

# TEMPO/GEO-CAPE synergy with GOES-R for aerosol retrievals

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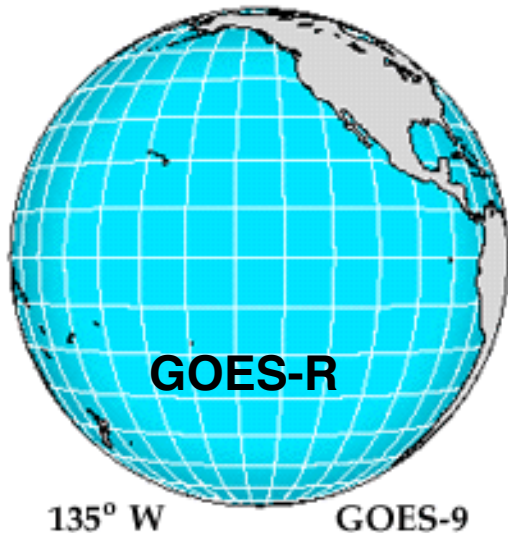
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# GOES-R

## to be launched in Oct. 2015

### ABI: Advanced Baseline Imager

**TABLE 1. Summary of the wavelengths, resolution, and sample use and heritage instrument(s) of the ABI bands. The minimum and maximum wavelength range represent the full width at half maximum (FWHM or 50%) points. [The Instantaneous Geometric Field Of View (IGFOV).]**

Future GOES imager (ABI) band	Wavelength range ( $\mu\text{m}$ )	Central wavelength ( $\mu\text{m}$ )	Nominal subsatellite IGFOV (km)	Sample use	Heritage instrument(s)
1	0.45–0.49	0.47	1	Daytime aerosol over land, coastal water mapping	MODIS
2	0.59–0.69	0.64	0.5	Daytime clouds fog, insolation, winds	Current GOES imager/sounder
3	0.846–0.885	0.865	1	Daytime vegetation/burn scar and aerosol over water, winds	VIIRS, spectrally modified AVHRR
4	1.371–1.386	1.378	2	Daytime cirrus cloud	VIIRS, MODIS
5	1.58–1.64	1.61	1	Daytime cloud-top phase and particle size, snow	VIIRS, spectrally modified AVHRR
6	2.225–2.275	2.25	2	Daytime land/cloud properties, particle size, vegetation, snow	VIIRS, similar to MODIS
7	3.80–4.00	3.90	2	Surface and cloud, fog at night, fire, winds	Current GOES imager

from Schmit et al., 2005.

# ABI Capability

	ABI	Current GOES Imager
Spectral Coverage	16 bands	5 bands
Spatial Resolution		
0.64 $\mu\text{m}$ Visible	0.5 km	~ 1 km
Other visible/near-IR	1.0 km	n/a
Bands ( $>2 \mu\text{m}$ )	2 km	~ 4 km
Spatial Coverage		
Full Disk	4 per hour	Scheduled (3 hrly)
CONUS	12 per hour	~4 per hour
Mesoscale	Every 30 sec	n/a
Visible (reflective bands)		
On-orbit calibration	Yes	No

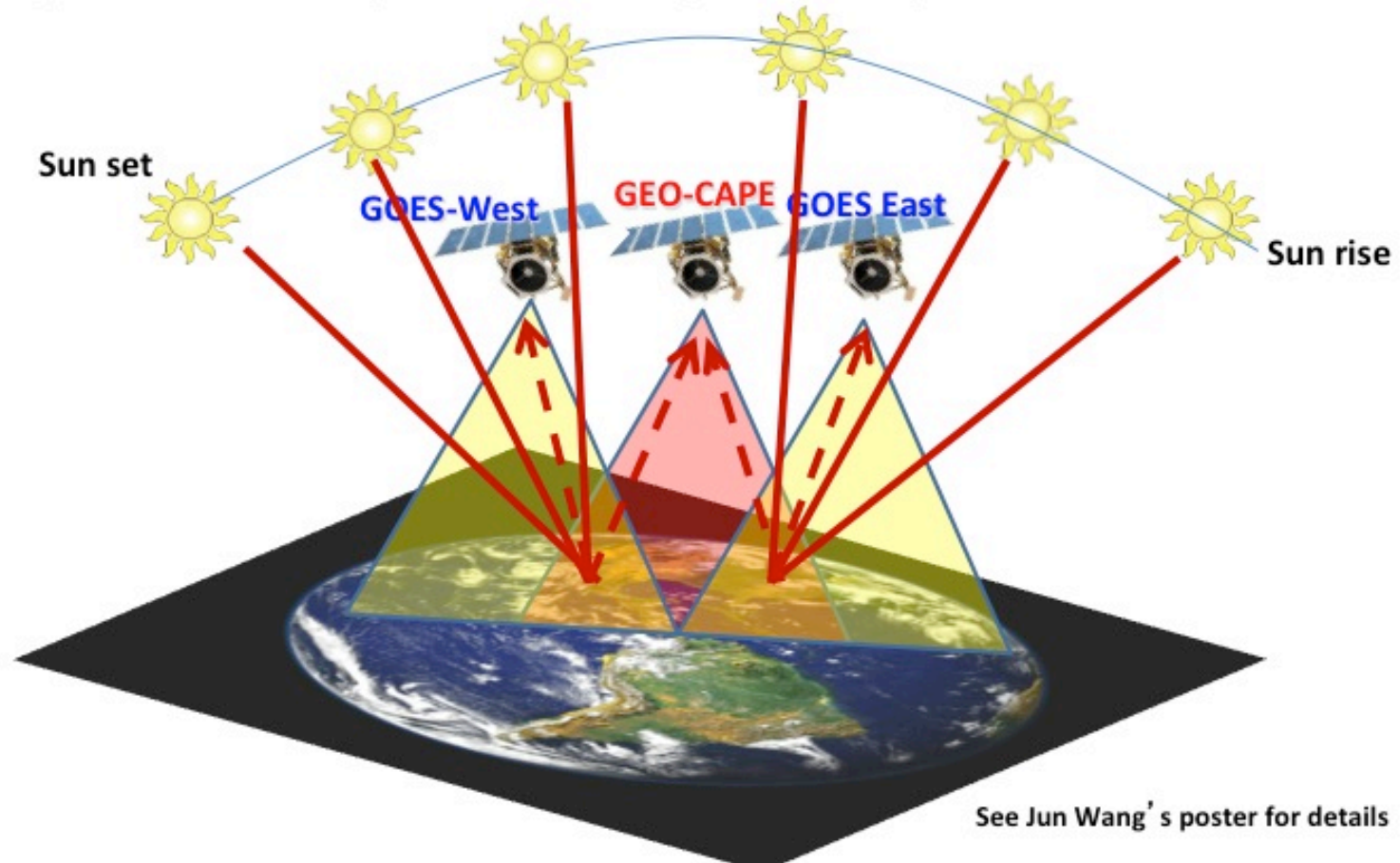
<http://www.goes-r.gov/>

Slide presented in GEO-CAPE Science Working Group Meeting, Columbia, MD  
22 – 24 Sep. 2009

## GEO-CAPE and GOES-R synergy

offers observations uniquely collected from dual viewing angles and multiple scattering angles to

- (1) To characterize non-spherical dust particles in the U.S. coastal region
- (2) derive the wind speed and stereo height of aerosol plume.

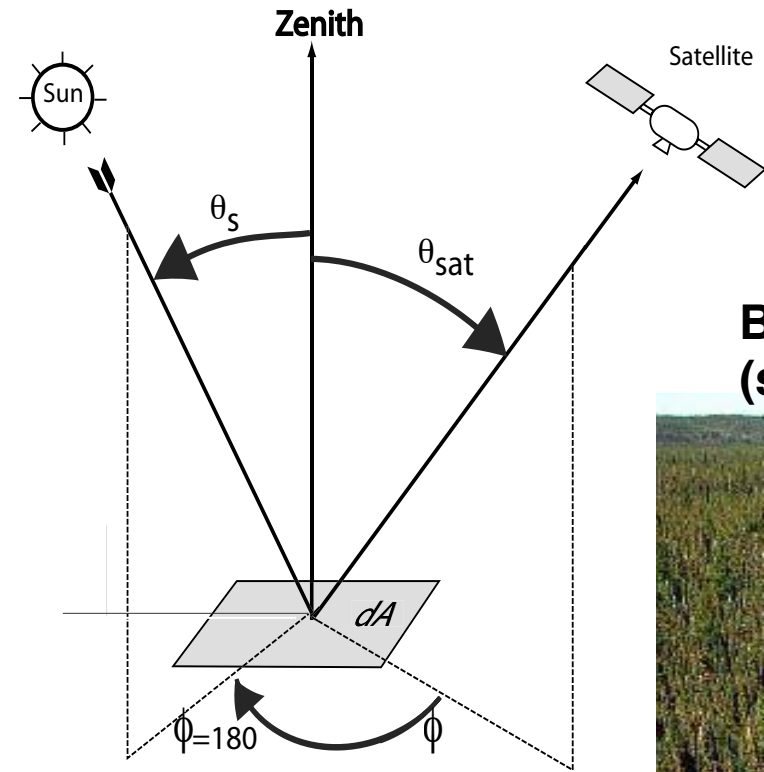


See Jun Wang's poster for details

# Boundary surface conditions for aerosol retrieval

## Surface bi-directional reflectance (BRDF)

- Surface reflectance has strong angular dependence.



**Backscattering  
(sun is behind)**



**Forward scattering  
facing the sun**



# How do we get BRDF from space?

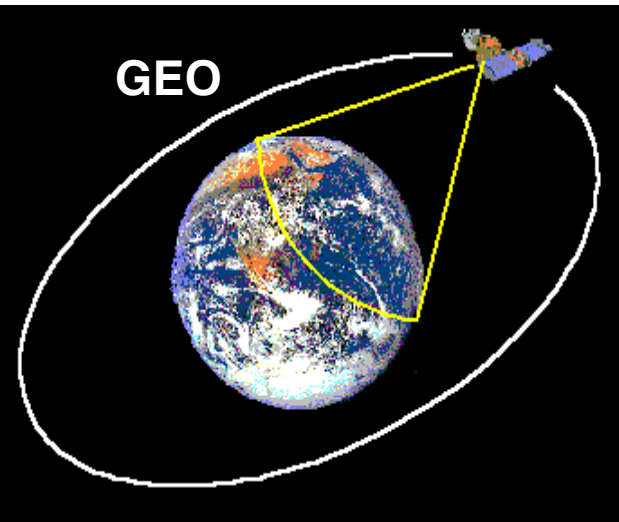


## MODIS-type land algorithm (Schaaf et al., 2002)

- RossThickLiSparse RTLS **Reciprocal** kernel combination:

$$R(\theta, \nu, \phi, \lambda) = f_{\text{iso}}(\lambda) + f_{\text{vol}}(\lambda)K_{\text{vol}}(\theta, \nu, \phi, \lambda) \\ + f_{\text{geo}}(\lambda)K_{\text{geo}}(\theta, \nu, \phi, \lambda)$$

- Retrieving 3 parameters every 16 days



## GOES-type algorithm (Knapp et al., 2005; Wang et al., 2003):

Minimum composite method: taking second minimum reflectance every 15-20 days.

Composite time window can be moving sequentially with date.

Surface reflectance is obtained at exact GOES reviewing geometry and schedule.

