Surface Reflectance Retrievals from GEMS Observations:

Algorithm Development, Validation Effort, and Sensitivity Test

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Outline

- **Introduction:**
  - **Goal, R_{sfc} Definition & Problem**
- **Timelines of the R_{sfc} Algorithm Development**
- **Algorithm Development**
  - **Cloud-Screening for R_{sfc} Derivation:**
    - **- Method & Pixel-resolution effect**
  - **Atmospheric Correction**
- **Validation of R_{sfc}:**
  - **Plans and On-going Efforts**
- **Sensitivity of R_{sfc} w.r.t. Radiometric Errors in TOA Reflectance**
- **Analysis on the Existing R_{sfc} Data Products**

Goal: *Providing Accurate Boundary Conditions for Radiative Transfer / Climate Models and Remote Sensing*

- ***Energetics:***
  - relating limited measurements of ***angular reflectance*** to ***flux albedo*** a crucial input parameter to climate/environment models.
- ***Remote sensing:***
  - characterizing surface ***anisotropy*** to interpret ***off-nadir*** radiances acquired by satellite sensors (e.g., for retrievals of aerosols and trace gases).

Definition of Surface Reflectance and Problem of Its Derivation

- ***Theory:*** **Simple definition,**

$$R_{sfc}(\lambda, \theta, \phi; \theta_0, \phi_0; t, x, y) = \frac{I(\lambda, \theta, \phi; \theta_0, \phi_0; t, x, y)_{reflected}}{I(\lambda, \theta_0, \phi_0)_{incident}}$$

but complicated multi-dimension (4~8) problem!

→ Need Time-dependent Bidirectional Reflectance Distribution Function (BRDF)

- ***Reality:*** ***at all-scale inhomogeneity***

mixture of diverse biomes, sfc moisture, etc.

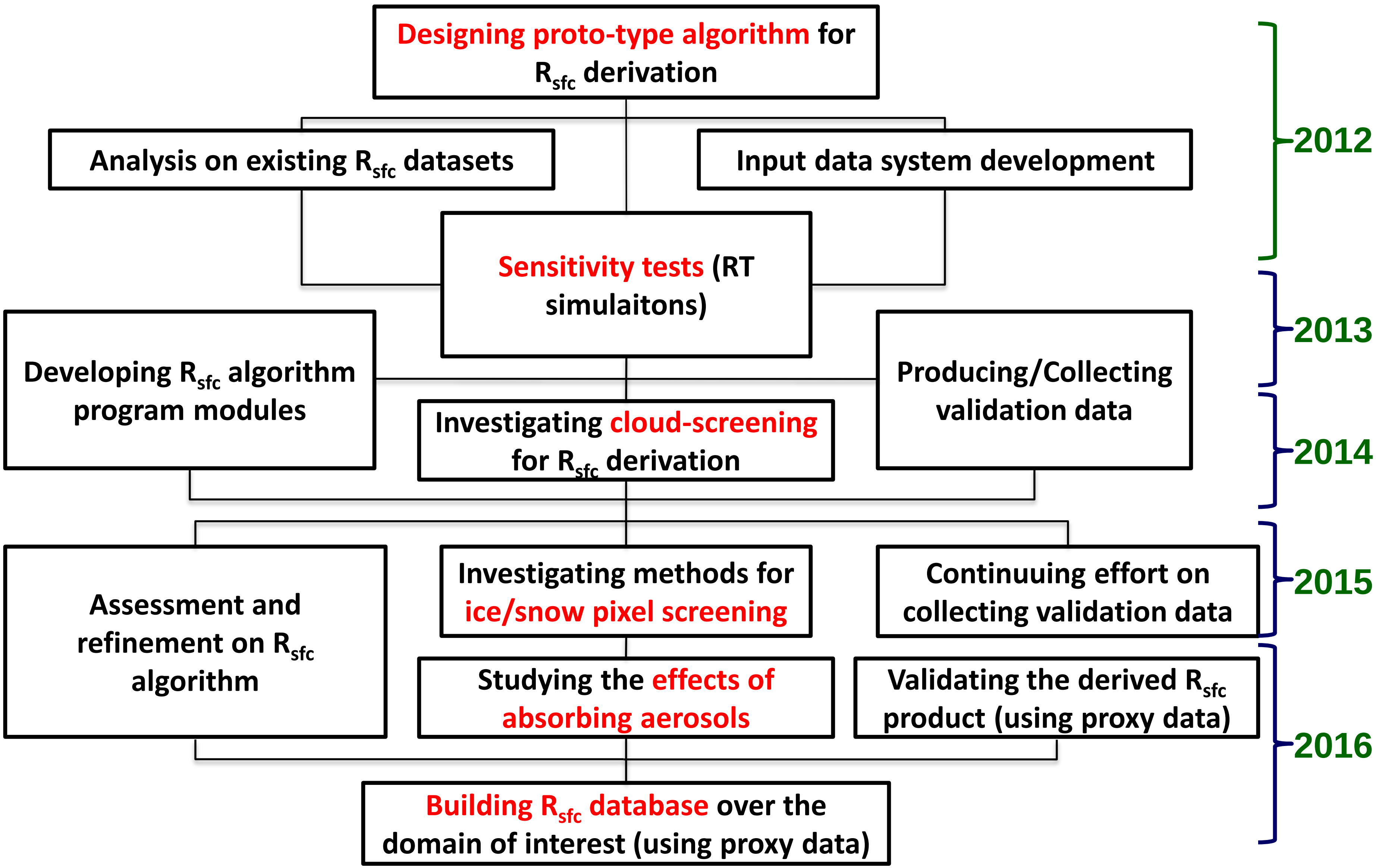
seasonal transitions

fine sand, rocks, gravel, shrub, dunes, etc.

vegetation, snow, small water bodies

Timelines for the R_{sfc} Algorithm Development

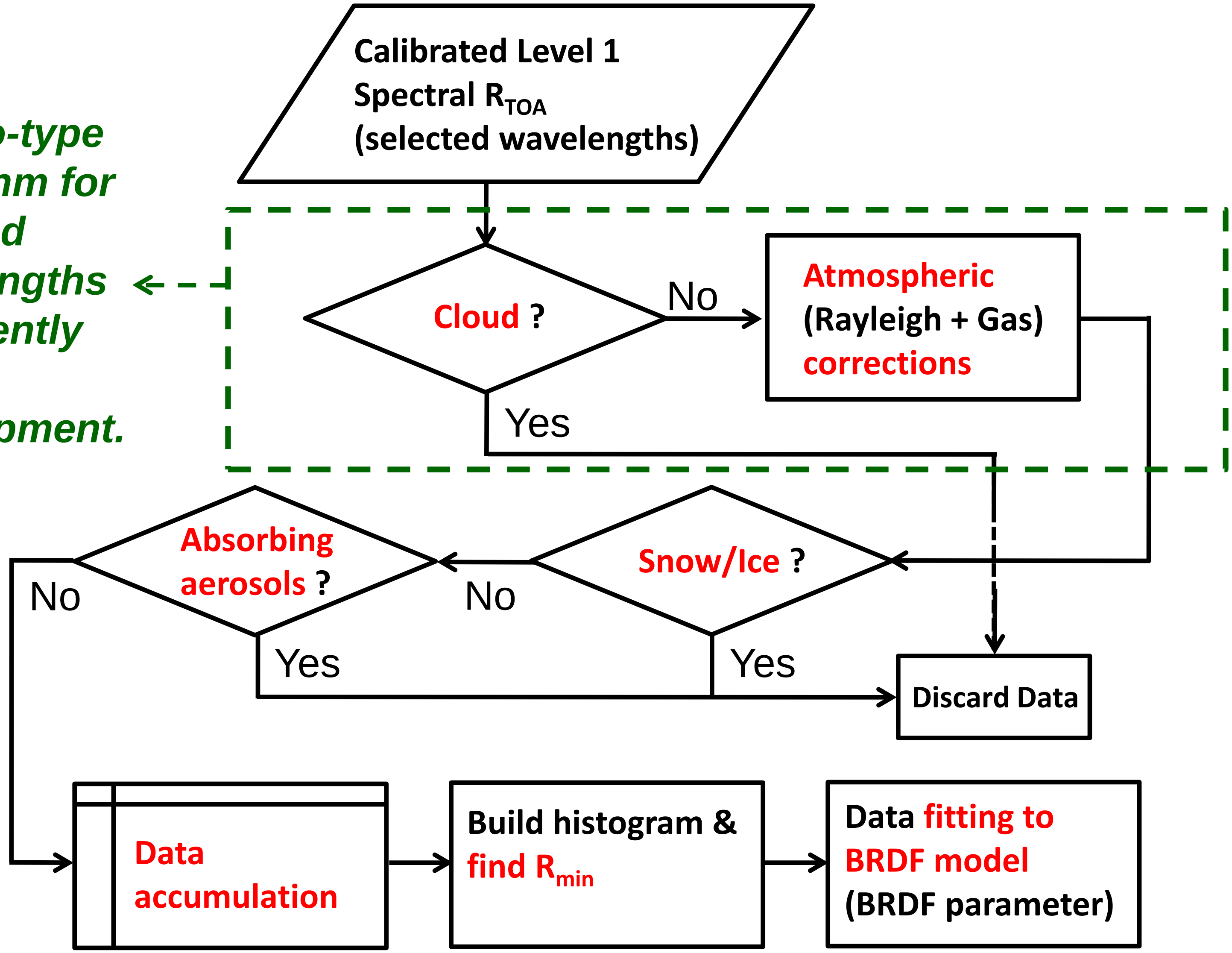
(plan)



The Algorithm: Flowchart for R_{sfc} Derivation

(Plan for GEMS, Work-in-progress)

A proto-type algorithm for selected wavelengths is currently under development.

