MODIS Atmosphere Team Webinar Series #9:
Overview of Collection 6 Cloud Optical Properties

Steven Platnick et al.

NASA Goddard Space Flight Center, Greenbelt, MD

17 Sept. 2014

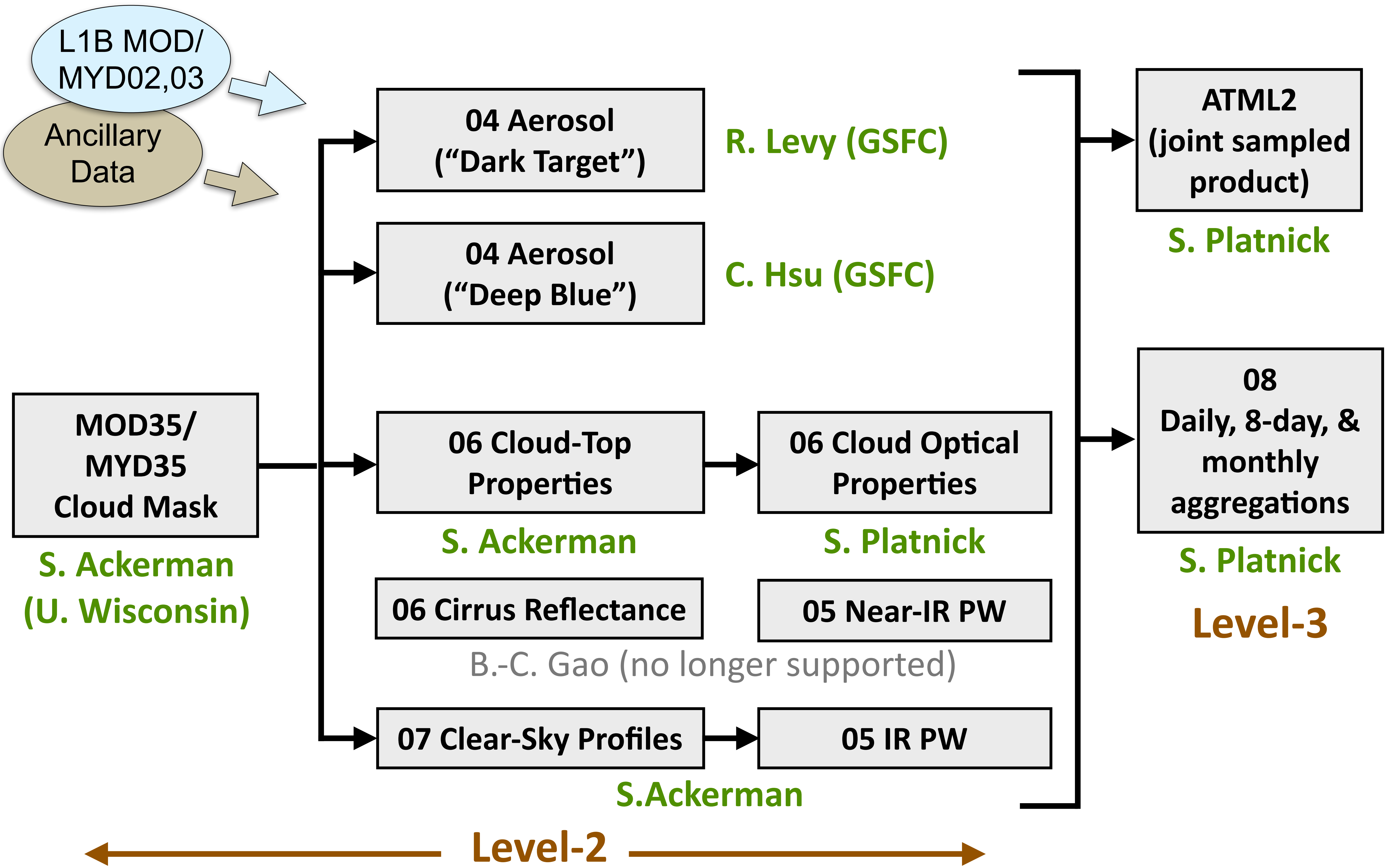
The Story So Far …

Atmosphere Team Webinar Schedule

http://aerocenter.gsfc.nasa.gov/ext/registration/

Topic	Presenter(s)	Date	Materials
Overview of Collect 6 update L1 Calibration Overview	Steve Platnick Jack Xiong	25-Jun-14	Presentation Video
MODIS Dark Target Global 10 Km Product	Rob Levy	2-Jul-14	Presentation Video
MODIS Aerosols Deep Blue	Andy Sayer	9-Jul-14	Presentation Video.
MODIS Aerosols Merged Dark Target: Deep Blue Product	Rob Levy / Andy Sayer	16-Jul-14	Presentation Video
MODIS Dark Target 3 Km Product	Leigh Munchak	23-Jul-14	Presentation Video
MOD035 Cloud Mask and Clear Sky Products: atmosphere profile & clear sky radiance maps	Steve Ackerman	13-Aug-14	Presentation Video
MOD06 Cloud Top Properties Product	Paul Menzel	20-Aug-14	Presentation Video
Archives and Data Acquisition	*To Be Determined.*	10-Sep-14	*Materials to Follow.*
MOD06 Cloud Optical Properties	Steve Platnick	17-Sep-14	*Materials to Follow.*
MOD08 Level 3 Product	Steve Platnick / Bill Ridgway	24-Sep-14	*Materials to Follow.*
Giovanni Aerosols Express	Jim Acker	1-Oct-14	*Materials to Follow.*
MODIS Atmosphere Product Resources	Richard Kleidman	8-Oct-14	*Materials to Follow.*
MAIAC 1 Km Aerosol Product	Alexei Lyapustin	15-Oct-14	*Materials to Follow.*

Atmosphere Team Product Organization and PIs



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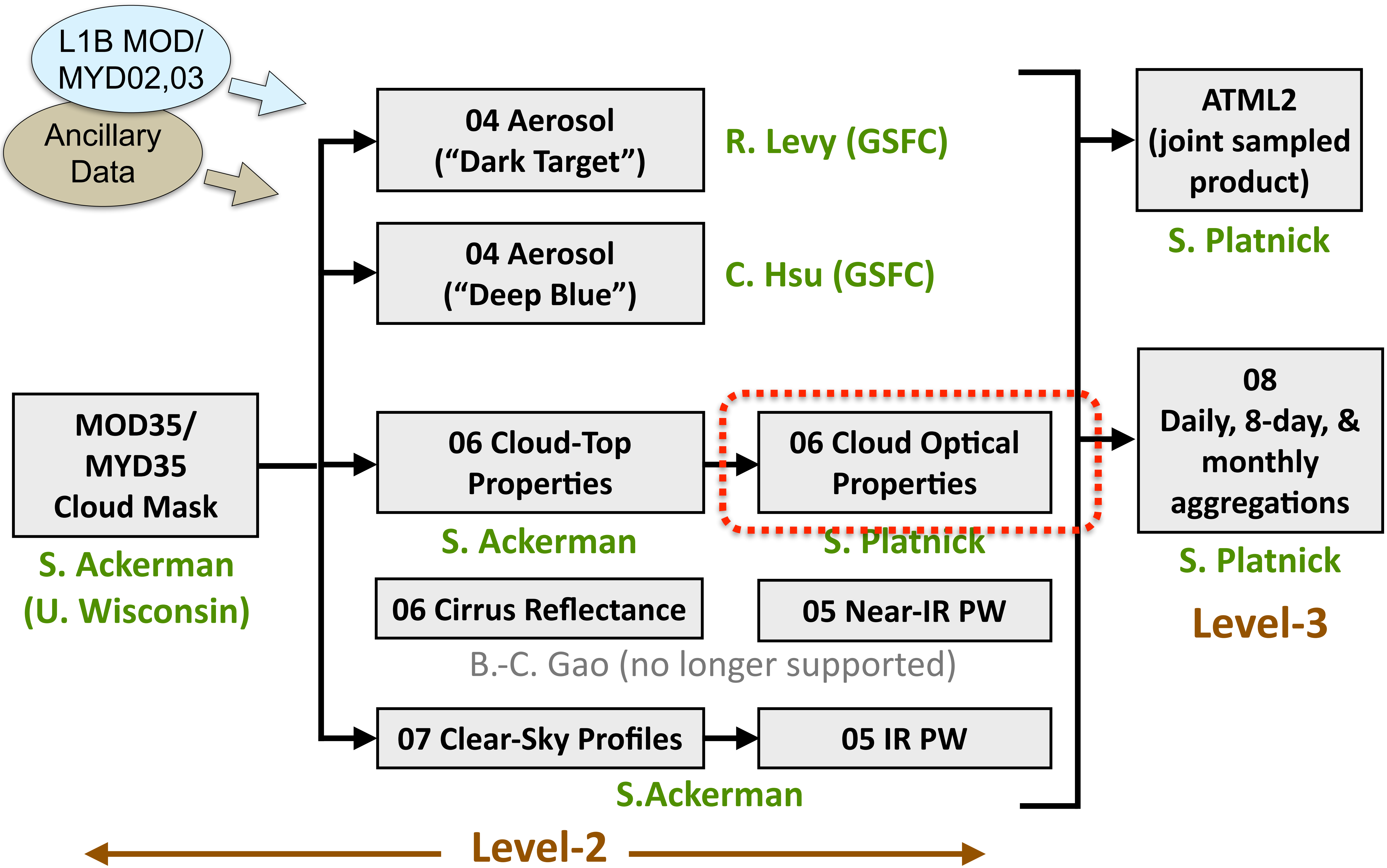

Atmosphere Team Collection 6 Production Status
(as of 17 Sept. 2014, see modis-atmos.gsfc.nasa.gov/validation.html)

- Cloud Mask (**MOD/MYD35**) and Atmospheric Profile (**MOD/ MYD07**) Terra/Aqua reprocessing started in 2012. Both reprocessed after L1B Band 5 trend correction implemented.
- Reprocessing of other L2 products from Aqua MODIS started on 6 December 2013. Was completed in spring 2014 but …
  - **MYD07**/**MYD05** IR PW: reprocessed all nighttime granules due to ancillary issue
  - **MYD06** Cloud Optical Properties being reprocessed from 1 January 2013 forward with updated gap-filled surface spectral albedo files
  - **MYD05** NIR PW: entire record reprocessed w/non-reaggregated L1B files
- Aqua L3 (**MYD08**) starting this week!
- Terra reprocessing code finalized. Start after completion of Aqua L3.

Outline

1. Who’s who
2. What are the MODIS L2 Cloud Optical Property Datasets?
3. “Quick Guide” to the Physical Basis of the Algorithm
4. Retrieval Challenges
5. What’s new? Major Collection 6 (C6) Changes and Example Results

1

MOD06 Collection 6 Contributors

Cloud Optical/Microphysical Properties

Steve Platnick
Michael King
Gala Wind
Kerry Meyer
Nandana Amarasinghe
Ben Marchant
Tom Arnold
Bob Holz
Zhibo Zhang
Paul Hubanks
Bill Ridgway
Jerome Riedi
Ping Yang
Andy Heidinger

Cloud-Top Properties

Steve Ackerman, Rich Frey, Paul Menzel, Bryan Baum

2

Cloud Optical Property Datasets

Terra MODIS:	**MOD06_L2.AYYYYDDD.HHMM.CCC.YYYYDDDHHMMSS.hdf**
Aqua MODIS:	**MYD06_L2.AYYYYDDD.HHMM.CCC.YYYYDDDHHMMSS.hdf**

*Science Data Set: An individual dataset within an HDF file (HDF4)

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  - Cloud Water Path (**LWP**, **IWP**)

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  - Uncertainty SDS for all COT, CER, WP retrievals

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  - Uncertainty SDS for all COT, CER, WP retrievals
  - Retrieval Fractions
  - Diagnostic datasets, QA, etc.

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Cloud Optical Property Datasets

User Guide - Appendix A Highlighted Rows

SDS name	Long Name	Dataset resolution (if applicable)
Above_Cloud_Water_Vapor_094	Above-cloud water vapor amount from 0.94um channel, ocean only, tau > 5.	1 km
Asymmetry_Parameter_Ice	Ice Asymmetry Parameter from the phase functions used to generate the forward lookup tables	–
Asymmetry_Parameter_Liq	Liquid Water Asymmetry Parameter from the phase functions used to generate the forward lookup tables	–
Atm_Corr_Refl	Atmospherically corrected reflectance used during cloud optical and microphysical properties retrieval	1 km
Band_Number	Band_Number	–
Brightness_Temperature	Observed Brightness Temperature from Cloudy Averaged Radiances in a 5x5 1-km Pixel Region	5 km
Cirrus_Reflectance	Cirrus Reflectance	1 km
Cirrus_Reflectance_Flag	Cirrus Reflectance Flag	1 km
Cloud_Effective_Emissivity	Cloud Effective Emissivity from Cloud Top Pressure Retrieval	5 km
Cloud_Effective_Emissivity_Day	Cloud Effective Emissivity from Cloud Top Pressure Retrieval, Day Only	5 km
Cloud_Effective_Emissivity_Nadir	Cloud Effective Emissivity from Cloud Top Pressure Retrieval for Sensor Zenith (View) Angles <= 32 Degrees	5 km
Cloud_Effective_Emissivity_Nadir_Day	Cloud Effective Emissivity from Cloud Top Pressure Retrieval for Sensor Zenith (View) Angles <= 32 Degrees, Day Data Only	5 km
Cloud_Effective_Emissivity_Nadir_Night	Cloud Effective Emissivity from Cloud Top Pressure Retrieval for Sensor Zenith (View) Angles <= 32 Degrees, Night Data Only	5 km
Cloud_Effective_Emissivity_Night	Cloud Effective Emissivity from Cloud Top Pressure Retrieval, Night Only	5 km
Cloud_Effective_Radius	Cloud Particle Effective Radius two-channel retrieval using band 7(2.1um) and either band 1(0.65um), 2(0.86um), or 5(1.2um) (specified in Quality Assurance 1km)from best points: not failed in any way, not marked for clear sky restoral	1 km
Cloud_Effective_Radius_PCL	Cloud Particle Effective Radius two-channel retrieval using band 7(2.1um) and either band 1(0.65um), 2(0.86um), or 5(1.2um) (specified in Quality Assurance 1km)from points identified as either partly cloudy from 250m cloud mask test or 1km cloud edges	1 km
Cloud_Effective_Radius_16	Cloud Particle Effective Radius two-channel retrieval using band 6(1.6um) and either band 1(0.65um), 2(0.86um), or 5(1.2um) (specified in Quality Assurance 1km)from best points: not failed in any way, not marked for clear sky restoral	1 km
Cloud_Effective_Radius_16_PCL	Cloud Particle Effective Radius two-channel retrieval using band 6(1.6um) and either band 1(0.65um), 2(0.86um), or 5(1.2um) (specified in Quality Assurance 1km)from points identified as either partly cloudy from 250m cloud mask test or 1km cloud edges	1 km
Cloud_Effective_Radius_1621	Cloud Particle Effective Radius two-channel retrieval using band 7(2.1um) and band 6(1.6um)from best points: not failed in any way, not marked for clear sky restoral	1 km
Cloud_Effective_Radius_1621_PCL	Cloud Particle Effective Radius two-channel retrieval using band 7(2.1um) and band 6(1.6um)from points identified as either partly cloudy from 250m cloud mask test or 1km cloud edges	1 km
Cloud_Effective_Radius_37	Cloud Particle Effective Radius two-channel retrieval using band 20(3.7um) and either band 1(0.65um), 2(0.86um), or 5(1.2um) (specified in Quality Assurance 1km)from best points: not failed in any way, not marked for clear sky restoral	1 km
Cloud_Effective_Radius_37_PCL	Cloud Particle Effective Radius two-channel retrieval using band 20(3.7um) and either band 1(0.65um), 2(0.86um), or 5(1.2um) (specified in Quality Assurance 1km)from points identified as either partly cloudy from 250m cloud mask test or 1km cloud edges	1 km
Cloud_Effective_Radius_Uncertainty	Cloud Effective Particle Radius (from band 7(2.1um)) Relative Uncertainty (Percent)from both best points and points identified as cloud edge at 1km resolution or partly cloudy at 250m	1 km
Cloud_Effective_Radius_Uncertainty_16	Cloud Effective Particle Radius (from band 6(1.6um) Relative Uncertainty (Percent)from both best points and points identified as cloud edge at 1km resolution or partly cloudy at 250m	1 km
Cloud_Effective_Radius_Uncertainty_1621	Cloud Effective Particle Radius Relative Uncertainty (Percent) using band 7(2.1um) and band 6(1.6um)from both best points and points identified as cloud edge at 1km resolution or partly cloudy at 250m	1 km
Cloud_Effective_Radius_Uncertainty_37	Cloud Effective Particle Radius (from band 20(3.7um)) Relative Uncertainty (Percent)from both best points and points identified as cloud edge at 1km resolution or partly cloudy at 250m	1 km
cloud_emiss11_1km	11 micron Cloud Emissivity at 1-km resolution from LEOCAT for All Clouds	1 km
cloud_emiss12_1km	12 micron Cloud Emissivity at 1-km resolution from LEOCAT for All Clouds	1 km

3

Algorithm "Quick Guide"

- 2-Channel reflectance algorithm. Retrieval datasets include:
  - 1 nominally non-absorbing band: 0.65 (land), 0.86 (ocean), 1.2 μm (snow/ice) + each of the following absorbing bands: 1.6, 2.1, 3.7 μm ⇒ 3 τ, 3 r_e retrievals
  - 2.1 μm combination has been the "primary" retrieval in previous collections
  - additional 1.6 & 2.1 μm band combination retrievals provided over snow/ice and water surfaces
- Look-Up Tables: Spectral bidirectional reflectance, effective emittance, flux reflectances/transmittances, clear sky transmittances
- Ancillary data: cloud mask, cloud-top pressure/temperature, NCEP GDAS, global spectral albedo maps, emissivity maps, snow/ice maps, …

3

Algorithm "Quick Guide"

Example COT, CER solution space: water clouds over snow/ice surface

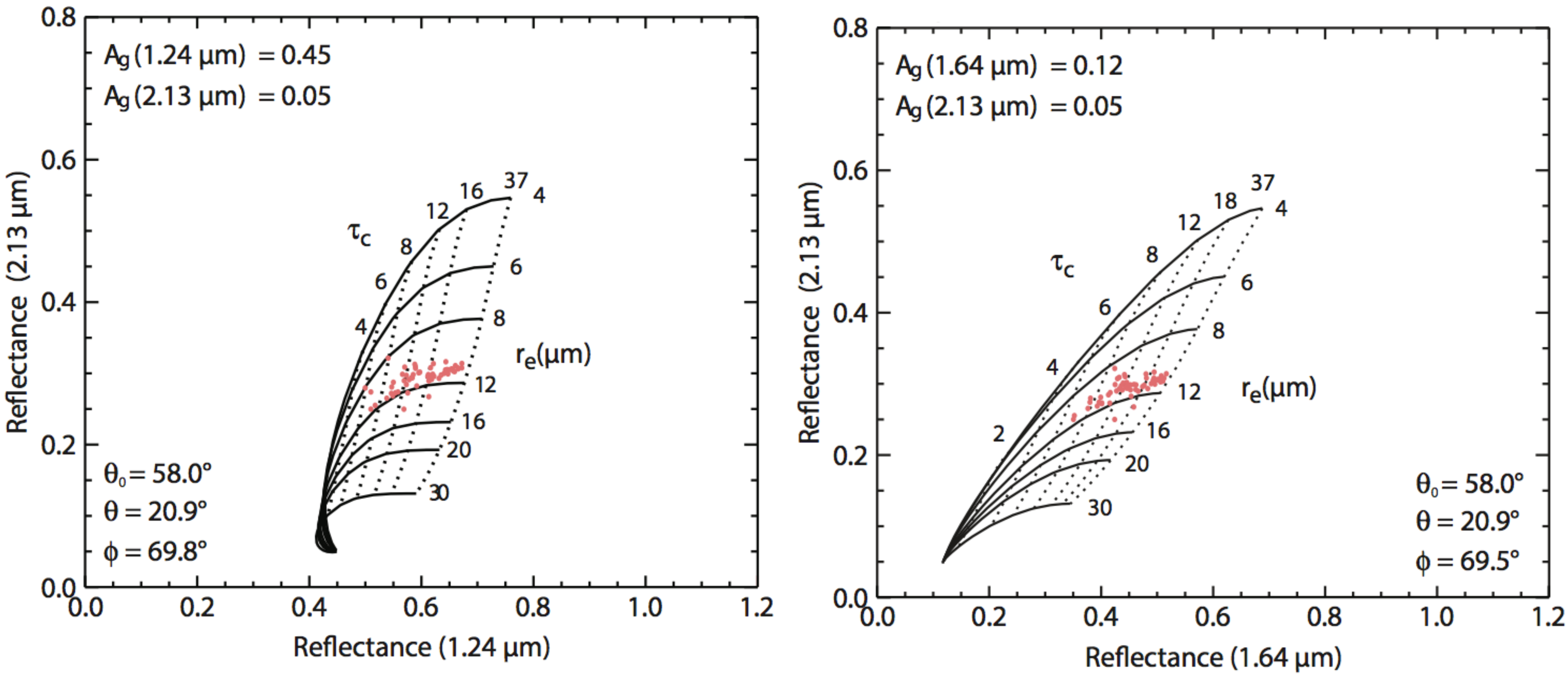


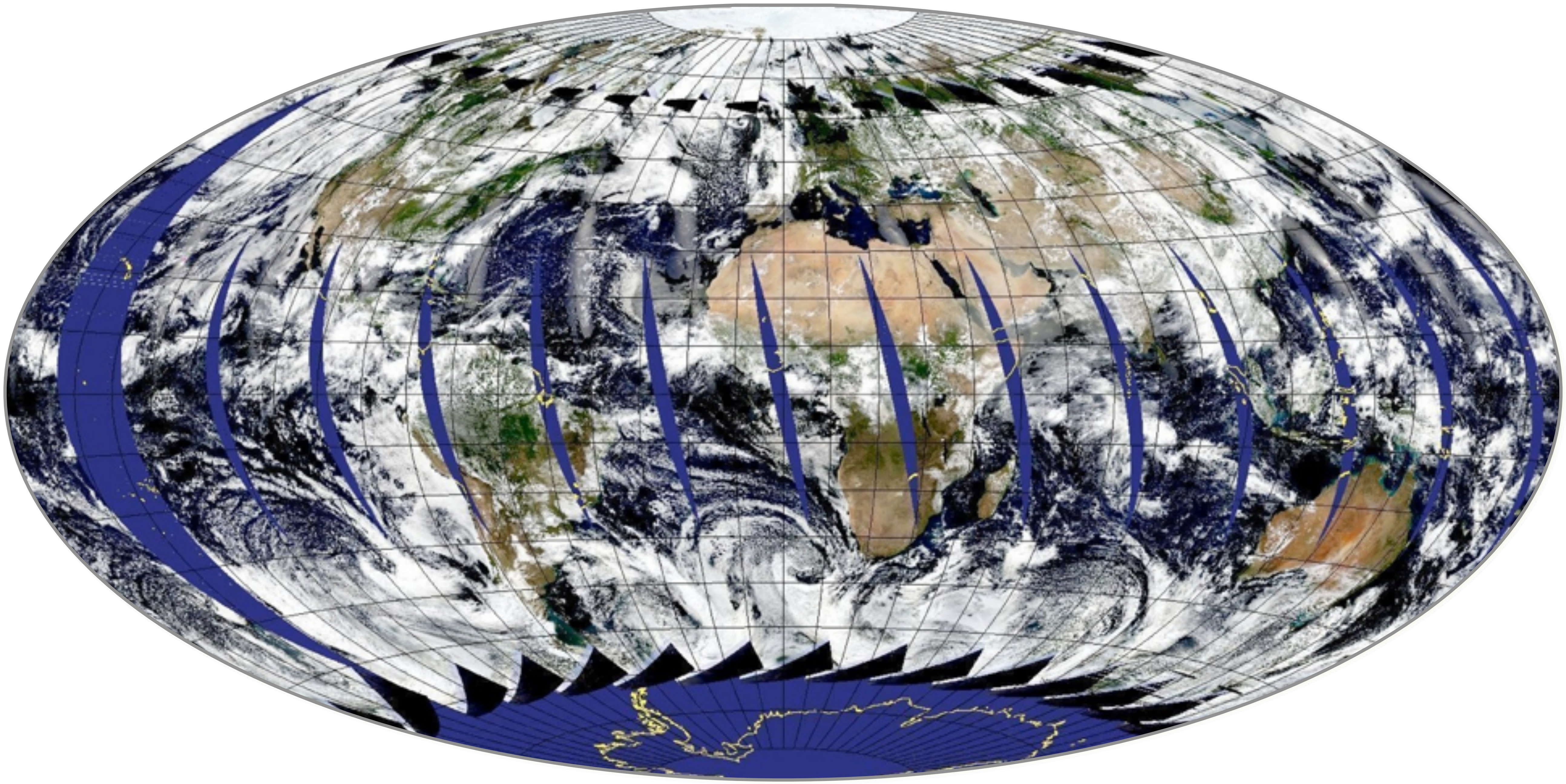
Fig. 1.2-1/-2. Theoretical relationship between the liquid water cloud reflectance function over a snow/ice surface at 1.24 and 2.13 µm (left panel) and 1.64 and 2.13 µm (right panel). COT and CER contours are indicated by the dashed and solid lines, respectively. Data from MODIS arctic observations is superimposed on the figures.

