# GEMS Cloud Algorithm Development: Preliminary Results and Remaining Issues

Yong-Sang Choi[1], Bo-Ram Kim[1], Heeje Cho[2],
Myoung Hwan Ahn[1], and Jhoon Kim[3]
[1]Ewha Womans University, Seoul, Korea
[2]Seoul National University, Seoul, Korea
[3]Yonsei University, Seoul, Korea

Acknowledgement:
Drs. P.K. Bhartia, C. Ahn, D. Haffner, etc. (SSAI/GSFC, NASA)
Dr. Piet Stammes (KNMI)

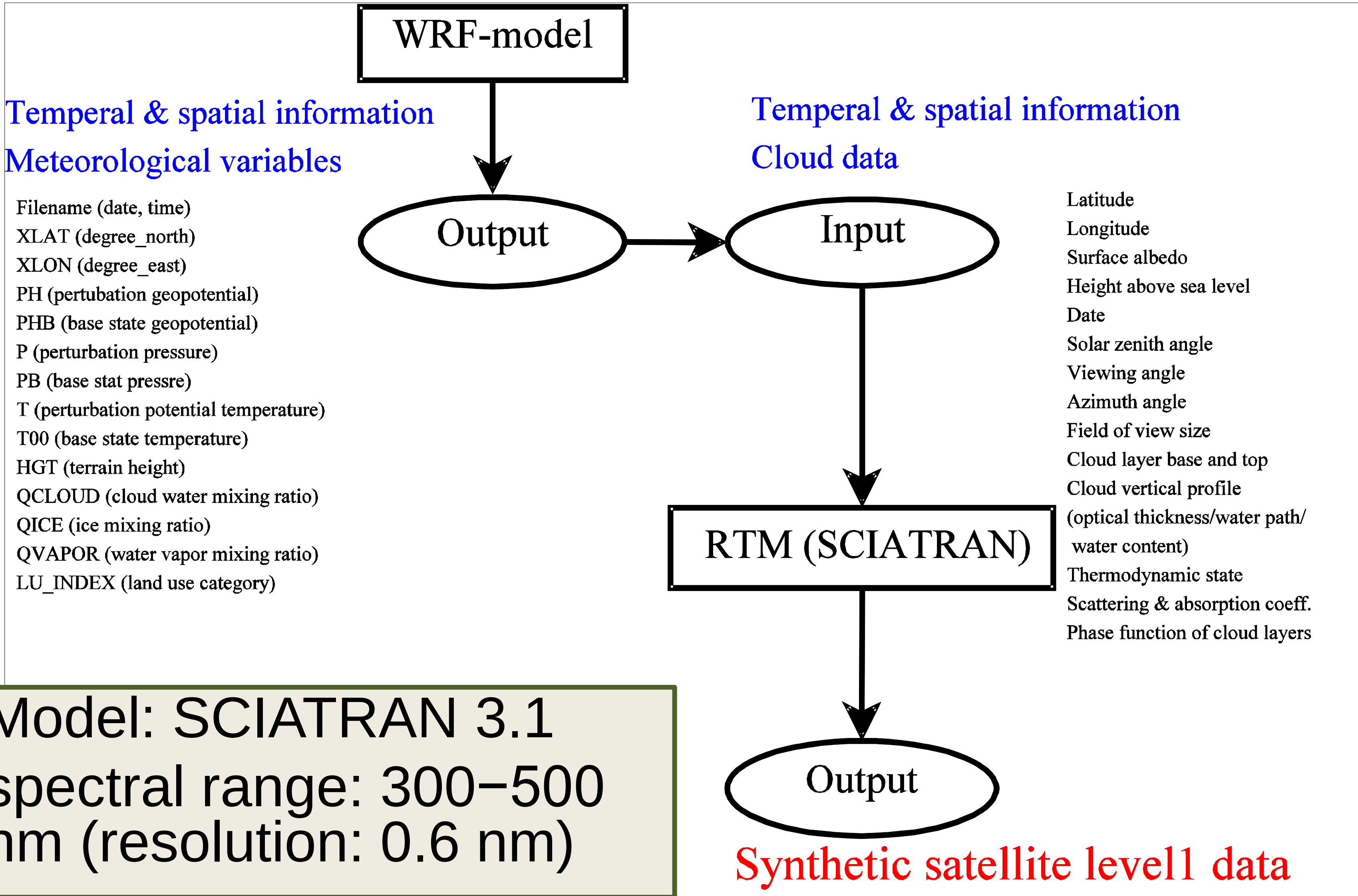
# Preliminary Results

# Introduction to cloud products

- Cloud radiative fraction
  - via effective cloud fraction (Mixed Lambertian Equivalent Reflector, MLER)
  - via geometrical cloud fraction (Mie Scattering Reflector)

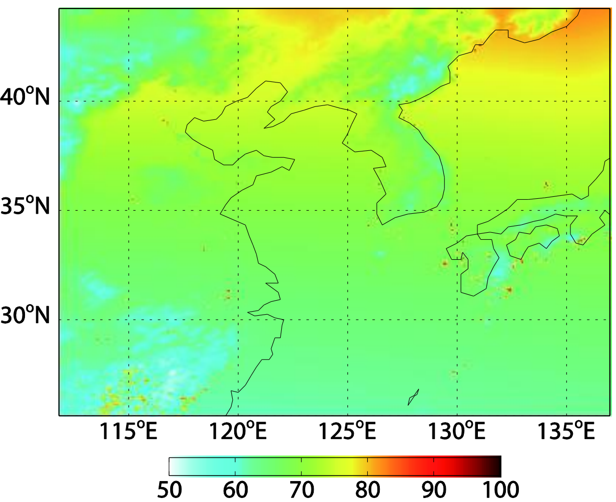
- Cloud pressure
  - UV cloud pressure ($O_2$-$O_2$ absorption band)
  - UV cloud pressure (UV-Visible bands; OMI and SCIAMACHY; Vasilkov et al., 2004)
  - IR climatological cloud-top pressure (TOMS)

# Synthetic data simulation



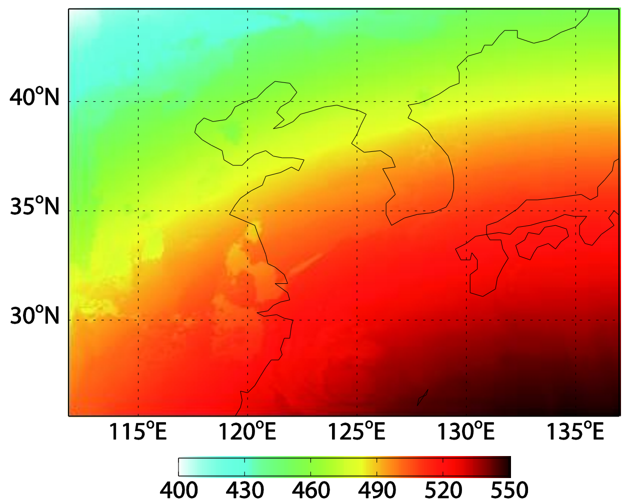

Model: SCIATRAN 3.1
spectral range: 300−500 nm (resolution: 0.6 nm)

