MAIAC Retrievals over Land and Ocean

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ICAP Meeting

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MAIAC: General Information

Status:

- *MAIAC is at MODAPS; C6+ re-processing of MODIS started (MCD19)*

Products (gridded):

- ***Atmosphere****: WV, CM, AOD, ~~SSA~~, aerosol type (background/smoke/dust), FMF (over water) @1km resolution;*
- ***Land Surface****: spectral BRDF (RTLS model, naturally gap-filled), BRF (surface reflectance) @1km and 500m in bands 1-12, albedo;*
- ***Detected Snow****: snow grain size, and sub-pixel snow fraction (1km);*

Multi-Angle Implementation of Atmospheric Correction (MAIAC)

Features

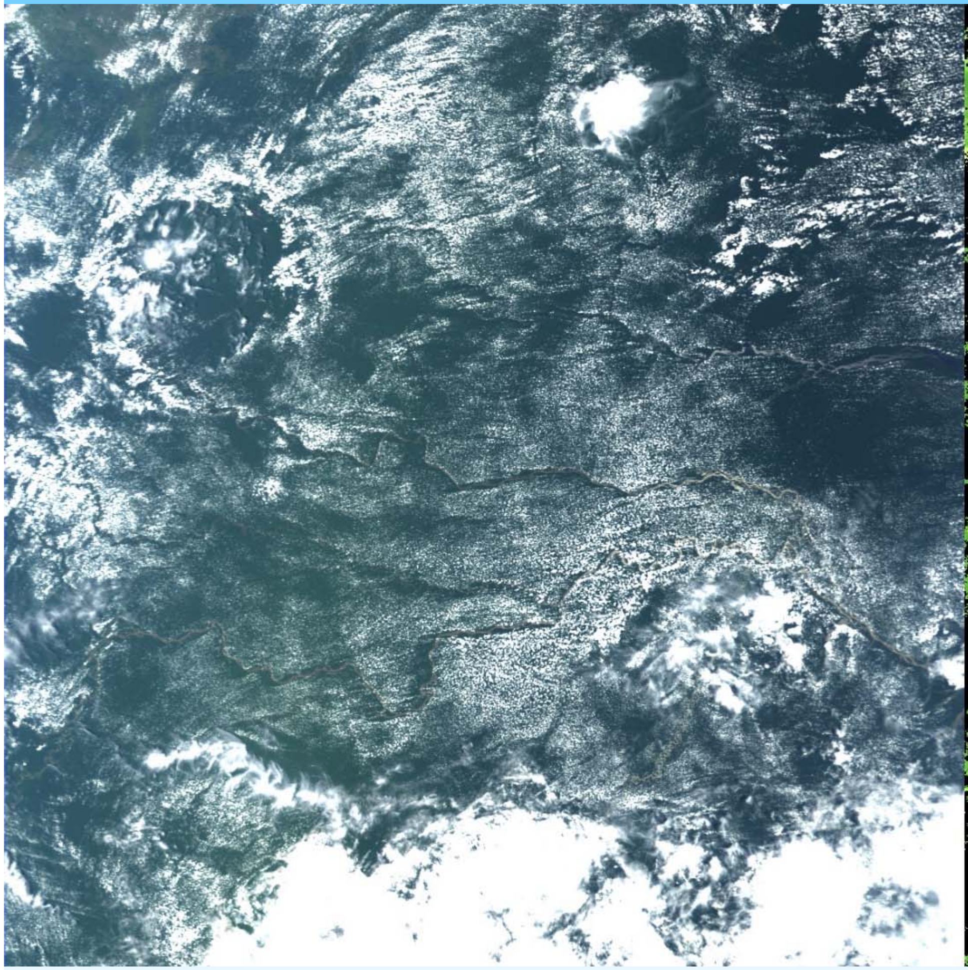
1. *Grid TOA L1B data to 1km fixed grid – work with polar-orbit data as with "geostationary": Observe the same grid cell over time. Min reflectance method to characterize SR spectral ratios. Slow change of surface helps detect "fast" variations from aerosols and clouds;*
2. *Sliding window algorithm – store 4-16 last days of measurements in memory;*
3. *Accumulate surface-related information for each grid cell (spectral BRDF; sub-pixel spatial variability from 500m bands; BT-contrasts etc.)*

Main Results

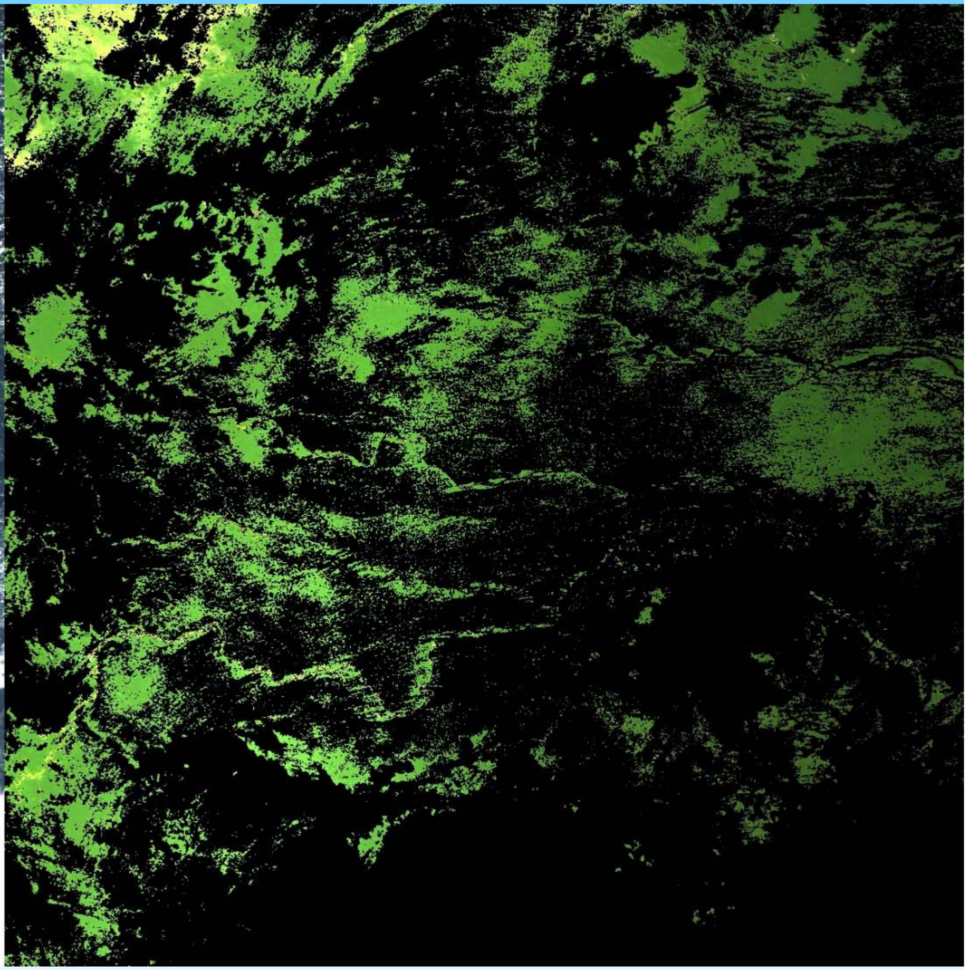
1. *Advanced cloud (snow) detection – particular improvements over tropics (a factor of 3-8 over Amazon for SR) and at northern lat. (vegetation analysis). All major publ. on Amazon in the last 4 yrs. based on MODIS used MAIAC.*
2. *AOD data globally over dark and bright land surface;*
3. *Aerosol at 1km resolution & low urban bias – strong interest from AQ community (~25 publ. in the last 2 years);*

Quality of Atmospheric Correction …

TOA RGB



BRF RGB



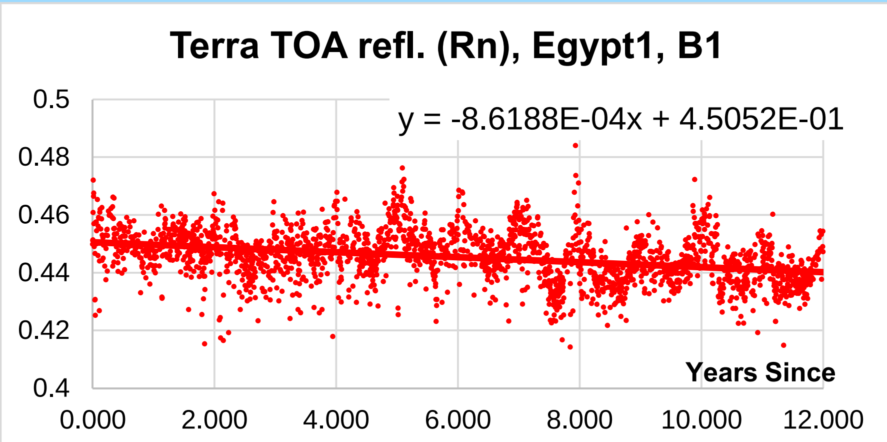
1200 km

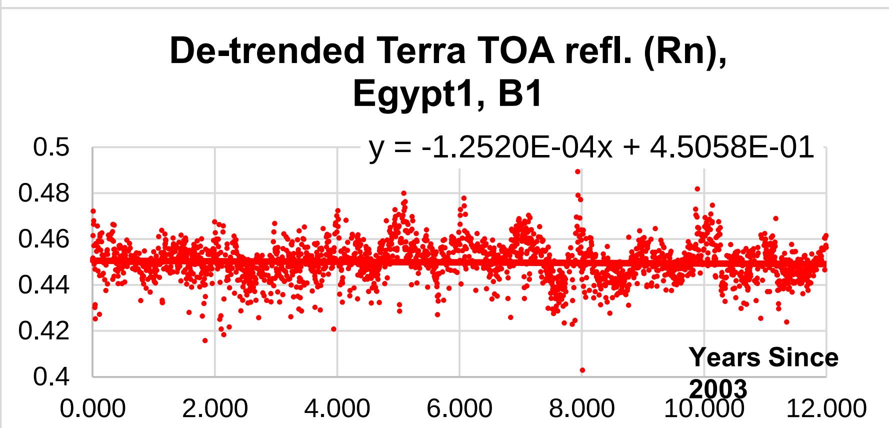
Decreasing brightness – moving from backscattering towards forward scattering

MODIS De-Trending and X-Cal

- New MCST RVS characterization for Aqua → new OBPG Terra Polarization Correction (PC) coefficients → MODAPS generated 50km L1B subsets for CEOS desert cal. sites;
- Method: a) run MAIAC retrievals (AOT, BRDF etc.); 2) compute TOA reflectance (R_n) for fixed geometry (VZA=0°, SZA=45°) and evaluate trends in both Terra and Aqua; 3) Apply de-trending and compute T-A X-calibration factor (gain correction for T)

Lyapustin, A., Y. Wang, X. Xiong, G. Meister, S. Platnick, R. Levy et al, **Science Impact of MODIS C5 Calibration Degradation and C6+ Improvements**, *AMT*, 7, 7281-7319, 2014.



