A new method to retrieve cirrus cloud height with MODIS/VIIRS observations

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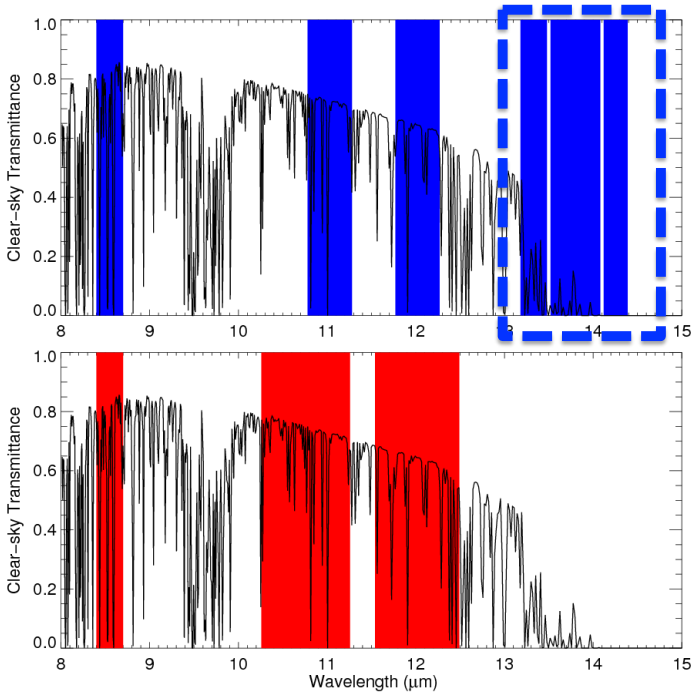
Outline

- **Motivation**
- **Review a traditional cloud height retrieval method: the CO_2 slicing**
- **A new cloud height retrieval method (1.38- and 1.24-μm)**
- **A case study with MODIS observations**
- **Summary and conclusions**

Motivation

Cloud top pressure/height algorithm for HIRS (on NOAA polar-orbiting platforms since ~1980) and MODIS based on absorbing channels within the 15-µm CO_2 band.



