

# Cloud Detection, Height and Optical Properties: MODIS Standard & MODIS/VIIRS Continuity Products

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MODIS/VIIRS Science Team Meeting  
College Park, MD  
20 November 2019

# Topics

- ▶ MODIS Standard Cloud Product Status (**MOD35, MOD06**)
  - C6.1 trend assessments
  - C7 major activities
- ▶ MODIS/VIIRS Continuity Product Status (**CLDMSK, CLDPROP**)
  - Continuity paradigm overview
  - Example results (L2 and L3)
  - Ongoing efforts
- ▶ New “atmosphere imager” web site, documentation, etc.

# Collection/Version History

MODIS Atmosphere Team Products (MOD/MYD 04, 05, 06, 07, 35, 08, ATML2)

<b>Collection</b>	<b>Start of Reprocessing MODIS Terra</b>	<b>Start of Reprocessing MODIS Aqua</b>
6.1	Sept. 2017 (completed Dec. 2017)	Dec. 2017 (completed March 2018)
6.0	2014	2013
5.1	2008	2008
5.0	2005	2005
4	2002	2002
3	2001	2002
1	2000	—

MODIS & VIIRS Cloud Continuity Products (CLDMASK, CLDPROP)

<b>Version</b>	<b>Start of Reprocessing</b>	<b>Public in LAADS</b>
1.1*	Aug. 2019 (completed Sept. 2019)	Nov. 2019 (L2 + L3)
1.0	March 2019 (completed Apr. 2019)	April 2019 (L2)

\* *improved thermodynamic phase wrt MOD06 heritage*

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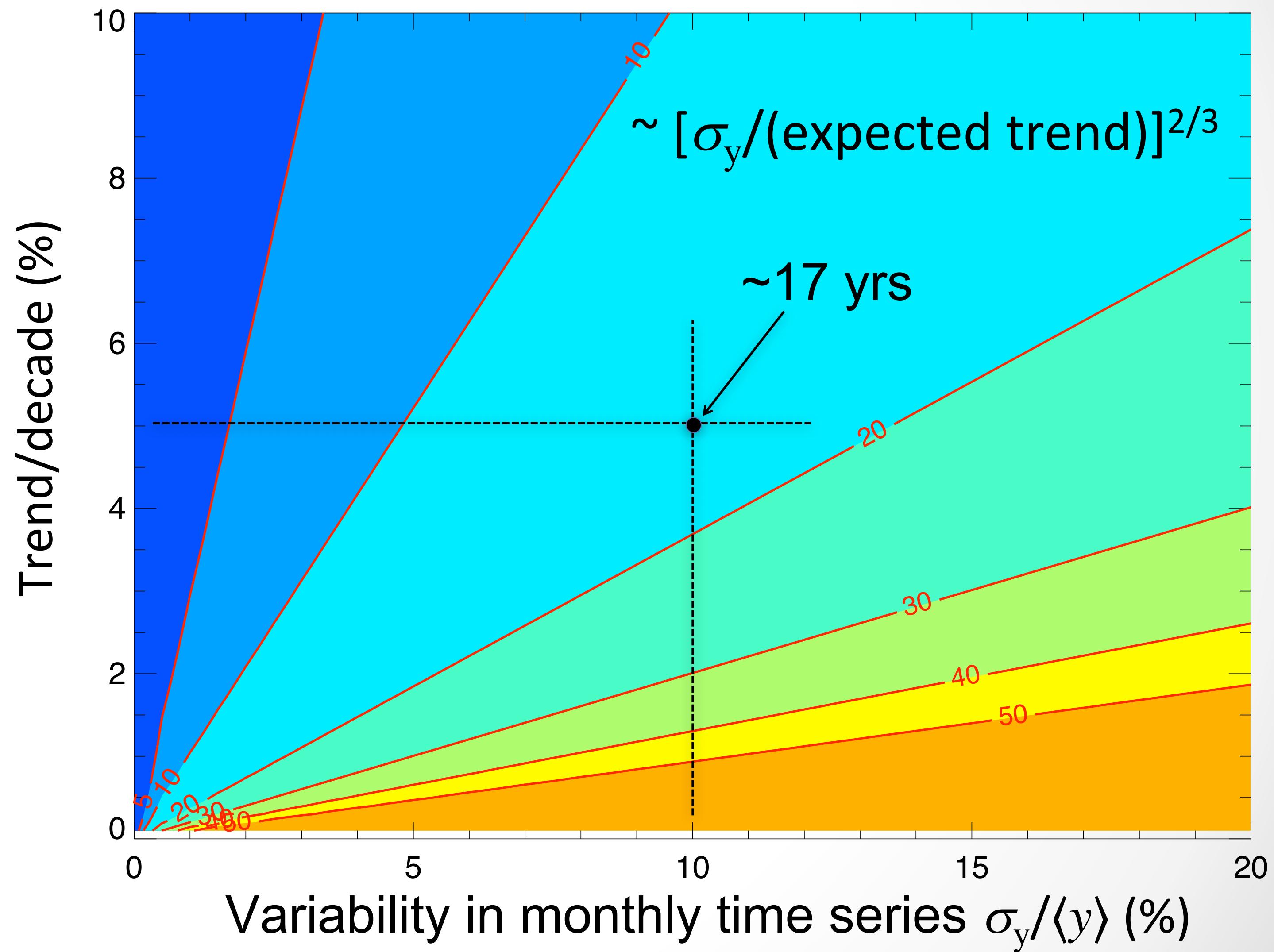
# MODIS Radiometric Stability Challenges: Reminder

