Antarctic Cloud Microphysical and Radiative Properties from Satellite Mid-IR Radiance Data

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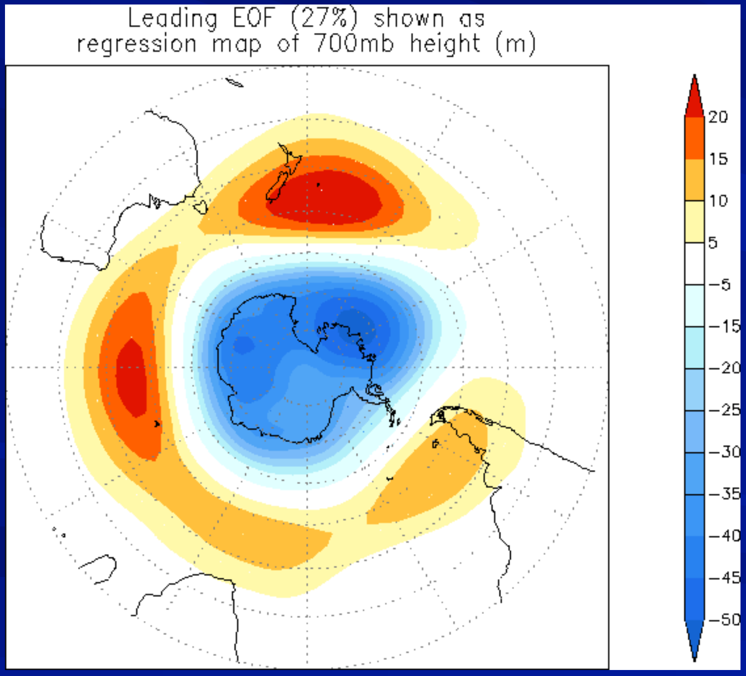
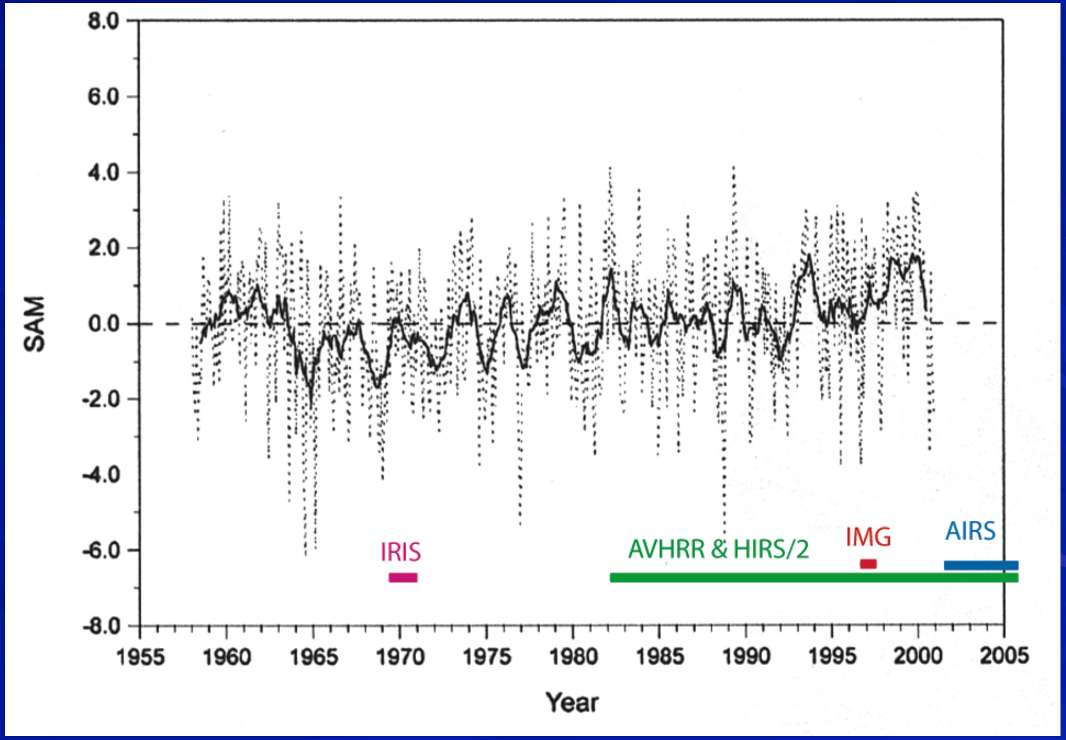
Antarctic Clouds and Climate

- Scientific Objective
  – Examine variability in cloud properties over several decades in response to the Southern Annular Mode (SAM)
  – Supported by NASA NNX08AF79G



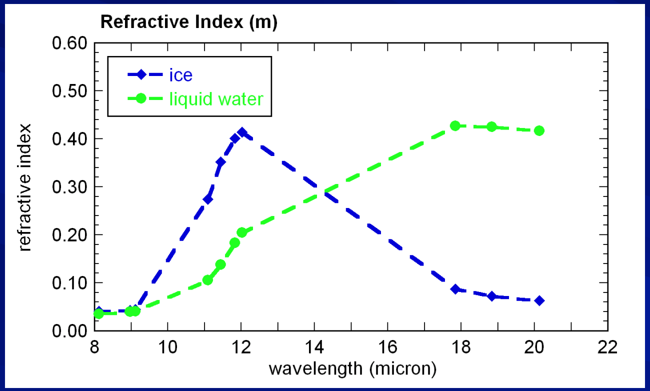


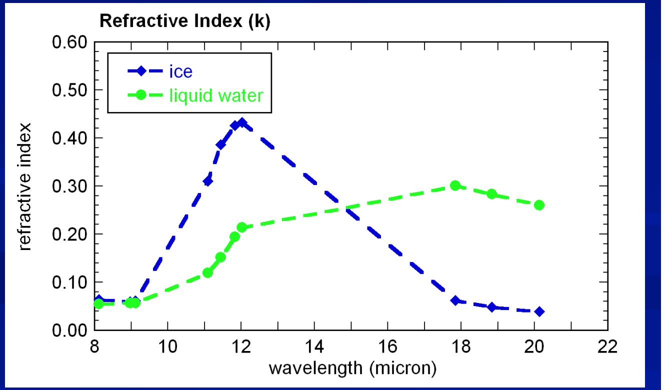
Sensors We Are Working With

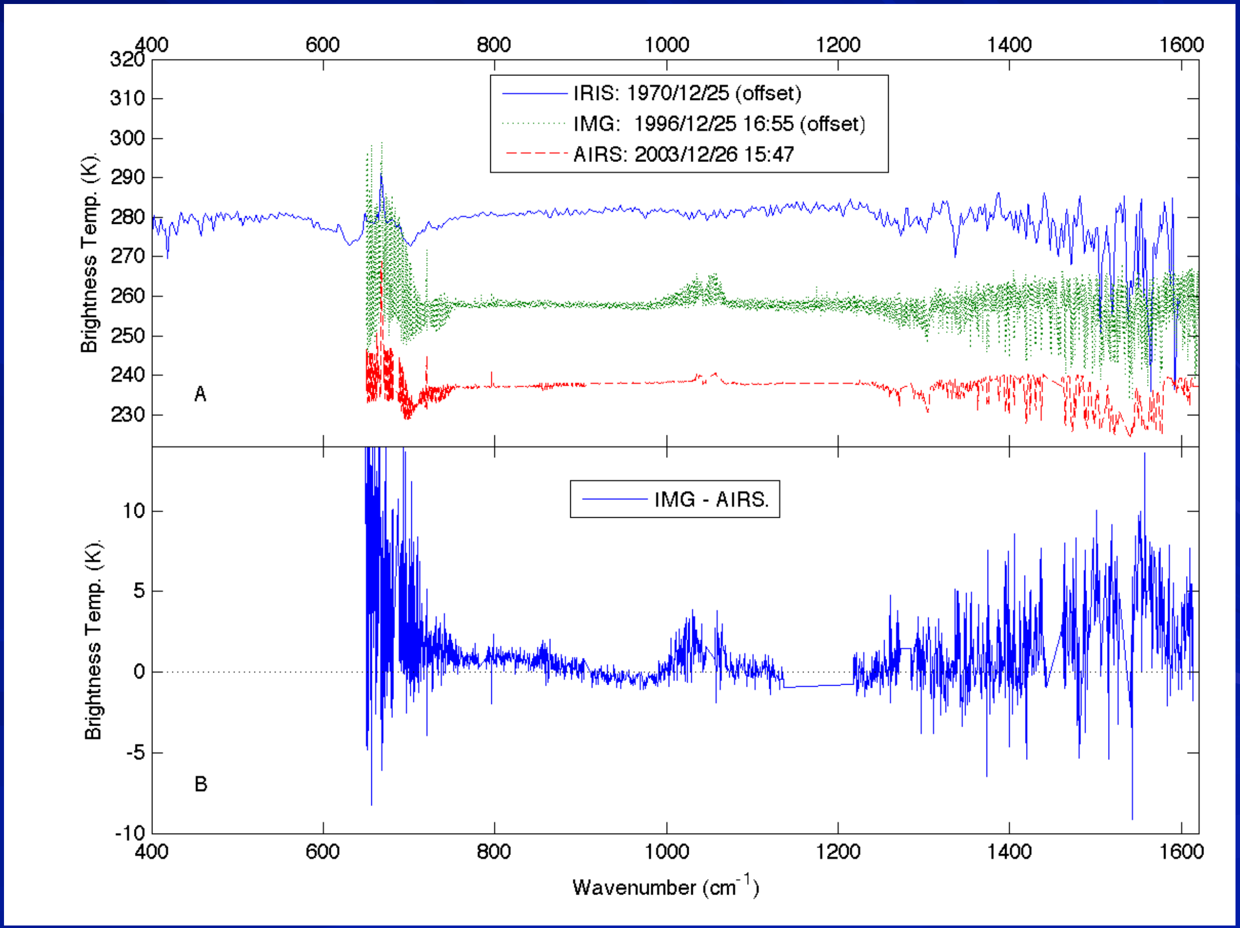
- Nimbus-4 IRIS (InfraRed Interferomoter Spectrometer)
  - Old iconic dataset, fun to work with
  - 8 months, 1970-71, SAM index consistently negative
- ADEOS IMG (Interferometric Monitor for Greenhouse Gases)
  - 8 months, 1996-97, SAM index consistently positive
  - We did considerable optical engineering for adequate data reduction (Walden et al., 2010, Applied Optics; Rowe et al., 2011; Optics Express)
  - Retrieval methods applicable to AIRS
- NOAA Polar Orbiter AVHRR
  - 20 year time history transitioning between low and high SAM index
- AIRS
  - Saving for last – known high data quality and ease of access
  - For 2006-present, can co-locate with CloudSat & CALIPSO