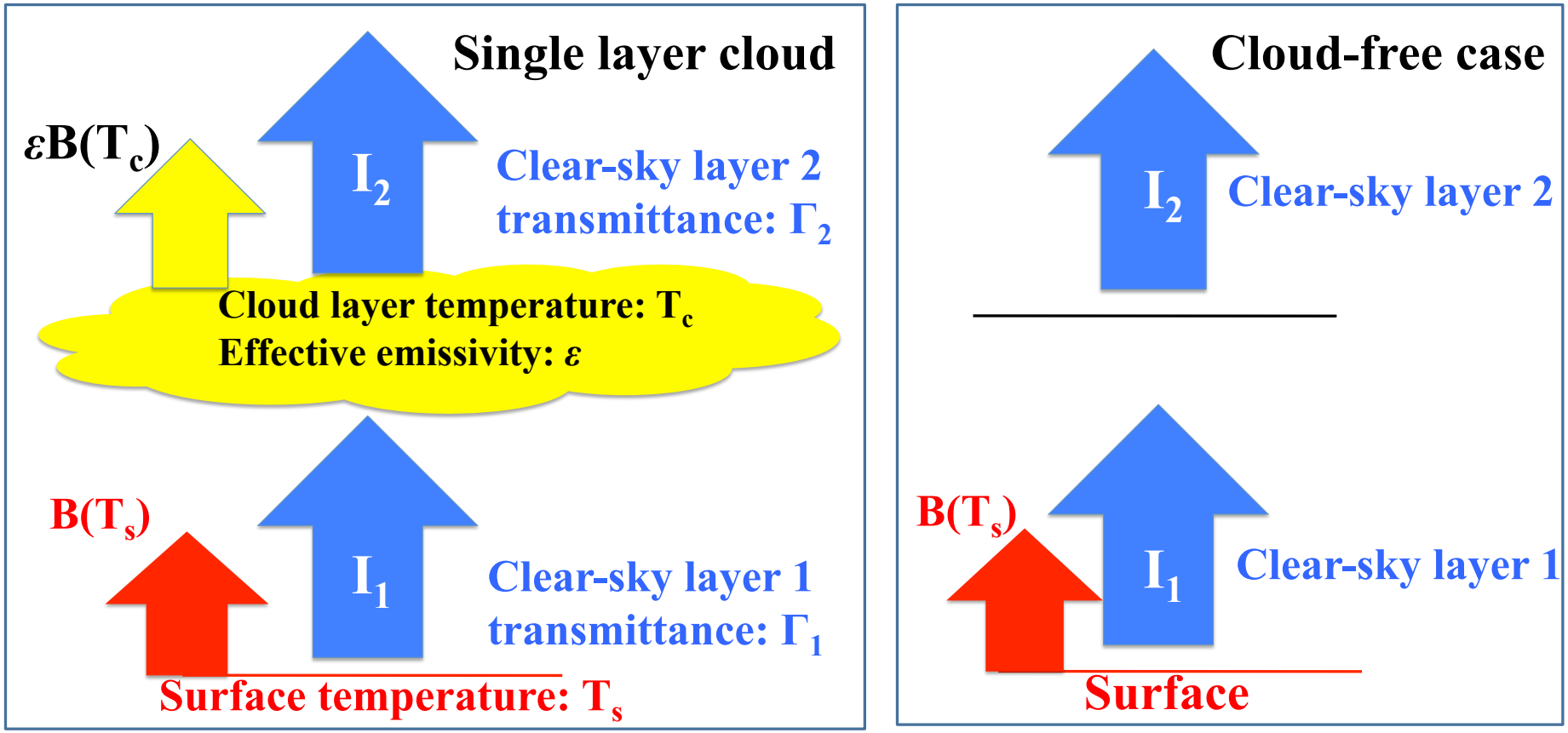
3 CO_2 channels

MODIS thermal infrared channels

VIIRS thermal infrared channels

Wang, C., S. Ding, P. Yang, A. E. Dessler, and B. A. Baum, 2012: A new approach to retrieving cirrus cloud height with a combination of MODIS 1.24- and 1.38-µm channels. *Geophys. Res. Lett.*, 39, L24806, doi: 10.1029/2012GL053854.

The CO_2 slicing technique (Smith and Platt, 1978)



Cloud height equation : $I_{cloudy} - I_{clear} = \varepsilon\Gamma_2[B(T_s)\Gamma_1 + I_1 - B(T_c)]$

Why CO_2 channels ?

If two channels are used:

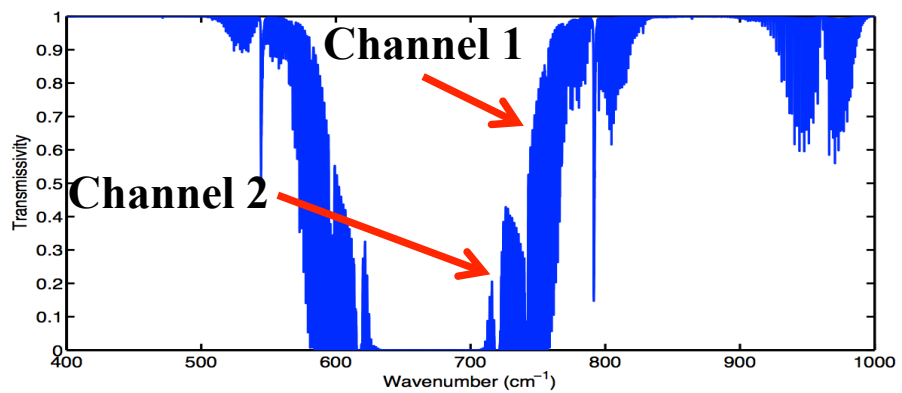
$$\frac{I_{TOA,\lambda 1} - I_{clear,\lambda 1}}{I_{TOA,\lambda 2} - I_{clear,\lambda 2}} = \frac{\cancel{\varepsilon_{\lambda 1}}\Gamma_{2,\lambda 1}[B_{\lambda 1}(T_s)\Gamma_{1,\lambda 1} + I_{1,\lambda 1} - B_{\lambda 1}(T_c)]}{\cancel{\varepsilon_{\lambda 2}}\Gamma_{2,\lambda 2}[B_{\lambda 2}(T_s)\Gamma_{1,\lambda 2} + I_{1,\lambda 2} - B_{\lambda 2}(T_c)]}$$

Basic conditions:

1. The two channels are close to each other.

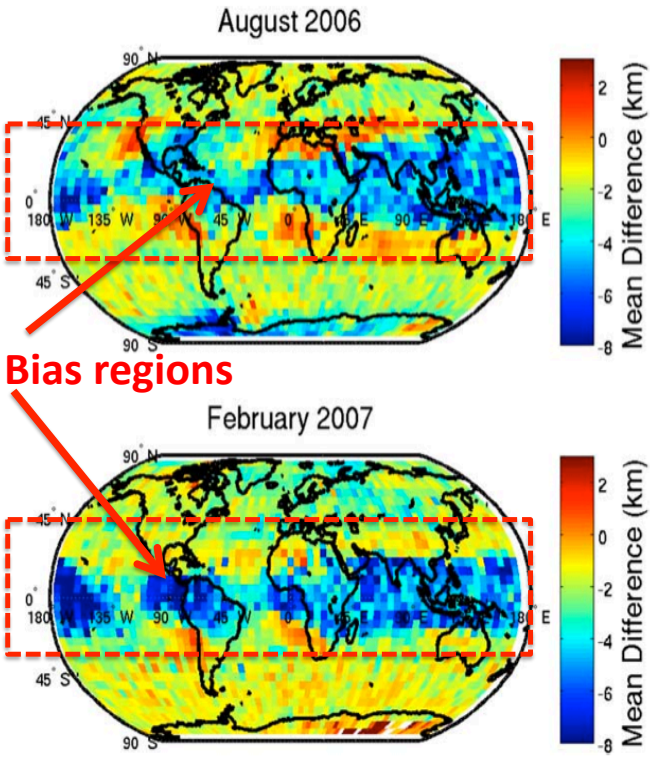
2. Gas absorptivity values in the two channels need to be different.