## ► L1B

- C5.1 => C6.0
  - Terra VNIR/SWIR radiometric corrections (RVS), corrected significant Cloud Optical Thickness (COT) trends
  - Aqua VNIR spatial “re-registration”, corrected small cloud scale retrieval issues
- C6.0 => C6.1
  - Terra IR cross-talk corrections, corrected significant trends in cloud amount and cloud top height trends
  - Further Aqua/Terra RVS corrections (primarily COT trends)

# Trend Detection

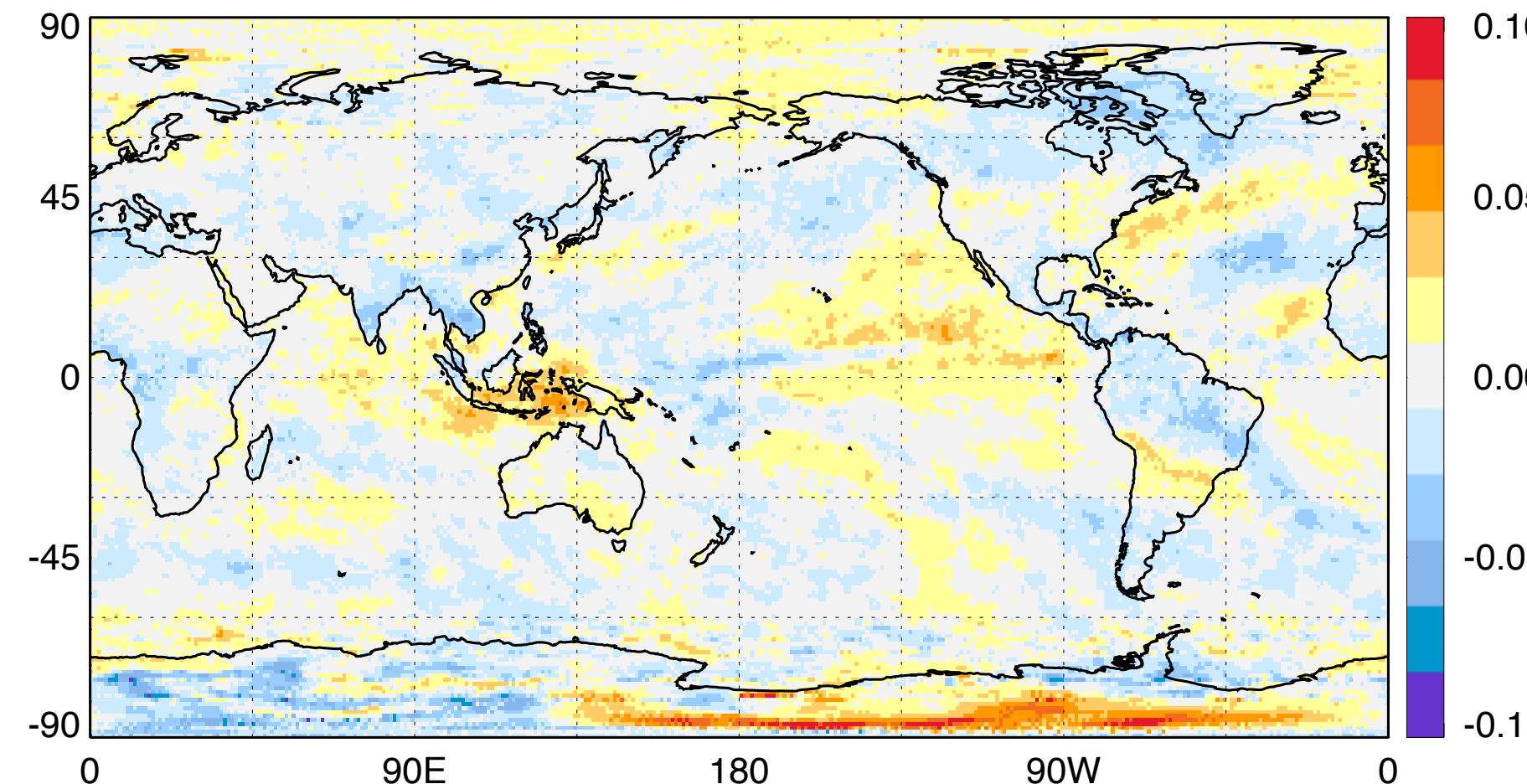
Number of Years Required to Detect a Trend  
(90% prob. of detecting a trend to a 0.05 statistical  
level, no autocorrelation)