3

Algorithm "Quick Guide"

Example Retrievals

2 July 2008, MODIS Aqua, 2105 UTC



3

Algorithm "Quick Guide"

Example Retrievals

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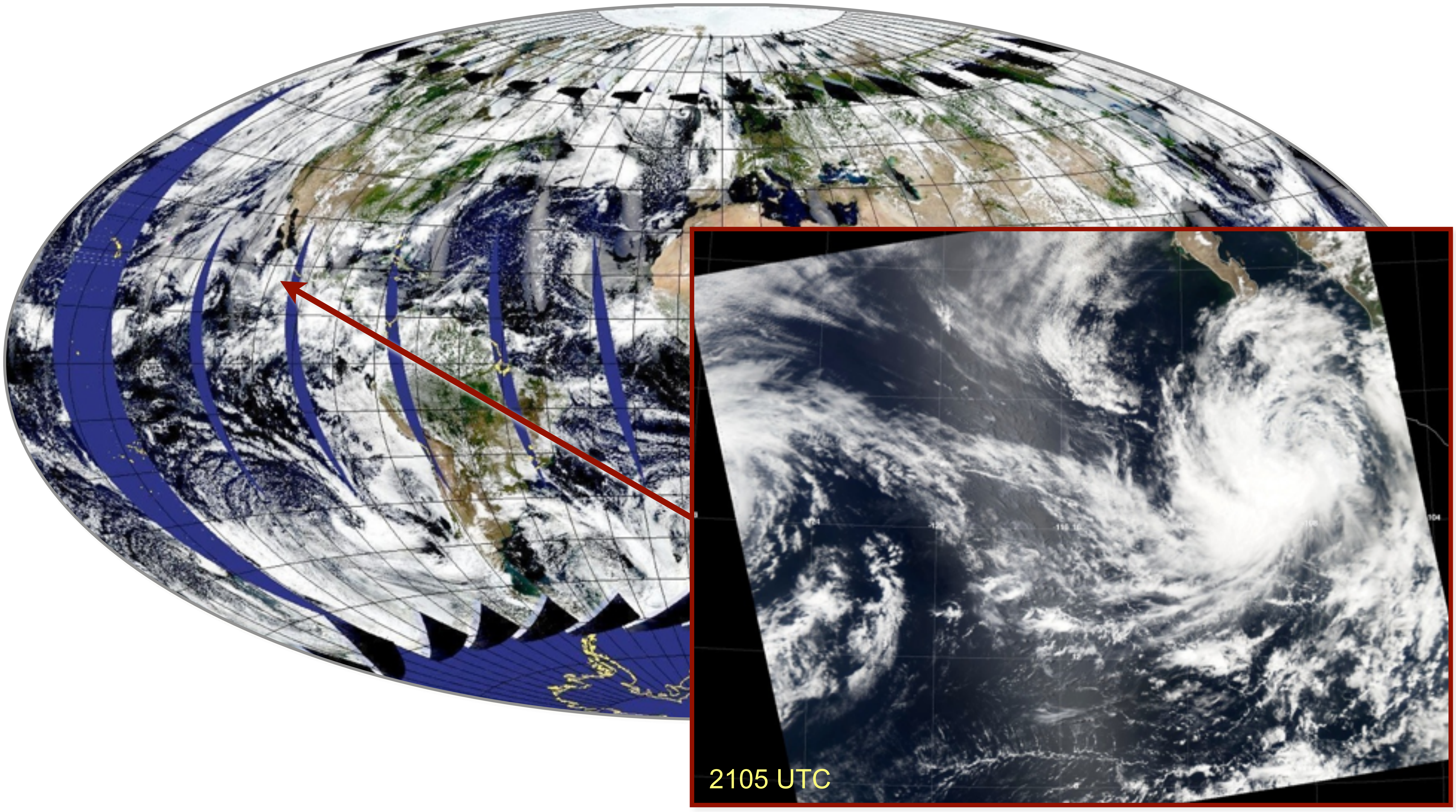

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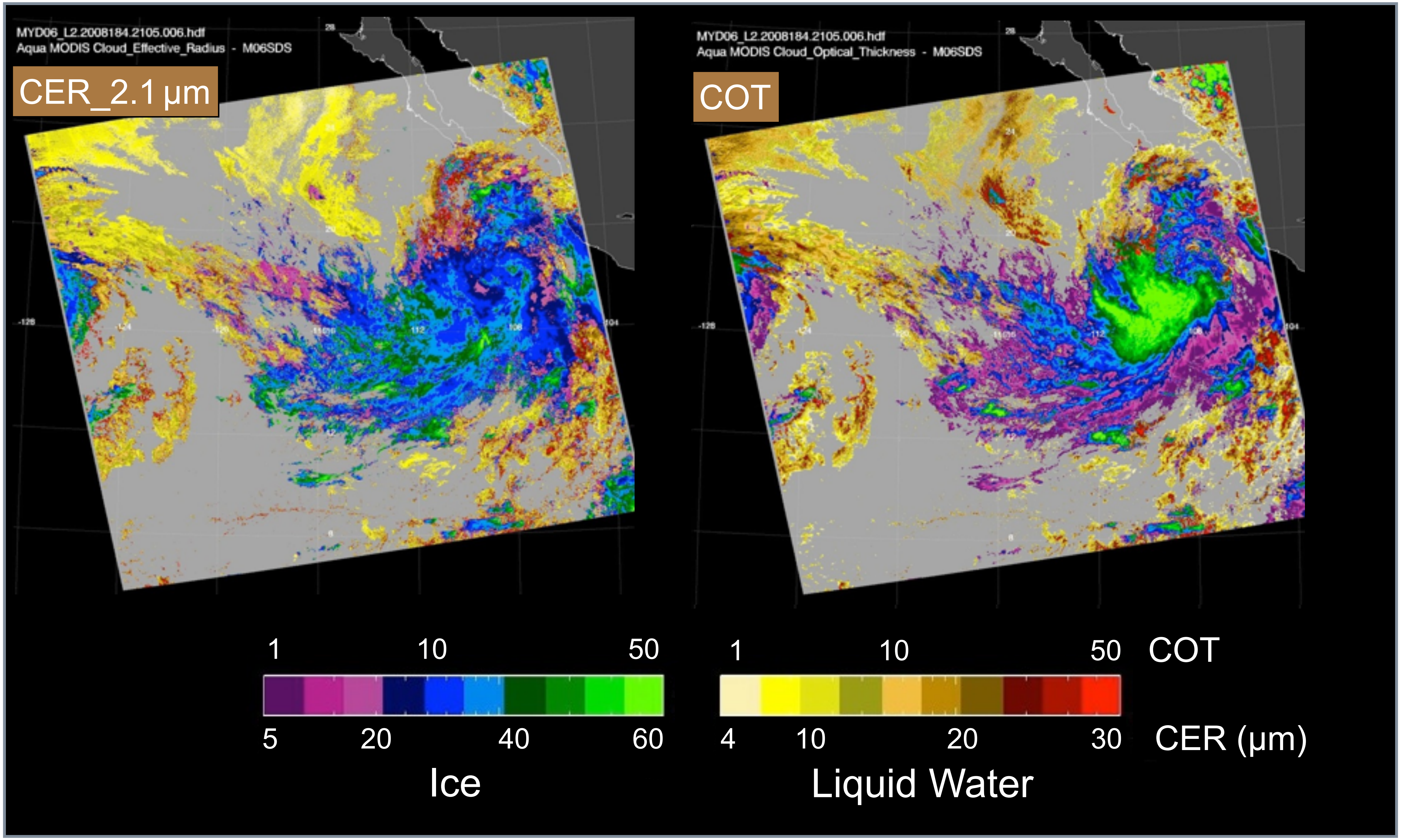
Example Retrievals



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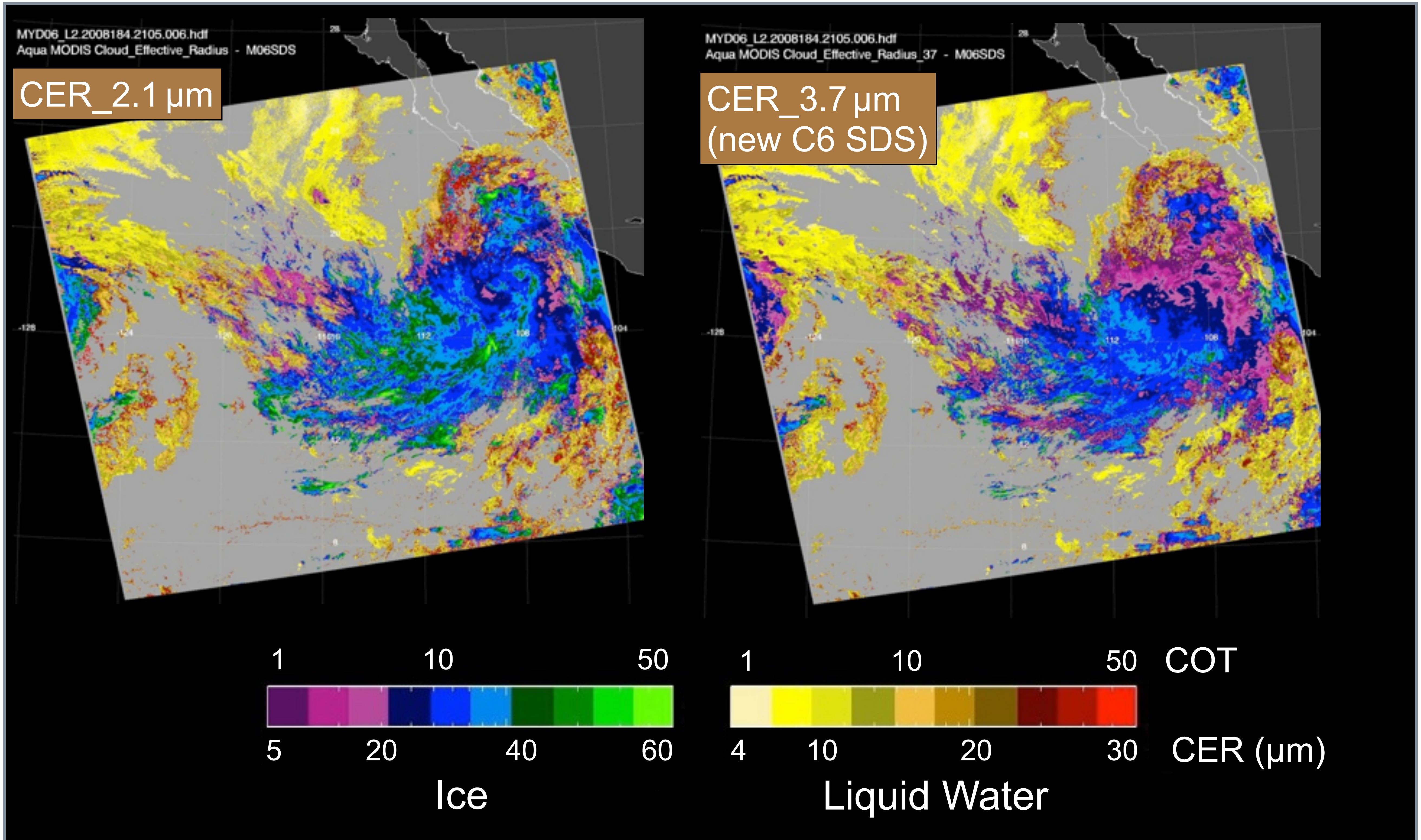
Algorithm "Quick Guide"

Example Retrievals



4

Challenges

- What is a cloud? What constitutes a cloudy FOV appropriate for a retrieval? What does it mean if a retrieval ‘fails’?
- What is the thermodynamic phase?
- Choice of forward radiative cloud model (e.g., ice radiative models)?
- Assigning retrieval uncertainties? How to account for above three items?
- How to use Quality Assessment (QA) bit assignments or related information to filter L3 retrievals?
  - discrepancies from different spectral channel pairs
  - partly-cloudy FOVs
  - multiphase/multilayer scenes (MODIS has a multilayer flag)

Subjectivity always comes into play. Sometime’s it’s explicit (developer says “I am making a choice”), sometimes it’s implicit.

4

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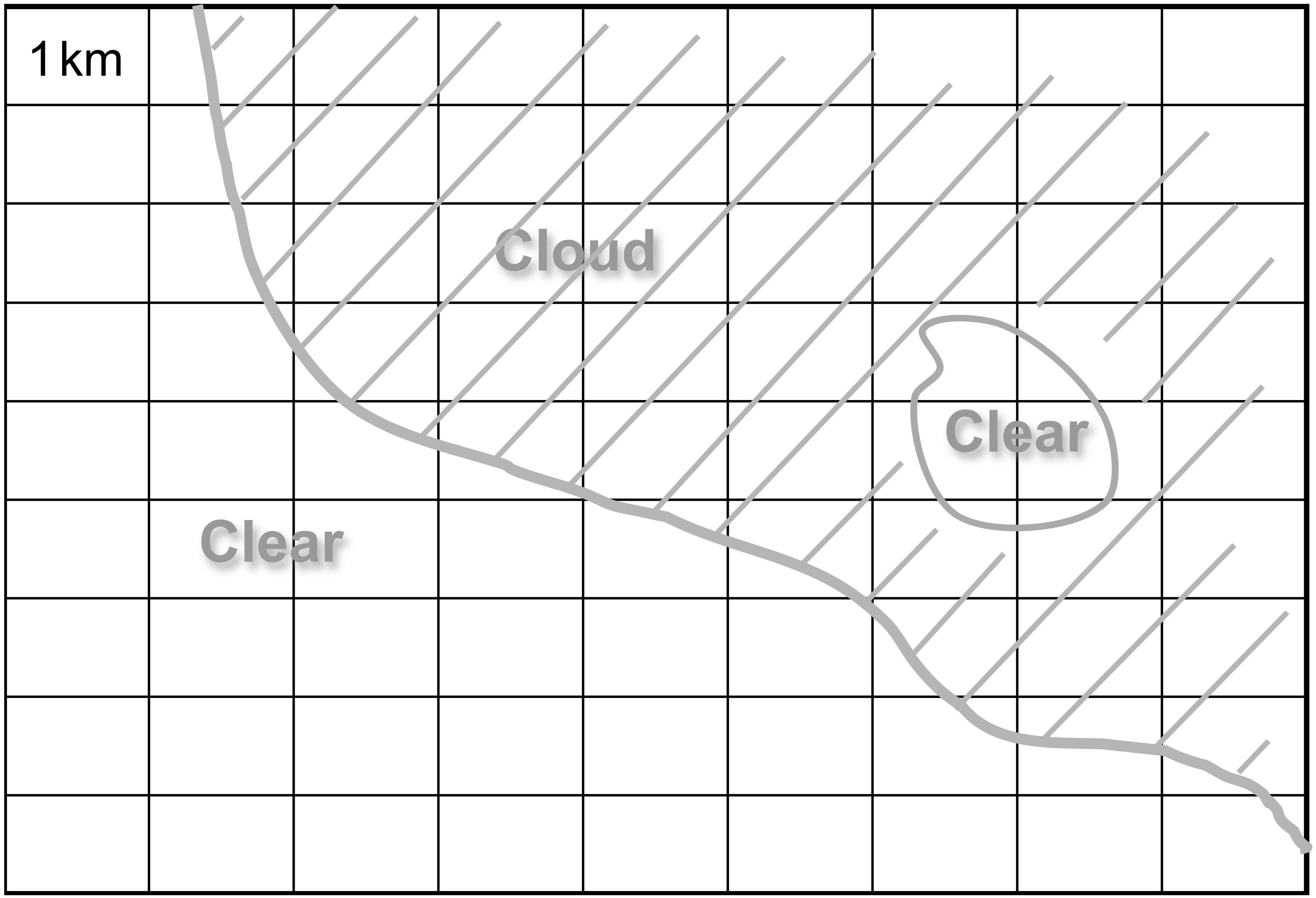
Don't Bother! No QA-filtering in C6 L3.
Provide separate SDSs for various pixel populations.

Subjectivity always comes into play. Sometime's it's explicit (developer says "I am making a choice"), sometimes it's implicit.

4

What is a cloud mask 'cloudy' FOV?

ideal 'pixel' doesn't exist!



4

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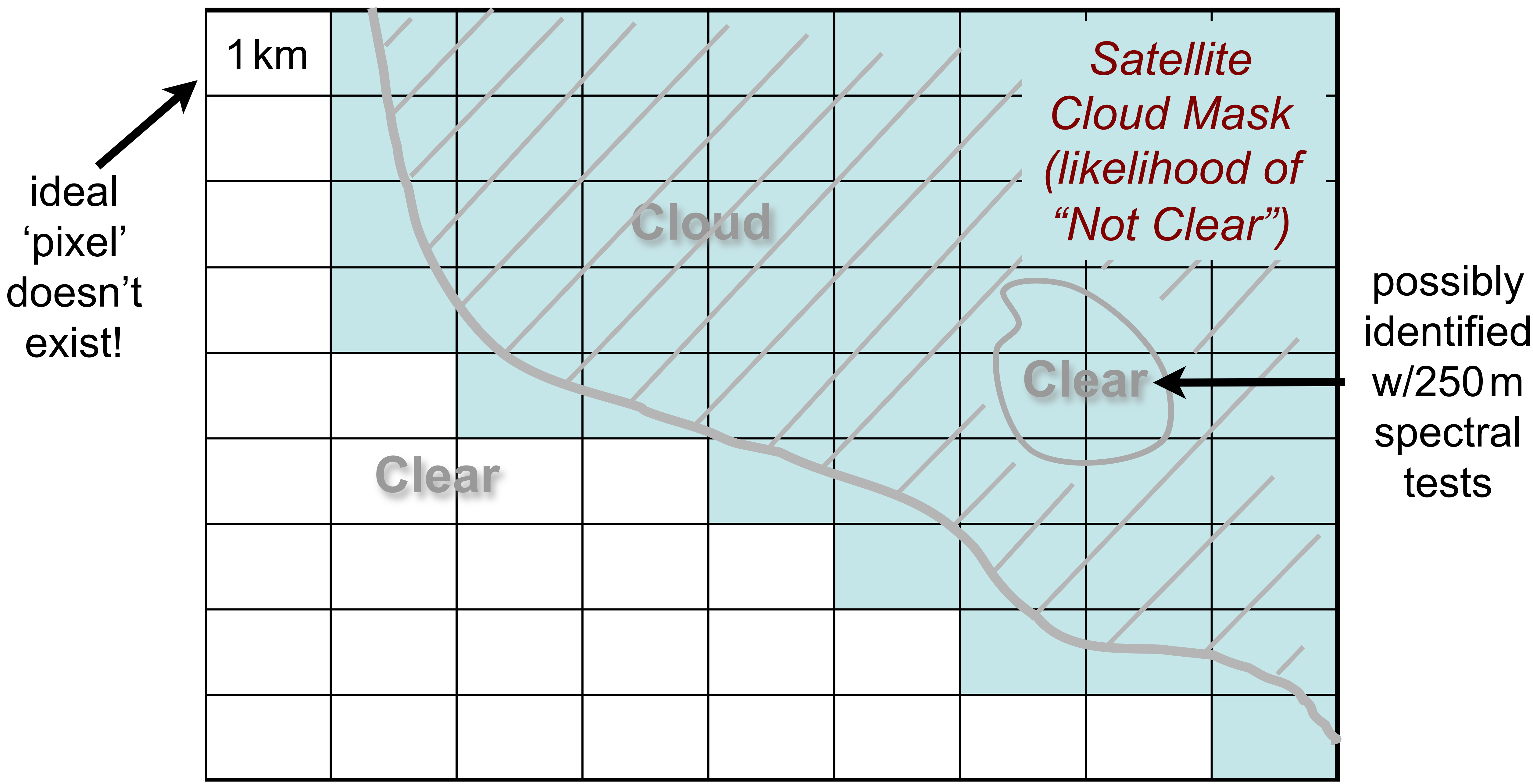

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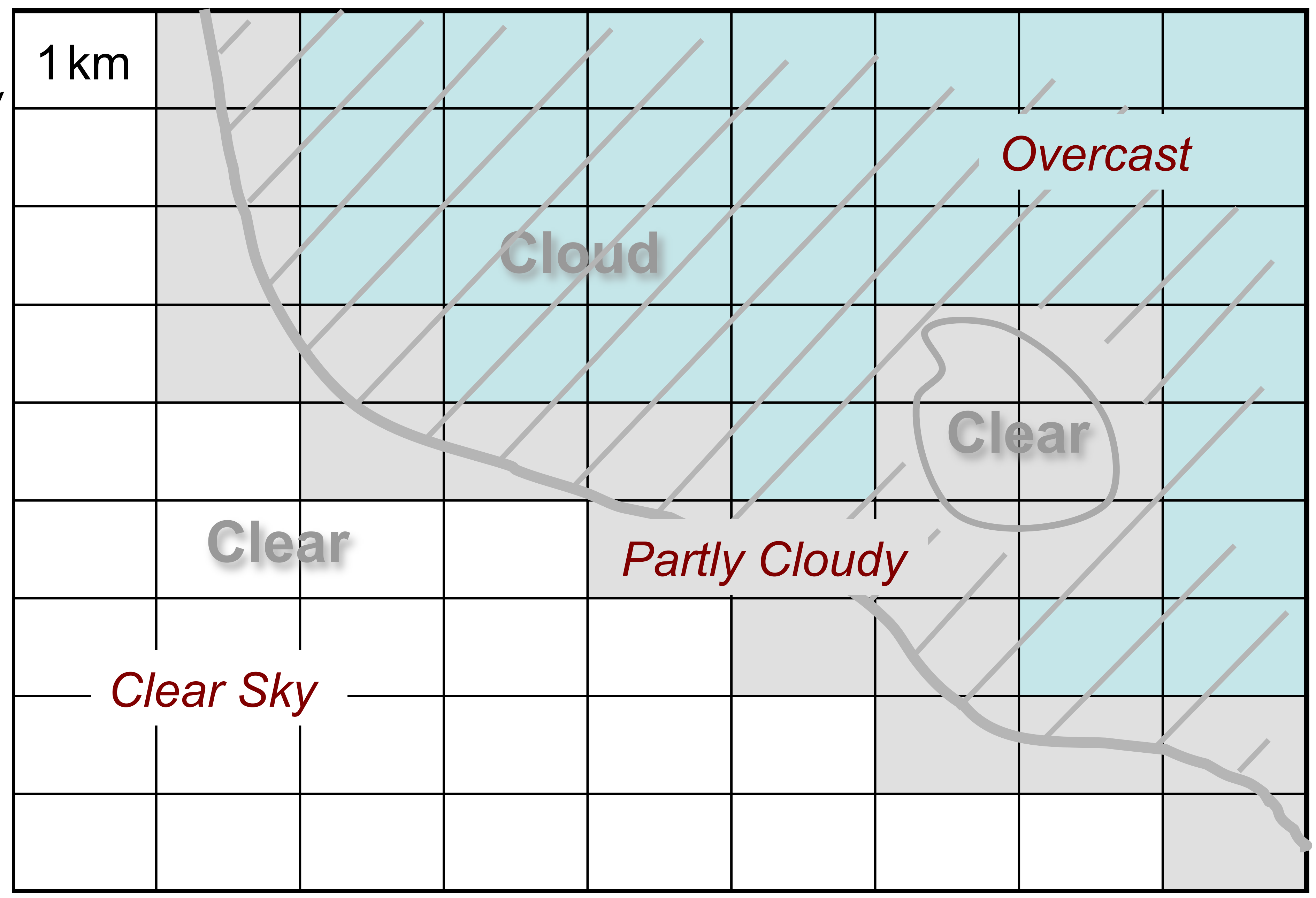
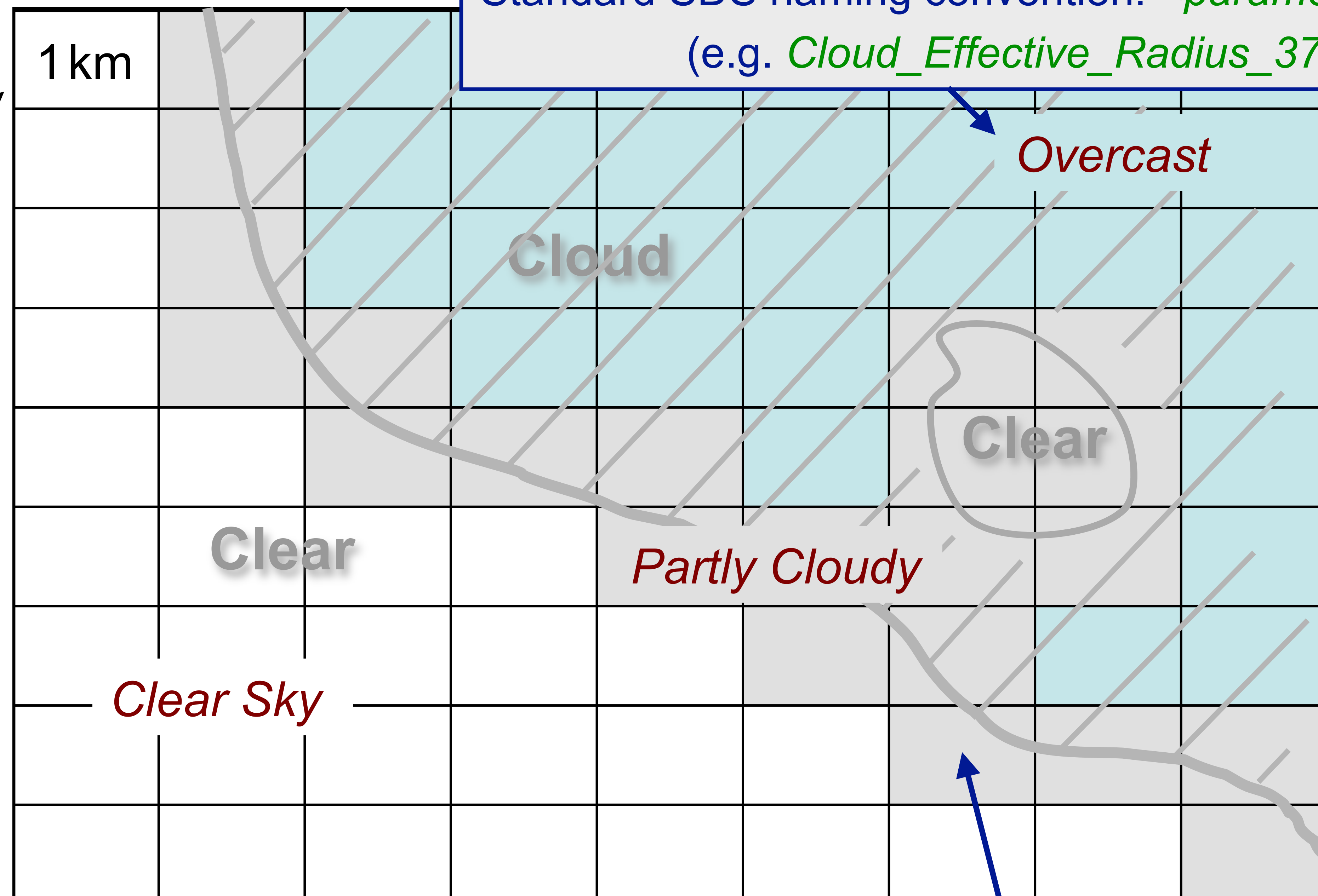


4

What is a cloud mask ‘cloudy’ FOV?