CO_2 channels near 15-μm satisfy the two conditions



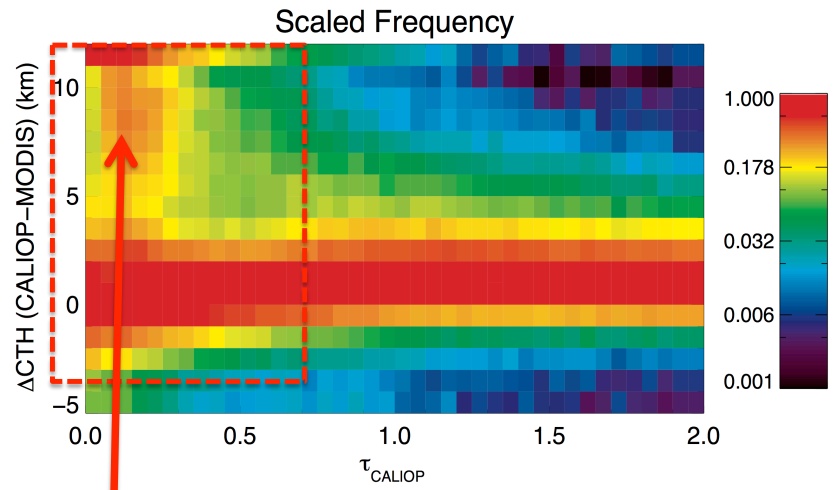
CO_2 transmissivity spectrum (U.S. standard profile)

Performance of the CO_2 slicing technique



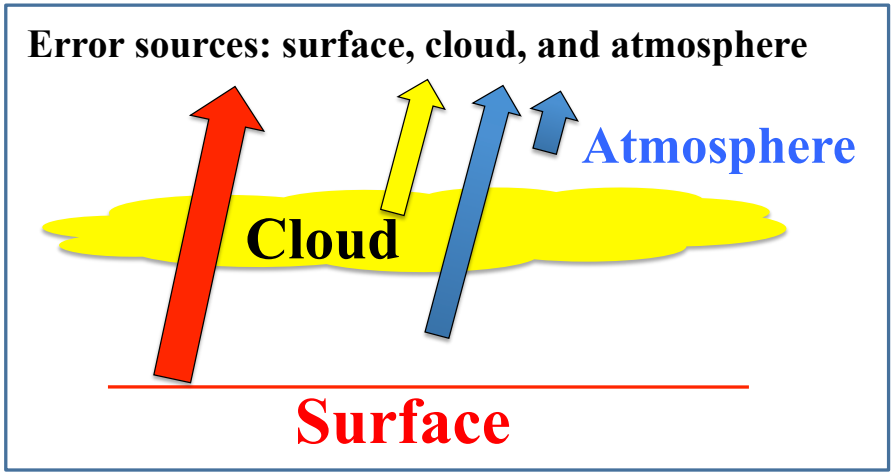
Holz et al., 2008

MODIS (CO_2 slicing technique) ~ CALIOP (Lidar) Cloud Top Height (CTH) Comparison



Scaled Frequency of ΔCTH (CALIOP-MODIS) as a function of cloud optical thickness.

Large Bias regions – optically thin clouds



Lesson from the CO_2 slicing technique

- **Principle:**
  - **Assumes the presence of a single-layered cloud**
  - **Method works with IR absorbing bands that have weighting functions that peak at different levels in the troposphere**
  - **Proven to be accurate for transmissive ice clouds**
- **Features:**
  - **Performs well for optically thick or moderately thick mid- to high-level clouds.**
  - **Becomes less accurate if clouds are optically thin.**

CTH retrieval -- New channel combination

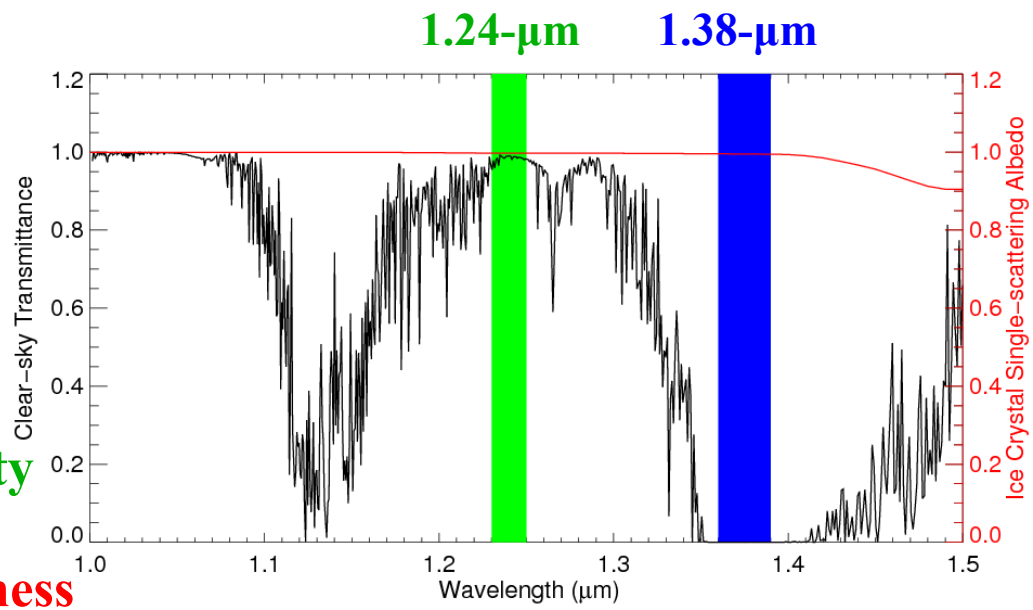
Condition 1: The two channels are close to each other.

Condition 2: A strong absorptive channel (primary) and a window channel (auxiliary).

Shortwave infrared (SWIR) channels: ignore thermal emission and Rayleigh scattering

The primary channel (1.38-µm):
- **Strong gas absorption**
- **One absorptive gas**

The auxiliary channel (1.24-µm):
- **Window band**
- **Similar cloud scattering property**



Objective: derive gas optical thickness above cloud (τ_g).

