Implications of new indices of refraction of water for simulated thermal emission from supercooled clouds in Antarctica

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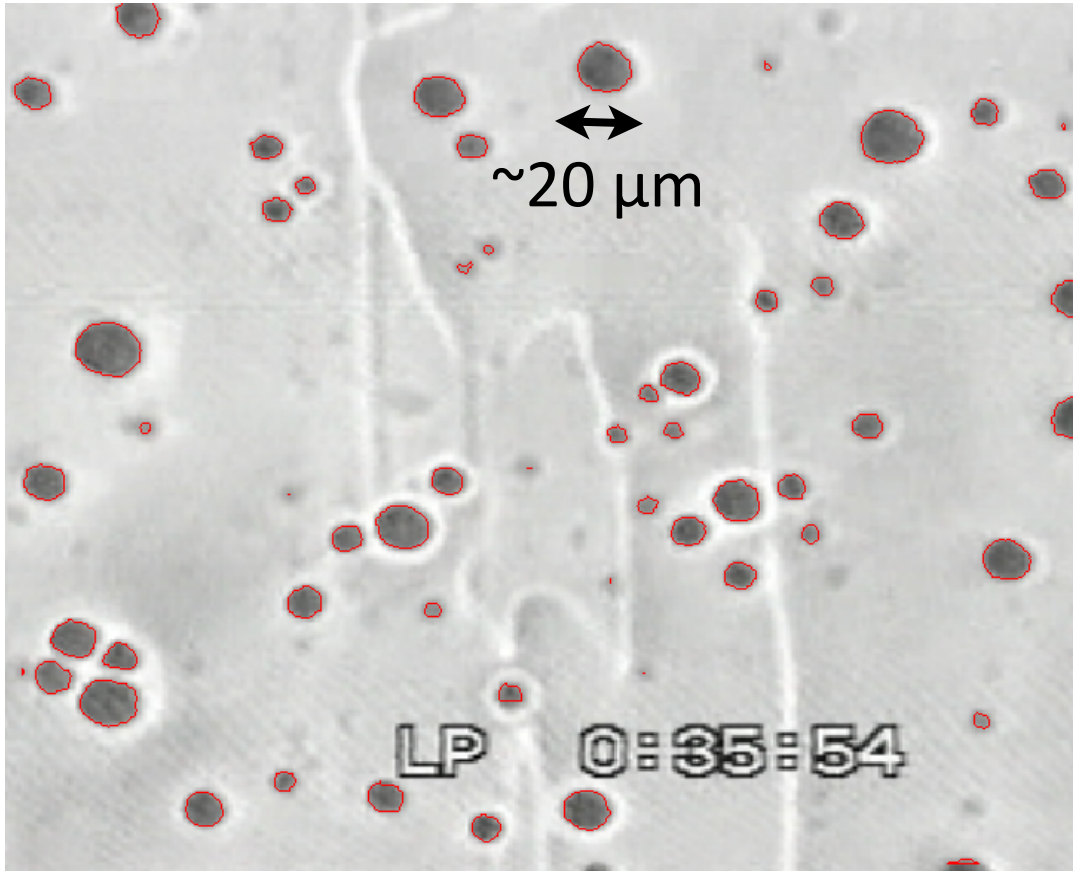
Scientific Committee on Antarctic Research (SCAR)
16-19 July 2012

Motivation

- Cloud radiative forcing is important for climate.
- Most radiance simulations use indices of refraction (IORs) for liquid clouds corresponding to $T > 0^{o}C$.
- But supercooled liquid clouds occur in the Antarctic and elsewhere.
- IOR spectra of supercooled water are now available (Zasetsky et al, 2005; Wagner et al, 2005).
- How important is it to include temperature-dependent IORs in radiance simulations of supercooled clouds?

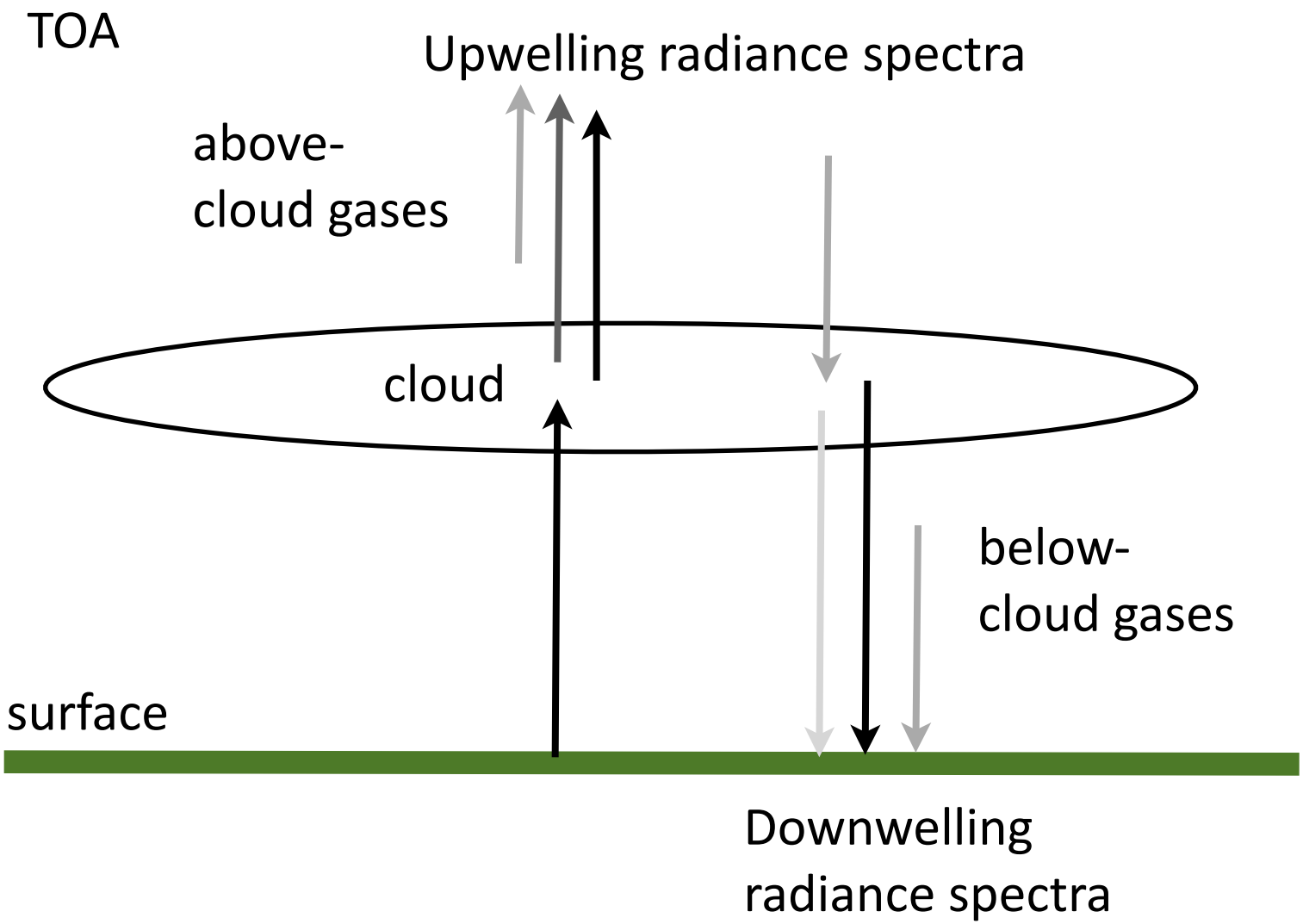
Observations of supercooled liquid water droplets at South Pole 2 Feb 2001, -32 C