# How is BRDF treated in aerosol retrieval algorithm?



## MODIS-type aerosol algorithm.

- Derive visible sfc. reflectance from NIR ref. at TOA (Levy et al., 2007)

$$\rho_{0.66}^s = f(\rho_{2.12}^s) = \rho_{2.12}^s * slope_{0.66/2.12} + yint_{0.66/2.12}$$

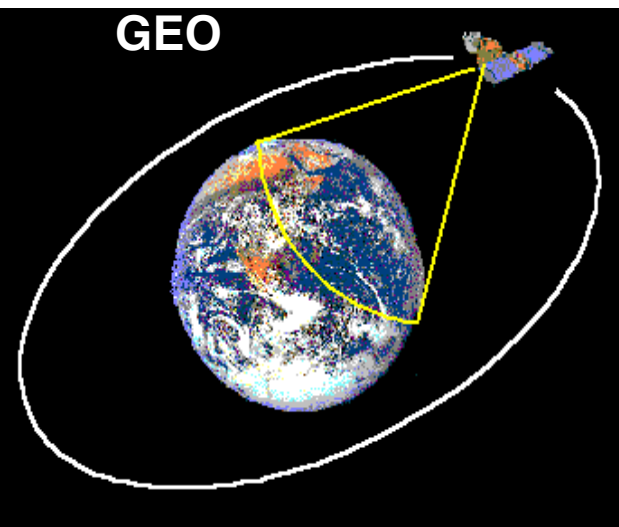
$$\rho_{0.47}^s = g(\rho_{0.66}^s) = \rho_{0.66}^s * slope_{0.47/0.66} + yint_{0.47/0.66}$$

- Vis/NIR ratio ~ NDVI and scattering angle, and is derived from MODIS land BRDF product.

**Research algorithm** (Drury et al., 2007; Wang et al., 2008):  
Dynamic lower envelop approach.

**OMI-type algorithm:**

from a database; assume isotropic surface.



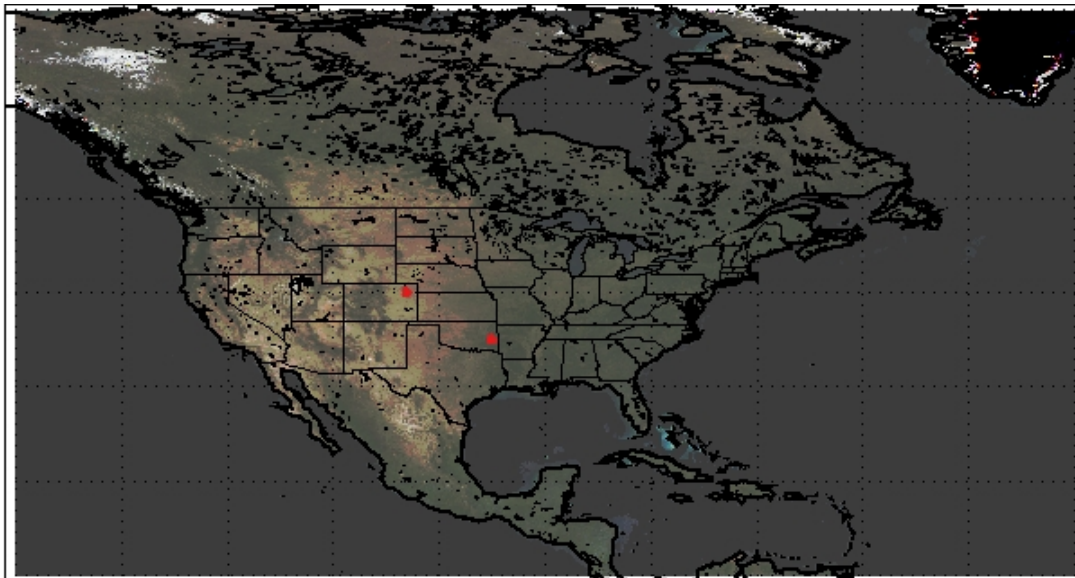
**Minimum composite method.**

## Questions

- Can we apply derive TEMPO visible reflectance from GOES-R 2.3  $\mu\text{m}$ ?
- If we apply minimum composite method to derive surface reflectance respectively at TEMPO and GOES-R geometry, what is their synergy in aerosol retrievals?

## Data

- MODIS BRDF in first week of Sep. 2012.
- Start with two locations, then move to N-America continent.

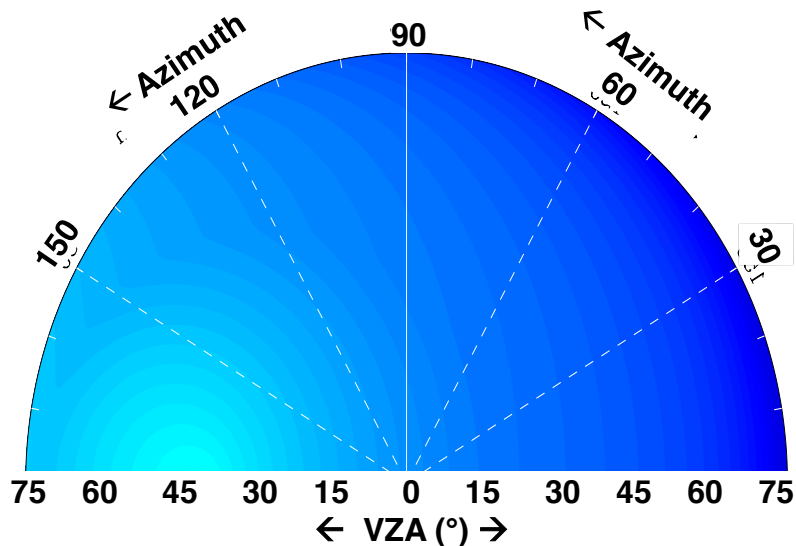




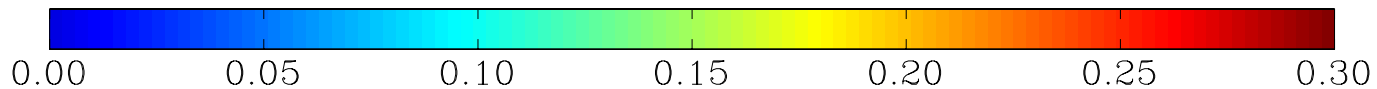
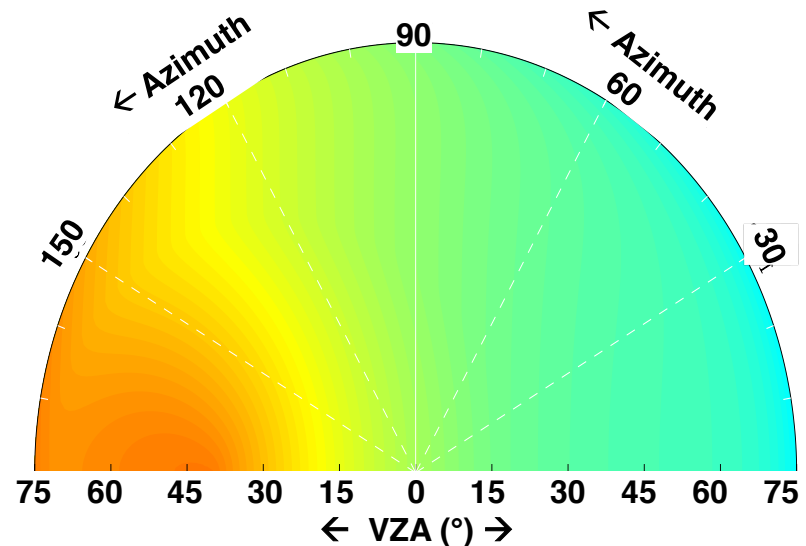
# Boundary surface conditions for aerosol retrieval BRDF

SZA = 40°

0.65  $\mu\text{m}$ , vegetation



0.65  $\mu\text{m}$ , soil

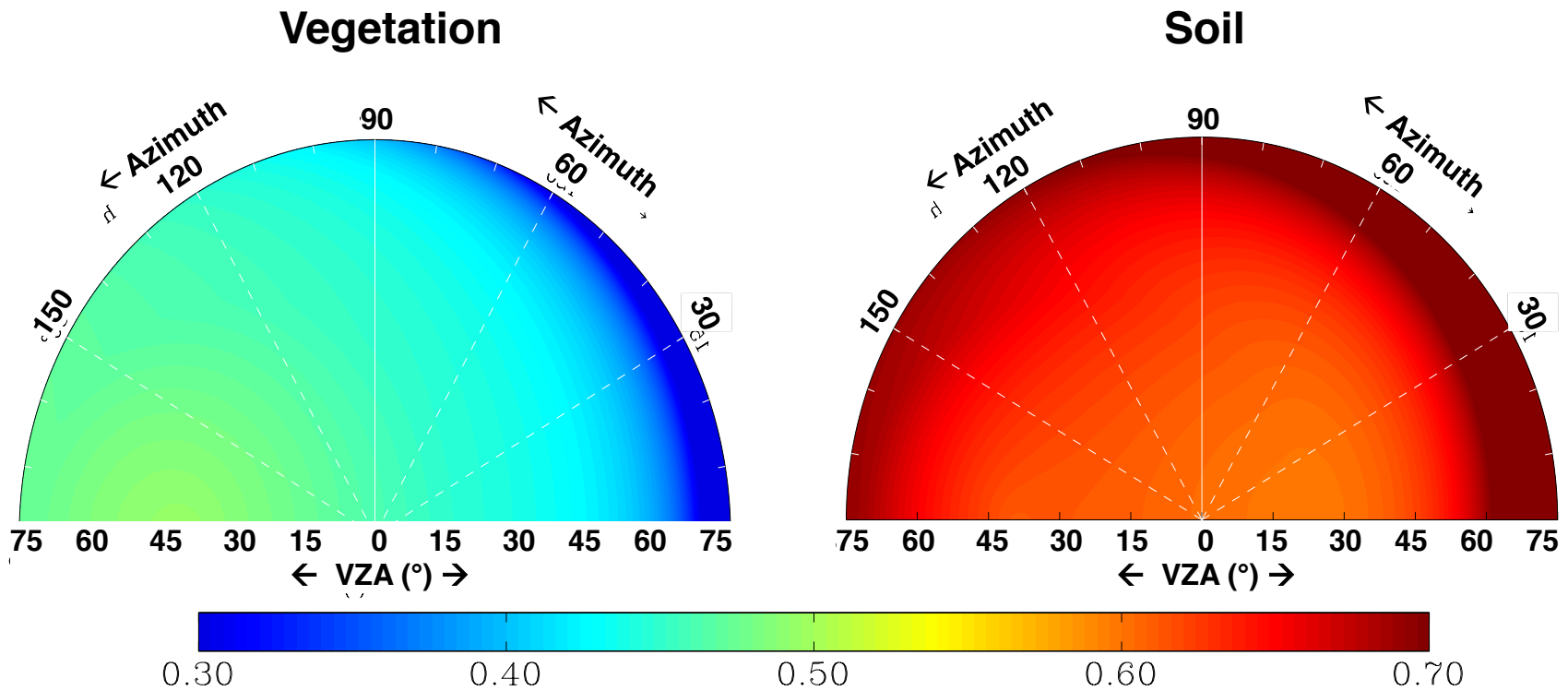


- RTLS model is not valid at large VZA or SZA
- Not a good assumption for aerosol retrieval that no change of surface properties in 16 days (first day precipitation, next day clear sky).

# Boundary surface conditions for aerosol retrieval

## Vis/NIR ratio

SZA = 40°

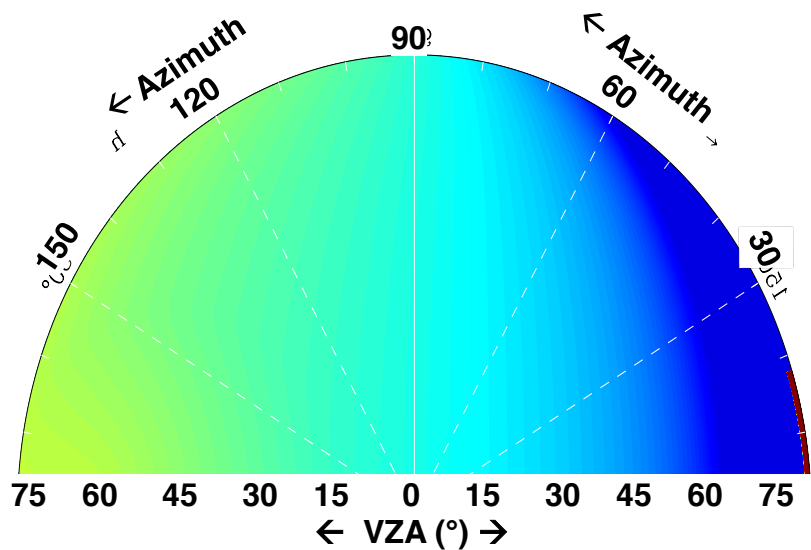


- Vis/NIR ratio shows strong and somewhat complex angular variations.
- Using NIR at one angle to estimate Vis at another angle appear to be very challenging: too many combinations and hard to parameterize.

