Separation of contributions from atmospheric scattering and surface reflectance in optical satellite imagery

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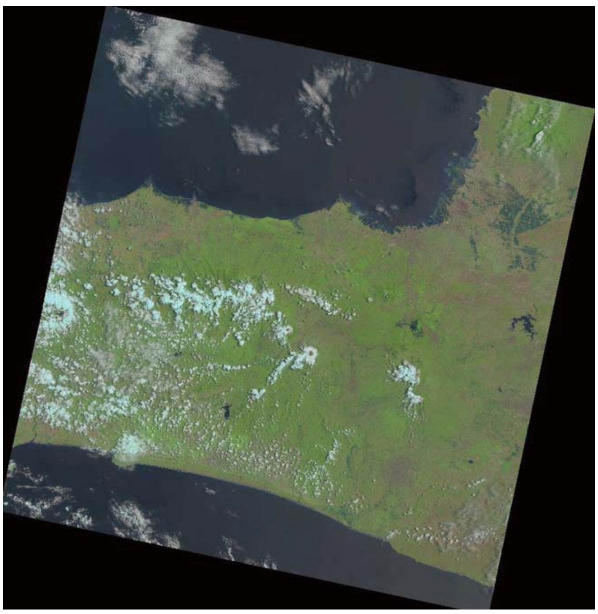
Organization of this presentation

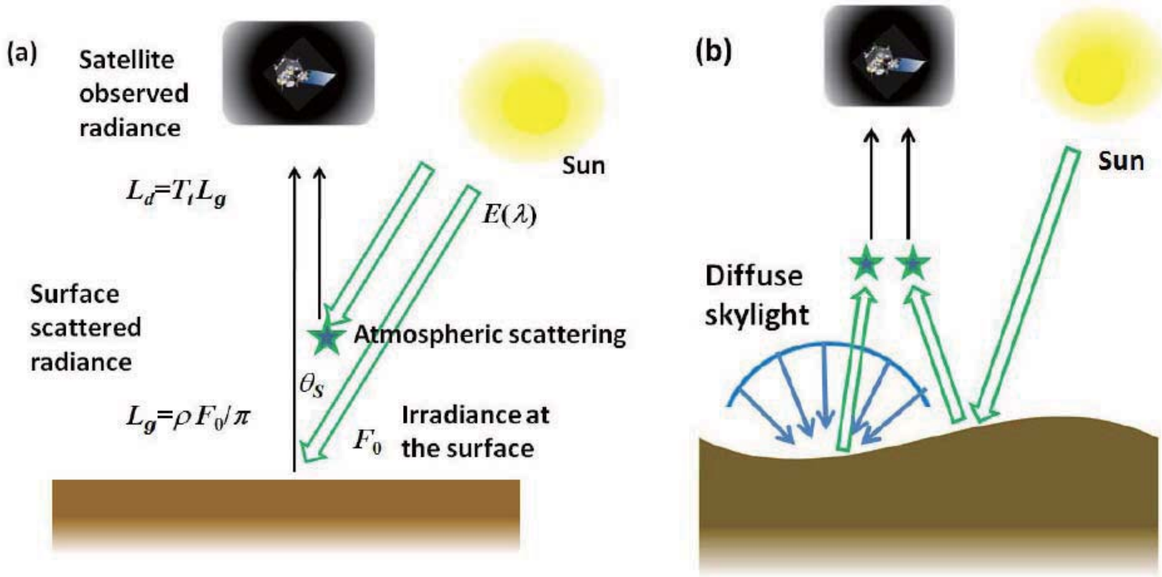
1. Introduction
2. Theory
3. Results and discussion
4. Conclusion



http://earthexplorer.usgs.gov/browse/landsat_8/2014/120/065/LC81200652014274LGN00.jpg