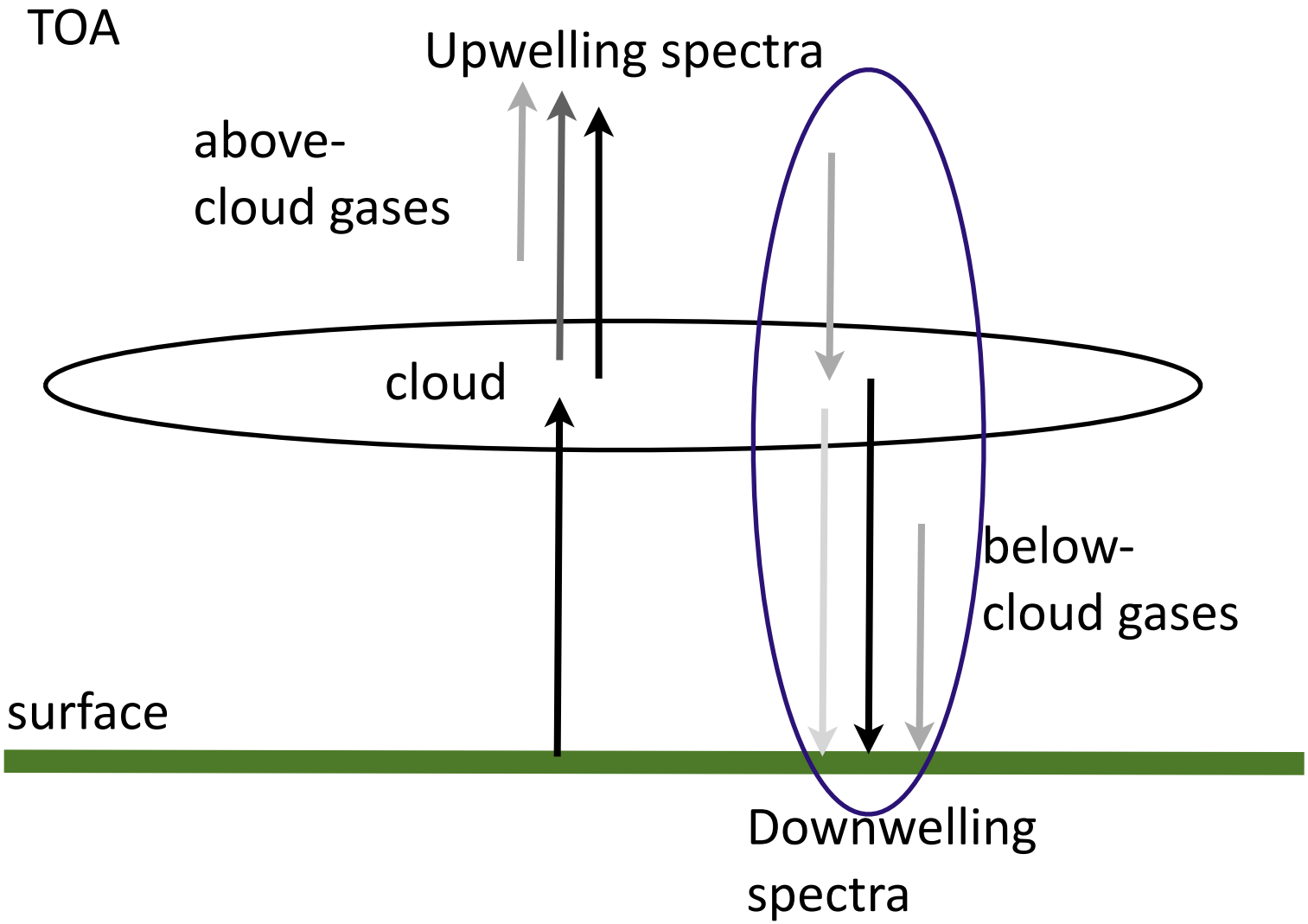
Walden et al., in preparation

Radiances

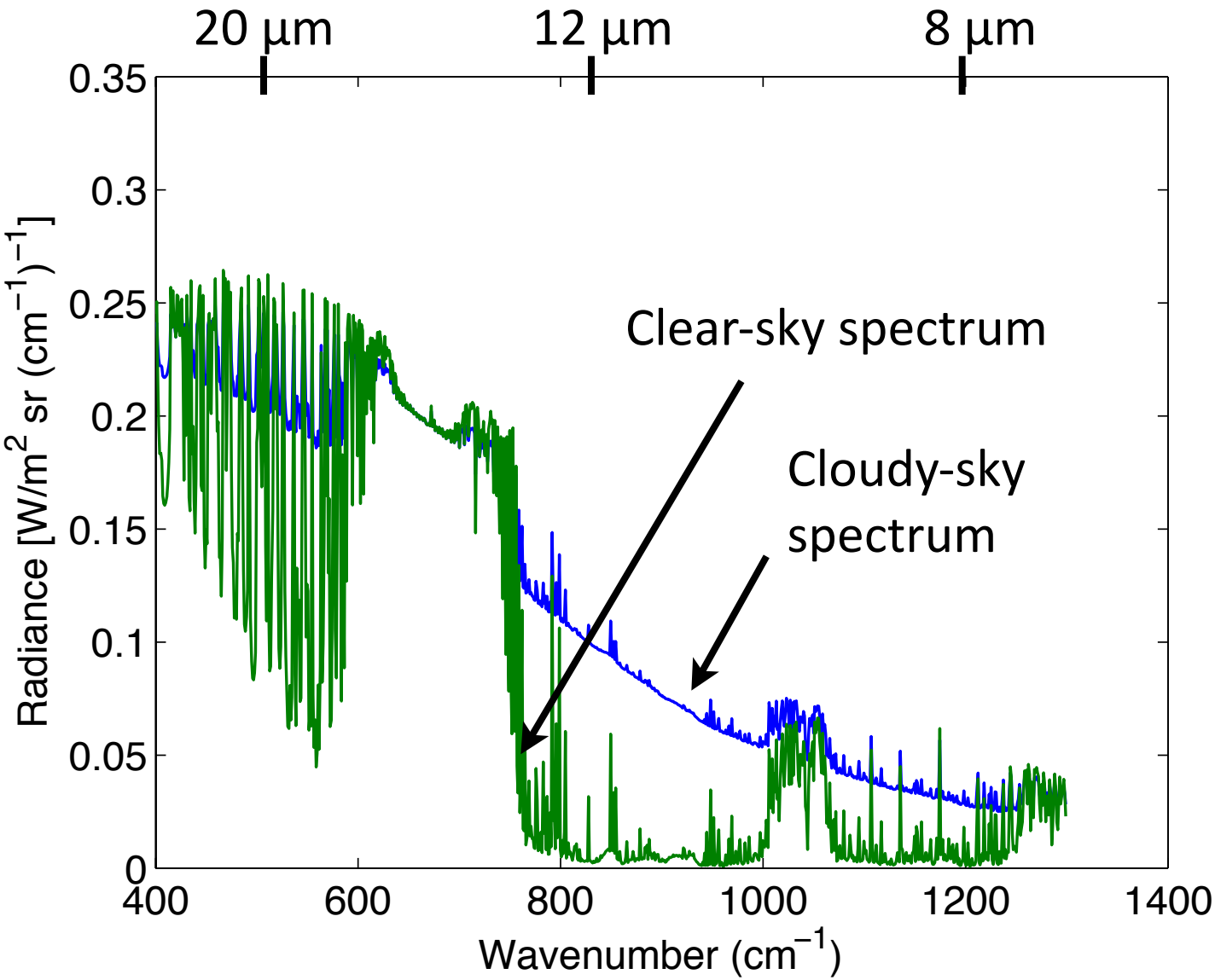
Thermal radiance [W m^2 sr^{-1} $(cm^{-1})^{-1}$]



