Radiation

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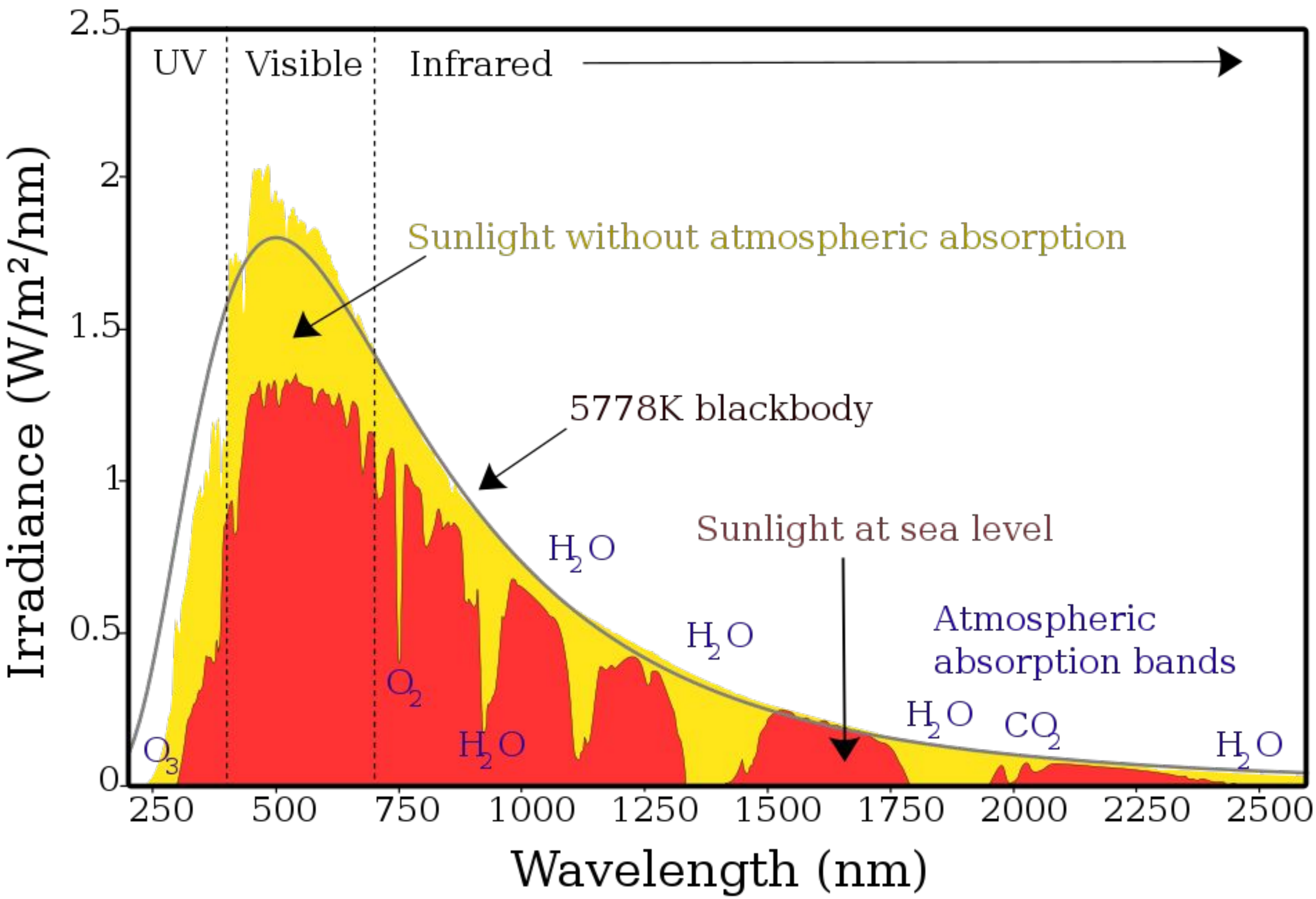
Outline

1. Radiative Transfer in the Atmosphere
2. Methods for solving radiative transfer
3. How CAM solves radiative transfer: RRTMG
4. Sub-grid variability for clouds (McICA)
5. The CAM Aerosol-Radiation Interface
6. Radiative Forcing

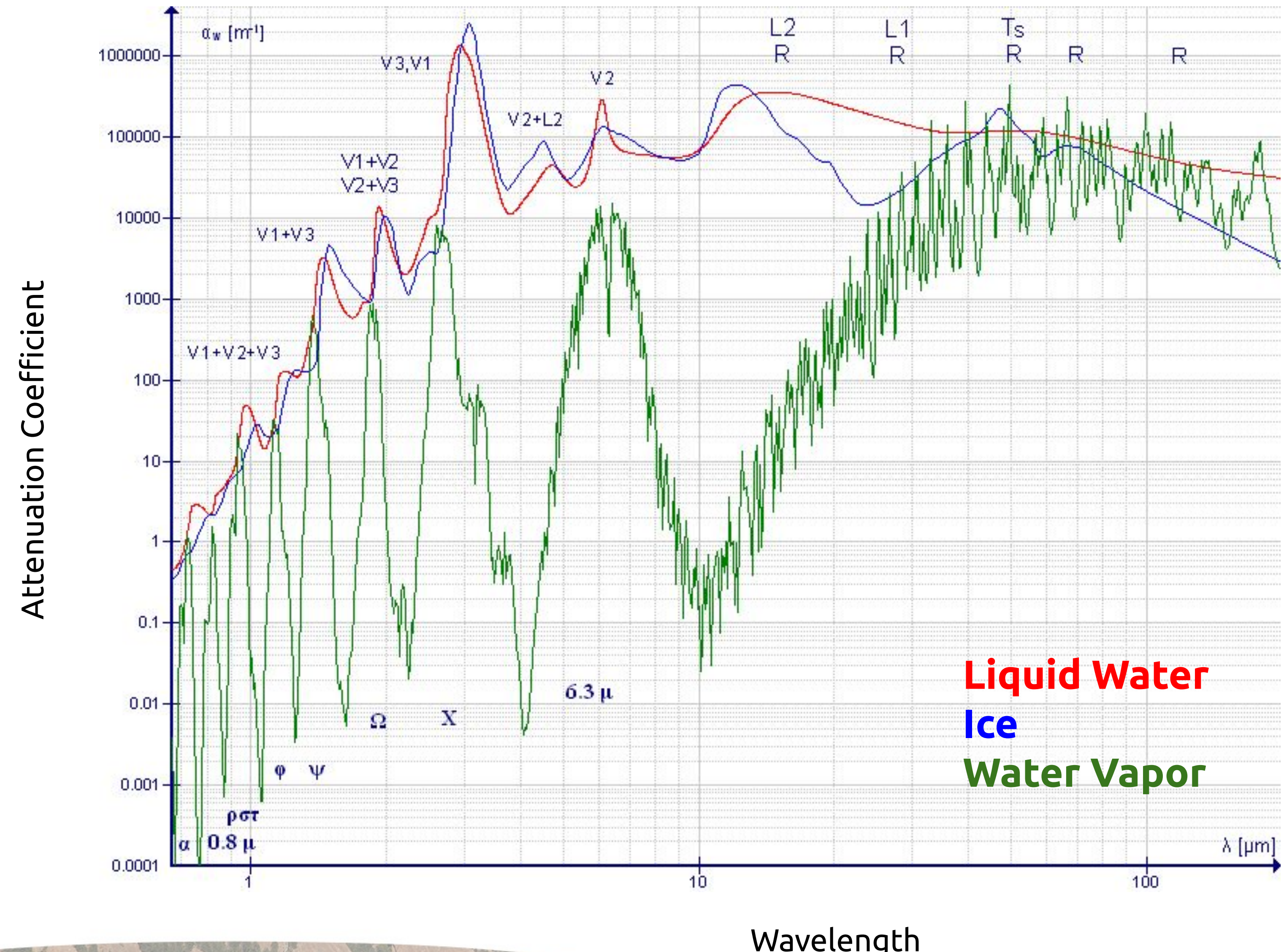
What does Radiation Do?

- Climate: energy balance of the planet
  - Gases: basic state & Impacts of greenhouse gases
  - Radiative transfer of heat between climate system components (mostly atmosphere and surface).
  - Clouds and condensed species (Aerosols) have unique challenges
- Weather: surface and atmospheric heating
  - What energy hits the surface
  - Clouds mediate this

Spectrum of Solar Radiation (Earth)