IRIS – One Unique Advantage

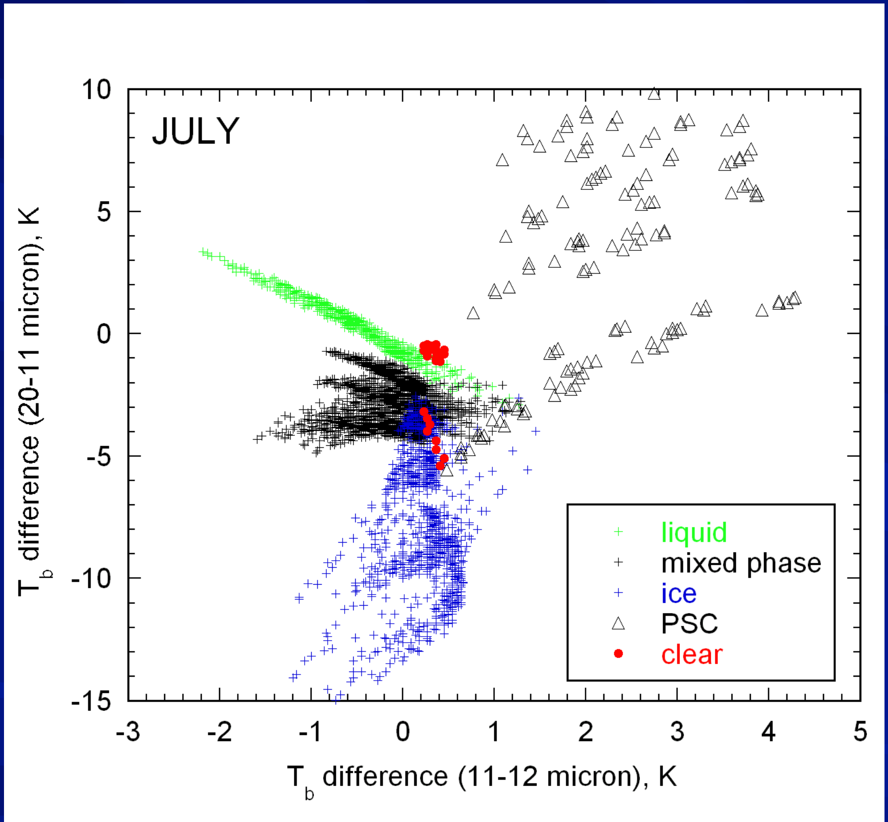
- Coverage out to 20 microns
- Contrast with standard mid-IR window facilitates phase detection

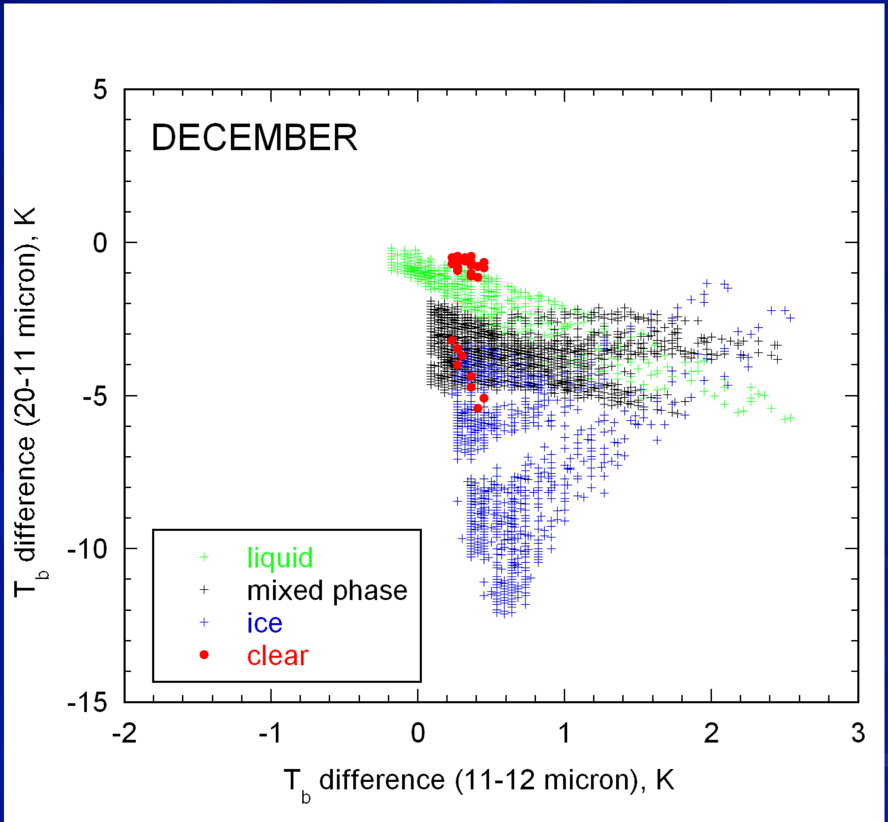






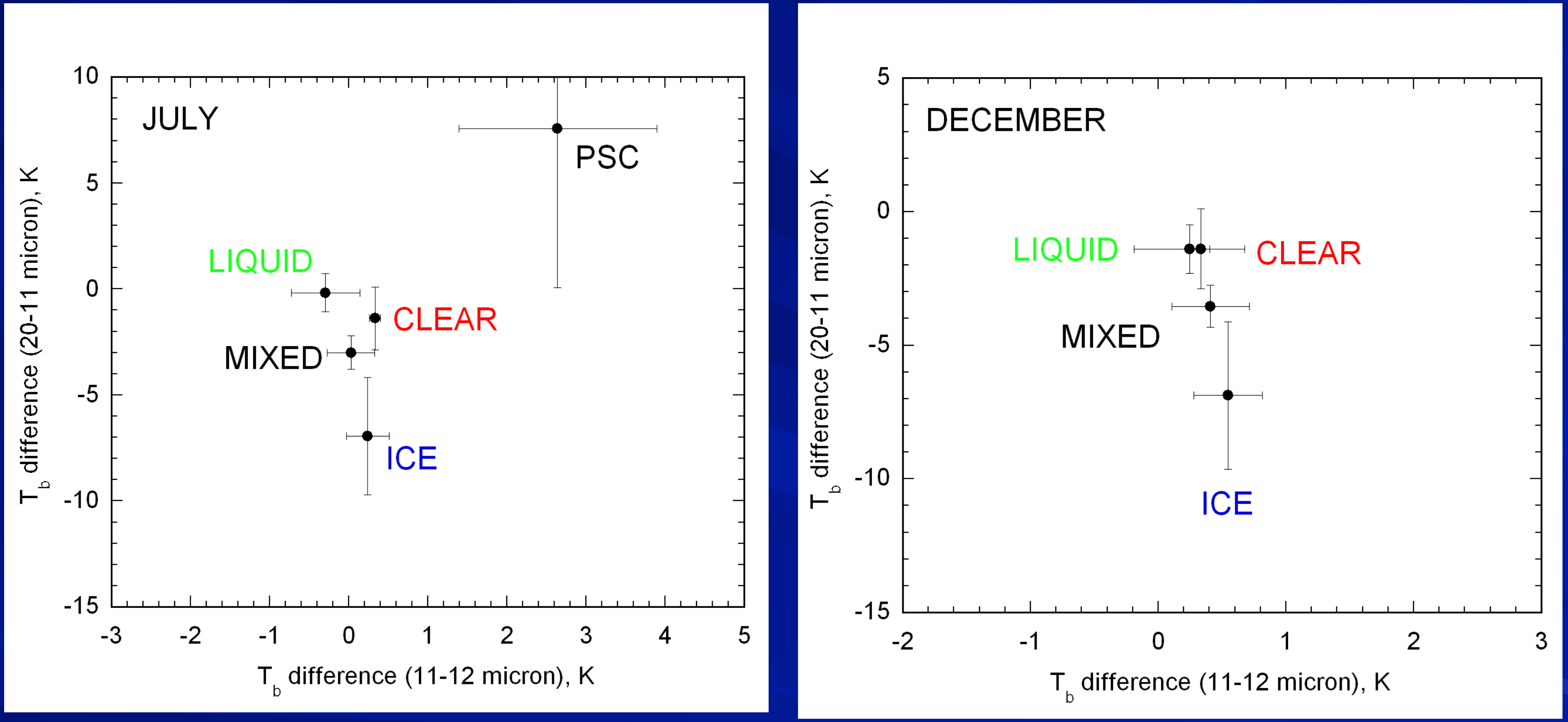
Radiative Transfer Simulations for IRIS over Antarctica





