Examination of 1.24 and 1.6 micron cloud optical depth retrievals over snow and ice surfaces

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Outline

- Objectives and Background of CERES Ed4
- Evaluations → CERES Ed4 Cloud Optical Depth over Snow/Ice Appear to be High
- Approach from This Study:
  (1) Examine impact of a new ice crystal reflectance model
  (2) Examine impact of using a different wavelength channel
- With new approach, Results of Snow/Ice Cloud Optical Depth
- Comparisons with MODIS ST
- Validation with CALIPSO
- Summary & Future Plans

Objectives and Background of CERES Ed4

- Improve accuracy and reliability of cloud optical depth retrievals using CERES MODIS and VIIRS cloud algorithms

- In CERES Ed4, Cloud optical depth retrieval over snow & ice surfaces

  (1) Ice crystal reflectance model

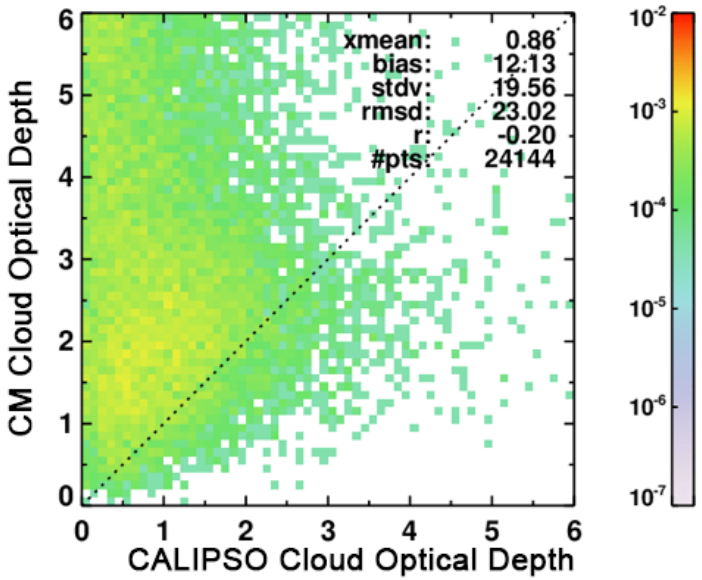
  roughened single habit ice columns (SHM)

  (2) Channel selection:

  1.24 μm

Evaluations → Ed4 Cloud Optical Depth over Snow/Ice Appear to be High

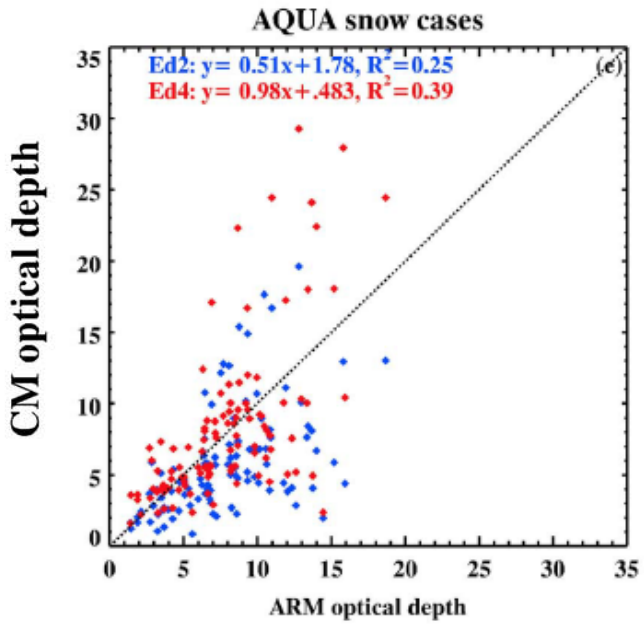
Thin cirrus over snow, global



- COD extremely biased high over snow
  - COD = 12.1 vs. 0.86
- No evaluation for thick ice clouds

- Yost et al., TGRS, 2019

Water τ over ARM NSA, over snow



- COD reasonable over NSA site
- Overcast, relatively thick clouds

- Dong et al. JGR, 2016

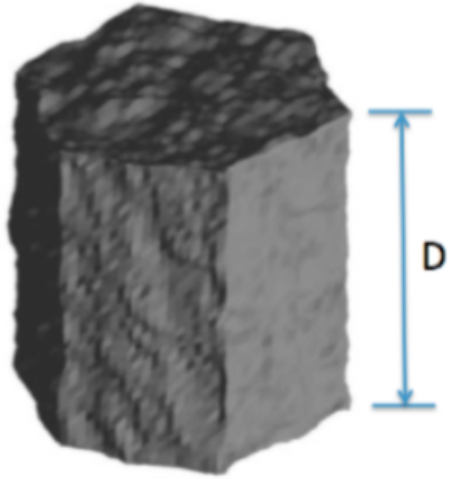
- COD retrieval for liquid water clouds not reliable, probably due to uncertainty in clear-sky radiance input
  - *appears to be too high on average*

- COD retrieval for ice not usable, more sensitivity to clear radiance uncertainty, single habit model overestimates COD

Approach from This Study
Examine impact of a new ice crystal reflectance model

CERES Ed4
Roughened single hexagonal column (SHM)

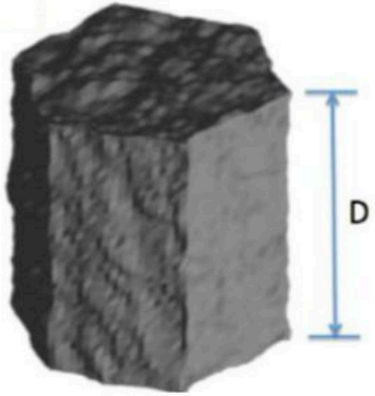
Habit-1:



Single column, D=L=2a, σ^2=0.5, V=0.65D^3

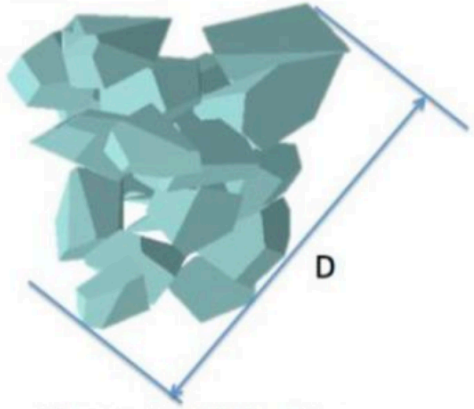
This study
Two-habit model (THM)

Habit-1:



Roughened Hexagonal Column
Single column, D=L=2a, σ^2=0.5, V=0.65D^3

Habit-2:



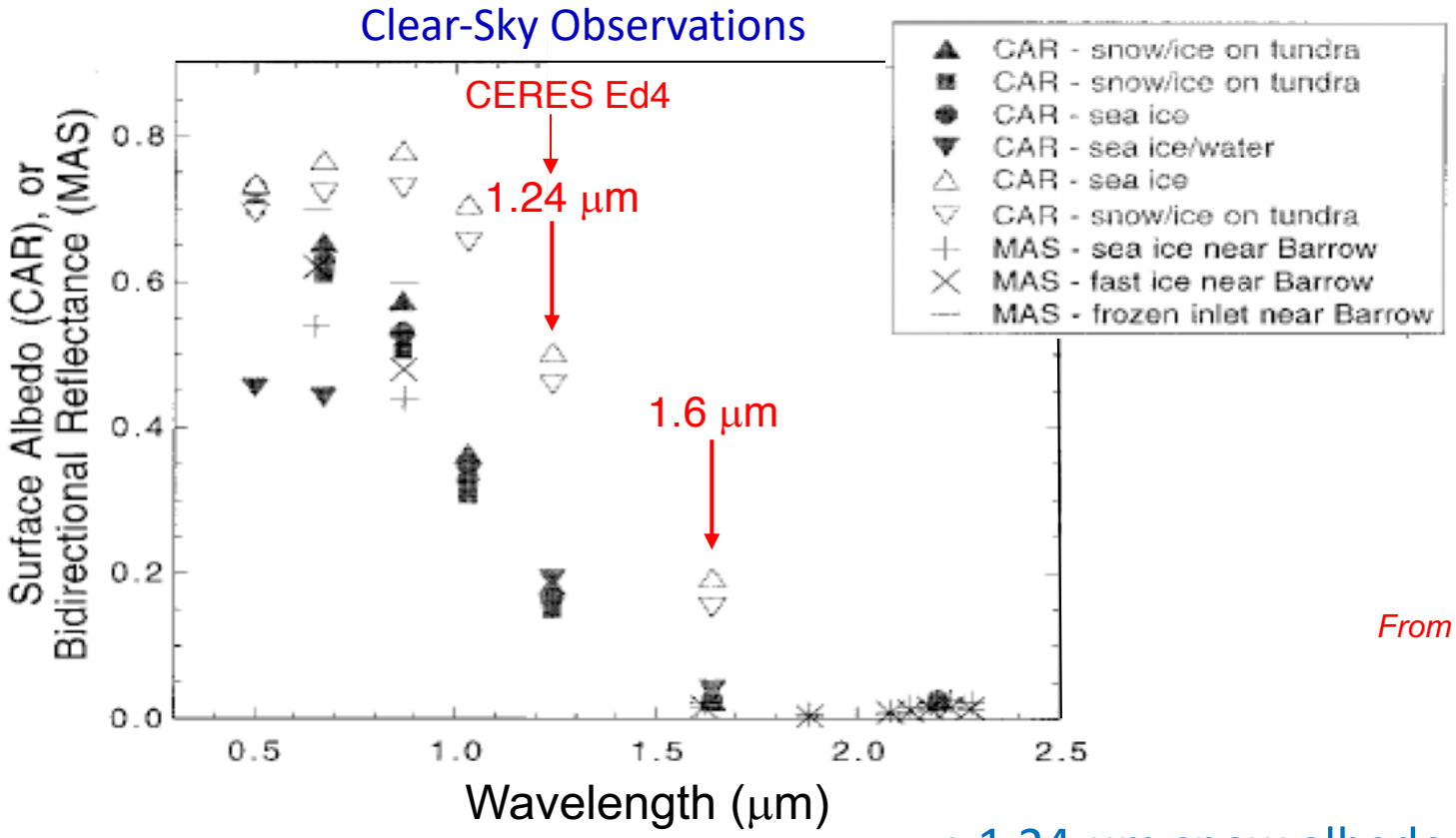
20-ensemble of 20-irregular-aggregates, randomly tilted surface, σ^2=0.5, V=0.053D^3

