Development of the GEMS surface reflectance retrieval algorithm

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Final Goals of This Study

- ***Development of an algorithm for deriving the spectral R_{sfc} at UV & VIS λs .***
- ***Derivation of R_{sfc} database to be used as input to the GEMS retrieval algorithms for trace gases & aerosols in the early stage of GEMS OBSs.***
- ***Provide a prototype of an algorithm to derive R_{sfc} (LER, if possible, BRDF) when enough actual GEMS OBSs are accumulated.***

Plan for the GEMS R_{sfc} algorithms

Year	Research Plan	Development
2014	• Testing the sensitivity of R_{sfc} derivation to geophysical / environmental parameters & OBS errors (2)	• Sensitivity test
2015	• Searching for methods to detect ice/snow pixels using MOD10 L2 data.	• Discarding snow/ice pixels • Collecting data for the validation
2016	• Retrieval of the LER for GEMS R_{sfc} product using OMI data • Comparison of retrieved LER with LER obtained from OMI	• Discarding absorbing aerosols using the ratio between 2 λs • Correction of BRDF effect (plan)

Scenario for GEMS Mission

- *Existing* R_{sfc} *data (e.g., OMI) have been used for any application that requires* R_{sfc} *as input.*

- *Existing data may be fitted to BRDF kernels of the VLIDORT basic input for vegetation, regolith & ocean with the MODIS land covers in order to account for differences in observation geometry between different satellites.*

- *Use* R_{min} *search method*, & BRDF parameters may be derived.*

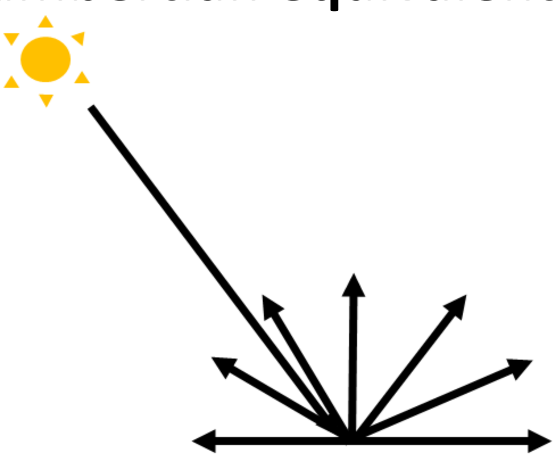
** R_{min} method: 1) divide earth surface into grid boxes; 2) accumulate Rayleigh-corrected R_{TOA} data at target λs; 3) search for a minimum value in each grid to ensure minimum aerosol influence.*

Surface reflectance (LER, BRDF)

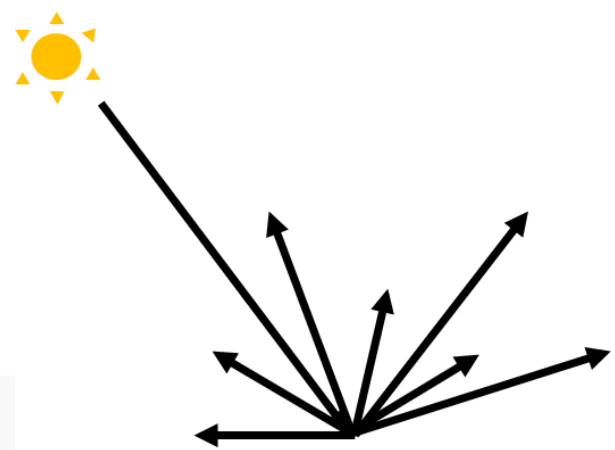
- ***Reality:*** *at all-scale inhomogeneity (λ, θ, ϕ; θ_0, ϕ_0; x, y, t)*

mixture ***seasonal*** ***sand, rocks, etc.*** ***vegetation, snow***

Lambertian equivalent R_{sfc} (LER)



BRDF



R_{sfc} theory

$$R_{TOA} = \frac{\pi L}{F_0 \cos \theta_0}$$

$$R_{TOA}(\theta_0, \theta_v, \varphi) = R_{atm}(\theta_0, \theta_v, \varphi) + \frac{T(\theta_0)T(\theta_v)R_{sfc}(\theta_0, \theta_v, \varphi)}{1 - R_{sfc}(\theta_0, \theta_v, \varphi)S^*}$$

$$R_{sfc}(\theta_0, \theta_v, \varphi) = \frac{R_{TOA}(\theta_0, \theta_v, \varphi) - R_{atm}(\theta_0, \theta_v, \varphi)}{T(\theta_0)T(\theta_v) + S^*(R_{TOA}(\theta_0, \theta_v, \varphi) - R_{atm}(\theta_0, \theta_v, \varphi))}$$

$$R_{atm}(\theta_0, \theta_v, \varphi) = R^1_{atm}(\theta_0, \theta_v, \varphi) + (1 - e^{-\frac{\tau_{total}}{\mu_0}})(1 - e^{-\frac{\tau_{total}}{\mu}})\Delta\tau_{total}$$

single scattering   multi-scattering   Vermote et al. (2006)

Lambertian approximation is more valid at shorter λs (weak anisotropy), while in the visible many surfaces are strongly anisotropic.

