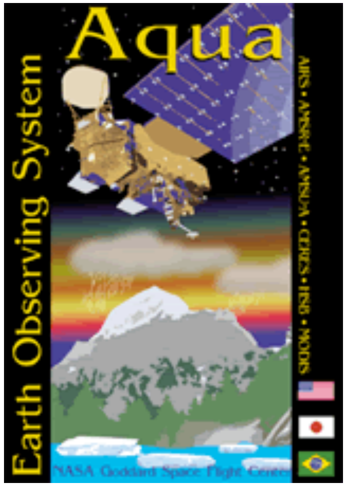
- MODIS dark-target (DT) aerosol retrieval ("MxD04_L2") is updated for Collection 6.
- Trending issues reduced with C6 calibration
- But still significant offsets (~0.02). Why? Sampling? diurnal cycles? Cloud masking?
- Still residual co-trending (<0.01 / decade)
- Calibration is suspect, trying different alternatives

Lyapustin, A., Wang, Y., Xiong, X., Meister, G., Platnick, S., Levy, R., Franz, B., Korkin, S., Hilker, T., Tucker, J., Hall, F., Sellers, P., Wu, A. and Angal, A.: Scientific impact of MODIS C5 calibration degradation and C6+ improvements, Atmos Meas Tech, 7(12), 4353–4365, doi:10.5194/amt-7-4353-2014, 2014.

Doelling, D.R.; A.Wu; X. Xiong; et al: The Radiometric Stability and Scaling of Collection 6 Terra- and Aqua-MODIS VIS, NIR, and SWIR Spectral Bands," IEEE-TGARS , 53, 8, 4520-4535, doi: 10.1109/TGRS.2015.2400928, 2015.

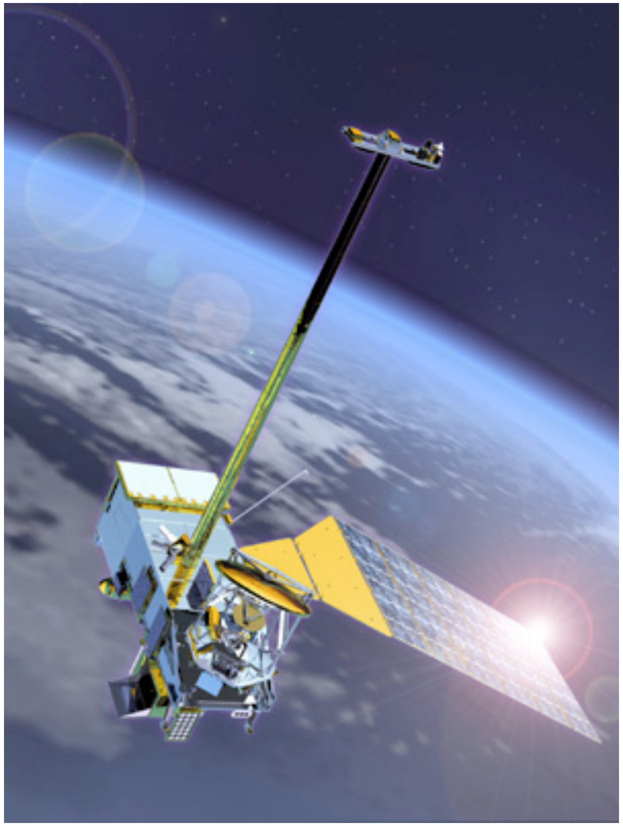
# Beyond MODIS?

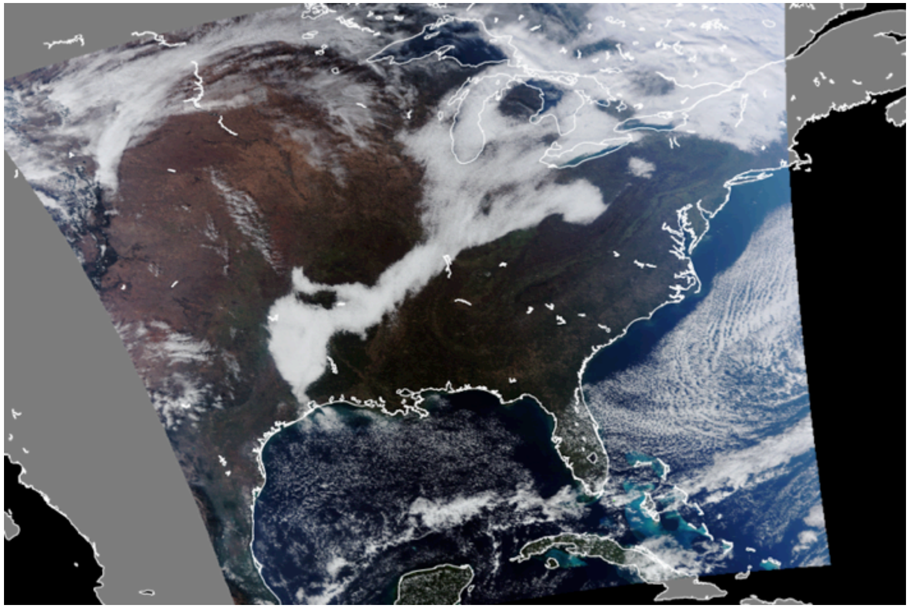
- Terra just celebrated its 15th birthday!
- At 13+,  Aqua ain't no spring chicken!
- Terra and Aqua MODIS instruments are both >2x original mission lifetimes
- MODIS won't be here forever
- How do we get to 20+ year aerosol data records?



# VIIRS?

Suomi-NPP (and future JPSS) VIIRS
Visible Infrared Imager Radiometer Suite





Can VIIRS "continue" the MODIS aerosol data record?

# VIIRS versus MODIS

**Orbit**: 825 km (vs 705 km), sun-synchronous, over same point every 16 days
Equator crossing: 13:30 on Suomi-NPP, since 2012 (vs on Aqua since 2002)

**Swath**: 3050 km (vs 2030 km); Granule size: 86 sec (vs 5 min)

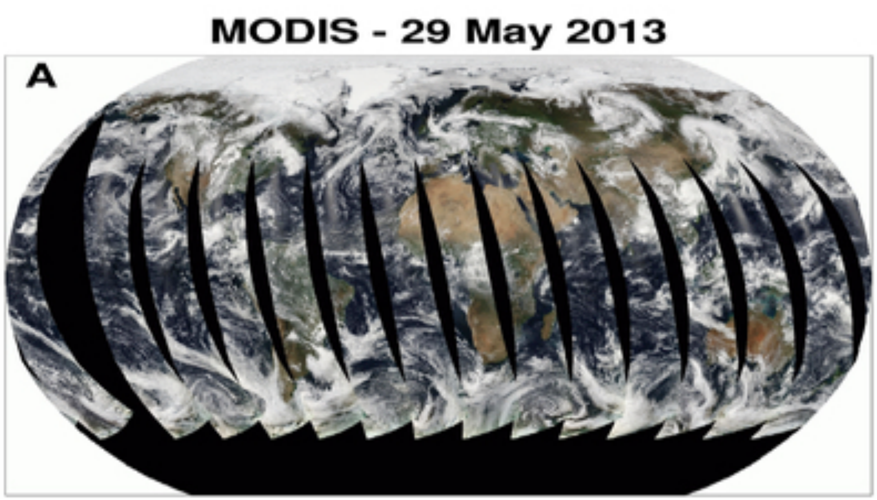
**Spectral Range**: 0.412-12.2μm (22 bands versus 36 bands)

**Spatial Resolution**: 375m (5 bands) 750m (17 bands): versus 250m/500m/1km

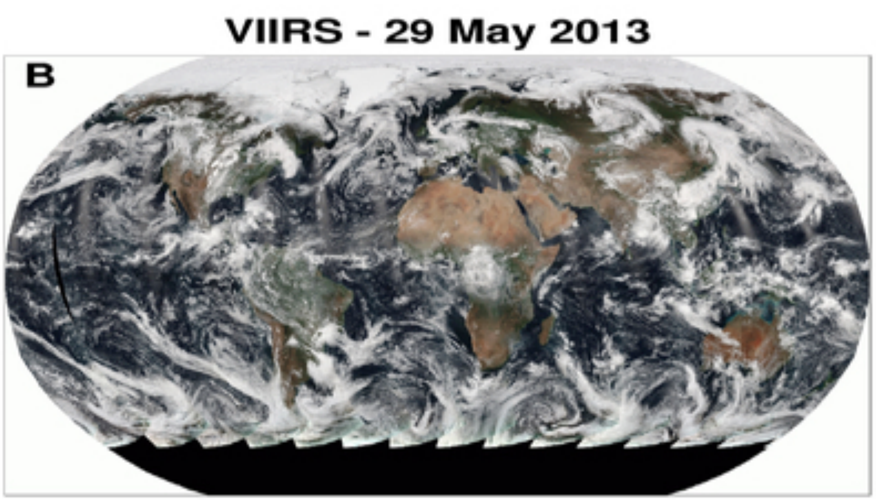
**Aerosol retrieval algorithms:** "Physics" similar, but different strategies

**Wavelength bands (nm) that could be used for DT aerosol retrieval**: 482 (466), 551 (553) 671 (645), 861 (855), 2257 (2113) → differences in Rayleigh optical depth, surface optics, gas absorption.

Aqua (13:30 Local Time, 14.6 revs/day)




Suomi-NPP (13:30 Local Time 14.1 revs/day);



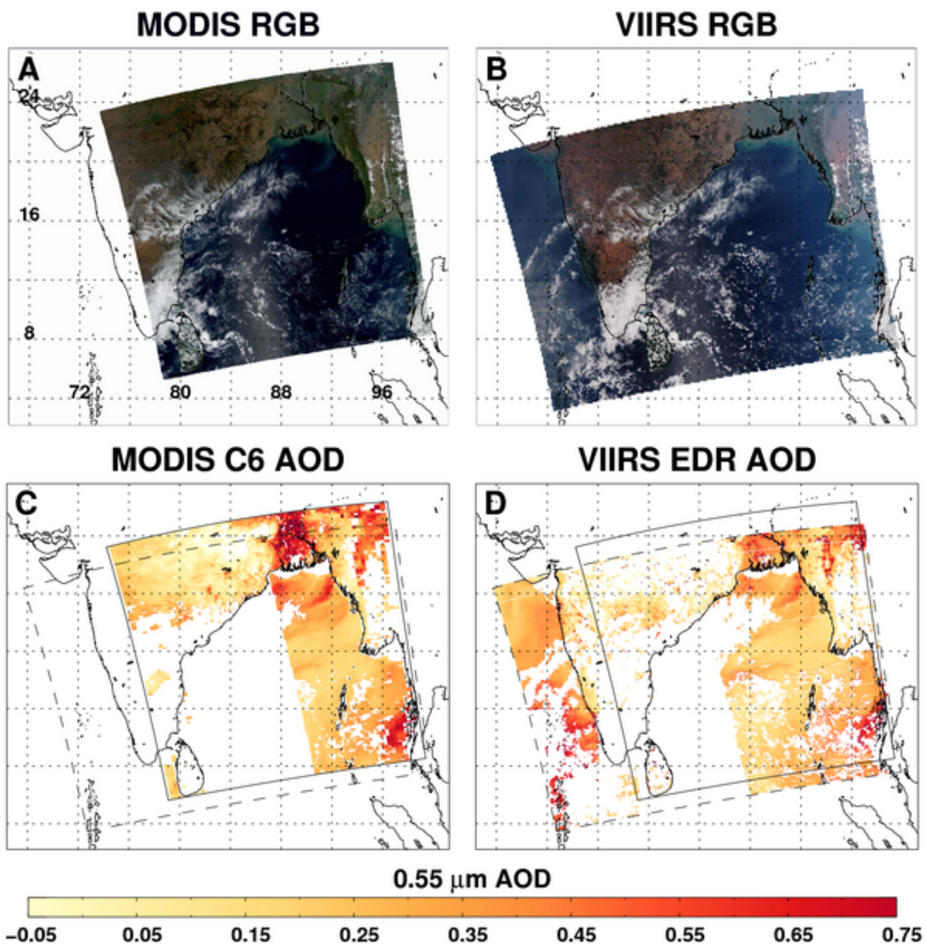
# VIIRS Aerosol Algorithm (NOAA-IDPS)

- Multi-spectral over dark surface
- Separate algorithms used over land and ocean
- 6 km resolution product – an integer multiple of scan lines
- Algorithm heritages
  - over land: MODIS atmospheric correction (e.g. the MOD09 product)
  - over ocean: MODIS aerosol retrieval (MOD04 product)
- Many years of development work:
- Retrieves: AOD (at 0.55 μm and spectral), Ångström Exponent (AE), Suspended Matter (aerosol classification), etc
- Provides data in HDF5 format (compared to HDF4-ish for MODIS)
- “Validated Stage 2” (published) since 23 Jan 2013. It is a “good” product, with similar error budgets as MODIS DT product.

From NOAA/NESDIS/STAR

# Aerosol retrieval: Different algorithms

Granules over India (Mar 5, 2013, 0735/0740 UTC)




**Ocean retrieval algorithm**

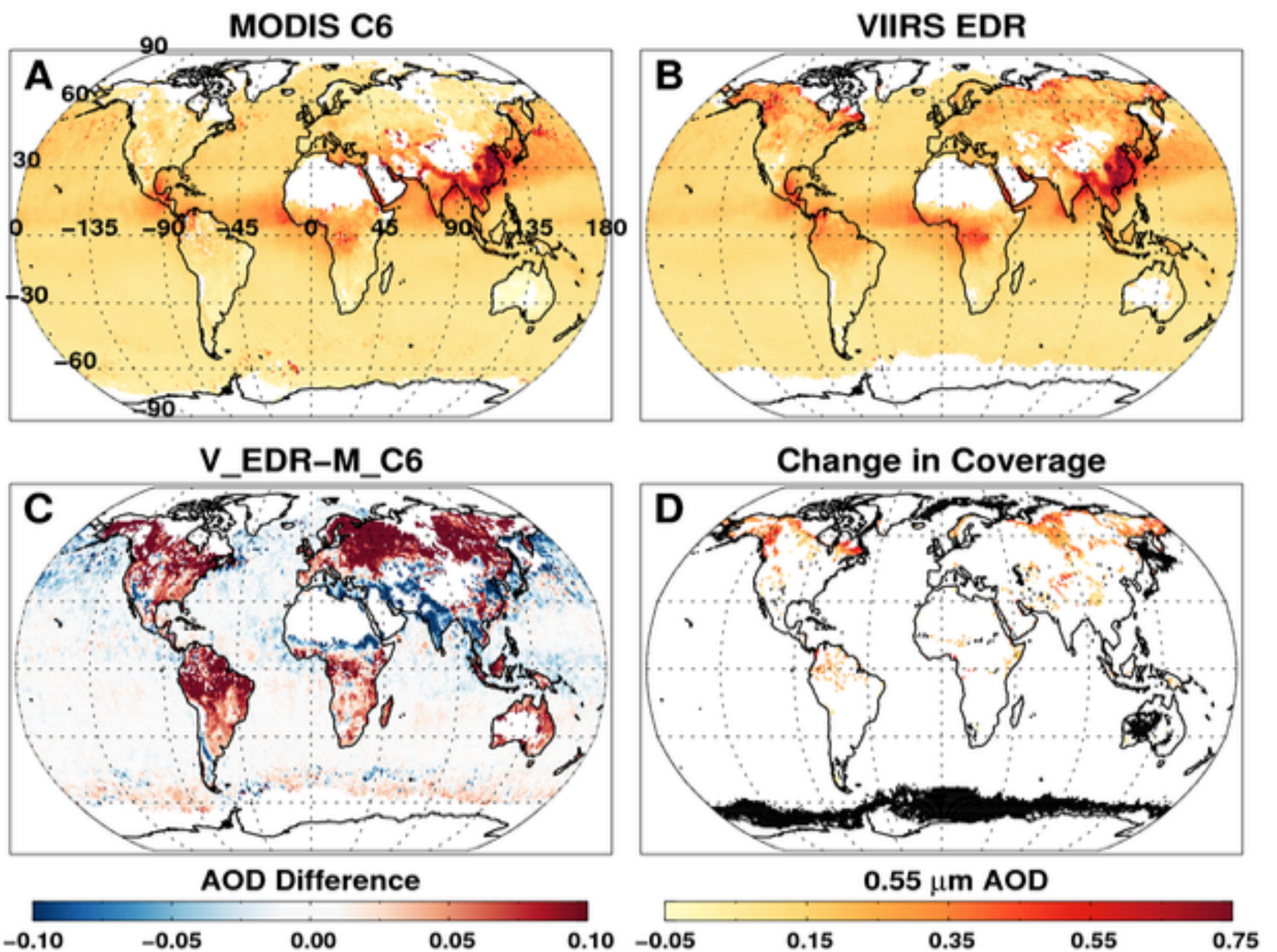
- "heritage" circa 1997 (Tanré, Kaufman, Remer,… )
- MODIS: C6 assumptions (Levy et al., 2013)
- VIIRS: C5-like assumptions (Remer et al., 2005)

**Land retrieval algorithm**

- "heritage" circa 1997 (Kaufman, Tanré, Vermote,…)
- MODIS: C6 "dark-target" (Levy et al., 2007, 2013)
- VIIRS: C5 "atmos. correction" (Vermote et al., 2008).

- Differences in wavelengths, cloud masks, pixel selection technique, quality assurance etc:
- Also, not exactly overlapping orbits (note 5 min difference).
- Note, 86 second VIIRS granules aggregated to 5 minutes.

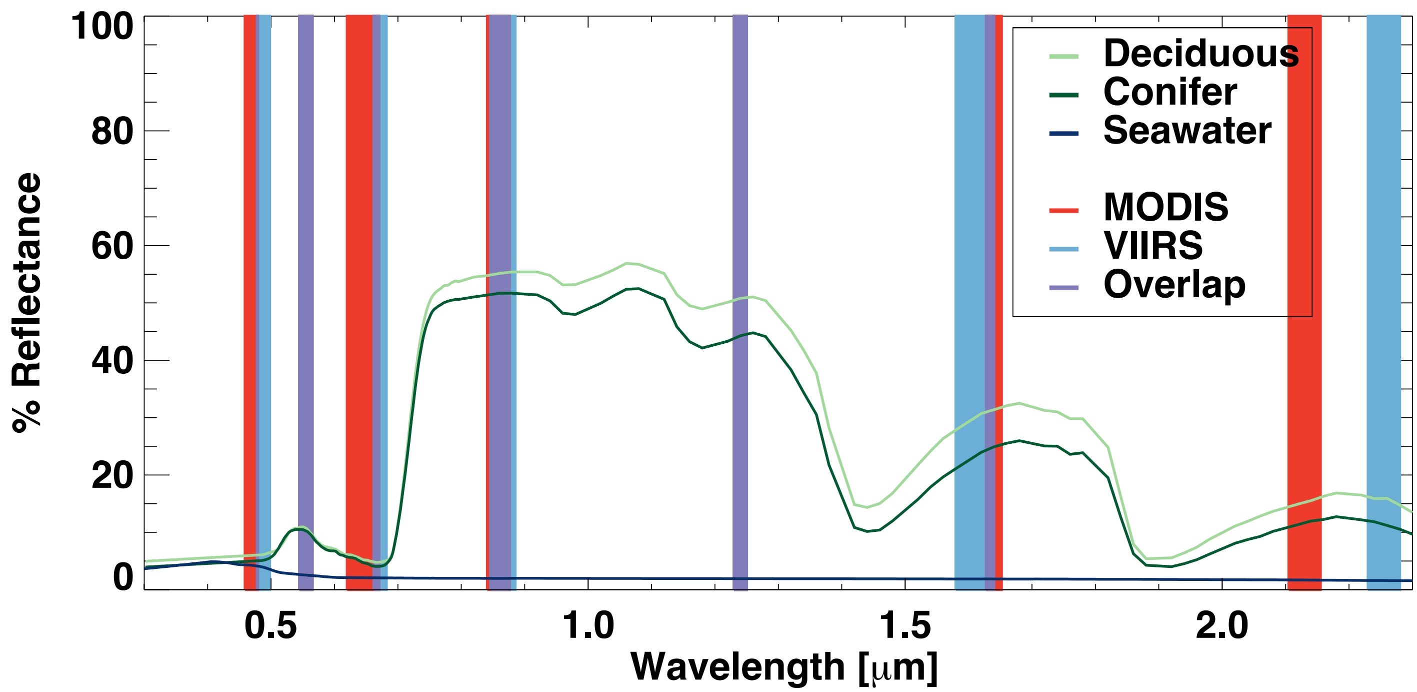
# Monthly mean AOD for Spring 2013 (Mar-May)




MODIS C6 and VIIRS-EDR are similar, yet too different

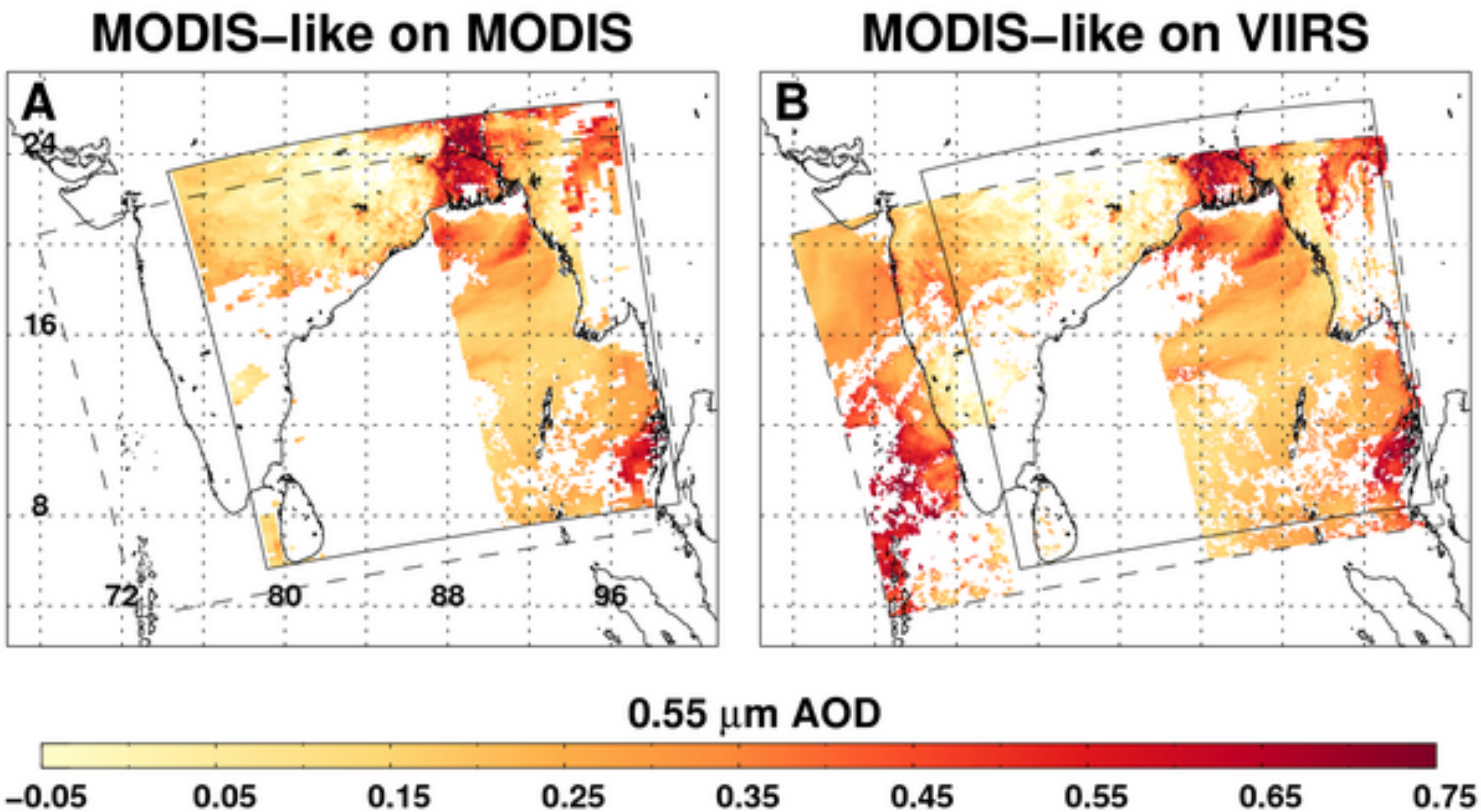
# Developing a MODIS-like algorithm for VIIRS

- The Intermediate file format (IFF) puts MODIS and VIIRS in "same common denominator" (University of Wisconsin)
- MODIS-IFF is 1 km resolution for all bands, VIIRS-IFF is 750 m (no high-resolution bands for either MODIS or VIIRS)
- Use 10 x 10 pixel retrieval boxes (so 10 km for MODIS; 7.5 km for VIIRS).
- Run lookup tables to account for different wavelengths



# Same algorithm on both platforms?

- Apply C6-like thresholds for cloud masking, pixel selection and aggregation
- Run “MODIS-like” algorithm on both M-IFF and V-IFF data

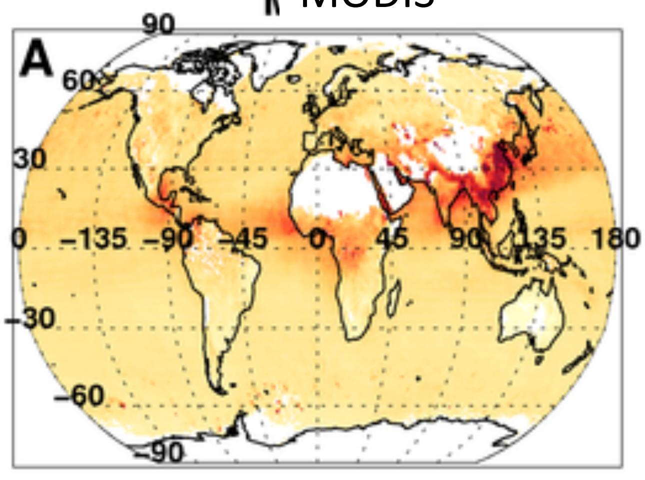



→ Much more similar AOD structure

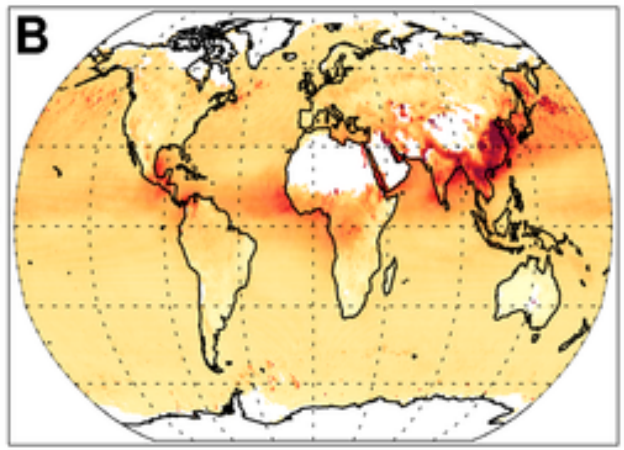
→ Still differences in coverage and magnitude. We are learning why. (Cloud masking/spatial variability thresholds?)

# Gridded seasonal AOD (Spring 2013)

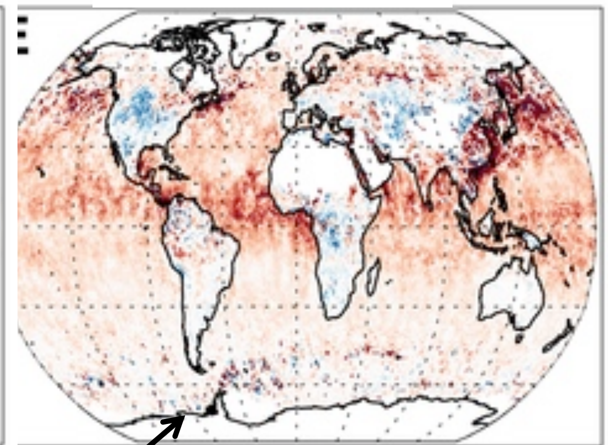
MODIS



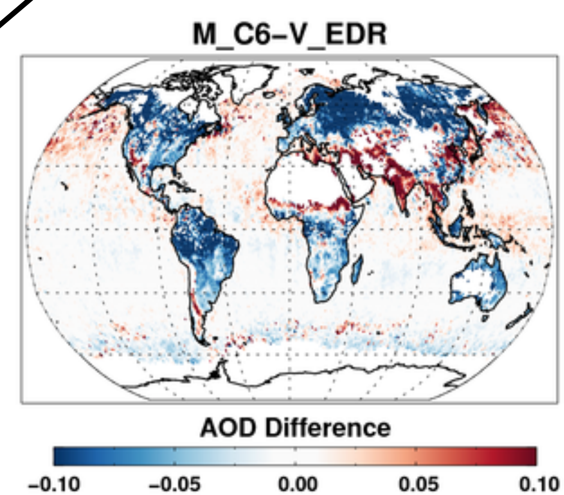

MODIS-like on VIIRS




Difference M - V



Versus…




MODIS-like on VIIRS has reduced global AOD differences and has similar global sampling

Systematic bias over ocean (VIIRS high by 15%)

Not systematic bias over land (VIIRS low by 5%)

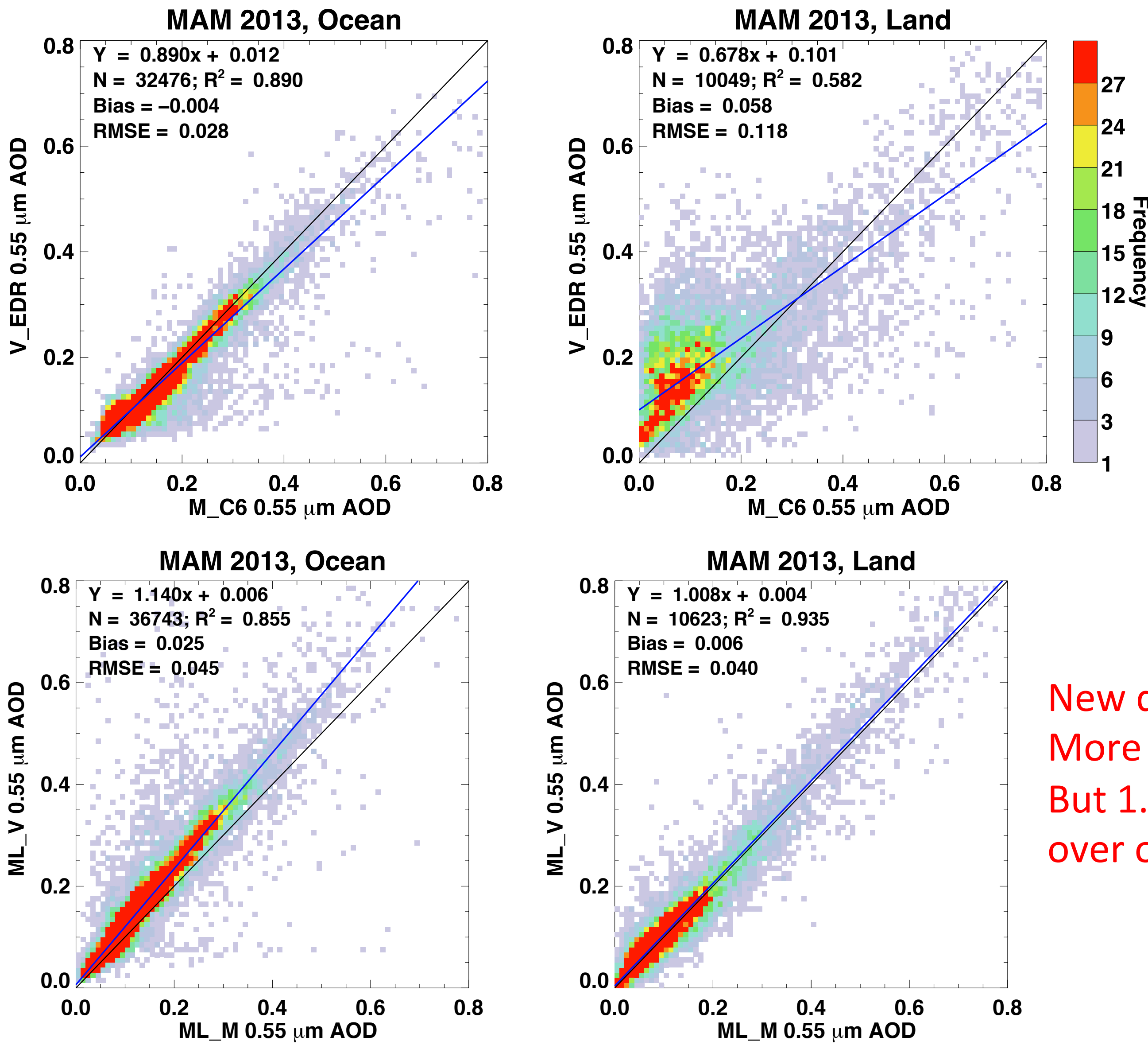
# Comparing gridded AOD (Spring 2013)

OCEAN

LAND

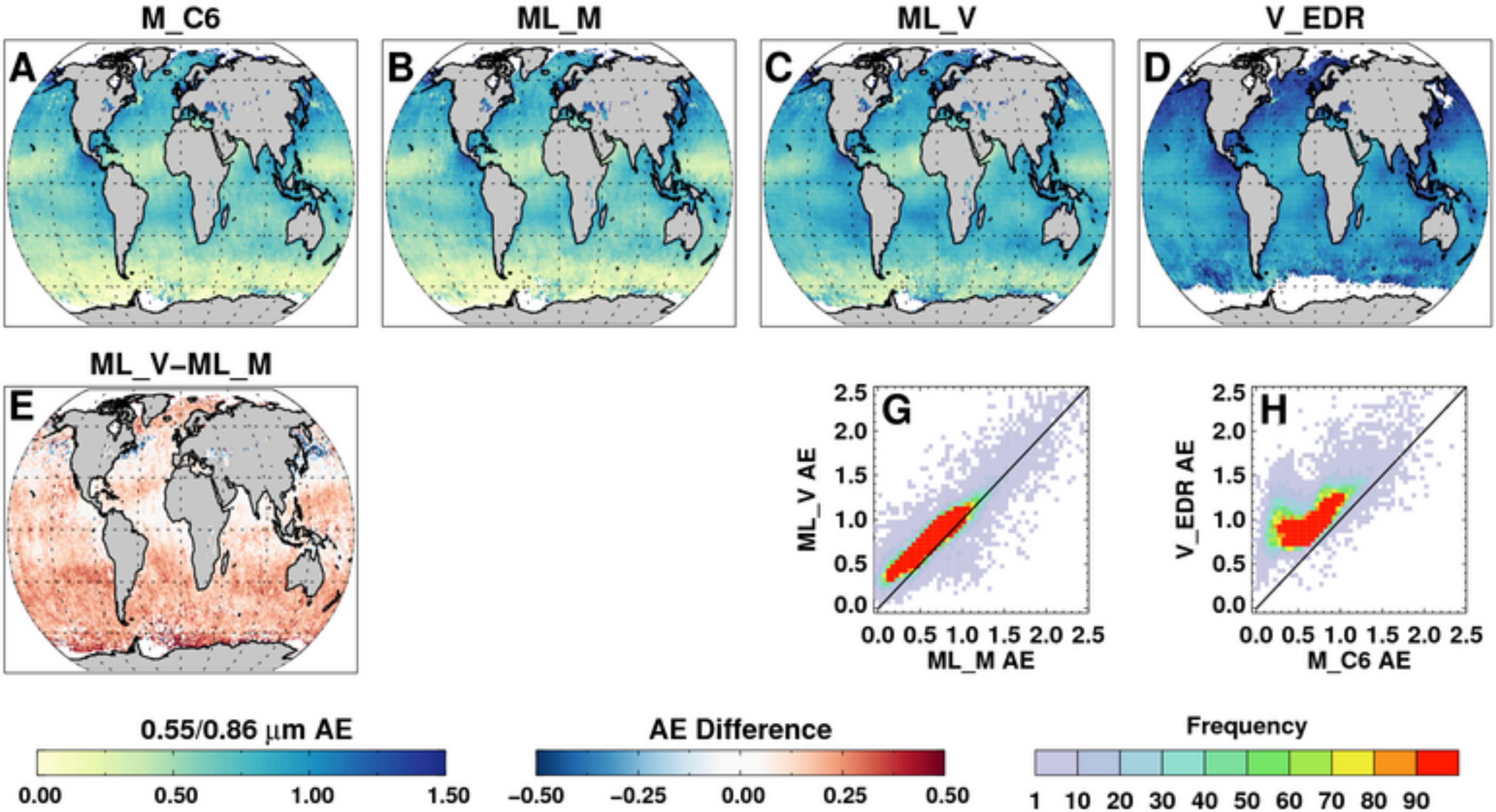
VIIRS_EDR vs MODIS

MODIS-like (VIIRS) vs MODIS




New data
More like MODIS
But 1.15 slope over ocean!

# Angstrom Exponent (0.55 / 0.86 μm)



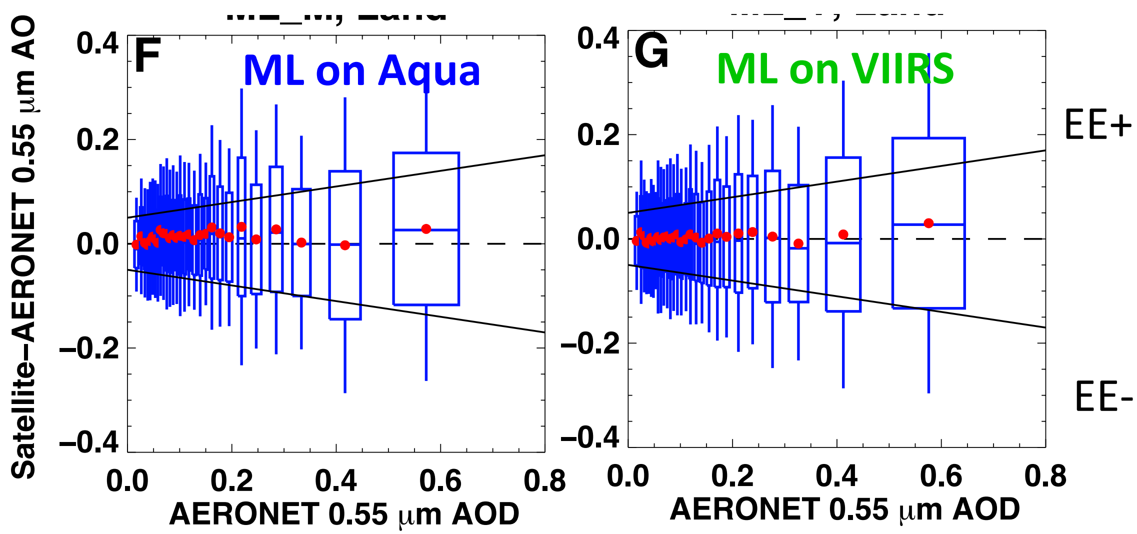

MODIS-like on VIIRS has Angstrom Exponent that looks much more like MODIS
Note: AE is calculated offline (from spectral AOD), and wavelengths are consistent

# “Validation”: 2013-2014, Land

scatterplots

| Sat | N | slope | Y-int | R | RMSE | Bias |
|---|---|---|---|---|---|---|
| **ML-M** | 4128 | 1.00 | 0.003 | 0.901 | 0.101 | 0.012 |
| **ML-V** | 4989 | 1.01 | -0.007 | 0.902 | 0.111 | 0.005 |

VIIRS vs MODIS (Aqua): March 2013-Feb 2014



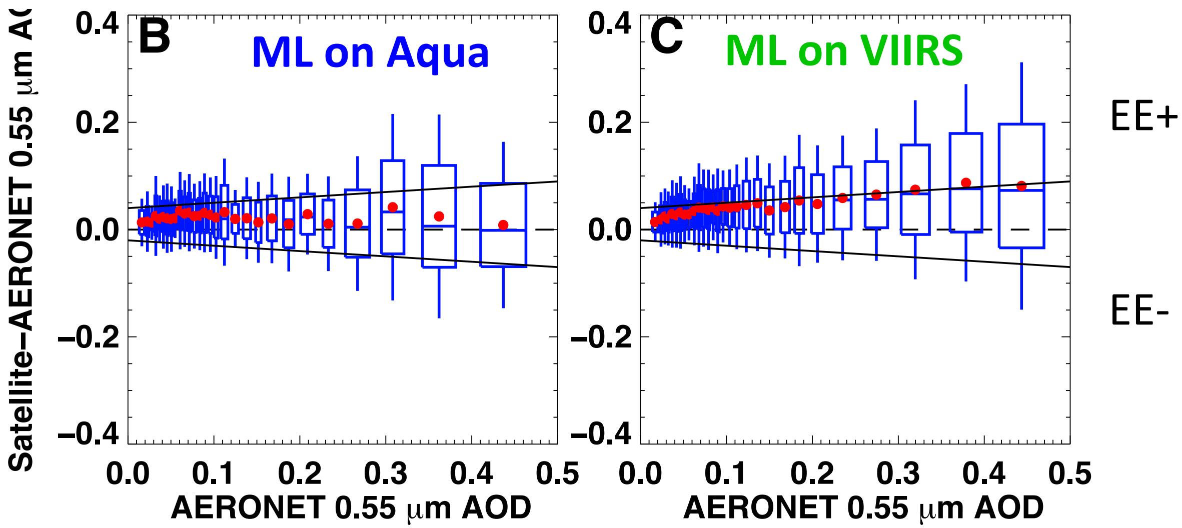

- EE% > 68%: Both VIIRS and MODIS-Aqua meet “expected error (EE) ” of ±(0.05 + 15%)
- Some metrics nearly identical: Corr = R=0.90, Slope=M=1.01, RMSE=0.10
- VIIRS is has even smaller bias than MODIS (due to negative **y-intercept**)

# "Validation": 2013-2014, Ocean

scatterplots

| Sat | N | slope | Y-int | R | RMSE | Bias |
|---|---|---|---|---|---|---|
| **ML-M** | 1399 | 0.98 | 0.02 | 0.931 | 0.070 | 0.021 |
| **ML-V** | 2297 | 1.17 | 0.02 | 0.949 | 0.078 | 0.044 |

VIIRS vs Aqua: Mar 2013-Feb 2014

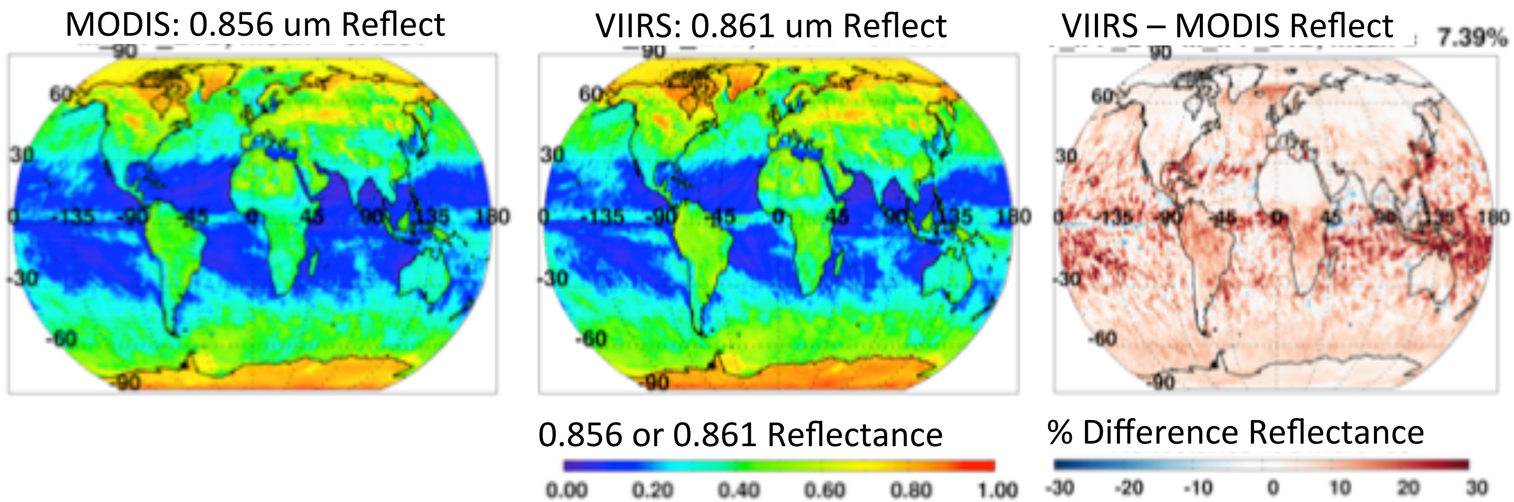



- VIIRS does not quite meet >68% within EE of ±(0.03 + 10%)
- Some metrics nearly identical:  Corr = R=0.93, Y-int=0.02, RMSE=0.07
- VIIRS is biased very high, but due to **slope = 1.17 versus 0.98**.

