Deriving the Reflectance and Properties of Land Surfaces from GEMS: Methodology, Sensitivity, Requirements, and Validation

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Outline

- **Sensor/Measurement requirements**

- **Surface reflectance (R_{sfc}) Requirements**

- **Algorithm development**
  - **Surface reflectance (R_{sfc})**
  - **Cloud-screening**
  - **Surface property (→Detection of vegetated surfaces)**

- **Validation plan**

Goal: *Providing Accurate Boundary Conditions for Physical Models*

- ***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).**

- **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!

→ 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

Sensor/Measurement Requirements for R_{sfc} Derivation

Signal-to-Noise Ratio (SNR) Required for R_{sfc} Retrievals

λ (μm)	Nominal Radiance ($Wm^{-2}\mu m^{-1}Sr^{-1}$)	Required SNR#
0.34	52.2	840
0.38	50.6	498
0.47	56.1	230
0.50	47.1	196
0.63	28.4	134

#SNR required to maintain NEΔR_{sfc}=0.001 → ***Precision of derived R_{sfc}***

$SNR = L_n / NE\Delta L_n = \rho^*_n / NE\Delta\rho^*_n$

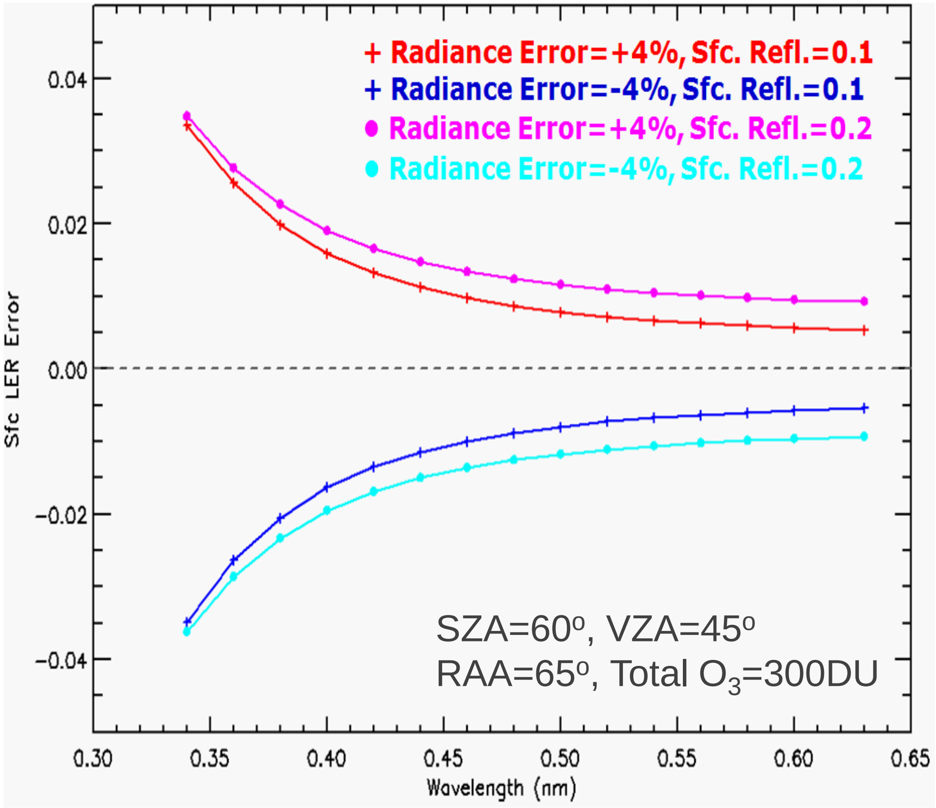
L_n: nominal radiance at TOA

ρ^*_n: nominal apparent reflectance

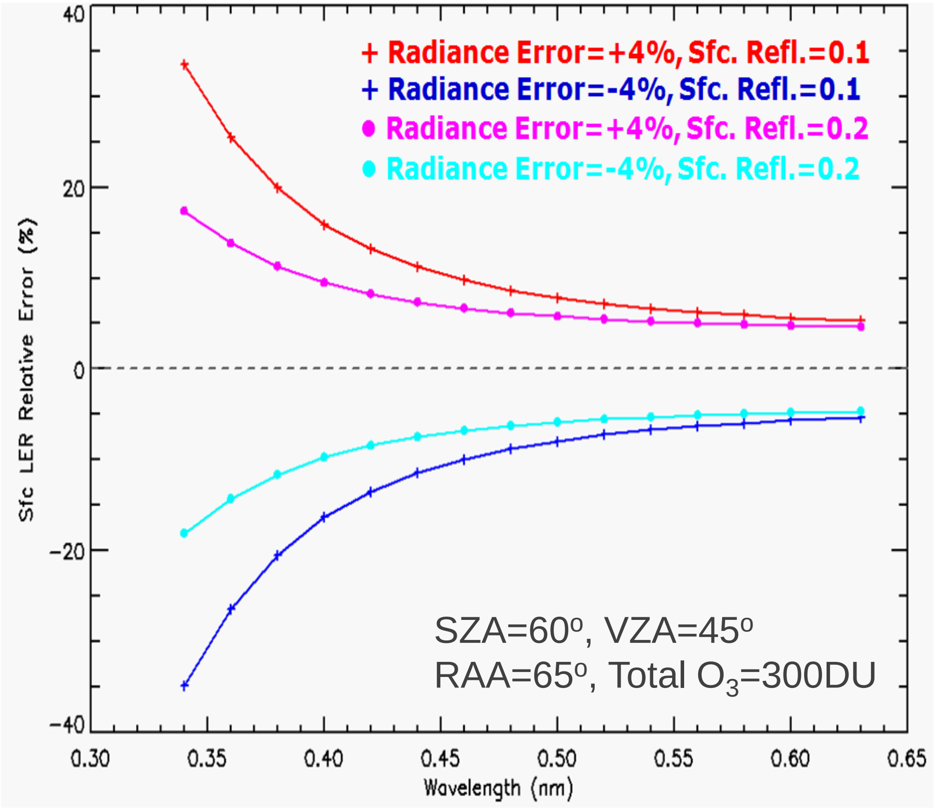
Simulation conditions: SZA=60º, VZA=45º, RAA=65º, Total O_3=300DU, No aerosol

R_{sfc} Error with Input TOA Radiance Errors of ±4%

Absolute Error



Relative Error (%)



→ Given the errors of TOA radiance, the higher the true R_{sfc}, the larger the absolute errors of the derived R_{sfc}.
→ In general, the errors of derived R_{sfc} decrease with increasing λs.