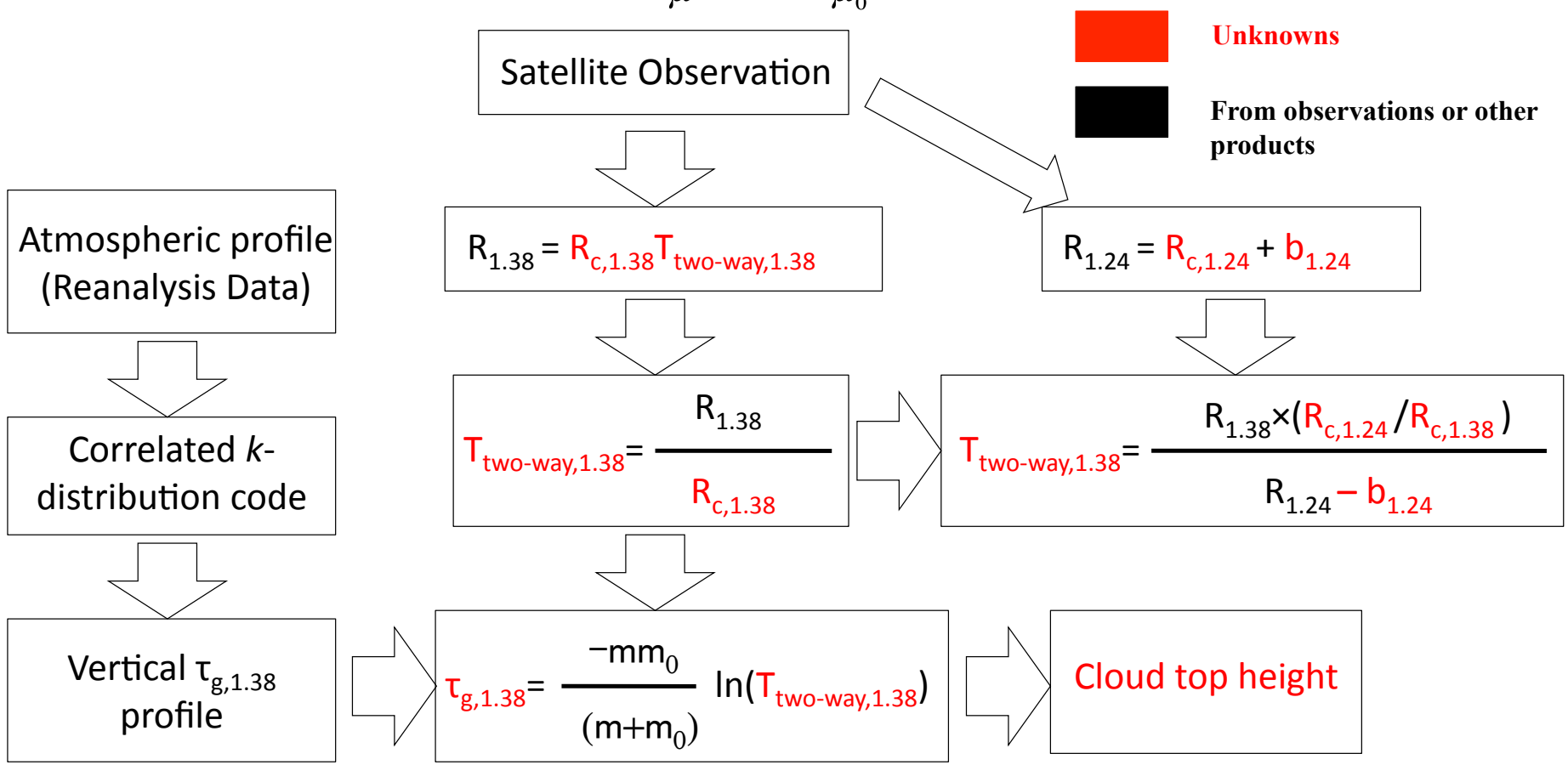
Both MODIS and VIIRS have the two SWIR channels

Retrieval method -- flowchart

Satellite observation: R_λ Surface contribution: b_λ Cosine of solar zenith angle: μ_0

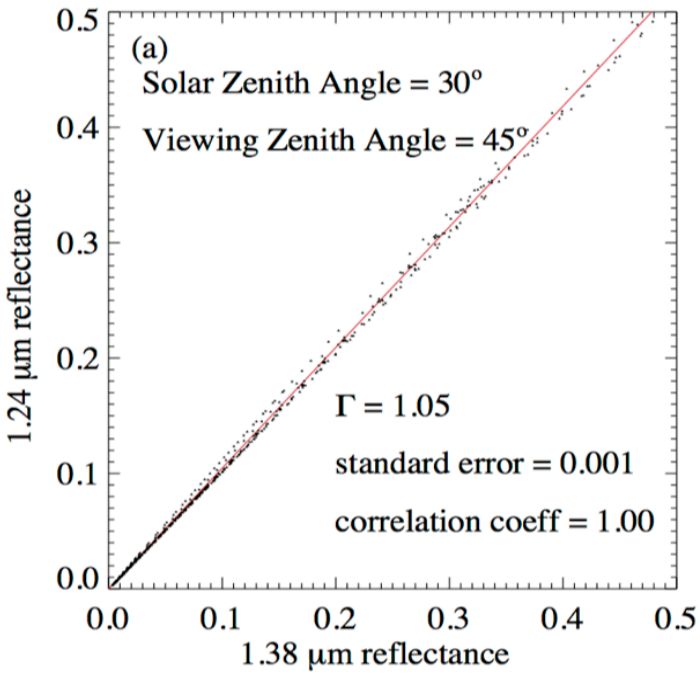
Cloud reflectance: $R_{c,\lambda}$ Gas optical thickness (above cloud): τ_g Cosine of viewing zenith angle: μ

$$\text{Two-way transmittance}: T_{two-way,\lambda} = \exp(-\frac{\tau_{g,\lambda}}{\mu})\exp(-\frac{\tau_{g,\lambda}}{\mu_0})$$