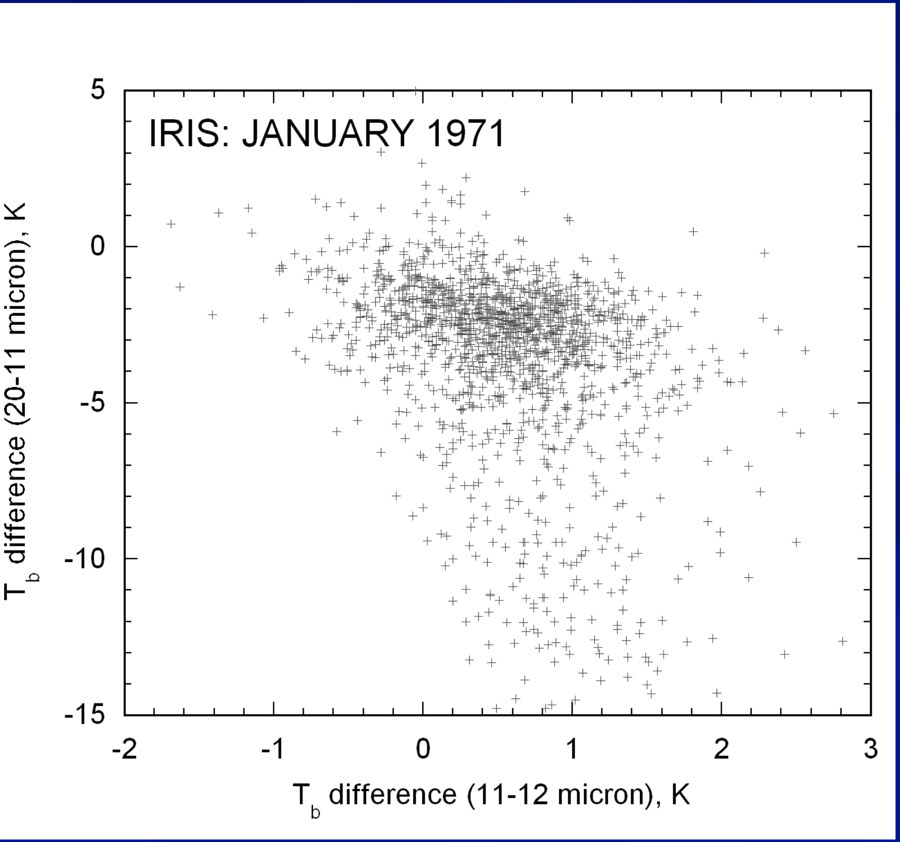
DISORT-based RT model coupling Antarctic climatological atmospheres with snowpack (Berque et al., 2004, *JAM*; Hudson and Brandt, 2005, *J Clim*)

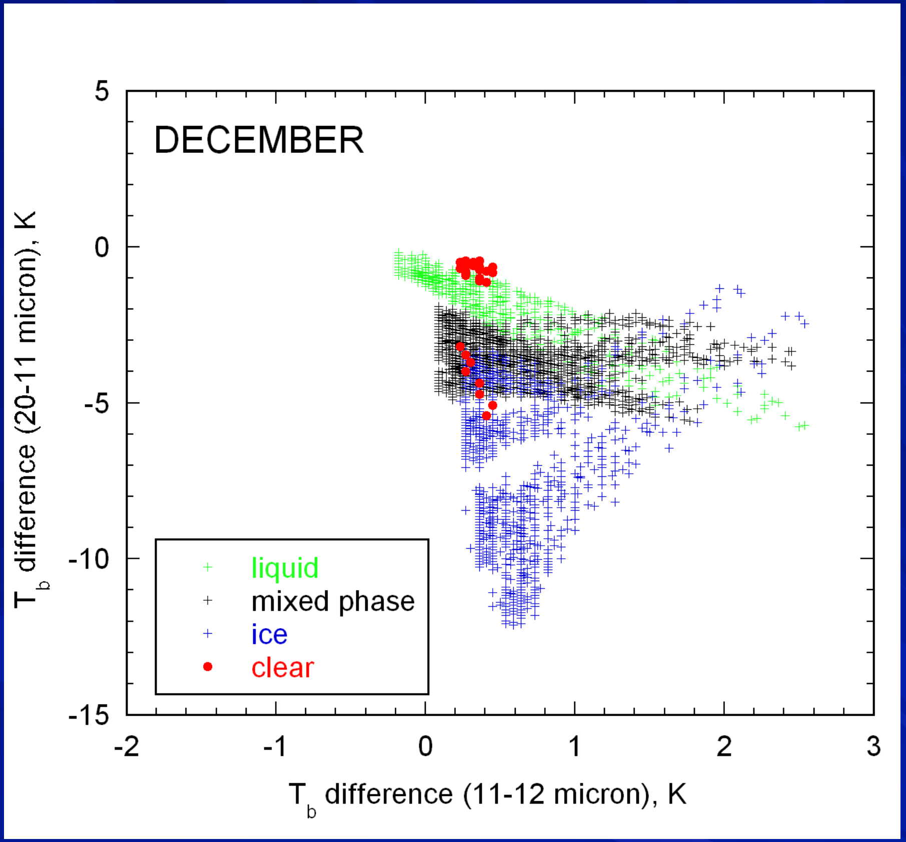
Radiative Transfer Simulation – Cluster Means



Most classes are distinct, but CLEAR will overlap (misclassify) by ~20% with either MIXED PHASE or LIQUID.

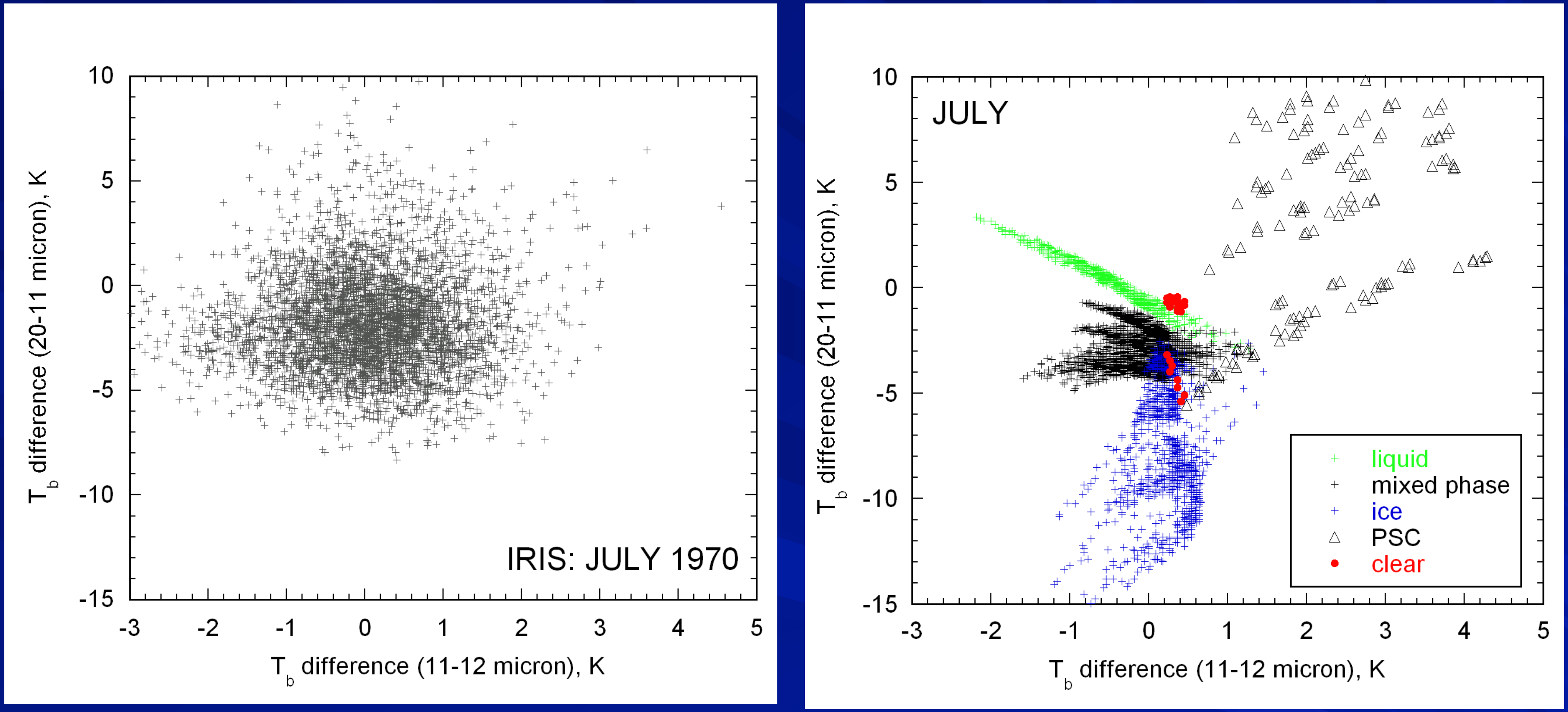
Summer Cases – January 1971





- Numerous ice clouds appear in this example.
- IRIS is capable of detecting them.
- What about the winter, when it’s much colder?

