Advances in the Remote Sensing of Cloud Optical Properties

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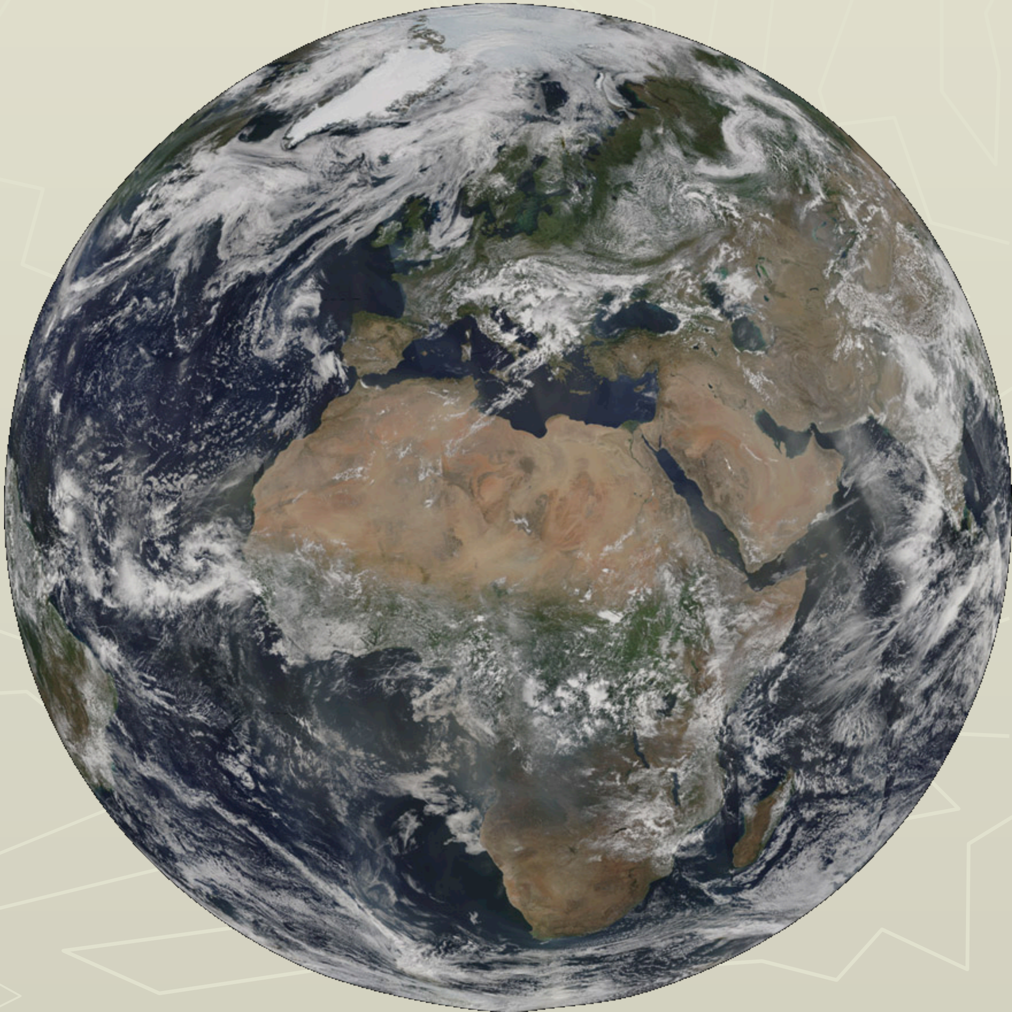
- Cloud remote sensing
  - Cloud optical thickness
  - Cloud effective radius
- MODIS observations
  - Cloud optical properties
    - ✓ Surface reflectance impact
    - ✓ Level-3 gridded products
    - ✓ Probability density function
      - ❖ Cloud optical thickness
      - ❖ Cloud effective radius
    - ✓ Joint probability density function
      - ❖ Cloud optical thickness & cloud effective radius
      - ❖ Cloud top pressure & cloud optical thickness



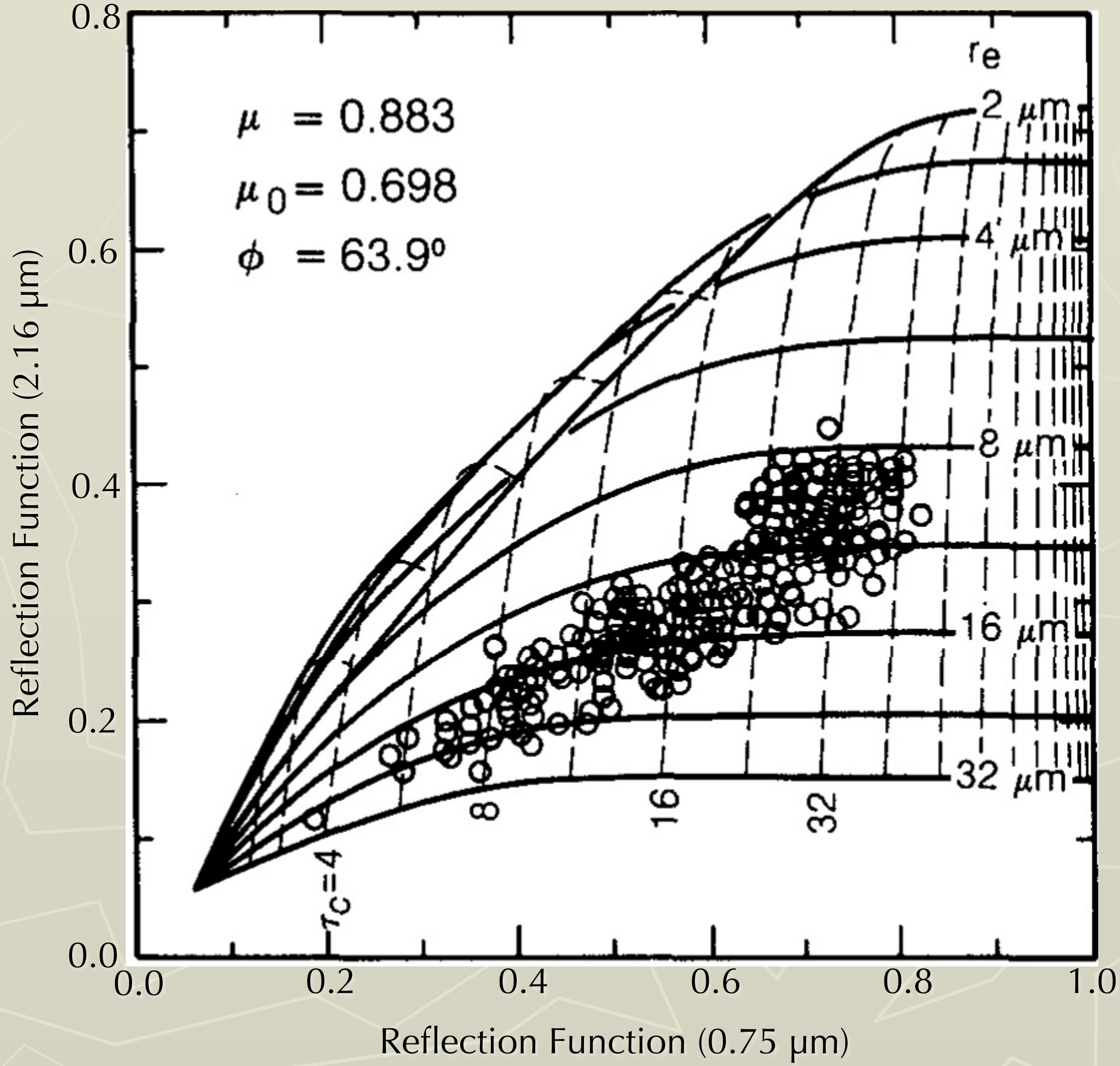
Cloud Optical & Microphysical Properties
(M. D. King and S. Platnick)

- Pixel-level cloud product during daytime at 1 km
  - Daytime defined as $\theta_0 < 81.4°$ to be consistent with cloud mask
- Critical input (especially for global processing):
  - Cloud mask: to retrieve or not to retrieve?
  - Cloud thermodynamic phase: liquid water or ice libraries?
  - Cloud top temperature, ancillary surface temperature: needed for 3.74 μm emission characterization (band contains solar and emissive signal), *T*(sfc) from NCEP, Reynolds SST
  - Atmospheric correction: requires cloud top pressure, ancillary information regarding atmospheric moisture & temperature (e.g., NCEP, other MODIS products)
  - Surface albedo: for land, ancillary information regarding snow/ice extent (e.g., NISE)

Retrieval of τ_c and r_e
(T. Nakajima and M. D. King)