Retrieval method – two unknowns $R_{c,1.24}/R_{c,1.38}$ and $b_{1.24}$

Cloud reflectance ratio: $\Gamma = R_{c,1.24} / R_{c,1.38}$



The ratio is a only a function of solar-satellite geometry

Surface contribution: $b_{1.24}$

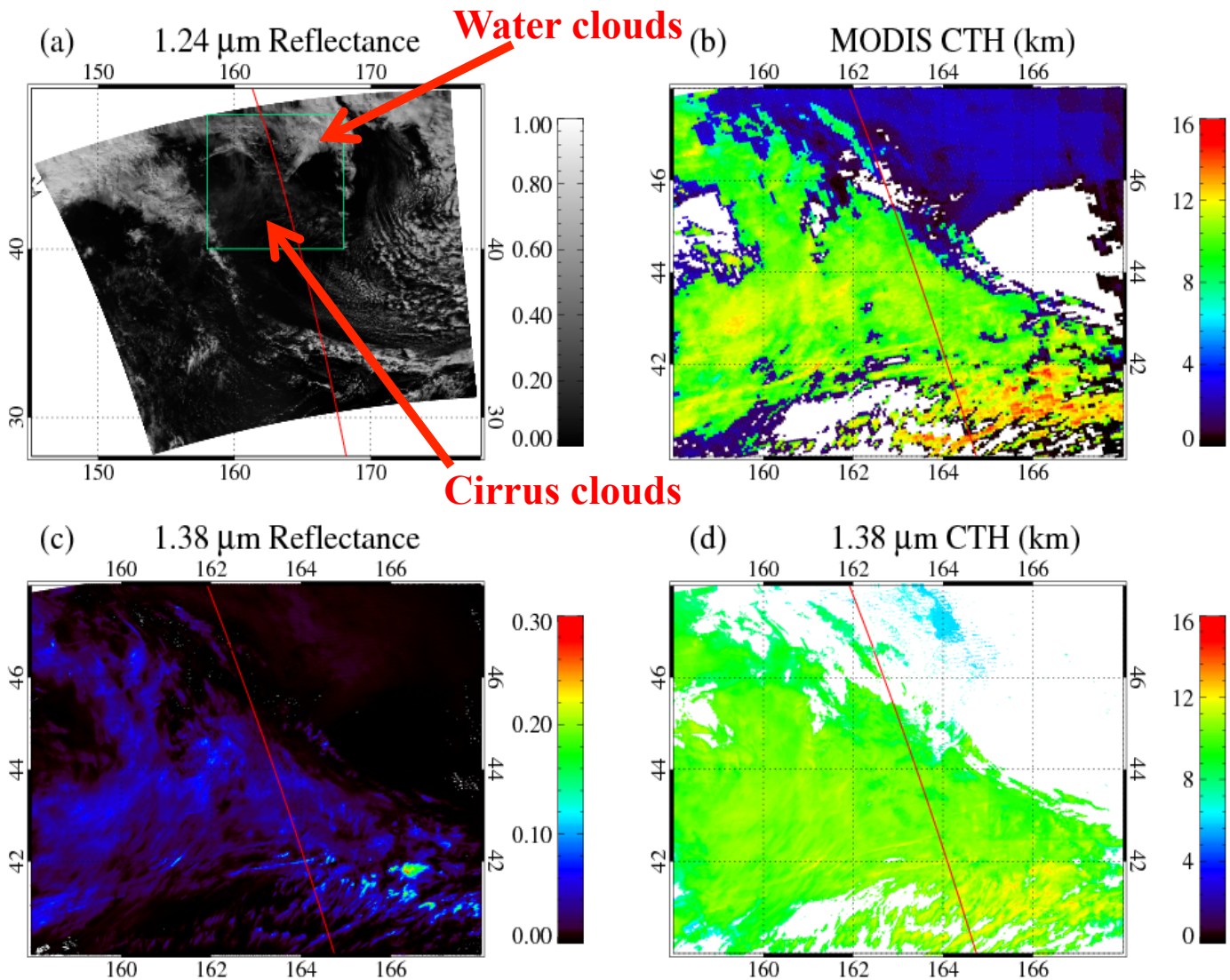
For optically thick and moderately thick clouds, $b_{1.24} << R_{obs,1.24}$. Assume $b_{1.24} = 0$.

For optically thin cloud, $b_{1.24} \sim R_{obs,1.24}$. We estimate $b_{1.24}$ based on the first-order of surface reflection:

$$b_{1.24} = \exp(-\frac{\tau_c}{\mu})\exp(-\frac{\tau_c}{\mu_0})R_s$$

R_s is surface bi-directional reflectance distribution function (BRDF), τ_c is cloud optical thickness (from MODIS/VIIRS products).