R_{sfc} Requirements for Data Products in the Downstream

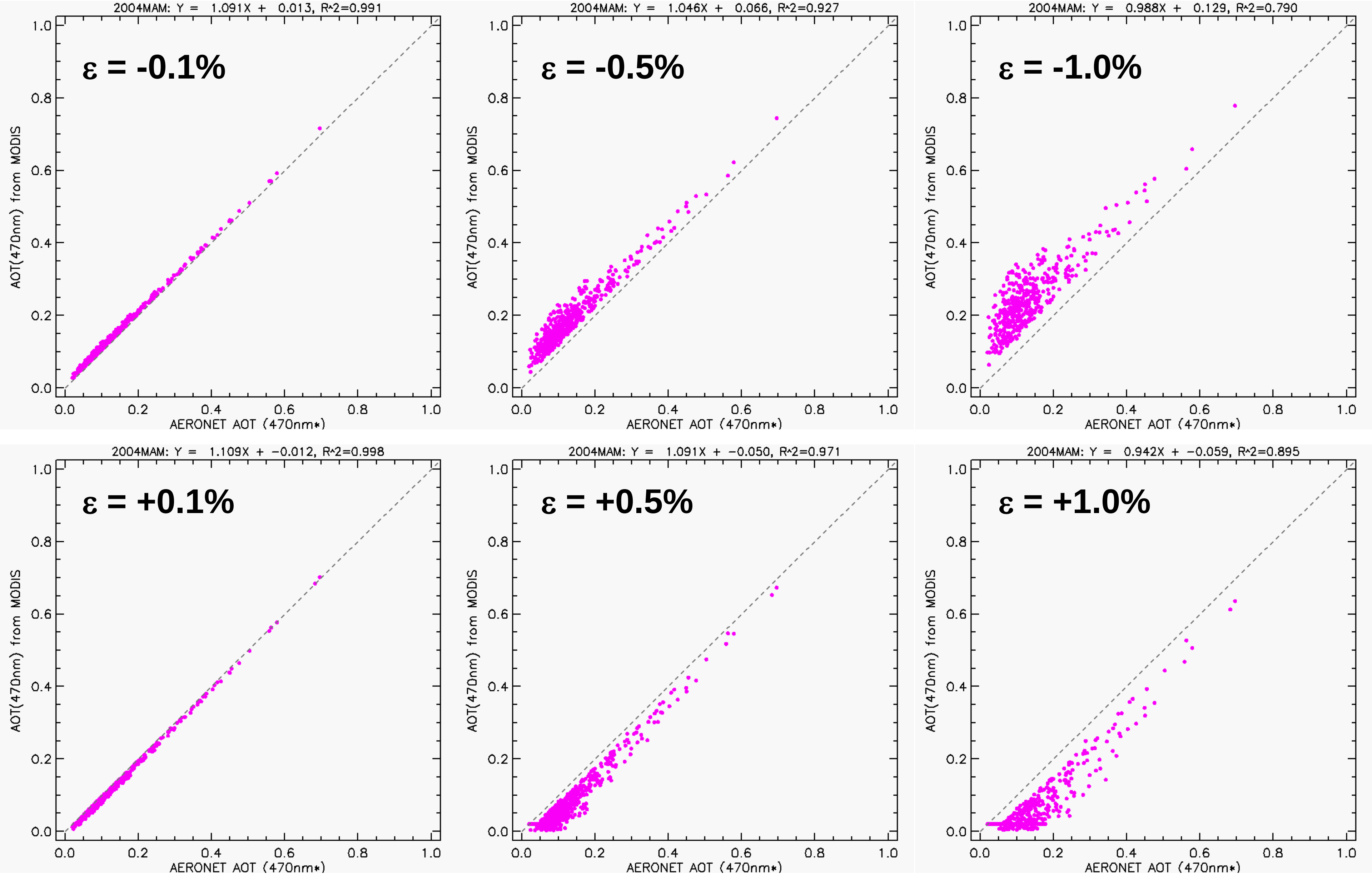
Sensitivity Test

Effects of R_{sfc} errors to aerosol retrievals

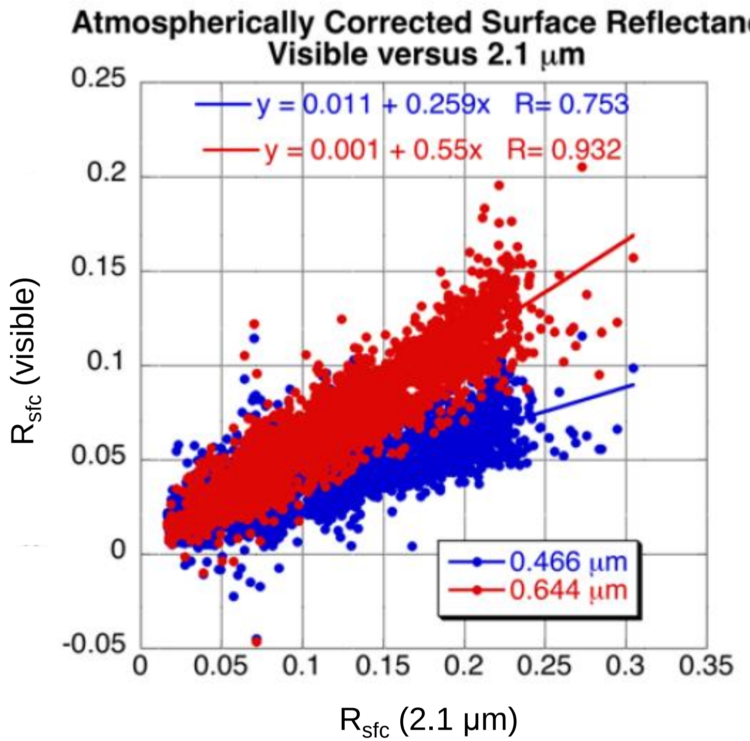
When simultaneous OBSs of MODIS R_{TOA} & AERONET AOT are available, the aerosol correction for deriving R_{sfc} from the R_{TOA} can be done using the AOT. Based on the R_{sfc} with systematic errors, we re-calculate MODIS AOT. For climate study, AOT error need be <0.1

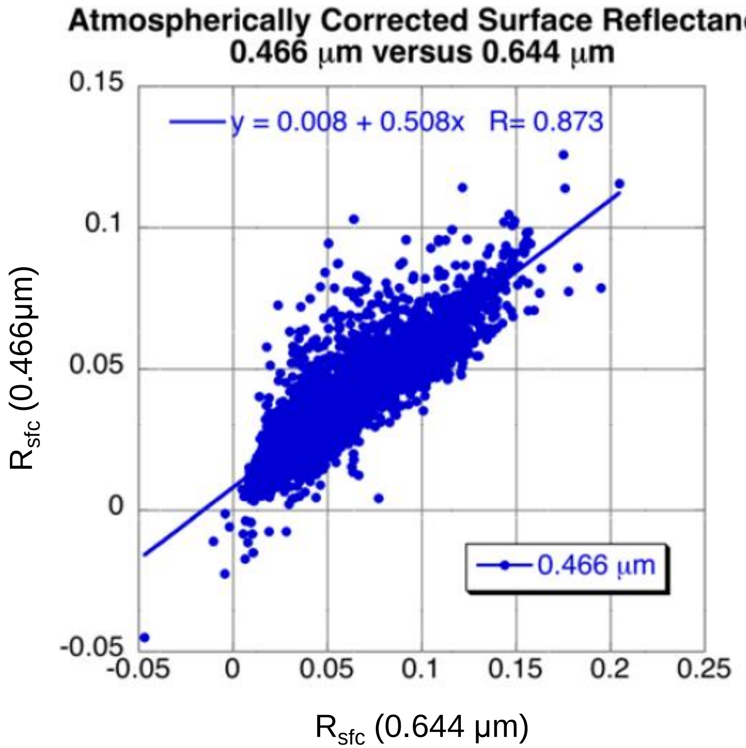
➔ R_{sfc} error < 1~2%, according to the sensitivity test.

Sensitivity of AOT Retrievals to Errors in R_{sfc}



R_{sfc} Estimation Adopted for Operational Aerosol Retrievals





R_{sfc} Estimation for MODIS Dark Target Aerosol Products over Vegetated Land Sfcs (Levy et al., 2007) :

✓ ***Employed empirical approach using a mid-IR (2.1micron), where aerosol influence is often negligible.***

✓ ***Angular anisotropy of R_{sfc} is implicitly accounted for.***

✓ ***Larger than 1% of R_{sfc} errors occur often.***

Requirements for R_{sfc}

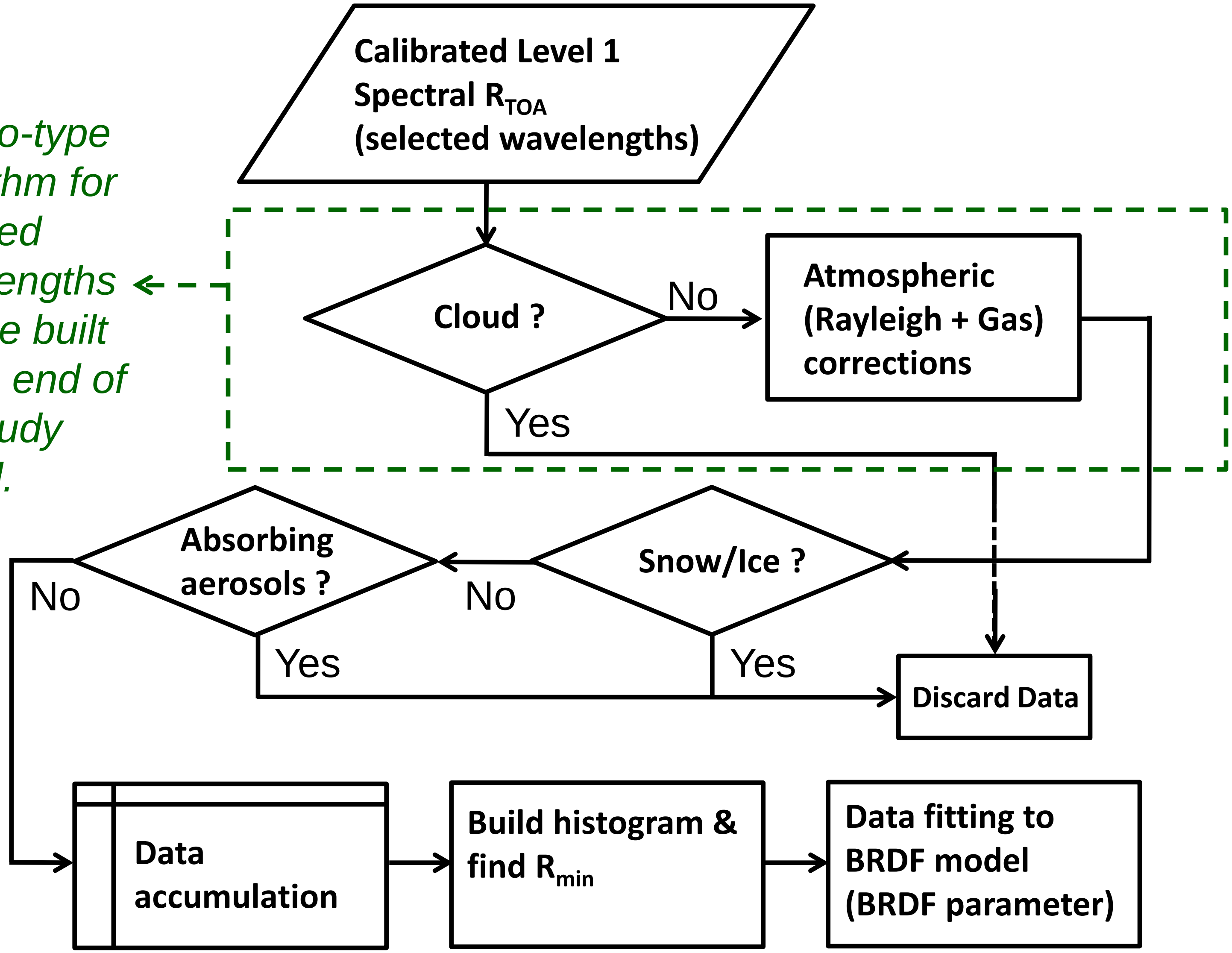
- ***Requirements are usually determined by higher level products (e.g., surface albedo: 2-5%[#], NDVI: 3%[#] for MODIS; aerosol retrieval ~2%)***
- ***Accuracy is primarily limited by the accuracies of***
  - ***satellite sensor calibration***
  - ***input atmospheric parameters (e.g., aerosol, trace gas, atmospheric pressure, etc.)***
  - ***RTM used for forward simulations***
  - ***cloud / cloud-shadow screening***

