Cloud Optical and Microphysical Properties Product

some "collection 5" efforts

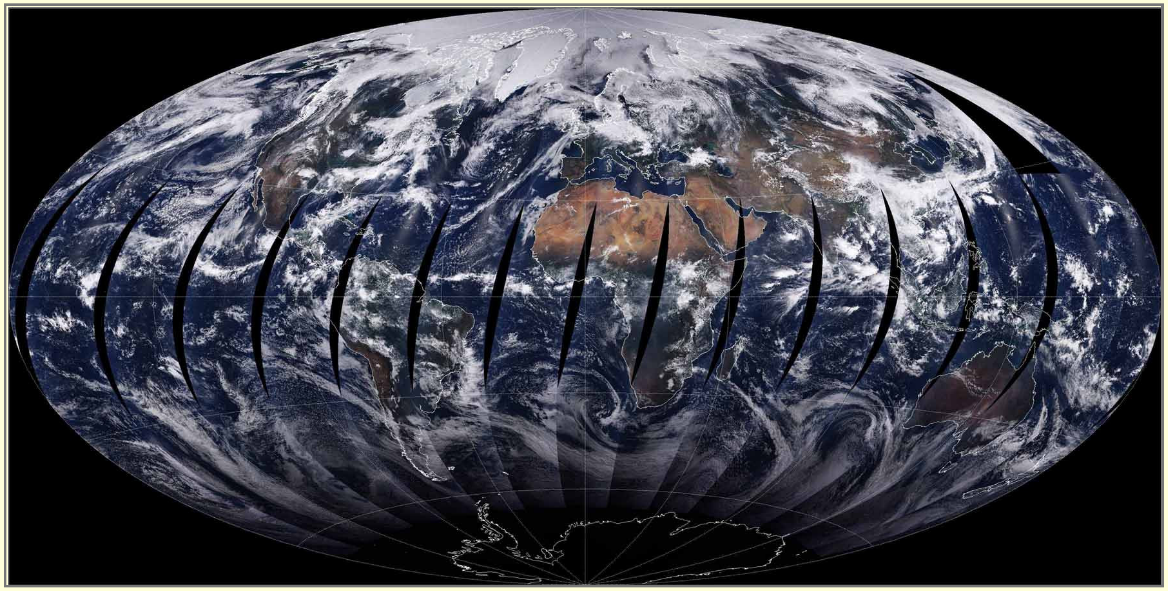
Steve Platnick

Brad Wind, Gala Wind, J. Riédi, et al.

MODIS Atmosphere Group Meeting

BWI Marriott

13-14 July 2004



Topics

- L2 collection 5 efforts & examples
  - Quantitative pixel-level uncertainty
  - Multi-layer/phase cloud detection
  - Sun glint, heavy aerosol detection
- L3 research effort

Future Processing Effort (collection 5)

- Collection: refers to a processing/reprocessing stream
  - Terra atmosphere algorithm deliveries in fall ‘04, Aqua in Dec ‘04
  - Aqua forward processing (L1B, L2) to begin in Jan ‘05

- MOD06 cloud retrieval algorithm expected improvements/additions:
  - Pixel-level uncertainty analysis
  - Multi-layer/phase cloud detection (non-opaque cirrus over water clouds)
  - Sun glint, heavy aerosol detection
  - Improved spectral surface albedo maps
  - Improved ice cloud libraries , atmospheric transmittance libraries
  - Implementation of 1.6-2.1 µm band combination retrieval for snow/ice surfaces and heavy aerosol over clouds
  - Code improvements, etc.

Pixel-level Retrieval Uncertainty Analysis

S. Platnick, B. Wind

Currently incorporating the effect of the following sources on inferred cloud-top reflectance:

1. Instrument calibration
2. Atmospheric correction uncertainty
3. Spectral surface albedo uncertainty

<u>Note</u>:

- Uses sensitivity derivatives calculated from reflectance libraries, e.g.:

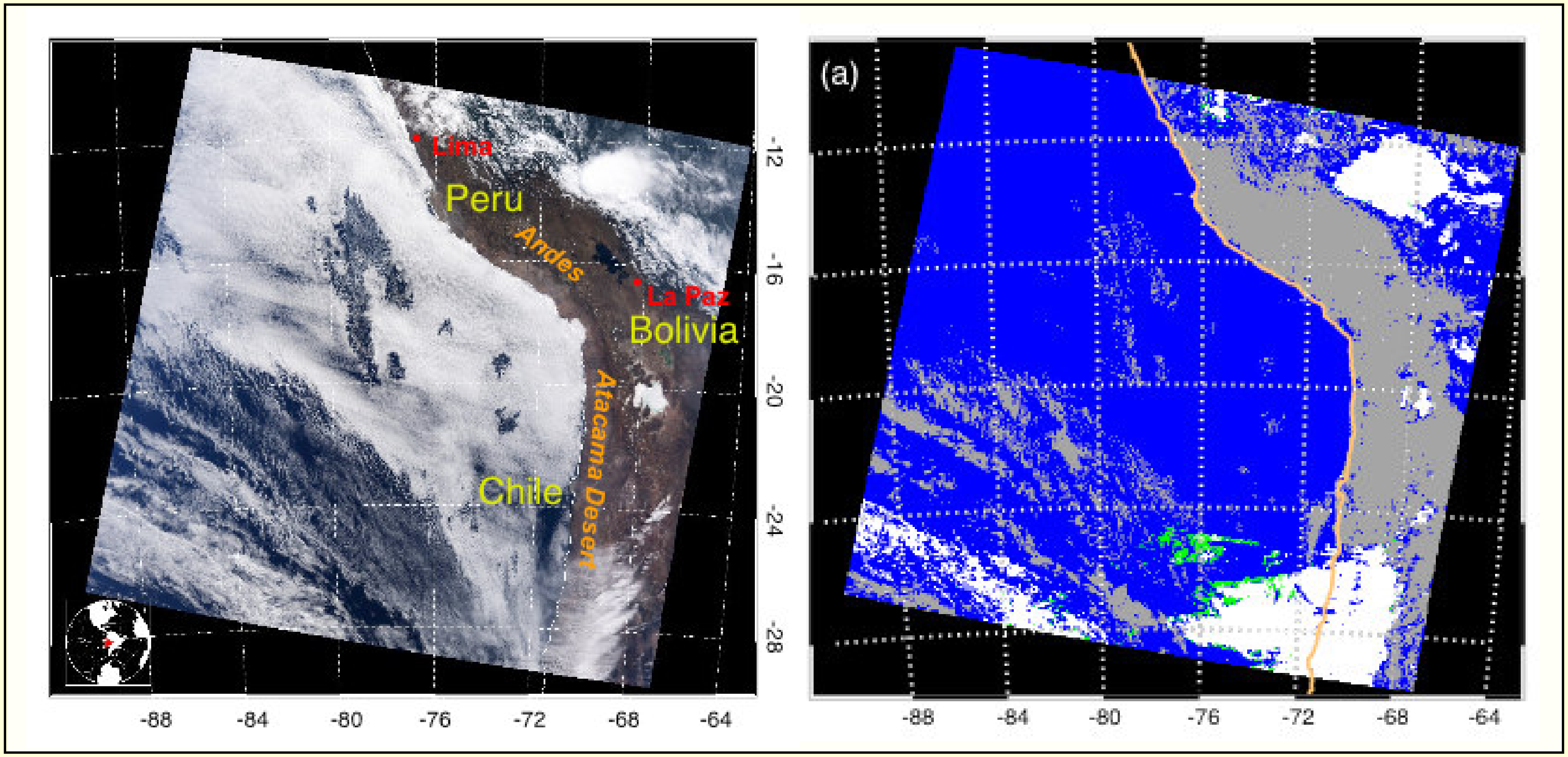
$$\left.\frac{\partial \tau}{\partial R_1}\right|_{R_2} = f\left(\left.\frac{\partial R_1}{\partial \tau}\right|_{r_e}, \left.\frac{\partial R_1}{\partial r_e}\right|_{\tau}, \left.\frac{\partial R_2}{\partial \tau}\right|_{r_e}, \left.\frac{\partial R_2}{\partial r_e}\right|_{\tau} \right)$$

- A likely minimum uncertainty, i.e., other missing components: (**ice cloud models**, **vertical cloud structure** including multi-layer clouds, …)
- Random L2 uncertainties may be reduced/eliminated during L3 aggregations

Retrieval Example

Terra granule, coastal Chile/Peru, 18 July 2001, 1530 UTC

[Platnick et al., *IEEE Trans. Geosci. Remote Sens.*, **41**]



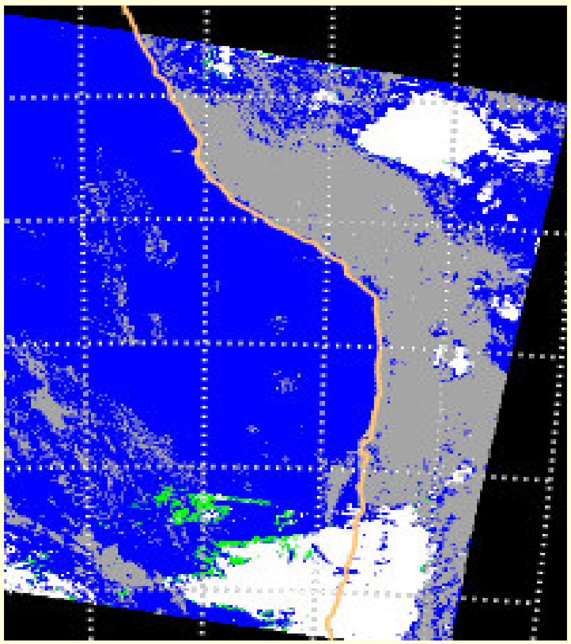
RGB true-color composite

phase retrieval

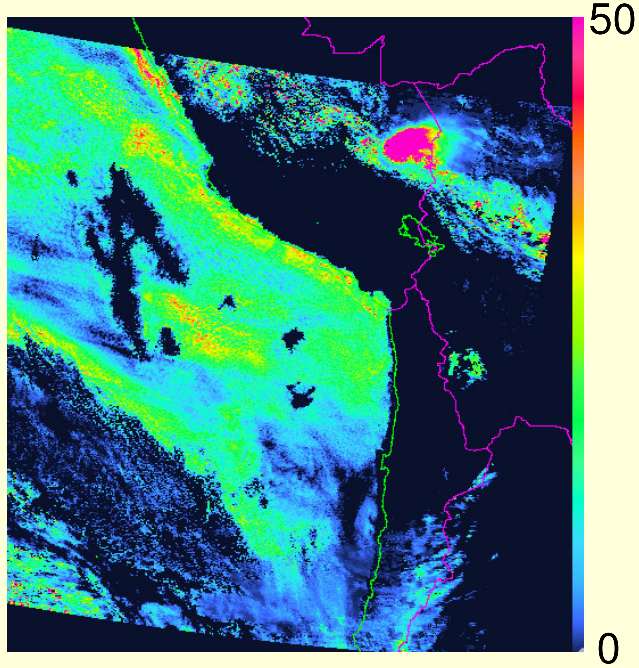
uncertain ice liquid water no retrieval

Pixel-level Uncertainty Analysis

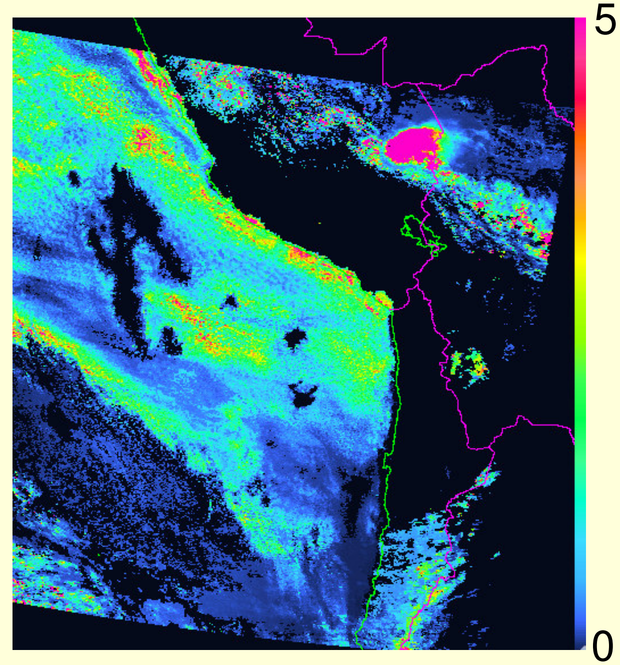
Peru granule (18 July 2001)



Phase (white = ice)



Cloud Optical Thickness

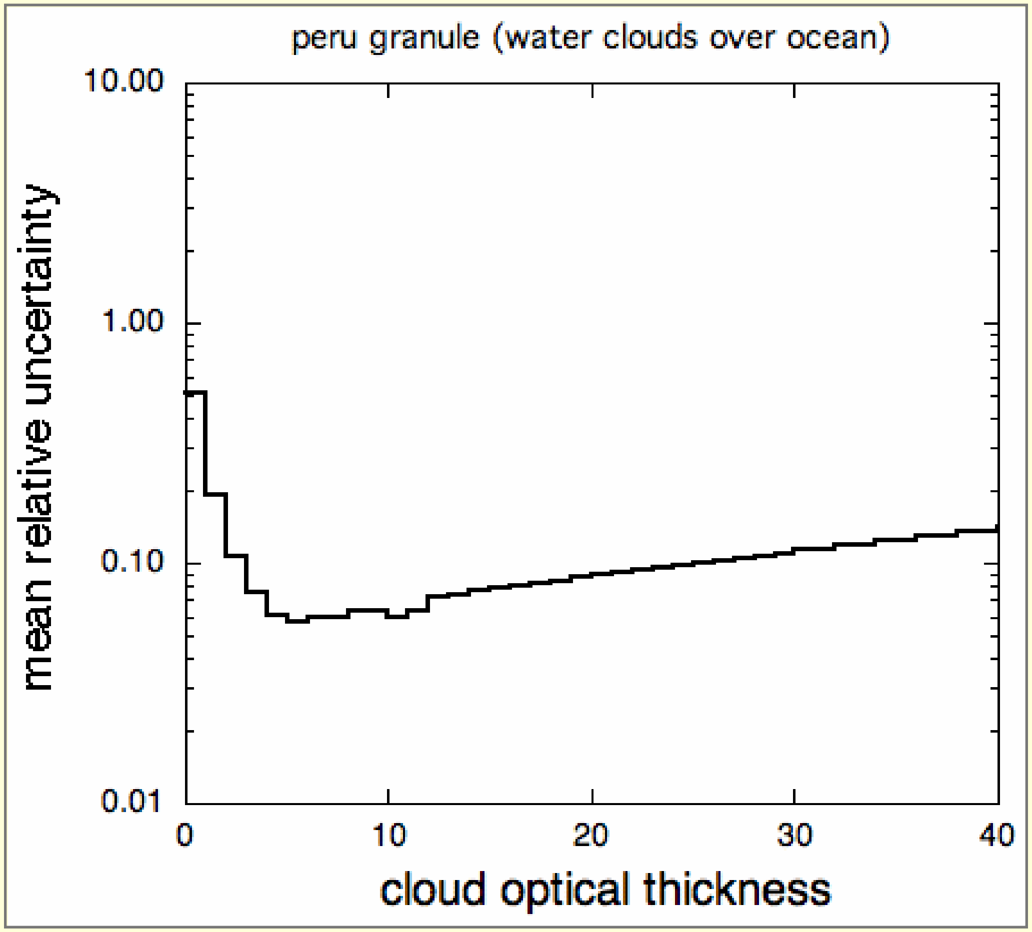


Cloud Optical Thickness Uncertainty

Pixel-level Uncertainty Analysis

Peru granule (18 July 2001)

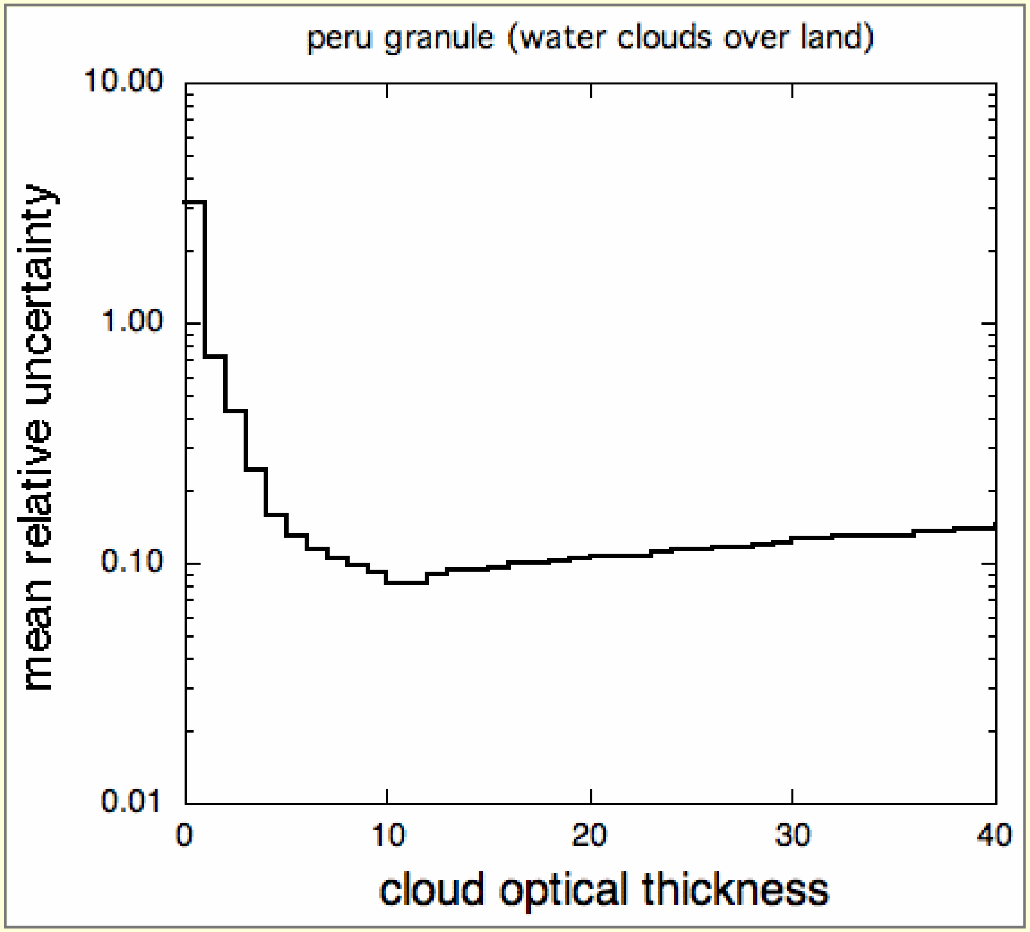
τ: water clouds over ocean



Pixel-level Uncertainty Analysis

Peru granule (18 July 2001)