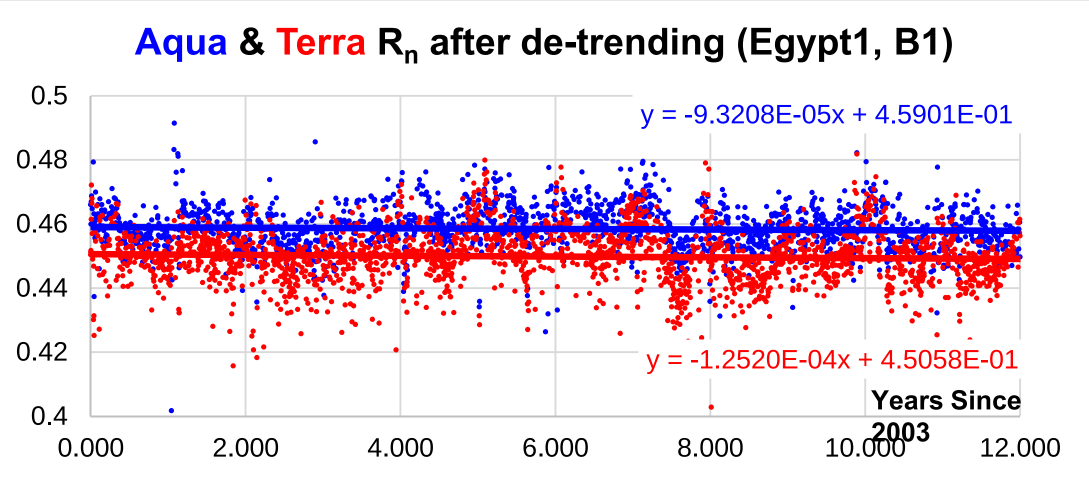


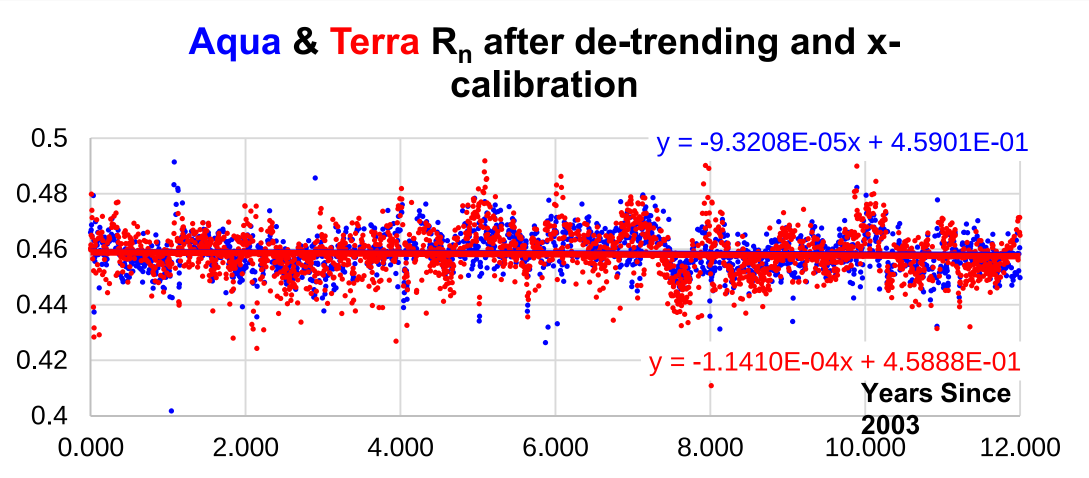
Average trend/year/unit_refl.

	Δ_{Terra}	σ_{Terra}	Δ_{Aqua}	σ_{Aqua}
TOA_B01	-1.6884E-03	2.6114E-04	1.5848E-06	3.9377E-04
TOA_B02	7.7780E-04	2.4303E-04	-6.5120E-05	3.5583E-04
TOA_B03	-8.8922E-04	4.5314E-04	-3.1763E-04	2.8486E-04
TOA_B04	-5.6629E-04	3.2829E-04	-3.9831E-05	5.0202E-04
TOA_B05	1.9477E-04	3.3019E-04	4.5784E-06	3.3528E-04
TOA_B06	-3.9516E-04	3.0211E-04	-3.1194E-04	2.8191E-04
TOA_B07	2.0259E-04	2.4491E-04	-5.8419E-04	3.2705E-04
TOA_B08	-1.2627E-03	1.0018E-03	-5.5178E-04	1.0915E-04
TOA_B09	-3.9874E-04	5.2176E-04	1.3724E-04	2.1120E-04
TOA_B10	-7.2800E-04	8.2601E-04	-3.0632E-04	7.1498E-04

Terra-Aqua X-Calibration

After de-trending, we can X-calibrate Terra to Aqua.
De-trending and X-cal. are standard parts of C6+ L1B data (C6 land)





Average X-gain for Terra

	Average	Stdev
TOA_B01	1.018776	0.000949
TOA_B02	1.000523	0.001054
TOA_B03	0.989436	0.001268
TOA_B04	1.00109	0.001448
TOA_B05	0.98862	0.001855
TOA_B06	0.997128	0.000898
TOA_B07	0.999368	0.000373
TOA_B08	1.003774	0.000948
TOA_B09	1.0014	0.001488
TOA_B10	1.014141	0.002077

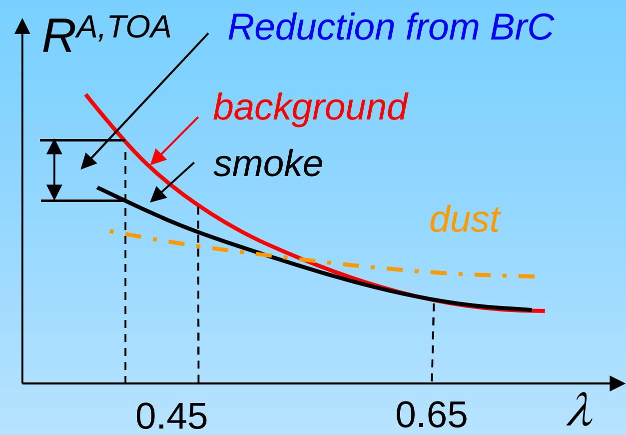
MAIAC Aerosol Type (Smoke/Dust)

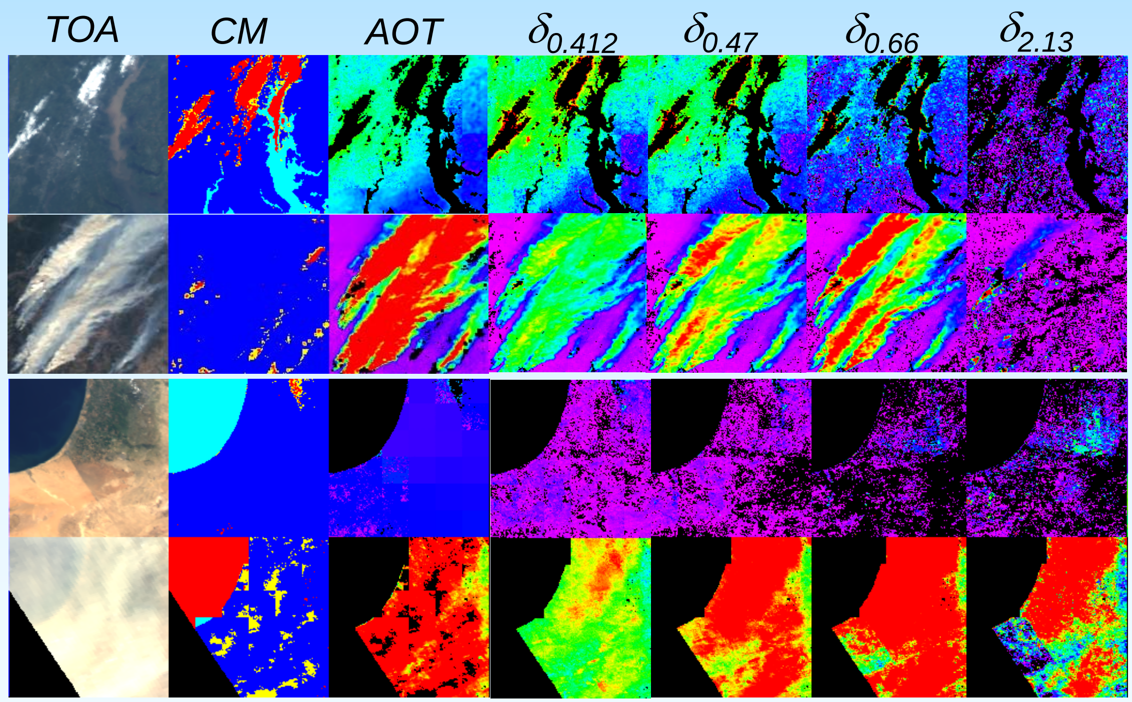
*Lyapustin, A. et al., 2012: Discrimination of biomass burning smoke and clouds in MAIAC algorithm, **ACP**, 12, 9679–9686.*