$L = Radiance\ observed\ from\ the\ sensor$

$F_0 = Extraterrestrial\ irradiance$

$\cos\theta_0 = cosine\ of\ SZA$

$\theta_V = SVZA$

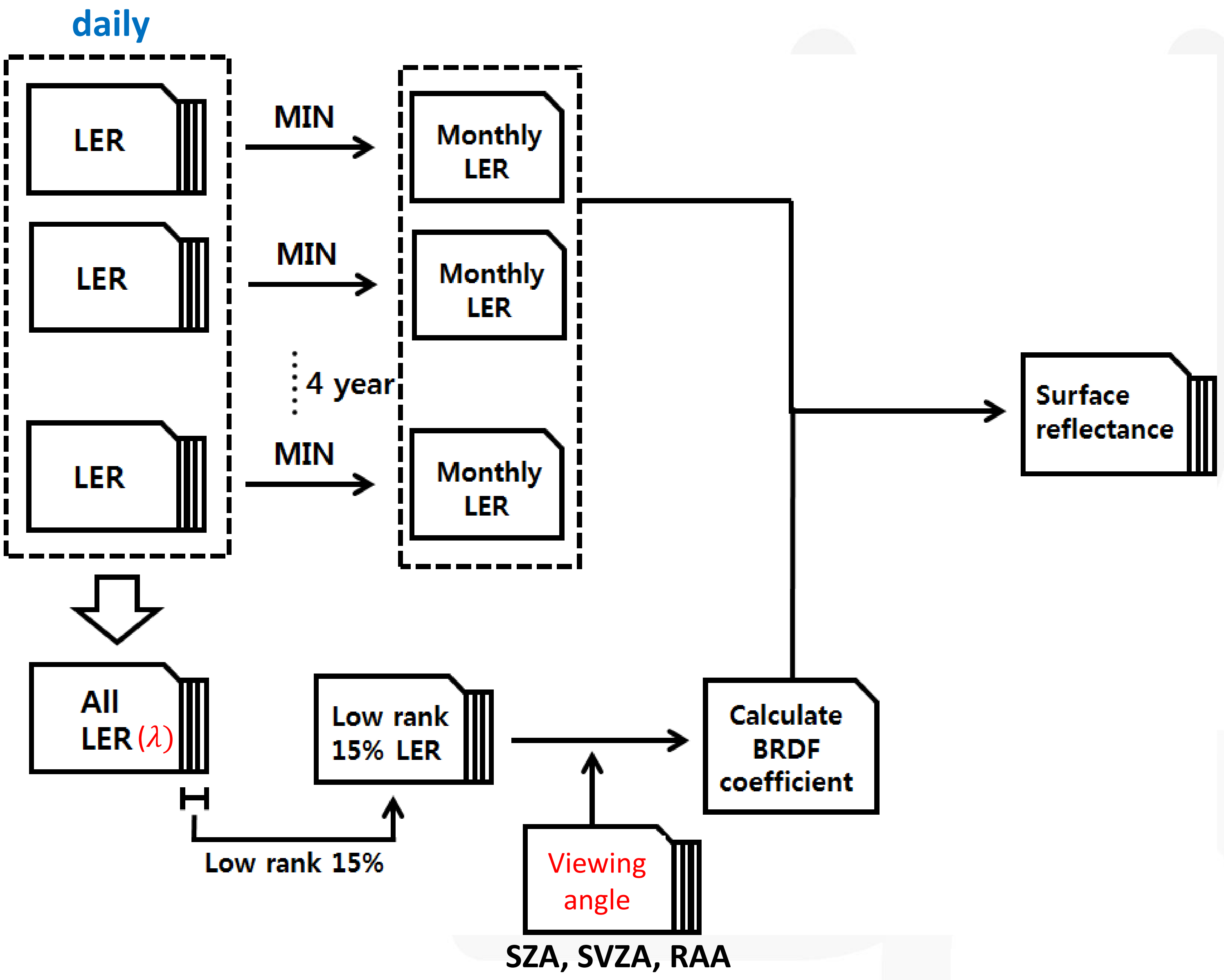
$\varphi = RAA$

$T = atmospheric\ transmittance$

$S^* = Spherical\ albedo\ of\ the\ atm.$

$\tau_{total} = total\ optical\ depth\ of\ both\ air\ molecules\ \&\ aerosols$

Flow chart for monthly R_{sfc} using accumulated LER, & calculation of BRDF coeff



Output at each pixel (ex, 3yr data)

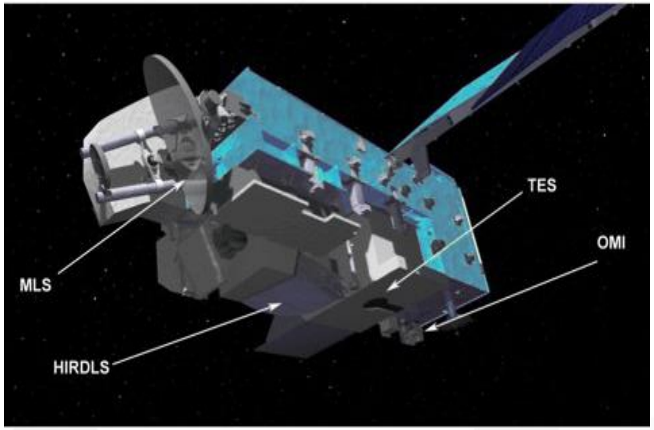
OUTPUT	UNITS	λ	BRDF
Lat	deg		
Lon	deg		-
λ	nm		
Monthly min R_{sfc} (12)	unitless	328, 335, 342, 345, 354, 367, 372, 376, 380, 388, 406, 416, 418, 425, 440, 442, 452, 463, 471, 477, 488, 494, 499 nm (23 λs)	Fitting BRDF kernels for Vegetation, Regolith & Ocean
Monthly R_{sfc} (36)	unitless		
Yearly min R_{sfc} (1)	unitless		
Yearly R_{sfc} (3)	unitless		
Monthly R_{sfc} Flag	unitless		
Yearly R_{sfc} Flag	unitless		