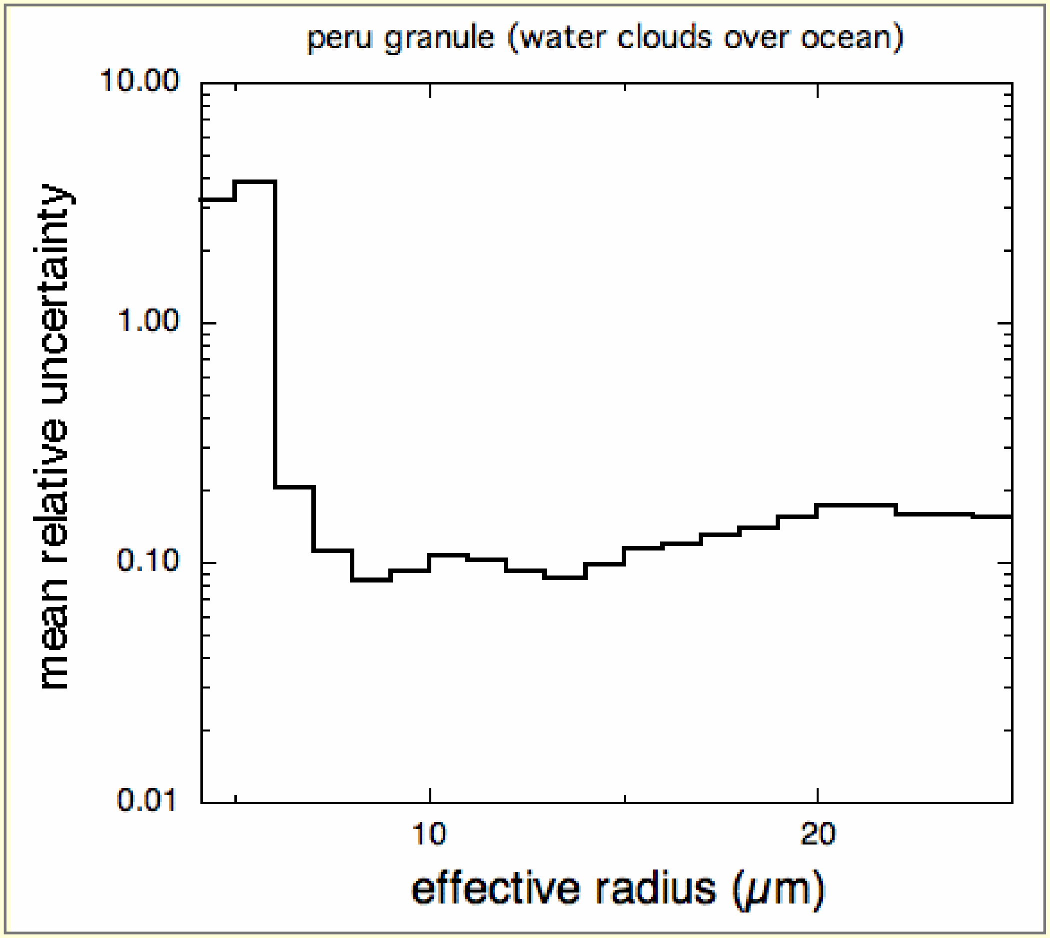
τ : water clouds over land



Pixel-level Uncertainty Analysis

Peru granule (18 July 2001)

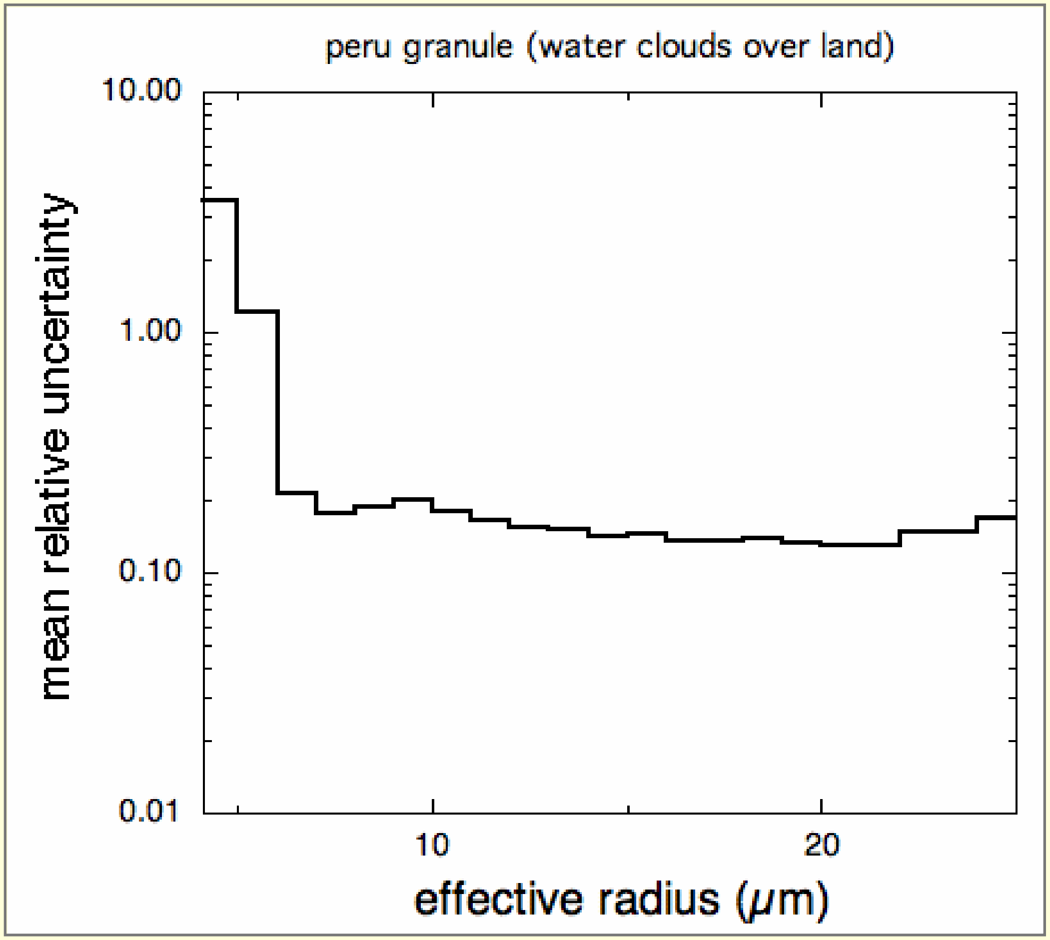
r_e: water clouds over ocean



Pixel-level Uncertainty Analysis

Peru granule (18 July 2001)

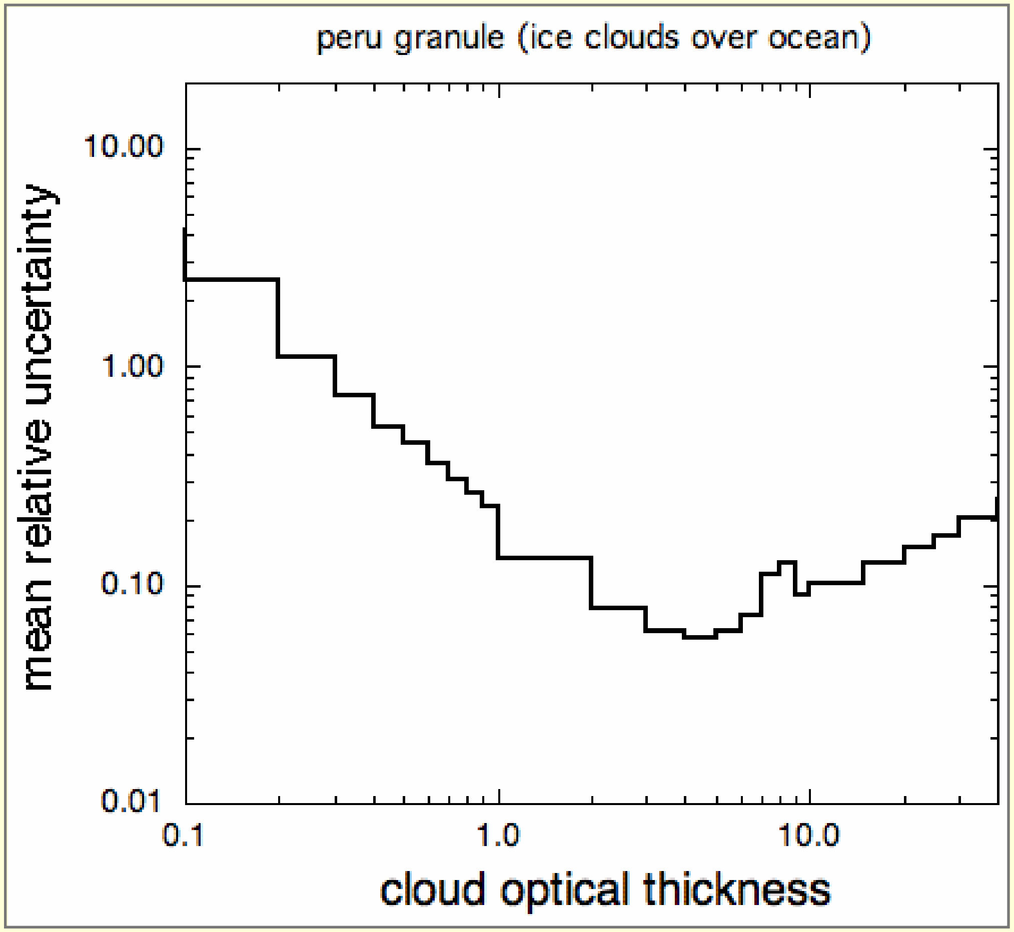
r_e: water clouds over land



Pixel-level Uncertainty Analysis

Peru granule (18 July 2001)

τ: ice clouds over ocean



Pixel-level Uncertainty Analysis

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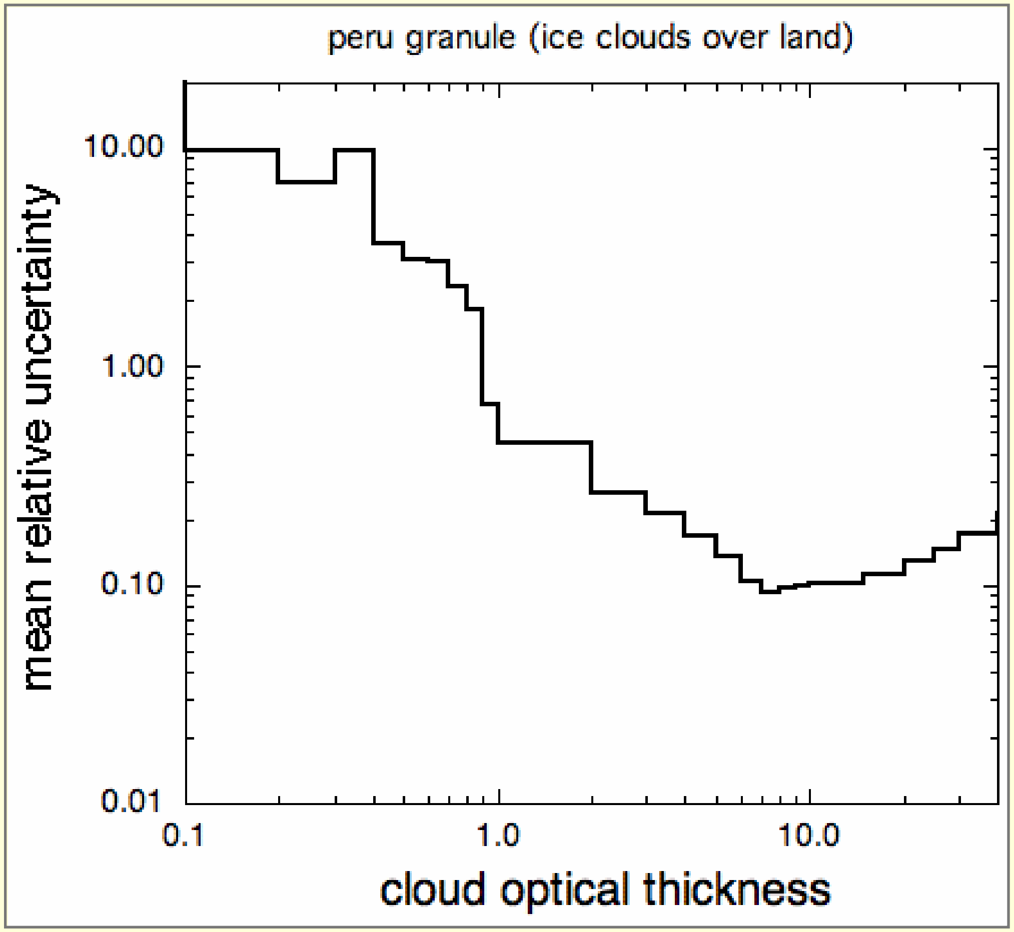
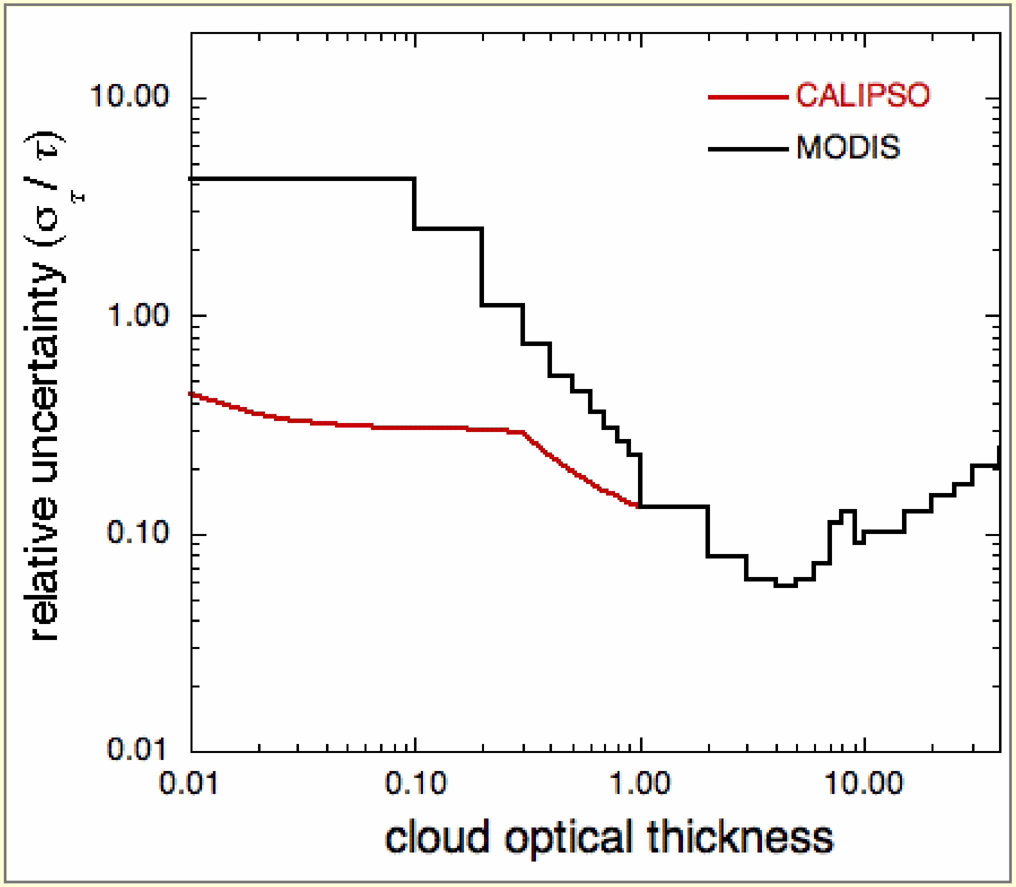
τ: ice clouds over land



Pixel-level Uncertainty Analysis

Peru granule (18 July 2001)

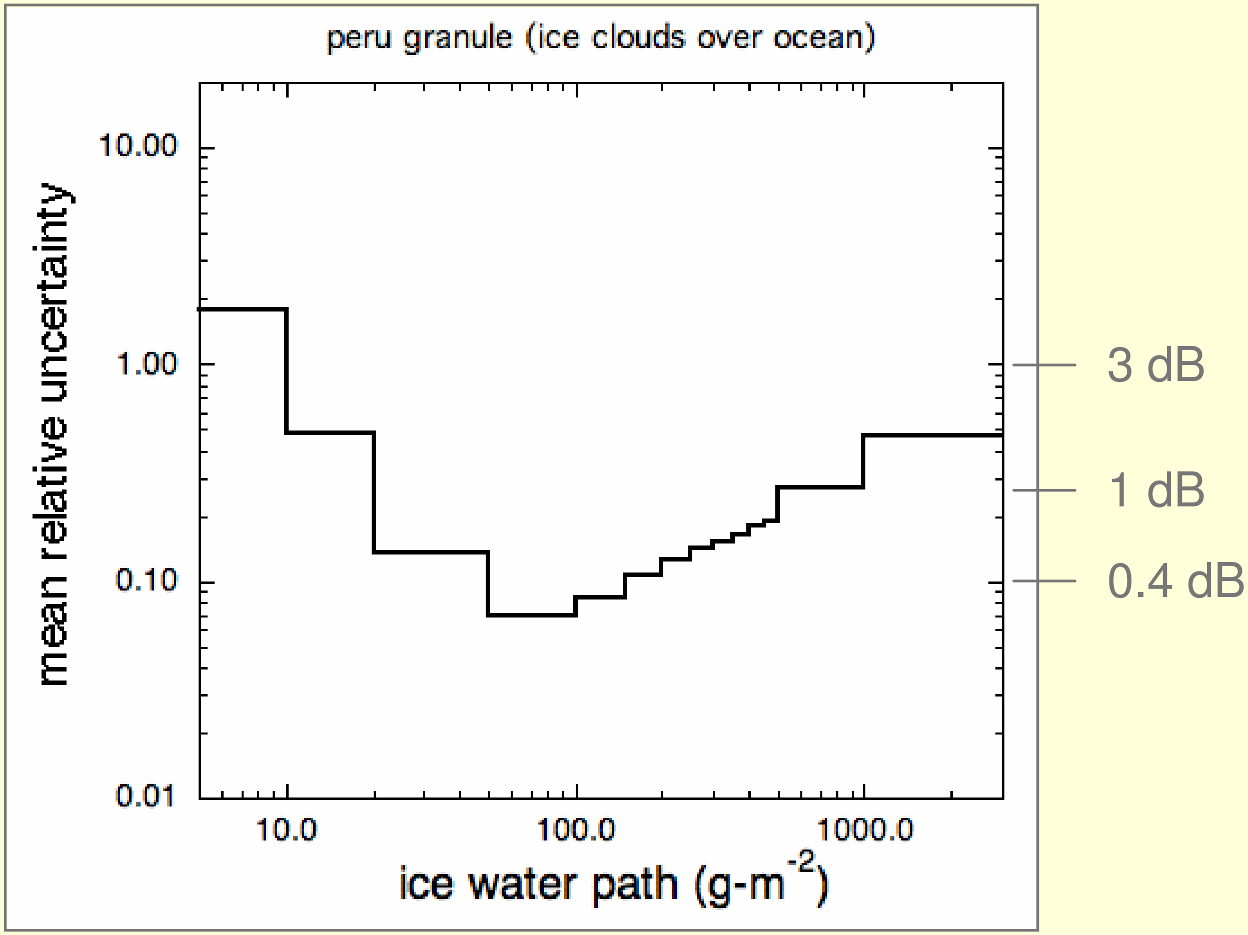
τ : ice clouds over ocean



Pixel-level Uncertainty Analysis

Peru granule (18 July 2001)