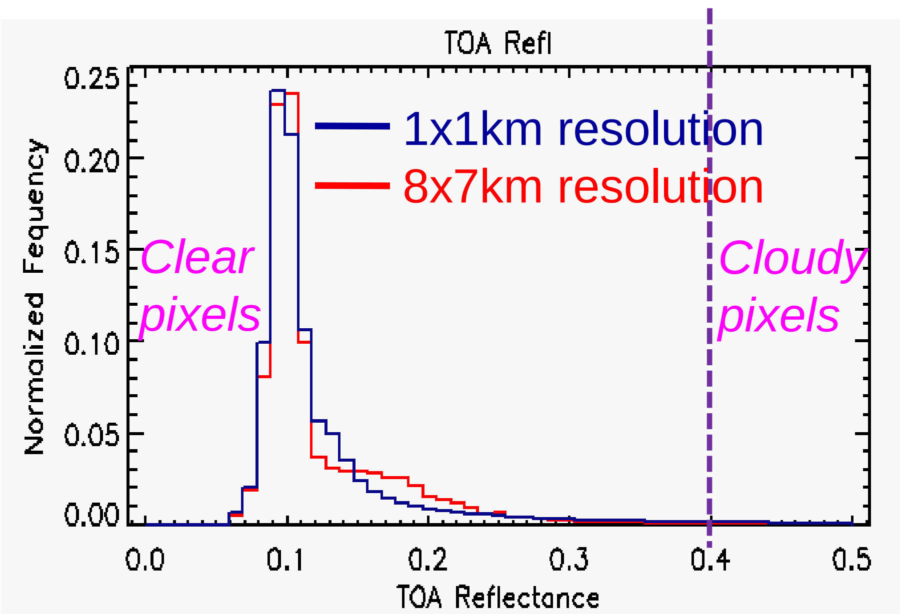


Algorithm Development I: Cloud-Screening for R_{sfc} Derivation

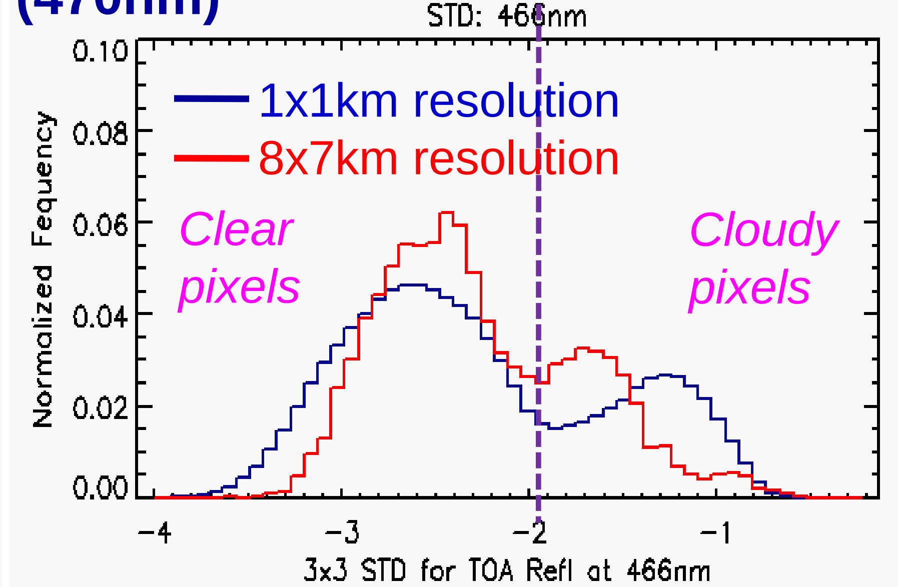
Cloud-screening for R_{sfc} Derivation (1)

- ✓**Thresholds of TOA reflectance (R_{toa})**
- ✓**Thresholds for spatial variability of R_{toa}**
- ✓**Ultraviolet Aerosol Index [UV AI] (plan)**
- ✓**Use of polar orbiting satellite data to filter out cirrus-prevailing scenes (plan)**

TOA Reflectance (470nm)



3x3-Pixel-STD of TOA Reflectance (470nm)



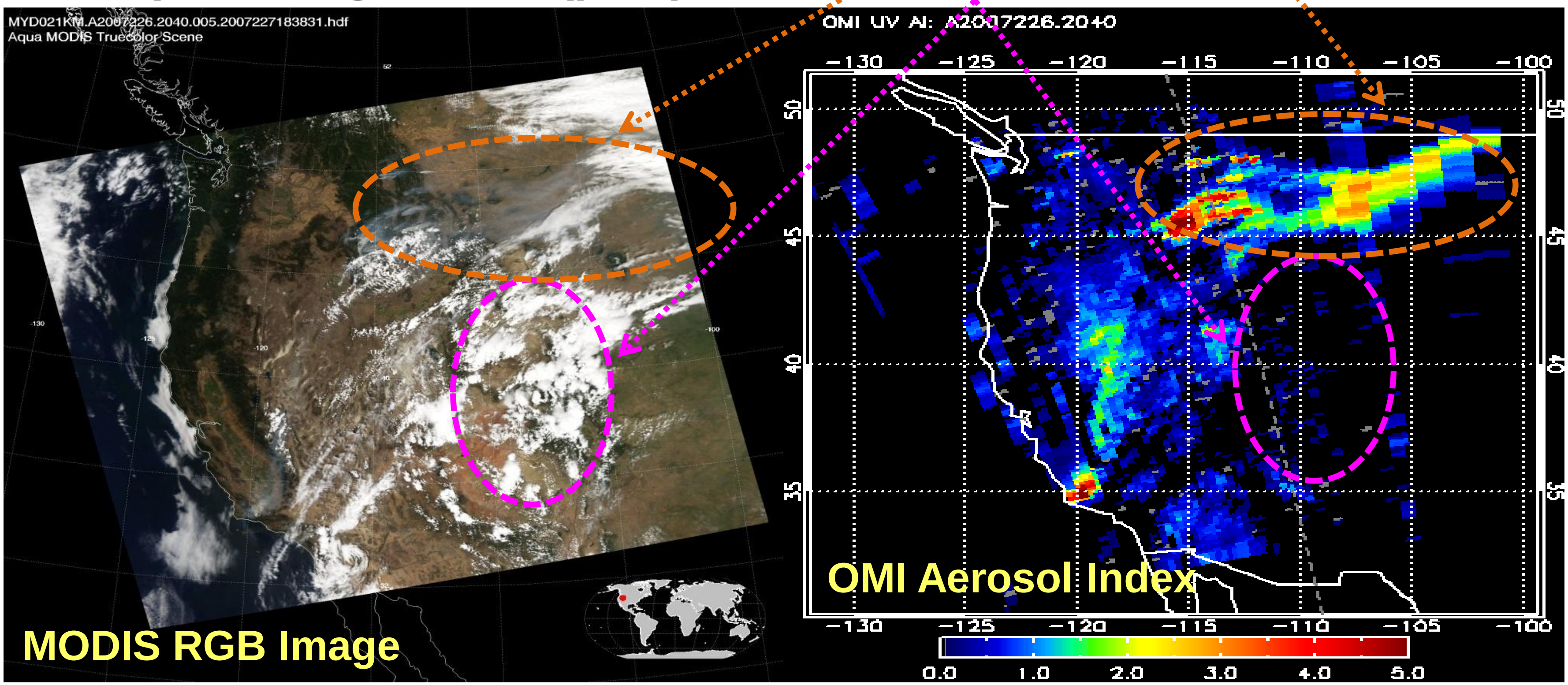
➔ Threshold values of TOA reflectance and its spatial variability for R_{sfc} derivation are being determined with consideration of sensor (pixel) spatial resolutions.

Cloud-screening for R_{sfc} Derivation (2)

- ✓Thresholds of TOA reflectance (R_{toa})
- ✓Thresholds for spatial variability of R_{toa}
- ✓**Ultraviolet Aerosol Index [UV AI] (plan)**
- ✓Use of polar orbiting satellite data to filter out cirrus-prevailing scenes (plan)

Smoke → high AI values

Clouds → AI~0



- **UV Aerosol Index (AI) tends to be close to zero for cloudy pixels.**
- **UV AI become higher for pixels with UV-absorbing aerosols.**

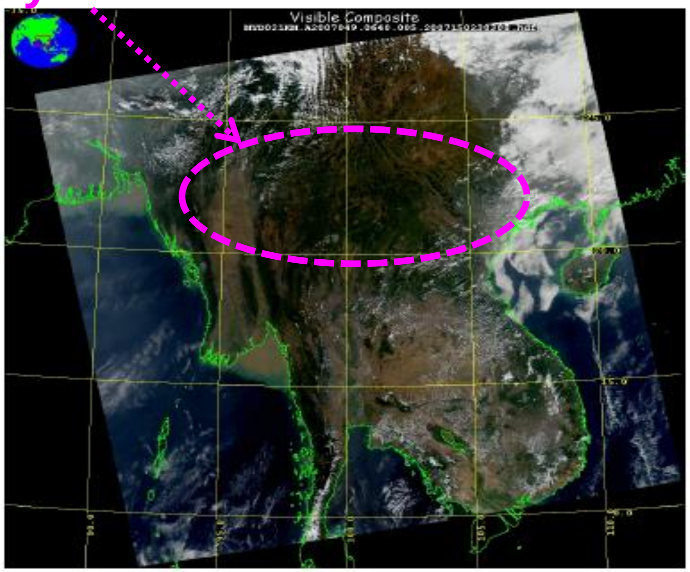
→ UV AI can be utilized for cloud-screening & absorbing aerosol detection in the process of R_{sfc} derivation.