Water IR Absorption

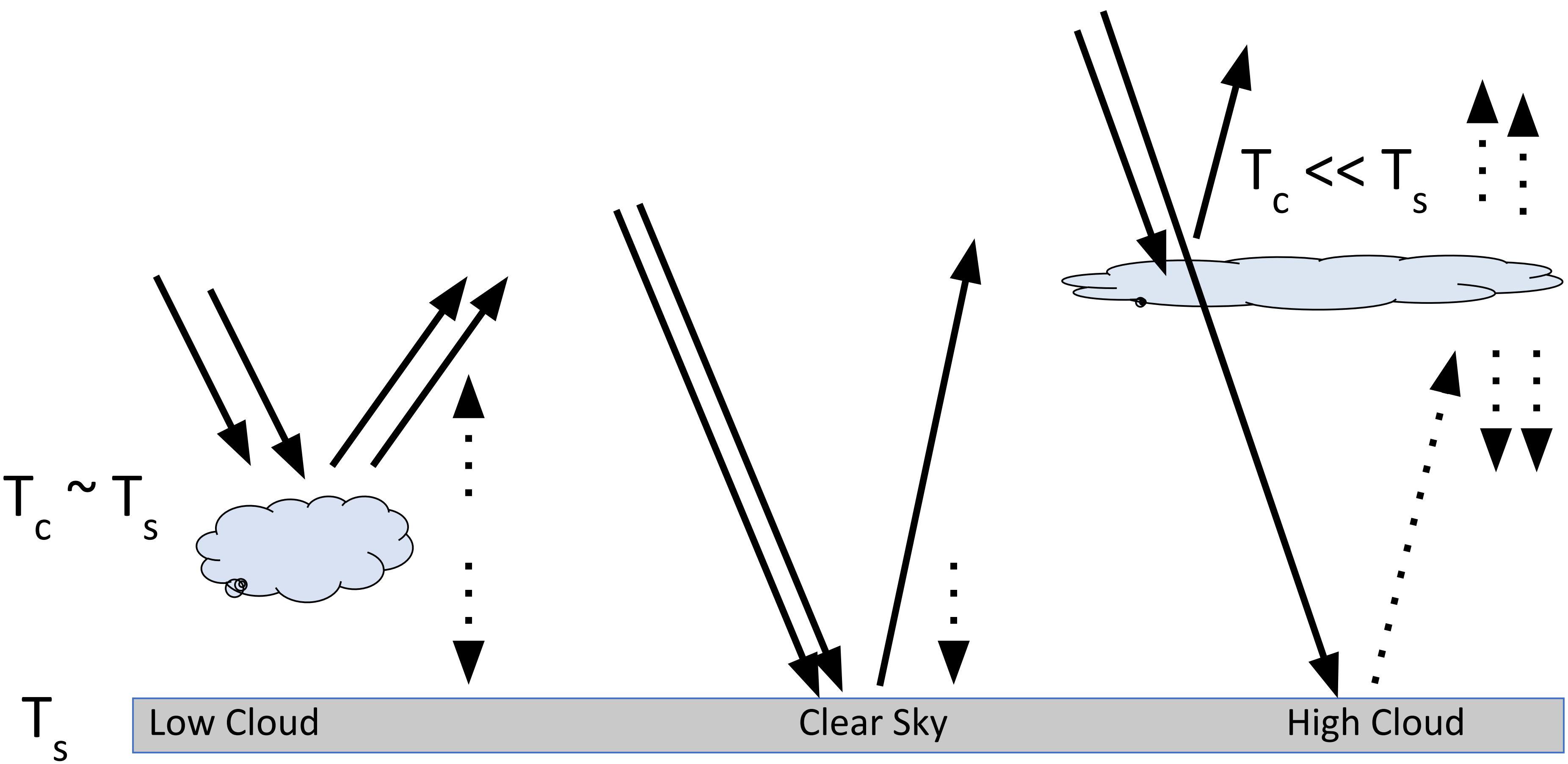


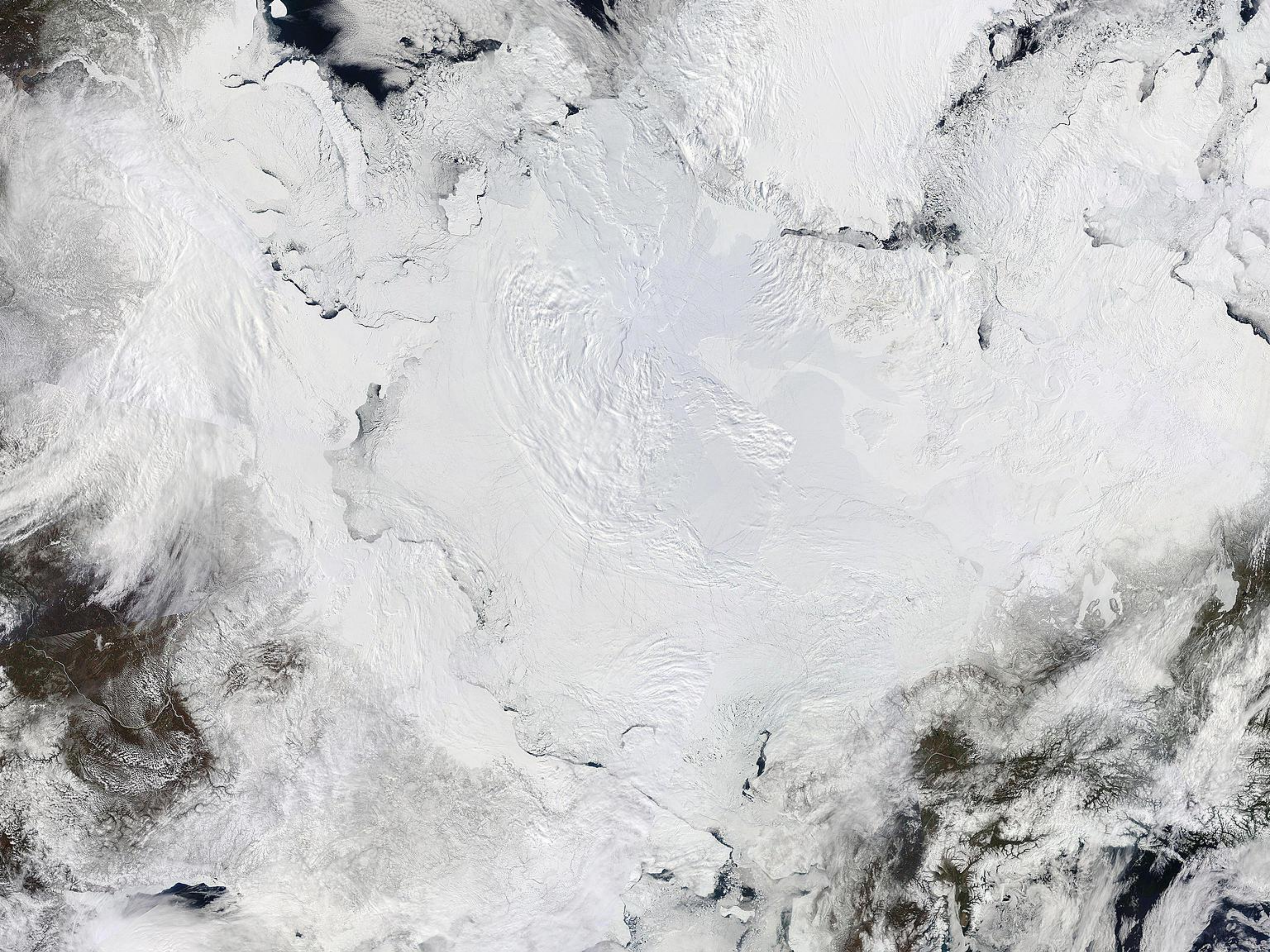
Cloud Radiative Effects in the Climate system

Solar (cooling) & Infrared (heating)

Solar = Shortwave (SW)

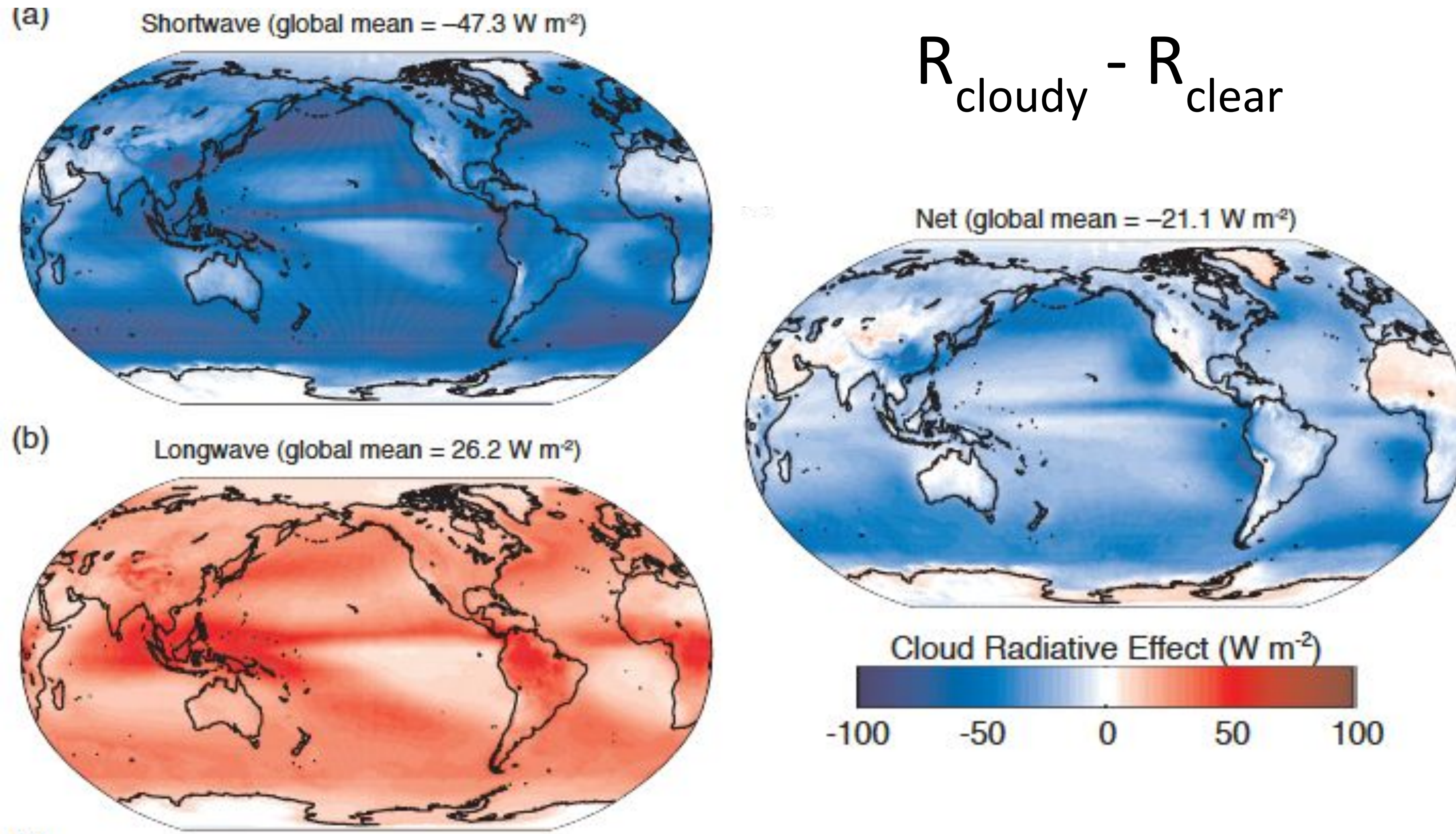
Infrared = Longwave (LW)