Standard SDS naming convention: *<parameter name>*
(e.g. *Cloud_Effective_Radius_37*)

ideal ‘pixel’ doesn’t exist!



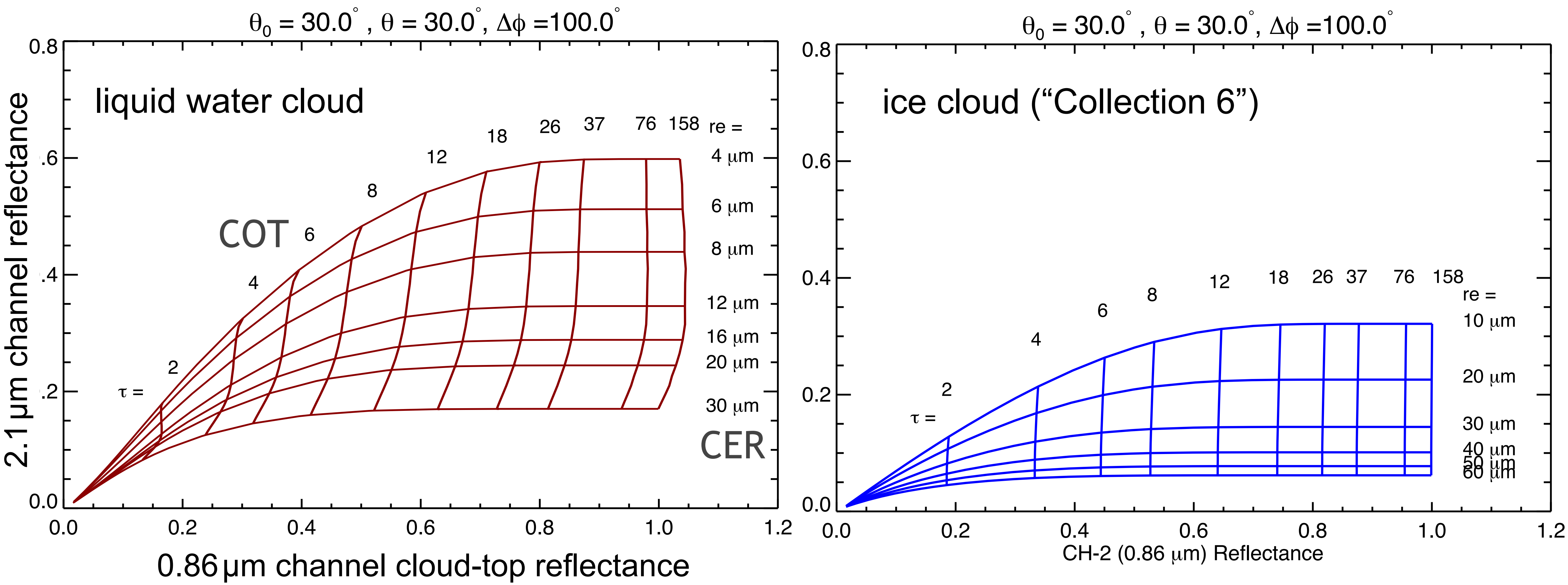
Pixel Categories Assigned by Clear Sky Restoral (CSR) Algorithm

New C6 SDS Category: *<parameter name>_PCL*
(e.g. *Cloud_Effective_Radius_37_PCL*)

Uncertainties: Measurement and Model

4

0.86 & 2.1 µm channel combination



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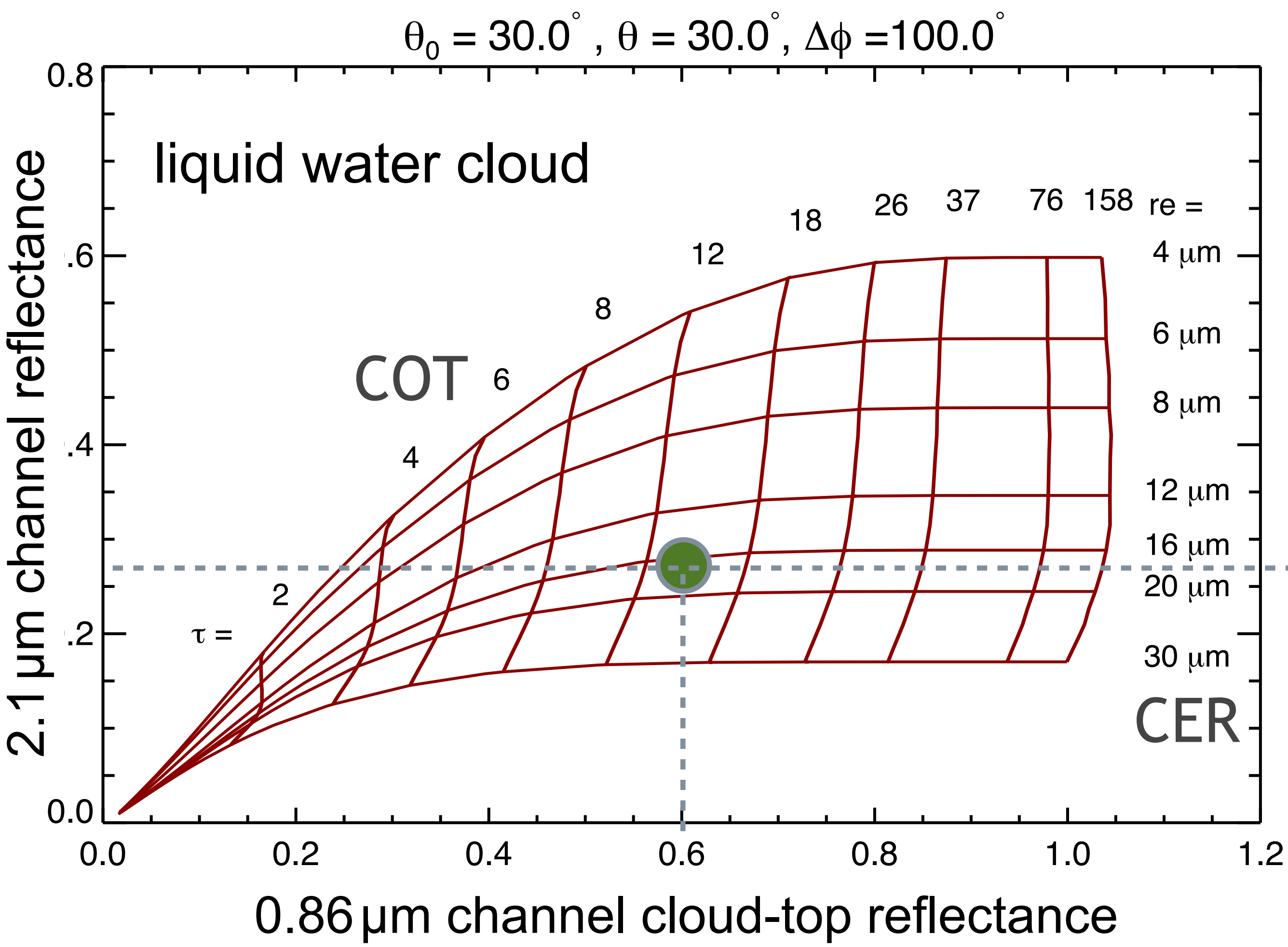

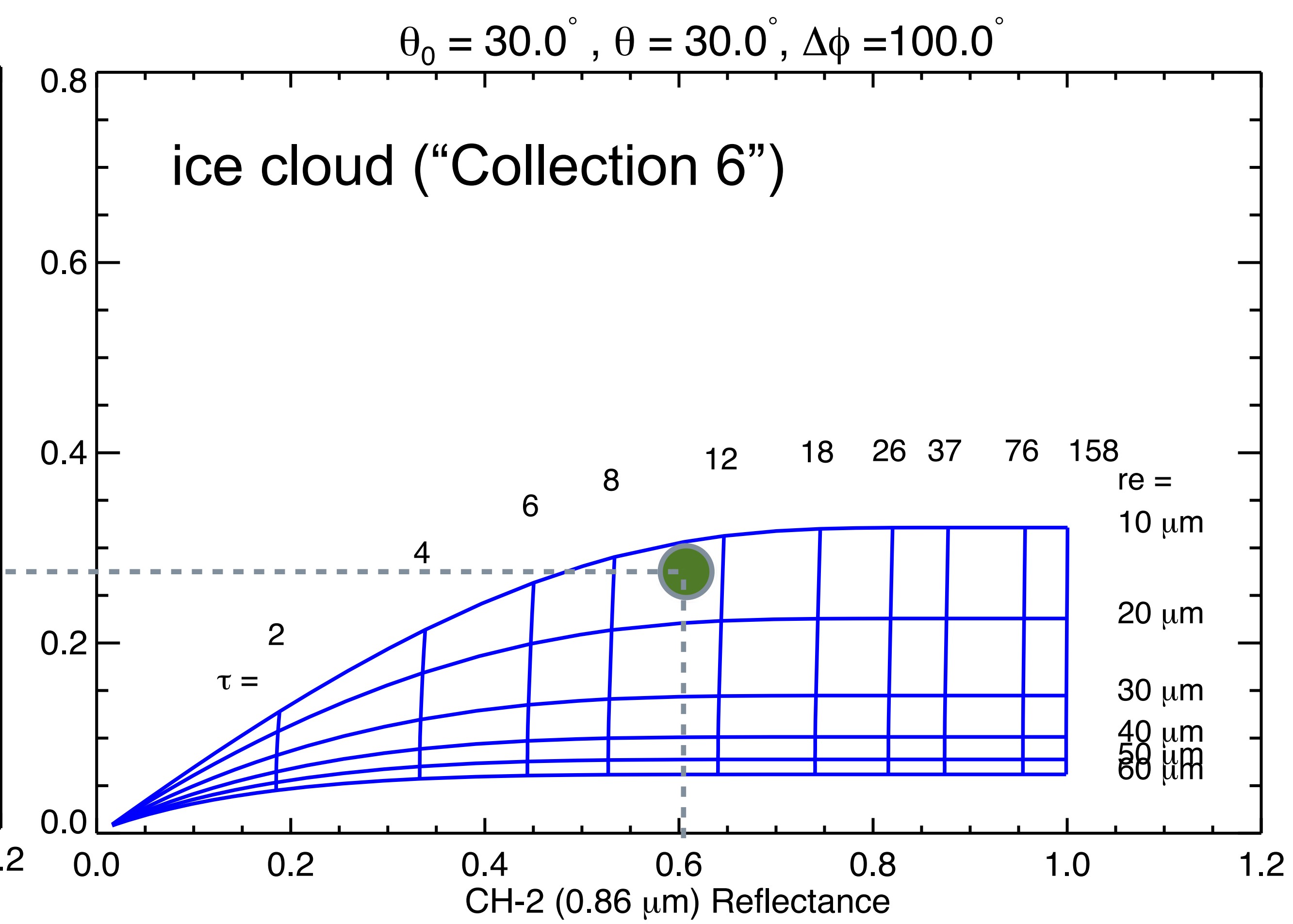

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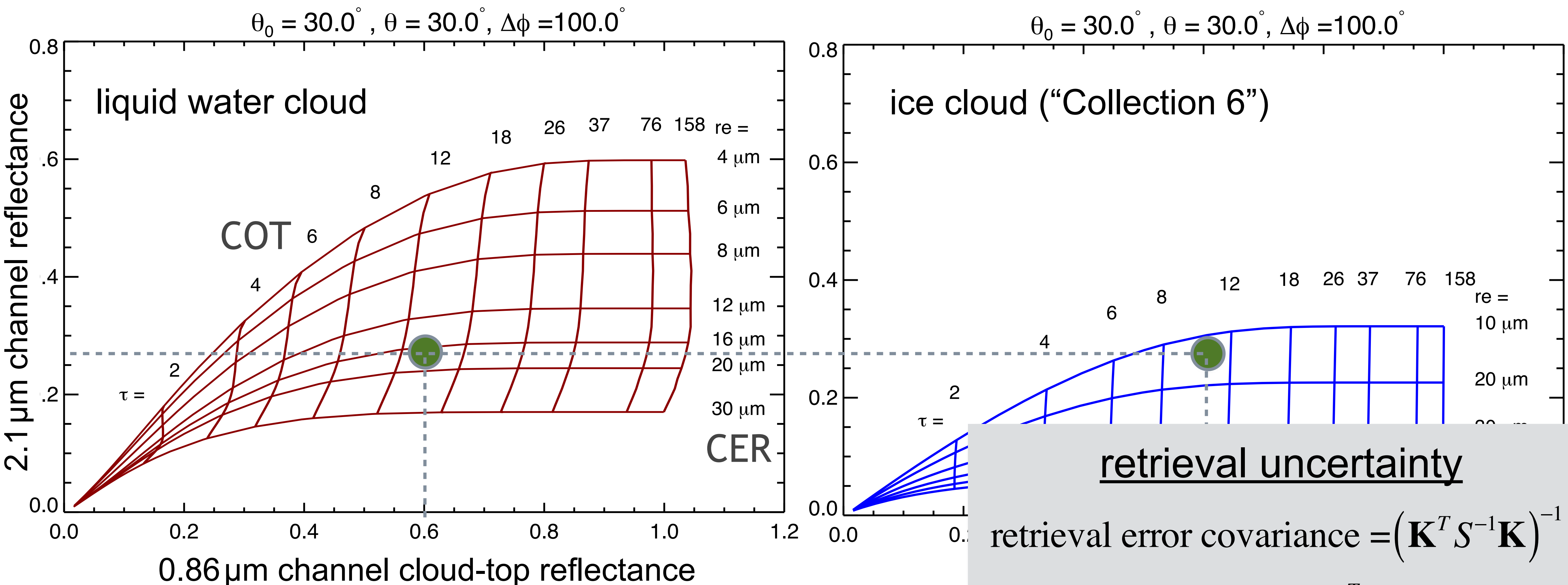


retrieval uncertainty

$$\text{retrieval error covariance} = \left(\mathbf{K}^T S^{-1} \mathbf{K}\right)^{-1}$$

$$\text{where } S = S_y + \mathbf{K}_m S_m \mathbf{K}_m^T$$

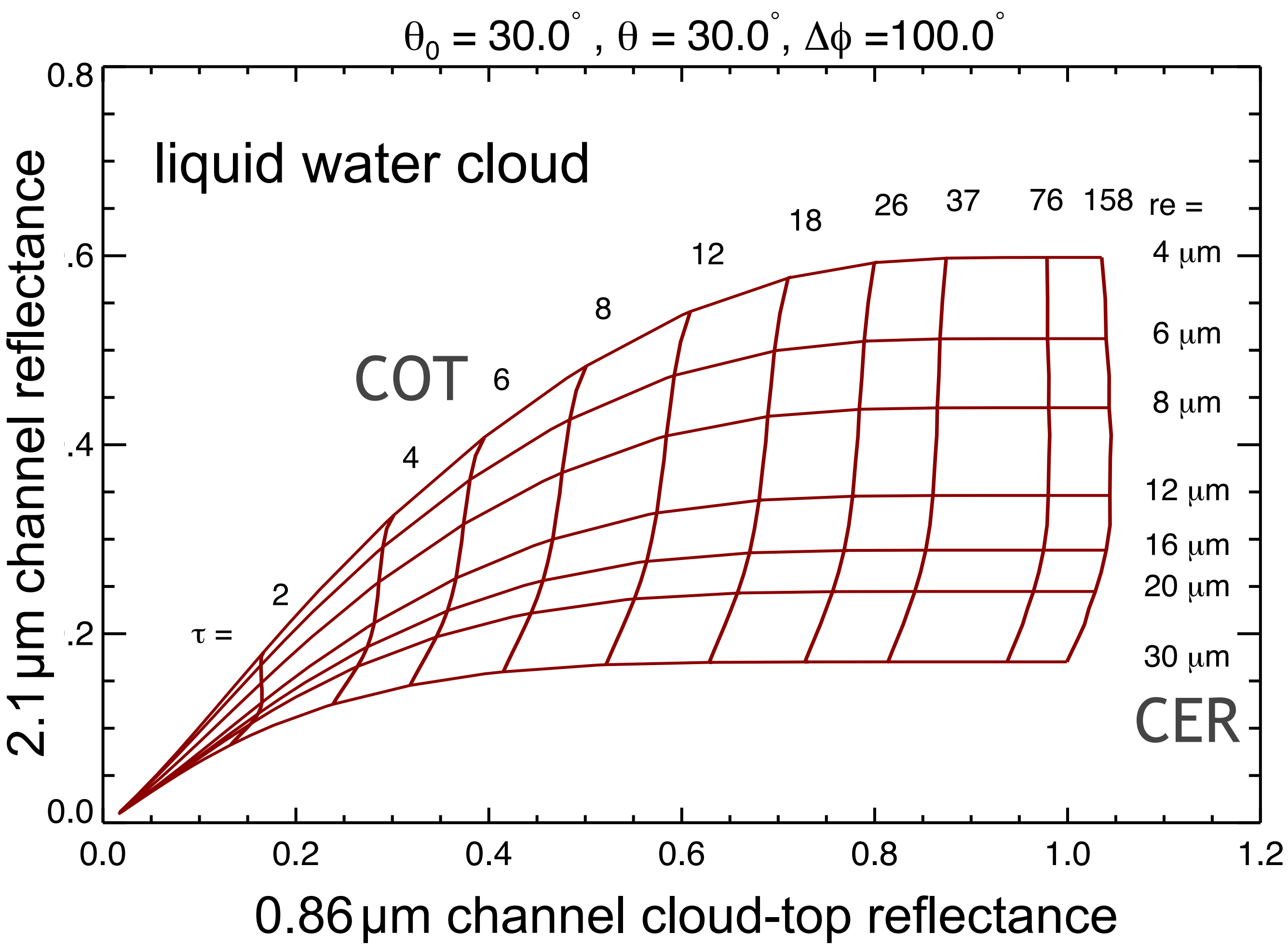
y (refl. meas.) uncertainty

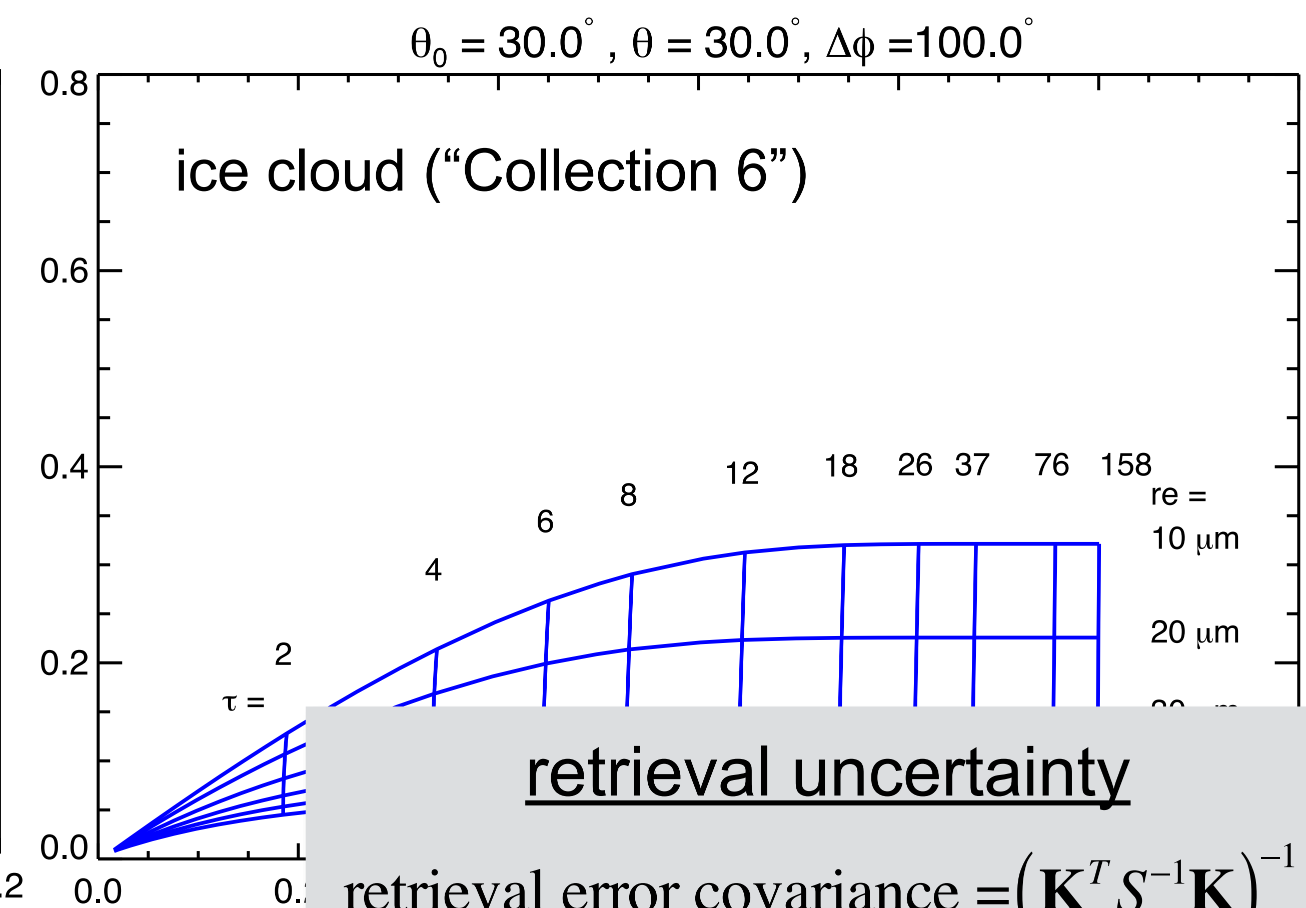
maps Model uncertainty into cloud-top reflect. uncertainty

4

Uncertainties: Measurement and Model

0.86 & 2.1 μm channel combination





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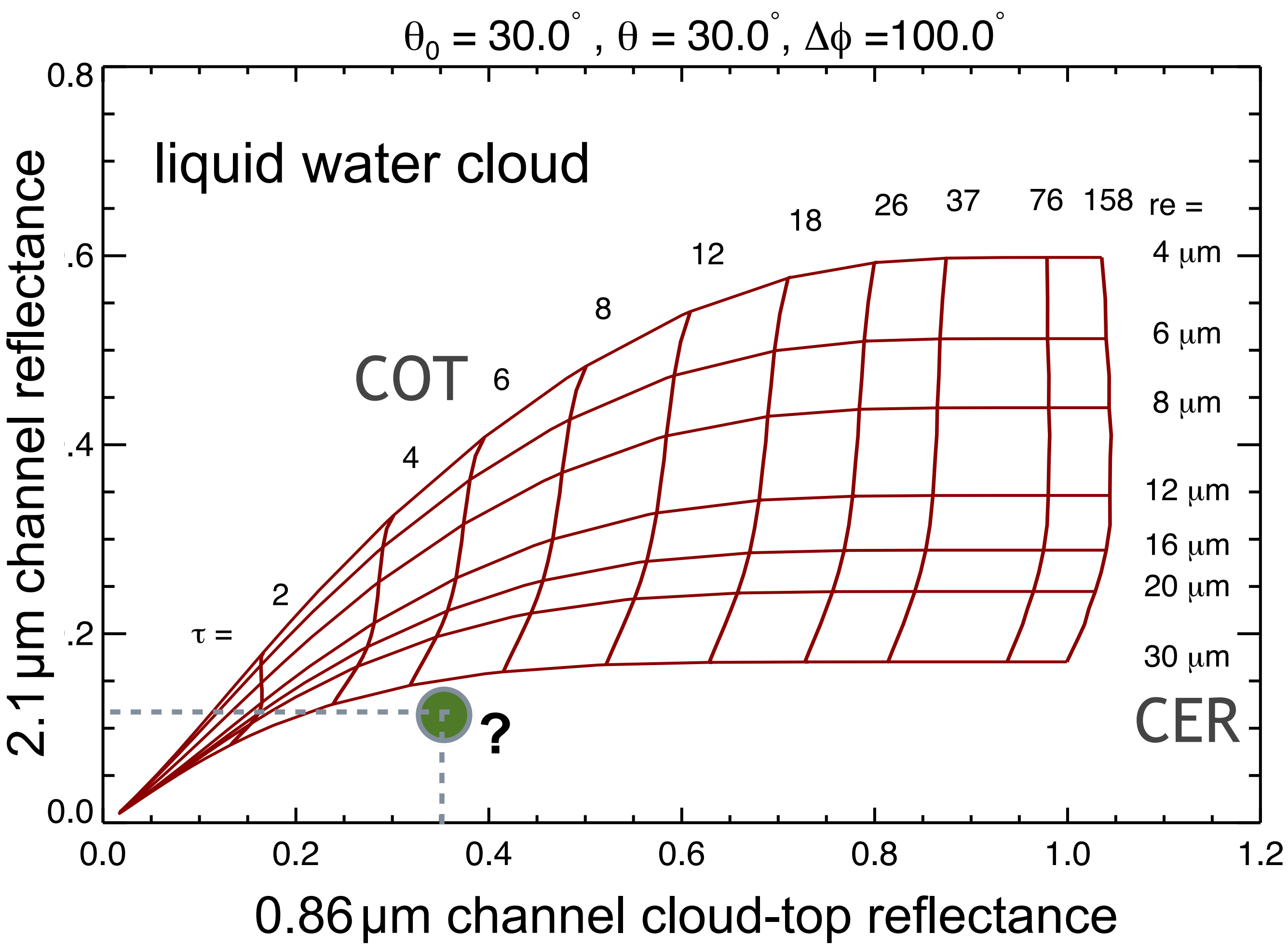