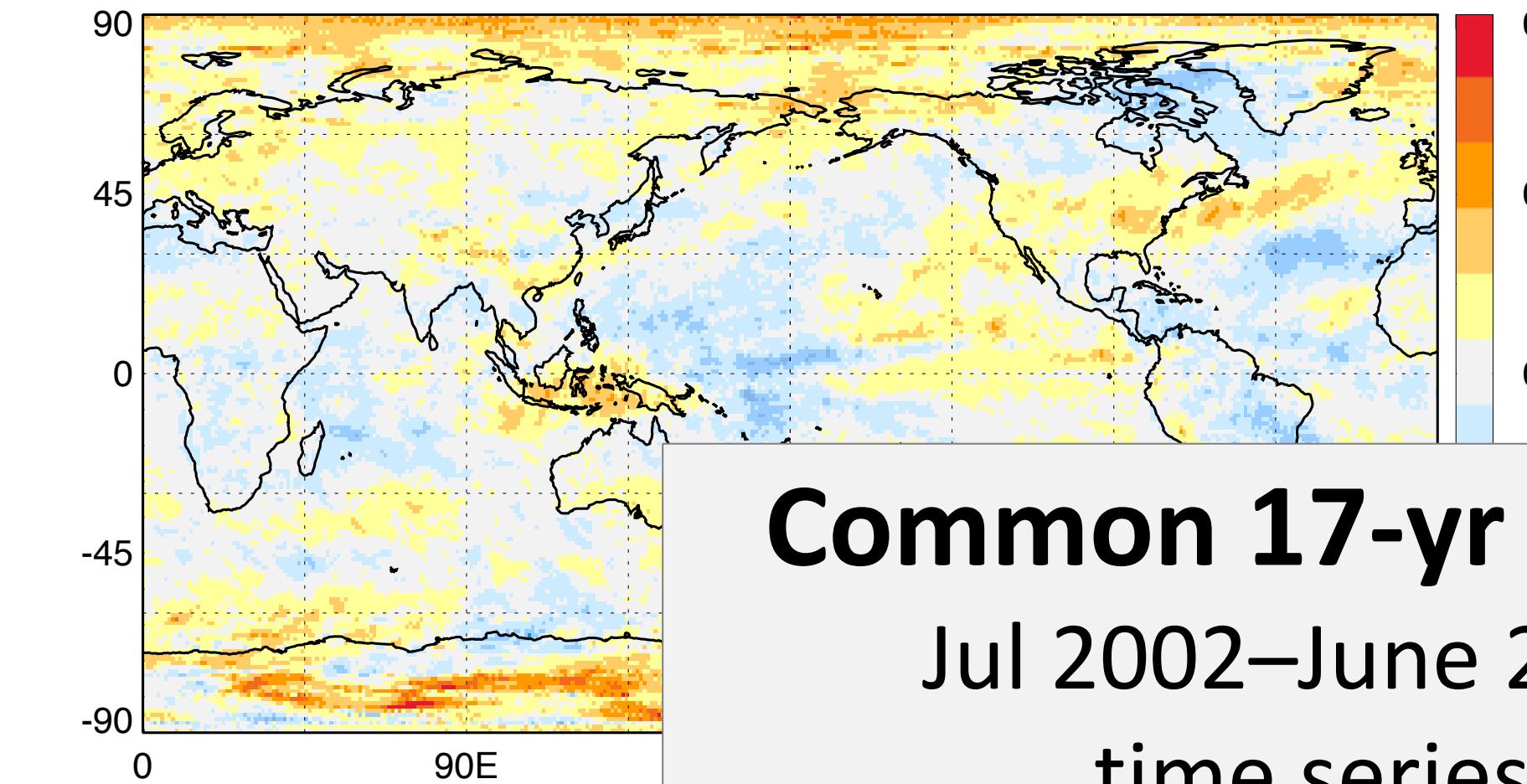
# C6.1 MODIS Terra vs Aqua Trends: High Cloud Fraction