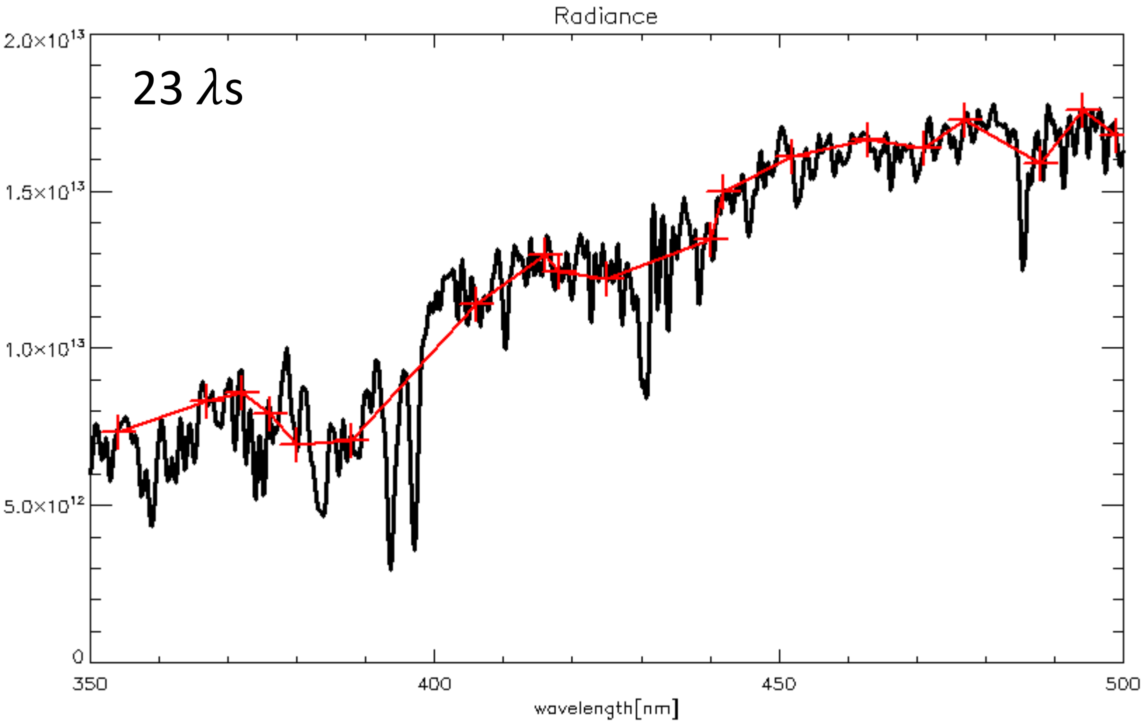
OMI data as proxy before GEMS

❖ **Input (L1B R_{TOA})**

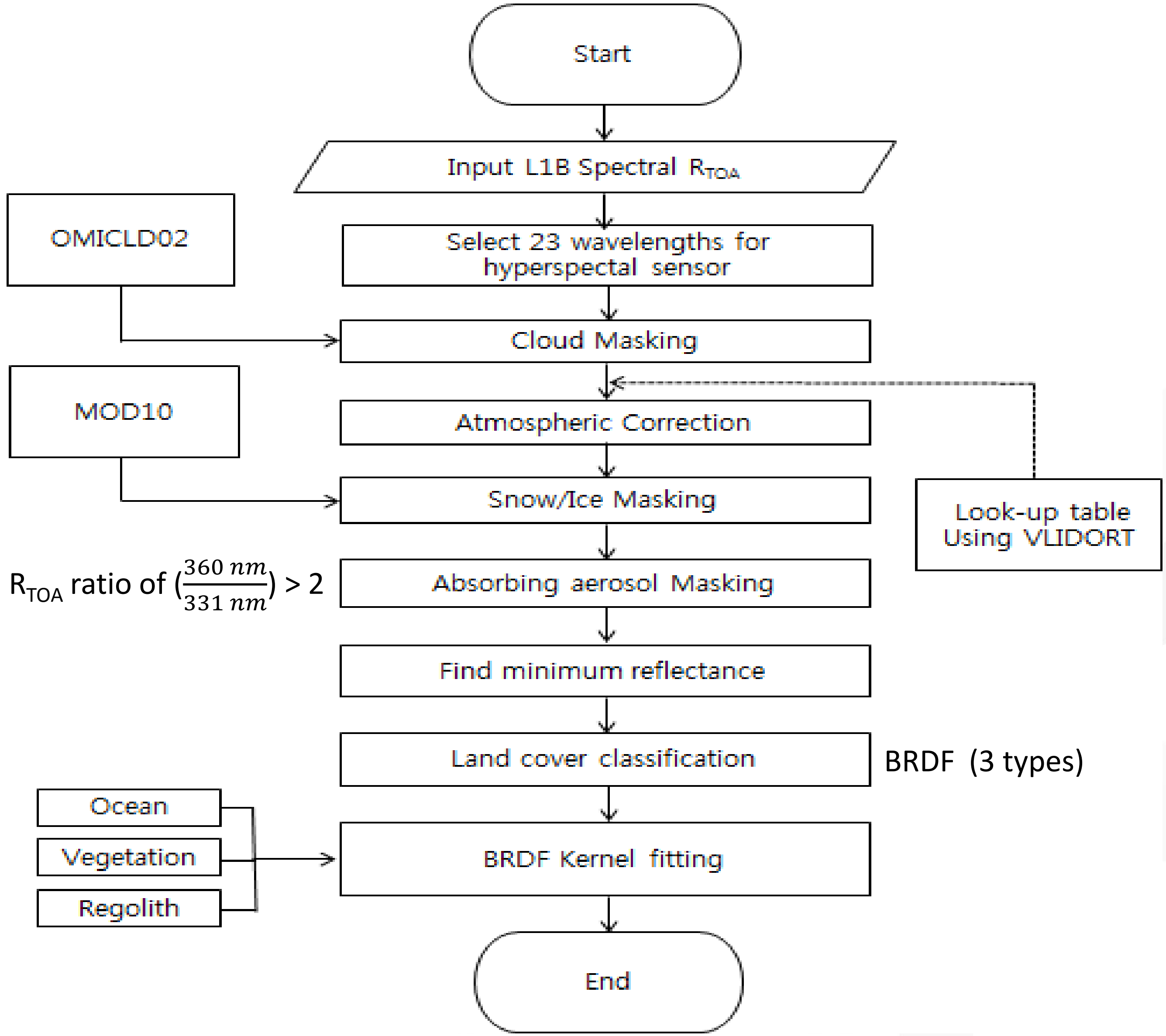
✓ Resolution: 13 x 24 km

✓ Hyperspectral λ
- UV-1 Ch = 270-314 nm
- UV-2 Ch = 306-380 nm
- VIS Ch = 350-500 nm