# Simulated synthetic radiances w/ WRF cloud (true) & effective cloud fraction



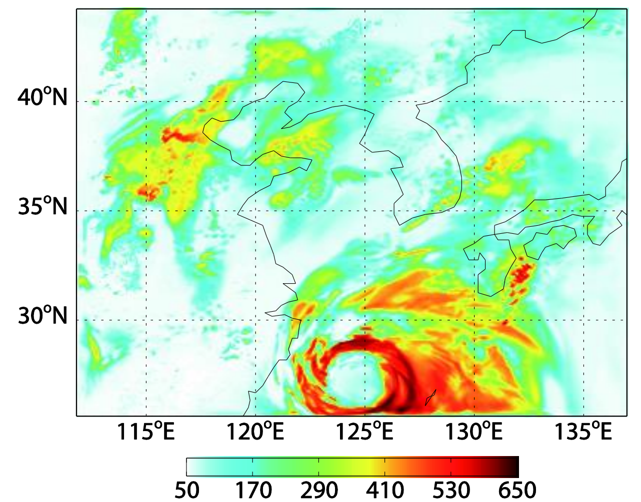

$$I_s$$

Clear-sky radiance




$$I_c^*$$

Overcast radiance assuming Lambertian reflector ($A_c = 0.8$)

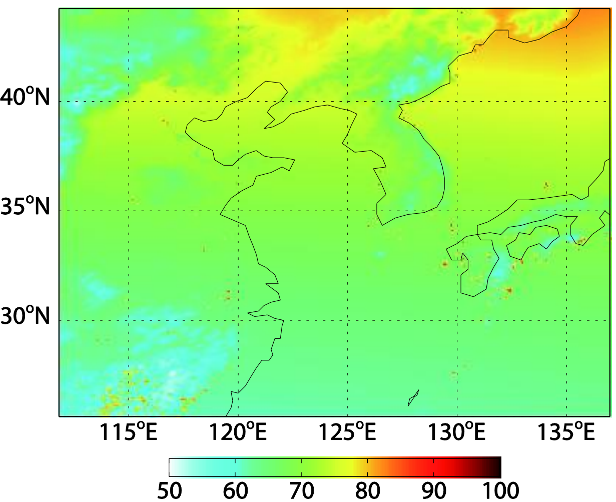



$$I$$

Measured radiance

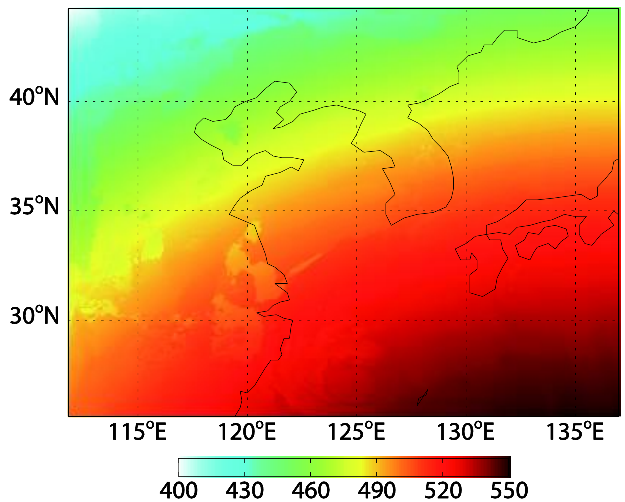
$$f_c = \frac{I - I_s}{I_c^* - I_s}$$

# Simulated synthetic radiances w/ WRF cloud (true) & effective cloud fraction



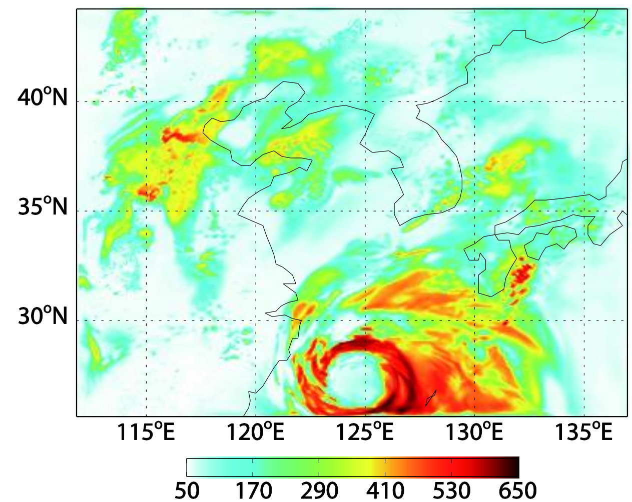

$I_s$

Clear-sky radiance

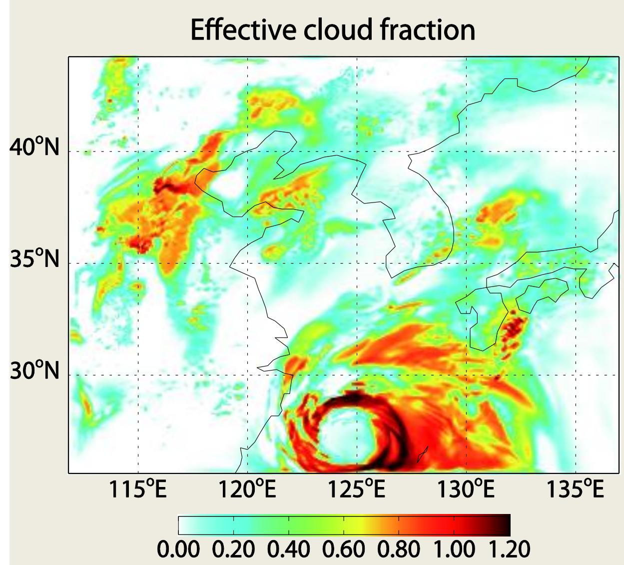



$I_c^*$

Overcast radiance assuming Lambertian reflector ($A_c$ = 0.8)




$$f_c = \frac{I - I_s}{I_c^* - I_s}$$



# The difference between effective cloud fraction and cloud radiative fraction

If S is the slant column of a trace gas

$$S = \int n(z) m(z) dz$$

$$m(z) = \frac{d \ln I}{d\tau(z)}; \quad \tau(z) = \sigma(z) n(z)$$

where, n is trace gas density, $\sigma$ is abs cross-section, and m is the differential airmass factor