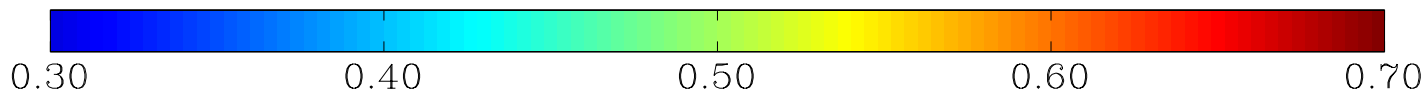
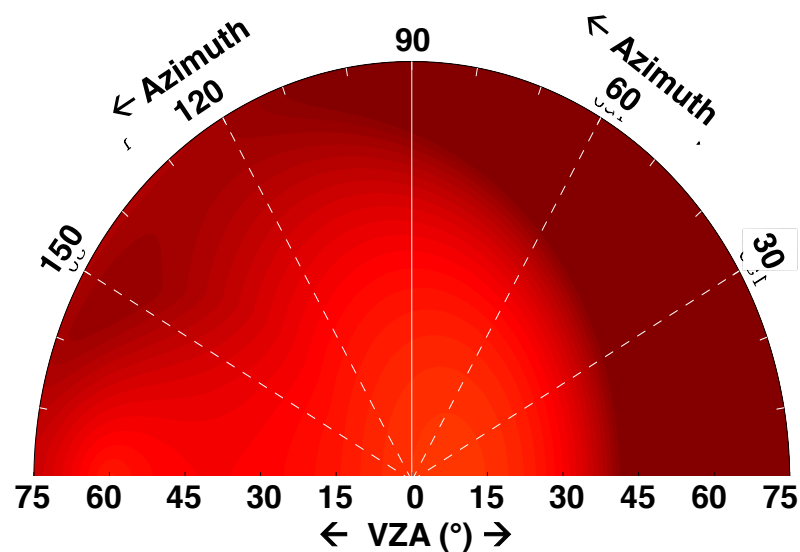
# Angular dependence of Vis/NIR ratio

SZA = 60°

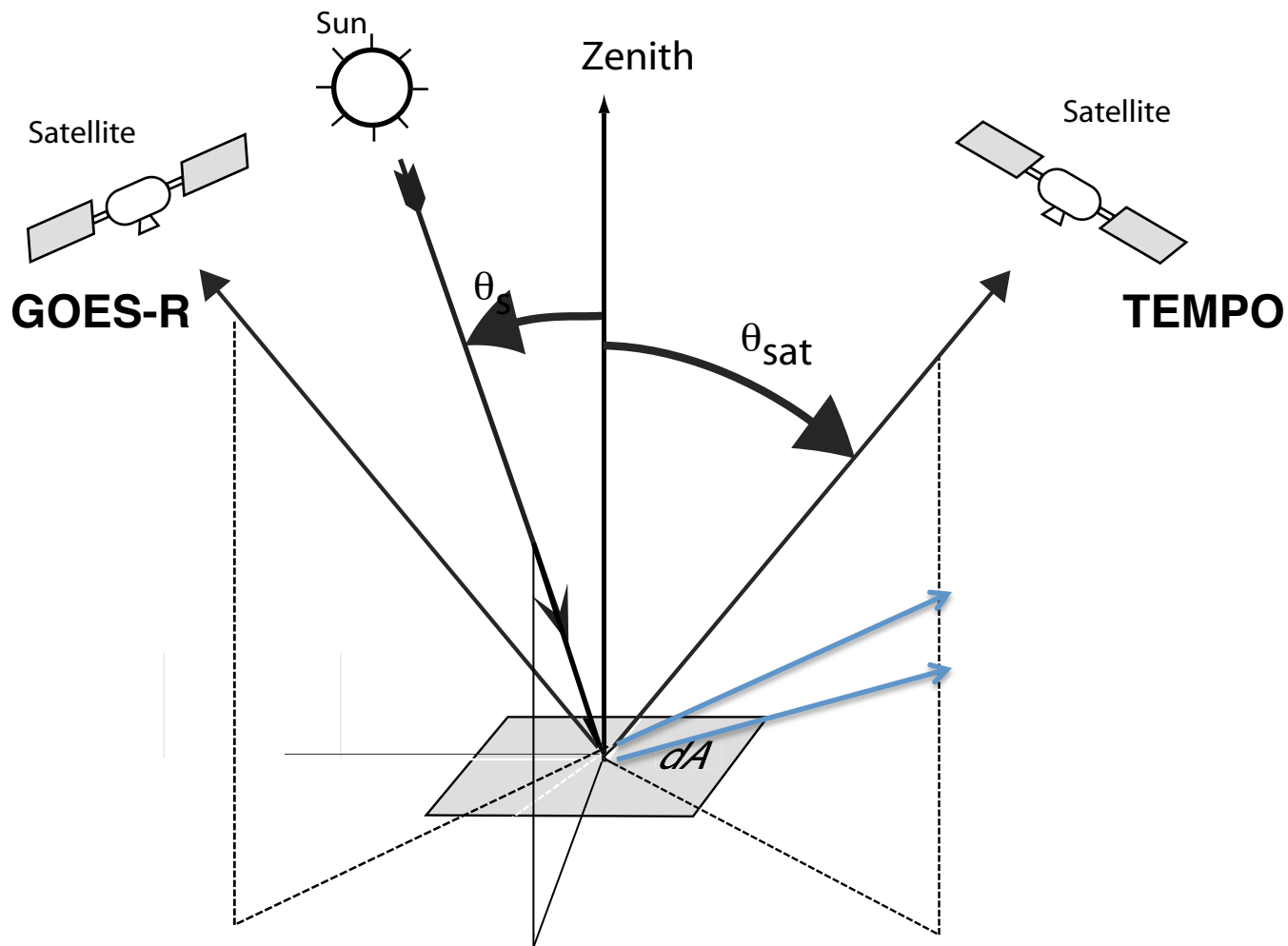
## Vegetation



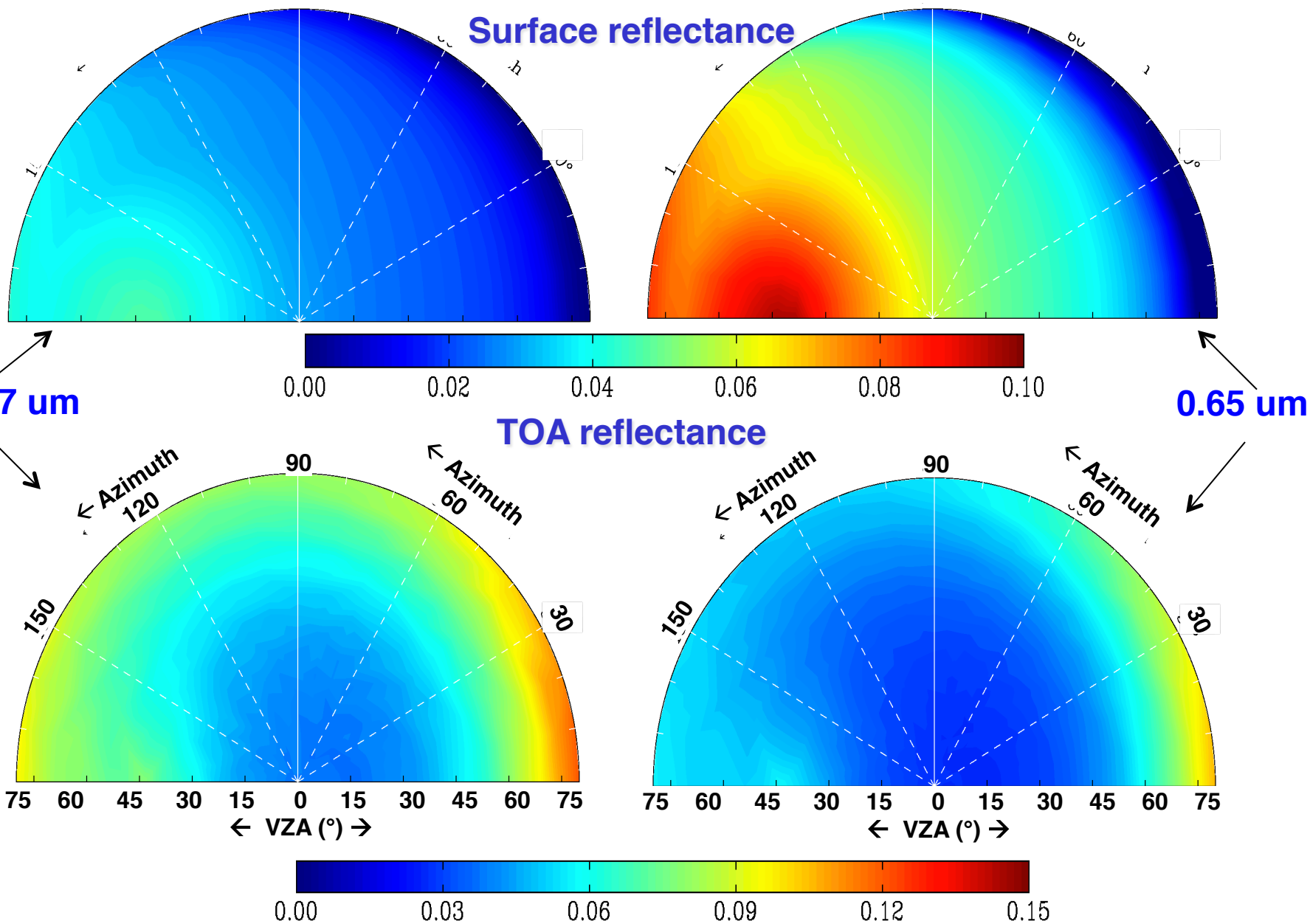
## Soil



- If we apply minimum composite method to derive surface reflectance respectively at TEMPO and GOES-R geometry, what is their synergy in aerosol retrievals?



# At shorter wavelength, aerosol effect rivals sfc. BRDF effect on reflectance at TOA



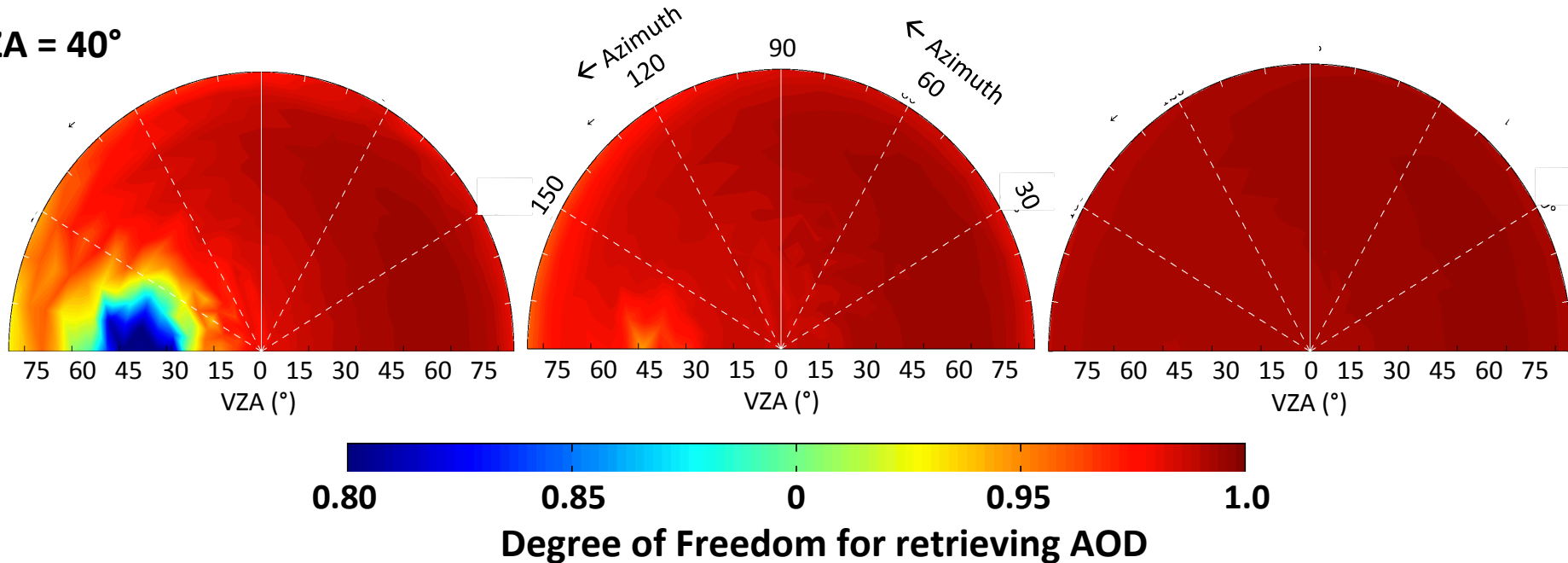
# Implication of BRDF for AOD retrievals