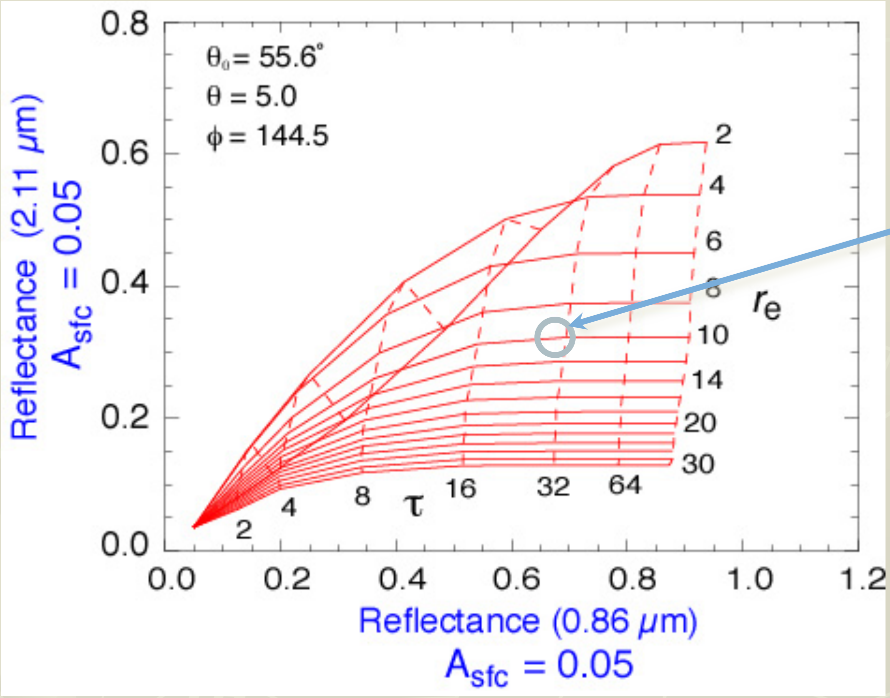
Cloud Optical Properties

- The reflection function of a nonabsorbing band (e.g., 0.75 μm) is primarily a function of optical thickness
- The reflection function of a near-infrared absorbing band (e.g., 2.16 μm) is primarily a function of effective radius
  - clouds with small drops (or ice crystals) reflect more than those with large particles
- For optically thick clouds, there is a near orthogonality in the retrieval of τ_c and r_e using a visible and near-infrared band

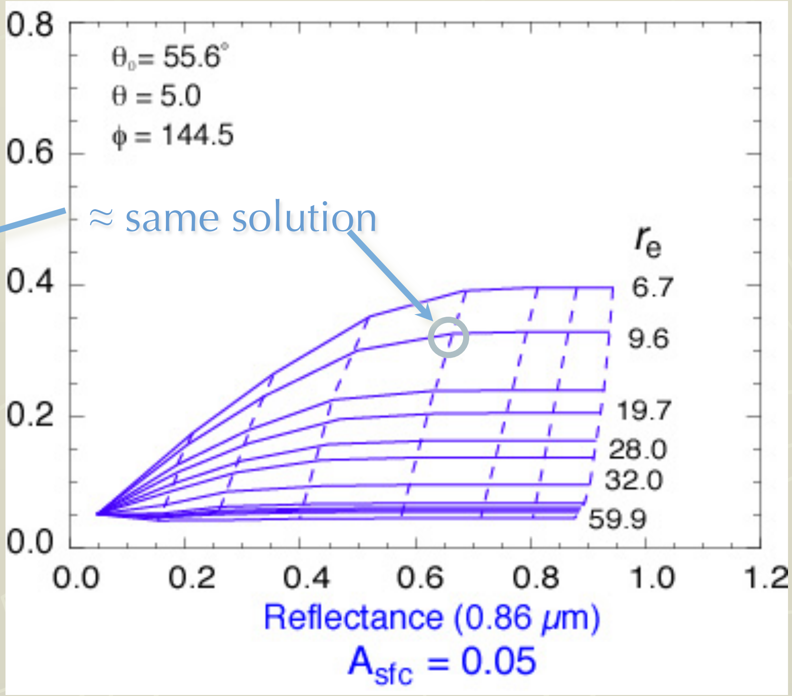


Nakajima and King (1990)
King et al. (1992)