*Phys. principles (~OMI) – **enhanced shortwave absorption** (Red →Blue →DB)*

$$R_\lambda^{Aer} = R_\lambda^{Meas} - R_\lambda^{Molec} - R_\lambda^{Surf}(\tau^a)$$ *- proxy of aerosol reflectance*

1) *n_i increases R→DB for OC (smoke) and dust;*
2) *Multiple scattering, for absorbing aerosols.*



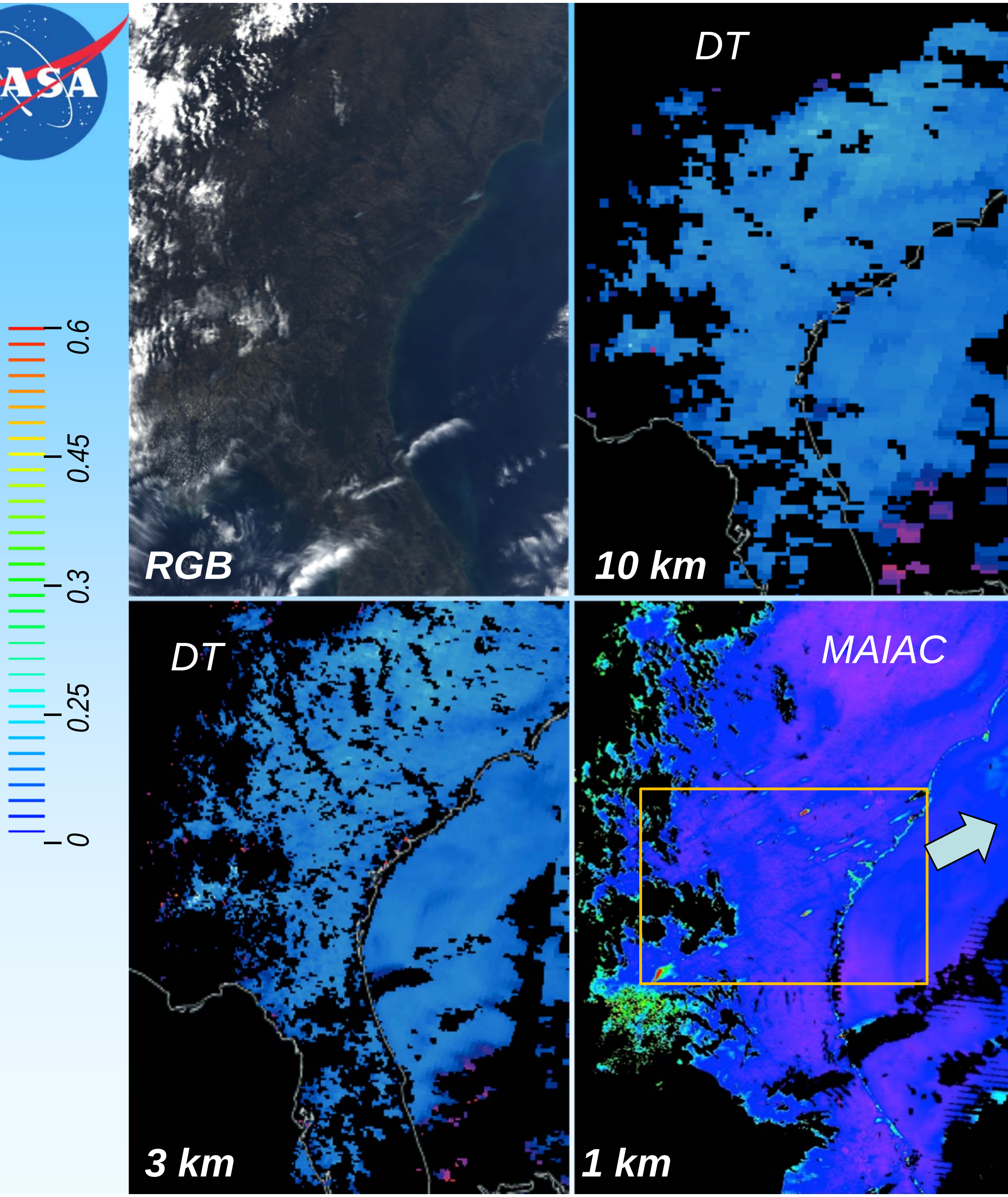


Backgr./Smoke/Dust

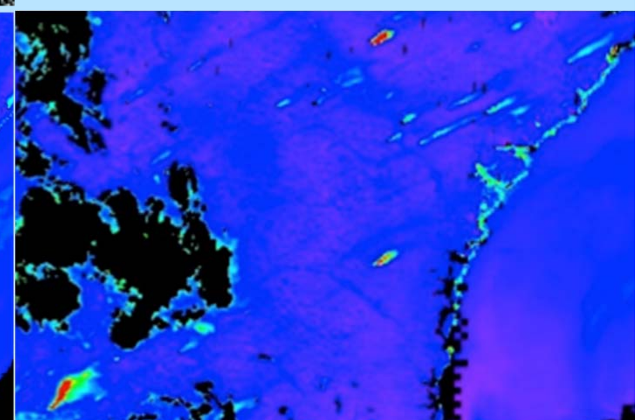
$$\delta_\lambda = R_\lambda^M - R_\lambda^T(\tau_{0.47}^a = 0.05)$$

