Jet Propulsion Laboratory
California Institute of Technology

Retrieval of cloud thermodynamic phase with SWIR imaging spectroscopy

David R. Thompson [1]
Ian McCubbin [1,2]
Bo-Cai Gao [3]
Robert O. Green [1]
Kerry Meyer [4]
Steven Platnick [4]
Eric Wilcox [2]

[1] Jet Propulsion Laboratory, California Institute of Technology
[2] Desert Research Institute
[3] Naval Research Laboratory
[4] Goddard Space Flight Center

US Government Support Acknowledged.

david.r.thompson@jpl.nasa.gov

Cloud phase has a large impact on radiative forcing

- Clouds cover 50% of Earth's surface (Mercury et al, RSE 2012)
- Water clouds reflect, ice clouds absorb (Wolters et al., JAMC 2008)
- Cloud phase estimation is a prerequisite to other retrievals such as particle size

david.r.thompson@jpl.nasa.gov

Existing VSWIR methods use band ratios

Typically normalized ratios in the 1600 nm region

Where absorption coefficients of liquid and ice differ

Examples

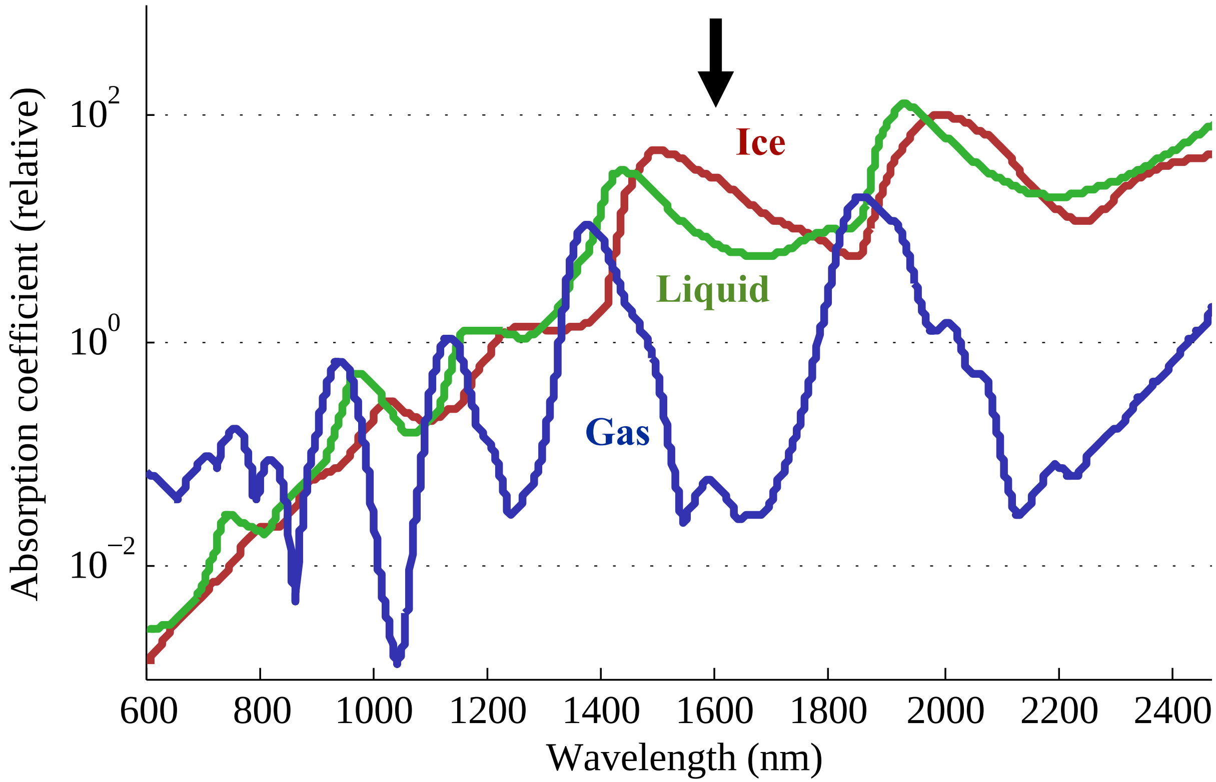
Erlich et al, 2008

Knap et al., 2002

Jakel et al., 2013

Chylek et al., 2004

Chylek et al., 2006



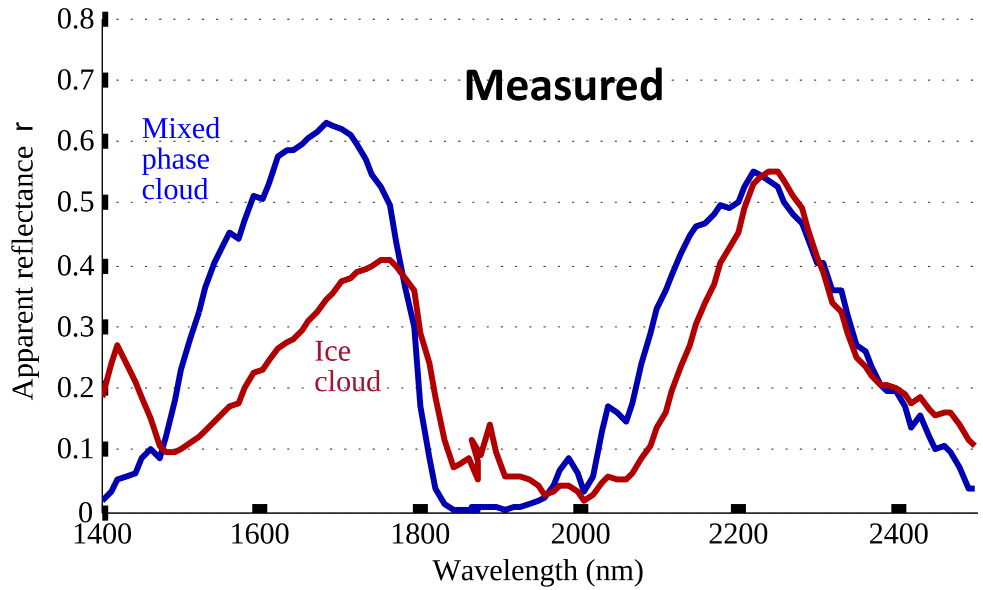
david.r.thompson@jpl.nasa.gov

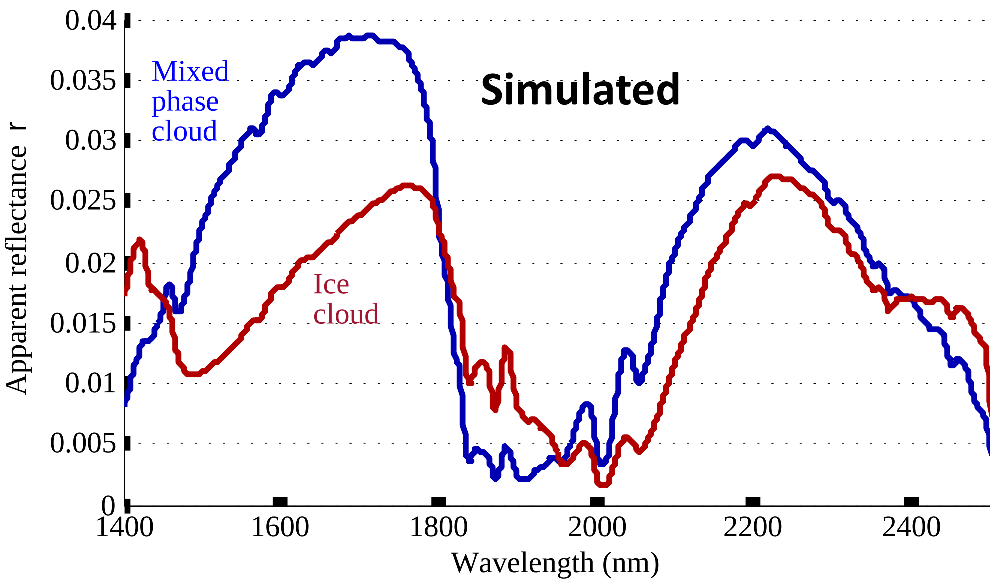
Can we retrieve thermodynamic phase using spectral data? We investigate in simulation:

- LibRadTran package (Mayer and Kylling, 2005)
- **DISORT radiative transfer** solver (Stamnes et al. 1988).
- **Liquid cloud properties** from Mie theory
- **Ice cloud properties** assume randomly-oriented, roughened ice particles (Baum et al., 2014; Heymsfield et al., 2013; Yang et al., 2013).
- **Solar irradiance** spectrum of Kurucz (1994)
- **Gas absorption** using REPTRAN parametrization (Gasteiger et al., 2014).