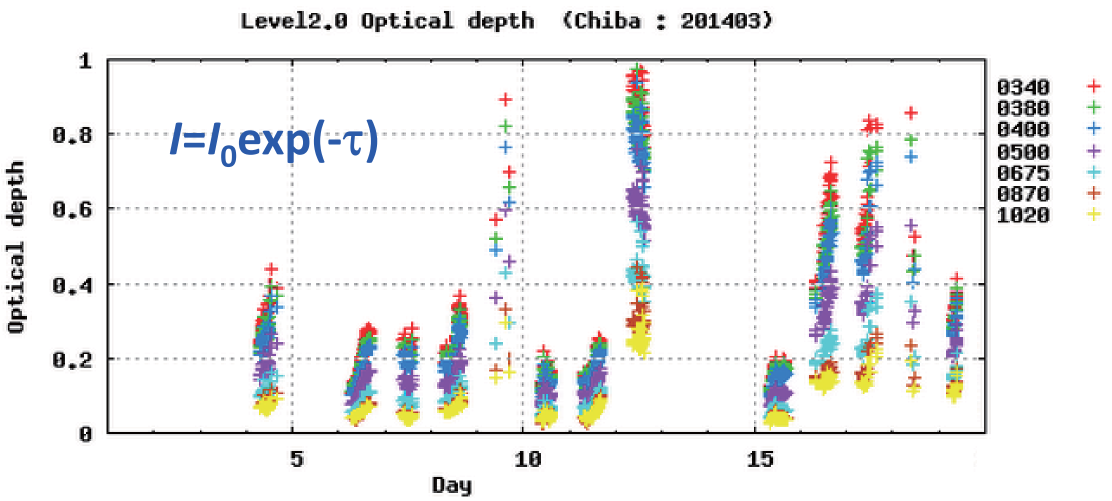
1. Introduction

➢ Spectral radiance observed with a satellite sensor is composed of a number of contributions from both ground reflection and atmospheric scattering.



Variation of aerosol optical thickness (AOT)

➢ The difficulty in analyzing satellite imagery comes from the variability of aerosol, liquid or solid particles floating in the atmosphere.
➢ The change in AOT (τ) can be directly measured with a sunphotometer that observes the intensity of solar irradiance at several wavelength bands.



2. Theory　Optical thickness τ

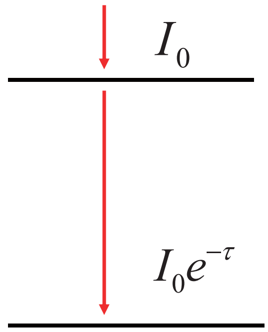
➢ Lambert-Beer's theory states that the change of light intensity (dI) is proportional to the product of I and dz:

Lambert-Beer's law

$$\frac{dI}{dz} = -\alpha I$$

constant α

$$I = TI_0 = I_0 e^{-\alpha z} = I_0 e^{-\tau}$$

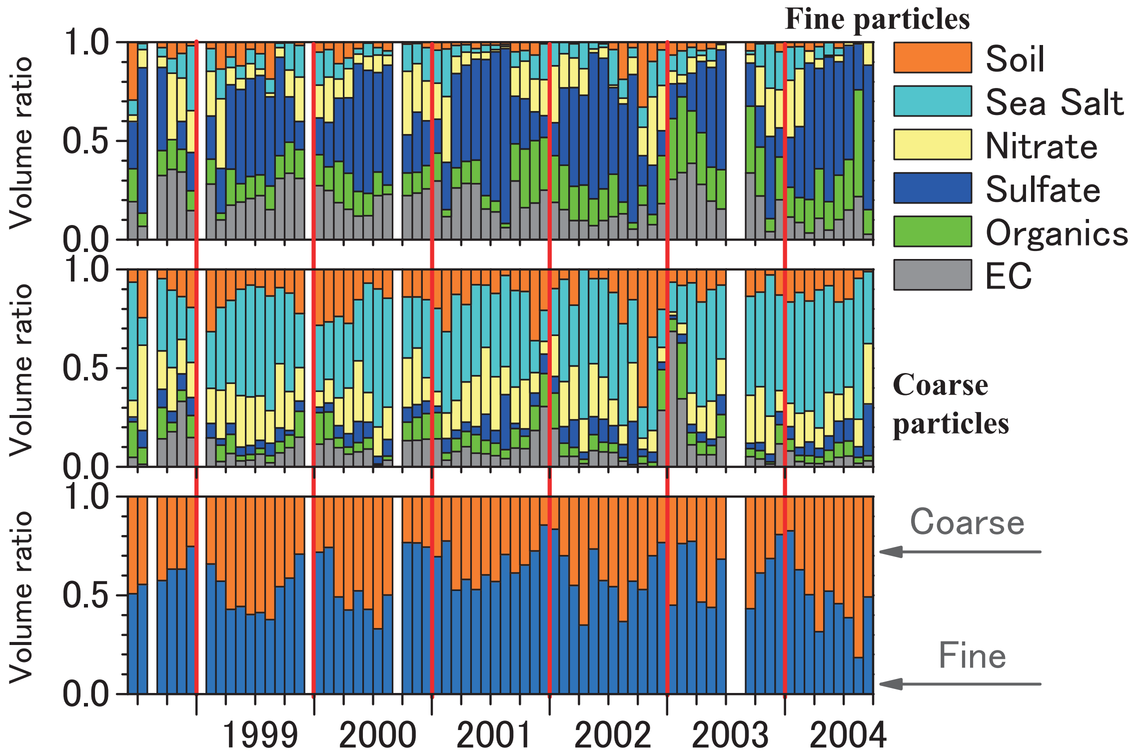


$\tau = \alpha z = (n\sigma) z$: optical thickness

($\tau = 1$ ➡ $I = 0.37 I_0$)