Cloud Optical & Microphysical Retrievals
Retrieval space examples



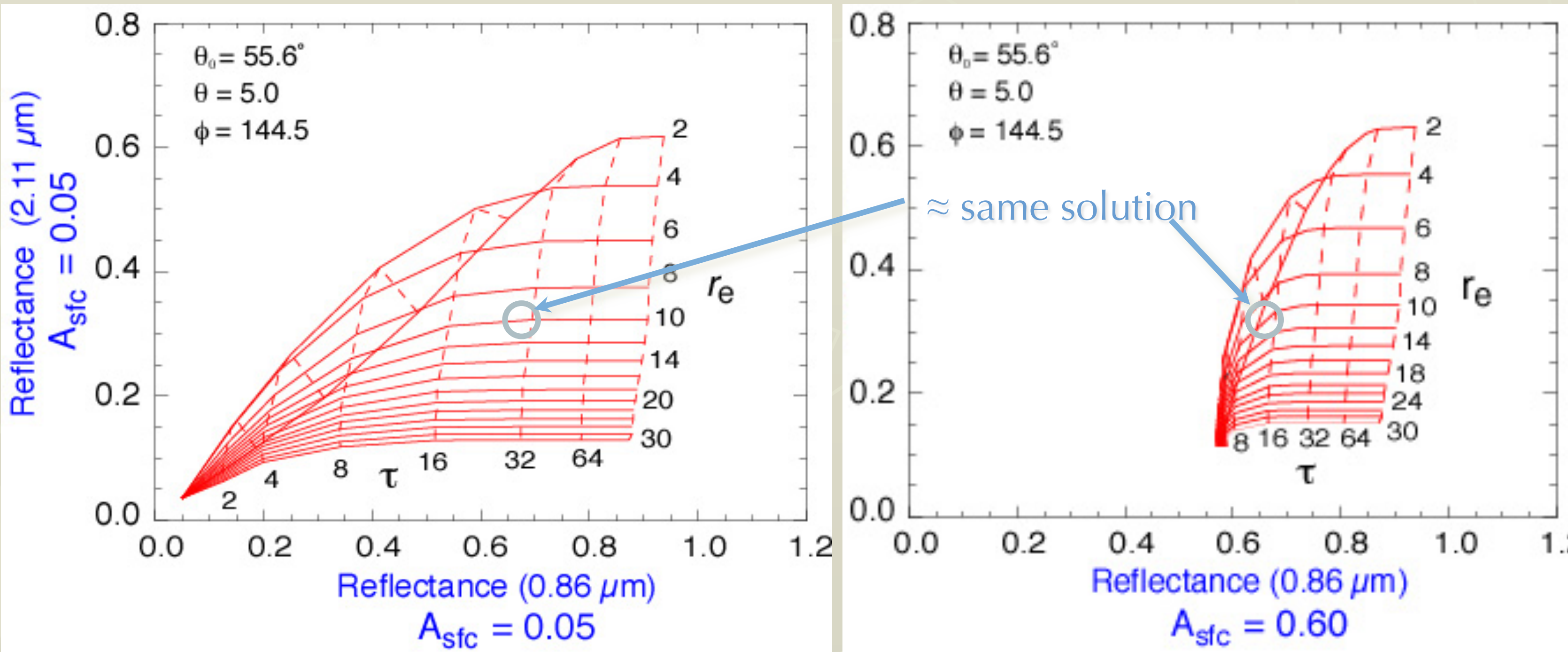
Liquid water cloud
ocean surface



Ice cloud
ocean surface

Cloud Optical & Microphysical Retrievals

Retrieval space examples



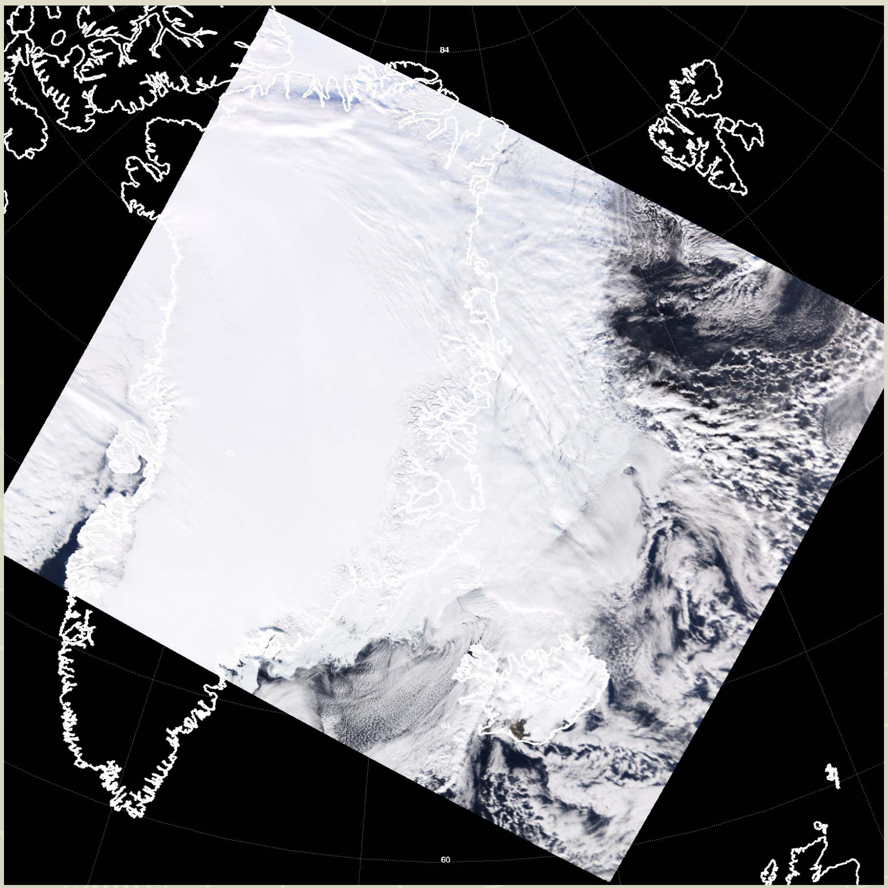
Liquid water cloud
ocean surface

Liquid water cloud
ice surface

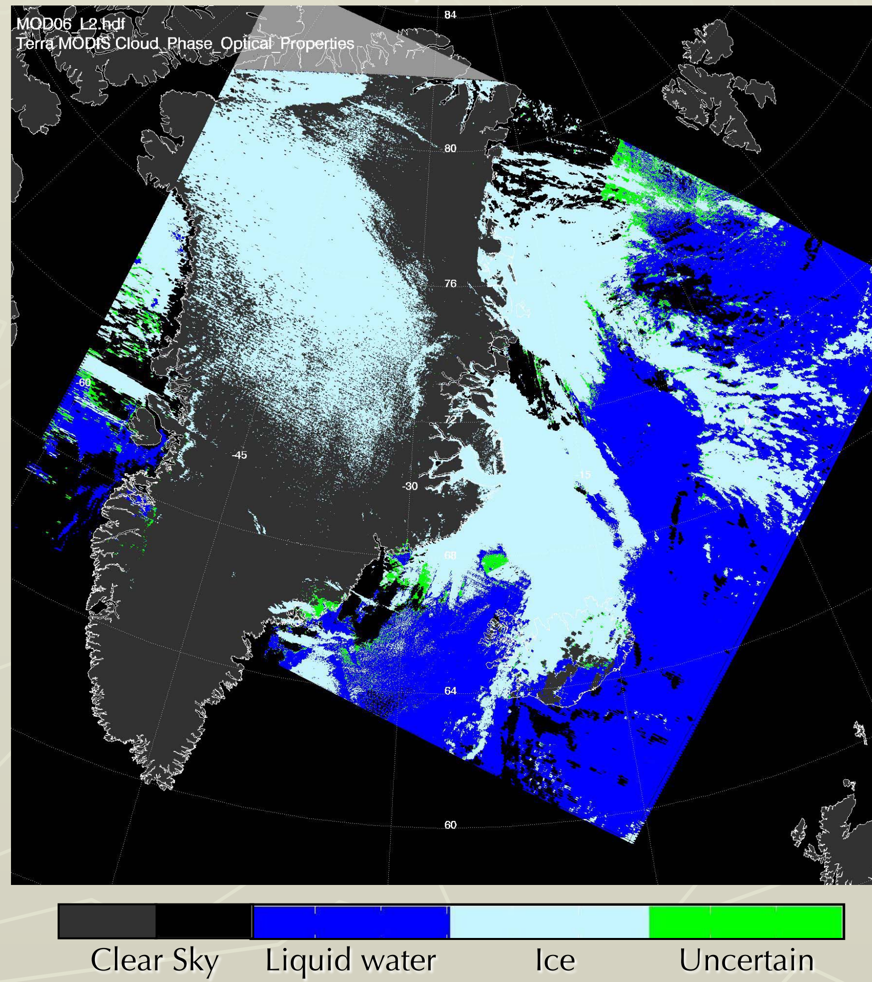
Terra/MODIS Cloud Thermodynamic Phase

(M. D. King, S. Platnick, J. Riedi et al. – NASA GSFC, U. Lille)

True Color Composite (0.65, 0.56, 0.47)



