ATM 265, Spring 2019
Lecture 10
Radiation
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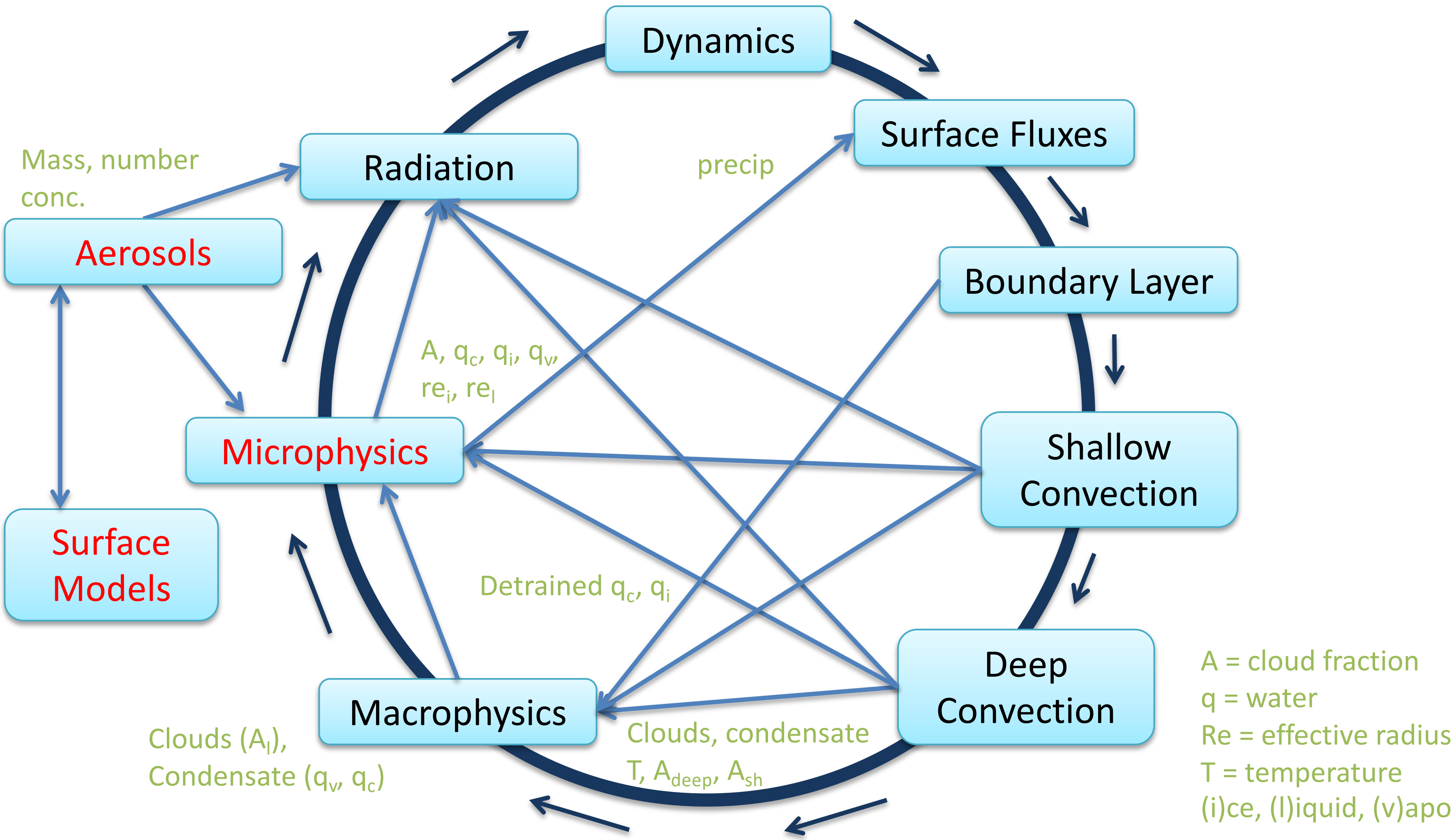
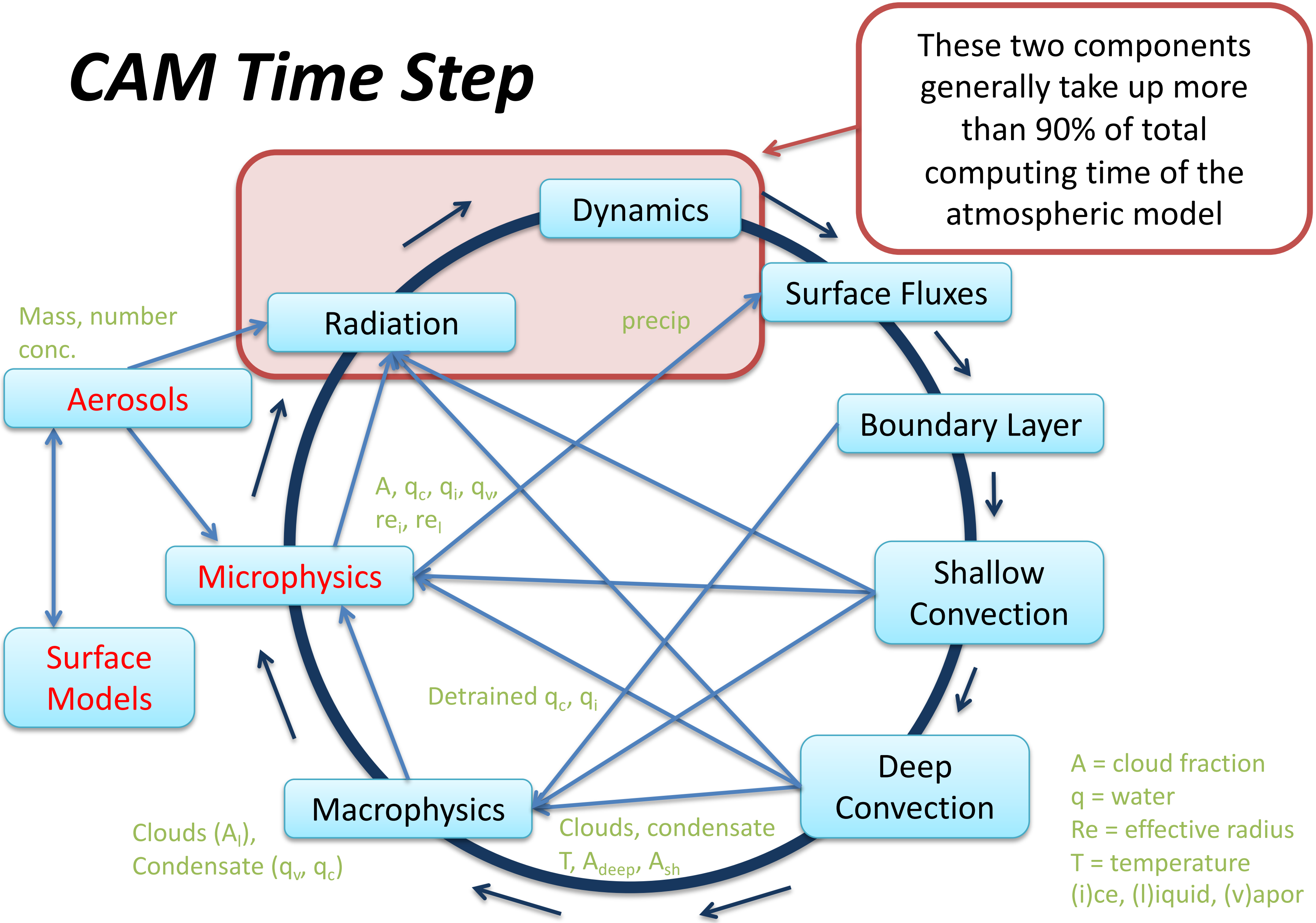
CAM Time Step