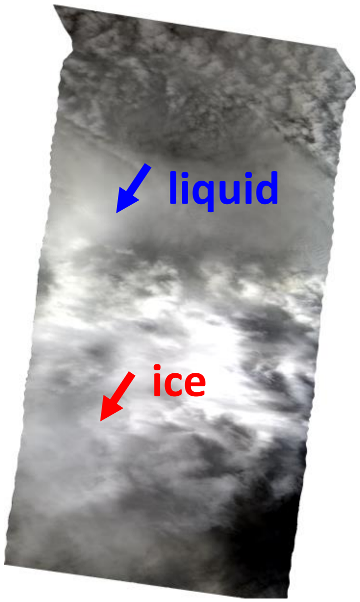
david.r.thompson@jpl.nasa.gov

Sanity check: Simulations vs. AVIRIS-C data





AVIRIS-C Flightline f150205r19



david.r.thompson@jpl.nasa.gov

Retrieval by fitting H_2O absorption

- Fit vapor, liquid and ice "equivalent absorption path lengths" [Gao & Goetz 1995]
- Linearized nonnegative least squares [Thompson et al., RSE 2015 (in press)]

$$-log(\rho(\lambda)) \approx l + \lambda m - \lambda n + \sum_j k_j(\lambda) u_j$$