Winter Cases – July 1970



- Surprisingly few ice clouds appear in this example.
- Signatures consistent with ice appear to represent larger particles.
- Many signatures consistent with PSCs.

Application of Maximum Likelihood Classifier

We apply a multivariate normal distribution…

$$p(\mathbf{v}|Ck)P(Ck) > p(\mathbf{v}|Cj)P(Cj) \quad \text{for all } j \neq k$$

	CLEAR	LIQUID	MIXED	ICE	PSC
July 1970	15.3	10.6	32.2	14.0	27.9
December 1970	18.4	38.9	25.7	16.6	
January 1971	15.8	29.2	24.6	29.7	

- Percent of scene classification assuming *a priori* conditional probability $C_{clear} = 0.5$.
- We may have some trouble discriminating between clear and mixed phase.
- Pure ice cloud, liquid water cloud, PSC much more distinct.

Publication of these results waiting on one new and important consideration!

Temperature-Dependent Optical Properties for Radiative Closure in Super-Cooled Water Clouds

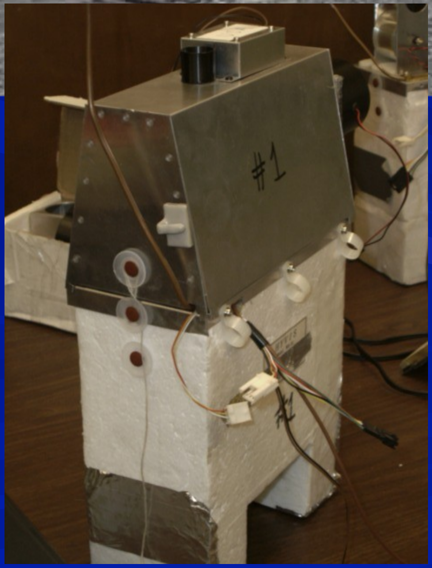
Penny Rowe, Steven Neshyba, and Von Walden

J Atmos Sci, 2012, in prep

- Case Study from 2001 SPARCLE Experiment
- South Pole Atmospheric Radiation and Cloud Lidar Experiment (SPARCLE)
  - Austral summer of 1999/2000
  - Full-year experiment in 2001
- Characterization of Super-Cooled Cloud
- Radiative Closure
  - Temperature-dependent Optical Properties of Super-cooled Water

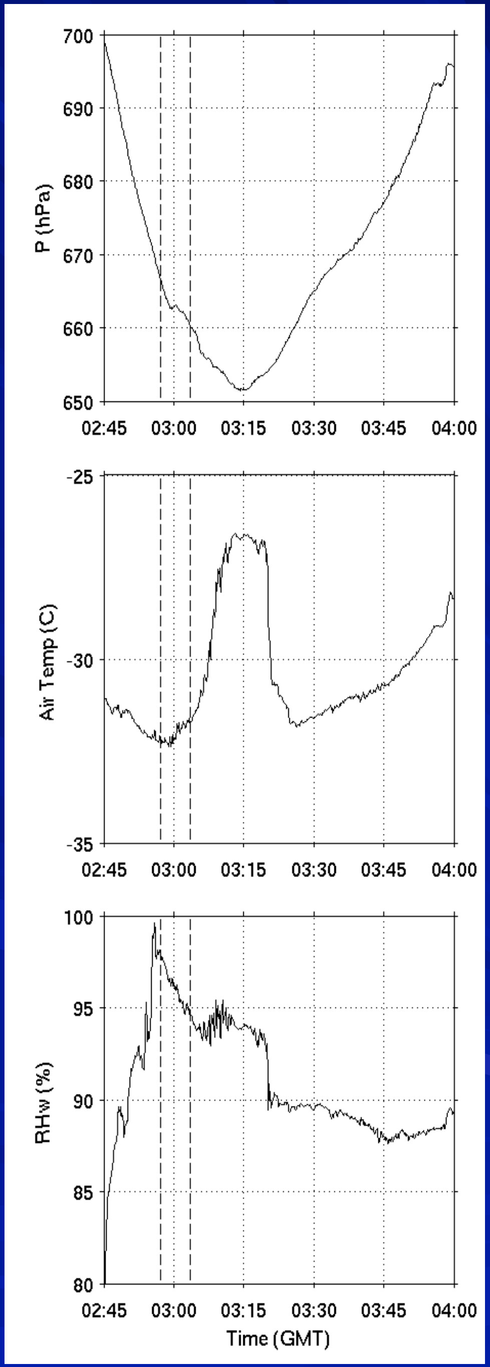
Instrumentation

- In-Situ Cloud Measurement
  - Tethered Balloon and Kite
  - Vaisala RS-80 sonde (TPU)
  - HYdrometeor VIdeoSonde (HYVIS)
    - (in collaboration with A. Heymsfield)
- Downwelling Radiance
  - Polar Atmospheric Emitted Radiance Interferometer (P-AERI)
- Atmospheric state
  - Micropulse Lidar (J. Spinhirne)
  - Routine radiosondes and ozonesondes

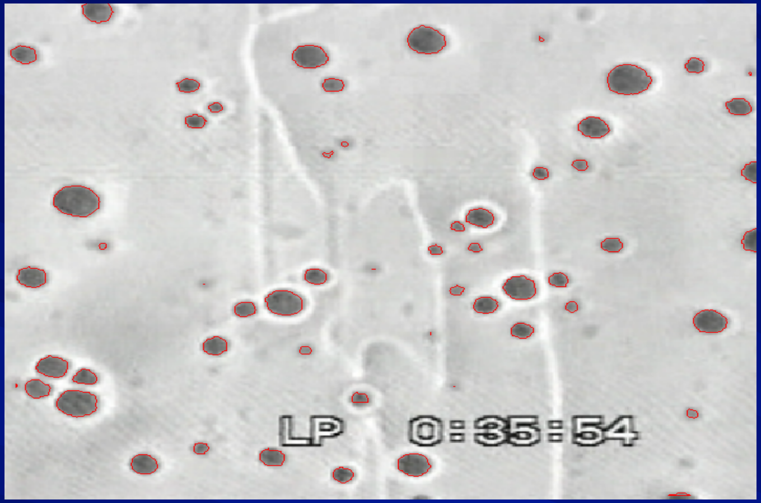


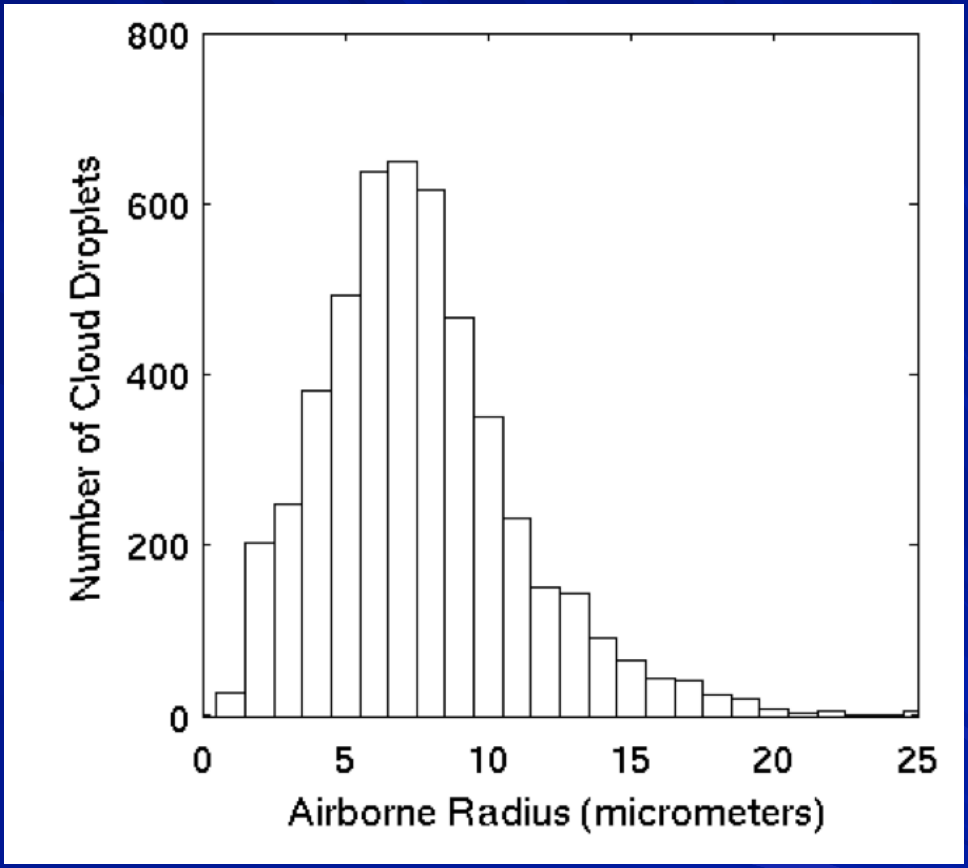
Case Study – Tethered Balloon Flight on 02 Feb 2001

- RS-80 sonde data from flight, 450 m agl
- Vertical dashed lines represent the time segment that was analyzed
  - Air temperature = -32 C
  - (minimum temp of flight)
  - RH (wrt water) = 95-98%
  - RH (wrt ice) = 120-130%