Cloud Radiative Effects

$R_{cloudy} - R_{clear}$



IPCC 2013 (Boucher et al 2013) Fig 7.7

Aerosols

Clear sky in Beijing, July 2010, 17:00 LT looking west

Radiation Parameterization

Typical Parameterization:

- LW absorption/emission,
- SW scattering/absorption
- Cloud absorption and scattering (aerosols too).
- Plane-parallel. (3D much more expensive)
- Single-scattering approximation

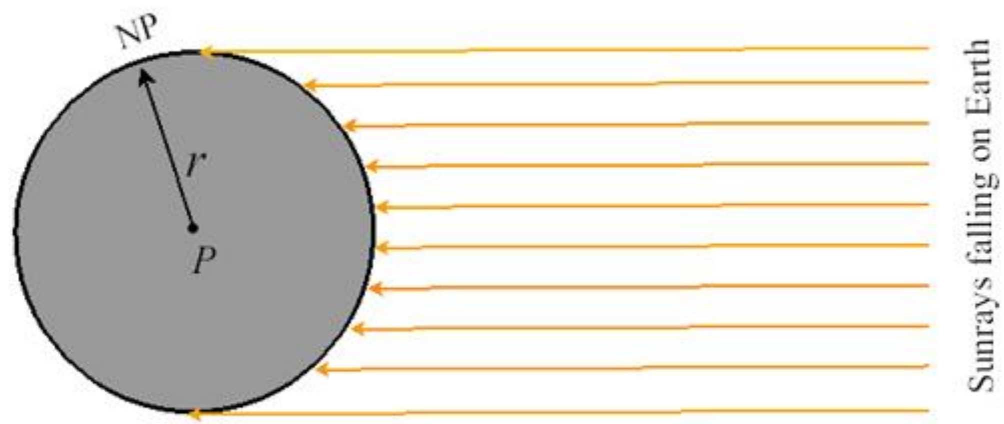
Methods for Solving Radiative Transfer

Assumptions:

- Plane-parallel (single column)
- Single-scattering approximation

Methods:

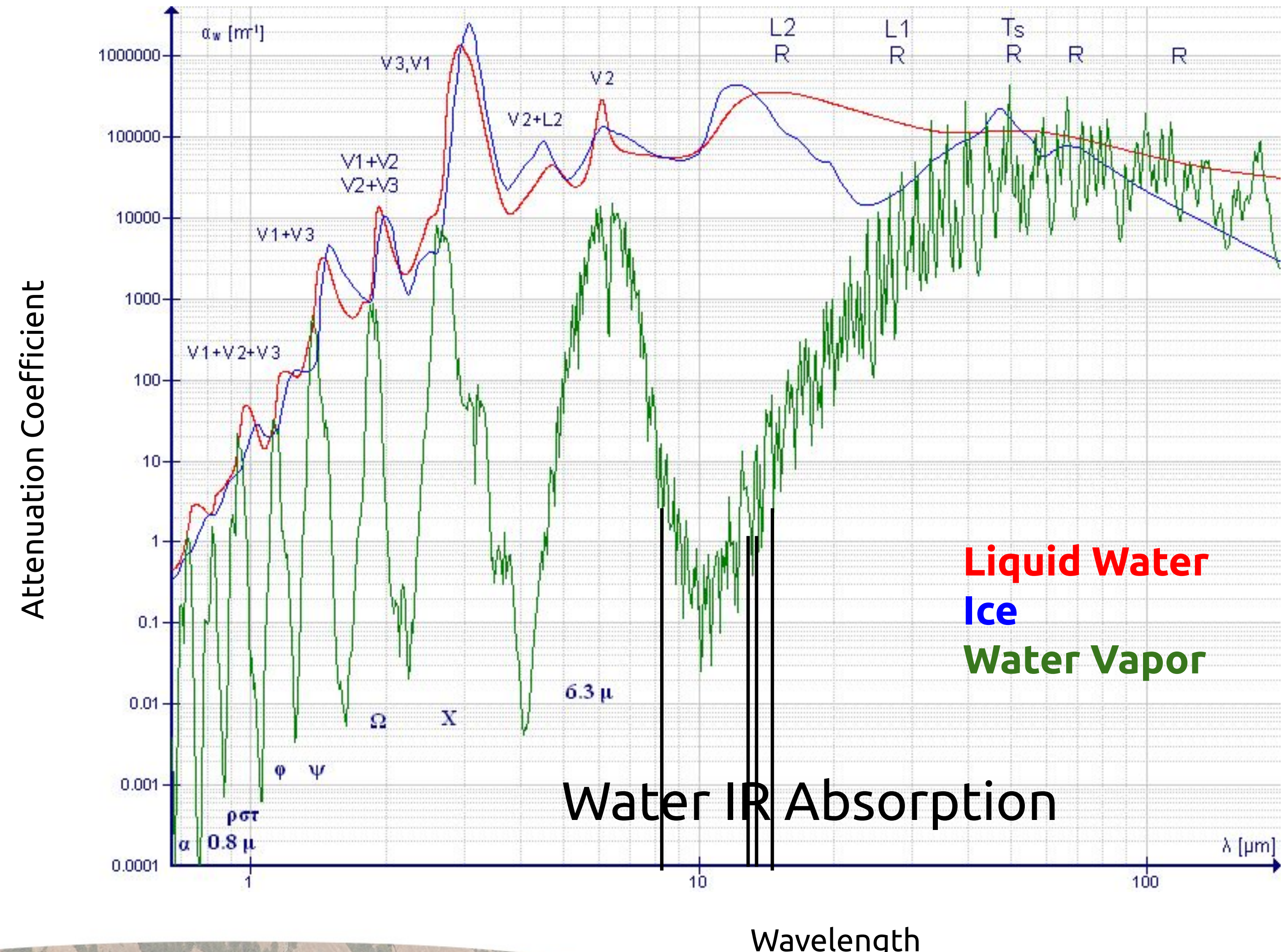
- Line-by-line
- Broadband
- Correlated-K



Plane Parallel Approximation

Methods: Line by Line

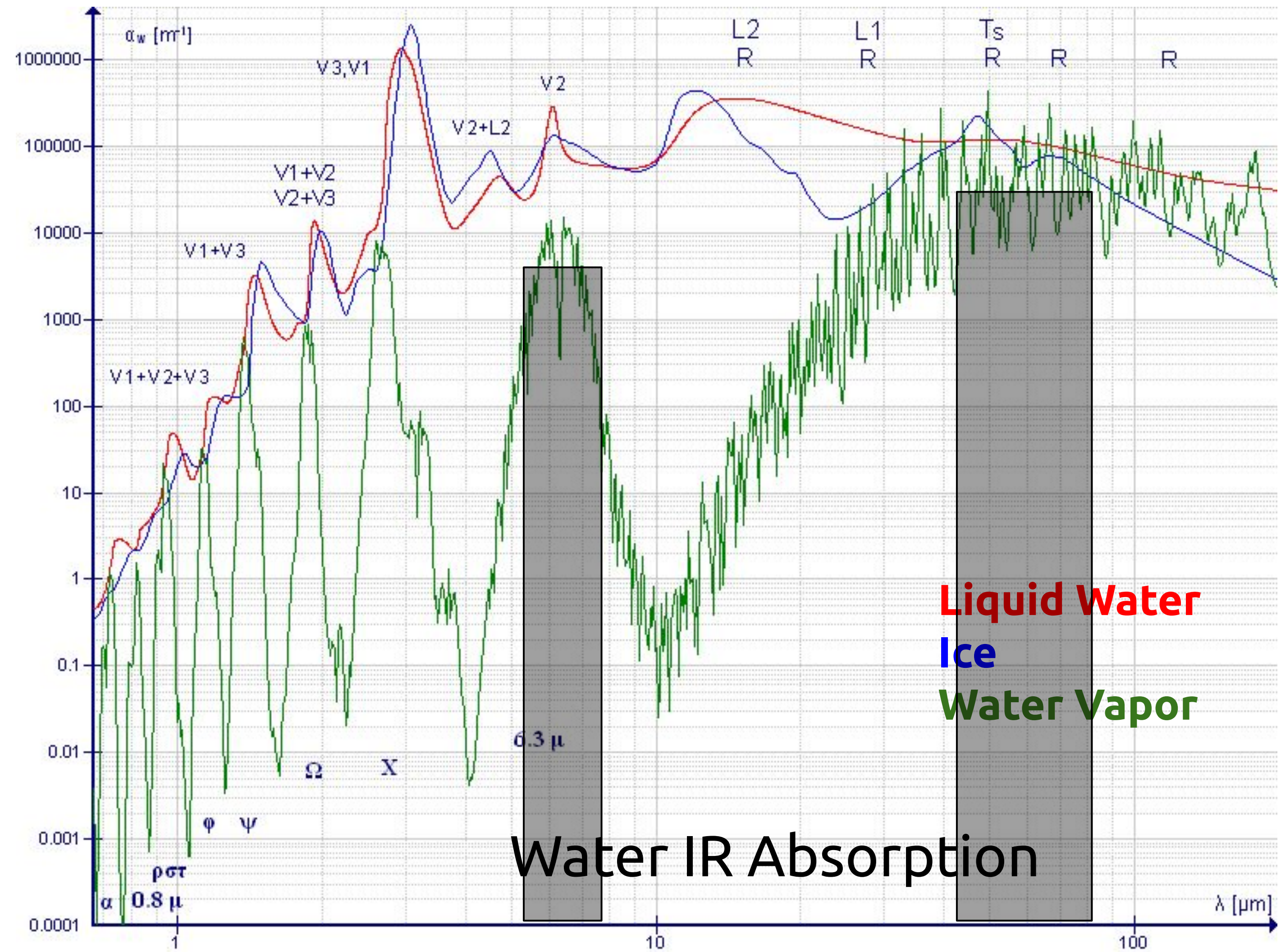
Typically 1000's of lines.
Most accurate, but expensive (treat every line)
Lines are partly 'empirical' (measured in lab, not theory)