Model	Abs.	Size
Backgr.	No	Small
Smoke	Yes	Small
Dust	Yes	Large

MAIAC and 3km DT

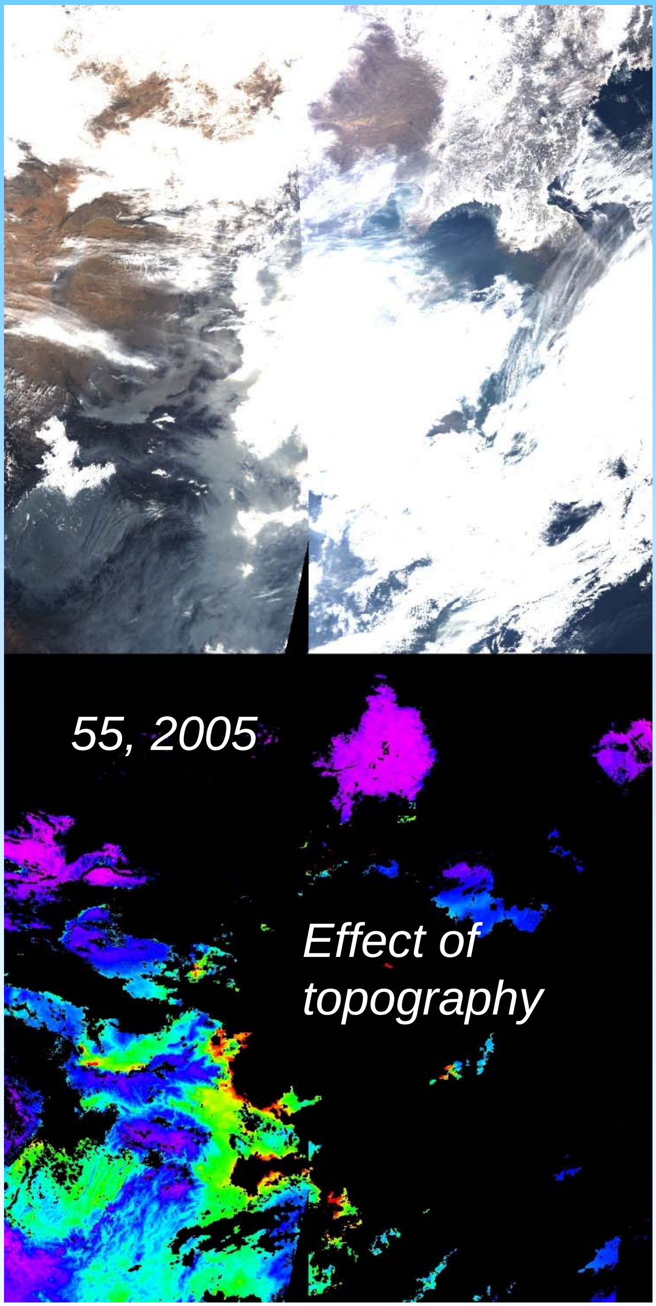


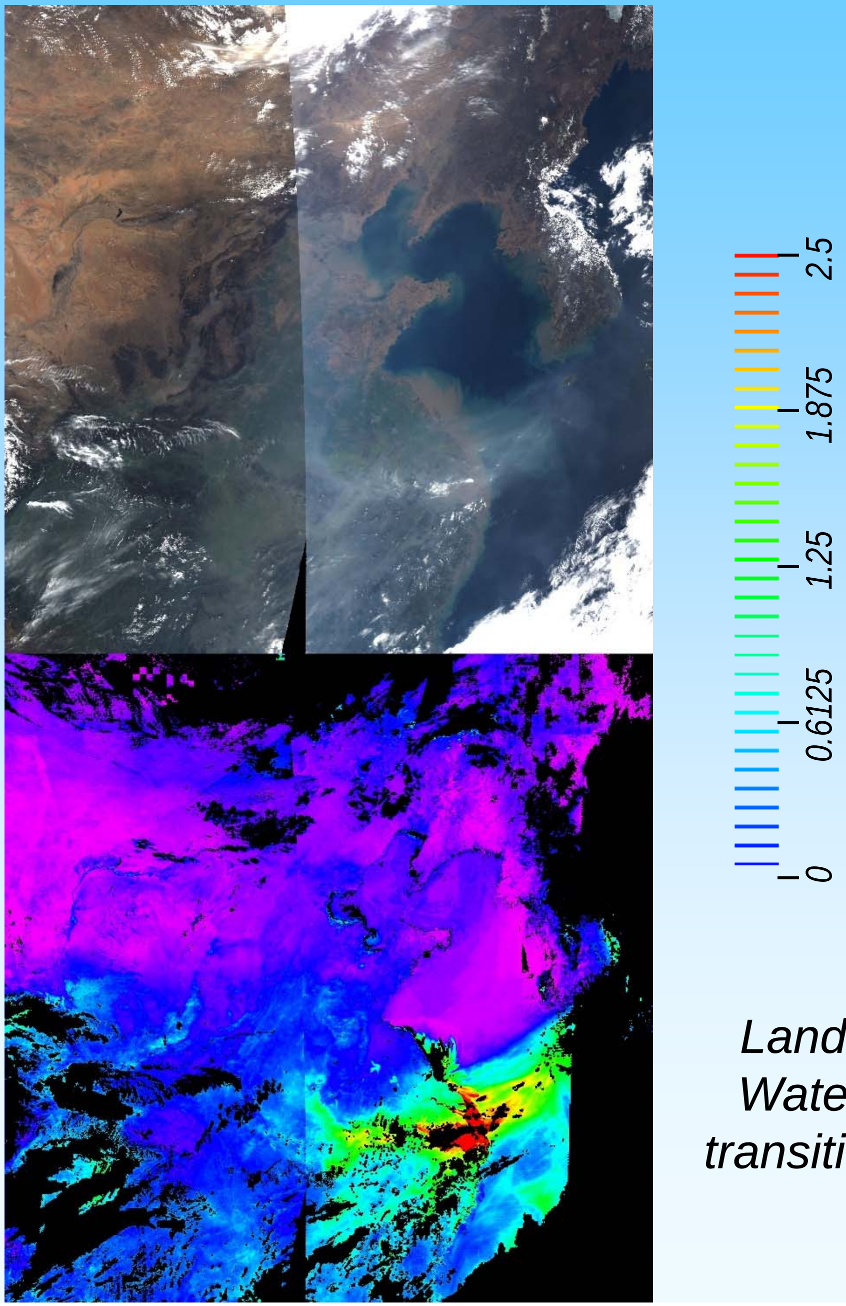
Direct upscaling 10→3km does not automatically give high-res. AOD



(from Pawan Gupta, NASA Applications Air Quality Program)