Cloud-screening for R_{sfc} Derivation (3)

- ✓Thresholds of TOA reflectance (R_{toa})
- ✓Thresholds for spatial variability of R_{toa}
- ✓Ultraviolet Aerosol Index [UV AI] (plan)
- **✓Use of polar orbiting satellite data to filter out cirrus-prevailing scenes (plan)**

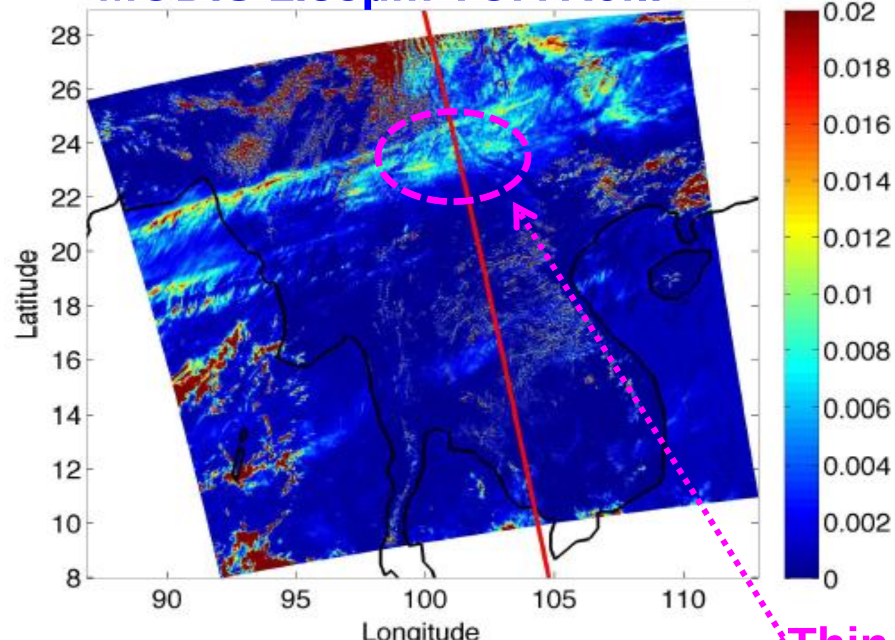
(Huang et al. 2012, JGR submitted)

Nearly Invisible Cirrus

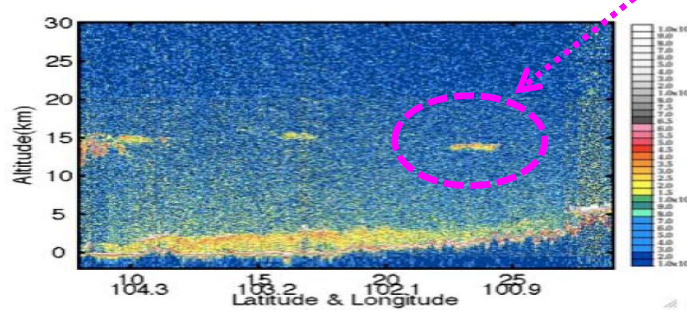


MODIS RGB Image

MODIS 1.38µm TOA Refl.



Thin Cirrus

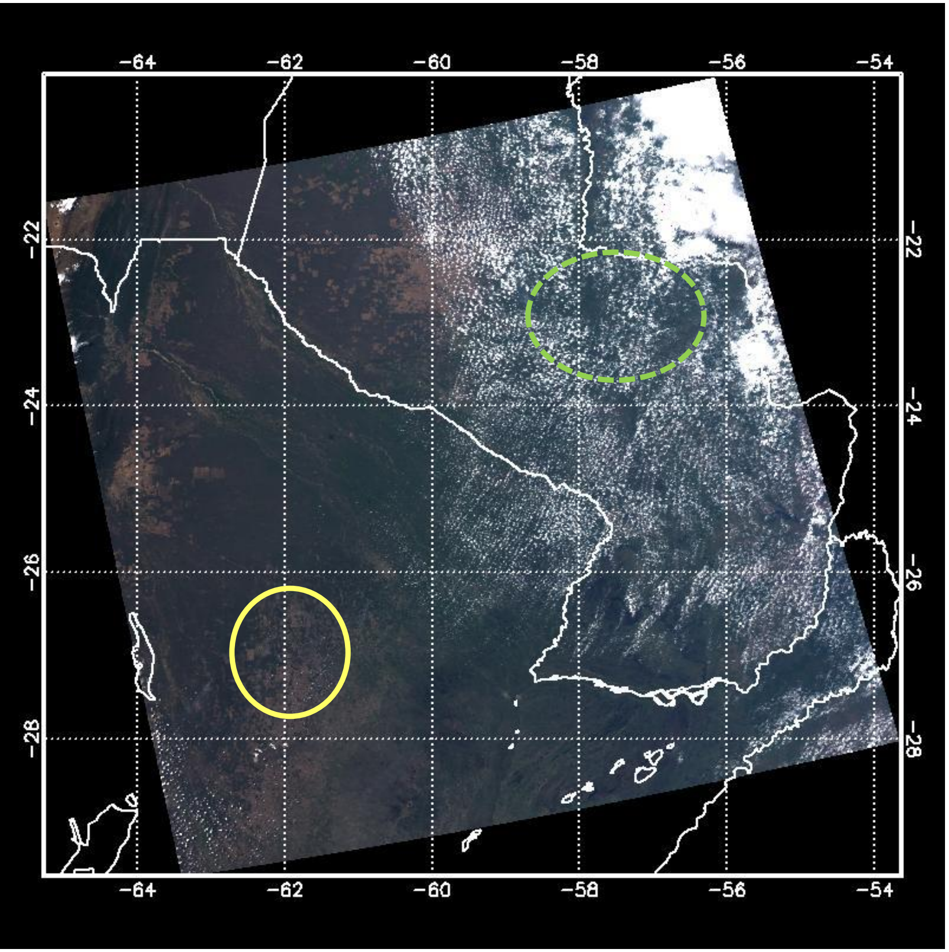


CALIPSO Back-scatter data

❖ Cirrus is often hard to be detected from UV/Visible observations.
→ We are checking possibility of using 1.38µm channels from polar-orbiting satellite sensor(e.g., VIIRS, MODIS).

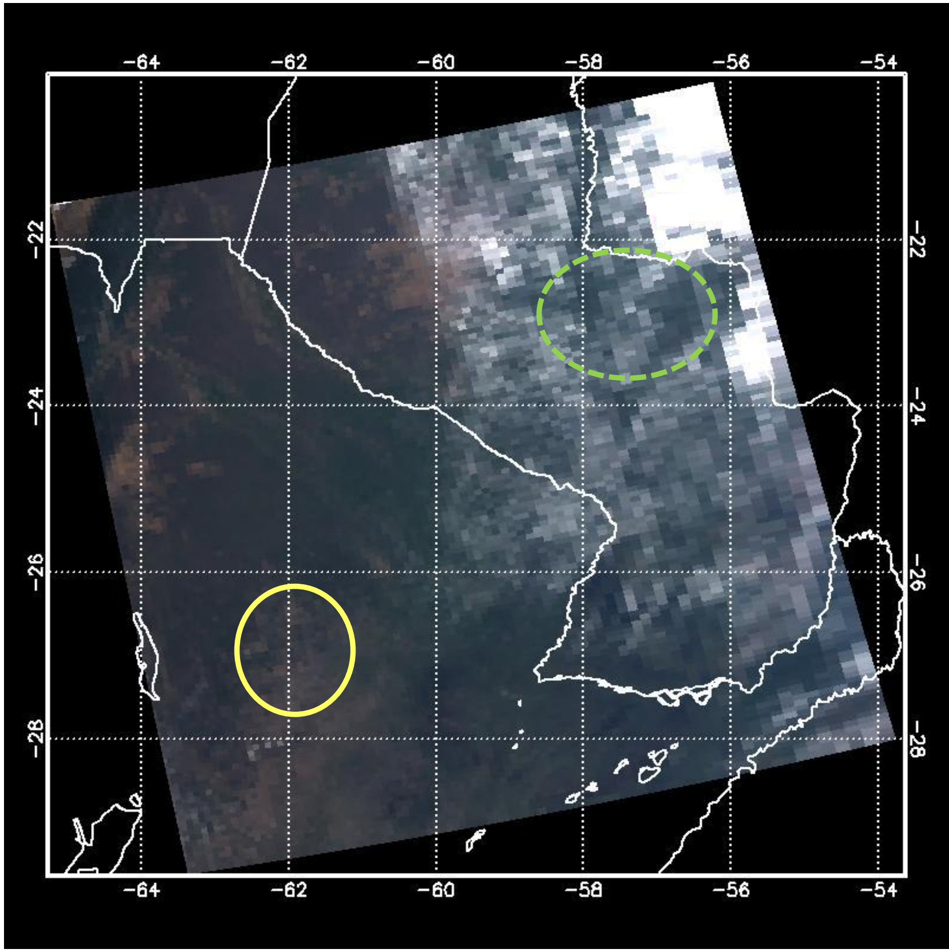
Cloud-Screening for R_{sfc} Derivation: Effects of Pixel Resolution