trend per decade

Terra C6.1 High CF Trend (abs.)



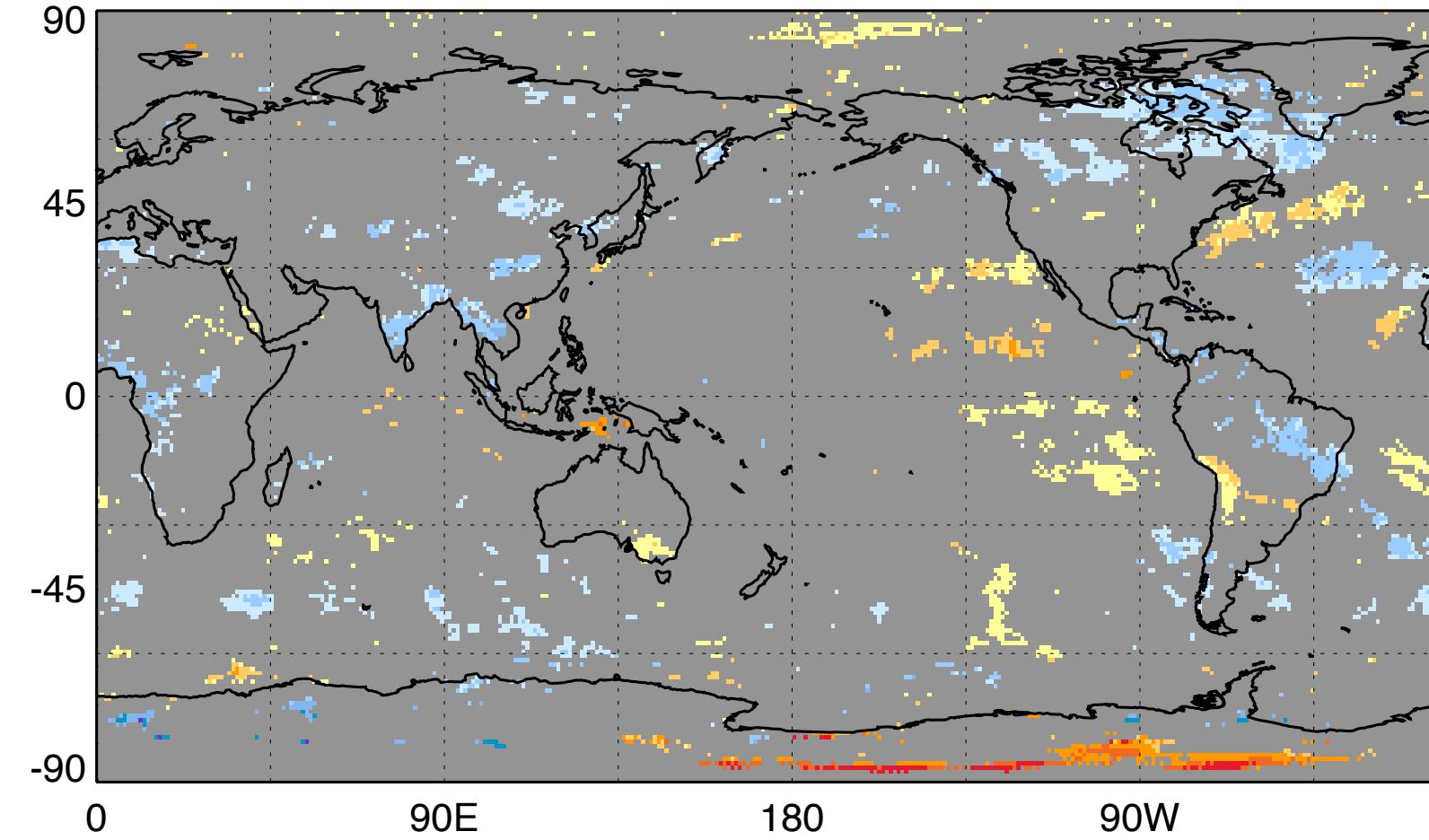
Aqua C6.1 High CF Trend (abs.)