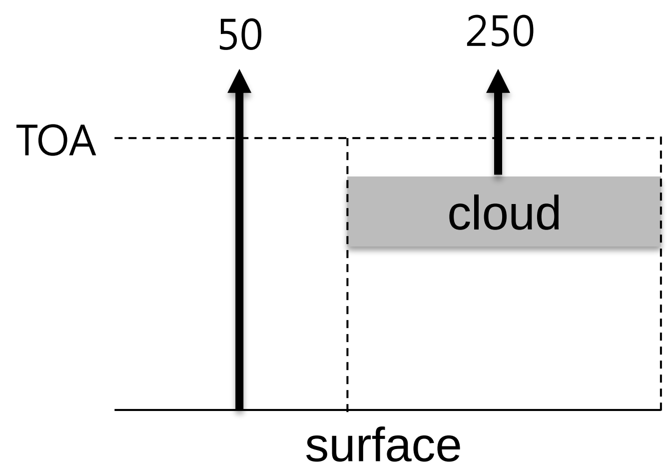
for MLER:

$$I = I_s (1 - f_c) + I_c^*(R_c = 0.8) f_c \Rightarrow f_c = \frac{(I - I_s)}{(I_c^* - I_s)}$$

$$m(z) = m_s(R_s)(1 - f_R) + m_c(R_c = 0.8) f_R \Rightarrow f_R = f_c \frac{I_c^*}{I}$$

where $R_s$ is surface reflectance, and $f_R$ is cloud radiative fraction

$$f_R = \frac{250}{50 + 250}$$




from Dr. P. K. Bhartia

For Mie:

$$I = I_s(1 - f_g) + I_c(\tau_c) f_g$$

$$m(z) = m_s(R_s)(1 - f_R) + m_c(\tau_c) f_R$$

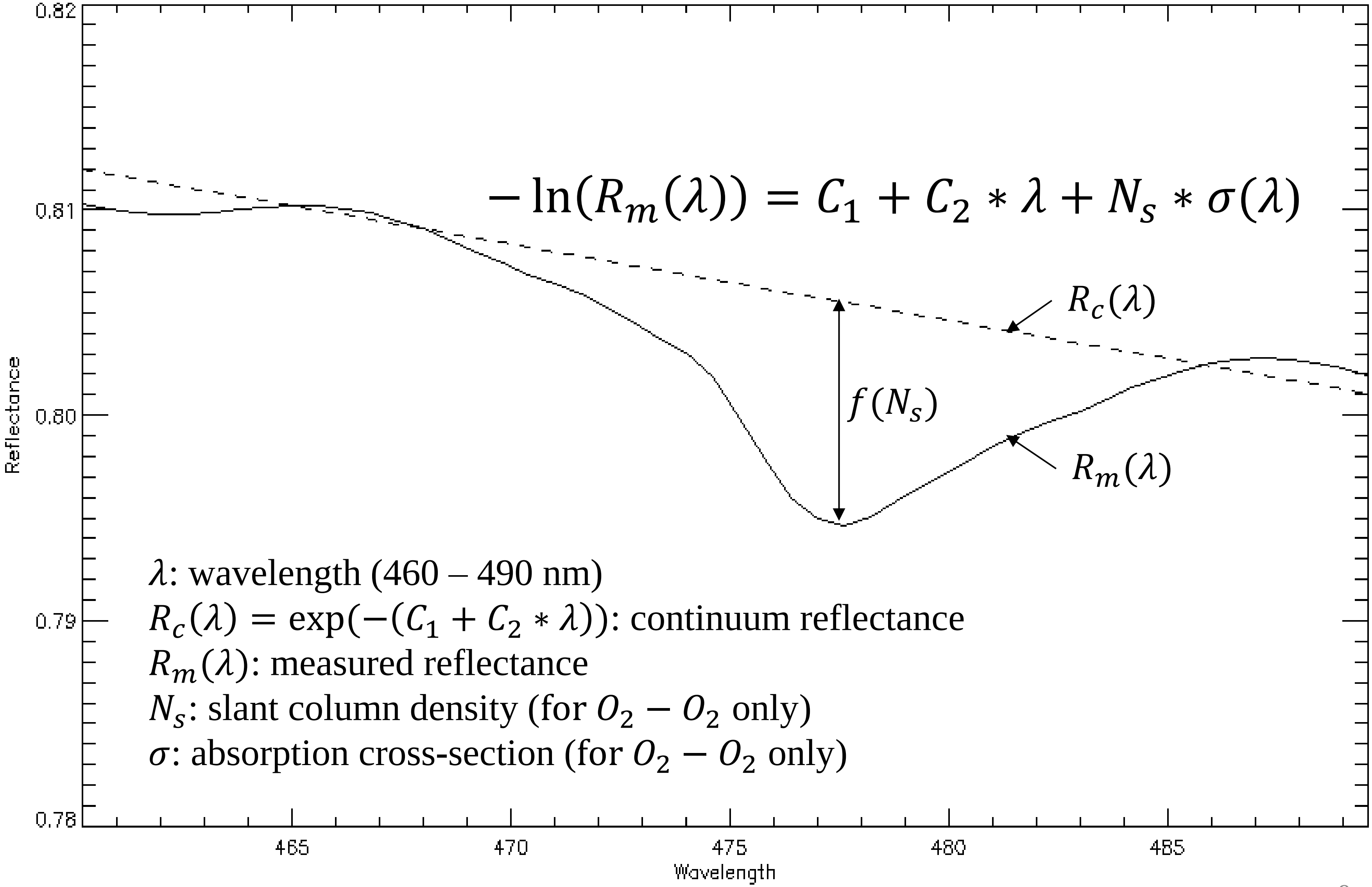
$$f_R = f_g \frac{I_c}{I}$$

where, $f_g$ is geometrical cloud fraction, and $\tau_c$ is cloud optical thickness

Note that IR/VIS cloud algorithms are retrieving this $f_g$ and $\tau_c$.