Methods: Broadband

Typically 10’s of bands.
Cost effective, but a big approximation
Subject to significant errors

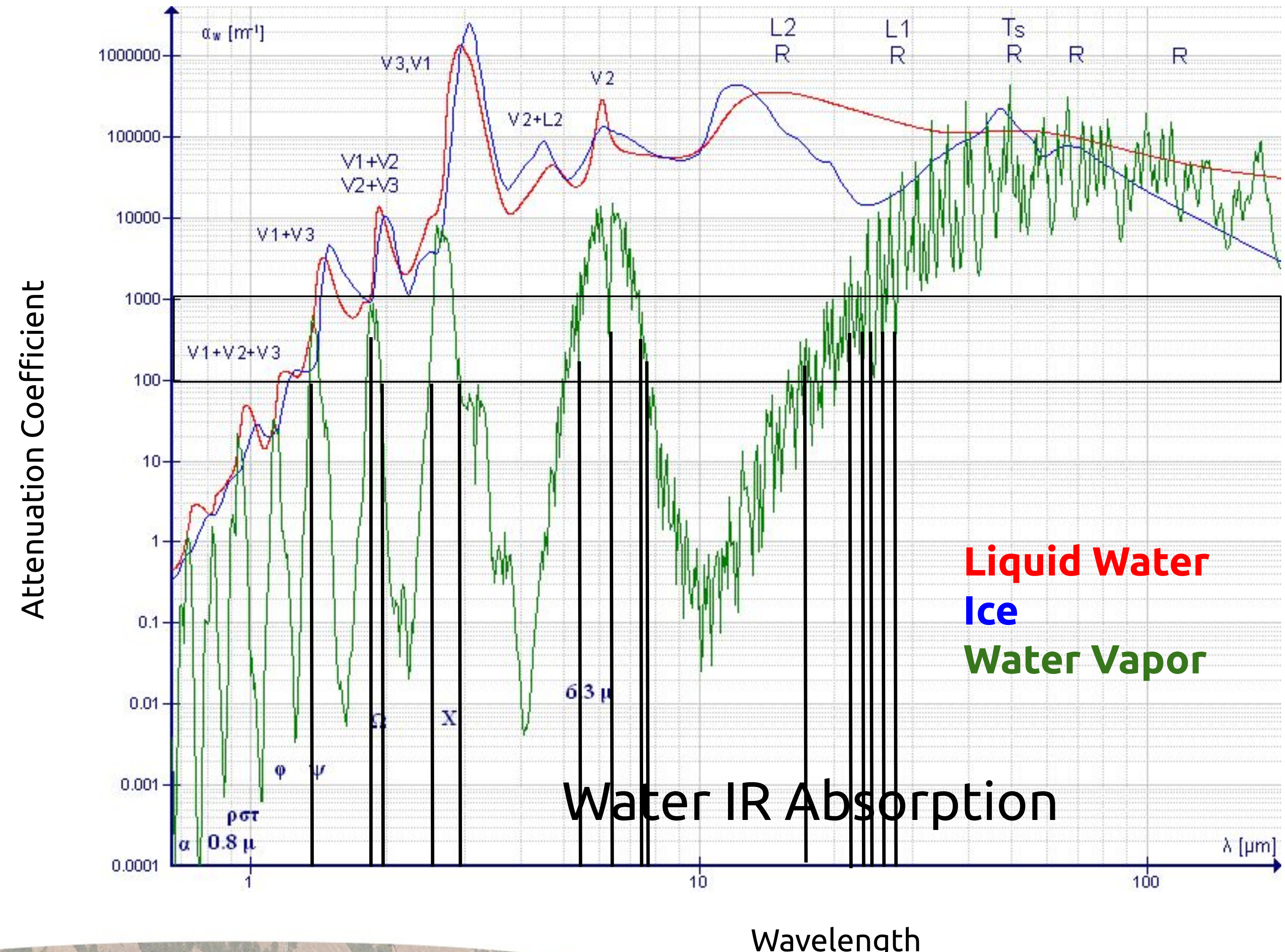
Attenuation Coefficient



Wavelength

Methods: Correlated-K

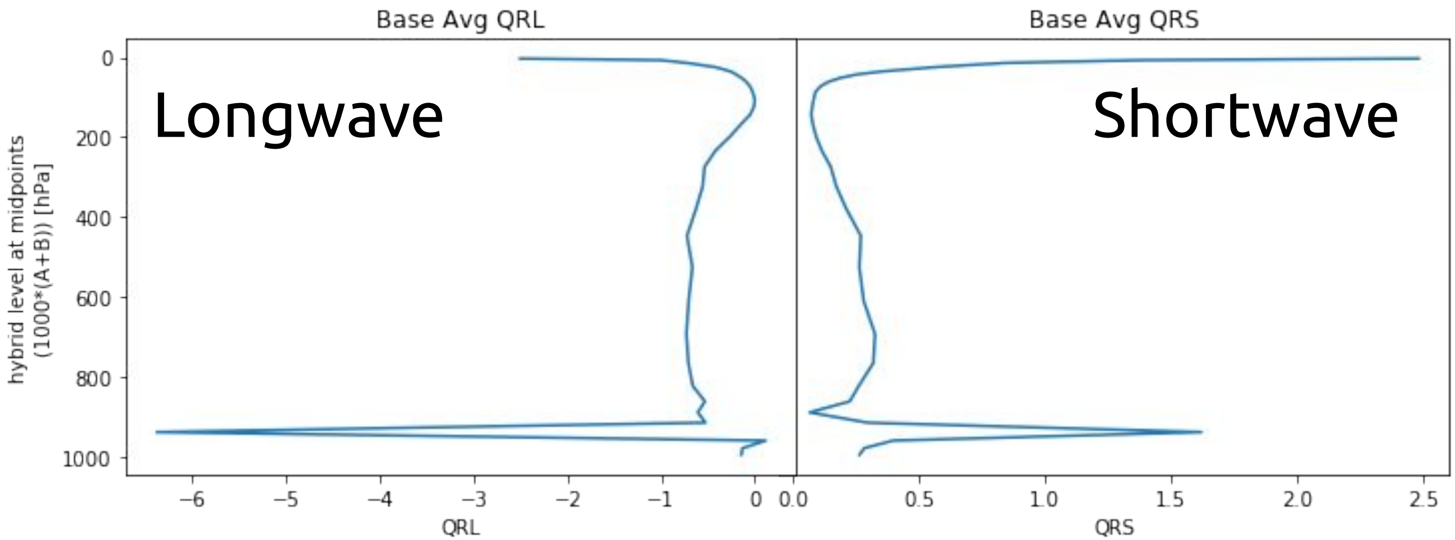
Typically ~100 bands.
Accurate and cost effective
Group bands by Absorption/Attenuation….

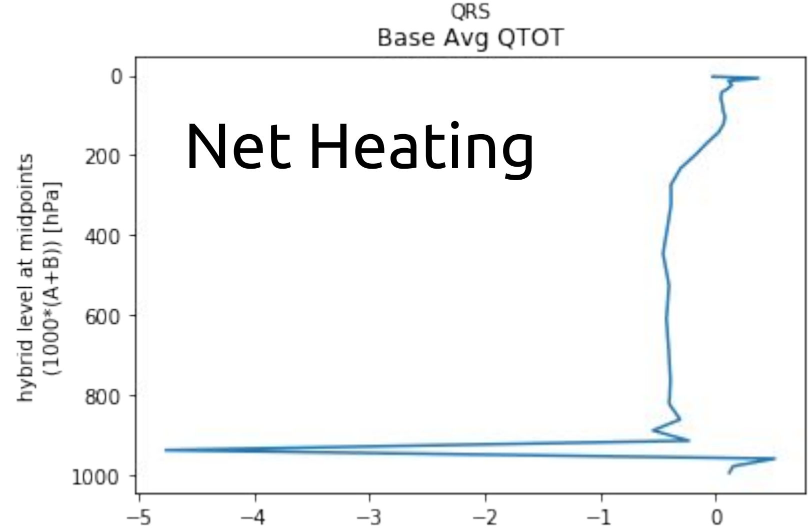


RRTMG Methods: Overview

- Correlated-k distribution for treating gases (sets spectral discretization)
- SW Transport calculations using two-stream (aka delta-eddington) in the single-scattering approximation in the SW.
- LW: same approach: neglect LW scattering
  - 2x faster without LW scattering,
  - LW scattering is about a 1-2% correction
  - LW is basically a 1-stream method computed at a single quadrature angle to represent full hemispheric irradiance.