GOES-R  
470, 640, 860 nm

TEMPO/GEO-CAPE  
340, 380, 470, 640 nm

GOES-R +  
TEMPO/GEO-CAPE

SZA = 40°



- **TEMPO/GEO-CAPE UV wavelengths improve DOFs in AOD retrieval.**
- **Strong synergy between GOES-R and TEMPO/GEO-CAPE during the time when one of them is at the direction close to the Sun's illumination angle.**
- **BRDF is considered with uncertainty of 20%.**

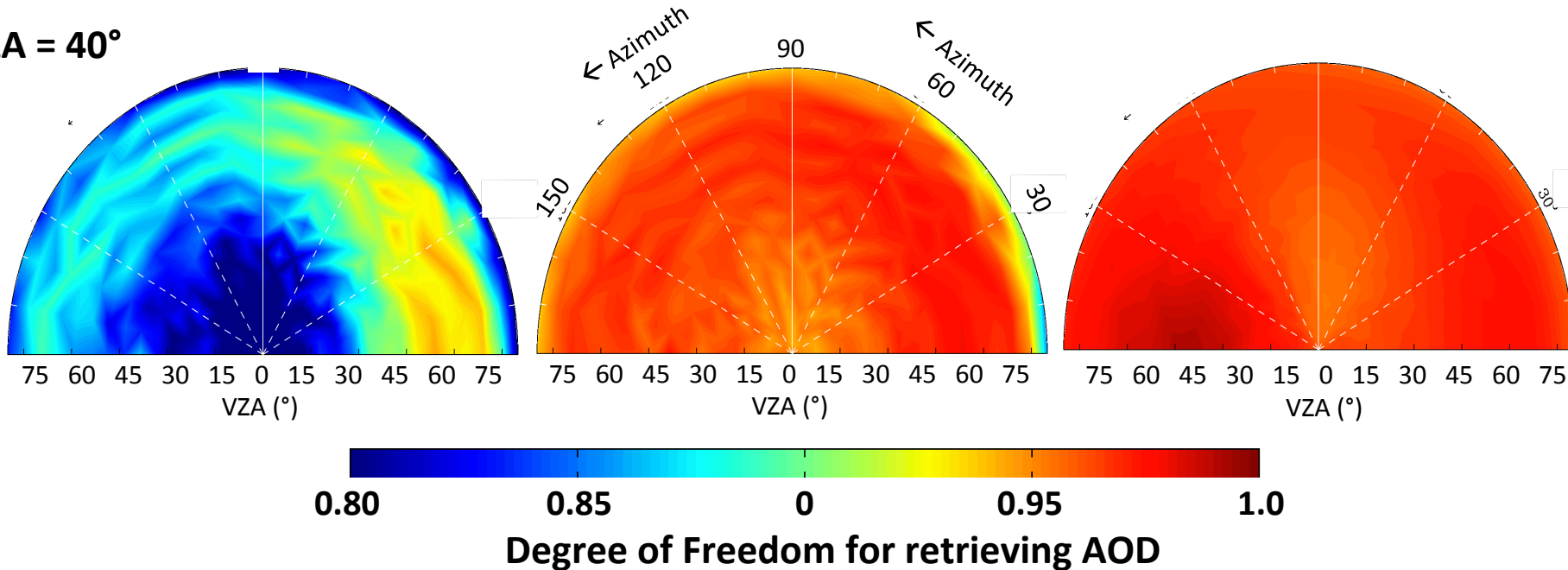
# Impact on fine-mode AOD retrieval

GOES-R  
470, 640, 860 nm

TEMPO/GEO-CAPE  
340, 380, 470, 640 nm

GOES-R +  
TEMPO/GEO-CAPE

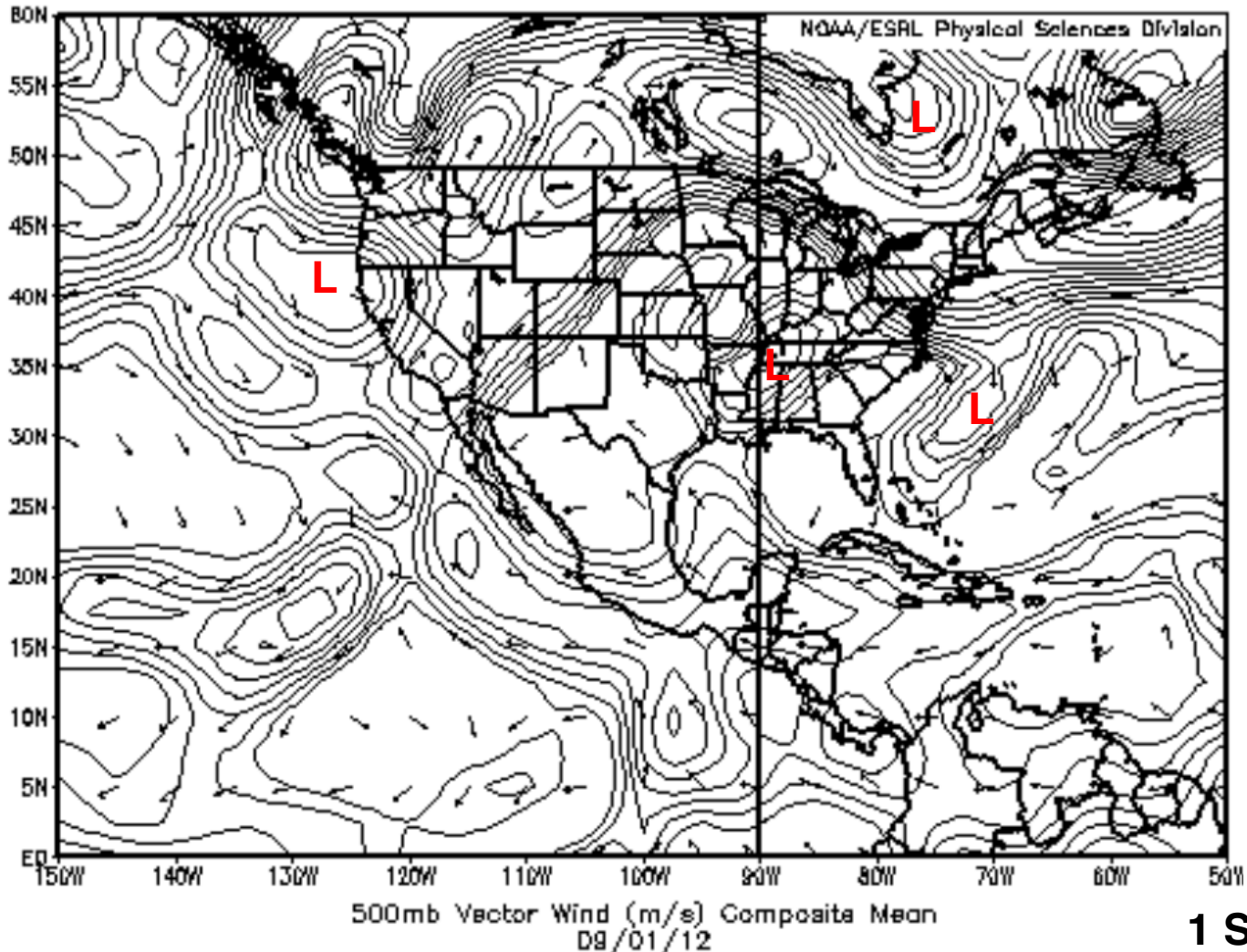
SZA = 40°



- BRDF appears to have less impact on retrieval of fine-mode AOD
- TEMPO/GEO-CAPE, due to its UV wavelength, is more sensitive for change of fine-mode AOD.
- Overall, synergy of GOES and TEMPO/GEO-CAPE can improve the retrieval of fine-mode AOD as well. Large spectral range offer more characterization of particle size.

**Move to the N-America continents. Examine the retrieval improvement by GOES+TEMPO synergy as a function of time and space?**

**Develop GEO satellite simulator based upon MODIS BRDF for surface, GEOS-Chem for atmosphere, and VLIDORT for radiative transfer calculation. Examine the retrieval over the TEMPO/GOES-E overlap regions.**

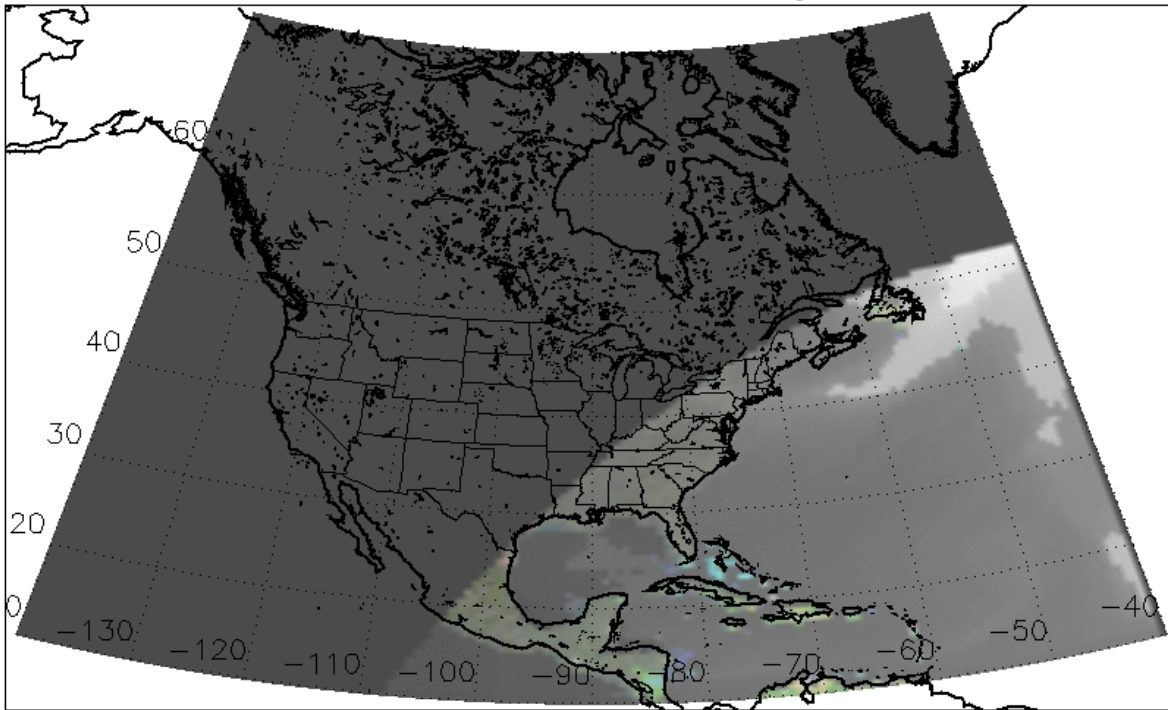




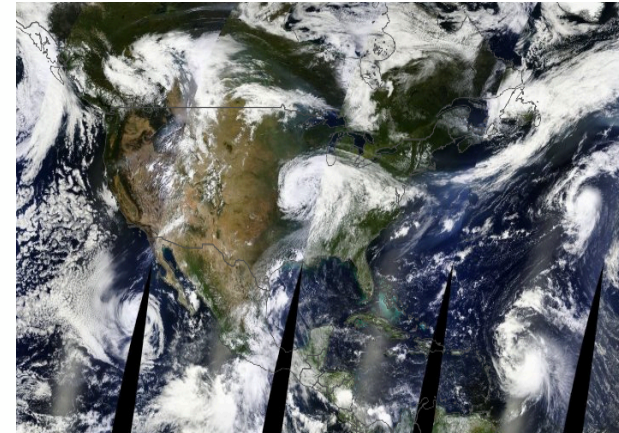
# Satellite simulator for TEMPO/GEO-CAPE