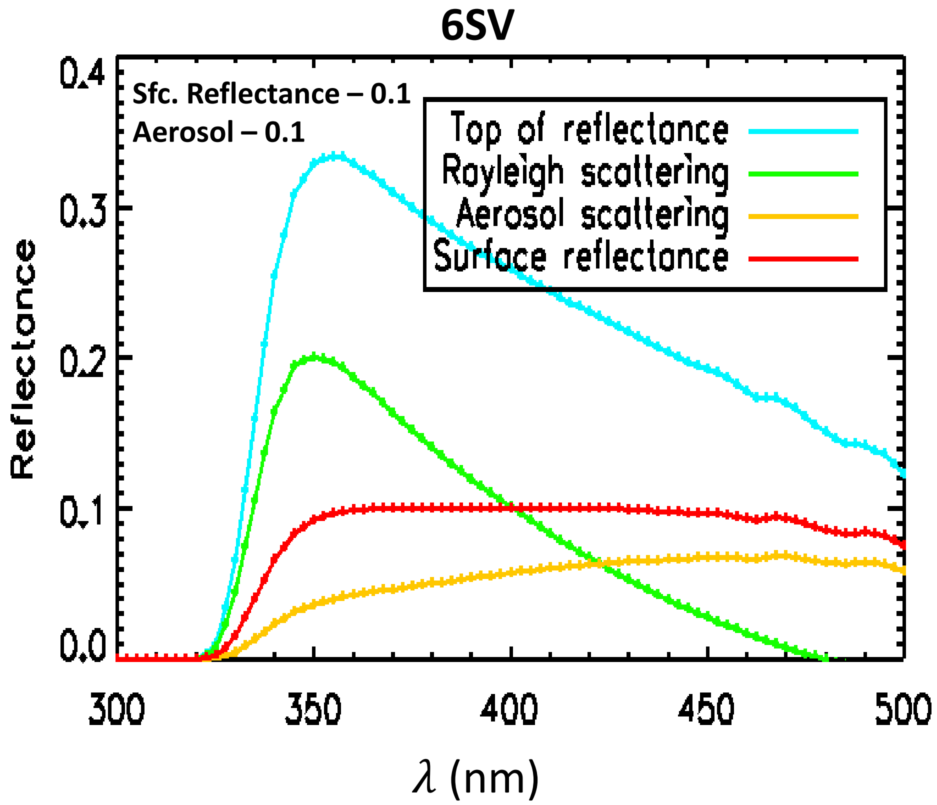


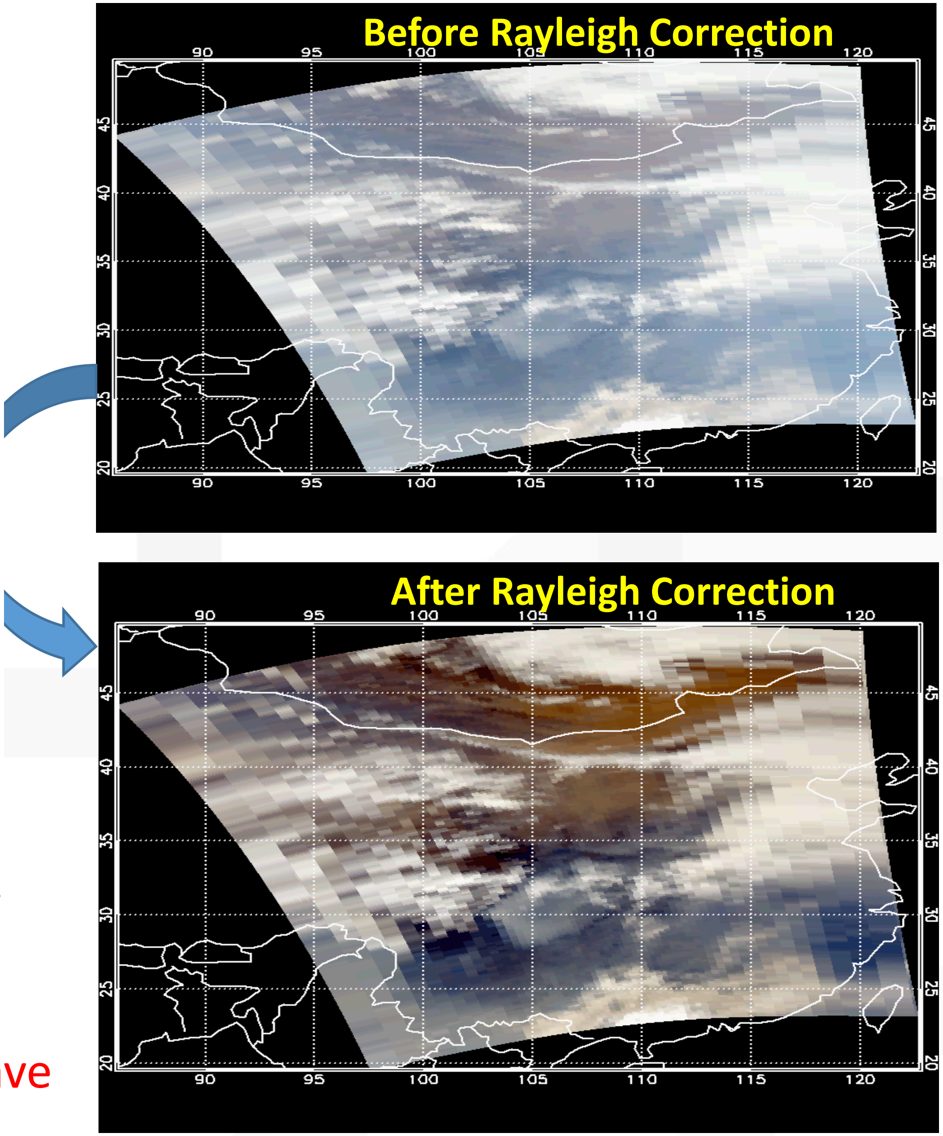


Flow diagram for deriving R_{sfc} from GEMS algorithm



Atmospheric correction

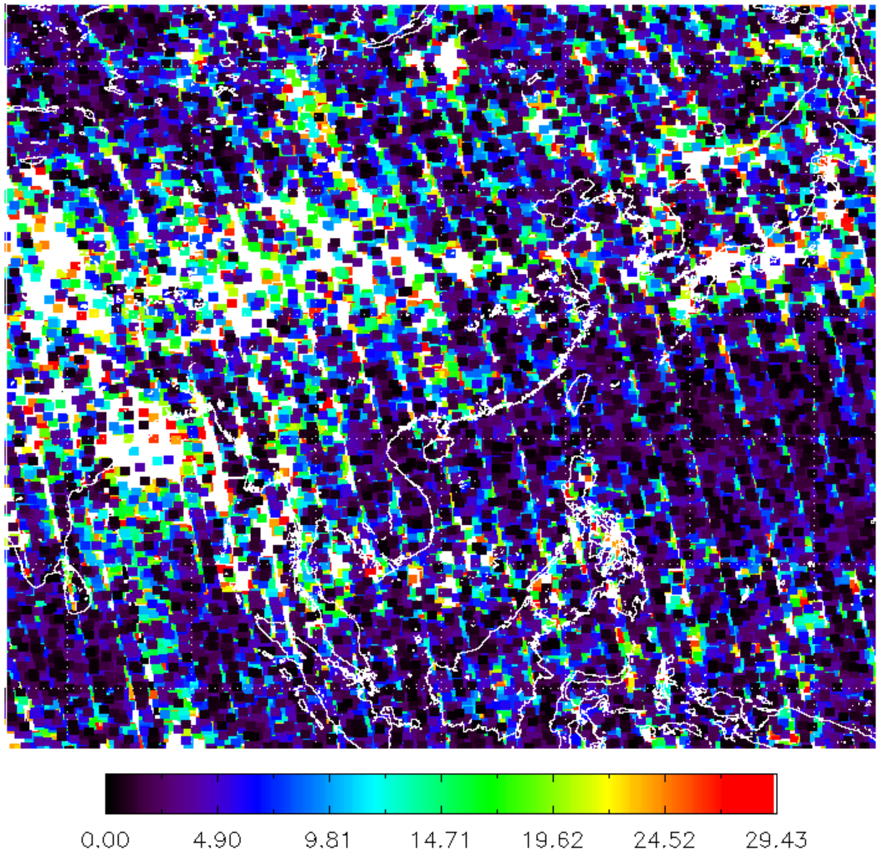




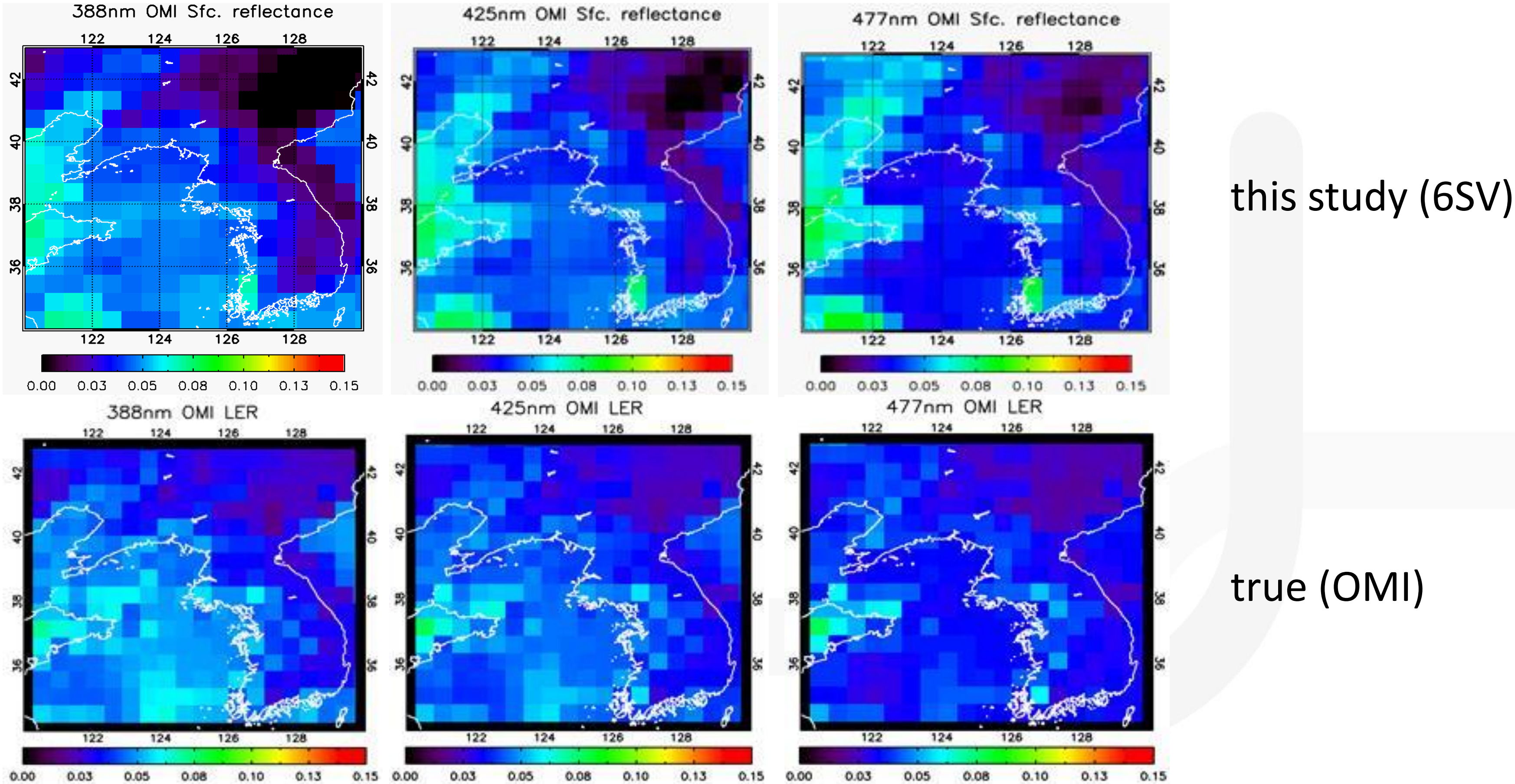
- RGB-like image from OMI (B=360nm, G=420nm, R=484nm) → Sfc features stand out after the Rayleigh correction.
- Based on 6SV, Rayleigh & aerosol corrections have to be done in order to derive R_{sfc} from R_{TOA}.