# Calibration? Again?

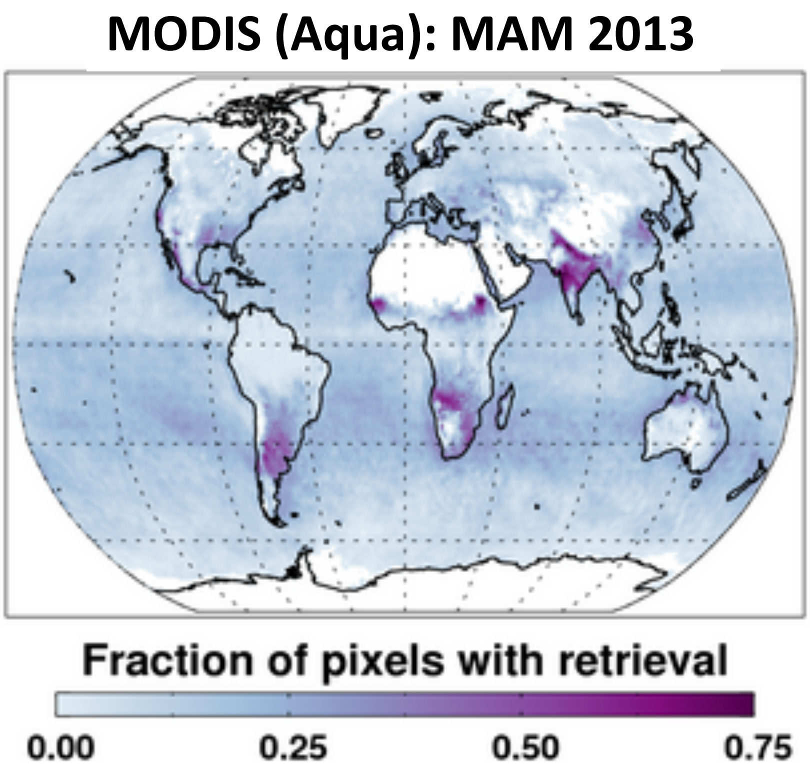
- Terra vs Aqua:
  - Ocean: Terra high by +0.017 or 13%;  Driven by slope
  - Land:  Terra high by +0.027 or 13%, Driven by y-offset

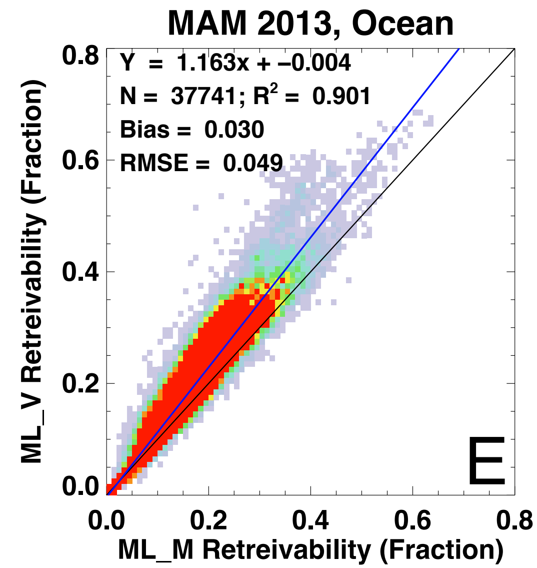
- VIIRS vs Aqua:
  - Ocean: VIIRS high by +0.25 or 20%; Driven by slope
  - Land:  VIIRS lower by -0.01 or 5%;  Driven by y-offset

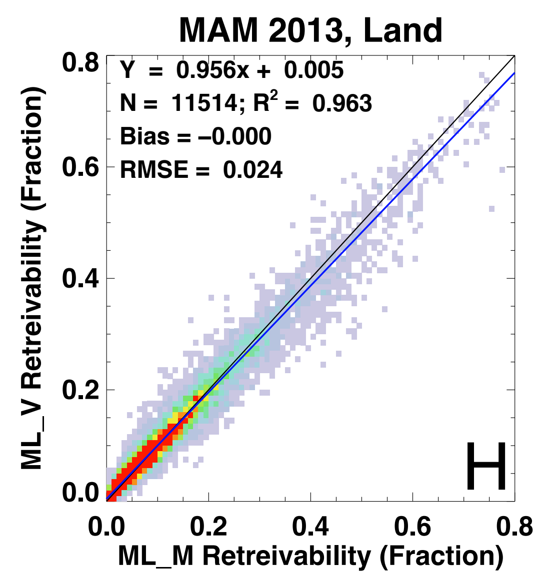



- VIIRS reflectance may be >2% high in some bands?   (e.g. Uprety et al., 2013)
- 2% high bias can give a 1.17 slope over ocean without the adding bias to land.
- Terra-Aqua differences are smaller, but they also to be calibration-driven..

# Retrievability: To retrieve or not to retrieve?



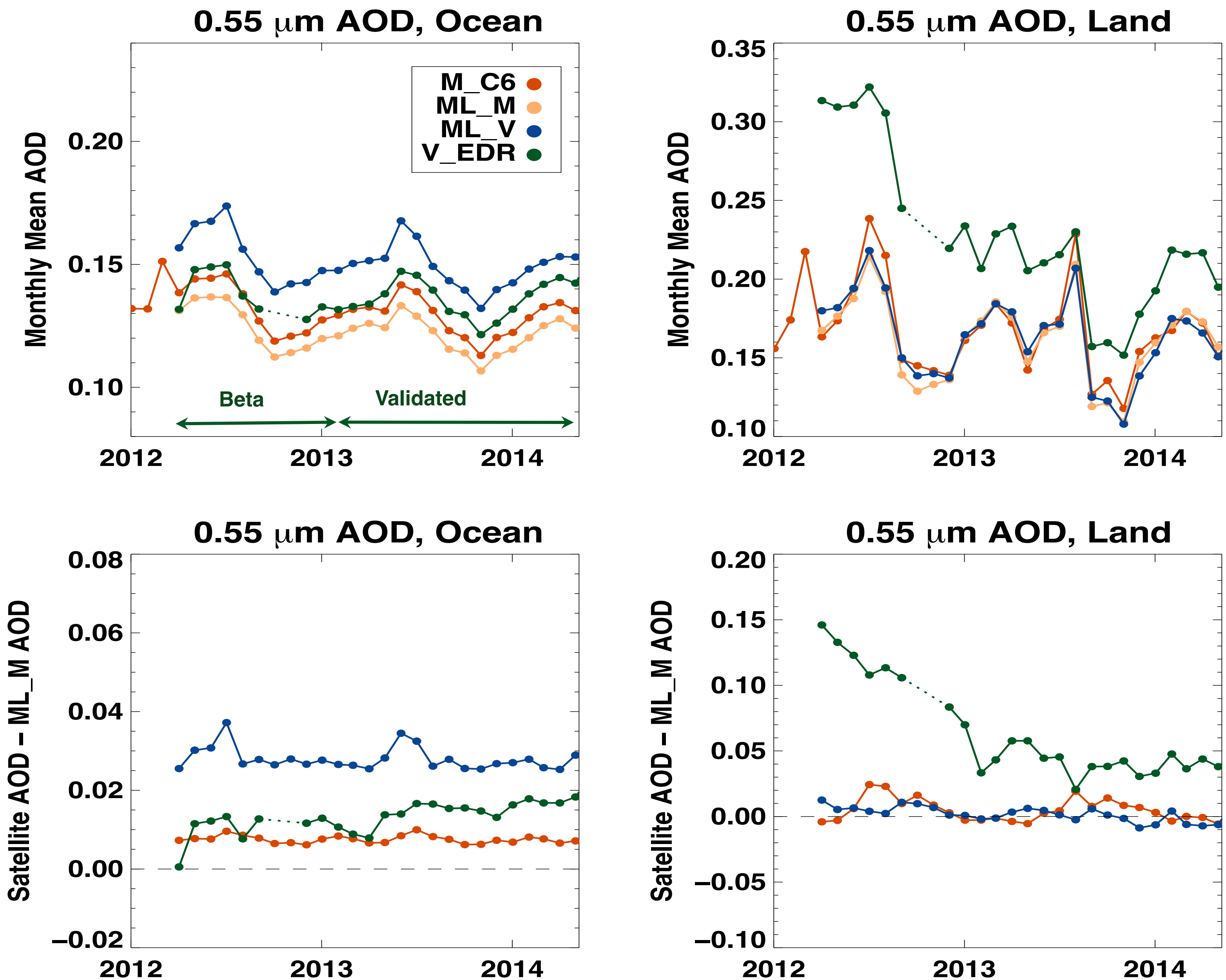




1°x1° retrieval fractions provided by the ML_V versus ML_M products during Spring 2013.

# Will VIIRS continue MODIS? How would we know?

- Convergence: of gridded (Level 3 –like) data
  - For a day? A month? A season?
  - What % of grid boxes must be different by less than X?
    - in AOD? In Angstrom Exponent? Size parameters?
- Sampling: Do instruments observe similar conditions?
- Retrievability: Do algorithms make same choices?
- Validation: Comparison with AERONET, MAN, etc?

# A time series (of sorts) so far



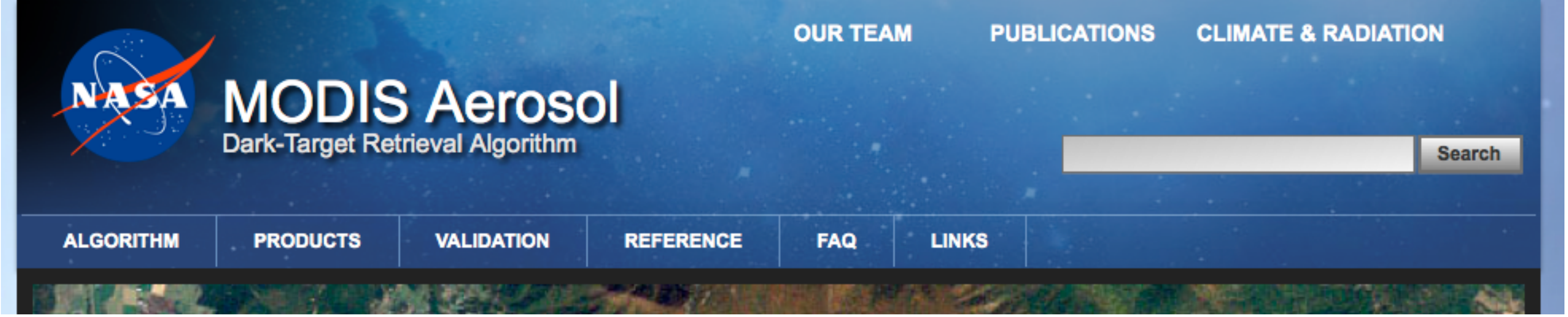
# Summary

- MODIS-DT Collection 6 –
  - Aqua/Terra level 2, 3 available now;
  - Extended diagnostics, DT/DB merge, science improvements
  - "Trending" issues reduced, but 15% or 0.02 Terra/Aqua offset remains .
- VIIRS-IDPS (MODIS-ish over ocean; not over land)
  - VIIRS is "similar" instrument, yet different then MODIS
  - The NOAA product has similar global EE to MODIS (over ocean).
  - With 50% wider swath, VIIRS has daily coverage
- VIIRS-DT – now,
  - Ensures *algorithm* consistency with MODIS DT.
  - IFF-based granules are being processed now (we are sharing)
  - 20% NPP/Aqua offset over ocean.
  - Paper under review for AMT ! (Some of you may review it?)
- VIIRS-DT - future,
  - We don't have "continuity" yet.
  - Move towards full resolution (includes I-bands)
  - Discussion here at MODIS-VIIRS Science Team meeting (formats, delivery, ATBDs, documentation, etc…)

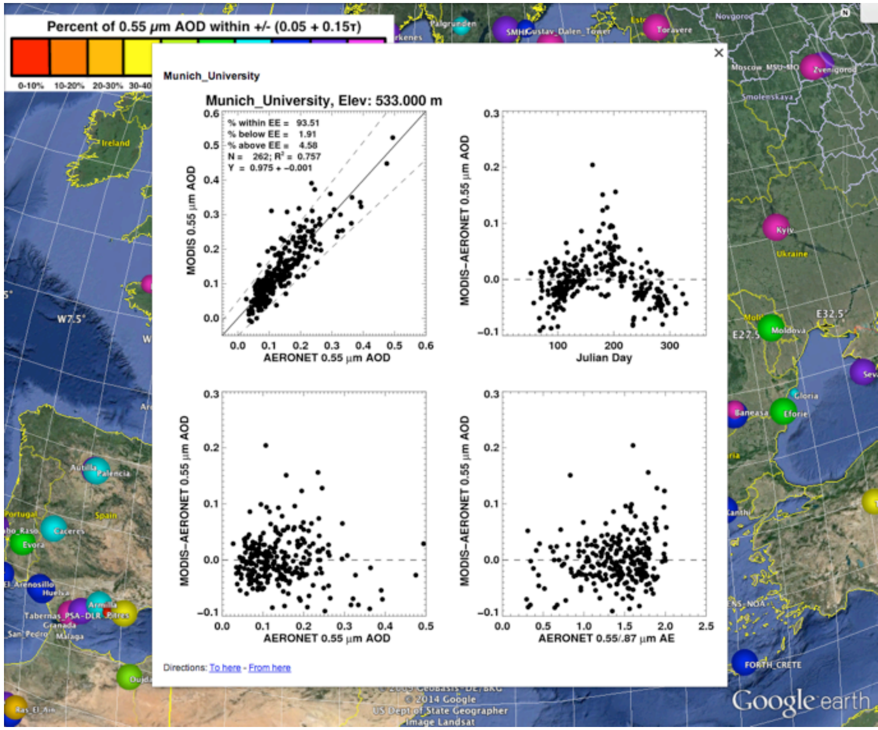
# Summary (cont)

- Can VIIRS continue the MODIS record?
  - We believe we need to apply the same algorithm
  - Calibration is a concern.
- We still need to define "how similar is good enough"?
- Which statistics must converge?
  - Expected error (validation)
  - Sampling
  - Means/variance
  - At 0.55 μm only? At other wavelengths?
  - Etc
- Improvements for "Collection 7"? which would be a joint MODIS/VIIRS product.

- Thank you Shobha for the invitation today.




- Web site /ATBDs being updated
- Reference for all things "dark target"
  - The algorithms and assumptions
  - Examples
  - Validation
  - Primary publications
  - Educational material
  - FAQ
  - Links to data access
  - Considering a "forum"




http://darktarget.gsfc.nasa.gov

STAR JPSS 2015 Annual Science Team Meeting

# The JPSS Risk Reduction Aerosol Optical Thickness Algorithm

Hongqing Liu and Istvan Laszlo

August 27, 2015

# Objectives

- Algorithm updates
  - Extend the range of aerosol optical thickness to [-0.05, 5.0]
  - Adopt MODIS aerosol models
  - Revise the spectral relationship of land reflectance
  - Combine the VIIRS-like and MODIS/ABI-like retrieval schemes over land
  - Refine the internal tests
  - Revise the quality control
- Cross-platform consistency
  - Apply a single algorithm on both JPSS and GOES-R

# Algorithm Comparison (Over Water)

| | IDPS | NOAA |
|---|---|---|
| **Internal Tests** | Turbid water; Sun glint; Sea ice | Bright cloud; Cirrus; Sea ice; Spatial homogeneity; Turbid/shallow water; Heavy aerosol |
| **Aerosol Models** | MODIS C4 | MODIS C5 |
| **Surface Reflectance** | $R_f+R_u+R_s$ | $R_f+(1-R_f)R_u+(1-W)R_s$ [Koepke, 1984] |
| **AOT Range** | [0.0, 2.0] | [-0.05, 5.0] |
| **Channel Used** | 0.67, 0.74(saturation), 0.86, 1.24, 1.61, 2.25 µm | **0.55**, 0.67, 0.74(saturation), 0.86, 1.24, 1.61, 2.25 µm |
| **Residual** | $\sum_{\lambda=1}^{n}\left(\rho_\lambda^m - \rho_\lambda^{LUT}\right)^2$ | $\sqrt{\sum_{\lambda=1}^{n}\left(\frac{\rho_\lambda^m - \rho_\lambda^{LUT}}{\rho_\lambda^m - \rho_\lambda^{Ray} + 0.01}\right)^2 \Big/ n}$ |
| **Ångström Exponent** | 0.86 vs. 1.61 µm | 0.55 vs. 0.86 µm<br>0.86 vs. 1.61 µm |
| **Inland Lakes** | No retrievals | Included |

# Algorithm Comparison (Over Land)

| | IDPS | NOAA |
|---|---|---|
| **Internal Tests** | Cirrus; Sunglint; Fire; Snow; Ephemeral water | Cloud; Cirrus; Snow; Spatial homogeneity; Ephemeral water; Heavy aerosol |
| **Aerosol Models** | AERONET | MODIS C5 |
| **Surface Reflectance Spectral Relationship** | Constant ratios | Linear relationship as functions of $NDVI_{SWIR}$, scene redness, and glint angle |
| **AOT Range** | [0.0, 2.0] | [-0.05, 5.0] |
| **Reference Channels** | 0.48 and 0.67 μm | 0.48 and 0.67 μm (SW scheme)<br>0.48 and 2.25 μm (SWIR scheme) |
| **Residual** | $\sum_{\lambda=1}^{n}\left(\alpha_\lambda^{corr}-\alpha_\lambda^{est}\right)^2$ | $\sqrt{\sum_{\lambda=1}^{n}\left(\frac{\rho_\lambda^m-\rho_\lambda^{LUT}}{\rho_\lambda^m-\rho_\lambda^{Ray}+0.01}\right)^2 / n}$ |

# Land Aerosol Algorithm

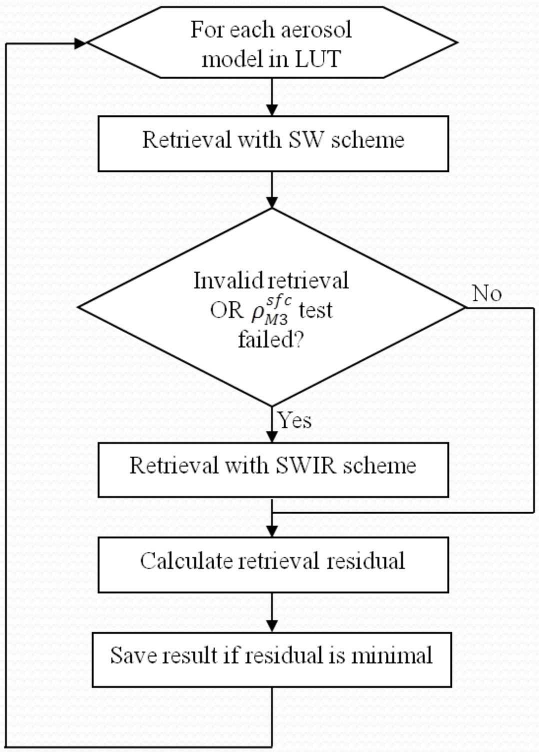
- IDPS VIIRS (SW scheme)
  - Surface reflectance at 0.48µm is estimated from 0.67µm
  - Pros: robust spectral surface reflectance relationship
  - Cons: strong atmospheric effect
  - Better performance at low AOTs

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

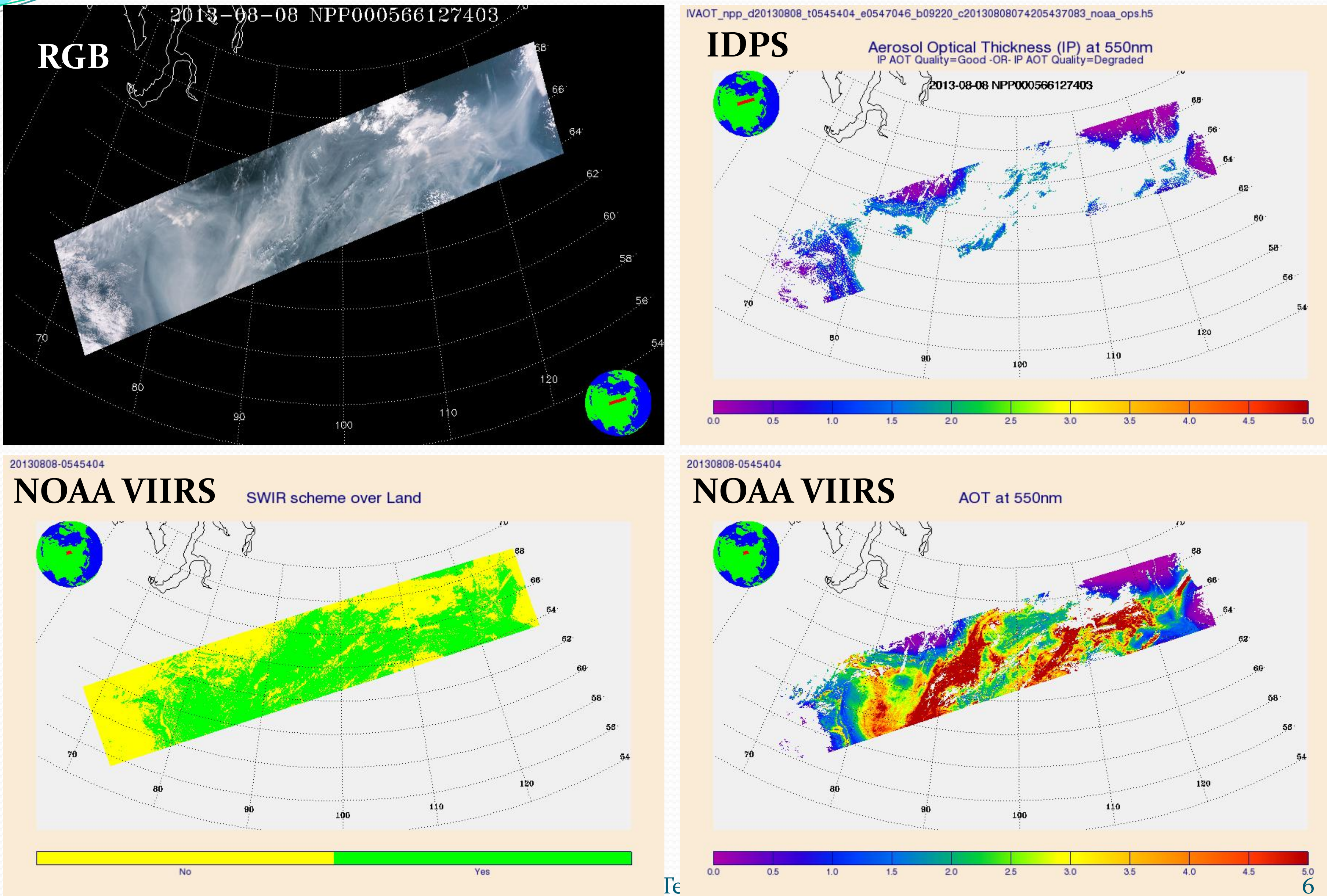
- JPSS Risk Reduction Aerosol Algorithm (NOAA VIIRS)
  - SW scheme as the first choice
  - Apply SWIR algorithm if
    - Invalid retrievals from SW scheme
    - Surface reflectance at 0.48µm is out of uncertainty range
  - Surface spectral reflectance relationship are linear functions of TOA redness ratio (TOA M5/M4 reflectance ratio), $NDVI_{SWIR}$ (TOA M8-M11/M8+M11) and glint angle (G)

$$Y = (c_1+c_2{*}Redness+c_3{*}NDVI_{SWIR}+c_4{*}G) + (c_5+c_6{*}Redness+c_7{*}NDVI_{SWIR}+c_8{*}G){*}X$$

where Y is the surface reflectance at band M5, M3, M1, M2; and X is the surface reflectance at M11, M5, M3, M3, respectively.



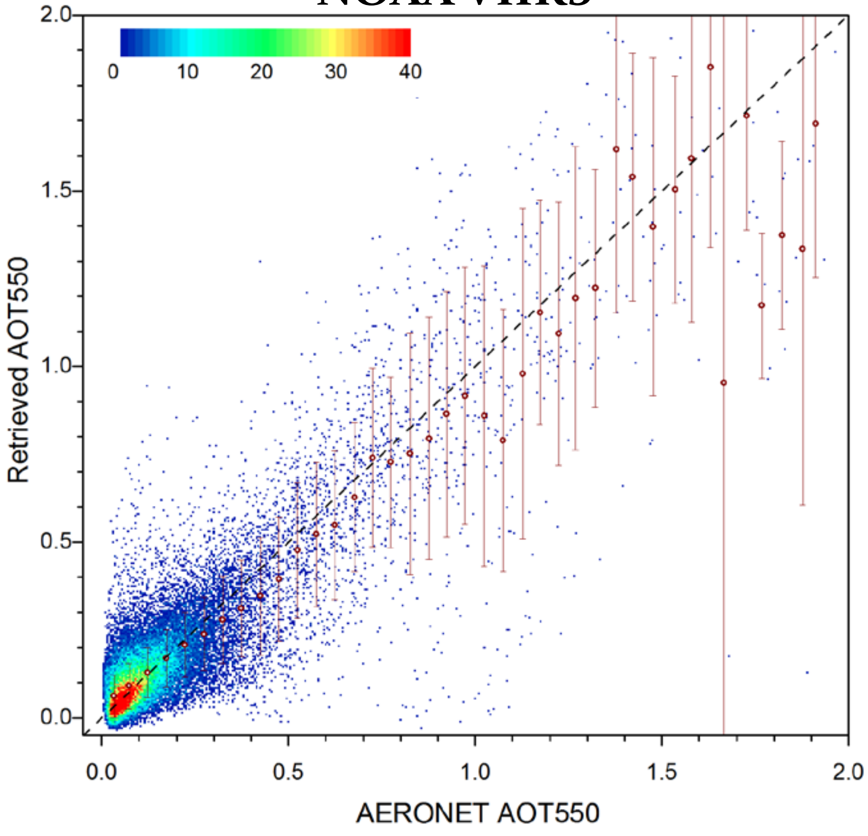
# Land Aerosol Algorithm (Example)



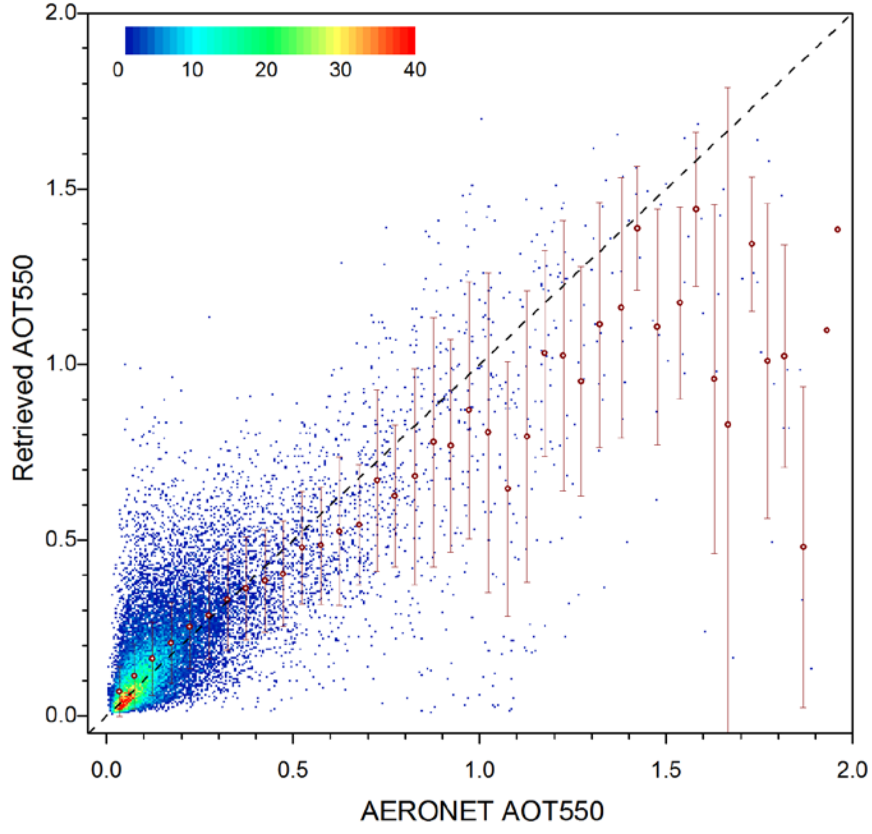
# Validation over Land

- Time period: Jan. 23, 2013 – Dec. 31, 2014
- High quality retrievals over AERONET stations
- 20-km radius (at least 400 retrievals), and 1-hr window (at least two measurements) for match-up
- AERONET L1.5 ground measurements

**NOAA VIIRS**




**IDPS VIIRS**

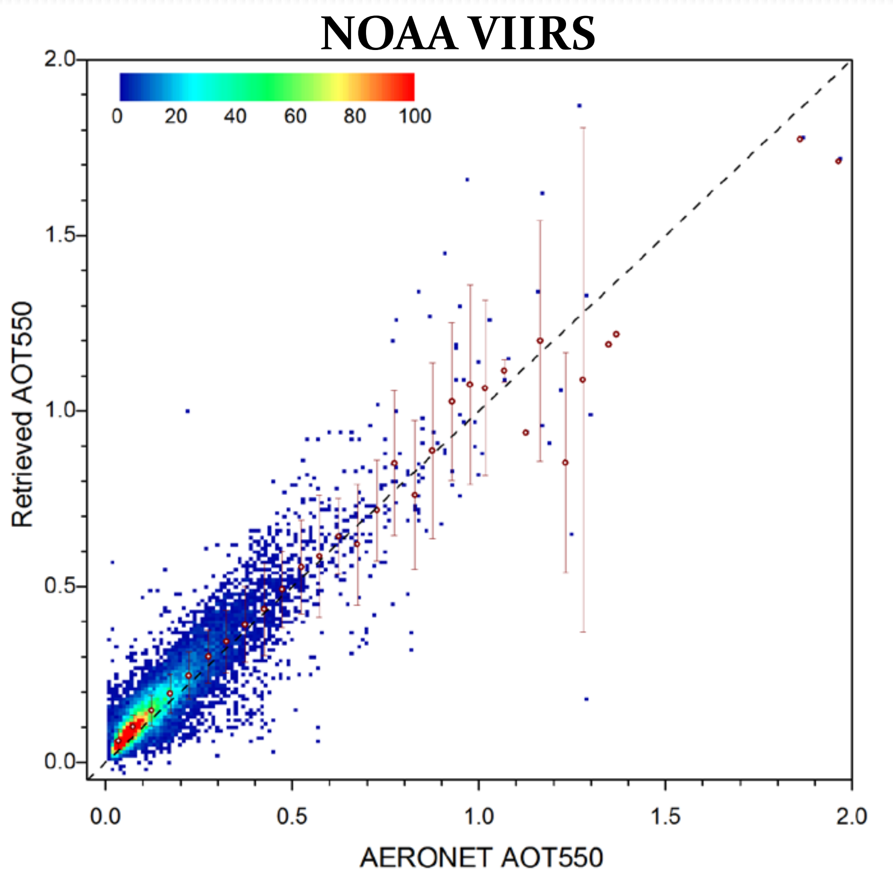


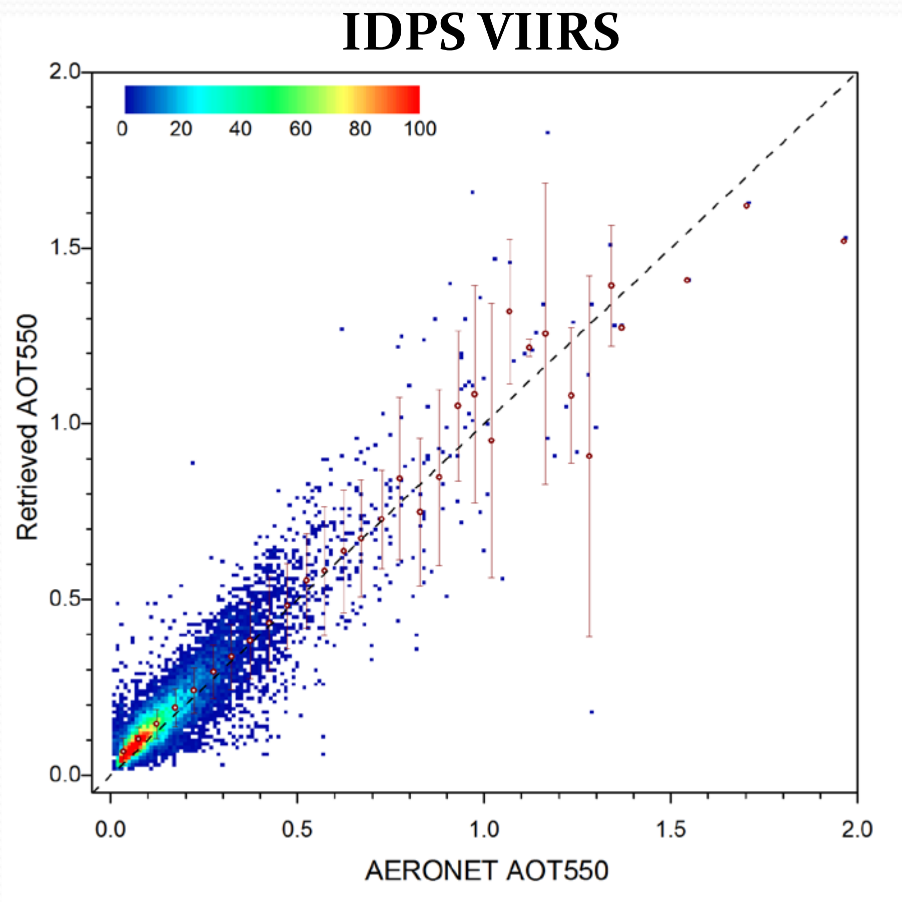
# Statistics

| LAND | | NOAA-VIIRS | IDPS-VIIRS | Requirement |
|---|---|---|---|---|
| <0.1 | Accuracy | 0.02 | 0.04 | 0.06 |
| | Precision | 0.06 | 0.09 | 0.15 |
| | Number | 17,451 | 9,563 | |
| [0.1, 0.8] | Accuracy | -0.01 | 0.02 | 0.05 |
| | Precision | 0.11 | 0.13 | 0.25 |
| | Number | 15,187 | 11,344 | |
| >0.8 | Accuracy | -0.11 | ***-0.26*** | 0.20 |
| | Precision | 0.41 | ***0.46*** | 0.45 |
| | Number | 539 | 454 | |
| All | Accuracy | 0.003 | 0.021 | |
| | Precision | 0.103 | 0.136 | |
| | Number | 33,177 | 21,361 | |

# Validation over Ocean

- Time period: Nov. 27, 2012 – Dec. 31, 2014
- High quality retrievals over AERONET stations
- 20-km radius (at least 200 retrievals), and 1-hr window (at least two measurements) for match-up
- AERONET L1.5 ground measurements



# Statistics

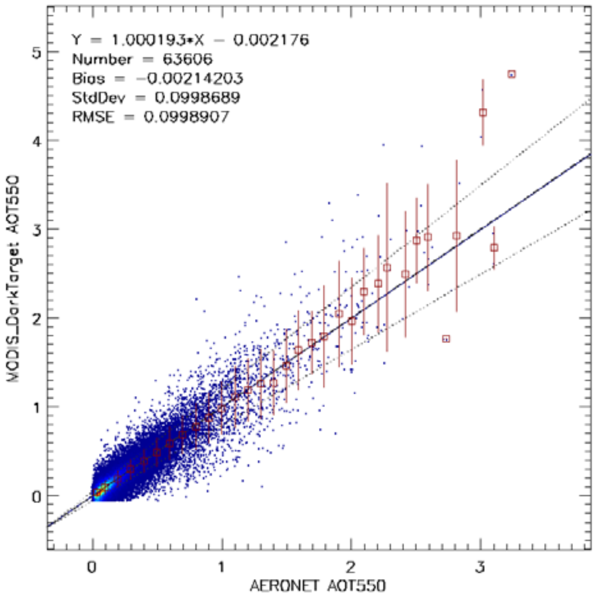
| Ocean | | NOAA-VIIRS | IDPS-VIIRS | Requirement |
|---|---|---|---|---|
| <0.3 | Accuracy | 0.03 | 0.03 | 0.08 |
| | Precision | 0.04 | 0.05 | 0.15 |
| | Number | 13,254 | 11,991 | |
| >=0.3 | Accuracy | 0.01 | 0.01 | 0.15 |
| | Precision | 0.13 | 0.14 | 0.35 |
| | Number | 1,315 | 1,301 | |
| All | Accuracy | 0.025 | 0.024 | |
| | Precision | 0.058 | 0.061 | |
| | Number | 14,569 | 13,292 | |

# Evaluation with MODIS Data

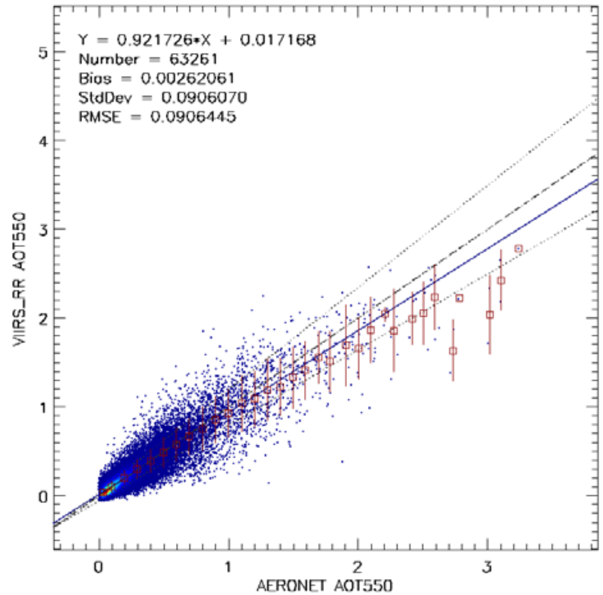
- Comparing different algorithms with same inputs
- VIIRS algorithms (IDPS and Risk-Reduction) are adapted to MODIS (Aqua) reflectance data available from Collection-6 Level-2 aerosol products
  - Create lookup tables with MODIS spectral response functions
  - Revise band-dependent coefficients
  - Derive spectral relationship of surface reflectance
- Match up with AERONET Level-2 measurements
  - MODIS 10km pixels within 50x50km domain
  - One-hour time window for ground measurements
  - Jul. 2002 – Dec. 2013

# Validation over Land

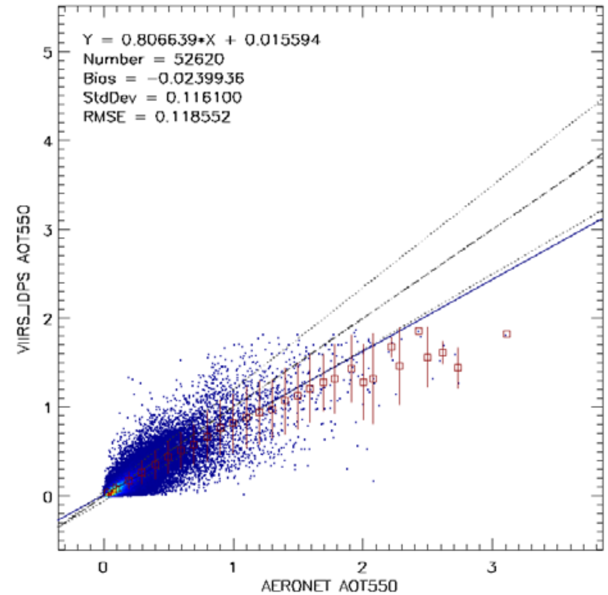
**MODIS**




**NOAA VIIRS**



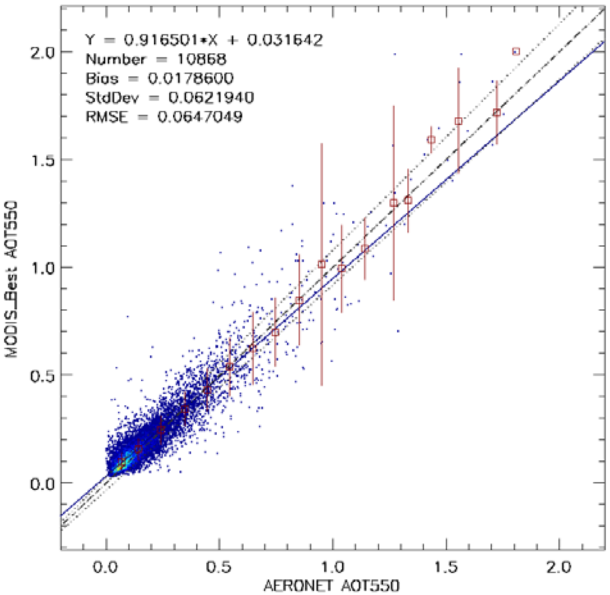

**IDPS VIIRS**



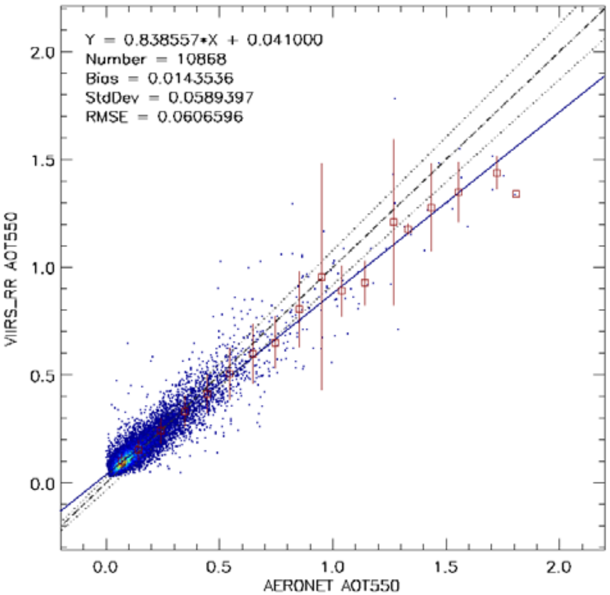

| Statistics | MODIS | NOAA-VIIRS | IDPS-VIIRS |
|---|---|---|---|
| Accuracy | -0.002 | 0.003 | -0.024 |
| Precision | 0.100 | 0.091 | 0.116 |
| #Match-ups | 63,606 | 63,261 | 52,620 |
| Correlation | 0.901 | 0.907 | 0.842 |
| %inUncRange | 70.83 | 79.28 | 72.78 |

# Validation over Ocean

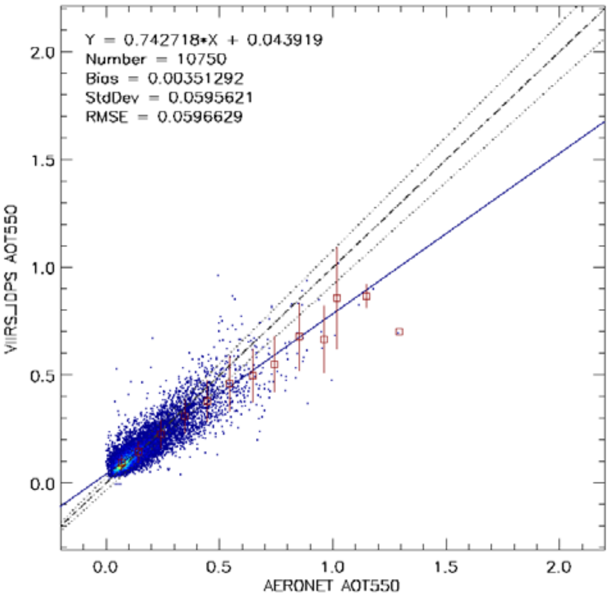
**MODIS**




**NOAA VIIRS**




**IDPS VIIRS**




| Statistics | MODIS | NOAA-VIIRS | IDPS-VIIRS |
|---|---|---|---|
| Accuracy | 0.018 | 0.014 | 0.004 |
| Precision | 0.062 | 0.059 | 0.060 |
| #Match-ups | 10,868 | 10,868 | 10,750 |
| Correlation | 0.916 | 0.922 | 0.878 |
| %inUncRange | 60.49 | 60.83 | 61.16 |

# Summary

- JPSS Risk Reduction Aerosol Algorithm was developed.
  - Single algorithm applied to both VIIRS and ABI
  - More functionalities with less number of line of code than the IDPS algorithm (~3500 vs. ~5600)
  - Wider spatial coverage than IDPS
  - More retrievals over significant aerosol events
  - Wider AOT range [-0.05, 5.0]
- Evaluation with AERONET shows better performance than IDPS over land.
- Evaluation with MODIS data shows comparable performance.