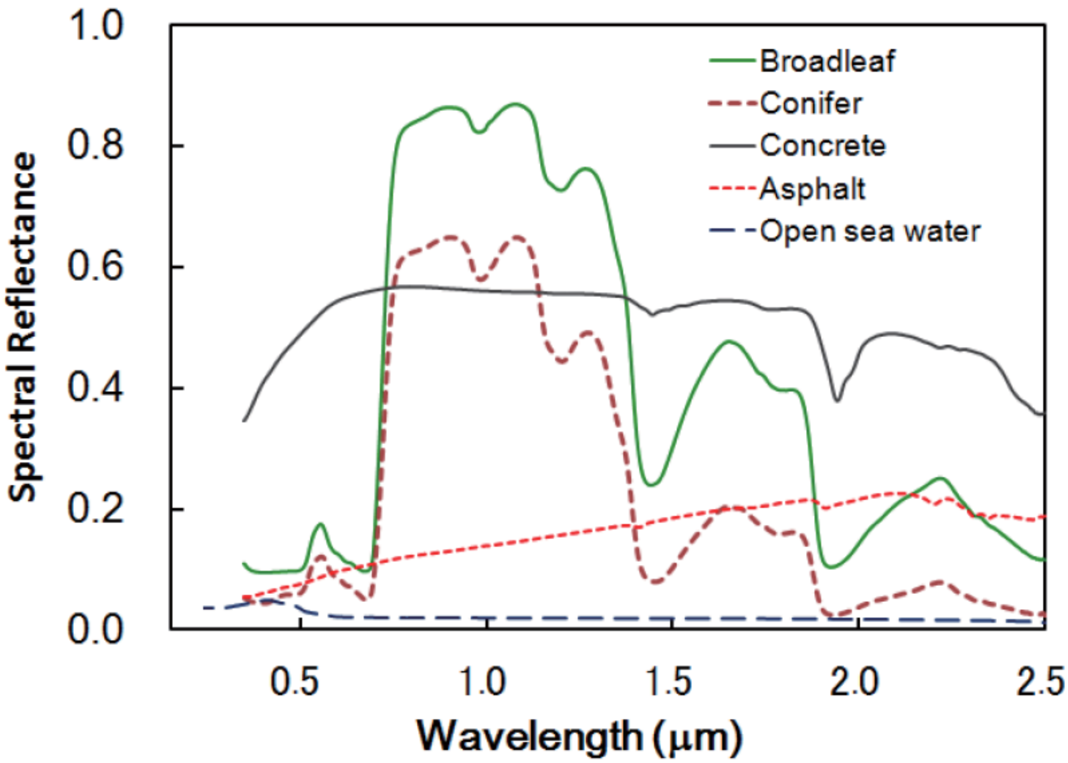
➢ Important aspect of AOT is that the value is proportional to the concentration and cross-section of the target particle.