[#] **From whitepaper by E. Vermote.**

The Algorithm: Flow Diagram for R_{sfc} Derivation

(Plan for GEMS, Work-in-progress)

A proto-type algorithm for selected wavelengths is to be built by the end of this study period.



Possible Scenario for GEMS mission

❖ ***Initial stage***

- ***Existing** R_{sfc} **data (e.g., OMI) may be used for any application that requires** R_{sfc} **as input***
- ***Existing data may be fitted to BRDF model(s) to account for differences in observation geometry between different satellites***

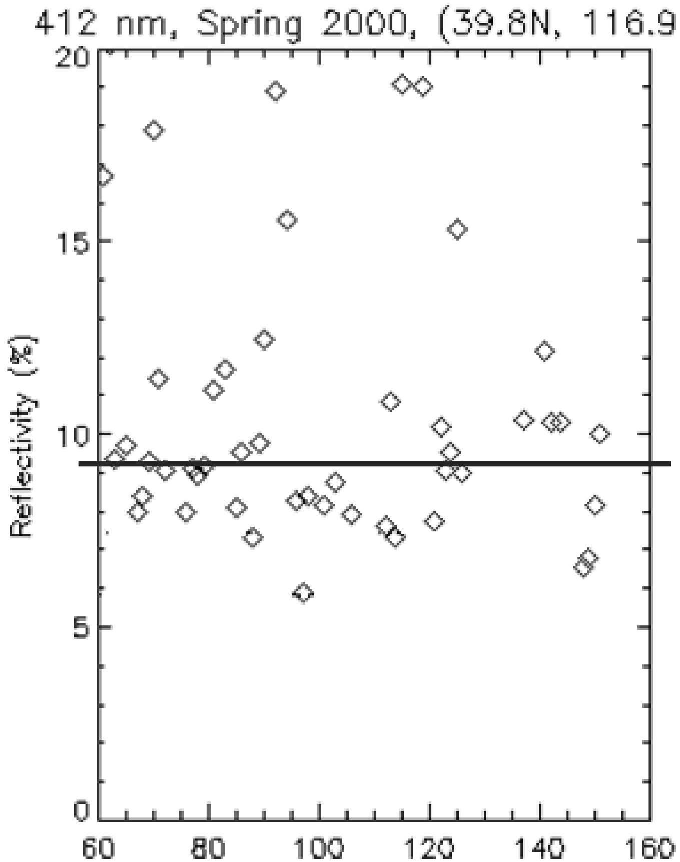
❖***Intermediate / latter stage of mission***

- ***Use** R_{min} **search method* (+ histogram method to remove outliers)***
- ***BRDF parameters may be derived***

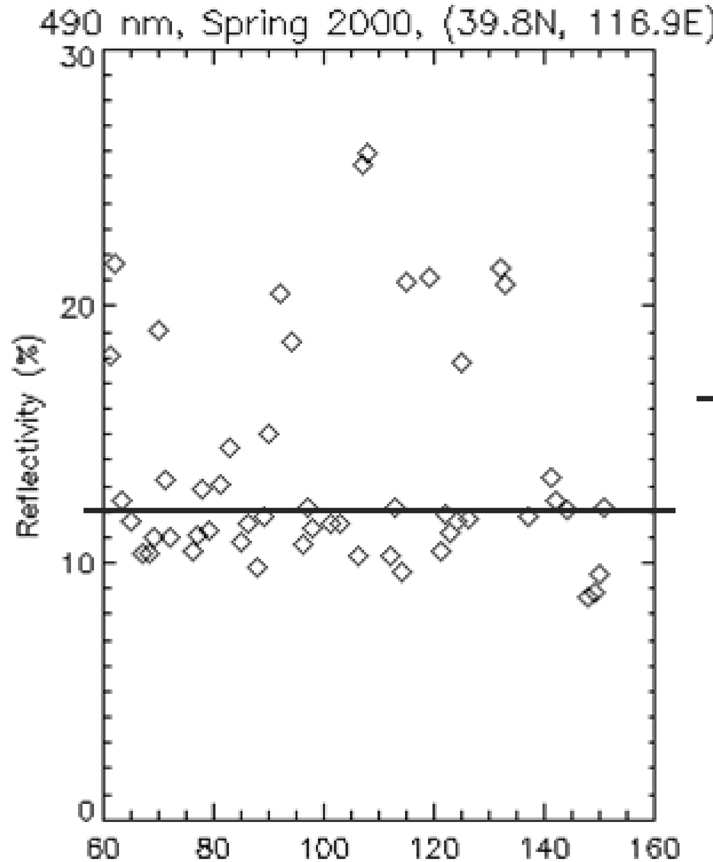
**** Minimum reflectance (R_{min}) search method: 1) divide earth surface into grid boxes; 2) accumulate Rayleigh-corrected TOA reflectance data at target wavelengths; 3) search for a minimum value in each grid to ensure minimum aerosol influence.***

Example: Derivation of R_{sfc} by Searching 'R_{min}' at a Given Location

412nm



490nm



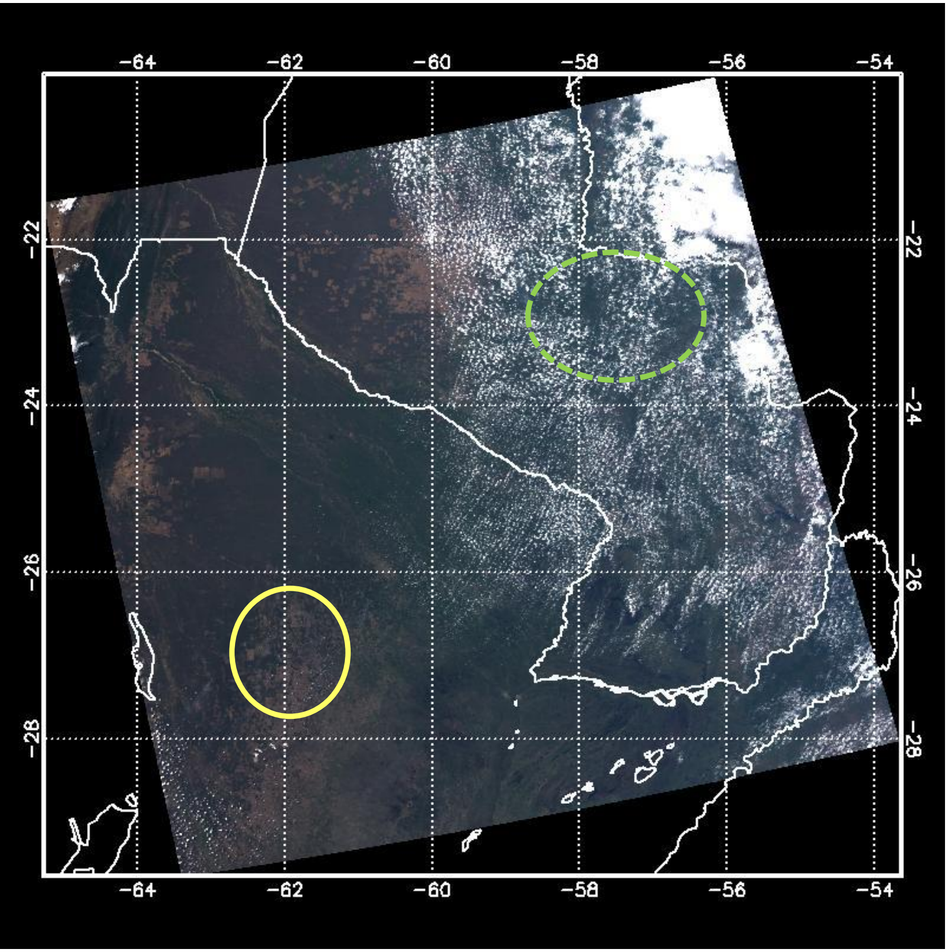
: Potential Surface Reflectance

Can we use an average of the lowest 2-20 percentile of Rayleigh-corrected reflectance as R_{sfc}? → Threshold to be determined empirically.