# JPSS Risk Reduction Suspended-mater Algorithm

Pubu Ciren[1] and Shobha Kondragunta[2]

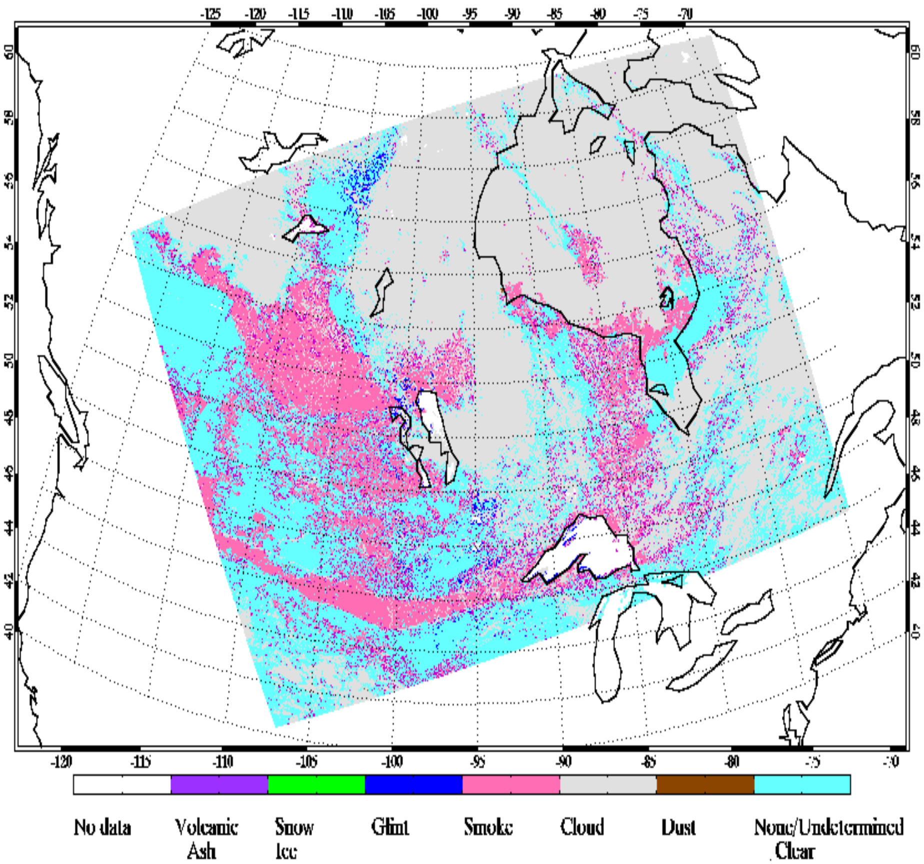
[1]IMSG@NOAA [2]NOAA/NESDIS/STAR

JPSS Annual Science meeting 2015
August 27, 2015

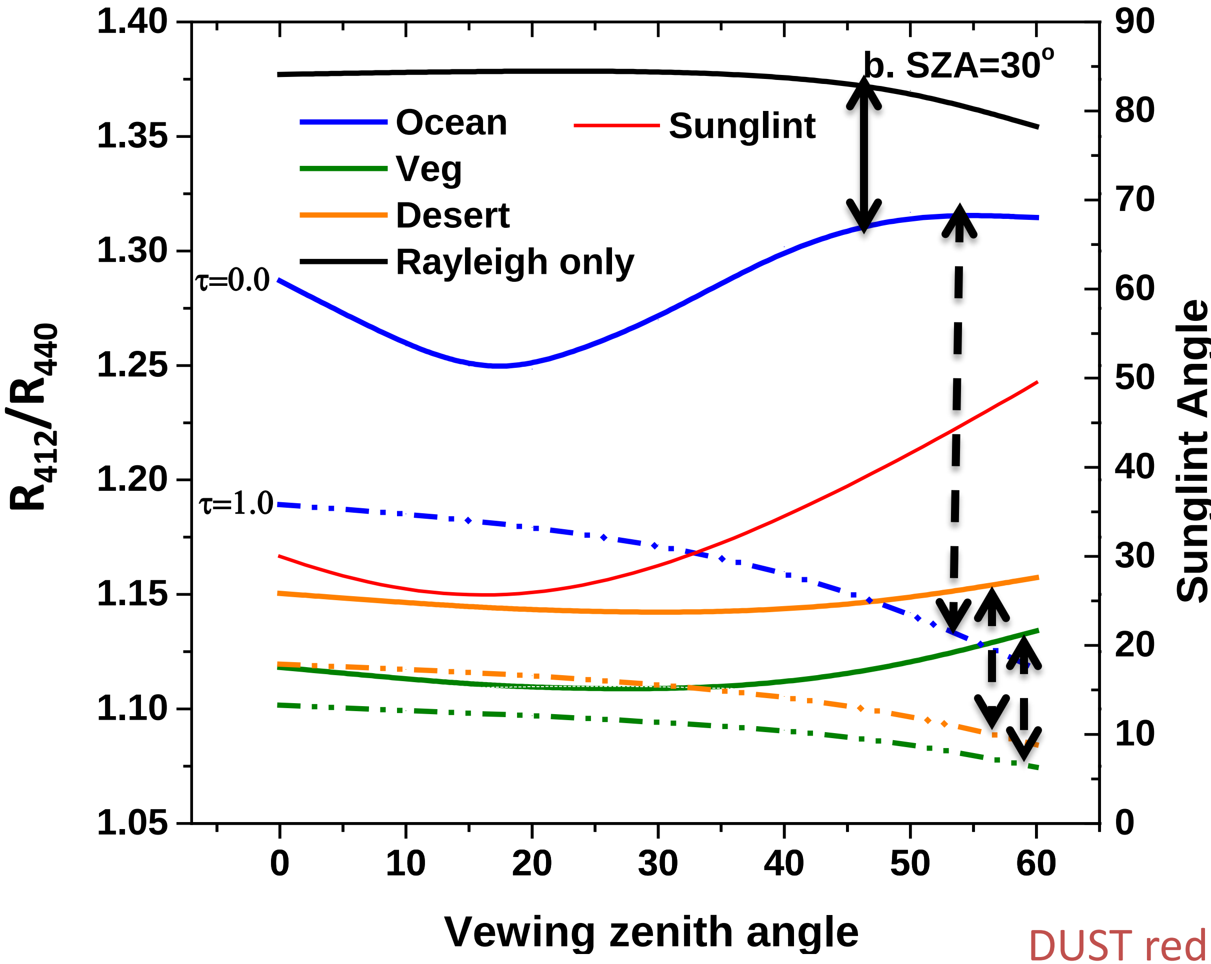
# JPSS Risk Reduction SM Product

**Output for each pixel( about 750m at nadir)**:

1. **SM type flags**: (1-presence;0-Absence)
   - ***Volcanic ash flag***
     ***passed on from Cloud mask***
   - ***Dust flag***
   - ***Smoke flag***
   - ***Others (none/unknown/clear)***
   - ***Cloud flag***
   - ***Snow/ice flag***
2. **Dust/smoke aerosol index values**
3. **quality flags (00/01/11)**
   low, medium and high quality for SM type



# 6S Radiative Transfer Simulations

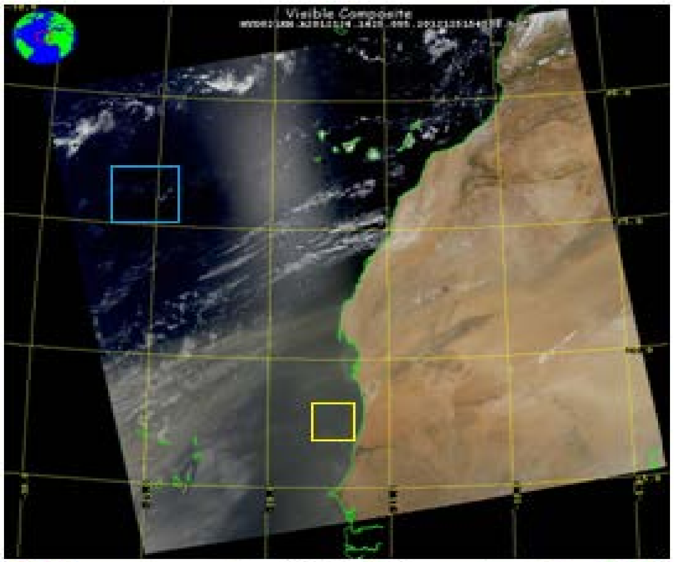



6S Simulations:

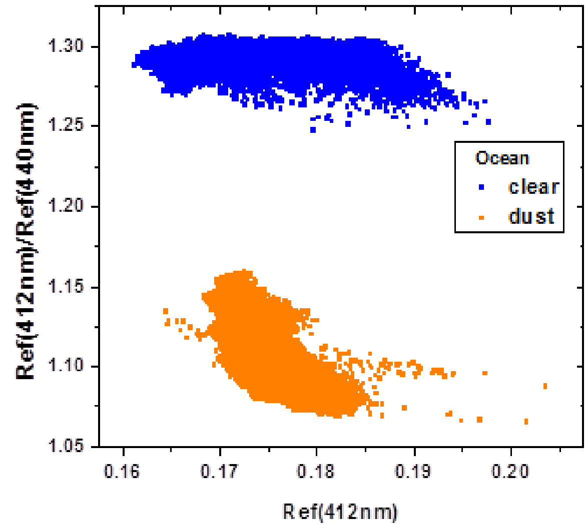
1. MODIS C5 dust aerosol model used
2. Desert, vegetation, ocean BRDF with easterly wind speed of 6 m/s are used to represent surfaces in 6S

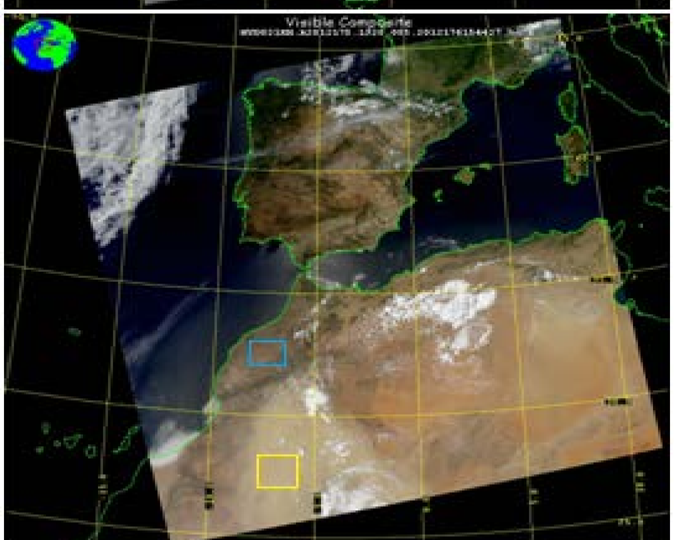
DUST reduces the contrast between 412nm and 440 nm as absorption by dust increases with decreasing wavelength.

# MODIS Observations: Dust vs. Clear Sky

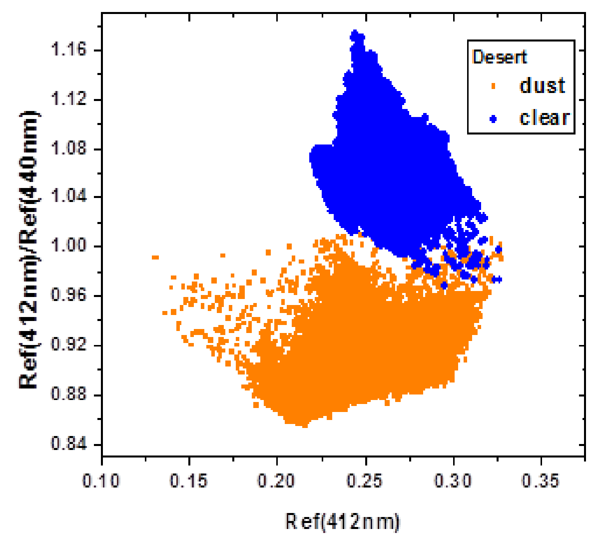



Over water

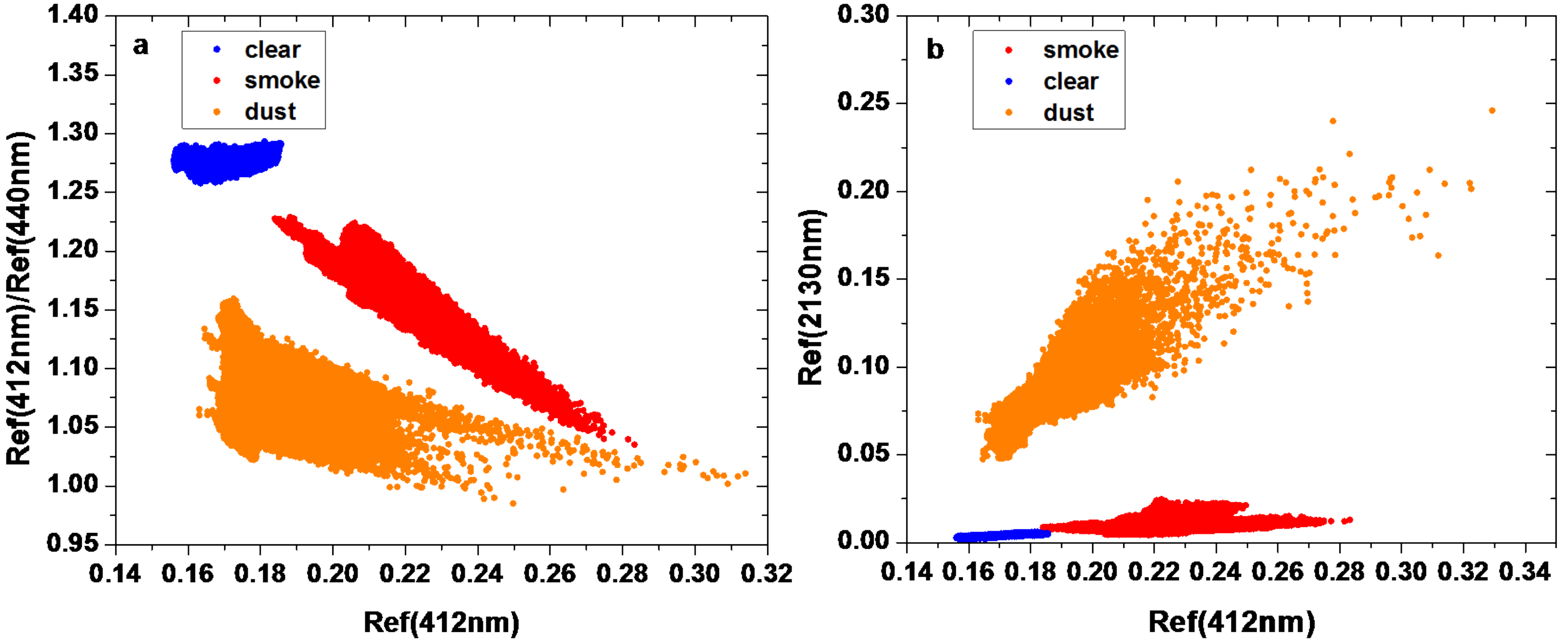



Over land



# Smoke and dust vs. Clear Sky




Smoke:

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

# Dust Aerosol Index (DAI)

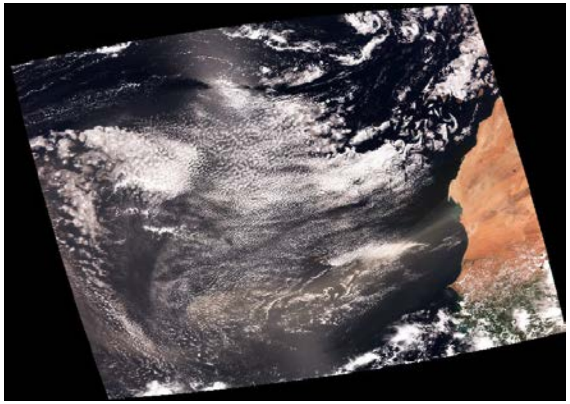
$$DAI = -100*[\log_{10}(R_{412nm}/R_{445nm}) - \log10(R'_{412nm}/R'_{445nm})]$$
$$NDAI = -10*[\log_{10}(R_{412nm}/R_{2250nm})]$$

$R'$ -- reflectance from Rayleigh scattering

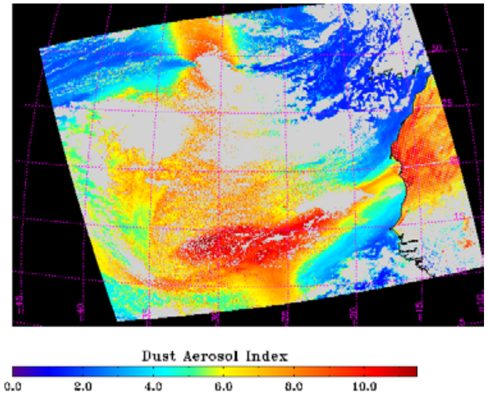
**Detection will not be performed for the following conditions:**

- **Clouds**
  - screened by using $R_{412nm}$ and cloud mask
- **Residual Clouds**
  - over water:
    screened by using 860nm spatial variability test.
  - Over land:
    screened by 412nm spatial variability test.
- **Bright surfaces**
  screened by using bright pixel index (normalized difference of 1.24 μm and 2.25 μm).
- **Turbid water**
  Screened with test based on Shi and Wang(2007) uses 746 nm and 1.24 μm measurements.
- **Sunglint (for dust only), snow/ice, fire hot spots**
  screened based on different tests (geometry, spectral etc.)

# JPSS SM Dust Detection



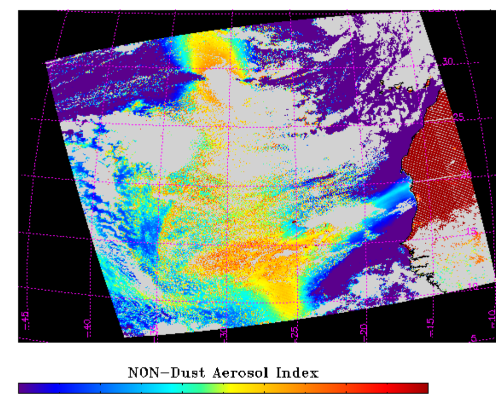
DAI after cloud screening



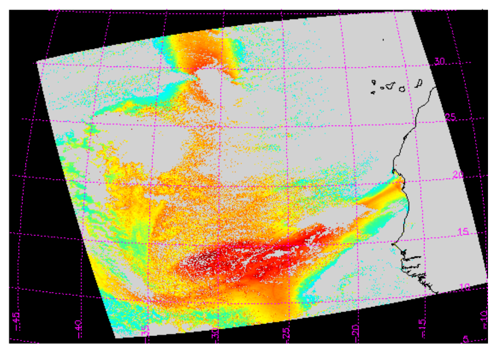

Dust is detected If DAI and NDAI pass these tests:

- **Water**: DAI ≥ 4 and NDAI ≥ -10
- **Land**: DAI ≥ 11.5 and NDAI ≥ 0

NDAI after cloud screening

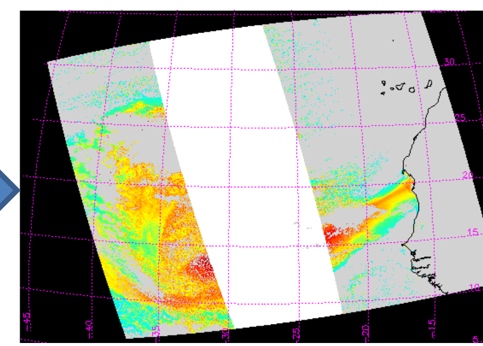



Dust flag



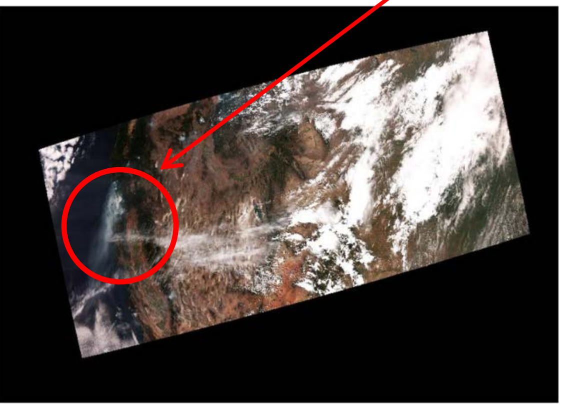
Sunglint flag

Final dust flag

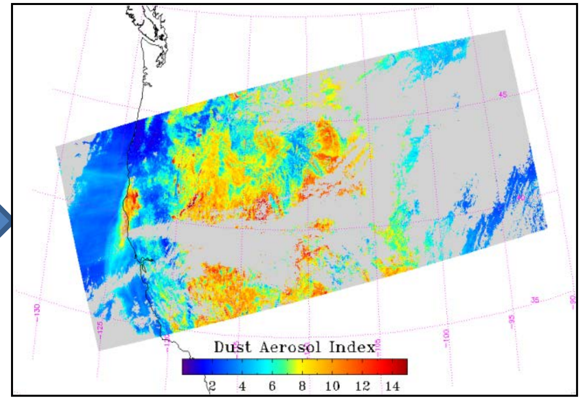


# JPSS SM Smoke Detection

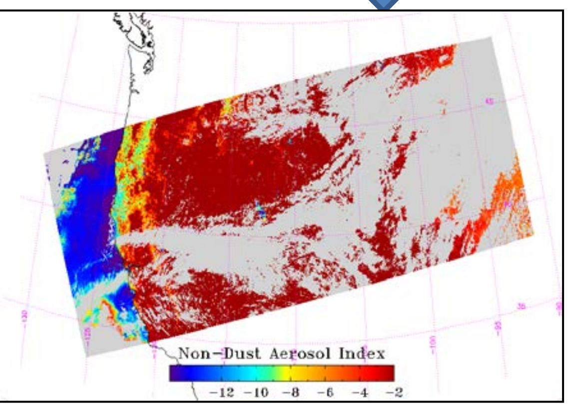
smoke



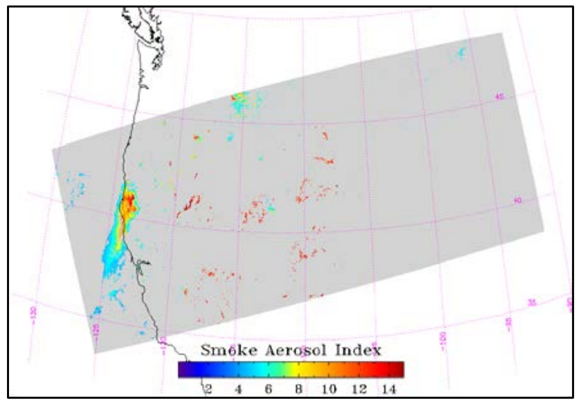
DAI after cloud screening




NDAI after cloud screening




Smoke flag




**Smoke is detected If DAI and NDAI pass these tests:**

– **Water:**

**thin smoke:**

**DAI ≥ 4.0 and NDAI ≤ -10.0 and $R_{410}$ < 0.1**

**thick smoke:**

**DAI ≥ 9.0 and NDAI ≤ -4.0**

– **Land:**

**thin smoke**

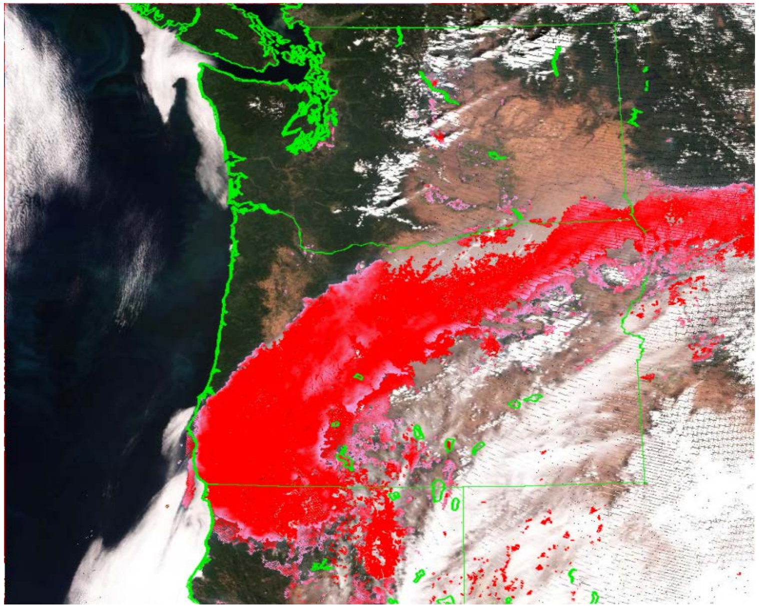
**DAI ≥ 5.0 and NDAI ≤ -2.0**

**thick smoke:**

**DAI ≥ 9.0 and NDAI ≤ -2.0 and 0.2<$R_{410}$ < 0.4**

# Dust and Smoke Detection Examples

Smoke plume shown in the VIIRS RGB image on August 3, 2014 Over west coast of U.S.

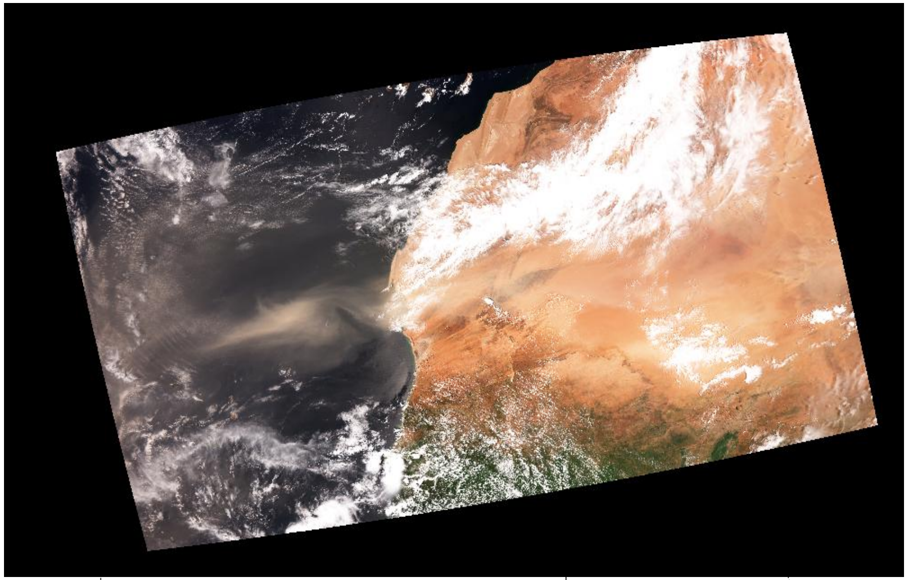


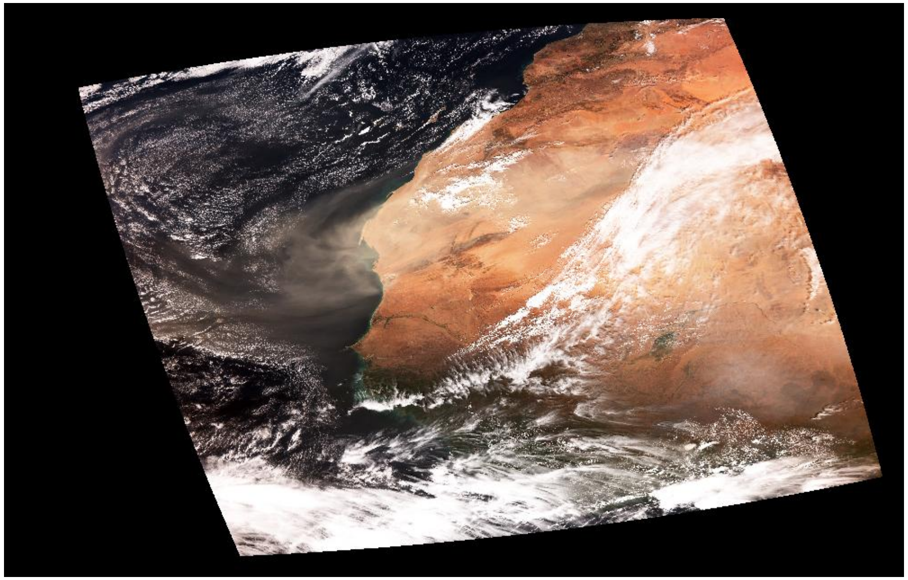
VIIRS smoke detection algorithm identifies the smoke plumes including the one removed from fire hot spots

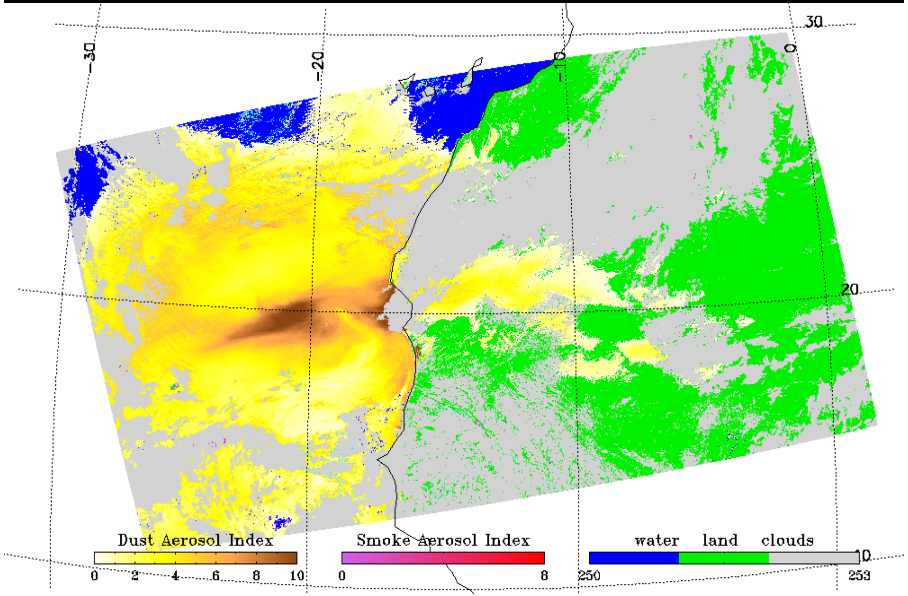
# Sahara dust outbreaks

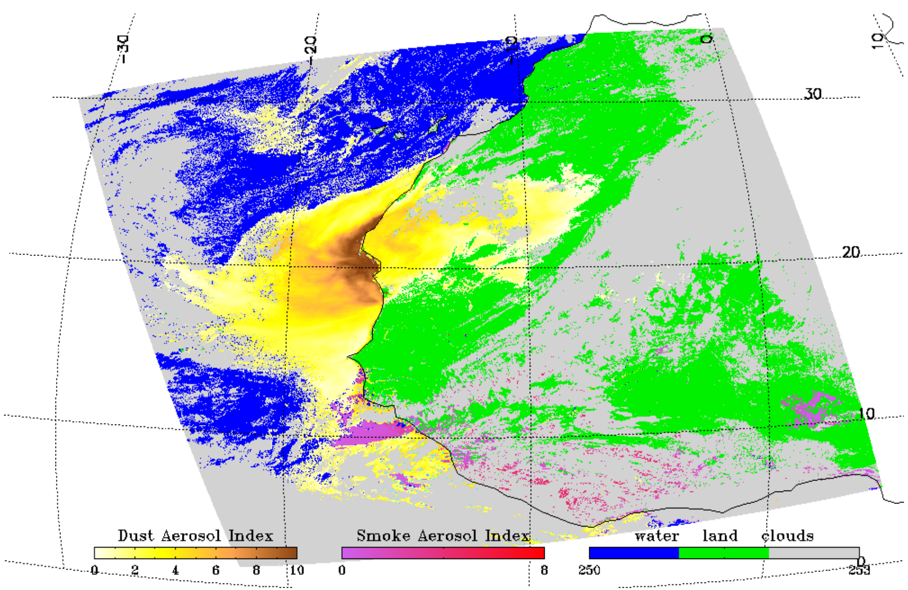
September 14, 2013

December 14, 2013



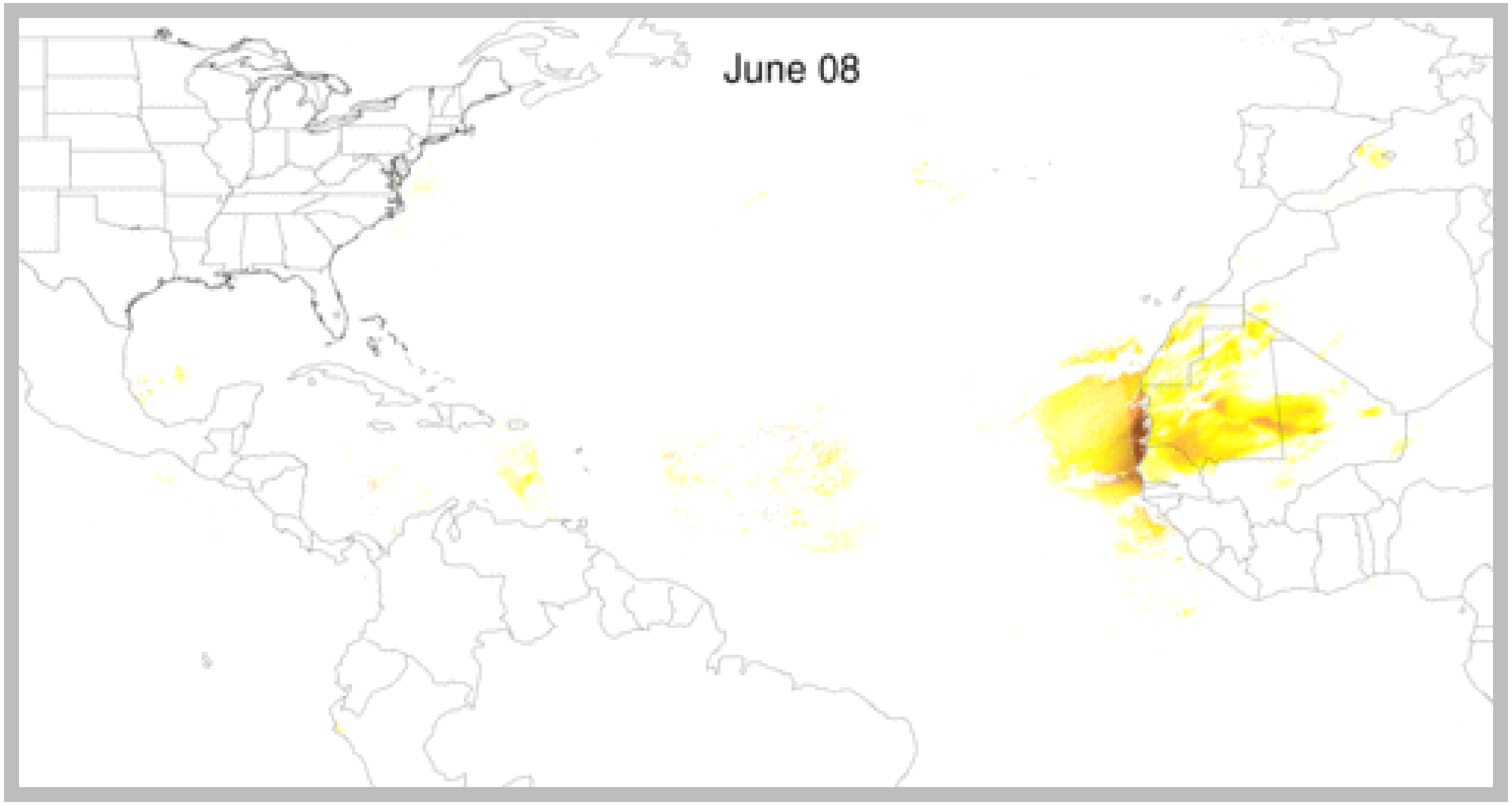




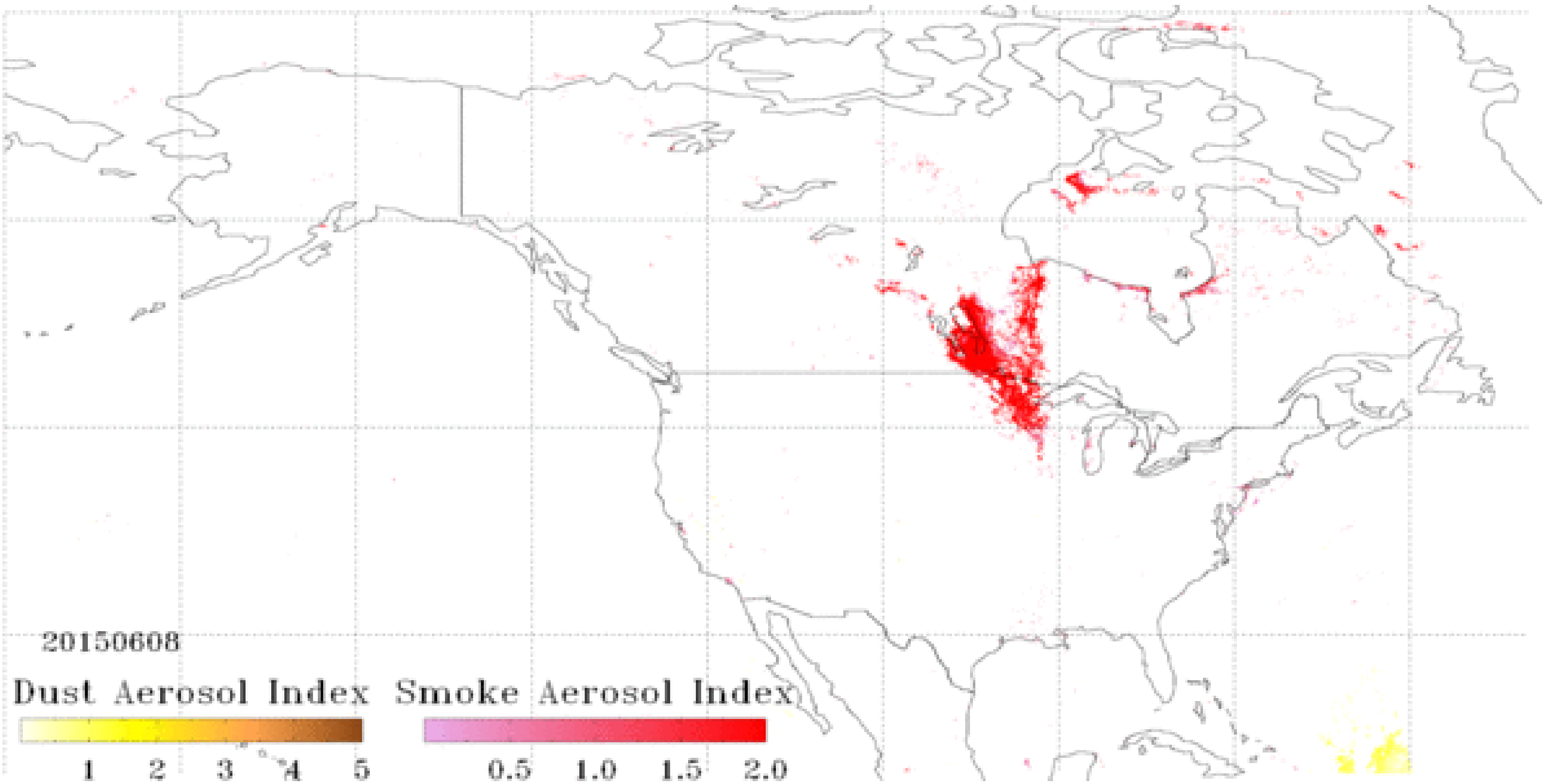
# Transatlantic dust transport

**Year of 2014**



# Smoke outbreak over U.S.

## 06/08 to 07/15/2015



# Validation Strategy

- Dust/smoke detection algorithm run on VIIRS data for the entire year of 2013 and 2014.
  - VIIRS smoke/dust detection matchup with AERONET Observations
  - VIIRS smoke and dust detection matchups with CALIPSO VFM
- Derive performance metrics
  - Accuracy
  - Probability of Correct Detection (POCD)
  - Probability of False Detection (POFD)

**TRUTH DATA**

| VIIRS | Yes | No |
|---|---|---|
| Yes | A | B |
| No | C | D |

**POCD = A/(A+C)**
**POFD = B/(A+B)**
**Accuracy* = (A+D)/(A+B+C+D)**

# VIIRS vs. CALIPSO

**Year of 2013 and 2014**

## Land

| Type | True positive | False positive | True negative | False Negative | Accuracy (%) | POCD (%) | FAR (%) |
|---|---|---|---|---|---|---|---|
| **DUST** | 10669 | 170 | 5676 | 2840 | 84.4 | 80.0 | 1.6 |
| **SMOKE** | 307 | 159 | 19534 | 14 | 99.1 | 96.7 | 34.1 |

## Water

| Type | True positive | False positive | True negative | False negative | Accuracy (%) | POCD (%) | FAR (%) |
|---|---|---|---|---|---|---|---|
| **DUST** | 297 | 11 | 139 | 10 | 95.4 | 96.4 | 3.3 |
| **SMOKE** | 601 | 507 | 7605 | 15 | 94.0 | 97.5 | 45.7 |

# VIIRS vs. AERONET (DUST)

| Stations | | True positive | False positive | True negative | False negative | Accuracy | POCD | POFD |
|---|---|---|---|---|---|---|---|---|
| Darkar | 2013 | 63 | 1 | 106 | 10 | 93.9 | 86.3 | 0.2 |
| | 2014 | 74 | 3 | 45 | 10 | 90.1 | 88.1 | 0.4 |
| Solar_Village | 2013 | 81 | 26 | 59 | 30 | 71.4 | 73.0 | 24.3 |
| | 2014 | 11 | 4 | 65 | 5 | 89.4 | 68.8 | 26.7 |
| Capo_Verde | 2013 | 44 | 0 | 56 | 3 | 97.1 | 93.6 | 0.0 |
| | 2014 | 53 | 1 | 17 | 1 | 97.2 | 98.1 | 0.2 |

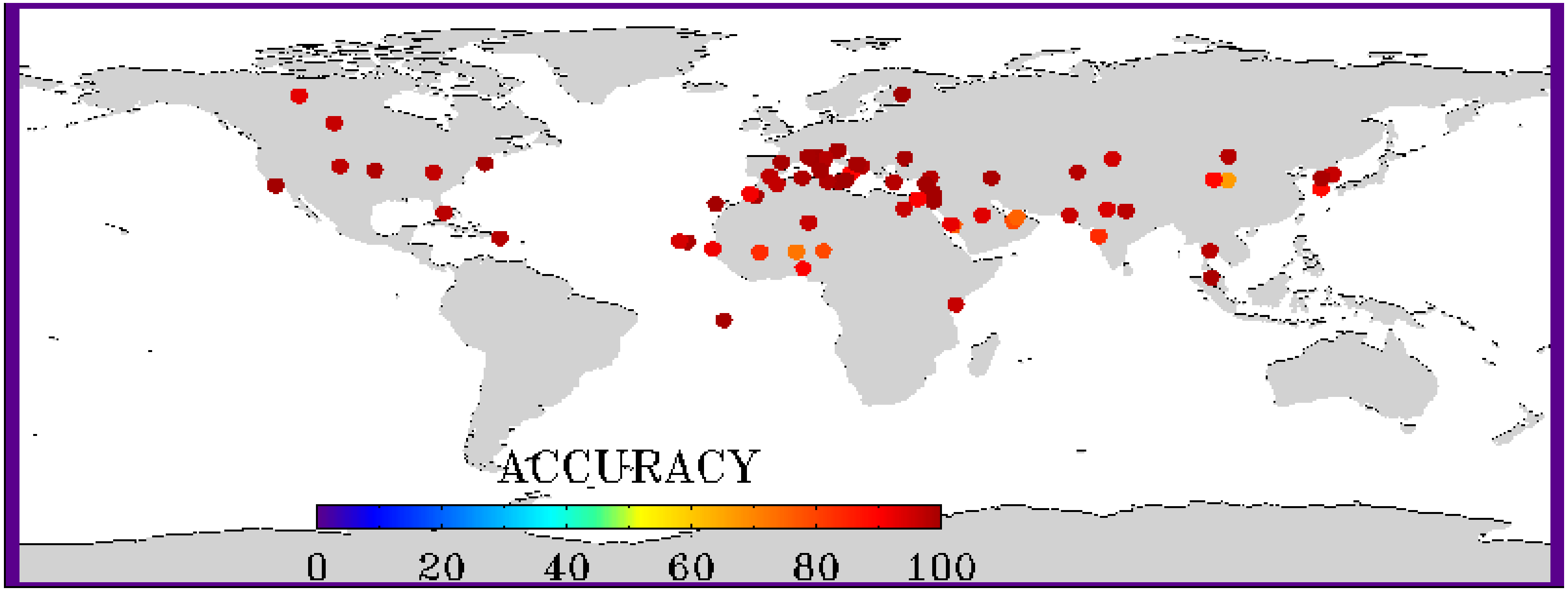
| Over 440 AERONET stations | Accuracy | POCD | POFD |
|---|---|---|---|
| Year of 2013 and 2014 | 98.5 | 84.6 | 14.7 |

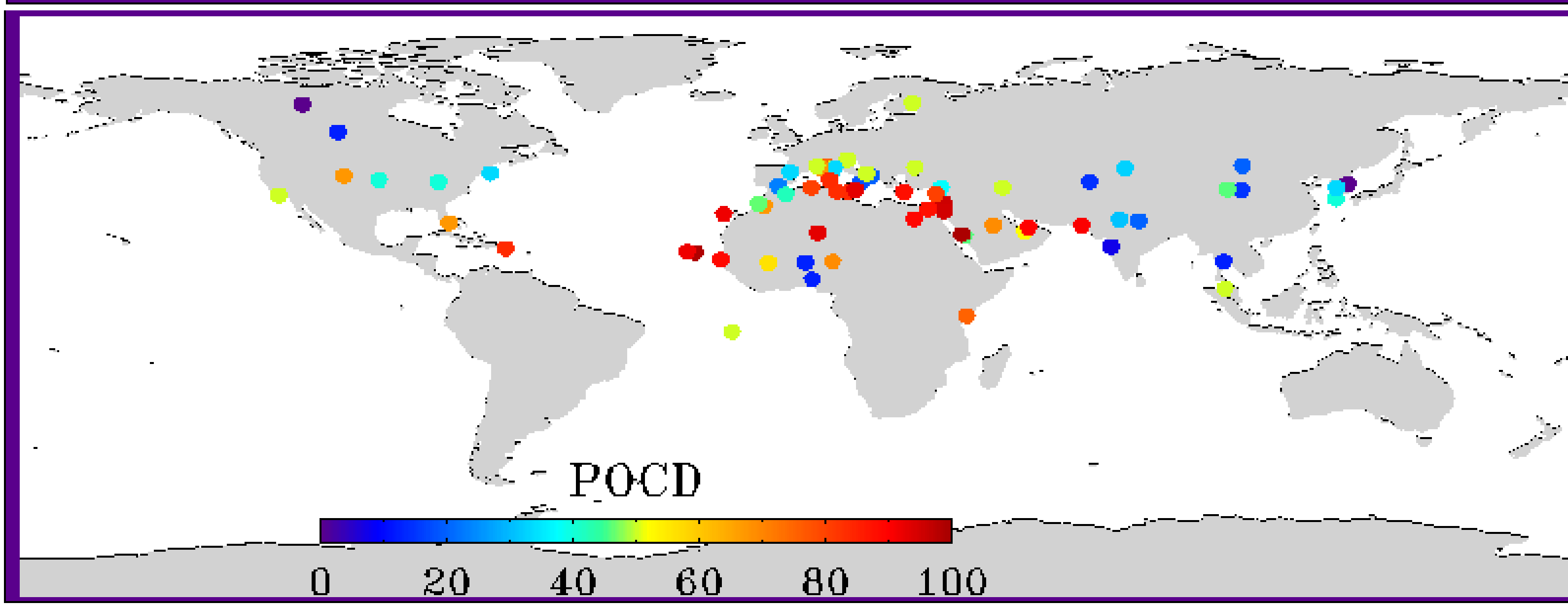
# VIIRS vs. AERONET (Smoke)

| Stations (Biomass – burning) | True positive | False positive | True negative | False negative | Accuracy | POCD | POFD |
|---|---|---|---|---|---|---|---|
| Alta_Floresta | 10 | 0 | 178 | 0 | 100.0 | 100.0 | 0.0 |
| Bonanza_Creek | 1 | 0 | 48 | 0 | 100.0 | 100 | 0.0 |
| Jabiru | 1 | 0 | 313 | 0 | 100.0 | 100.0 | 0.0 |
| Moscow_MSU_ MO | 16 | 2 | 92 | 1 | 97.2 | 94.1 | 11.0 |
| Tomsk_22 | 17 | 1 | 83 | 0 | 99.0 | 100.0 | 5.0 |
| Yakutsk | 22 | 1 | 88 | 1 | 98.2 | 95.6 | 4.3 |

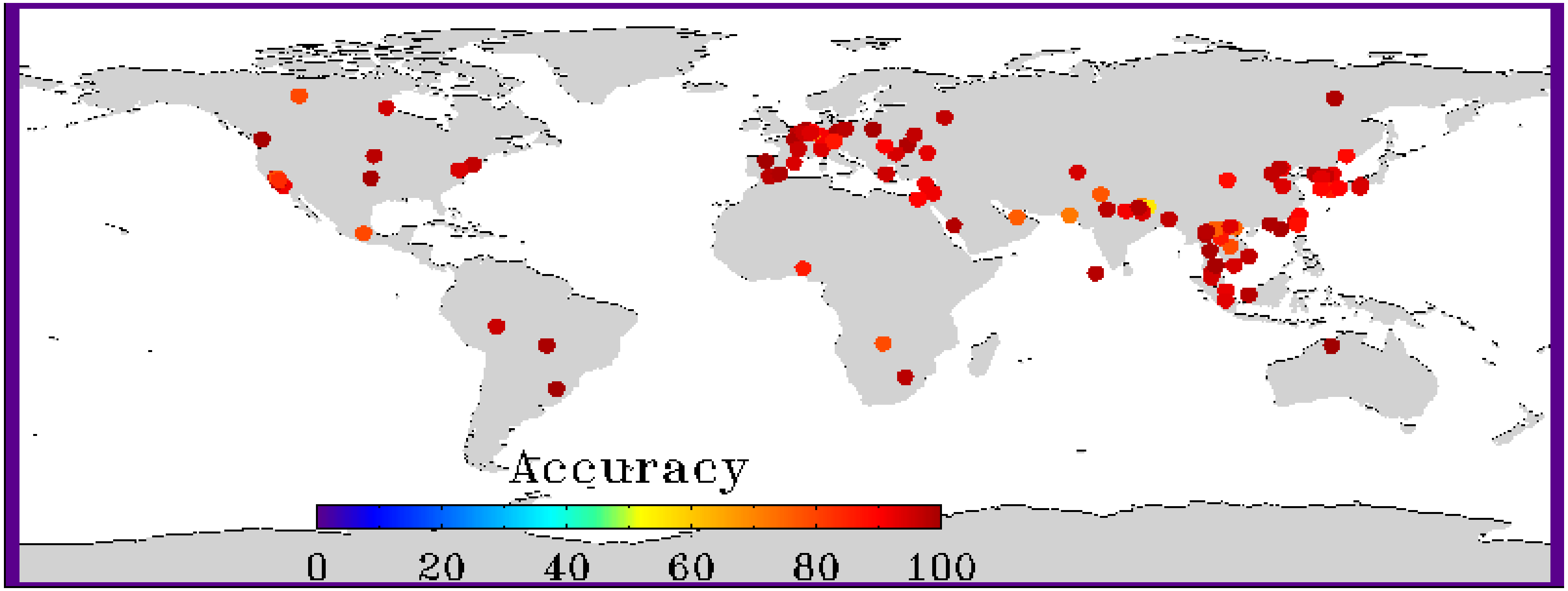
| Over 401 AERONET stations | Accuracy | POCD | POFD |
|---|---|---|---|
| Year of 2013 and 2014 | 97.5 | 91.6 | 18.5 |

