# Lecture 11. Applications of passive remote sensing:

# Remote sensing clouds.

Materials of Lecture 10 and problem solving examples

## SOLAR SPECTRUM

**Upward/downward intensity in the plane-parallel atmosphere with scattering/absorption (see Lecture 5):**

$$I_\lambda^{\uparrow}(\tau,\mu,\varphi) = I_\lambda^{\uparrow}(\tau^*,\mu,\varphi)\exp(-\frac{\tau^*-\tau}{\mu}) + \frac{1}{\mu}\int_{\tau}^{\tau^*}\exp(-\frac{\tau'-\tau}{\mu})\ J_\lambda^{\uparrow}(\tau',\mu,\varphi)d\tau'$$

$$I_\lambda^{\downarrow}(\tau,-\mu,\varphi) = I_\lambda^{\downarrow}(0,-\mu,\varphi)\exp(-\frac{\tau}{\mu}) + \frac{1}{\mu}\int_{0}^{\tau}\exp(-\frac{\tau-\tau'}{\mu})\ J_\lambda^{\downarrow}(\tau',-\mu,\varphi)d\tau'$$

$$J(\tau,\mu,\varphi) = \frac{\omega_0}{4\pi}\int_0^{2\pi}\int_{-1}^{1} I(\tau,\mu',\varphi')P(\mu,\varphi,\mu',\varphi')d\mu' d\varphi' + \frac{\omega_0}{4\pi}F_0 P(\mu,\varphi,\mu_0,\varphi_0)\exp(-\tau/\mu_0)$$

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## THERMAL SPECTRUM

**Upward/downward intensity in the plane-parallel atmosphere with emission/absorption**

$$I_\lambda^{\uparrow}(\tau;\mu;\varphi) = I_\lambda^{\uparrow}(\tau^*;\mu;\varphi)\exp(-\frac{\tau^*-\tau}{\mu}) + \frac{1}{\mu}\int_{\tau}^{\tau^*}\exp(-\frac{\tau'-\tau}{\mu})\ B_\lambda(\tau')d\tau'$$

$$I_\lambda^{\downarrow}(\tau;-\mu;\varphi) = I_\lambda^{\downarrow}(0;-\mu;\varphi)\exp(-\frac{\tau}{\mu}) + \frac{1}{\mu}\int_{0}^{\tau}\exp(-\frac{\tau-\tau'}{\mu})\ B_\lambda(\tau')d\tau'$$

# Approximate eqs:

## SOLAR SPECTRUM

**Cloud reflectivity (conservative scattering: $\omega_0$ =1):**

$$R_{cld} = \frac{(1-g)\tau}{1+(1-g)\tau}$$

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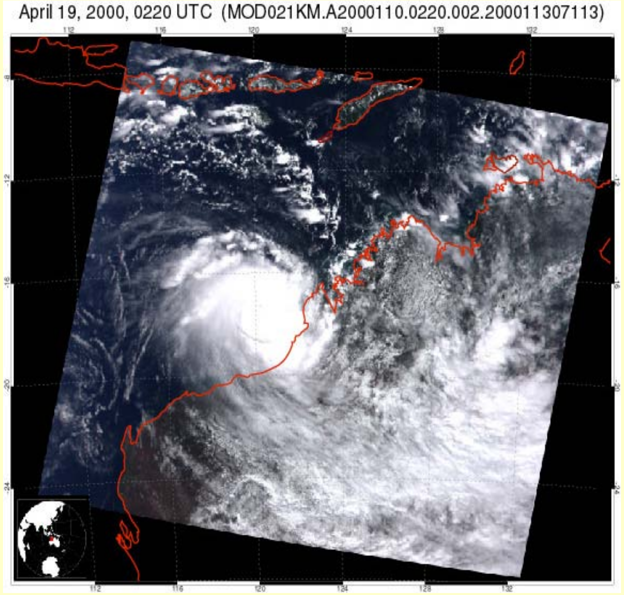
## THERMAL SPECTRUM