Thermodynamic Phase

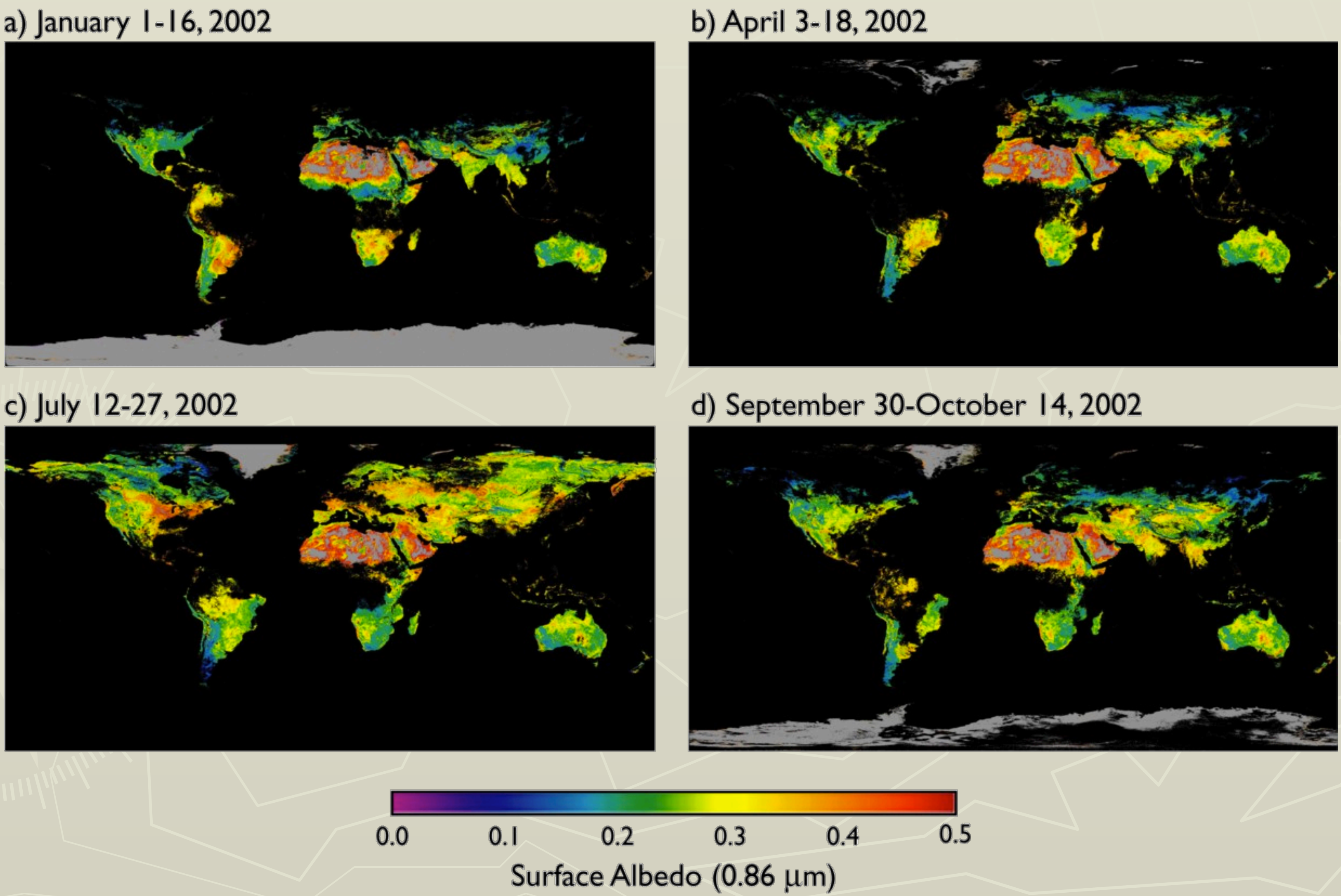


March 22, 2001

Collection 5

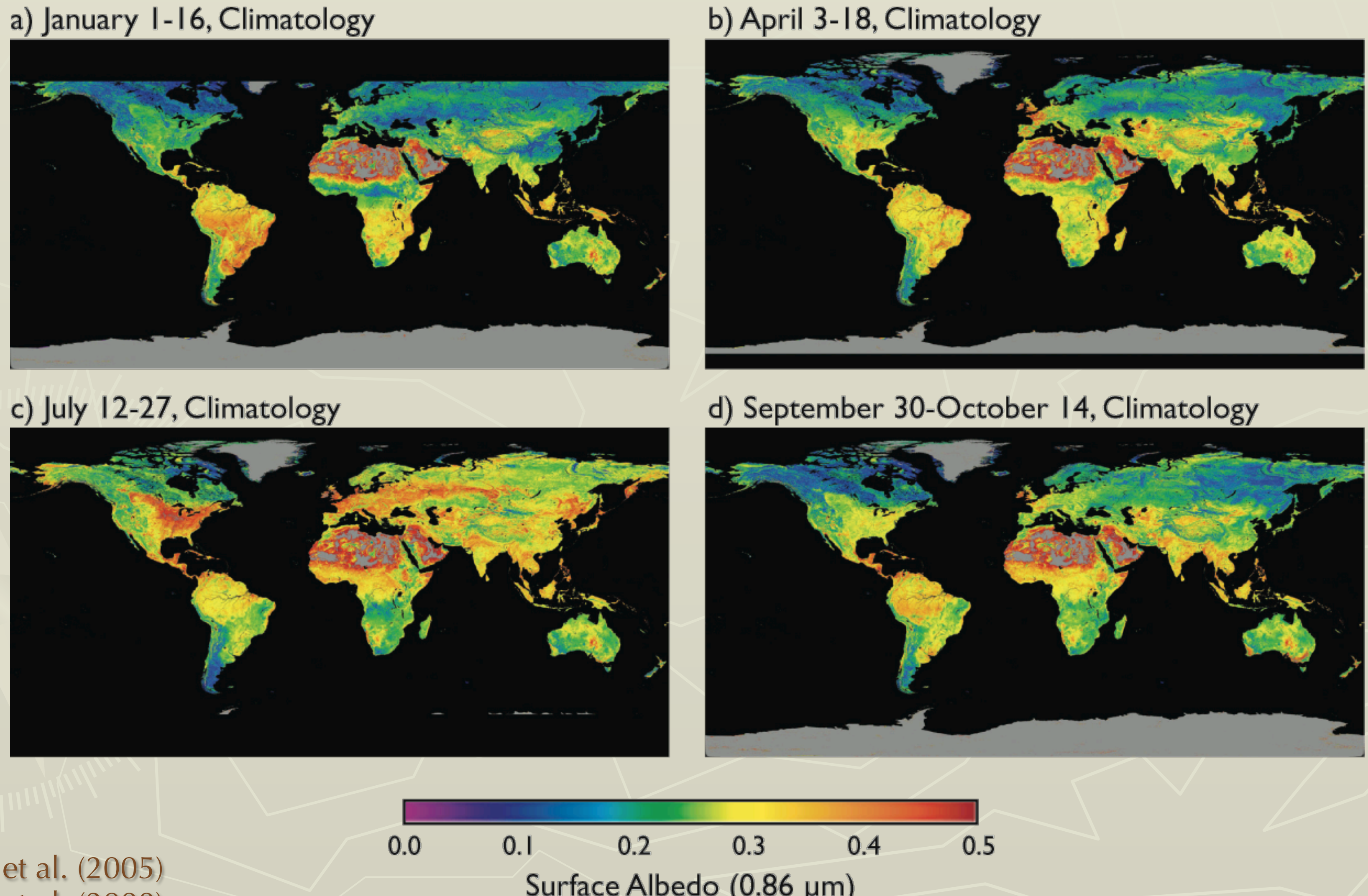
Conditioned MODIS Surface Albedo Maps

$\lambda = 0.858\ \mu m$



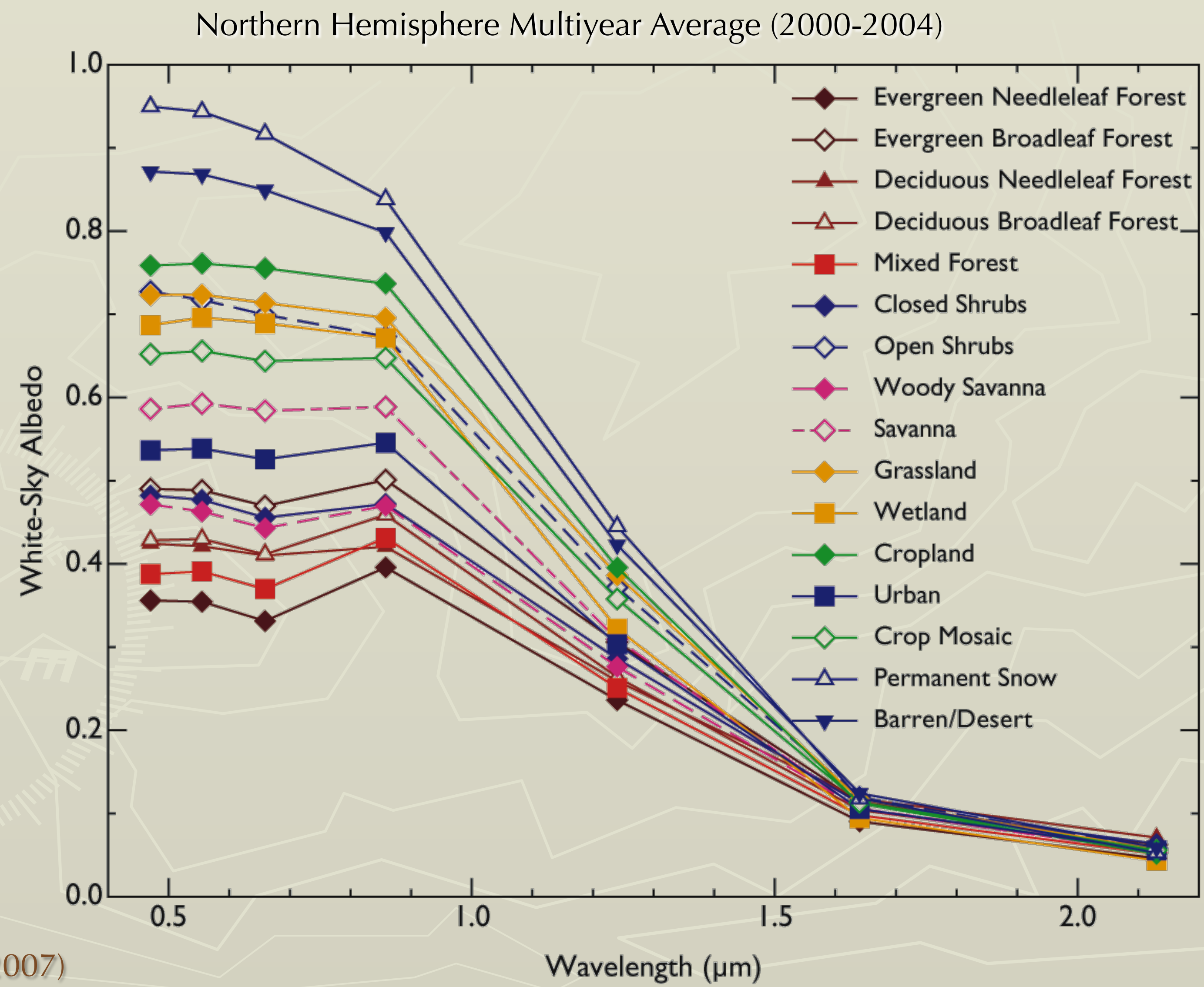
Spatially Complete Surface Albedo Maps

λ = 0.858 μm



Moody et al. (2005)
Moody et al. (2008)

Snow Albedo by IGBP Ecosystem
(E. G. Moody, M. D. King, C. B. Schaaf, D. K. Hall, S. Platnick)