Preliminary result in progress

LER: GEMS domain, Jul 2005-2006



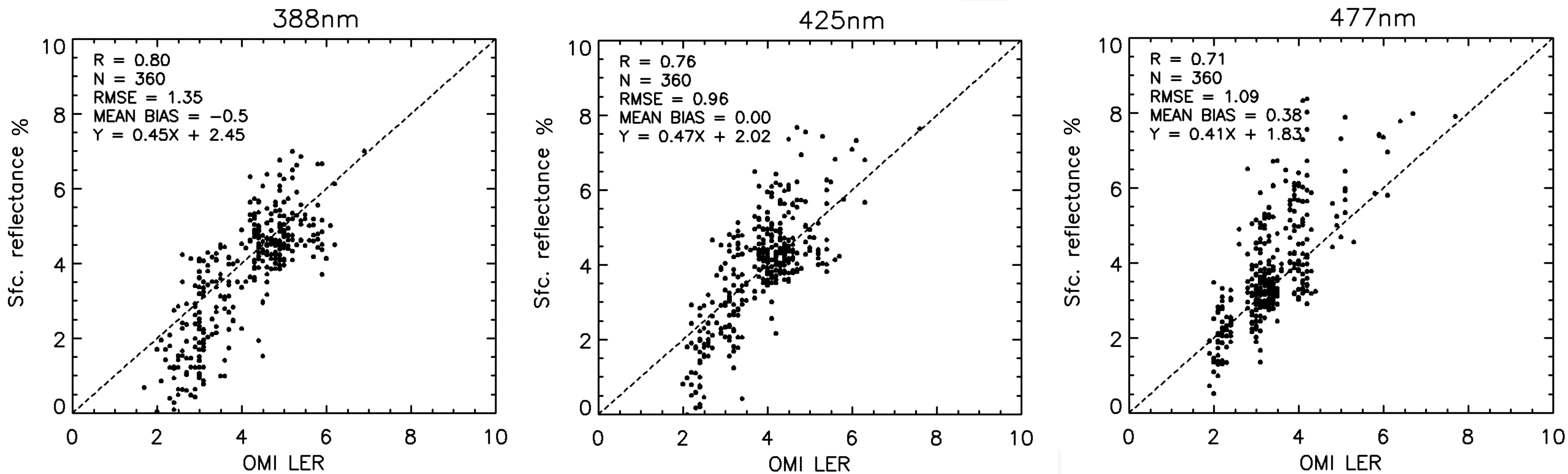
Validation



- Compare LER_{GEMS} with LER_{OMI} near Korea (0.5° X 0.5°) at 3 λs, using OMI data during 2005-2008.
- Large LERs in Shandong of China, low in E coast of S Korea & similar in the Yellow Sea.
- Different in northern area of N Korea due to topography, & after its correction (VLIDORT), & then apply LER_{GEMS} to BRDF.

Validation

Scatter plots between R_{min} derived from OMI L1B in this study & the OMI sfc LER



– Comparably good agreement between LER_{GEMS} & LER_{OMI} ($R > 0.7$, $RMSE < 0.015$)

– LER_{GEMS} is overestimated when filtering of the aerosol effect is not sufficient. → *Extend data-period or rigorous aerosol correction over China.*

Validation plan

- **Area:** GEMS viewing area
  (5S-55N, 75E-145E)

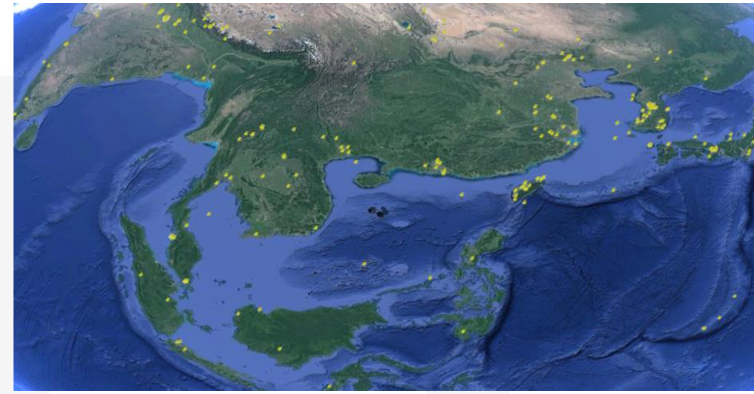
- **Period: 2005.1.1 - 2006.12.31**

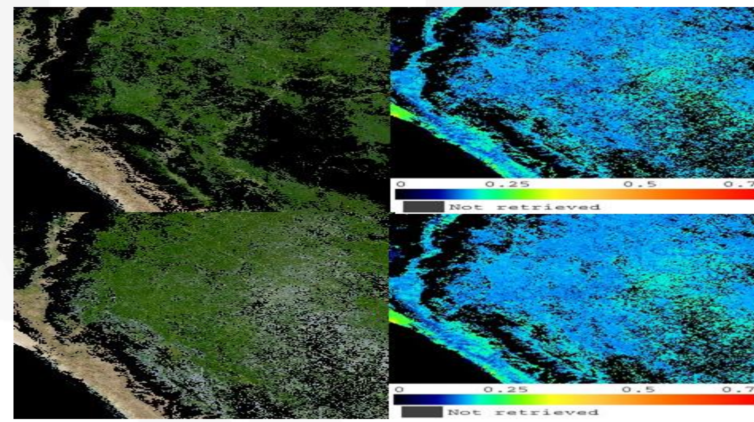
- **Datasets**

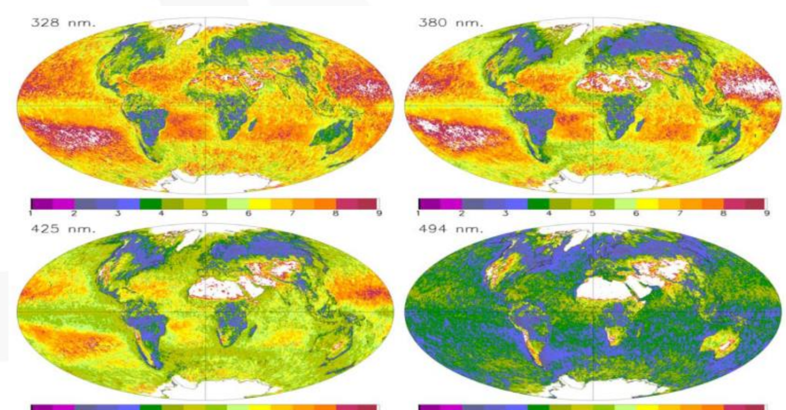
➢ **MODIS MCD43 product**
  - ✓ Black-sky albedo (LER$_{GEMS}$ comparison)
    - no downward diffuse comp, directional hemis R
  - ✓ White-sky albedo
    - no directional downward comp, isotropic diffuse comp
  - ✓ Blue-sky albedo