Compact particle, smaller asymmetry factor, therefore smaller COD

Yang et al. 2016
Loeb et al. 2018

Approach from This Study
Examine impact of using a different wavelength channel

Spectral Snow & Ice Albedos/Reflectances

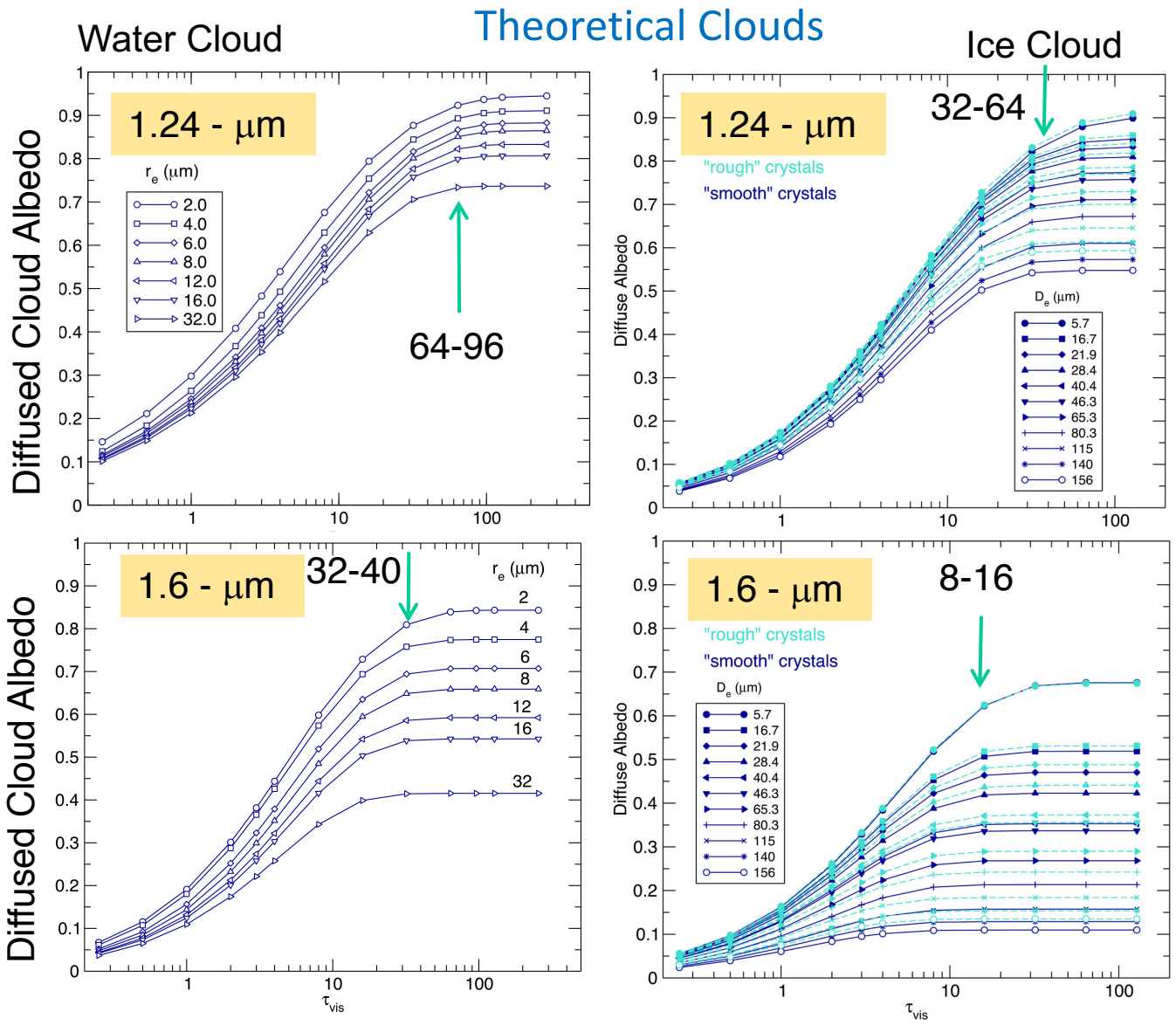


From Platnick et al., JGR, 2001

- 1.24-μm snow albedo: 0.13 - 0.50
- 1.62-μm snow albedo: 0.02 – 0.19

- Surface reflectance uncertainty much higher for 1.24 μm
- Snow stronger absorber for 1.6 μm than 1.24 μm

Examine impact of using a different wavelength channel - Conti



- Liquid COD saturation, 1.24 μm: ~ 64-96
  1.62 μm: ~ 32-40
- Ice COD saturation, 1.24 μm: ~ 32-60
  1.62 μm: ~ 8-16

- 1.24 μm greater COD range available
- Actual saturation COD depends on particle size and angular configurations

Three Snow / Ice Cloud Optical Depth Retrievals

CERES Ed4

(1) Single Habit Model (SHM), 1.24 μm

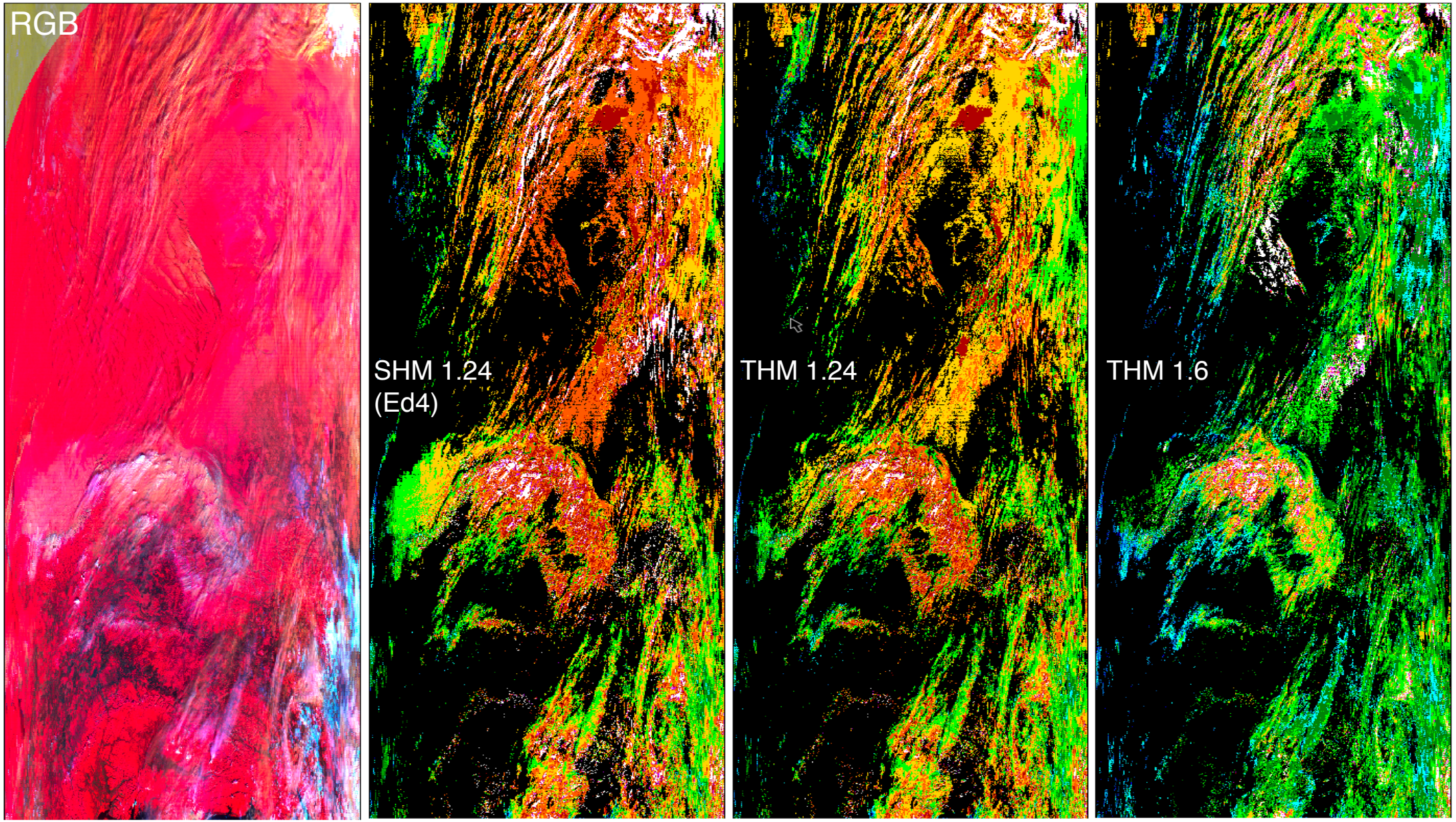
This Study

(2) Two Habit Model (THM), 1.24 μm

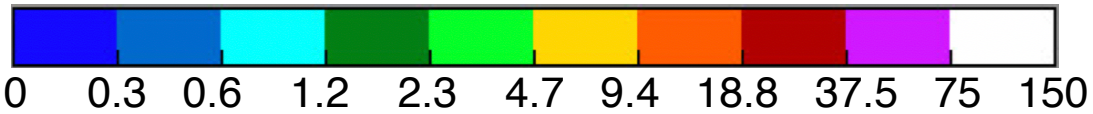
(3) Two Habit Model (THM), 1.6 μm

Pixel level cases and monthly global maps & stats

Cloud Optical Depth

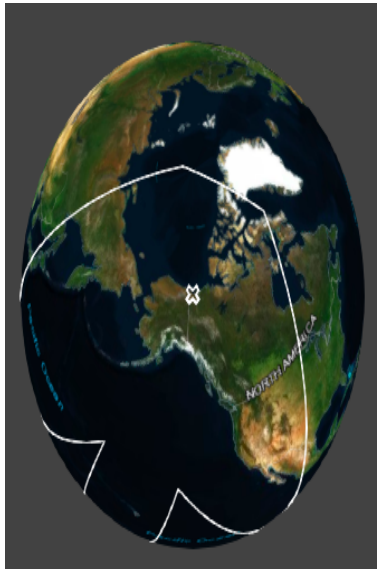


RGB



Terra MODIS
March 15
2009 UTC 21

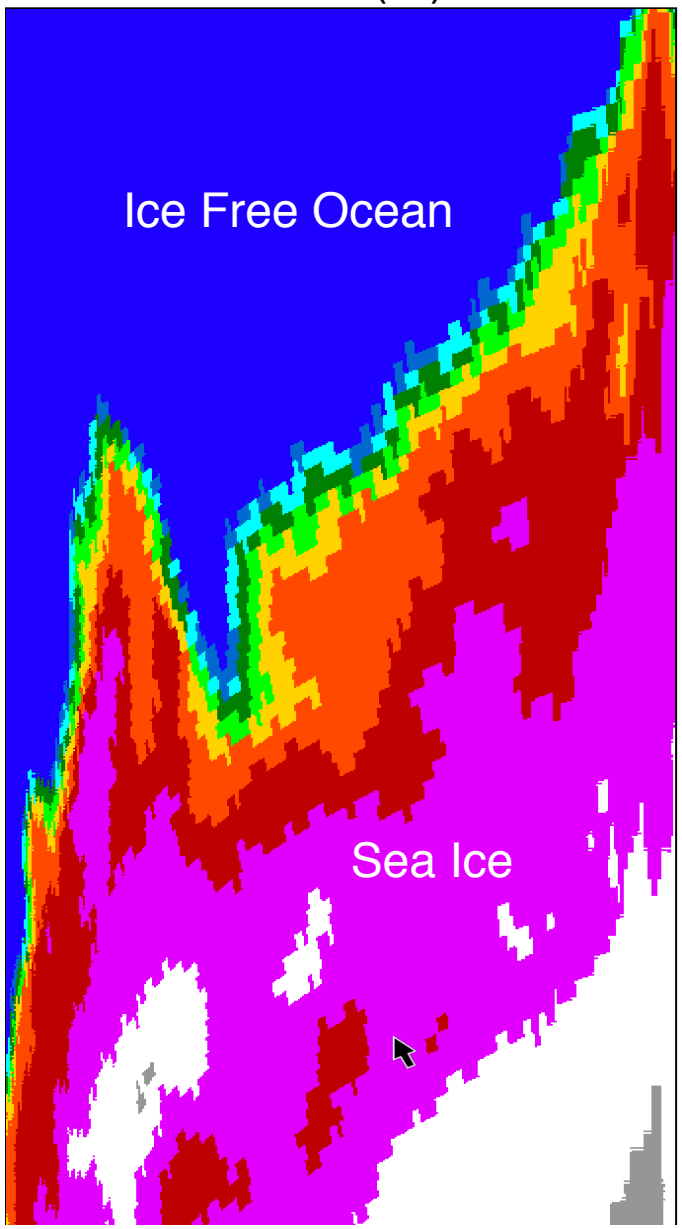
Over Canada

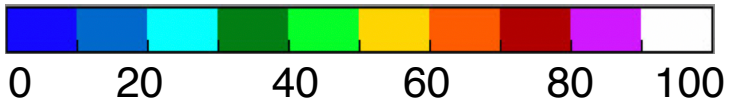


Terra MODIS, Sept. 1st, 2009 UTC 10

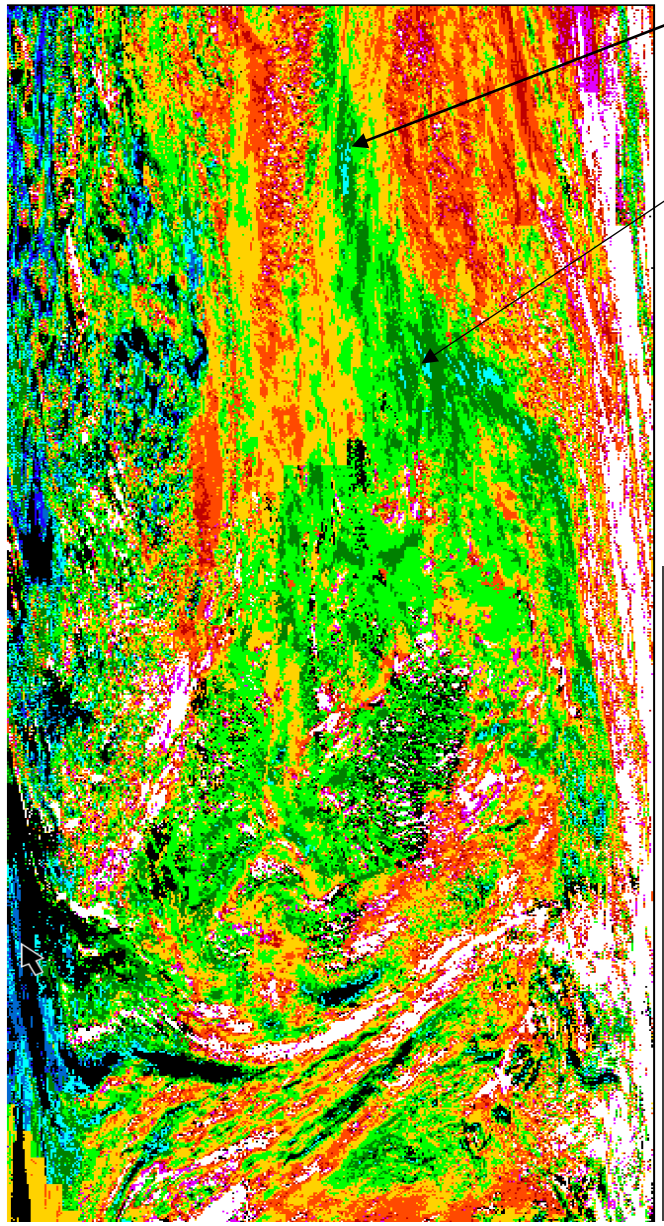
RGB

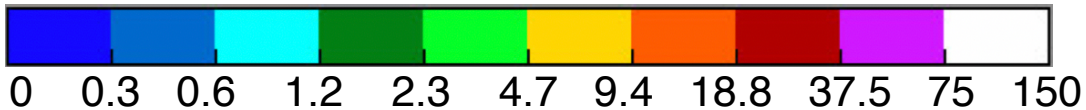
Sea Ice (%)