**1 Sep. 2012; SZA > 75° is masked out;  
cloud is not considered**

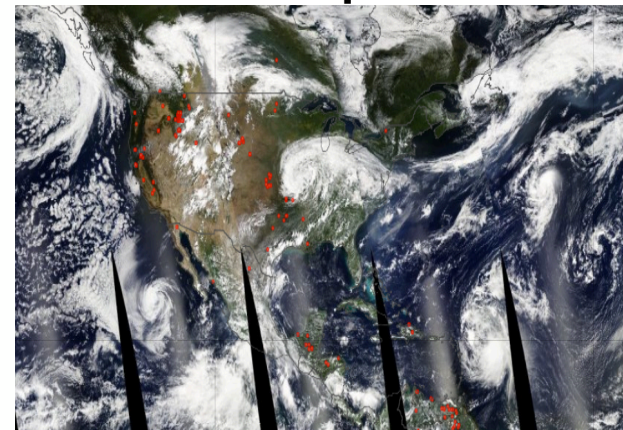
GEOS-Chem Satellite Simulator: RGB Image 20120901 14:30



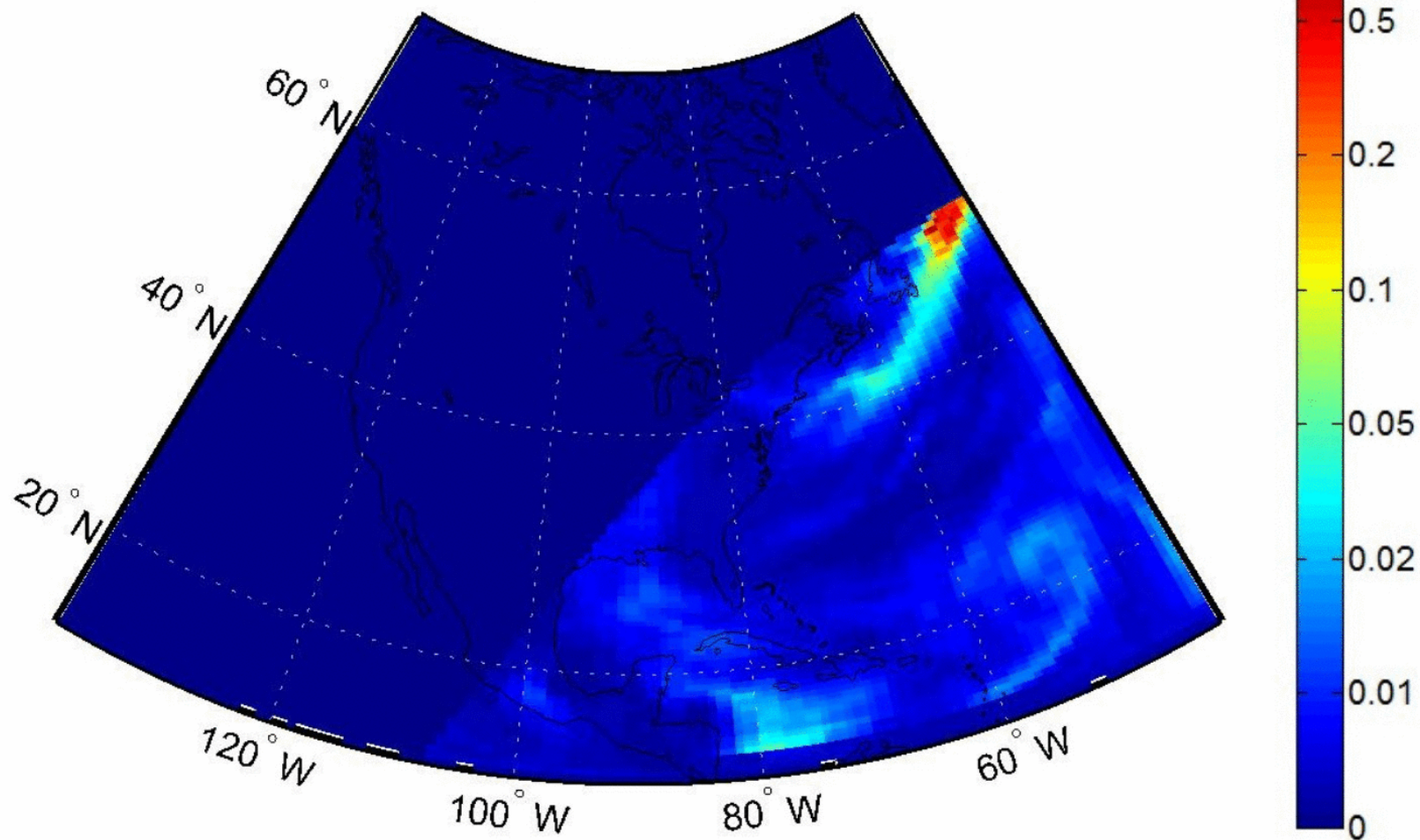
**Terra**



**Aqua**

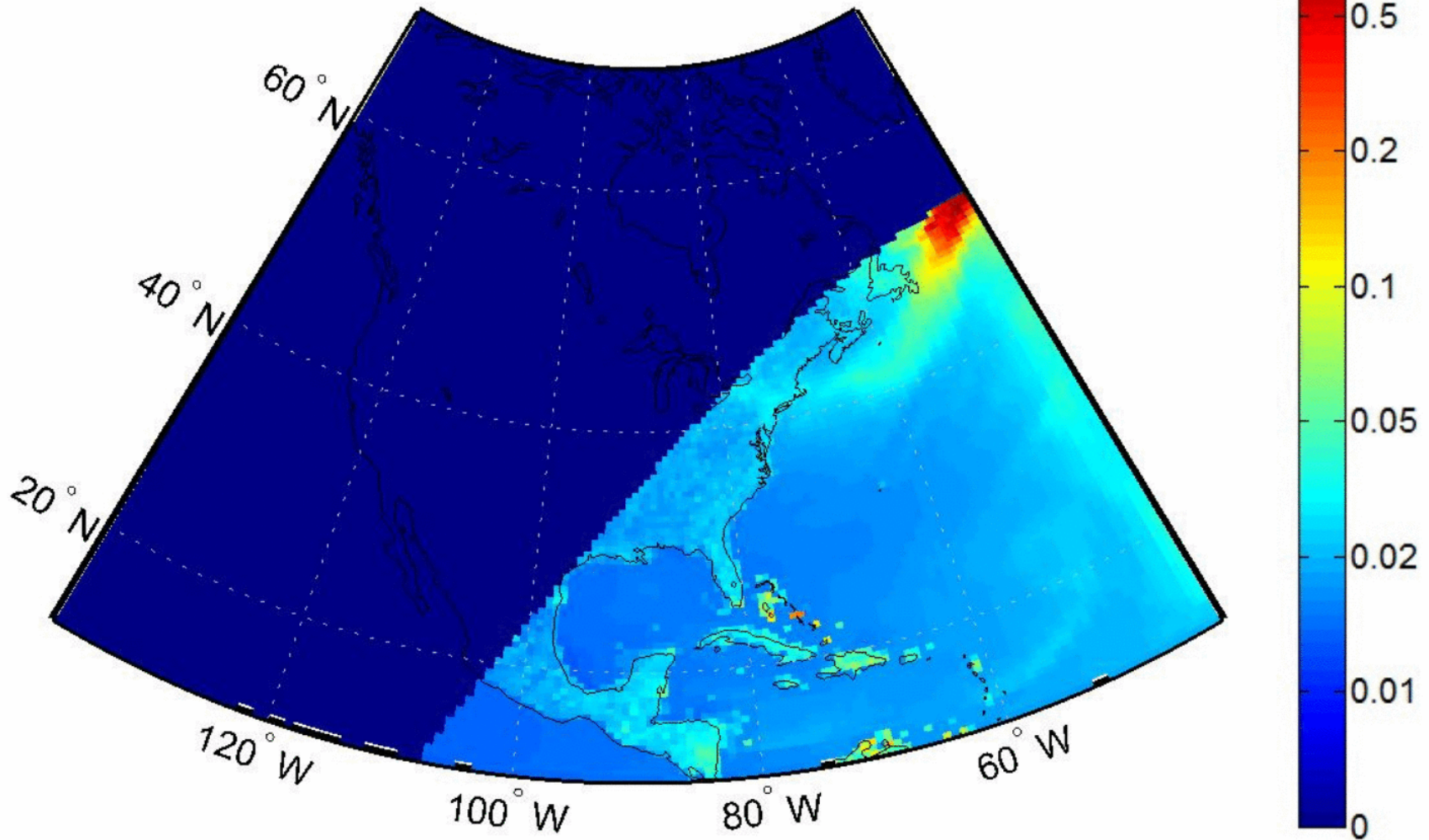


Aerosol Optical Thickness (AOT)  
2012-09-01, 14:30



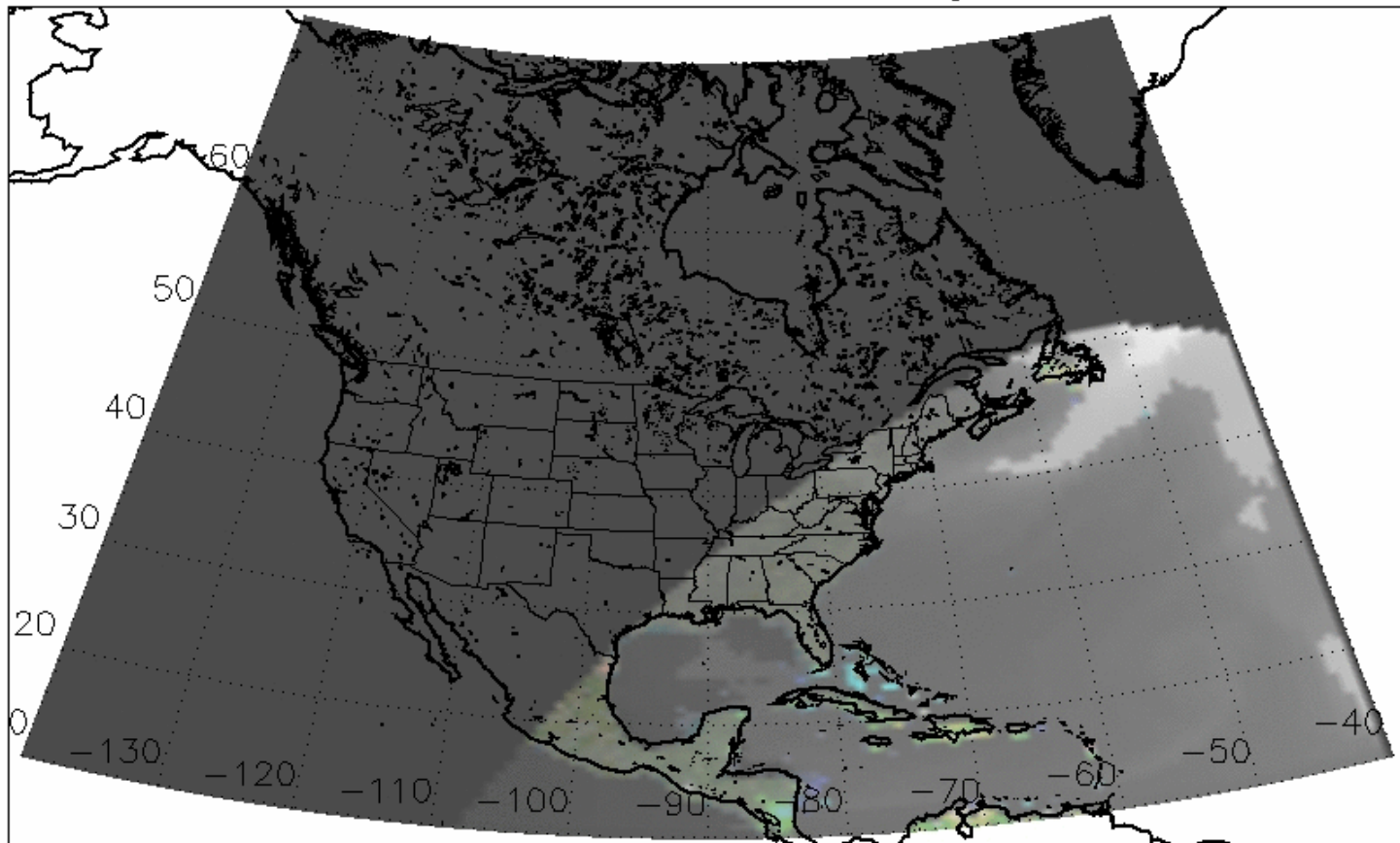
**GEO at 100W@  
 $\ln(I_{\text{SFC}}/I_{\text{TOA}}) \sim \text{AOD}$**