➢ **LER from OMI**

➢ **AERONET:** Ground-based AOD

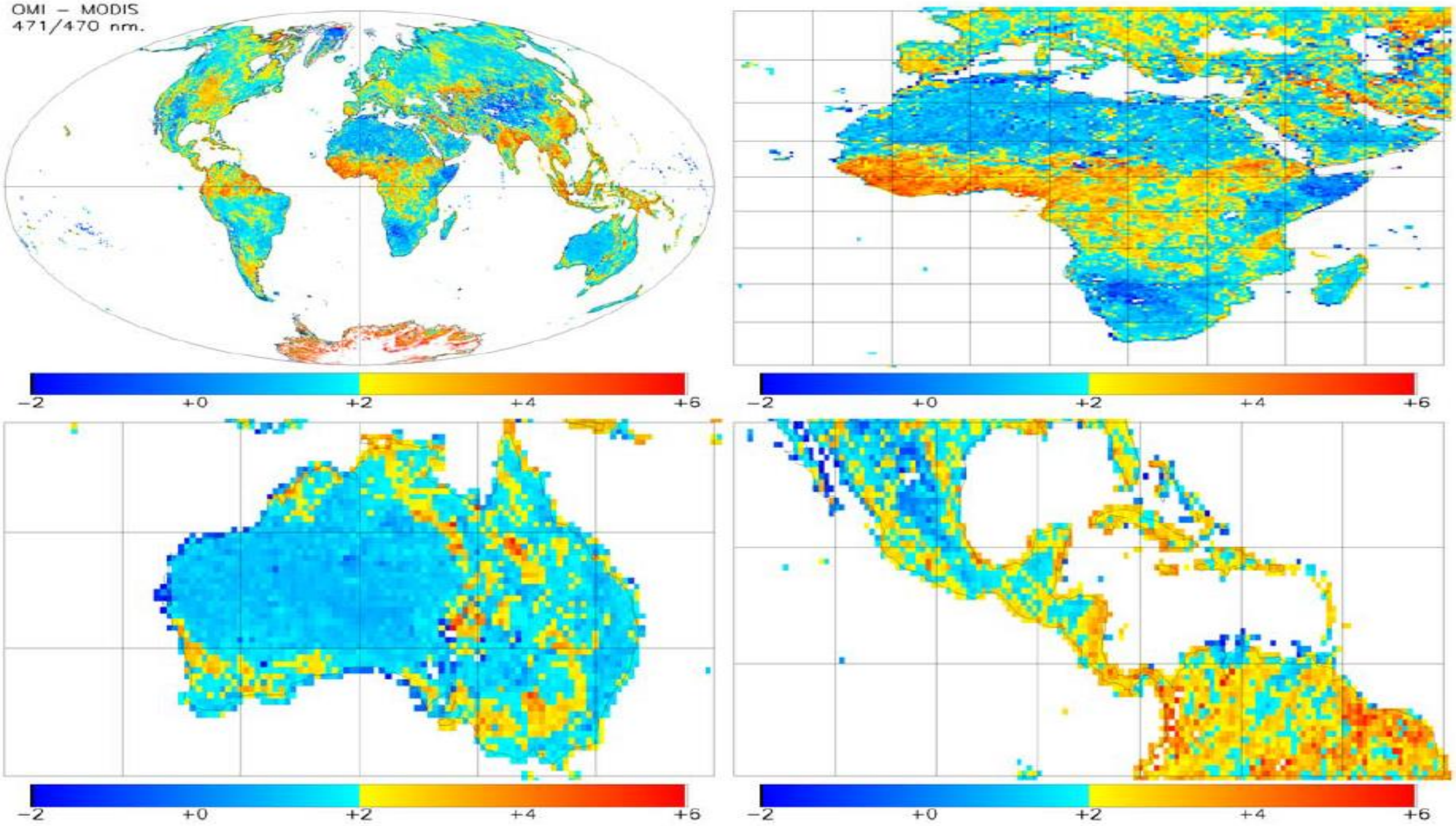






Kleipool et al., 2008

Example of validation (Kleipool et al. 2008)



- Comparison (OMI minus MODIS) of OMI LER data (X 100) with MODIS black sky albedo at 470 nm.
- Good agreement is over bare land, ice & deserts (0.01 higher LER_{OMI}; $BRDF_{MODIS}$ consistent with LER).
- Cloud problems in OMI data are visible over convective regions.
- LER_{OMI} is 0.02 higher for other land covers.
- We expect the above similar results in the LER_{GEMS} case.

R_{sfc} Anisotropy: Correction for BRDF Effects

- ***When enough samples of bi-directional R_{sfc} data can be derived for wide range of sun-satellite viewing geometries for given locations, BRDF models can be determined by fitting those data to a suitable BRDF kernel ft.***

- ***This method may be a little bit challenging for OMI OBSs, but it may work for GEMS OBSs, considering its higher spatio-temporal resolutions.***

An Application using Ross-Li BRDF Model:

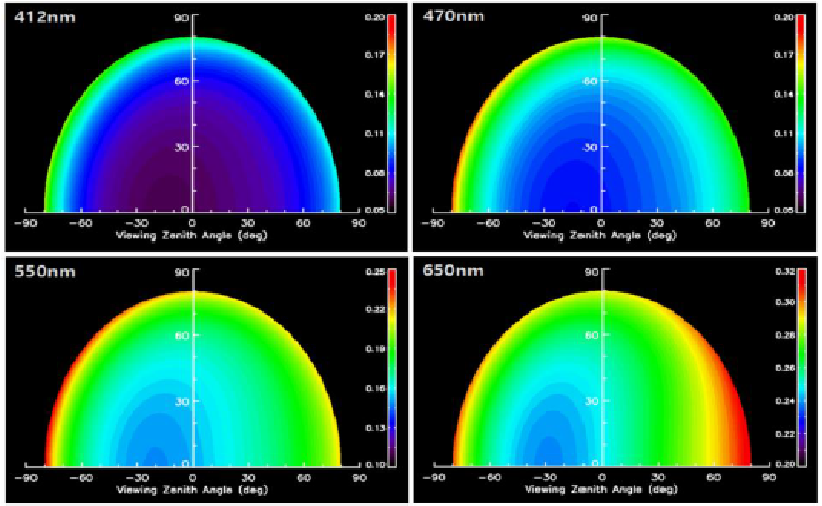
Example of A BRDF Kernel

$$R(\theta_0,\theta_v,\phi,\Lambda) = f_{iso}(\Lambda) + f_{vol}(\Lambda)\,K_{vol}(\theta_0,\theta_v,\phi) + f_{geo}(\Lambda)K_{geo}(\theta_0,\theta_v,\phi)$$

$$K_{vol} = \frac{(\pi/2-\xi)\cos\xi + \sin\xi}{\cos\theta_0 + \cos\theta_v} - \frac{\pi}{4}$$

$$K_{geo} = O(\theta_0,\theta_v,\phi) - \sec\theta_0' - \sec\theta_v' + \frac{1}{2}(1+\cos\xi')\sec\theta_0'\sec\theta_v'$$