Cloud Optical Depth



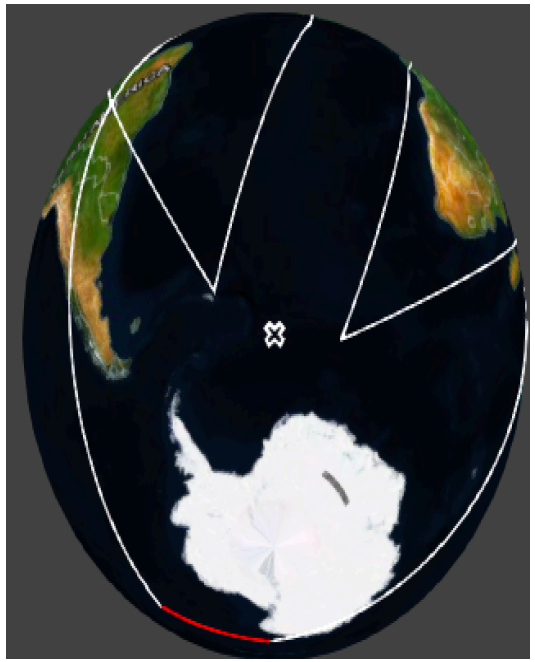


0.6 μm (ice free)

1.6 μm (ice covered)

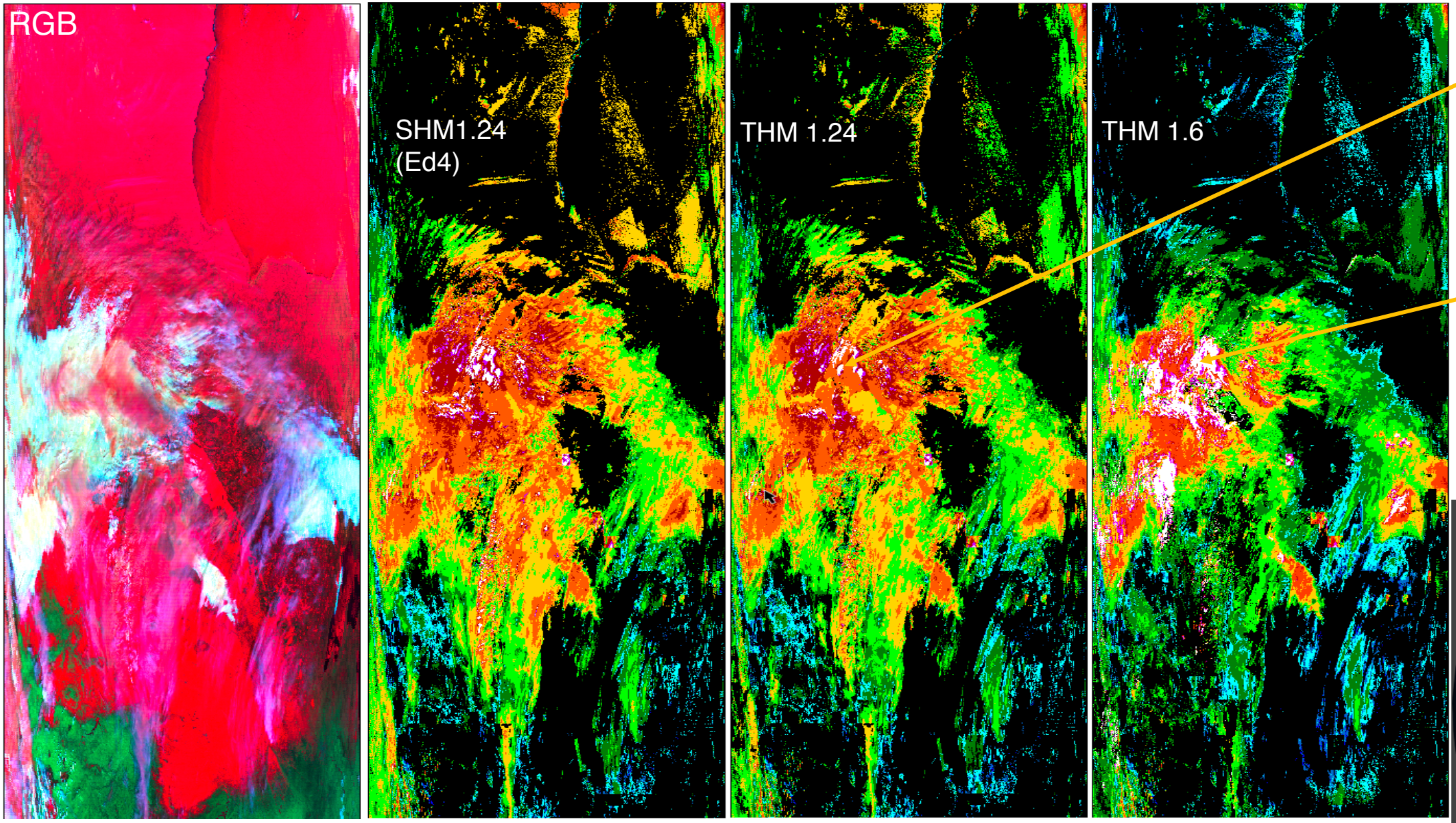
- Consistent optical thickness between visible and 1.6 μm