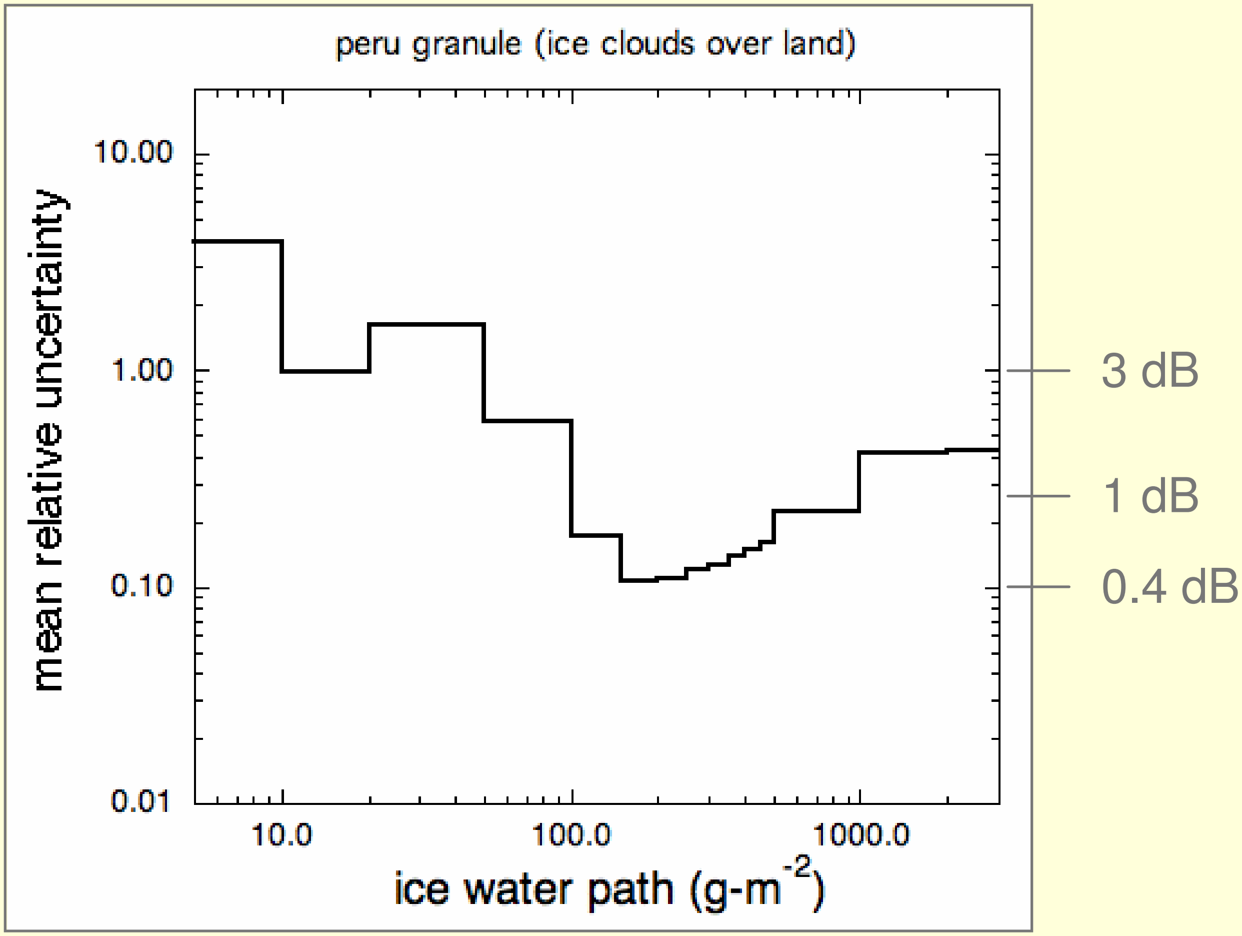
***IWP*: ice clouds over ocean**



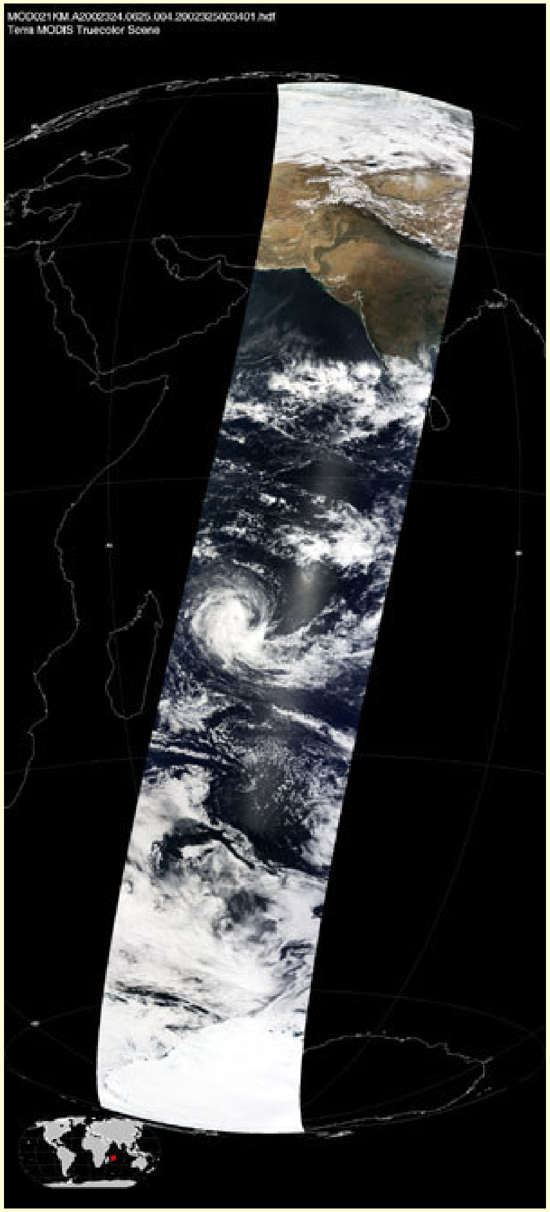
Pixel-level Uncertainty Analysis

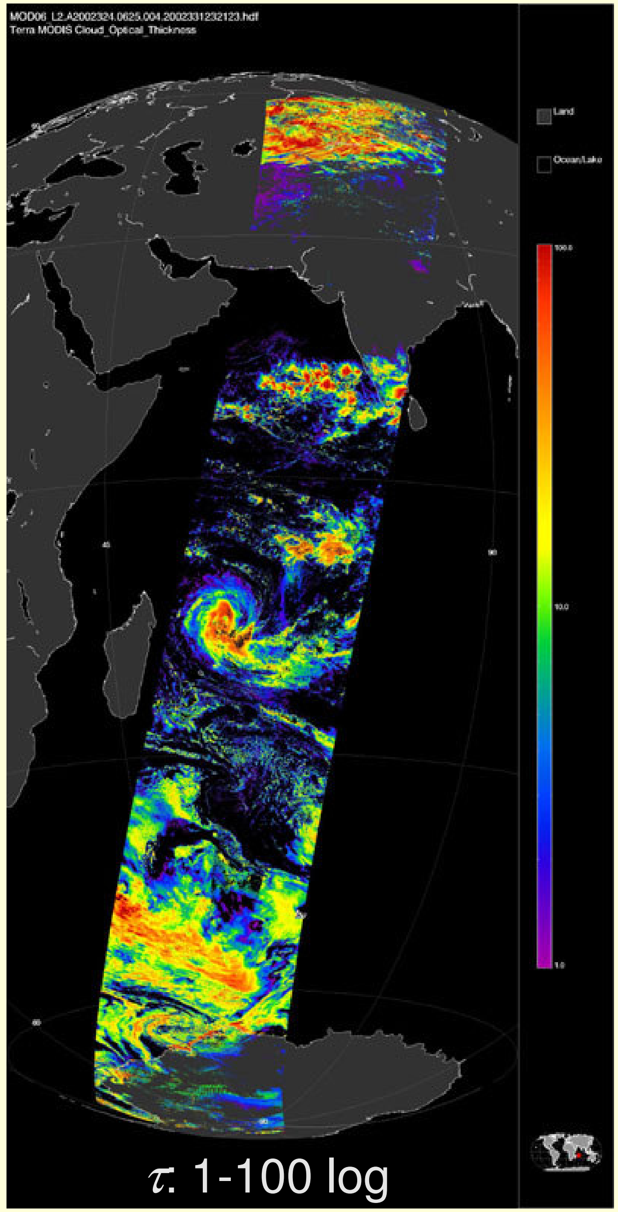
Peru granule (18 July 2001)

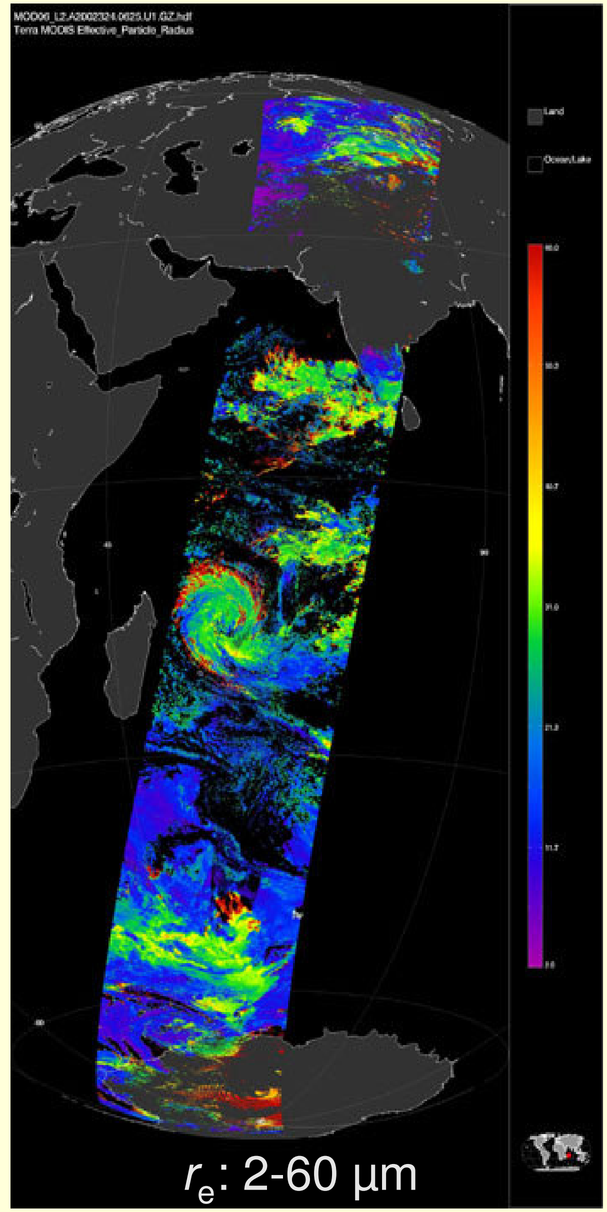
***IWP*: ice clouds over land**



Pixel-level Uncertainty Analysis - Terra MODIS orbit (20 Nov 2002)







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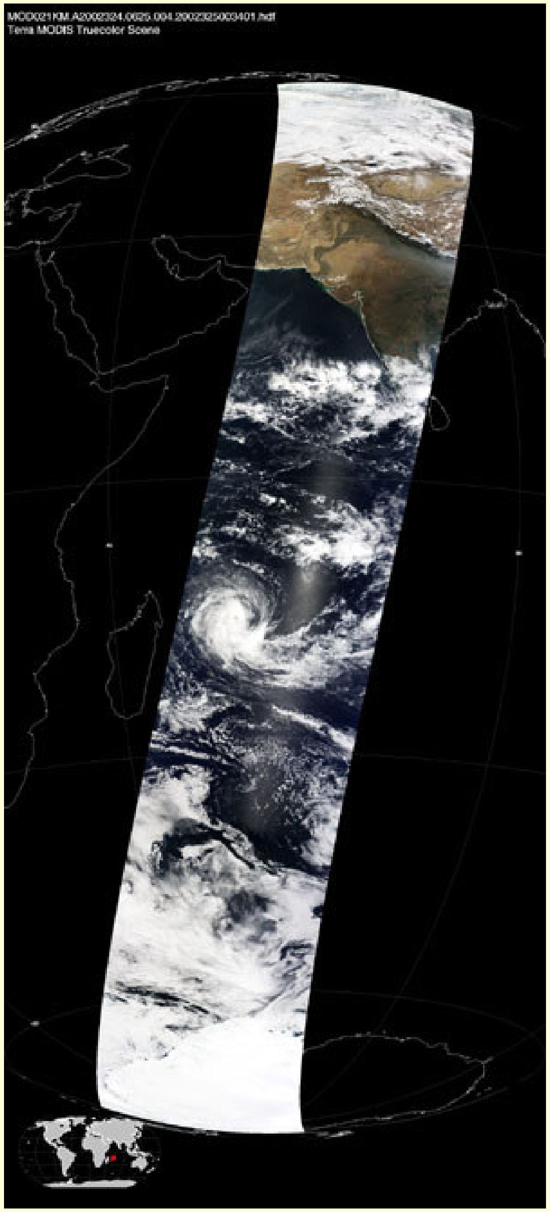
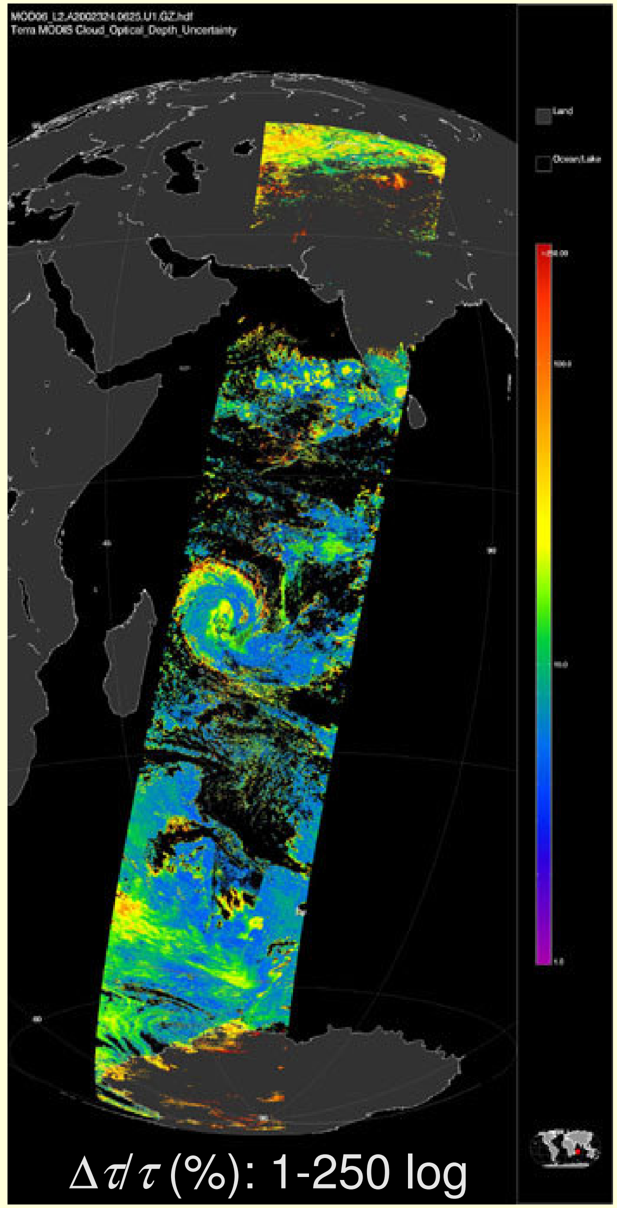
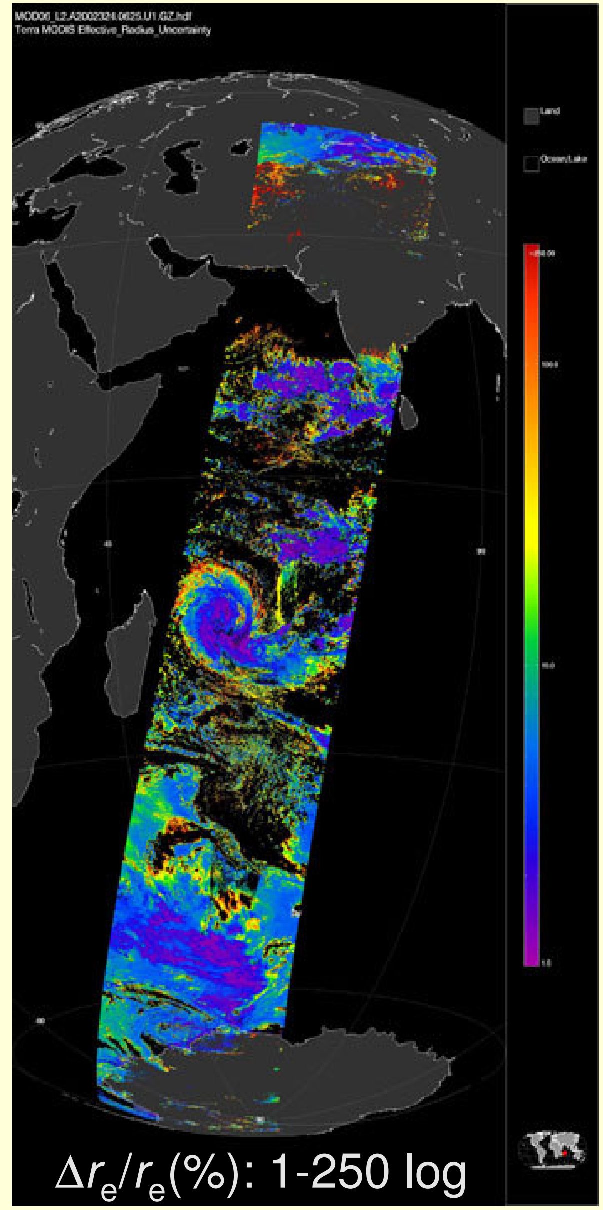
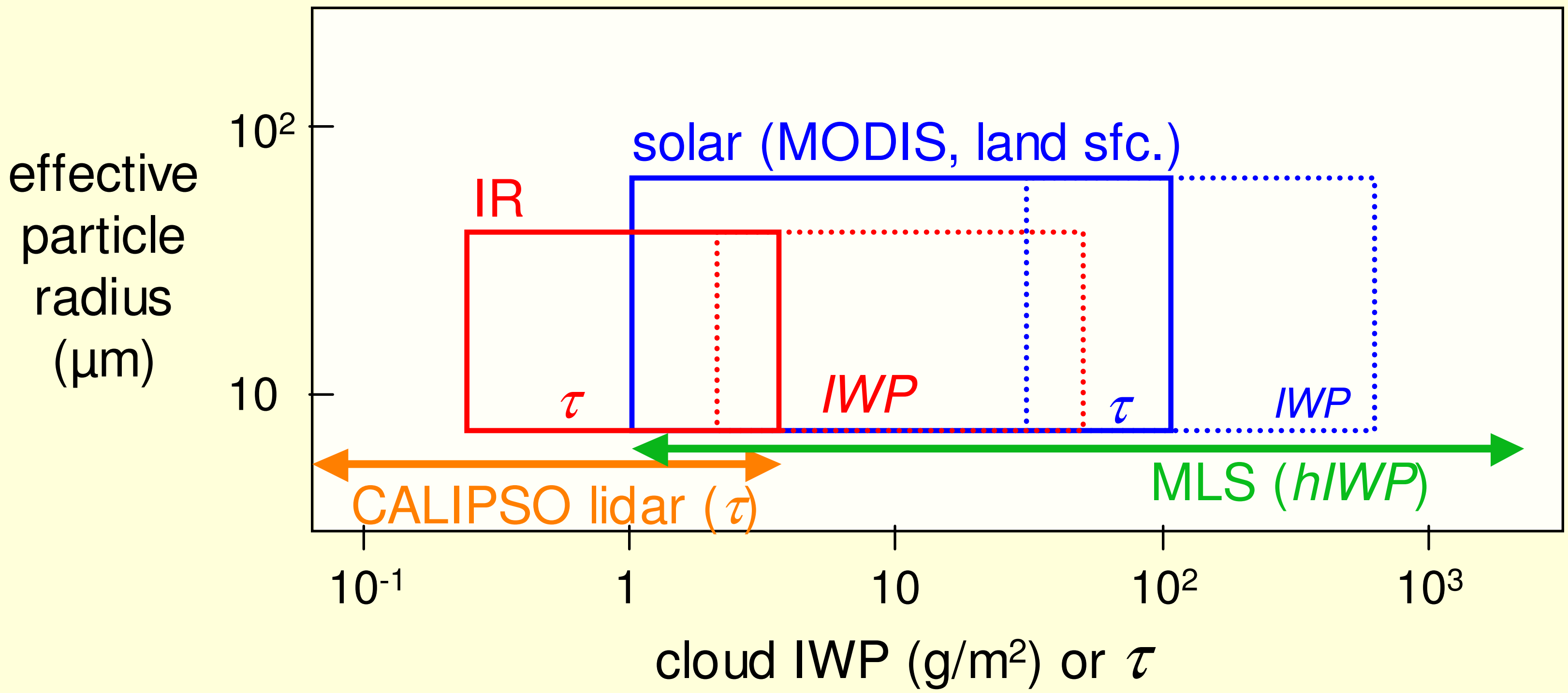