Long-term aerosol analysis at Chiba University

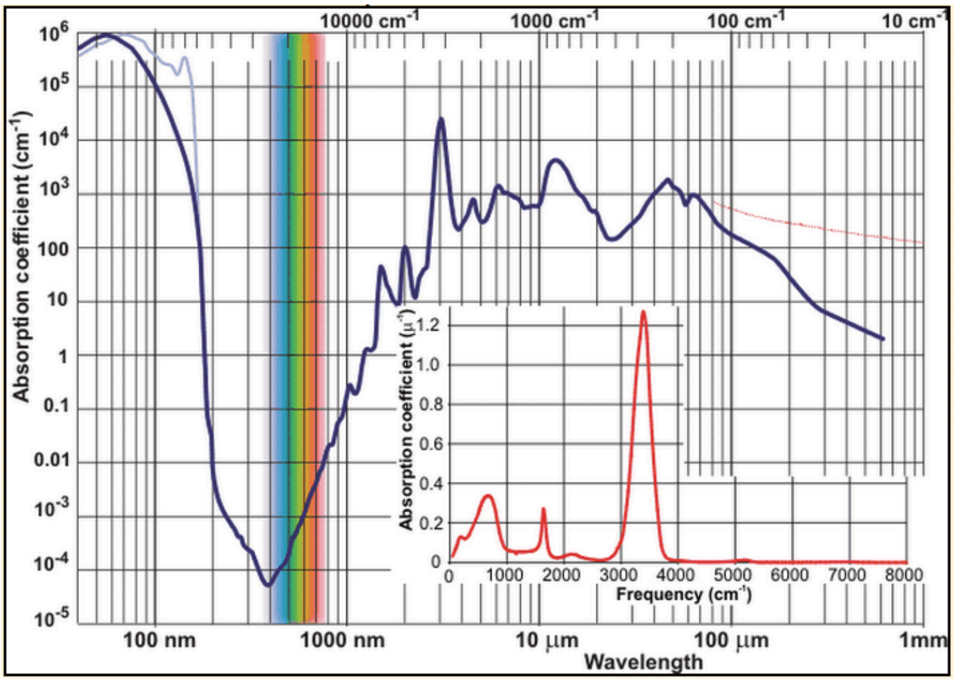


S. Fukagawa et al., Atmos.Environ., 40, 2160-2168 (2006)

Typical spectral reflectance



Absorption coefficient for water



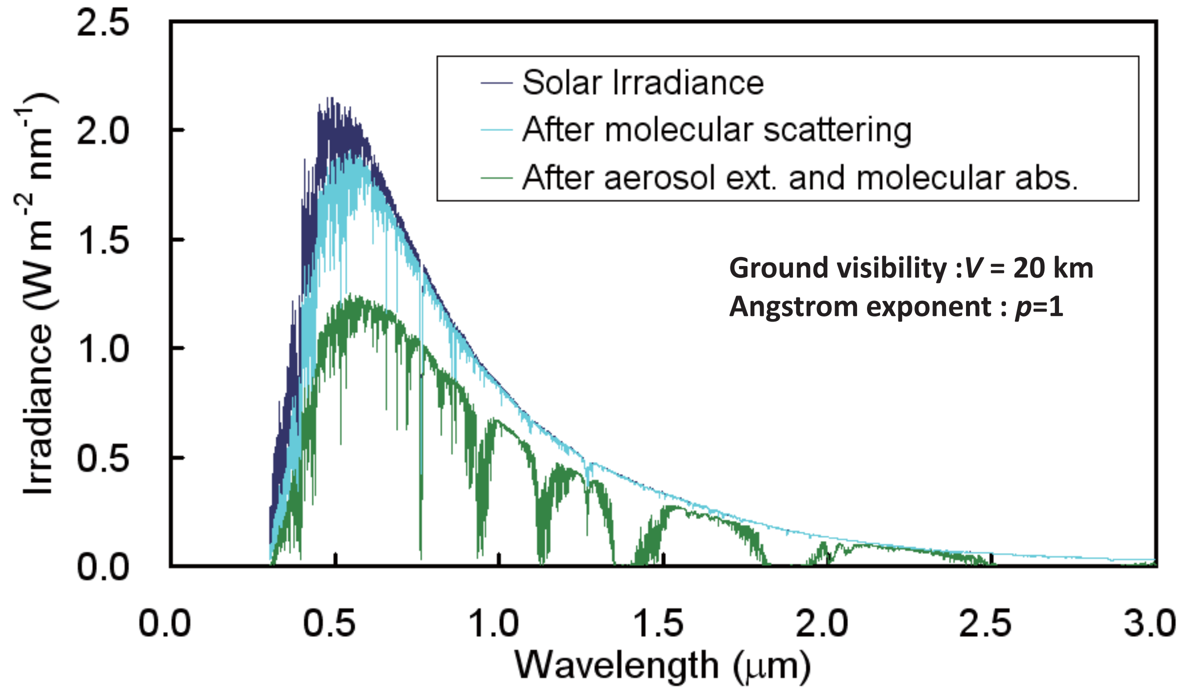
http://www.lsbu.ac.uk/water/vibrat.html

HDTV image of the Earth from Luna Orbiter

SELENE, November 7, 2007

http://www.jaxa.jp/press/2007/11/20071113_kaguya_j.html

Spectral Irradiance of solar radiation



Cross-section of Rayleigh scattering
- Scattering due to Air Molecules (N_2, O_2, Ar, ...)

$$\sigma_R(\lambda) = \frac{8\pi}{3}\left(\frac{\tilde{\alpha} k^2}{4\pi\varepsilon_0}\right)^2 = \frac{8\pi}{3}\left(\frac{\tilde{\alpha}}{4\pi\varepsilon_0}\cdot\frac{4\pi^2}{\lambda^2}\right)^2$$
$$= (4.30\times10^{-31})\left(\frac{550}{\lambda}\right)^4$$

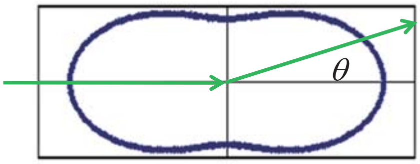
$k=2\pi/\lambda$ wavenumber

$\tilde{\alpha}$ molecular polarizability

At $\lambda = 550$ nm,

$$\frac{\tilde{\alpha}}{4\pi\varepsilon_0} = 1.7361\times10^{-30}\ [\mathrm{m}^3]$$