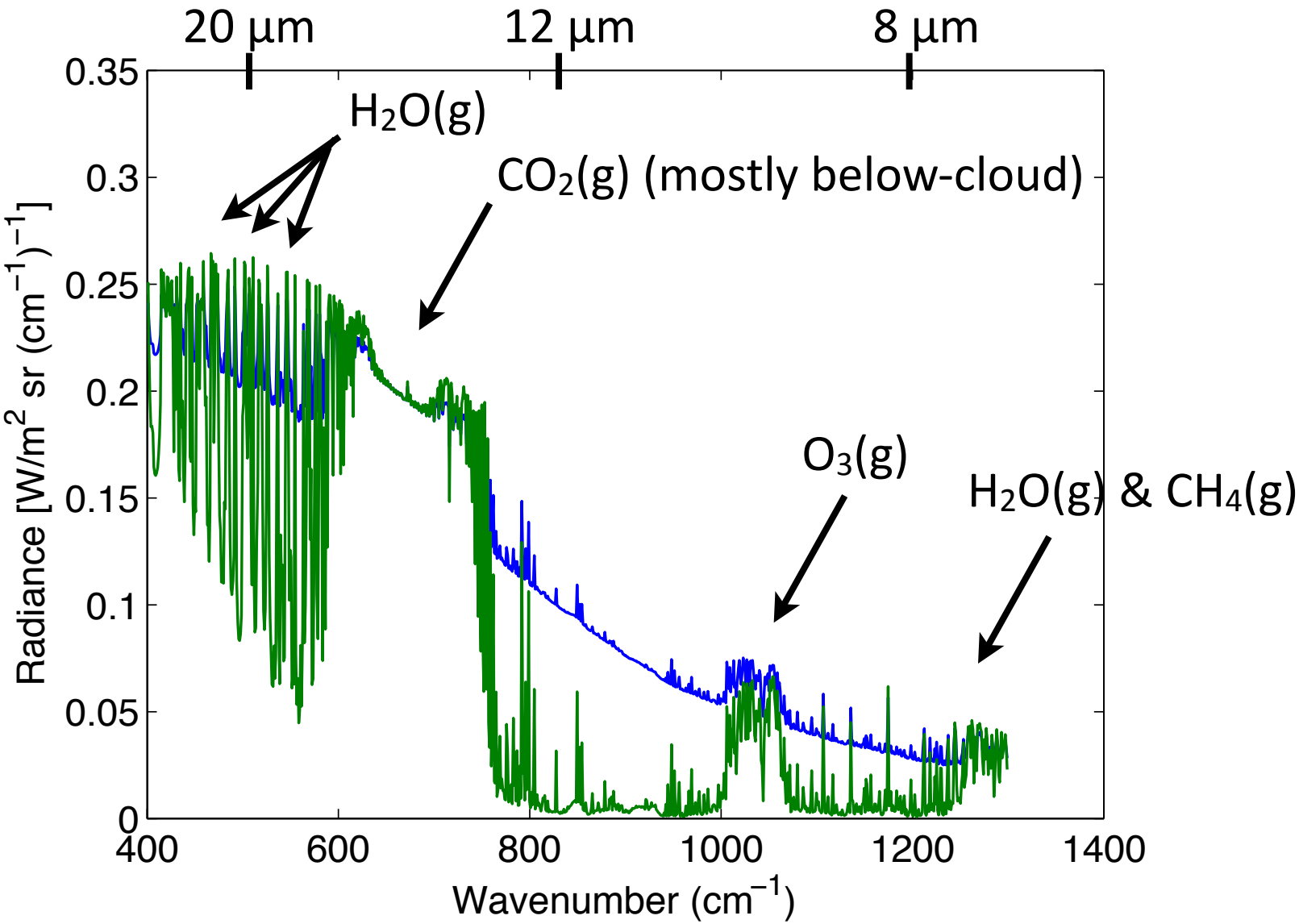
Thermal radiance from the atmosphere



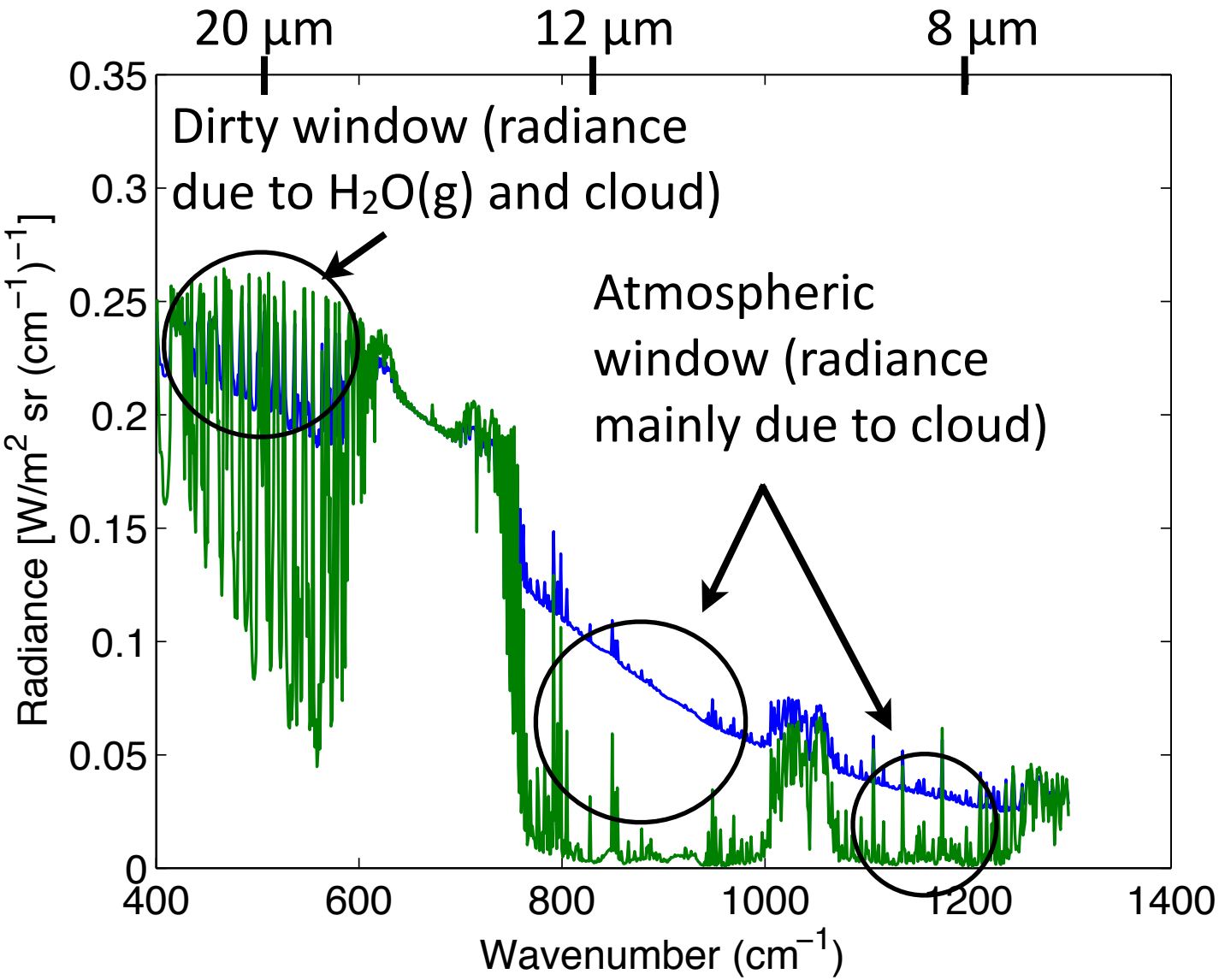
Downwelling radiance: effect of clouds



Downwelling radiance: gases

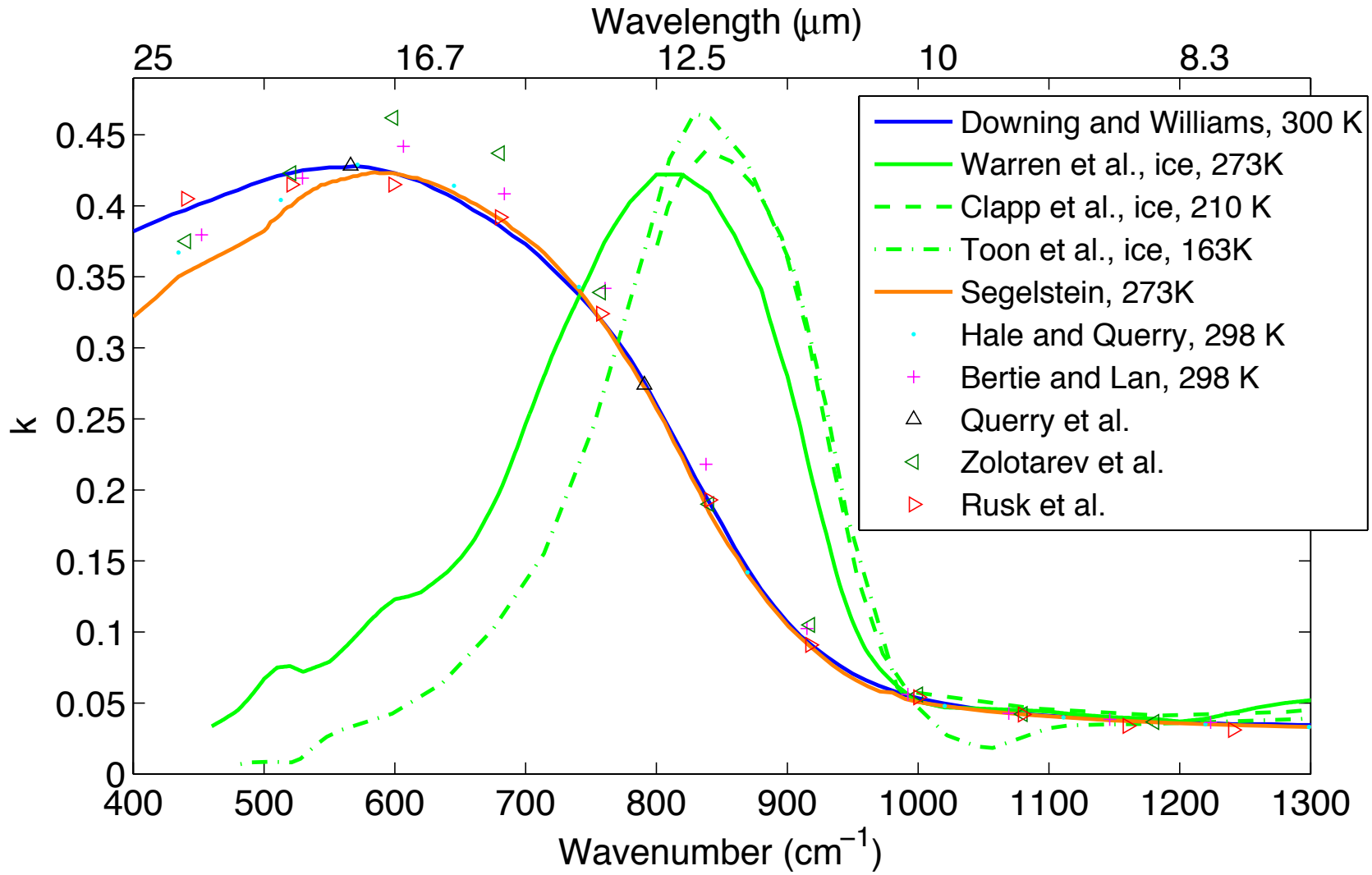


Downwelling radiance: windows

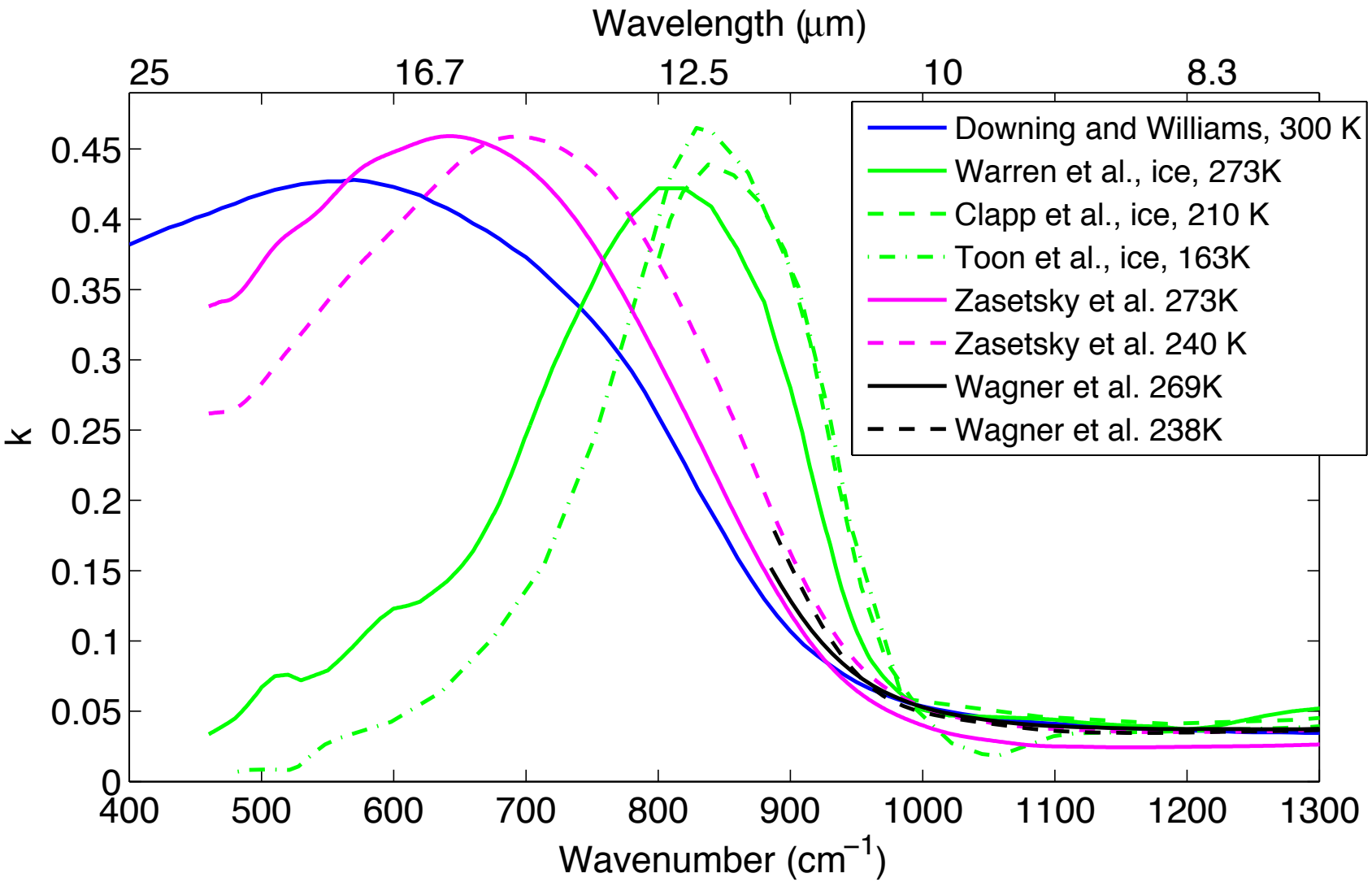


k-spectra

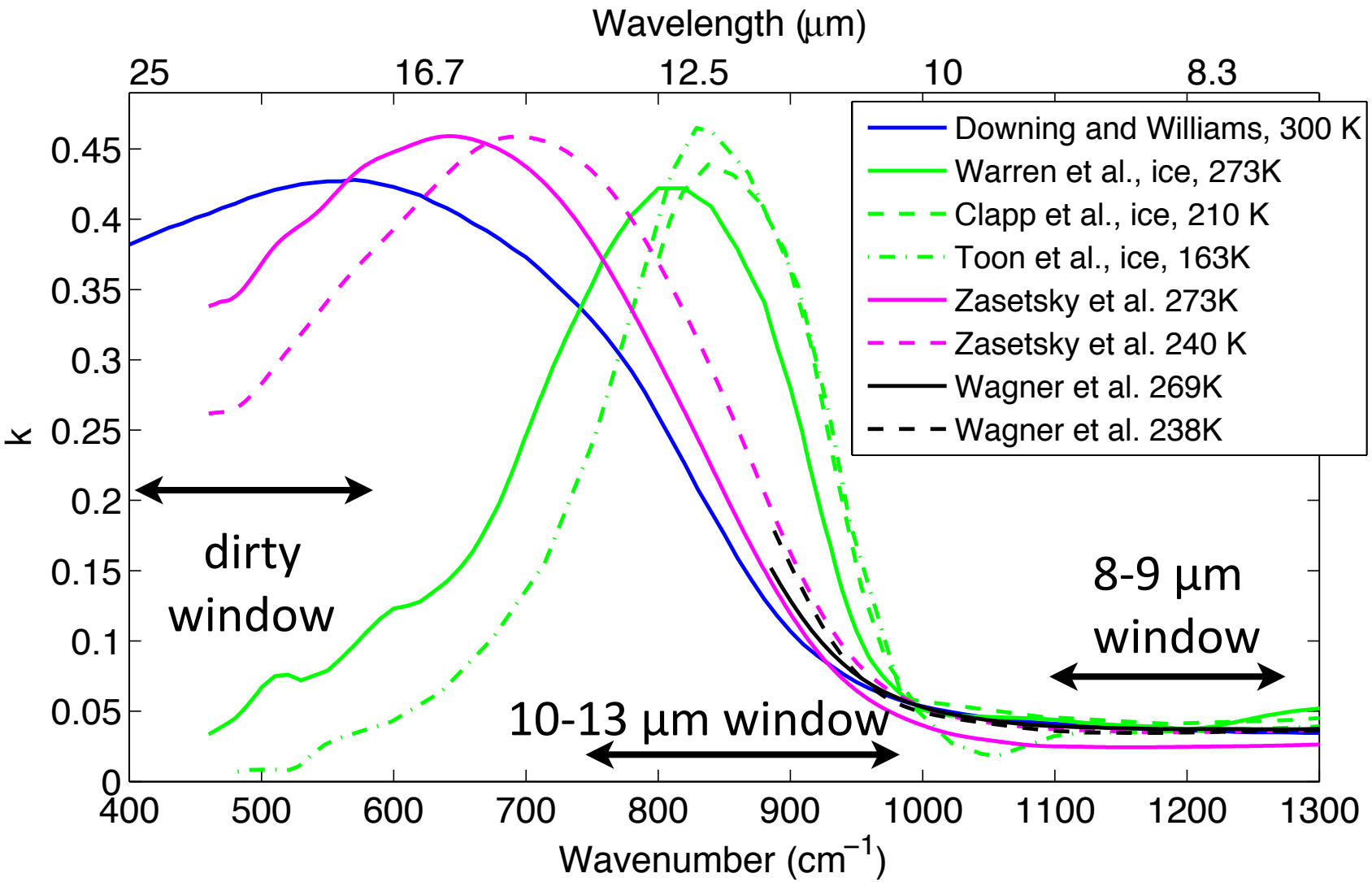
k-spectra of condensed phases: liquid vs ice