Over Southern Ocean



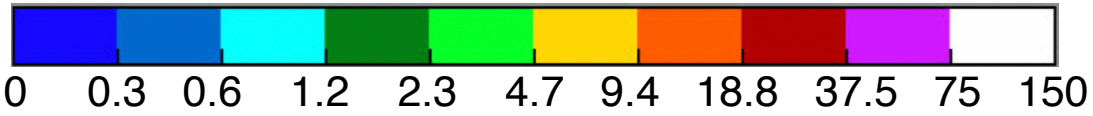
Terra MODIS, March 15, 2009 UTC 17

Cloud Optical Depth

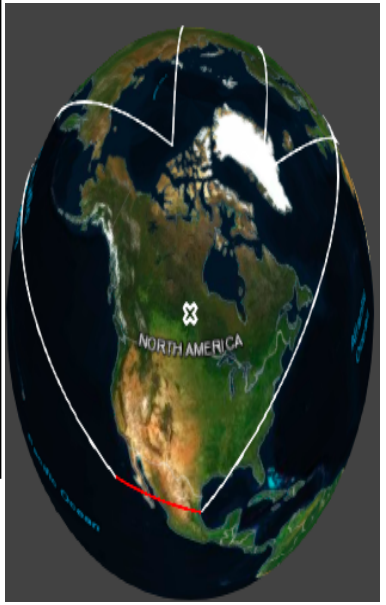


THM 1.24 has better sensitivity for thicker clouds

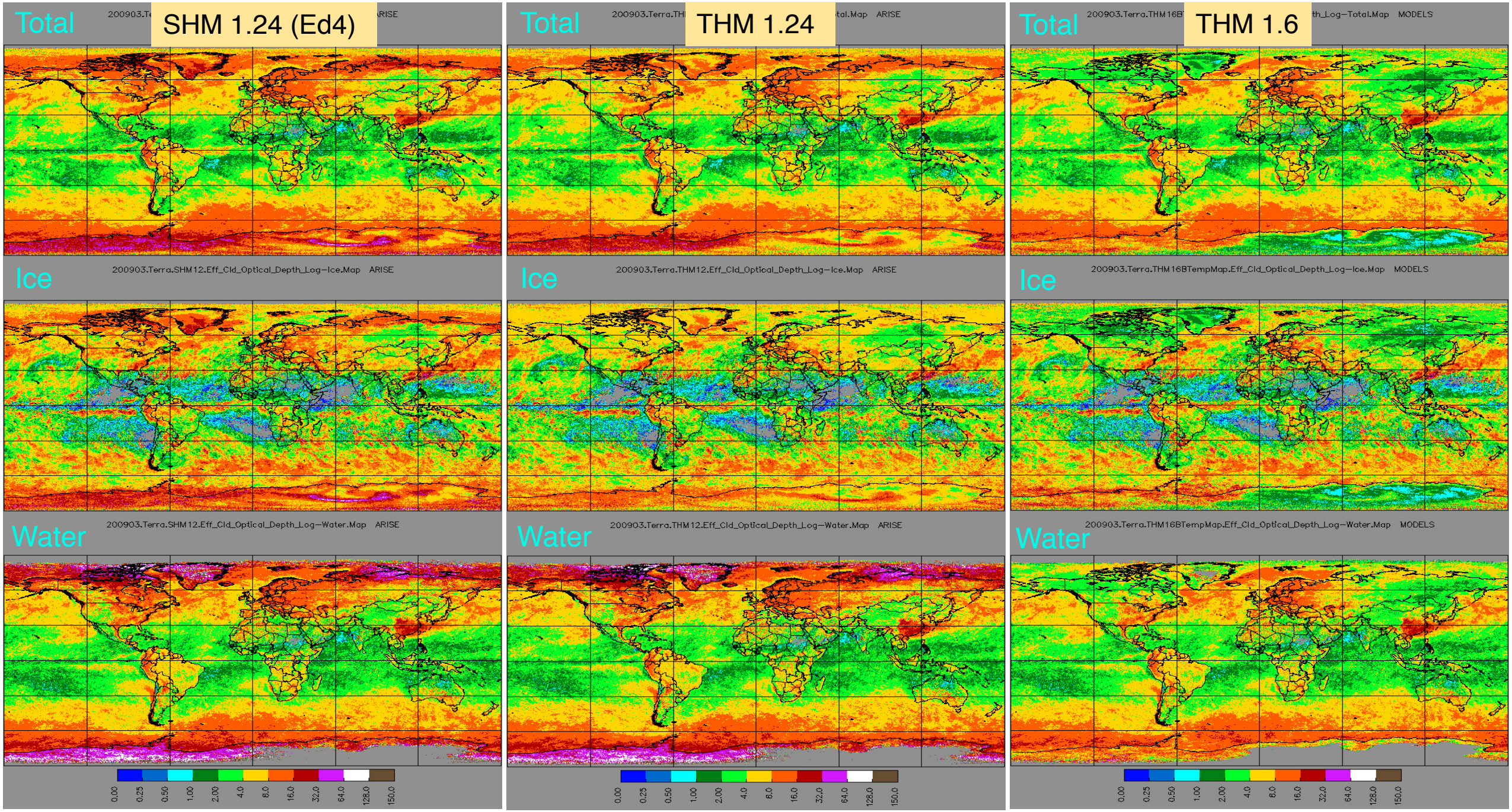
1.6 saturates for thick clouds



Over Canada

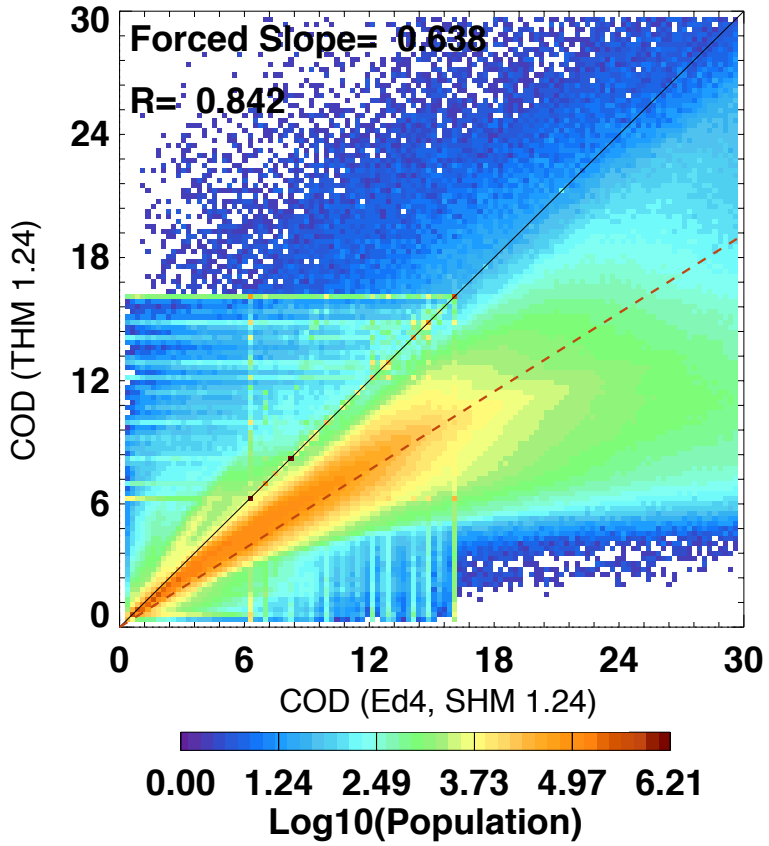


Cloud Optical Depth, Terra MODIS, March 2009



Ice Cloud Optical Depth Scatterplots, Terra-MODIS, March 2009

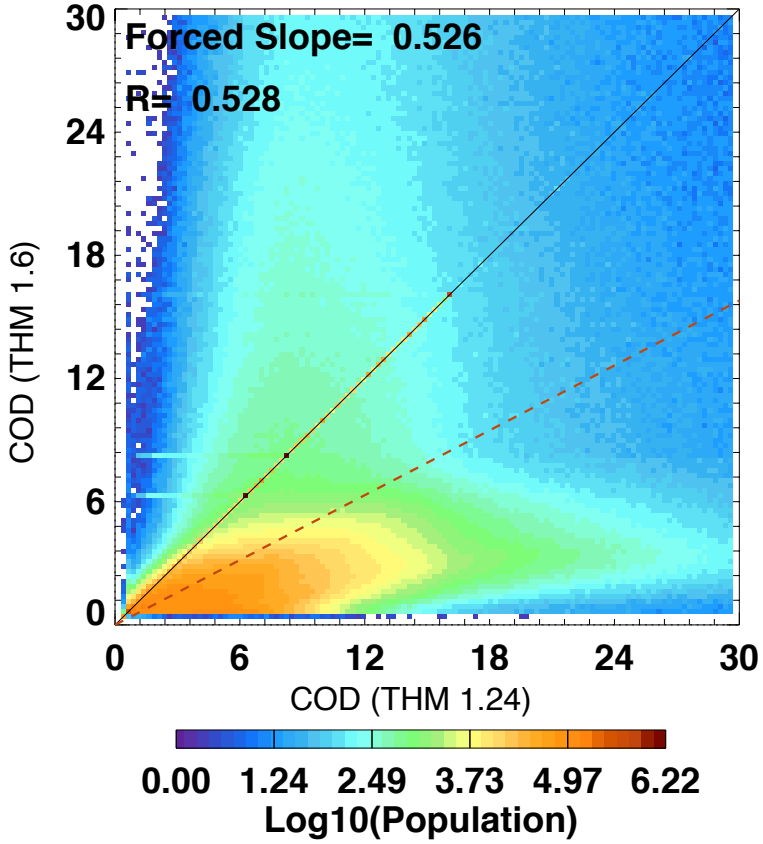
THM 1.24 .vs. SHM 1.24 (Ed4)



N= 42136137.

	Mean	(StdDev)
SHM12	8.48(	5.55)
THM12	5.84(	3.41)
Y-X	-2.64(	3.26)
RMS(	4.19).....	

THM 1.6 .vs. THM 1.24



N= 31797983.

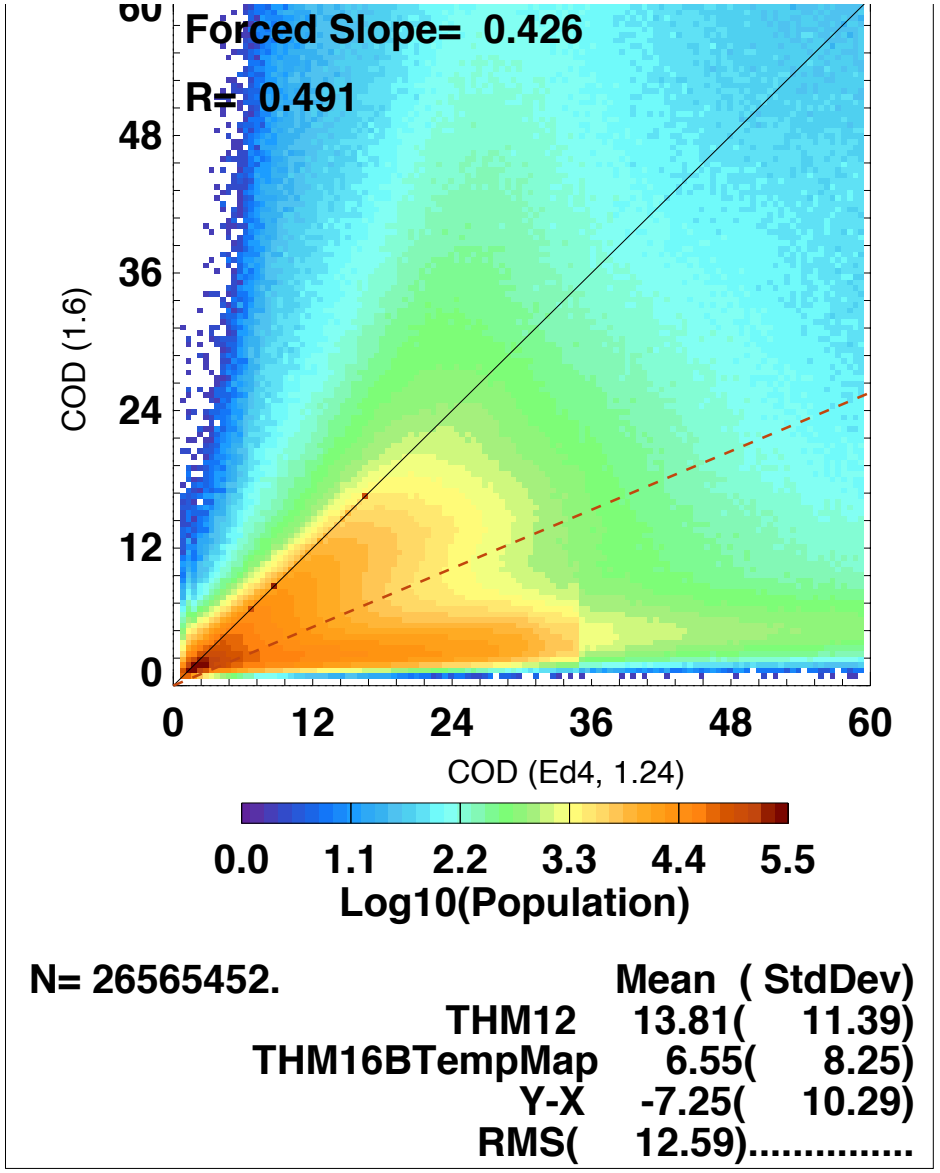
	Mean	(StdDev)
THM12	6.57(	4.22)
THM16BTempMap	3.44(	4.29)
Y-X	-3.13(	4.14)
RMS(	5.19).....	

COD Averages

Ed4:	8.5 (5.6)
THM 1.24:	5.8 (3.4)
THM 1.6:	3.5 (4.3)

Liquid Water Cloud Optical Depth Scatterplots, Terra-MODIS, March 2009

1.6 .vs. 1.24 (Ed4)

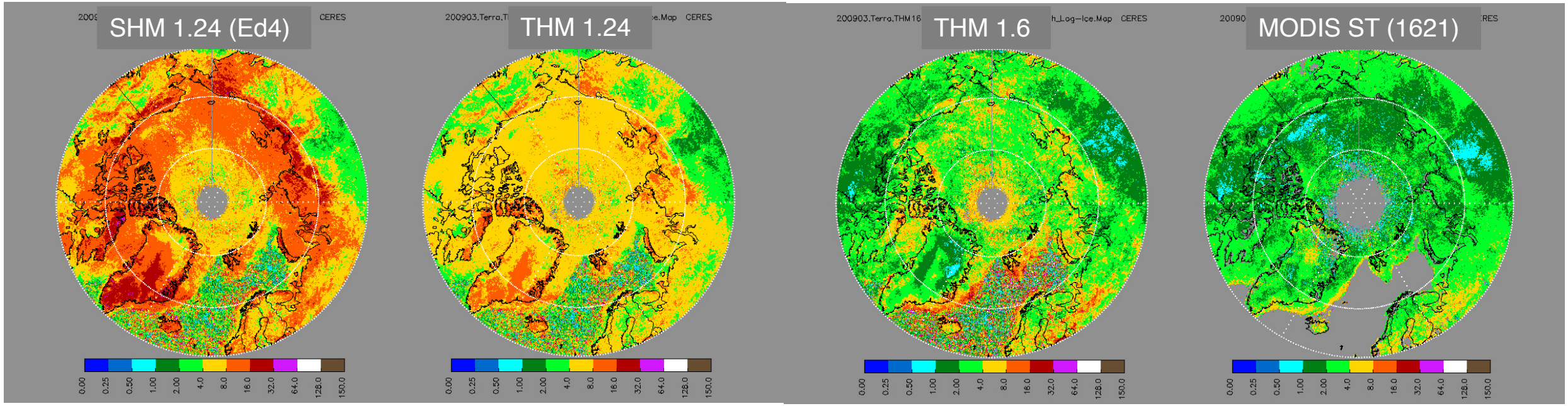


COD Averages	
1.24 (Ed4):	13.8 (11.4)
1.6:	6.6 (8.3)

Comparison with MODIS ST retrieval (1621)

Ice Cloud Optical Depth over Snow & Ice surface (Northern Polar Regions)
Terra-MODIS March 2009

Ice Cloud



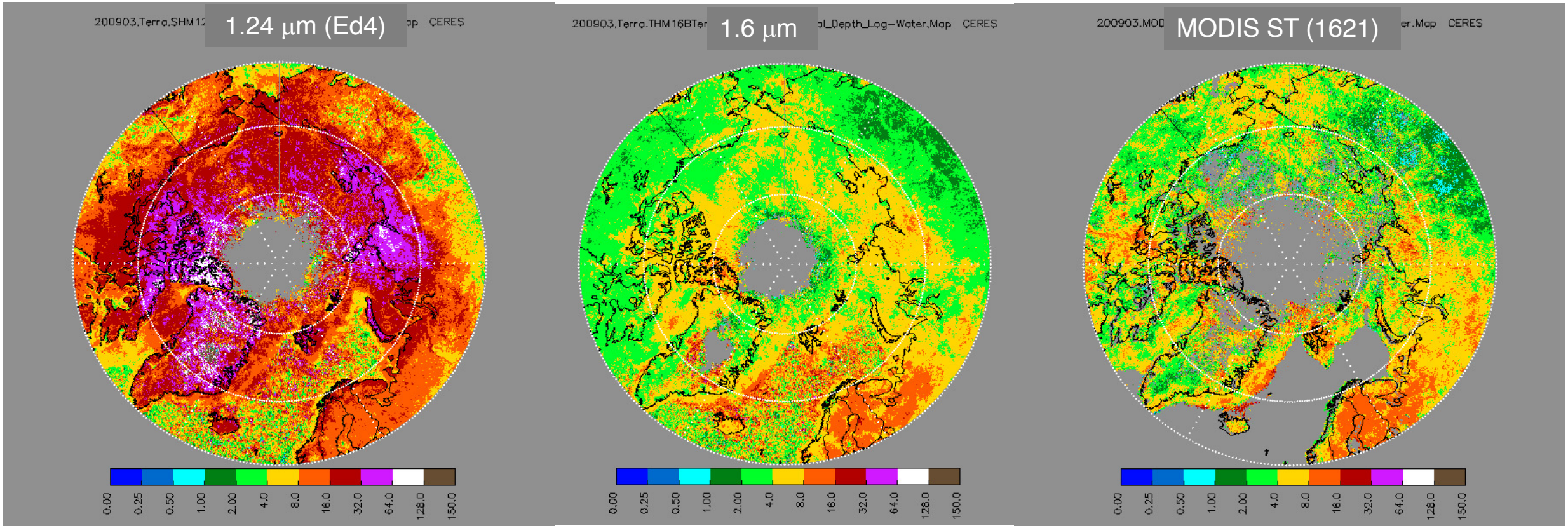
Ice COD Average (0 – 30)