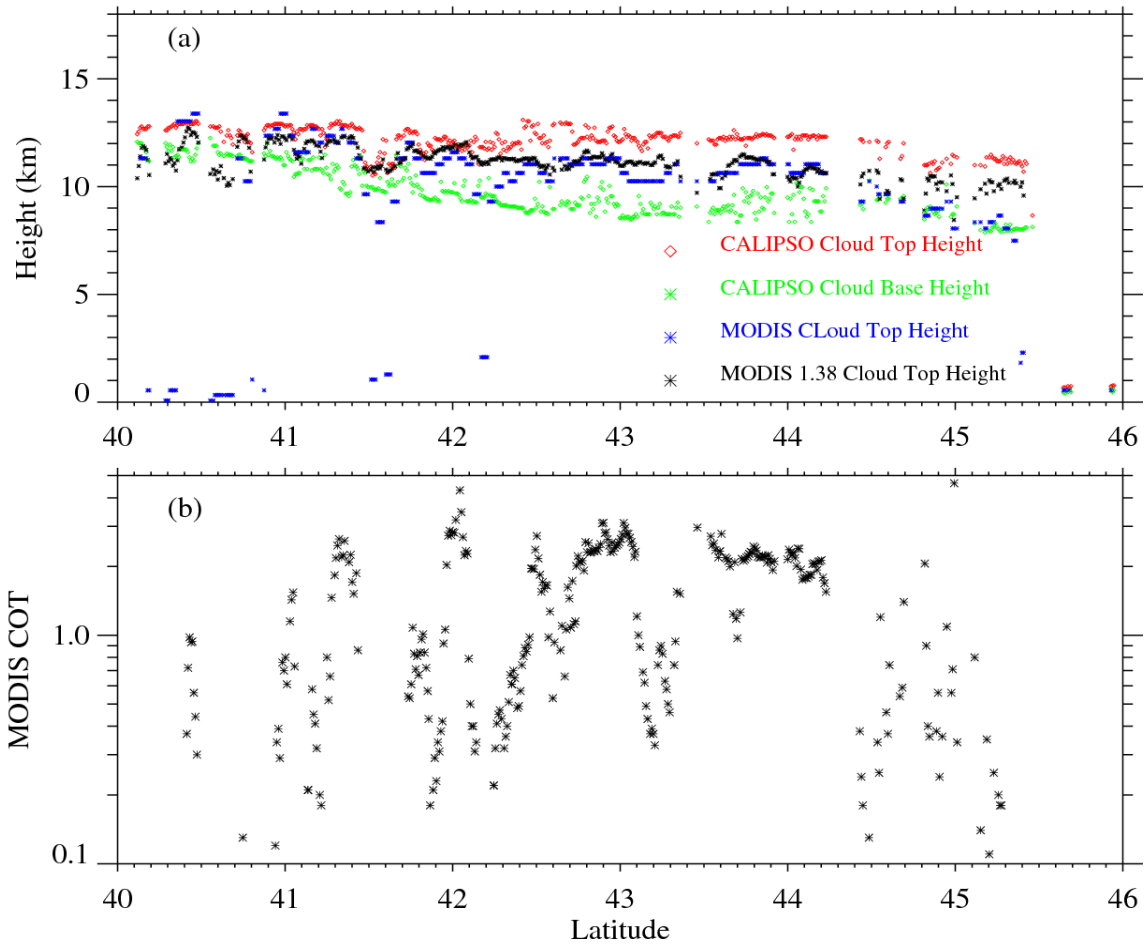
Case study – Granule image



Granule information:
Aqua/MODIS L1B
Sep. 09, 2008 (Ocean)

The new approach highlights thin cirrus clouds but misses water clouds.

Case study – Vertical image



If cloud is optically thick, MODIS CTH and 1.38-CTH are consistent with each other.

If cloud is optically thin, the new method performs better than MODIS product.