RGB Image: 1x1km Resolution



→ **RGB image from 1km resolution MODIS data**

RGB Image: 8x7km Resolution

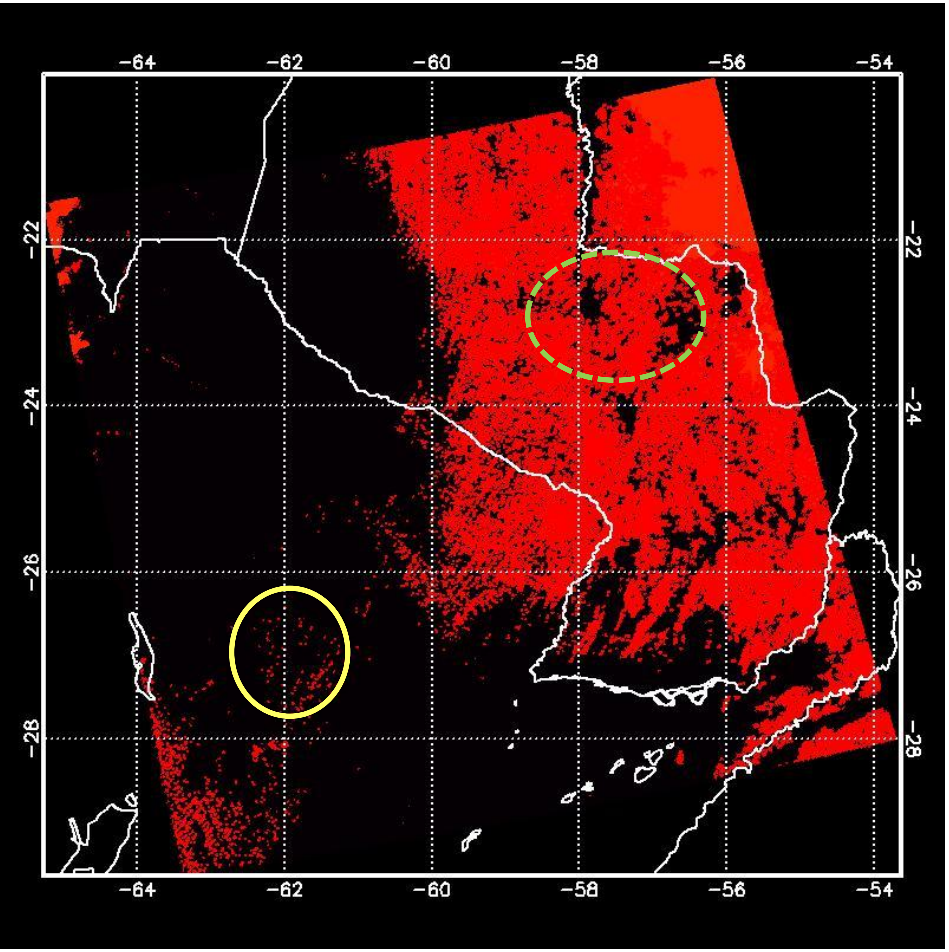


→**RGB image from aggregated pixels with 8x7km resolution**

→**Signals from small-scale clouds and surface features are smeared out.**

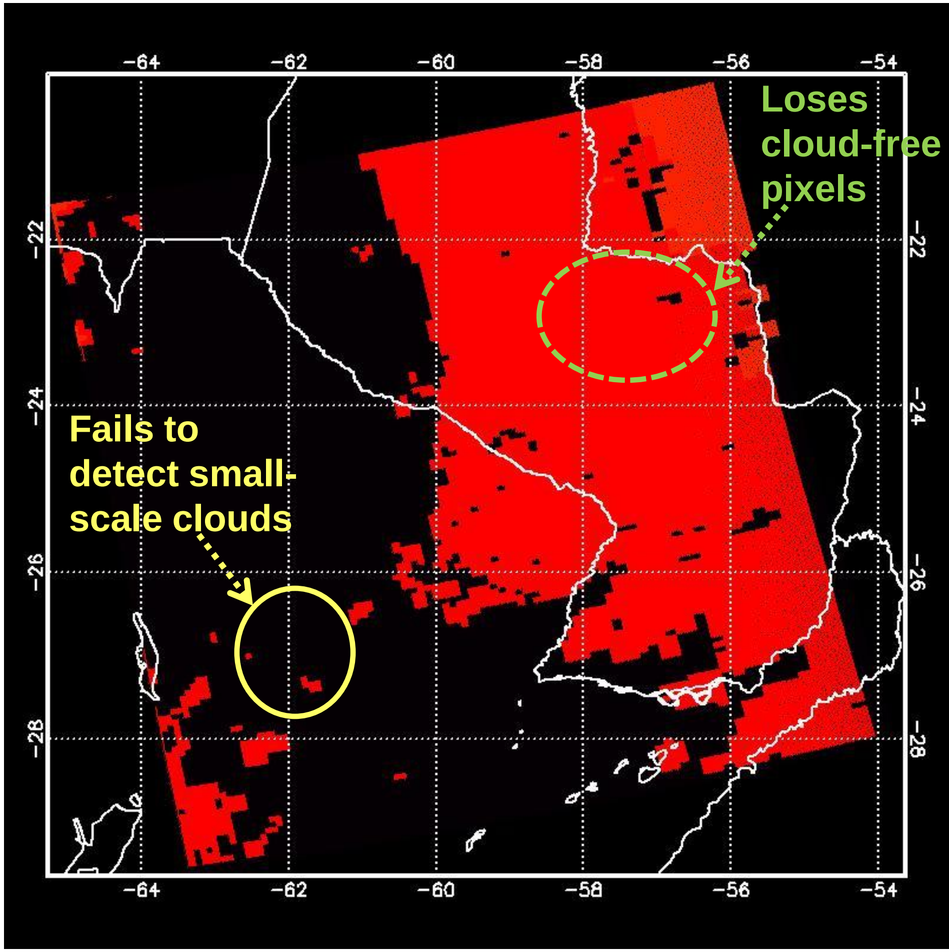
Cloud-Screening for R_{sfc} Derivation: Effects of Pixel Resolution

Cloud Mask: 1x1km Resolution



→ **Cloudy pixels in red. Cloud-masking based on combination of reflectance threshold and spatial variability of visible bands.**

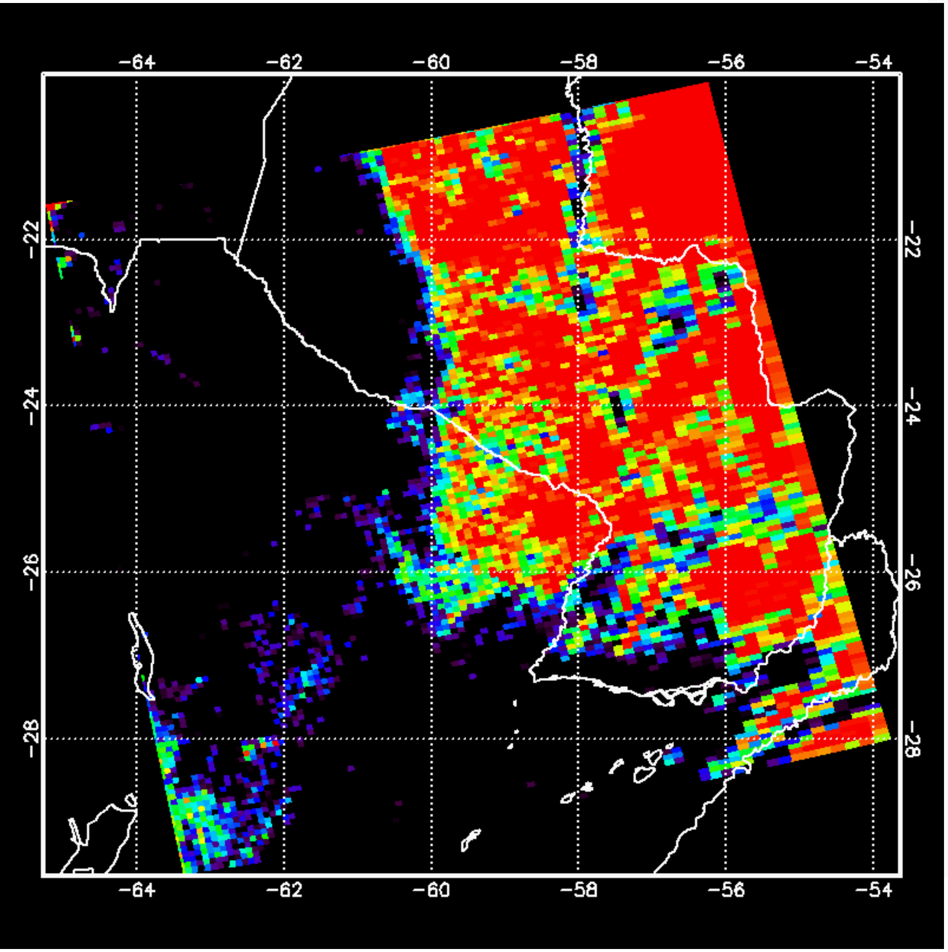
Cloud Mask: 8x7km Resolution



→**Results with same cloud-masking applied to 8x7km data.**
→**Missing small-scale clouds and losing some cloud-free pixels.**