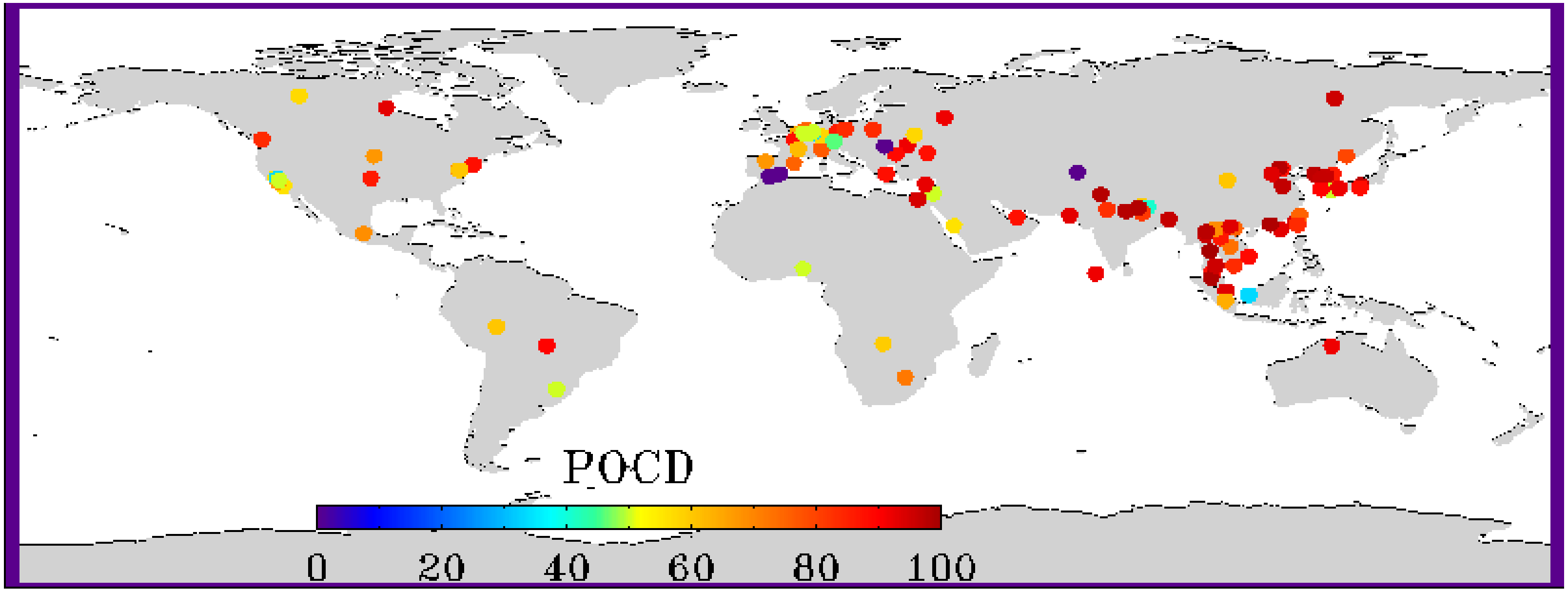
# VIIRS vs. AERONET (dust)



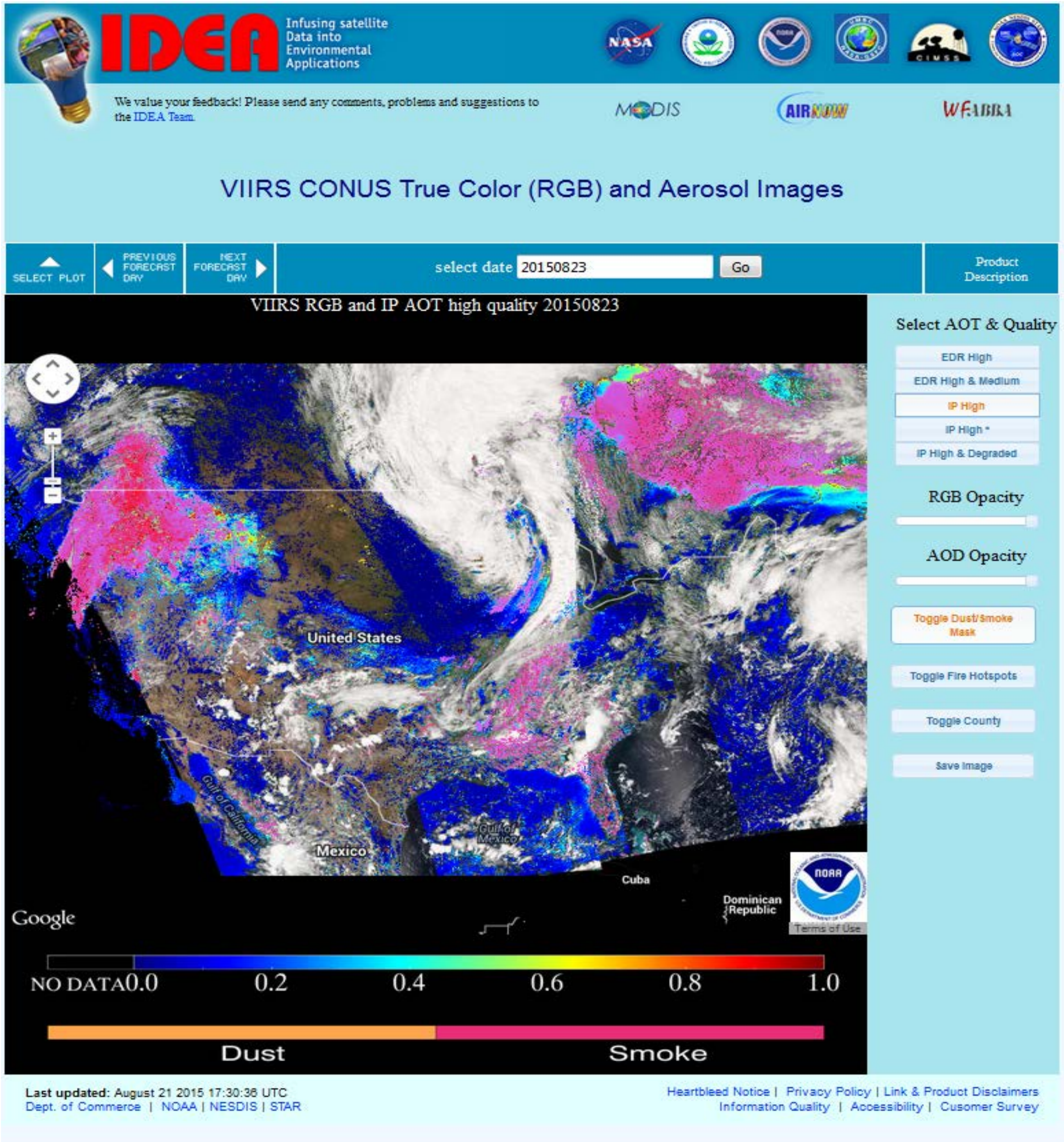
# VIIRS vs. AERONET (smoke)



# Near-real time run of JPSS SM algorithm on S-NPP VIIRS DB data

1. JPSS RR SM algorithm has been Implemented by using near-real time S-NPP VIIRS DB data over both CONUS and OCONUS
2. It provides daily monitoring of smoke/dust event OVER CONUS and Alaska



# Summary

- JPSS RR Suspended Matter algorithm is simple, fast, and easy to be implemented operationally.
- Validation results indicated that Accuracy and POCD for dust and smoke detection can be as high as 90% and 80 %, respectively.
- Additional investigation of data artifacts (false detections) is required to enhance product accuracy.

# Assimilation of aerosol optical depth data from NPP VIIRS in a global aerosol model


Edward J. Hyer[1]

Peng Lynch[2]

Min Oo[3]

Yingxi Shi[4]

Ted McHardy[4]

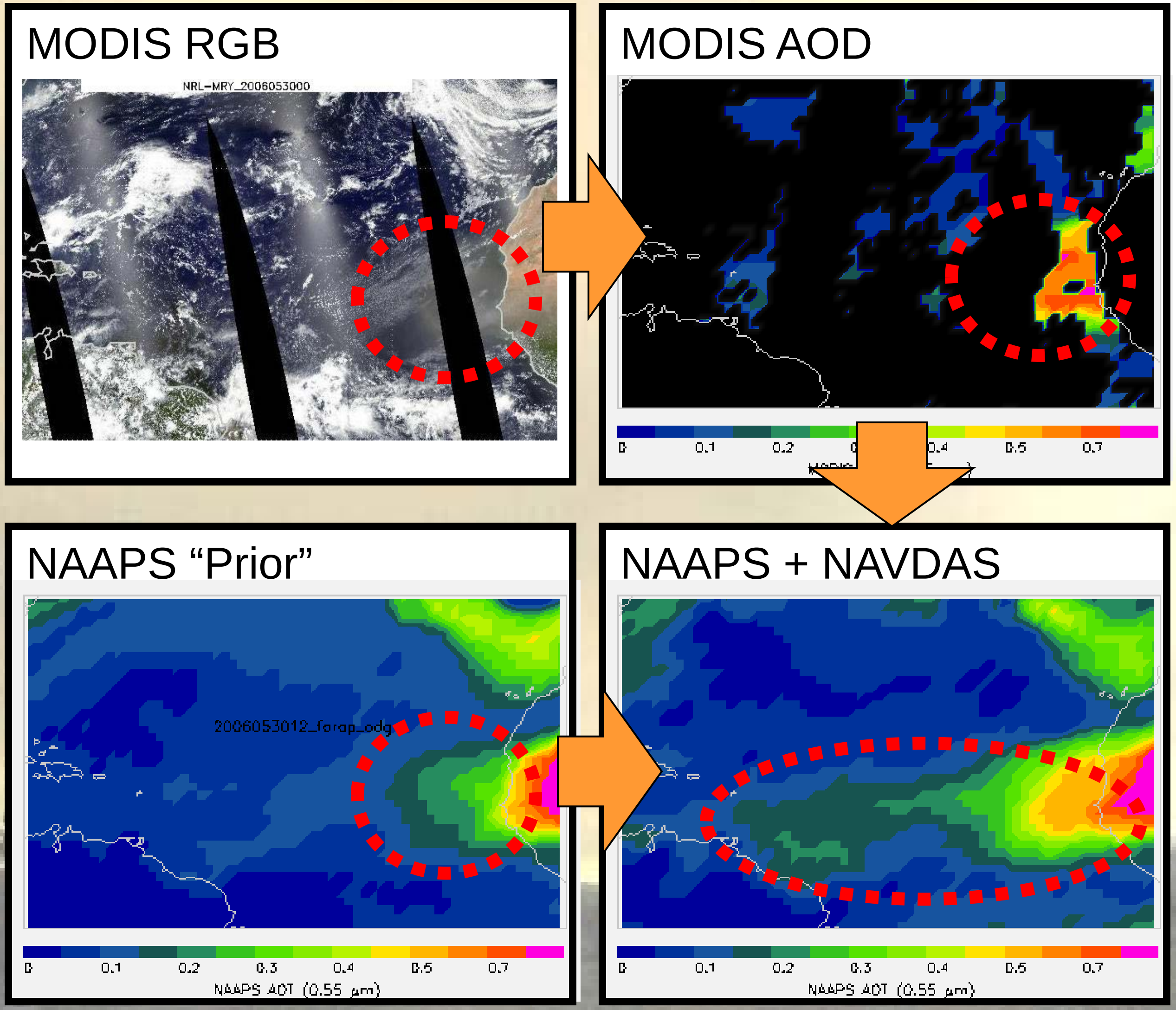
Jianglong Zhang[4]

1. NRL, Monterey, CA
2. Computer Science Corporation
3. University of Wisconsin CIMSS
4. University of North Dakota

# In This Talk

- Data Requirements for Aerosol Assimilation
- Preparation of NPP VIIRS products for assimilation
- Assimilation Results
- Conclusions / Prospects

# Navy Global Aerosol Forecasting



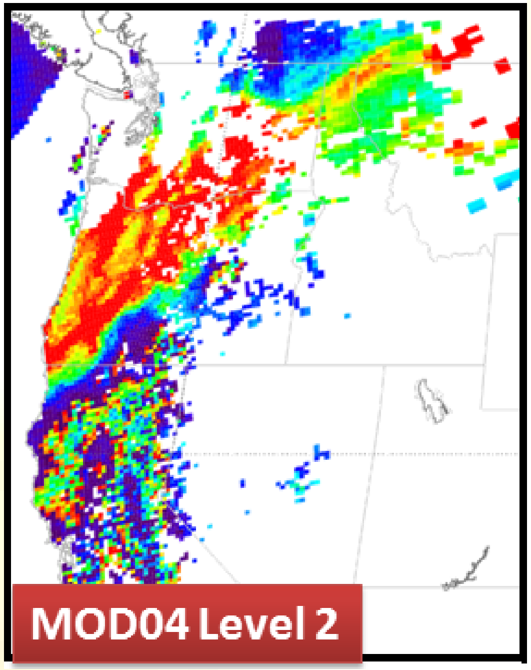

- **Navy Aerosol Analysis and Prediction System (NAAPS) operational since 2005**
- **Navy Variational Data Assimilation System for AOD (NAVDAS-AOD) Operational at FNMOC from September 2009 (MODIS over ocean)**
- **Global MODIS is assimilated operationally as of February 2012**
- **J.L. Zhang et al., "A System for Operational Aerosol Optical Depth Data Assimilation over Global Oceans", JGR 2008.**

# Why Does Assimilation-Grade AOD Matter?

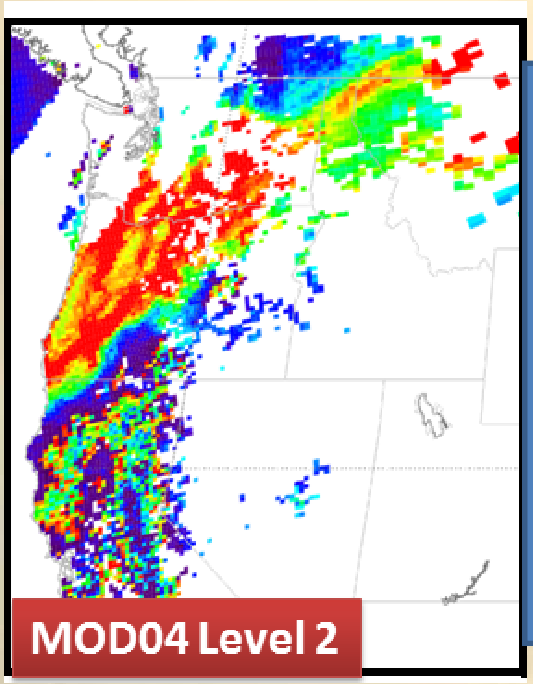
- Aerosol analysis and forecasting requires AOD for assimilation
- Assimilation has specific requirements
  - Minimize outliers
  - Correct persistent bias
  - Quantify residual uncertainty
- Level 2 AOD products are not good enough
  - Correlated bias
  - Limited error characterization

# Preparation of Satellite Data for Assimilation


**Level 2 MOD04 (NASA) or VAOOO EDR (JPSS) data is generated by upstream data centers – spatial resolutions of a few km**



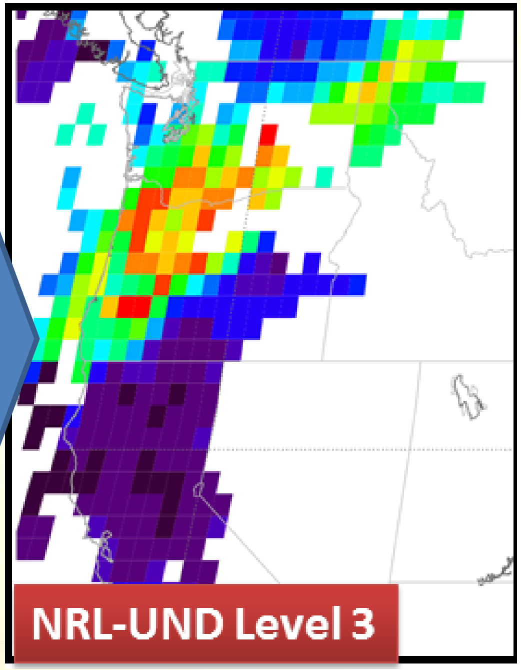
# Preparation of Satellite Data for Assimilation




AOD data process developed by NRL and UND, includes

- Aggressive cloud filtering
- Ocean wind speed correction
- Land albedo correction
- land surface and snow filters
- Microphysical AOD bias correction

0.5 degree product distributed to public via NASA LANCE (MxDAODHD)




- Developed by NRL/UND for MODIS Collection 4&5
- 0.5 degree product distributed to public via NASA LANCE (MxDAODHD)

# NRL's process for QA/QC of new satellite AOD products: 5 stages

**Starting with a multi-month record of L2 data…**

1. L2/L2 comparison to AERONET at full resolution
2. L2/L2 comparison to MODIS

**Generation of candidate L3 AOD…**

3. L3/L3 comparison to currently assimilated datasets

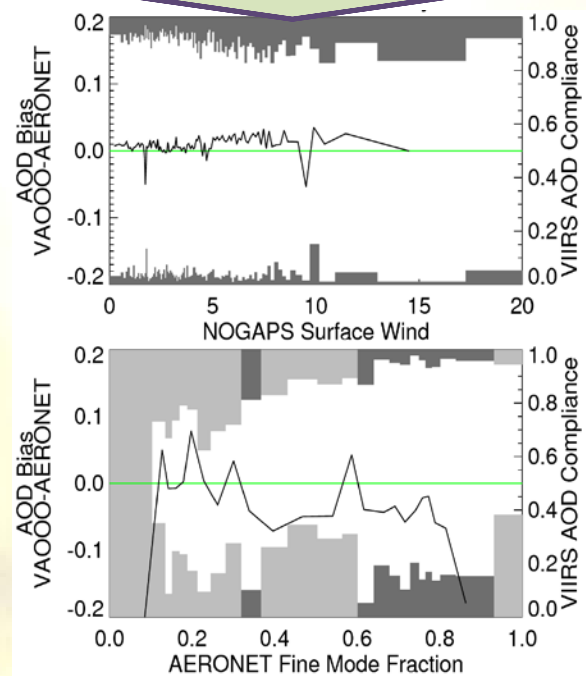
**Test runs of NAAPS+NAVDAS-AOD using new data…**

4. Model/Model comparison of analyzed aerosol fields using different AOD inputs
5. Model/AERONET comparison and model verification

# Stage 1: L2 comparison to AERONET

- Utility:
  - Diagnosis of retrieval behavior
  - Understanding sources of retrieval uncertainty

Stable performance over a wide range of wind speed.




High bias for coarse particles

- Plots are based on VIIRS aerosol products from IDPS (only QA='High') and AERONET Level 1.5 for February 2013-November 2014. Solid lines show the mean AOD bias in each bin; gray bars indicate the fraction of retrievals falling outside of an expected error of $0.05+0.2\tau_{AERONET.}$
- (Top) VIIRS EDR shows a small trend of increasing AOD bias with wind speed, with increasing positive errors at high winds.
- (Bottom) Comparison of VIIRS bias as a function of AERONET fire mode fraction (only pairs with tA>0.4 were used) indicates that the VIIRS EDR has better performance retrieving fine-mode aerosols. Extreme high and low values of fine mode fraction are generally in plumes near the source.
  - **NOTE: Negative errors for these plumes have significant representativeness error because of the disparity of scale between the satellite and AERONET**.

# Stage 2: L2/L2 comparison to MODIS

VAOOO-MYD04 matchup product from NASA Atmospheres PEATE at U. Wisconsin

- Produced for every overlapping swath
- Packaged as HDF
- Available from UW PEATE
- MODIS Collection 5 only
- Available for 201202-201405

Every MODIS-Aqua scene is checked to see if there is an overlapping VAOOO scene within 15 minutes

For each MYD04 10km Level 2 footprint in the scene, VAOOO footprints whose centers fall within the MYD04 footprint are selected

  – Even if MODIS does not retrieve AOD for that footprint, it is included in the matched product

- Matched product includes all MYD04_L2 SDS
- For VAOOO, product includes:
  - AOT/EPSP for:
    - Mean, all QA
    - Mean, QA = Moderate+|High
    - Nearest EDR retrieval
      - all QA|Moderate|High QA

**Questions to address with these data**

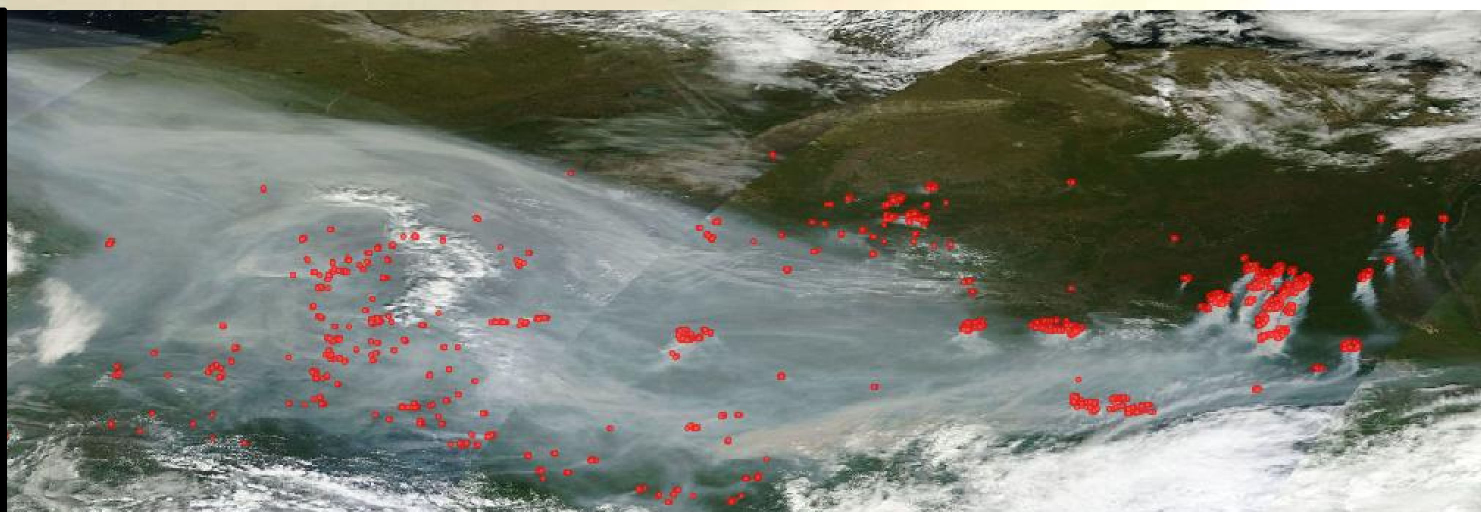
- What is the relative behavior of the two retrievals?
- VIIRS product retrieves limited range of AOD vs MOD04
  - IVAOT retrieves 0 > AOD > 2
  - MOD04 retrieves -0.05 > AOD > 5
  - What is the impact of these limits on matchup data coverage?
  - What is the impact on 1:1 AOD comparisons?
- Is there any discernible cloud contamination bias in VIIRS
  - This would be on top of any MODIS C5 bias

# Stage 2 Case Study: Russia Summer 2013

- Russian fires summer 2013
- Bounding box = 50-70N, 75-125W
- 7/23 to 8/23/2013

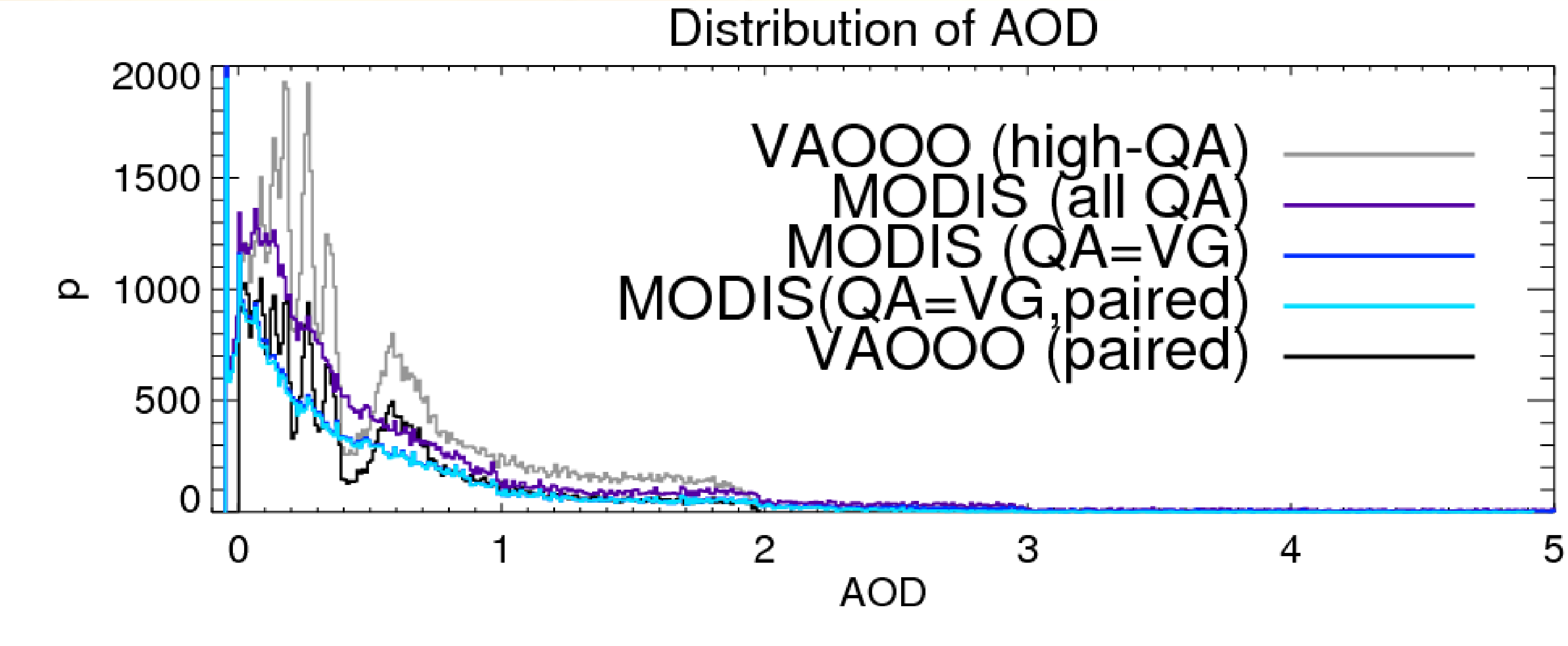
N=262,825 MODIS footprints

- 77521 valid MODIS (51197 QA=very good)
- 88061 valid VIIRS (QA=high [other QA levels not considered])
- MODIS QA values: 19% very good, 4% good, 3% marginal, 73% not retrieved
- **48,132** footprints with both MYD04 and VAOOO highest QA retrievals



NASA LANCE Worldview
MODIS Aqua 3 August 2013

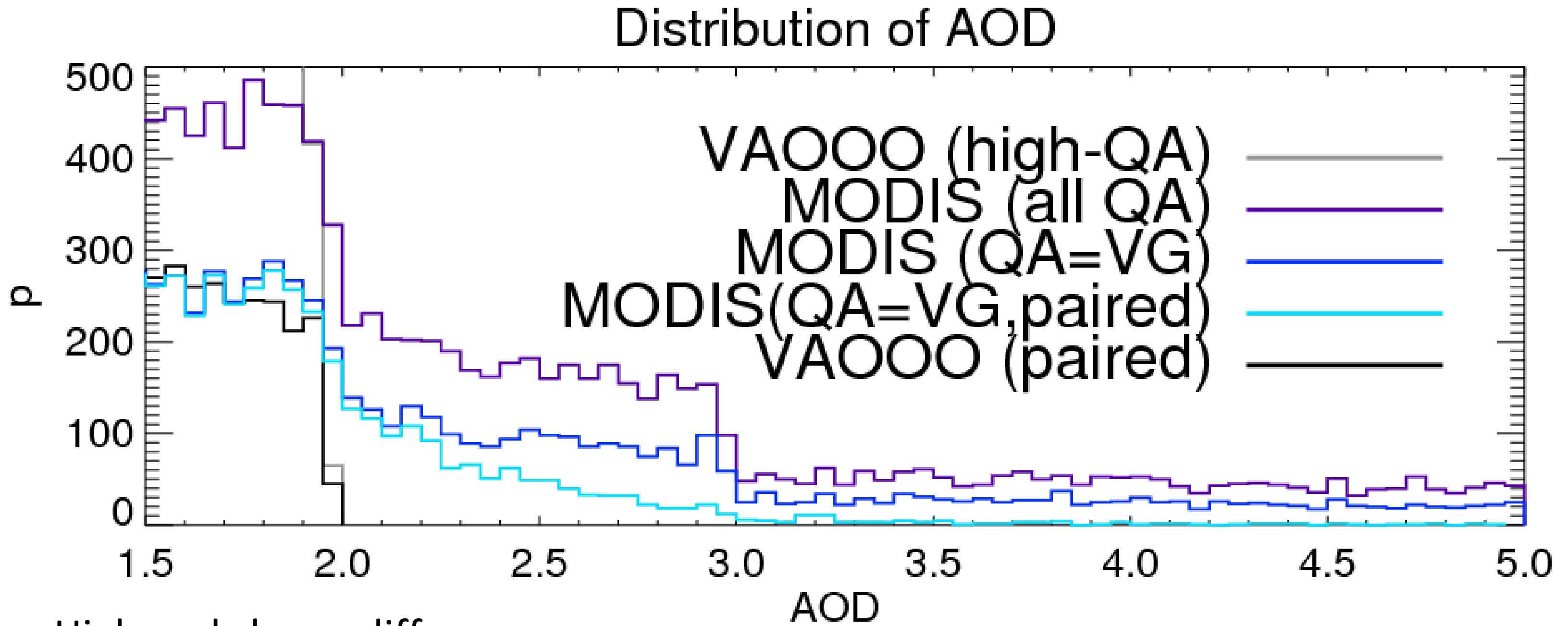
# Russia Case – AOD distributions




Giant Smoke Plume = very long tail

- VAOOO AOD distribution is far from smooth
- MODIS is smooth, close to lognormal
- MODIS range = -0.05 to 5.0 VIIRS range = 0.0 to 2.0
- Paired distributions look very different
    - VAOOO = black, MODIS = aqua

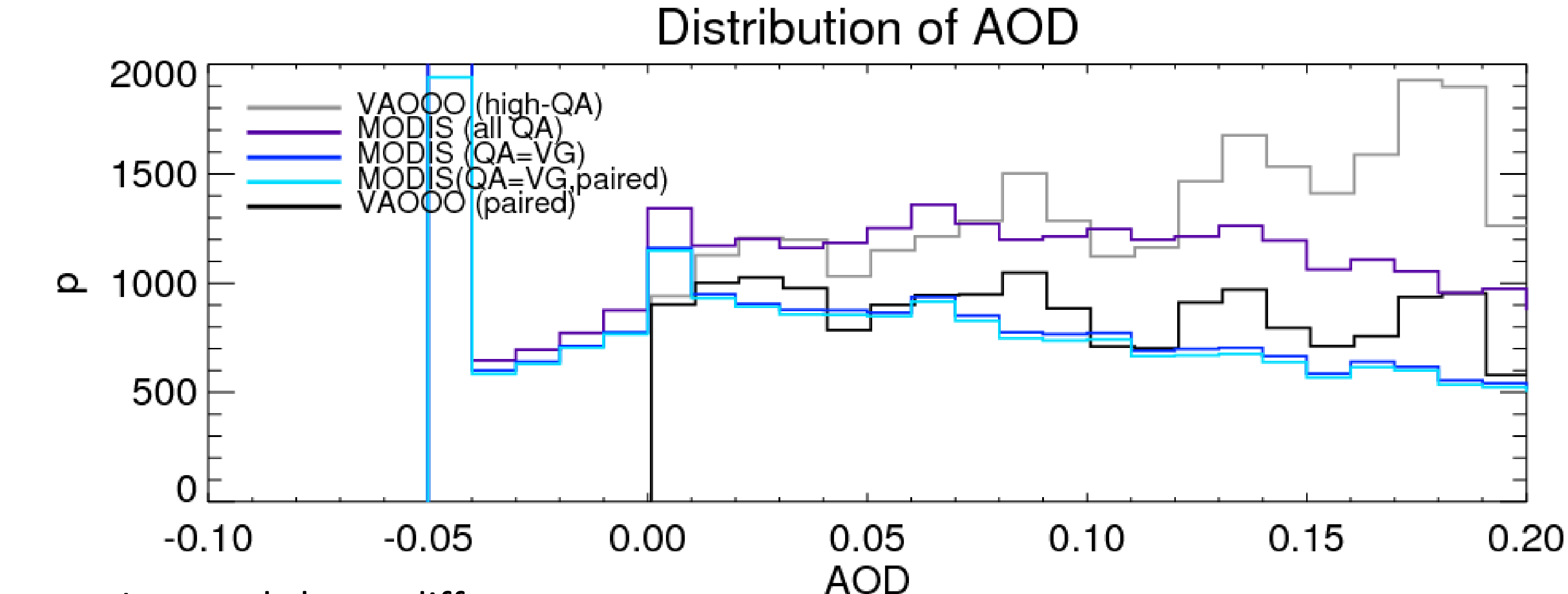
# Russia Case – AOD distributions




High end shows differences

- VAOOO cannot retrieve above AOD=2.0
  - QA=VG (blue) and paired (aqua) diverge above AOD=2.0
  - Consistent with positive AOD truncation in VAOOO

# Russia Case – AOD distributions

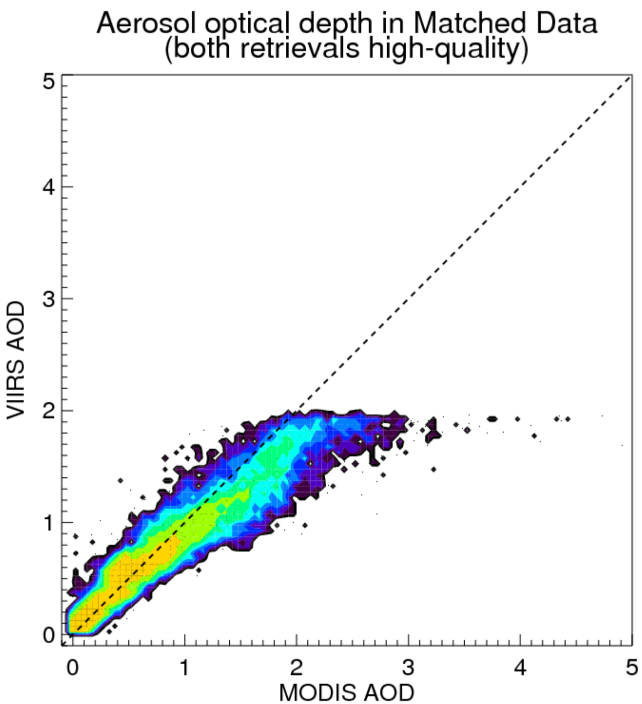


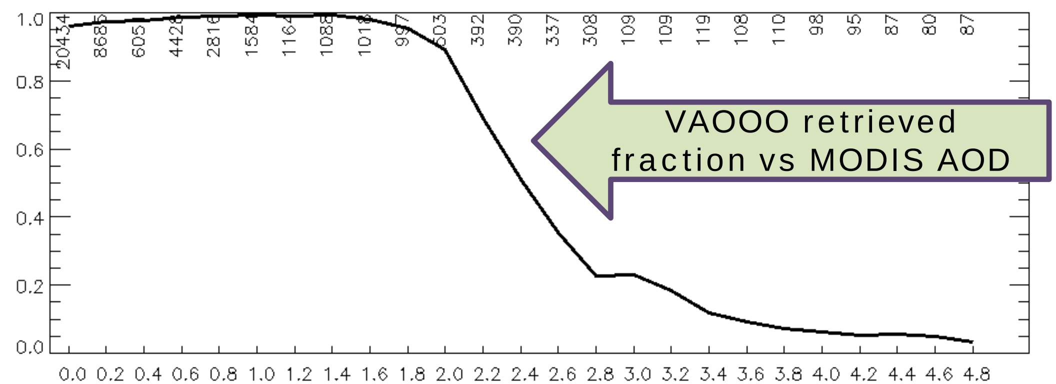

Low end shows differences

- Lots of MODIS negative AOD values
    - QA=VG (blue) and paired (aqua) match, except in lowest bin
    - Consistent with negative AOD truncation in VAOOO?
- Above 0.0, MODIS looks smooth, VAOOO distribution is uneven

# Russia case– VIIRS AOD and retrieval success vs MODIS AOD

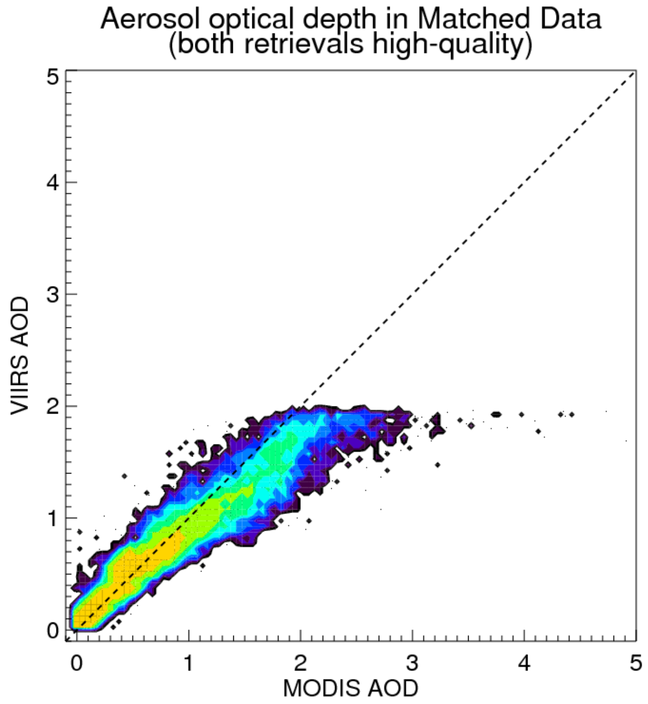
- VIIRS and MODIS have slope close to 1.1 up to VAOOO~1.2
- Truncation effect at high AOD is clearly evident even at single-retrieval level (MODIS retrievals with high AOD paired with nearby successful VIIRS retrievals with AOD<2)

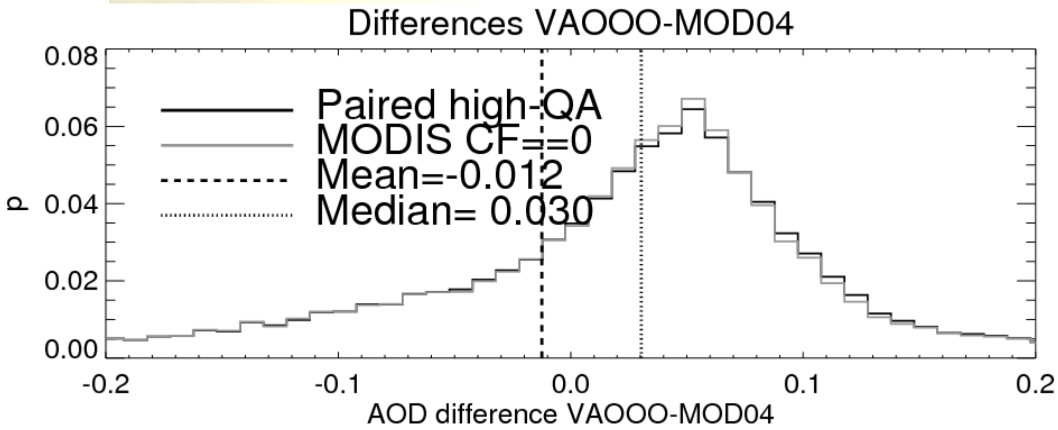


# Russia case– VIIRS AOD vs MODIS

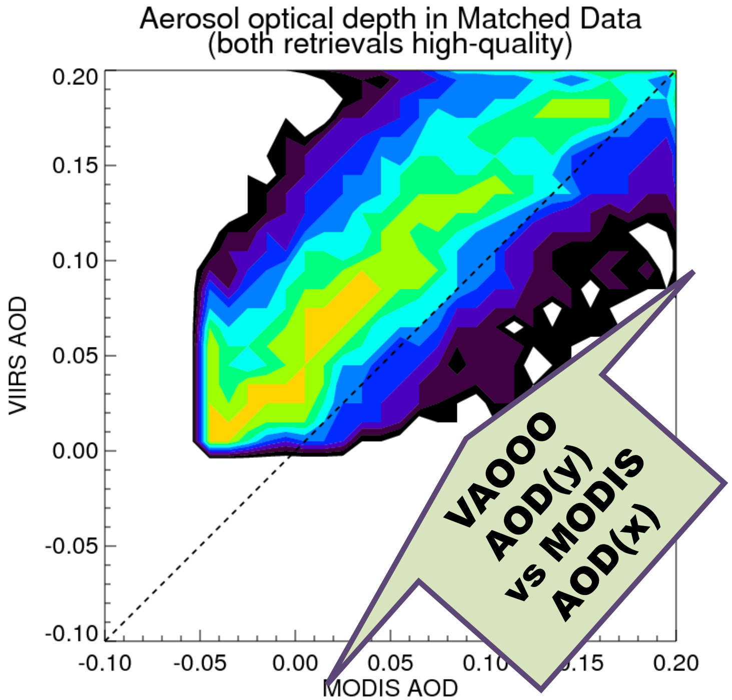
- In the mean, MODIS > VIIRS
  - Weighted by high-AOD tail
- In the median, VIIRS > MODIS
  - Weighted by low AODs

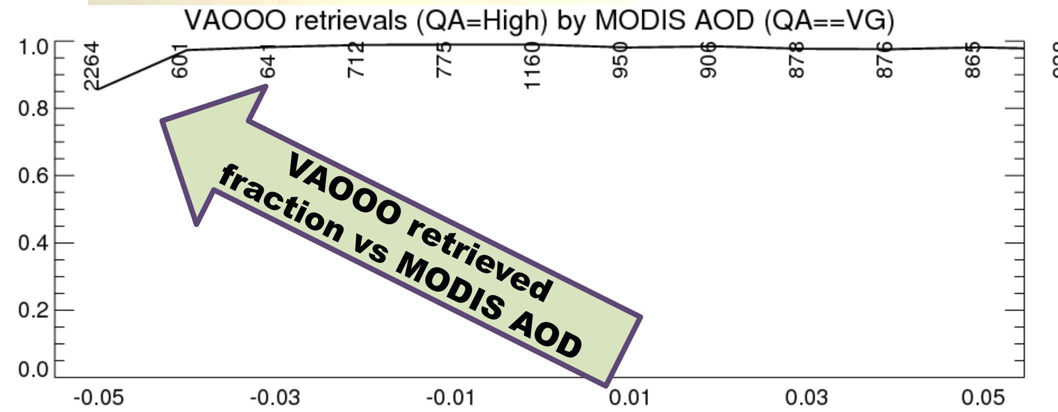


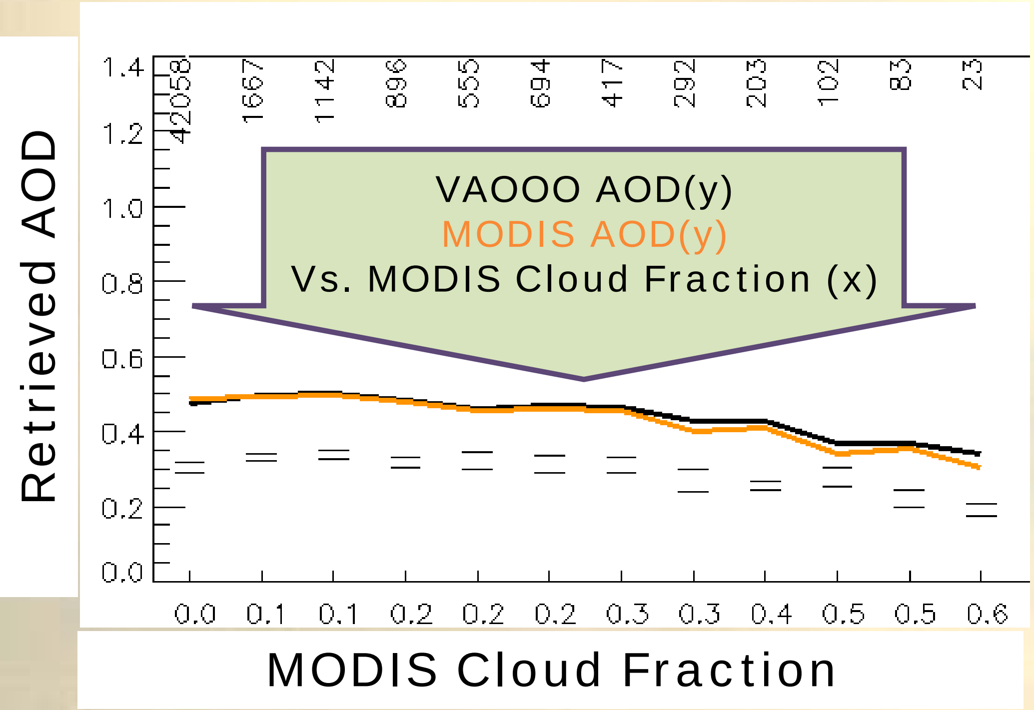
# Russia case– VIIRS AOD and retrieval success vs MODIS AOD

- VIIRS has clear positive offset vs MODIS
- MODIS has large fraction of negative AOD retrievals
- Scatter is greater than ocean case
- Significant evidence of truncation at low end
    - MODIS retrieves negative AOD, VIIRS cannot retrieve even nearby
    - This effect is not nearly enough to offset positive bias in unpaired means



# AOD vs MODIS Cloud Fraction (sensor comparison)




- Uses only paired retrievals with MODIS QA=='very good' & VAOOO QA==High
- **BLACK:** Median VAOOO AOD (nearest QA==high) as a function of MODIS Cloud Fraction.
- **ORANGE:** Median MODIS AOD (QA=VG only) as a function of MODIS Cloud Fraction.
- Mean AOD is high for this study area
- VAOOO and MOD04 track closely
- VAOOO is very slightly higher at high cloud fraction
- **Not evidence for cloud leakage in VAOOO**

# Conclusions from L2/L2 matchup study

- This comparison does not indicate any evidence of cloud leakage in VAOOO
- Major impact of AOD upper limit of 2.0
  - After averaging of data, this will cause significant bias
- Detectable impact of AOD lower bound of 0.0
  - Not likely a large source of bias
- VAOOO is ~0.06 higher than MODIS Collection 5 Dark Target for clean conditions in continental Russia
  - Other validation suggests the answer is in between
  - This large discrepancy complicates combined use of these datasets

# Stage 3: L3 comparisons of gridded AOD products

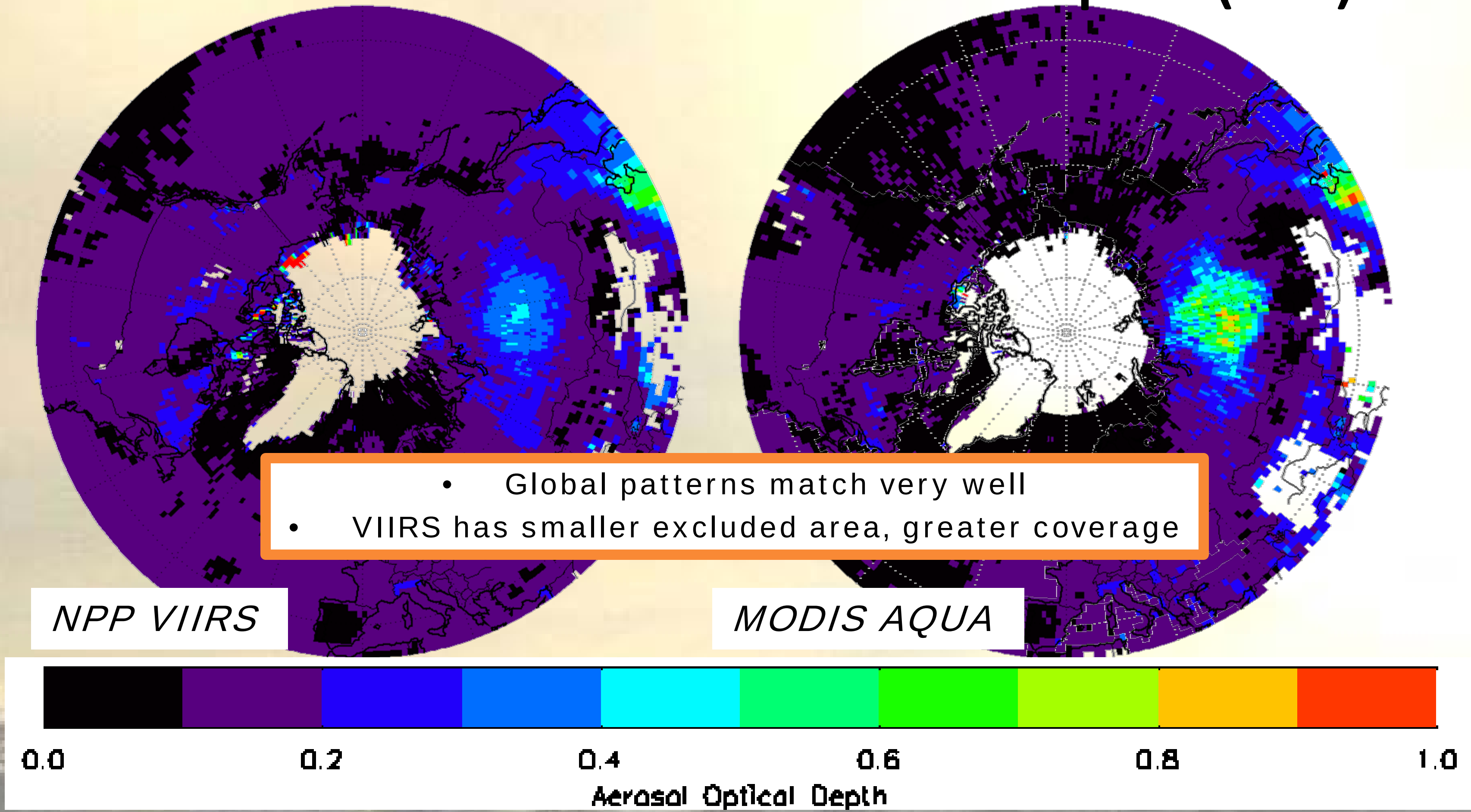
- Compare VIIRS after QA/QC with MODIS after QA/QC
- Compare VIIRS+MODIS AOD to MODIS-only
- **PROS:**
  - Products can be evaluated separately and jointly
  - Effects on assimilation system can be inferred by directly testing coverage and consistency
  - Effects of data filtering can be quickly examined
- **CONS: No ground truth.**
  - This analysis is less useful for diagnosing the retrievals' behavior.