Basics: Heating Rates CGILSS11





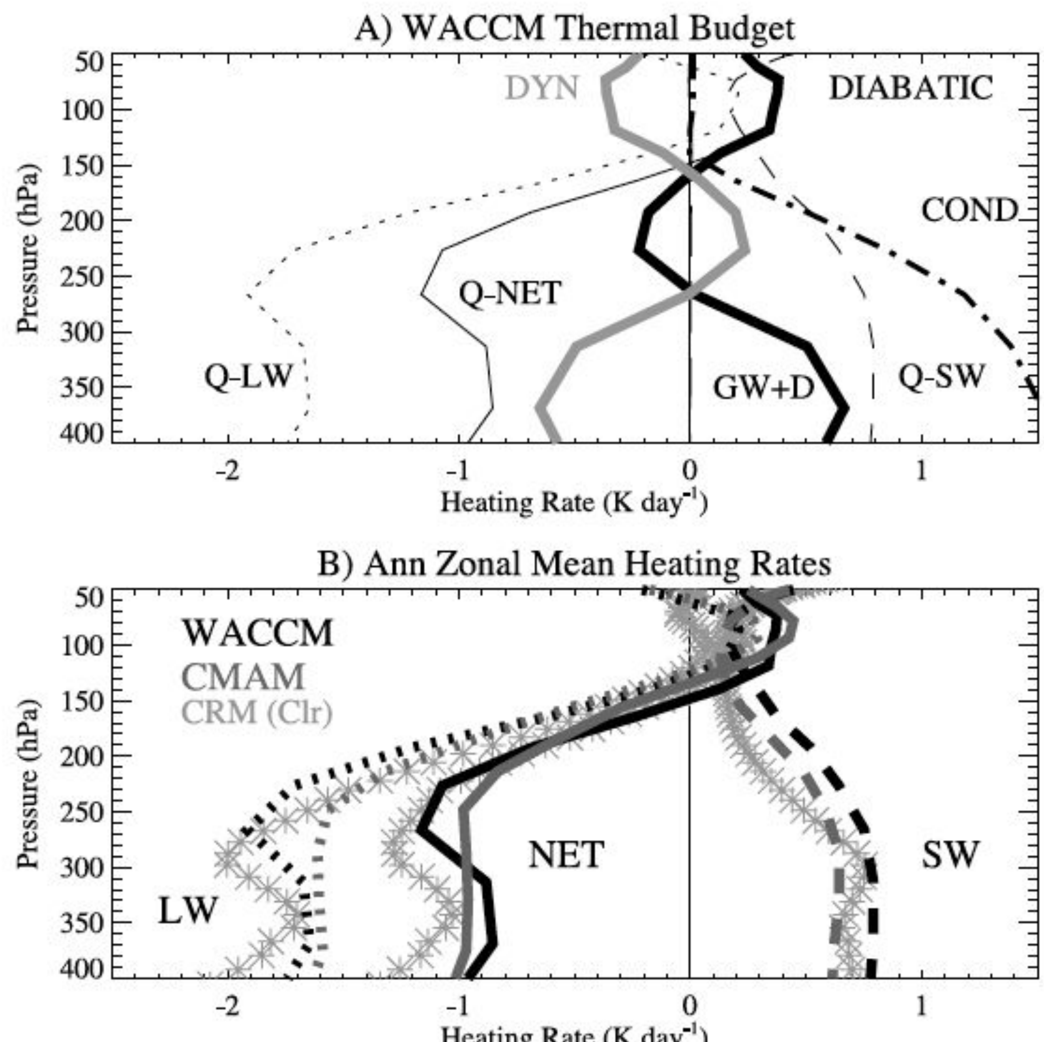
- Clearsky Cooling in Troposphere
- Cloud top cooling & absorption
- Ozone Heating

Aside: Tropical Tropopause

Near tropopause: Transition between net radiative cooling (H2O) and warming (O3).

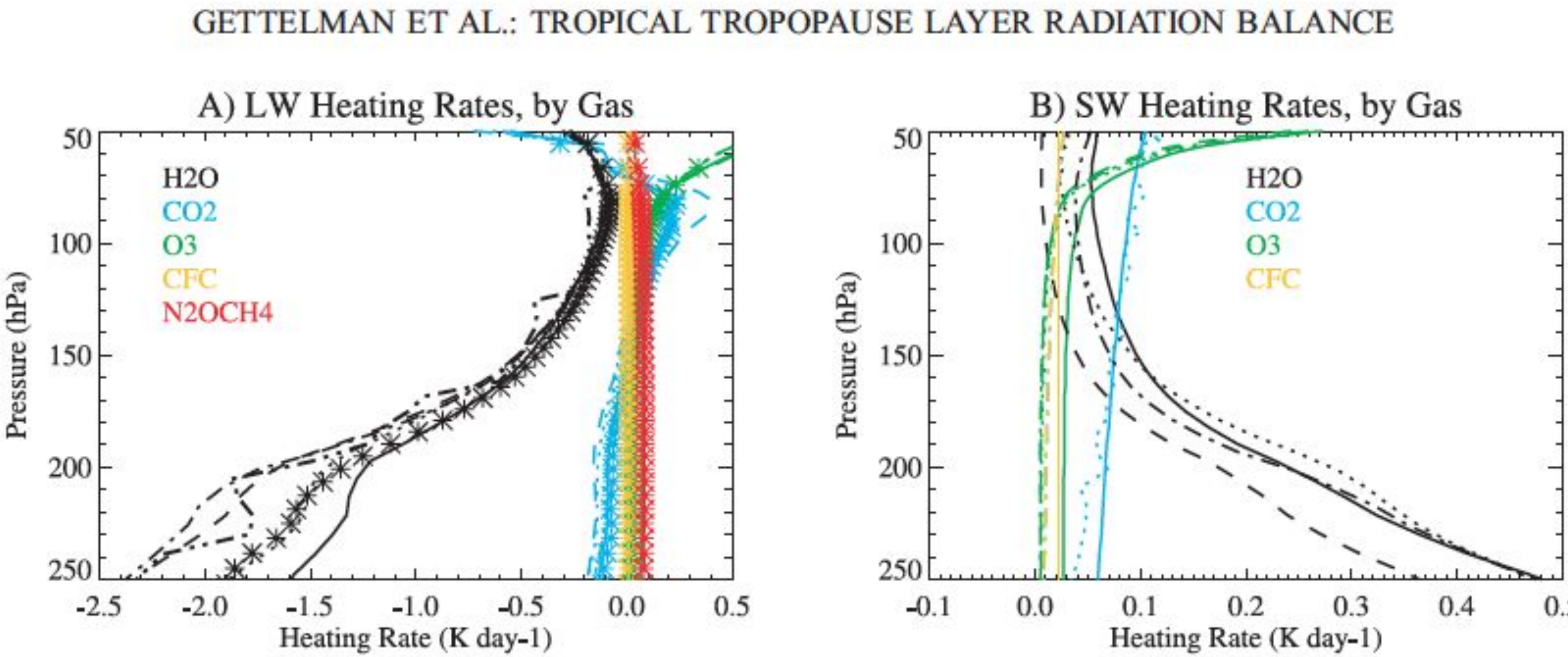
Zero Rad Heating = base of the Tropical Tropopause Layer