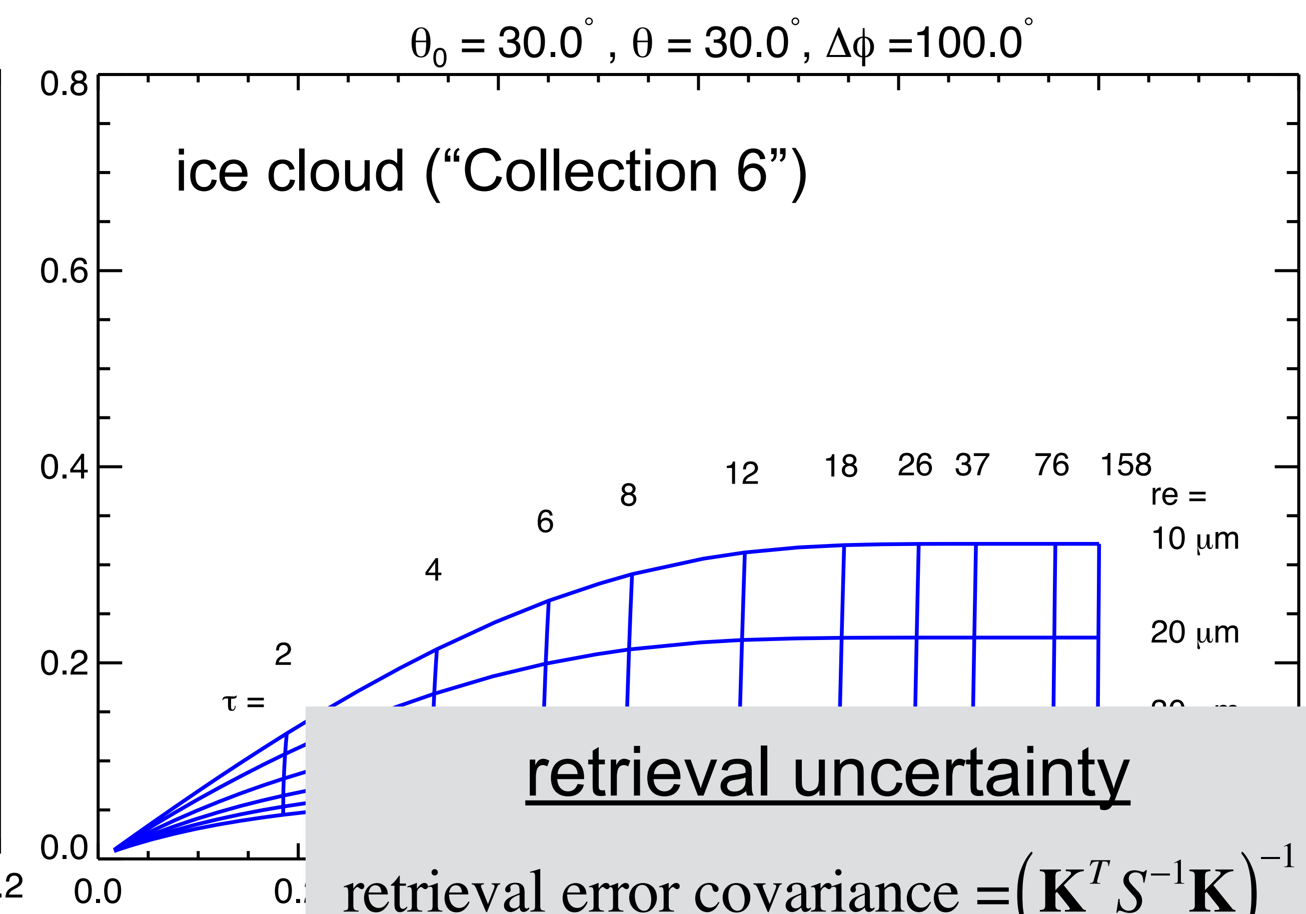

retrieval uncertainty

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where $S = S_y + \mathbf{K}_m S_m \mathbf{K}_m^T$

y (refl. meas.) uncertainty

maps Model uncertainty into cloud-top reflect. uncertainty

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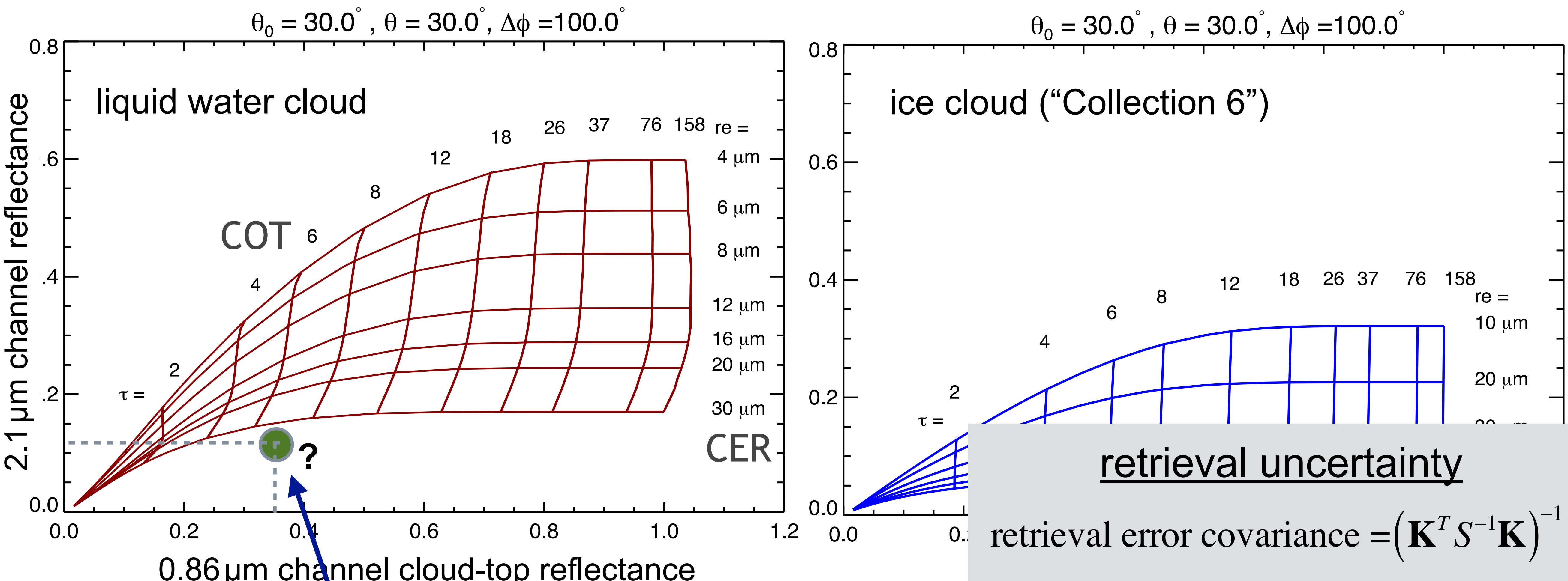
Uncertainties: Measurement and Model

0.86 & 2.1 µm channel combination



"Failed" Retrieval
(*Retrieval_Failure_Metric_**:
new SDS for C6)

retrieval uncertainty

retrieval error covariance $= \left(\mathbf{K}^T S^{-1} \mathbf{K}\right)^{-1}$

where $S = S_y + \mathbf{K}_m S_m \mathbf{K}_m^T$

y (refl. meas.) uncertainty

maps Model uncertainty into cloud-top reflect. uncertainty

What's New?
Major Categories

- Radiative Transfer
- Algorithm
  - Retrieval Science
  - QA and pixel-level filtering
  - Pixel-level uncertainty
- L1B characterization/trend corrections

5

Overview of Major C6 Changes

See Appendix G User Guide

Category	Collection 5	Collection 6	Notes
Radiative Transfer			
Cloud Model: all phases	Combined discrete ordinate LUT (small COT) + asymptotic theory parameters (large COT)	Full reflectance, flux, and emissivity LUTs across retrieval space/geometry. LUT entries provided for multiple scattering component only; phase function provide in file for direct calculation of single scattering component.	• Single approach (LUT) => easier retrieval code maintenance. • LUT grid designed to limit median linear interpolation error to << 1%. • Separation of single scattering component => fewer LUT grid points and interpolations during processing. • Required DISORT code mod to improve efficiency for BRF-specified surfaces.
Ice Cloud Model	Variable habit (smooth) vs. size/ empirical distributions. Relatively large asymmetry parameter (*g*) and highly dependent on CER.	Single habit (severely roughened aggregated columns) w/analytic distribution (gamma, _	• Smaller *g* reduces COT & provides closure with non-opaque IR COT retrievals. • Constant *g* vs. CER. • SWIR/MWIR particle absorption decreases => larger retrieved CER.
Surface Ancillary Datasets	Team-designed nominal annual gap-filled spectral albedo dataset using Terra C5 product MOD43.	New dynamic gap-filled spectral albedo dataset derived from Aqua+Terra C5 MCD43B3. Emissivity dataset from MOD06 CT product for spectral consistency.	• C6 albedo dataset provided higher temporal resolution than C5 (8 day interval, 16 day average). • Sea-ice spectral albedo dataset same as for C5.
Ocean Surface BRDF	Lambertian (5%)	Cox-Munk BRDF for 3 wind speeds (3, 7, and 15	• Independent ocean LUTs with Cox-Munk explicitly modeled.
Incorporation of Model Error Sources	N/A	LUT includes sensitivity datasets for and Cox-Munk wind vector.	No explicit model error sources used in C5 uncertainty calculations.

5

Overview of Major C6 Changes

See Appendix G User Guide

Category	Collection 5	Collection 6	Notes
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Cloud Model: all phases	Combined discrete ordinate LUT (small COT) + asymptotic theory parameters (large COT)	Full reflectance, flux, and emissivity LUTs across retrieval space/geometry. LUT entries provided for multiple scattering component only; phase function provide in file for direct calculation of single scattering component.	• Single approach (LUT) => easier retrieval code maintenance. • LUT grid designed to limit median linear interpolation error to << 1%. • Separation of single scattering component => fewer LUT grid points and interpolations during processing. • Required DISORT code mod to improve efficiency for BRF-specified surfaces.
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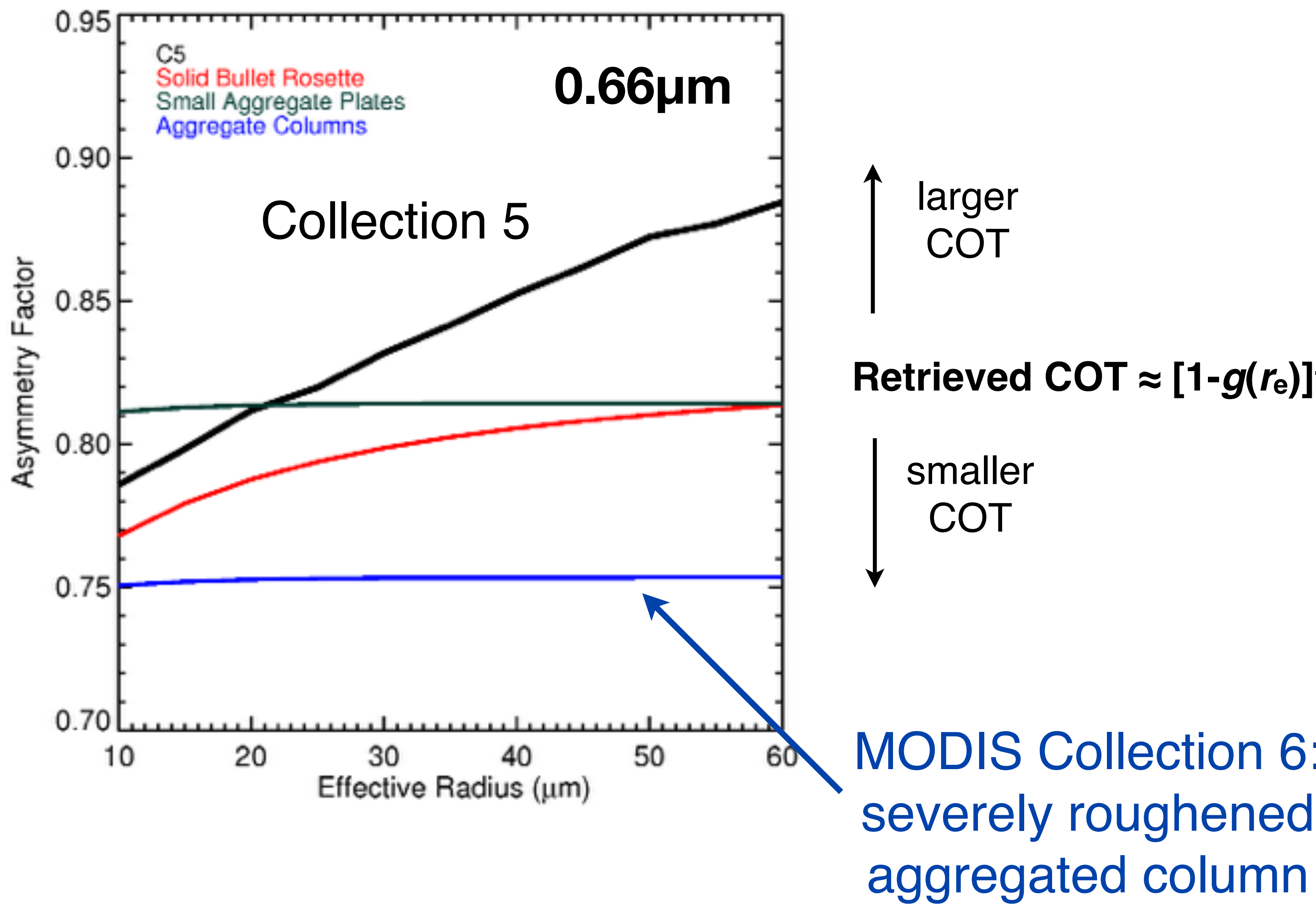
Ice Cloud Radiative Models

(P. Yang et al.)



Retrieved COT ≈ $[1-g(r_e)]^{-1}\,2R/(1-R)$

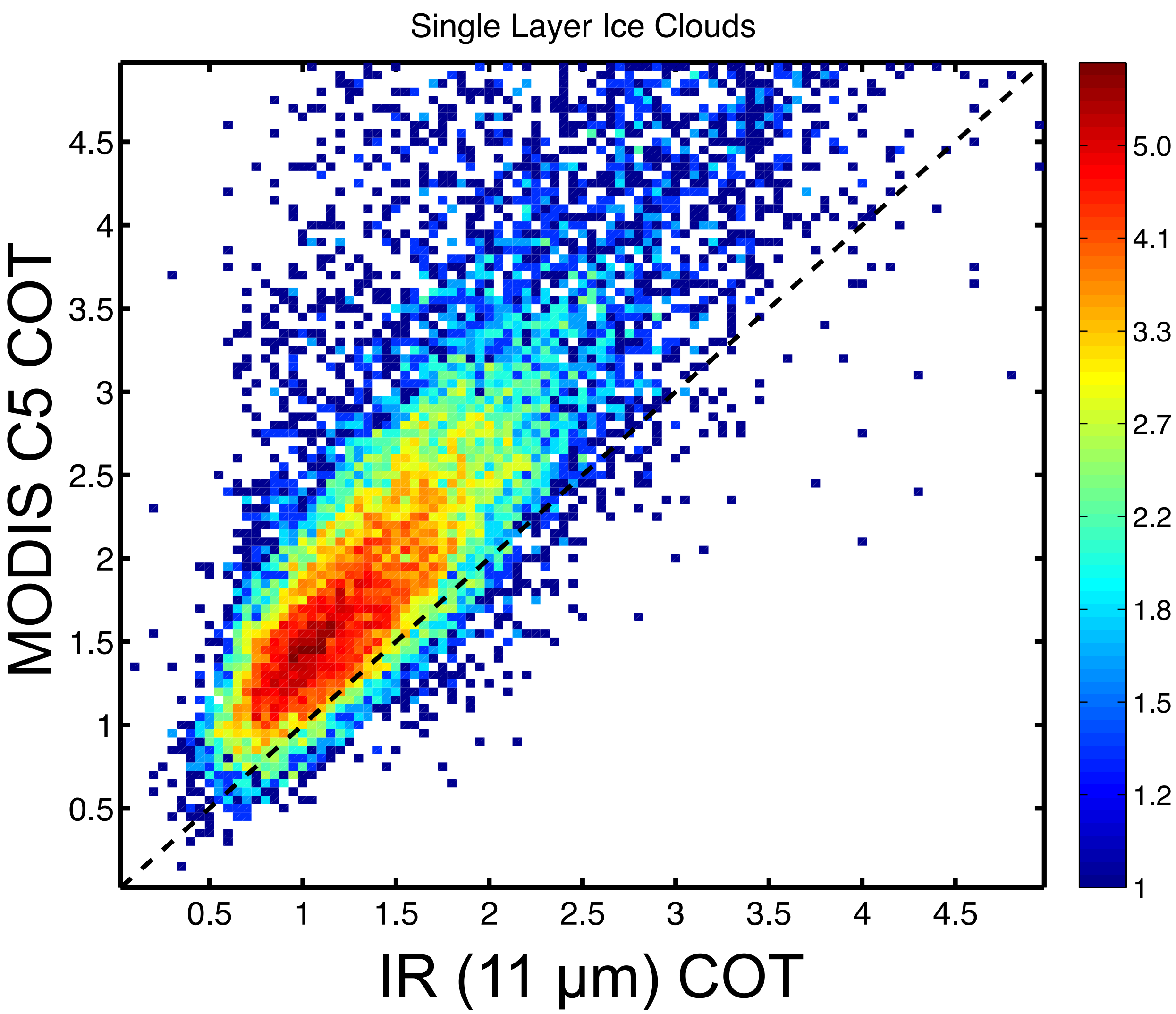
Ice and Liquid Scattering Properties vs. CER are reported in MOD06 as attributes (e.g., *Asymmetry_Parameter_Ice*)

5

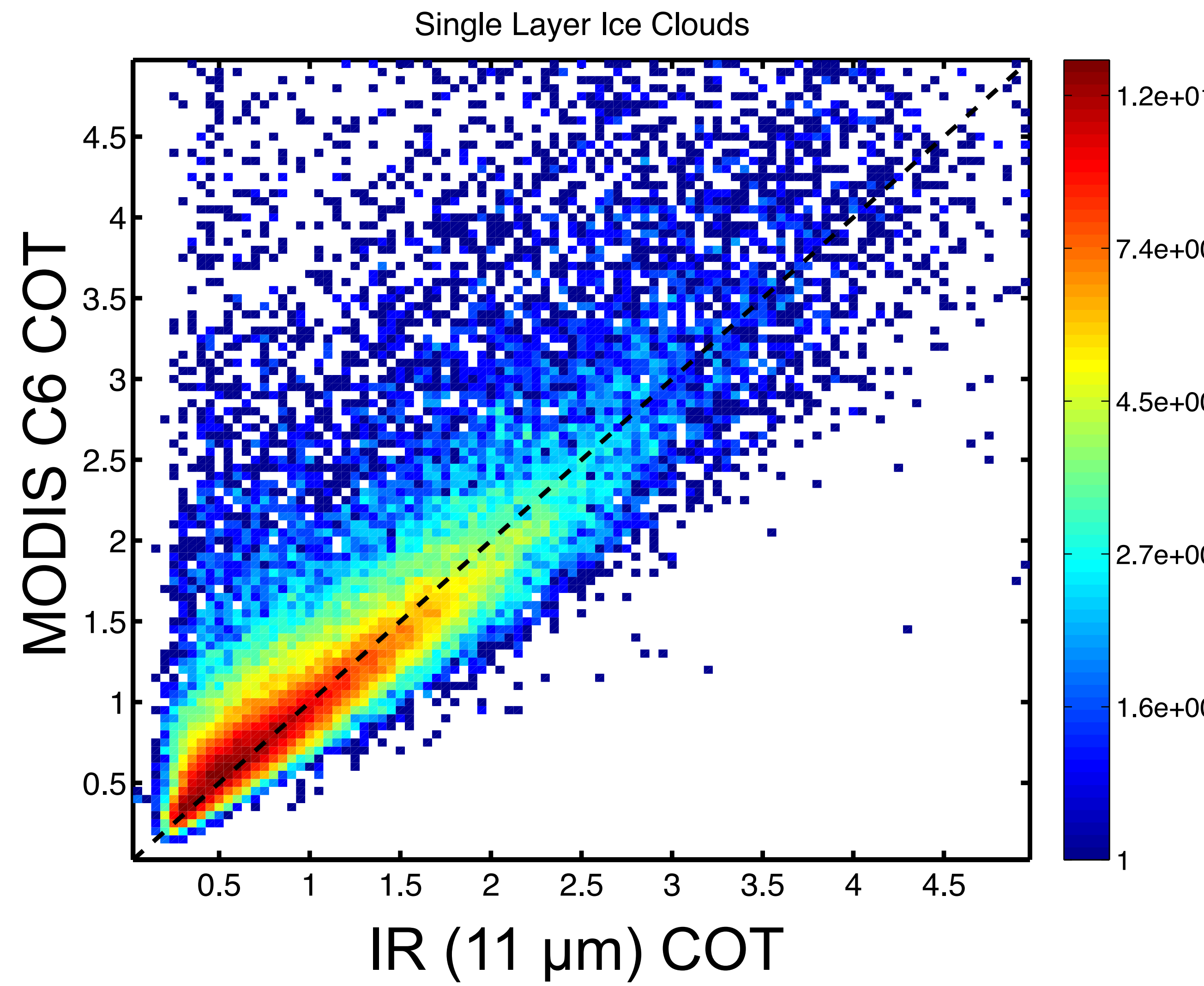
Ice Cloud Radiative Models

(R. Holz et al.)

IR COT Retrieval Closure Studies



C5 Models
(variable habit distribution)



C6 Models
(severely roughened aggregated columns)

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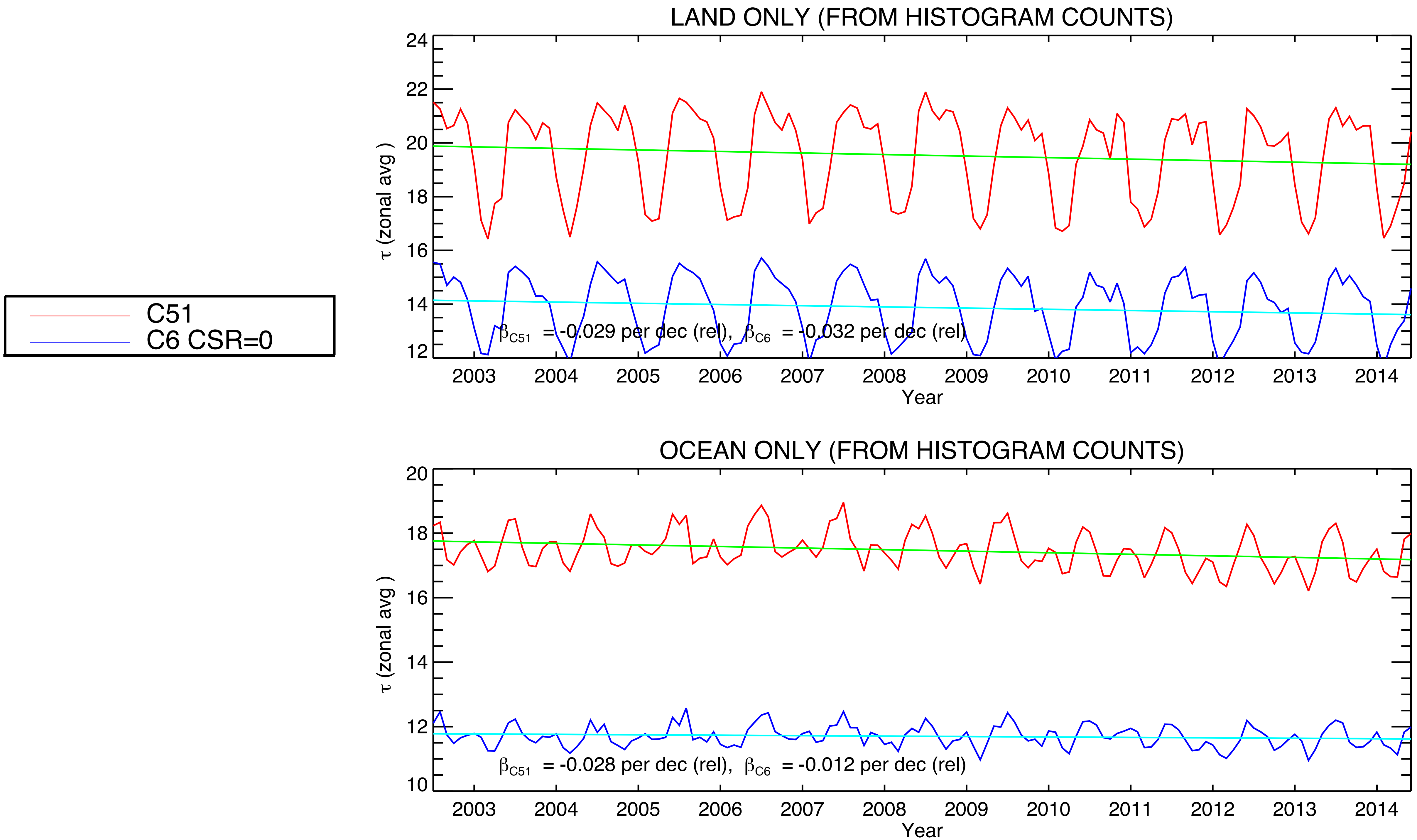
Ice Phase Cloud C6 vs. C5 Results

Aqua COT Monthly Mean Time Series, Jul 2002–Jun 2014, ±60°
(derived from histograms w/common COT_{max}=100)