SHM (1.24)	THM (1.24)	THM (1.6)	MODIS ST
9.0 (2.7)	6.8 (4.1)	2.9 (3.9)	3.3 (3.7)

- THM 1.6 COD comparable with MODIS ST, ~ 0.4 smaller than MODIS ST
- MODIS ST has more no-retrieval

Liquid Water Optical Depth over Snow & Ice surface (Northern Polar Regions)
Terra-MODIS March 2009

Water Cloud



Liquid COD Average (0 – 60)

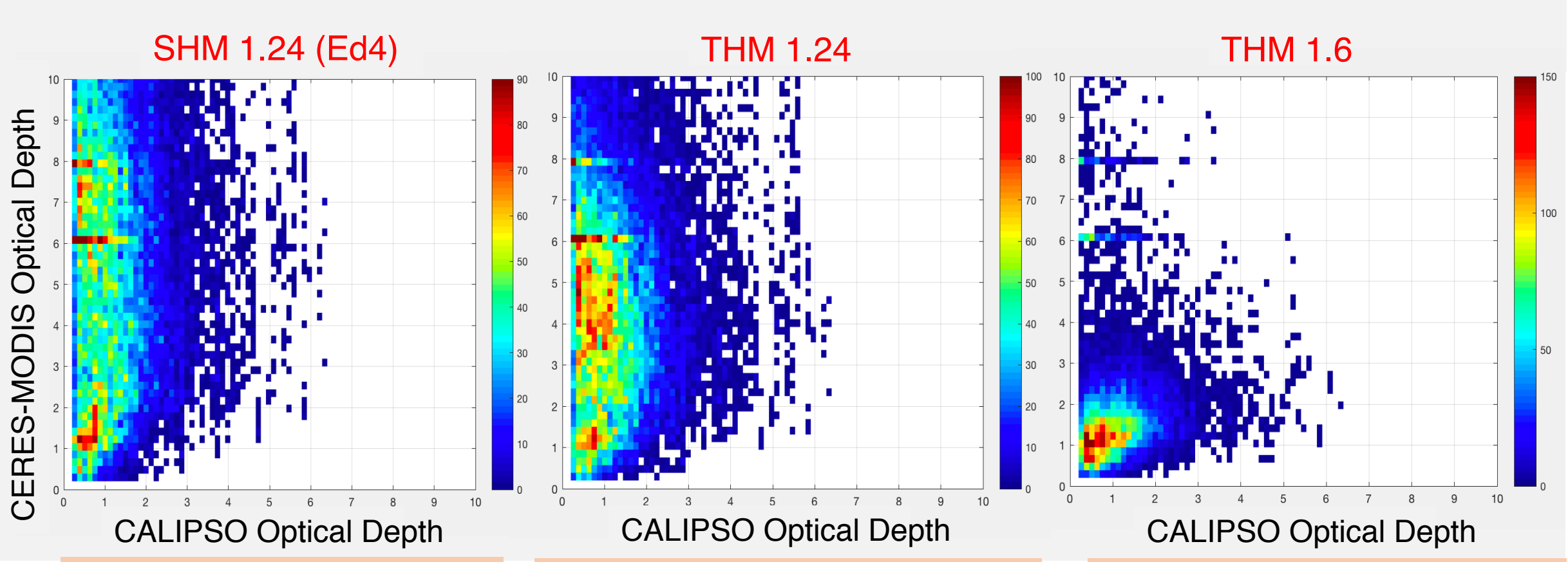
Ed4 (1.24 μm)	1.6 μm	MODIS ST (1621)
14.0 (11.2)	8.5 (9.9)	8.6 (7.9)

- 1.6 COD agrees with MODIS ST well
- MODIS ST has lots no-retrieval over snow covered land or call them ice

Validation with CALIPSO

Ice Clouds Optical Depth Scatterplots, C3M, April 2009

Single layer, transparent, ice clouds over snow/ice



Mean COD (Ed4): **8.0** (12.5)

Mean COD (THM 1.24): **5.3** (5.5)

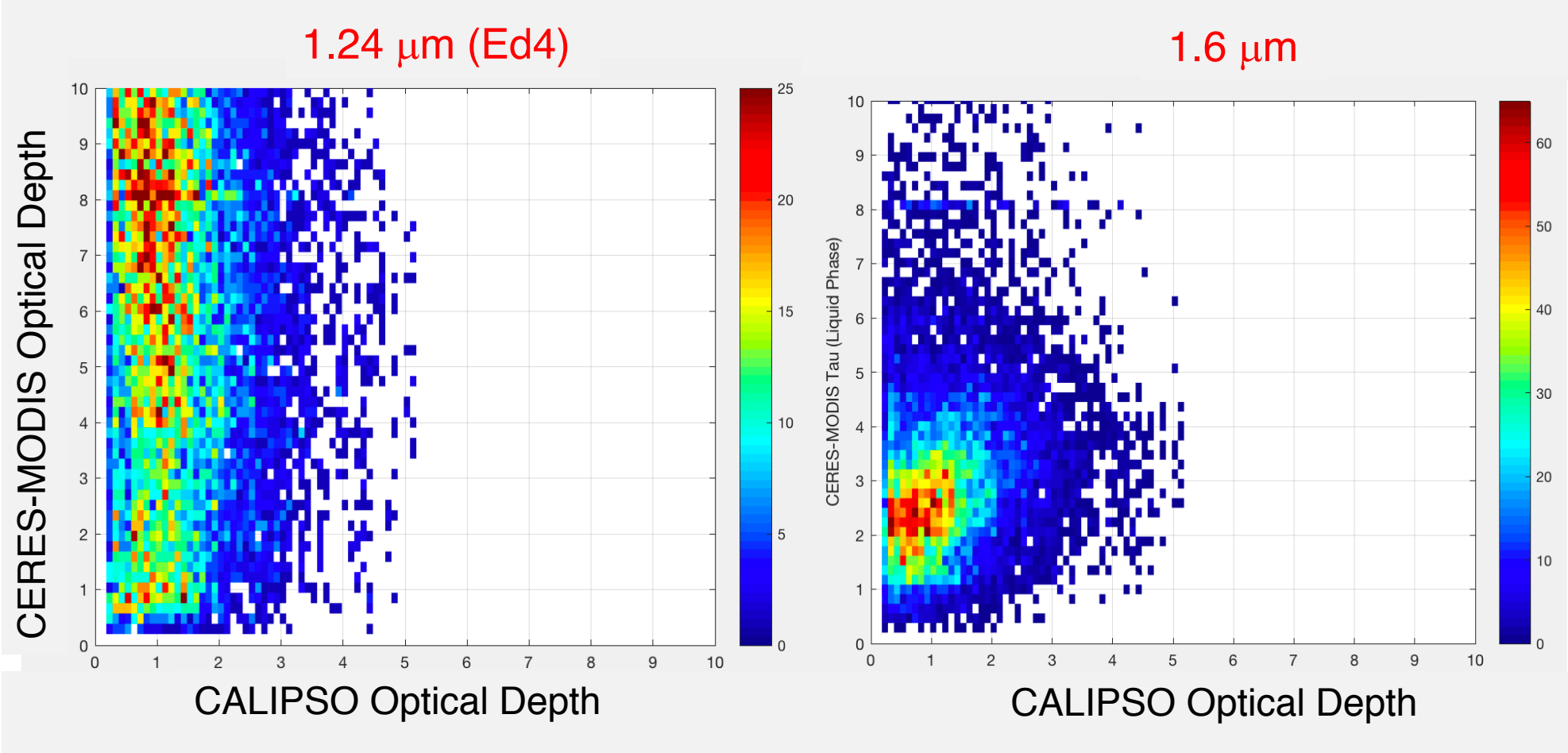
Mean COD (THM 1.6): **3.7** (11)

Mean COD (CALIPSO): **1.1** (0.76)

- Ed4 extremely biased high
- THM 1.6 the best choice to retrieve thin cirrus clouds

Liquid Water Clouds Optical Depth, Validation with CALIPSO, C3M, April 2009

Single layer, transparent clouds, over snow/ice



Mean COD (Ed4): **9.8** (8.6)

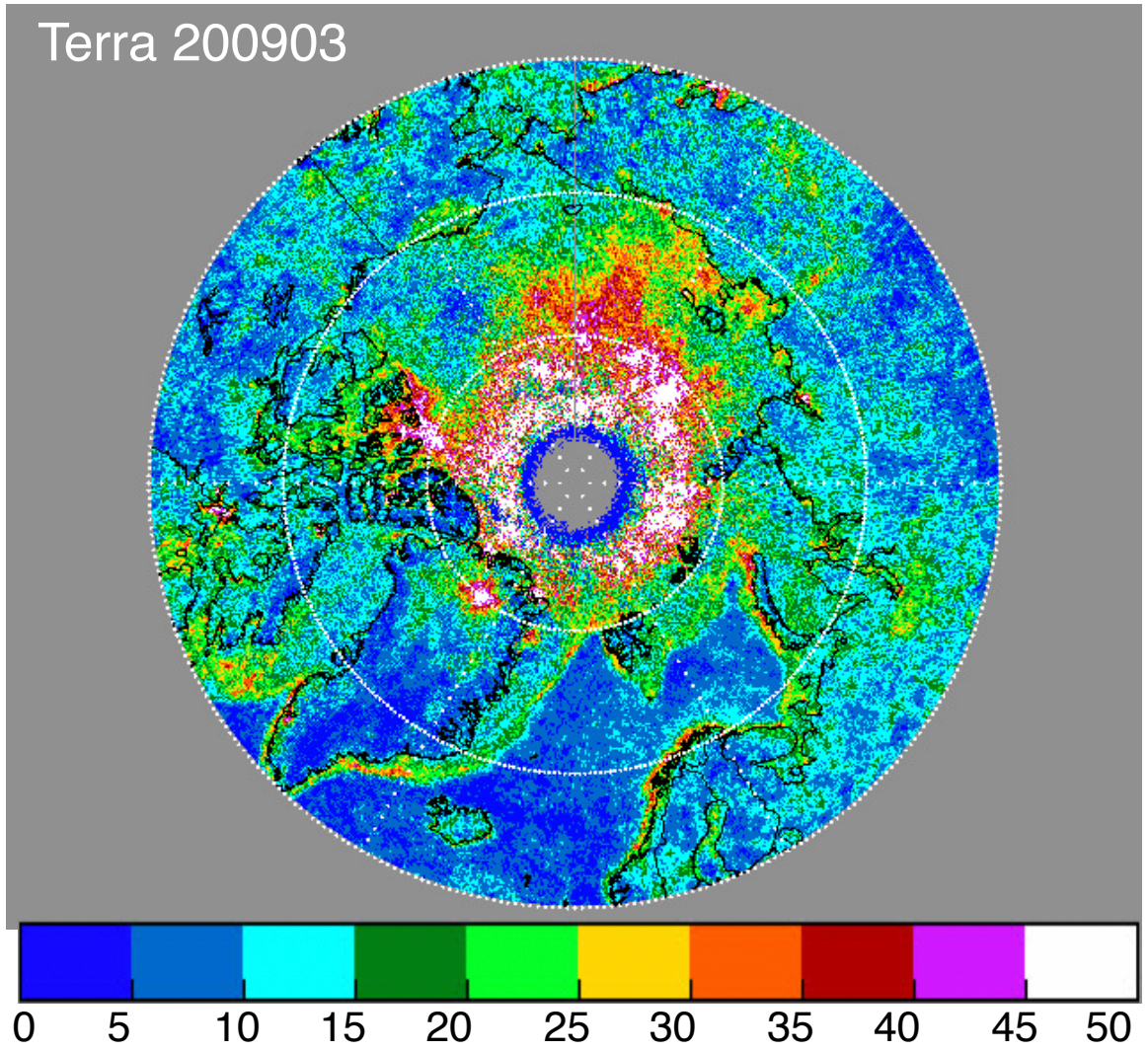
Mean COD (1.6): **3.4** (4.0)

Mean COD (CALIPSO): **1.3** (0.8)