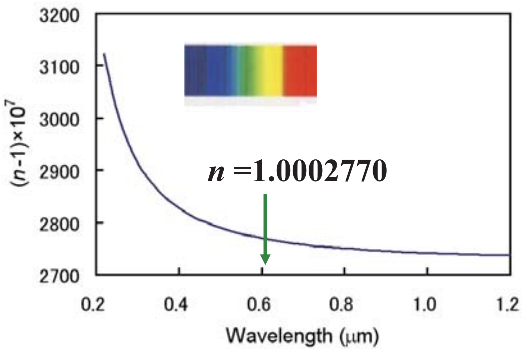
↑ 1.7120 @ 1064 nm



Polarizability and constant of refraction

Lorentz−Lorenz equation

$$\frac{\tilde{\alpha}}{4\pi\varepsilon_0} = \frac{n-1}{2\pi n_{15}}$$



$\tilde{\alpha}$: molecular polarizability

n_{15} : molecular number density at 15℃

Constant of refraction can be precisely determined as a function of wavelength and temperature

(values for air molecule)

n_{15}= 2.5469 ×10^{25} m^{-3}

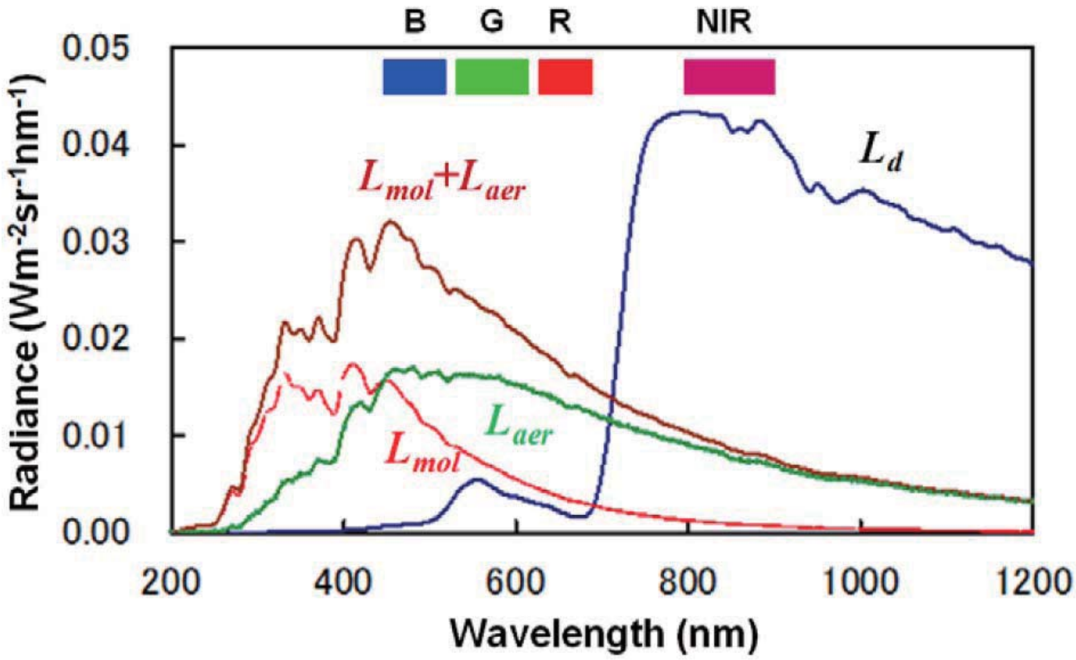
λ = 355 nm : $\tilde{\alpha}/(4\pi\varepsilon_0)$ = 1.7864 × 10^{-30} m^3