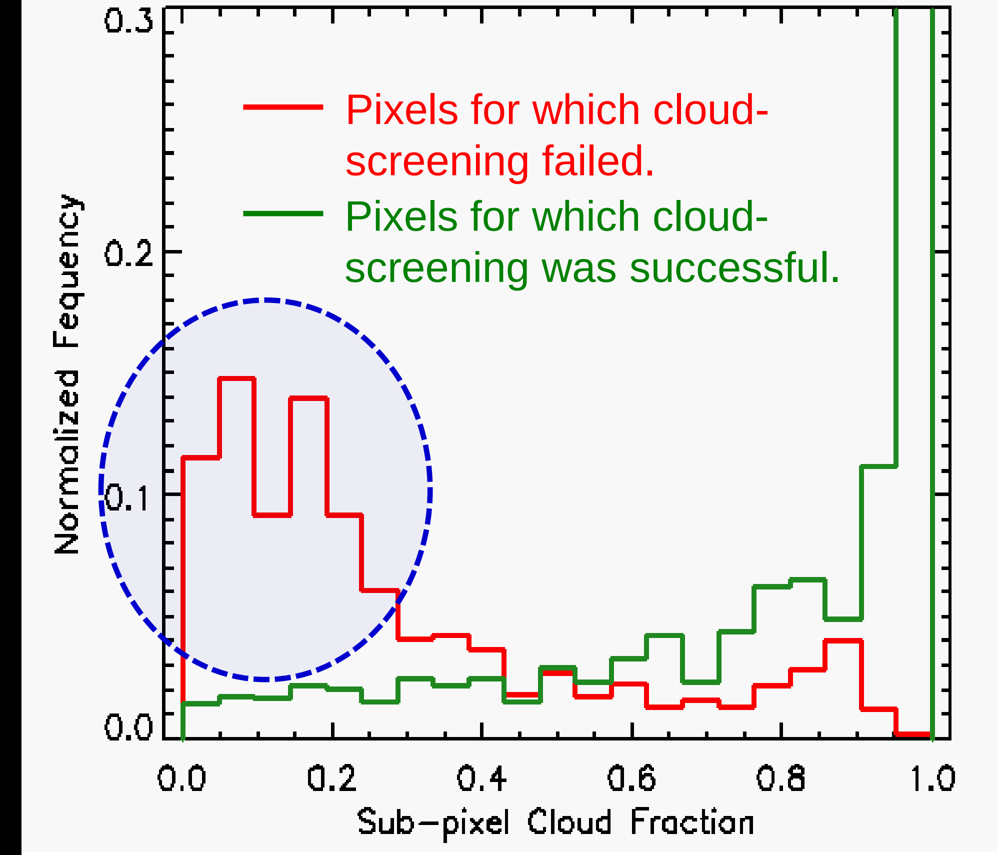
Cloud-Screening for R_{sfc} Derivation: Effects of Pixel Resolution

Cloud Fraction: 8x7km Resolution



→ **Sub-pixel cloud fraction for 8x7km pixels. Cloud-screening was made using 1x1km resolution data to estimate the cloud fraction.**

Conditional Histogram for Sub-Pixel Cloud Fraction



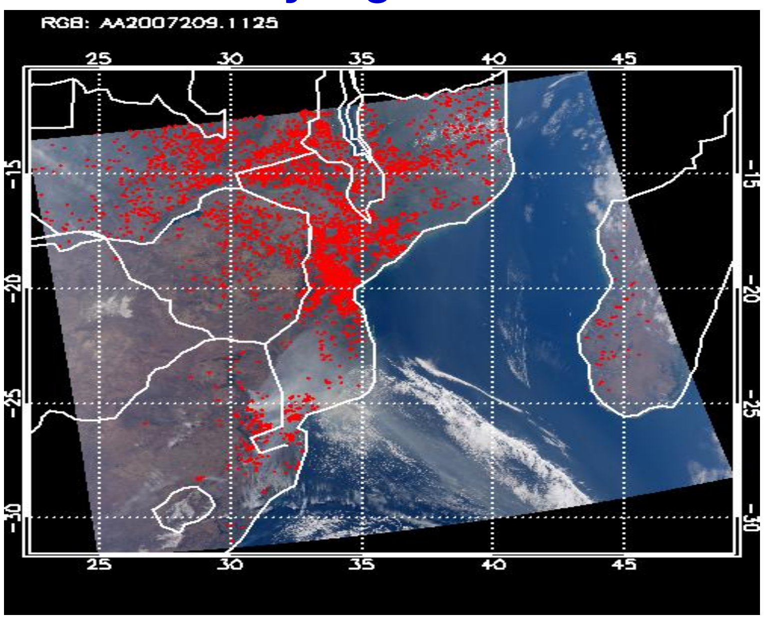
→At a low spatial resolution, cloud-screening often fails to detect cloudy pixels with small-scale clouds taking a small portion of each pixel.

Algorithm Development II: Atmospheric Correction for R_{sfc} Derivation

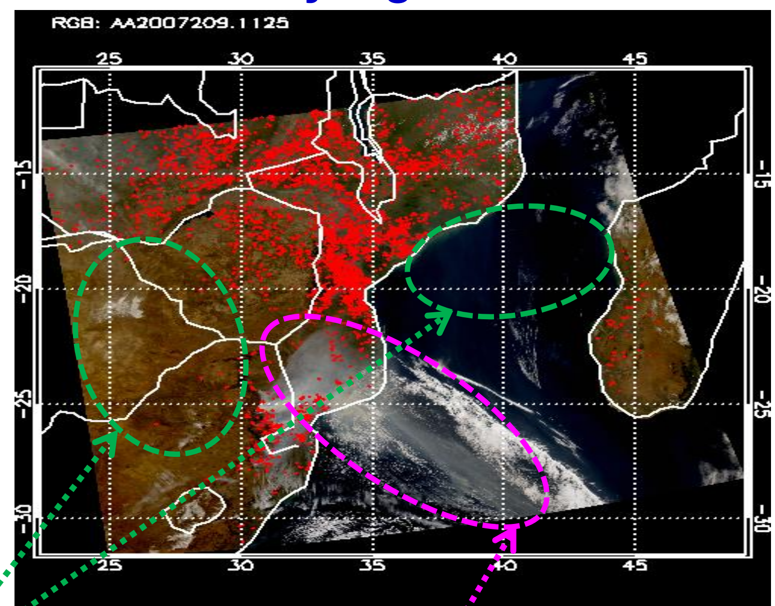
Atmospheric Correction (Rayleigh Scattering and Aerosol Scattering + Absorption)

- ✓ **Multiple scattering/reflection effects by air molecules need to be removed to derive R_{sfc} by searching for R_{min}.**
- ✓ **To produce R_{sfc} validation data, accurate AOT data and aerosol optical property models that represent the background aerosol conditions in the region of interest are necessary. → Under investigation.**

Before Rayleigh Correction



After Rayleigh Correction



Areas for which R_{sfc} may be derived.

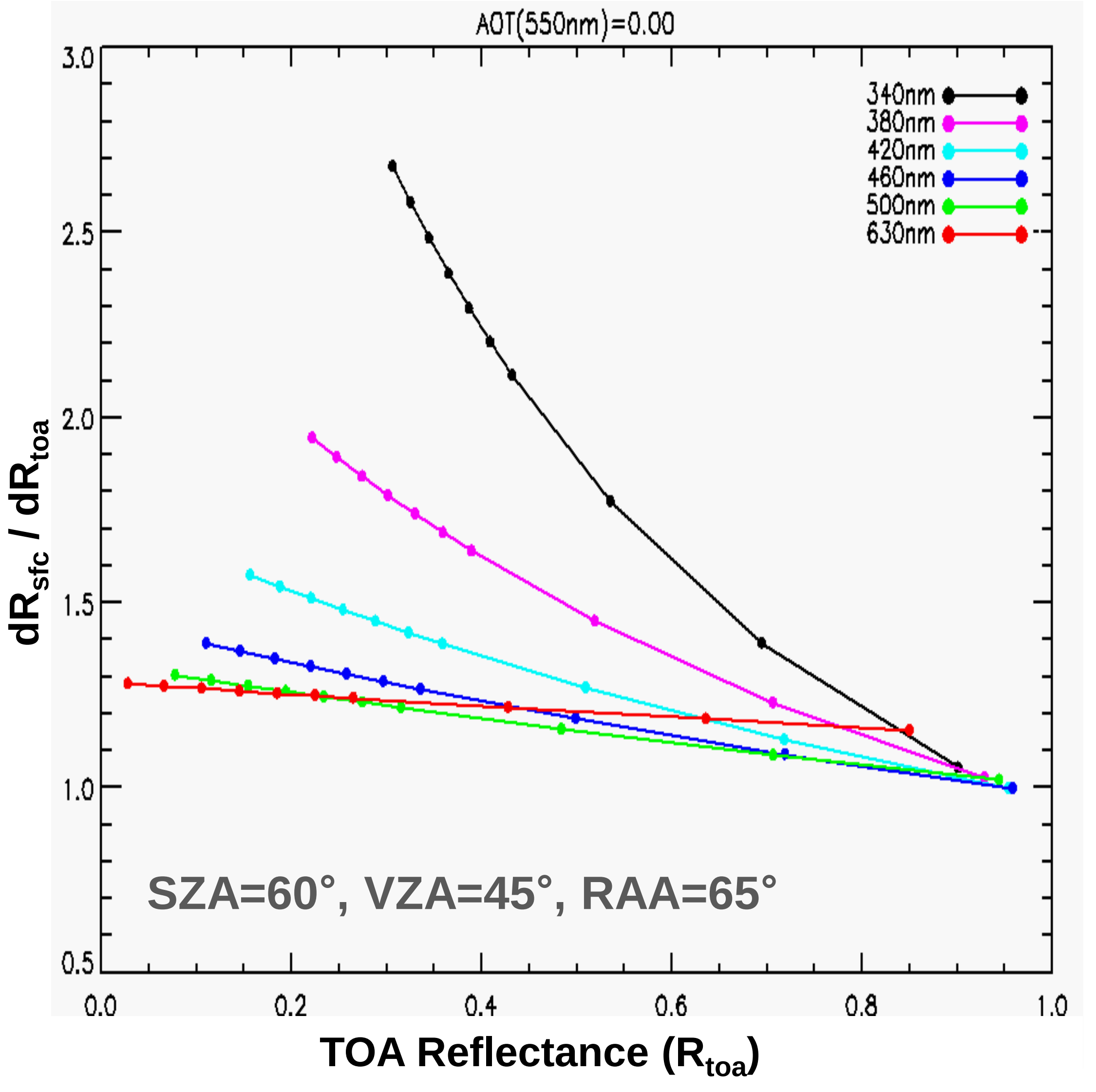
Area with heavy aerosol loading. → Not suitable for R_{sfc} derivation.