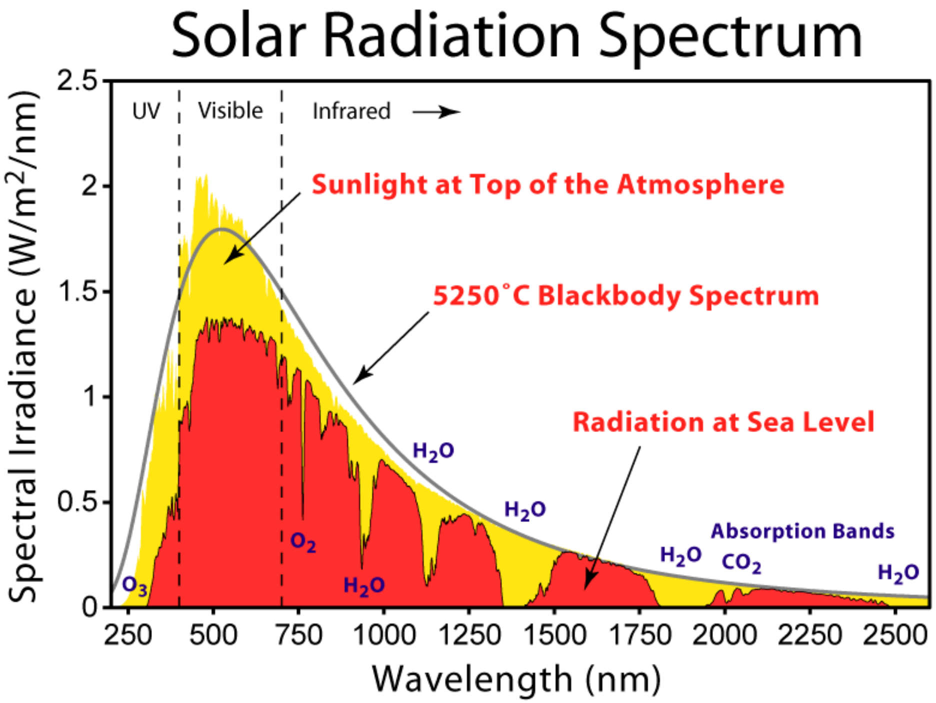
Source: Rich Neale, Julio Bacmeister

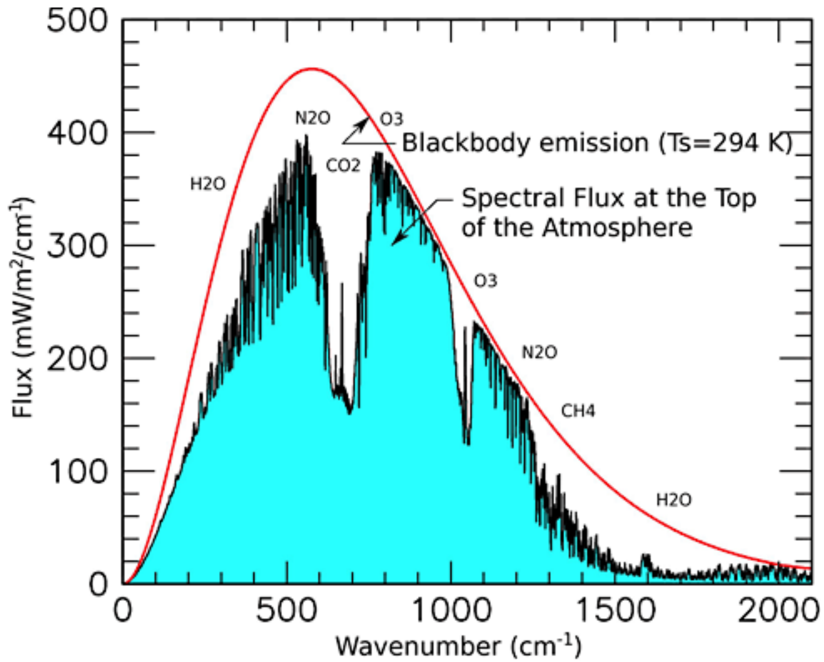


CAM Time Step



Radiation

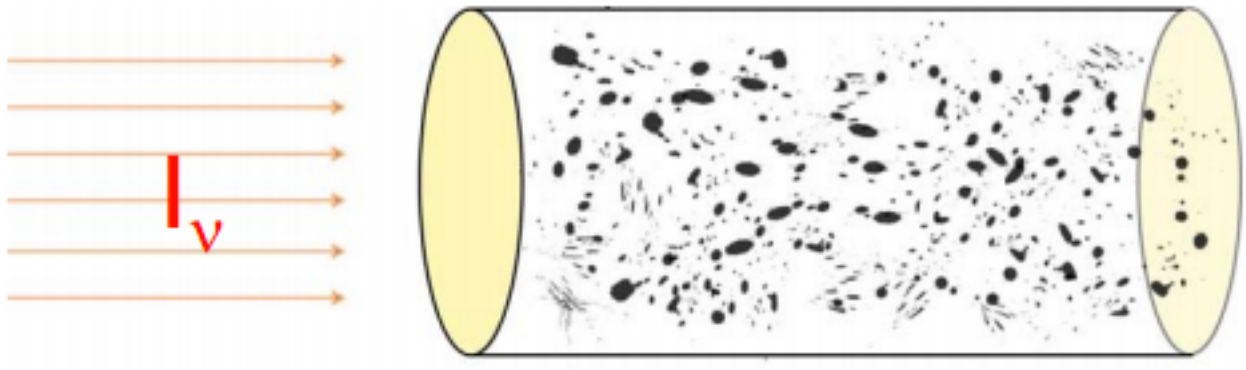




Incoming solar radiation is largely composed of short-wavelength and high-frequency photons. Outgoing surface-emitted radiation is composed of long-wavelength and low-frequency photons.