# NPP VIIRS pre-processor

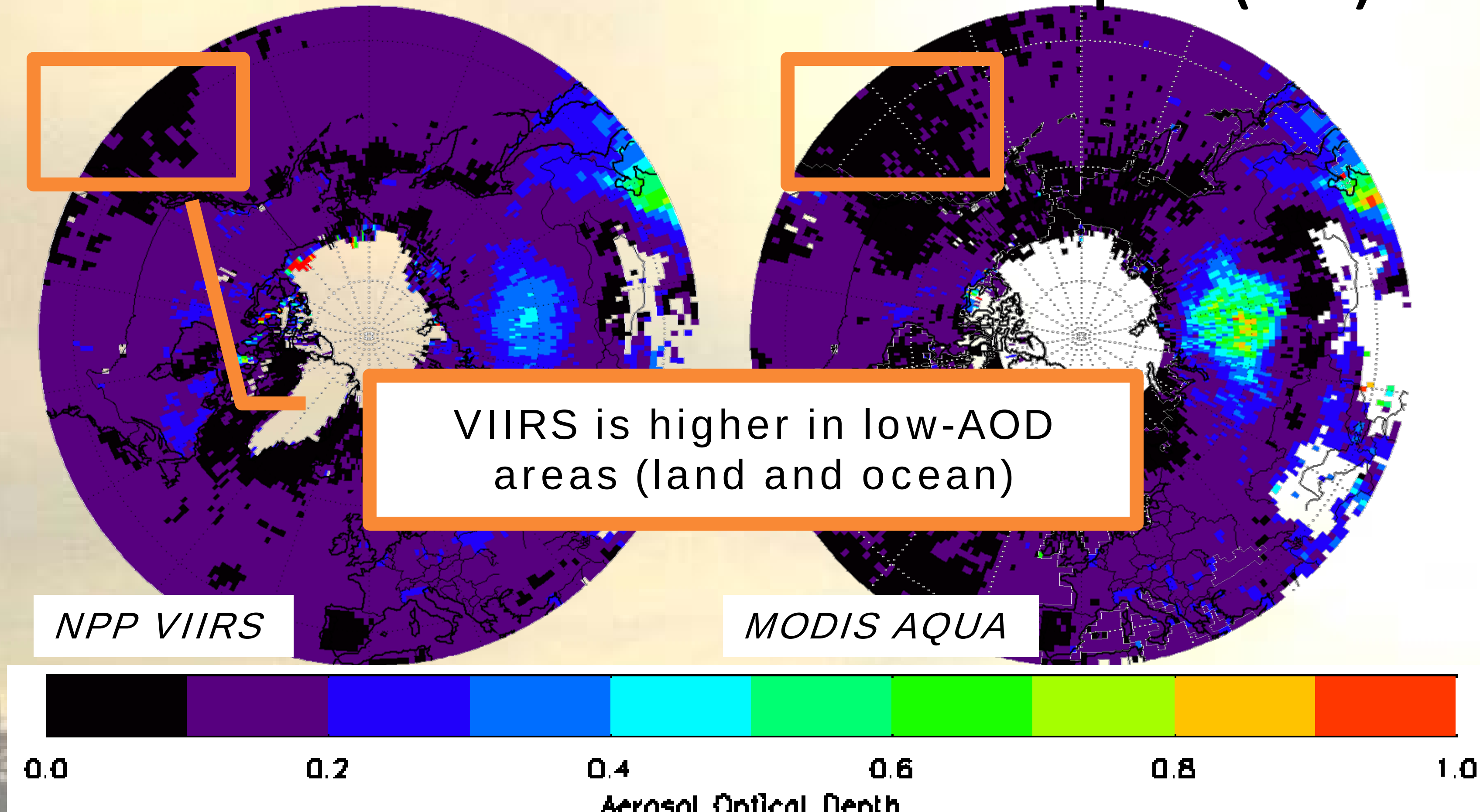
- 1-degree, 6-hour
  - **Operational NAAPS now 1/3°**, 1° used for testing
- "fullQA" uses information packaged with EDR granules
  - QA = 'Good' (highest EDR QA value)
  - Cloud mask, cloud proximity, snow flags, glint flags
  - No textural filtering (this is a cal/val experiment, not an operational candidate)
- Results shown using 12 months of data
  - 2013.01.24.00 to 2014.01.12.00

# VIIRS 'fullQA' AOD vs NRL-UND Level 3 MODIS-Aqua (C5)

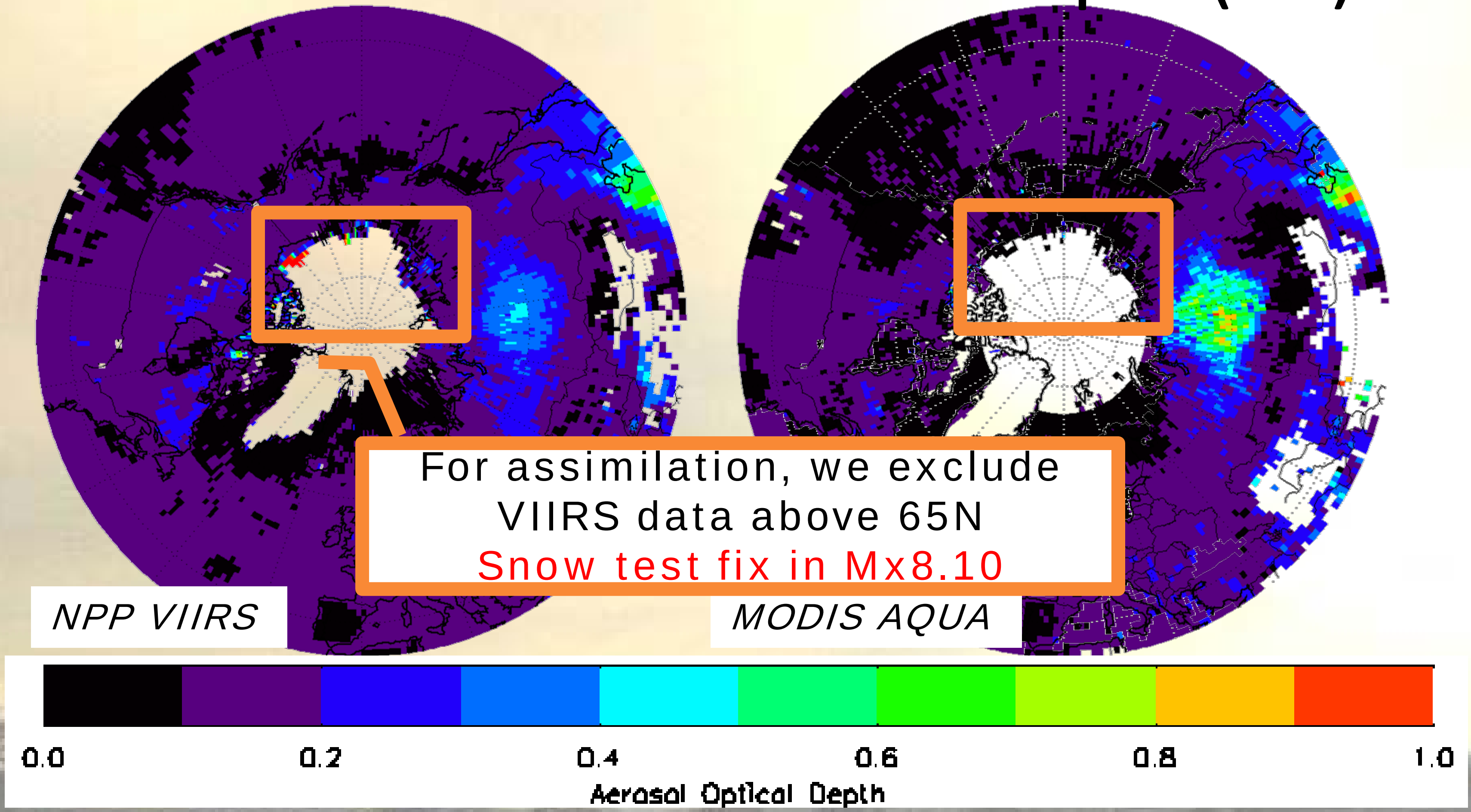
- Global patterns match very well
- VIIRS has smaller excluded area, greater coverage



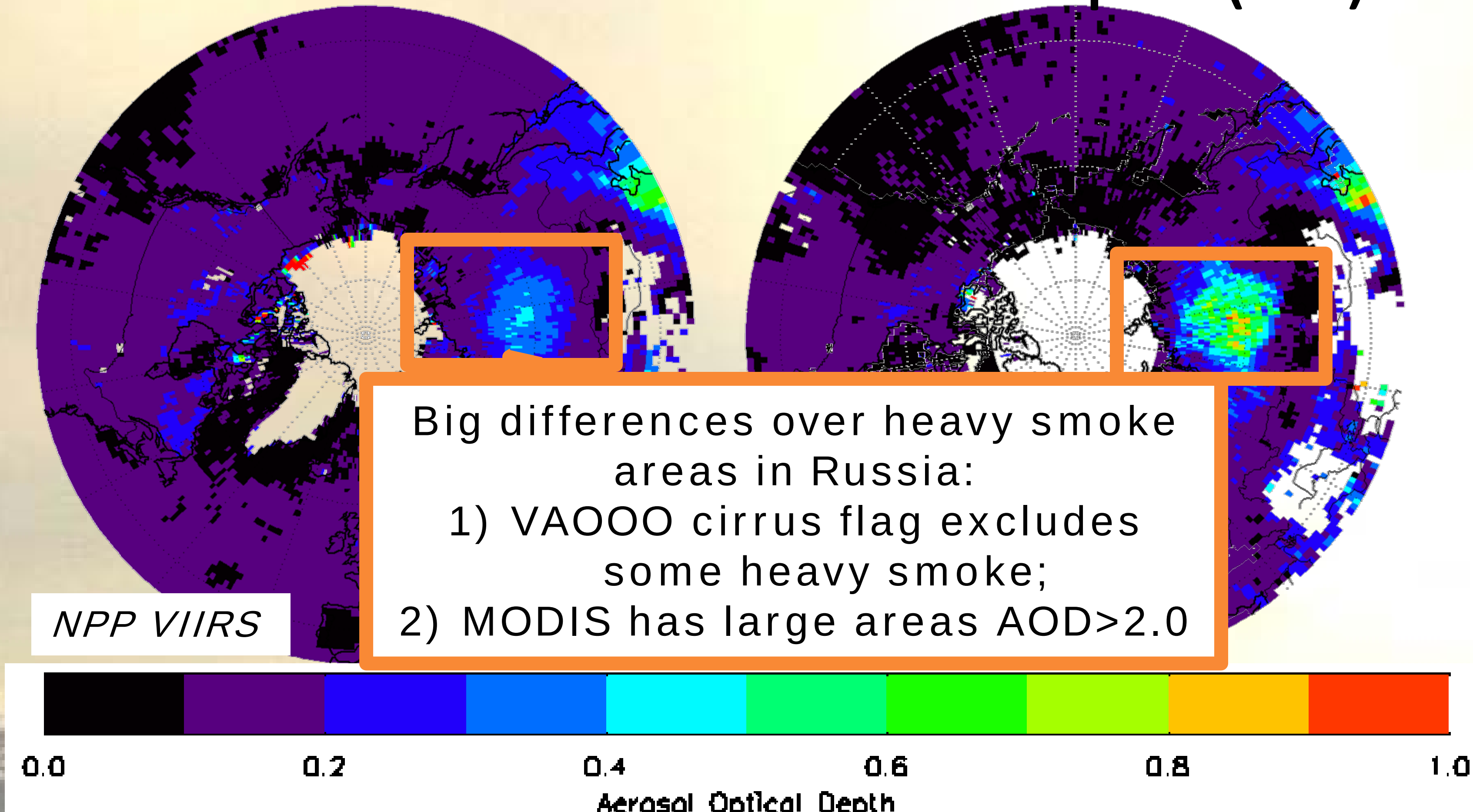
# VIIRS ‘fullQA’ AOD vs NRL-UND Level 3 MODIS-Aqua (C5)



# VIIRS ‘fullQA’ AOD vs NRL-UND Level 3 MODIS-Aqua (C5)



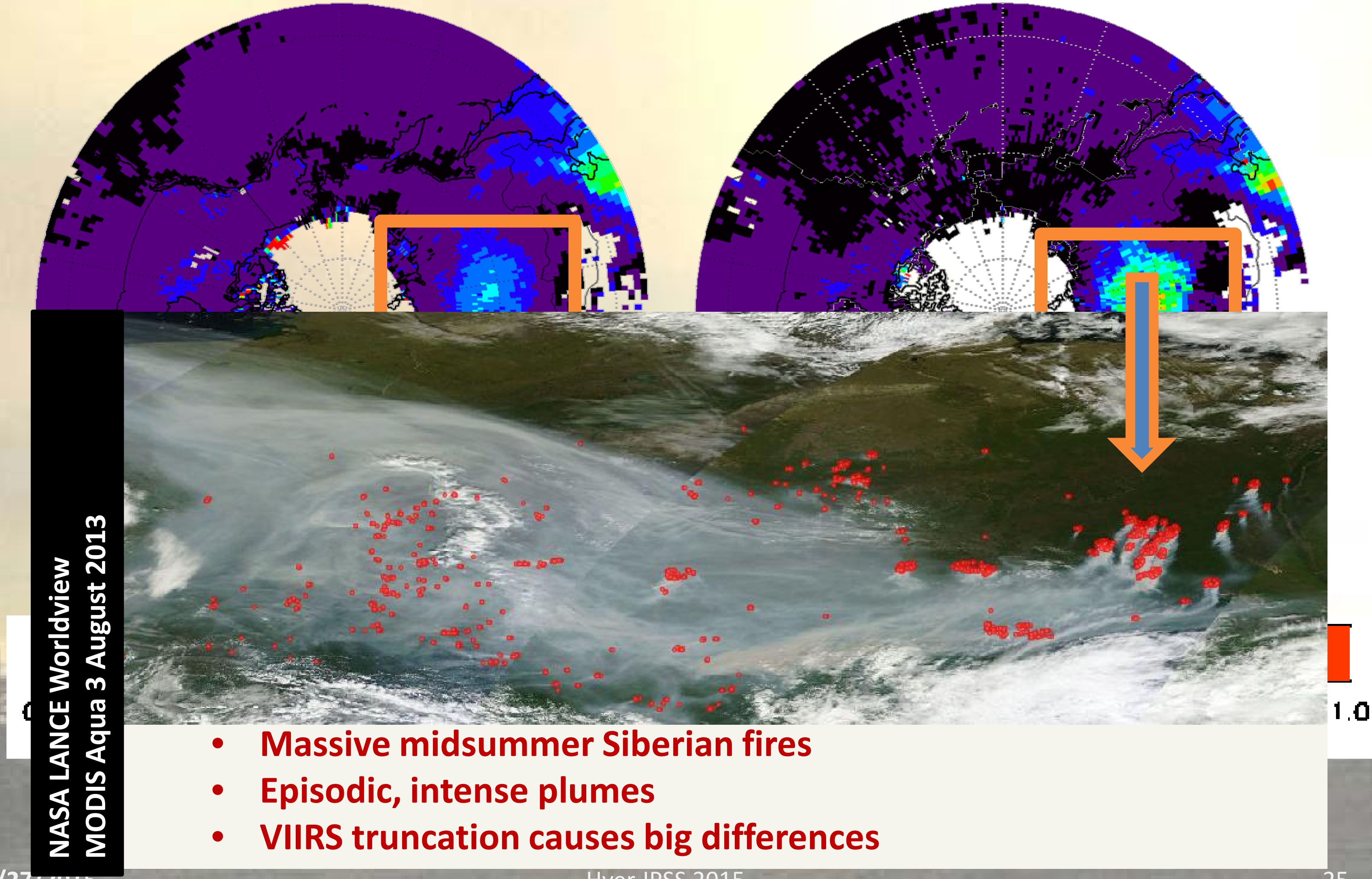
# VIIRS ‘fullQA’ AOD vs NRL-UND Level 3 MODIS-Aqua (C5)




Big differences over heavy smoke areas in Russia:

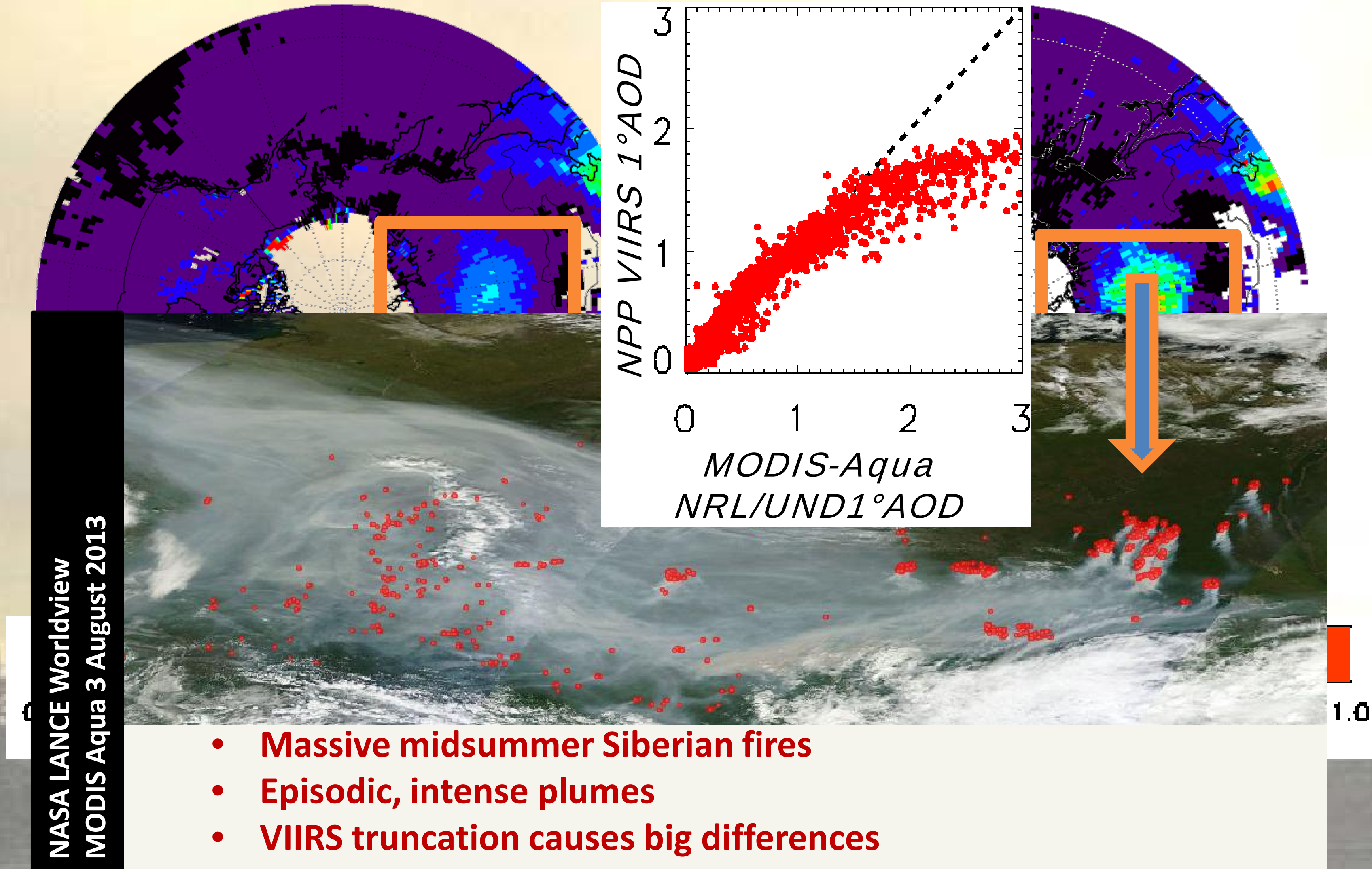
1) VAOOO cirrus flag excludes some heavy smoke;
2) MODIS has large areas AOD>2.0

# Differences over heavy smoke




- **Massive midsummer Siberian fires**
- **Episodic, intense plumes**
- **VIIRS truncation causes big differences**

# Differences over heavy smoke

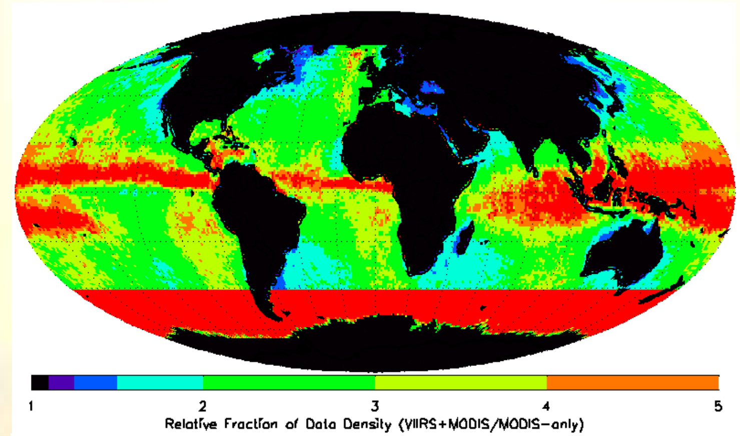


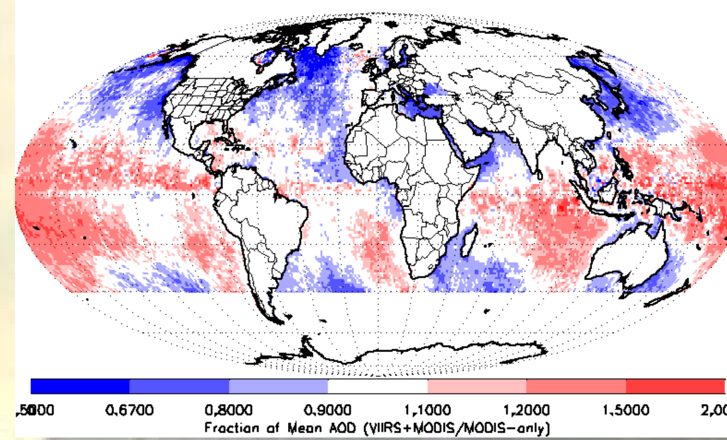

- Massive midsummer Siberian fires
- Episodic, intense plumes
- VIIRS truncation causes big differences

# Stage 3: L3 comparisons of gridded AOD products (ocean-only)

- (Top) Data density of VIIRS+MODIS/MODIS shows dramatic increases in data availability near the ITCZ. Solid red area below 40S reflects exclusion of that area in NRL/UND MODIS AOD product.
- (Bottom) Fractional change in mean observed AOD for VIIRS+MODIS/MODIS
    - decreased AOD over high-latitude oceans
    - increased AOD near the equator.

**Increased availability of data in partially cloudy regions is an expected consequence of higher spatial resolution; however, the cloud filtering in the NRL-UND MODIS L3 product is very strict, and it is likely that cloud proximity effects contribute to the VIIRS AOD in the ITCZ region.**



# After Stage 3, an aerosol analysis is generated with NAVDAS-AOD

- Cycling runs combine 6-hour NAAPS forecasts with NAVDAS-AOD analysis
- Can be easily run for multiple months/years
- All run properties are identical except AOD data input to NAVDAS-AOD
  - MODIS-only (current NAAPS operational setup)
  - MODIS+VIIRS
  - These results use only over-ocean VIIRS AOD

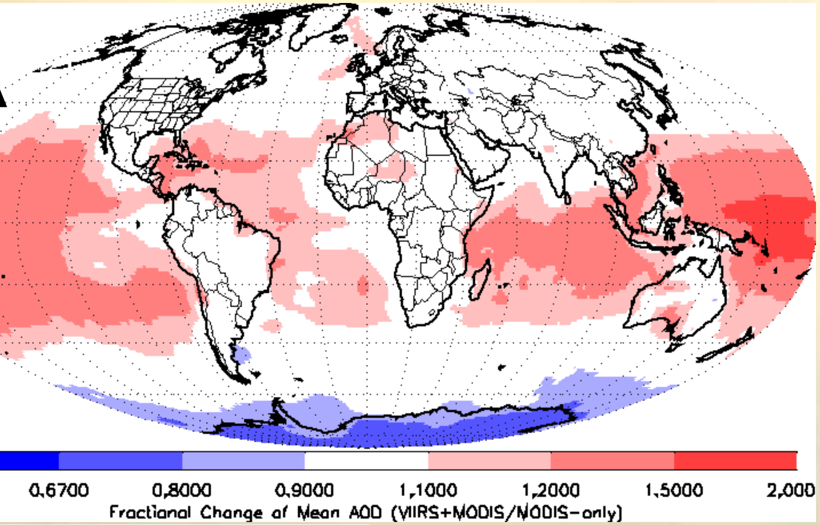
# Stage 4: comparison of analyzed aerosol fields from NAAPS

An aerosol re-analysis is generated using NAAPS including cycling assimilation of one or both AOD datasets. This results in a continuous global field of aerosol properties reflecting the information content of the AOD datasets.

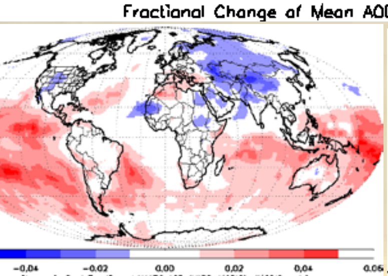
- **PROS:**
  - Allows examination of spreading of information in space and time
  - Allows examination of model consequences of AOD data choices
- **CONS:**
  - Analysis is weakly linked to AOD retrieval.
  - Analysis contaminated by biases in underlying model sources/sinks.
  - Effects of AOD values and AOD observation density convolved.

# Stage 4: comparison of analyzed aerosol fields from NAAPS

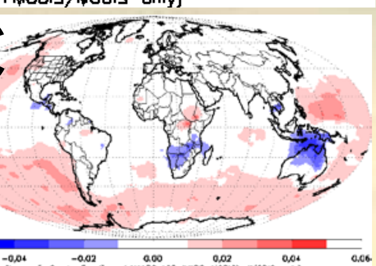
A




B



C



(A) Fractional change of mean NAAPS AOD, (MODIS+VIIRS)/(MODIS-only)

- VIIRS observations near the equator are clearly seen to increase optical depths throughout the tropical oceans.
- VIIRS observations in the southern oceans reduce analyzed AOD values over Antarctica
  - Note: absolute concentrations are low over Antarctica in all analyses.

(B-C) Effect of VIIRS data on the fraction of NAAPS AOD from dust (B) and smoke (C).

- Addition of aerosol mass in tropical ocean manifests as increase in dust fraction

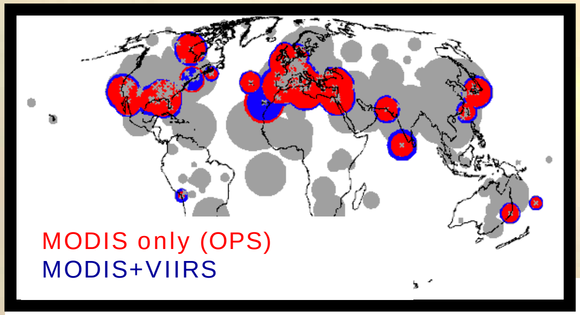
Interactions between the assimilated AOD observation density and the biases of the native NAAPS model source functions result in imbalances in aerosol composition. **For instance, a greater number of observations during the burning season in southern Africa, which is overestimated by the FLAMBE smoke source used in NAAPS, will bring down the AOD in that region and reduce the smoke AOD contribution in the annual average.**

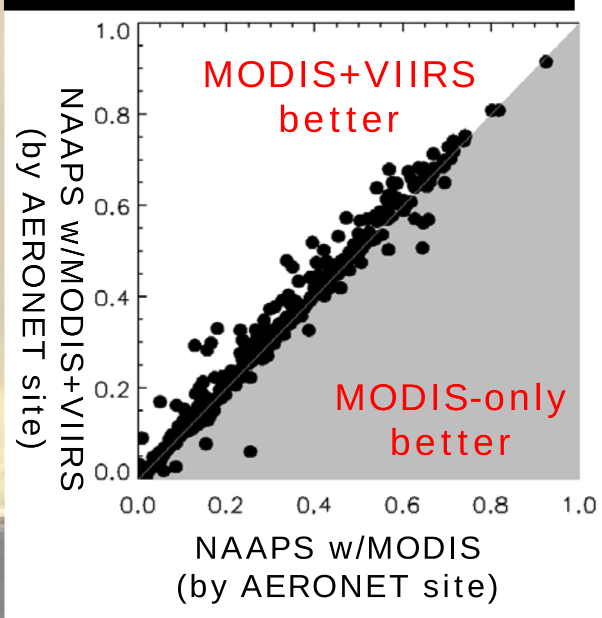
# Stage 5: Comparison of NAAPS analyzed AOD to AERONET

- NAAPS analyzed AOD is compared to AERONET for model verification
- This is our final determination if assimilation of AOD data is making NAAPS "better" or "worse"
- **PROS:**
  - Ground truth—a better match to AERONET is a better analysis/forecast
    - (assuming you are not assimilating AERONET)
- **CONS:**
  - This analysis does not provide much insight into the details of the model processing and the AOD data.

# VIIRS Over-ocean NAAPS assimilation test results

AOD Correlation ($r^2$) at AERONET stations




VIIRS over-ocean AOD assimilation tests

- VIIRS processing
  - All in-granule quality flags
  - Buddy check
  - Cloud proximity check
  - Textural filtering
- NAAPS AOD analysis results:
  - VIIRS+MODIS better than MODIS only
  - RMSE reduced at 234 of 399 AERONET stations (not shown)
  - correlation (r2) vs AERONET L1.5 increased at 272 of 399 stations
    - Colored symbols on map indicate stations where r2 differed by more than 0.05
  - VIIRS data have positive bias, driving up NAAPS AOD
    - Sites that had low bias got better, sites with high bias got worse
    - With stronger filtering, it should be possible to reduce this effect

# Results and Next Steps

- Operational implementation of VIIRS assimilation
- Testing of new VIIRS data products, especially over land
- Thank you!!
  - Sponsors: JPSS, NASA AQAST, NRL
  - JPSS Aerosol Cal/Val Team

# Backup Slides

# VIIRS Aerosol Products (1)

- **Aerosol Optical Thickness (AOT)**
  - for 11 wavelengths (10 M bands + 550 nm)
- **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) and aerosol model identified by the aerosol algorithm
- **Only day time data**
- **Only 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

# VIIRS EDR vs MODIS L2 Aerosol Products

| | Aqua-MODIS | Suomi NPP-VIIRS |
|---|---|---|
| **Swath Width** | 2330 km | 3000 km |
| **Sensor bands used for aerosol retrieval.** | 0.411, 0.466, 0.554, 0.646, 0.856, 1.242, 1.629, 2.114 µm | 0.412, 0.445, 0.488, (0.550), 0.555, 0.672, 0.746, 0.865, 1.24, 1.61, 2.25 µm |
| **Pixel size, nadir** | 0.5 km | 0. 75 km |
| **Pixel size, edge of scan** | 2 km | 1.2 km |
| **Product resolution, nadir** | 10x10 km (20x20 500m pixels) | 6x6 km (8x8 750m pixels) (AOT and Angstrom exponent) |
| **Product resolution, scan edge** | 40x20 km | 12.8x12.8 km |

Compared with MODIS, VIIRS has:

- Improved coverage: gap-free daily observation around the globe
  - enabled by the wider swath
- Improved spatial characteristics Swath-edge pixels are 2x nadir, vs 4x for MODIS

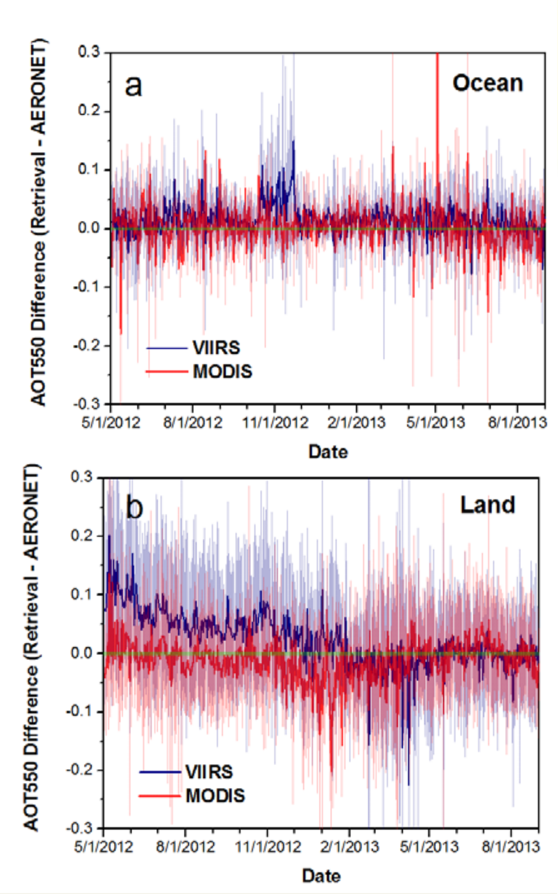
- Algorithm Differences:
- Retrieval of AOD is done at the pixel level: aggregation of AOD values is done to produce the EDR product.
- Over-land algorithm (like MOD09 atmospheric correction) retrieves a single aerosol model, a mix of fine and coarse; over-ocean algorithm (like MOD04) retrieves fine and coarse mode properties separately.

# VIIRS Aerosol Resources

- **Two peer-reviewed publications**
  - Jackson et al. JGR 2013
  - Hongqing Liu et al. JGR 2014
- **NOAA VIIRS Air Quality Workshop (from 2013):** http://alg.umbc.edu/aqpg/viirs_workshop/
  - Many useful talks, special notice to talk by Rohit Mathur (EPA) on satellite products and AQ models
- **VIIRS aerosol user's guide and fully revised ATBD** (technical description): http://www.star.nesdis.noaa.gov/smcd/emb/viirs_aerosol/documents.php

# VIIRS Aerosol Cal/Val

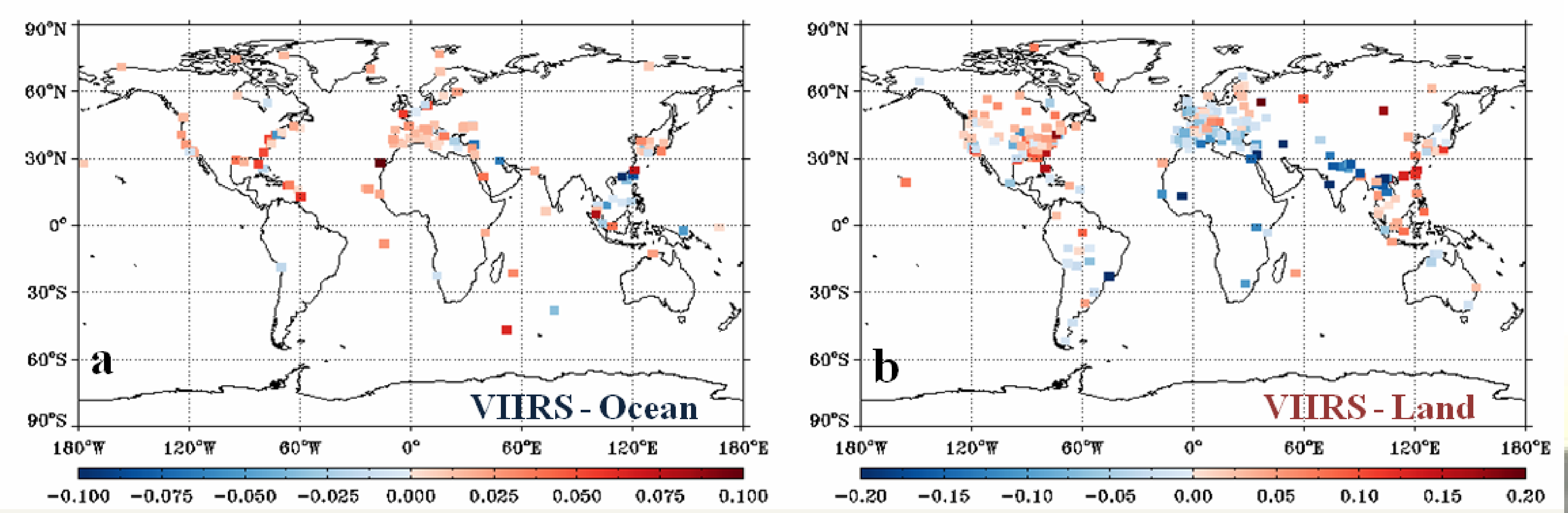
- AERONET sun photometers are the gold standard
  - Accuracy and precision exceed what is expected even from the best satellite products
  - Data should not be used uncritically in regions with thin cirrus (Chew et al. *Atm. Env* 2011; Huang et al. *JGR* 2011*)*
- Right: time series of AERONET vs VIIRS AOD (blue) and MODIS-Aqua C5 AOD (red) over ocean (top) and land (bottom).
  - Evolution of VIIRS algorithm (blue) can be seen
  - MODIS Collection 5 (red) and VIIRS have similar accuracy after 1/24/2013




Hongqing Liu et al., *JGR* 2014

# VIIRS Aerosol Cal/Val

- VIIRS and MODIS ocean retrievals have similar errors vs AERONET
- Pattern of biases over land is very different for VIIRS vs MODIS Collection 5
- MODIS Collection 6 (now in production) has reduced biases over land (Levy et al. *ACP* 2013), different patterns from VIIRS




Hongqing Liu et al., *JGR* 2013

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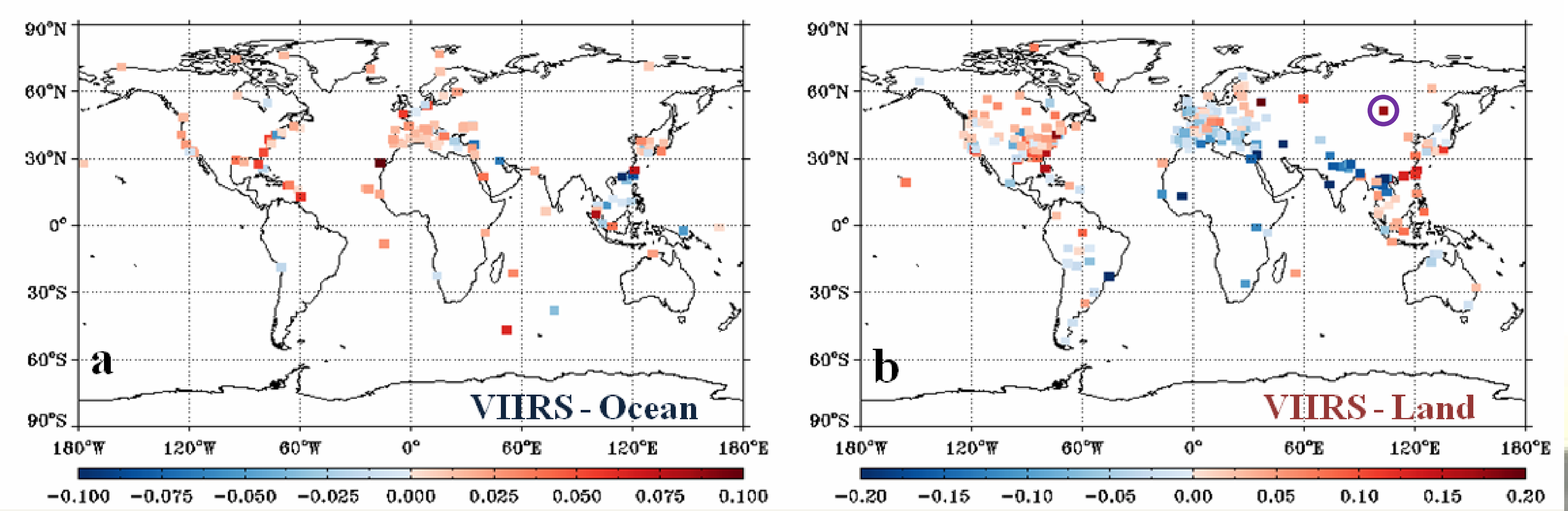



Hongqing Liu et al., *JGR* 2013

# Development toward global aerosol DA system at NCEP

Jun Wang, Jeff Mcqueen (NOAA/NWS/NCEP/EMC)

Sarah Lu (SUNY at Albany)

Shobha Kondragunta, Qiang Zhao (NESDIS)

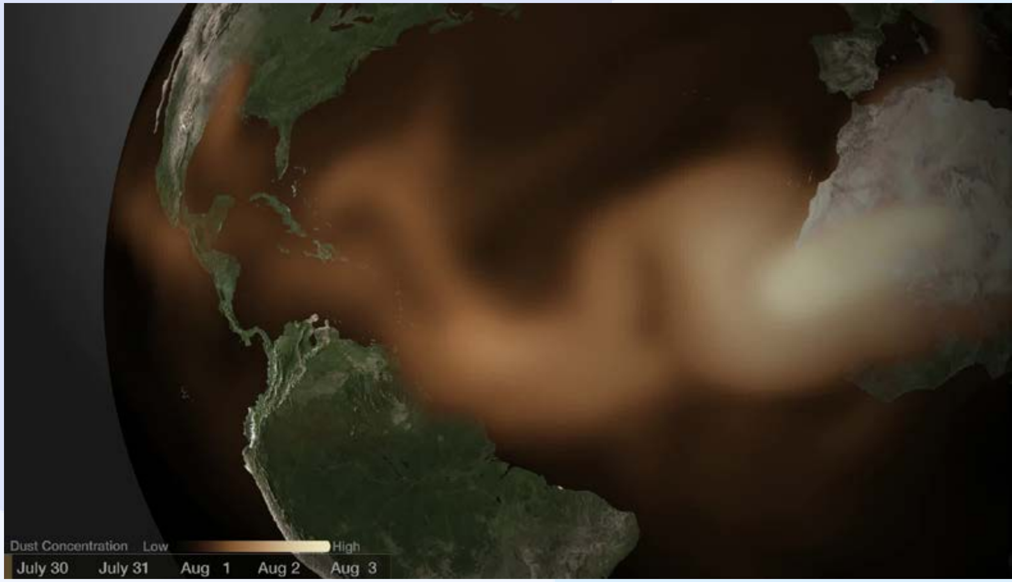
Arlindo da Silva (GSFC)