Shape of a Sampled BRDF

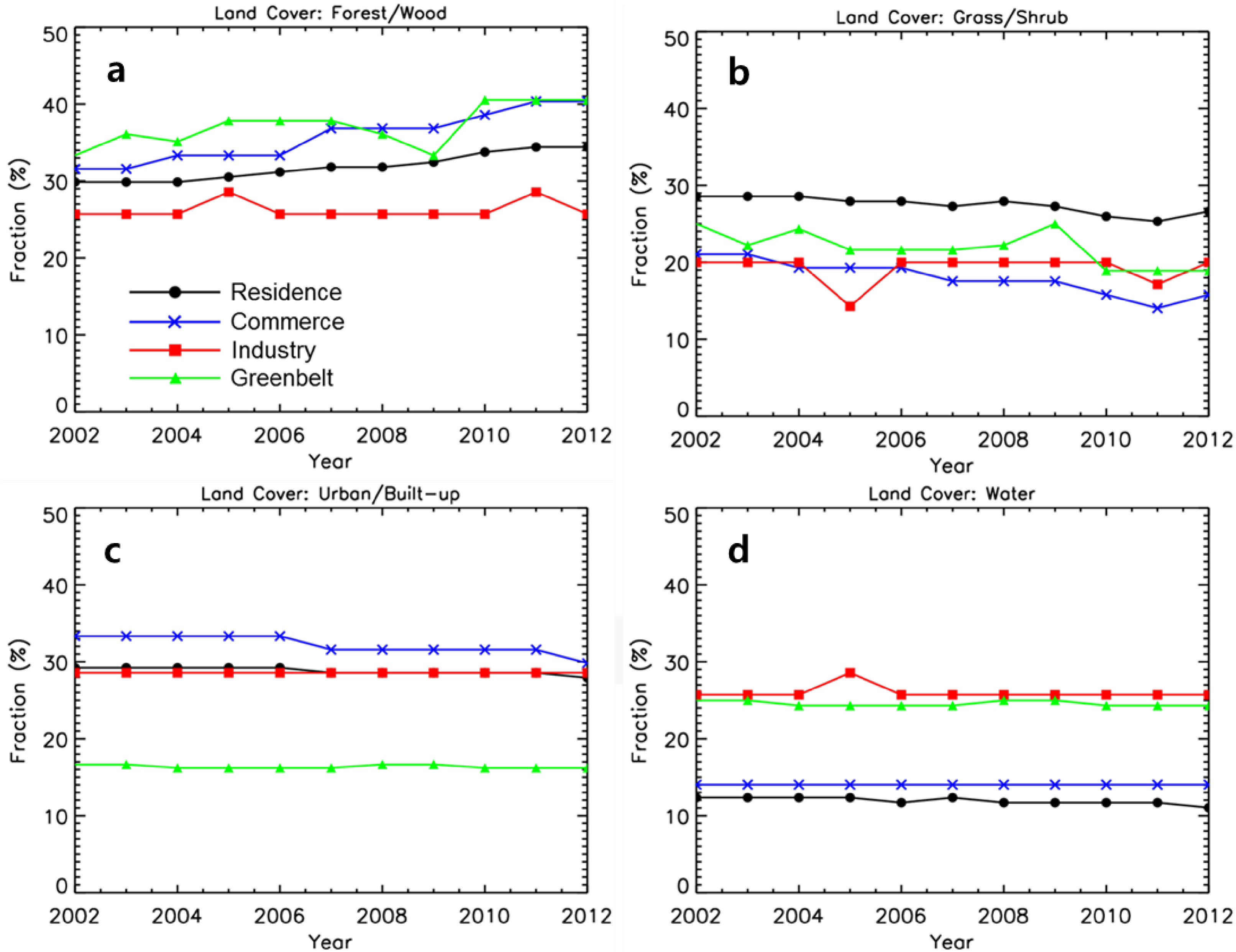


BRDF input

Surface type	Input	Reference
Water	Oceanic pigment concentration, Wind speed, Wind direction azimuth angle, Oceanic salinity	Cox & Munk (1954)
Vegetation	Isotropic coeff, Volumetric coeff, Geometric shadowing coeff, Hot spot magnitude, Hot spot width	Ross (2012)
Regolith	Surface particle single scattering albedo, Surface particle asymmetry factor, Hot spot magnitude, Width of hotspot	Hapke (1981)

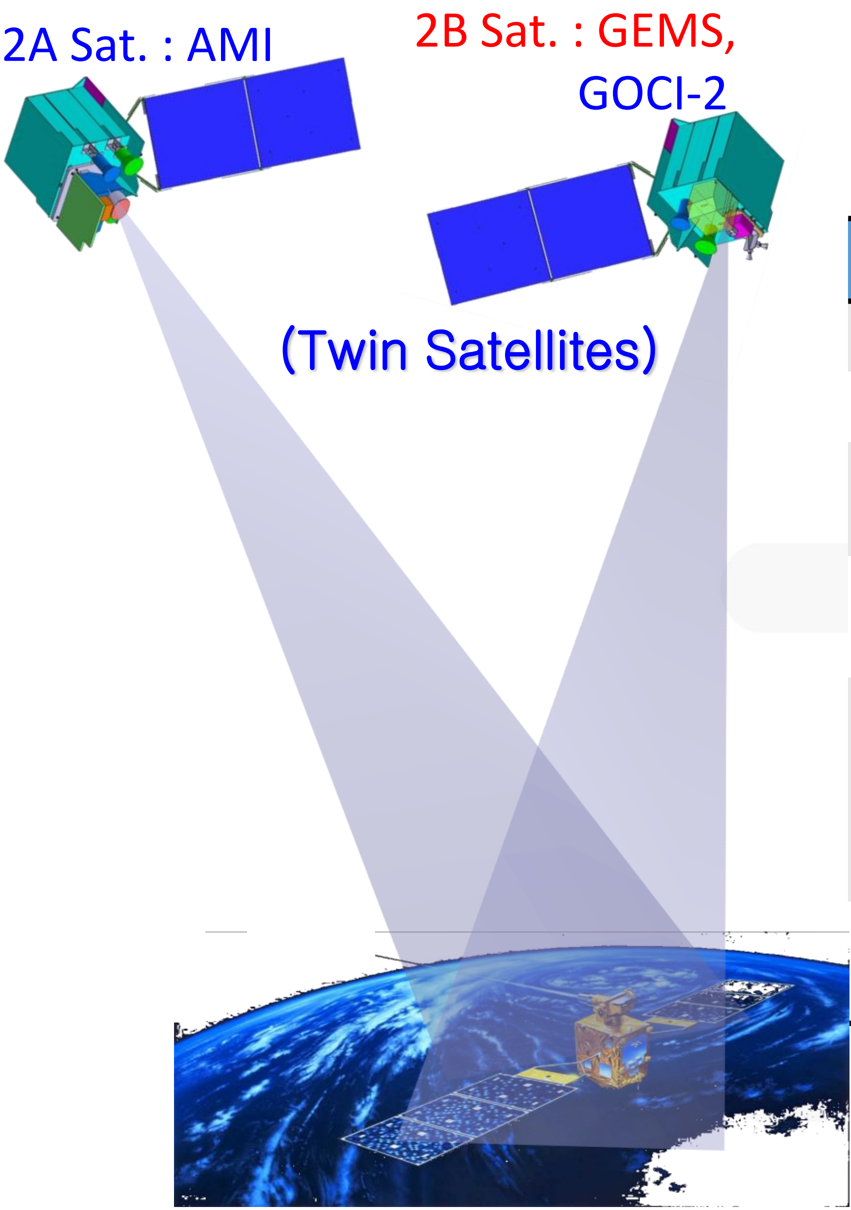
Summary

- The LER is derived from the GEMS R_{sfc} retrieval algorithm by using the proxy data.
- The results showed that the retrieved LER was in good agreement with the LER obtained from OMI ($R > 0.7$, $RMSE < 0.015$).
- More data will be collected to obtain better results in LER retrieval.
- The R_{min}(GEMS) results will be improved with correction of BRDF effect.
- Based on BRDF-kernel driven model, methods to consider the anisotropy of R_{sfc} are being developed.
- The validations will be performed in order to investigate the accuracy of the product from the GEMS R_{sfc} retrieval algorithm.