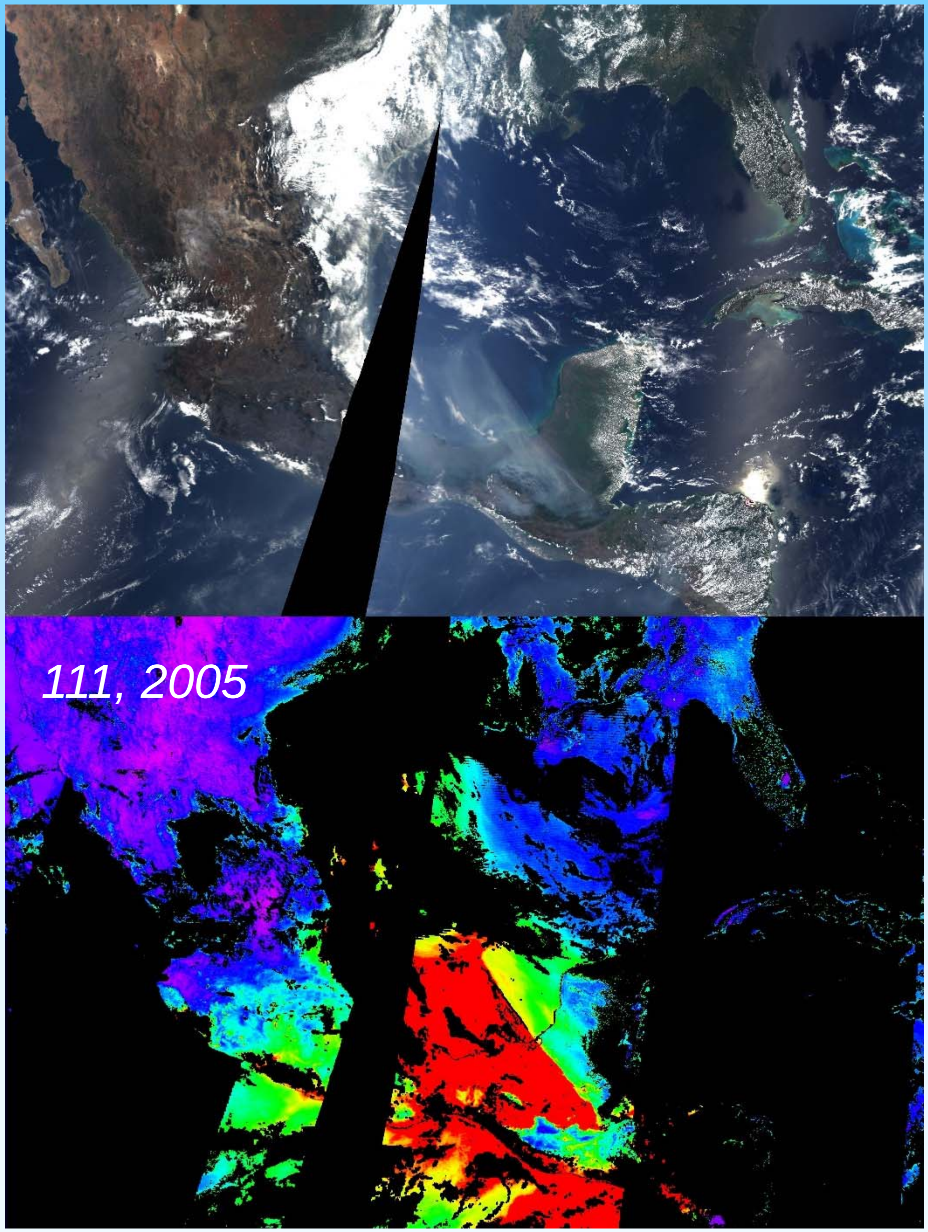
Pollution in China

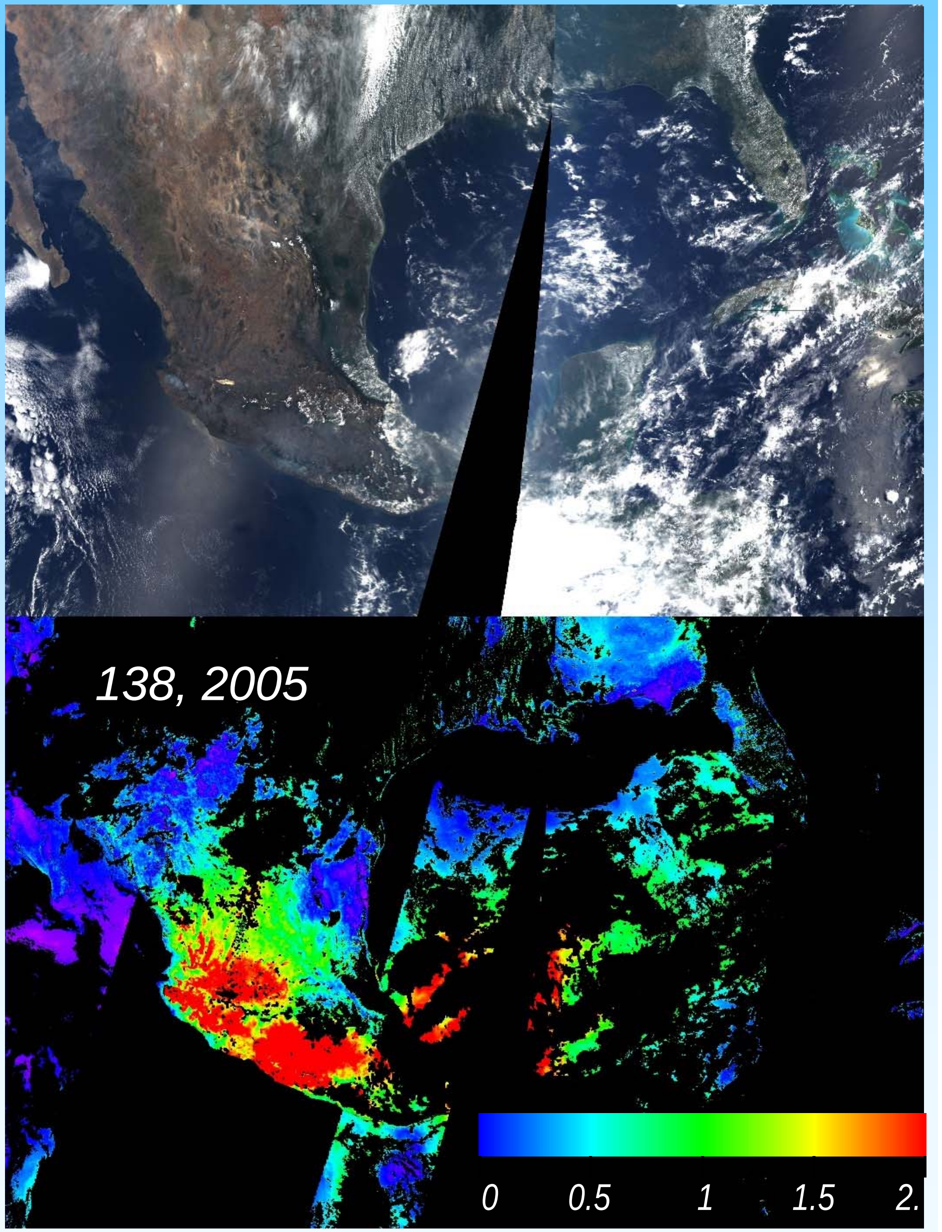




Land-Water transition

Mexican Gulf, Agricultural Burning





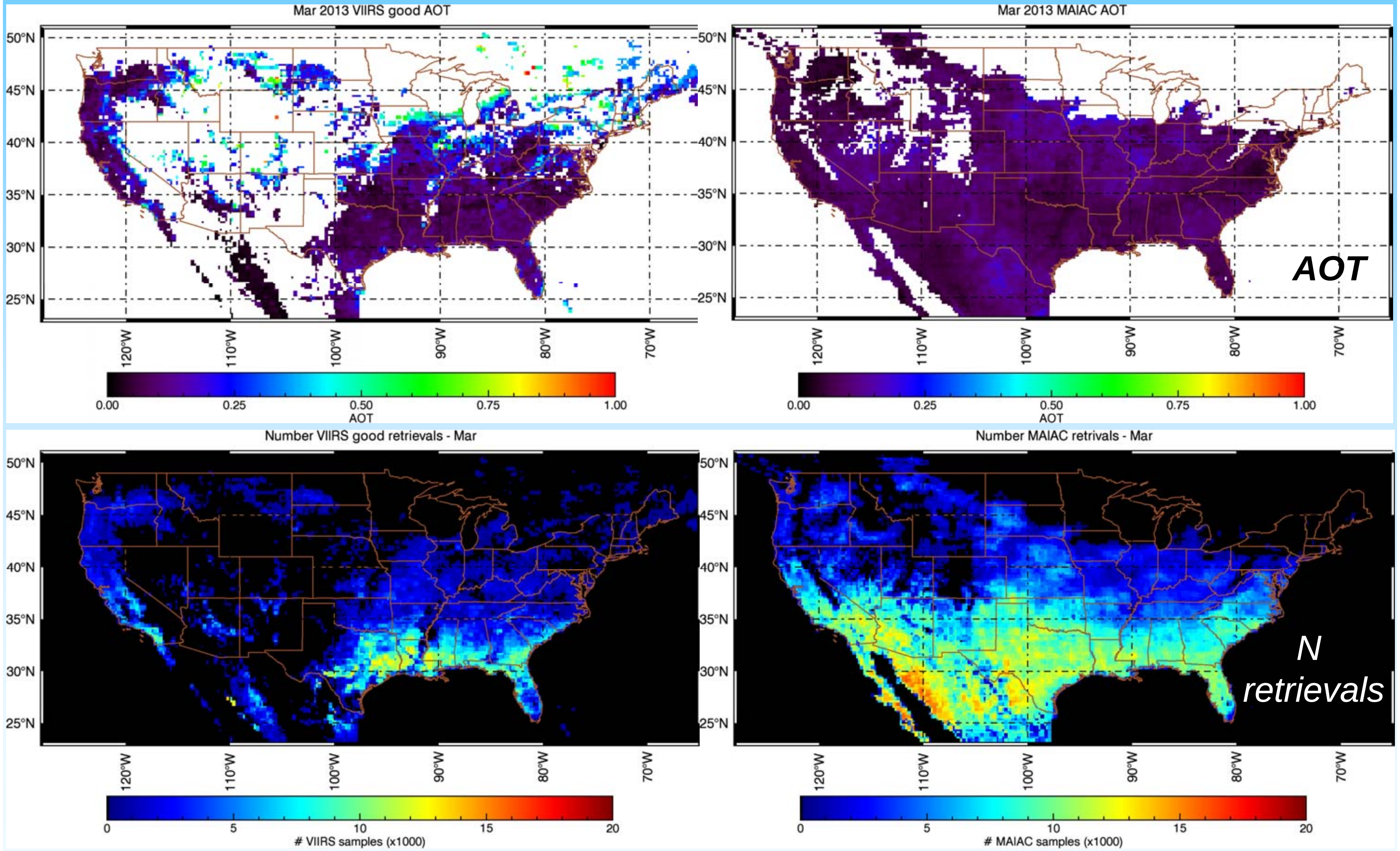
COMPARISON WITH VIIRS

Superczynski,S., S. Kondragunta and A. Lyapustin, Evaluation of the Multi-Angle Implementation of Atmospheric Correction (MAIAC) Aerosol Algorithm through Intercomparison with VIIRS Aerosol Products and AERONET***, JGR*, 22, *3005-3022,* 2017**

VIIRS AOT IP vs MODIS MAIAC (25km)

March, 2013

NOAA VIIRS | *MAIAC MODIS*



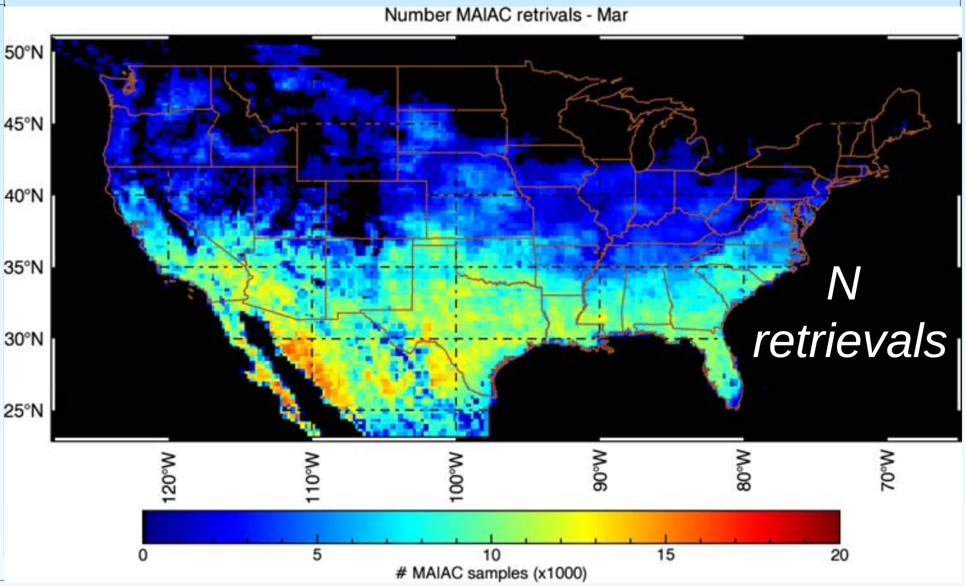
VIIRS AOT IP vs MODIS MAIAC (25km)

August, 2013

NOAA VIIRS

MAIAC MODIS

AOT



Comparison with AERONET (20km)

NOAA VIIRS

MAIAC MODIS

Bias vs AOT

Bias vs SR

AERONET Validation for North America

(MODIS Aqua)

Hiren Jethva, Omar Torres, Mian Chin et al., *NASA GeoCAPE Project*

AERONET Locations

N_SITES=64

N_SITES=107 (including DRAGON)

Legends for the Scatter-plots

	Spatial Window	ΔT	N_{min}
BLACK	***5 km² averaged***	±15min	5
BLUE	***10 km² averaged***	±15min	20
GREEN	***20 km² averaged***	±15min	80
RED	***40 km² averaged***	±30min	320

East Coast USA

***V1* (*top*: ver. of 2014; 2002-2013) vs *V2* (*bottom*: ver. of 2017; 2002-2016)**

v1

v2

v1

v2

West Coast USA

***V1** (**top**: ver. of 2014; 2000-2013) vs **V2** (**bottom**: ver. of 2017; 2000-2016)*

v1

v2

v1

v2

Summary Plots

East Coast

N=17558
rmse=0.075
R=0.871

v1

v2

N=27137
rmse=0.061
R=0.892

West Coast

N=23134
rmse=0.073
R=0.620

N=32768
rmse=0.065
R=0.805

RMSE and Correlation Improved for both Eastern and Western USA Sites

AERONET Validation for South America

(MODIS Aqua+Terra)

Martins, V., A. Lyapustin et al., *Validation of High Resolution MAIAC Aerosol Product over South America, JGR, in review*

Validation over Different Land Cover Types

19 AERONET Sites
&
6 LC Types

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AERONET AOD Validation

Small negative bias at high AOT (biomass burning)

Terra vs Aqua Analysis

Low bias: El Nino years

1) Very good consistency between Terra and Aqua AOD records from MAIAC;

2) If any residual AOD trend exists, it is lower than ~0.03 per decade

Lyapustin, A., Y. Wang, X. Xiong, G. Meister, S. Platnick, R. Levy et al, **Science Impact of MODIS C5 Calibration Degradation and C6+ Improvements**, *AMT*, 7, 7281-7319, 2014.