EMC GSI-EnKF group

# Current Operational NEMS GFS Aerosol Component

## Current State

- Near-real-time operational system
- The first global in-line aerosol forecast system at NCEP
- AGCM : NCEP's NEMS GFS
- Aerosol: GSFC's GOCART
- 120-hr dust-only forecast once per day (00Z), output every 3-hr
- ICs: Aerosols from previous day forecast and meteorology from operational GDAS
- Implemented into NCEP Production Suite in Sept 2012




## Ongoing Activities and Future Plans

- Use near-real-time smoke emissions from satellites (collaborating with NESDIS /GSFC) **FY15**
- Full package implementation (dust, sea salt, sulfate, and carbonaceous aerosols) **FY16**
- Aerosol analysis using VIIRS AOD **FY17**
- Provide aerosol information for potential downstream users
  - Aerosol lateral boundary conditions for regional operational air quality model CMAQ **FY16**
  - NESDIS's SST retrievals, CPC-EPA UV index forecasts

# NGAC dust verification: event Jul 30 – Aug 3, 2013

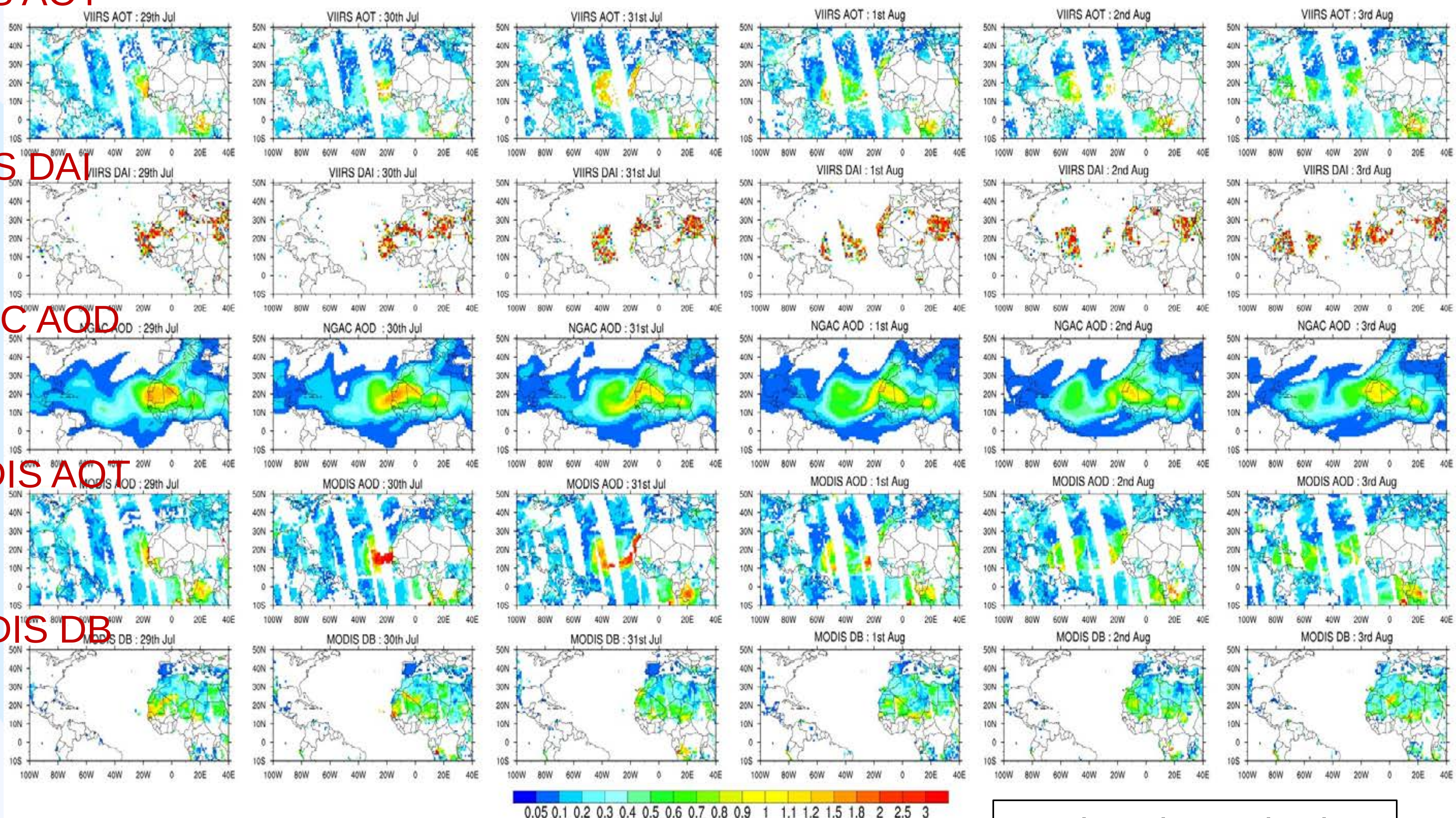
VIIRS AOT

VIIRS DAI

NGAC AOD

MODIS AOT

MODIS DB




Partha Bhattacharjee

VIIRS data source:
http://www.star.nesdis.noaa.gov/smcd/emb/viirs_aerosol/products_gridded.php

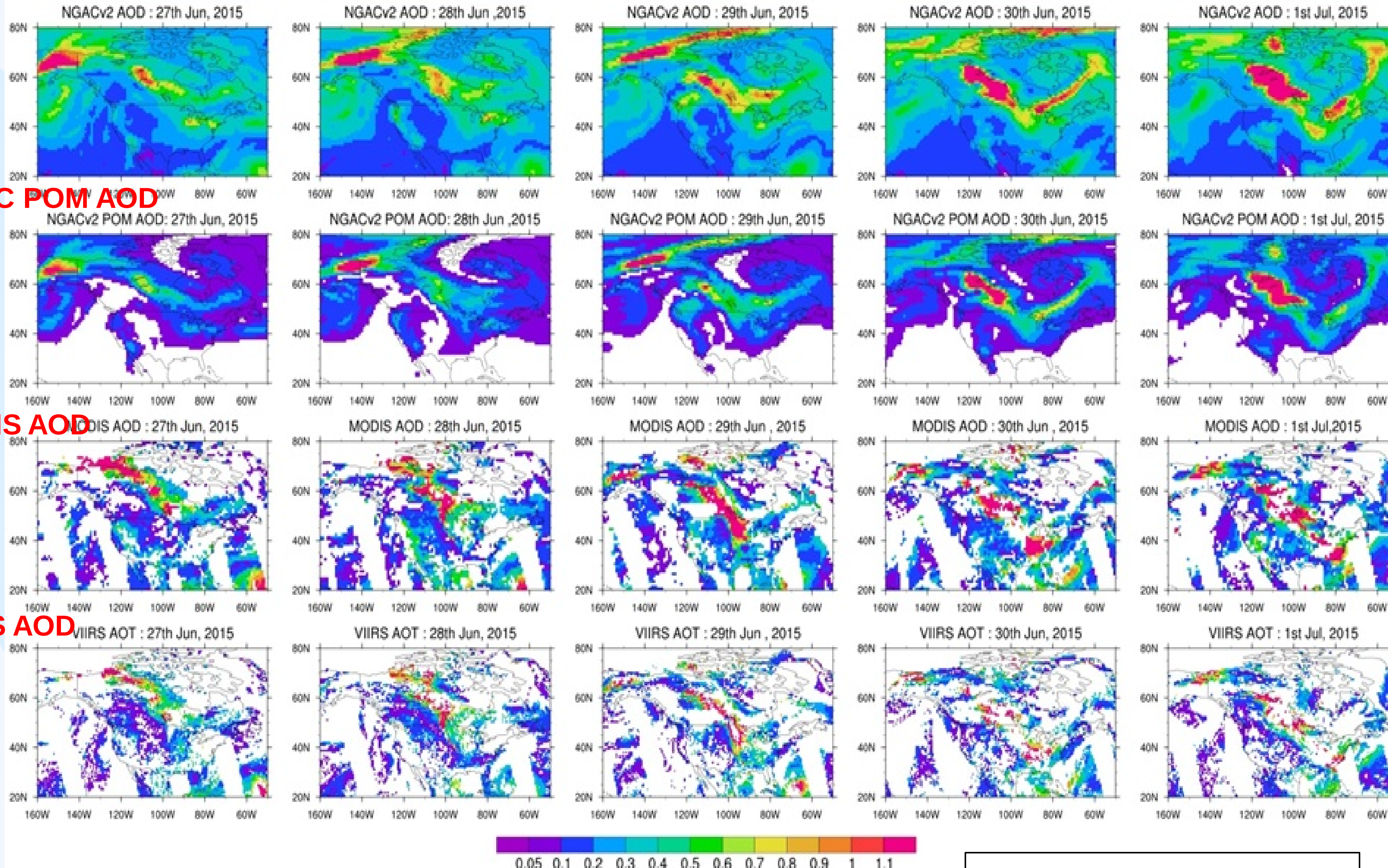
# Smoke Event on Jun 27- Jul 1, 2015

**NGAC AOD**

**NGAC POM AOD**

**MODIS AOD**

**VIIRS AOD**

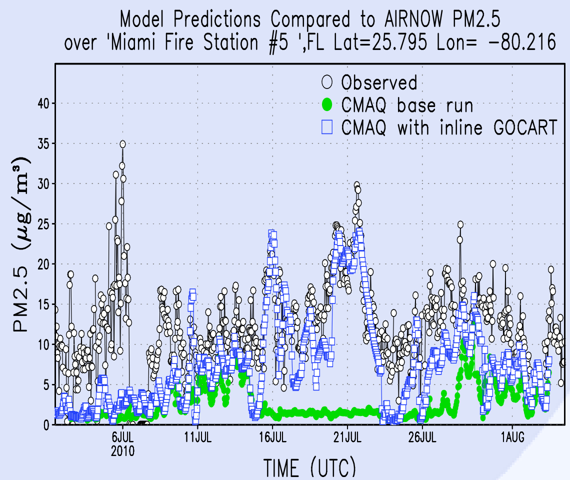


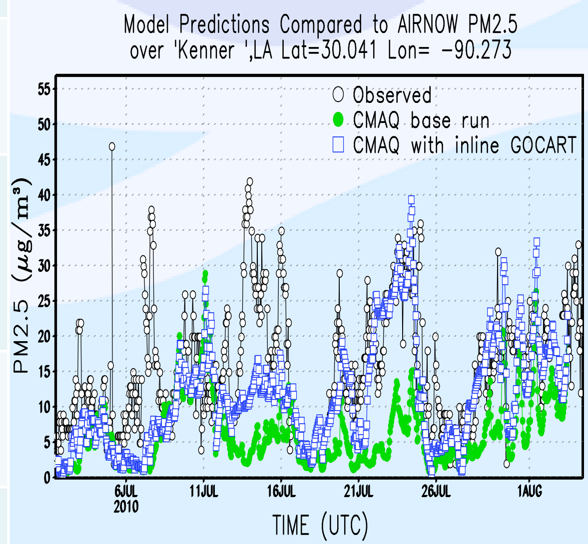

Partha Bhattacharjee

# Dynamic LBCs for regional models

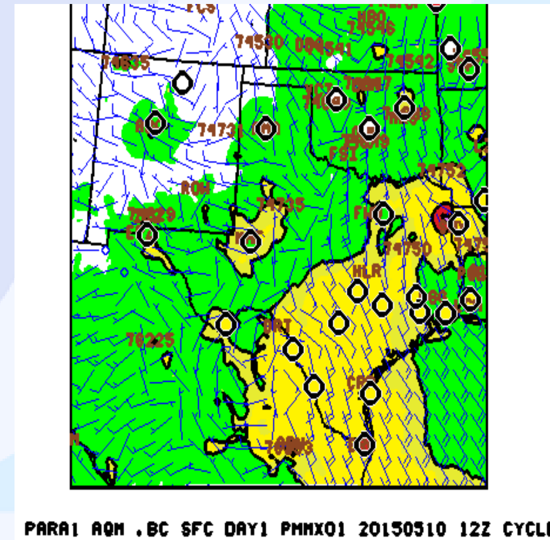
- Baseline NAM-CMAQ with static LBCs versus experimental NAM-CMAQ with dynamic LBCs from NGAC, verified against AIRNOW observations
- The inclusion of LBCs from NGAC prediction is found to improve PM forecasts, and it is in CMAQ Q12016 implementation.

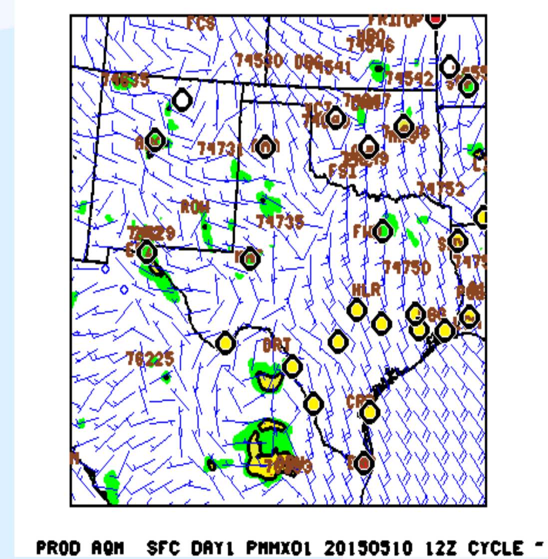
| | CMAQ Baseline | CMAQ Experimental |
|---|---|---|
| Whole domain July 1 – Aug 3 | MB= -2.82 R=0.42 | MB= -0.88 R=0.44 |
| South of 38°N, East of -105°W July 1 – Aug 3 | MB= -4.54 R=0.37 | MB= -1.76 R=0.41 |
| Whole domain July 18– July 30 | MB= -2.79 R=0.31 | MB= -0.33 R=0.37 |
| South of 38°N, East of -105°W July 18– July 30 | **MB= -4.79 R=0.27** | **MB= -0.46 R=0.41** |



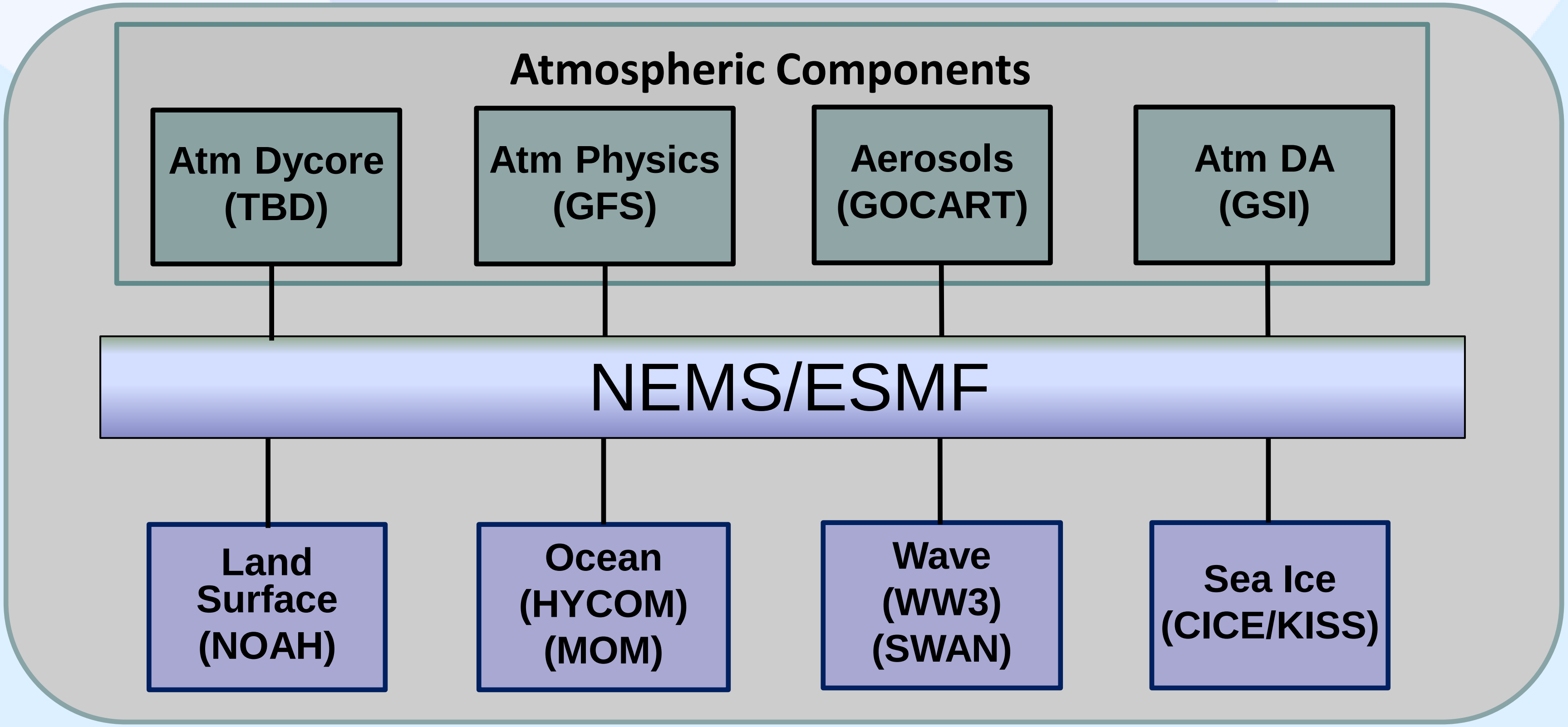




**Dust event on 20150510**
**CMAQ PARA vs PROD**



# NGGPS Prediction Model Components



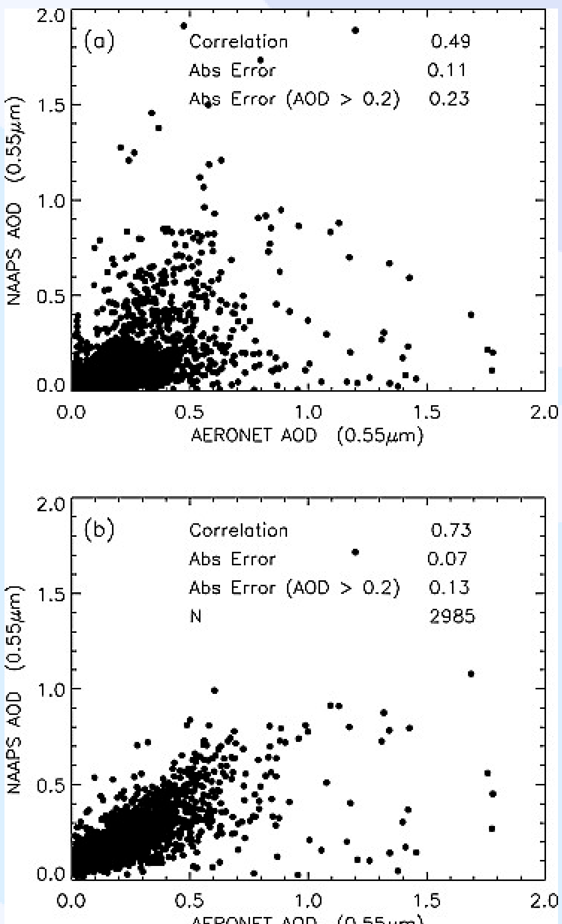

- NGGPS implementation plan development includes an aerosol team
- Development of dust/aerosol capabilities is underway by universities and federal labs

Ivanka Stajner (NWS)

# AEROSOL AOD Data Assimilation

- Other centers (e.g., NRL, ECMWF, GMAO) are assimilating MODIS AOD
- The assimilation of aerosol observations has proven successful in providing initialization for aerosol forecasts as well as improving aerosol forecast skills

Figure 1 AERONET AOD versus NAAPS AOD for 5-month (January – May 2006) non-assimilation run (top) and NAAPS runs with the aerosol data assimilation process (bottom). Zhang, J. et al. 2008



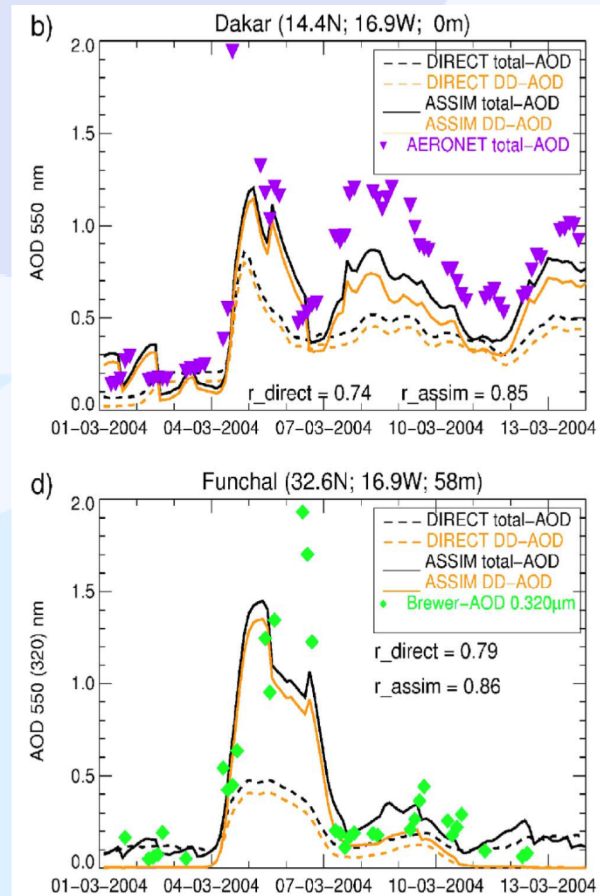




Figure 2 Time series of AOD at 550nm at 2 AERONET sites from ECMWF aerosol modeling system. Mangold, A. et al. 2011

# Aerosol data assimilation development in NCEP

- NCEP operational global aerosol model was built upon multi-agency collaboration including NCEP, NASA, NESDIS and universities.
- NCEP aerosol data assimilation project was suspended in 2012 due to budgetary constraints.
- NCEP aerosol analysis development is aligned with NWS's efforts to develop the NGGPS that represents the interaction between the atmosphere, ocean, wave, sea ice, land surface, and chemistry (aerosol)
- NCEP Aerosol data assimilation is build upon existing partnership and also leverage expertise in NOAA laboratories and research communities under NGGPS program.
- NGAC aerosol data assimilation using VIIRS AOD is funded by JCSDA from 2015-2016

# VIIRS AOD Data Assimilation

- Other centers (e.g., NRL, ECMWF, GMAO) are currently assessing the VIIRS aerosol products.

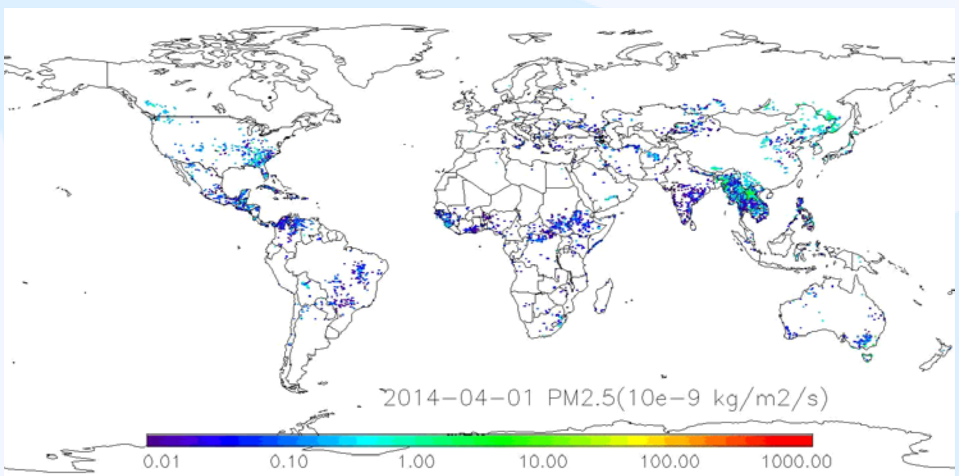
- NCEP is developing the AOD data assimilation capability and is focusing on VIIRS products (instead of the "MODIS then VIIRS" approach).

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

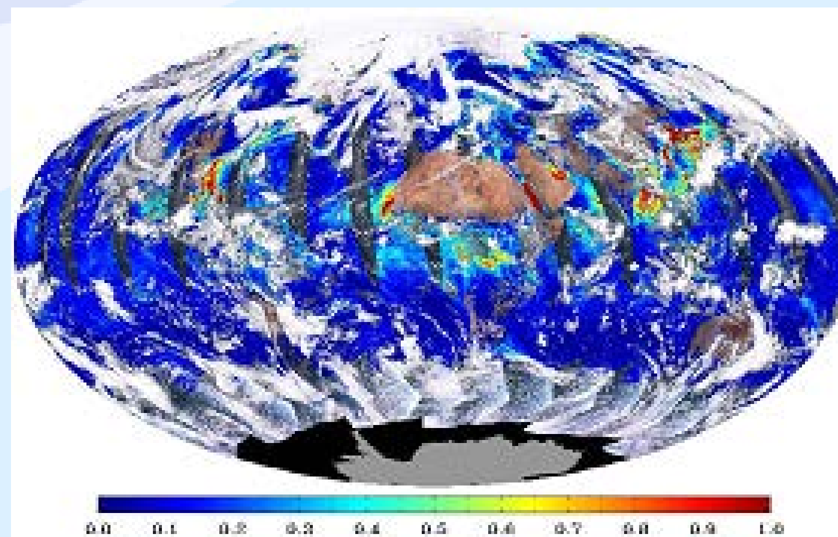
# Using satellite data to improve aerosol forecasting

- Collaborations among NOAA/NCEP, NOAA/NESDIS, NASA/GSFC, and SUNYA
- Research activities:
  (1) Data assimilation of satellite aerosol observations
  (2) Near-real-time biomass burning emissions from satellite observations

Near-real-time biomass burning emissions from multiple satellites




Aerosol observations from VIIRS

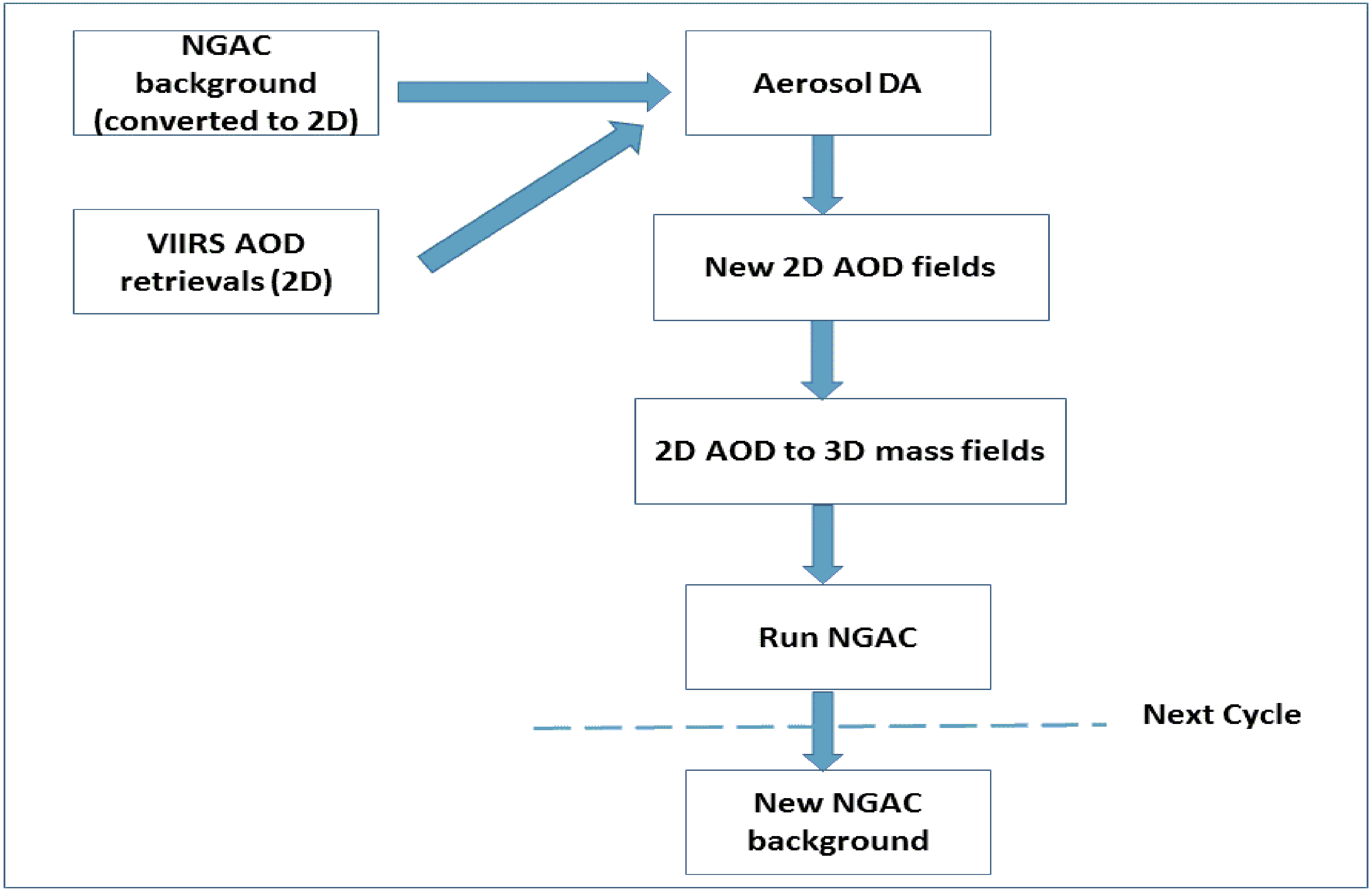


*From NOAA/NESDIS/STAR website*

# NGAC data assimilation implementation plan

- The global aerosol analysis system at NCEP will be implemented with incremental updates
  - The first phase is based on GSI framework using VIIRS AOD as input observations and the NGAC output as first guess
  - The system will be extended to use multi-sensor and multi-platform aerosol observations and evolve to an EnKF system
- The primary outcomes include:
  - Improved operational global real-time aerosol forecasts. JPSS aerosol information will be assimilated in the NWS operational data assimilation system for the first time.
  - A prototype global coupled system with aerosol modeling and data assimilation capabilities.

# NGAC Data Assimilation flow chart



# Ongoing activity and Future plan

- Efforts are underway to ensure EMC's R&D and NGGPS program are aligned
  - Develop an aerosol analysis in the EnKF portion of the hybrid EnKF-GSI data assimilation system
    - using NEMS GFS Aerosol Component (NGAC, NOAA's global aerosol forecast system) output as first guess
    - aerosol measurements from MODIS and VIIRS as input observations
    - The Local Ensemble Transform Kalman Filter (LETKF)
    - Analysis weights will be computed for each vertical column in order to project 2-dimensional aerosol optical depth (AOD) information to the full 3-dimensional field.
  - The observations will be extended to include multi-sensor and multi-platform aerosol observations.

# Thank You

United States Environmental Protection Agency

# Use of VIIRS AOT in Hierarchical Autoregressive Model to Predict Daily $PM_{2.5}$


**Jim Szykman**[1]

Joint work with Erin Schliep[2], Alan Gelfand[2], David Holland[1]

[1]National Exposure Research Laboratory
U.S. EPA, Office of Research and Development, RTP, NC 27711
[2]Duke University, Durham, NC 27708


***Session 7e: Clouds and Aerosol Breakout***
***STAR JPSS, 2015 Annual Science Team Meeting***
***24-28 August 2015***
***College Park, MD***

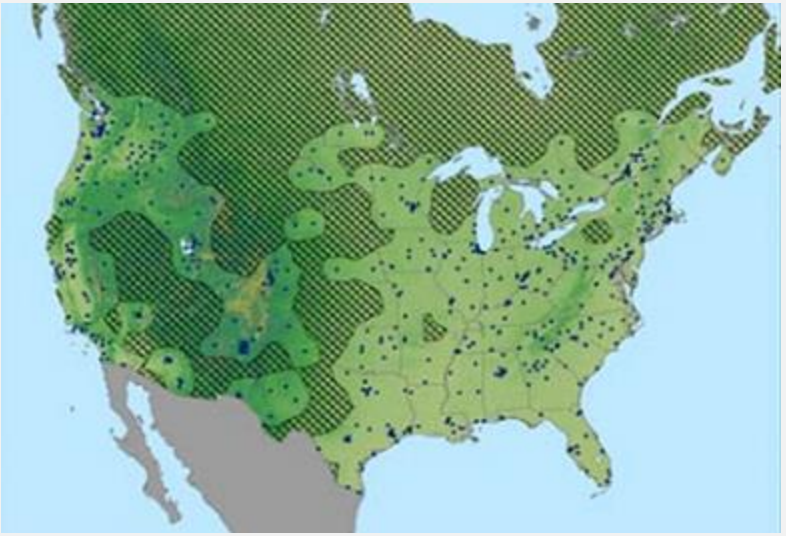
# Motivation

- Spatial and temporal coverage of existing $PM_{2.5}$ monitoring - significant data gaps resulting in over 36 million Americans (~40% of the area) not covered by a monitoring network

- Demand for accurate air quality characterization in community surveillance/human health analyses

- Chemical Transport Models require extensive emission inventories for model predictions – often do not capture high $PM_{2.5}$ concentrations associated with wildfires

- Daily AOT is a measure of the true state of the atmosphere for aerosols

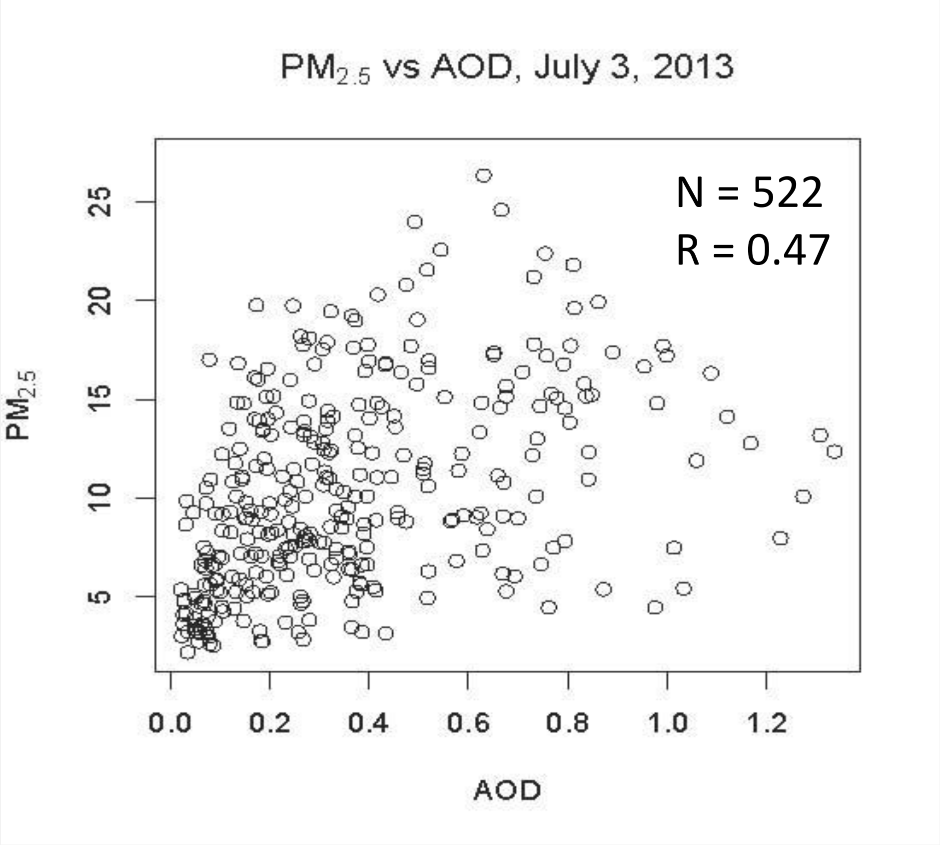


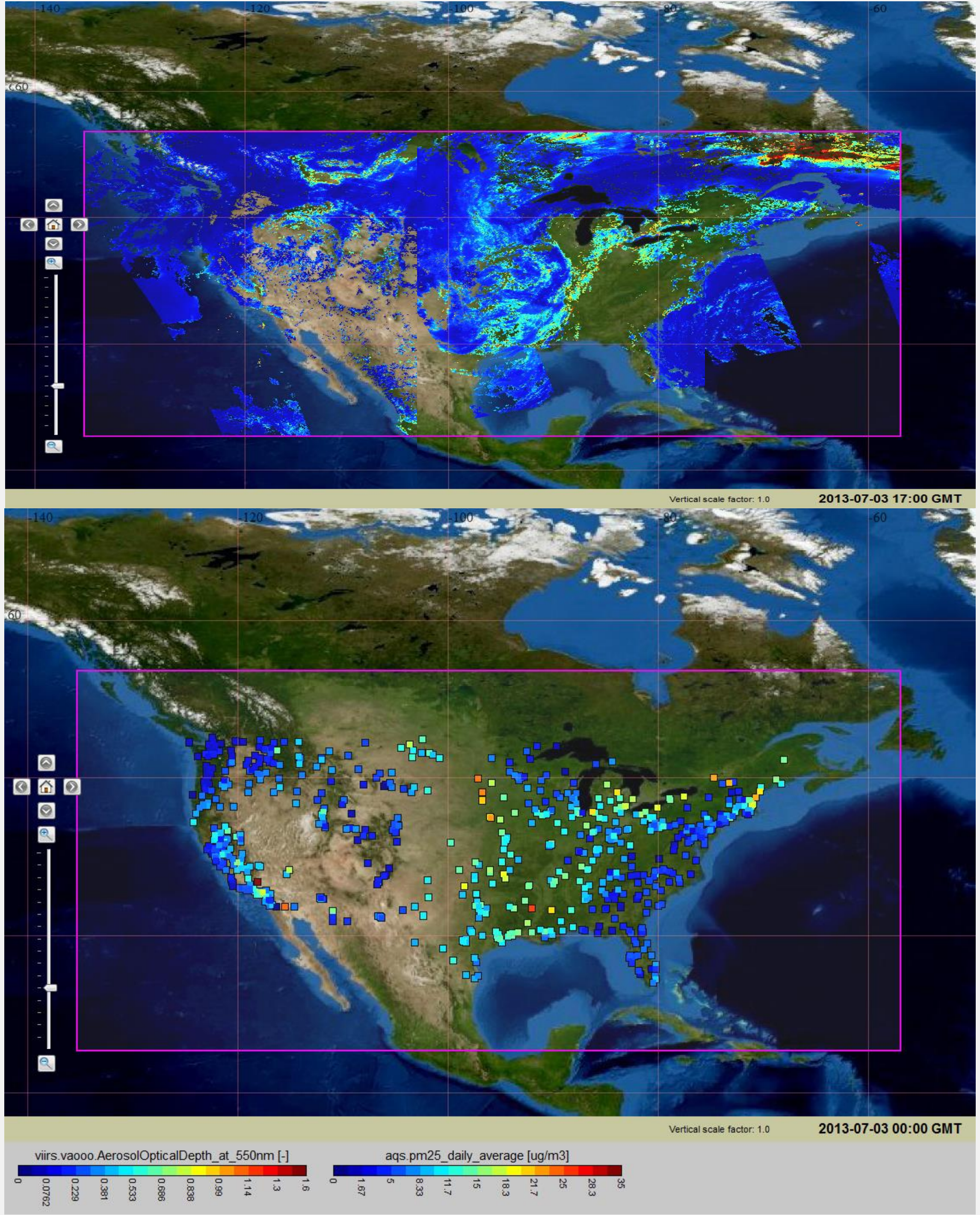
**Additional information needed for spatial prediction of $PM_{2.5}$ in the hatched areas**

# Challenges with AOT and surface PM2.5 in fusion models

- Correlation between the two data sources varies both in time and in space
- Data sources are temporally and spatially misaligned
- Extensive missing data in both the monitoring data and satellite data
  - AOT observed at 64% of grid cells with monitoring stations
  - Daily observations rate for study period 45% - 83%

United States
Environmental Protection
Agency



# Hierarchical Autoregressive Model

Model consecutive day average $PM_{2.5}$ across CONUS using daily spatially-varying coefficients:

- VIIRS AOT data - day-specific spatially-varying intercept and coefficient
- Account for missingness in AOT data via model-based imputation at missing grid cells
- Autoregressive term based on previous day surface $PM_{2.5}$ concentrations
- Meteorological covariates (daily avg. T and RH)

EPA United States Environmental Protection Agency

# Autoregressive Model

$$P_t(s)= \alpha_{0,t} + \beta_{0,t}(s) + (\alpha_{1,t} + \beta_{1,t}(s))A_{i,t} + X_t(s)\gamma + \rho P_{t-1}(s)+ E_t(s) \quad (M1)$$

$\alpha_{0,t}$ and $\alpha_{1,t}$ - global intercept and AOT coefficients for day t

$X_t(s)$ - vector of location and day specific meteorological covariates

$\gamma$ - vector of coefficients

$\beta_{0,t}(s)$ and $\beta_{1,t}(s)$ - spatially varying intercept and AOT coefficients for day t

$E_t(s)$ - error

**Schliep E. M., A. E. Gelfand, and D. M. Holland, *Autoregressive spatially-varying coefficient models for predicting daily PM2:5 using VIIRS satellite AOT*, Adv. Stat. Clim. Meteorol. Oceanogr, submitted Aug 2015**

# Model Comparison

Competing submodels nested within model

<u>Global intercept:</u>

$P_t(s) = \alpha_{0,t} + \beta_{0,t}(s) + (\alpha_{1,t} + \beta_{1,t}(s))A_{i,t} + X_t(s)\gamma + \rho P_{t-1}(s) + E_t(s)$ (S1)

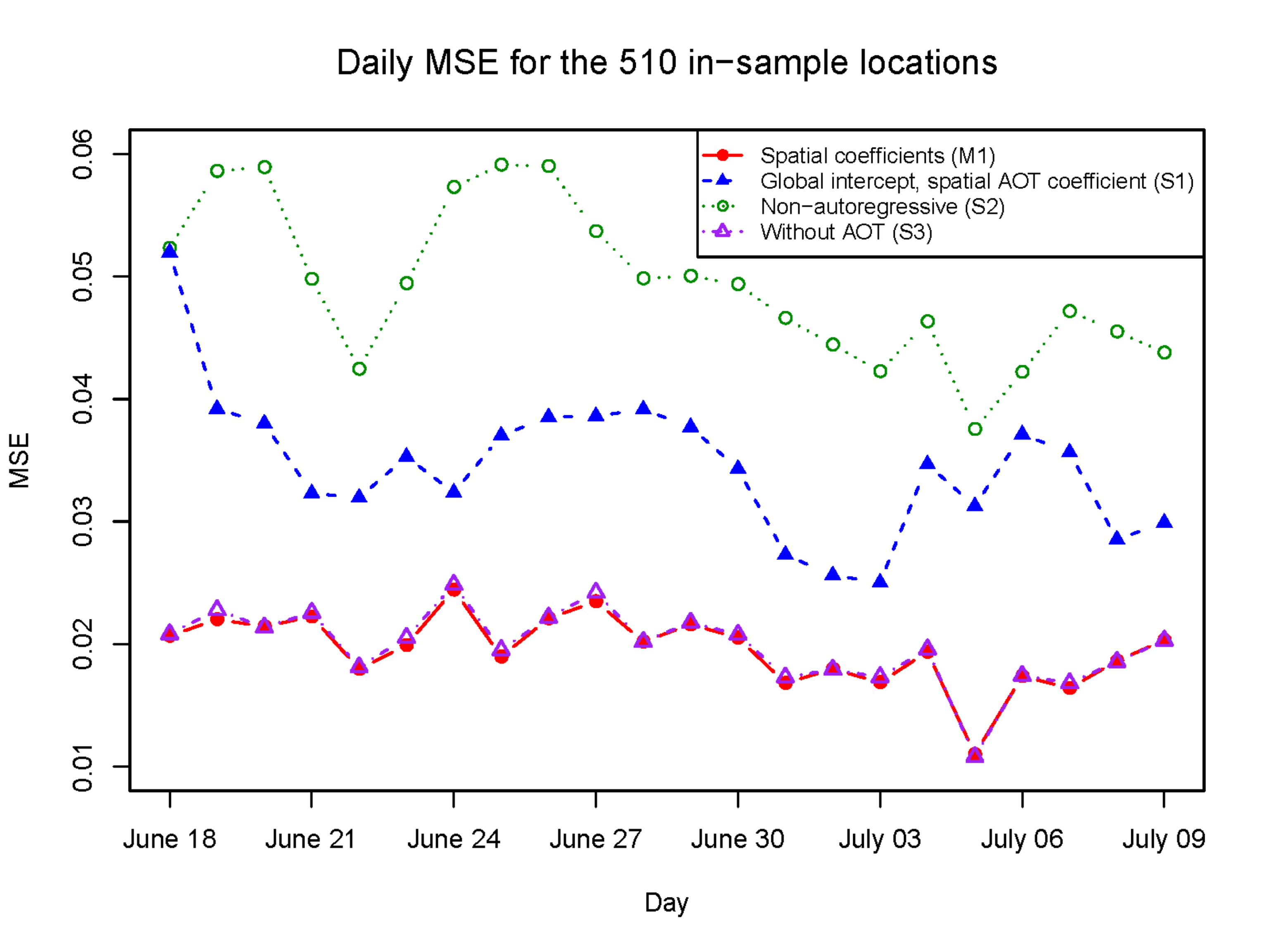
<u>Non-autoregressive:</u>

$P_t(s) = \alpha_{0,t} + \beta_{0,t}(s) + (\alpha_{1,t} + \beta_{1,t}(s))A_{i,t} + X_t(s)\gamma + \rho P_{t-1}(s) + E_t(s)$ (S2)