"Top of Atmosphere" reflectance

Continuum terms

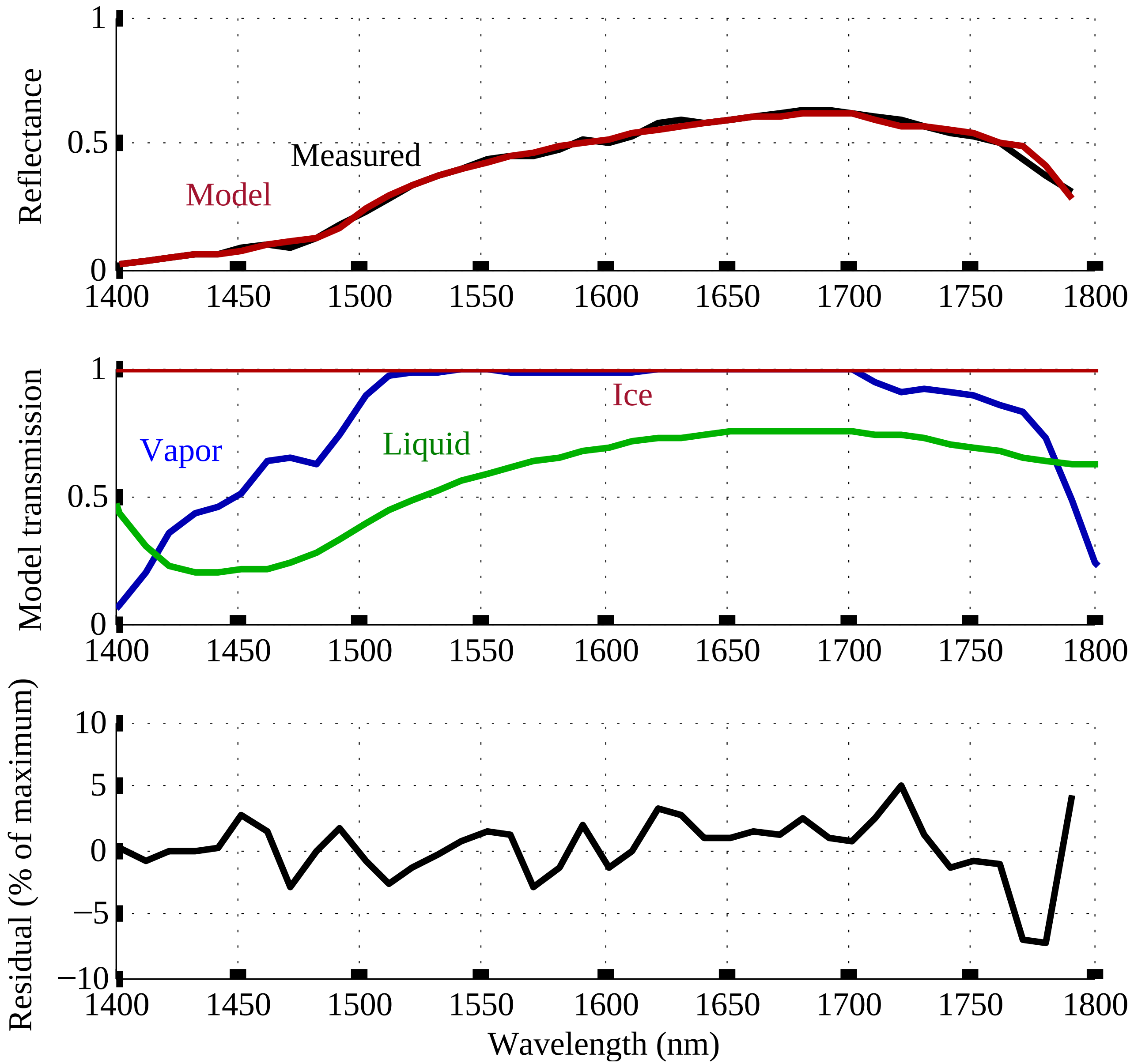
Absorption coefficient for absorber j

Absorption path length

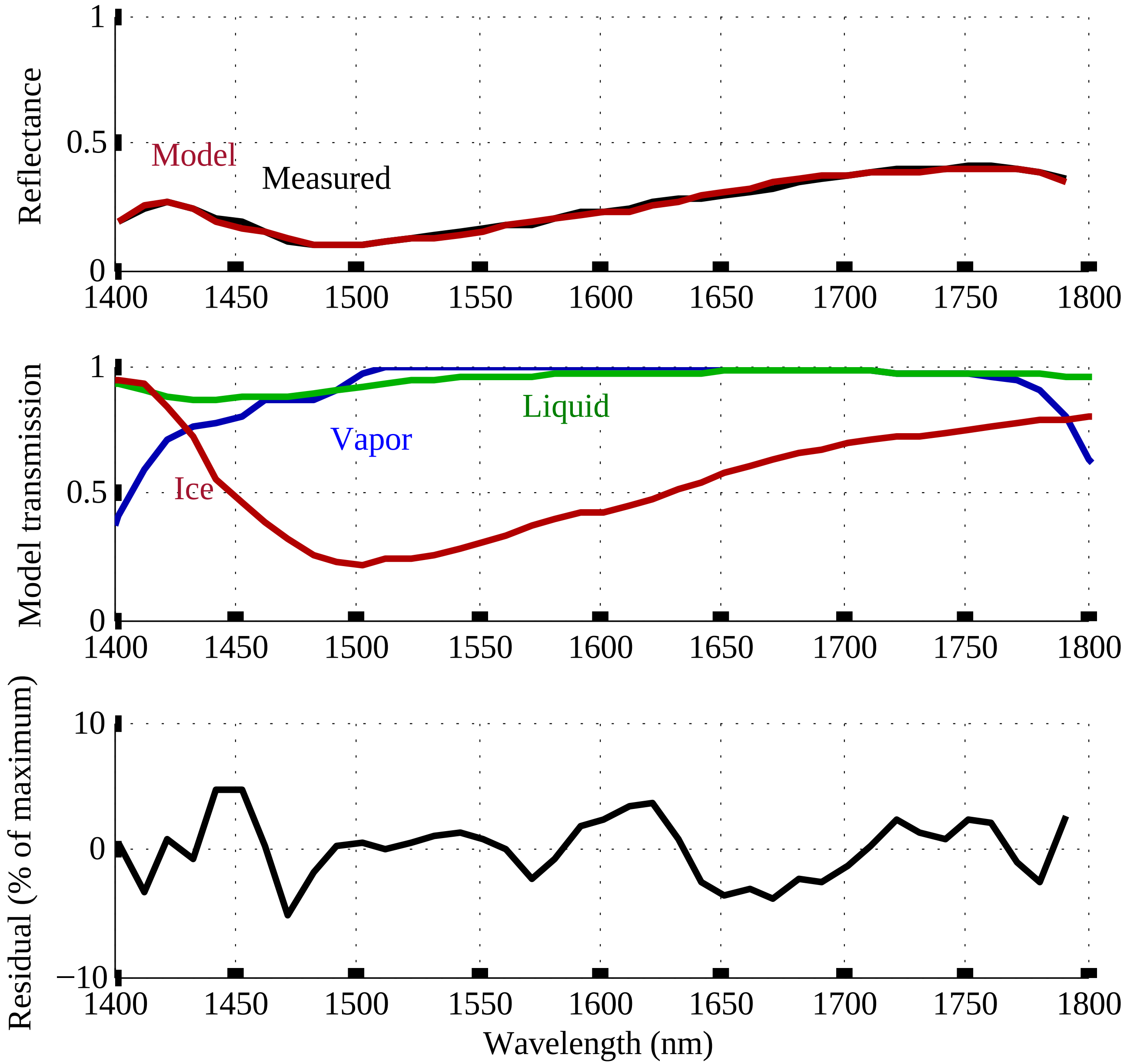
Gao, B.C., & Goetz, A.F. Remote Sensing of Environ. 52(3), 1995..