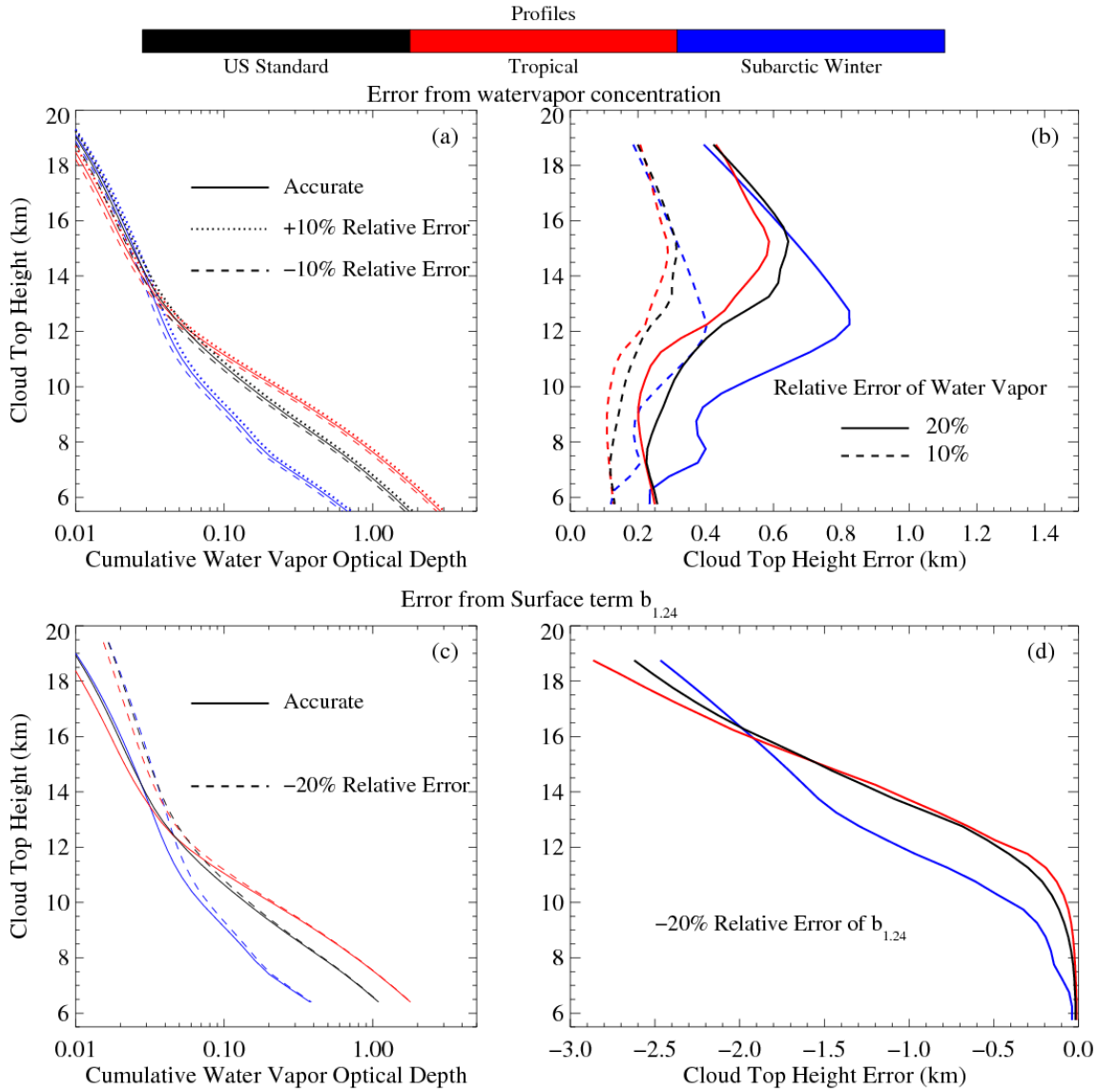
Cloud top height comparisons

Summary and conclusions

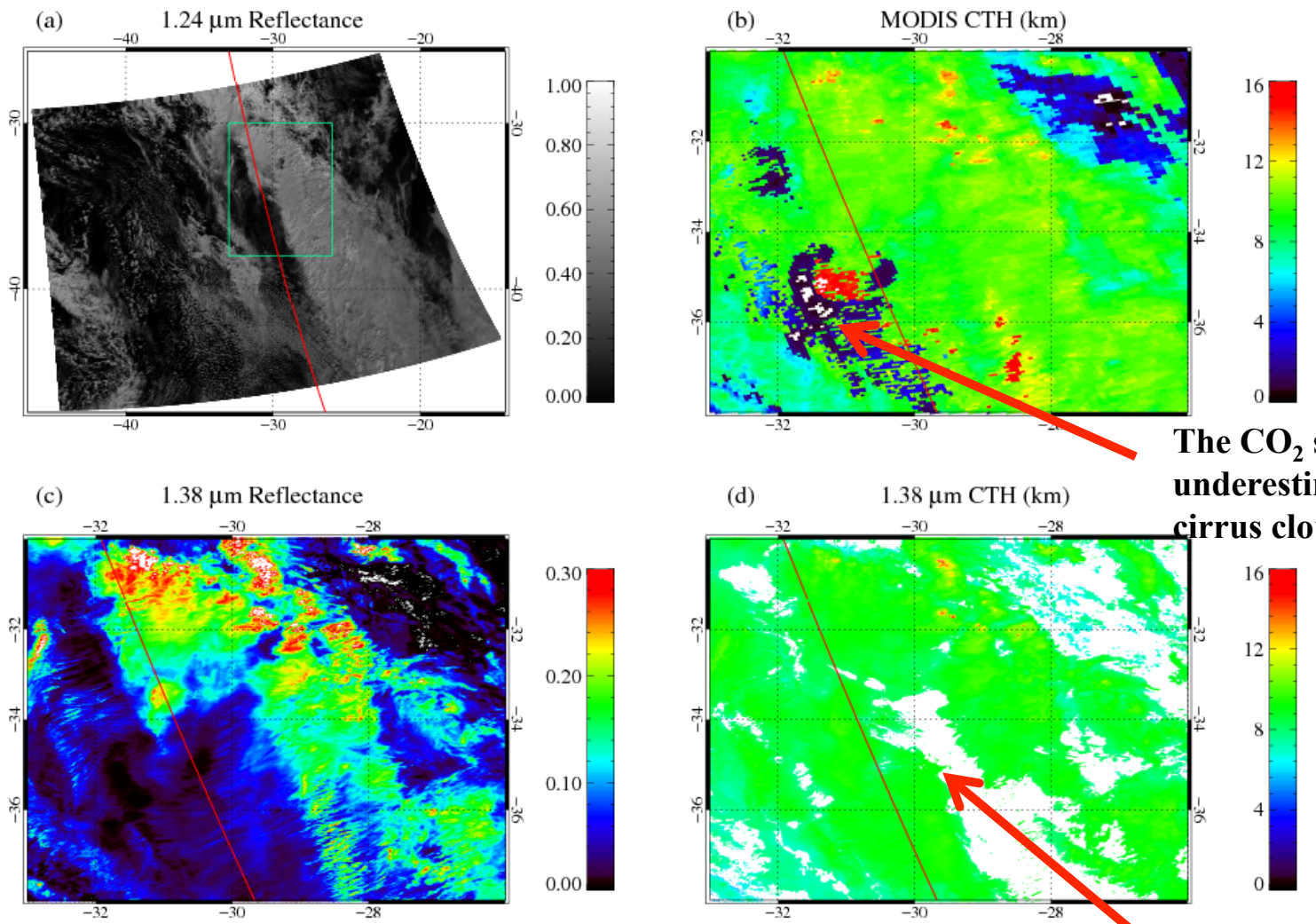
- **The new method can be considered to be a complementary approach :**
  - **Sensitive to thin cirrus cloud.**
  - **Accurate: Errors from temperature profiles and multiple gas absorption can be avoided.**
  - **Rapid: A radiative transfer model is not needed.**
  - **Useful for instruments with the 1.24- and 1.38-µm channels but without the CO_2 channels (e.g., VIIRS).**