Yoo et al. (2015, ACP)

GEO-KOMPSAT 2



- Launch: 2018-2019

- **Specification**

	2A	2B	
Payload	AMI	GOCI-2	GEMS
Lifetime		10 yrs	
Channels	16	13	1000
λ range	0.4 - 13 μm	375 - 860 nm	300-500 nm
Spatial resolution	0.5 / 1 km (Vis) 2 km (IR)	250 m@ eq 1 km (FD)	7 x 8 km^2 @ Seoul 3.5x8 km^2 (aerosol)
Temporal resolution	10 min (FD)	1 hr	1 hr

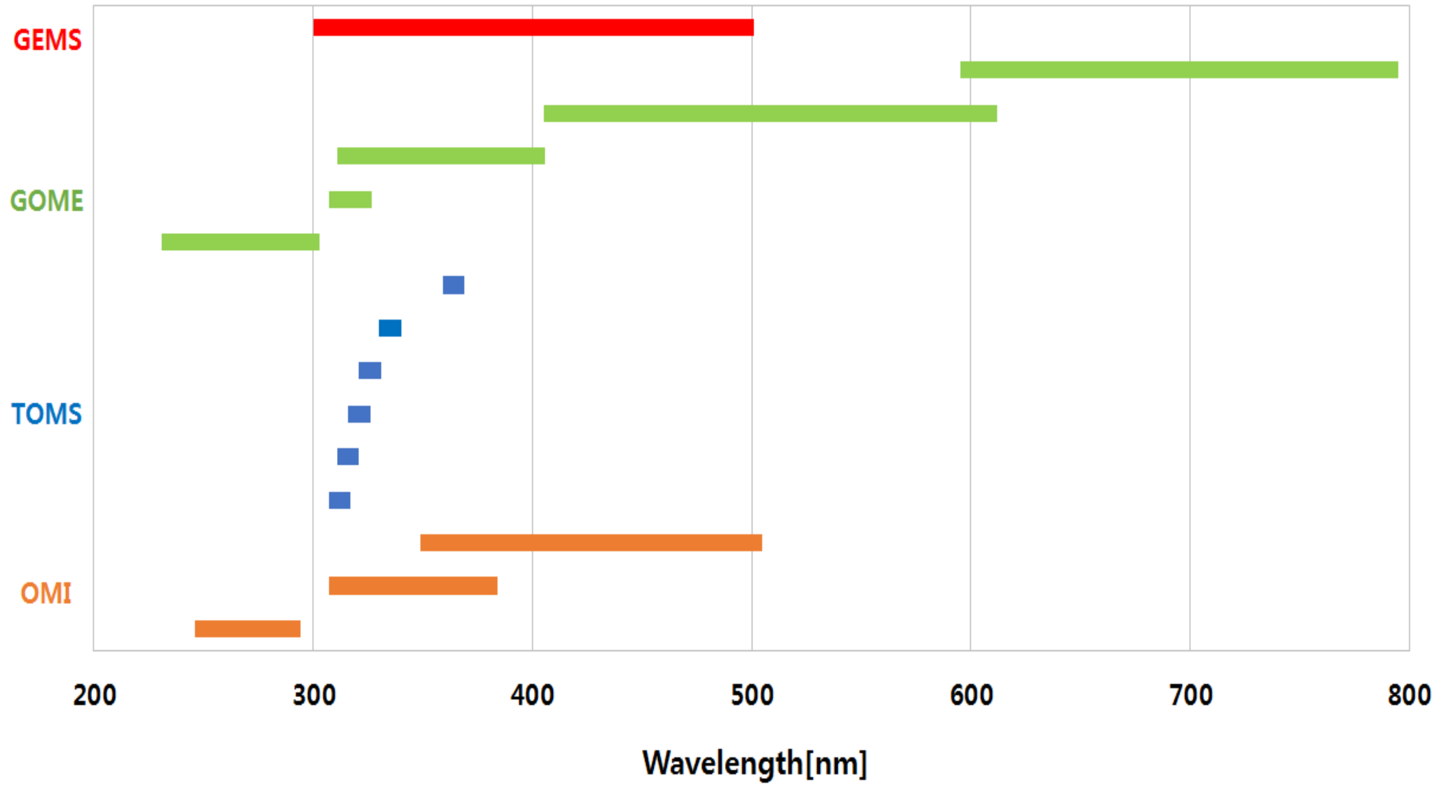
GEMS Concept of Operations

- GEMS OBS Timeline (TBD)

Operation mode		Observation Freq. (min)	E-W Scan coverage (@lat. of Seoul)
Normal		60*	75E – 145°E (70 deg wide)
Special	EA (East Asia)	60*	110°E – 140°E (30 deg wide)
	EEA (Enhanced East Asia)	60*	115°E – 130°E (15 deg wide)
	LA (Local Area)	< 30	In emergency by ground command

- Imaging time 30 min + Transmission 30 min
  to avoid mechanical disturbance with GOCI-2
- Wheel offloading will be performed in one of GEMS & GOCI-II imaging slots
  4 consecutive months in GEMS slots and another 4 consecutive months in GOCI-II slots

1. Introduction



< λ range of OMI, TOMS, and GEMS sensors>

- GEMS : 300-500 nm
- TOMS : 307, 311, 316, 321, 330, 359 nm
- GOME : 231-302, 307-316, 311-405, 405-611, 595-794 nm
- OMI : 264-311, 307-383, 349-504 nm

1. Introduction

Baseline products (#16)

Product	Importance	Min	Max	Nominal (cm^{-2})	Accuracy	Window (nm)	Spat Resol (km^2)@Seoul	SZA (deg)	Algorithm
NO_2	O3 precursor	$3x10^{13}$	$1x10^{17}$	$1x10^{14}$	$1x10^{15}$ cm^{-2}	425-450	7 x 8 x 2 pixels	< 70	BOAS DOAS
SO_2	Aerosol precursor Volcano	$6x10^{8}$	$1x10^{17}$	$6x10^{14}$	$1x10^{16}$ cm^{-2}	310-330	7 x 8 x 4 pixels x 3 hours	< 50 (60*)	
HCHO	VOC proxy	$1x10^{15}$	$3x10^{16}$	$3x10^{15}$	$1x10^{16}$ cm^{-2}	327-357	7 x 8 x 4 pixels	< 50 (60*)	
CHOCHO							7 x 8 x 4 px	< 50	
TropLO3 TropUO3 StratO3 TotalO3	Oxidant Pollutant O_3 layer	$4x10^{17}$	$2x10^{18}$	$1x10^{18}$	3%(TOz) 5%(Stra) 20(Trop)	300-340	7 x 8	< 70	OE TOMS
AOD AI SSA AEH	Air quality Climate	0 (AOD)	5 (AOD)	0.2 (AOD)	20% or 0.1@ 400nm	300-500	3.5 x 8	< 70	Multi-λ O_2O_2 Ring
[Clouds] ECF CCP	Retrieval Climate	0 (COD)	50 (COD)	17 (COD)		300-500	7 x 8	< 70	O_2O_2 RRS
Surface Property	Environment	0	1	-		300-500	3.5 x 8	< 70	Multi-λ
UVI Solar Ira	Public health	0	12	-			7 x 8	< 70	

Input for VLIDORT

INPUT	UNITS	INPUT	UNITS
Irradiance Exponent (UV-2)	photon/s*cm^2*sr*nm	Irradiance Exponent (VIS)	photon/s*cm^2*sr*nm
Irradiance Mantissa (UV-2)	photon/s*cm^2*sr*nm	Irradiance Mantissa (VIS)	photon/s*cm^2*sr*nm
λ Coeff (UV-2)	unitless	λ Coeff (VIS)	unitless
λ Reference Column(UV-2)	unitless	λ Reference Column (VIS)	unitless
Pixel Quality Flags (UV-2)	unitless	Pixel Quality Flags (VIS)	unitless
Radiance Exponent (UV-2)	photon/s*cm^2*sr*nm	Radiance Exponent (VIS)	photon/s*cm^2*sr*nm
Radiance Mantissa (UV-2)	photon/s*cm^2*sr*nm	Radiance Mantissa (VIS)	photon/s*cm^2*sr*nm
Lat (UV-2)	degree	Lat (VIS)	deg
Lon (UV-2)	degree	Lon (VIS)	deg
Terrain Height (UV-2)	meter	Terrain Height (VIS)	meter
SAA (UV-2)	degree	SAA (VIS)	deg
SZA (UV-2)	degree	SZA (VIS)	deg
SVAA (UV-2)	degree	SVAA (VIS)	deg

Vector code LInearized Discrete Ordinate Radiative Transfer