Figures from Corey Bettenhausen at NASA GSFC

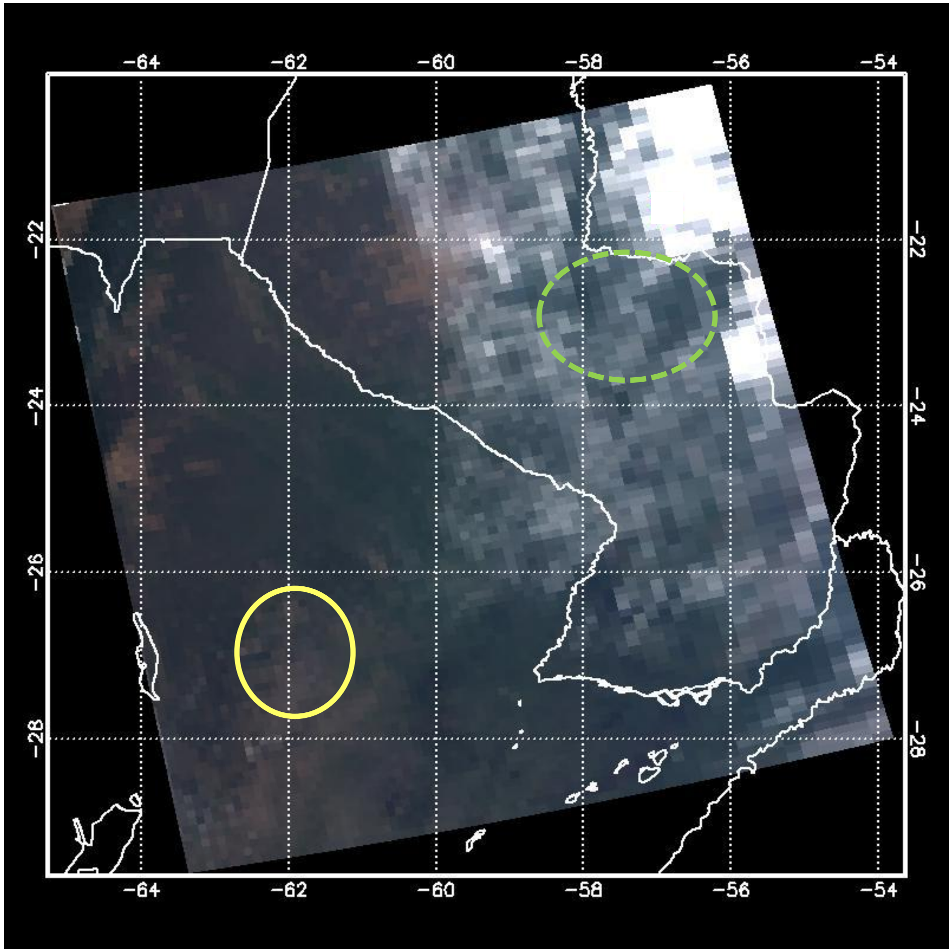
Cloud-Screening for R_{sfc} Derivation

RGB Image: 1x1km Resolution



→ RGB image from 1km resolution MODIS data

RGB Image: 10x10km Resolution

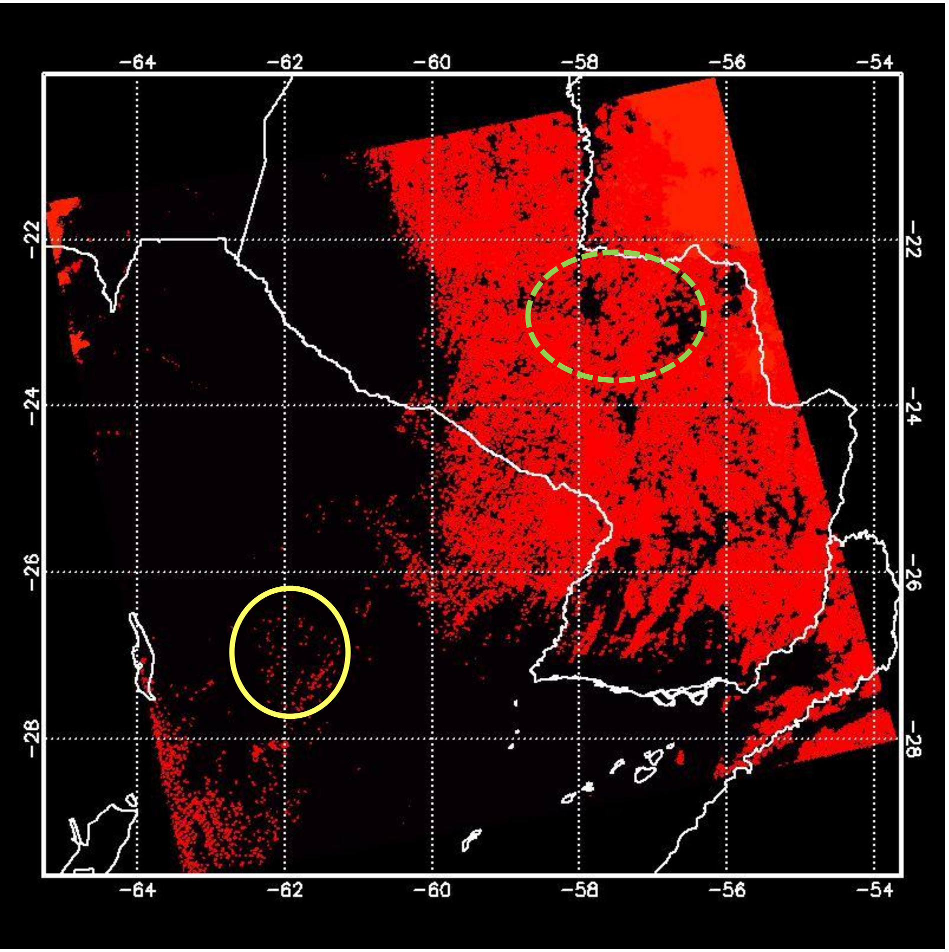


→RGB image from aggregated pixels with 10km resolution

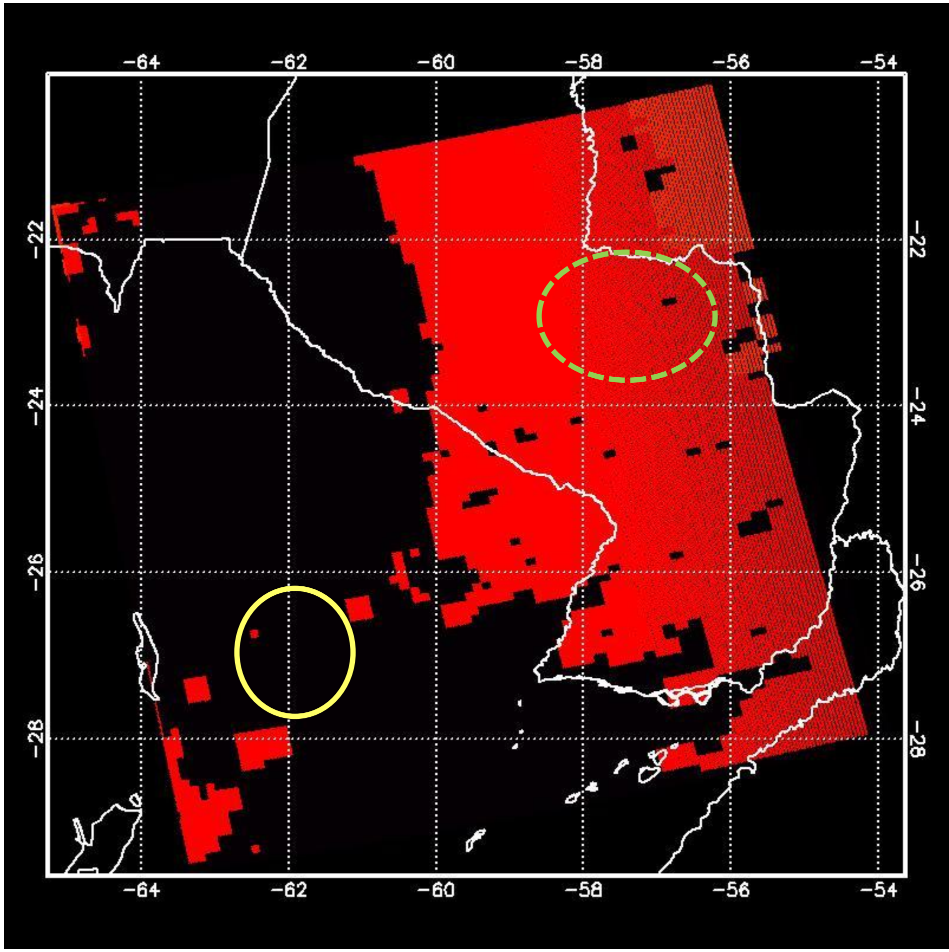
→Blurry small-scale clouds and surface features

Cloud-Screening for R_{sfc} Derivation

Cloud Mask: 1x1km Resolution



Cloud Mask: 10x10km Resolution



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

→Results with same cloud-masking applied to 10km data.
→Missing small-scale clouds and losing some non-cloudy pixels.