Both types of radiation are susceptible to absorption or reflection by the major chemical constituents of the atmosphere (H_2O, CO_2, CH_4)

Radiation



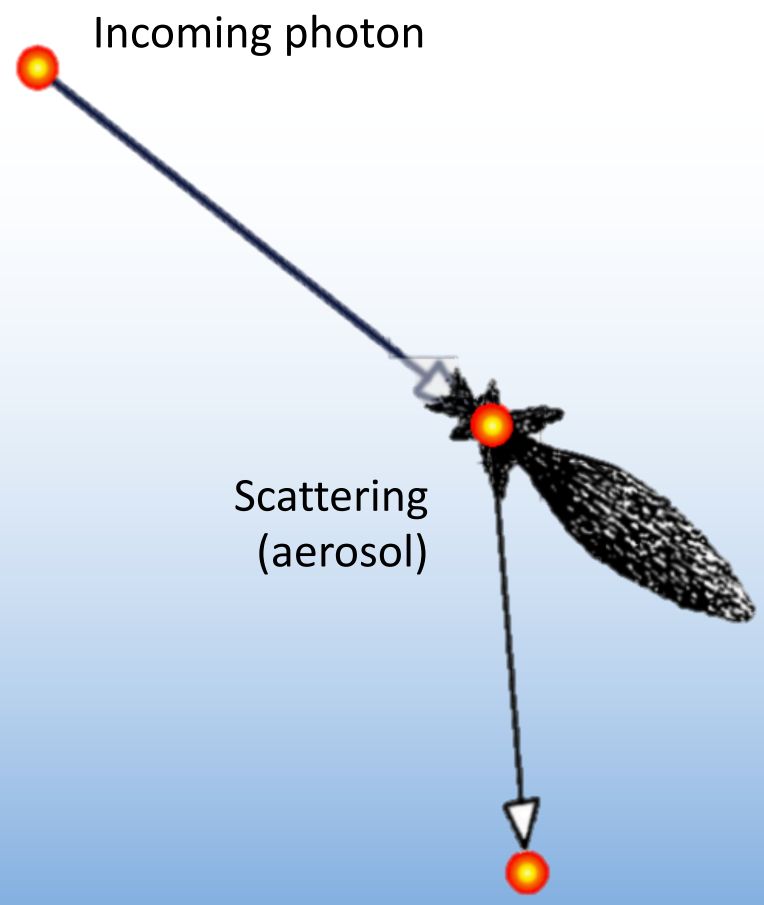
A photon received from the sun has four possible fates:

- Scattering (in the atmosphere)
- Absorption (in the atmosphere)
- Absorption (by the surface)
- Reflection (by the surface)

Radiation

By the rules of radiative transfer, an incoming photon will be scattered in accordance with a **phase function**.