k-spectrum of condensed phases: effect of supercooling



k-spectrum of condensed phases: effect of supercooling



Radiance Simulations

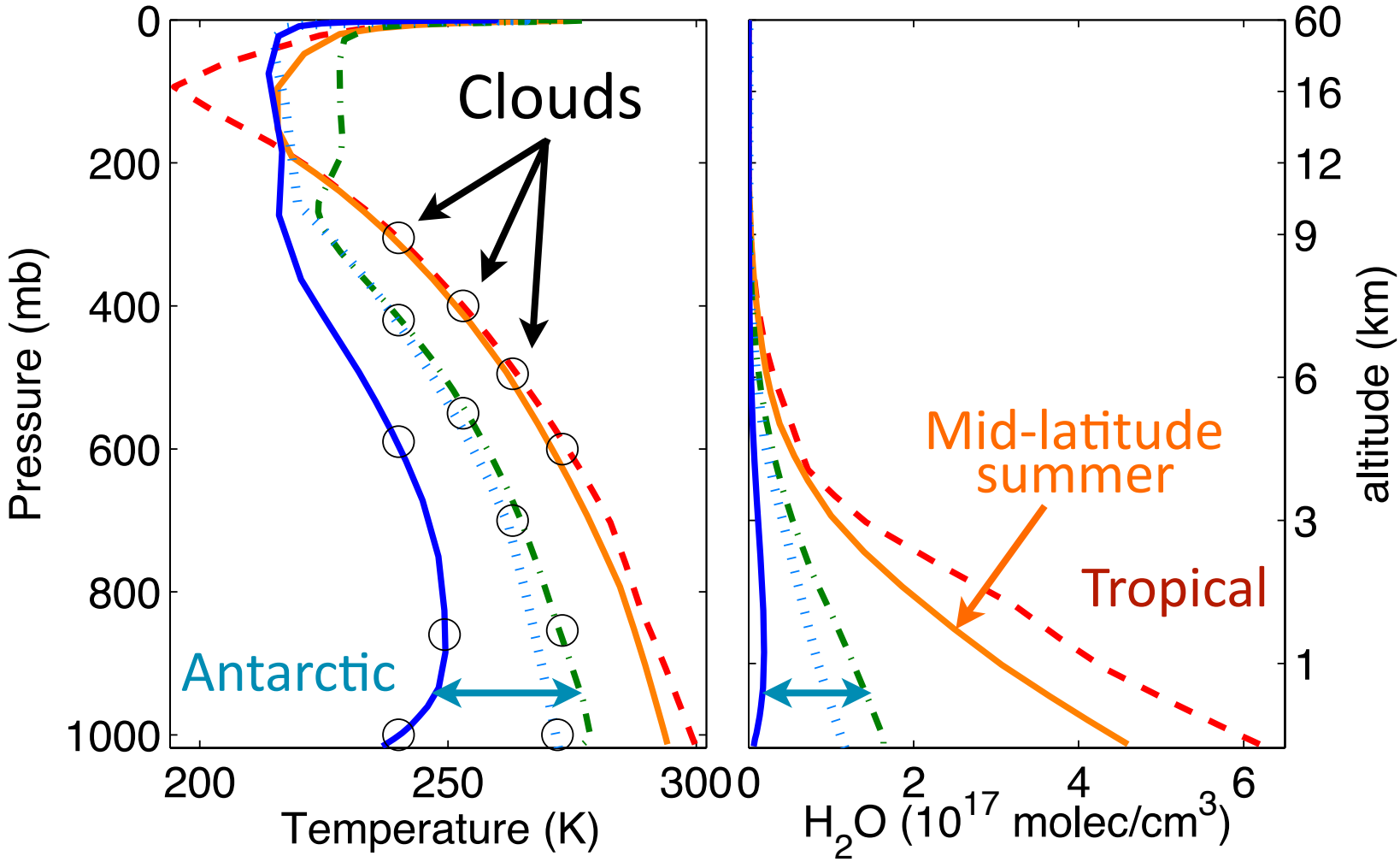
Computational Methods

- LBLRTM for optical depths of trace gases
- DISORT for radiative transfer (absorption/scattering)
- Mie theory (spherical cloud droplets) used to get single scattering parameters using:
  - Temperature-independent k-spectra ("Warm Liquid", D&W, 300K)
  - Temperature-dependent k-spectra ("Cold Liquid", 240, 253, 263 K)
- Variety of atmospheric and cloud conditions

Atmospheric and Cloud Conditions

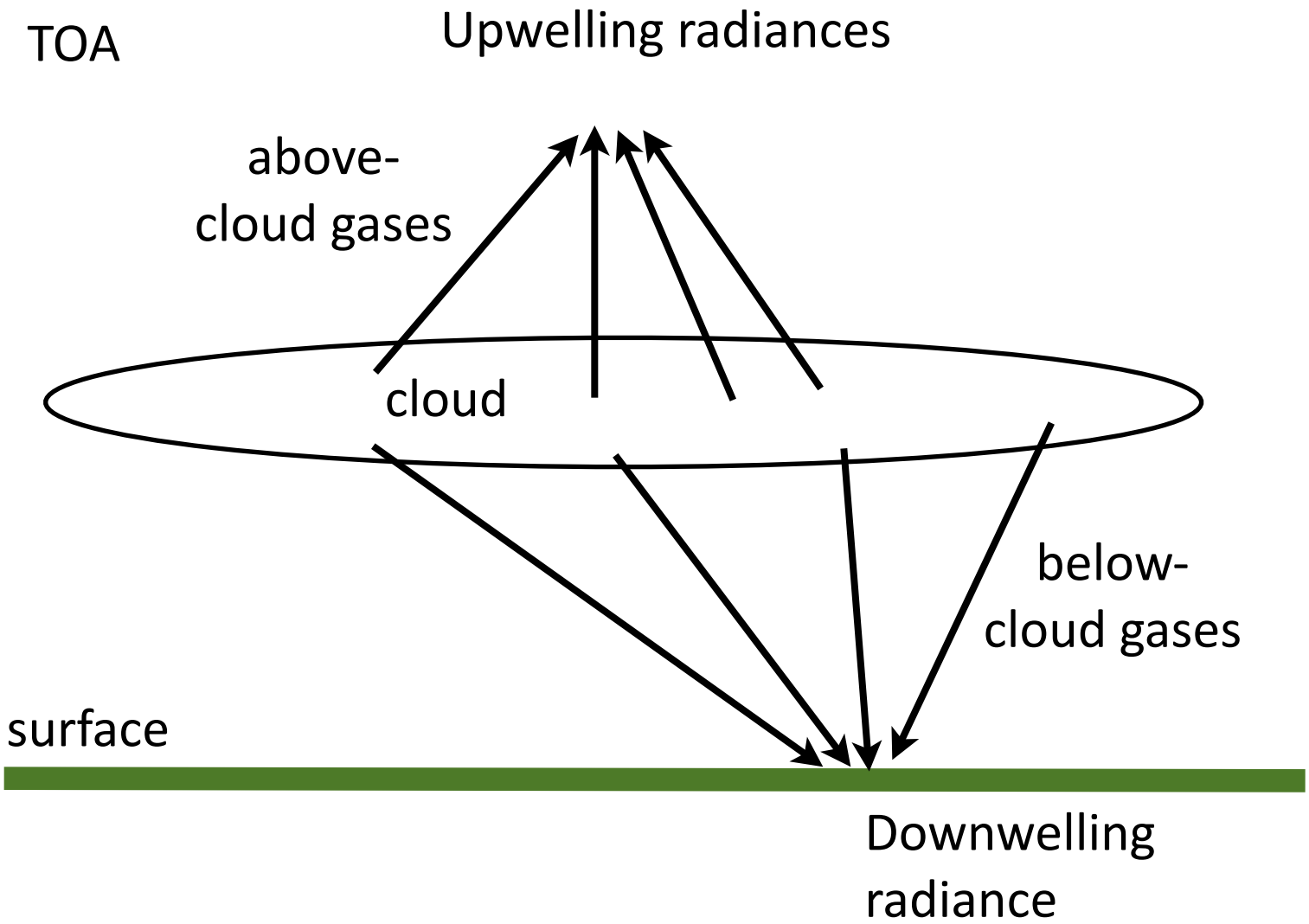
- Atmospheric temperatures and humidities
  - Tropical to Polar
  - Based on standard atmosphere models of McClatchey et al (1975) and
  - Based on Polar radiosoundings
- Supercooled cloud temperatures: 240, 253, 263 K
- Upwelling (TOA) and downwelling (surface)
- Liquid water paths: 4, 8, 11 g/m^2
- Particle effective radii: 5, 10, 15 μm