Estimating Surface Properties from GEMS Observations:

Scene Identification (e.g., Detecting vegetated areas)

Typical Approaches:

- ✓**RGB Image: Qualitative based on visual examination**

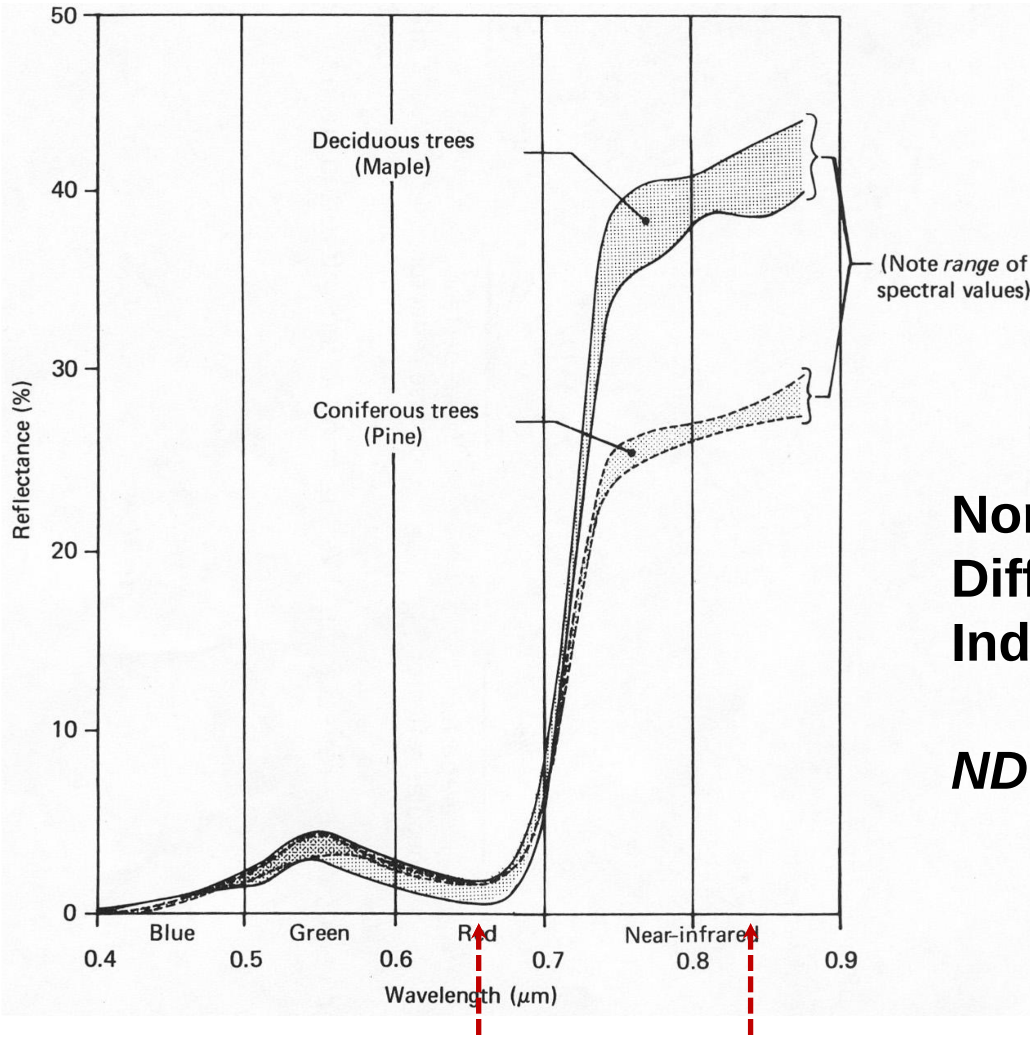
- ✓**NDVI (Normalized Difference Vegetation Index)**

  NDVI = (NIR-Red)/(NIR+Red)

  → An NIR (and Red?) band is out of the spectral coverage of GEMS

- ✓**Need a Method for GEMS (assumption: 300nm-630nm spectral coverage) ?**

Generalized Spectral Reflectance Envelopes for Deciduous and Coniferous Trees



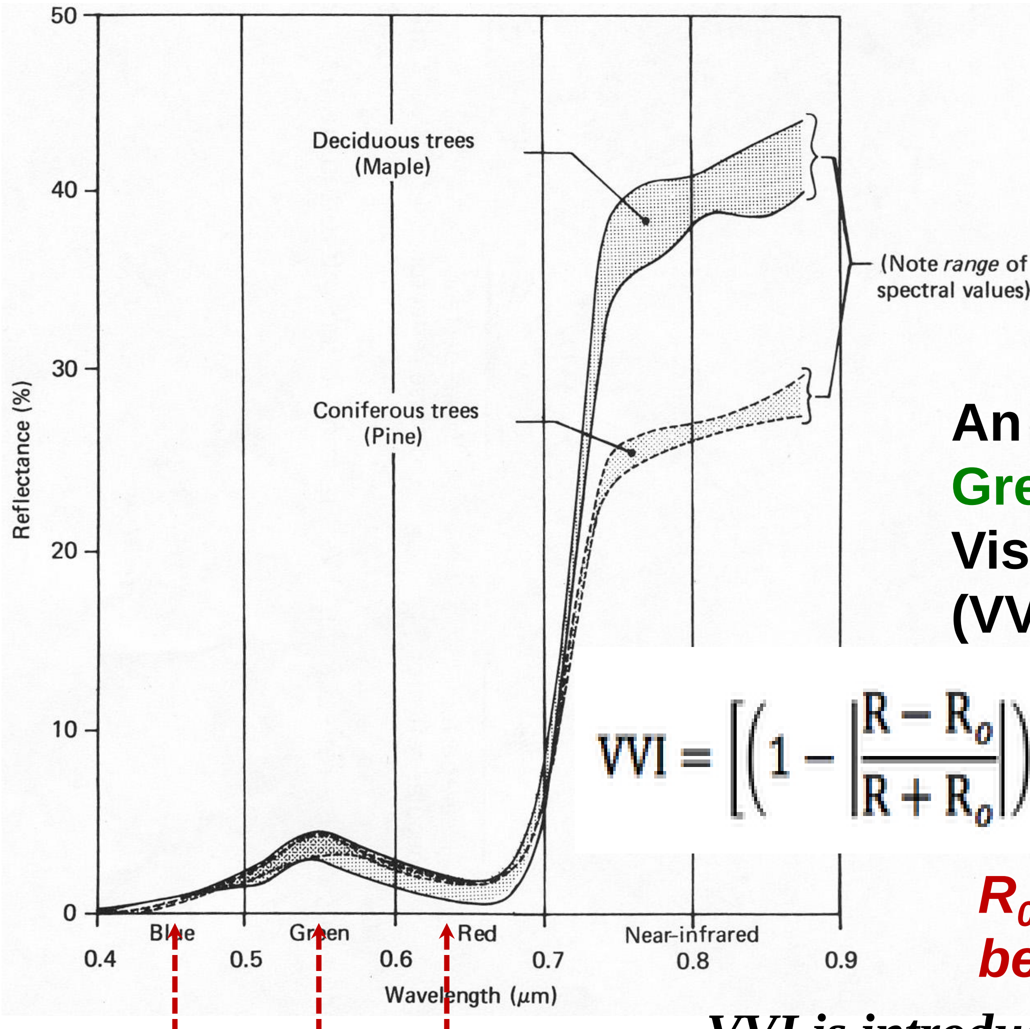
Conventional Approach

Normalized Difference Vegetation Index (NDVI)

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

Figure adapted from Lillesand et al. (2004; Kalensky and Wilson, 1975)

Generalized Spectral Reflectance Envelopes for Deciduous and Coniferous Trees



A Possible Application for GEMS-like Instruments

An Index to Examine Greenness of scenes – Visible Vegetation Index (VVI)?

$$VVI = \left[\left(1 - \left|\frac{R - R_0}{R + R_0}\right|\right)\left(1 - \left|\frac{G - G_0}{G + G_0}\right|\right)\left(1 - \left|\frac{B - B_0}{B + B_0}\right|\right)\right]^{1/w}$$