The phase function describes the angle (in 3D) of an outgoing photon which has interacted with a particle in the atmosphere (air, water or aerosol)



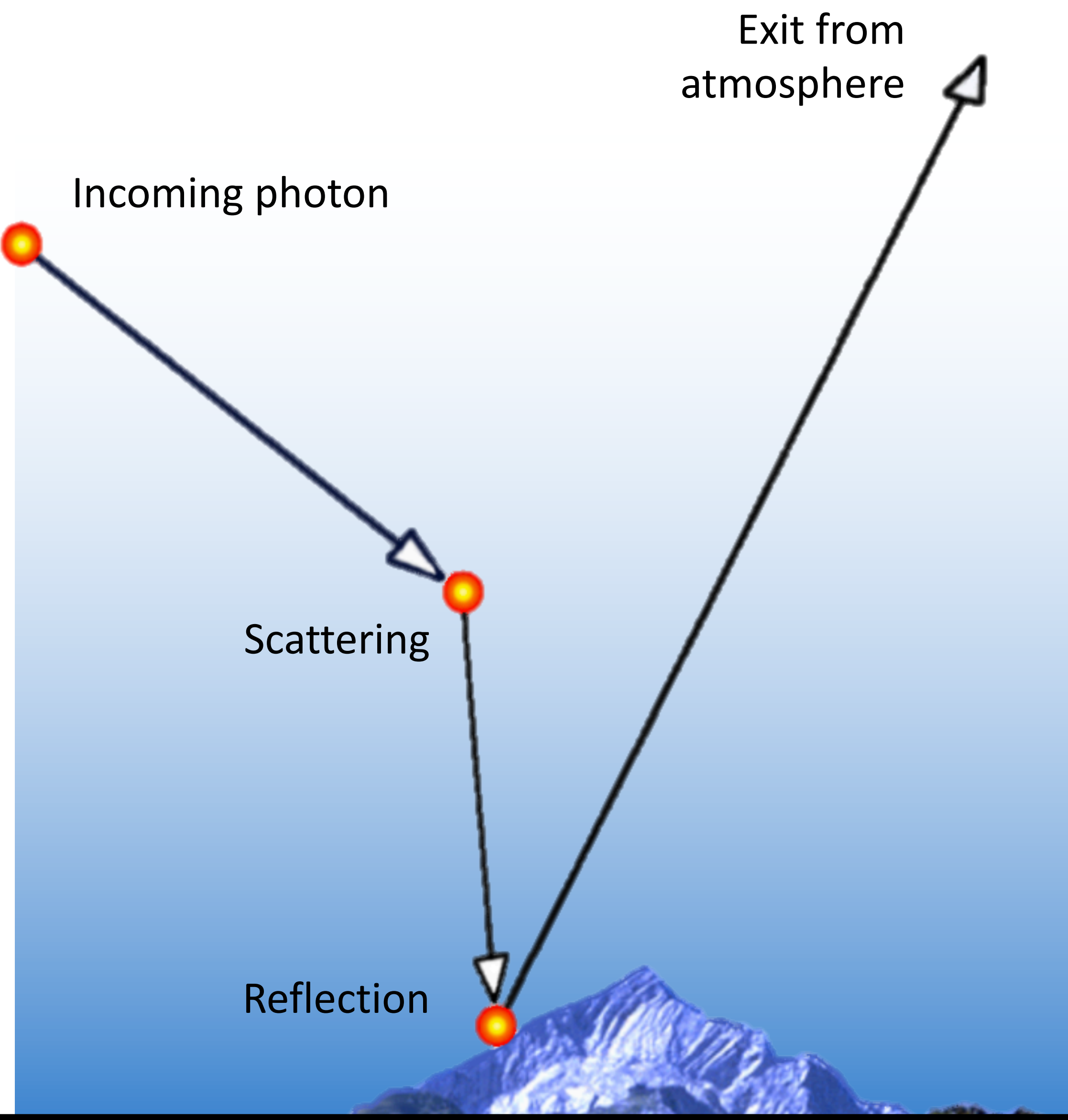
Radiation