Approximate/Qualitative Solution Space vs. Method

~ 3dB (100% relative error)



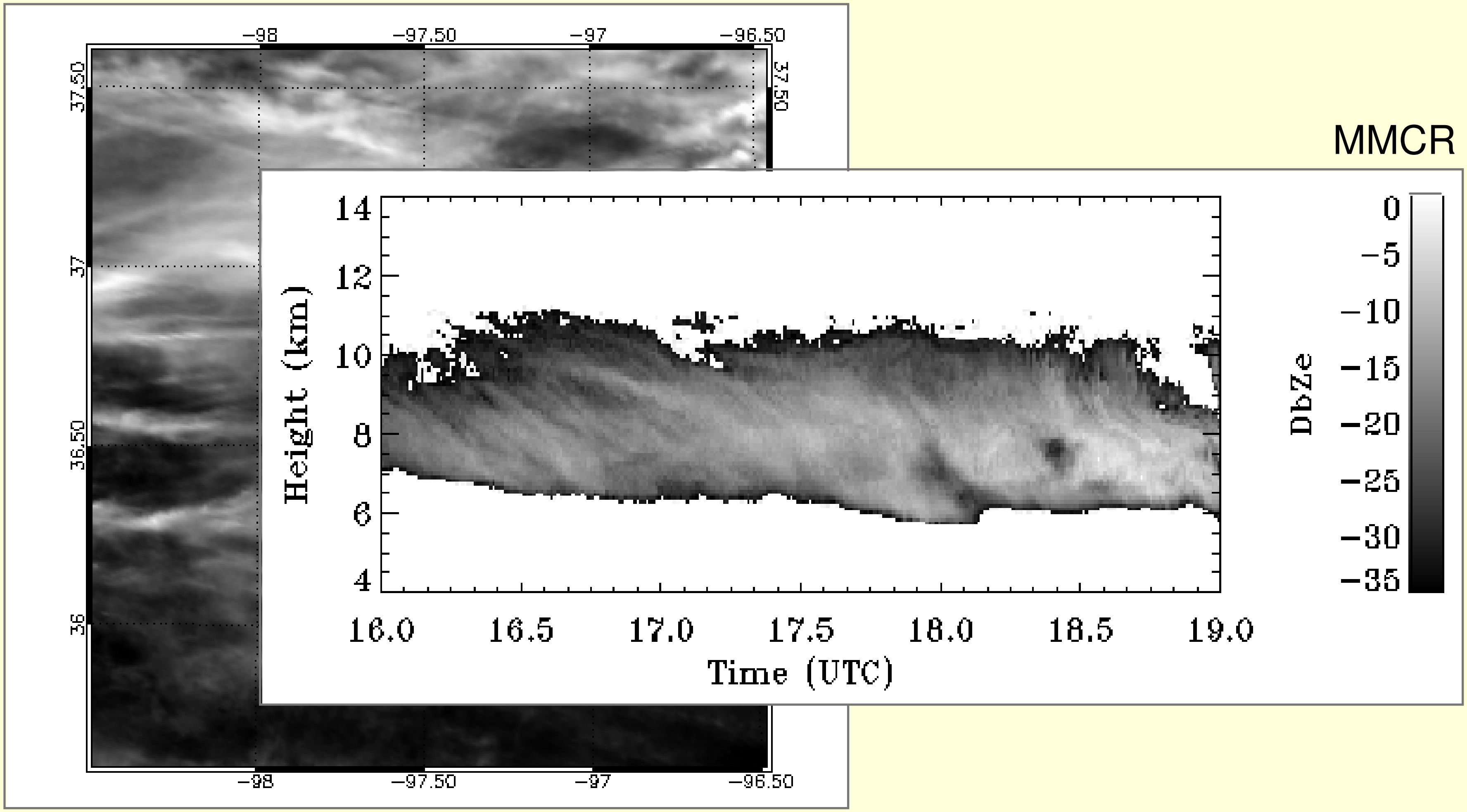
Example Validation Efforts

Cirrus Validation - SGP ARM site

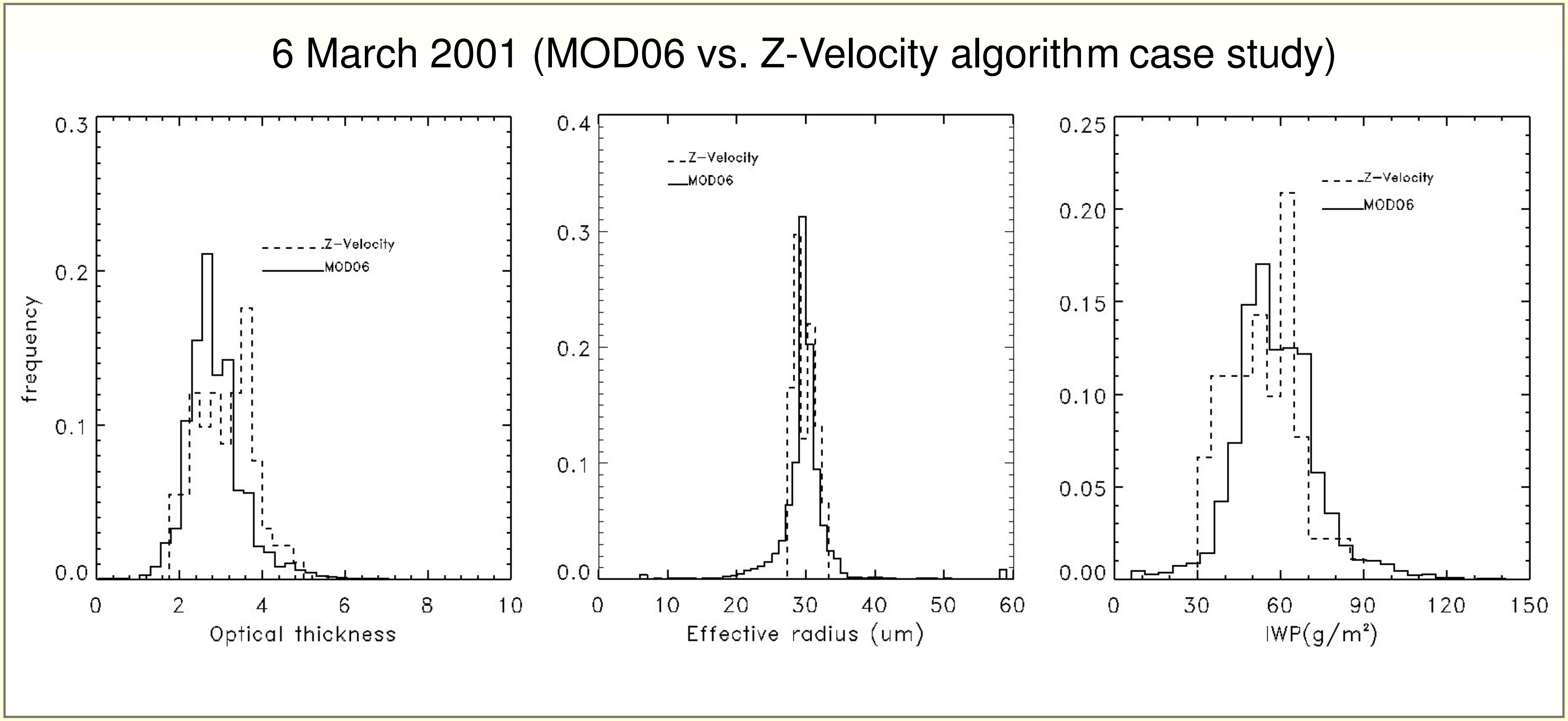
Mace, Zhang, Platnick, King, Minnis, Yang *(J. Appl. Meteor.,* accepted)

MODIS Terra, 6 March 2001, 1735 UTC

MMCR

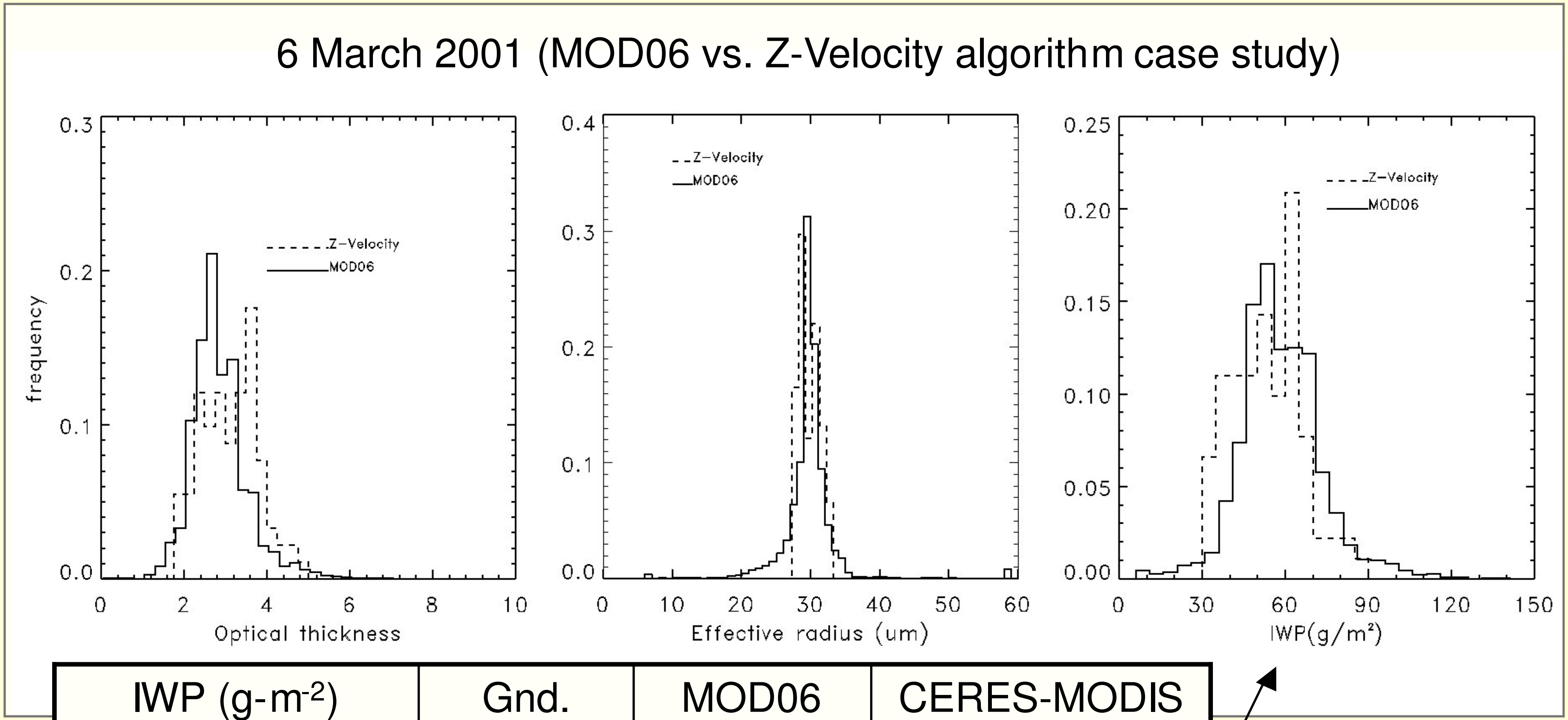


Cirrus Validation - SGP ARM site, cont.



Cirrus Validation - SGP ARM site, cont.

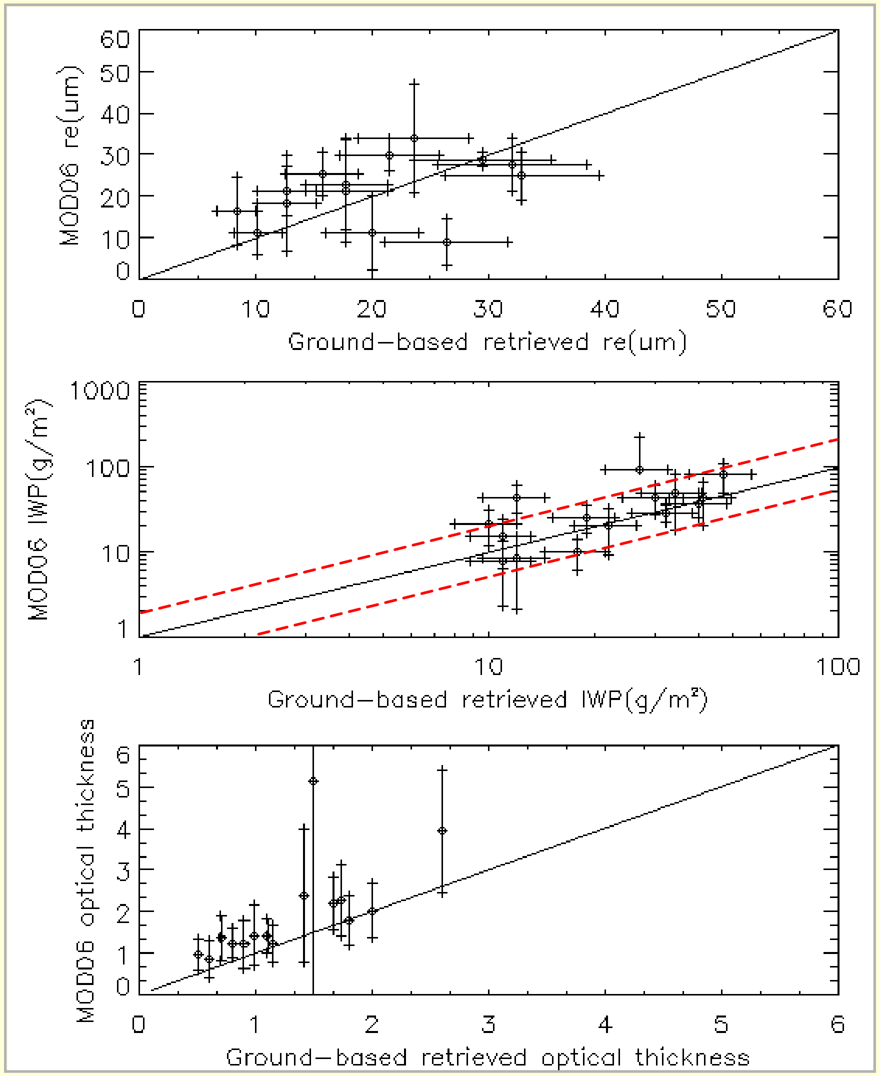
Case study 6 March 2001



IWP (g-m^{-2})	Gnd.	MOD06	CERES-MODIS
mean	54	57 (+6%)	59 (+9%)
sdev	12.7	15.0	18.0

Cirrus Validation - SGP ARM site, cont.

15 overpasses, single layer cirrus
(MOD06 vs. Z-Radiance algorithm case study)



~ 3dB relative error

Cloud multilevel/phase detection

G. Wind, S. Platnick

- Utilizes differences between:

    1. Inferred above-cloud PW between CO_2 slicing (+ NCEP moisture fields) and 0.94 µm solar reflectance retrieval

    2. IR and SWIR phase retrieval

Cloud multilevel/phase detection

G. Wind, S. Platnick

• Utilizes differences between:

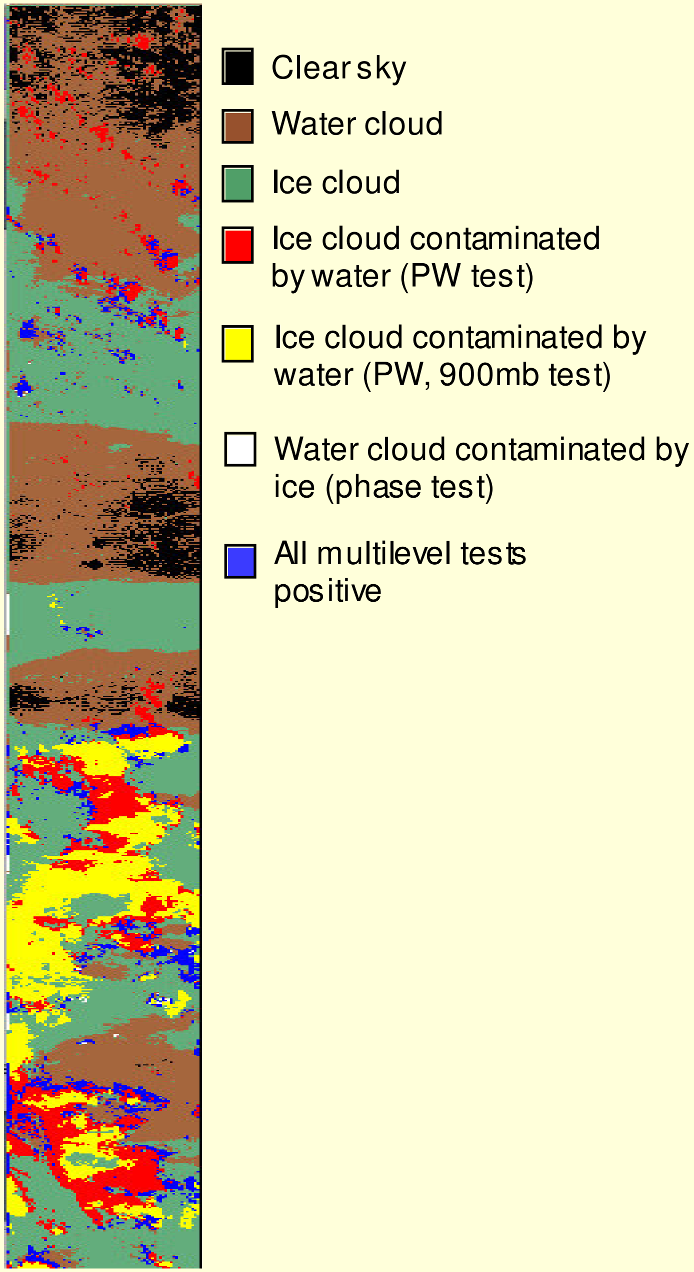
1. Inferred above-cloud PW between CO2 slicing (+ NCEP moisture fields) and 0.94 µm solar reflectance retrieval ➡ identify ice retrieval contaminated by water cloud