$-\log(I/I_0)$  (470 nm)  
2012-09-01, 14:30

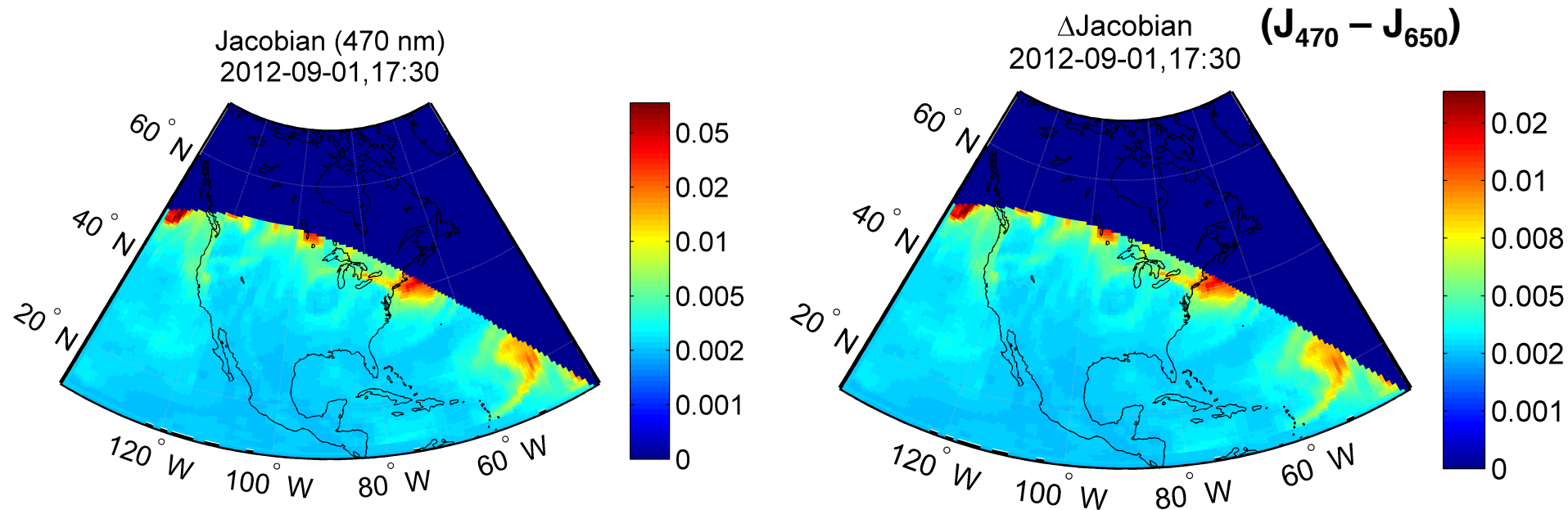


## Overlap area between GEO@75W and @100W

GEOS-Chem Satellite Simulator: RGB Image 20120901 14:30



# Spatial Distribution of Jacobians

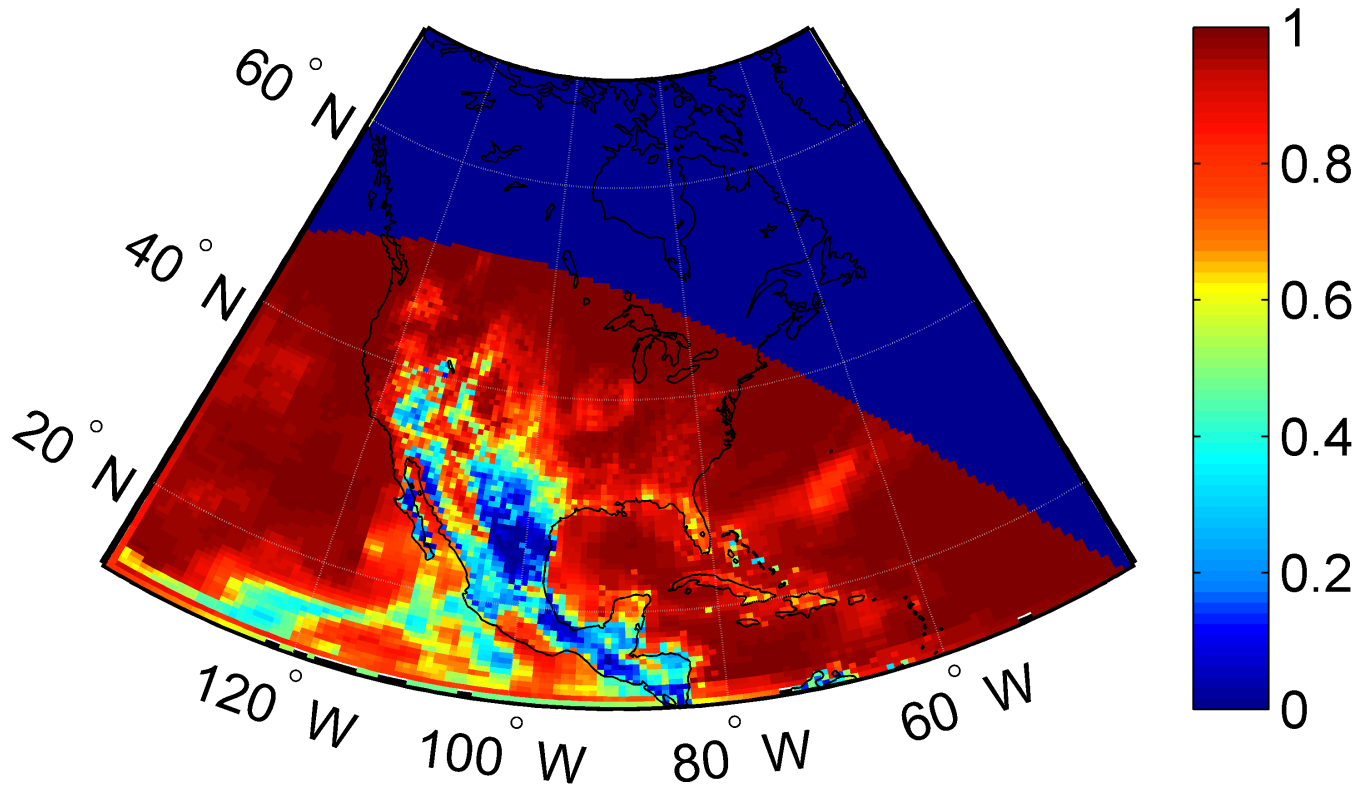


**Jacobian of radiance w.r.t. AOD are now analyzed spatially as a function of time. They can be used to:**

- (1) analyze the GOES and TEMPO/GEO-CAPE synergy in retrievals;**
- (2) for OSSE studies looking at the GOES and TEMPO/GEO-CAPE synergy for improving emission estimate.**

# Analyze of DOFs for AOD 75W

Averaging Kernel Matrix  
2012-09-01, 17:30



# Summary

- At large VZA or SZA, BRDF model fitting has large errors, and **minimum composite method** is recommended to derive the surface visible reflectance for TEMPO and/or GOES aerosol retrieval.
- Deriving **TEMPO VIS/GOES-R NIR ratio** have potential, but needs to consider the **directional difference**. A simple MODIS-type parameterization is not likely to be effective. If GOES-R has reliable retrieval of BRDF, why not? Otherwise, perhaps not practically feasible – limited by the cost.
- **Strong synergy** exists between TEMPO and GOES for improving AOD and fine-mode AOD retrievals. TEMPO: UV channels, low sfc. reflectance + high sensitivity to aerosols; GOES: add a different viewing angle and measurements. Significant improvement during time **when TEMPO is near the sun illumination angle while GOES is not**.
- Given strong geometry dependence in the aerosol retrieval, we need to **study the distribution of aerosol retrieval improvement in GEO-CAPE/ TEMPO and GOES-R series overlap regions as a function of time**.

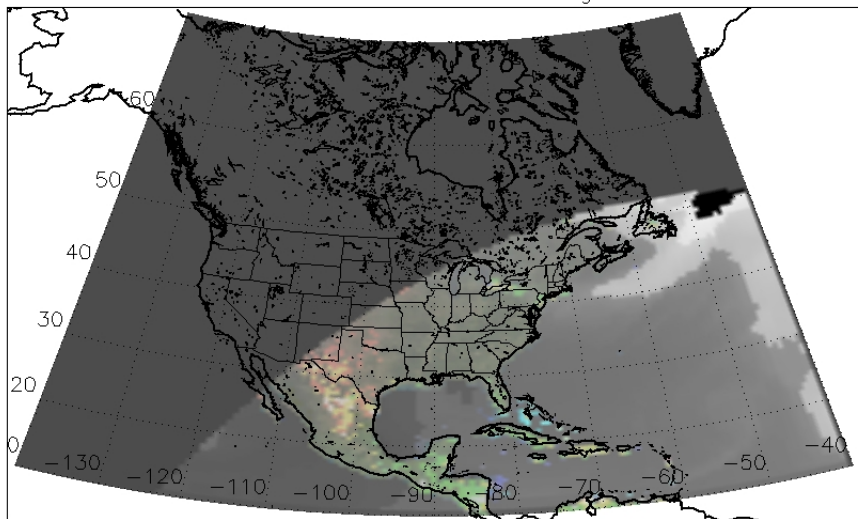
**With many thanks to NASA GEO-CAPE program.**