**Atmospheric features (cloud) with emission/absorption**

$$I_\nu^{\uparrow}(0;\mu) = B_\nu\left(T_{src}\right)\left(1-\varepsilon_{cld}\right) + B_\nu\left(T_{cld}\right)\varepsilon_{cld}$$

# <u>Why clouds are white?</u>




**…***because cloud particles scatter all color wavelengths by the same amount. All colors are represented in this scattered light and cloud therefore appears white.*

# Optical properties of clouds

Effective radius

$$r_e = \frac{\int \pi r^3 N(r) dr}{\int \pi r^2 N(r) dr}$$

Liquid water content

$$LWC = \rho_w V = \frac{4}{3} \rho_w \int \pi r^3 N(r) dr$$

Extinction coefficient of cloud droplets

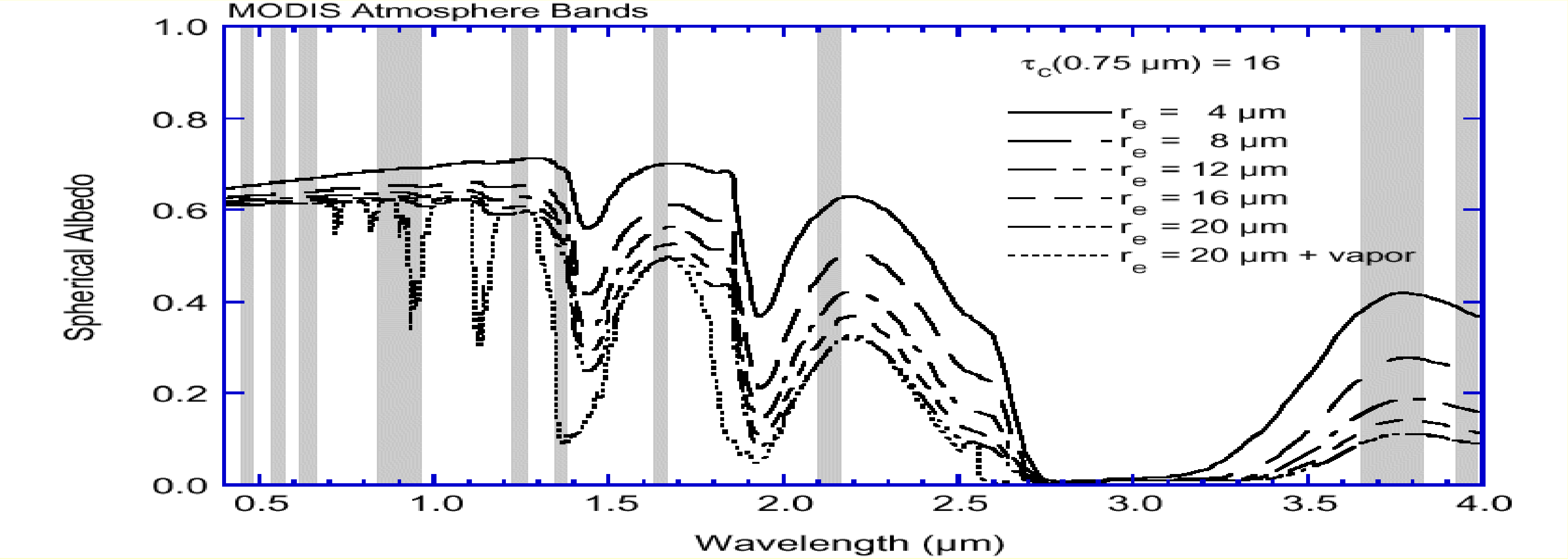
$$k_e = \int \sigma_e(r) N(r) dr = \int Q_e \pi r^2 N(r) dr$$