AERONET CWV Validation

*Vitor Souza Martins, **Image Processing Division**/INPE, group of Dr. Claudio C.F. Barbosa.*

1. *Accuracy within 15%*
2. *CWV from MODIS Aqua has a “dry” calibration bias (~10%)*

WV-AOT-Clouds …

TOA RGB

$AOT_{0.47}$

Aqua: 2011, DOY 212, 17:30

Sub-grid WV variability

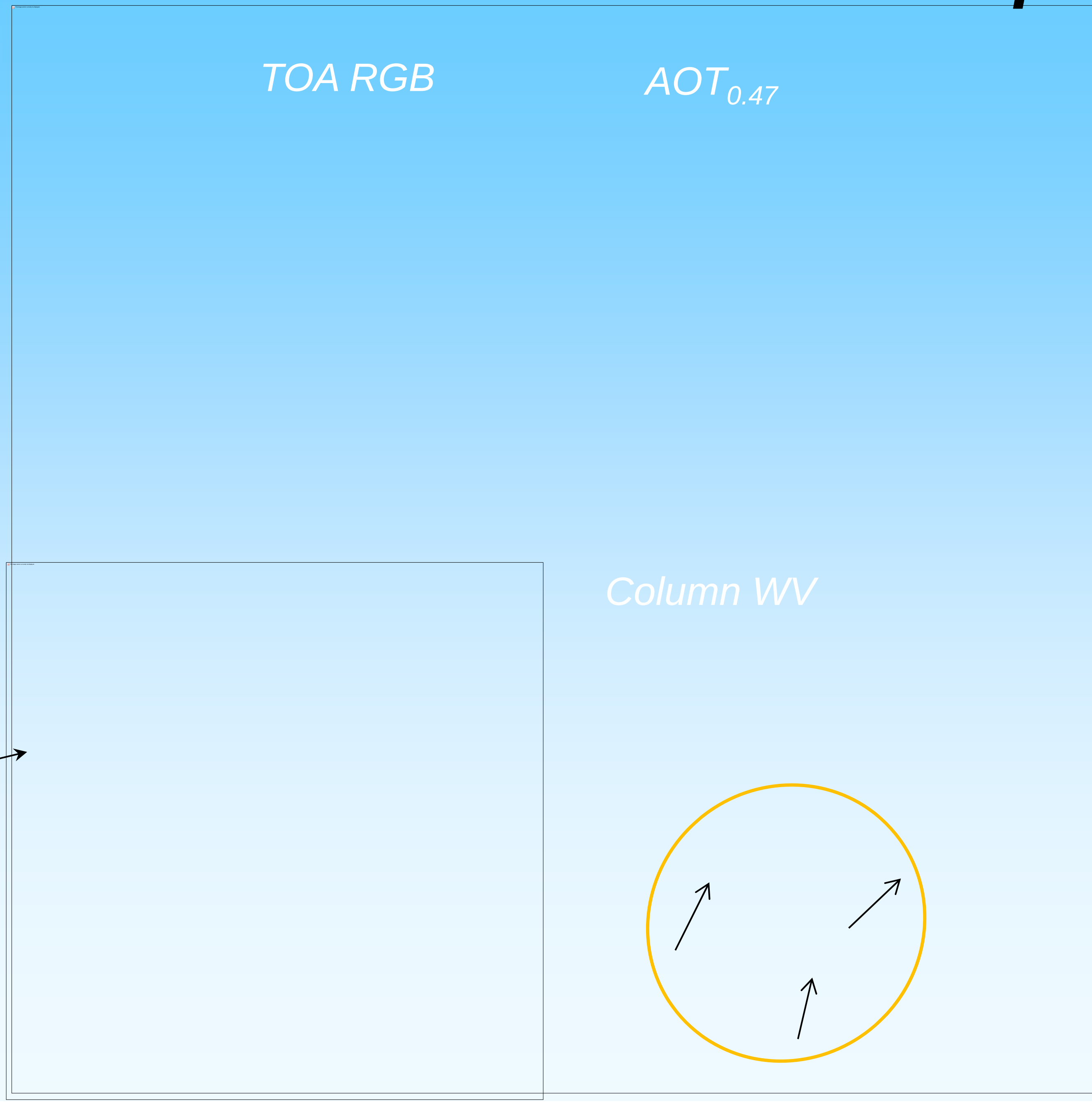
Column WV

5 cm 4 3 2 1 0

Cloud processing or hygroscopic growth next to cloud

Mountain Waves in Water Vapor

400km



Lyapustin, A., M. J. Alexander, L. Ott, A. Molod, B. Holben, J. Susskind, and Y. Wang, *Observation of mountain lee waves with MODIS NIR column water vapor, GRL, 41, 2014.*

Aqua: 2011, DOY 153, 17:50

Terra: DOY 153 16:10

δ~3-5km

Climate Signal in WV?

*Vitor Souza Martins, **Image Processing Division**/INPE, group of Dr. Claudio C.F. Barbosa.*

1. *Total change: δWV~0.7-0.8 cm*
2. *Calibration trend: δWV_C~0.2-0.5 cm*
3. *Net trend: ~0.2-0.5cm WV in 15 yrs.*

- climate signal?

AERONET Validation over IGP

(MODIS Aqua)

Mhawish, A., Banerjee (*Banaras Hindy University*),
M. Sorek-Hamer (curr. post doc. at *NASA Ames*)

AERONET Validation

6 AERONET Sites; Seasonal Analysis: 3×3km^2

MAIAC needs seasonal LUT for post-monsoon biomass burning (overestimation)

AERONET Validation

MAIAC vs DT and DB over IGP

Mhawish, A., T. Banerjee, D.M. Broday, A. Misra and S.N. Tripathi, *Evaluation of MODIS Collection 6 aerosol retrieval algorithms over Indo-Gangetic Plain: Implications of aerosols types and mass loading*, *RSE*, in review

Alg.	R	rmse	MAE	EE,%
DT	0.832	0.218	0.147	61.3
DB	0.827	0.214	0.163	53.8
MAIAC	0.87	0.167	0.113	69.1

MAIAC vs DB over Sahara and Arabian Peninsula

(MODIS Terra+Aqua)

Overview of Algorithms

Deep Blue:

- *2/3-band retrieval (412nm, 550nm and 640nm);*
- *Seasonal SR database from min reflectance method (MRM); fit to quadratic function in scattering angle;*
- *Retrieve AOT and SSA at 10km (nadir) resolution;*

MAIAC:

- *2/3-band retrieval (466nm, 550nm and 2.13μm);*
- *Dynamic characterization of SR-ratios using MRM from previous 2 months, updated monthly;*
- *3 Angular Bins (nadir, forward scattering, back-scattering)*
- *Retrieve AOT at 1km (gridded).*

Retrievals over Water

Cape Verde

Wallops

$AOT_{0.47}$

FMF

AERONET

AERONET

Retrievals over Deserts

Solar Village

Sede Boker

$AOT_{0.47}$

$AOT_{0.47}$

AERONET

AERONET

Tracking Dust Storm

MAIAC
Aqua

5-2005

DB

Tracking Dust Storm

MAIAC
Aqua

6-2005

DB

Storm: N-NW

MAIAC
Aqua

100-2005

DB

Dust Storm: Arabian Peninsula

MAIAC
Aqua

220-2005

DB

Noise: Nadir to Backscattering

MAIAC
Terra

205-2005

DB
Terra

Angular Bias (~~diurnal pattern~~)

Terra

Aqua

125-2005
MAIAC

DB
Terra

DB
Aqua

MAIAC-DB Monthly Comparison

(5 yr. average, 2005-2010)

Dec

M

D

Jan

M

D

Feb

M

D

Mar

M

D

MAIAC-DB Monthly Comparison

(5 yr. average, 2005-2010)

Apr

M

D

May

M

D

Jun

M

D

Jul

M

D

MAIAC-DB Monthly Comparison

(5 yr. average, 2005-2010)

Aug

M

D

Sep

M

D

Oct

M

D

Nov

M

D

Characterizing Aerosol Absorption Using GLI (ADEOS-II) Data

Overview

- ***Funding from NASA GeoCAPE project***
- ***Idea: study synergy between GOES-R and TEMPO***
  - *GOES-R provides high spatial resolution and VIS-SWIR-TIR bands (CM/snow, surface change, AOT, BRF/BRDF/Albedo surface suite etc. from MAIAC)*
  - *TEMPO gives a hyperspectral coverage in UV-VIS at 2x4km^2;*
  - *Opportunity for retrieval of AOT, SW absorption, and H_{eff}.*
- ***Started with GLI on ADEOS-II:***
  - *10:30am orbit; 1600km swath (VZA<45°), 4 days global coverage*
  - *Almost MODIS-like spectrally (for 1km bands):*
    - *Lacks NIR WV bands at 0.94μm; adds 399.7, 388nm;*
    - *Lacks 500m bands; Some bands at 250m, LAC mode;*
  - *Launched in Dec. 2002; Data available Feb.-October 2003.*

Adapting MAIAC to GLI

- *Downloaded global GLI archive*
- *Started with North America*
- *Gridding to MODIS-like 1km and 500m:*
  - *250m data are available for only ~40% of observations. Generated 500m data partly from 250m data, and partly from 1km data.*
- *GLI calibration from 10-8-2008 (http://suzaku.eorc.jaxa.jp/GLI/cal/vcoef/index.html)*

- ***Adapted MAIAC for GLI processing***
  - *MAIAC MODIS re-mapped to GLI bands;*
  - *GLI LUT (VRT for UV – green λ);*
  - *Tuning required (CM; length of Queue etc.);*
- ***Limitations of GLI**:*
  - *2.2μm band has original res. 250m, but provided at 2km by JAXA;*
  - *Lack of NIR (0.94 um) bands for CWV retrieval;*
  - *Issues with band-to-band registration (1-2 pixels - colored cloud edges).*
- ***General performance achieved.***