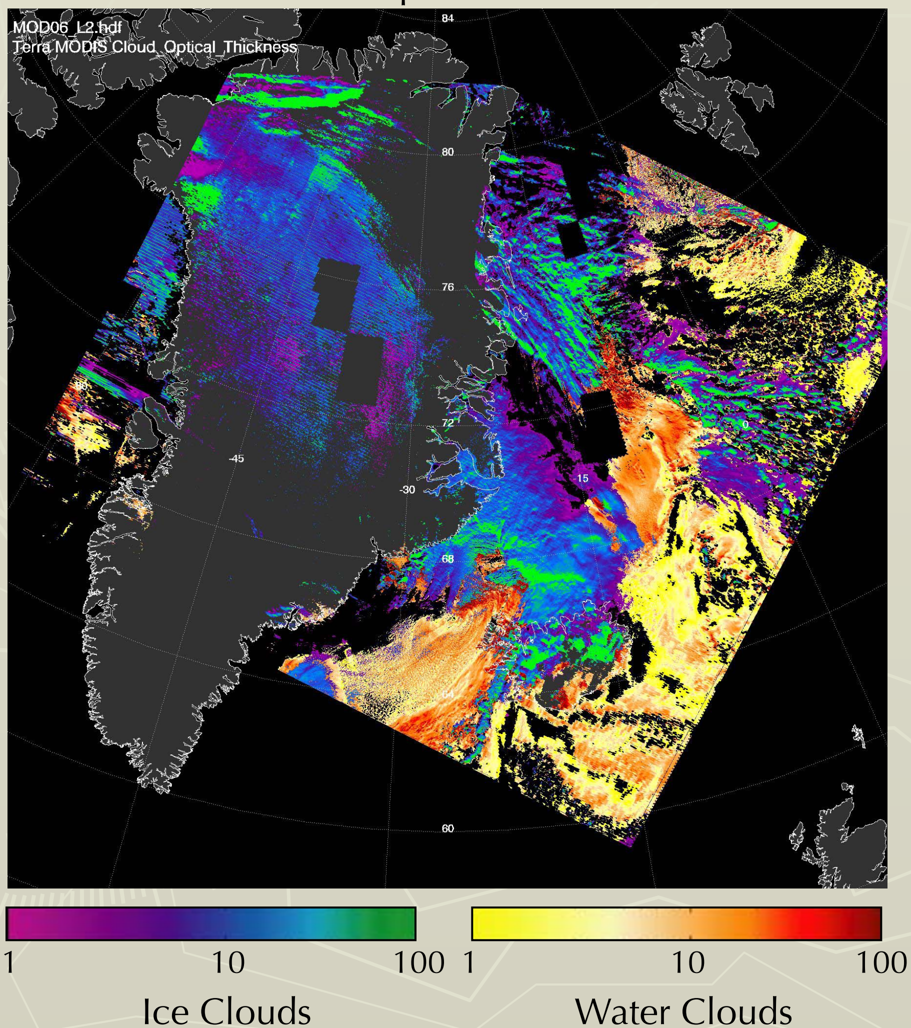


Moody et al. (2007)

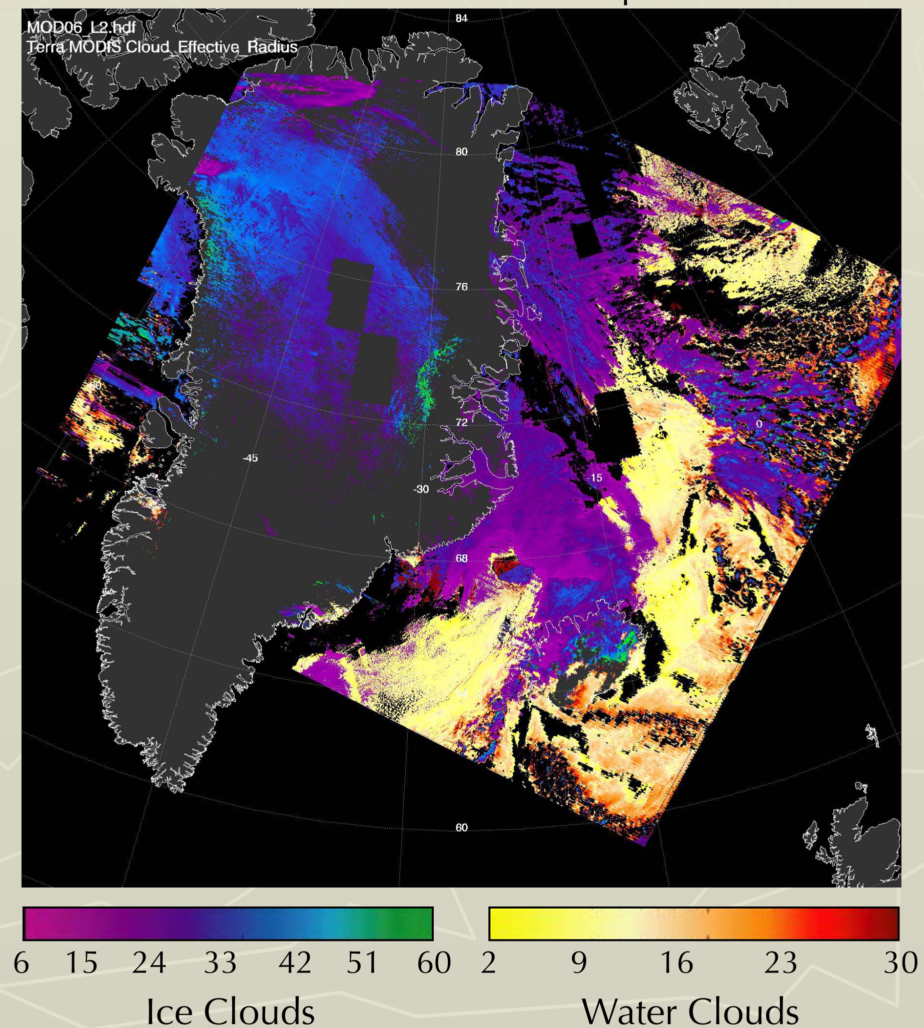
Cloud Optical Thickness and Effective Radius

(M. D. King, S. Platnick – NASA GSFC)

Cloud Optical Thickness



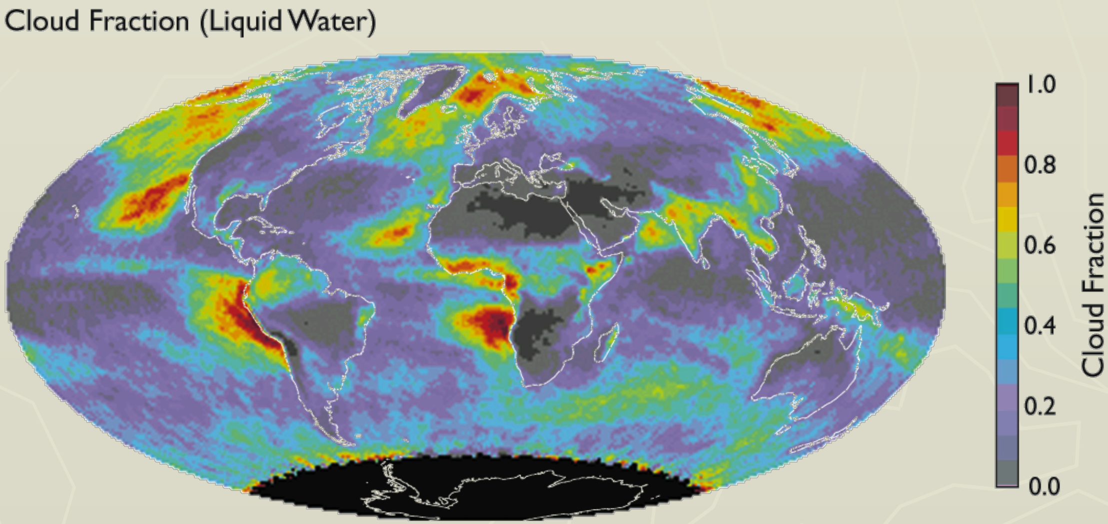
Cloud Effective Radius (μm)

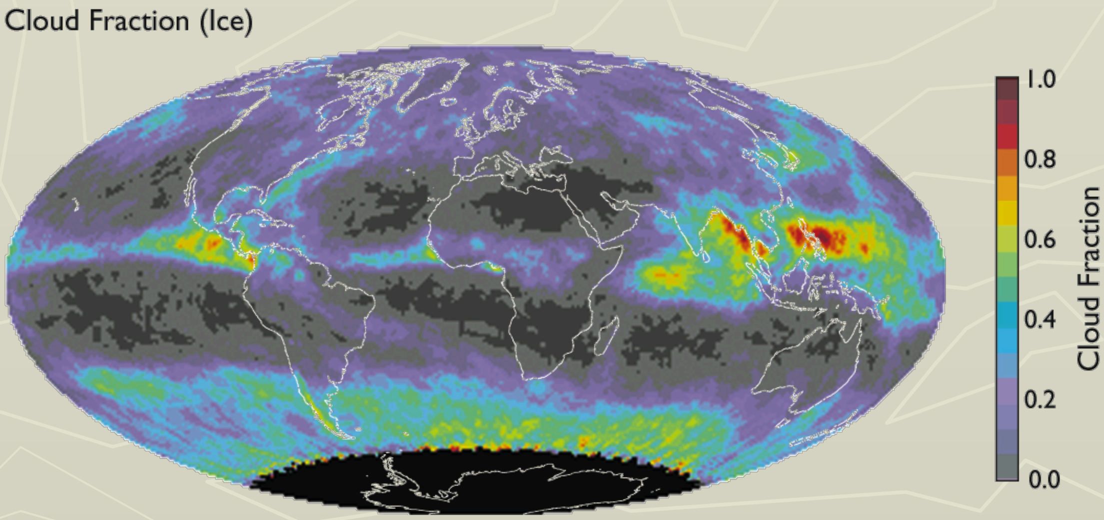


Monthly Mean Cloud Fraction by Phase
(M. D. King, S. Platnick et al. – NASA GSFC)