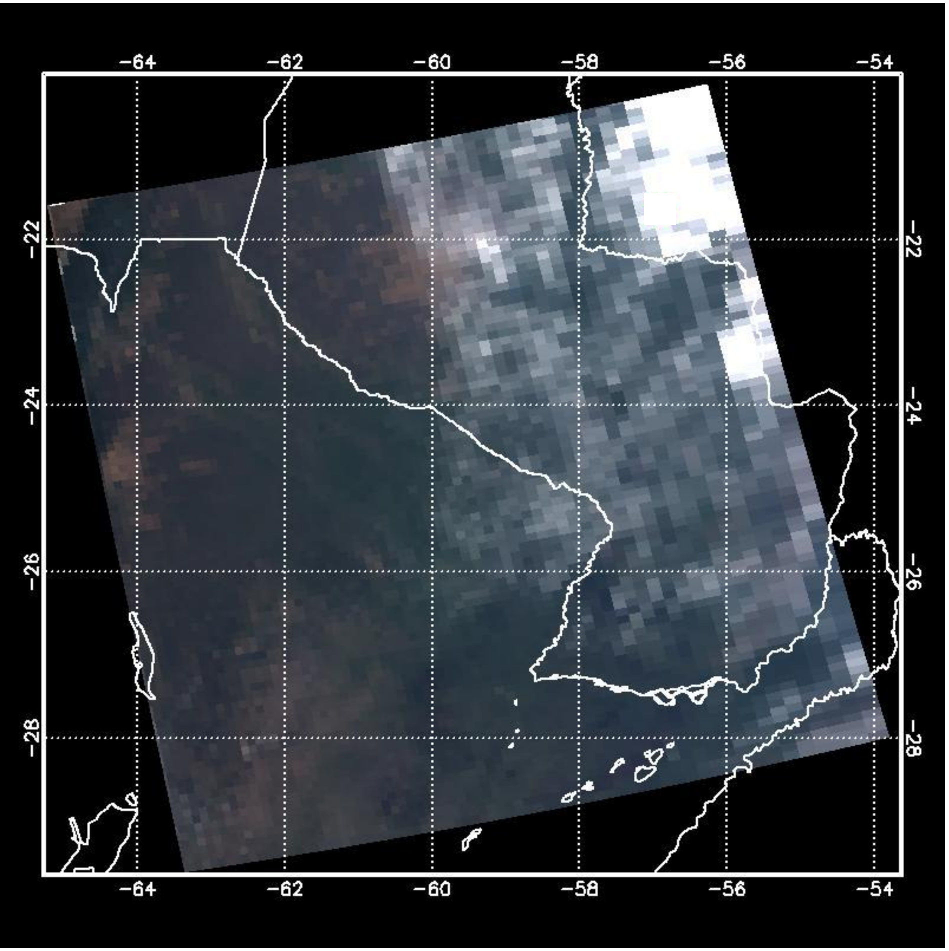
R_0, G_0, and B_0: Coeff. to be derived empirically.

VVI is introduced at http://phl.upra.edu/

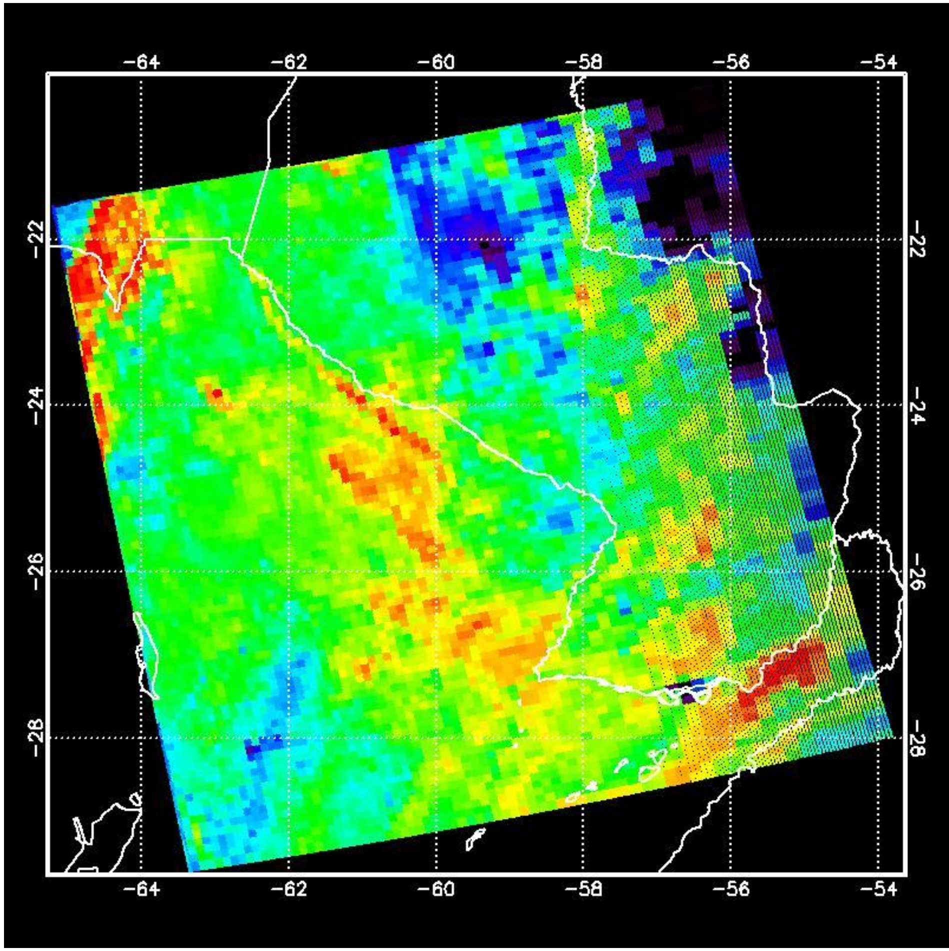
Figure adapted from Lillesand et al. (2004; Kalensky and Wilson, 1975)