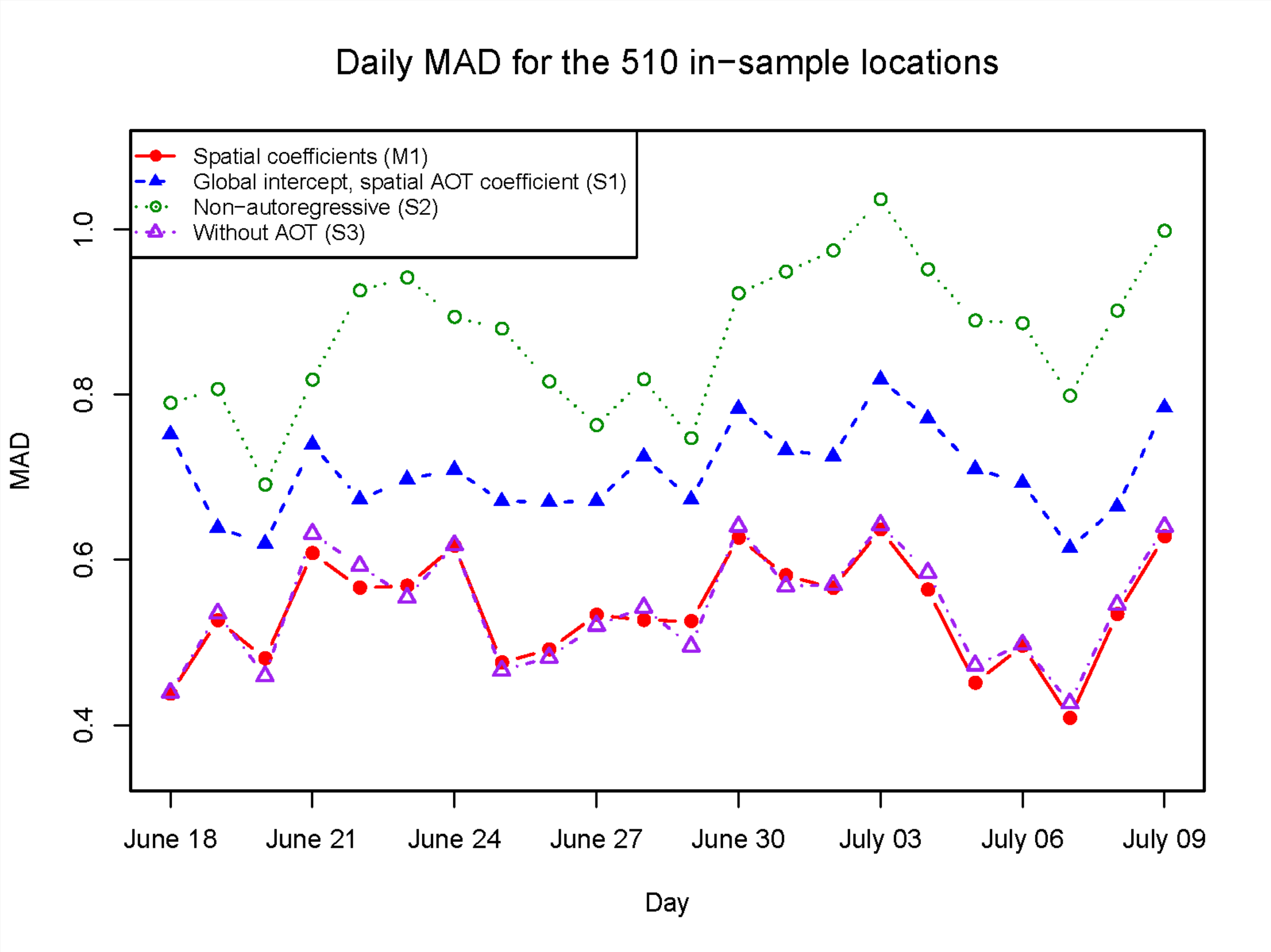
<u>Without AOT:</u>

$P_t(s) = \alpha_{0,t} + \beta_{0,t}(s) + (\alpha_{1,t} + \beta_{1,t}(s))A_{i,t} + X_t(s)\gamma + \rho P_{t-1}(s) + E_t(s)$ (S3)

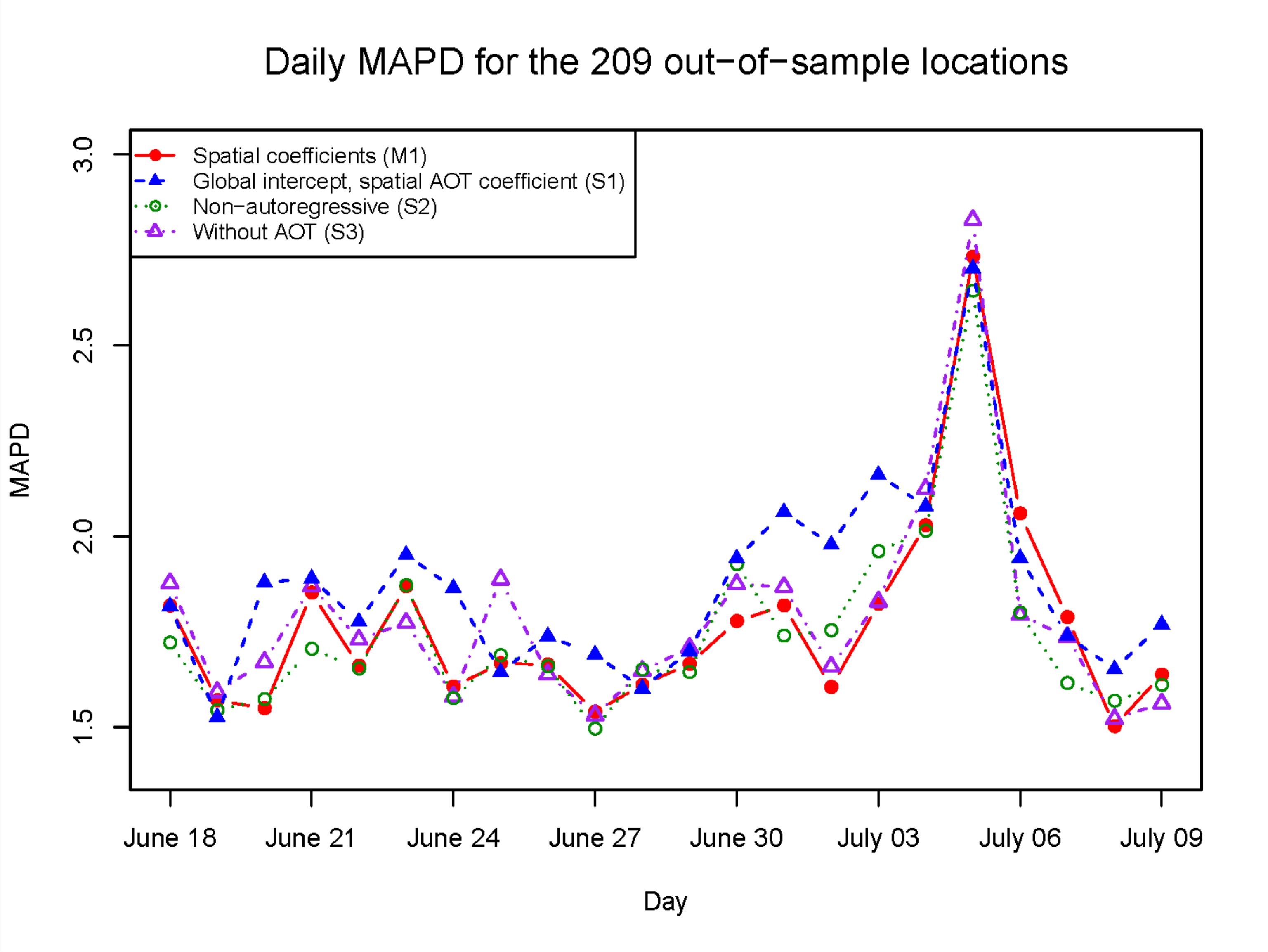
# Model Comparison



# Model Comparison



# Model Comparison



# Summary and Conclusion

- Use of VIIRS AOT in hierarchical autoregressive model to model daily average $PM_{2.5}$ concentration across CONUS
- Several submodels considered to quantify improvement in daily $PM_{2.5}$ prediction using AOT
- Model comparison results show limited predictive capability with AOT, results consistent Paciorek and Liu (2009)
- Factors likely influencing use of AOT in model
  - Missing AOT data
  - Vertical structure of aerosols – need to develop improved scaling of AOT for aerosol aloft.

# EPA considering use of ceilometer (CL-51) as viable technology for PAMS mixing layer measurement

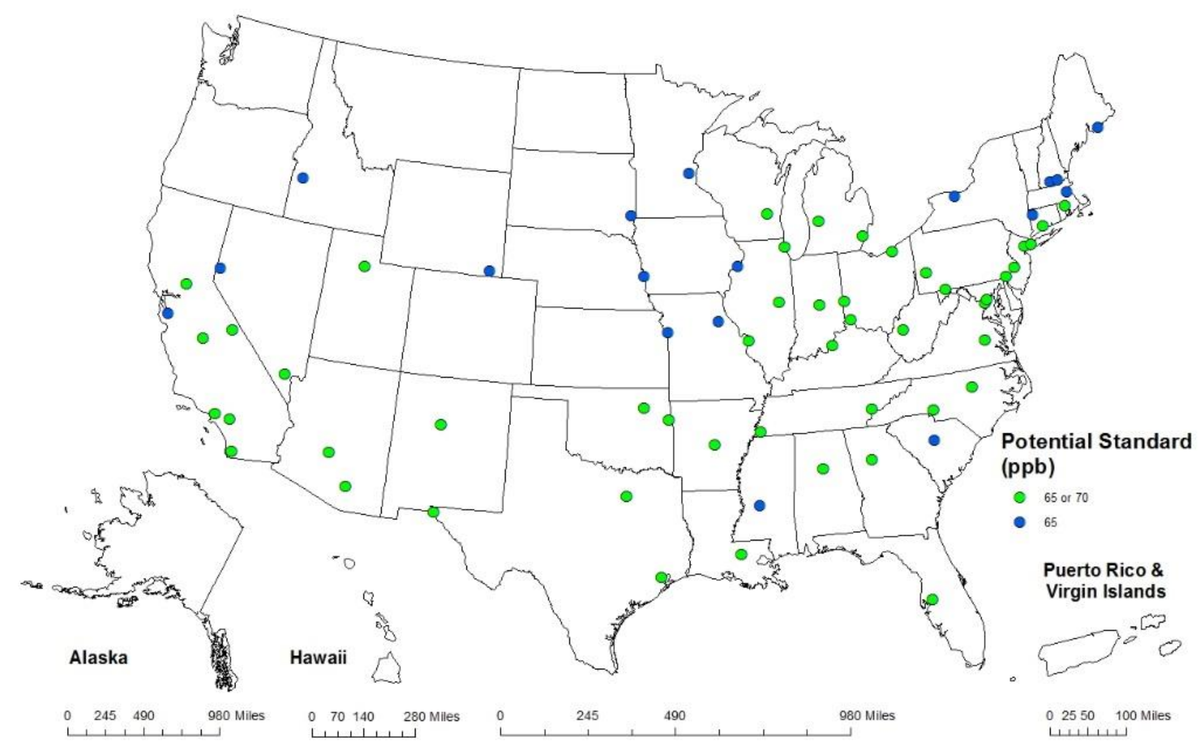
**Vaisala CL-51 Ceilometer Stated Characteristics:**

- Cloud reporting range: 0…43,000 ft (0…13km)
- Backscatter profiling range: 0…49,200 ft (0…15km)
- Can operate in all weather
- Fast measurement - 6 second measurement cycle
- Reliable automatic operation
- Good data availability
- Eye safe diode laser (LIDAR)

CL-51 positioned next to Space Science and Engineering Center, University of Wisconsin Mobile Lab

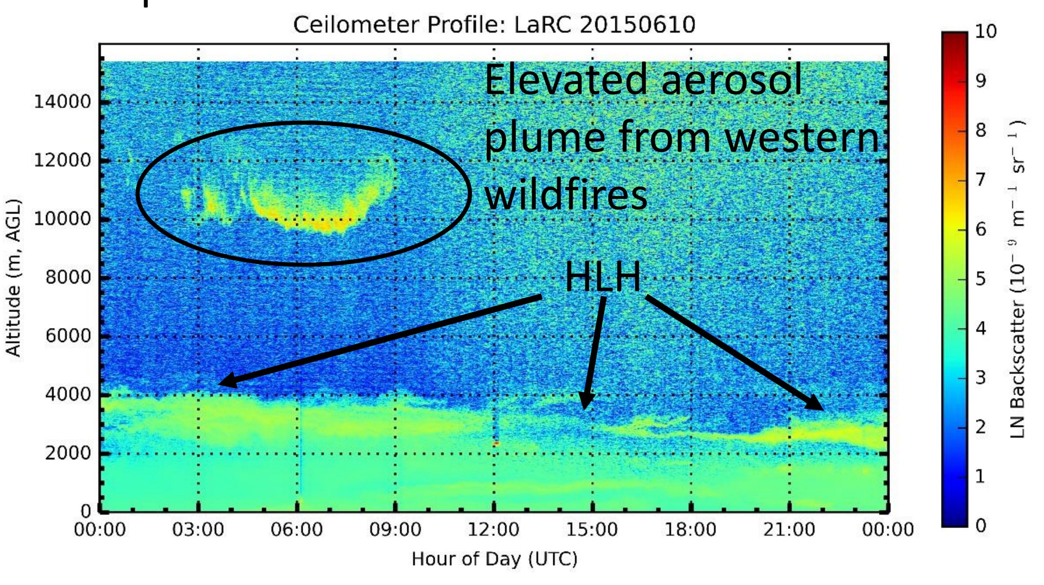
# EPA Photochemical Assessment Monitoring Station (PAMS) program

## Potential Site Locations for ceilometer (CL-51) Network




Map based on 2011-2013 ozone design values
PAMS requirements will be based on 2014-2016 data

- Future CL-51 Network would allow for continuous aerosol profile measurement to define HLH on a regional basis
- CL-51 provides backscatter profile (~910 nm) up to 15.4 km



***Disclaimer: Although this work was reviewed by EPA and approved for presentation, it may not necessarily reflect official Agency policy. Mention of products or trade names does not indicate endorsement or recommendation for use by the Agency.***

# VIIRS Aerosol Case Study: An Air Quality Forecaster's Perspective

**Amy K. Huff**
**Department of Meteorology**
**Pennsylvania State University**

STAR JPSS Annual Science Team Meeting
August 27, 2015

# Operational Air Quality Forecasting

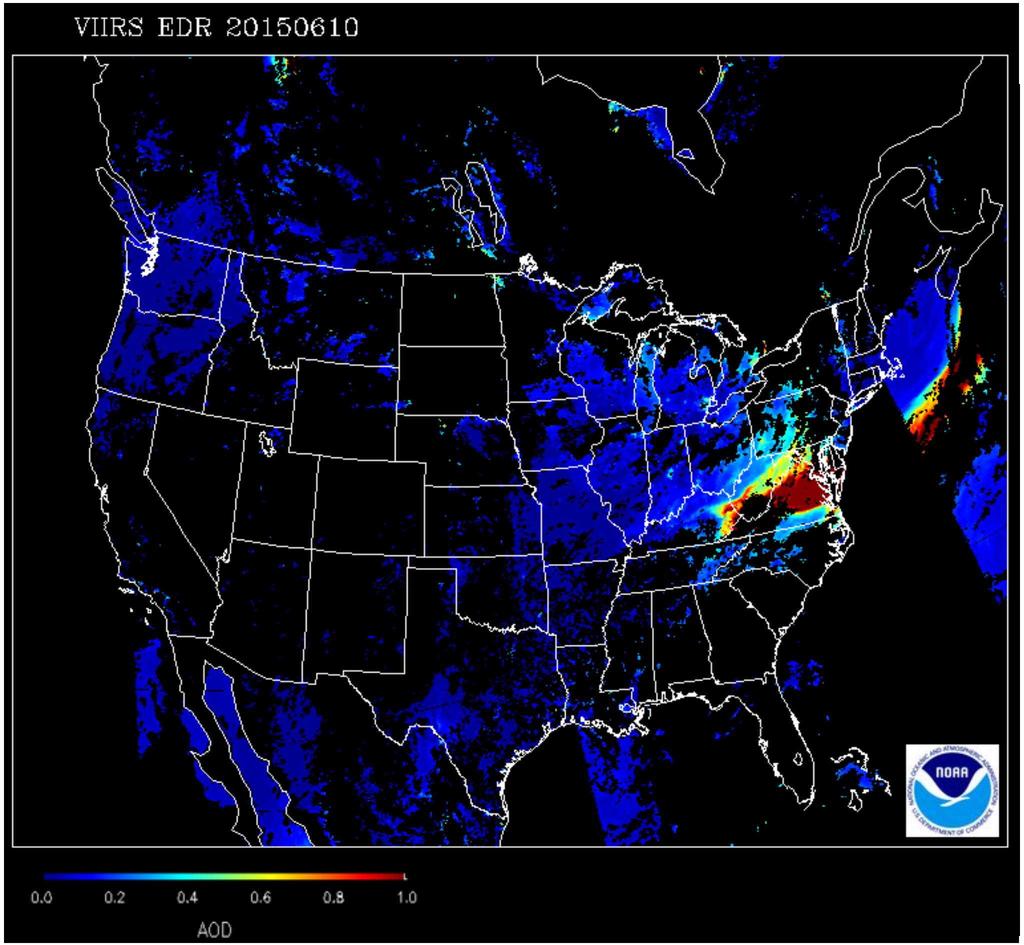
- State, local, and tribal agencies issue air quality forecasts to protect the public from the adverse health effects of criteria pollutants
  - 43 states plus Washington, DC
  - $O_3$, $PM_{2.5}$, $PM_{10}$ most commonly forecasted pollutants
  - Based on EPA's color coded Air Quality Index (AQI)
  - Air Quality Alert (AQA) issued when forecasted air quality is Code Orange or higher
  - Forecasts issued by mid-afternoon (~3 PM) for next day; some agencies do morning updates
  - Forecasts available on state and local websites and EPA's AirNow national website (http://www.airnow.gov/)

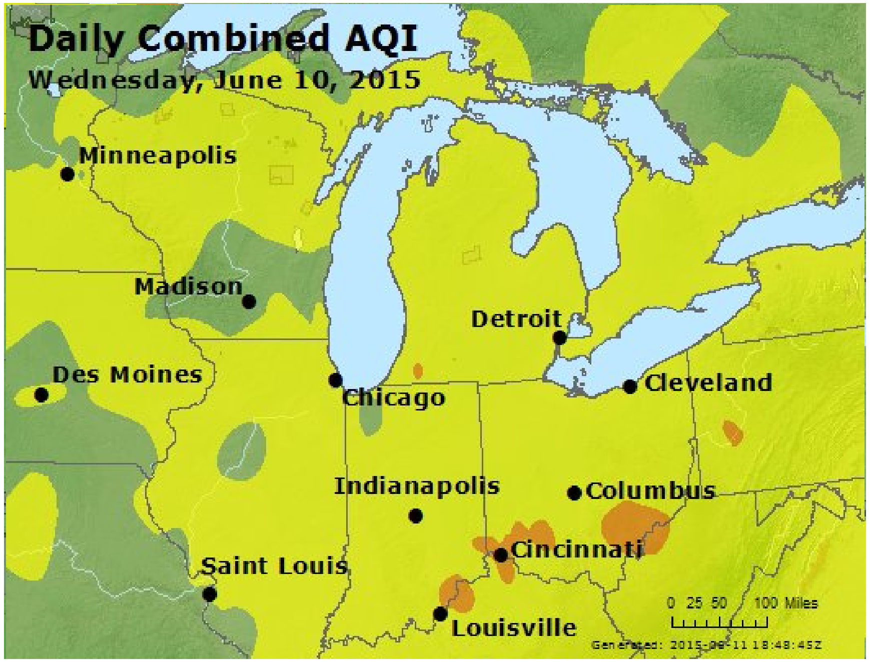
# Smoke is a Major Issue for AQ Forecasts

- $O_3$ and $PM_{2.5}$ concentrations in the Mid-Atlantic region are a primarily function of:
  - Synoptic and mesoscale weather conditions
  - Emissions of pollutants ($PM_{2.5}$) and precursors ($O_3$, $PM_{2.5}$)
  - Air mass transport (i.e., "dirty" air from upwind that is rich in pollutants and precursors)
- Smoke from wildfires, either local or transported, can have a significant impact on $O_3$ and $PM_{2.5}$
  - Most of the forecasting tools we use, including statistical and numerical models, do not include effects of smoke
  - So we rely heavily on satellite aerosol products to forecast the impacts of smoke!

# Wildfire Smoke Case Study: June 11, 2015

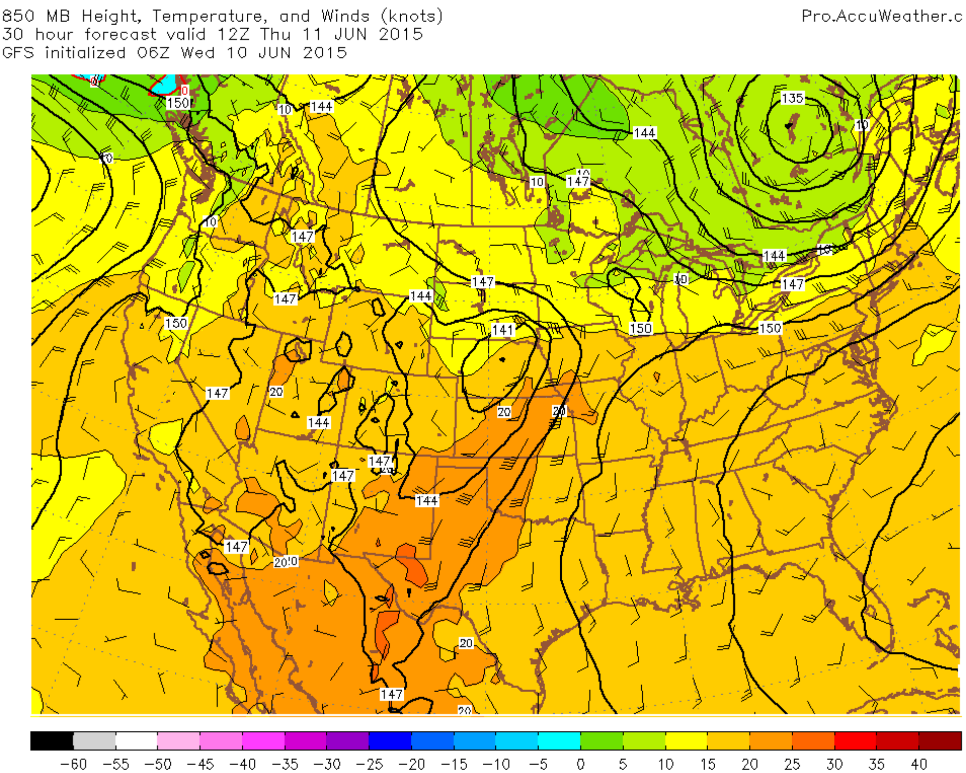
- In early June, smoke from fires burning in central Canada was transported south and east into the US, impacting the northern Plains, Great Lakes, Ohio River Valley, and Mid-Atlantic regions
- When will smoke impact surface air quality in Mid-Atlantic?

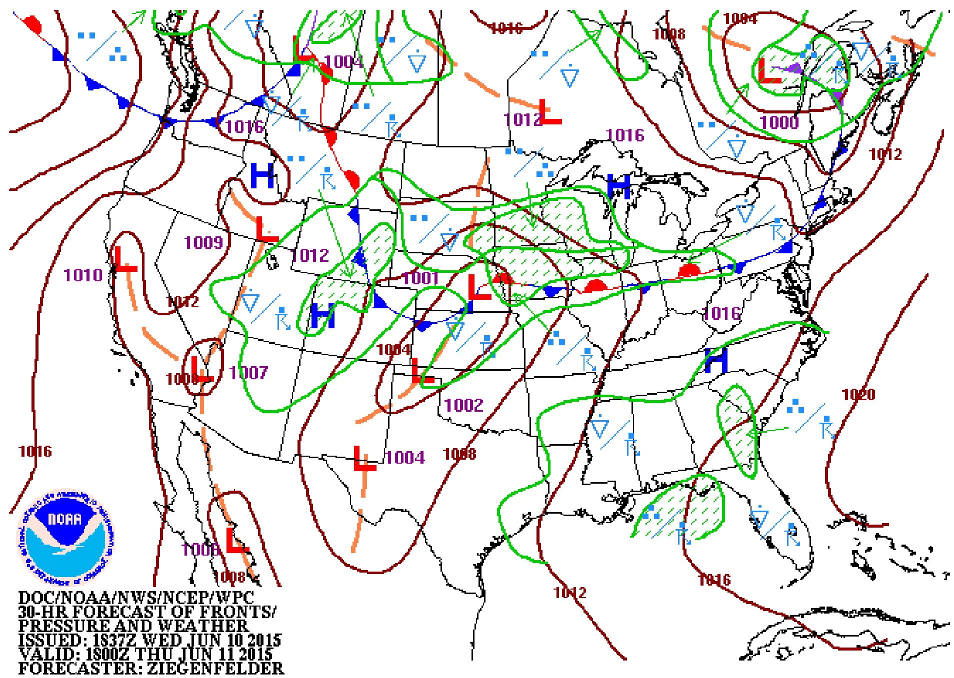


# June 11 Weather Conducive for $O_3$ Formation

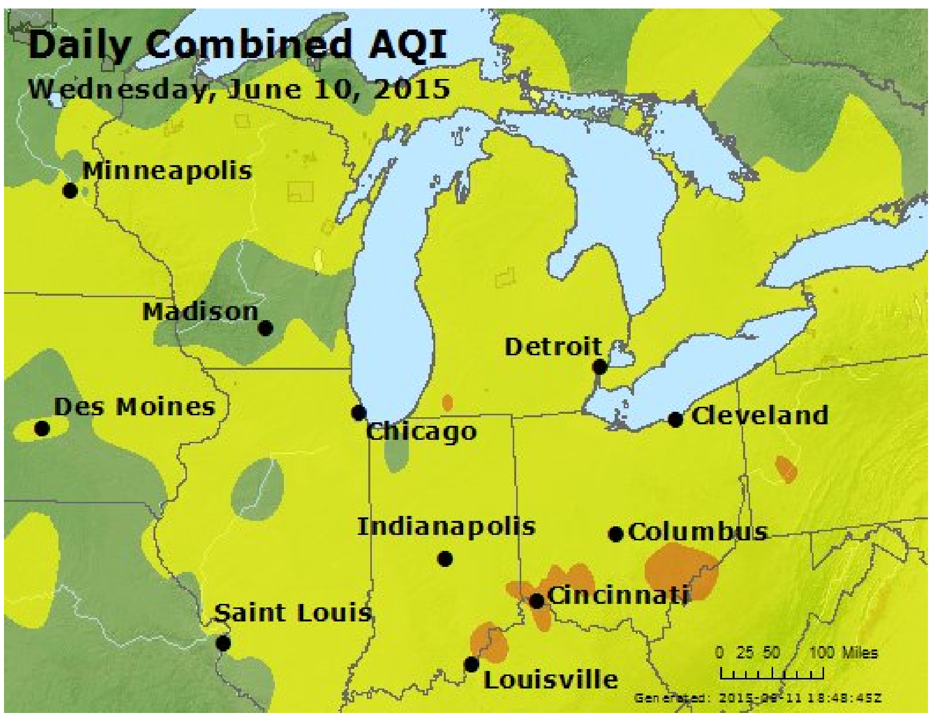
- A "ridge" of high pressure was centered over the Southeast US, with high pressure at the surface
  - Sunny skies, light surface winds, hot ($T_{max} \geq 90°F$) in Mid-Atlantic
- Weak "back door" cold front approaching in afternoon, but not expected to develop clouds/thunderstorms until evening

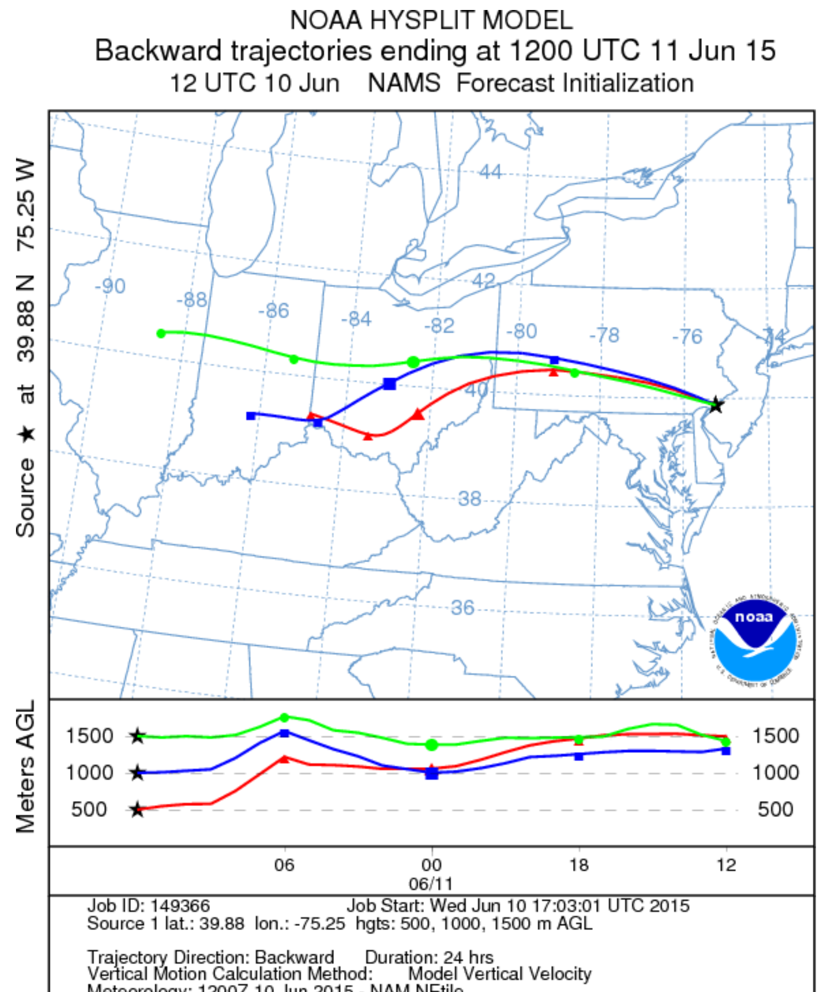


# What is Impact of Transported Smoke?

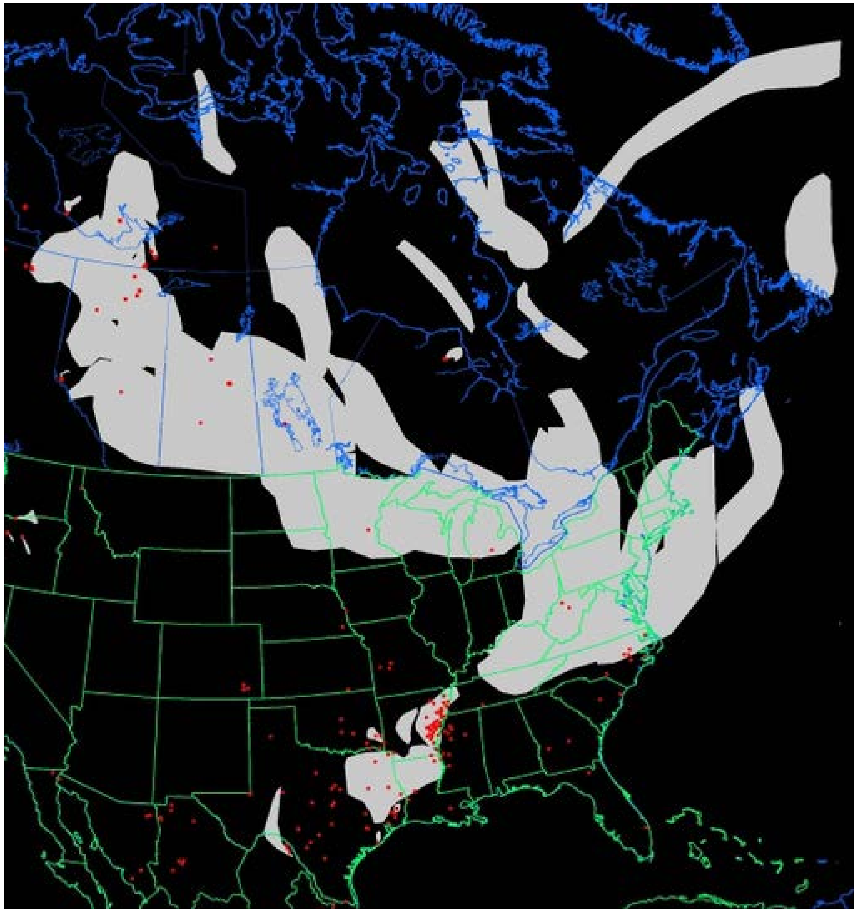
- HYSPLIT backward air mass trajectory analysis shows air that will be in PHL morning of June 11 coming from IN/OH (ORV)
- Previous day (June 10), Code Orange $O_3$ and upper Code Yellow $PM_{2.5}$ in ORV due to smoke

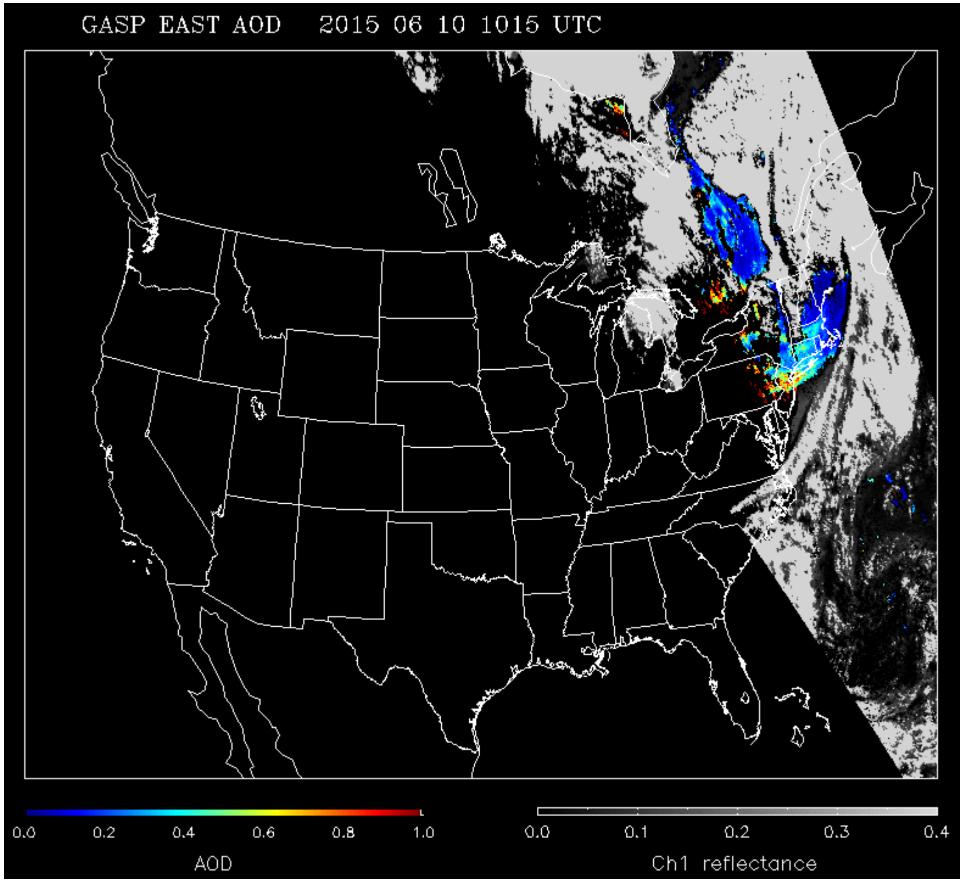


# It's 1-2 PM June 10; Forecast for June 11 is Due 3 PM

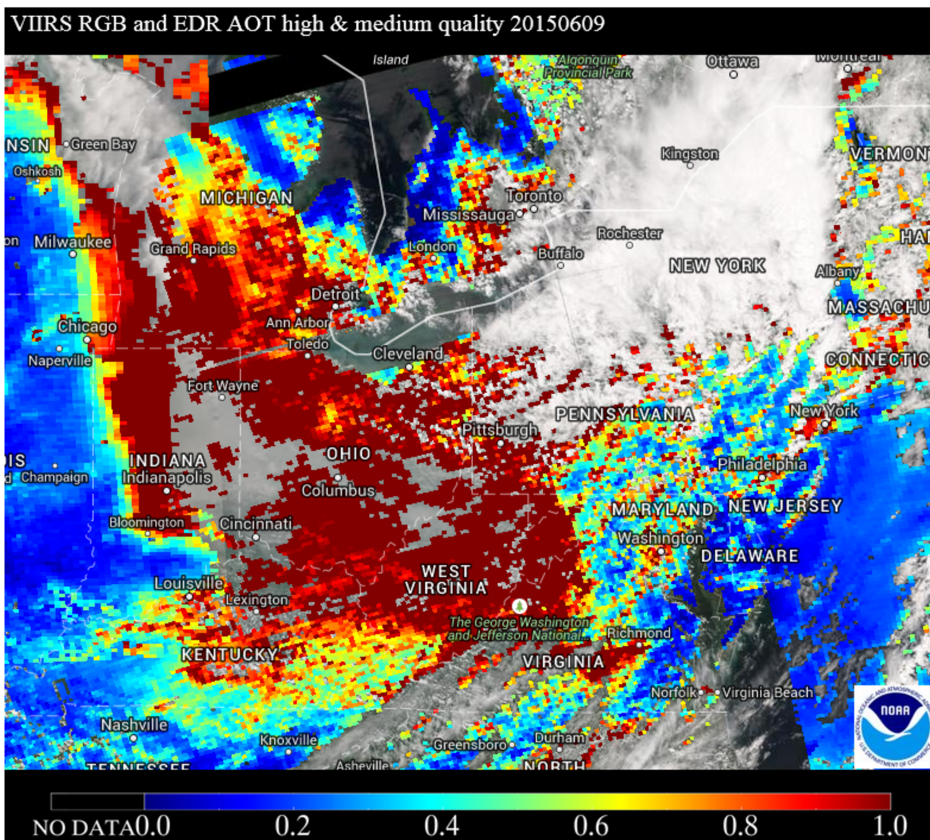
- NOAA HMS analysis shows smoke over Mid-Atlantic on June 10; no substantial impact on surface AQ yet
- GASP shows thickest plume continuing to move east

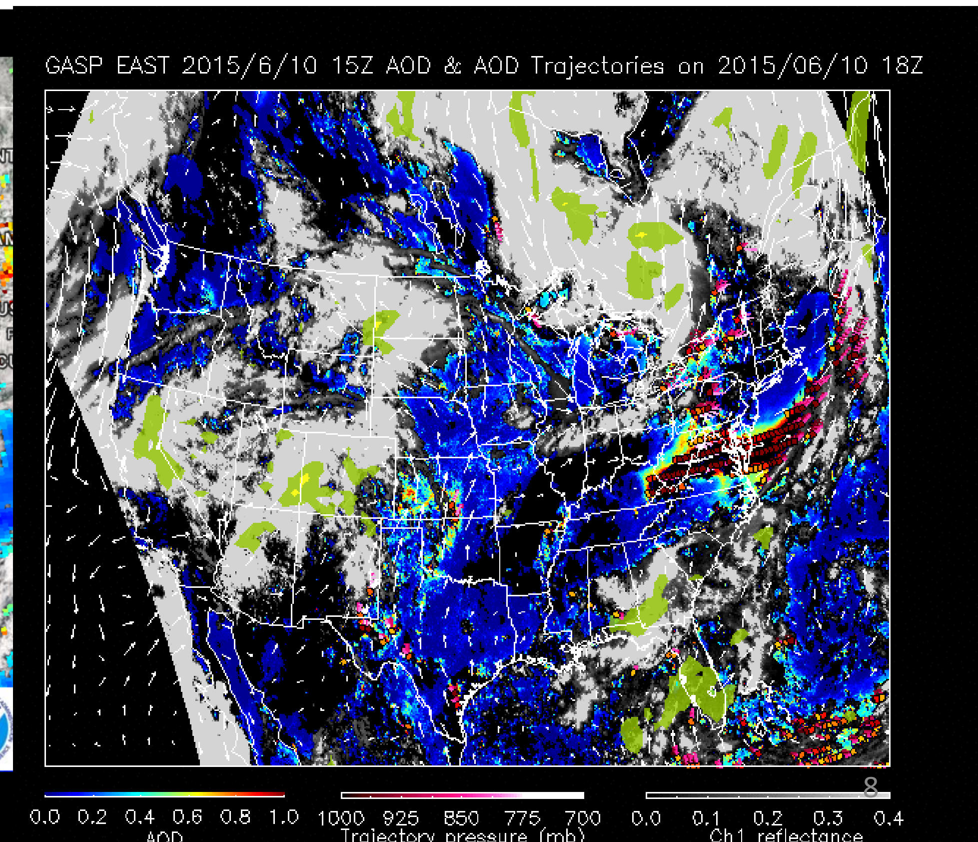




# Best Forecast Tool is IDEA Forward Trajectories

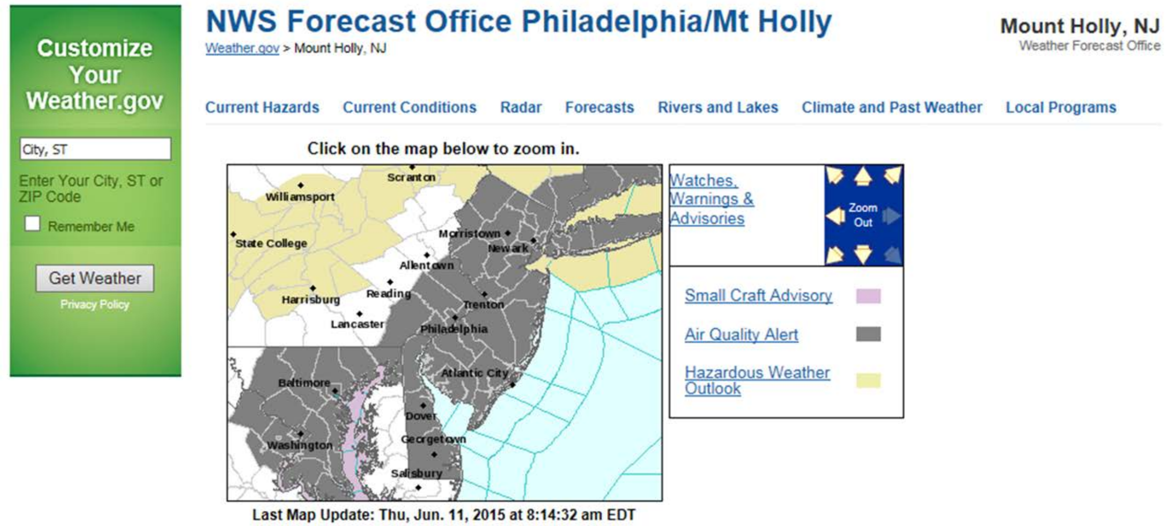
- Numerical air quality models don't include smoke in boundary conditions, so they can't help us
- Only way to determine impact of smoke is IDEA 48-hr aerosol forward trajectories; have to use GASP b/c VIIRS not available by forecast time
- VIIRS zoom-in from previous day (June 9) also helpful for seeing where thickest smoke plume is (gives idea of transport)

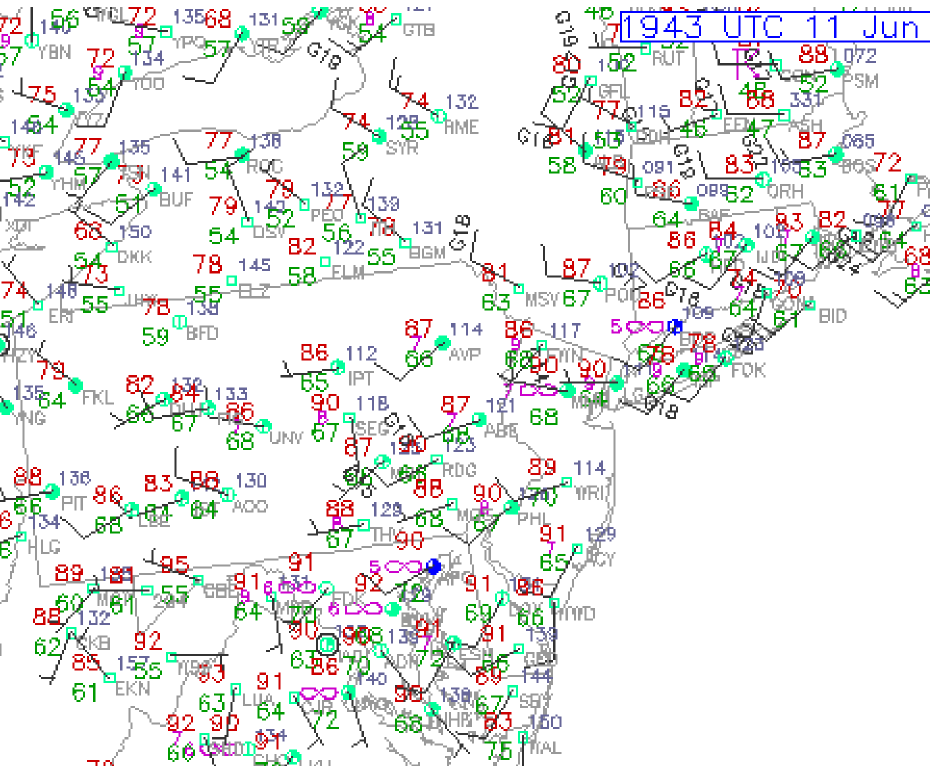


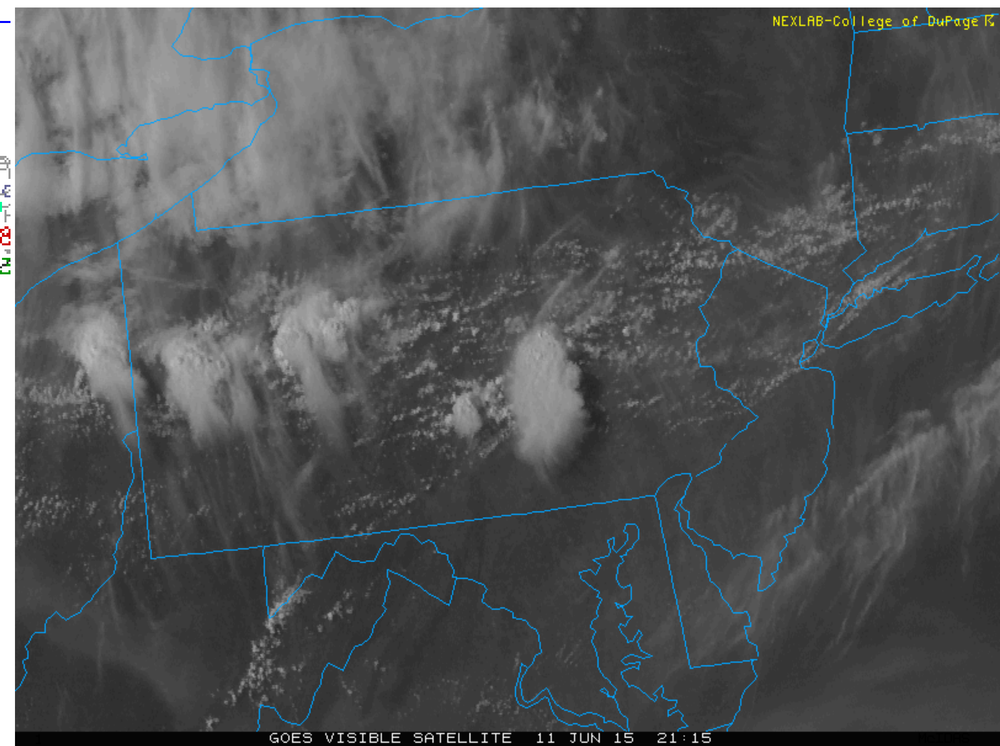



# June 11: Forecasted and Observed Code Orange $O_3$

| OBSERVED | PHL | Delaware |
|---|---|---|
| $O_3$ (ppb) | 92 | 94 |
| $PM_{2.5}$ (µg/m³) | 33.6 | 23.9 |