Atmospheric Profiles

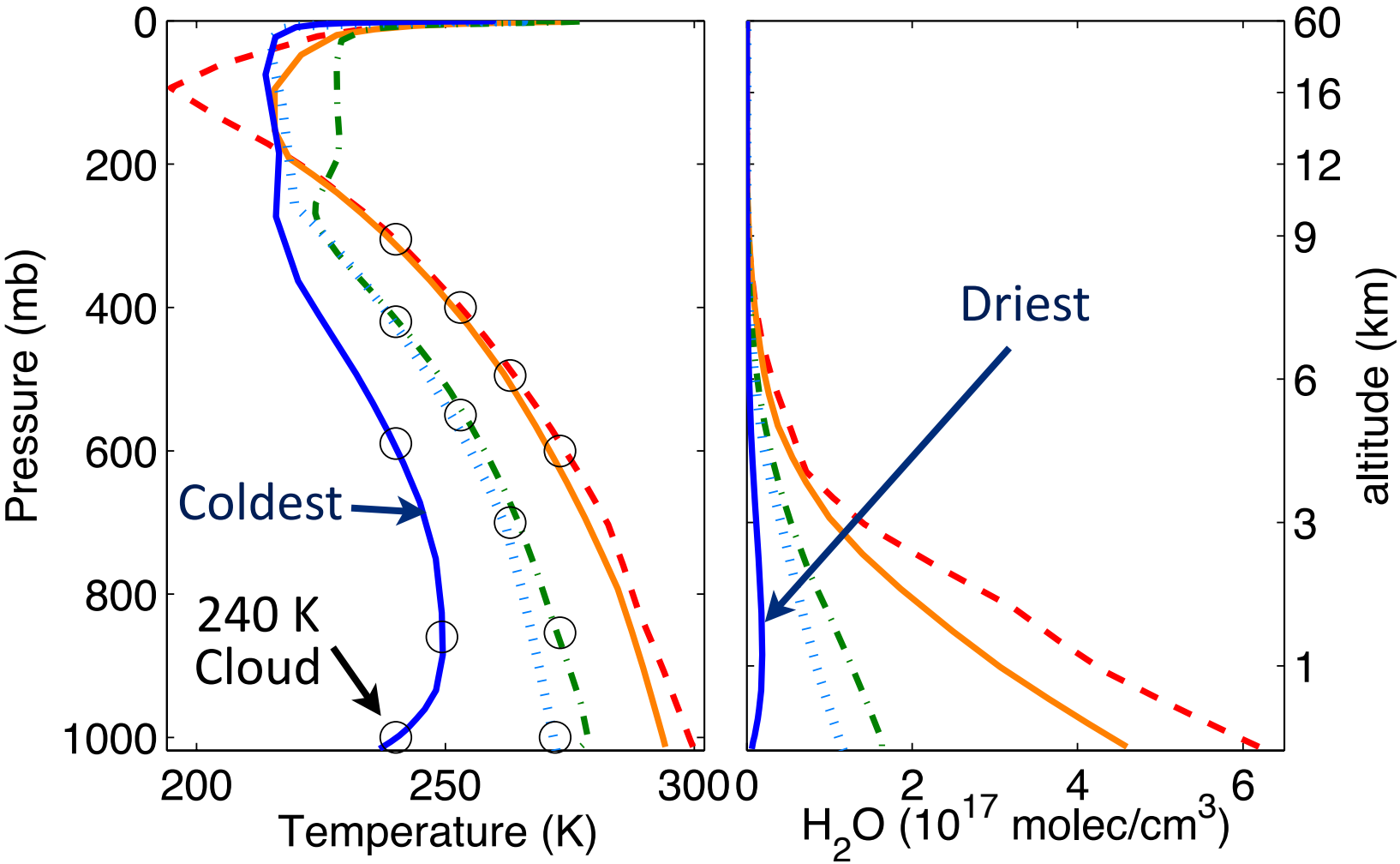


Results

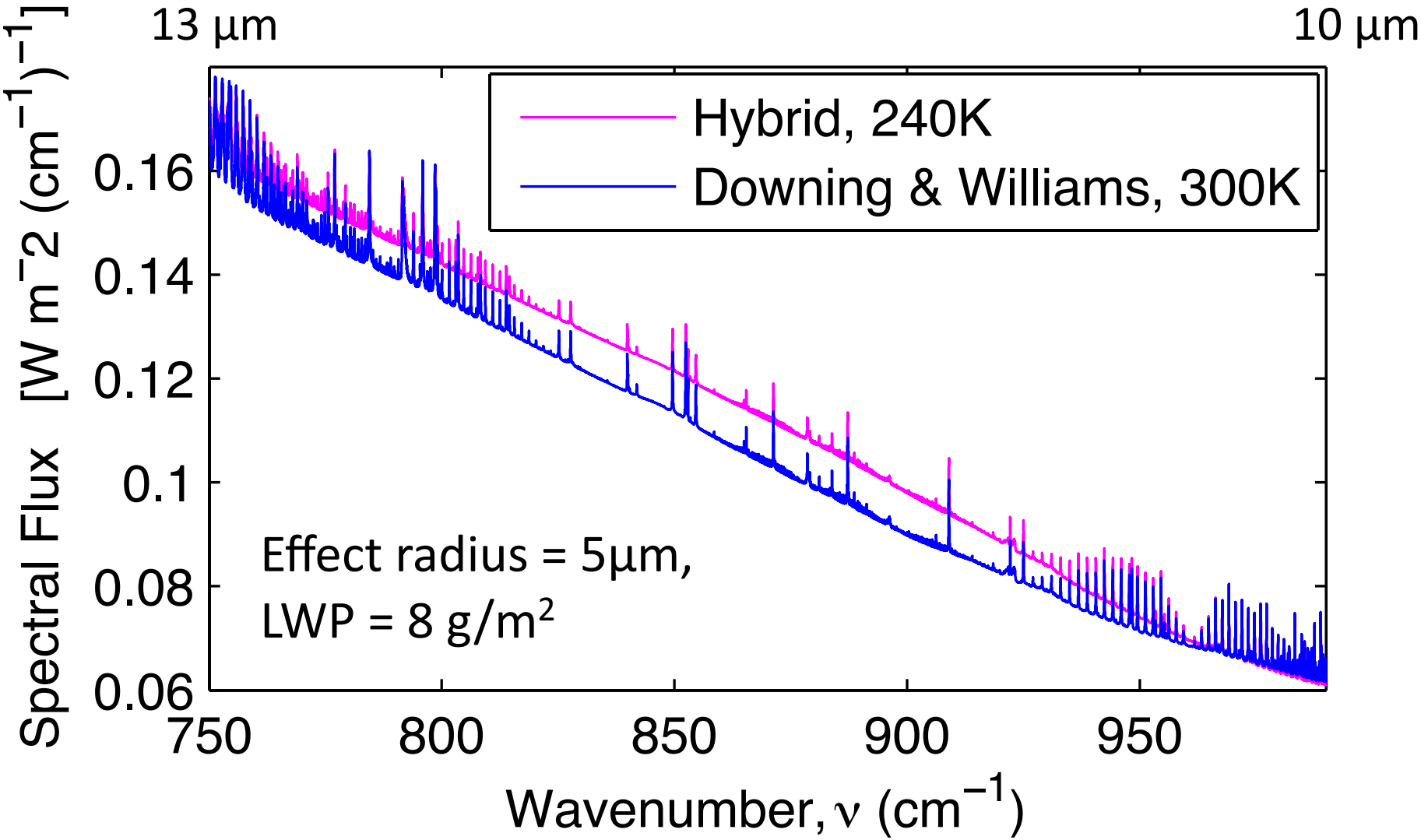
Spectral flux [W m^2 $(cm^{-1})^{-1}$]



The coldest, driest model
(Antarctic coastal winter or interior summer)



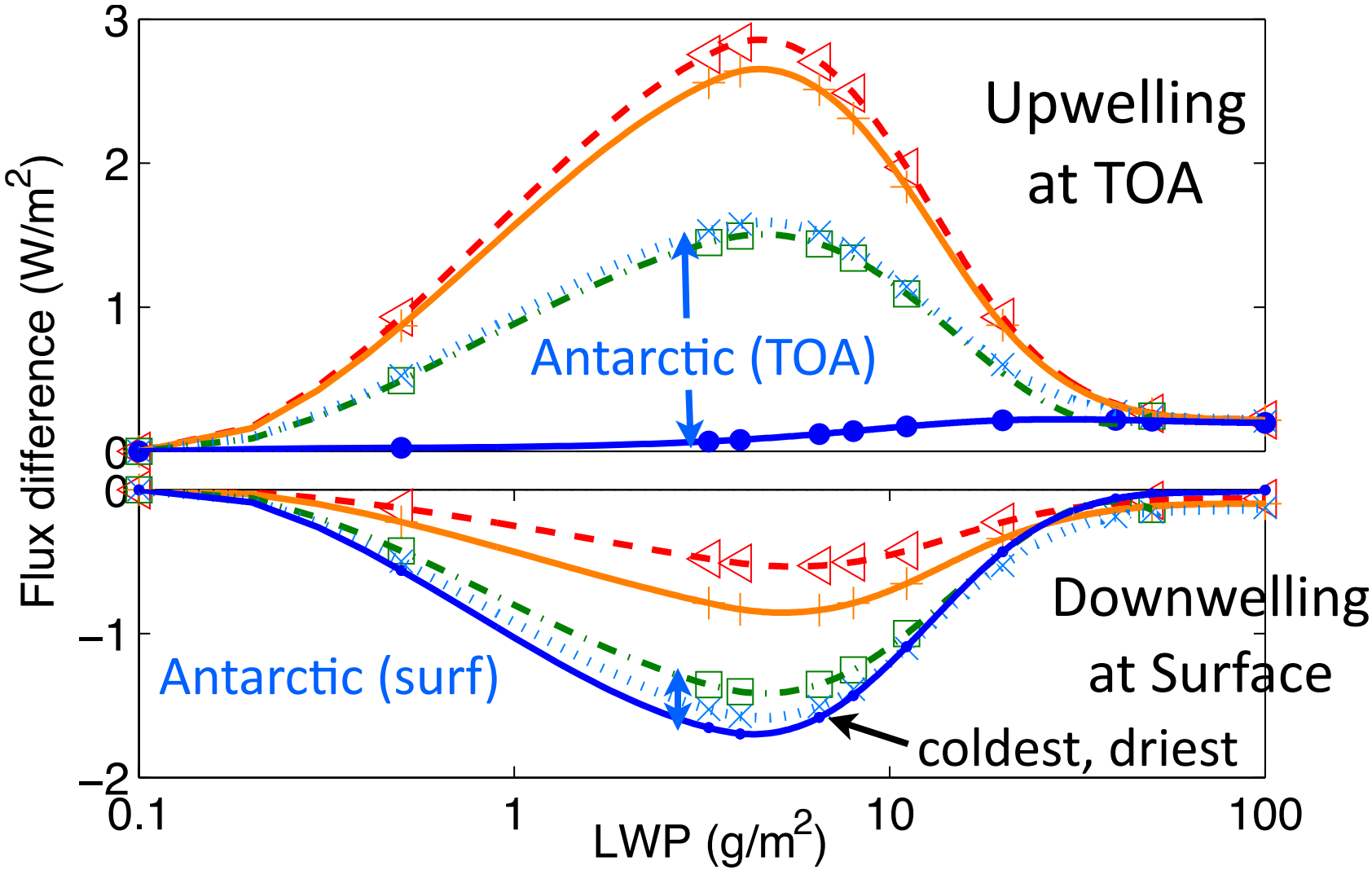
Downwelling spectral flux at surface for Cold, Dry Extreme