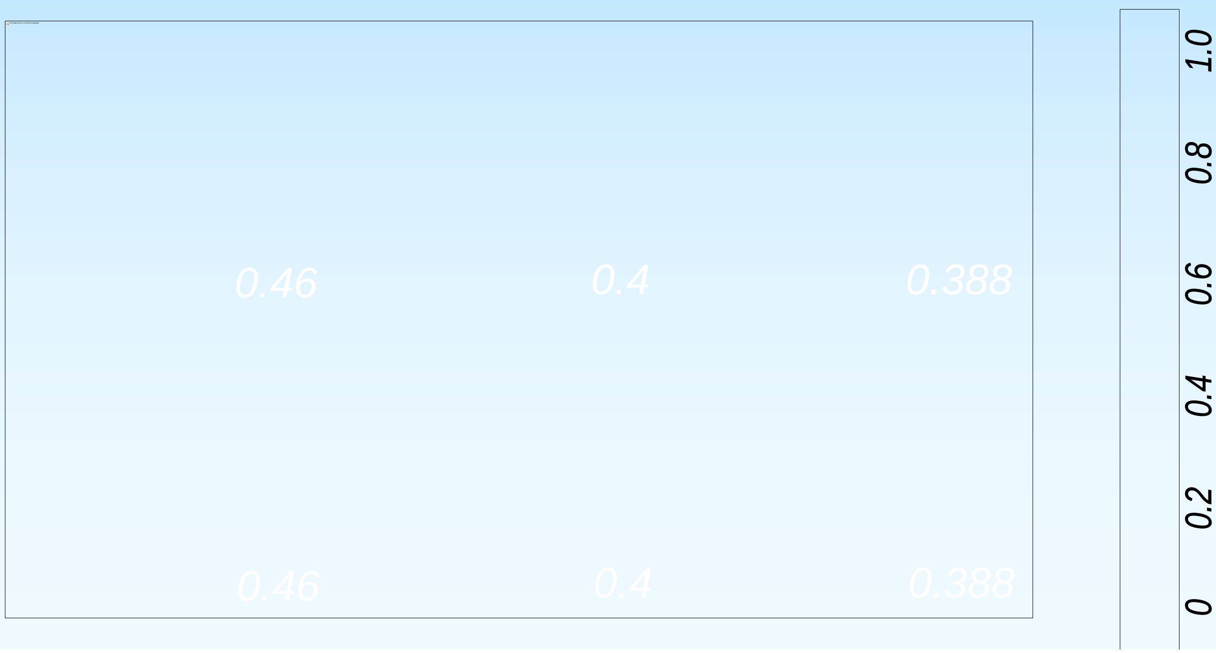
Algorithm and Assumptions

- *MAIAC has a dynamic characterization of SRC,* $b_{0.46}=\rho_{0.46}/\rho_{2.2}$ using min reflectance method. *For GLI, also compute* $b_{0.40}$, $b_{0.388}$
- *Run standard MAIAC → cloud mask,* $AOT_{0.46}$*, aer. type (smoke), spectral surface BRDF etc.*
- *Assuming aerosol model (SD, (n,k), profile and* $AOT_{0.46}$*), retrieve k (SSA) at 0.4 and 0.388μm* *independently* *using separate LUT with variable refIM (5 values, k=0.001-0.02) by matching measured radiance.*
- *Evaluate AAE:* $k_{\lambda}=k_{0.55}(\lambda/0.55)^{-AAE}$*. Given AAE, repeat joint inversion for* $(AOT, k)_{0.46}$ *by best fit to measurements at 0.46, 0.4 and 0.388 μm.*

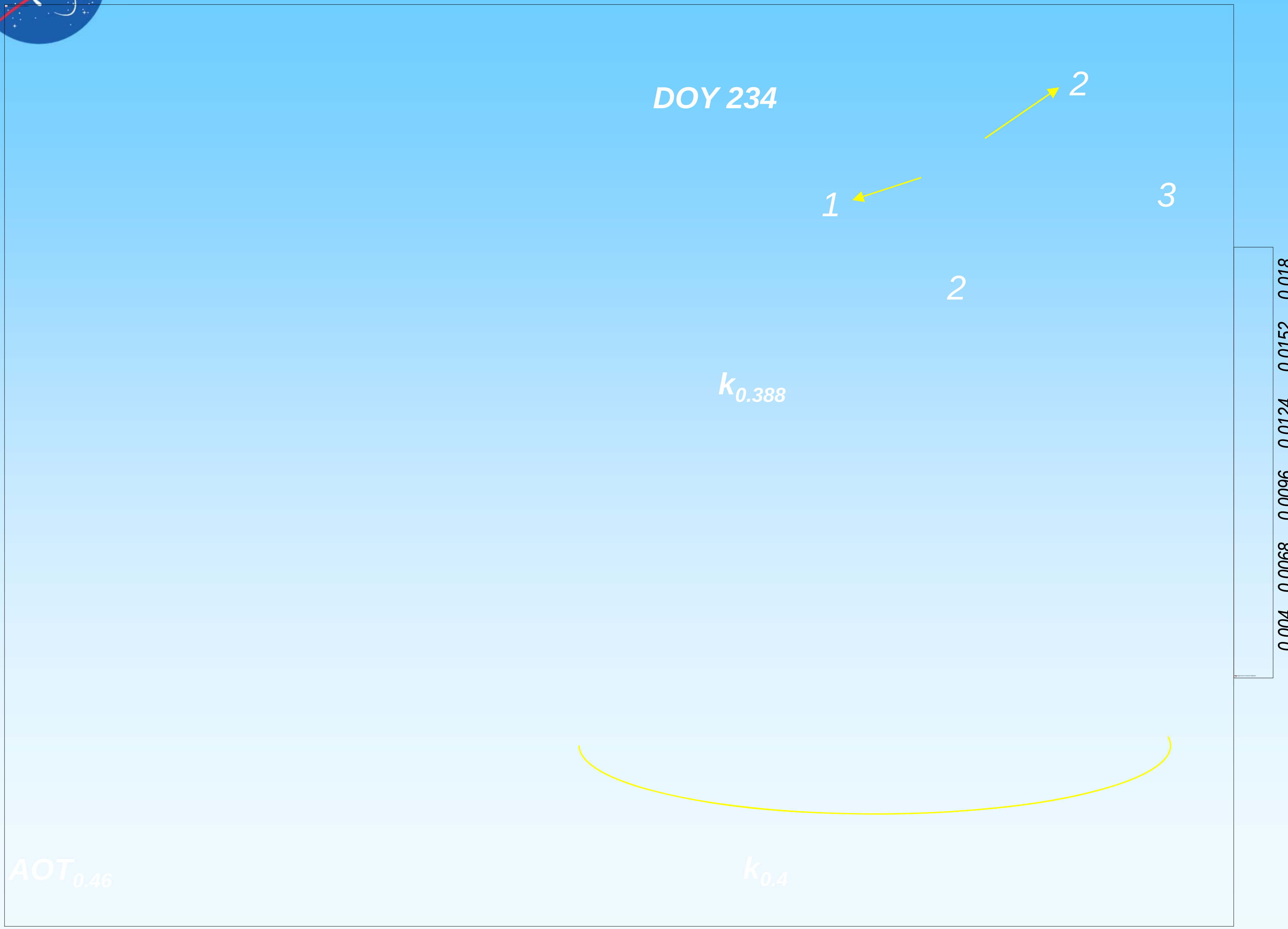
SRC for the East Coast USA

SRC, _FS

SRC, _BS



1. High, Moderate and Low Absorption



2. Canadian Forest Fires: Low Abs./AAE

DOY 152

$k_{0.388}$

$AOT_{0.46}$ $k_{0.4}$

DOY 153

$k_{0.388}$

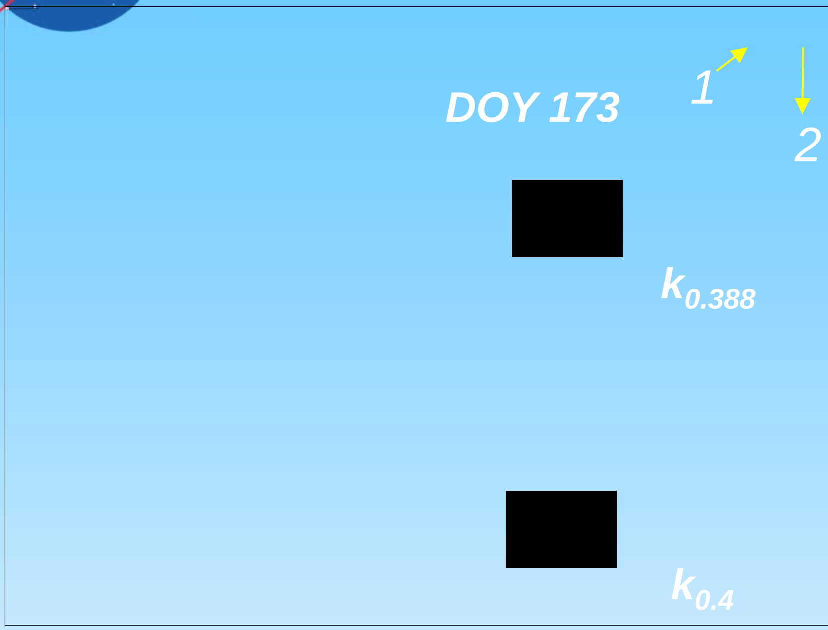
$AOT_{0.46}$ $k_{0.4}$

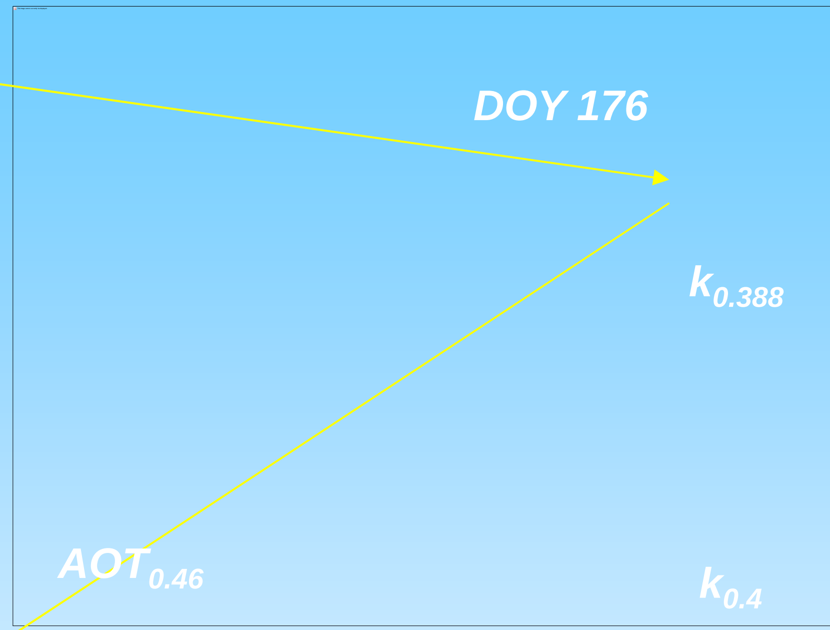
0.004 0.0068 0.0096 0.0124 0.0152 0.018

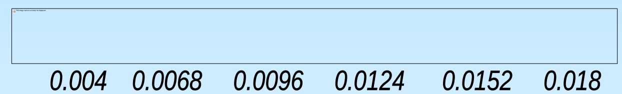
2. Late Spring, East Coast USA; transported smoke, moderate absorption (unusual for the East Coast)