2. IR and SWIR phase retrieval ➡ water cloud retrieval contaminated by ice cloud

multilayer/phase detection

MAS, CRYSTAL-FACE
7-26-2002, track 5

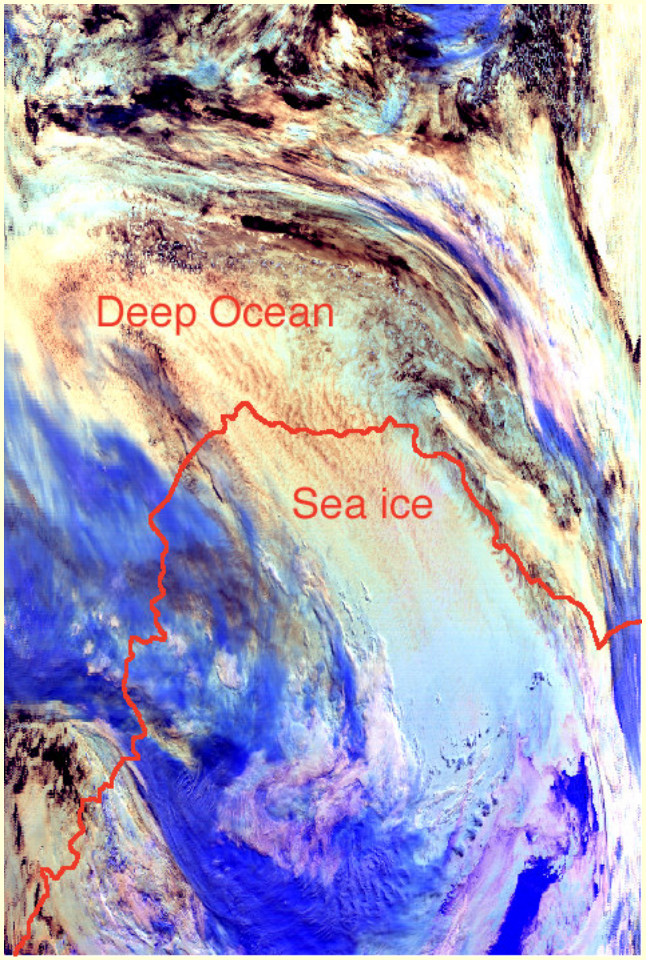
R(1.61) G(0.66) B(1.87)



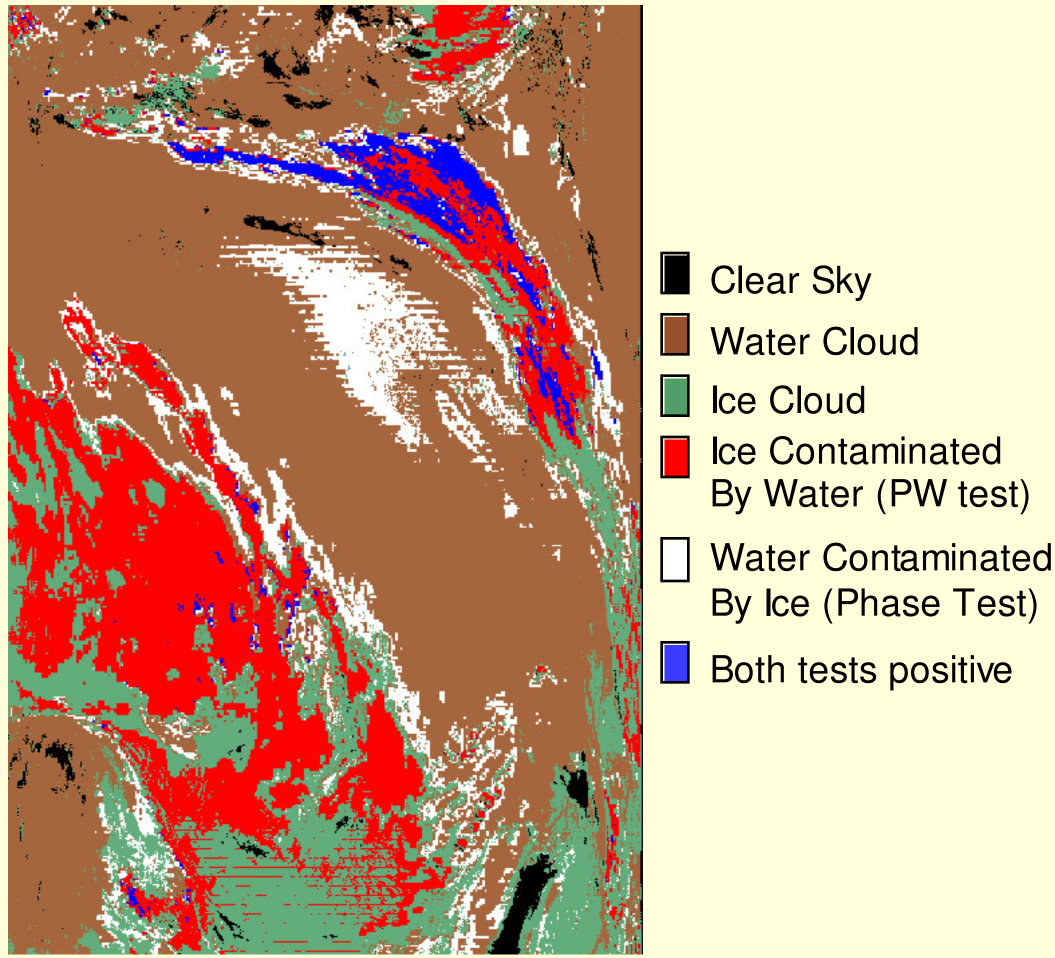
Multi-layer map

multilevel/phase detection

MODIS Terra, Antarctic Ocean 11-20-2002



RGB composite (2.1, 1.6, 0.55 µm)



Multi-layer map

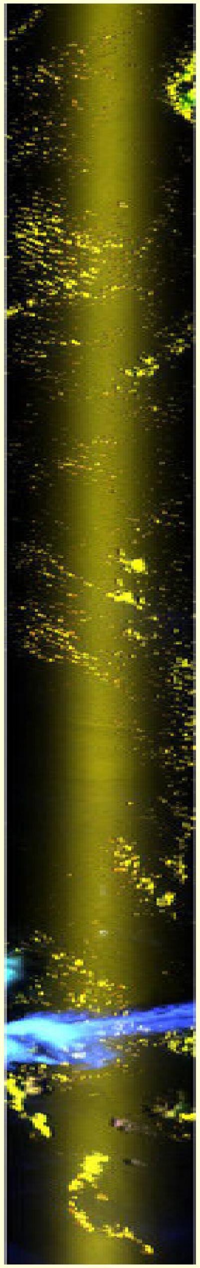
Sun Glint & Heavy Aerosol Detection

J. Riédi, G. Wind, et al.

- Problem
  - Difficulty in discriminating heavy aerosol (e.g., dust outbreak) and sun glint from cloud in current version
  - Dust aerosol —> water cloud; Pollution aerosol —> ice cloud
- Approach
  - Combination of spatial variance tests and possibly spectral dependence tests (TBD)

sunglint detection

MAS, CRYSTAL-FACE
7-26-2002, track 3



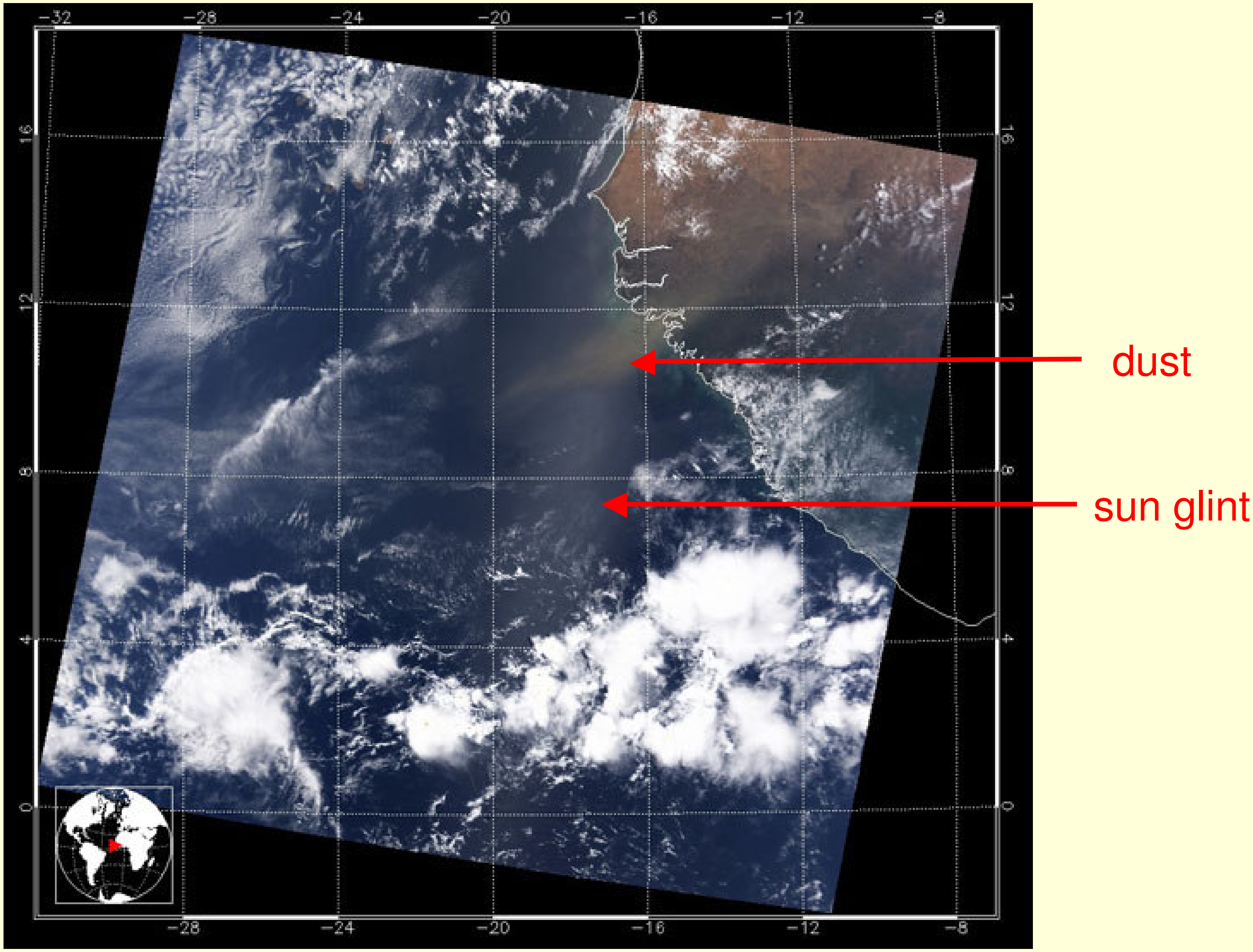
R(1.61) G(0.66) B(1.87)

Sunglint/phase map

- Clear sky
- Water cloud
- Ice cloud
- Sunglint, no cloud
- Cloud edge detected

Sun Glint & Heavy Aerosol Detection Example

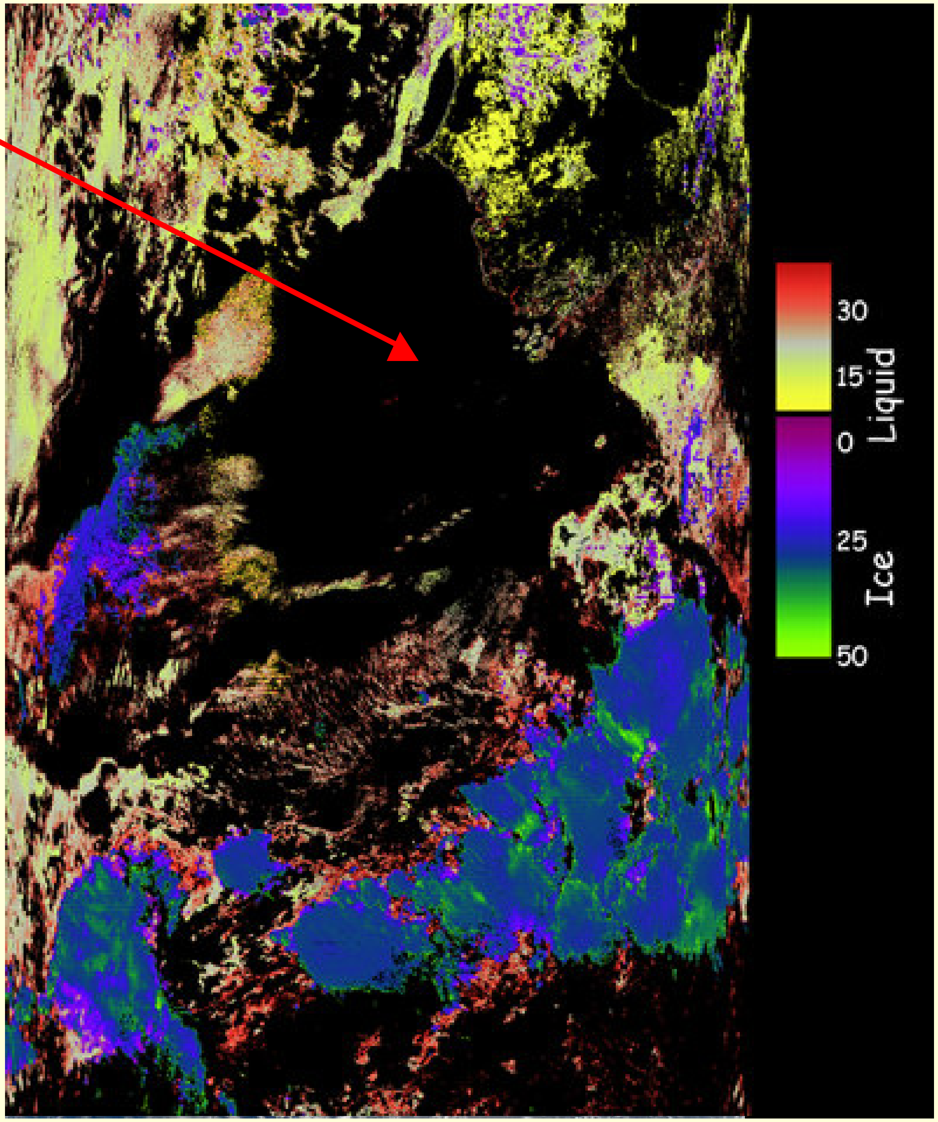
Terra, 8 May 2001, 1200 UTC, Saharan Dust



Sun Glint & Heavy Aerosol Detection Example

Terra, 8 May 2001, 1200 UTC, Saharan Dust

dust



S. Platnick, MODIS AGM, 14 July 2004

Global Analysis of MODIS Level-3 Cloud Properties and their Sensitivity to Aggregation Strategies

(data & analysis grant)

- **Investigators**

PI: Steve Platnick

Co-I's: Steve Ackerman (U. Wisconsin), Robert Pincus (NOAA-CIRES), Michael King, Bryan Baum (LaRC, U. Wisconsin CIMSS)

Collaborators: Lazaros Oreopoulos (JCET, UMBC), Jean-Jacques Morcrette (ECMWF)

Consequences of pixel-level errors?

- MODIS L3 aggregations provide statistics relevant to large-scale GCM domains. Therefore …

Overarching science question:

To what extent do systematic pixel-level retrieval errors bias spatial/temporal aggregations?

An approach:

Since difficult to determine error as well as separate into random and bias components, what is the aggregation sensitivity to parameters expected to influence retrieval error (solar/viewing geometry w/segregation by cloud type, phase, surface, τ_c, r_e, ...)?

Research Approach

- Investigate global L3 distribution and correlations of various cloud products. Initial emphasis on hemispheric, land/ocean, tropical/midlatitude convective, marine stratocumulus regimes.

- Design/create research-level aggregation code (i.e., exist outside of production facility) w/capability of answering science questions.

- Analyze aggregation sensitivities by excluding various parts of geometry/retrieval space.

- Explore use of theoretical retrieval sensitivity calculations in weighting L2 data.

- Make a variety of L3 daily and monthly data sets available for use by researchers interested in MODIS cloud aggregations, including ECMWF (non-angular grid, reduced volume), UMBC (L. Oreopoulos), GMAO.