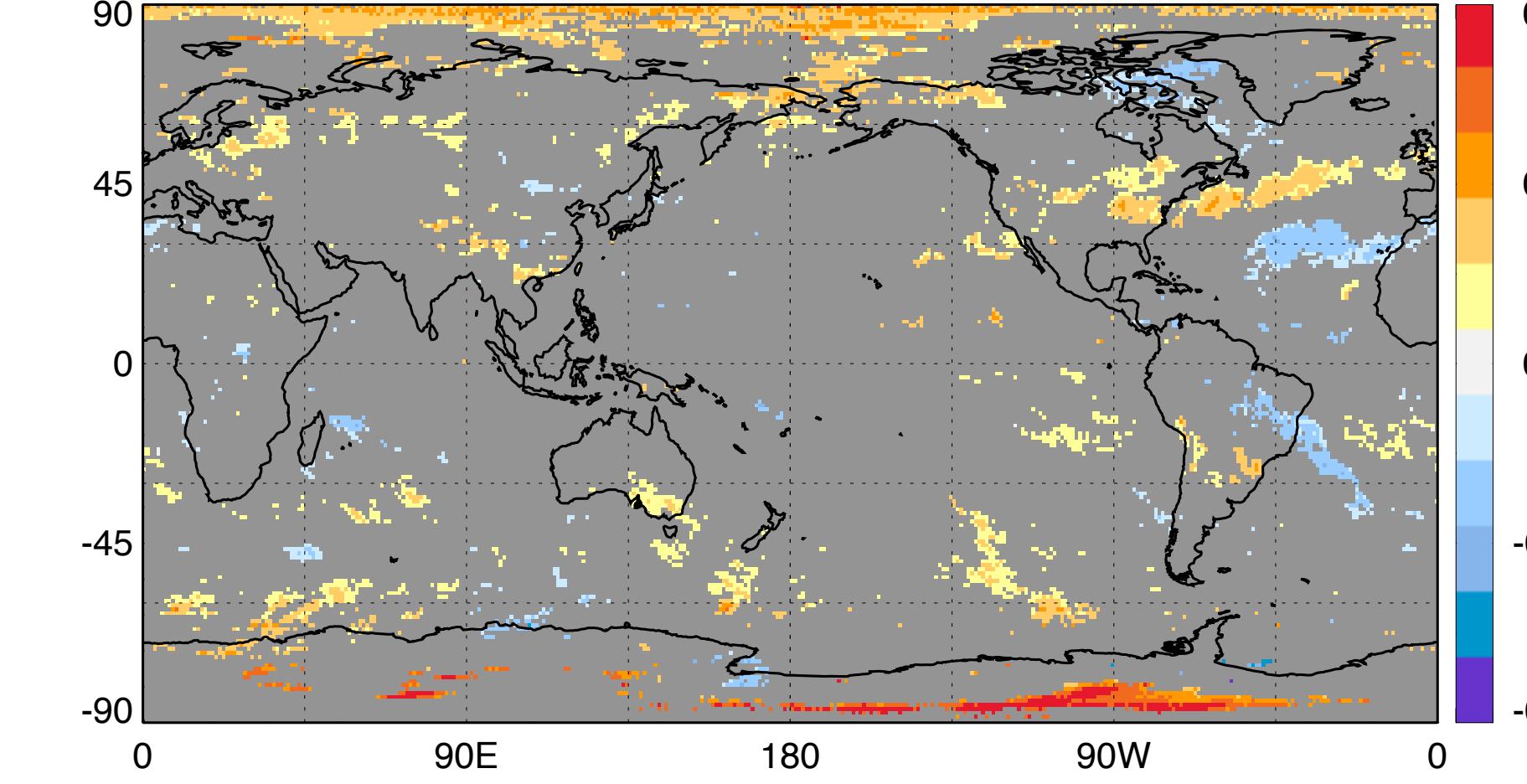
**Common 17-yr record**  
Jul 2002–June 2019  
time series

trend  
masked by  
5% sig.  
level

5% significance level(trend only)