λ = 532 nm : $\tilde{\alpha}/(4\pi\varepsilon_0)$ = 1.7384 × 10^{-30} m^3

λ = 1064 nm: $\tilde{\alpha}/(4\pi\varepsilon_0)$ = 1.7120 × 10^{-30} m^3

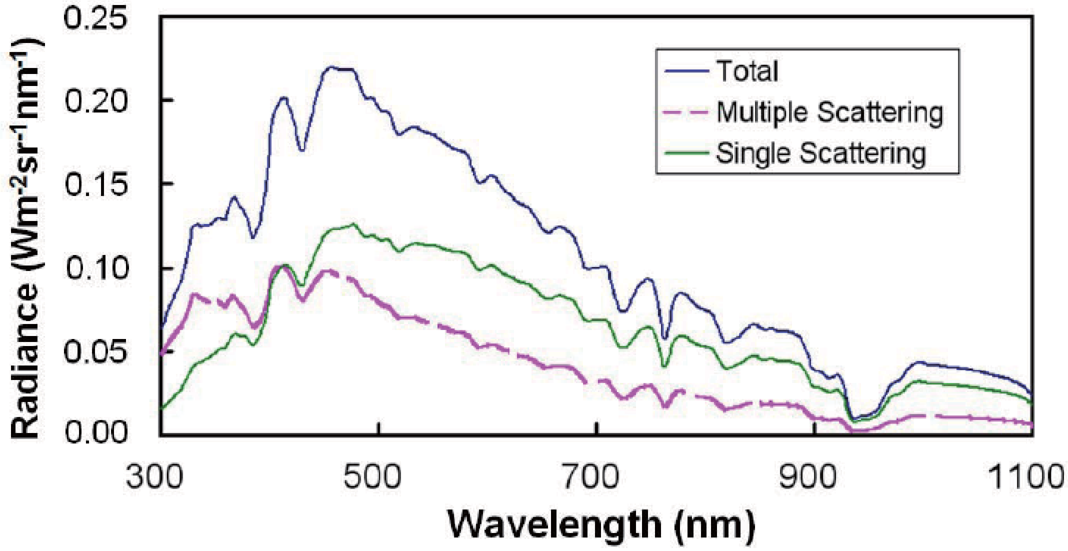
Lord Rayleigh
1842-1919

3. Results　Radiance simulated for satellite bands



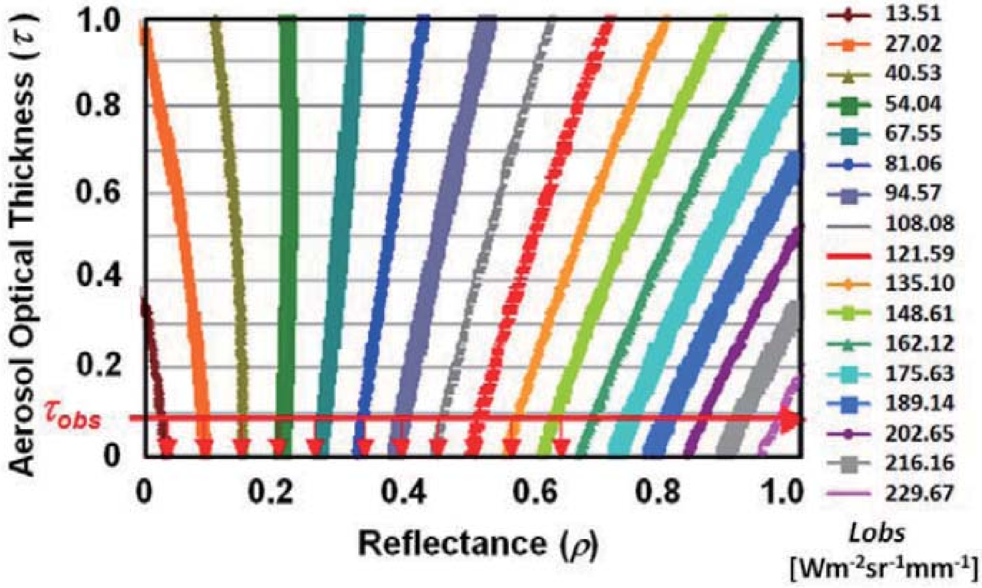
➢ **Radiance due to the scattering in the atmosphere ($L_{mol} + L_{aer}$) and radiance due to the surface reflection (L_d) are simulated assuming only the single scattering contributions.**

Effect of multiple scattering



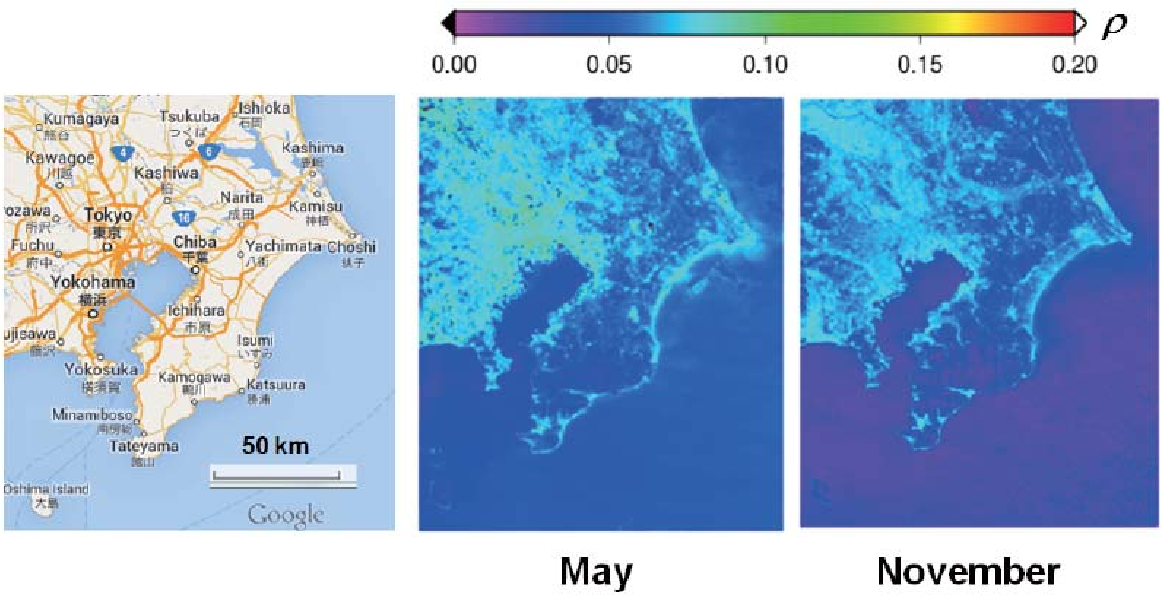
➢ **Simulation with the MODTRAN radiative transfer code with the following parameters; atmospheric model = midlatitude summer, aerosol model = maritime, ground visibility = 20 km, solar zenith angle =20 deg, view zenith angle = 60 deg, view azimuth = same as the solar azimuth.**