Red dots in the above images stand for the locations of wildfire hot spots.

Sensitivity Test:

Sensitivity of R_{sfc} w.r.t. Radiometric Errors in TOA Reflectance

Sensitivity of Spectral R_{sfc} with respect to the Errors in TOA Reflectance (R_{toa})



- ✓ **The radiometric uncertainty in R_{toa} has an impact on the accuracy of the derived R_{sfc}.**
- ✓ **The changes in R_{sfc} w.r.t. the changes in R_{toa} (i.e., dR_{sfc} / dR_{toa}) indicate the sensitivity of R_{sfc} to the radiometric errors in R_{toa}.**

➔ The shorter the wavelength, the higher the sensitivity.

➔The lower the R_{sfc}, the higher the sensitivity.

The closed-circle symbols corresponds to simulation results with R_{sfc} values of 0.001, 0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.50, 0.75, and 1.0, respectively at each given wavelength.

Validation of the Derived R_{sfc} :
Plans and On-going Efforts

Validation Methods for R_{sfc}

❖ ***Ground-based Measurements***

- ✓ ***Relatively-low / Moderate cost***
- ✓ ***Relatively short data reduction processing required***
- ✓ ***Point-wise measurements, not representative to a large area***
- ✓ ***Manual-intensive to cover large areas***

❖ ***Air-borne Measurements***

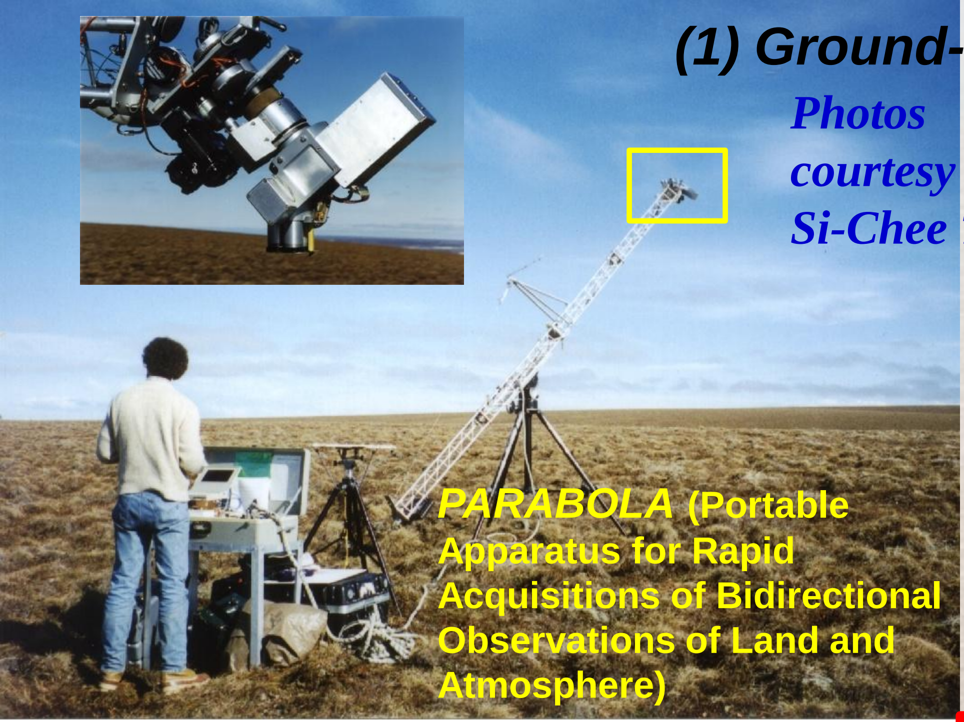
- ✓ ***Higher cost***
- ✓ ***Moderately large spatial coverage***
- ✓ ***Requires diverse manpower***
- ✓ ***Need intensive post-measurement processing***

❖ ***Atmospheric Correction with a priori Aerosol Information***

- ✓ ***Lowest cost when using existing aerosol measurement systems (e.g., AERONET)***
- ✓ ***Relatively homogeneous and low aerosol loading are required.***

(1) Ground-based Measurements

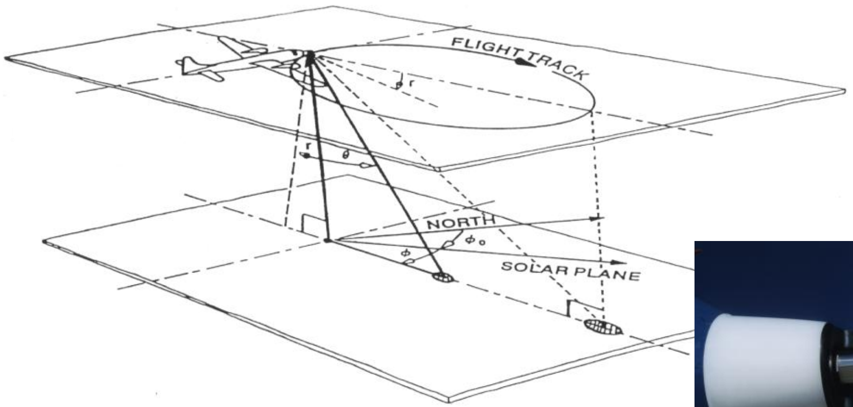
Photos courtesy of Si-Chee Tsay



PARABOLA **(Portable Apparatus for Rapid Acquisitions of Bidirectional Observations of Land and Atmosphere)**

ASD FieldSpec Pro attached to a telescope mount

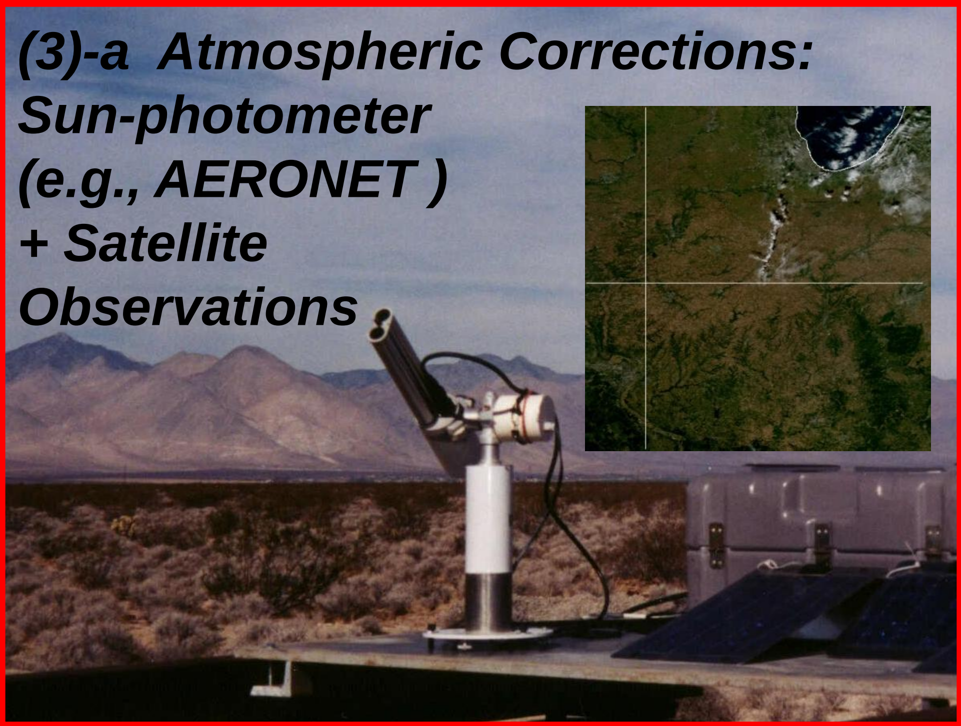
(2) Air-borne Measurements



Cloud Absorption Radiomter (CAR)
King *et al*., 1986

(3)-a Atmospheric Corrections:

Sun-photometer (e.g., AERONET) + Satellite Observations



(3)-b Atmospheric Corrections:
Hand-held Sun-photometer + Satellite Observations

Microtops II® Sun-photometer at GWNU

Model 540 MICROTOPS II®

A 5-channel hand-held sun-photometer for measuring aerosol optical thickness (AOT) with a GPS system to automatically acquire geo-location, altitude, and observation time information.