Extra Slides

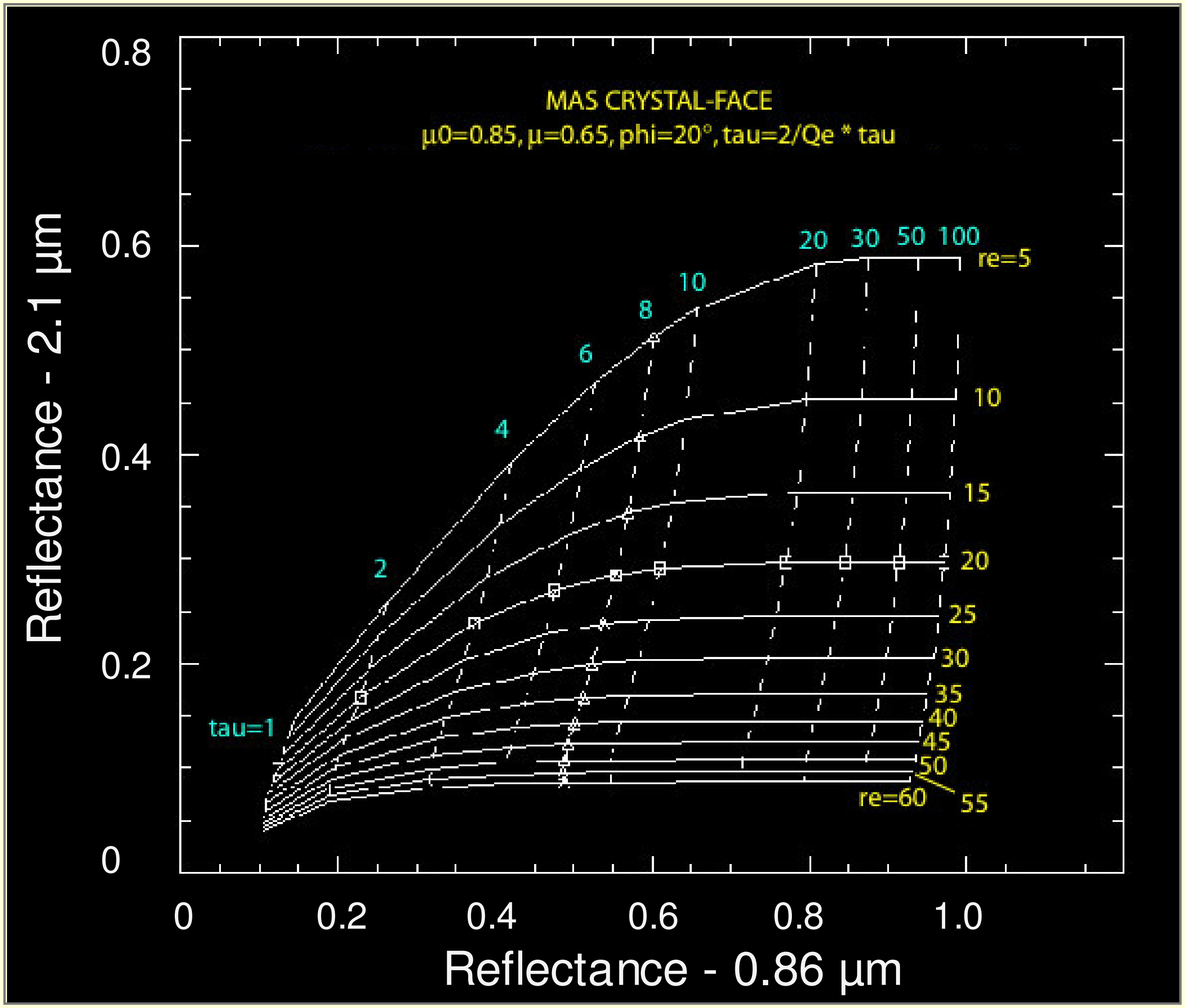
MODIS Solar Reflectance Retrieval
MOD06 – Cloud Optical & Microphysical Properties

Pixel-level cloud product for **daytime** observations at **1 km**

- Cloud optical thickness (τ), effective particle radius (r_e), water path, thermodynamic phase
- liquid water and ice clouds, global retrievals (land, water, snow/ice)
- Algorithm overview
  - Use single water non-absorbing band (0.65, 0.86, 1.2 µm) w/three absorbing bands (1.6, 2.1, 3.7 µm) => **1 τ, 3 r_e** (***2.1 µm derived r_e is primary***).
  - Short-wavelength band choice: 0.65 µm (land), 0.86 µm (ocean), 1.2 µm (snow/ice)
  - Surface spectral albedo from MODIS ecosystem and albedo products
  - Retrieval gives homogeneous-equivalent cloud properties

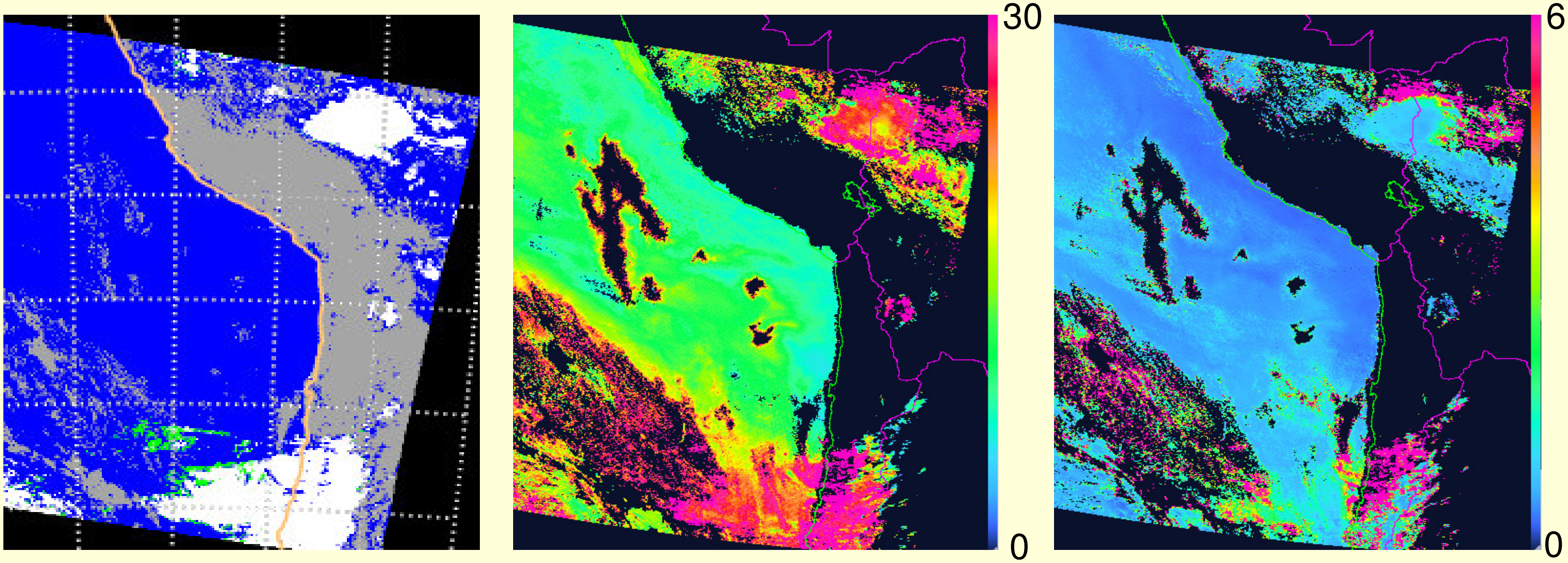
Solar Reflectance Method

retrieval space example - ice cloud over ocean surface



Pixel-level Uncertainty Analysis

Peru granule (18 July 2001)

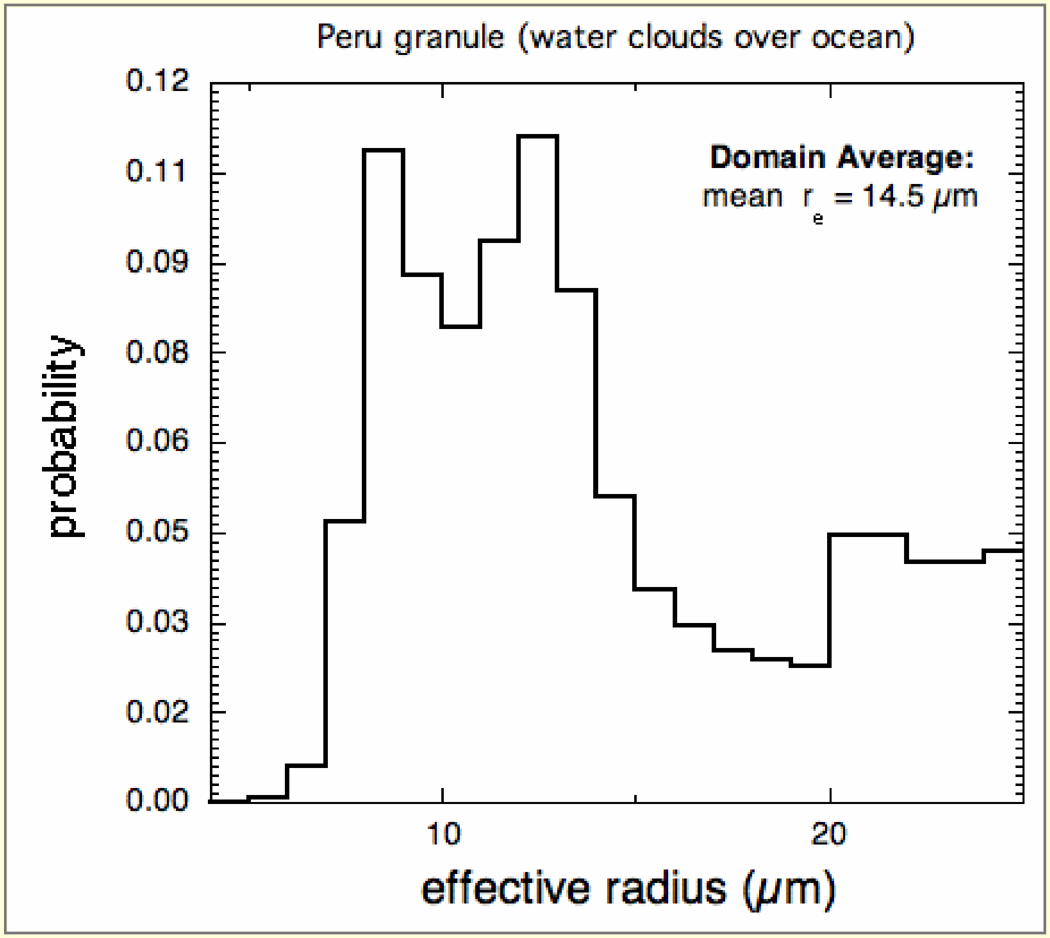


Phase (white=ice) Effective radius (µm) Effective radius Uncertainty (µm)

Pixel-level Uncertainty Analysis

Peru granule (18 July 2001)

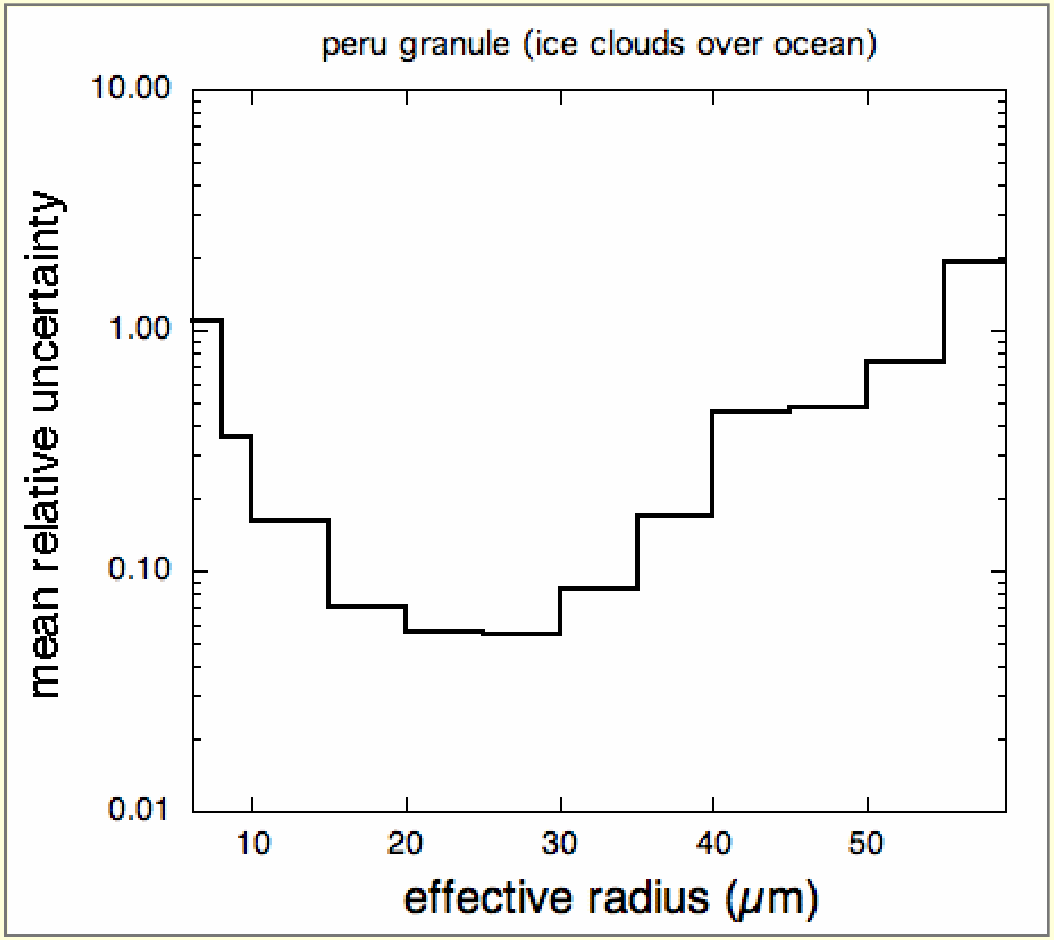
r_e: water clouds over ocean



Pixel-level Uncertainty Analysis

Peru granule (18 July 2001)

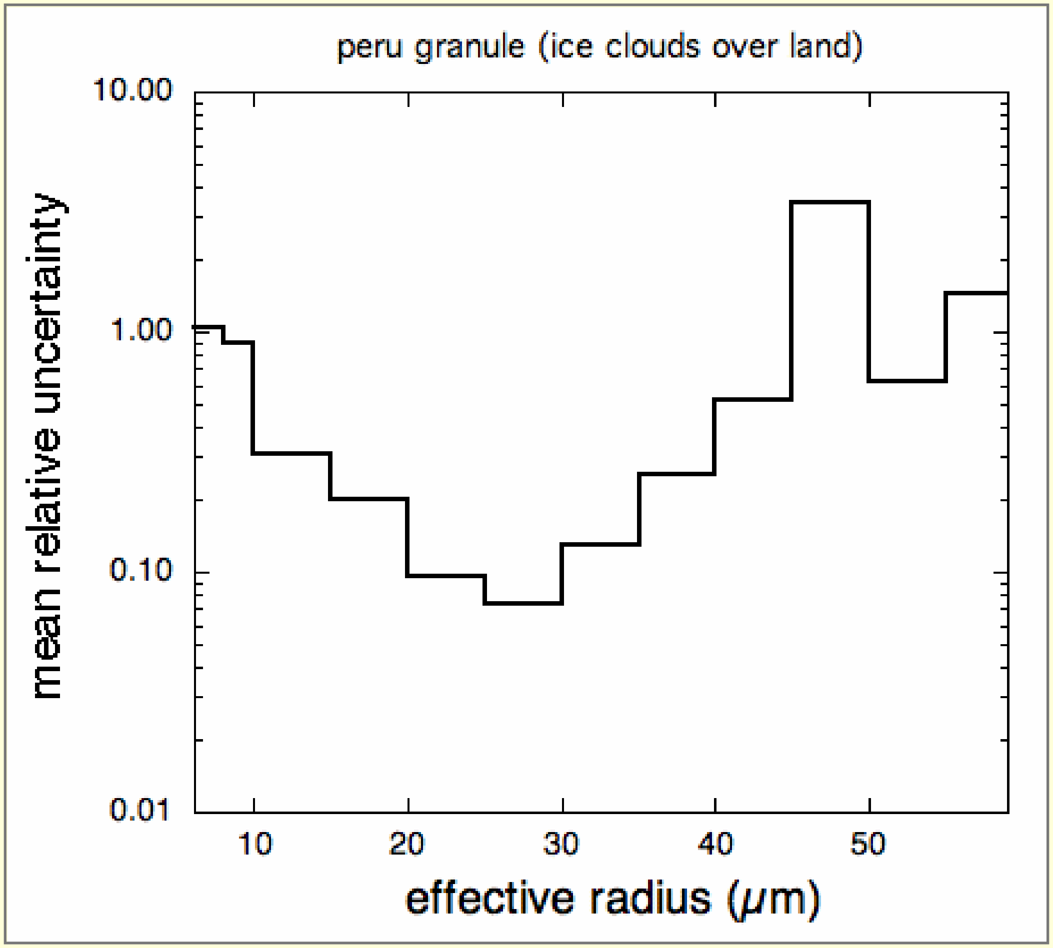
r_e: ice clouds over ocean



Pixel-level Uncertainty Analysis

Peru granule (18 July 2001)

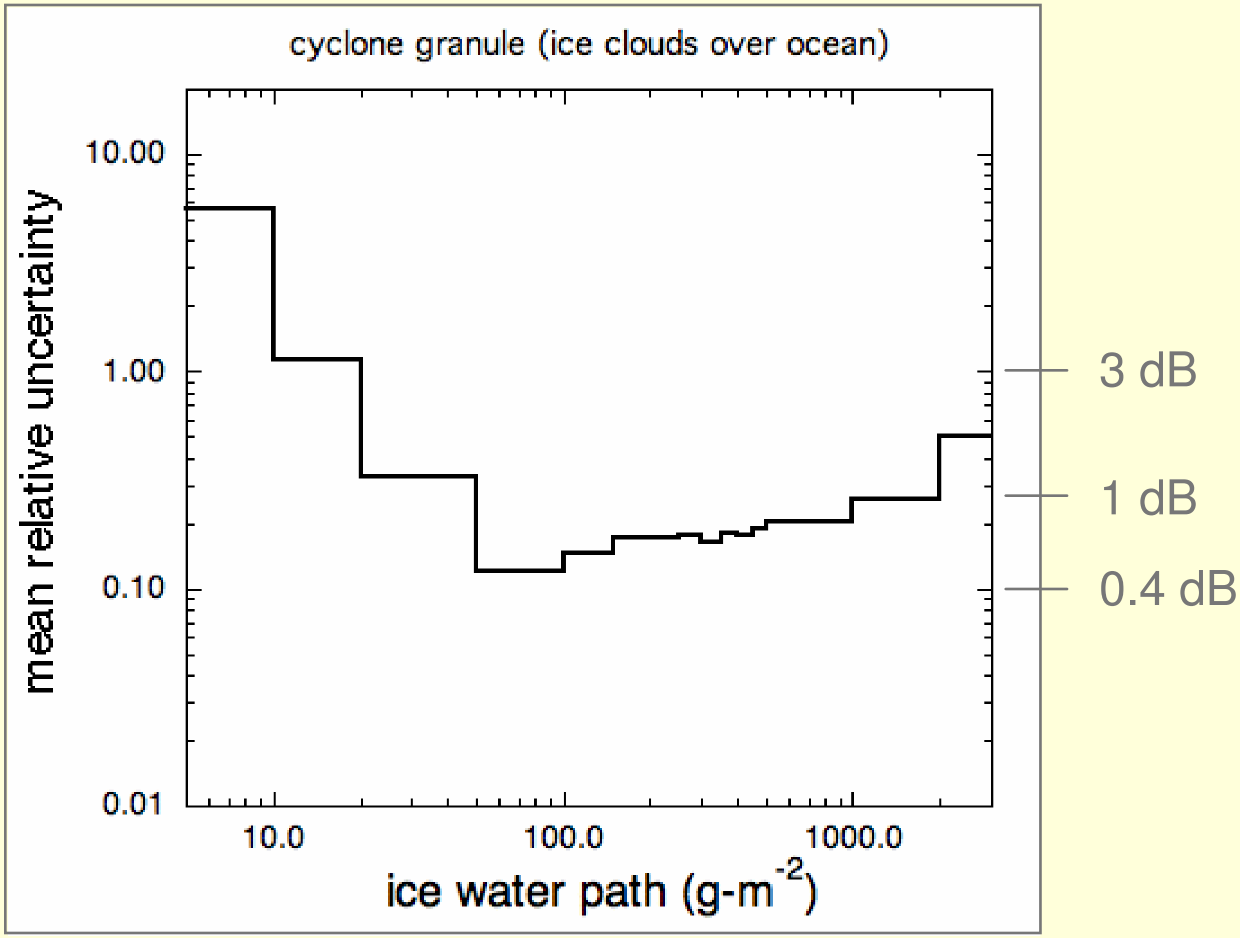
r_e: ice clouds over land



Pixel-level Uncertainty Analysis

Cyclone granule (20 Nov. 2002)

IWP **: ice clouds**



Cloud optical/microphysical properties from reflectance measurements - **Spherical Particles**

In general:

$$R_\lambda = R(\tau_\lambda, \varpi_{0,\lambda}, g_\lambda)$$

For Mie scattering (spheres, **water droplets**), 3 optical variables can be reduced to 1 optical & 1 microphysical:

$$R_\lambda \approx R(\tau_{\lambda_0}, r_e)$$

$$r_e \equiv \frac{\int_0^\infty r^3 n(r)dr}{\int_0^\infty r^2 n(r)dr} = \frac{3}{4}\frac{\langle V \rangle}{\langle A_{cs} \rangle}$$

Cloud optical/microphysical properties from reflectance measurements - **Spherical Particles**, cont.