A photon which reaches the ground can either be **reflected** or **absorbed**.

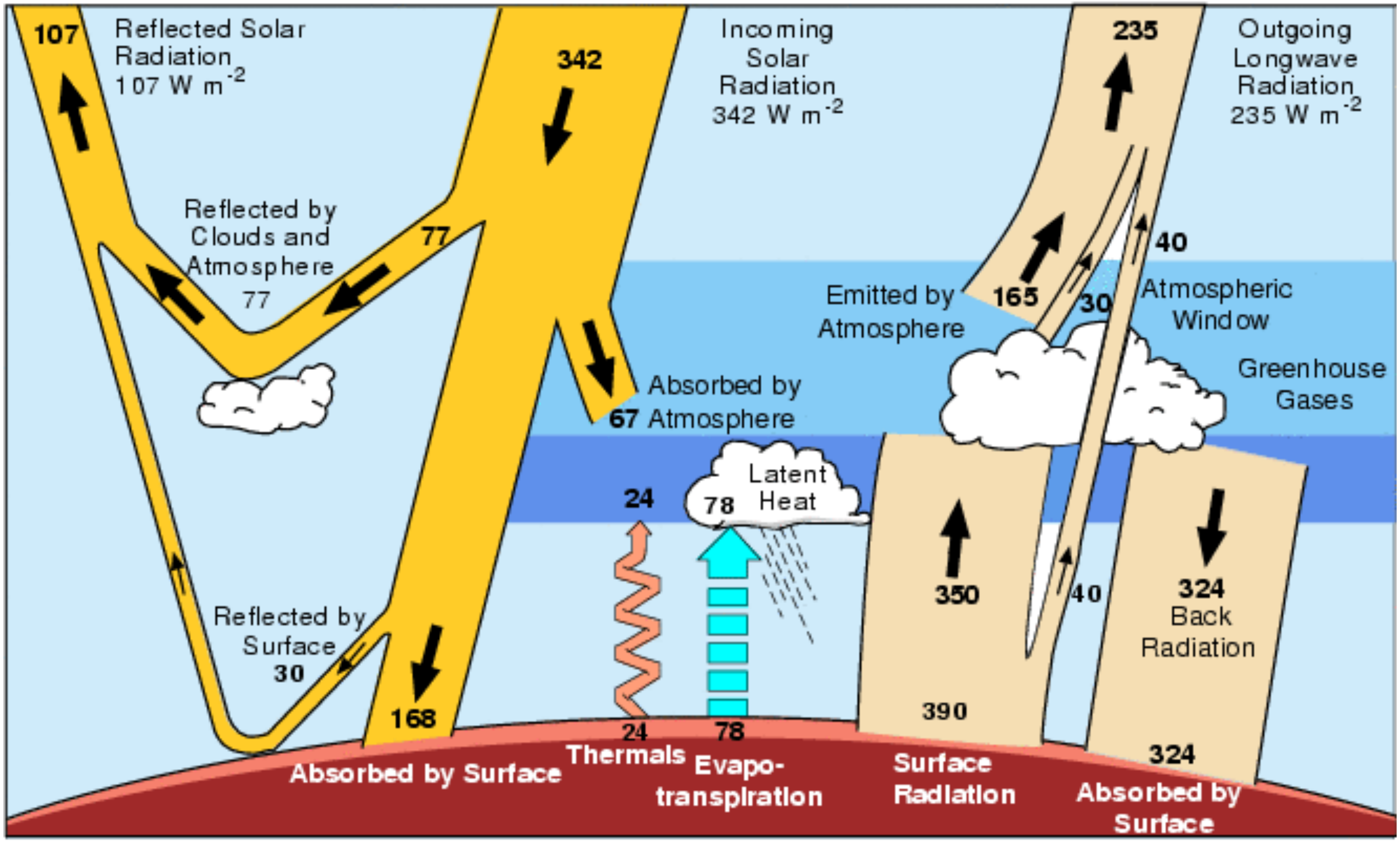
The **probability of reflection** is controlled by the **surface albedo**.