July 2006 (Collection 5)
Terra

- Liquid water clouds
  - Marine stratocumulus regions
    - ✓ Angola/Namibia
    - ✓ Peru/Ecuador
    - ✓ California/Mexico
- Ice clouds
  - Tropics
    - ✓ Indonesia & western tropical Pacific
    - ✓ ITCZ
  - Roaring 40s

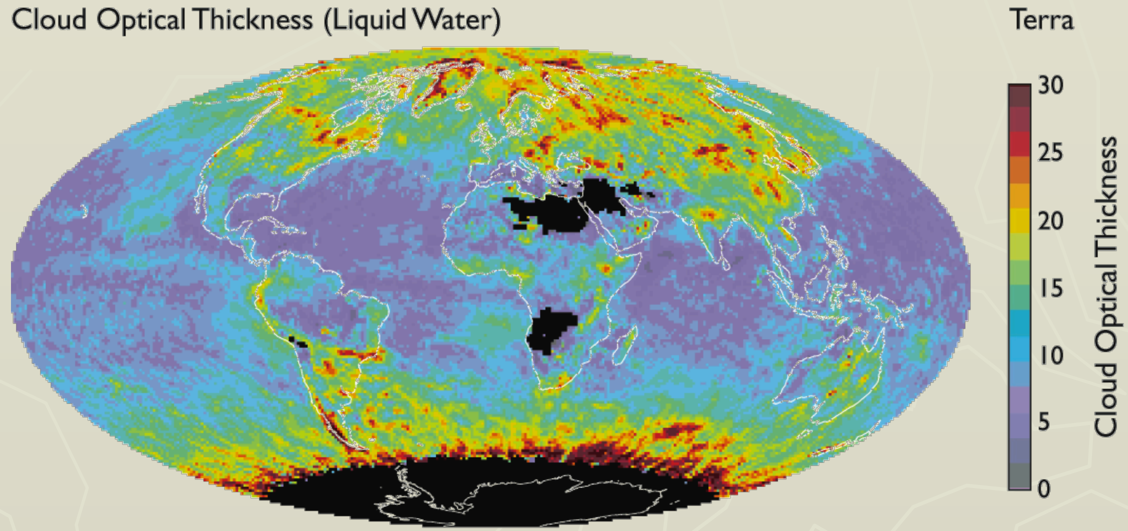


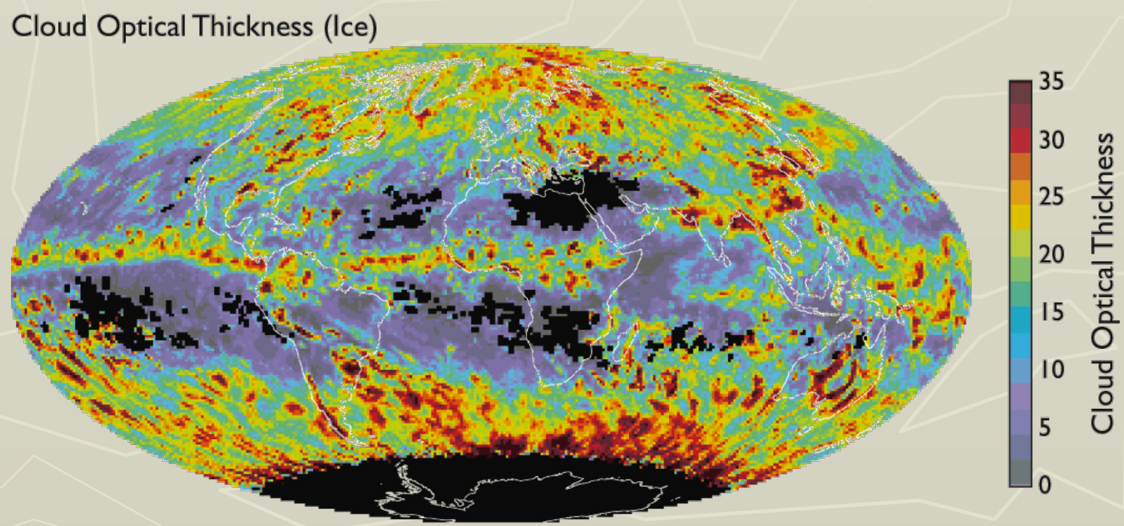


Monthly Mean Cloud Optical Thickness
(M. D. King, S. Platnick et al. – NASA GSFC)

July 2006 (Collection 5)
Terra (QA Mean)

- Liquid water clouds
  - Marine stratocumulus $\tau_c \sim 15$
  - Higher optical thickness over land than ocean
    - ✓ Cloud optical thickness near 5 in Indian Ocean
  - High optical thickness around roaring 40s
- Ice clouds
  - Larger in tropics (ITCZ)
  - High where deep convection occurs
    - ✓ Congo basin
    - ✓ Amazon basin
  - High optical thickness around roaring 40s
  - Higher over land than ocean



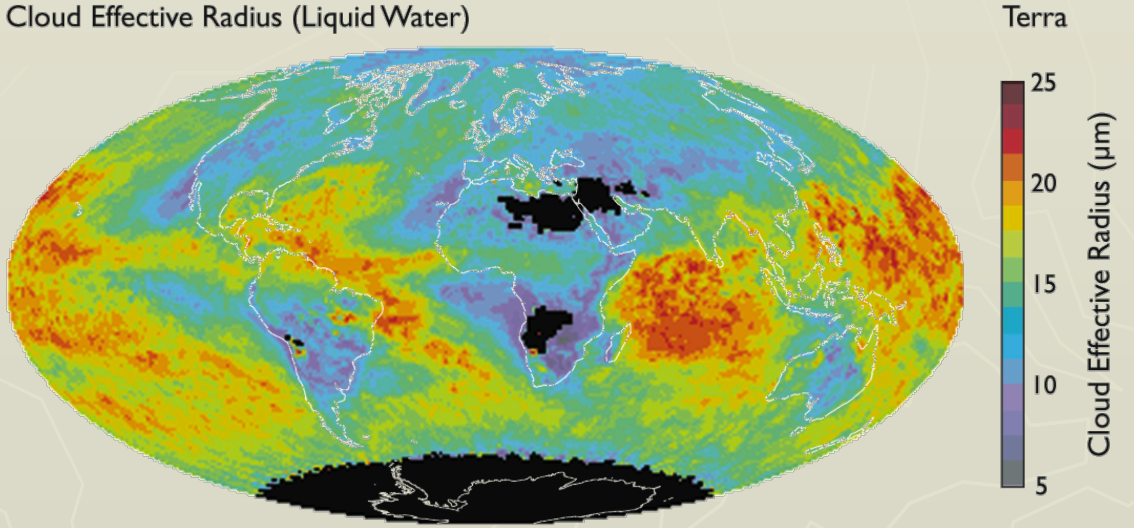


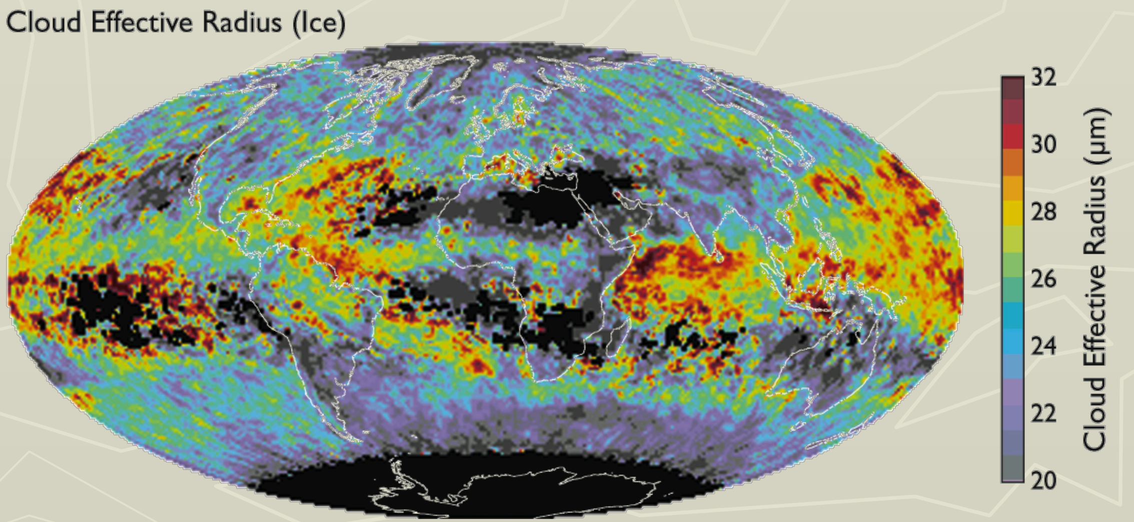
Monthly Mean Cloud Effective Radius
(M. D. King, S. Platnick et al. – NASA GSFC)