Detecting Vegetated Areas: RGB Image & NDVI

RGB Image



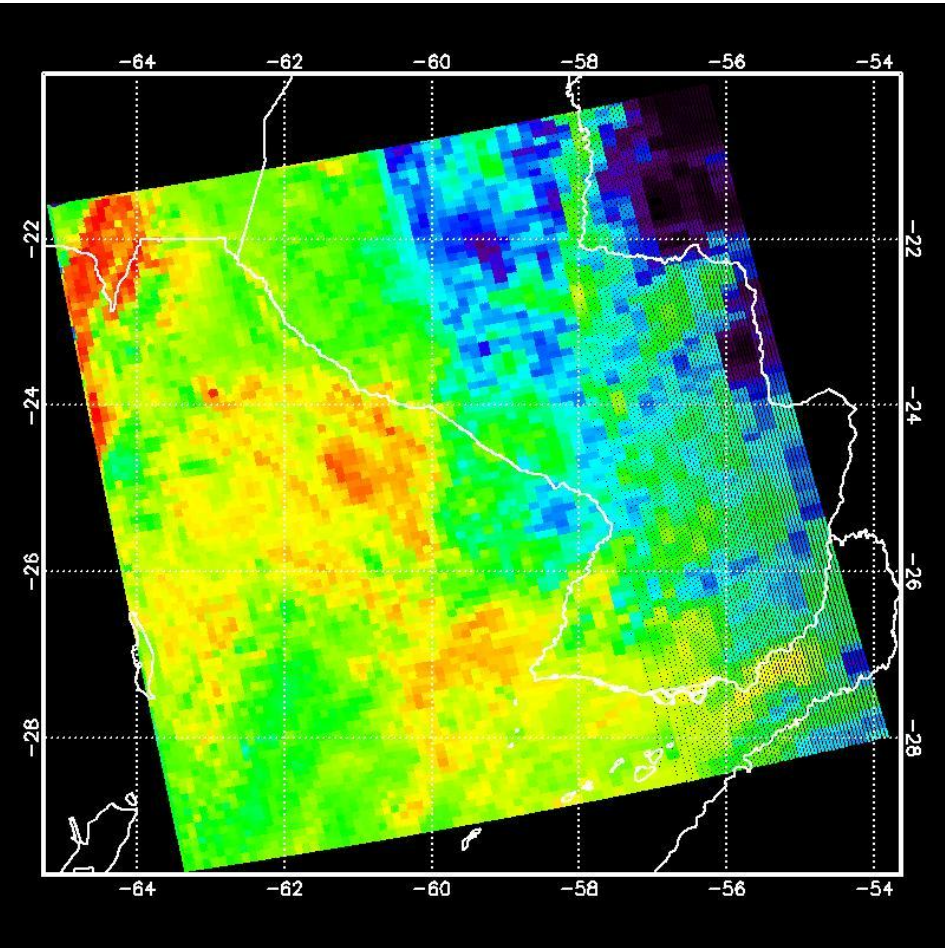
NDVI



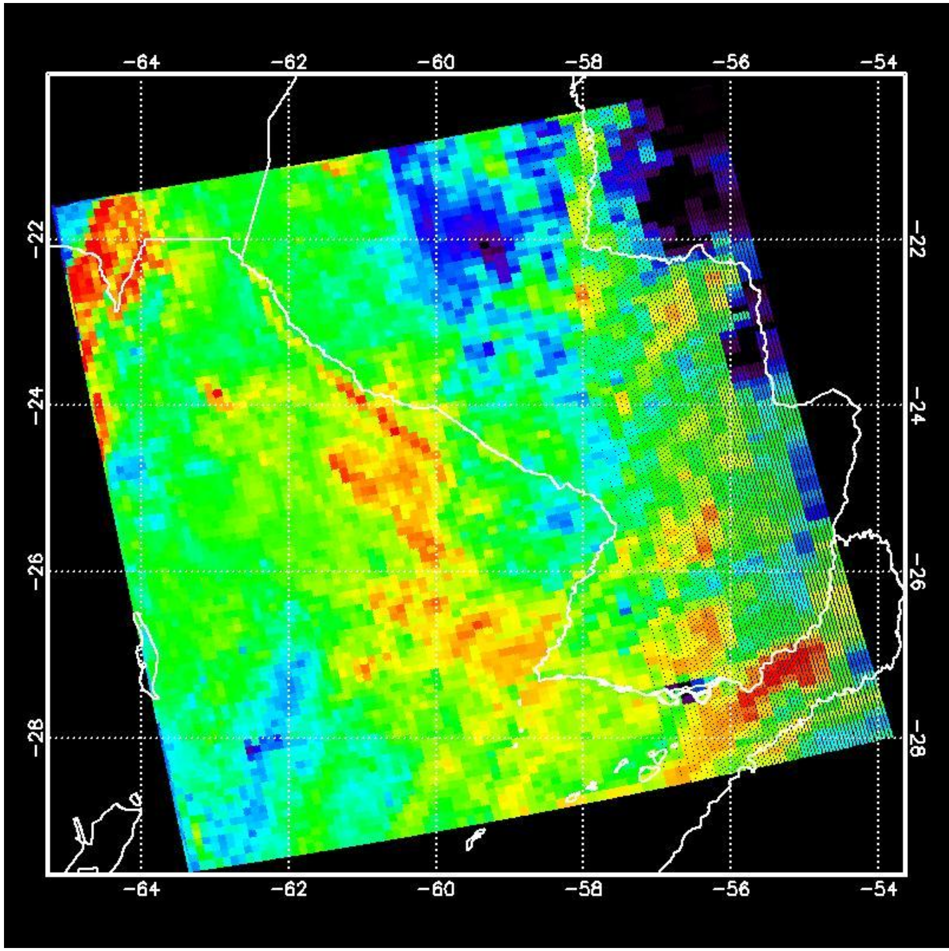
NDVI Map: 1) Vegetated surfaces shown in green/yellow/red; 2) Clouds and arid/semi-arid surfaces in blue/purple/black.

Visible Vegetation Index v.s. NDVI

Visible Vegetation Index (VVI)



NDVI

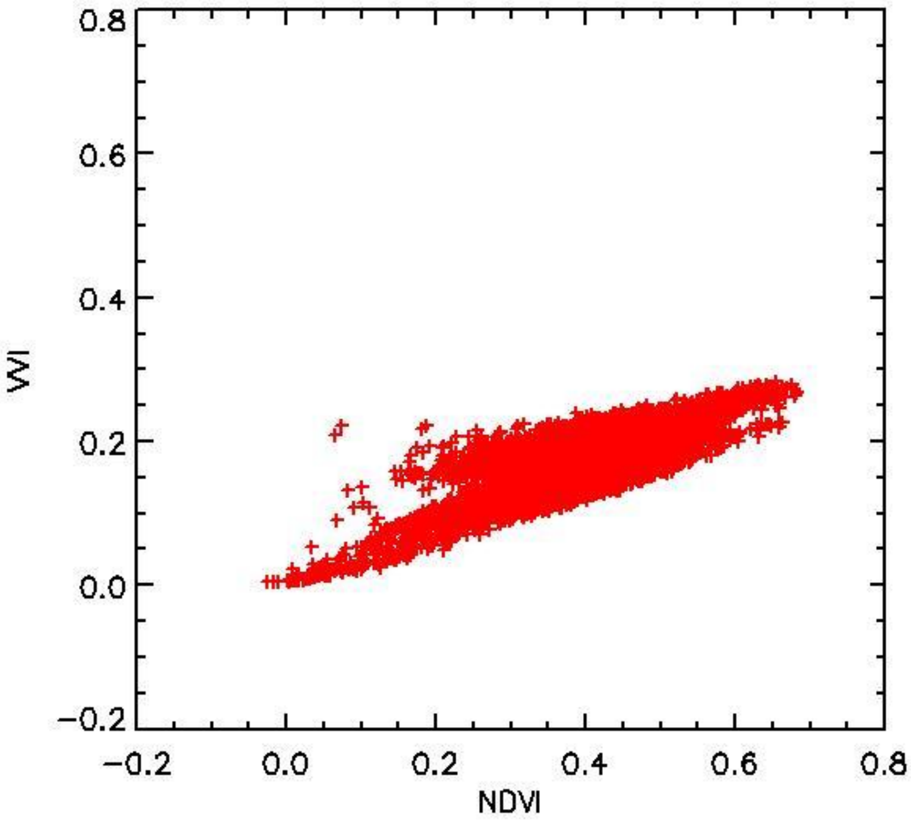


✓**Similar general distribution patterns between VVI index and NDVI.**

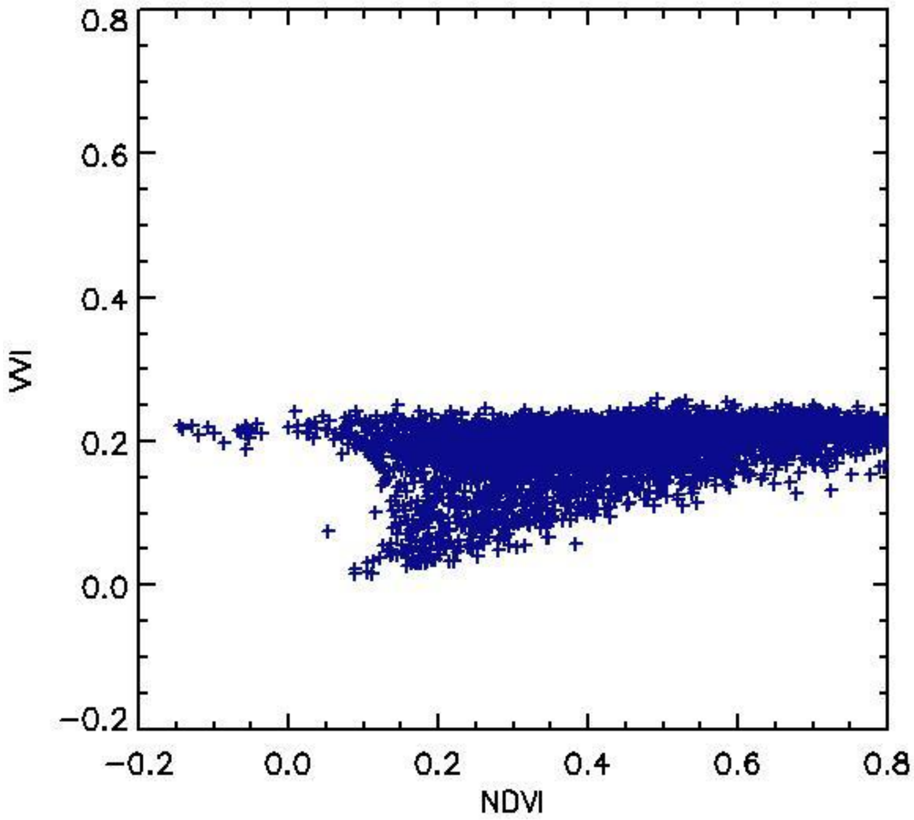
✓**Similar sensitivity of VVI for clouds with NDVI, but VVI seems to bear a weaker sensitivity to barren surfaces.**

Visible Vegetation Index v.s. NDVI

10x10km Resolution



1x1km Resolution



→It seems possible to link VVI to NDVI, but it should be noted that there is significant spatial-resolution dependency of the relationship between VVI and NDVI.
→ Further investigation is necessary.