Calculating flux differences from simulated radiances

- Integrate spectral flux over wavenumber from 740-960 cm^{-1} to get flux (W/m^2)
- Calculate the flux difference: Flux(T-indep) - Flux(T-dep)

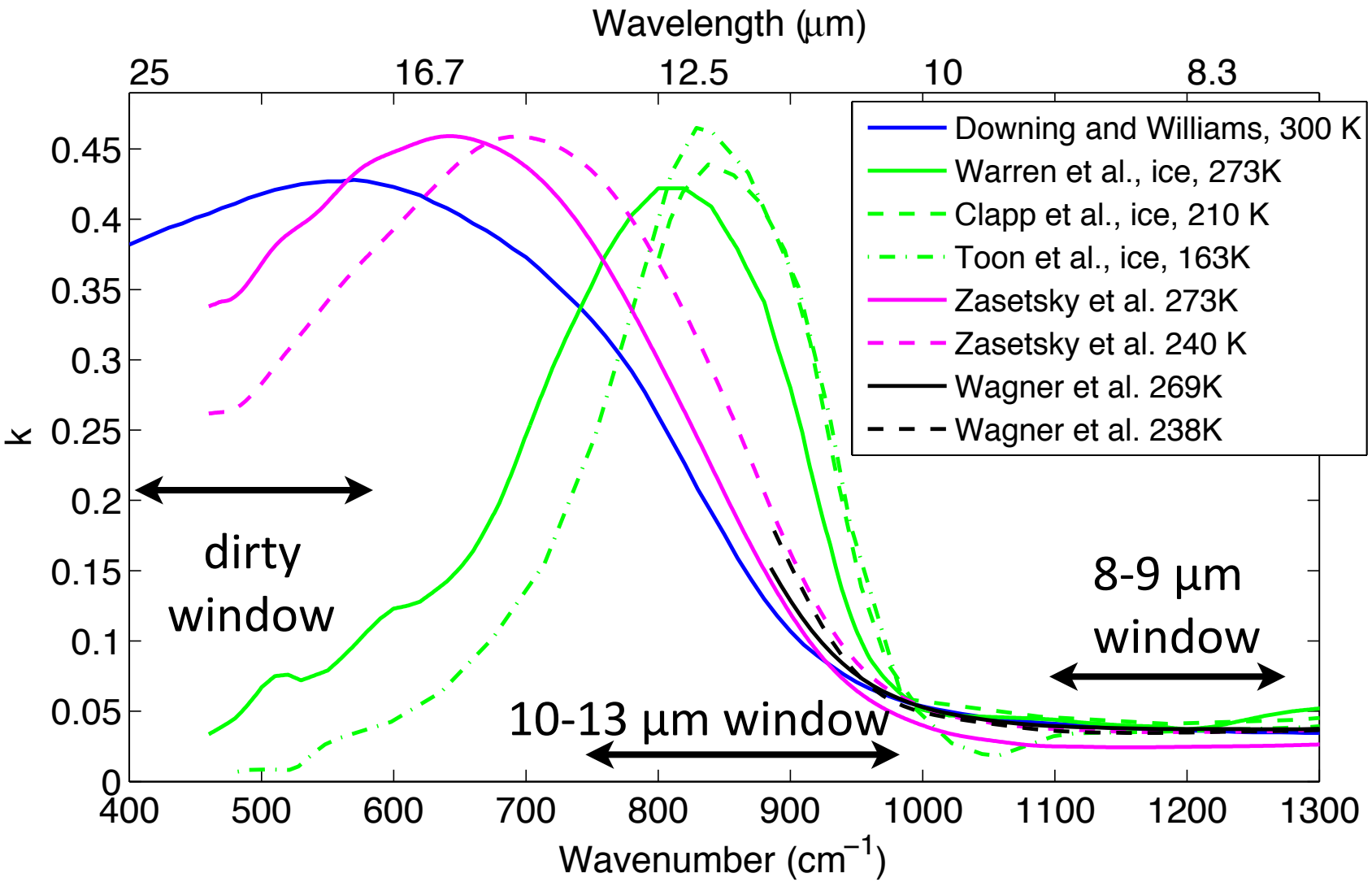
Flux Differences
(r_e=5 μm, cloud at 240 K)



Conclusions: Consequences of neglecting T-dependence

- 10 to 13 μm window: In the Antarctic summer, simulations using a T-indep k-spectrum underestimate the longwave heating at the surface due to supercooled liquid cloud.
- 8 to 9 μm window: Too much uncertainty in k-spectra from to determine temperature-dependence there.
- Dirty window: Opposite effect as 10 to 12 μm window, but much smaller.

k-spectrum of condensed phases: effect of supercooling



Acknowledgments

- Funding source: Experimental Program to Stimulate Competitive Research (EPSCoR), NSF EPS 0814387
- Surface emissivity data obtained from the MODIS UCSB emissivity library (http://www.icess.ucsb.edu/modis/EMIS/html/em.html)
- Eureka radiosondes were obtained from the Integrated Global Radiosonde Archive (IGRA)

Extra Figures ...

Radiance from a cloud depends on k-spectrum

In the absence of scattering ...

$$R_{cld} \approx B \times \left[1 - e^{-\tau} \right]$$

$$B(\nu, T_{cld}) = \text{Planck Function}$$

$$\tau = \text{optical depth} \propto LWP \times k(\nu)$$

$$LWP = \text{Liquid Water Path } (\text{g/m}^2)$$

$$k = \text{ imaginary part of index of refraction}$$

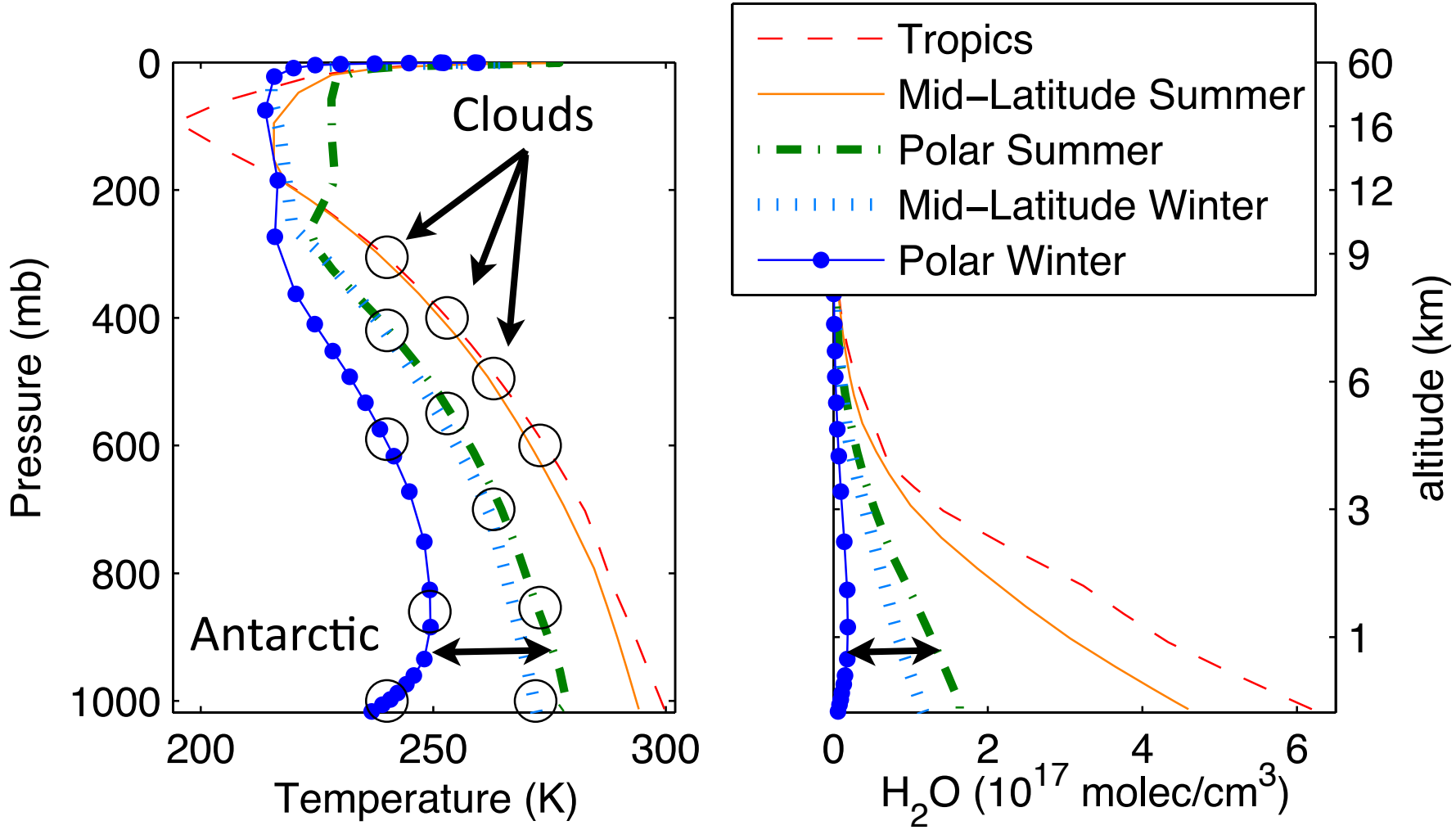
Outline

- Cloudy-sky radiances
- Imaginary part of IOR, or k-spectrum.
  - Ice
  - Liquid at 273K+ (Temperature-independent)
  - (New) Liquid from 240K to 273K (T-dependent)
- Radiance simulations
- Flux differences calculated from radiance simulations: T-independent vs. T-dependent