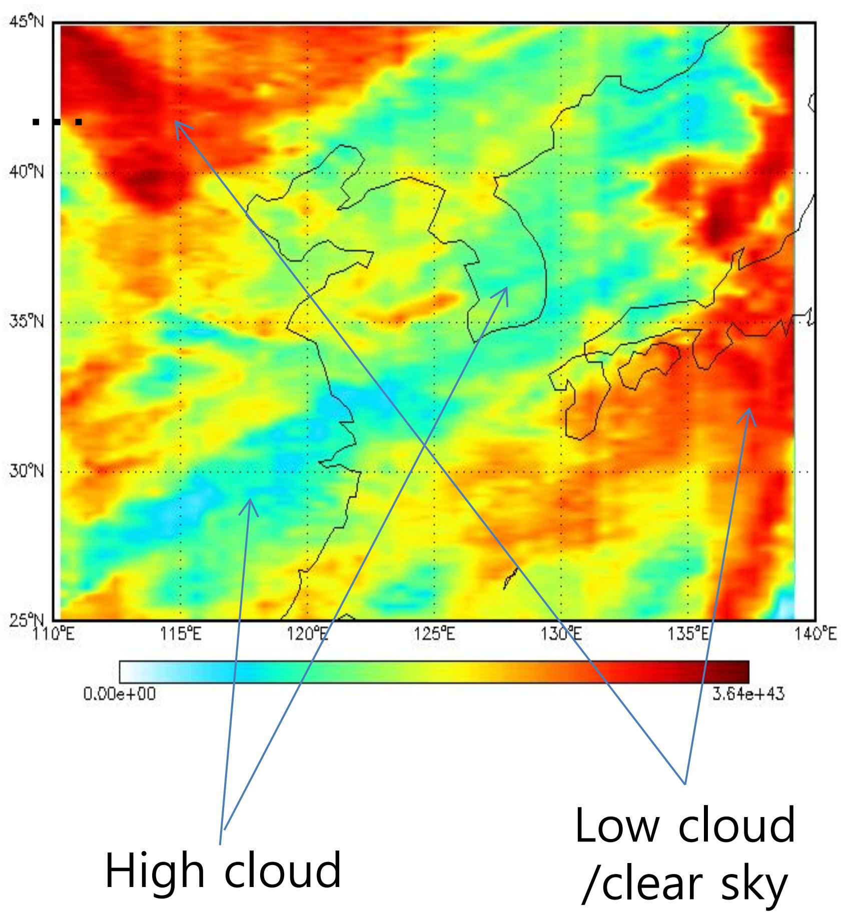
from Dr. P. K. Bhartia

# Concept of cloud pressure retrieval

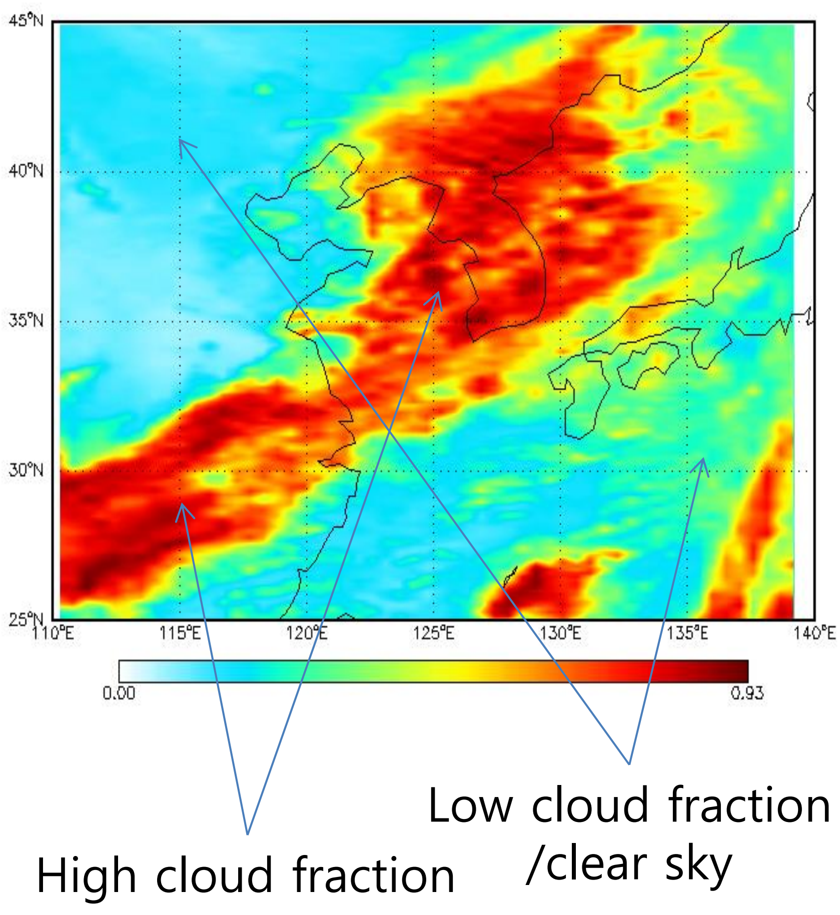


# Preliminary results from the GEMS prototype algorithm (input: OMI L1b)

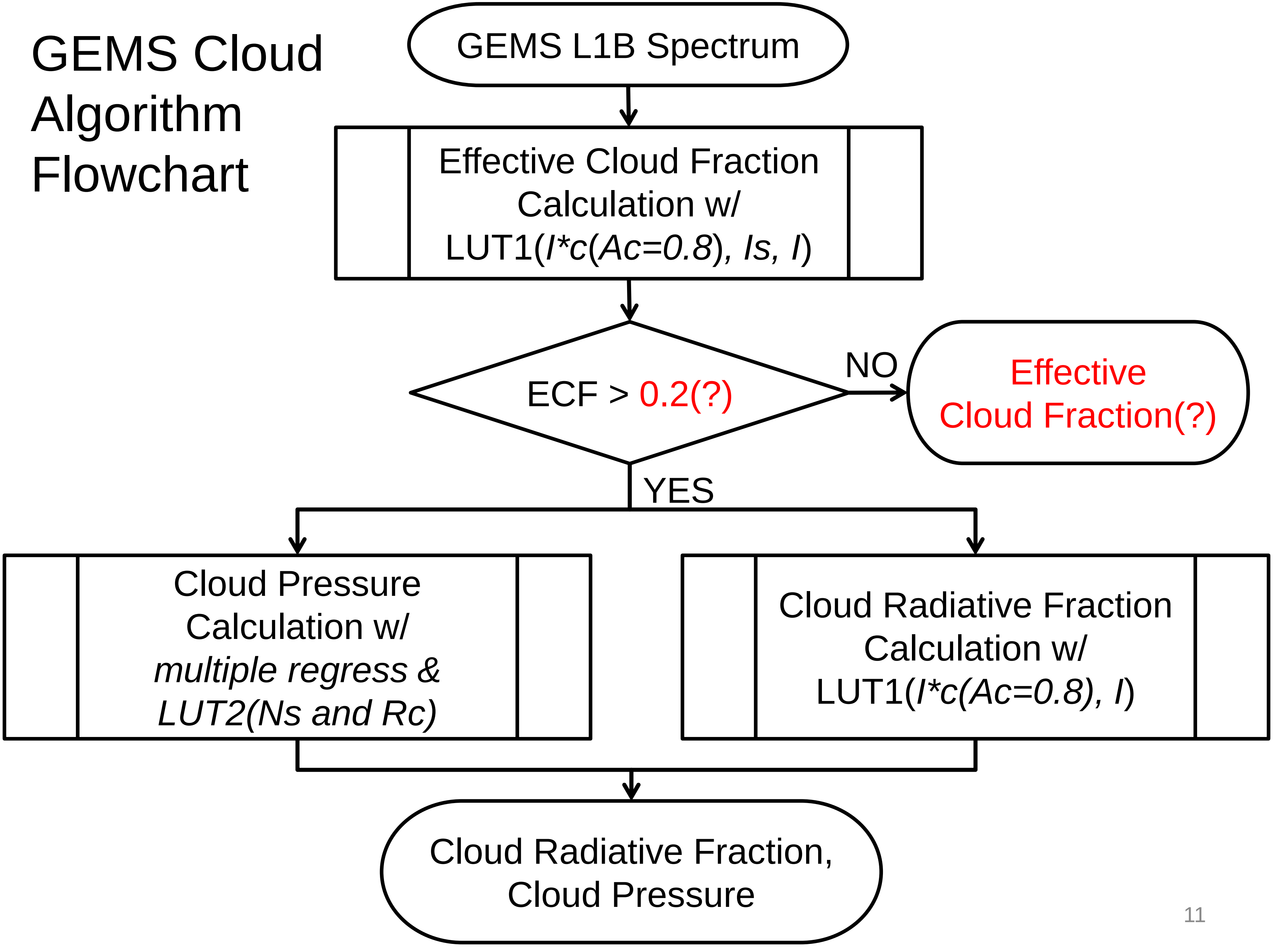
**Slant column density**




**Continuum reflectance**



# GEMS Cloud Algorithm Flowchart



# Look-up table constitution

## VLIDORT inputs for cloud radiative fraction retrieval

| Variables | Values |
|---|---|
| Solar zenith angle | 0°, 30°, 60°, 81° |
| Viewing zenith angle | 0°, 40°, 70° |
| Relative azimuth angle | 0°, 90°, 180° |
| Surface pressure | 1013, 950, 850 hPa |
| Surface reflectance | 0.05, 0.1, 0.2 |
| Cloud fraction | 0, 0.1, 0.2, 0.4, 0.7, 1.0 |

**VLIDORT calculation**

LUT1

**Radiances (I, Is, I*c)**
**(at which wavelength?)**

## VLIDORTs for cloud pressure retrieval

| Variables | Values |