5% significance level(trend only): with  $DF = N_{\text{eff}}/2$



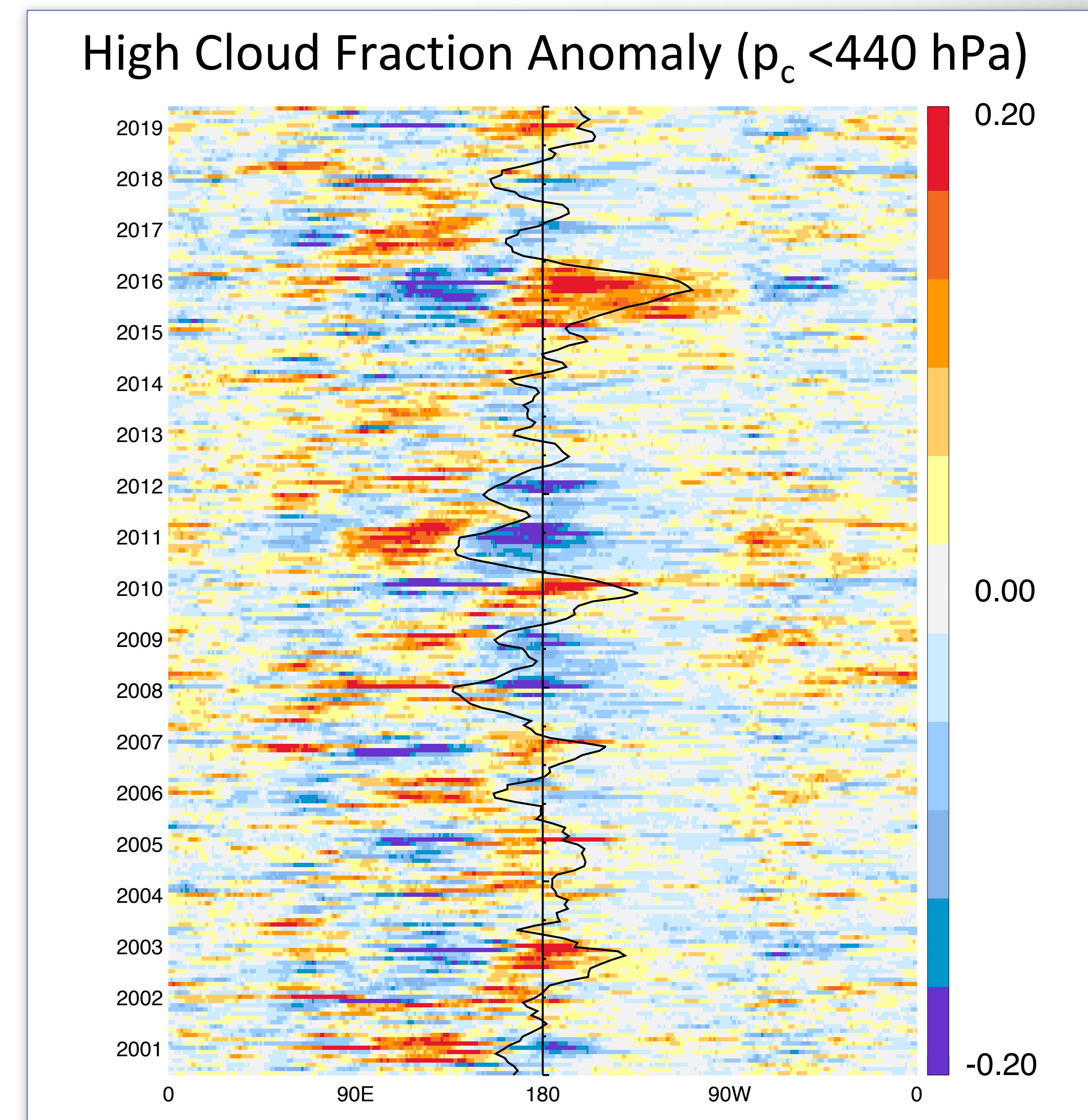
# C6.1 MODIS Terra High Clouds vs. El Nino Southern Oscillation (ENSO)