Where condensation heating is no longer balancing radiative cooling



Gettelman & Birner 2007

Aside: Tropical Tropopause



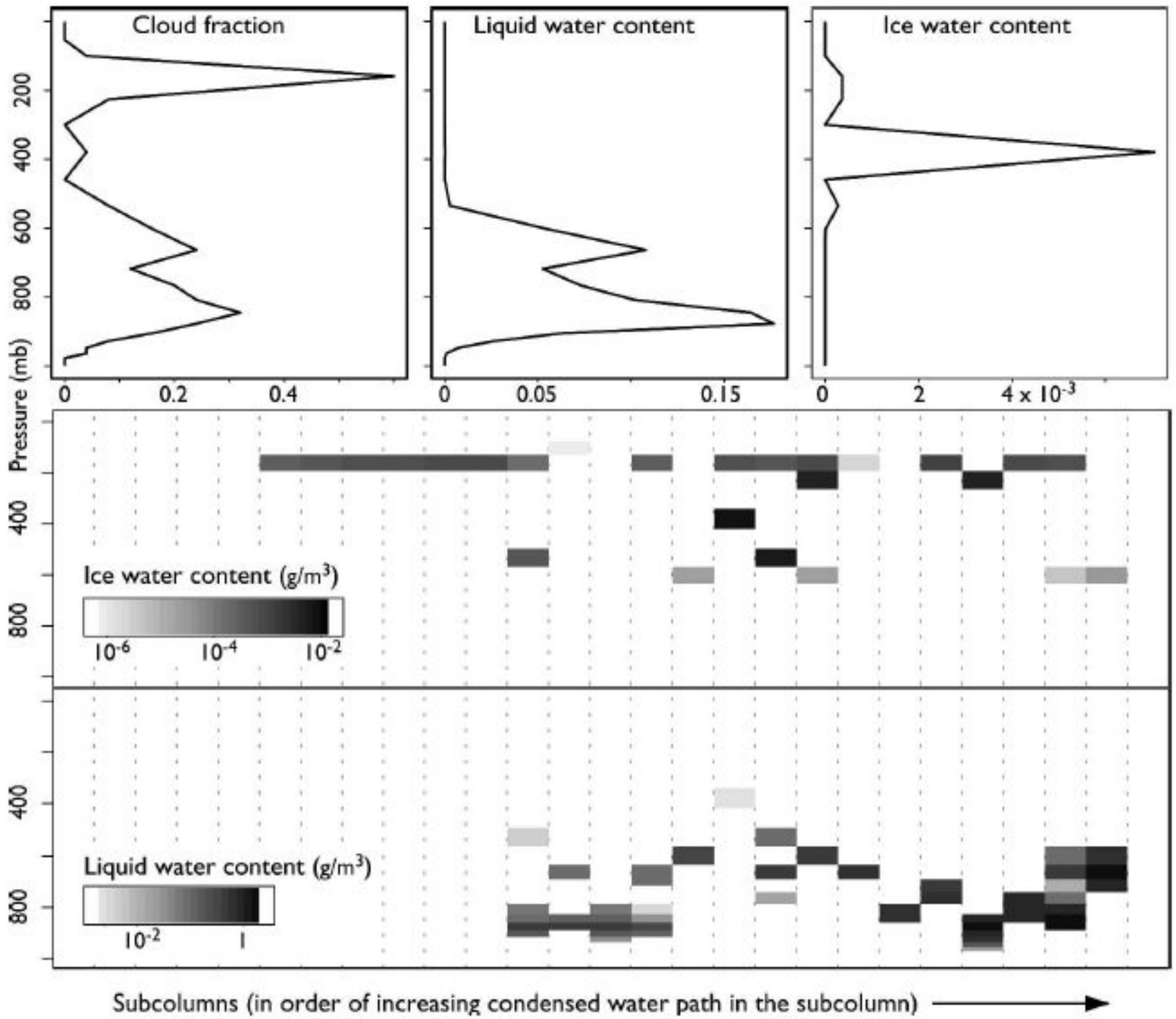
Can break down the heating rates by gases

- LW: H2O most important. Note CO2 rad heating in lower strat
- SW: H2O (smaller), O3 in stratosphere, CO2 all the way through

Cloud Overlap

- RRTMG methods on sub-columns that include gases and condensed species (clouds and aerosols)
- Pre-computation of optical properties for clouds and aerosols,
  - Depends on some parameters (e.g. effective radius for cloud drops, with more complicated parameters for ice and aerosols)
- Sub-columns to treat sub-grid variability in clouds
  - Cloud Overlap
  - Correlation of water vapor and condensed cloud
- Monte Carlo Independent Column Approximation (McICA)
  - Sample the subc-olmns for efficiency

Cloud Overlap



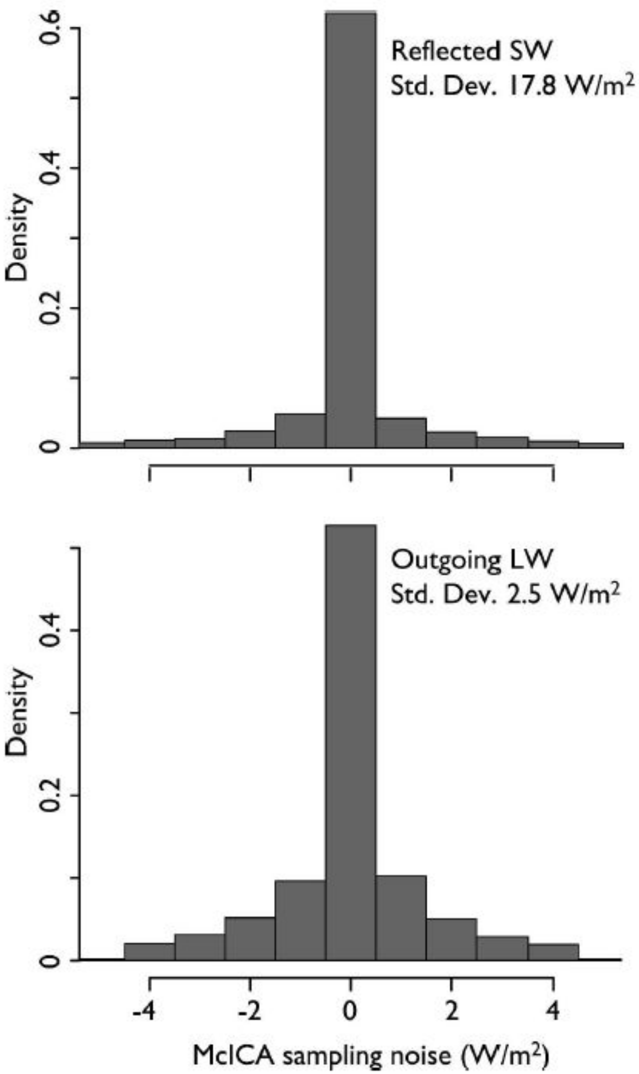
Pincus et al 2006

McICA
Monte carlo Independent Column Approximation

- Sub-grid variability of clouds (cloud fraction) requires radiation to “guess” cloud overlap.
- Assume clouds maximally overlap if they are in neighboring levels
- Assume clouds randomly overlap if there is a vertical gap between clouds
- Construct independent columns that satisfy the cloud fraction and cloud overlap model
- Sample the independent columns when performing the radiative transfer computation in each of the 128 correlated-k bands
- [Each independent column is applied to a different “color” of light]
- Enough monte-carlo samples converge to full radiative transfer though collection of independent columns.

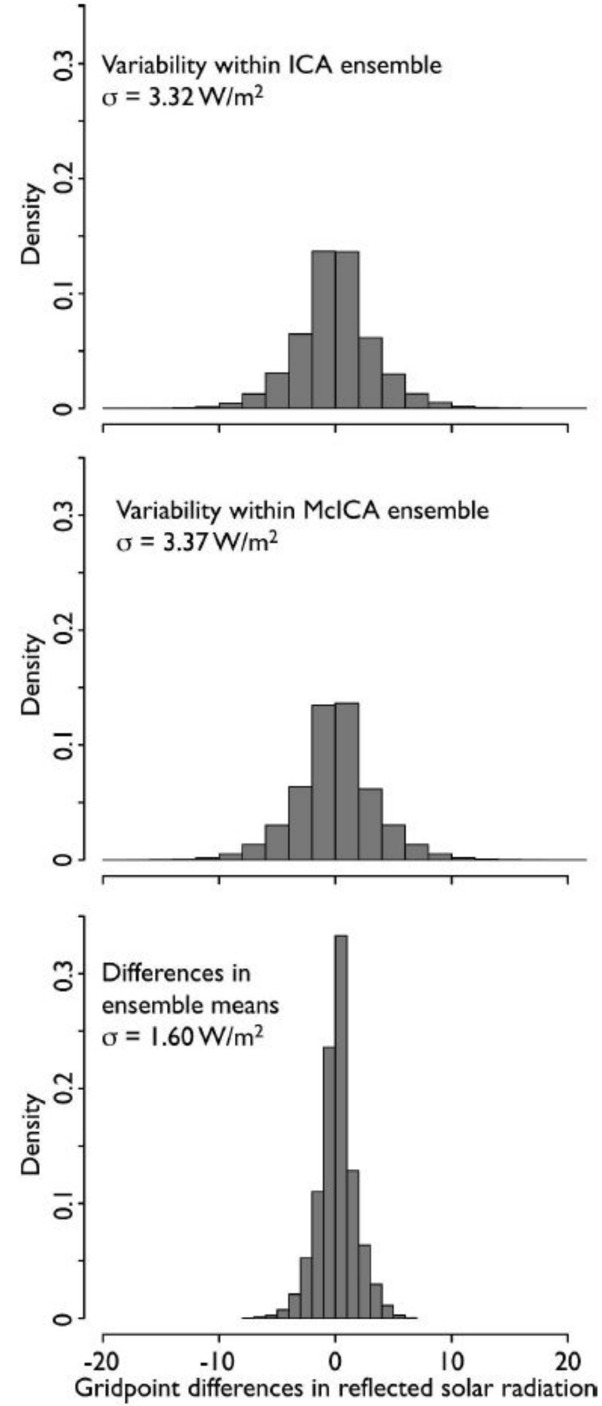
McICA Sampling Noise

Pincus et al 2006: AM2 (GFDL Model)



Differences between sampling every subcolumn (ICA) and (McICA)

Variations in ICA ensemble v. McICA ensemble larger than ensemble mean diffs



Aerosols and Radiation

- Aerosol optical properties (like clouds) have slow variation across the spectrum
- No subgrid fraction
- Strongest net flux effect is in solar
  - Scattering and absorption
- Small net flux effect in the longwave
- But: significant stratospheric LW heating
  - Volcanic eruptions / geoengineering

Aerosol-Radiation Interface

- RRTMG
  - Radiative transfer,
  - McICA,
  - gas phase optics.
- Condensed phase optics (in-cloud and aerosol optics) are 'parameterizations' based on microphysical state and are computed externally to RRTMG.
- Optics are assumed to be function of band, but constant for each correlated-k band inside of each band
- Optics are based on microphysical state of clouds/aerosols

Optics Based on Microphysics

Ice clouds

- Morphology fixed: shape recipe based on mid latitude cirrus (Mitchell)
- Size distribution

Liquid clouds

- Fully consistent mie calculations with mu and lambda parameters from cloud drop size distribution