Case Study - HYVIS

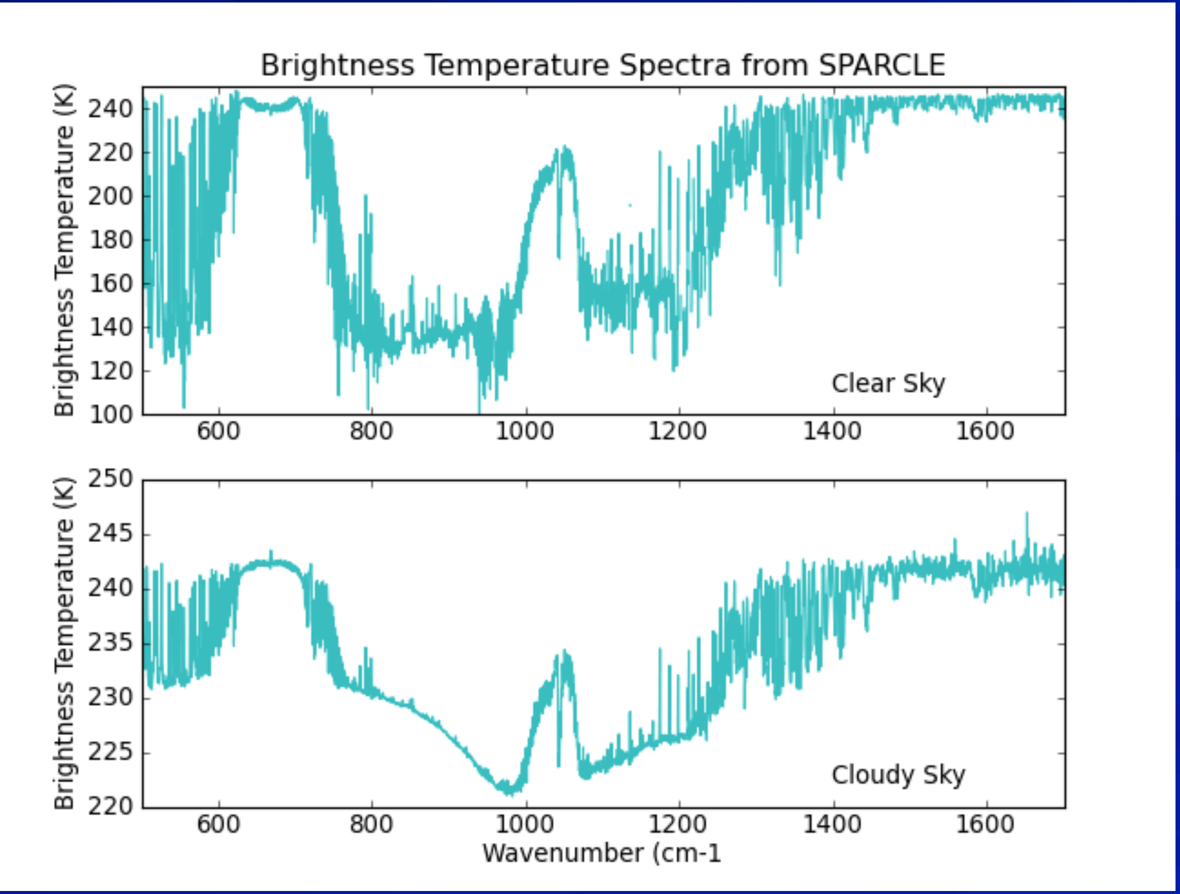




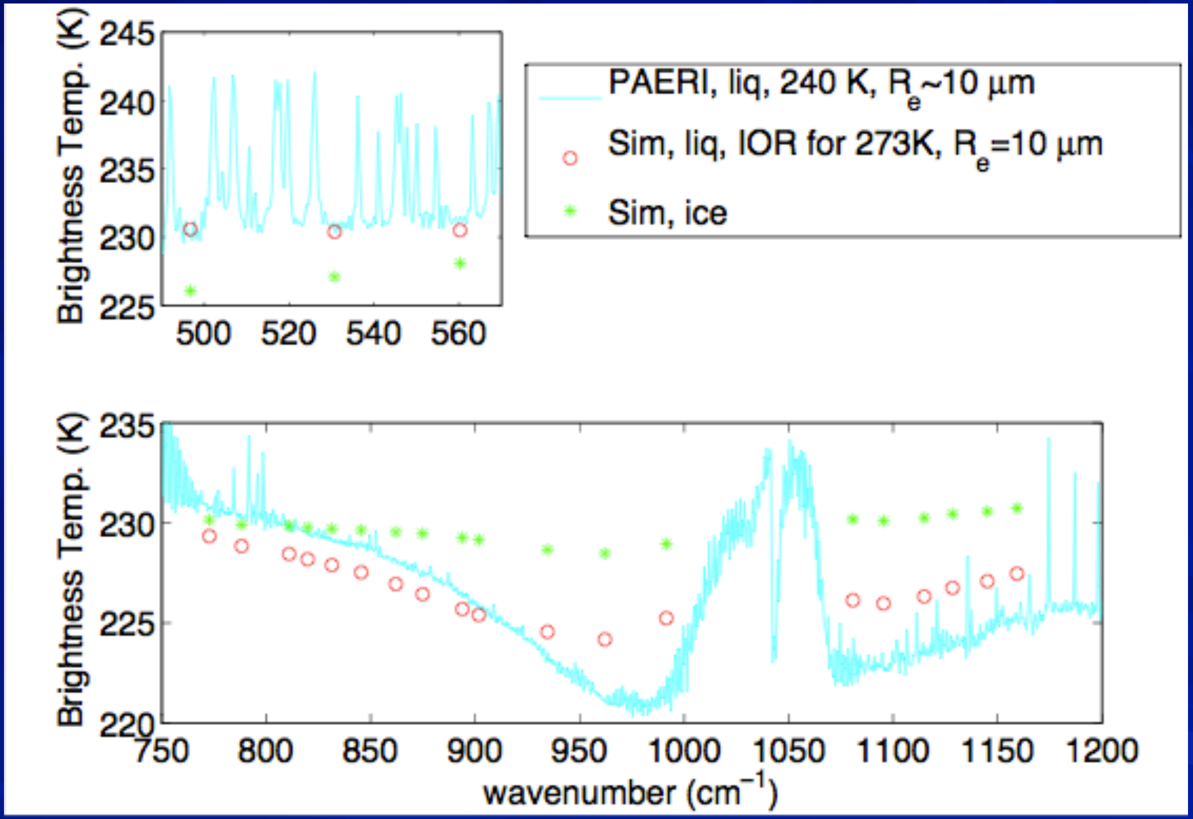
- Droplet Size Distribution
  - Effective radius is about 10 μm.
  - Width of equivalent log-normal distribution is about 0.5.

Radiative Closure

- Measurements of downwelling radiance from the PAERI can be compared to simulations (LBLDIS, DISORT, LBLRTM)