- Ed4 extremely biased high
- 1.6 μm the best choice to retrieve thin clouds

Issue with THM 1.6
High no-retrieval percent

No Retrieval Percent



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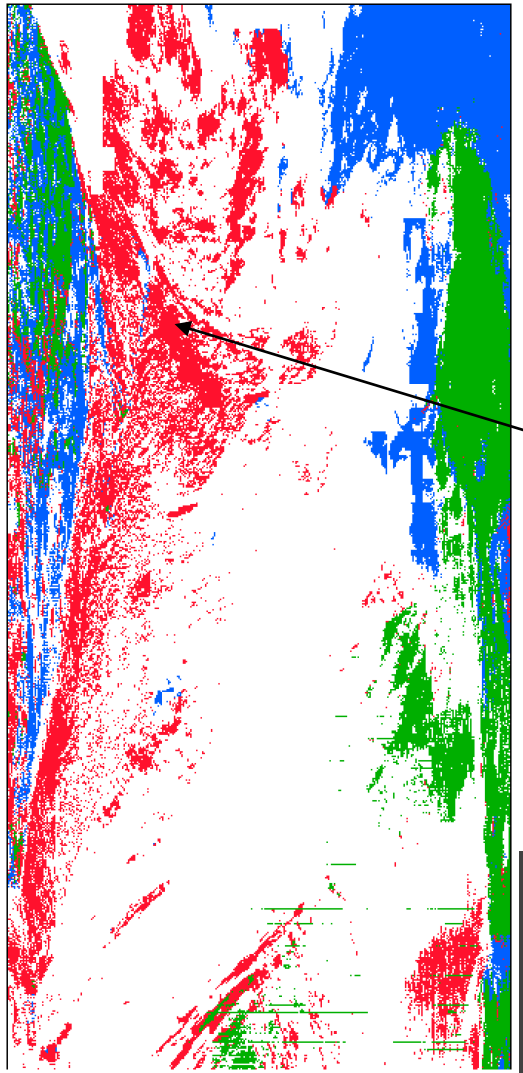
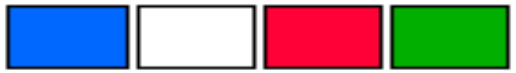
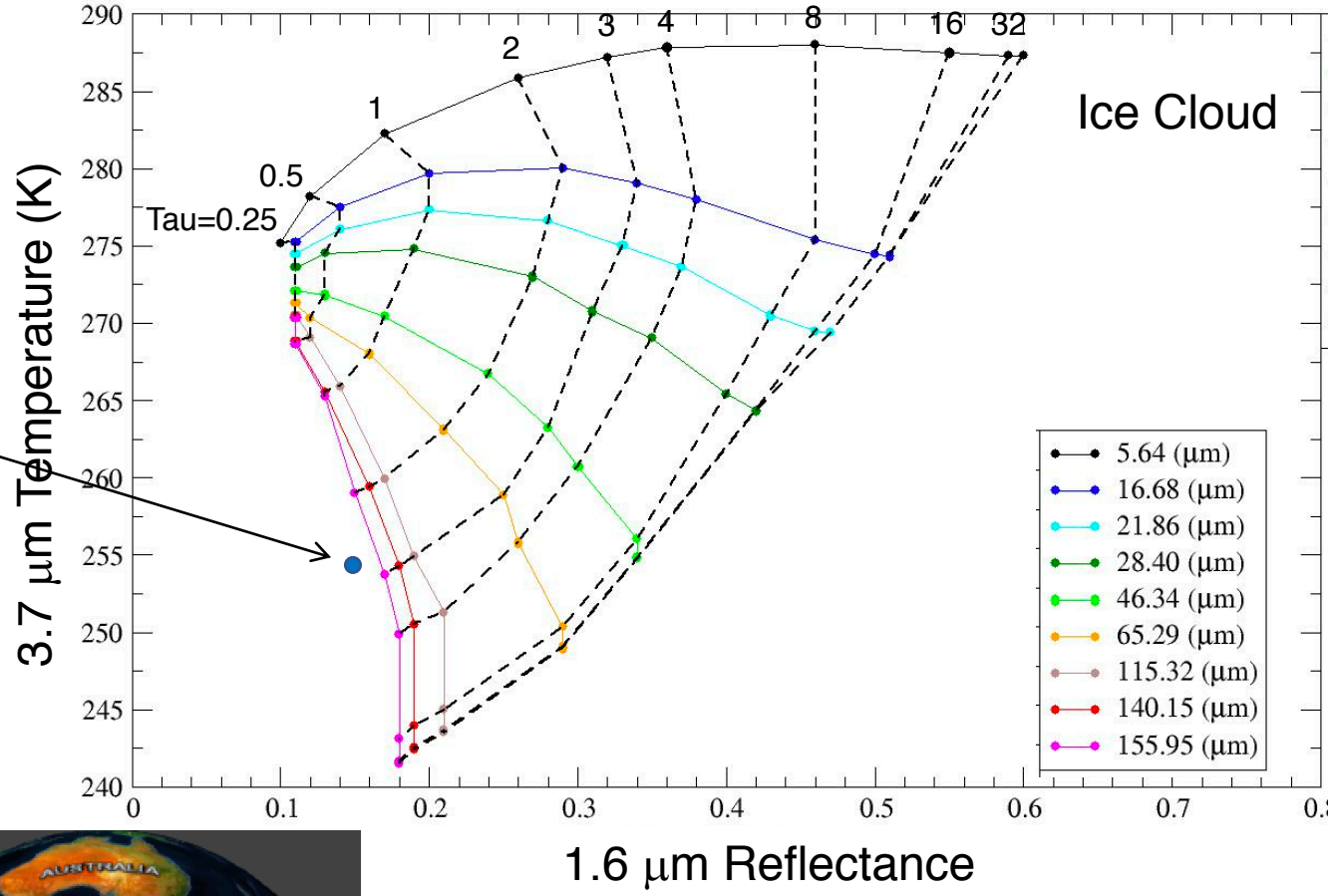
RGB