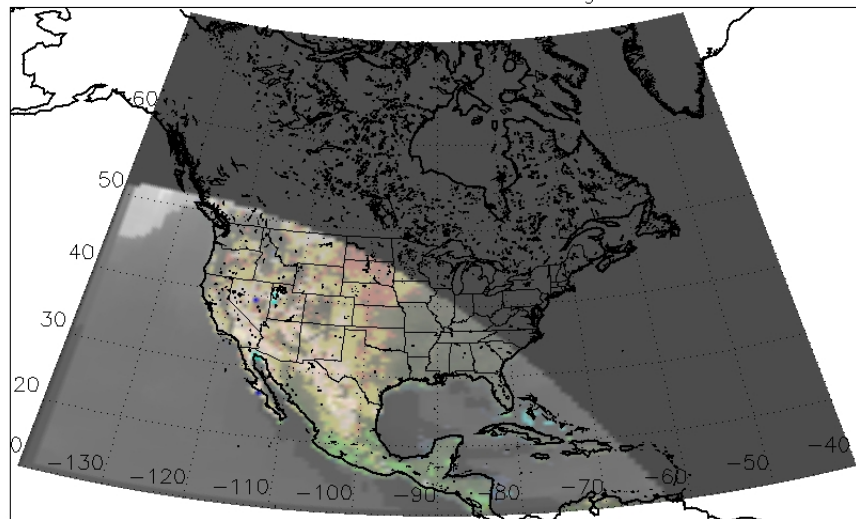
# Back-up slides

# GEO @100W

GEOS-Chem Satellite Simulator: RGB Image 20120901 15:30

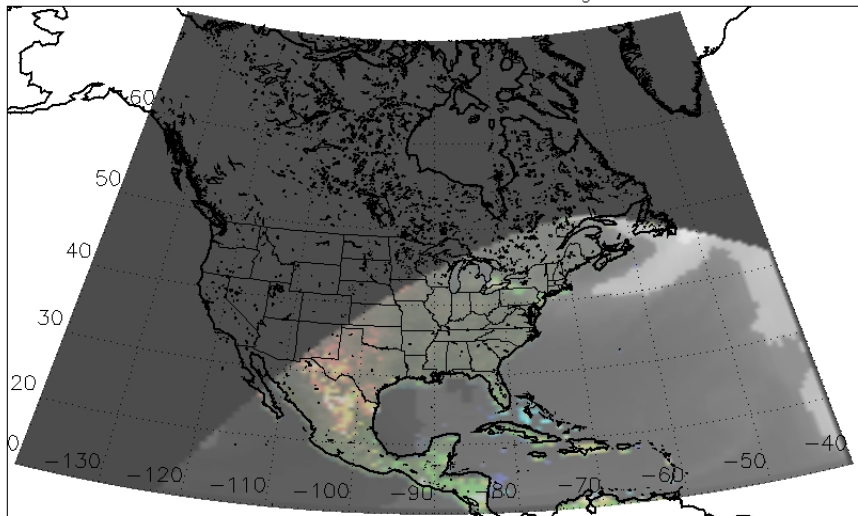


GEOS-Chem Satellite Simulator: RGB Image 20120901 20:30

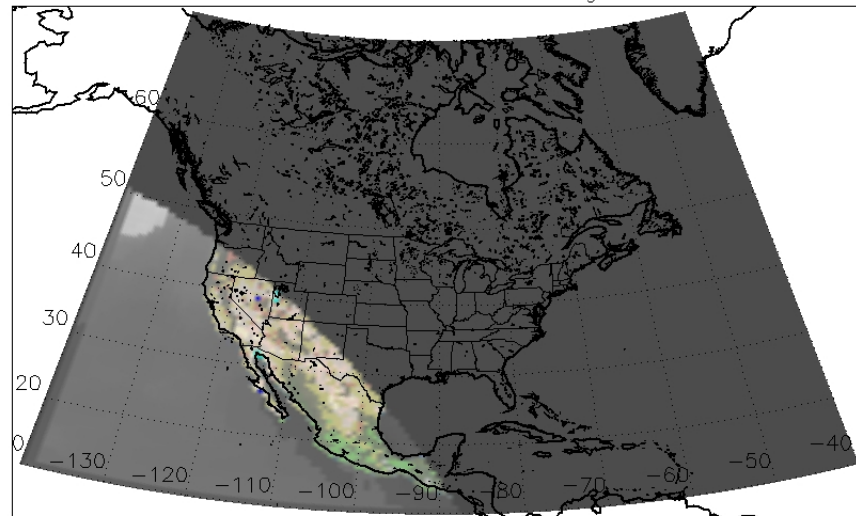


# Overlap region between GEO @75W and 100W

GEOS-Chem Satellite Simulator: RGB Image 20120901 15:30

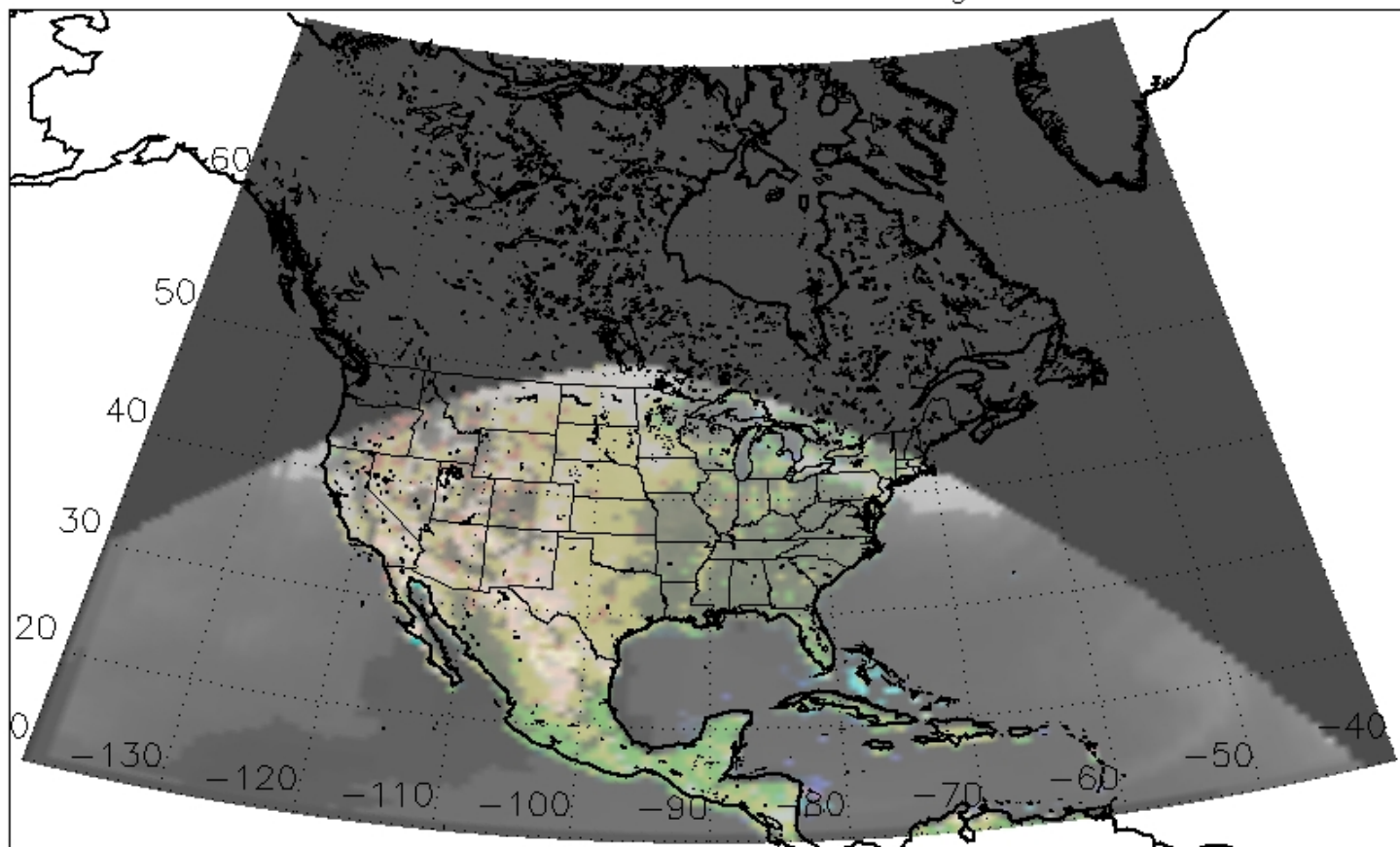


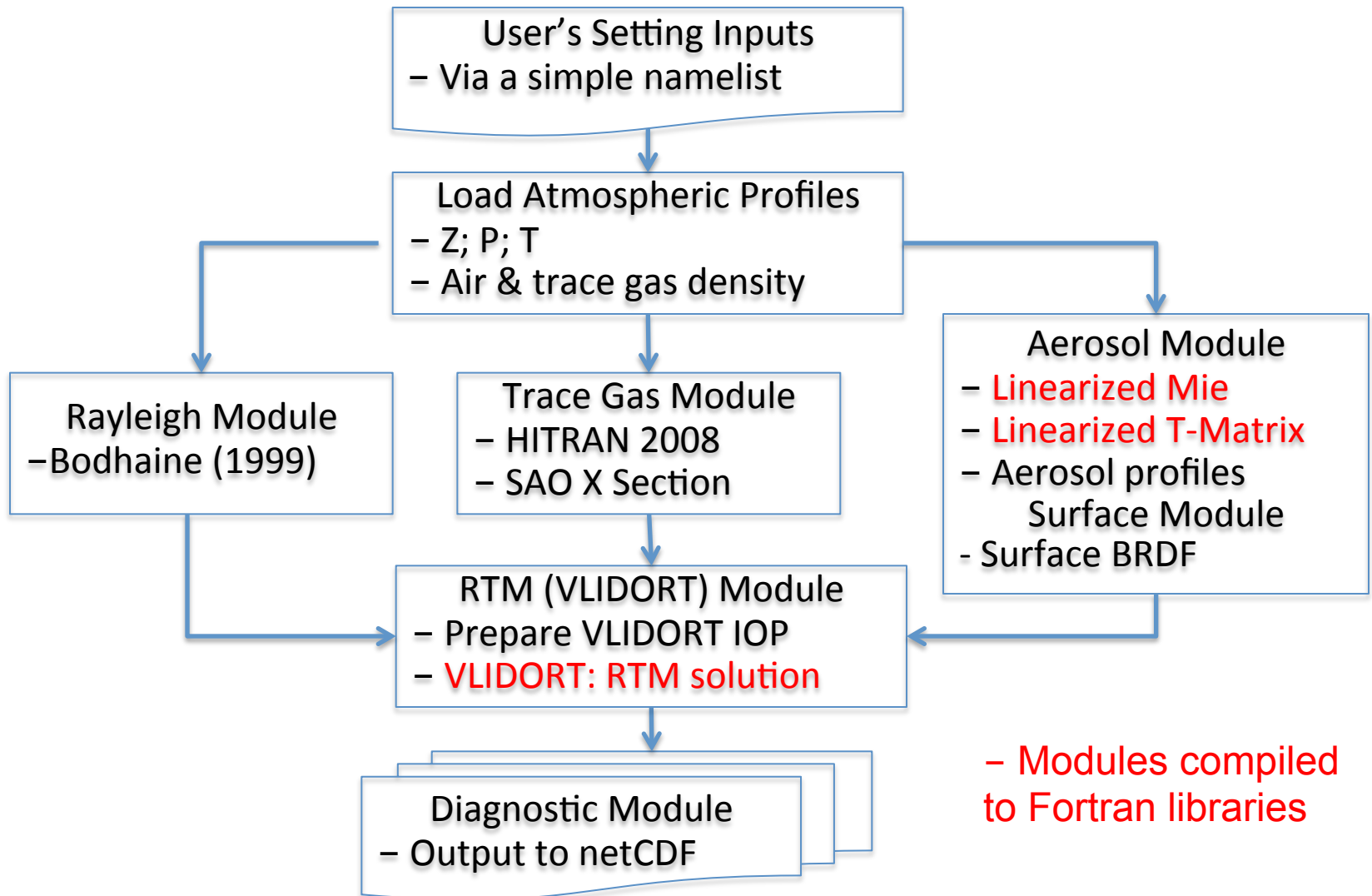
GEOS-Chem Satellite Simulator: RGB Image 20120901 20:30



## Overlap at: 1730

GEOS-Chem Satellite Simulator: RGB Image 20120901 17:30





- Modules compiled to Fortran libraries

# Aerosol Module

## – Linearized Mie and T-Matrix codes

- Apply to spherical (Mie) and non-spherical (T-Matrix) particles
- Inputs: wavelength, refractive index, size distribution, and shape
- Calculates aerosol single scattering optical properties
- Also, derivatives of optical properties with respect to size parameters, and refractive index, and shape factor

## – Aerosol vertical profiles

- Three type of vertical profiles have been implemented

- 1<sup>st</sup>, uniform profile, aerosol is evenly distributed in vertical.

- 2<sup>nd</sup>, exponential-decreasing profile:  $p(z) = \int_{+\infty}^z \tau(z) dz = \tau_0 \exp\left(-\frac{z}{H}\right)$

- 3<sup>rd</sup>, quasi-Gaussian shape:  $p(z) = \frac{K f(z)}{[1 + f(z)]^2}$

where  $f(z) = \exp(-\sigma_{hw} |z - z_{peak}|)$  for half-width constant  $\sigma_{hw}$  and peak height  $z_{peak}$ .