|---|---|
| Solar zenith angle | 0°, 30°, 60°, 81° |
| Viewing zenith angle | 0°, 40°, 70° |
| Relative azimuth angle | 0°, 90°, 180° |
| Surface pressure | 1013, 950, 850 hPa |
| Surface reflectance | 0.05, 0.1, 0.2 |
| Cloud pressure | 800, 600, 350 hPa |
| Cloud fraction | 0, 0.1, 0.2, 0.4, 0.7, 1.0 |

**VLIDORT calculation**

LUT2

**Slant column density (Ns)**

**Continuum Reflectance (Rc)**

# Remaining issues

(also for cloud breakout session on Thursday)

# Issue: Cloud algorithm refinement

- Cloud radiative fraction:
  - at which wavelength? or assume independence of $\lambda$?
  - need additionally cloud mask?

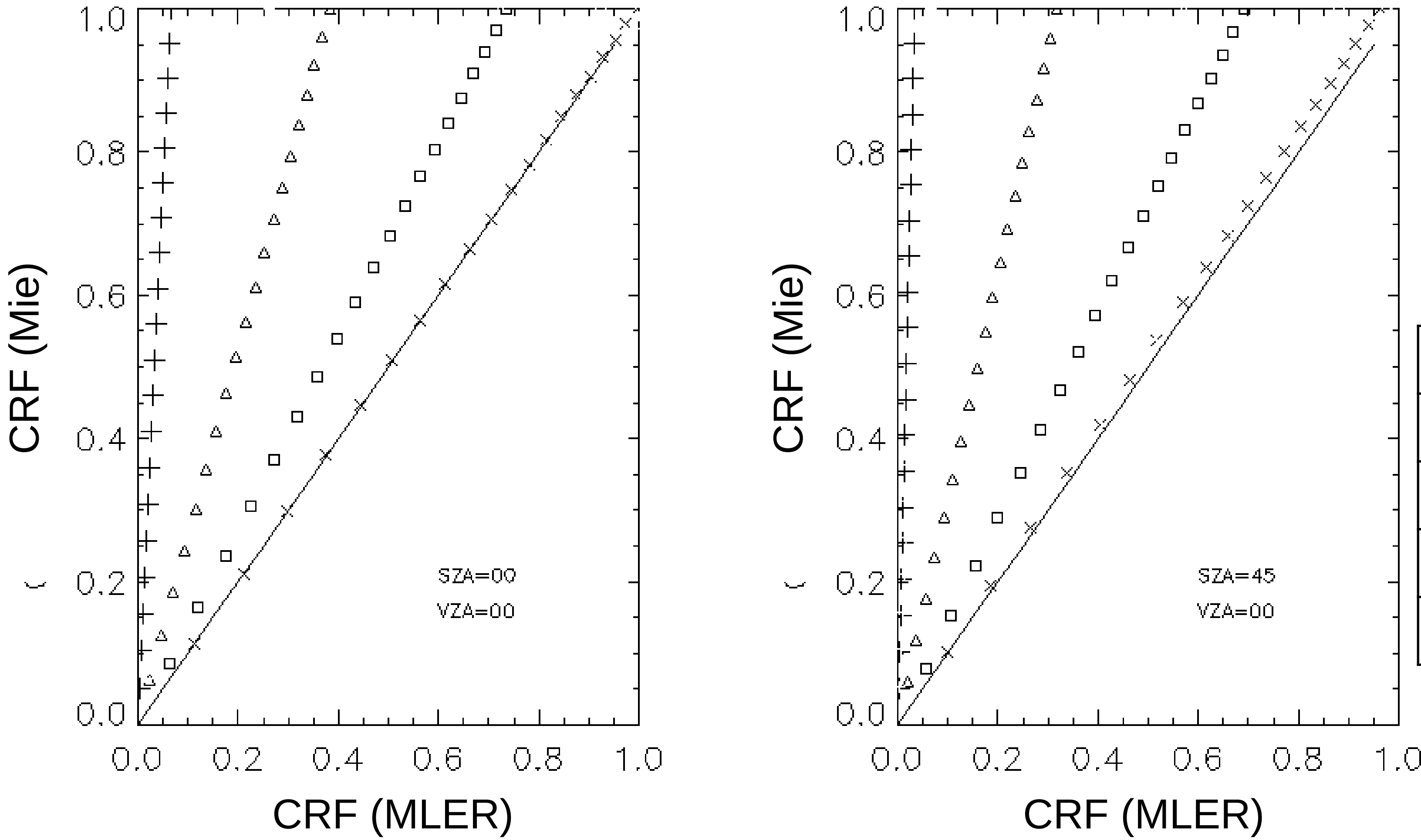
- Cloud pressure:
  - The method to obtain slant column density
    - *Multiple regression*
    - DOAS fitting
    - Iterative minimum variance procedure
    - Direct fitting
    - Or any idea?