Thompson, D.R., et al., Remote Sensing of Environ. (in press). http://dx.doi.org/10.1016/j.rse.2015.02.010

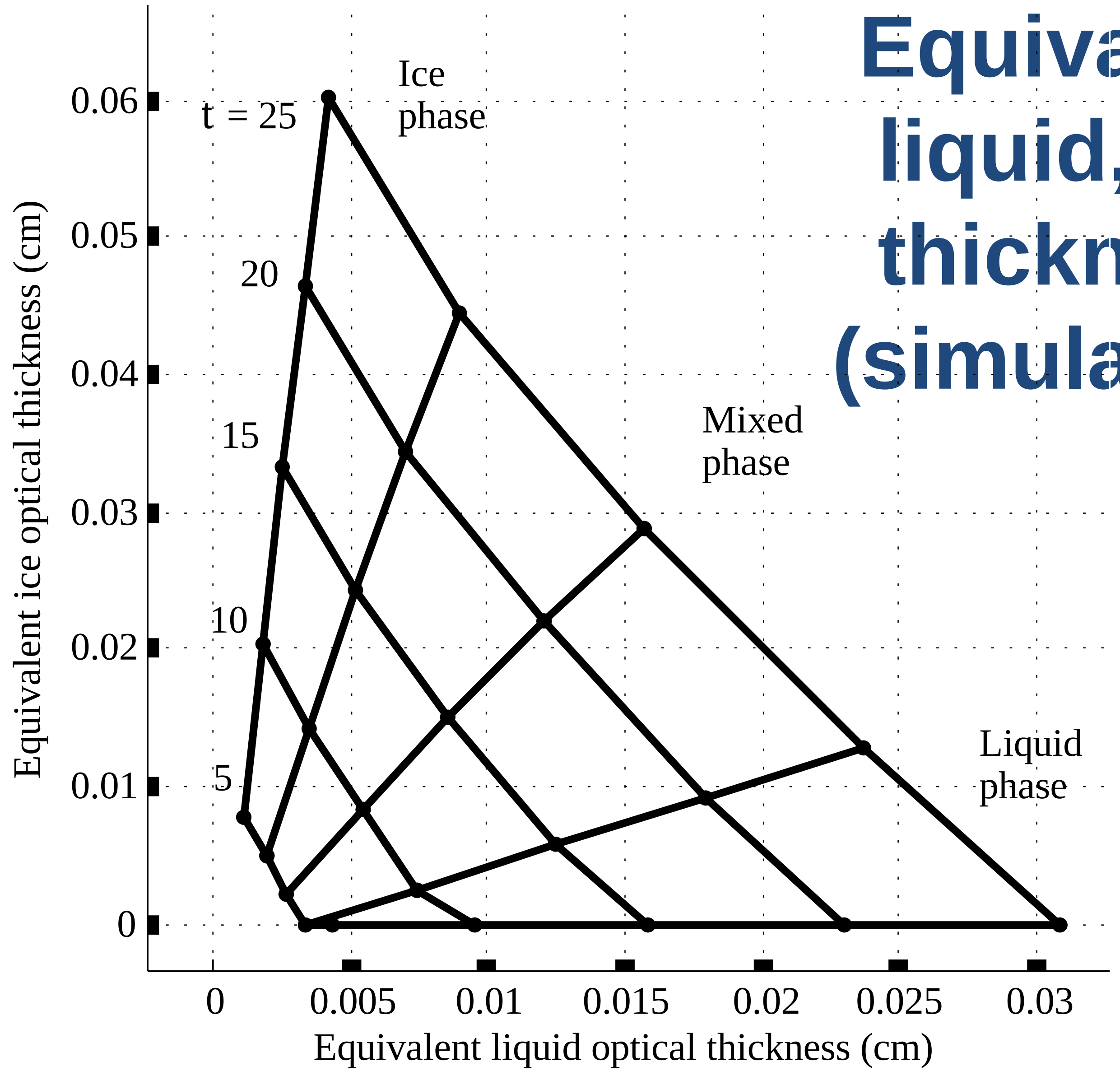
Example fit for liquid cloud



Example fit for ice cloud



Equivalent liquid, ice thickness (simulation)