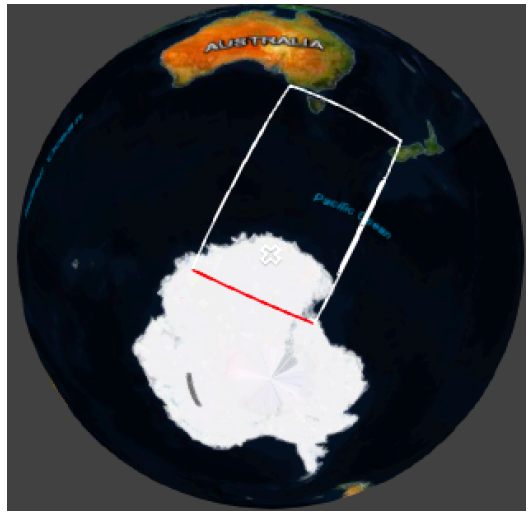




Water Ice No-Ret Clr

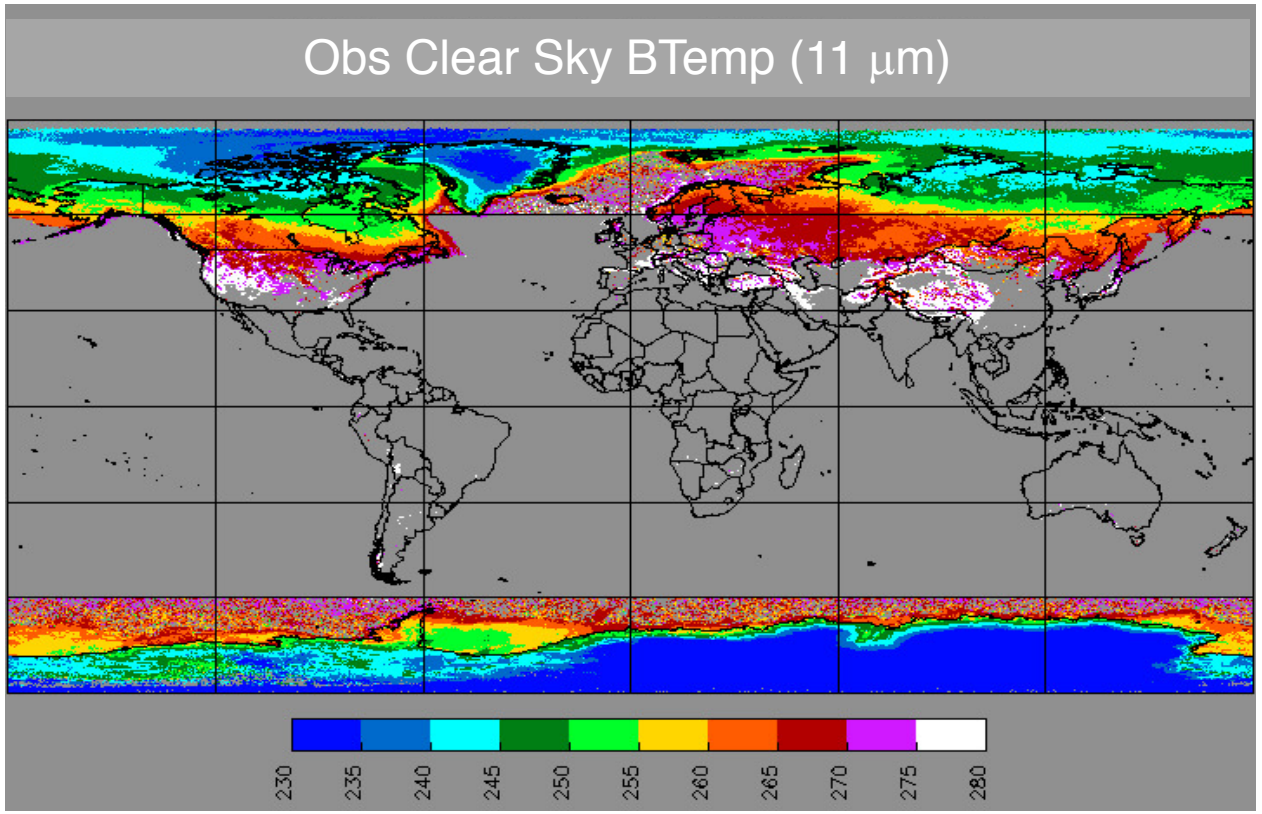
SZA=71 VZA=22 AZA=112

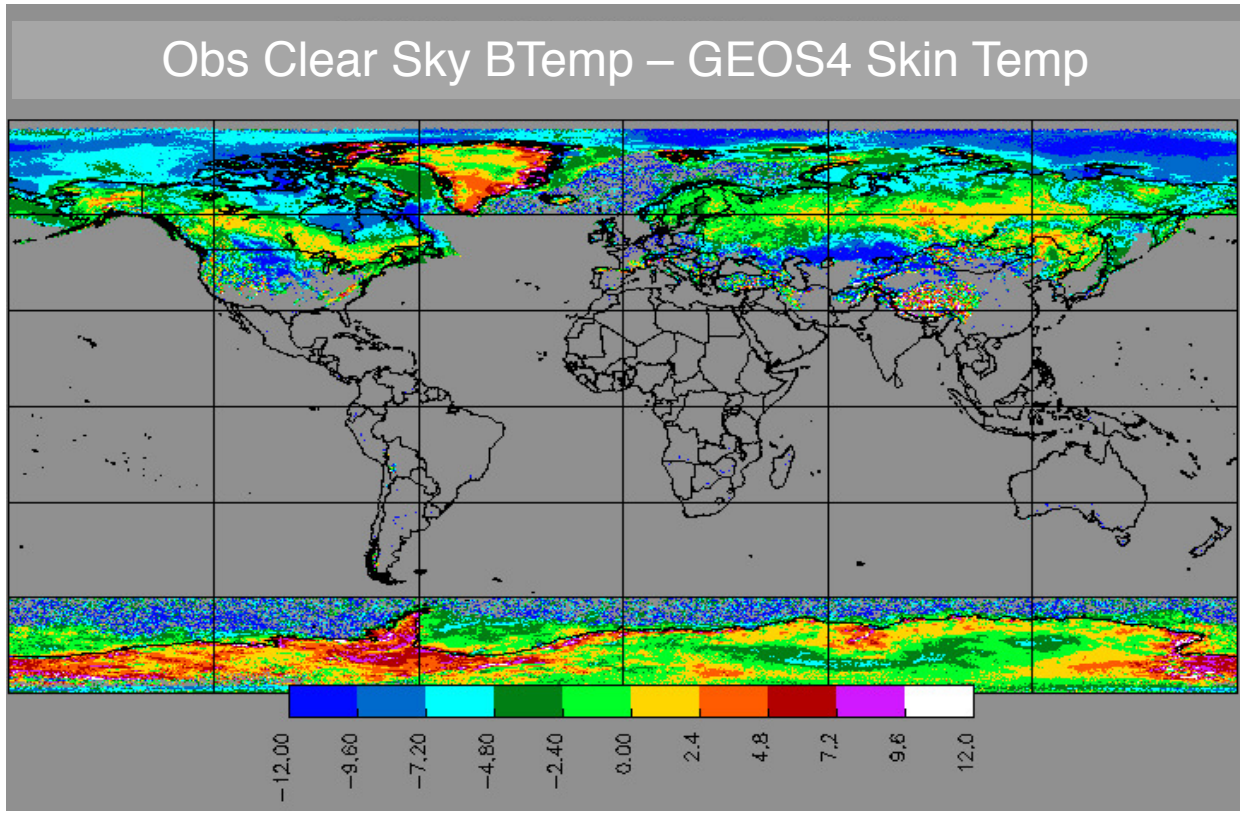




Over Antarctica

Terra-MODIS, March 2009, Over snow & ice surfaces



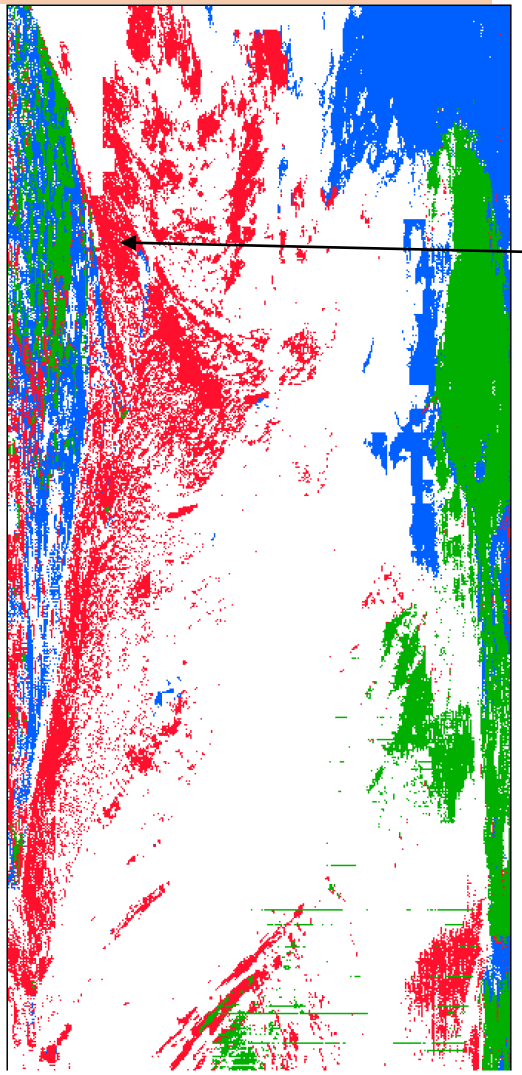


K	GEOS4 Skin Temp	Obs ClearSky BTemp (11μm)	Diff (Obs CS Btemp – GEOS4 SkinT)
Permanent Snow	234.7	235.6	0.9
Sea Ice Covered Ocean	255.1	249.5	-5.6
Snow Covered Land	259.0	255.7	-3.3

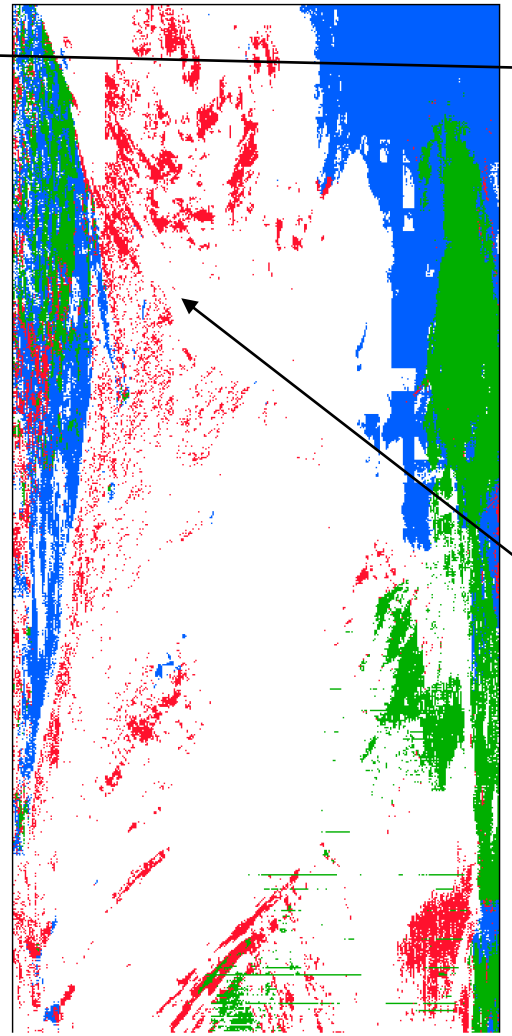
- GEOS4 Skin T too warm for sea ice covered ocean and some of snow covered land
- GEOS4 Skin T ok over permanent snow sfc except near coasts, where MOA Skin T a little too cold.