# Issue: Impact assessments on gases or cloud retrievals

- To what extent, the errors in cloud retrievals have effects on gas/aerosol retrievals?
  - Theoretical tests for the validity of gas/aerosol retrievals over cloudy regions

- To what extent, the errors in the cloud algorithm inputs have effects on cloud retrievals per se?
  - Surface reflectance
  - $O_3$, and aerosol profiles in forward simulations

# Issue: Choosing cloud model to define cloud fraction



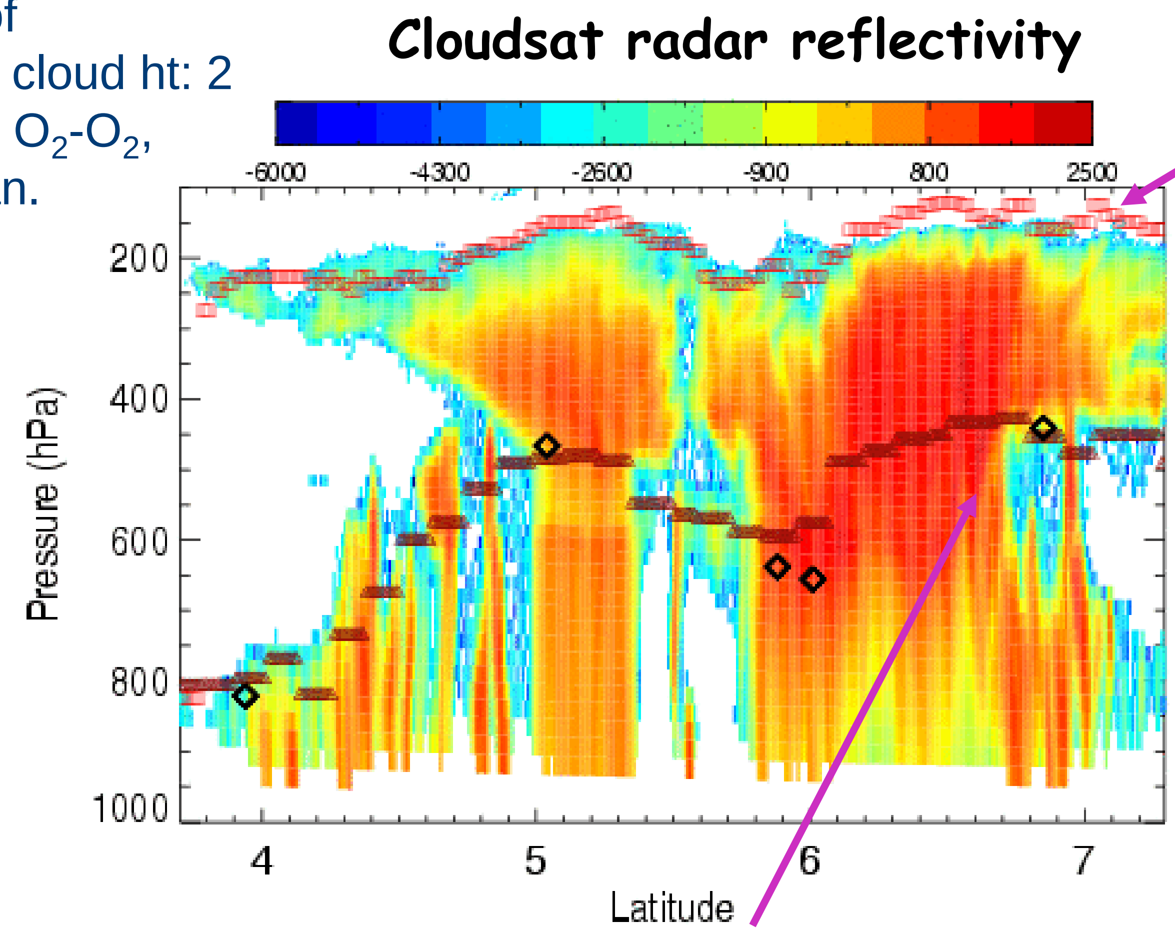

| | τ |
|---|---|
| + | 0.3 |
| △ | 3.0 |
| □ | 10 |
| X | 30 |

# Issue: Combination with ABI/GK-2A

- IR/VIS cloud fraction
  - may be used as “geometrical" cloud fraction, in a similar way to Mie cloud model (Independent pixel approximation).
- IR/VIS Cloud top pressure (?)
  - probably looking at different cloud level.
- Temporal & spatial inconsistency
  - just few minute difference can cause large bias in cloud parameters
- Wavelength dependence

# Multi-phase Cloud Effects

There are 5 different methods of estimating cloud ht: 2 TIR, $O_2$-A, $O_2$-$O_2$, and Raman.




MODIS cloud-top press is insensitive to cloud vertical structure

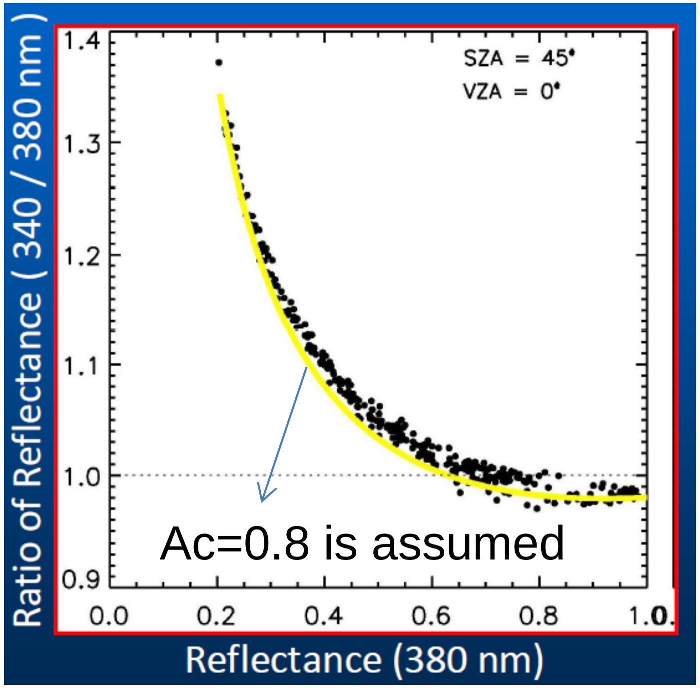
Cloud Optical Centroid press calculated using OMI-measured Rot Raman Scattering is sensitive to cloud vert structure (ref : Vasilkov *et al*.,JGR, ’08)