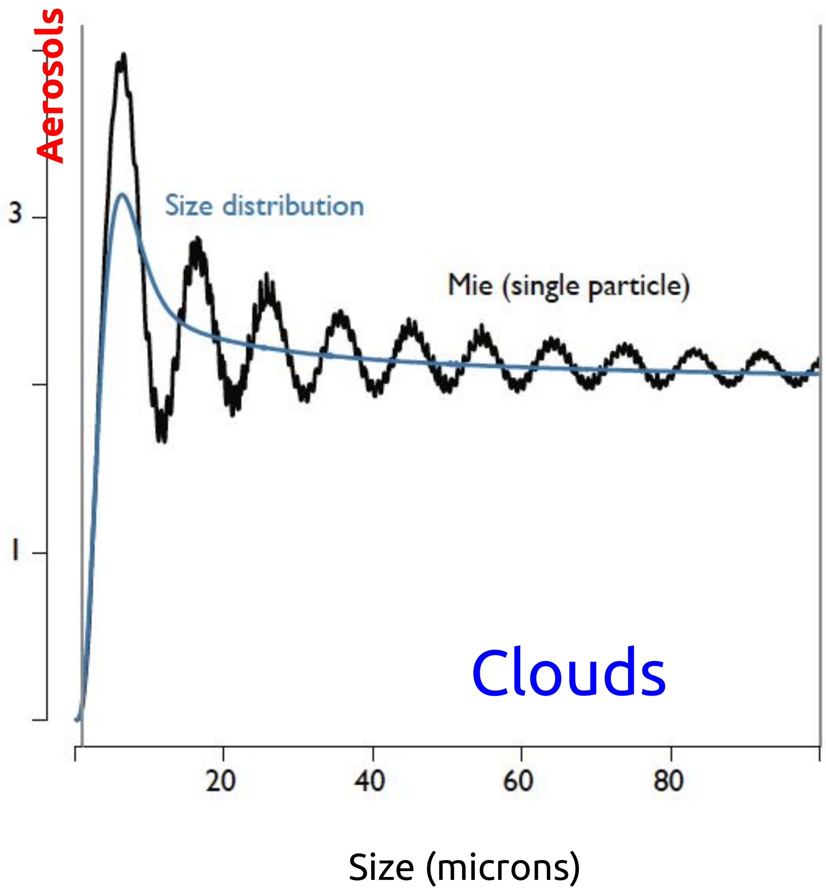
MAM aerosol

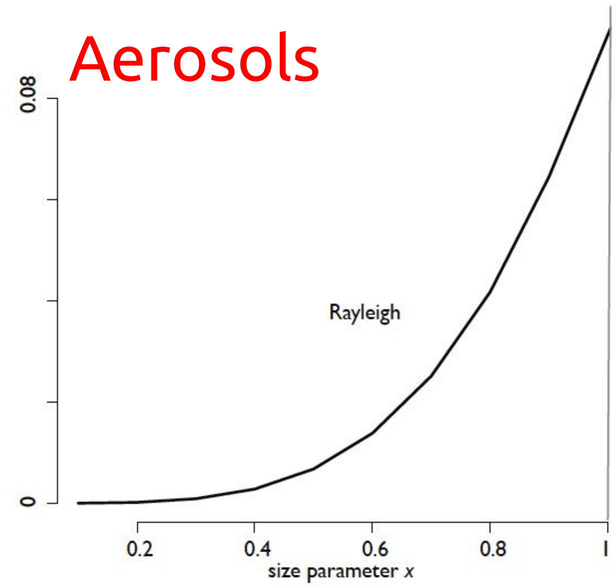
- 3, 4, or 7-bins of internally mixed aerosol
- number-weighted average of index of refraction of composition
- Log-normal size distribution with fixed width and varying radius
- Water-vapor uptake

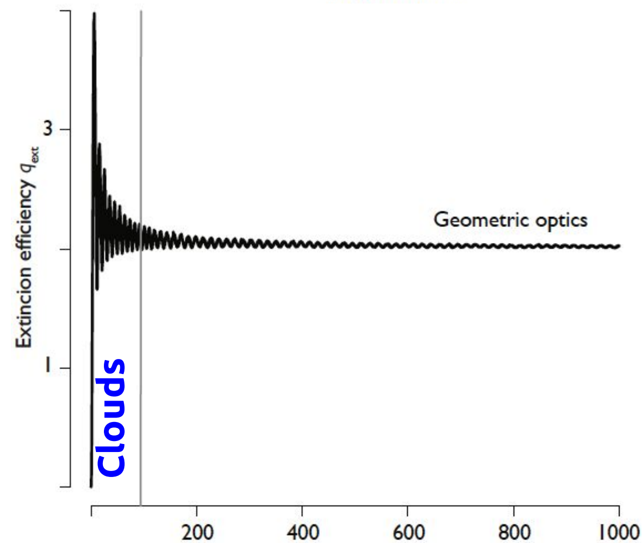
BAM aerosol

- Externally mixed with single-chemical composition
- Lognormal distribution with fixed (dry) radius and width
- Water-vapor update based on relative humidity

Liquid Cloud/Aerosol Optics

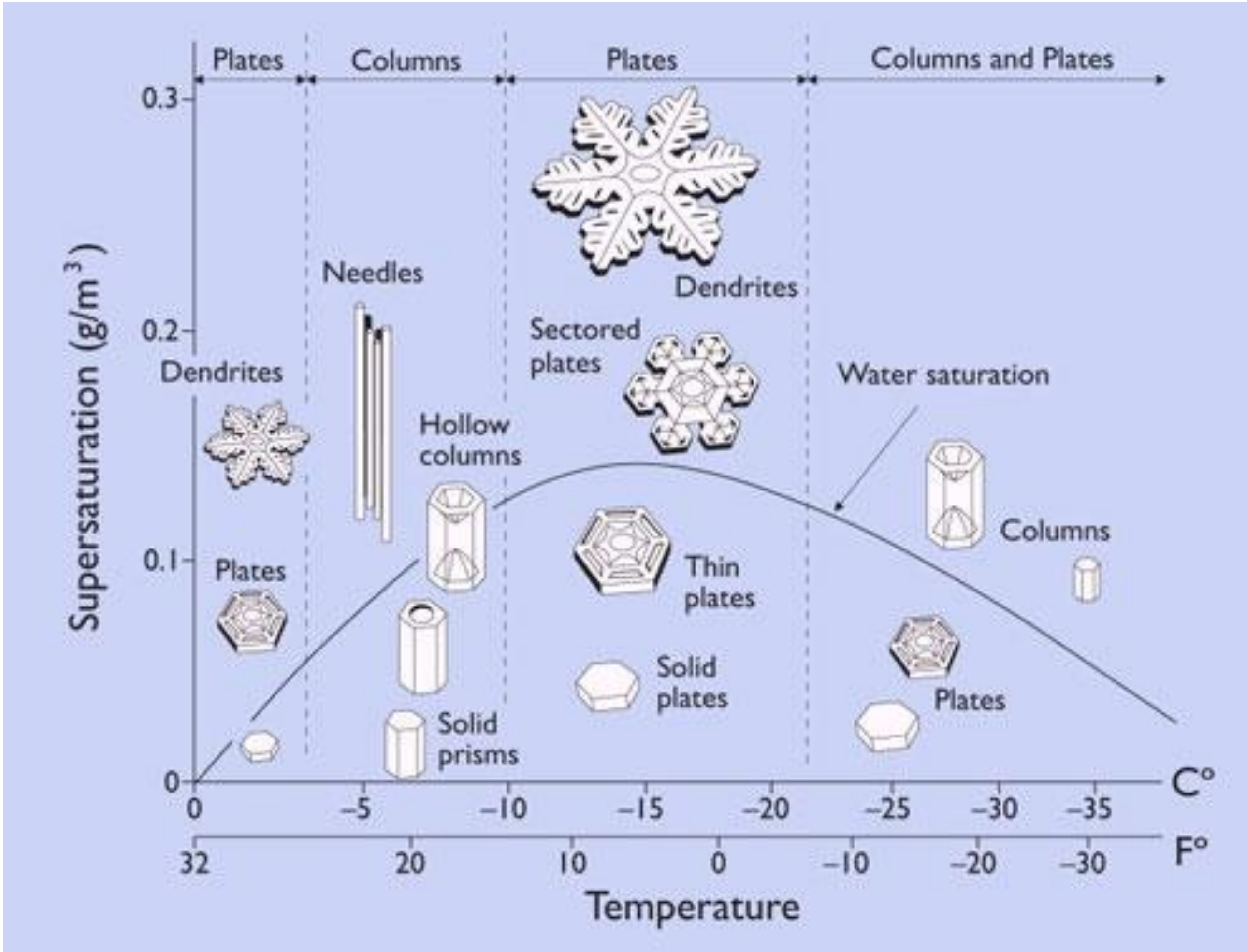






Precipitation

Ice Optics



CAM uses a specified habit mix appropriate for mid-latitude cirrus (-20 to -35˚C)