# Importance of VIIRS Aerosol Products for Air Quality Forecasting

- VIIRS RGB and AOD essential for identifying smoke plume transport upwind
  - Gives forecasters a heads-up when smoke may be heading toward our forecast area
  - Use in conjunction with surface $PM_{2.5}$ measurements to determine when smoke is impacting surface air quality
  - Also useful for retrospective analysis/exceptional events
- VIIRS zoom-in tool on IDEA very helpful for identifying thickest parts of smoke plume
- IDEA 48-hour aerosol trajectories **critical tool** for identifying when smoke will reach surface in forecast area
  - Need to use GASP trajectories b/c VIIRS not available by 1-2 PM

ARL

Air Resources Laboratory

Conducting research and development in the fields of air quality, atmospheric dispersion, climate, and boundary layer

NOAA

# Air Quality Forecasting and Reanalysis
## (optimizing assimilation of column AOT & sfc data)

Pius Lee[1], Youhua Tang[1], Jeff McQueen[2], Shobha Kondragunta[3], Li Pan[1], Daniel Tong[1], Hyun Kim[1], Mark Liu[3], Sarah Lu[4], Jun Wang[5], Greg Carmichael[6], Ted Russell[7], Dick McNider[8], Brad Pierce[9], Edward Hyer[10], Jim Szykman[11], Yang Liu[12], Min Huang[1], Chuanyu Xu[5], Ho-Chun Huang[5]

[1] Air Resources Lab. (ARL), NOAA Center for Weather and Climate Prediction (NCWCP), College Park, MD
[2] Environmental Modeling Center (EMC), NCEP, NCWCP, College Park, MD
[3] NOAA/ESDIS/STAR, College Park, MD
[4] State University of New York, Albany, NY
[5] I.M. Systems Group Inc. Rockville, MD
[6] College of Engineering, University of Iowa, Iowa City, IA
[7] School of Civil and Environmental Engr., Georgia Institute of Technology, Atlanta, GA
[8] Department of Atmospheric Science, University Alabama, Huntsville AL
[9] National Environmental Satellite and Information Service (NESDIS), Madison, WI
[10] Naval Research Laboratory, Monterey, CA
[11] U.S. EPA, Hampton, VA
[12] Department of Environmental Health, Emory University, Atlanta, GA

Georgia Tech

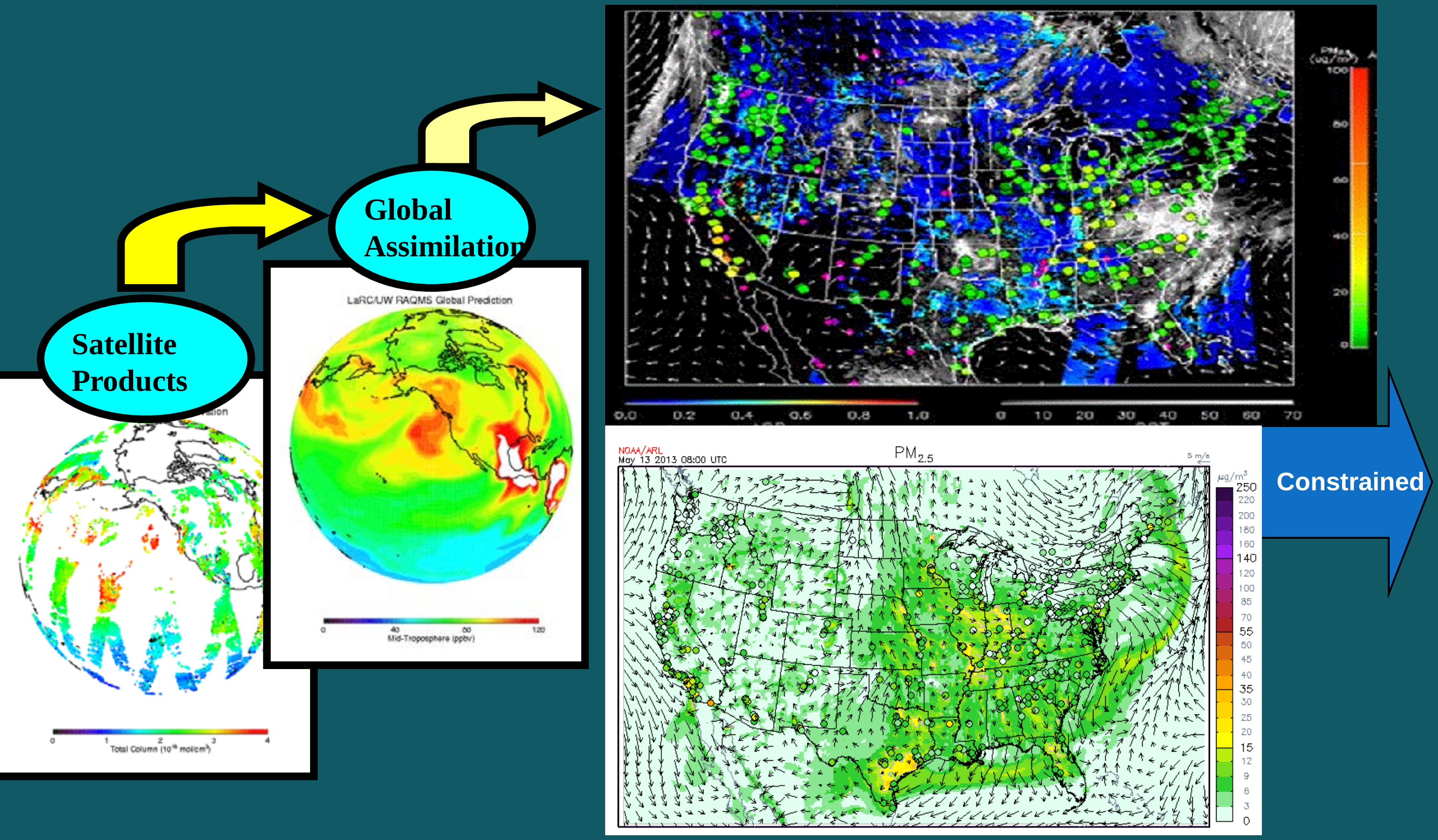
UNIVERSITY OF MARYLAND

THE UNIVERSITY OF IOWA
Iowa City, Iowa

AQAST

# Upcoming AQAST Project: Air Quality Reanalysis

## (*Translating Research to Services*)




+ AQ Assessments

+ State Implementation Plan Modeling

+ Rapid deployment of on-demand rapid-response forecasting; e.g., new fuel type,…, etc.

+ Health Impacts assessments

+ Demonstration of the impact of observations on AQ distributions

+ Ingestion of new AQAST products into operations

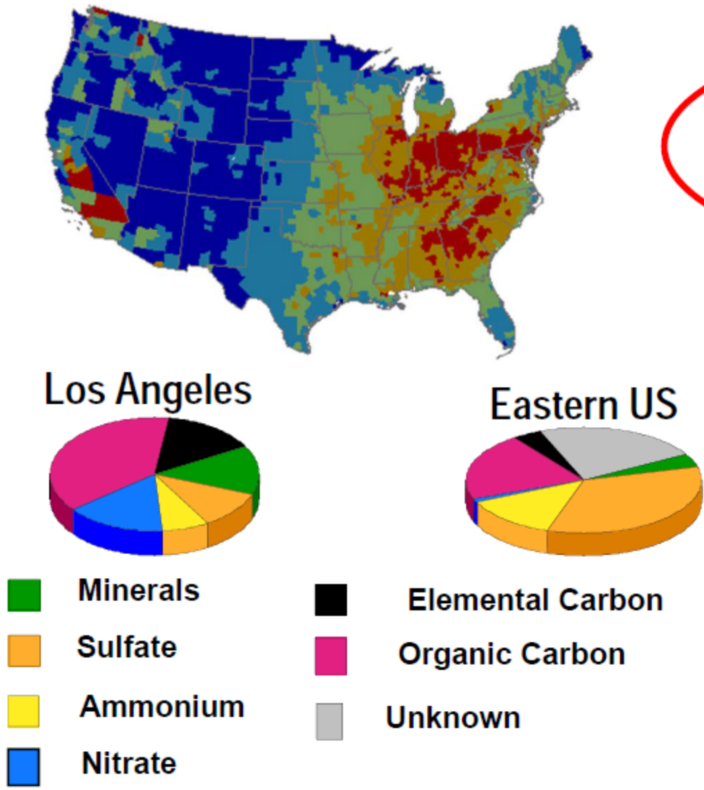
**http://acmg.seas.harvard.edu/aqast/projects.html**

**Courtesy: Dan Costa**
**“New Directions in Air Quality Research at the US EPA”**

# Public Health Burden of $PM_{2.5}$

**(Fann et al., 2011)**

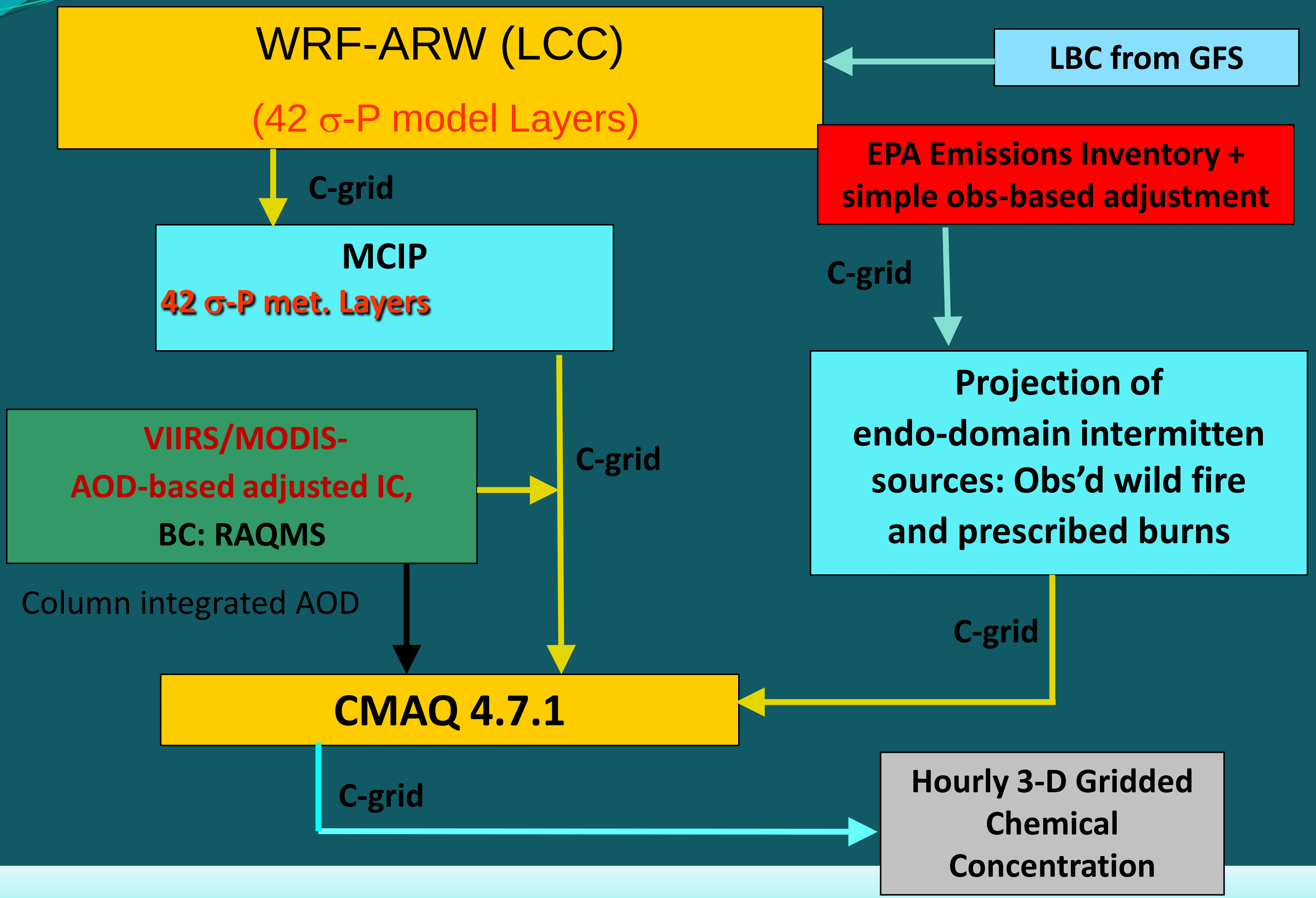
Percentage of $PM_{2.5}$ related deaths due to 2005 air quality levels by county




| Summary of National $PM_{2.5}$ impacts due to 2005 air quality | |
|---|---|
| Excess mortalities (adults)[A] | 130 to 320,000 |
| Percentage of all deaths due to $PM_{2.5}$[B] | 5.4% |
| *Impacts among Children* | |
| ER visits for asthma (<18 yr) | 110,000 |
| Acute bronchitis (age 8-12) | 200,000 |
| Exacerbation of asthma (age 6-18) | 2,500,000 |

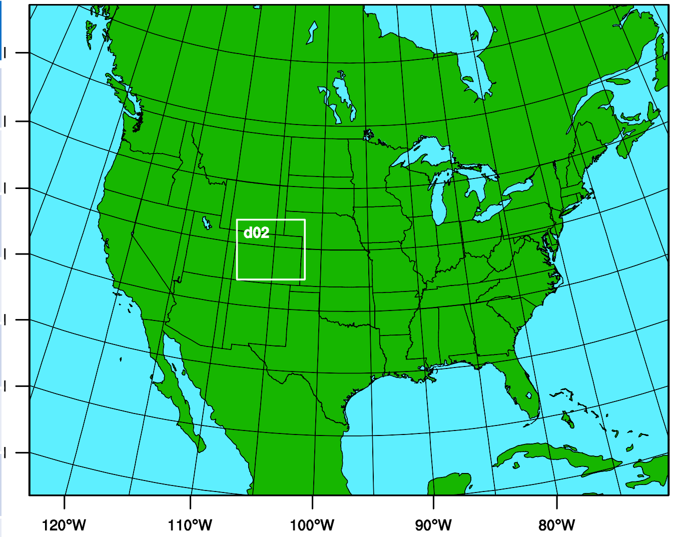
[A] Range reflects use of alternate PM mortality estimates
[B] Population-weighted value using Krewski et al. (2009) PM mortality estimates

# WRF_ARW-MCIP-CMAQ forward model



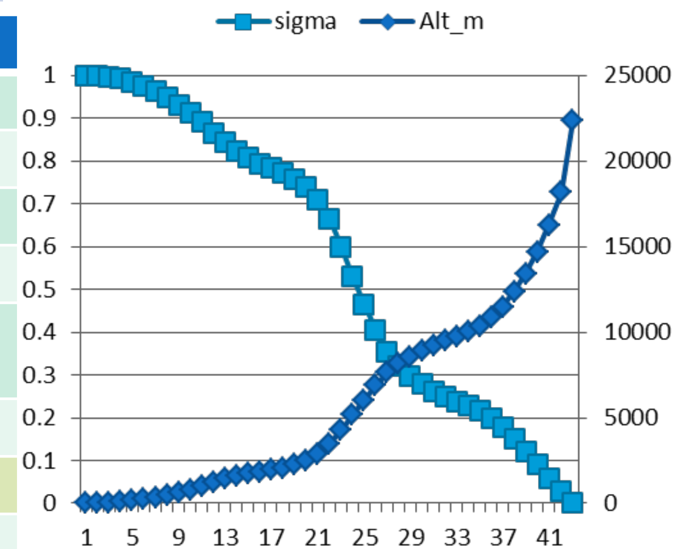
# WRF_ARW-MCIP-CMAQ model physics and chemistry options

| WRF-ARW | Both North America (12 km) & CONUS (4 km) |
|---|---|
| Map projection & grid | Lambert Conformal & Arakawa C staggering |
| Vert. co-ordinate | 42 σ-p unevenly spaced levels |
| advection | RK3 (Skamarock and Weisman (2008)) |
| SW & LW radiation | RRTMG (Iacono et al. 2008)) |
| PBL Physics | Mellor-Yamada-Janjic (MYJ) level 2.5 closure |
| Surface layer scheme | Monin-Obukhov Similarity with viscous sub-layer |
| Land Surface Model | NCEP NOAH |
| Cloud Microphysics | Thompson et al. (2008) |
| Cloud convective mixing | Betts-Miller-Janjic Mass adjustment |

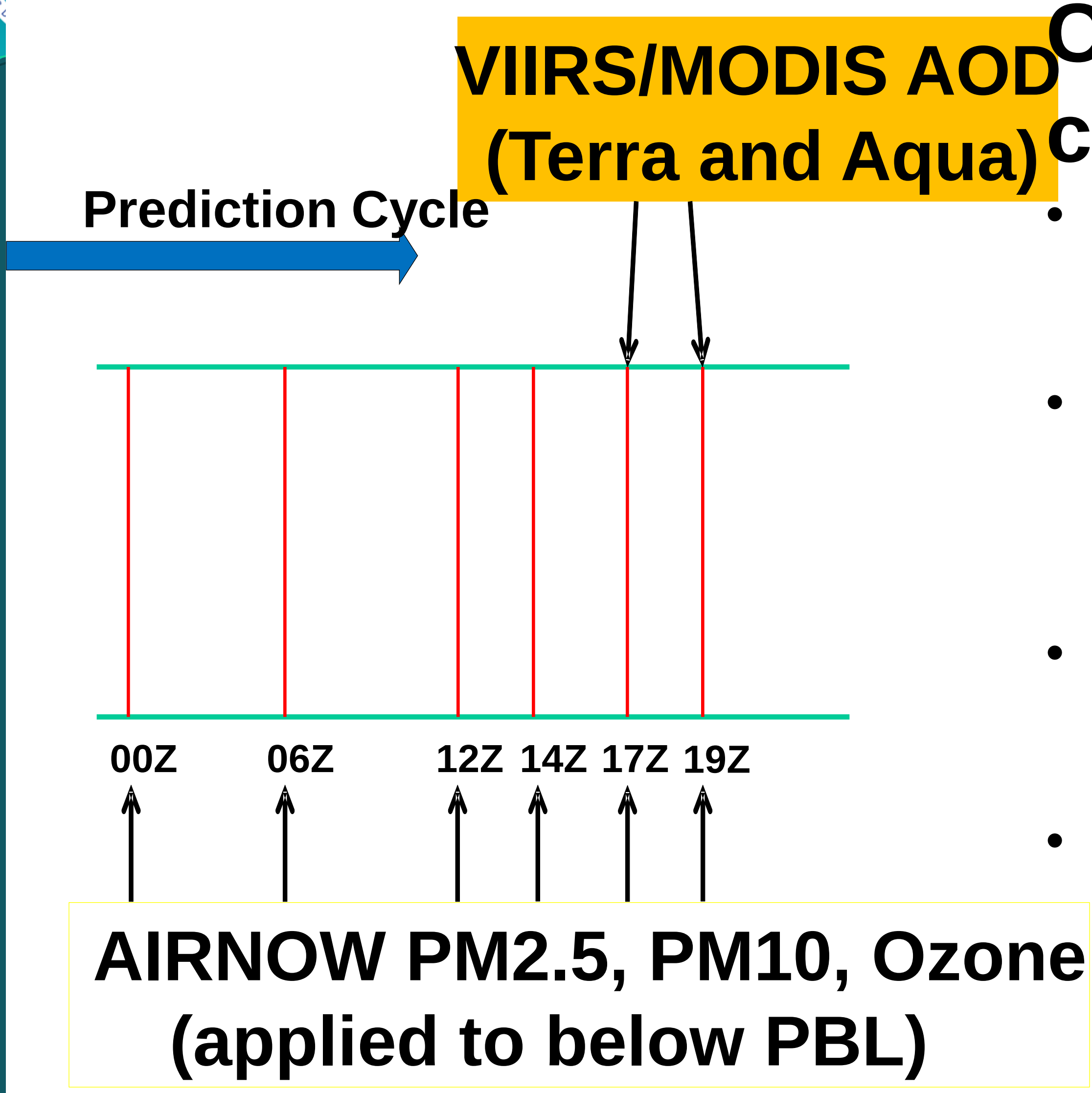



**AQ forecast**: ^12 km nested to 4 km

| CMAQ4.7.1 | Both CONUS(12 km) & SENEX (4 km) |
|---|---|
| Map projection & grid | Lambert Conformal & Arakawa C staggering |
| Vert. co-ordinate | 42 σ-p unevenly spaced levels |
| Gas chemistry | Cb05 with 156 reactions |
| Aerosol chemistry | Aero5 with updated evaporation enthalpy |
| Anthropogenic emission | 2008NEI as base year, mobile projected using AQS*, area and off-road used CSPR^, point source uses 2012 CEM data |
| | WRAP oil and gas emissions data |
| Biogenic emission | BEIS-3.14 |
| Lateral BC | RAQM (B. Pierce) |




**42 vertical layers**




# CMAQ base v5.0.2: cb05_ae5)

- 2008 anthropogenic emission inventory projected to 2011
- NOAA HMS (hazard mapping system) fire emission with Bluesky algorithm
- GOES cloud fraction adjustment provided by U. of Alabama at Huntsville
- RAQMS lateral boundary condition every 6 hours.

# Optimal Interpolation (OI)

- OI is a sequential data assimilation method. At each time step, we solve an analysis problem

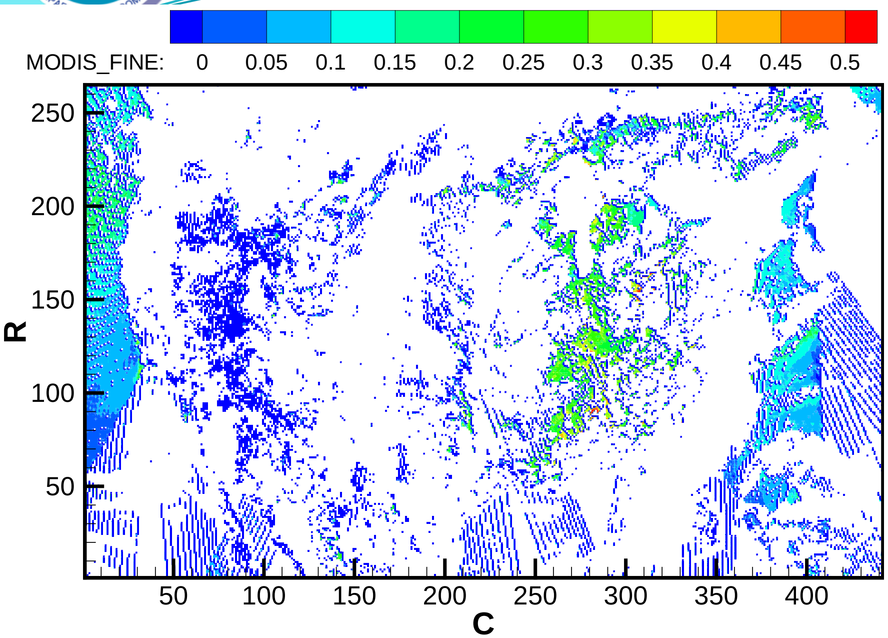
$$X^a = X^b + BH^T(HBH^T + O)^{-1}(Y - HX)$$

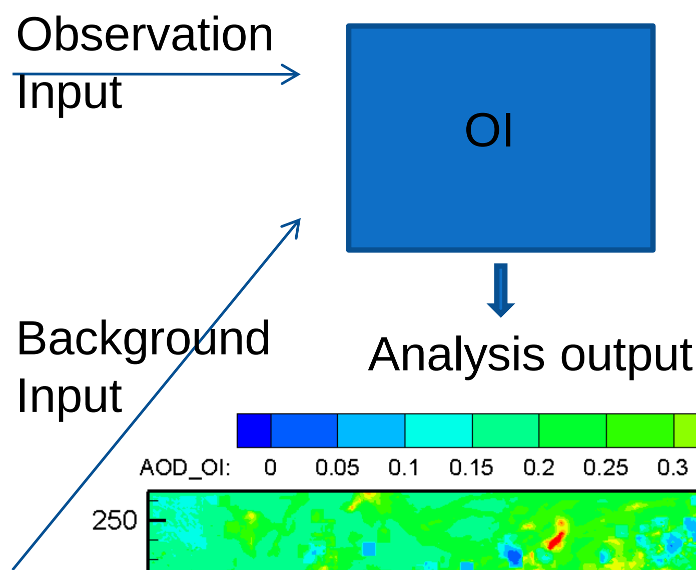
- We assume observations far away (beyond background error correlation length scale) have no effect in the analysis
- In the current study, the data injection takes place at 1700Z daily

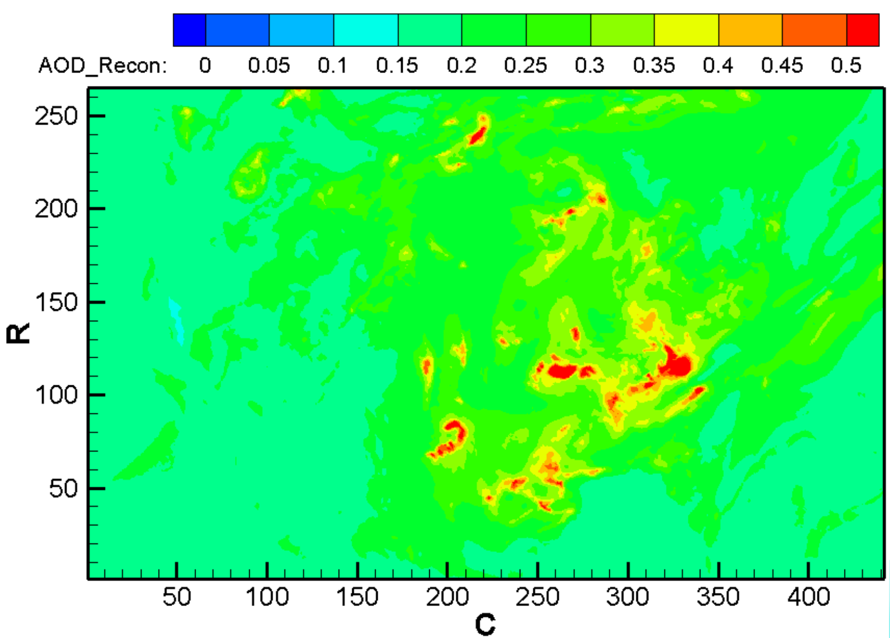
Chai et al. *JGR* 2006

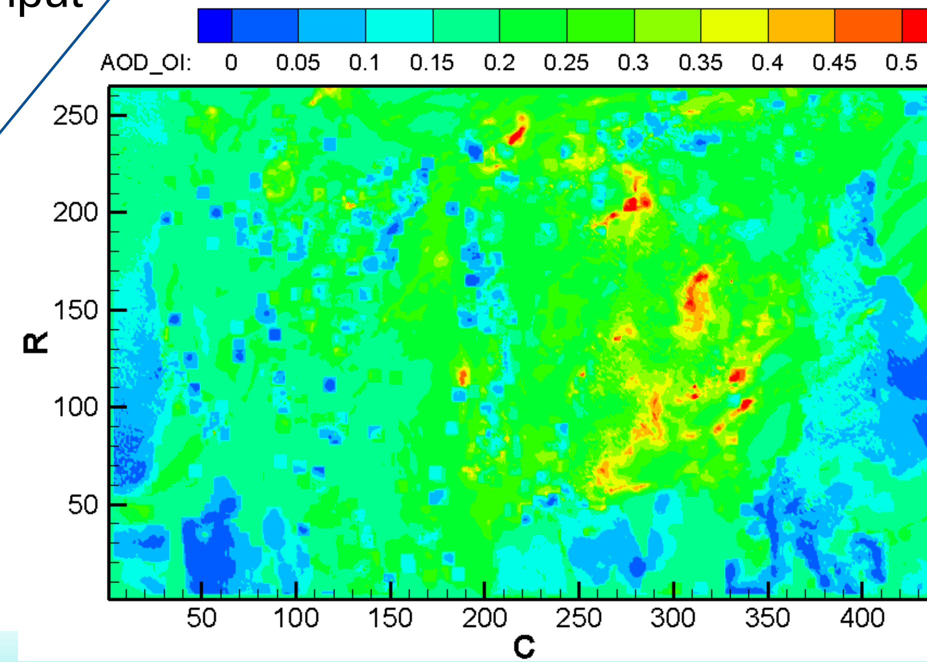
# Objective (A): Improve PM forecast

Methodology of OI: Take account for background input; Obs; and physical processes from model



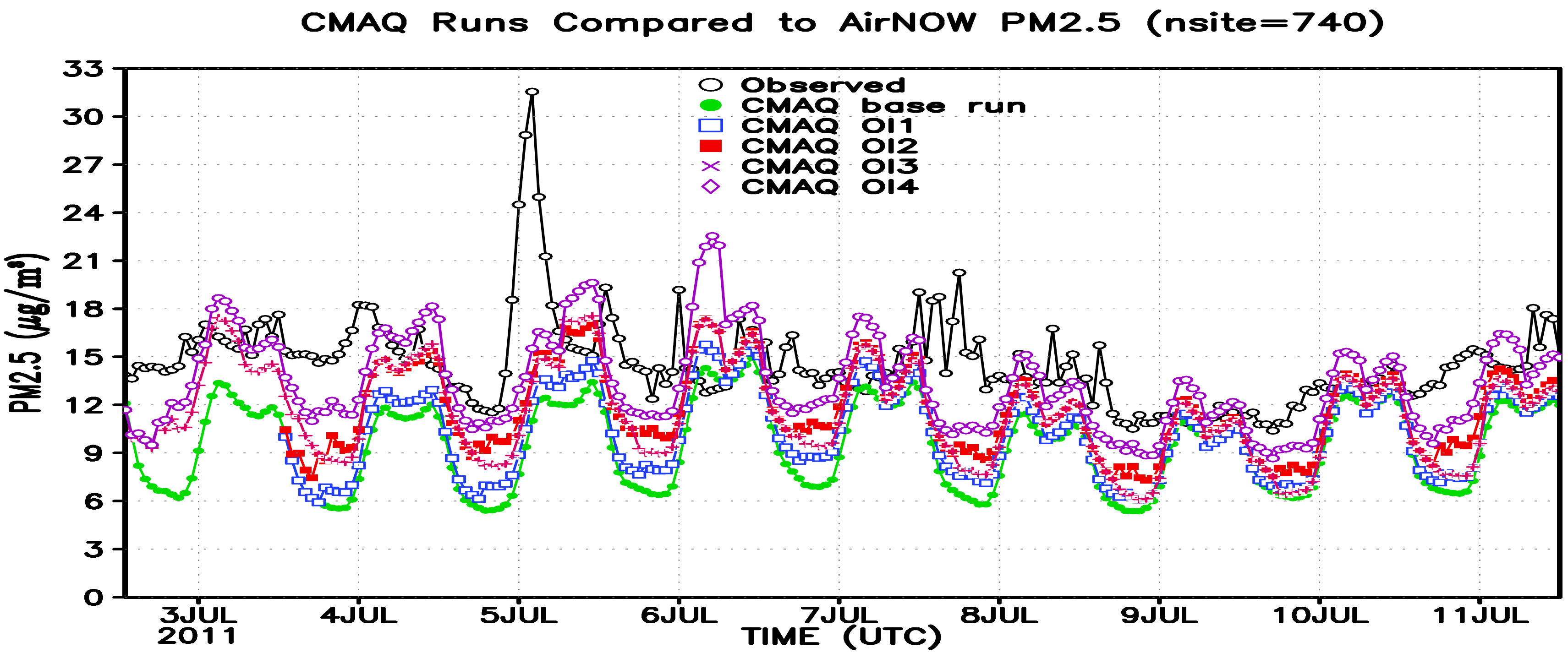



**Hourly Statistic Results for CONUS 12Z, 07/06/2011- 12Z, 07/07/2011**

| Cases | $O_3$ | PM2.5 |
|---|---|---|
| Base case | R=0.53 MB=2.54 | R=0.23 MB= -7.14 |
| OI1 | R=0.56 MB=2.36 | R=0.24 MB= -2.63 |
| OI2 | R=0.58 MB=1.06 | R=0.39 MB= -1.33 |
| OI3 | R=0.52 MB=2.08 | R=0.36 MB= -1.89 |
| OI4 | R=0.56 MB=1.55 | R=0.40 MB= -0.11 |



| | Aqua-MODIS | Suomi NPP-VIIRS |
|---|---|---|
| **Orbit altitude** | 705 km | 824 km |
| **Equator crossing time** | 13:30 LT | 13:30 LT |
| **Granule size** | 5 minutes | 86 seconds |
| **Swath** | 2330 km | 3040 km |
| **Sensor zenith angle range** | ±64° | ±70° |
| **Valid solar zenith angle (for high quality)** | < 82° | ≤ 65° |
| **Sensor bands used for aerosol retrieval** | 0.412, 0.466, 0.554, 0.646, 0.856, 1.24, 1.63, 2.11 μm | 0.412, 0.445, 0.488, 0.555, 0.672, 0.746, 0.865, 1.24, 1.61, 2.25 μm |
| **Pixel size, nadir** | 0.25, 0.5, and 1 km | 0.375 and 0.75 km |
| **Bow-tie effects** | Yes | No |
| **Product resolution, nadir** | 10 km | 6 km (AOT and Angstrom exponent)<br>0.75 km (Suspended matter) |
| **Product resolution, edge** | 40 km | 10 km (AOT and Angstrom exponent)<br>1.2 km (Suspended matter) |
| **Products, land (vegetated regions)** | AOT (Dark Target Approach) | AOT, Angstrom exponent, Suspended matter |
| **Product, land (deserts, urban regions)** | AOT, Angstrom exponent, Dust single scattering albedo (Deep Blue Approach) | None |
| **Products, ocean** | AOT (7 wavelengths), Size (fine mode fraction) | AOT (11 wavelengths), Angstrom exponent, Suspended matter |
| **Global gridded product** | Level 3 daily, 8-day, monthly mean | None |

Courtesy: C. Hsu et al.

## Summary

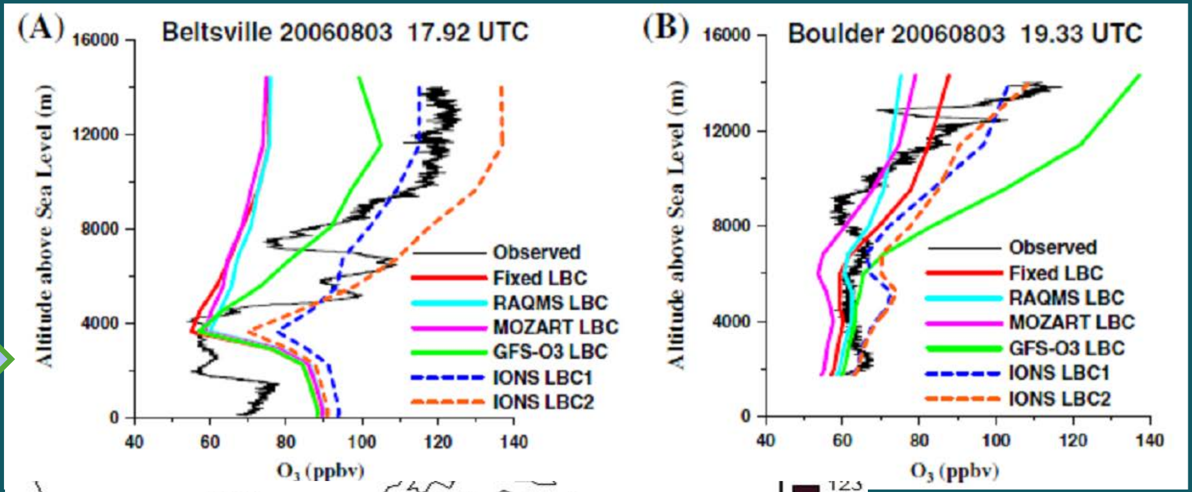
- The optimal interpolation (OI) assimilation combining AirNOW surface measurements and VIIRS/MODIS AOD yielded significantly better results than the base case, especially on reducing mean biases, and the OI technique is sensitive to its uncertainty setting.
- The assimilation relies on the temporally and spatially available measurement data, which is always limited.
- Some of our assumptions, such as the aerosol speciation ratios and vertical distribution, need to be further verified.

# *EXTRA SLIDES*

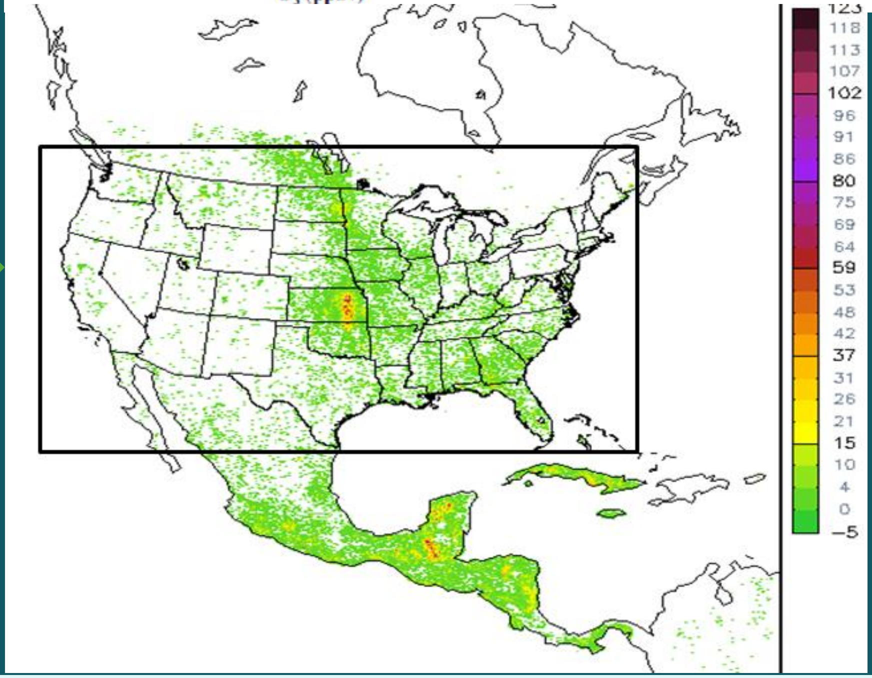
Contact:
Pius.Lee@noaa.gov
http://www.arl.noaa.gov/

**Next data set**
**To be include**
**In data assimilation?**

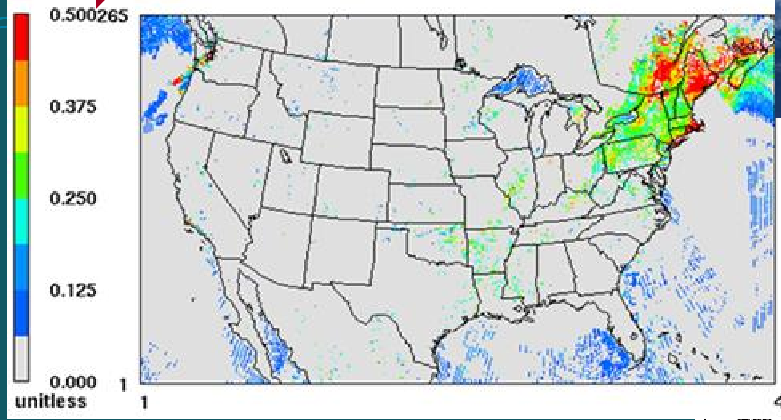
**MLS & MODIS AOD from global Model: e.g., RAQMS**



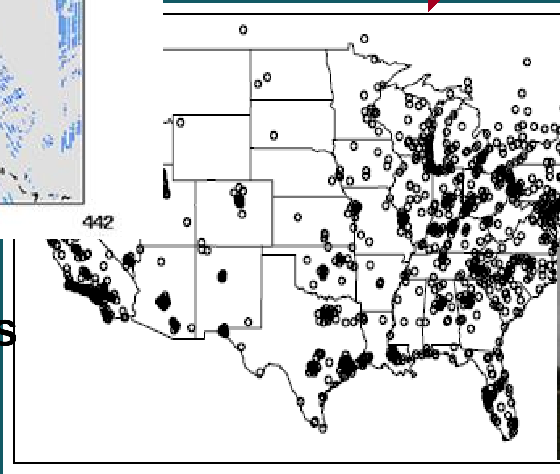

**Exo-domain as well as endo-domain wild fires & prescribed burns**



## MODIS obs




## AIRNow



## Cloud-obs Photolysis rates

**GOES-MCIP INTERFACE**

Cloud transmissivity (calculated from satellite retrieved cloud albedo), cloud top pressure, and cloud fraction are prepared for input to MCIP

**MODIFIED MCIP**

GOES retrievals replaces MM5 cloud information being passed to CMAQ. Cloud fraction, transmissivity, cloud base and top heights are passed to CMAQ.

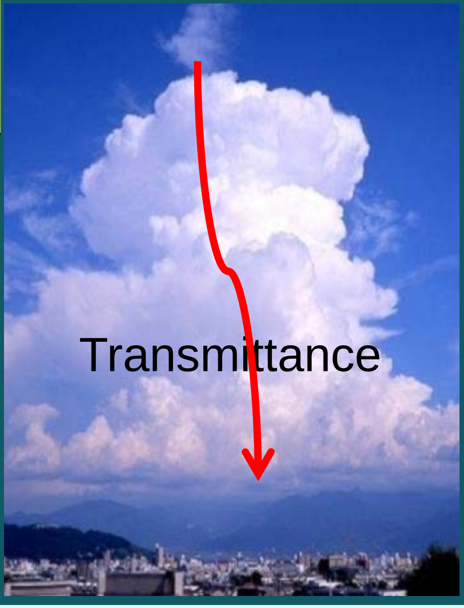
**PHOT in CMAQ**

In subroutine PHOT, clear sky photolysis rates will be adjusted for cloud cover based on GOES cloud fraction and cloud transmissivity information.

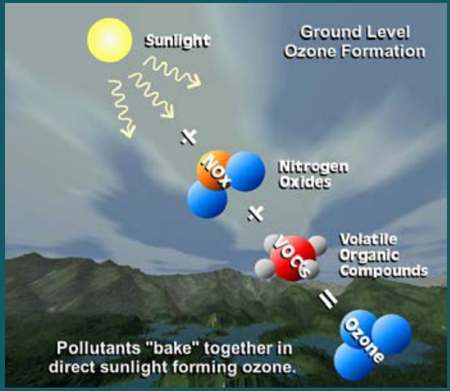
Interpolated in between.

Cloud Base According to Lifting Condensation Level

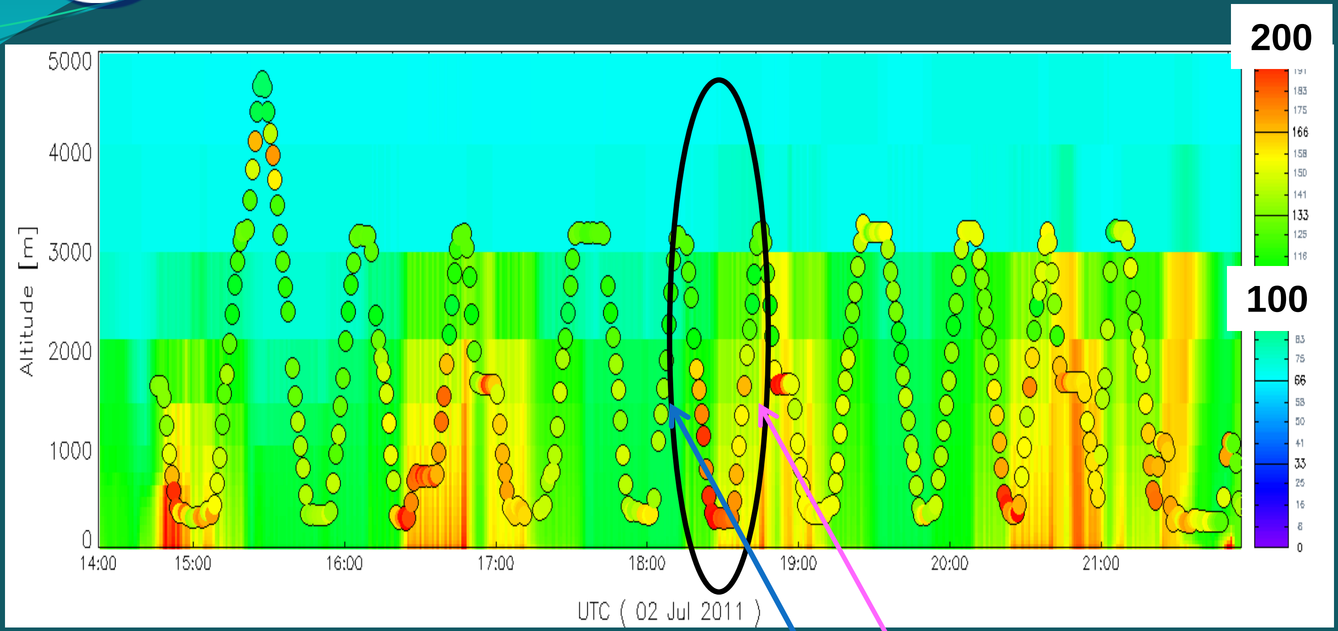
$$T_c = B / \ln\left[\frac{A\varepsilon}{wp_0}\left(\frac{T_0}{T_c}\right)^{1/k}\right]$$




## Isoprene & PAR



# CO (ppb) along the P3 Flight – July 2 2011: AOD_DA case vs. Obs




P3 Three and a half loops:
Beltsville
Padonia
Fairhill
Aldino
Edgewood
Essex
Chesapeake Bay