Emission by the surface can also contribute long-wave (outgoing) radiation to the atmosphere.

Reflection by the surface contributes short-wave (outgoing) radiation to the atmosphere.



Global Heat Flows



Kiehl and Trenberth 1997

Radiation (Plane-Parallel)

This is the basic equation that describes **short-wave radiation**

Intensity of radiation

Multiple scattering

$$\mu \frac{dI(\mu,\phi)}{d\tau} = I(\mu,\phi) - \frac{\omega}{4\pi}\int_0^{2\pi}\int_{-1}^{1} P(\Theta) I(\mu',\phi') d\mu' d\phi'$$
$$- \frac{\omega}{4\pi} P(\mu,\phi;-\mu_0,\phi_0+\pi) S_0 \exp(-\tau/\mu_0)$$

Optical depth

Single scattering from sunlight

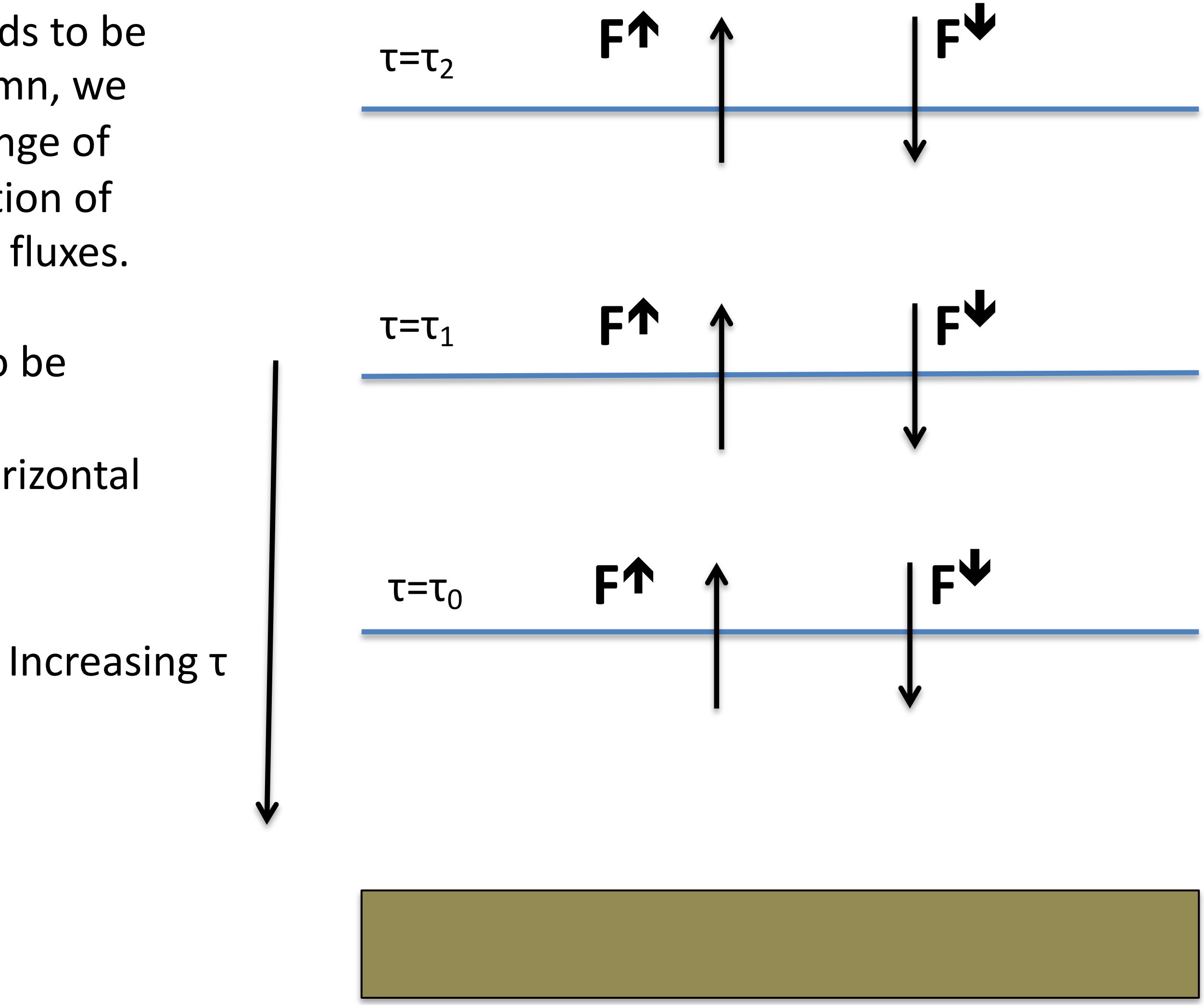
Solar constant

Incident angle

Radiation (Plane-Parallel)

Since the radiation needs to be treated in a single column, we approximate the exchange of radiation as a combination of upward and downward fluxes.

Radiation is assumed to be azimuthally isotropic (independent of the horizontal direction).



Radiation (Azimuthally Averaged)

Intensity of radiation

Multiple scattering

$$\mu \frac{dI}{d\tau} = I(\tau) - \frac{\omega}{2} \int_{-1}^{1} P(\mu, \mu') I(\tau, \mu') d\mu'$$

$$- \frac{\omega}{4\pi} S_0 P(\mu, -\mu_0) \exp(-\tau/\mu_0)$$

Optical depth

Single scattering from sunlight

Incident angle

Radiation (Eddington Method)

Multiple scattering

This is really the hard part.