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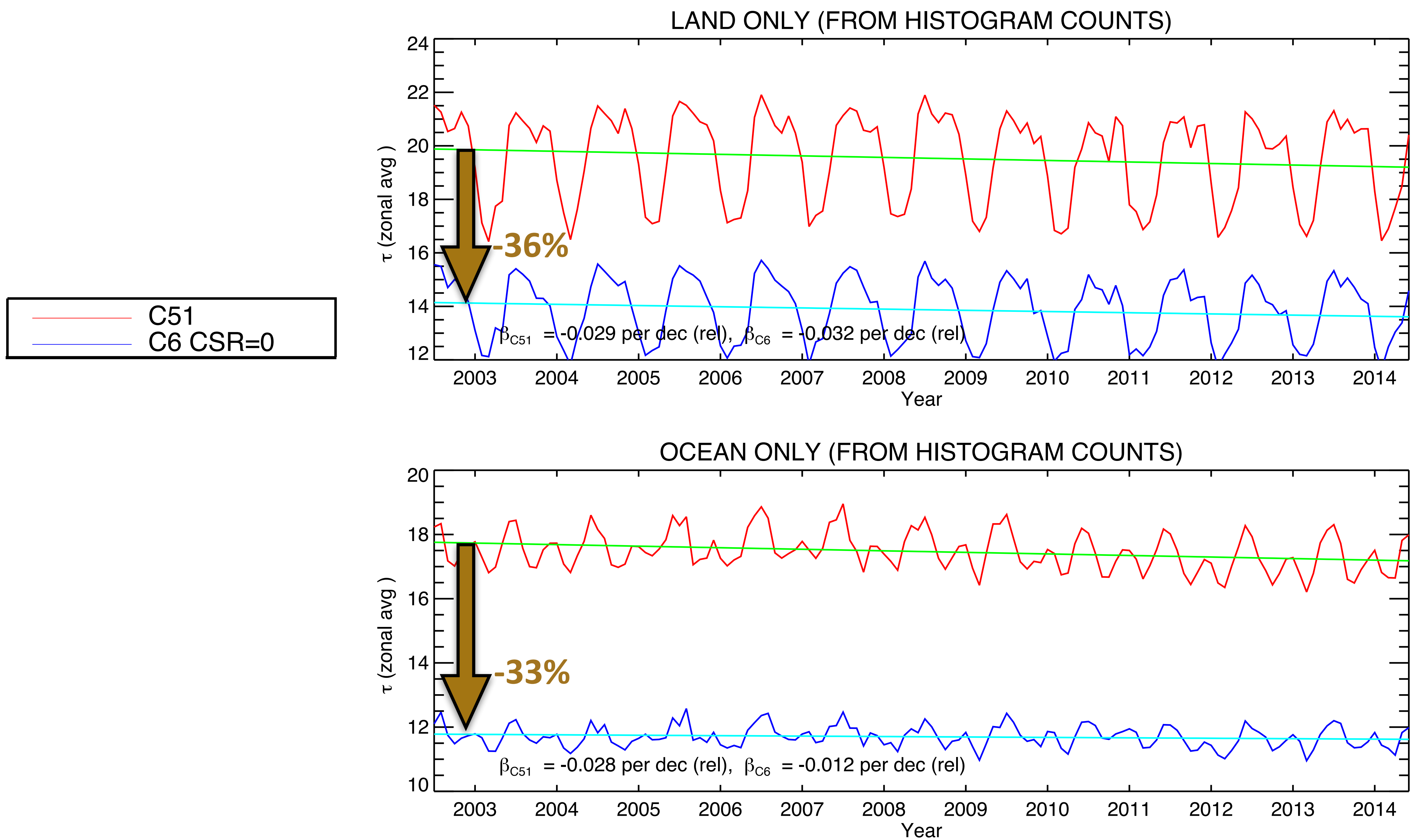
(derived from histograms w/common COT_{max}=100)



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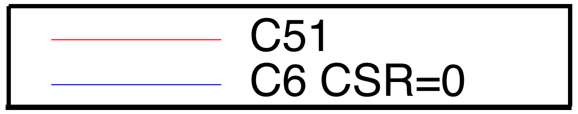
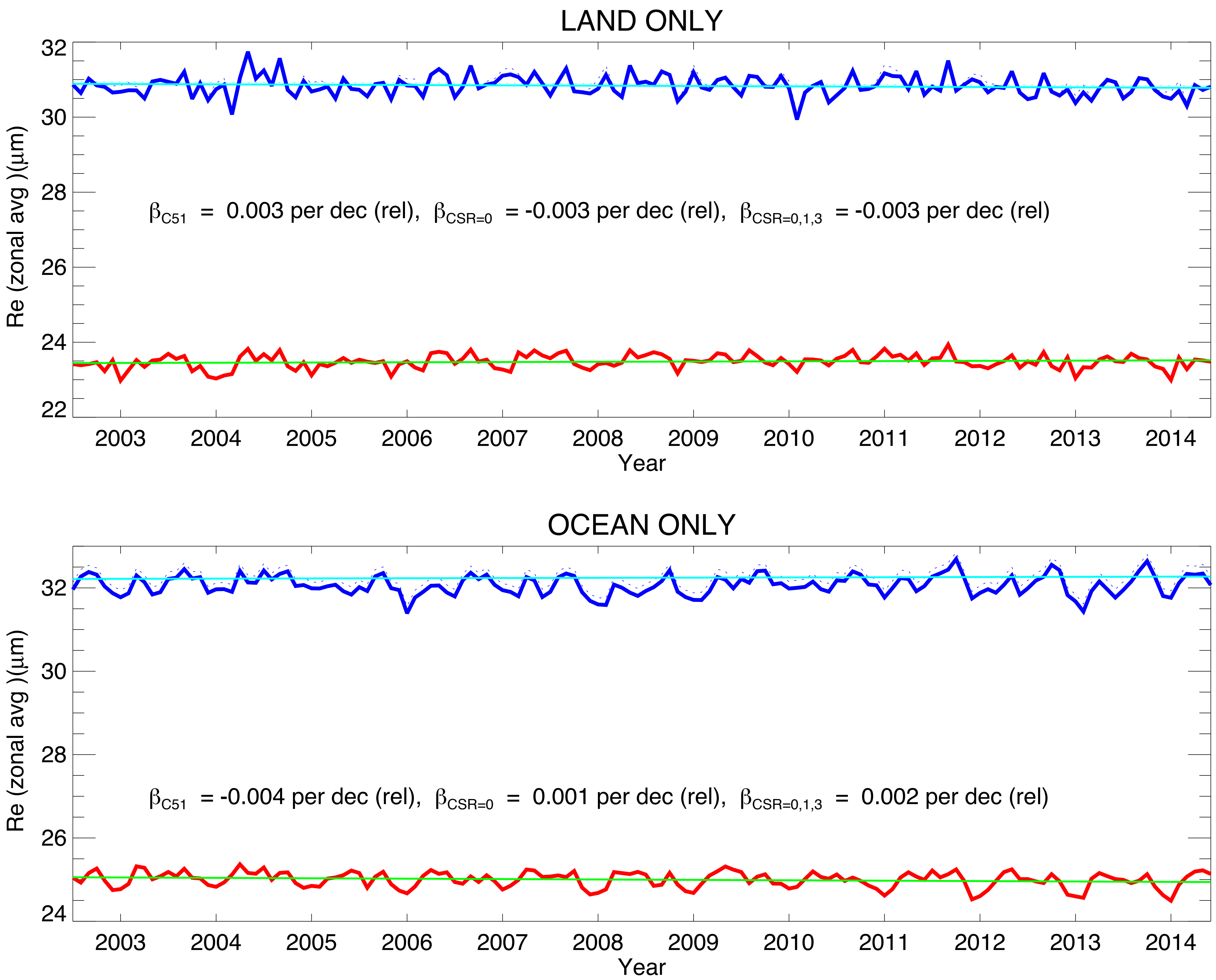
Ice Phase Cloud C6 vs. C5 Results

Aqua CER Monthly Mean Time Series, Jul 2002–Jun 2014, ±60°





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Ice Phase Cloud C6 vs. C5 Results

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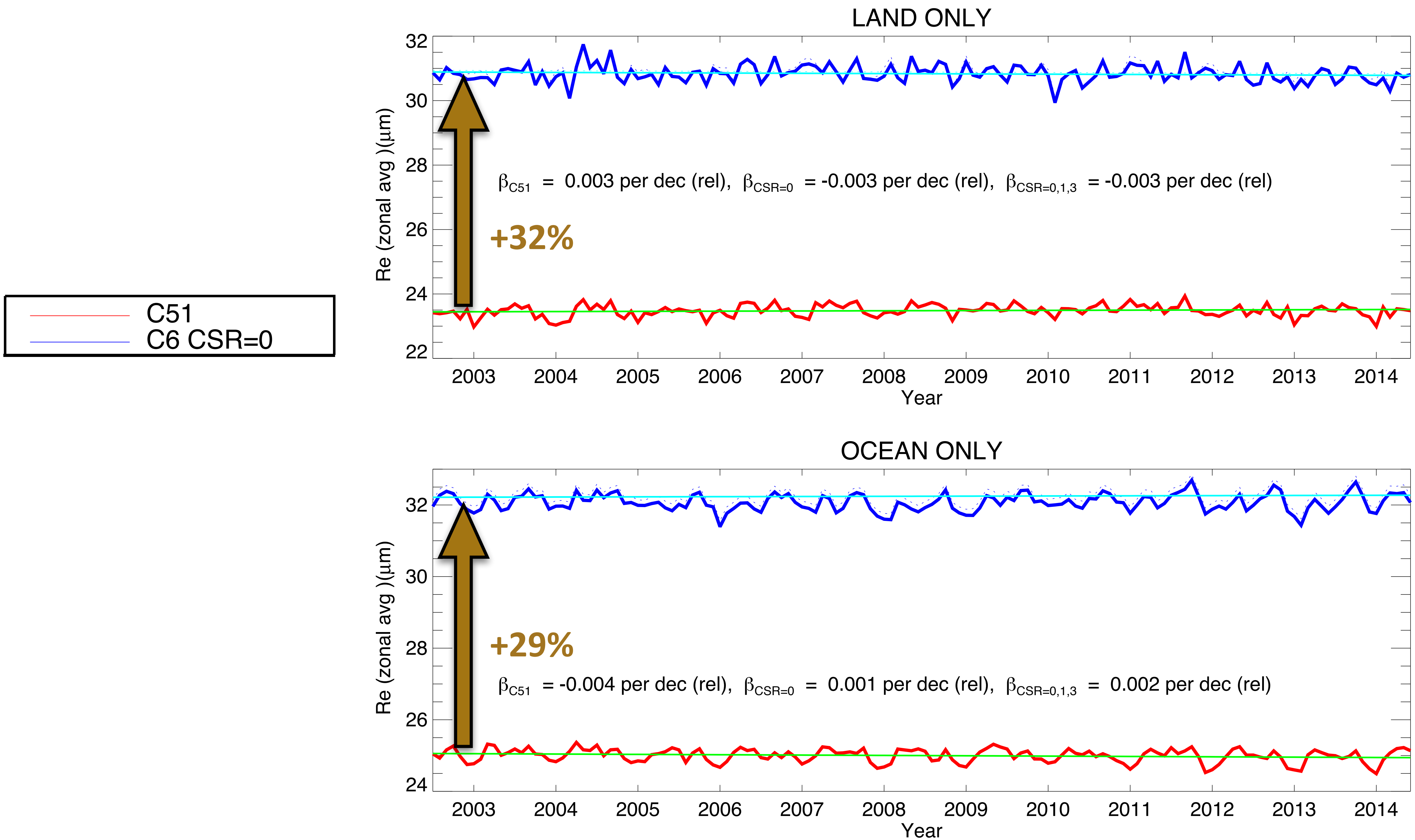

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Overview of Major C6 Changes

Category	Collection 5	Collection 6	Notes
Level-1 Analysis/Corrections			
Band 1,2 trend detection/correction	N/A	COT monthly anomaly trend analysis	Used to justify MCST work with desert site response-vs-scan angle corrections.
Aqua Band 1,2 250m–>1km aggregation	N/A	Used to improve known Aqua VNIR focal plane mis-registration w/SWIR, MWIR, and IR focal planes	Impacts Aqua COT and CER statistics in heterogeneous low cloud regions.
Algorithm - Retrieval Science			
Retrieval channel pairs	CER differences for VNIR-SWIR/MWIR channel pairs (relative to standard VNIR-2.1 µm).	Full retrievals reported separately for as many as 4 spectral channel pairs.	• Doesn't filter alternate channel pair retrievals by success of standard retrieval. • Allows for separate evaluation/ aggregation of all channel pairs.
Cloud-Top (CT) Pressure/Temperature	Used 5 km MOD06 CT product.	Uses new 1km MOD06 CT product. Incorporates non-unity cloud emissivity from optical retrieval into low cloud CT retrievals that use IR window channel.	
Thermodynamic Phase	Used SWIR/VNIR ratio tests as a proxy for particle size that was then used to indicate phase.	SWIR/VNIR ratio tests replaced w/ separate ice and liquid retrievals. Uses new tri-spectral IR phase product. Eliminates use of individual cloud mask tests. Weights applied to various tests in lieu of strict logical approach.	• Algorithm tests/weights validated against CALIOP, POLDER products. • Significant skill improvement seen for most regions (e.g., land, ocean, snow/ice) though still limited by available spectral bands.
Misc.	N/A	Numerous science and code infrastructure performance improvements.	• Improved processing efficiency. • Easier code maintenance, porting to other sensors.

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Cloud Retrieval Phase

(B. Marchant et al.)

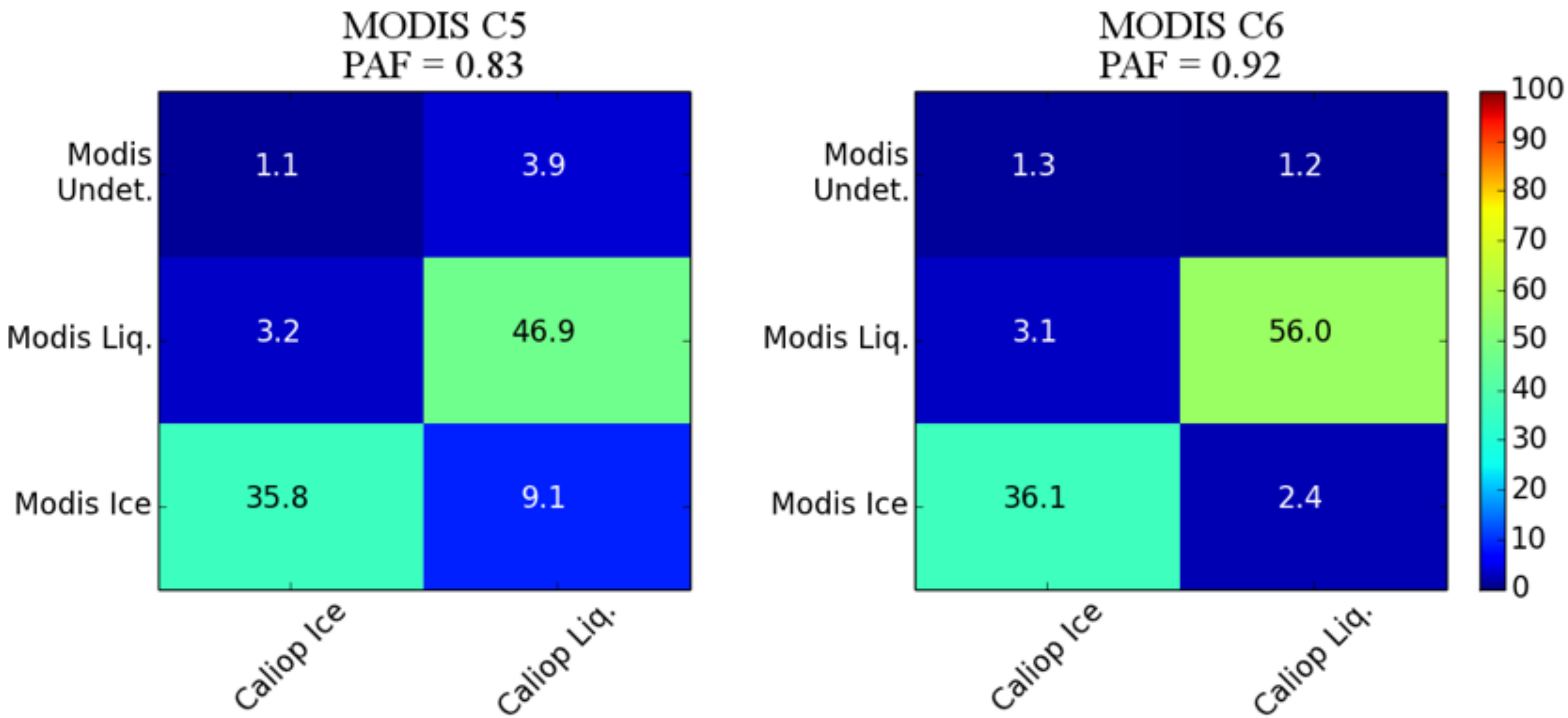

Figure 2.4-2. Global thermodynamic phase evaluation of the MODIS Aqua C5 and C6 algorithms vs. CALIOP over all surface types during January 2008. The population is from all colocations where CALIOP observed a single phase in the column. The overall Probability of Phase Agreement (PAF) skill score increases by ~10% for C6.

SDS name: *Cloud_Phase_Optical_Properties*

Cloud Retrieval Phase

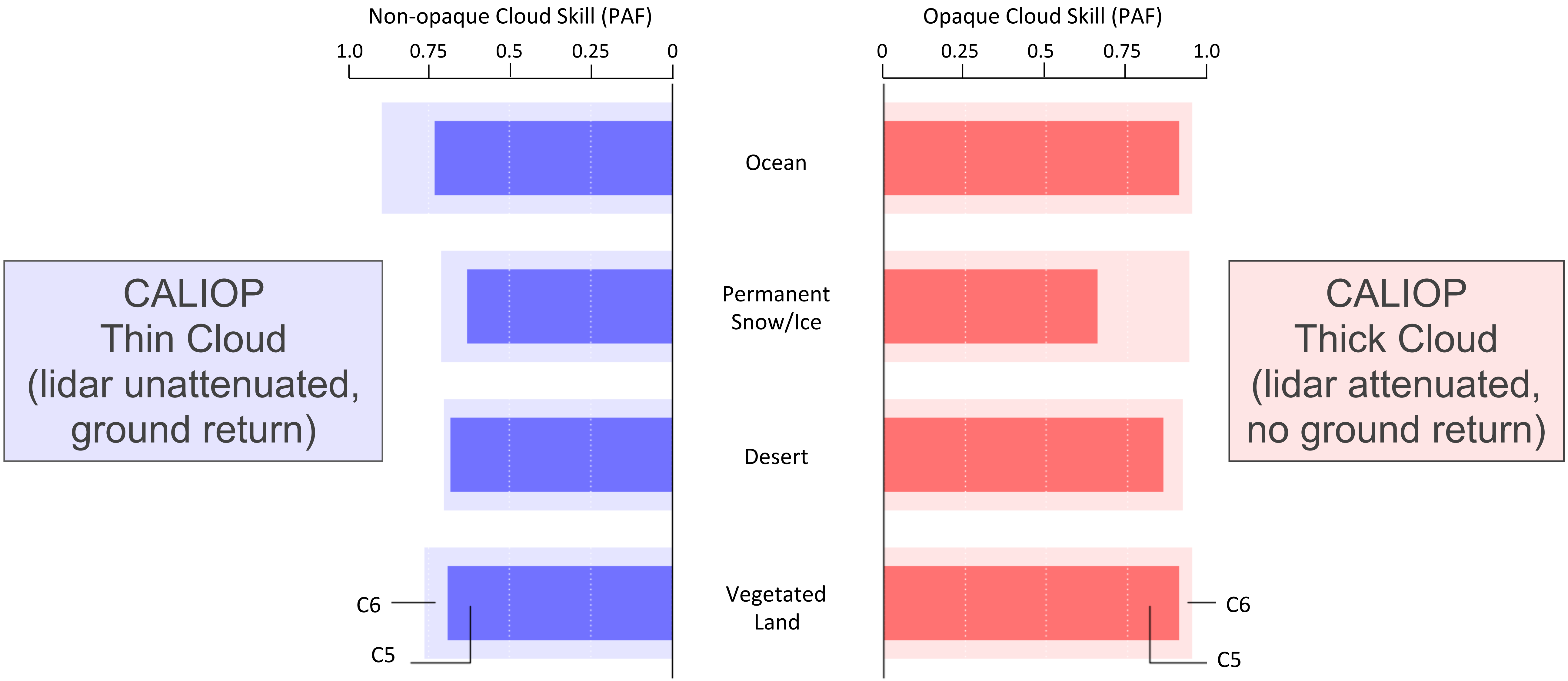

Figure 2.4-3. Global thermodynamic phase evaluation of the MODIS Aqua C5 and C6 algorithms vs. CALIOP for a variety of surface types during January 2008. The population is from all collocations where CALIOP observed a single cloud phase throughout the column. The bar plots to the left are for scenes where the lidar was not completely attenuated by the cloud layers (COT less than about 3); bars to the right are for scenes where the lidar was completed attenuated (no ground return).

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Cloud Retrieval Phase Granule Example

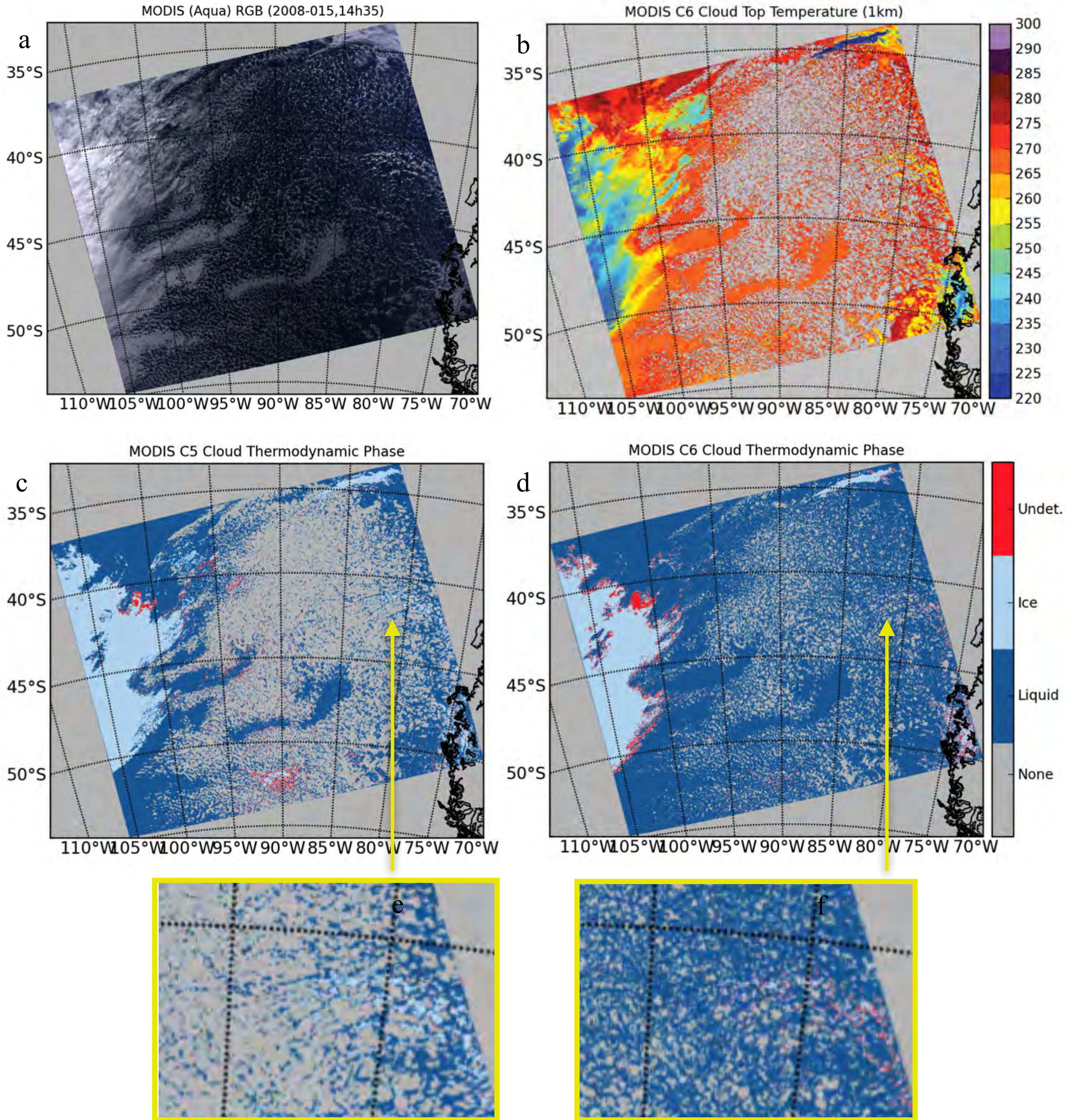

Figure 2.4-7 Example C5 and C6 phase retrievals for an Aqua data granule showing low marine clouds through much of the central/eastern portion of the image (RGB composite in panel a). Cloud-top temperatures from MYD06 are shown in panel b, while C5 and C6 phase are in panel c and d, respectively. An area with substantial broken clouds is shown in the bottom two panels (e and f) indicating less ice cloud retrievals for the C6 phase algorithm.