Hovmöller plot:

Jul 2000–June 2019,  $\pm 15^\circ$  lat

solid line:

ENSO 3.4 index

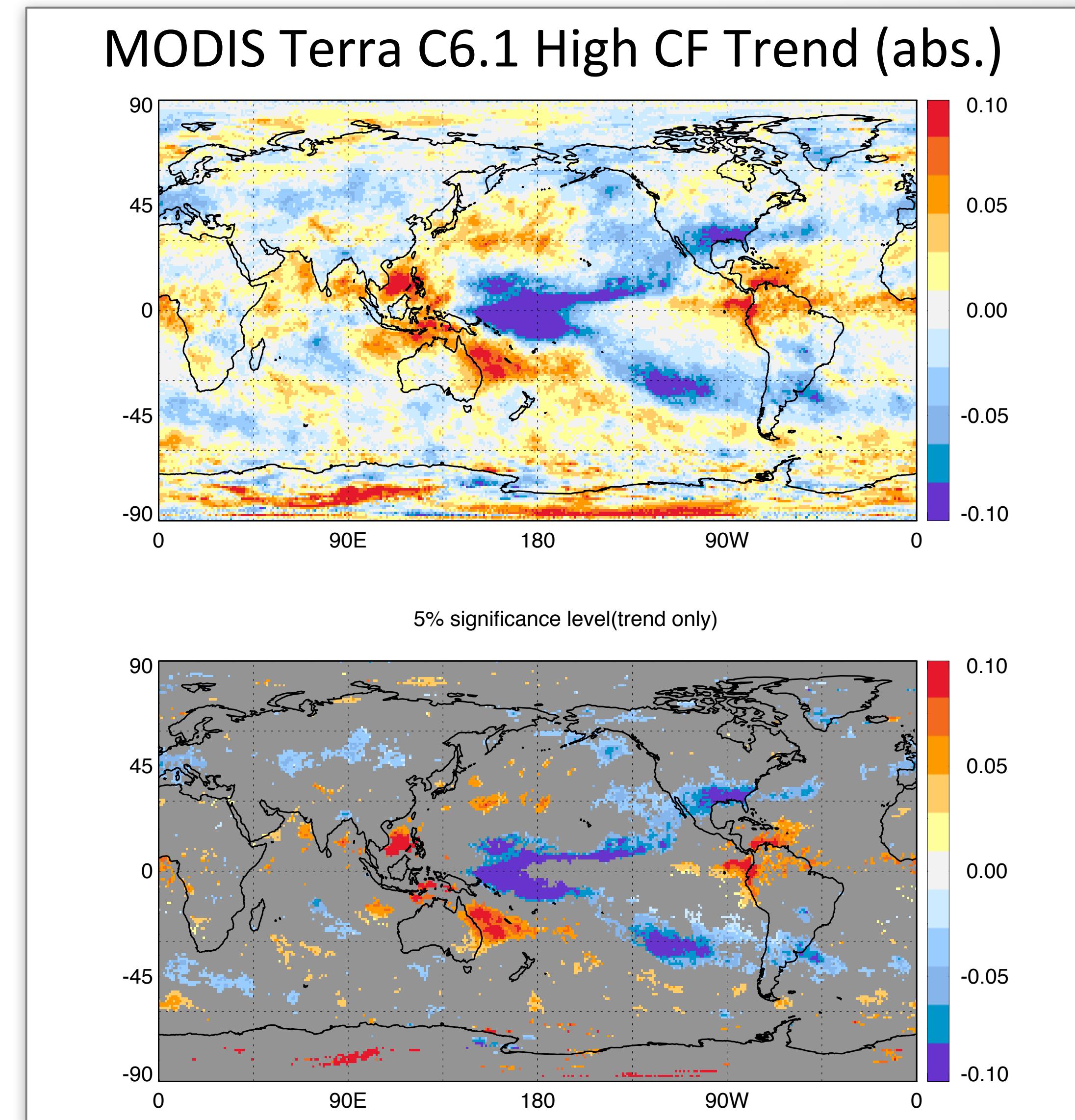


# C6.1 MODIS Terra Trends: High Cloud Fraction

**12 year record**  
Jul 2000–June 2012  
time series

trend per  
decade