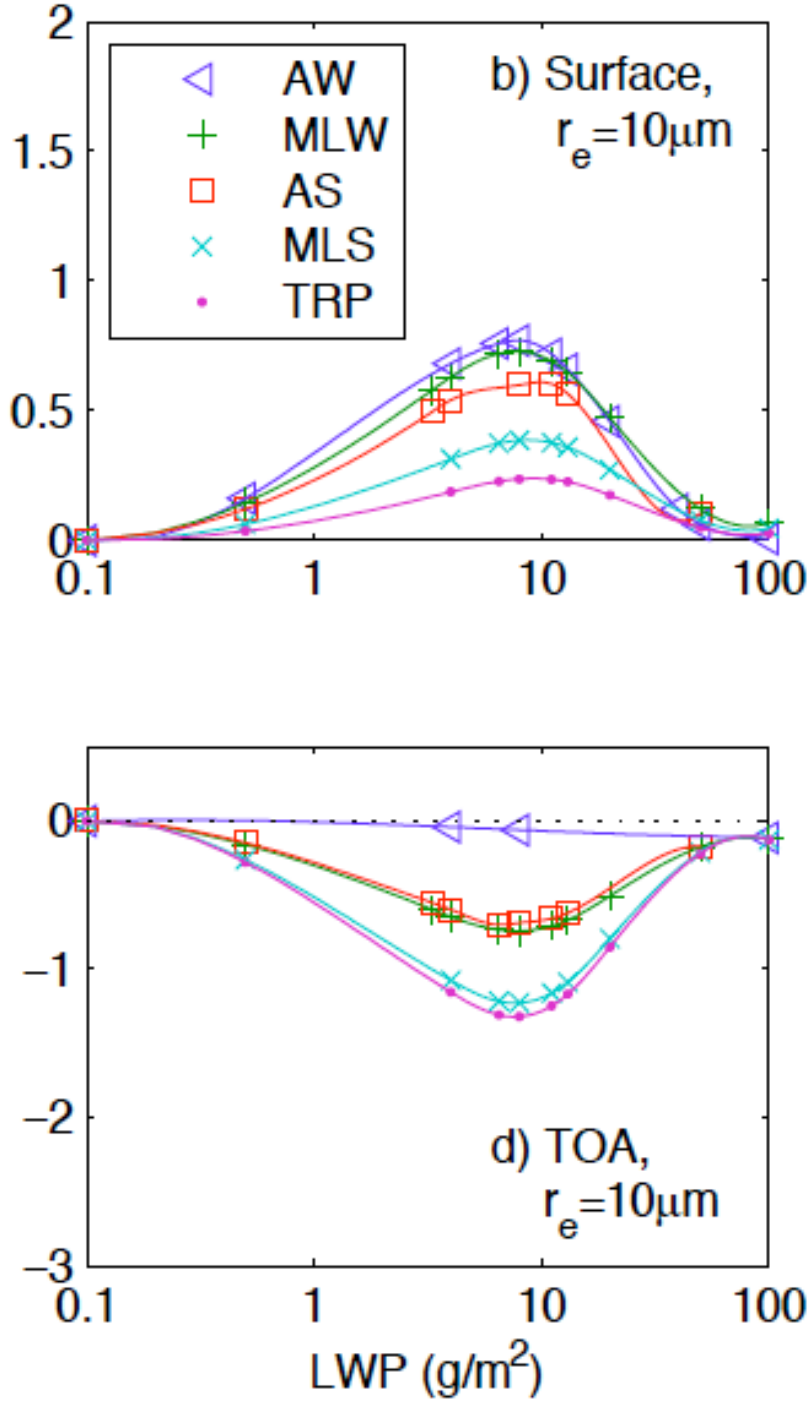
Atmospheric Profiles

- Polar Summer (PS): Consistent with Arctic summer, Antarctic coastal summer, based on summertime radio-soundings at Eureka, Canada, 2006-2008
- Polar winter (PW): Consistent with Arctic winter, Antarctic interior summer, based on wintertime radio-soundings at Eureka, Canada, 2006-2008.
- Midlatitude summer & winter (MLS, MLW) based on McClatchy et al 1975
- Tropics (TRP) based on McClatchy et al 1975

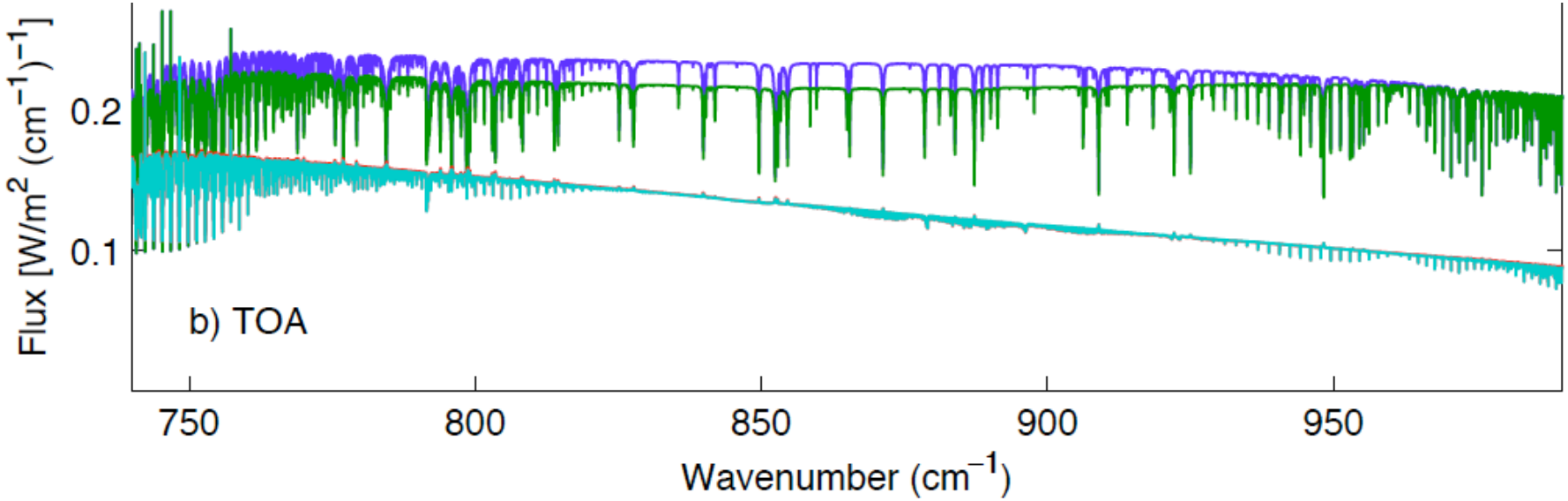
Atmospheric profiles



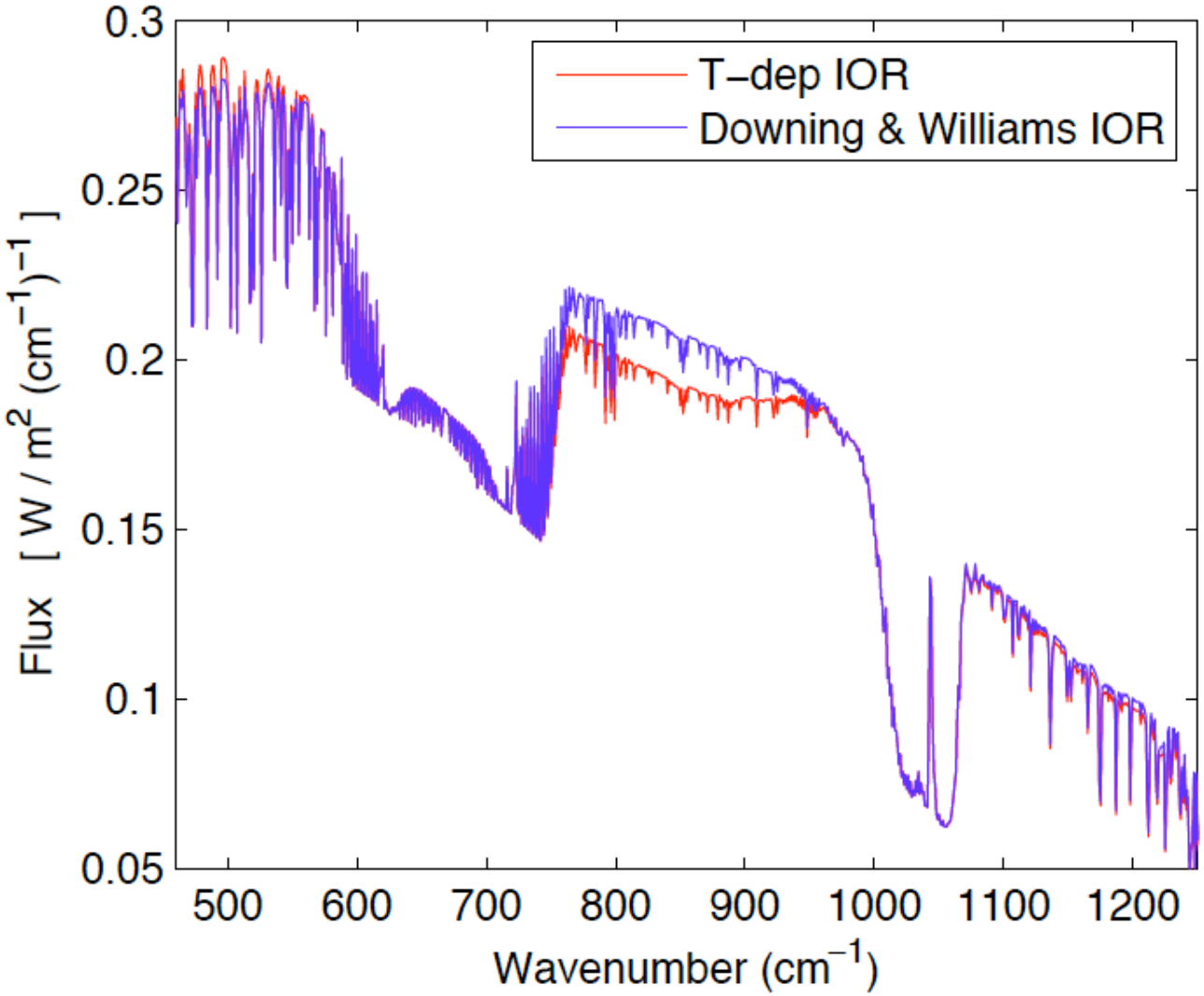
Flux impacts (r_e=10 μm)