- **Spectral configurations: 340, 440, 675, 870, 936nm → (4 aerosol + 1 water vapor channels)**
- **Uncertainty of AOT in each channel < 0.05.**

→ One set (and more in the near future) of this instrument will be utilized to produce validation datasets.

Production of Aerosol Data to Validate Satellite-based Surface Reflectance

AERONET AOT v.s. Microtops II® AOT
(GWNU, 1 Mar – 31 May, 2012 during the DRAGON-K Field Campaign)

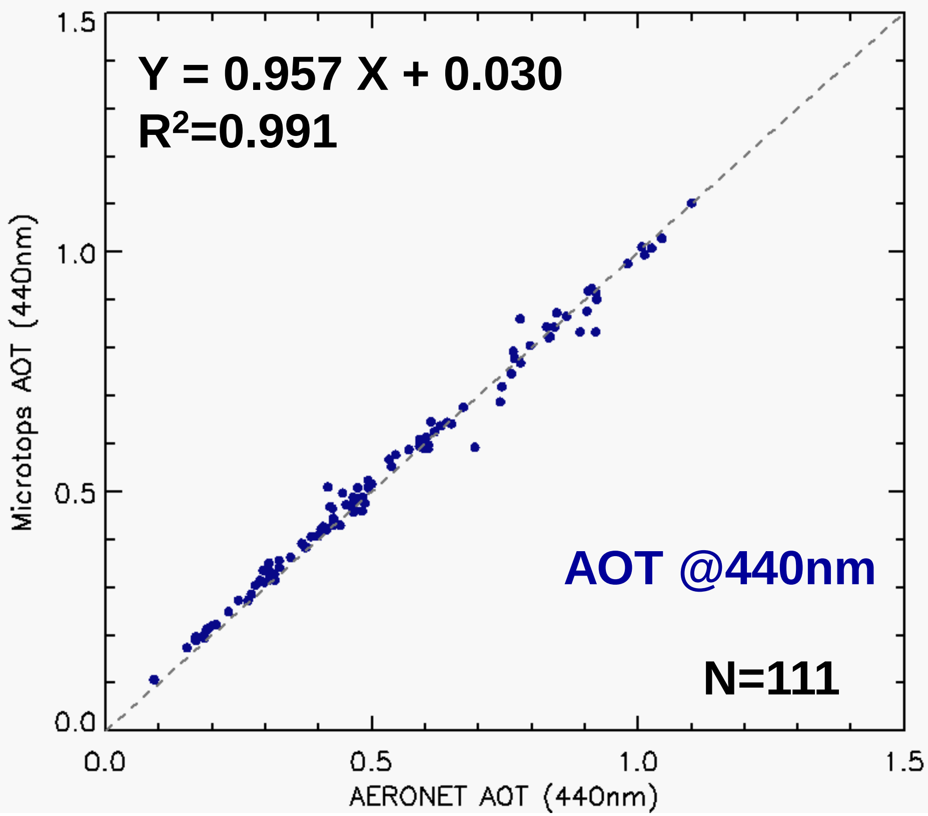


Table. Microtops II AOT observation statistics at GWNU during DRAGON-K.

Period	# of Measurements
March, 2012	269
April, 2012	819
May, 2012	695
June, 2012	130
July, 2012	168
March – July, 2012	2081

➔ **Good agreements were observed between AERONET and Microtops AOT.** **(It seems better than the estimated uncertainty level[±0.05] for Microtops.)**

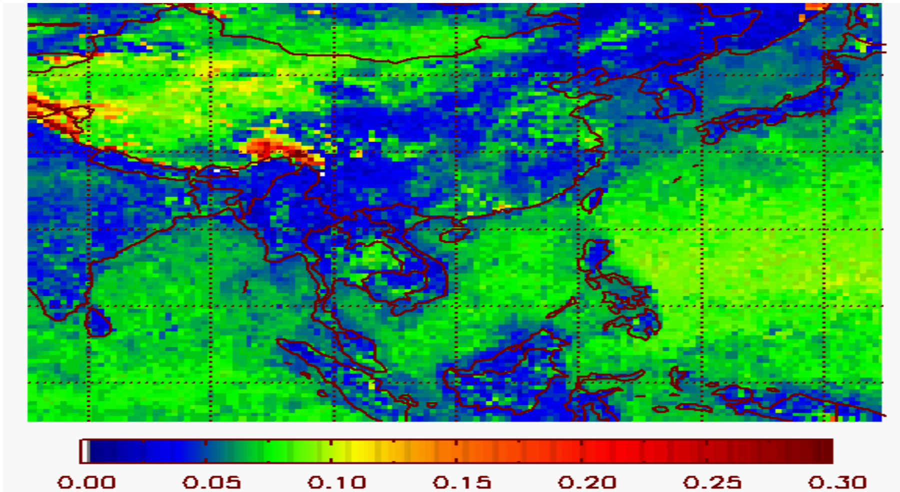
➔ **More Microtops AOT observations where AOT measurements are scarce are being planned.**

Temporal window of match-ups 15min (within ±7.5min from the Microtops II® obs.)

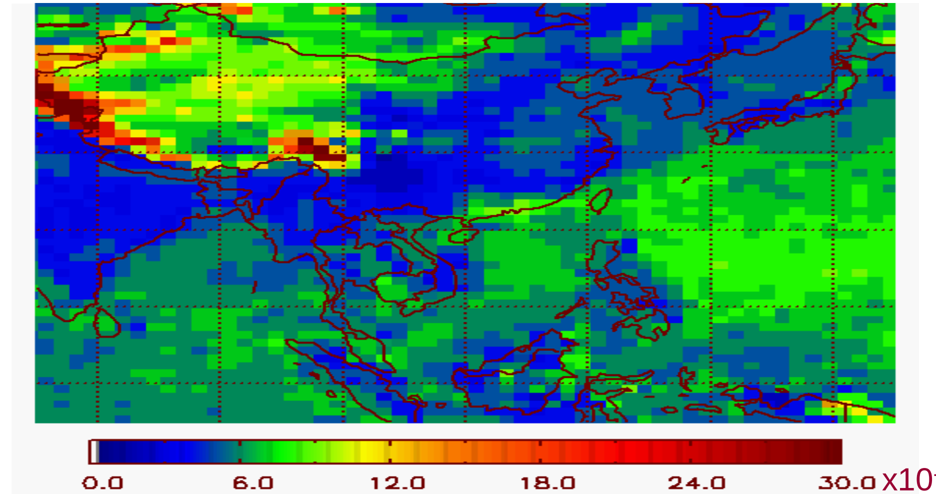
Analysis on Existing R_{sfc} Data Products

R_{sfc} from OMI, TOMS, and SeaWiFS over the GEMS Domain

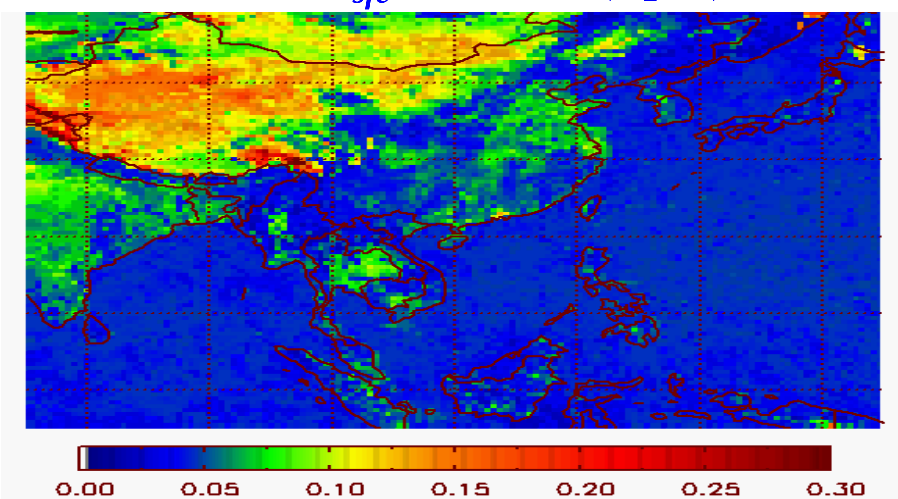
OMI R_{sfc} at 380nm (April)



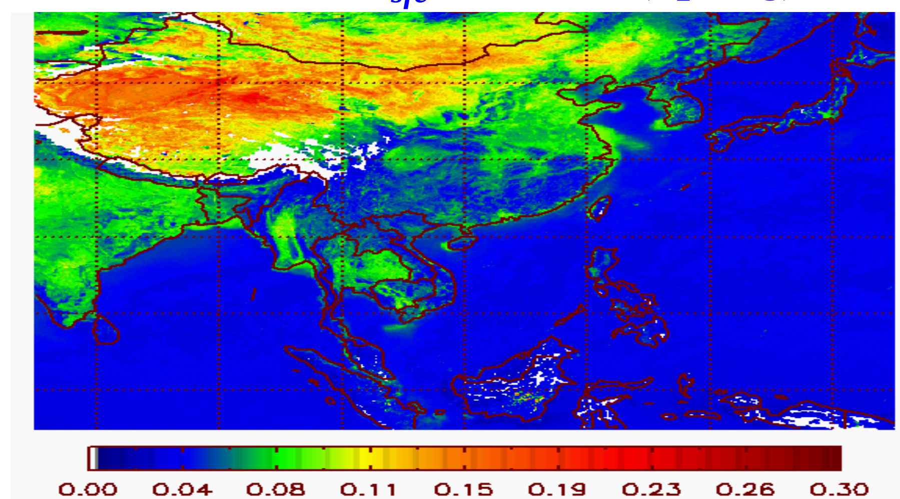
TOMS R_{sfc} at 380nm (April)