Radiative Forcing

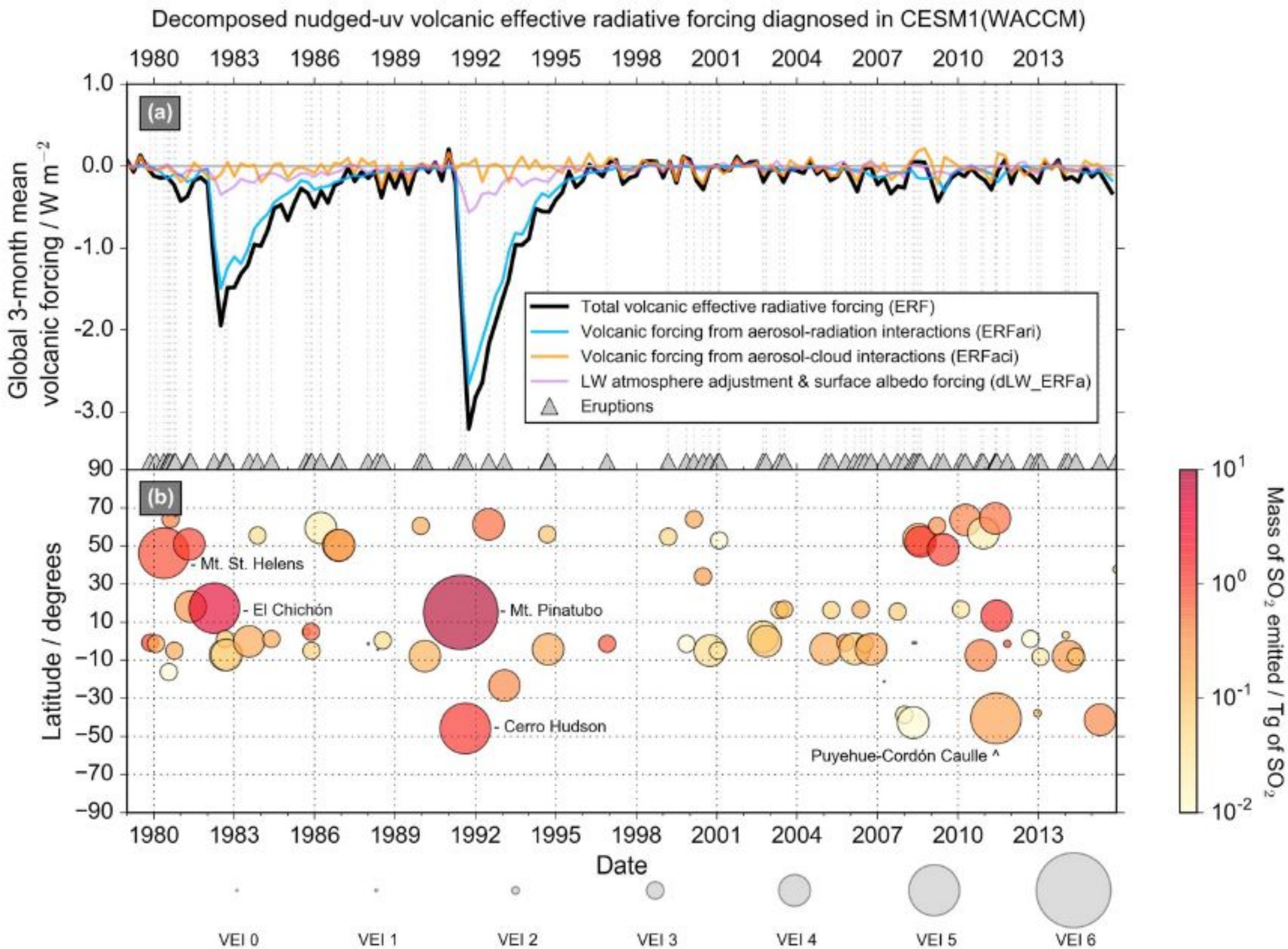
"Change in net top-of-atmosphere flux due to change in composition/emissions/optics/surface"

- **Instantaneous Radiative Forcing (IRF)**
  - Net Flux change due to a change in composition given a specific time-sample-sequence of atmospheric states.
- **Radiative Forcing (RF)**
  - Same as IRF, except the stratosphere temperature is allowed to relax under the assumption of fixed stratospheric dynamics (but heating changes)
- **Effective Radiative Forcing (ERF)**
  - Allow land and atmosphere to respond, but fix ocean temperatures
- **ERF w/TS correction**
  - Like ERF, but recompute TOA flux with surface temperatures adjusted back to original case for the flux computation

How to Calculate RF

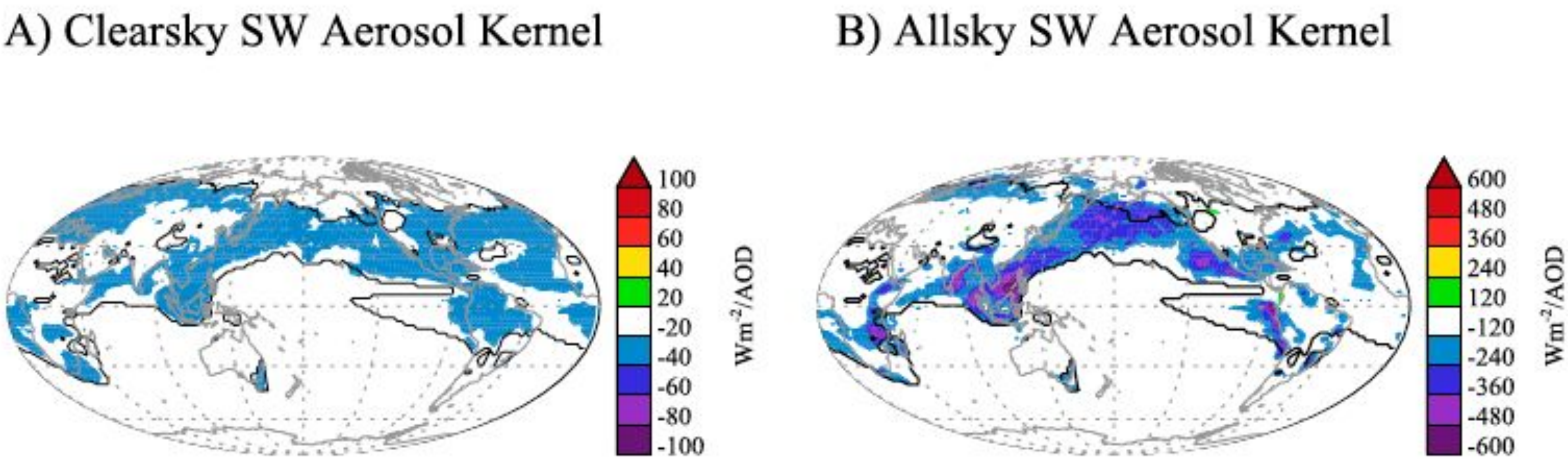
- Difference of 2 runs (but climate noise)
- Alternative method:
  - Additional 'diagnostic' radiation call
  - Can remove one gas at a time
  - Can also remove aerosols
  - Yields an RF, Difference of two of these is ERF
- Examples follow
  - Exercise will show how this 'rad_diag' works (namelist parameter)
- Also: PORT (Parallel Off-Line Rad Transfer)
  - Method to calculate column radiation off line for a collection of columns (like the whole planet)
  - Good for RF calculations

Volcanic ERF

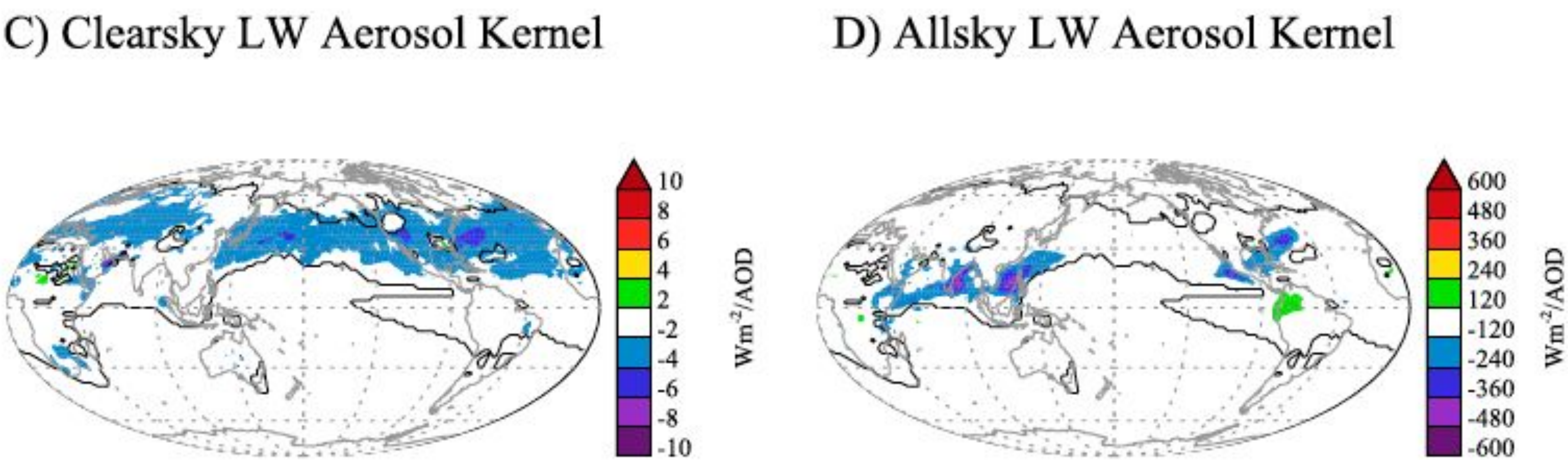


Schmidt et al 2018

Anthropogenic Aerosol ERF



Aerosol Kernel of Wm-2/AOD from CAM5 Present - Pre Industrial Simulations
To get ERF multiply by dAOD



Summary

- CAM Solves Rad Transfer using Correlated-k (RRTMG)
- Condensed phase optics vary by species
  - Liquid, Ice, Aerosols
  - Optics (tau) fed into radiation (Not part of RRTMG)
- Sub-grid variability for clouds (McICA)
- CAM Has Capabilities to manipulate the radiation code, e.g. Radiative Forcing