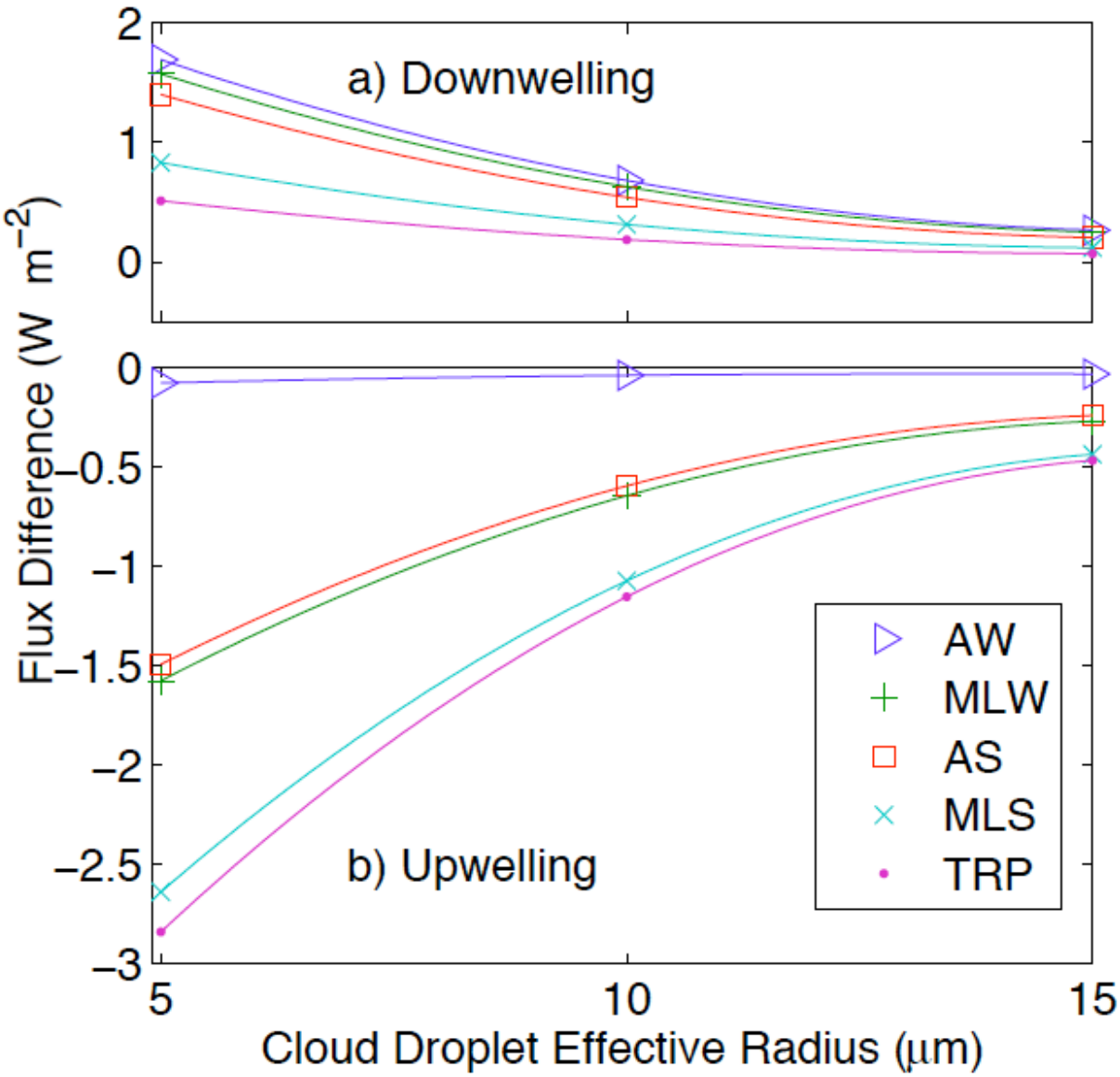
Upwelling flux at TOA



Upward spectral flux at top of atmosphere



Trends with respect to cloud droplet size



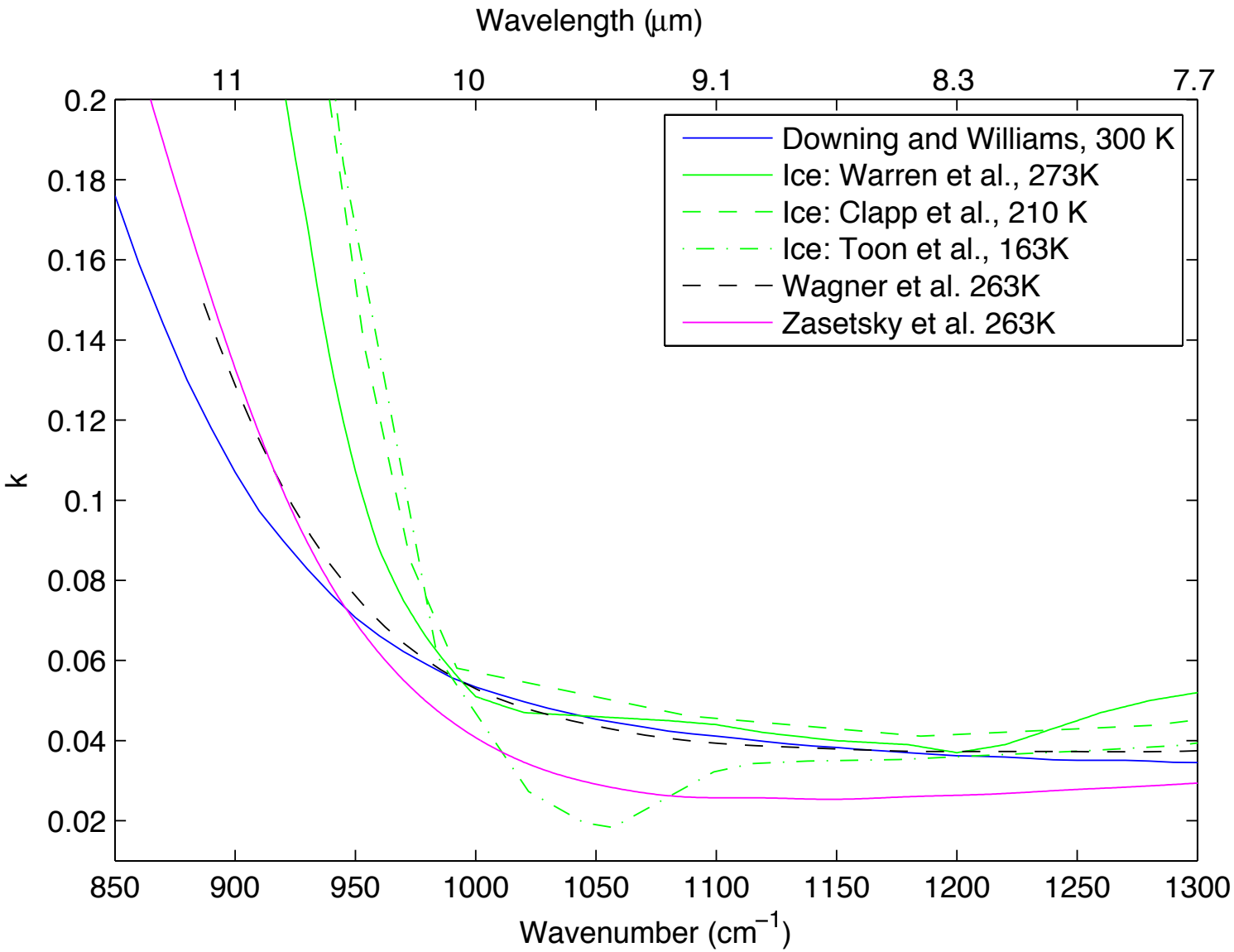
Model limitations & assumptions

- LBLRTM for optical depths of clear skies
- DISORT for downwelling & upwelling spectral flux (spectral radiance integrated over viewing angles)
- Clouds are single-layer, liquid-only
- Sun is below the horizon
- Surface emissivity models: Snow/ice, land, sea
- CO_2 set to 2011 level
- "Atmospheric window" fluxes are integrated from 740-960 cm^{-1} (W/m^2)

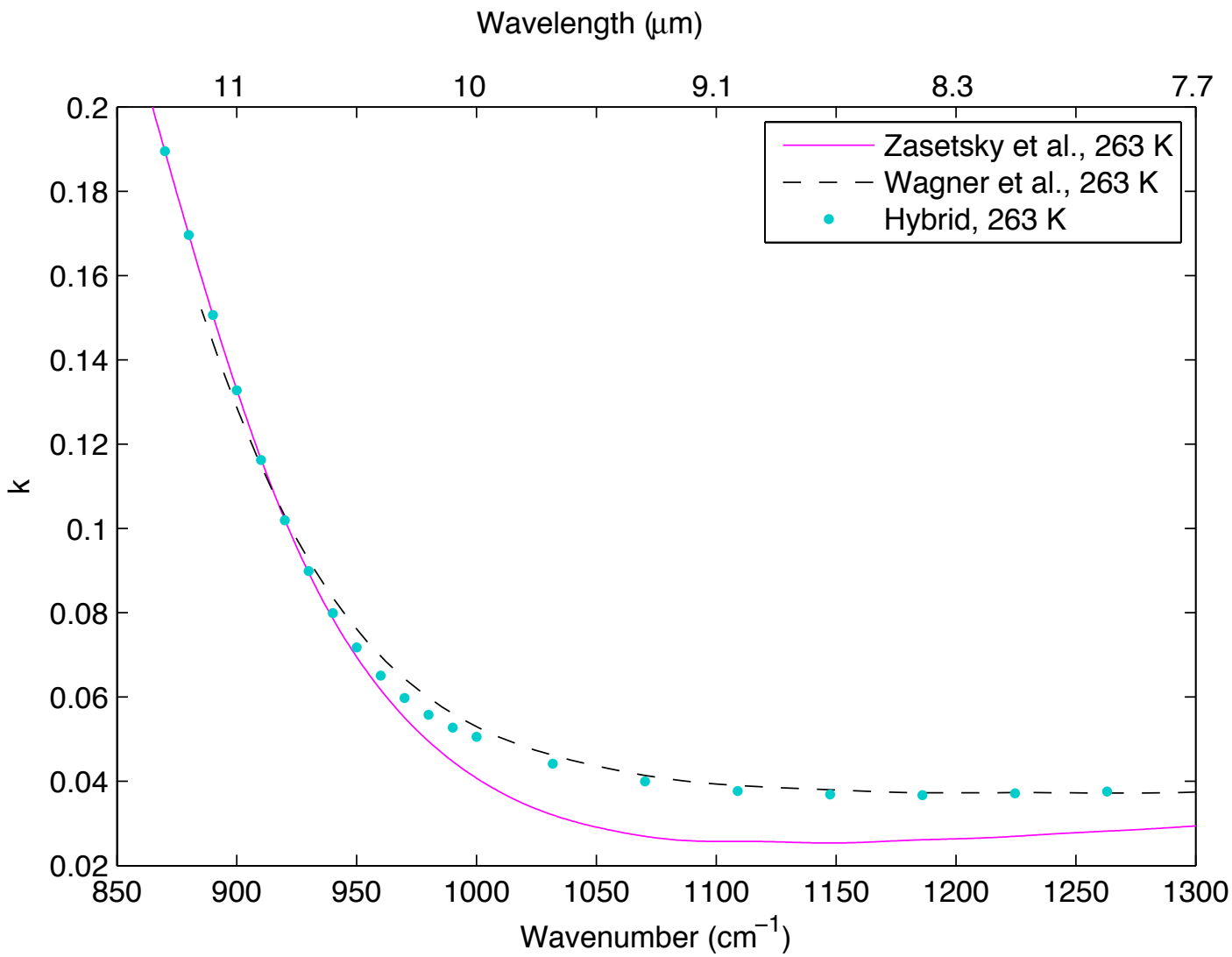
Spectral Flux and k-spectra of clouds

- Spectral flux is wavenumber-dependent.
- The wavenumber dependence of cloud absorption/ emission derives mainly from variations in the index of refraction ("IOR spectra").
- Most of the emission in the thermal IR depends on the imaginary part of IOR ("k-spectra").
- Integrating over wavenumber gives flux.

k-spectrum of condensed phases:



Wagner et al vs Zasetsky et al at 263K



Wagner et al vs Zasetsky et al at 240K