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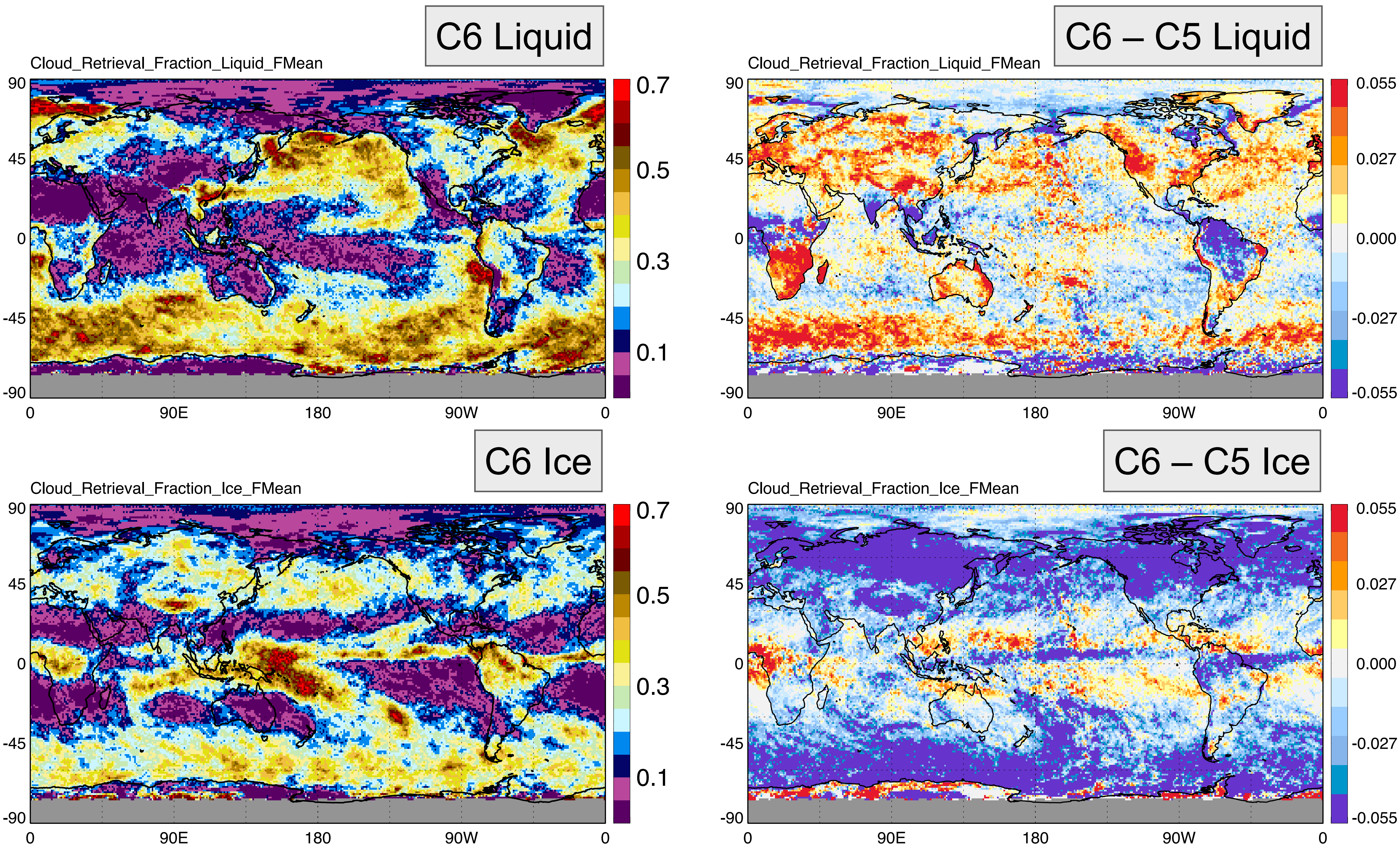
Global Changes in Cloud Retrieval Phase

Successful Retrieval Fraction by Collection (CSR=0 for C6)



5

Overview of Major C6 Changes

Category	Collection 5	Collection 6	Notes
Algorithm - Pixel Quality Assessment (QA)/Filtering			
Updated 'Clear Sky Restoral' (CSR) algorithm	N/A	Improve discrimination between heavy aerosol (smoke/dust) and glint from low uniform cloud population.	Added explicit aerosol model tests. Replaced 1.38 μm cloud height discrimination tests w/CT 'method' flags.
Pixels identified as not-overcast and/or cloudy FOV by CSR algorithm	Do not retrieve CSR-identified pixels	Attempt retrievals on CSR-identified pixels and, if successful, write results to separate dataset (SDS).	Separate SDS allows for analysis of CSR population w/out need to read/ interpret QA assignments.
Failed Retrieval Metrics ('failure' defined as the simultaneous COT, CER solution being outside of LUT space)	No failure metrics reported	The following metrics are reported: nearest COT, nearest CER, relative distance from 2D measurement point to nearest LUT solution point.	Allow users to understand failure mode (e.g., large CER, small COT) for cloudy FOVs not meeting 1D fwd. model assumptions. Potentially useful for radiative studies, comparison with other observational datasets, and high resolution LES models.
Multilayer cloud detection	*Wind et al.* (2010)	Updated multilayer cloud detection using additional tests from *Pavolonis and Heidinger* (2004).	
Retrieval Confidence QA	2-bit assignment	Not actively assigned. Superseded by pixel-level uncertainty SDS.	QA assignments confusing to users, lack of consistency across products. L3 users directed to "Uncertainty of Mean" SDS derived from pixel-level uncertainties.
Sub-pixel Heterogeneity	N/A	Bands 1 & 2 250 m reflectance heterogeneity included in MOD35 and MOD06 dataset.	Heterogeneity partial predictor for marine liquid water cloud spectral differences.

5

Overview of Major C6 Changes

Category	Collection 5	Collection 6	Notes
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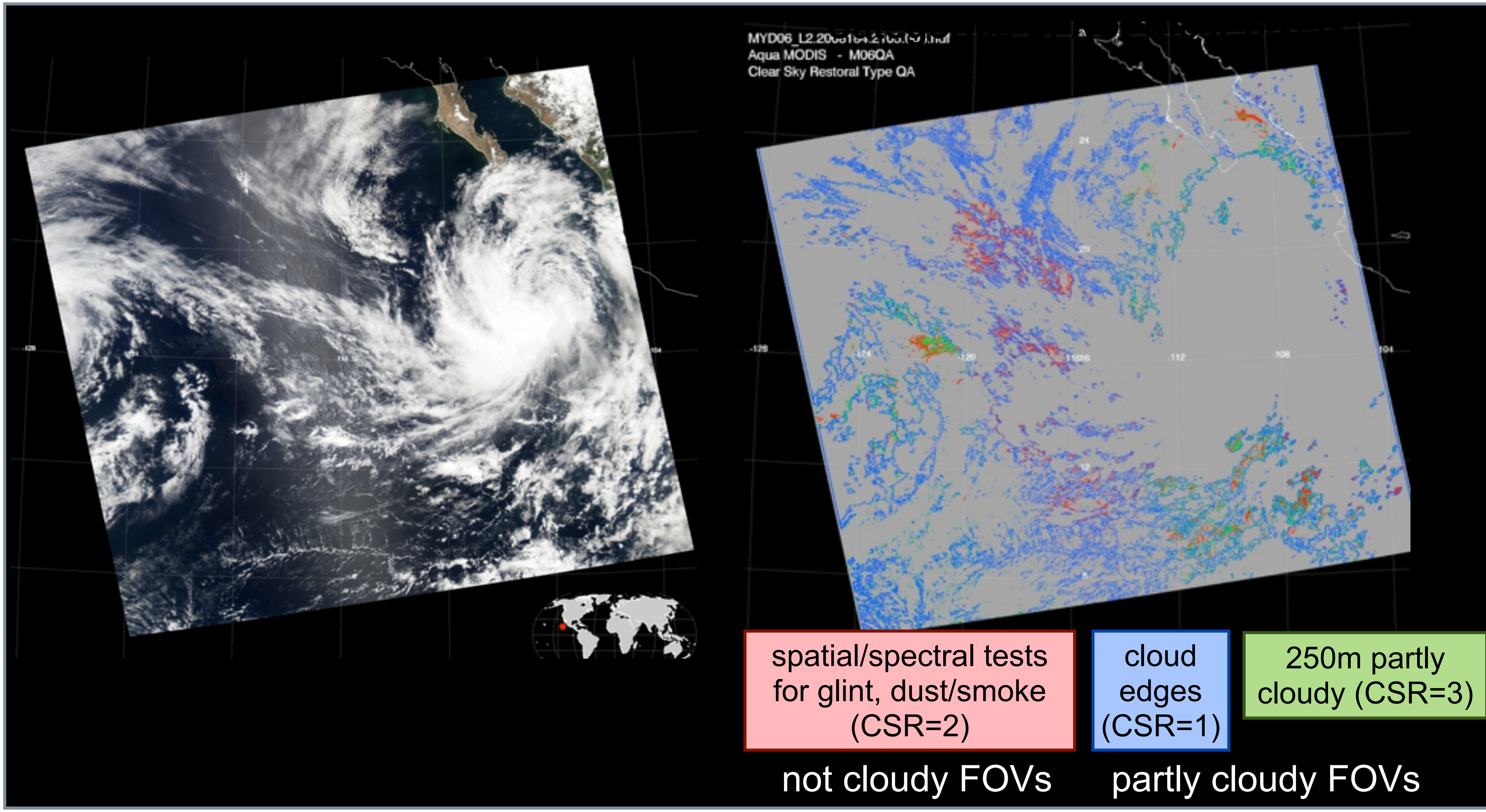
5 Clear Sky Restoral (CSR) QA bits in Quality_Assurance_1km

(K. Meyer et al.)

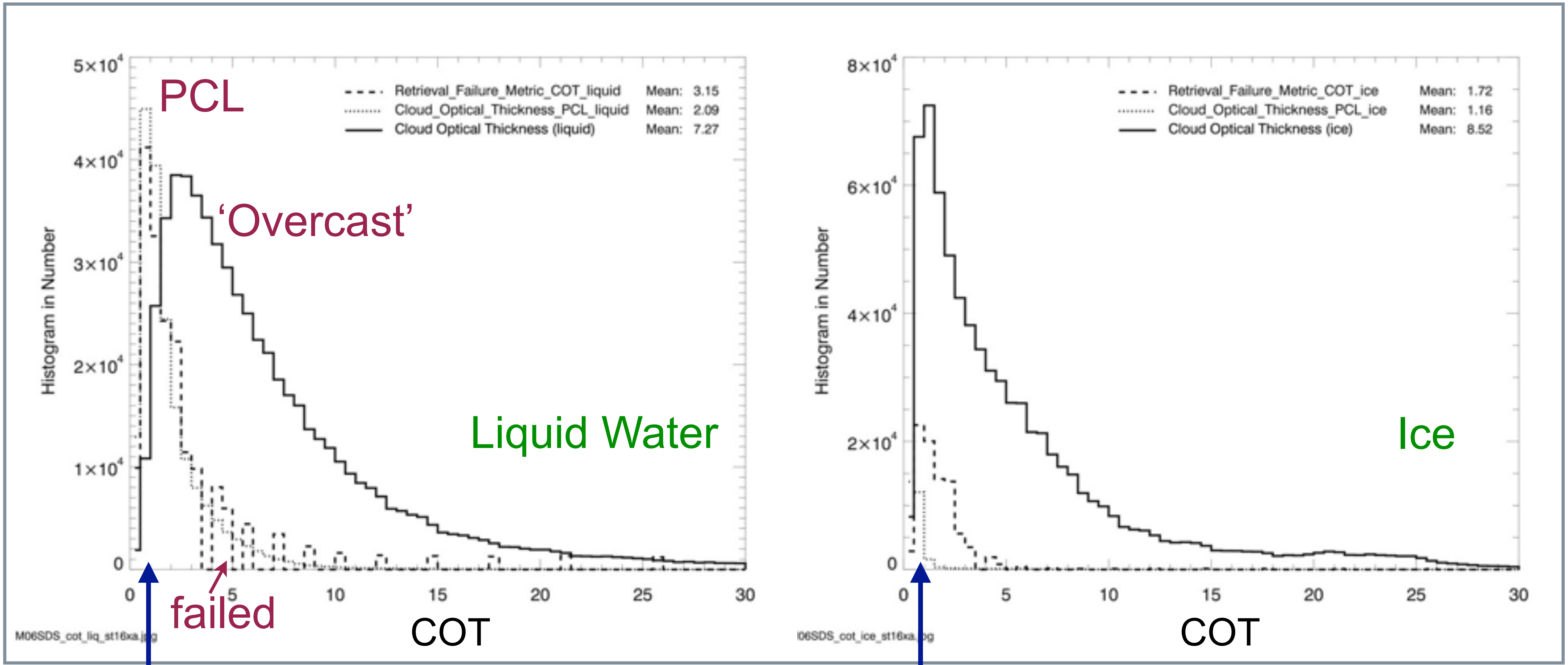


2 July 2008, MODIS Aqua, 2105 UTC

3

Clear Sky Restoral (CSR): “Partly Cloudy” vs. “Overcast”

Cloud Optical Thickness Histograms



COT for PCL pixels have very small mode as expected

Clear Sky Restoral (CSR): Not Cloudy Determinations

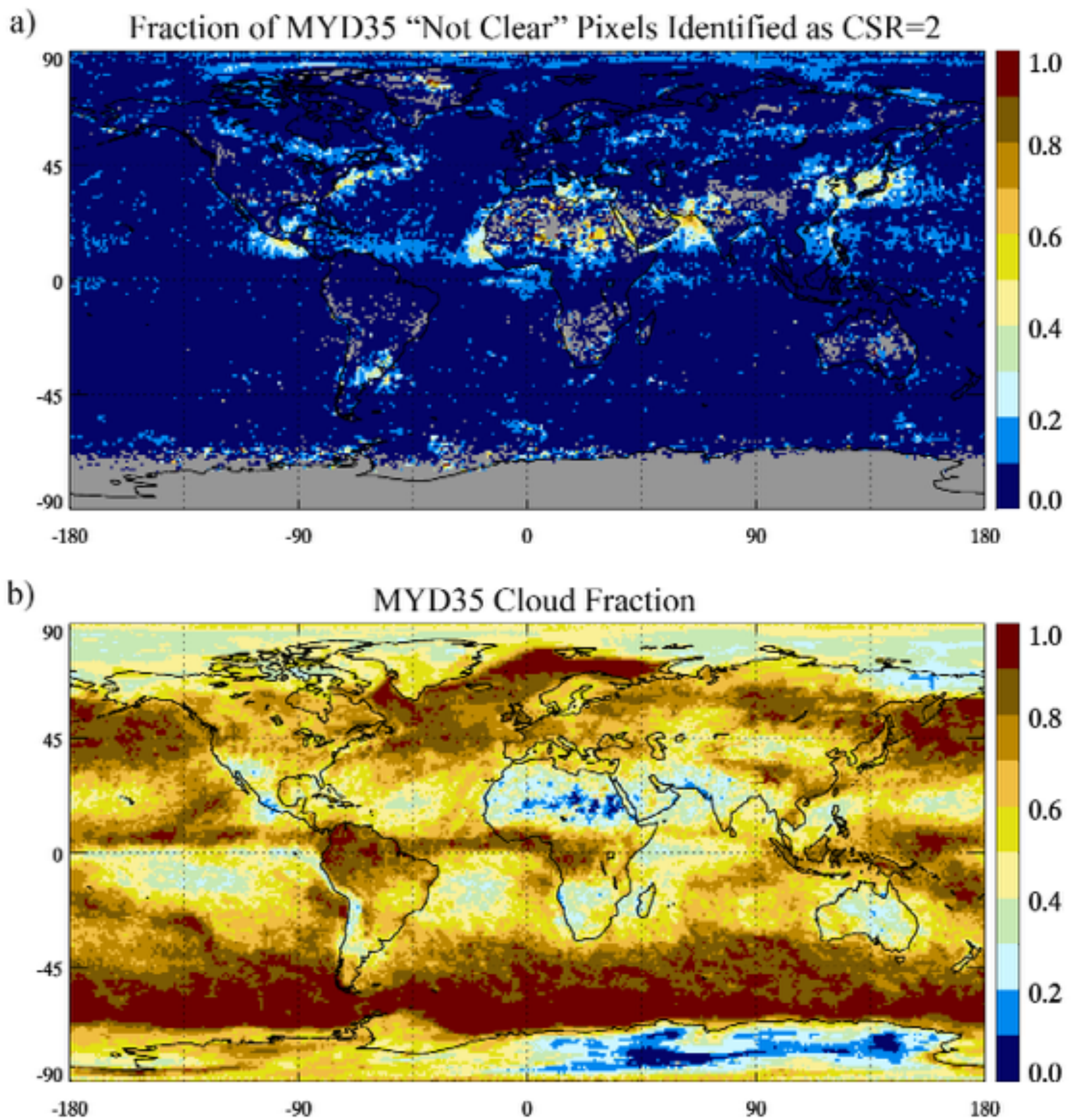
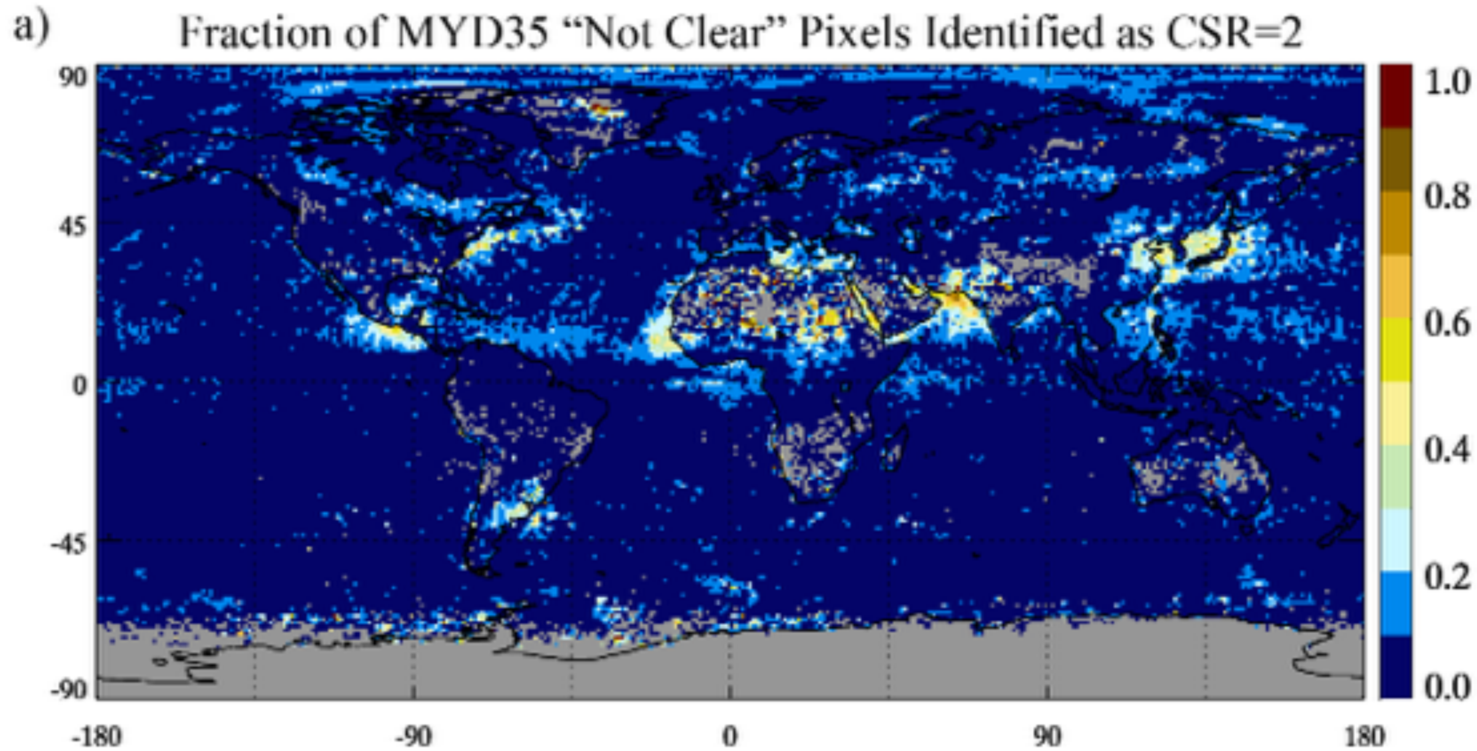
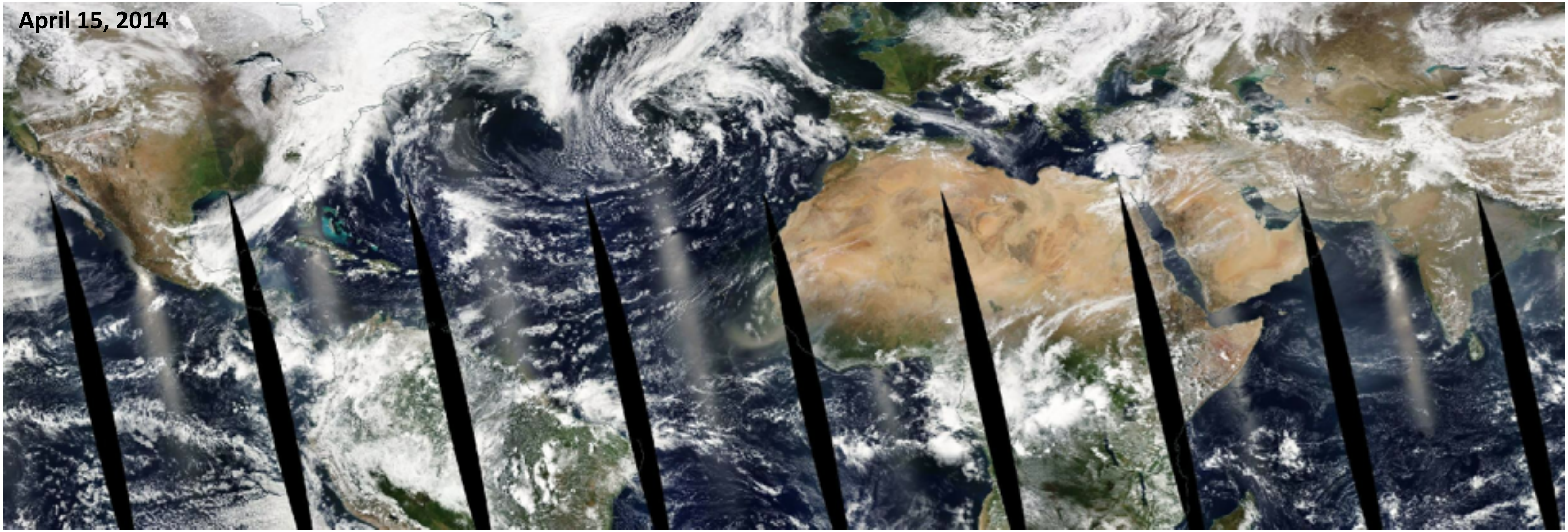


Figure 2.8-3. Monthly fraction of MYD35 "not clear" pixels identified as CSR = 2 (a) and MYD35 cloud fraction (b) for April 2005 Aqua MODIS.

Clear Sky Restoral (CSR): Not Cloudy Determinations





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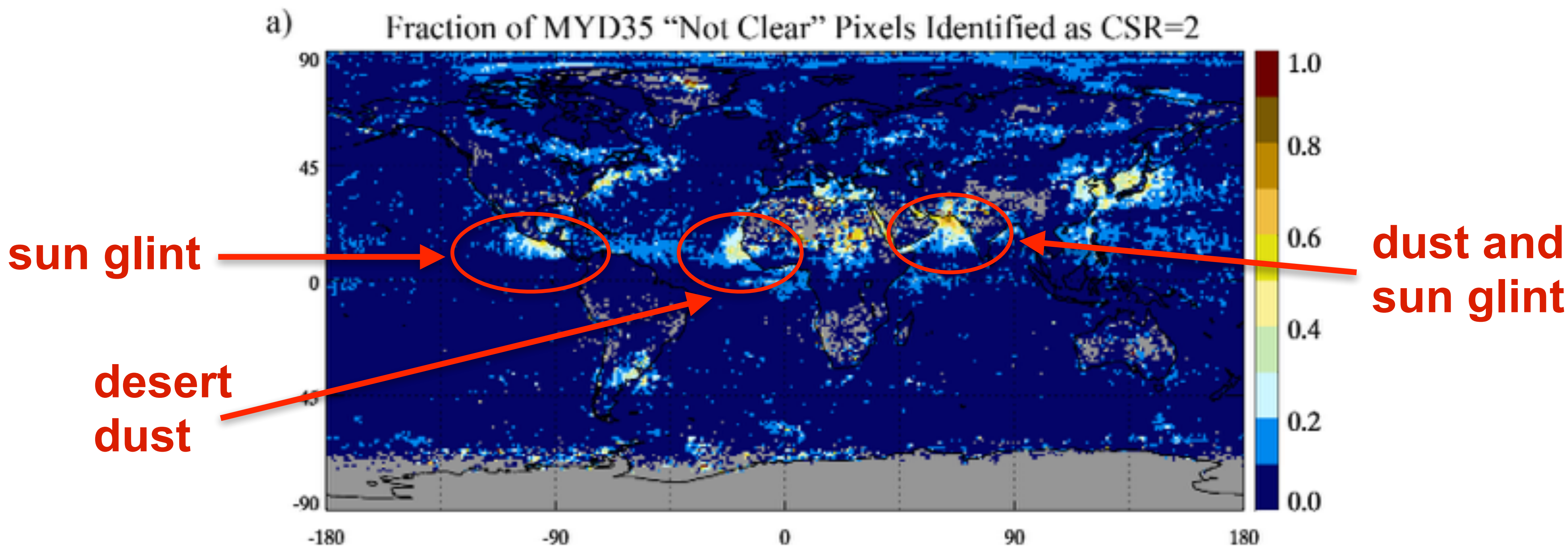

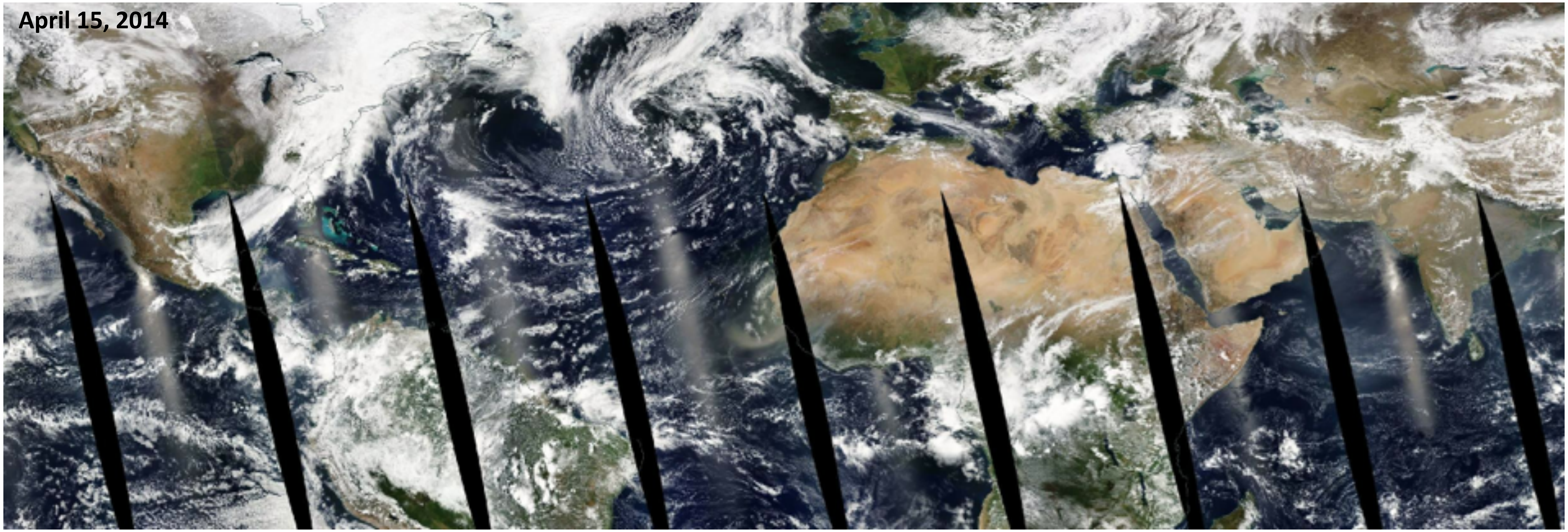

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Spectral CER and Sensitivity to PCL