July 2006

Terra (QA Mean)

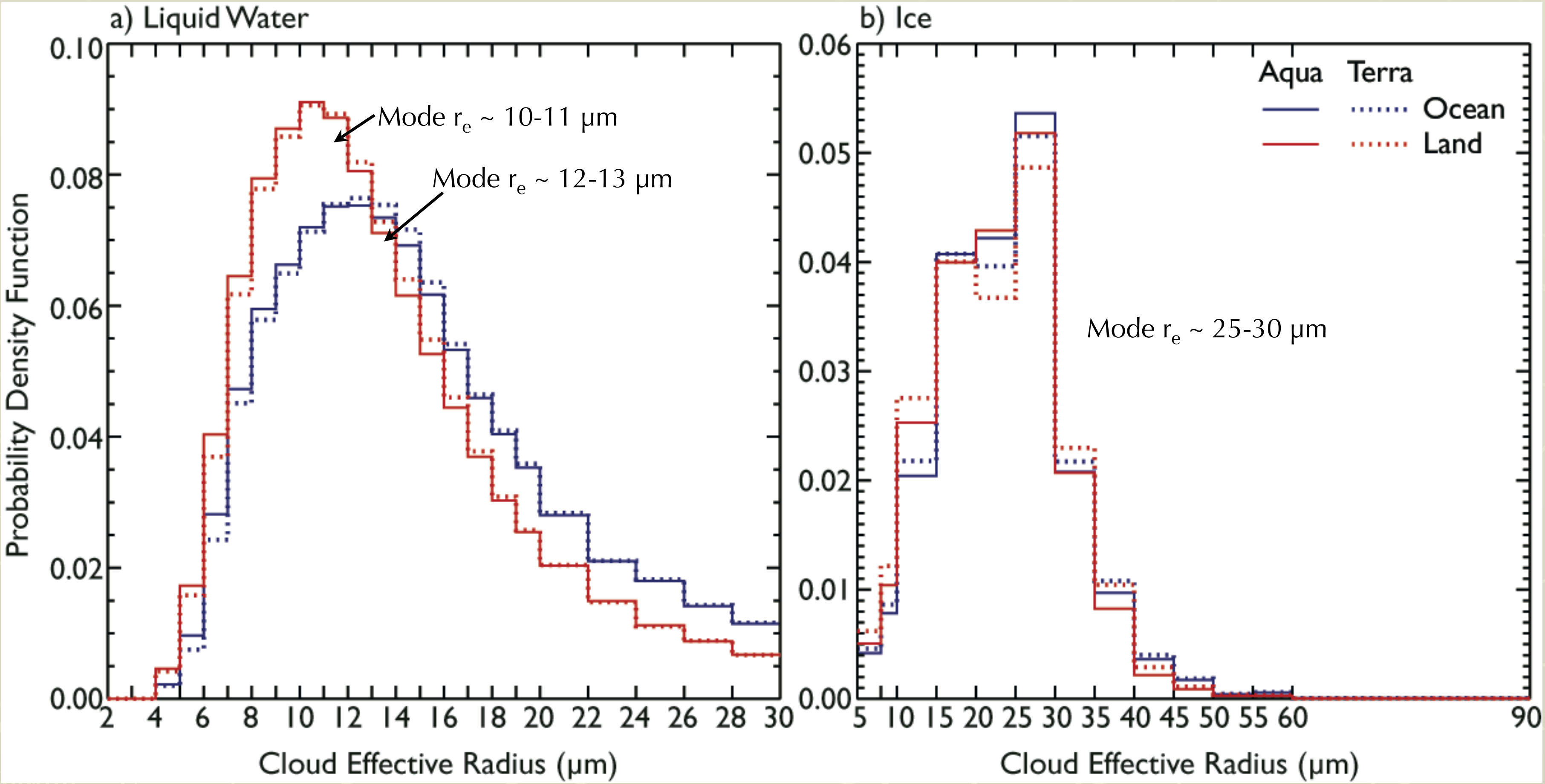
- Liquid water clouds
  - Larger drops in SH than NH
  - Larger drops over ocean than land
    - ✓ Due to cloud condensation nuclei (aerosols)
- Ice clouds
  - Larger in tropics than high latitudes
    - ✓ Anvils
  - Small ice crystals at top of deep convection





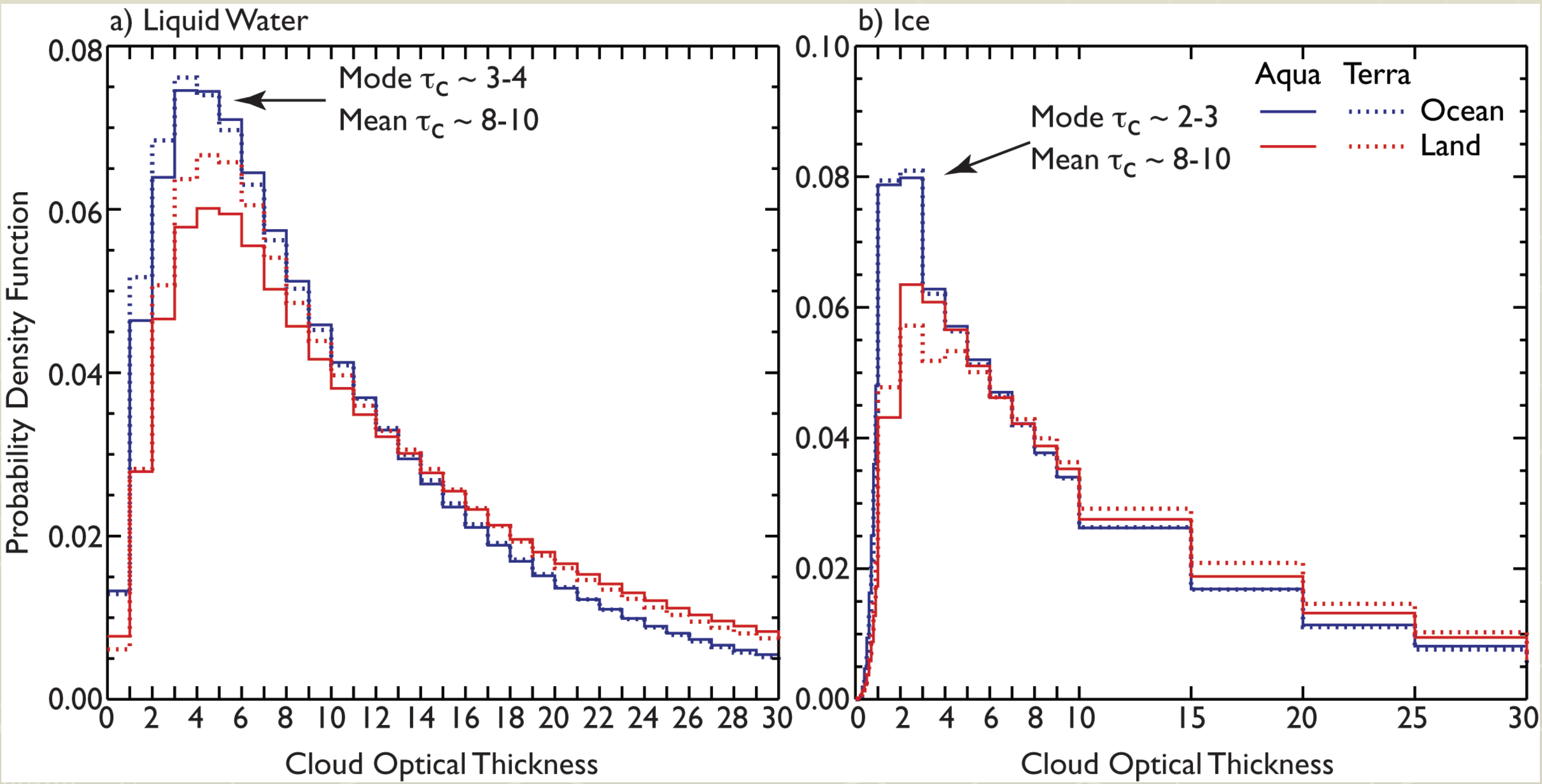
Probability Distribution of Cloud Effective Radius
(M. D. King, S. Platnick et al. – NASA GSFC)