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***

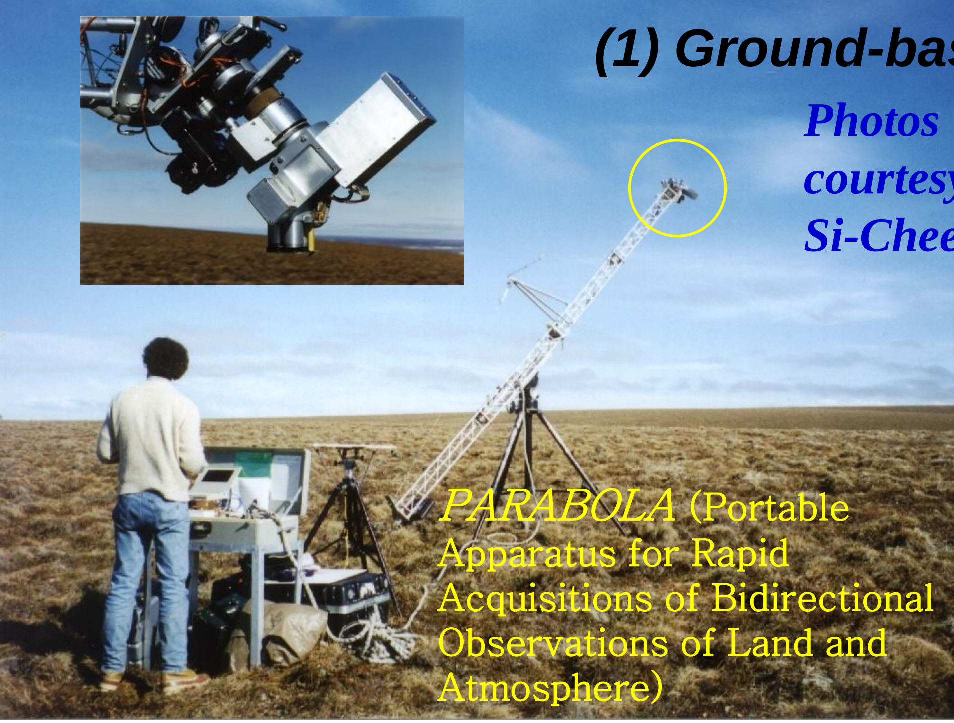
❖ ***Air-borne Measurements***

- ✓ ***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

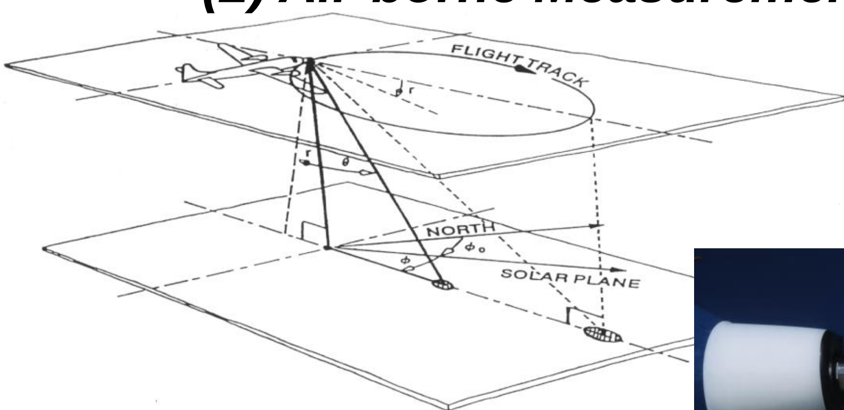


Photos courtesy of Si-Chee Tsay

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

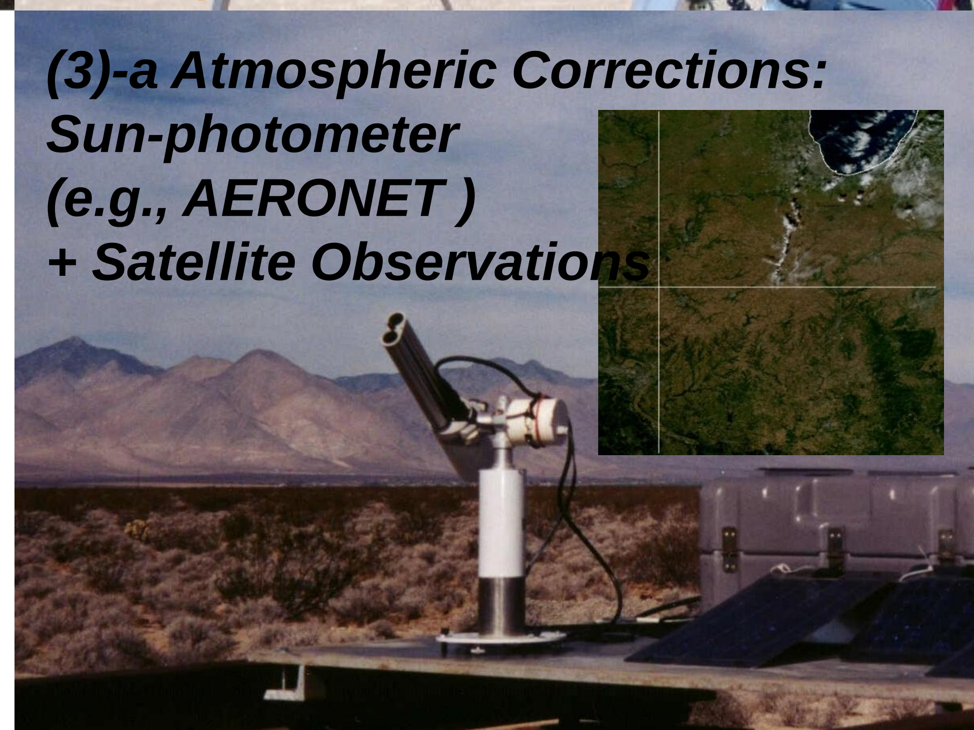
ASD FieldSpec Pro attached to a telescope mount

(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

Photo from http://aeronet.gsfc.nasa.gov/

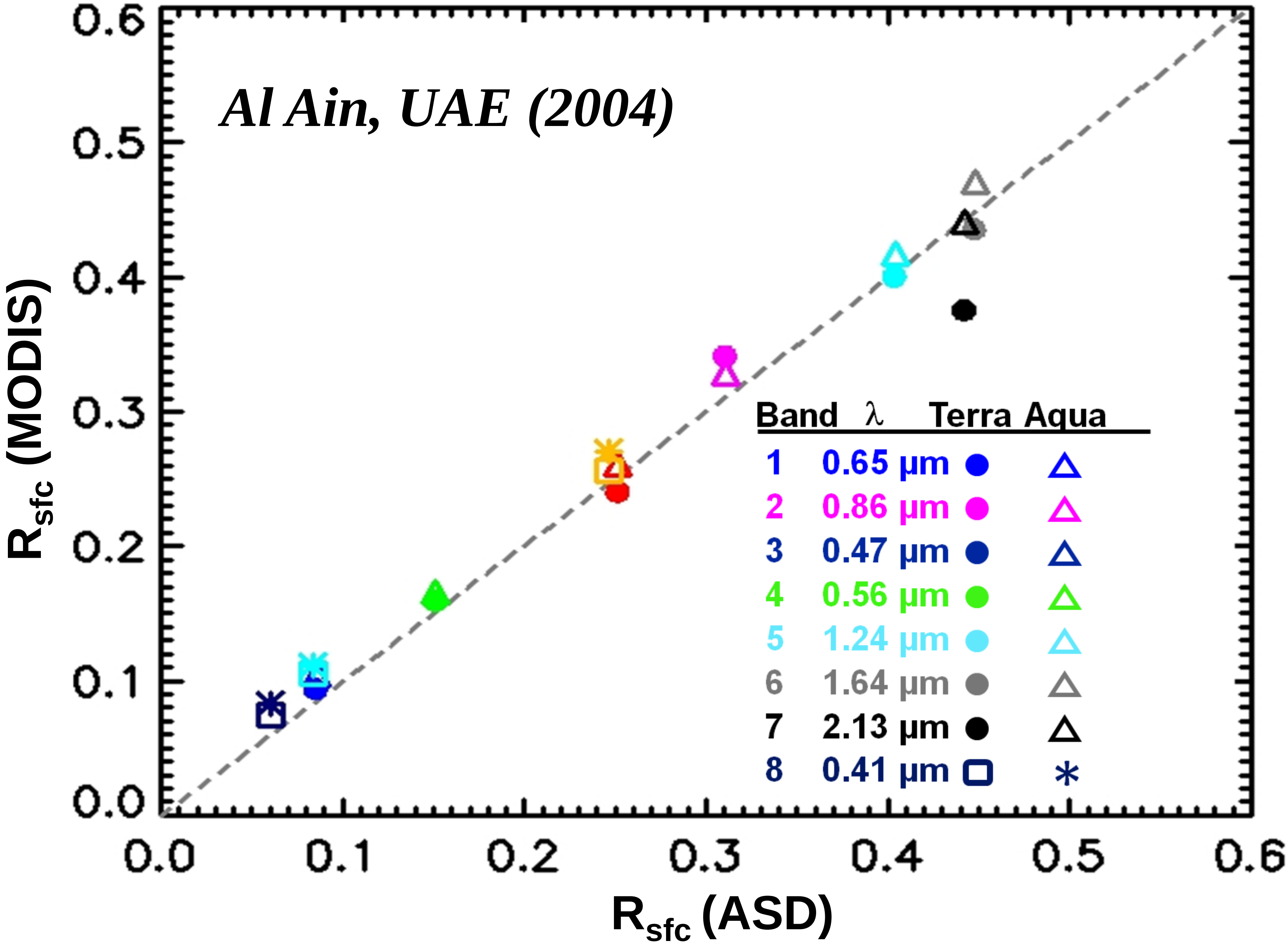
Model 540 MICROTOPS II

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

- **Spectral configurations: 340, 440, 675, 870, 936nm → (4 aerosol + 1 water vapor channels)**
- **Uncertainty of AOT in each channel < 0.02.**

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

Example of R_{sfc} Evaluation



Summary

- ***R_{min} search method is applicable to GEMS (the spectral region, 300-500(630)nm; based on literature).***

- ***Considering the necessary accuracy of downstream data products (e.g., aerosols), R_{sfc} accuracy requirement is estimated to be around 1-2%.***

- ***Surface properties (e.g., detection of vegetated area) can be estimated if spectral coverage is extended to red λs (e.g., ~630nm)***

- ***Strategy, technique, and instrument for validation are being prepared.***