r_e is a radiative parameter, but with certain assumptions, it can be used with τ to estimate column water mass/unit area (water path):

$$\tau \approx \Delta z \int_0^\infty 2A_{cs}(r)\, n(r)\, dr = 2\langle A_{cs}\rangle N \Delta z$$

$$WP = \Delta z \int_0^\infty \rho_W V(r)\, n(r)\, dr = \rho_W \langle V\rangle N \Delta z$$

$$WP = \frac{2\rho_W}{3}\,\tau r_e$$

Assumption: vertically homogenous cloud layer, i.e., $N, r_e \neq f(z)$

Cloud optical/microphysical properties from reflectance measurements - **Crystal/Irregular Particles**

In general:

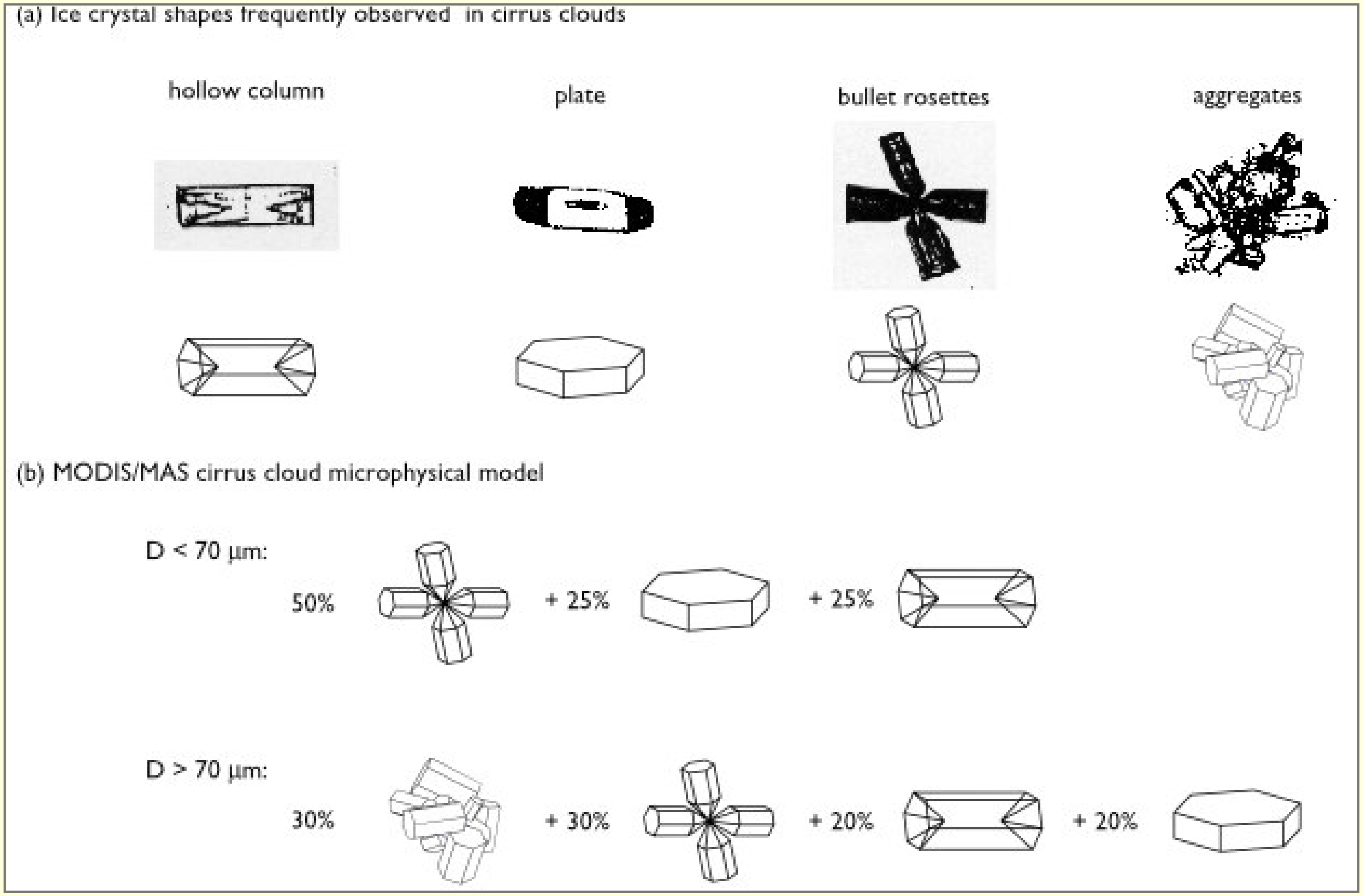
$$R_\lambda = R\left(\tau_\lambda, \varpi_{0,\lambda}, g_\lambda\right)$$

3 optical variables can perhaps(?) be reduced to 1 optical & 2 microphysical:

$$R_\lambda \approx R\left(\tau_{\lambda_0}, r_e, Habit\ \ mixture\right)$$

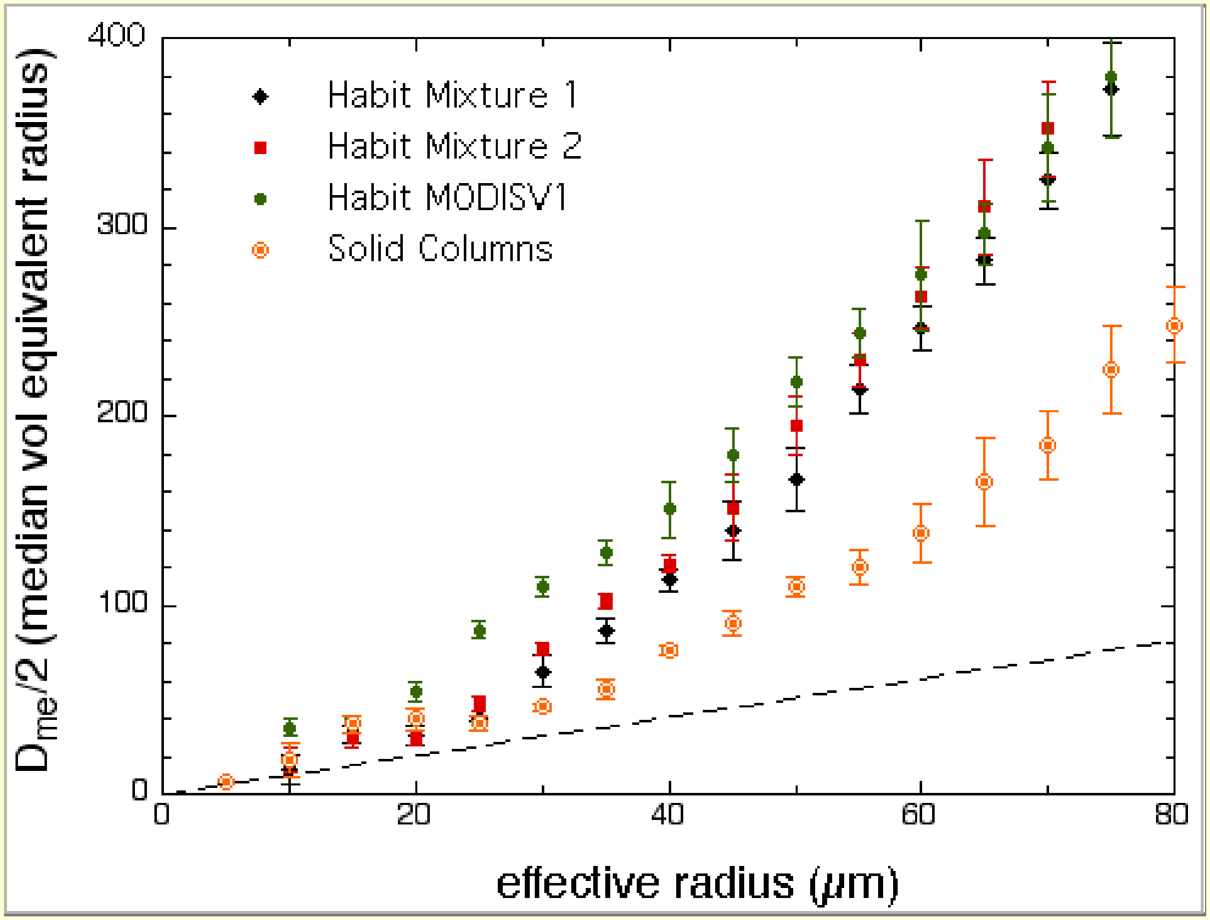
$$\text{if } r_e \equiv \frac{3}{4}\frac{\langle V \rangle}{\langle A_{cs} \rangle} \Rightarrow WP = \frac{2\rho_i}{3} \tau r_e$$

MODIS operational (collection 4) ice crystal library habits/mixtures



Example Pseudo-Empirical r_e - D_{me} Relations

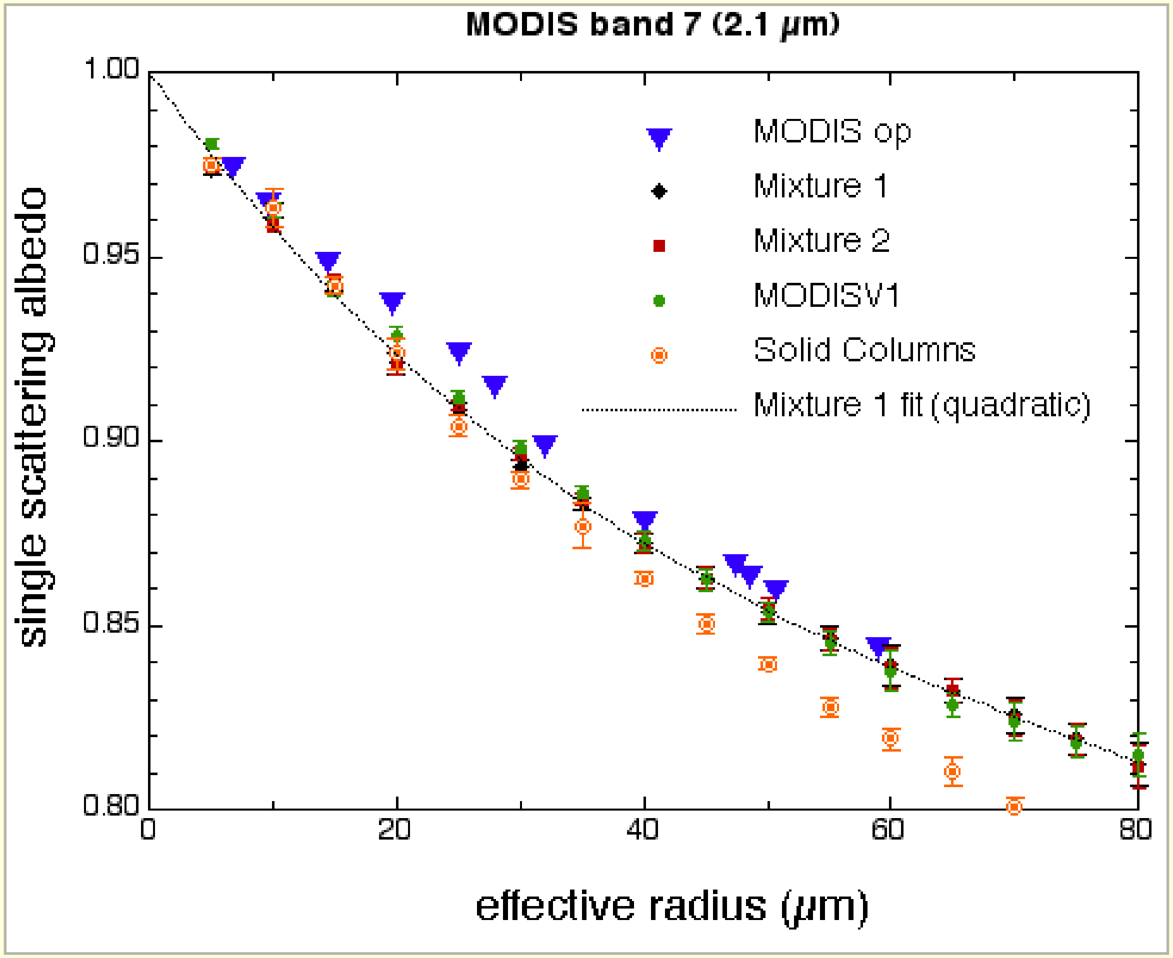
B. Baum, A. Heymsfield, P. Yang



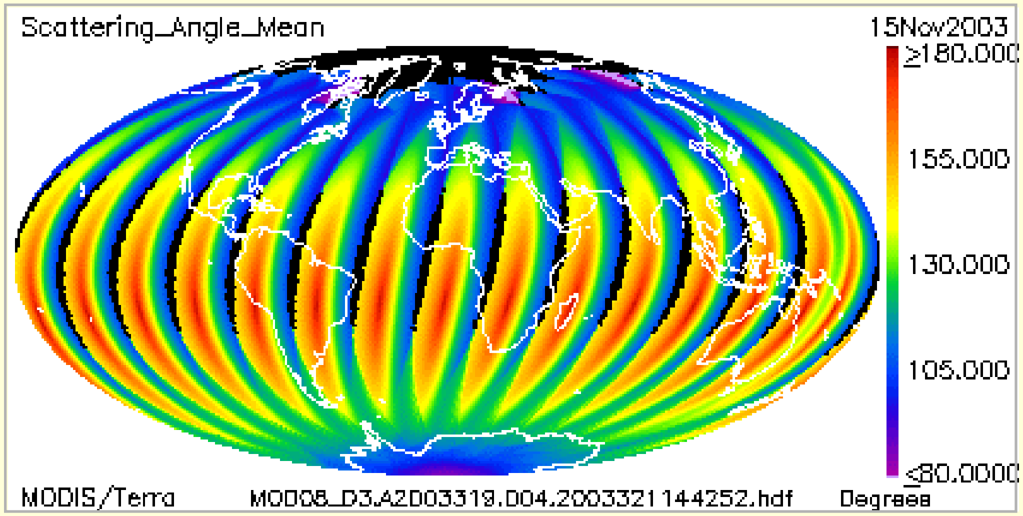
Note: *the tail can wag the Dme*

Sensitivity of Scattering Parameters to Habits/Mixture

B. Baum



Terra geometry (Nov. 15, 2003)



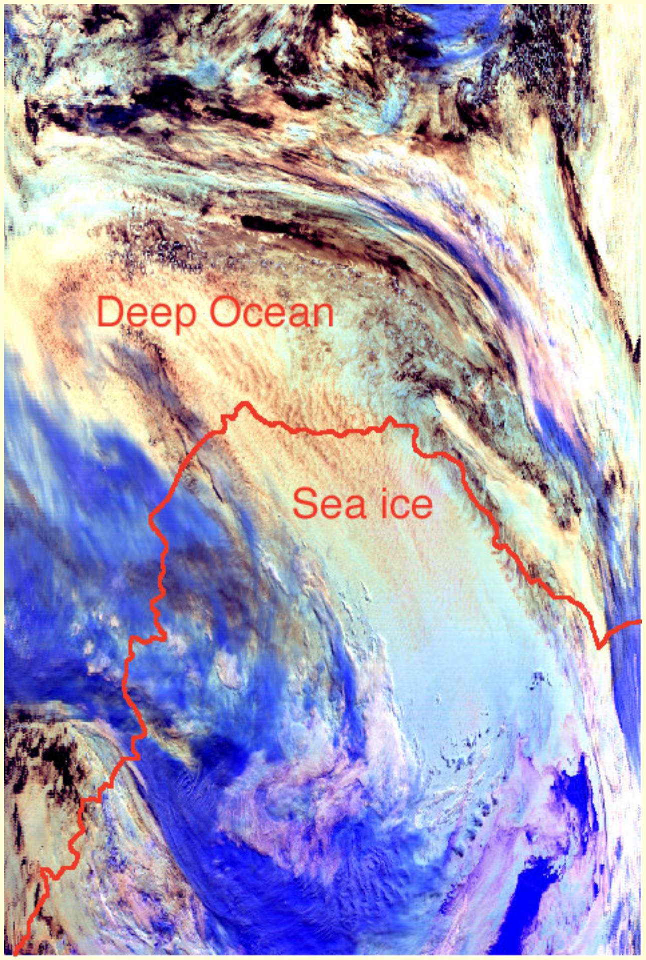
scattering angle (deg)

=> scan-dependent view angle & azimuth, orbital-dependent solar angle

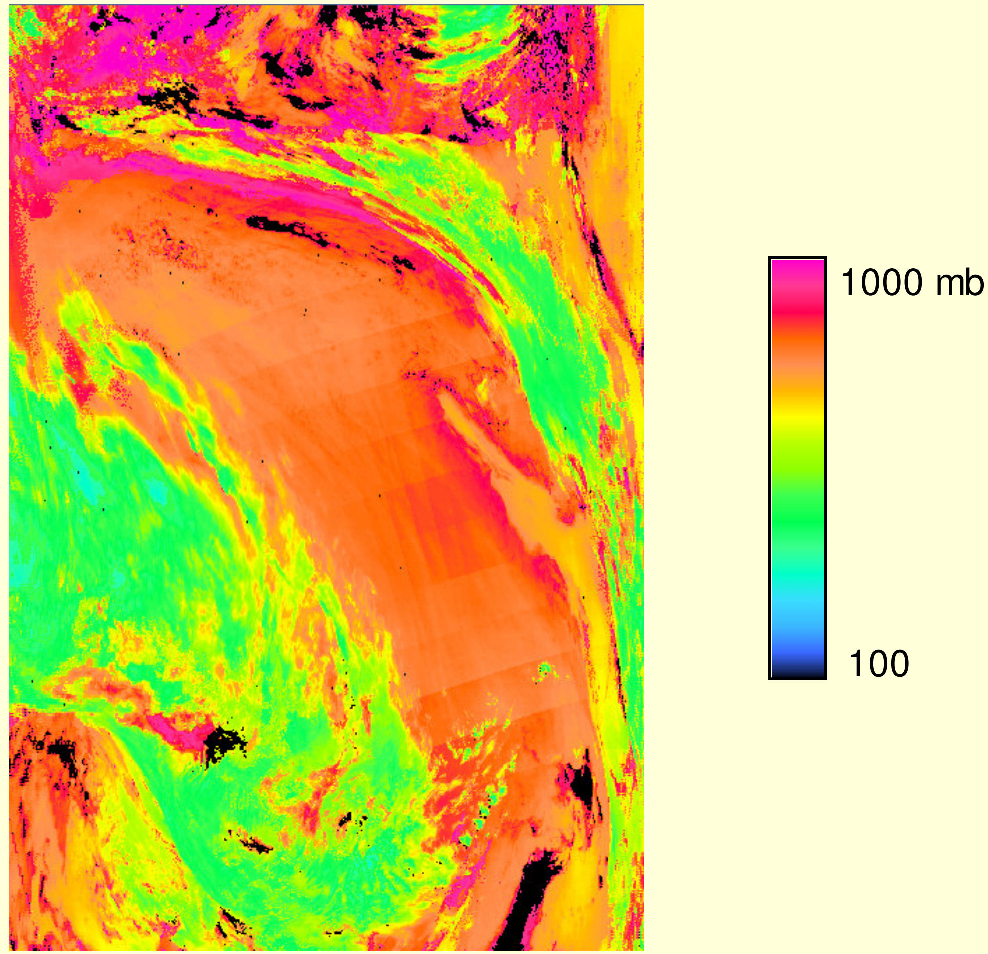
multilevel/phase detection, example

MODIS Terra, Antarctic Ocean 11-20-2002

RGB composite (2.1, 1.6, 0.55 µm)