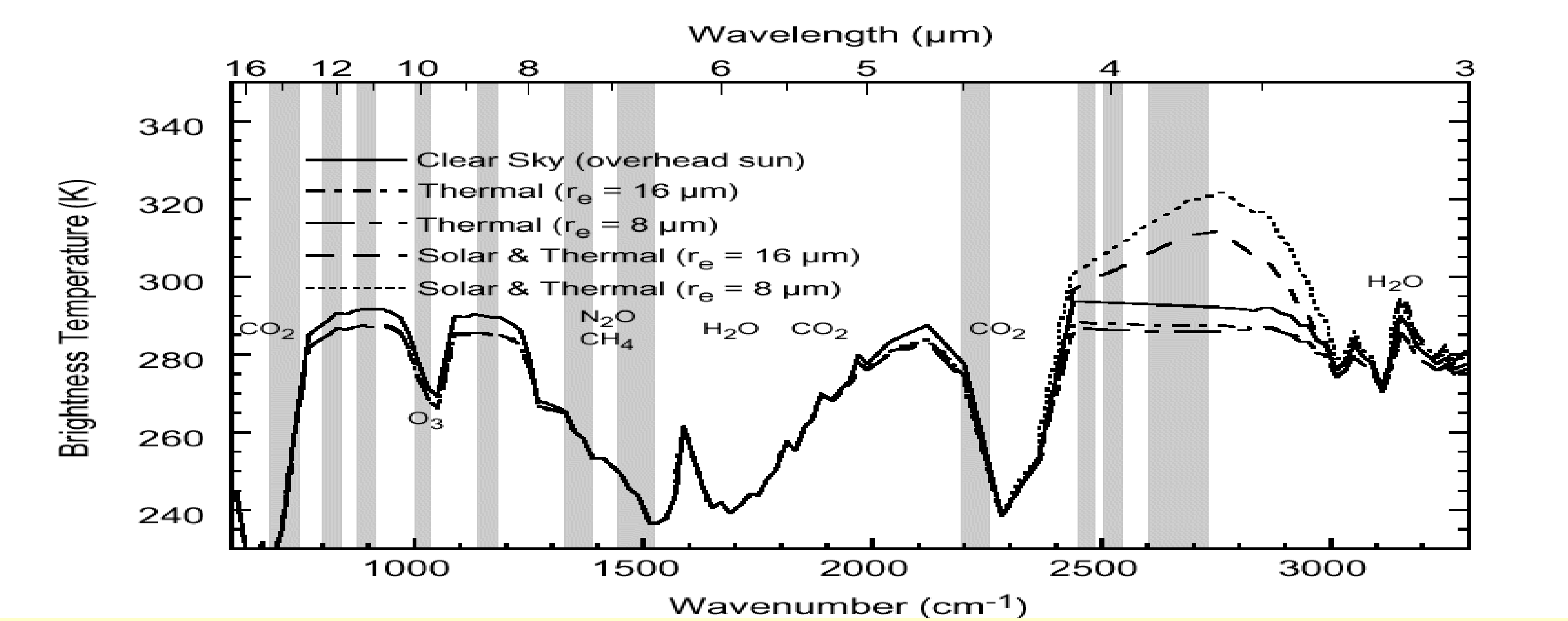
If $Q_e$ ~2 → $$k_e \approx \frac{3}{2} \frac{LWC}{r_e \rho_w}$$

For a cloud layer of ΔZ

(LWP=LWC*ΔZ) → $$\tau \approx \frac{3}{2} \frac{LWP}{r_e \rho_w}$$

# Effects of water clouds on solar reflectance and IR brightness temperature:



**What does the color of a cloud mean on the TV weather shows?**

**http://profhorn.meteor.wisc.edu/wxwise/satir/IRCloud.html**

## Problem

A cloud 2 km thick with mean temperature of 220 K overlies a surface with T= 285K which emits like a blackbody. At 11 $\mu$m, it can be assumed that the atmosphere above and below cloud is transparent to the radiation.

a) If emissivity of a cloud is $\varepsilon = 1$, what is the brightness temperature that will be measured by a satellite radiometer with channel centered at 11 $\mu$m?

b) If emissivity of a cloud is $\varepsilon = 0$, what is the brightness temperature that will be measured in this case?

ANSWER:

a) Temperature of cloud, T=220K

b) Temperature of surface, T=285K