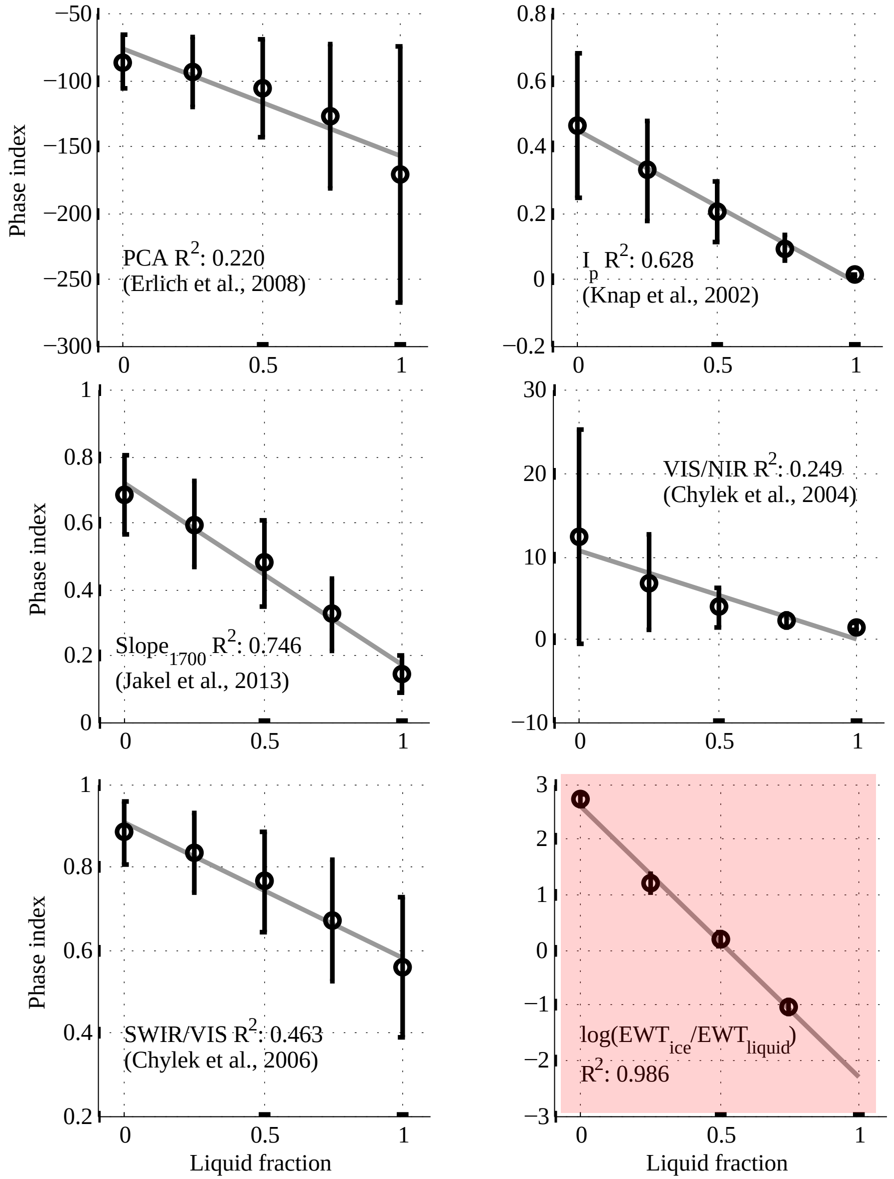


david.r.thompson@jpl.nasa.gov

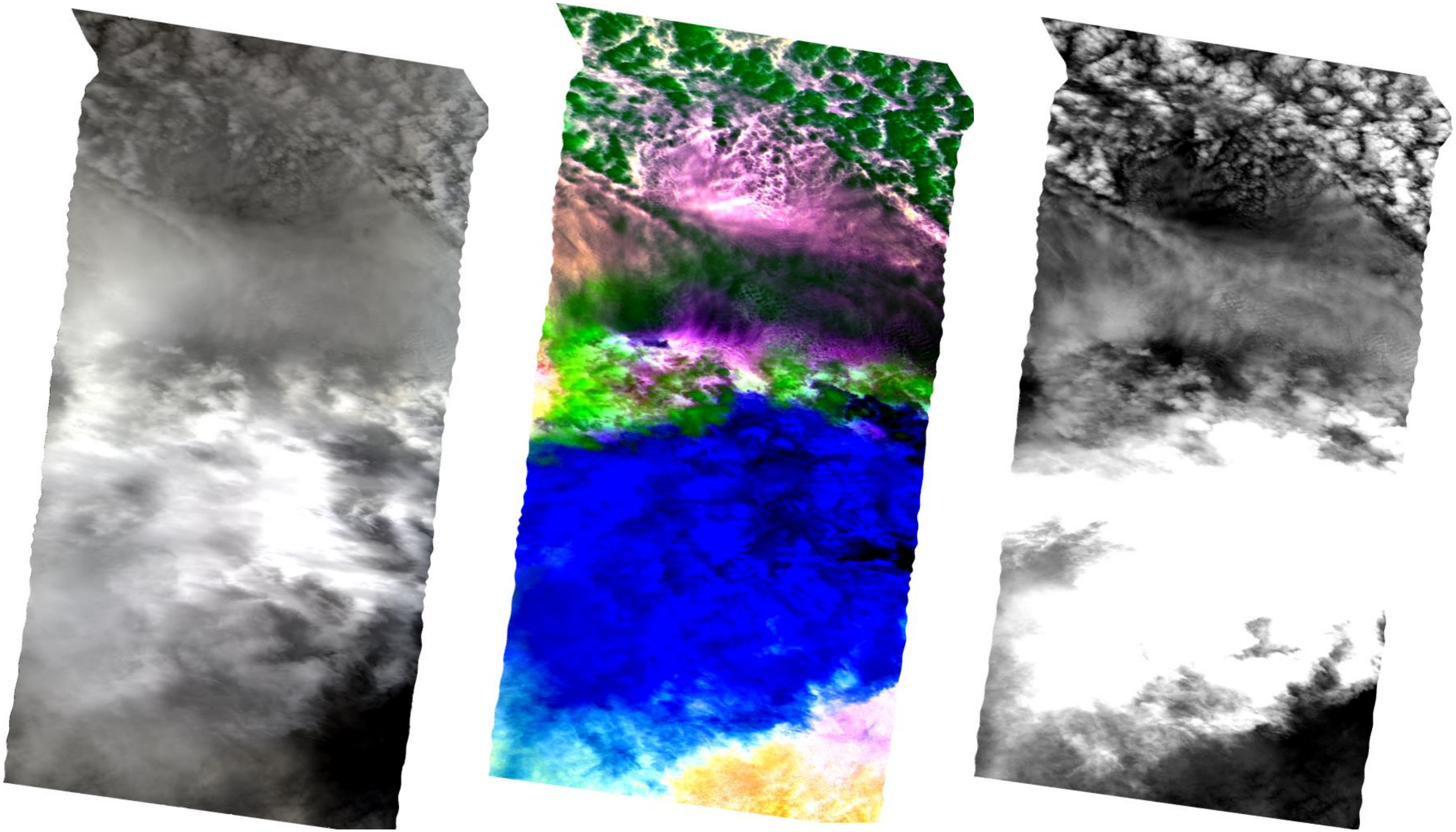
Spectroscopic retrievals vs. status quo methods

Error bars show 1-sigma deviation for varying surface albedo and particle sizes

Method	R^2
Ehrlich et al. (2008)	0.220
Knap et al. (2002)	0.628
Jäkel et al. (2013)	0.746
Chylek and Borel (2004)	0.249
Chylek et al. (2006)	0.463
log EWT ratio	**0.986**



AVIRIS-C (2 Feb 2015 run 19)



RGB Reflectance　　Ice Liquid Vapor　　Pressure altitude (1-4km)

Next steps

In situ validation

Investigation of other retrievals (particle size, e.g.)

david.r.thompson@jpl.nasa.gov

Thanks!