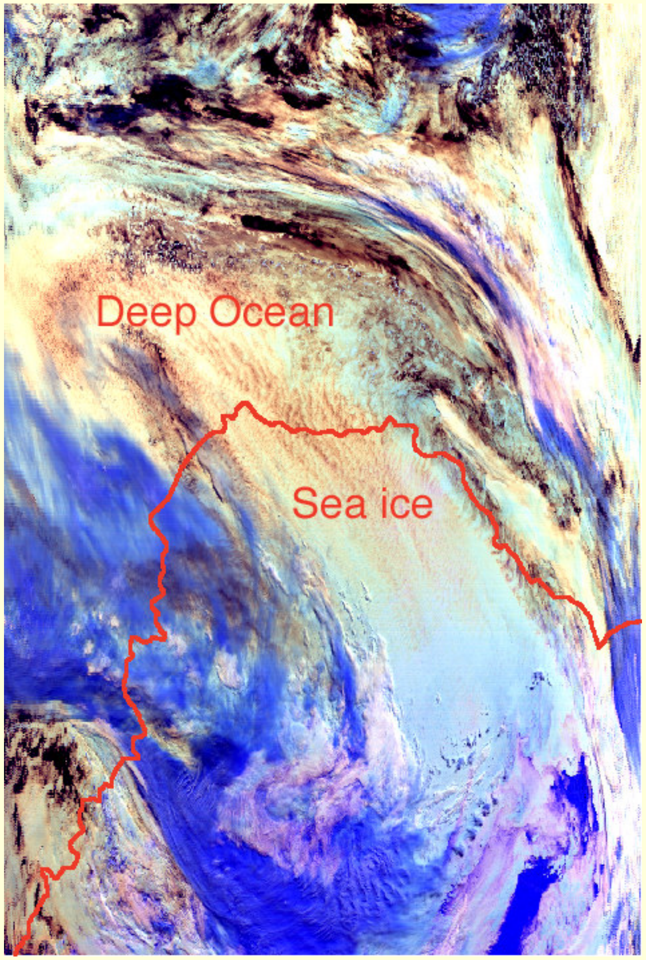
Cloud top pressure (CO2 slicing)



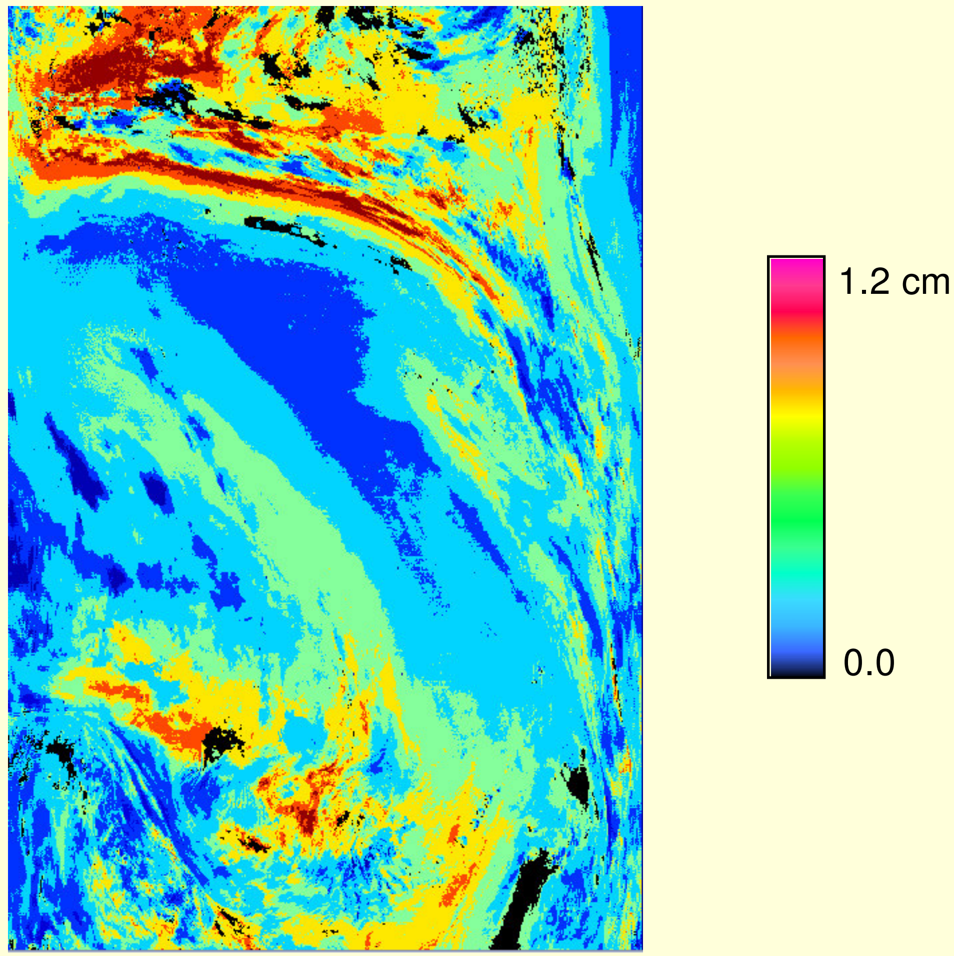
multilevel/phase detection, example

MODIS Terra, Antarctic Ocean 11-20-2002

RGB composite (2.1, 1.6, 0.55 µm)

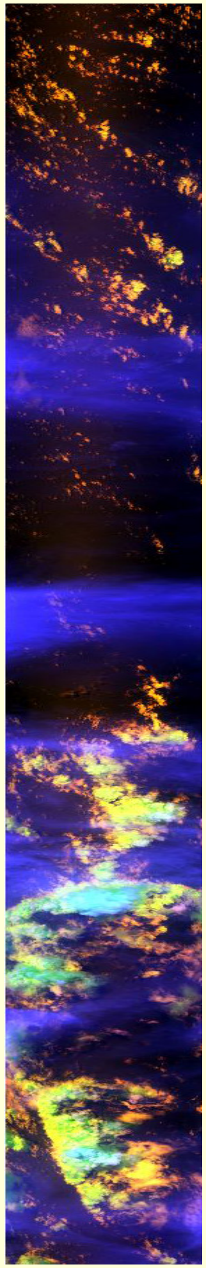


0.94 µm above-cloud PW

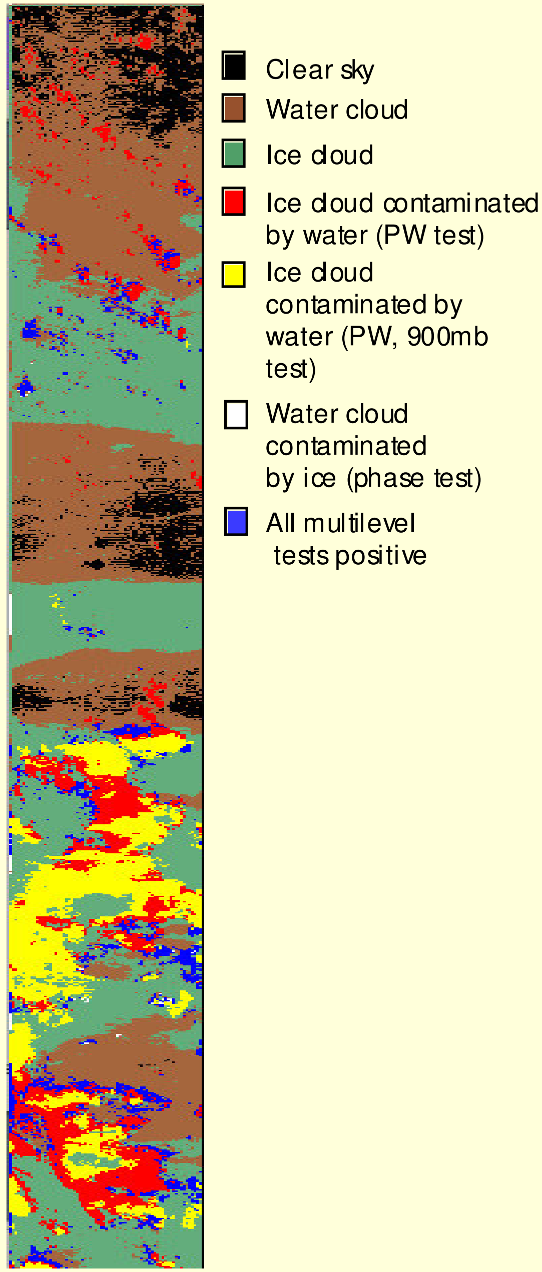


multilayer/phase detection

MAS, CRYSTAL-FACE 7-26-2002, track 5



R(1.61) G(0.66) B(1.87)



Multi-layer map

8

0

Cloud optical thickness

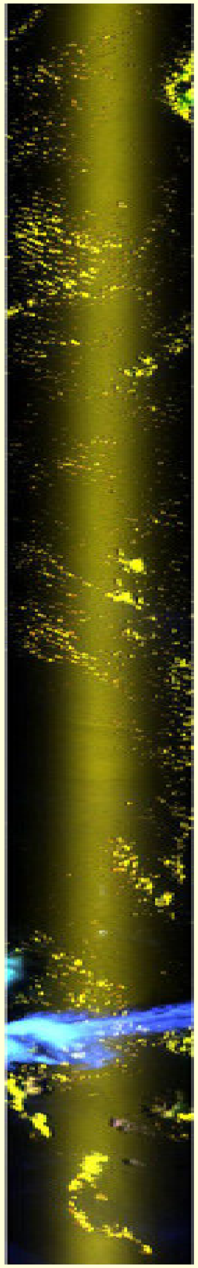
60

0

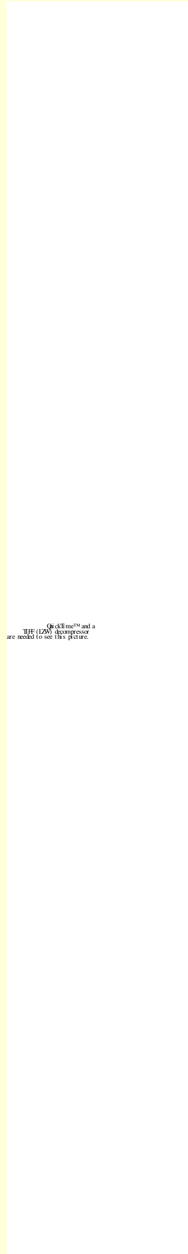
Effective particle radius (µm)

sunglint detection

MAS, CRYSTAL-FACE 7-26-2002, track 3

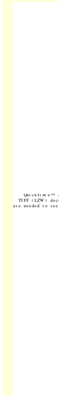


R(1.61) G(0.66) B(1.87)

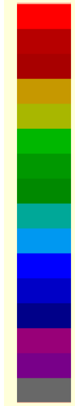


Sunglint/phase map

- Clear sky
- Water cloud
- Ice cloud
- Sunglint, no cloud
- Cloud edge detected, No retrieval



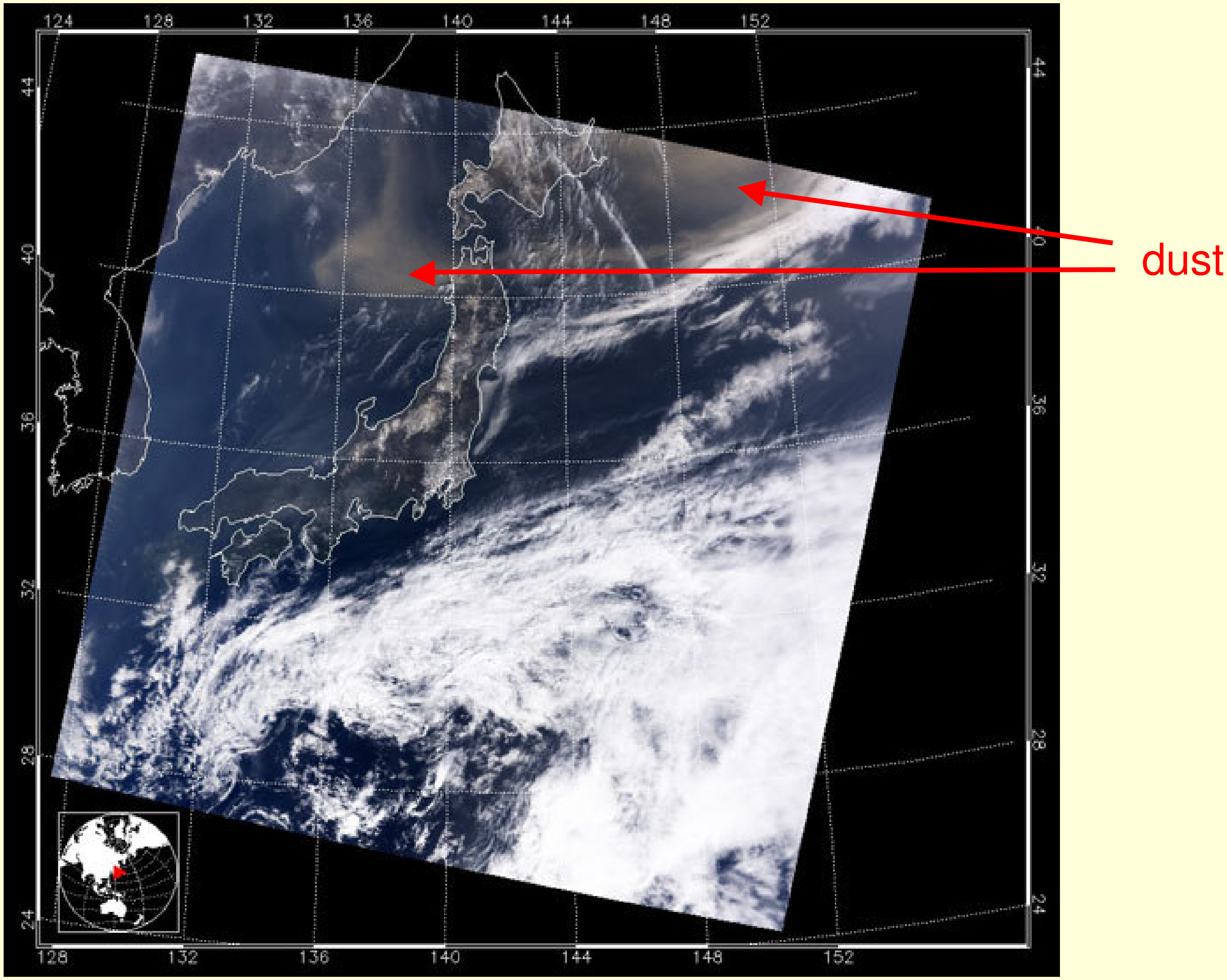
Cloud optical thickness



Effective particle radius (µm)

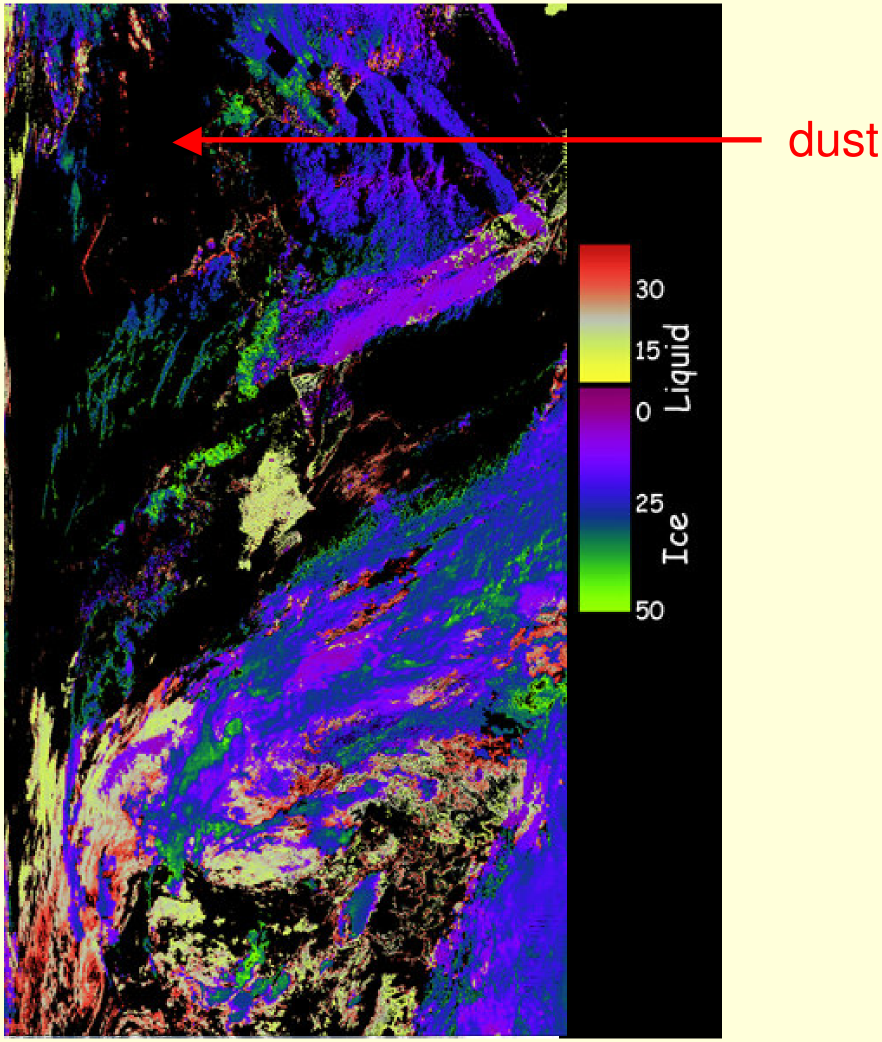
Sun Glint & Heavy Aerosol Detection Example

Terra, 10 April 2001, 1200 UTC, Asian Dust & Pollution



Sun Glint & Heavy Aerosol Detection Example

Terra, 10 April 2001, 1200 UTC, Asian Dust & Pollution



MODIS Atmosphere Level-3 Aggregation Summary

- 1° grid spatial; daily, 8-day, monthly temporal – all atmosphere products
- Statistics (mean, sdev, min, max, QA-weighting)
- Histograms (pdf's): 1-D and 2-D

2-D cloud parameter combinations (collection 4):

parameter	τ_c	r_e	T_c	ε_c
τ_c		X	X	X
r_e			X	X
p_c				X

- L3 code designed to aggregate L2 data sets only (monthly file contains ~ 800 statistical data sets). **For maintenance (sanity) reasons, code not capable of mathematical or logical manipulation of L2 data!**

Science Questions

- To what extent do aggregations show significant differences and/or correlations by hemisphere, land/ocean, regionally (e.g., tropical convection vs. midlatitude ice clouds; marine stratocumulus regimes)?

- Are aggregations sensitive to the geometry/retrieval space (due to 3-D geometry, pixel-level retrieval sensitivity, etc.)? How do aggregations change by elimination of certain parts of the space (e.g, exclude view angles regions, backscatter azimuth, etc.)? To what extent can changes be equated with bias “error”?

- Can pixel-based retrieval sensitivity/error calculations (include geometry and retrieval solution dependence) be used to weight L2 retrievals to reduce bias error?

- Are other girds or statistics more useful for forecast/climate model evaluation and diagnosis?