Aqua MODIS April 2005

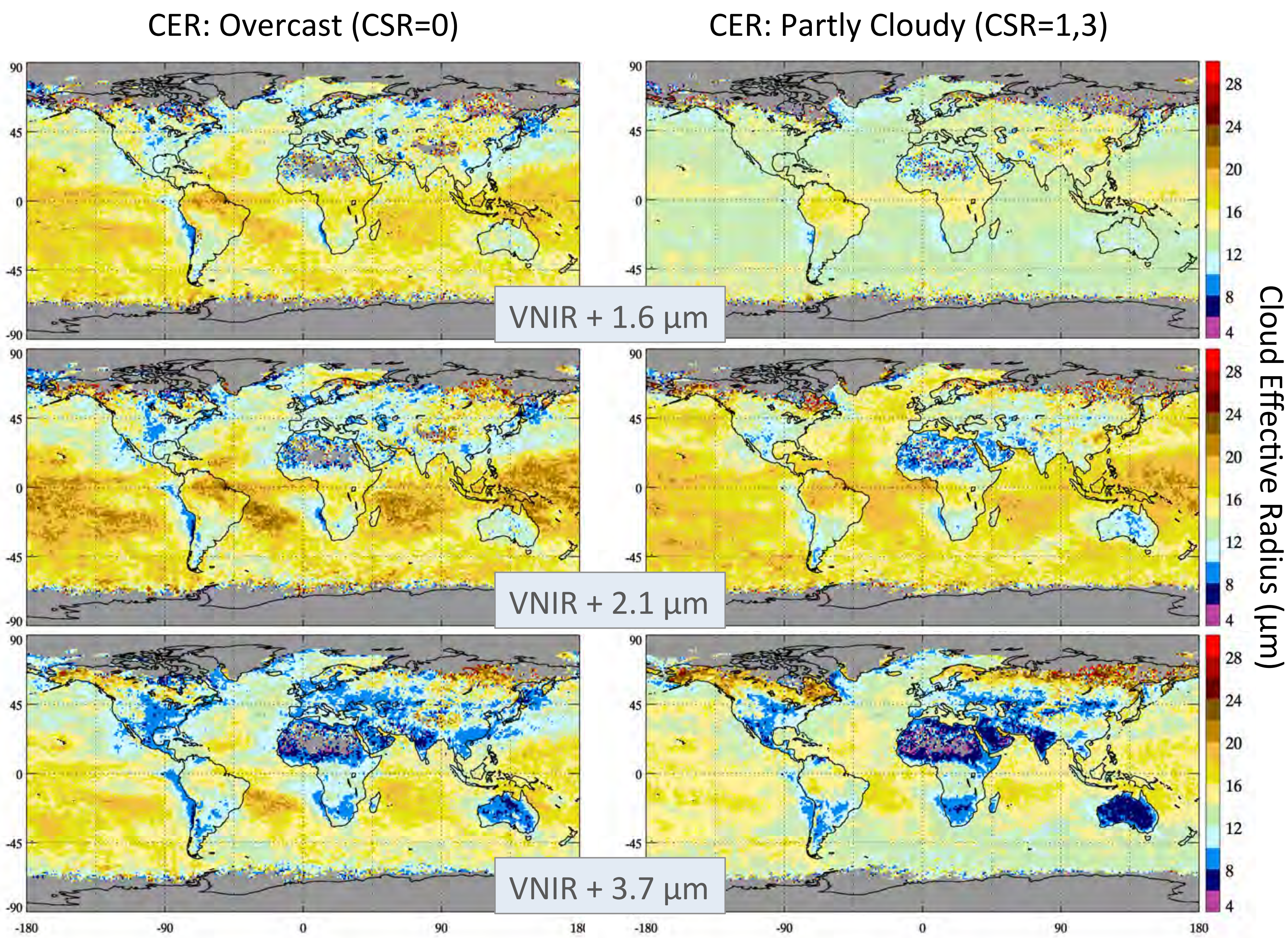

Figure 2.5-4. Aqua MODIS monthly (April 2005) mean 1° gridded effective radius for three separate SWIR/MWIR spectral channel combinations, filtered for liquid water pixels with cloud-top temperatures greater than 270K. Panels on the left are aggregated from pixels that the clear sky rostral (CSR) algorithm identifies as "overcast"; panels to the right are identified as "partly cloudy".

Spectral CER and Sensitivity to PCL

Aqua MODIS April 2005

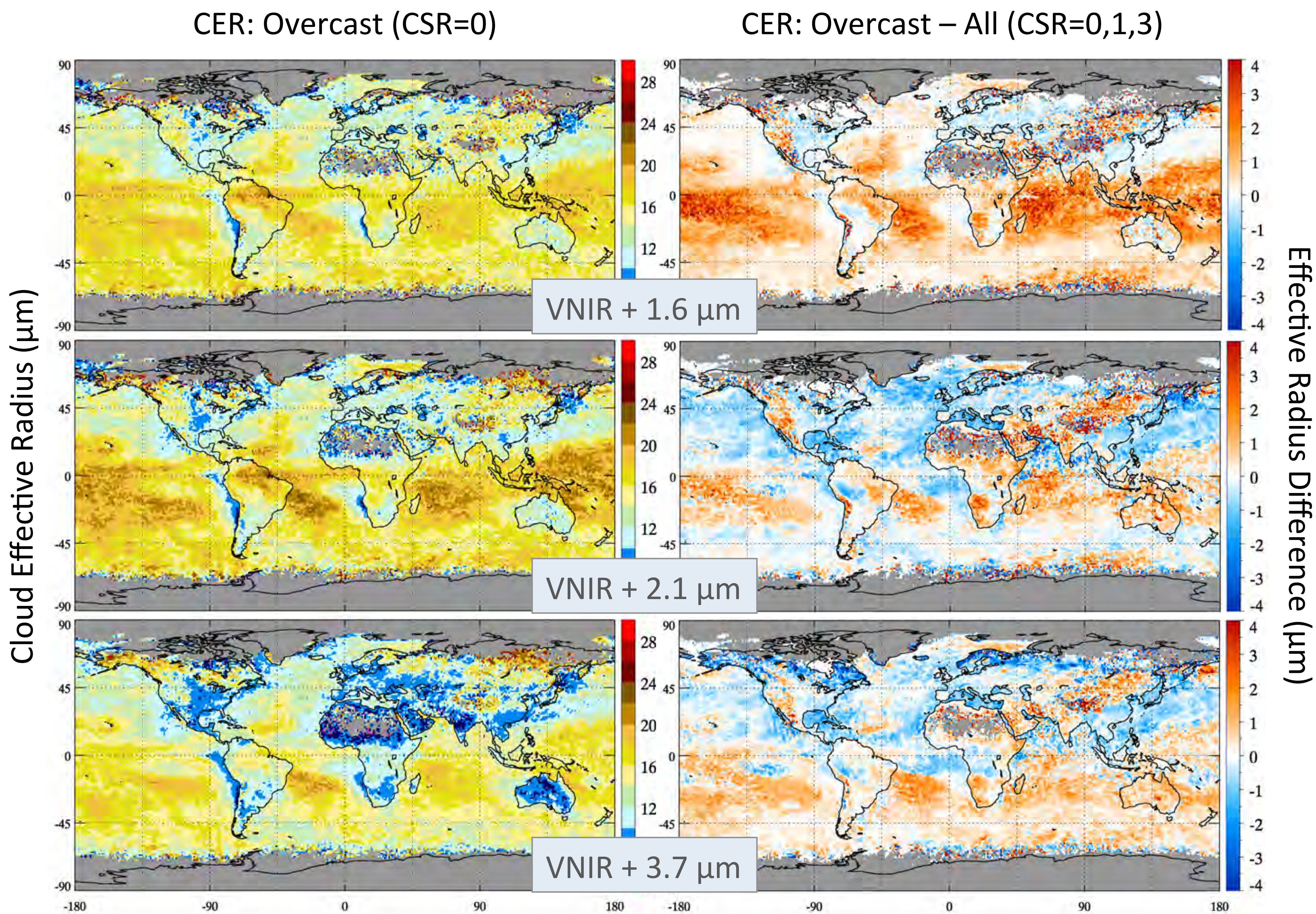

Figure 2.5-5. Same as Fig. 2.5-4 but for the right panels showing the difference CER calculated as the mean for overcast pixel population minus the mean for the total (overcast + partly cloudy) population.

What Does CER_2.1 >> CER_3.7 Mean?

- CER_2.1 more sensitive to **3-D radiative effects** than CER_3.7 (LES studies) and CER_2.1>>CER_3.7 associated with larger 250m **horizontal heterogeneity** (empirical studies) [*Zhang and Platnick*, 2011; *Zhang et al.*, 2012]

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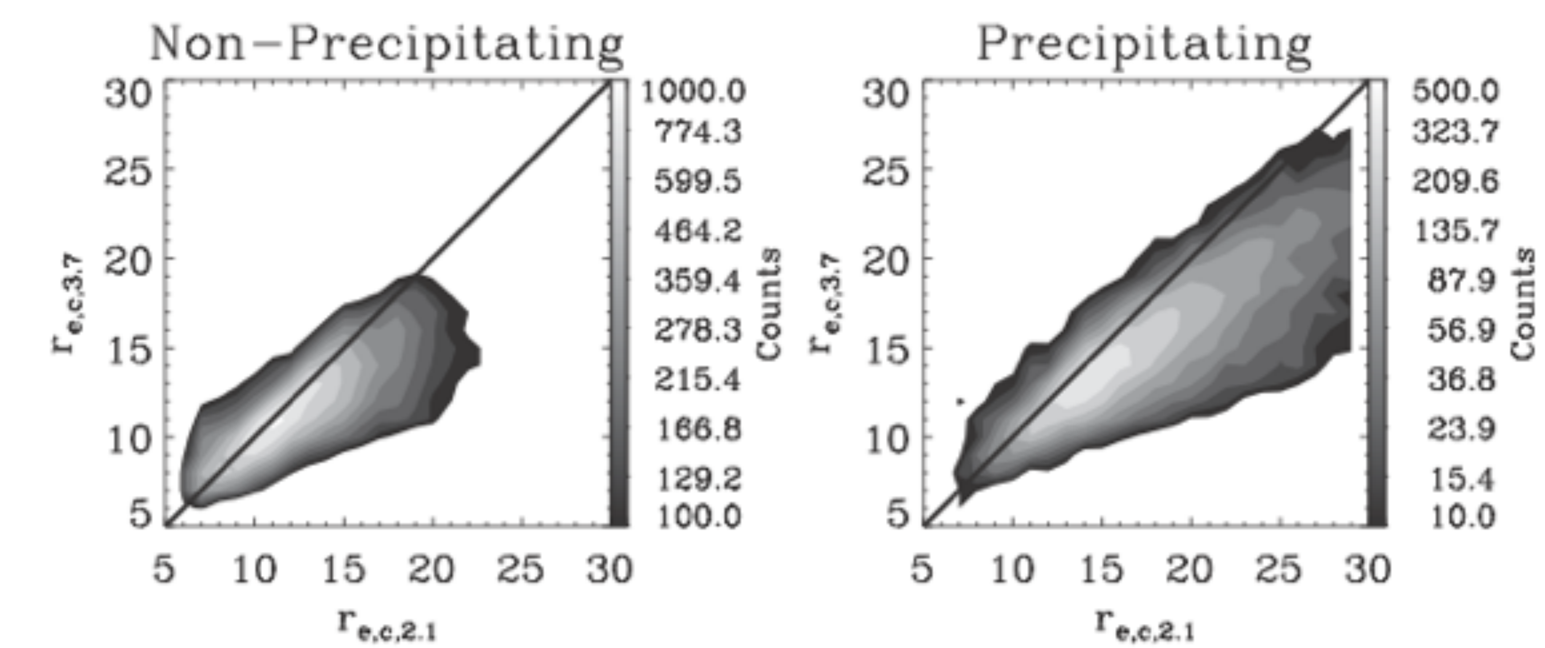

FIG. 4. Joint PDFs of the MODIS r_e estimates for the 3.7- and 2.1-μm channels. Below $r_{e,2.1}$ of 10 μm, the two estimates agree well, with the 3.7-μm channel slightly overestimating the 2.1-μm channel. Above this threshold, $r_{e,2.1}$ overestimates $r_{e,3.7}$ by increasing amounts.

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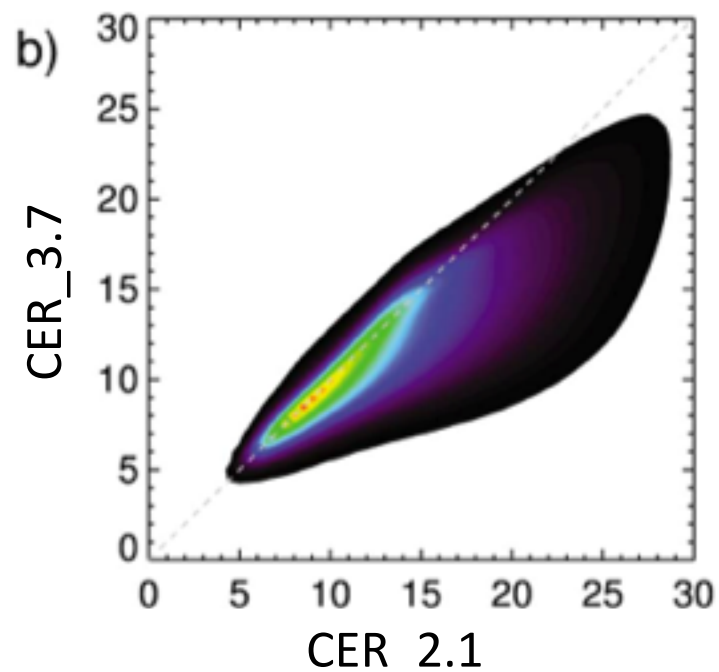

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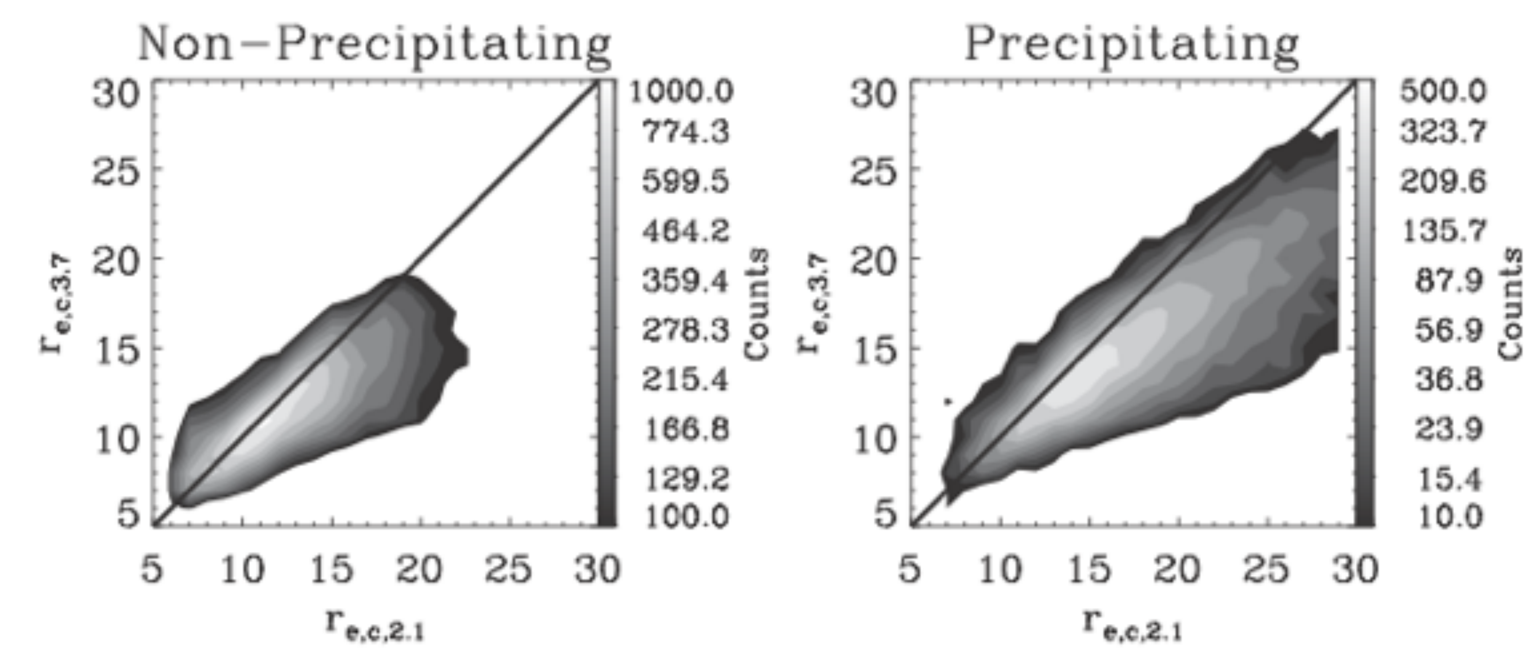

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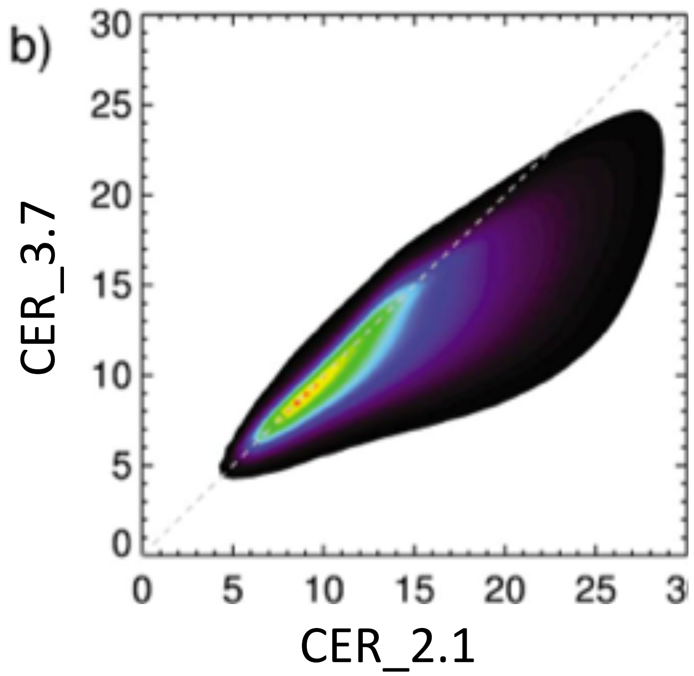
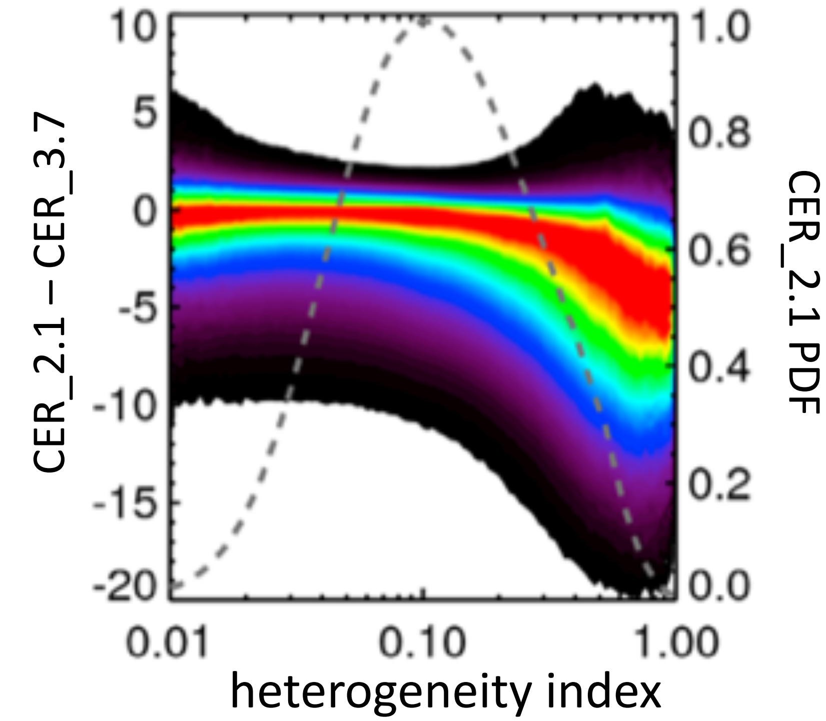




- CER_2.1>>CER_3.7 associated with **drizzle** (CloudSat) [*Lebsock et al.*, 2011

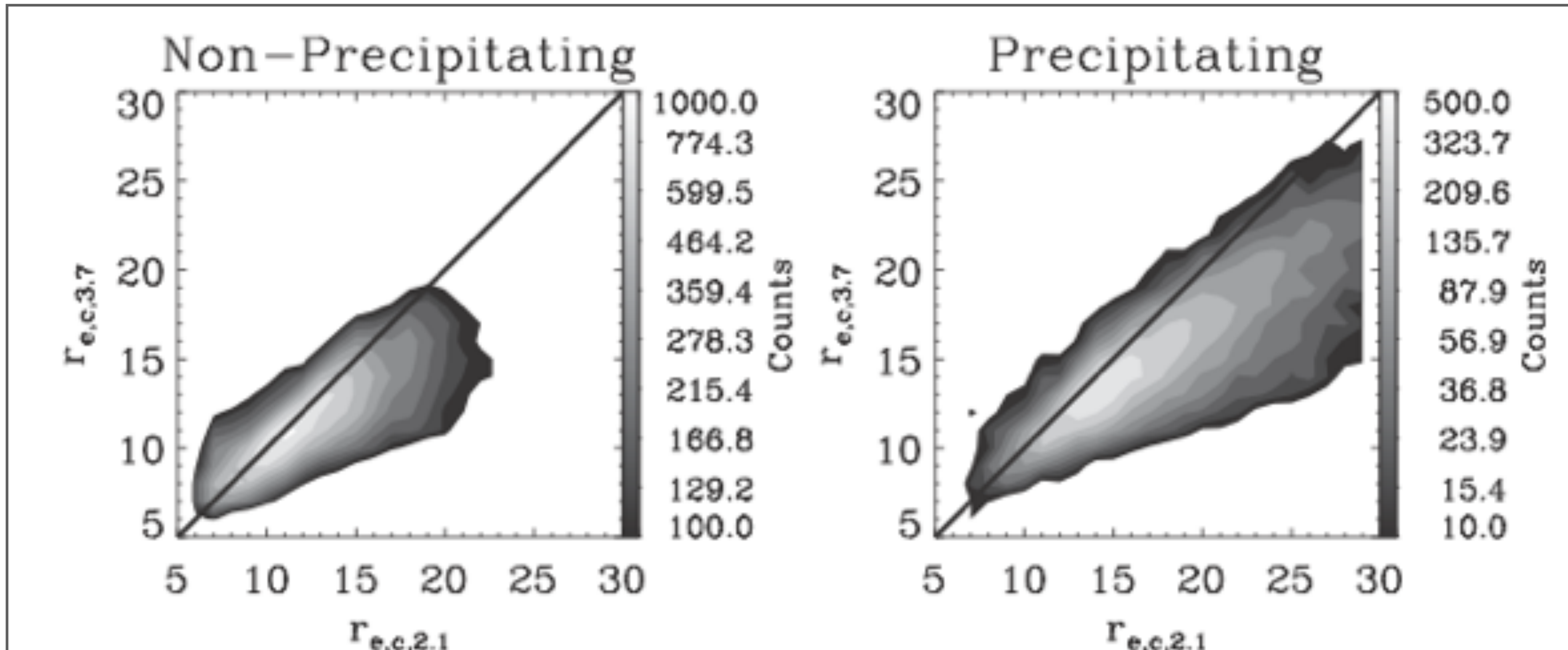


FIG. 4. Joint PDFs of the MODIS r_e estimates for the 3.7- and 2.1-μm channels. Below $r_{e,2.1}$ of 10 μm, the two estimates agree well, with the 3.7-μm channel slightly overestimating the 2.1-μm channel. Above this threshold, $r_{e,2.1}$ overestimates $r_{e,3.7}$ by increasing amounts.