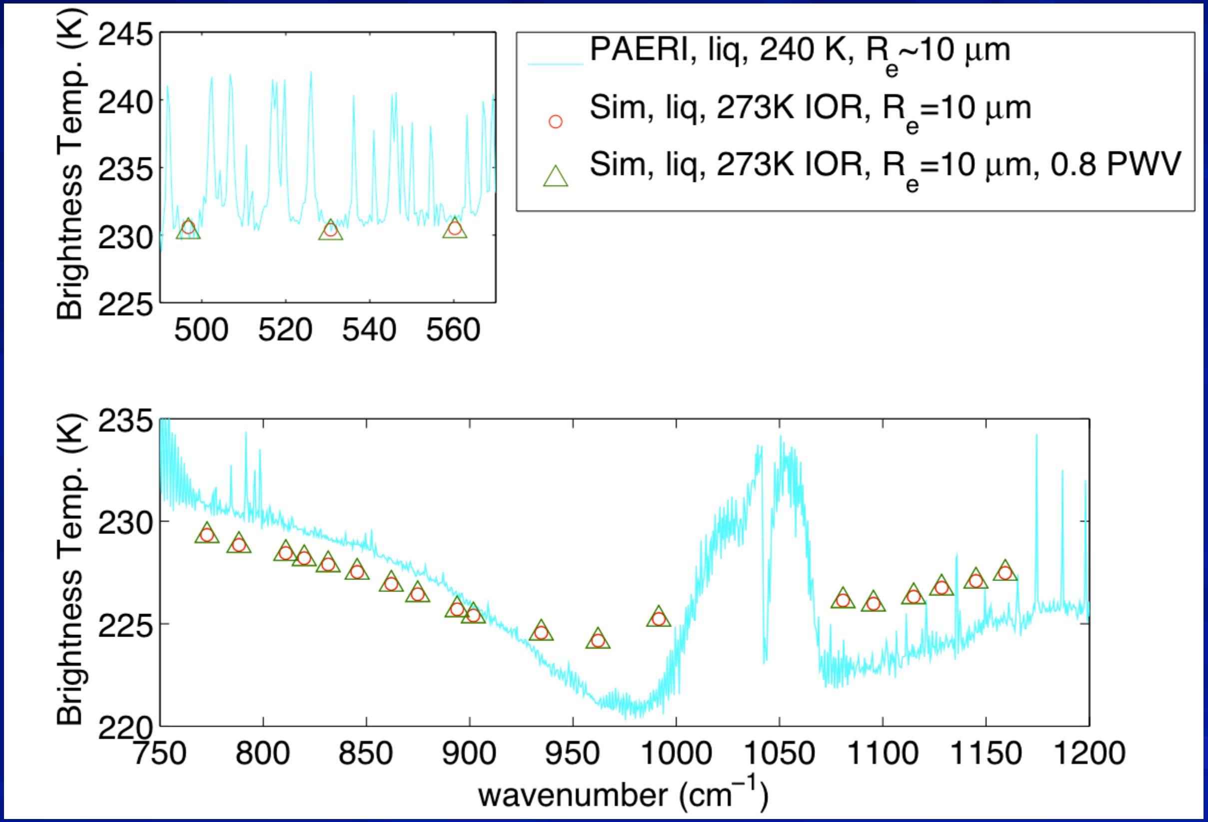


Radiative Closure



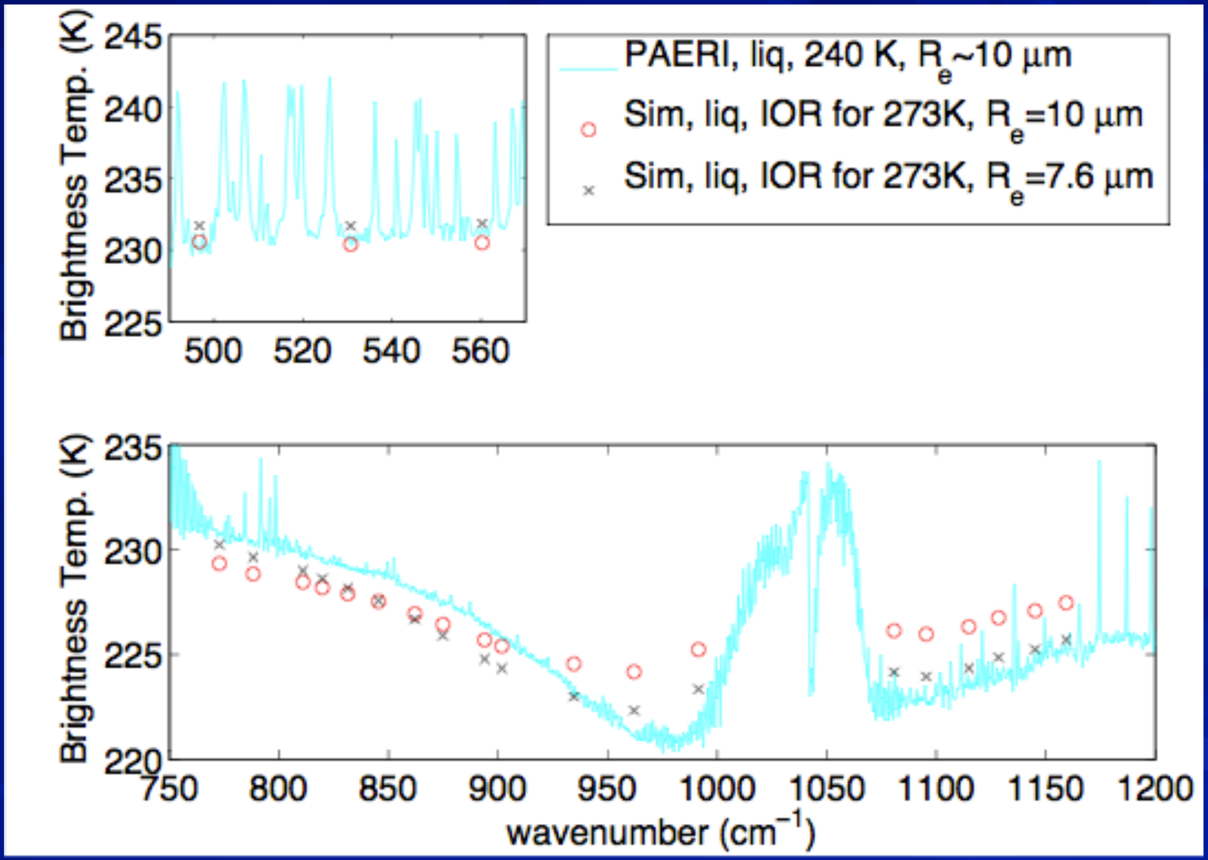
- This is *not* an ice-only cloud.
- Also a poor fit for a liquid cloud.

Radiative Closure



Large changes in the Precipitable Water Vapor cannot explain the radiance differences.

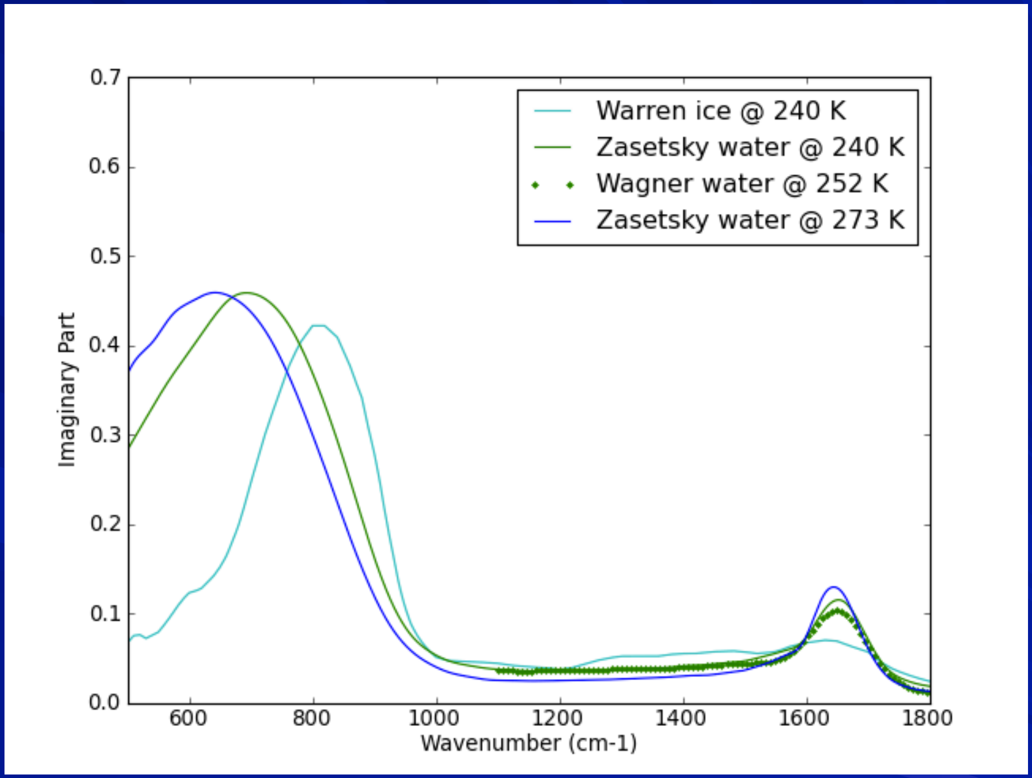
Radiative Closure



- Better fit if we use smaller effective radius.
- But the fit is still not very good.

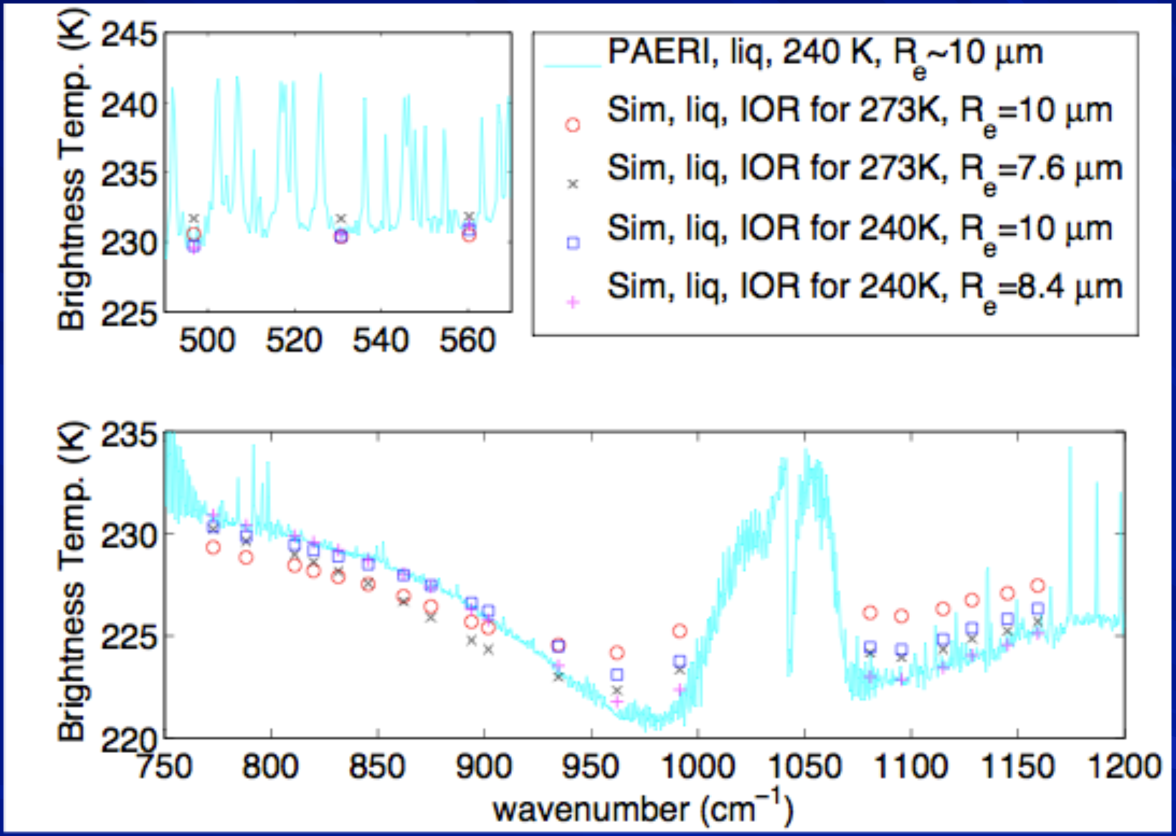
Temperature-Dependent Optical Properties

- Index of refraction (IOR) of super-cooled water in *J. Phys. Chem.*
  - Zasetsky et al (2005)
  - Wagner et al (2005)



Water IORs typically come from Warren Wiscombe's REFWAT code, which uses Ray (1972).