Relationship between the surface reflectance (ρ) and aerosol optical thickness (τ)



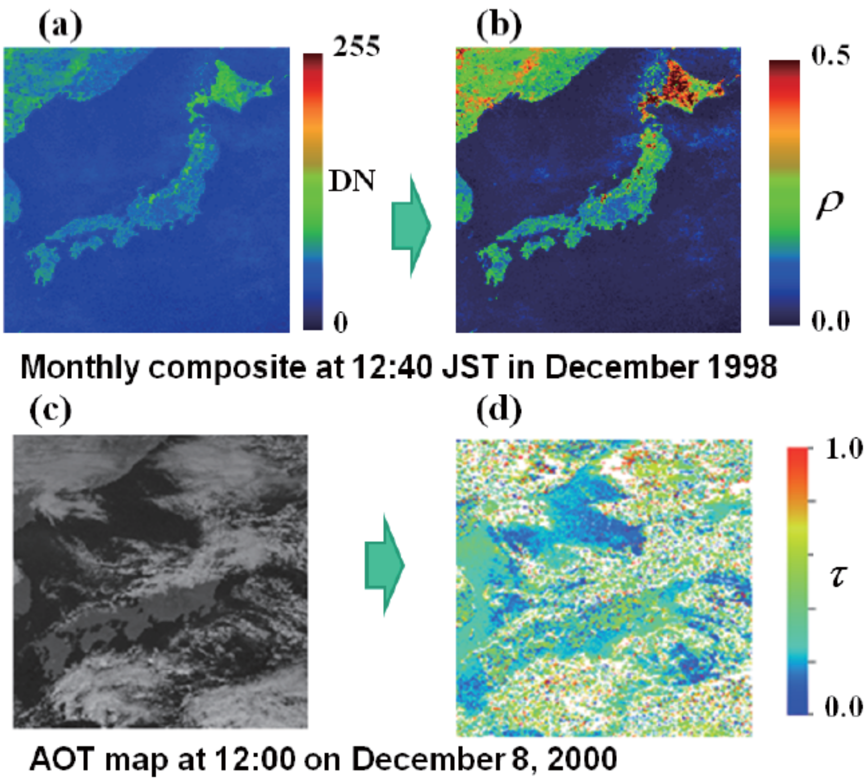
➢ Typical relationship between ρ and τ for various values of satellite observed radiance (L_{obs}) simulated for MODIS band 4 (540 - 560 nm). When τ is small, the surface reflectance can readily be estimated from the value of L_{obs}.

Monthly reflectance maps around Tokyo based on MODIS



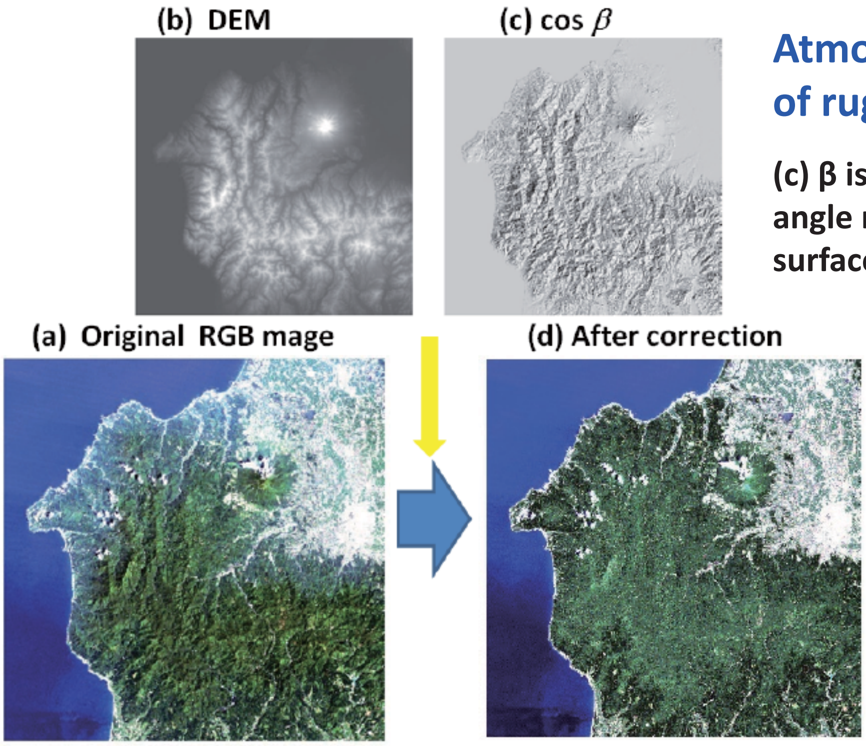
➢ The monthly reflectance maps are derived from MODIS band 4 (540 - 560 nm) during 2007-2009. Pertinent aerosol information was derived from ground-based spectroradiometer (EKO, MS-720) observation at Chiba University.