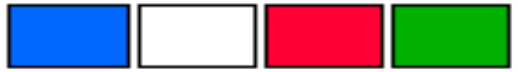
Terra-MODIS September 26, 2009 UTC 23

Using GEOS4 Skin T

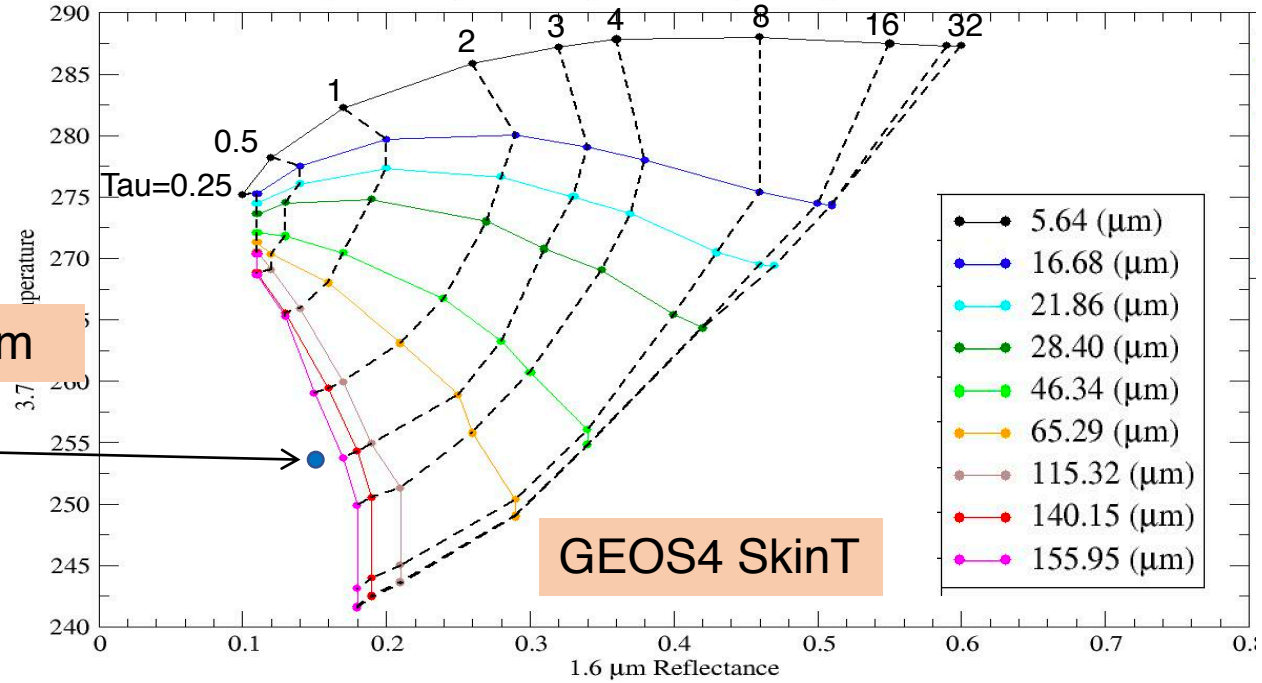


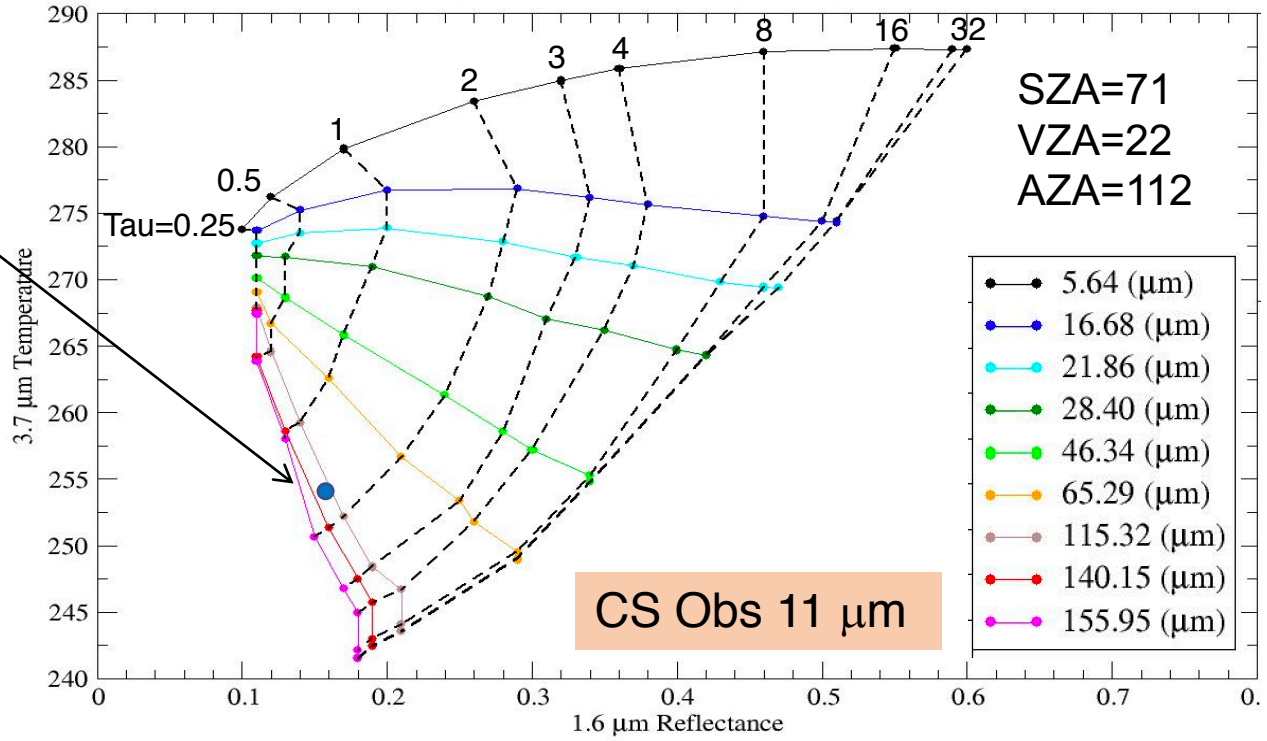
Using Obs CS BTemp 11 μm





Water Ice No-Ret Clr





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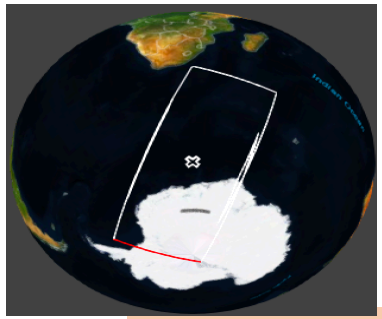
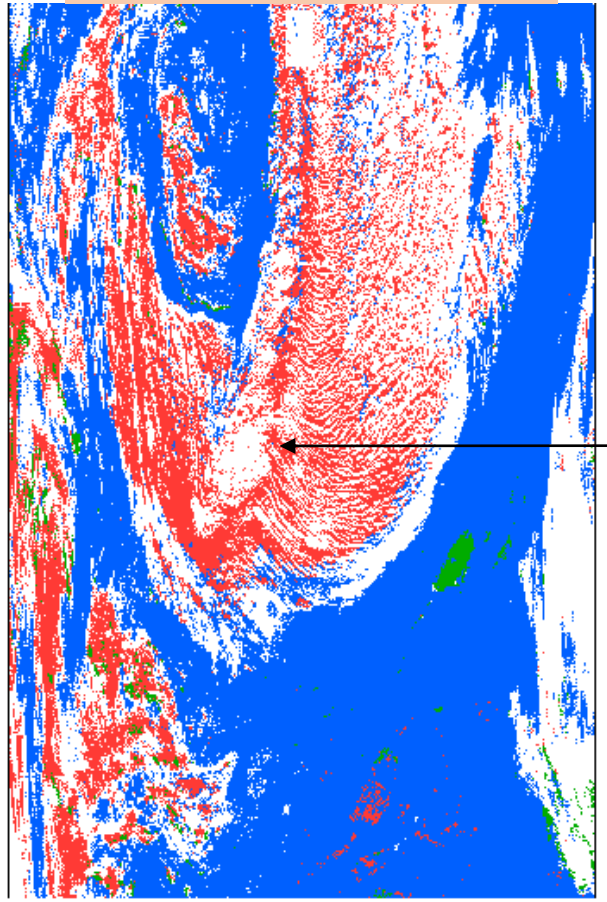
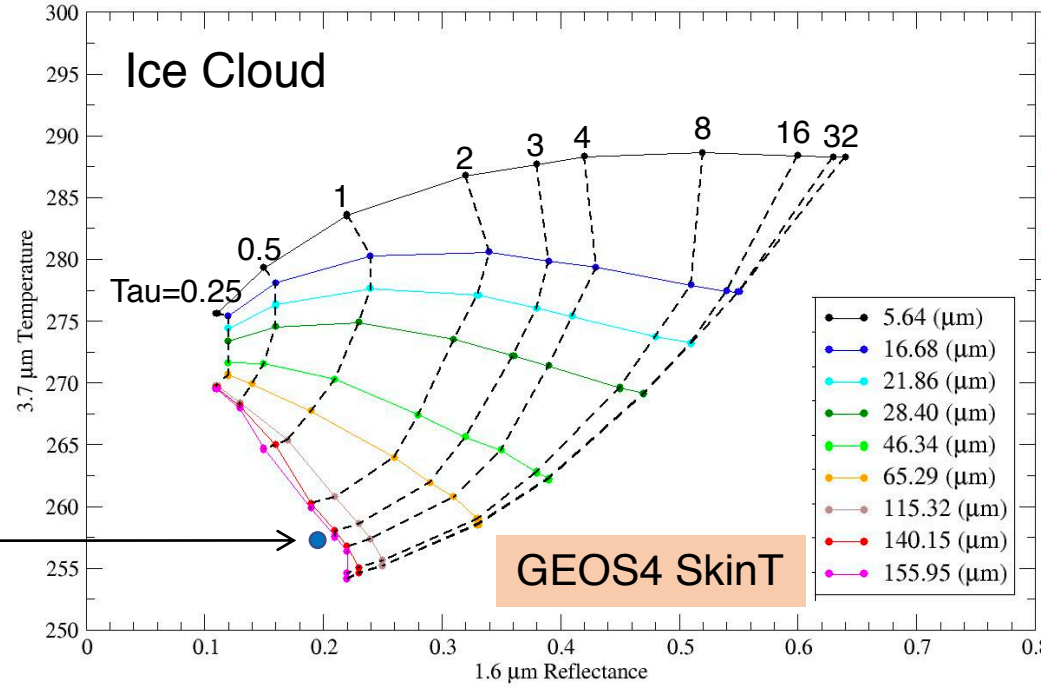
Over Southern Ocean

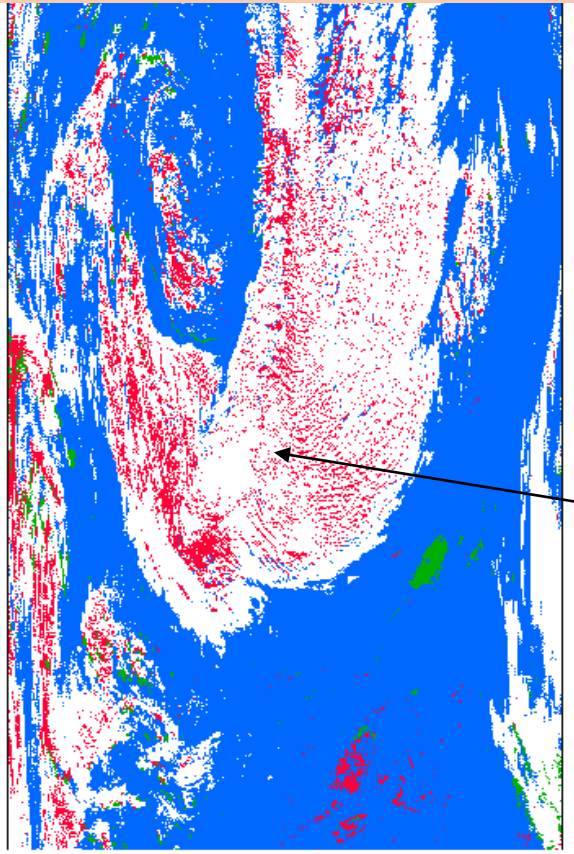


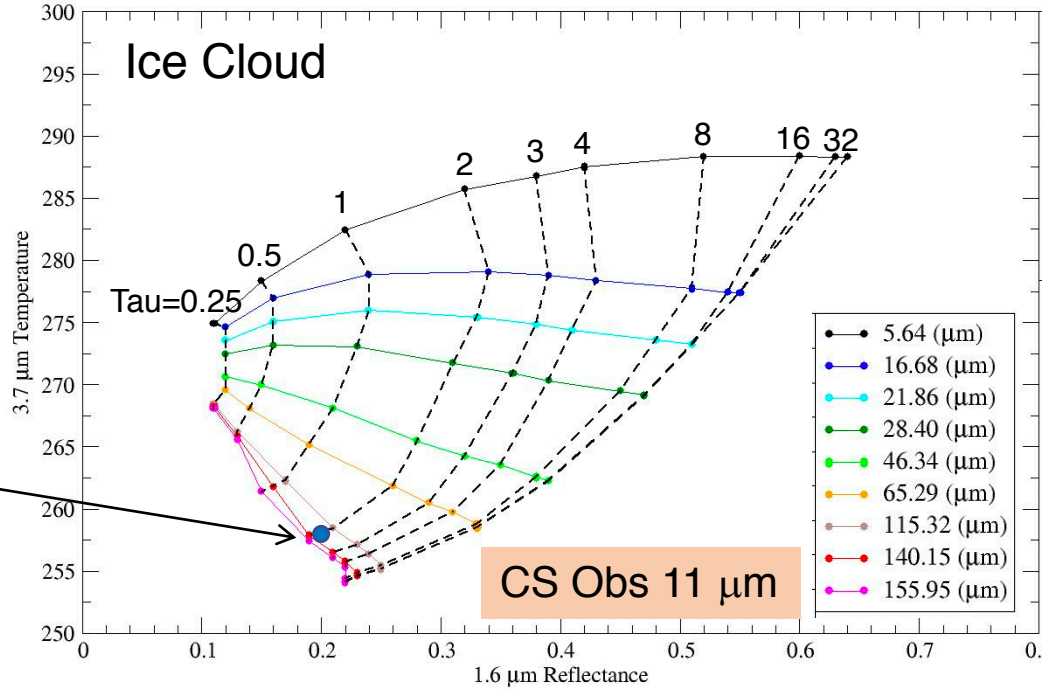
Using GEOS4 Skin T

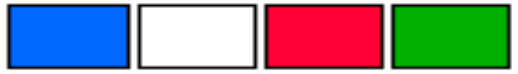




Using Obs CS BTemp 11 µm

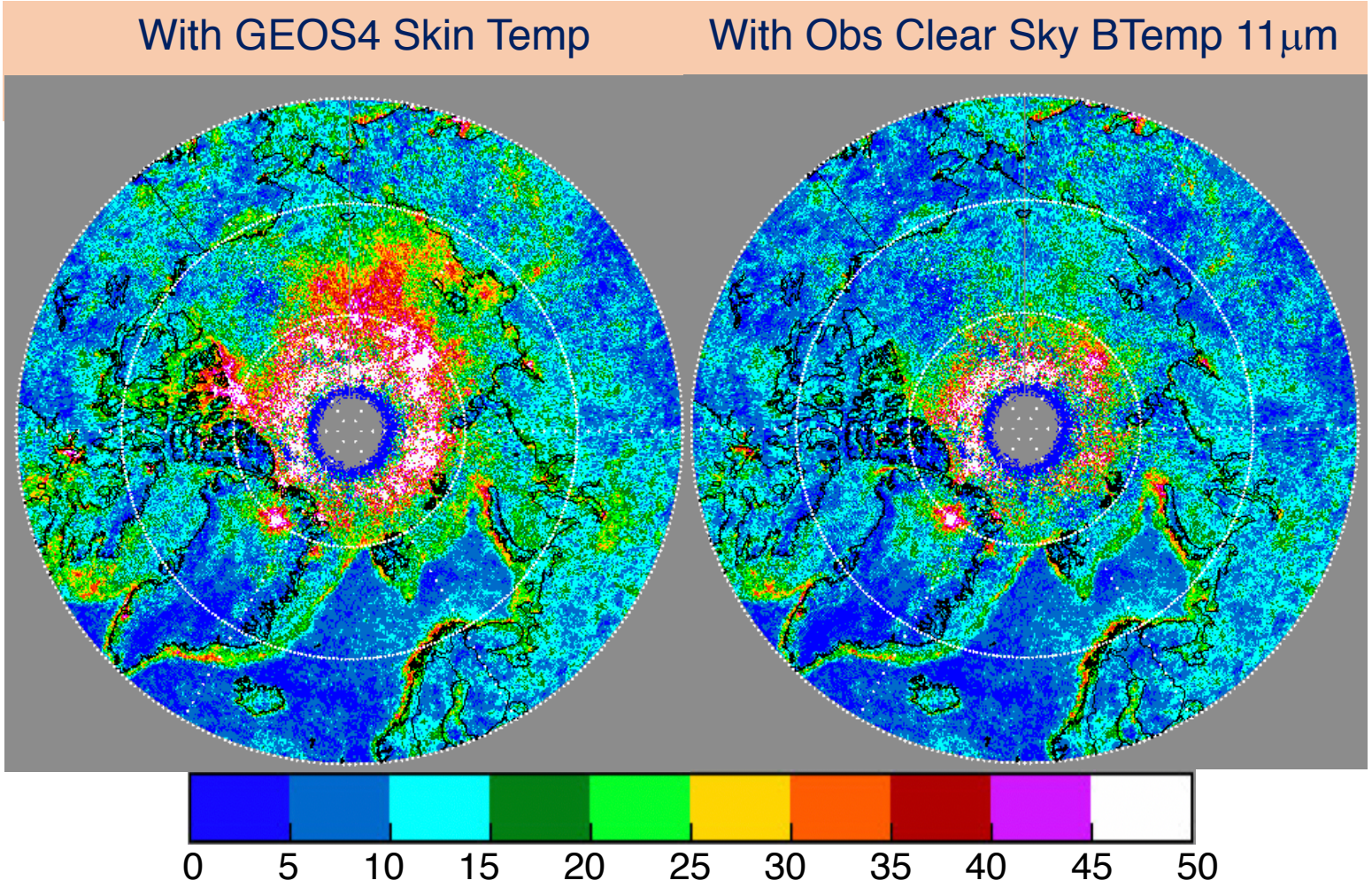






Water Ice No-Ret Clr

No Retrieval Percent, Terra MODIS, March 2009



Avg No Retrieval = 15%

Avg No Retrieval = 11%

- Improvement over sea ice ocean and snow covered land

Summary

- THM 1.6 μm the best picking up optically thin clouds, but saturates at Tau (ice) ~ 16-20, Tau (water) 32-40
  THM 1.24 μm better sensitivity up to 32-60 for ice clouds, 64-96 for water

- Mean optical depth
  - Ice (tau < 30): SHM (1.24) ~ 8.5
    THM (1.24) ~ 5.8
    THM(1.6) ~ 3.4
  - Liquid water (Tau < 60) : 1.24 μm ~ 13.8
    1.6 μm ~ 6.6

- Comparison with MODIS ST:
  - Ice (tau < 30): MODIS ST mean tau = 4.9, ~1.5 larger than THM 1.6
  - Water (tau < 60) : MODIS ST agrees well with THM 1.6 over Greenland, larger than THM 1.6 over Arctic Ocean

- CALIPSO Validation (for single transparent ice clouds):
  - CALIPSO ~ 1.13 (0.8)
  - THM 1.6 ~ 3.7 (11)
  - THM 1.24 ~ 6.5
  - SHM 1.24 (Ed4) ~ 13.3

- GEOS4 Skin T ~ 5.6 K too warm over sea ice ocean, and 3.3 K warm over snow covered land.
  Using observed clear sky MODIS 11 μm, reduced no retrieval from 15% to 11%.

Future Plan

- Combine THM1.6 & THM1.24

  Ice Clouds:

  tau < 8 – 16 → use THM 1.6

  tau > 8 – 16 → use THM 1.24

  Water Clouds:

  tau < 32 – 40 → use 1.6 μm

  tau > 32 – 40 → use 1.24 μm

- GEOS 4 skin temperature too warm for snow & ice covered ocean and land. What to do? Updating snow / ice covered surface temperature with 11 μm BTemp observations? Or hoping an improved version of GEOS skin T?