Radiative Closure

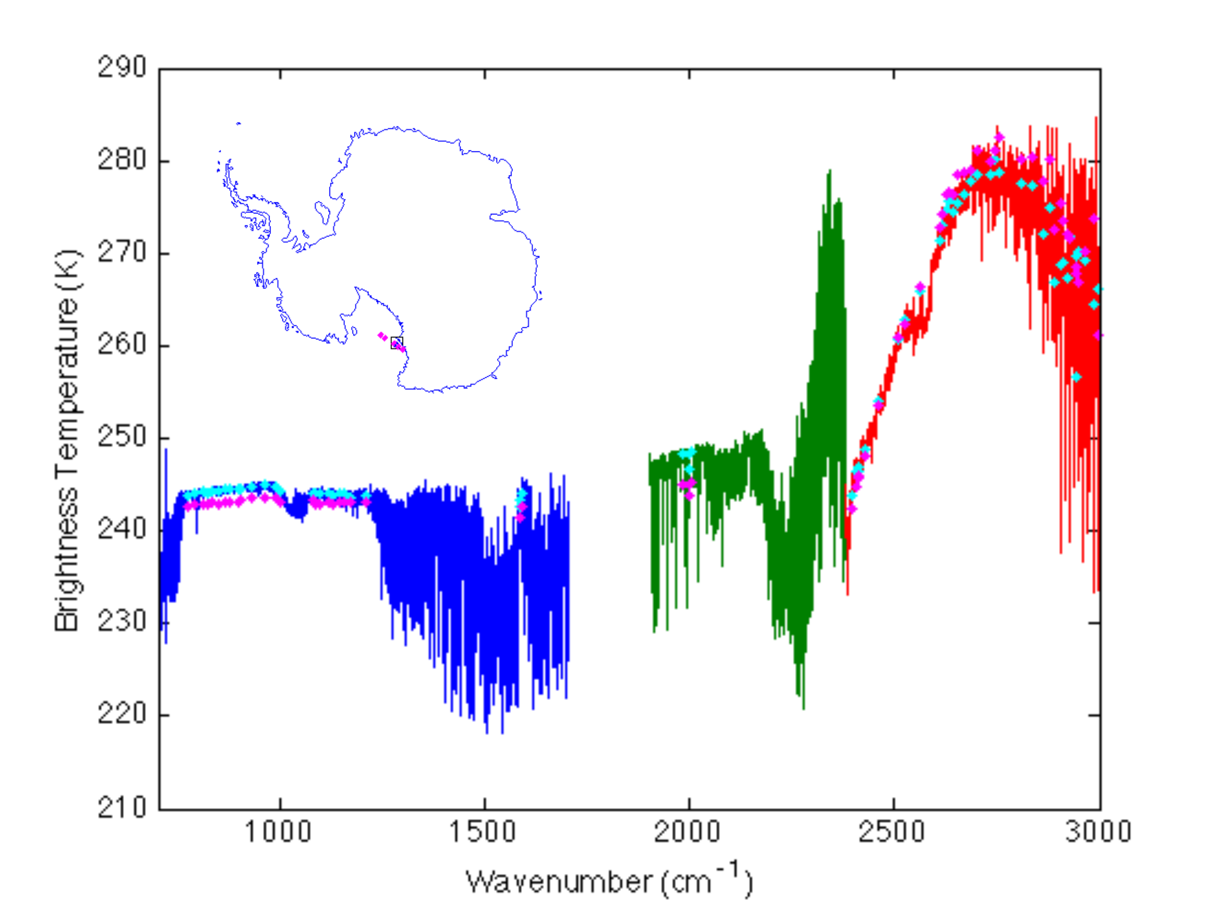


Best

Using Zasetsky's index of refraction (IOR) for 240 K gives excellent agreement, especially for an effective radius of 8.4 µm.