## Model Verifications: Jacobian

– Using the finite difference method:

○ FD Gradient =  $[ I(x+\Delta x) - I(x) ] / \Delta x$

– Jacobian of Stokes parameters with respect to

○ AOD (bi-mode X 1)

○ SSA (bi-mode X 1)



Shown in the next slide

○ Aerosol mass concentration (bi-mode X 1)

○ Refractive index (bi-mode X 2)

○ Size distribution parameters (bi-mode X 2 or 3)

○ Vertical profile (bi-mode X 1 or 2)

○ Shape factor (coarse mode X 1)

○ Surface reflectance (1)

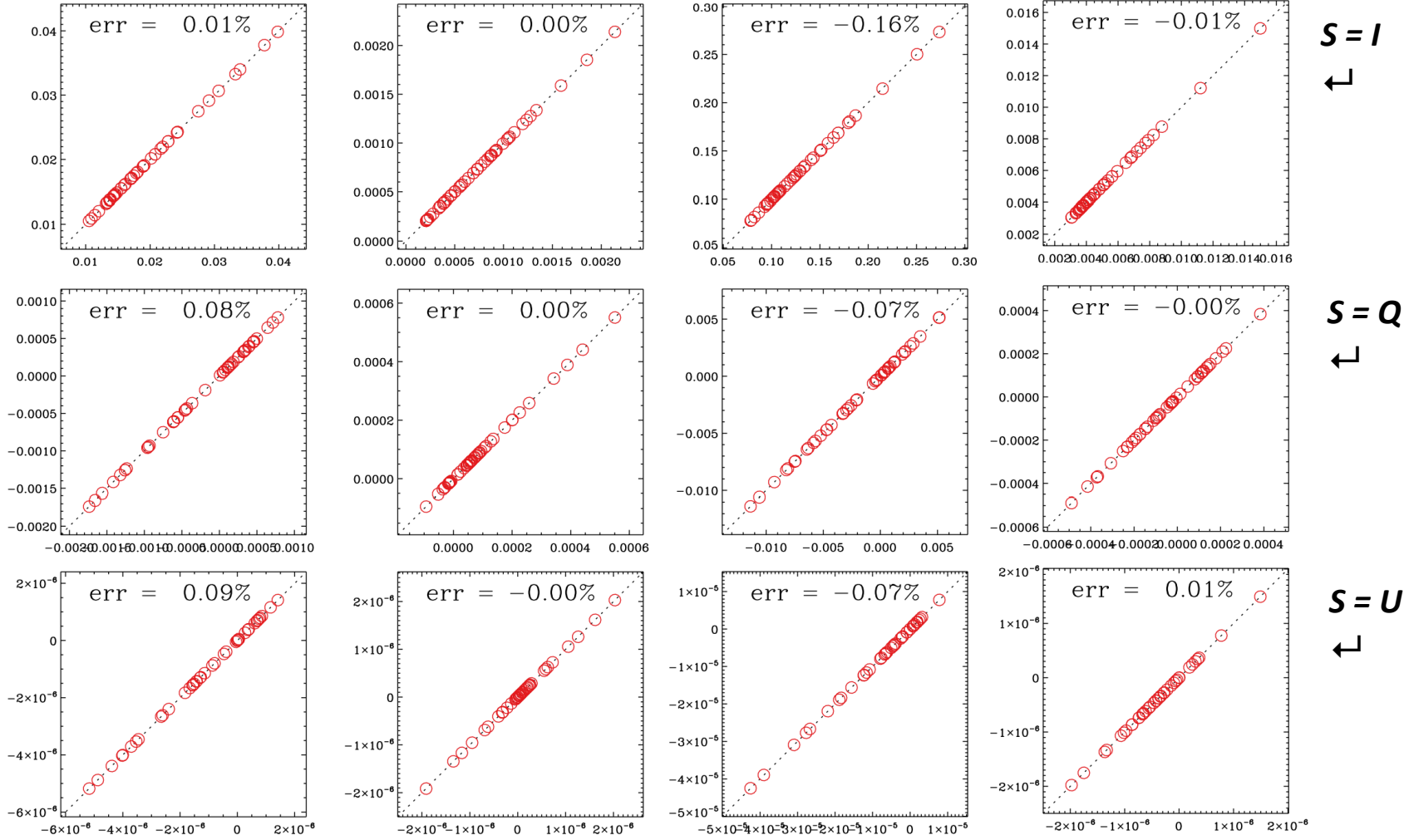


Not shown, but similar to the verifications for Jacobians to AOD and SSA

# Model Verifications of Analytic Jacobian ( $x \partial S / \partial x$ )

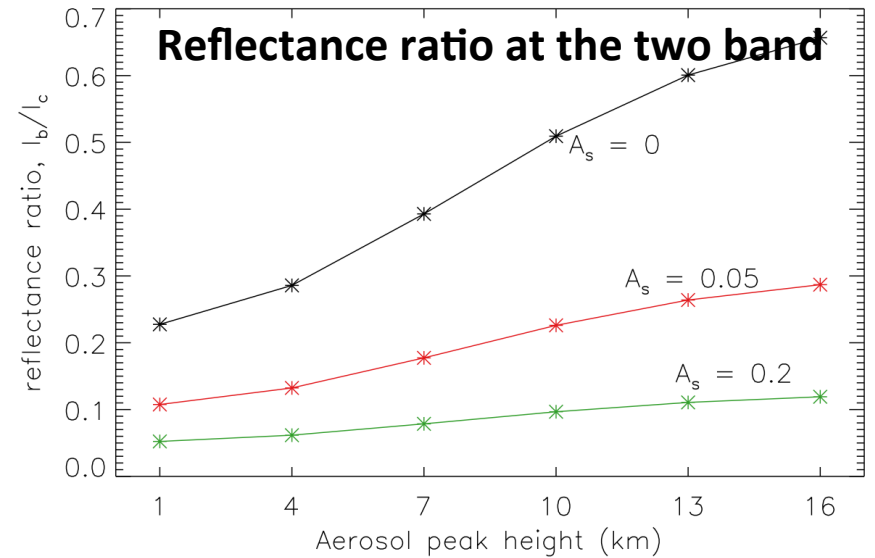
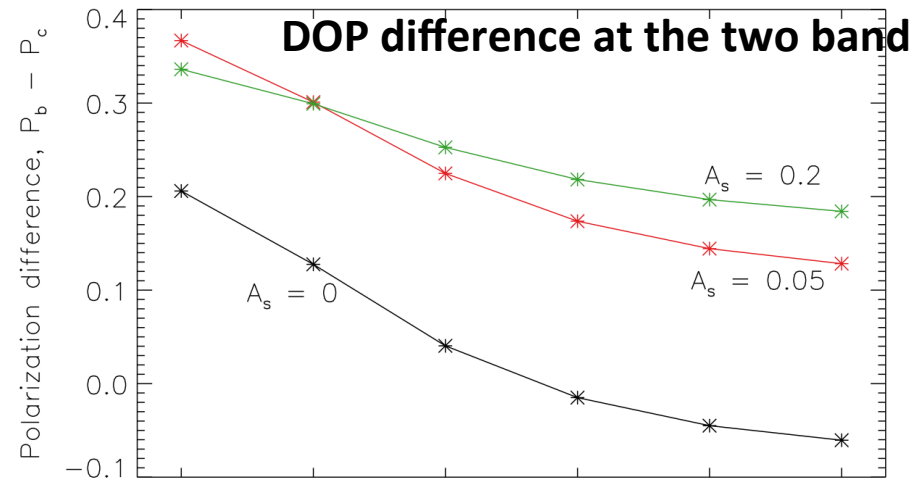
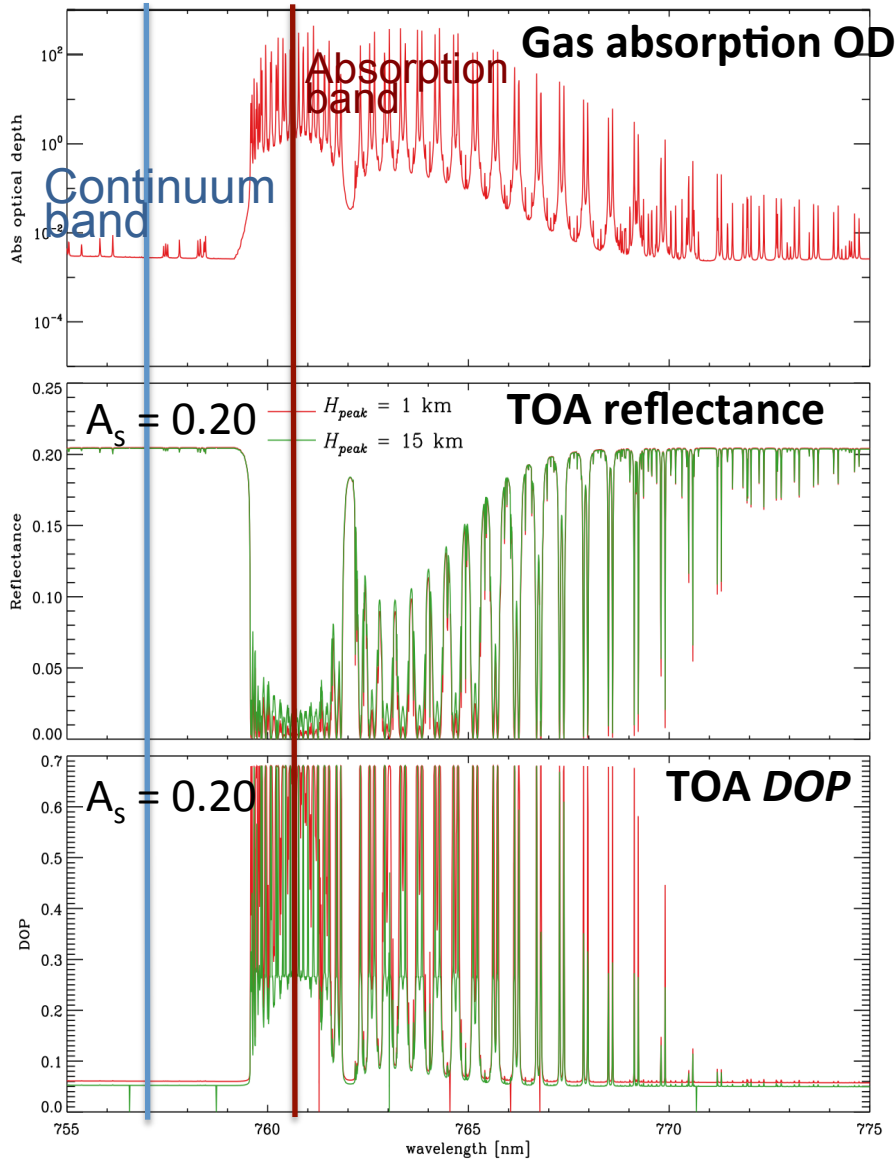
$x = \text{fine mode AOD}$     $x = \text{coarse mode AOD}$     $x = \text{fine mode SSA}$     $x = \text{coarse mode SSA}$

Analytic Jacobians



Finite Difference Gradients

# Application: Sensitivity of $I$ and $DOP$ to aerosol plume height in O2-A





# Food for thoughts

- Retrieval is an inverse problem: # of unknowns > # of measurements as both atmosphere and surface change in daily and/or finer temporal scale.
- Retrieval of aerosols are affected by assumed properties of surface and atmosphere. Land surface change is assumed to be less fast than atmosphere; but these are all relative and sometimes are not the case.

# Outline

- Can we apply derive TEMPO visible reflectance from GOES-R 2.3  $\mu\text{m}$ ?
- If we apply minimum composite method to derive surface reflectance respectively at TEMPO and GOES-R geometry, what is their synergy in aerosol retrievals.
- Incorporate the RTLS BRDF model into the UNL's Particle Retrieval Testbed for studying synergy between two GEOs.
- Develop GEO satellite simulator based upon MODIS BRDF for surface, GEOS-Chem for atmosphere, and VLIDORT for radiative transfer calculation. Examine the retrieval over the TEMPO/GOES-E overlap regions.