July 2006



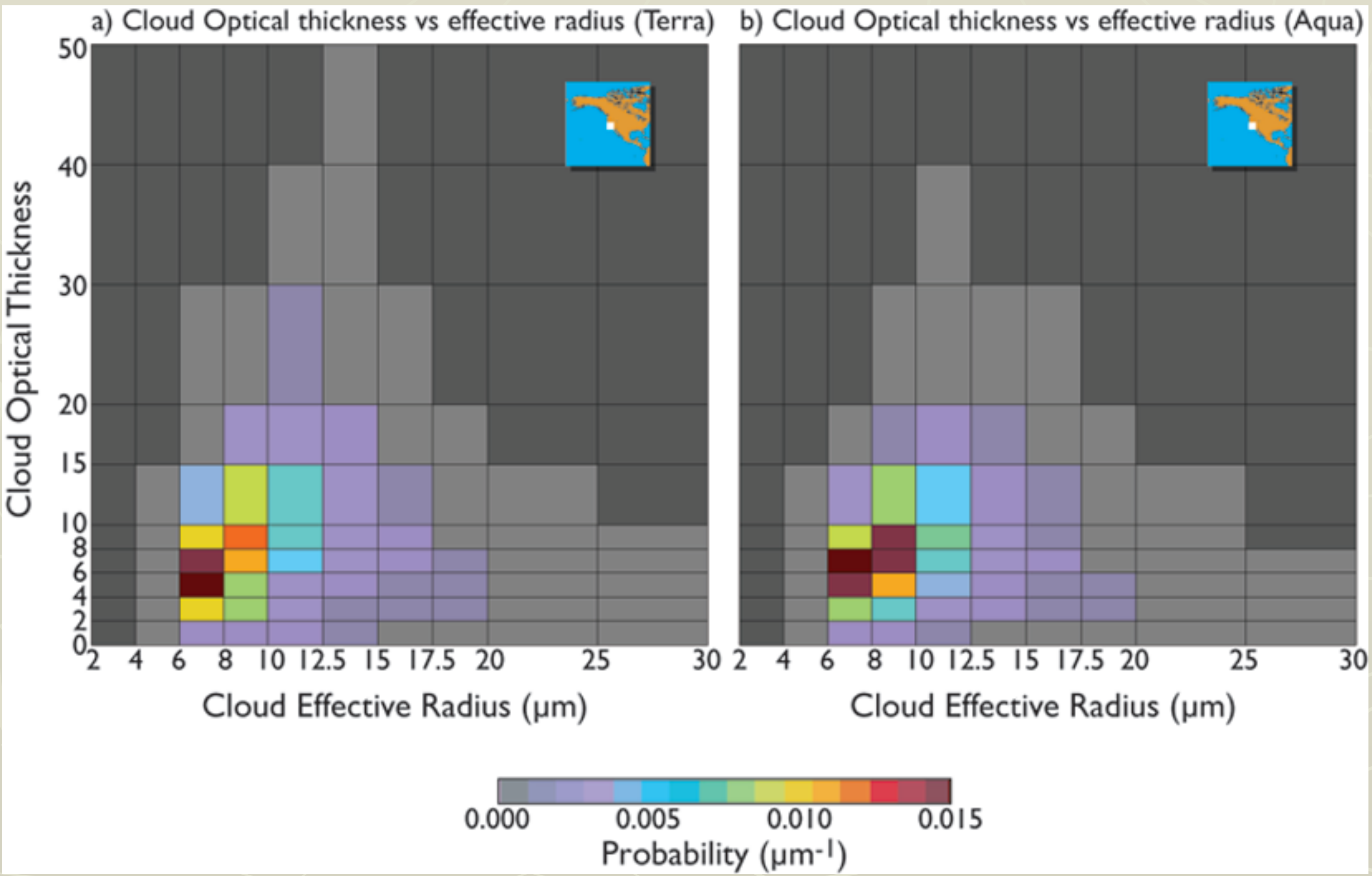
Probability Distribution of Cloud Optical Thickness
(M. D. King, S. Platnick et al. – NASA GSFC)

July 2006



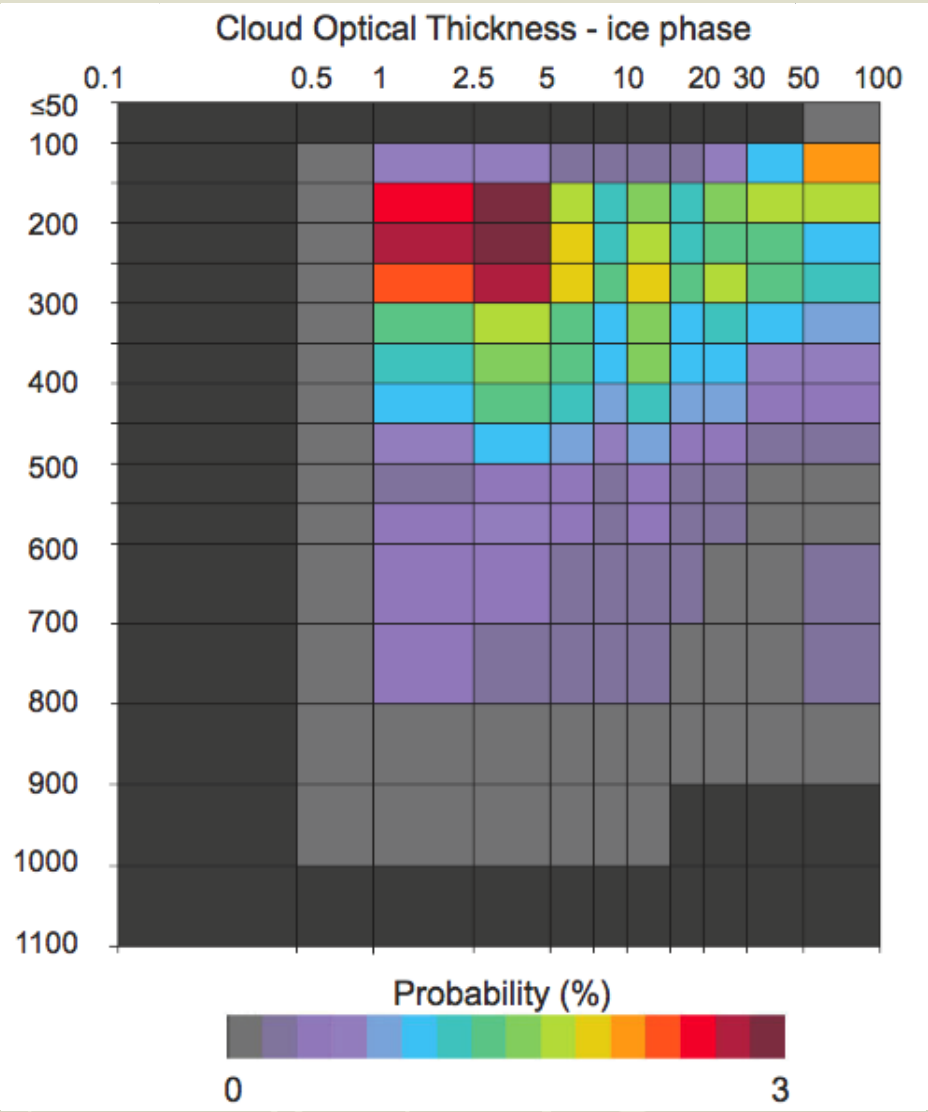
MODIS τ_c vs r_e Joint Histograms
Liquid Water Clouds over Ocean

32°-40°N, 117°-125°W
July 2006



MODIS and ISCCP-like τ_c vs p_c Joint Histograms

50°N-50°S
Terra
August 2001



Summary and Conclusions

- Remote sensing of cloud optical thickness, effective radius, and integrated water path
  - Enabled by airborne multispectral measurements of cloud reflectance obtained by the MCR onboard the ER-2 aircraft during FIRE II marine stratocumulus experiment
    - ✓ Carefully chosen spectral bands
    - ✓ In situ airborne observations for comparison
- Key publications that have had a long and influential role in cloud remote sensing
  - Nakajima, T., and M. D. King, 1990: Determination of the optical thickness and effective particle radius of clouds from reflected solar radiation measurements. Part I: Theory. *J. Atmos. Sci.*, **47**, 1878-1893. [397 citations]
  - Platnick, S., M. D. King, S. A. Ackerman, W. P. Menzel, B. A. Baum, J. C. Riedi, and R. A. Frey, 2003: The MODIS cloud products: Algorithms and examples from Terra. *IEEE Trans. Geosci. Remote Sens.*, **41**, 459-473. [396 citations]
  - King, M. D., W. P. Menzel, Y. J. Kaufman, D. Tanré et al., 2003: Cloud and aerosol properties, precipitable water, and profiles of temperature and water vapor from MODIS. *IEEE Trans. Geosci. Remote Sens.*, **41**, 442-458. [271 citations]

Dr. Didier Tanré

Radiative transfer, aerosol remote sensing, colleague, & friend

Didier
Maryland, 1989

MODIS Science Team, 1996