Case Study for IMG Retrieval

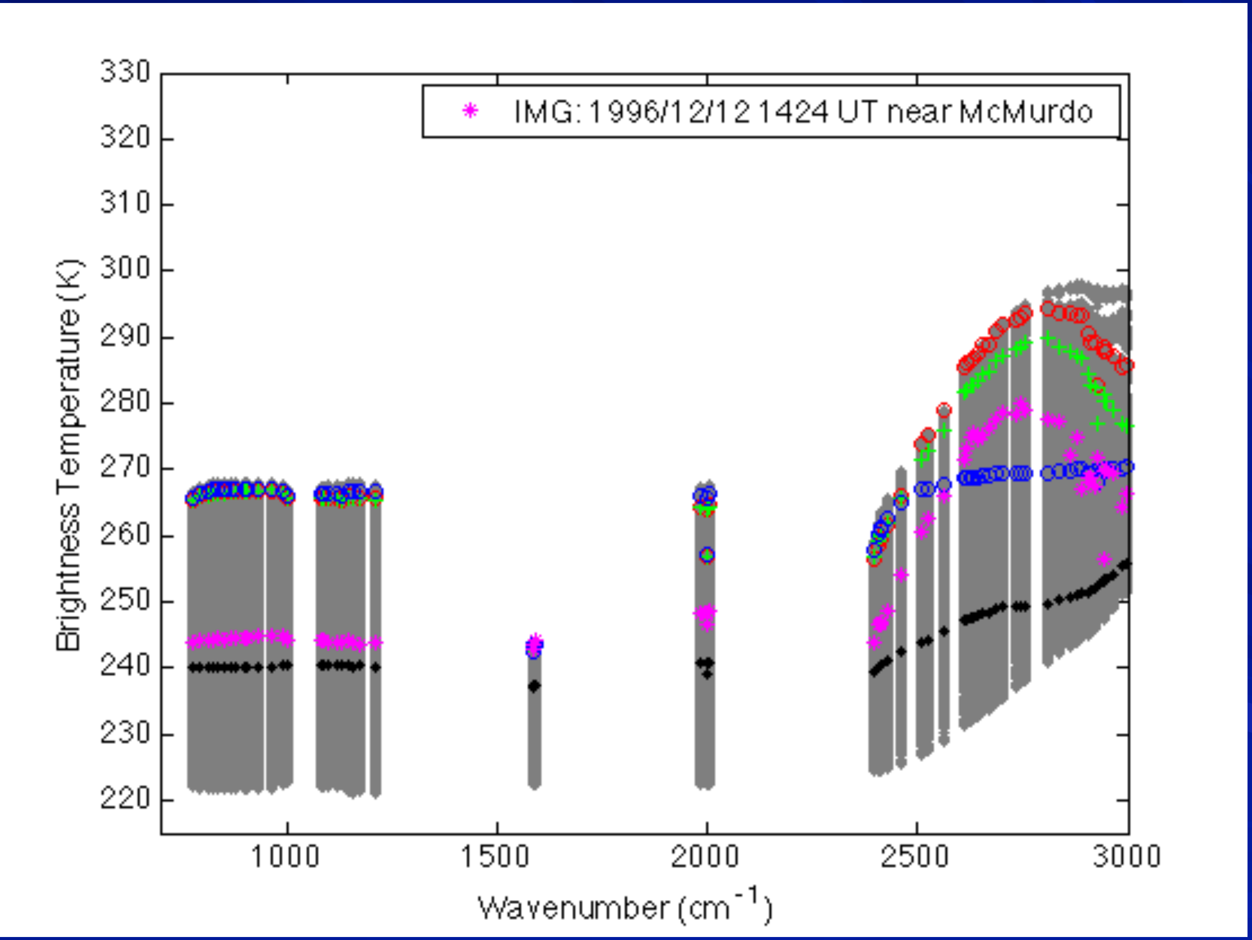
Over McMurdo Station, 12 DEC 96



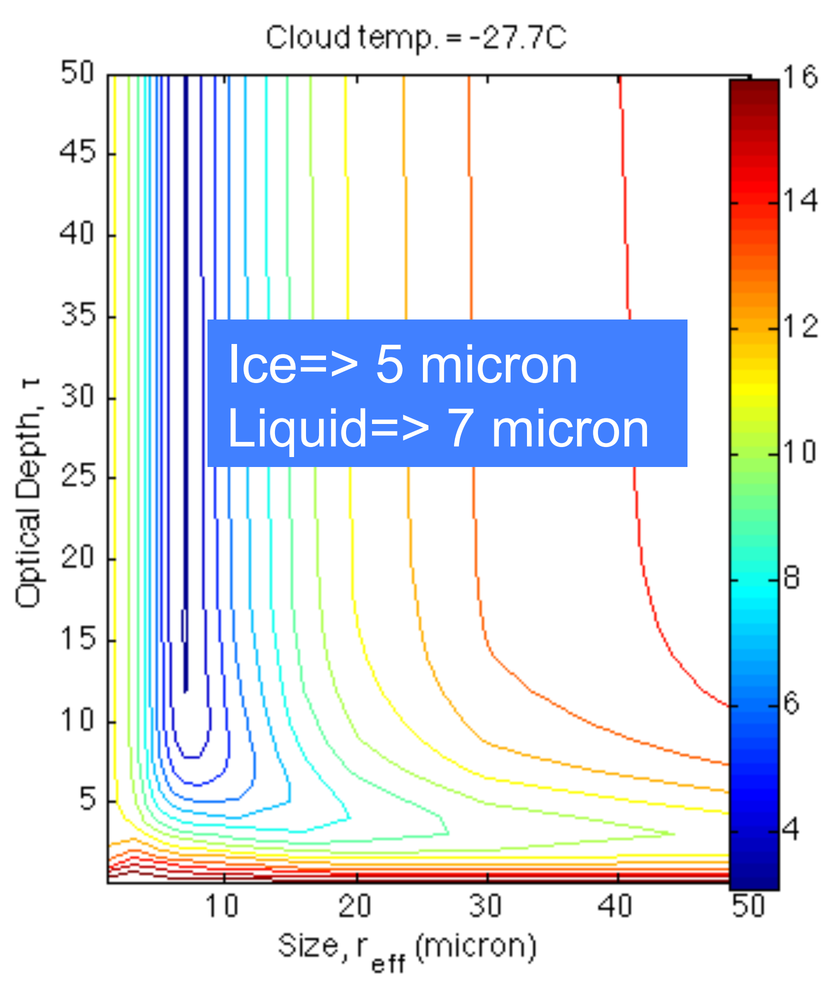
Database of simulated radiances

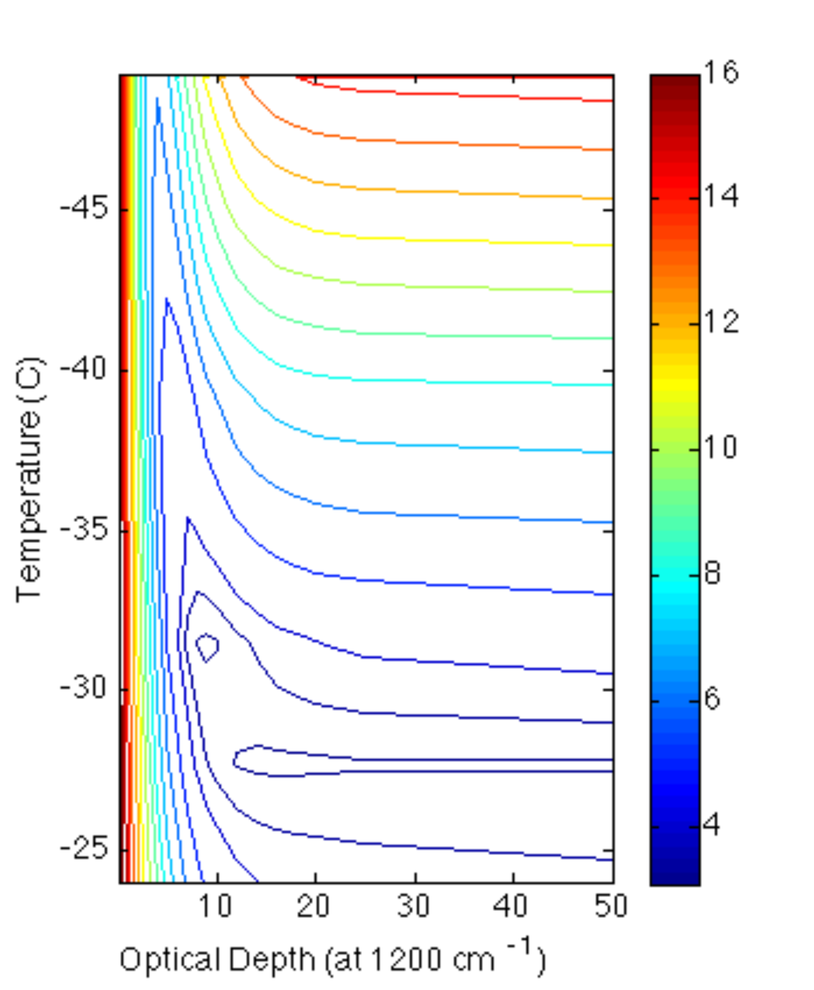
- Atmospheric Profiles
- Line-by-Line RTM (LBLRTM; Clough et al. 2005)
- DISORT (Stamnes et al. 1988)
- LBLDIS (Turner et al. 2003)
- Lambertian surface, Emissivity needs refining
- Single cloud layer
- Cloud optical depth, height, particle size,
- Phase: liquid or ice. No mixed phase yet.
- Using forward RT calculations for each case.

The database:
Radiosonde profile, SZA~80

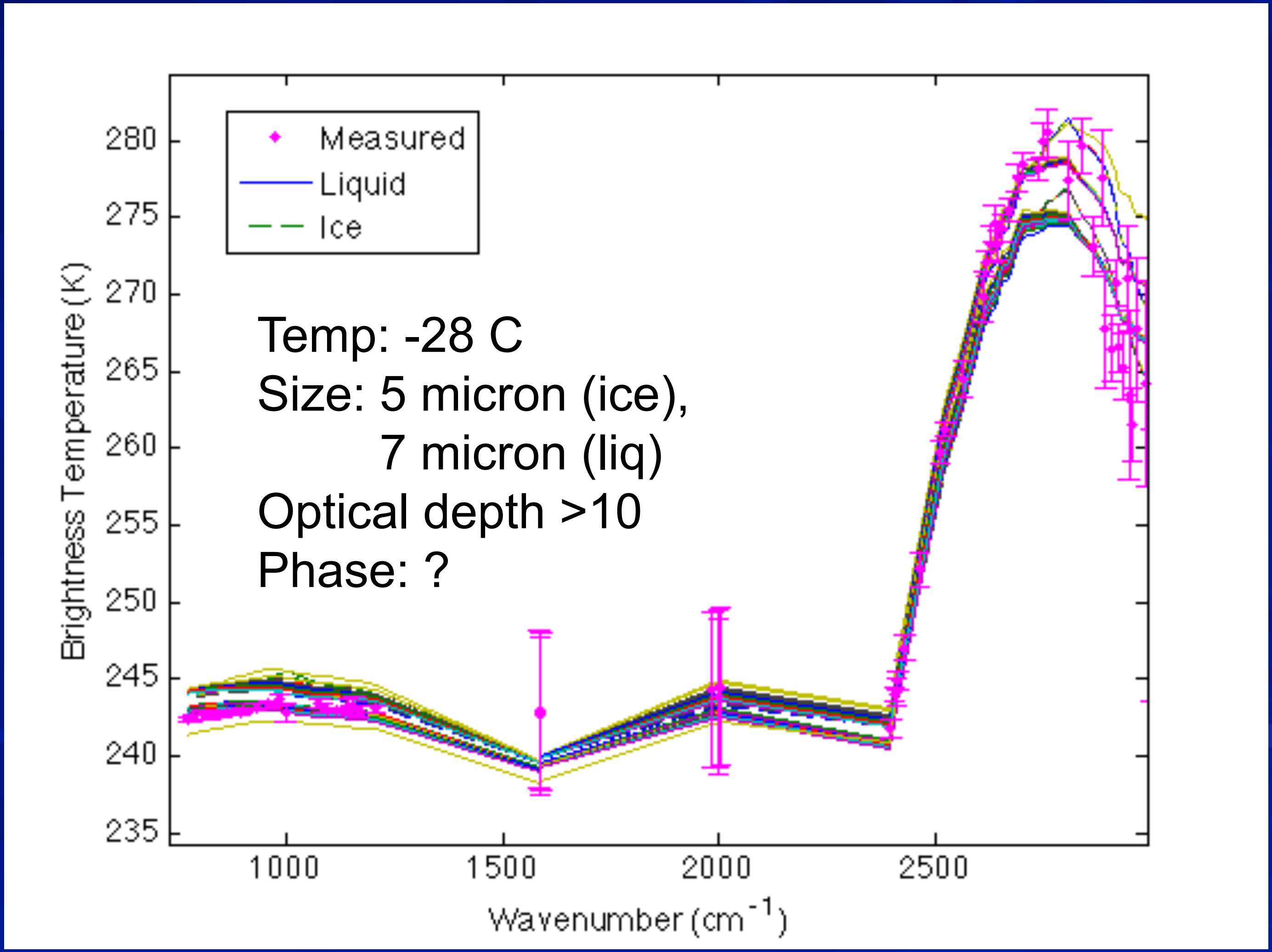


RMS differences between IMG Measurement and Simulations





Case Study: Results



Conclusions

- Antarctica is where satellite remote sensing is needed most, but where remote sensing retrievals are most difficult.
- A future sounder covering out to 20 microns would enable reliable cloud phase detection at high latitudes.
- Optical properties for super-cooled clouds recommended in polar regions (or high up in troposphere).
- Using IMG or AIRS alone
  - can retrieve particle size and temperature
  - more difficult to retrieve phase and optical depth
- We welcome collaboration with other AIRS investigators!