The AVIRIS-C team
The Calwater-2 investigation

Backup slides

david.r.thompson@jpl.nasa.gov

Backup

Cloud reflectance in visible and SWIR, vs. particle size and optical depth

Visible wavelengths are sensitive to optical depth

SWIR is sensitive to particle size

Figure from [Wolters et al., JAMC 2008]

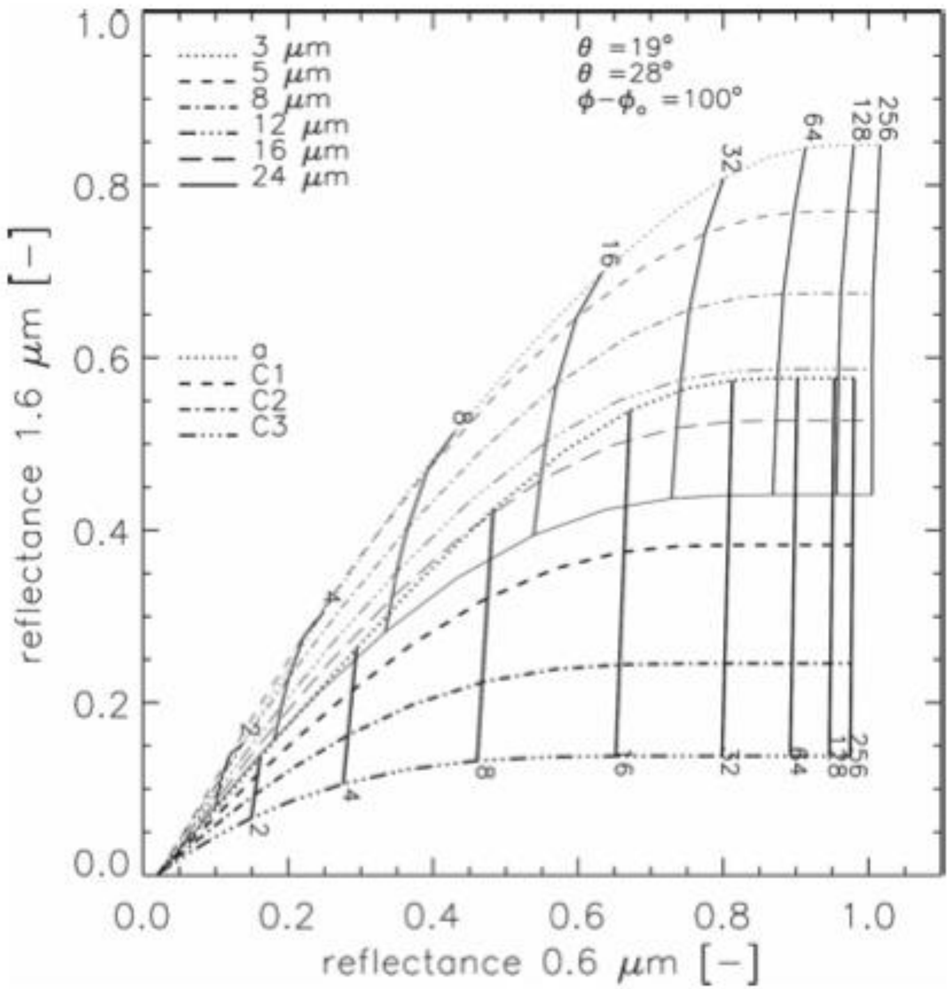


FIG. 2. Modeled 0.6- and 1.6-μm reflectances for $\theta_0 = 19°$, $\theta = 28°$, and $\phi - \phi_0 = 100°$. Cloud optical thickness is denoted by various vertically oriented lines, and the effective radius is denoted by horizontally oriented lines. Water particles are represented in the top part of the graph, and ice particles are shown in the bottom part.

david.r.thompson@jpl.nasa.gov