OMI R_{sfc} at 490nm (April)



SeaWiFS R_{sfc} at 490nm (Spring)

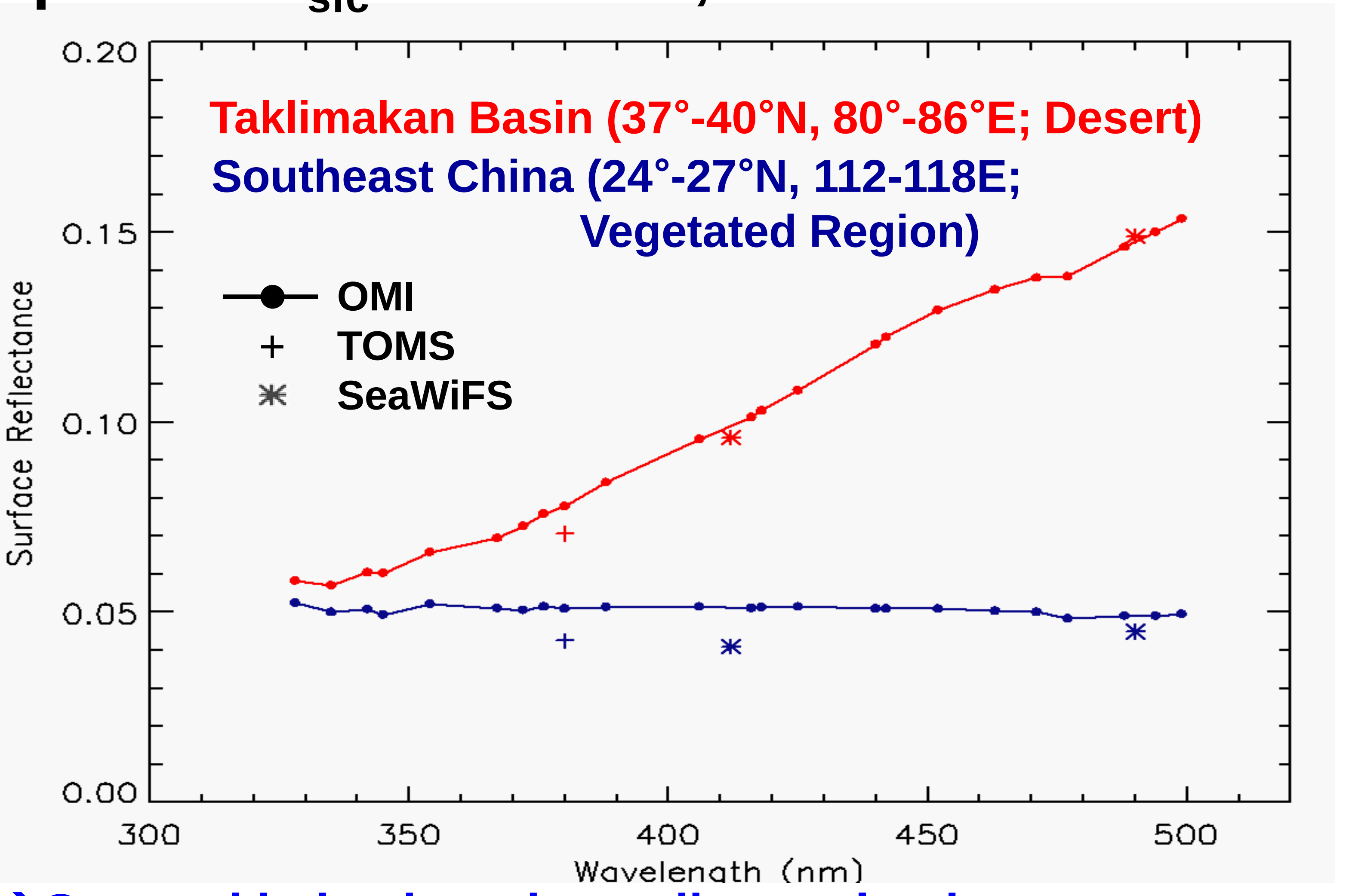


→Each product shows similar patterns at given wavelengths.

→TOMS R_{sfc} tends to be lower than OMI R_{sfc}.

Spatial resolutions: OMI 0.5x0.5deg; TOMS 1.25x1deg; SeaWiFS 0.1x0.1deg.

Spectral R_{sfc} from OMI[#], TOMS[#] and SeaWiFS[&]

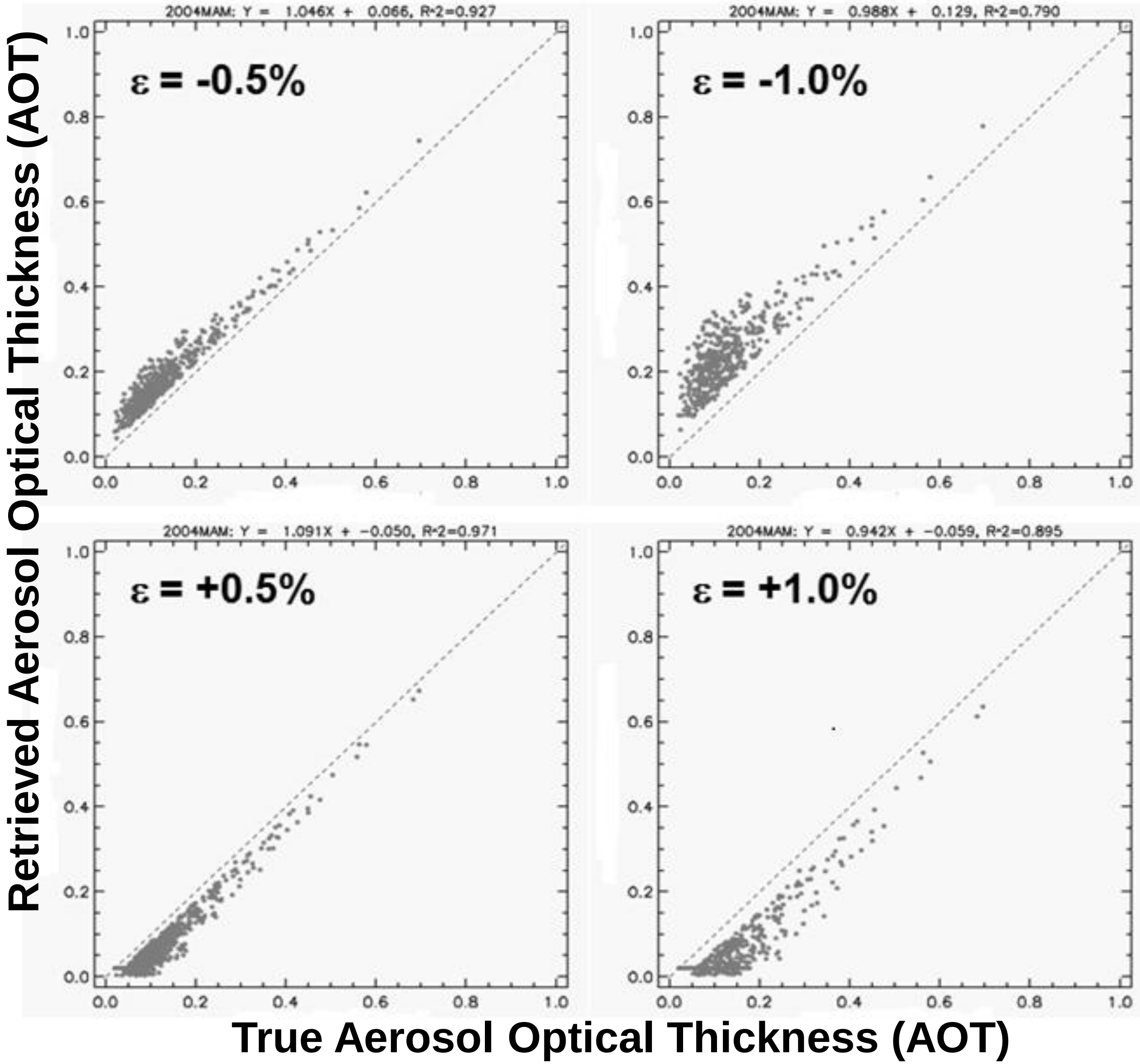


→Spectral behaviors depending on land cover types are consistent between R_{sfc} products.

→ Up to 1%(areal mean) of differences were found between R_{sfc} products.

(#data for April; &data for Spring)

Example. The Impact of R_{sfc} Error on the Data Products in the Downstream → Errors in AOT Retrievals



Retrieved AOT v.s. True AOT when forced Rsfc errors (Ɛ) were given to the aerosol retrieval algorithm as input.

→ About ±1% (=0.01) of R_{sfc} errors may result in up to ±0.2 of AOT errors at blue wavelengths for low to intermediate aerosol loading conditions.

Summary

- ❖ R_{min} search method is to be utilized for GEMS to derive R_{sfc} (300-500nm).

- ❖ Cloud-screening algorithm module is under development by considering the effects of spatial resolution of pixel (sensor footprint).

- ❖ Aerosol data for R_{sfc} validation are being collected and produced.

- ❖ Existing R_{sfc} data products from OMI, TOMS, and SeaWiFS are being analyzed (a) to understand the characteristics of R_{sfc} in the domain of interest and (b) to determine the level of uncertainty in the derived R_{sfc}.