- Phase function depends on type of particle
- Integral needs to be taken over all incident angles

$$\mu \frac{dI(\mu,\tau)}{d\tau} = I(\mu,\tau) - \frac{\omega}{2}\int_{-1}^{1} P(\mu,\mu')I(\tau,\mu')d\mu'$$
$$- \frac{\omega}{4\pi} S_0 P(\mu,-\mu_0)\exp(-\tau/\mu_0)$$

Radiation (Eddington Method)

$$\mu \frac{dI(\mu,\tau)}{d\tau} = I(\mu,\tau) - \frac{\omega}{2}\int_{-1}^{1} P(\mu,\mu')I(\tau,\mu')d\mu' - \frac{\omega}{4\pi} S_0 P(\mu,-\mu_0)\exp(-\tau/\mu_0)$$

Multiple scattering

Eddington method:

- Approximate intensity as a linear function of μ

$$I(\tau,\mu) = I_0(\tau) + I_1(\tau)\mu$$

Delta-Eddington method:

- Approximate phase function as a forward peak plus a smooth phase function P'

$$P(\mu,\mu') = 2f\delta(1-\mu+\mu') + (1-f)P'(\mu-\mu')$$

Radiation

- In CAM, longwave and shortwave heating rates are evaluated every model hour.
- Shortwave radiation is handled via the Delta-Eddington method within each layer (discretization of the optical depth τ)
- Each radiation band is discretized by wavelength and treated separately.
- Radiative fluxes are computed at the edge of each layer.
- Calculation is very costly (only evaluated once per model hour over the sunlit portions of the model Earth)
- For more information: http://www.cesm.ucar.edu/models/atm-cam/docs/description/node22.html
- More information on RRTMG: http://rtweb.aer.com/rrtm_frame.html