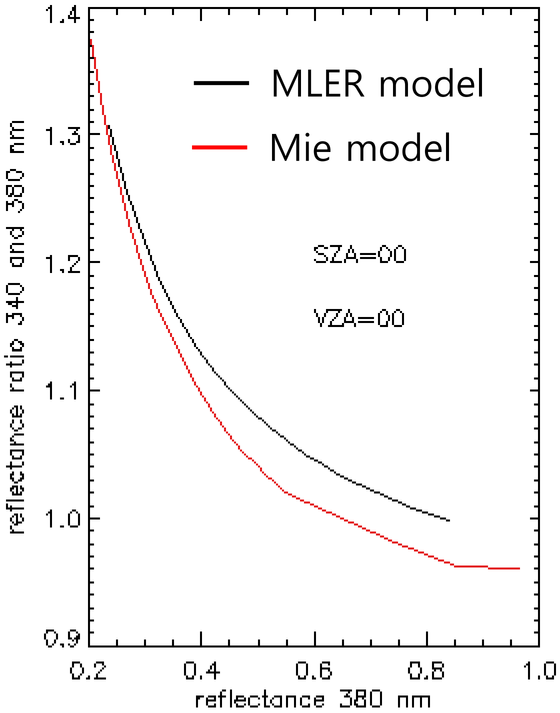
# Thank you

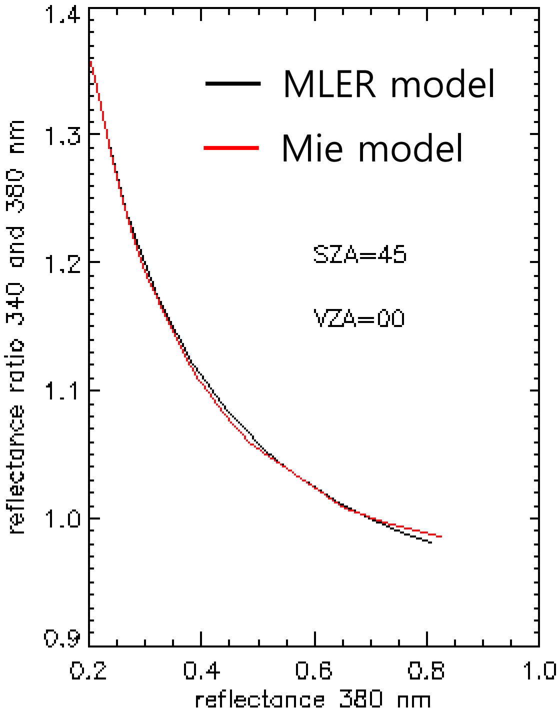
# Appendices

# Issue: Choosing cloud model to define cloud fraction

TOMS ATBD




The dependence of R(340 nm)/R(380 nm) on R(380 nm) may agree between cloud models at certain geometry (SZA=45°, VZA=0°), but may not agree elsewhere.

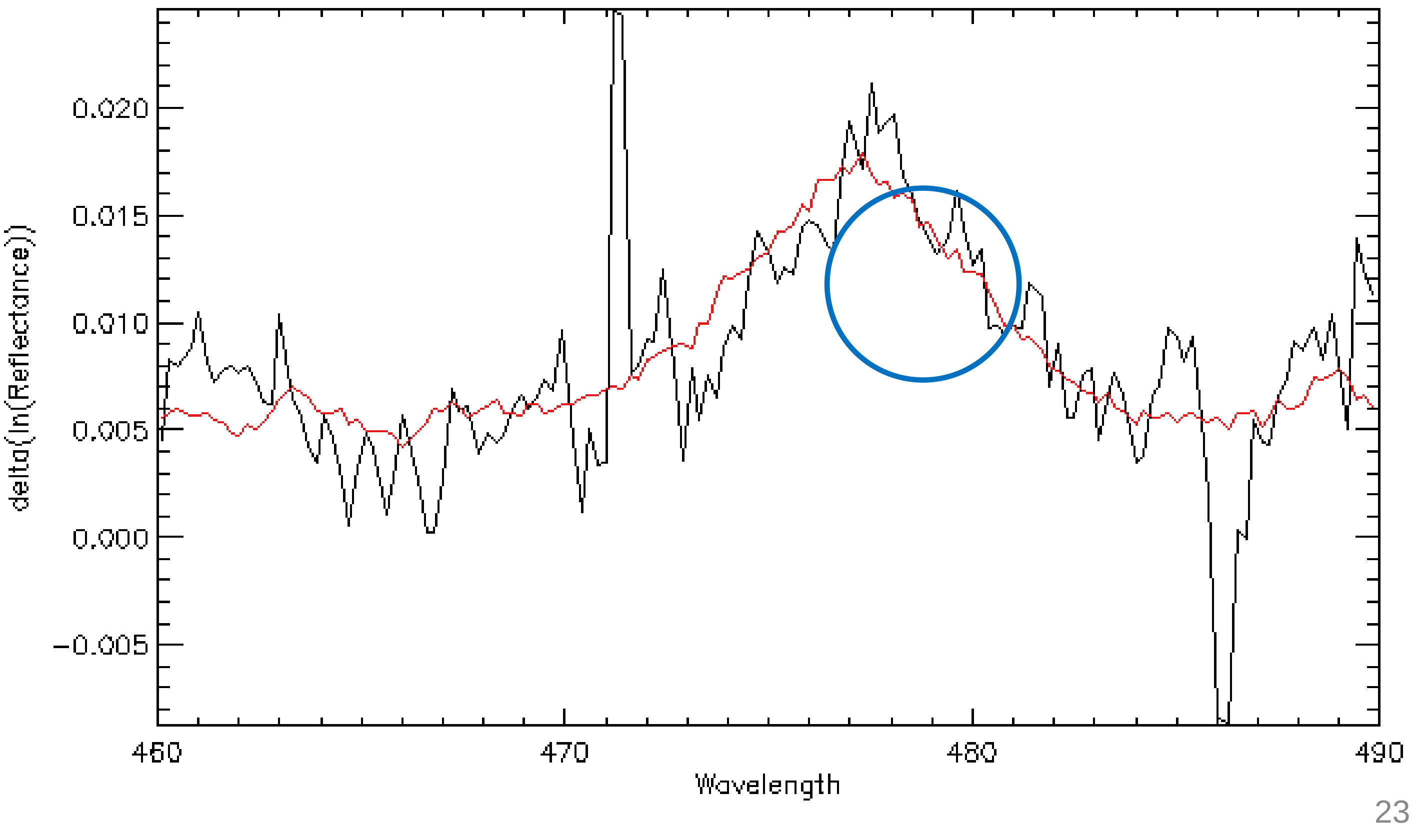
# Multiple regression

$$-\ln(R_\lambda) = C_1 + C_2 * \lambda + N_{s,O_2-O_2} * \sigma_{O_2-O_2} + N_{s,O_3} * \sigma_{O_3} + N_{s,NO_2} * \sigma_{O_2-O_2}$$

| | $C_1$ | $C_2$ | $N_{s,O_2-O_2}$ | $N_{s,O_3}$ | $N_{s,NO_2}$ | $\overline{(y-\hat{y})^2}$ |
|---|---|---|---|---|---|---|
| Only O2-O2 | -0.15 | 0.44E-02 | 1.88E43 | - | - | 1.37E-05 |
| O2 and O3 | -0.10 | 0.43E-02 | 2.00E43 | 3.10E17 | - | 1.36E-05 |
| O2 and NO2 | -0.17 | 0.44E-02 | 1.85E43 | - | 9.78E15 | 1.33E-05 |
| All | -0.14 | 0.44E-02 | 1.96E43 | 2.71E17 | 9.35E15 | 1.32E-05 |