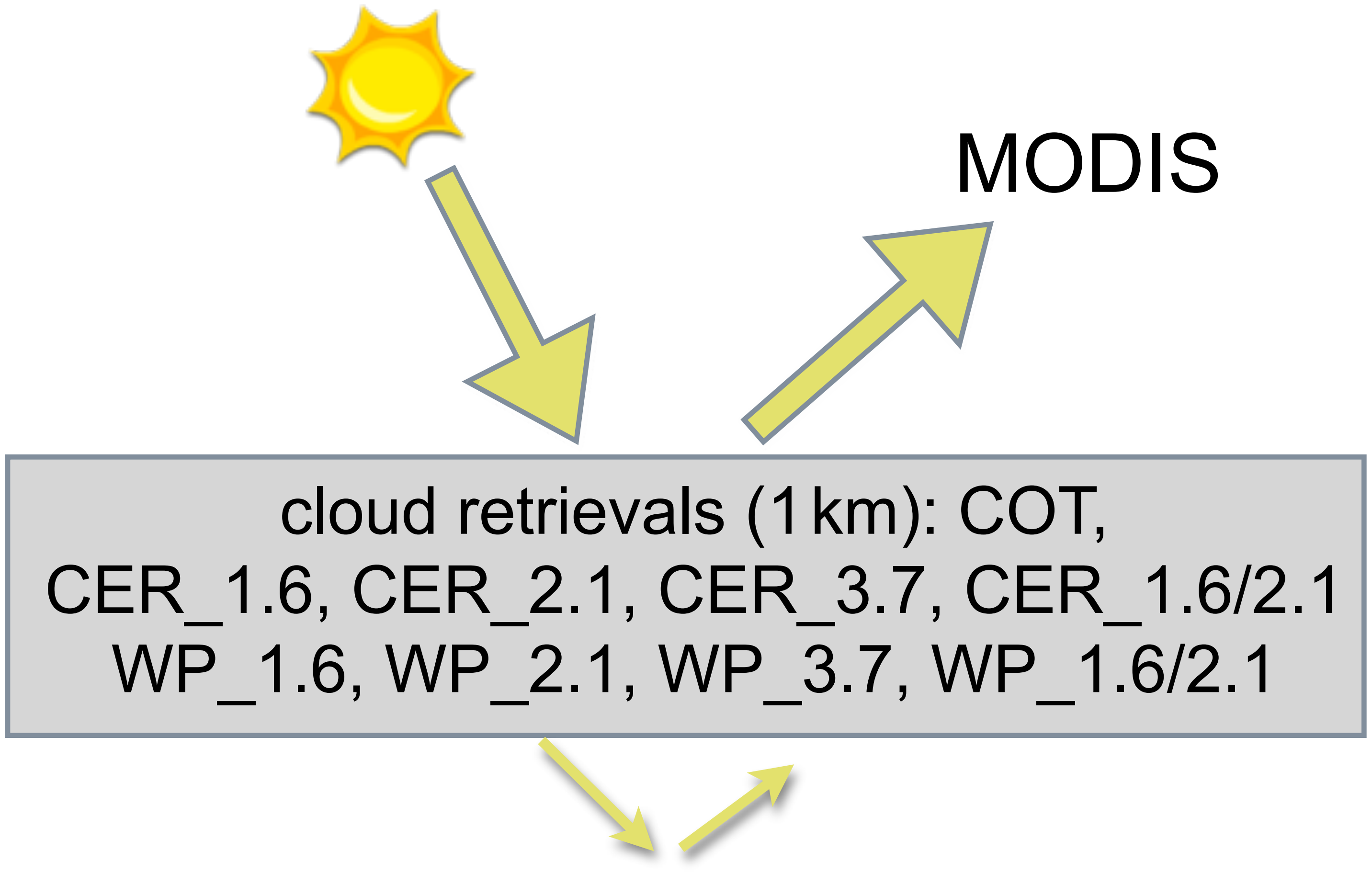
5

Overview of Major C6 Changes

Category	Collection 5	Collection 6	Notes
Algorithm - Pixel Level Uncertainty			
Instrument Calibration	Combined with model error sources and fixed at 5% relative	Uses L1B scene-dependent pixel-level spectral uncertainty indices (improved for C6)	Reduces combined uncertainty in many cases.
Model Errors		See LUT above for details.	
3.7 µm Emission Error Sources	Not included	Accounts for effective cloud and surface emissivity including dependence on ancillary water vapor field.	More realistic (larger) 3.7 µm channel CER and water path uncertainties.

4

Pixel-Level Error Sources **Explicitly Included** in C6 Uncertainty Calculations



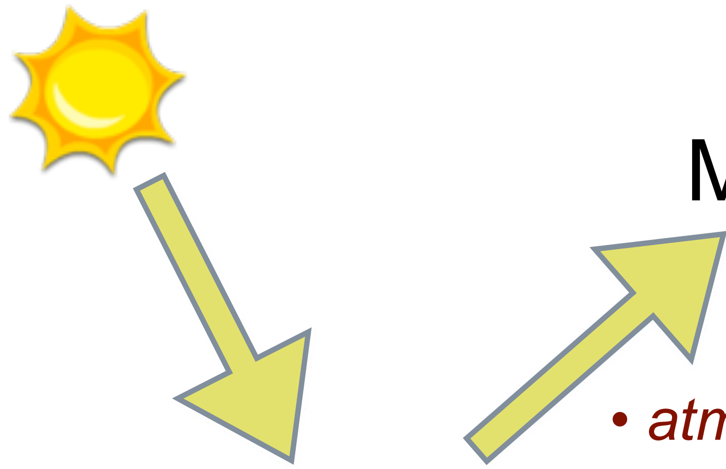
surface spectral reflectance/emission

Plane-Parallel Fwd. Model

cloud masking, cloud-top pressure provided through separate algorithm team (S. Ackerman et al.)

4

Pixel-Level Error Sources **Explicitly Included** in C6 Uncertainty Calculations



MODIS

- *instrument calibration (pixel-level, L1B file)*
- *atmospheric corrections: q (fwd. model LUT), O_3*

cloud retrievals (1 km): COT,
CER_1.6, CER_2.1, CER_3.7, CER_1.6/2.1
WP_1.6, WP_2.1, WP_3.7, WP_1.6/2.1

- *cloud model: droplet size distribution v_{eff}*

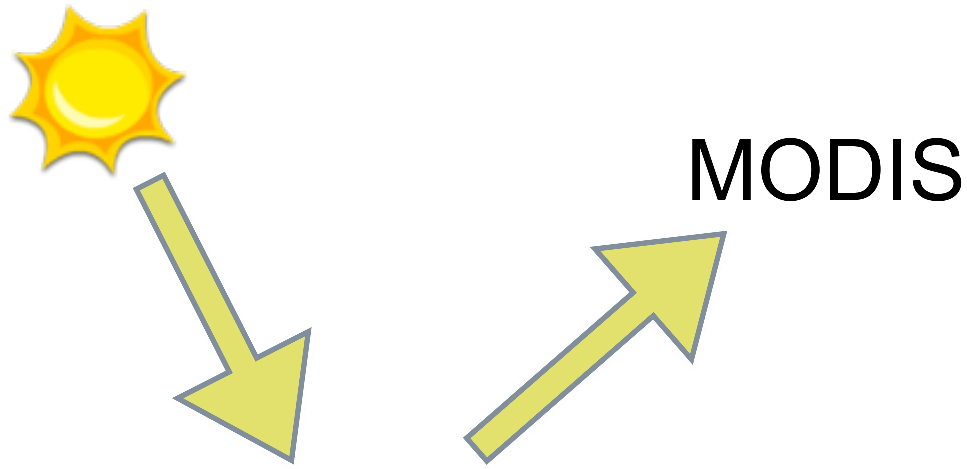
surface spectral reflectance/emission

Plane-Parallel Fwd. Model

- *Surface reflectance –*
  Ocean: Cox-Munk wind speed/direction
  Land: MODIS-derived gap-filled product
  Snow/ice: MODIS-derived gap-filled database
- *3.7 µm retrievals: T_{sfc}, low cloud T_c retrievals, F_0*

cloud masking, cloud-top pressure provided through separate algorithm team (S. Ackerman et al.)

Pixel-Level Error Sources **Not Included** in C6 Uncertainty Calculations



cloud retrievals (1 km): COT,
CER_1.6, CER_2.1, CER_3.7, CER_1.6/2.1
WP_1.6, WP_2.1, WP_3.7, WP_1.6/2.1

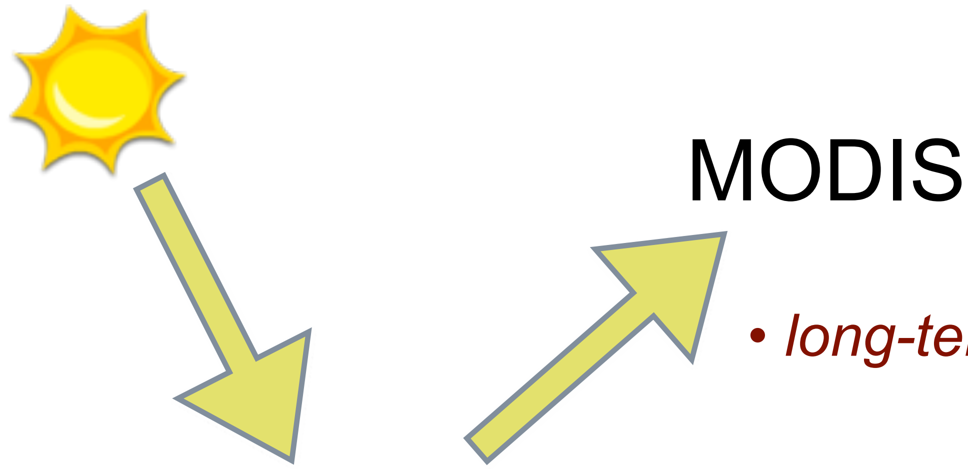
surface spectral reflectance/emission

Plane-Parallel Fwd. Model

cloud masking, cloud-top pressure provided
through separate algorithm team
(S. Ackerman et al.)

4

Pixel-Level Error Sources **Not Included** in C6 Uncertainty Calculations



• *long-term radiometric bias/drift*

cloud retrievals (1 km): COT,
CER_1.6, CER_2.1, CER_3.7, CER_1.6/2.1
WP_1.6, WP_2.1, WP_3.7, WP_1.6/2.1

• *cloud model: vertical and horizontal heterogeneity (3-D radiative effects)*

More egregious cases accounted for by flagging obvious partly cloudy pixels

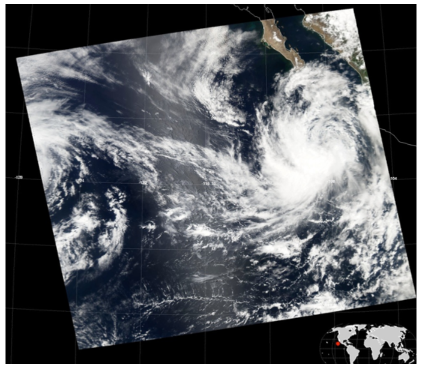
surface spectral reflectance/emission

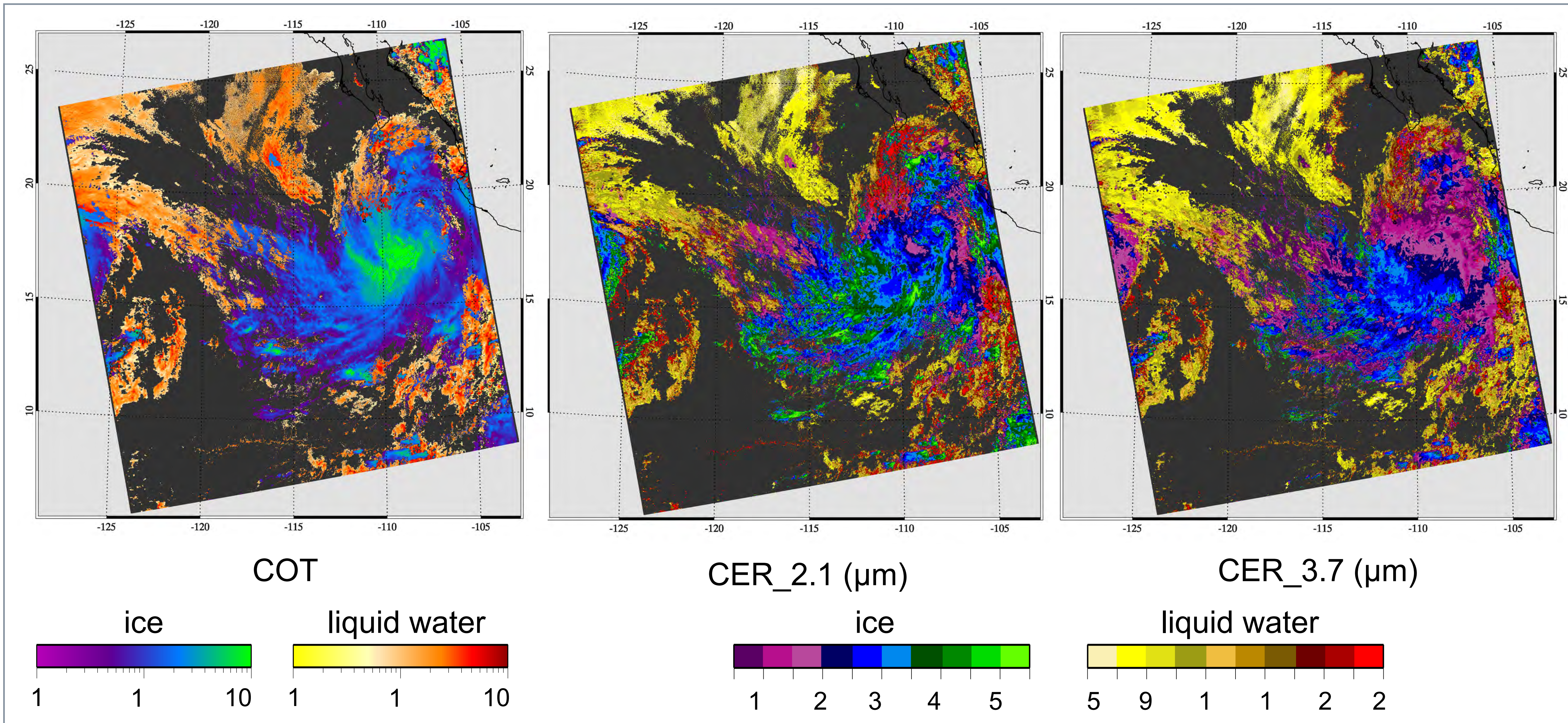
Plane-Parallel Fwd. Model

cloud masking, cloud-top pressure provided
through separate algorithm team
(S. Ackerman et al.)

Pixel-Level Retrievals

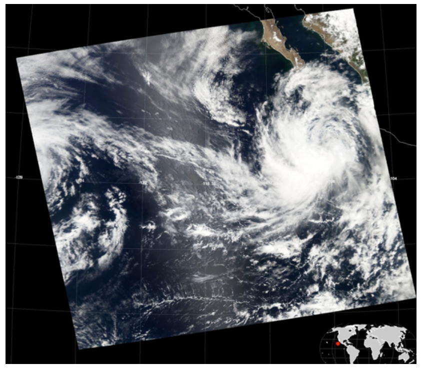
2 July 2008, MODIS Aqua C6, 2105 UTC
(best quality pixels only, CSR=0)

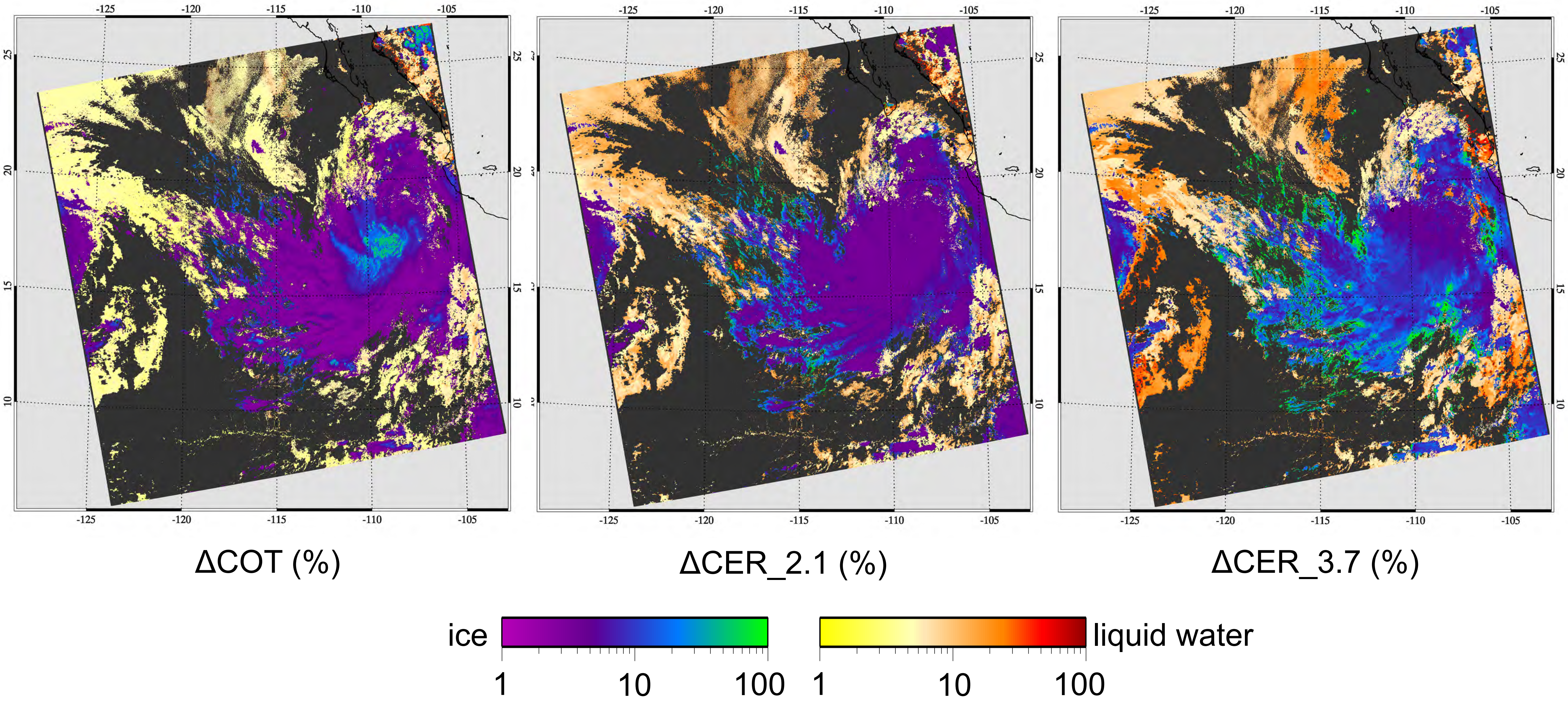




Pixel-Level Retrieval Uncertainties

2 July 2008, MODIS Aqua C6, 2105 UTC
(best quality pixels only, CSR=0)

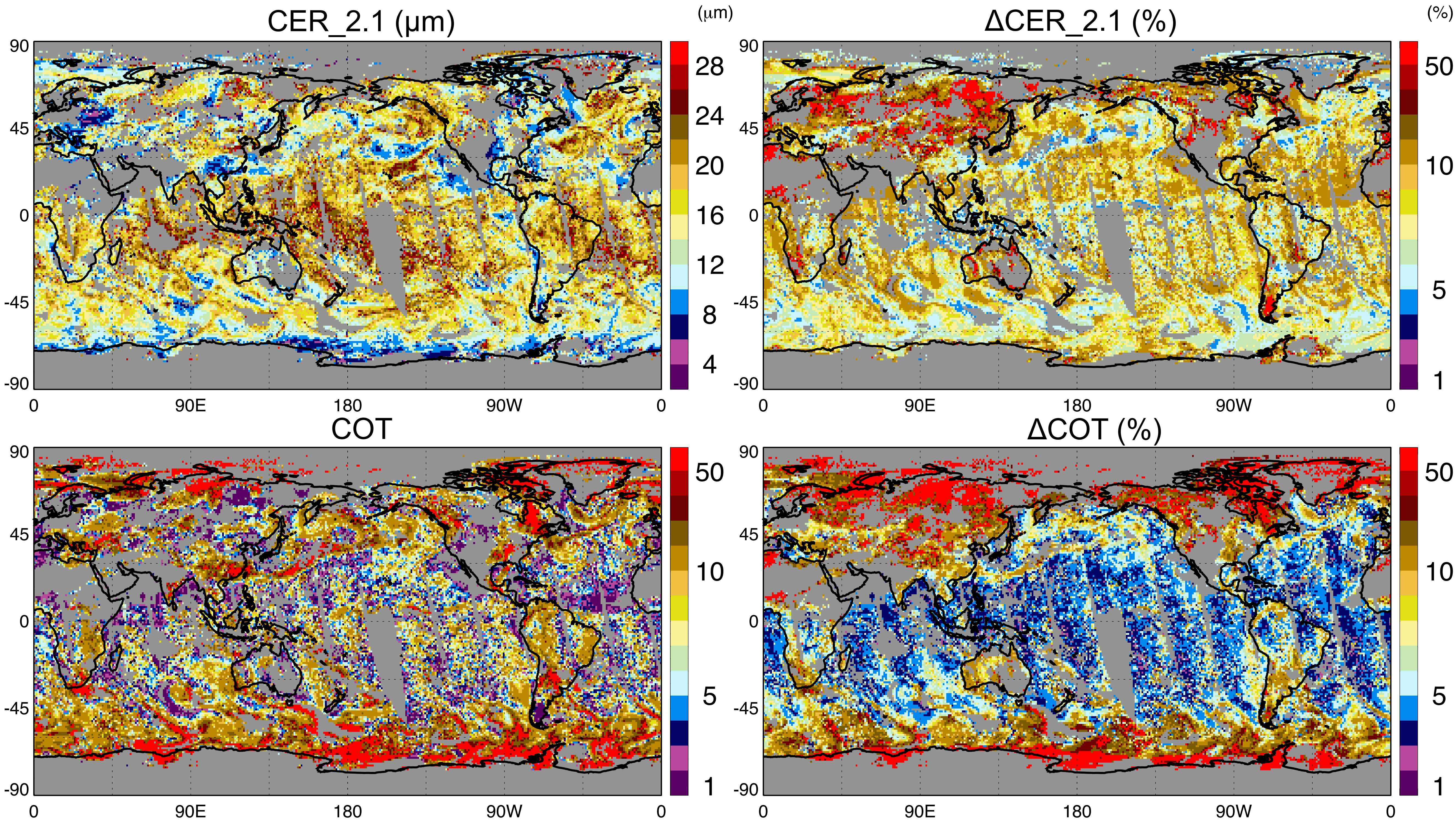




Uncertainties in Aggregated Means: Daily

Daily Means for Liquid Water Clouds

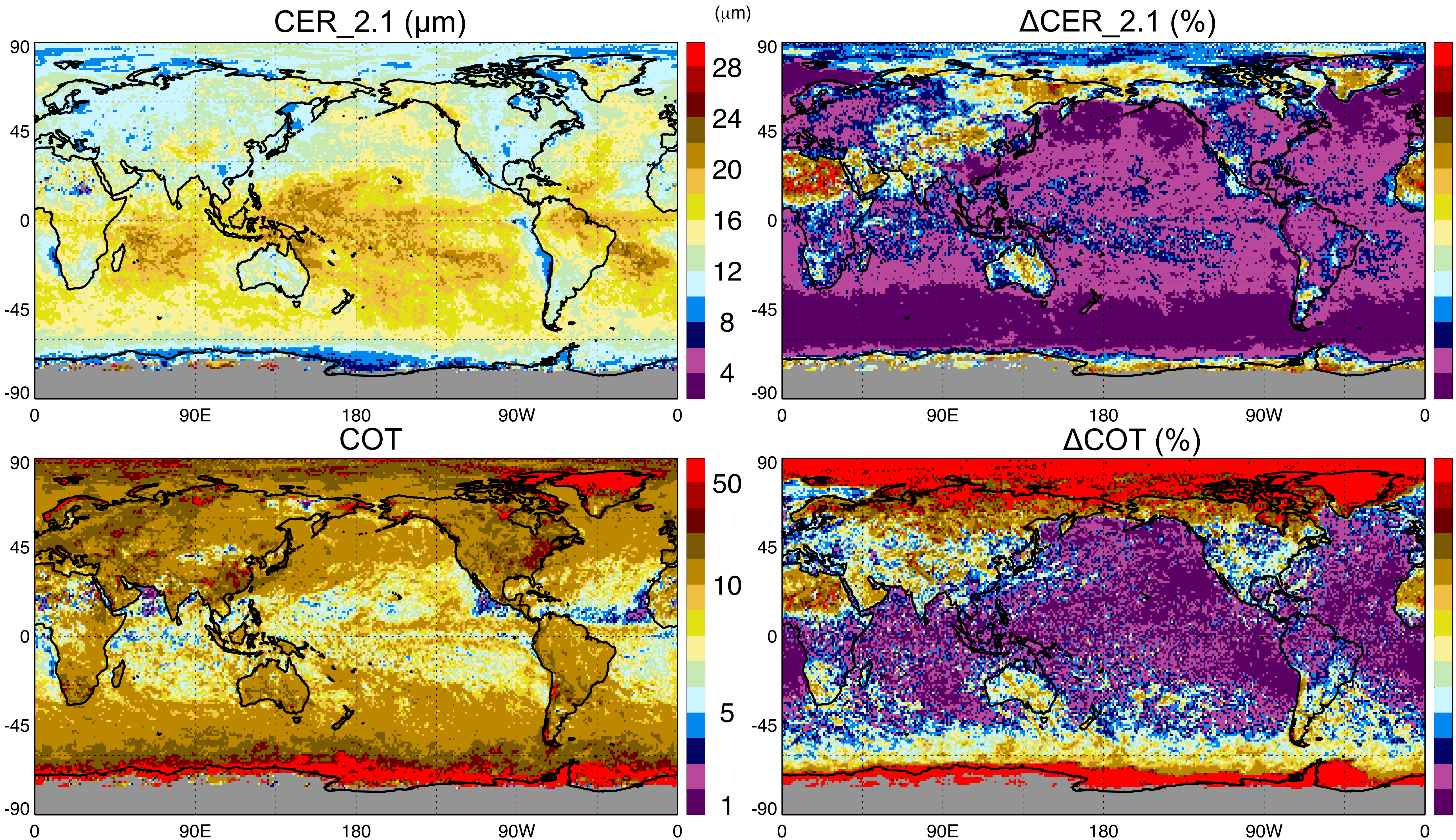
Single Day Uncertainty (1 April 2005) w/pixel-to-pixel error correlation = 1



Uncertainties in Aggregated Means: Monthly

Monthly Means for Liquid Water Clouds

Monthly Uncertainty (April 2005) w/day-to-day error correlation = 0



Cloud Optical Properties Summary

- Significant changes/enhancements throughout C6
  - User Guide (beta version): modis-atmos.gsfc.nasa.gov/products_C006update.html
- MOD06 COP is portable!
  - Runs on VIIRS, SEVIRI (ICARE), airborne (eMAS, MASTER, AMS)
- Useful links/references
  - L2 Global Browse imagery: modis-atmos.gsfc.nasa.gov/IMAGES/index.html. Selected products, resolution, longitude.
  - L3 Aqua MODIS Browse: modis-atmos.gsfc.nasa.gov/IMAGES/08_D3.html
  - Known problems page: modis-atmos.gsfc.nasa.gov/validation.html