Separation of surface reflectance and aerosol information from GMS 5 meteorological satellite data.



➢ Monthly composite approach was taken for deriving reflectance map, and the resulting surface information (reflectance distribution, ρ map) was employed for estimating the distribution of aerosol optical thickness (AOT, τ map).

Atmospheric correction of rugged terrain



(c) β is the solar incidence angle measured from the surface normal.

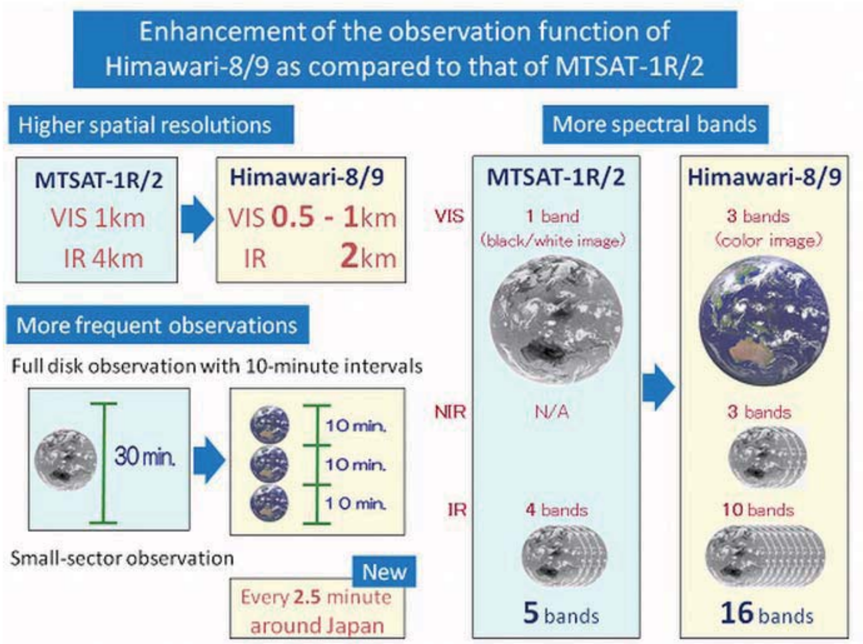
(d) The reflectance image after the topographic correction (terrain slope effect and illumination effect).

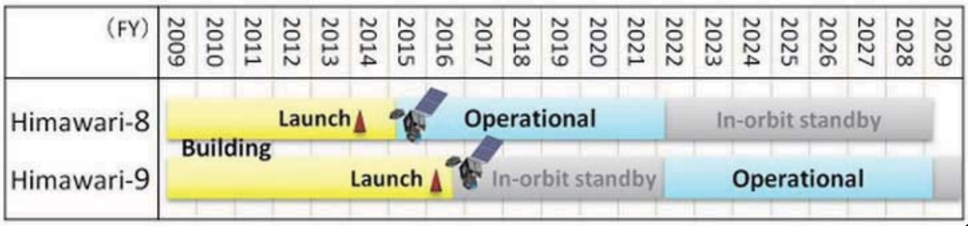
(a) Original image based on Landsat TM data taken on July 26, 1997. The area is in the northern part of main island (Honshu) in Japan, with a volcano Mt. Iwaki (1625 m).

Himawari 8 & 9 (JMA)

Advanced features:
➢ 500 m resolution
➢ observation every 10 min
➢ RGB bands, 16 bands in total

➢ To be operated from 2015





4. Conclusion

➢ This paper has described the spectral appearance of atmospheric radiance components in comparison with the spectral reflectance behavior of usually encountered surface coverage.

➢ For the case of relatively limited area coverage (< 100 km), the aerosol property observed with a ground-based instrument such as a compact spectroradiometer can fully be utilized to implement precise evaluation of the atmospheric effects.

➢ For the case of wider area coverage (~ 1000 km), as exemplified in the case of GMS-5 data, the monthly composite approach is effective for obtaining clear (low AOT) images with limited influence of atmospheric effects. The resulting reflectance map (ρ-map) can be exploited for deriving the AOT distribution map (τ-map) for turbid images.

➢ We have also discussed the implementation of atmospheric correction over rugged areas, taking the detailed topographic information into account.