# Multiple regression

- Black: [OMI L1B] − [retrieved continuum: $C_1 + C_2 * \lambda$]
- Red: [Linear fitting] − [retrieved continuum]
- Blue circle is the O2-O2 absorption band.



# Cloud models

| Cloud model | Assumption | Definition | |
|---|---|---|---|
| LER | Lambertian reflector | $I_m = I_a + \frac{R * T}{1.0 - Sb * R}$ | |
| MLER | Cloud, Lambertian reflector albedo = 0.8 | $I_m = I_s(R_s, p_s) * (1 - f_c) + I_c(R_c, p_c) * f_c$ | Recommended for operational retrieval |
| C1 cloud | Cloud cover =1, Mie scattering cloud | $I_m = I_c(\tau_c)$ | |
| C1 cloud, IPA | Mie scattering cloud | $I_m = I_s(1 - f_g) + I_c(\tau_c) f_g$ | Recommended for error estimation |
| Isotropic cloud | Cloud as isotropic surface | - | Make up for weakness of MLER concept |

# Cloud model (LER)

- Lambertian Equivalent Reflectivity (LER) as:

$$I_m = I_a + \frac{R * T}{1.0 - Sb * R}$$

$I_m$: TOA radiance

$I_a$: Rayleigh scattering radiance

$T$: Transmittance

$Sb$: Spherical albedo

$R$: Lambertian equivalent scene reflectivity

# Cloud model (MLER)

- Mixed LER as:

$$I_m = I_s(R_s, p_s) * (1 - f_c) + I_c(R_c, p_c) * f_c$$

- This concept is used calculating effective cloud fraction.
- Weak point: no evidence of cloud albedo definition.

# Cloud model (IPA)

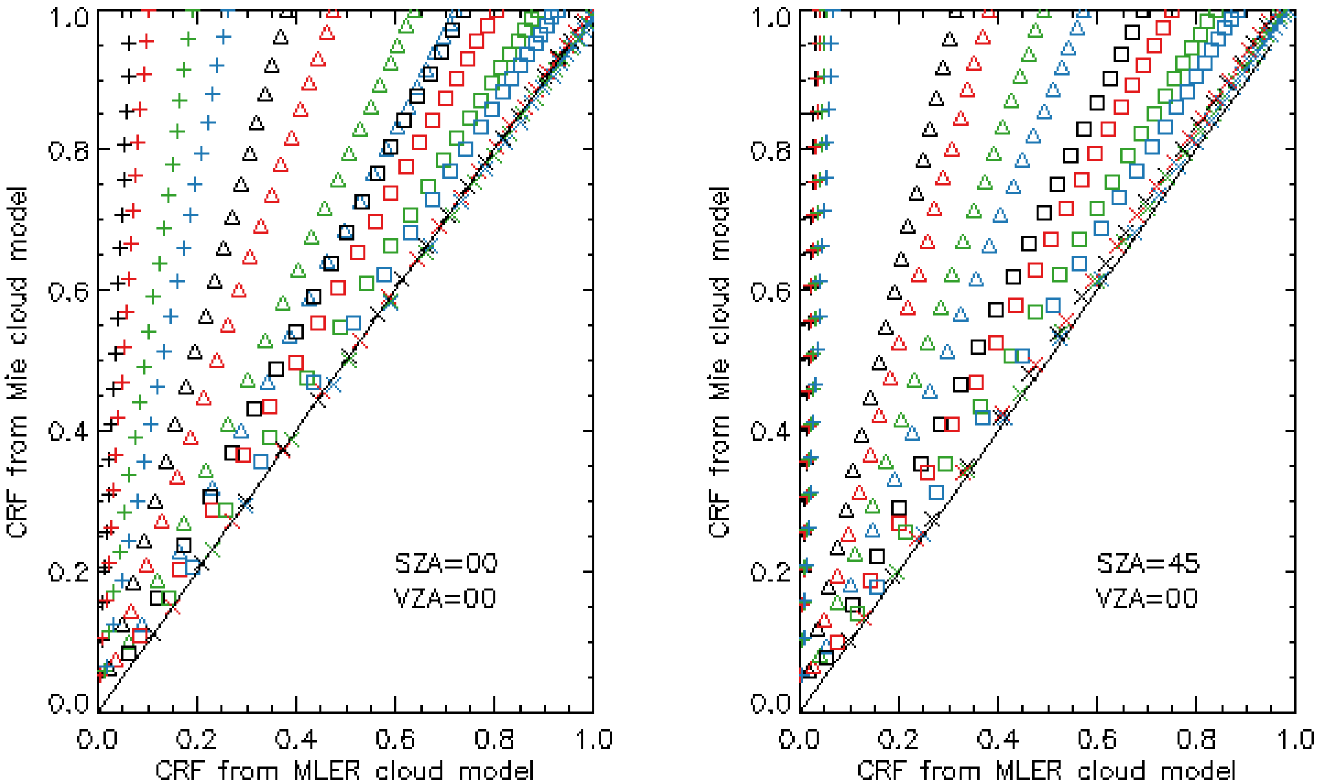
- Radiance is calculated in IPA cloud model:

$$I = I_s\left(1 - f_g\right) + I_c(\tau_c)f_g$$

- Mie cloud, independent pixel approximation (IPA) have similar concept with MLER, except Lambertian cloud in MLER is replaced with Mie cloud.
- Mie cloud involves cloud macro and micro physics parameters like cloud thermodynamic state and cloud size distribution.

# Cloud model study

- This figure shows cloud radiance fraction from different optical thickness and wavelength. In long wavelength, it has big discrepancy for optical thickness difference




| Symbol | TAU |
|---|---|
| + | 0.3 |
| △ | 3.0 |
| □ | 10 |
| X | 30 |

| Color | WL (nm) |
|---|---|
| Black | 320 |
| Red | 354 |
| Green | 420 |
| blue | 475 |