- **Future work:**
  - **Lower level clouds (water clouds).**
  - **Multi-layered clouds.**

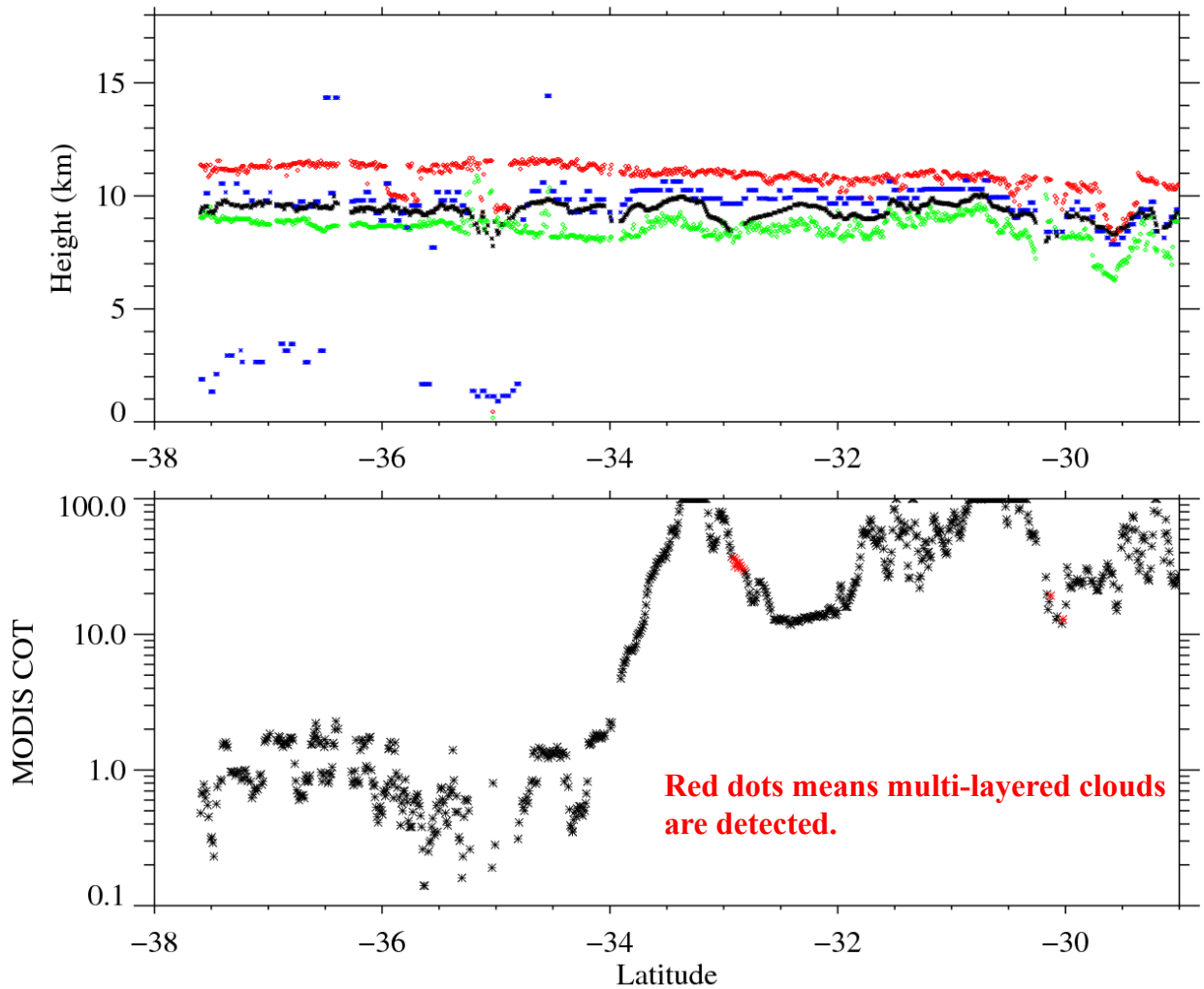
Back up – Error analysis



Back up – Case study 2



The CO_2 slicing method underestimate the CTH of thin cirrus cloud.

The new method fails if multi-layered clouds exist.

Backup -- Case study 2