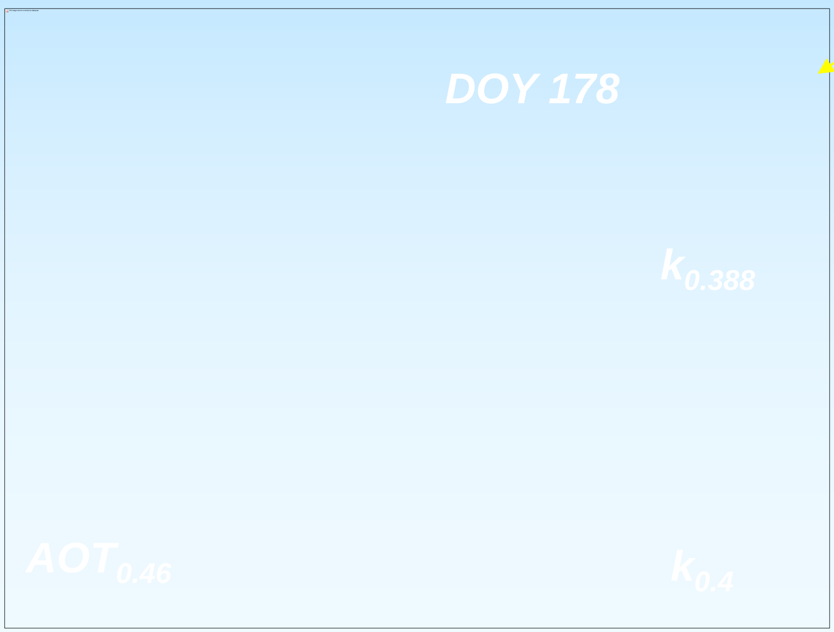
- Moderate-to-low Absorption, $k_{0.4}$~0.006 – 0.009, $k_{0.388}$~0.009 – 0.012

3. Aging and Humidification









3. High atmospheric moisture in Midwest and East Coast USA:

Aging and humidification of transported smoke reduces absorption and AAE

4. At High Resolution, Near Sources

DOY 245

$k_{0.388}$

$k_{0.4}$

LA, urban pollution

DOY 272

$k_{0.388}$

$AOT_{0.46}$

$k_{0.4}$

0.004 0.0068 0.0096 0.0124 0.0152 0.018

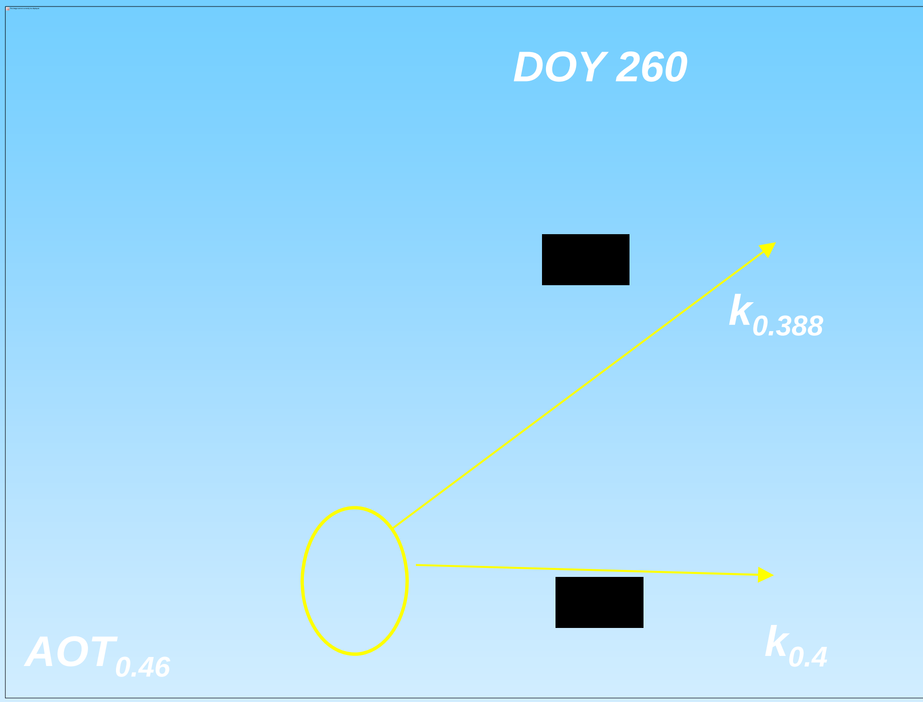
DOY 241

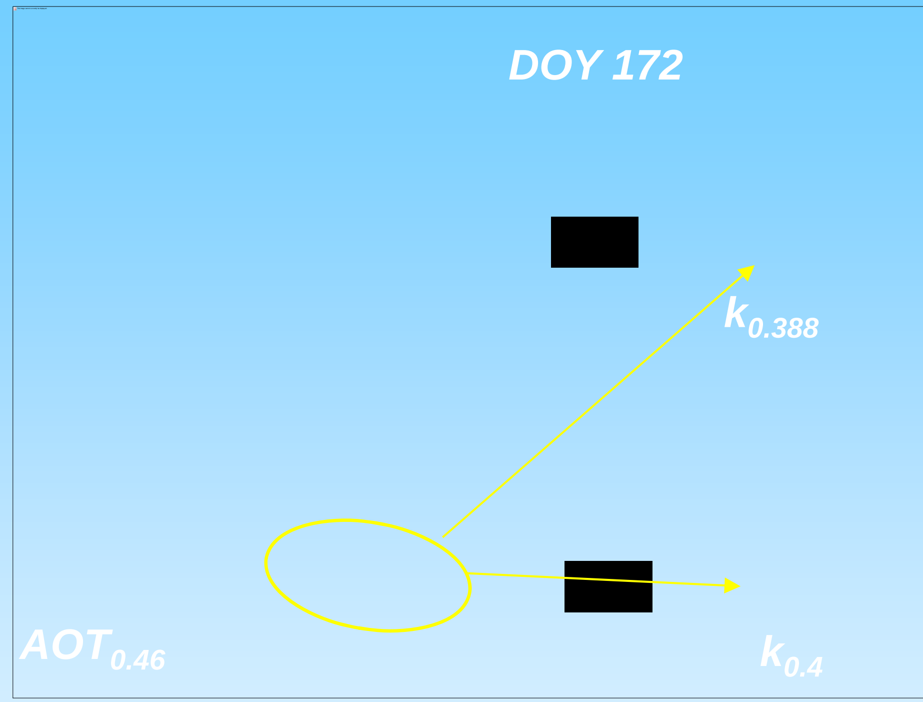
$k_{0.4}$

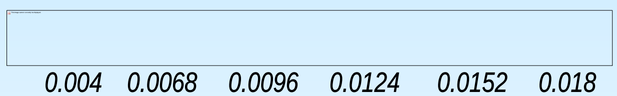
4.1 Absorption is often higher at the epicenter of fire

4.2 Urban pollution shows low absorption and low AAE

5. Evaporating Clouds







5. Despite relatively large AOT, evaporating clouds display lack of near-UV absorption and its spectral dependence. Implication for air quality (AOT-PM) predictions: these aerosols sit at the effective cloud height and have little relation to near-ground $PM_{2.5}$.

Conclusions

- *Robust separation of background regime from local or transported smoke*
- *Very strong dynamics of BrC in time (space) from emission*
- *New: aging of BC under sufficient RH and disappearance of absorption. Hydrophobic$\rightarrow$hydrophilic transformation doesn't seem to explain observations. Extended RH exposure leading to chemical activation of BC?*
- *Smoke transport is a "snapshot over time": coupling with CTM fields (e.g. winds) and MODIS WV will allow study natural aging, effect of relative humidity etc.*
- *Most interesting: retrieve AOT, k_λ, AAE from 3 measurements (0.46, 0.4, 0.388μm) $\rightarrow$ separate BC ($k \sim \lambda^0$), BrC ($k \sim \lambda^{-b}$) and other (weakly or non-absorbing) at scales resolving fire plumes (1km). CTMs assume spectral dependence of BrC and use fixed relative concentrations BC/BrC, BrC/POC etc.*

From GLI, we can get a global satellite picture of these properties in natural environment.

Kirchstetter, Novakov, JGR, 2004

All Mixing Models Enhance BC-absorption

Comparison between particle-resolved composition model (PartMC-MOSAIC) with Uniform Mixture Approximation

E_{abs}~1.3/>2 for diverse/uniform composition

… because …

mass fraction of coating is smaller for particles with large BC amount

Ambient RH always enhances absorption (Yellow vs Blue)

Fierce, L., T. Bond et al. Black carbon absorption at the global scale is affected by particle-scale diversity in composition. *Nat. Commun*. 7:12361 doi: 10.1038/ncomms12361 (2016).