trend  
masked by  
**5% sig.**  
**level**

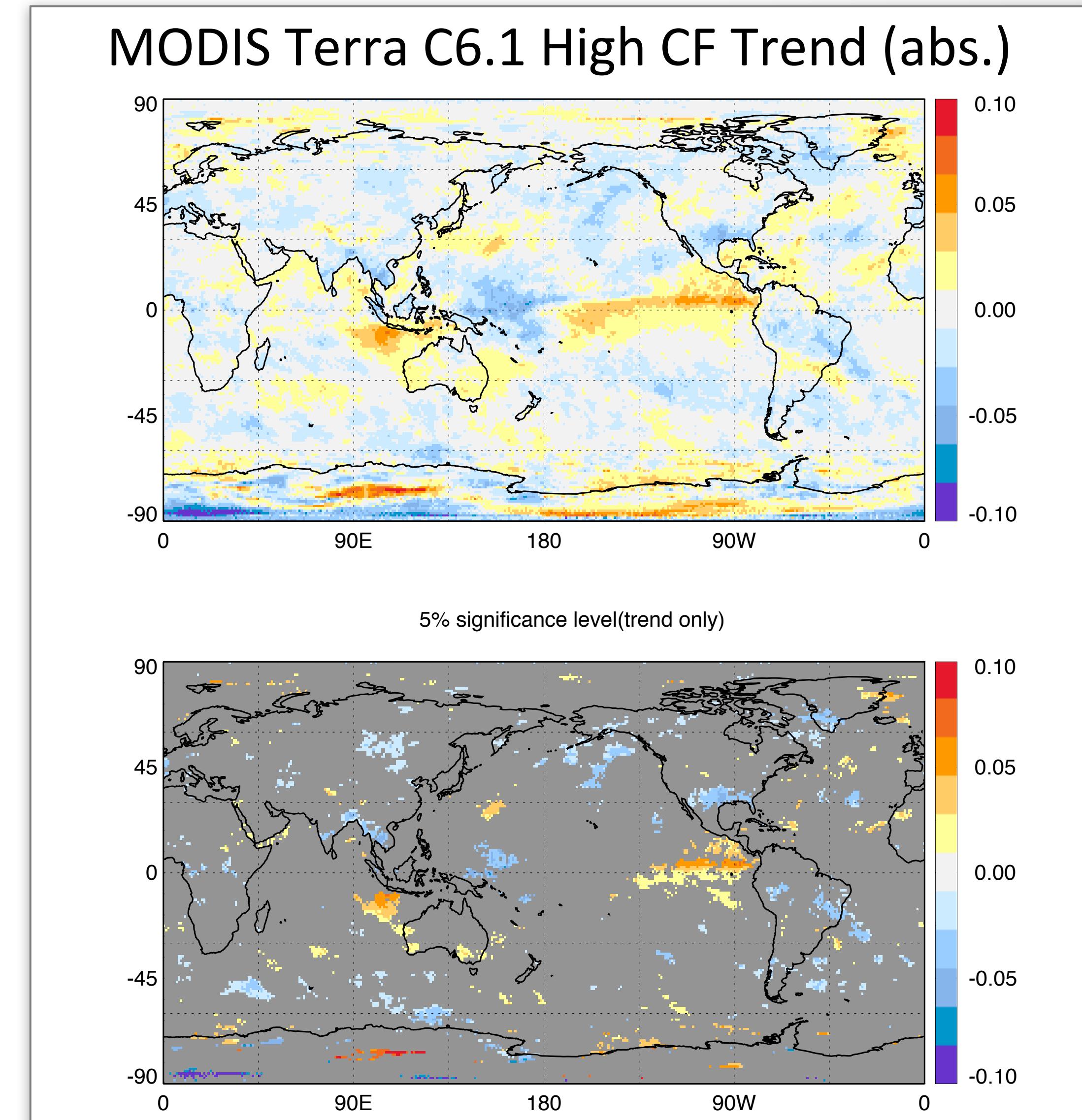


# C6.1 MODIS Terra Trends: High Cloud Fraction

**17 year record**  
Jul 2000–June 2012  
time series

trend per  
decade

trend  
masked by  
**5% sig.**  
**level**

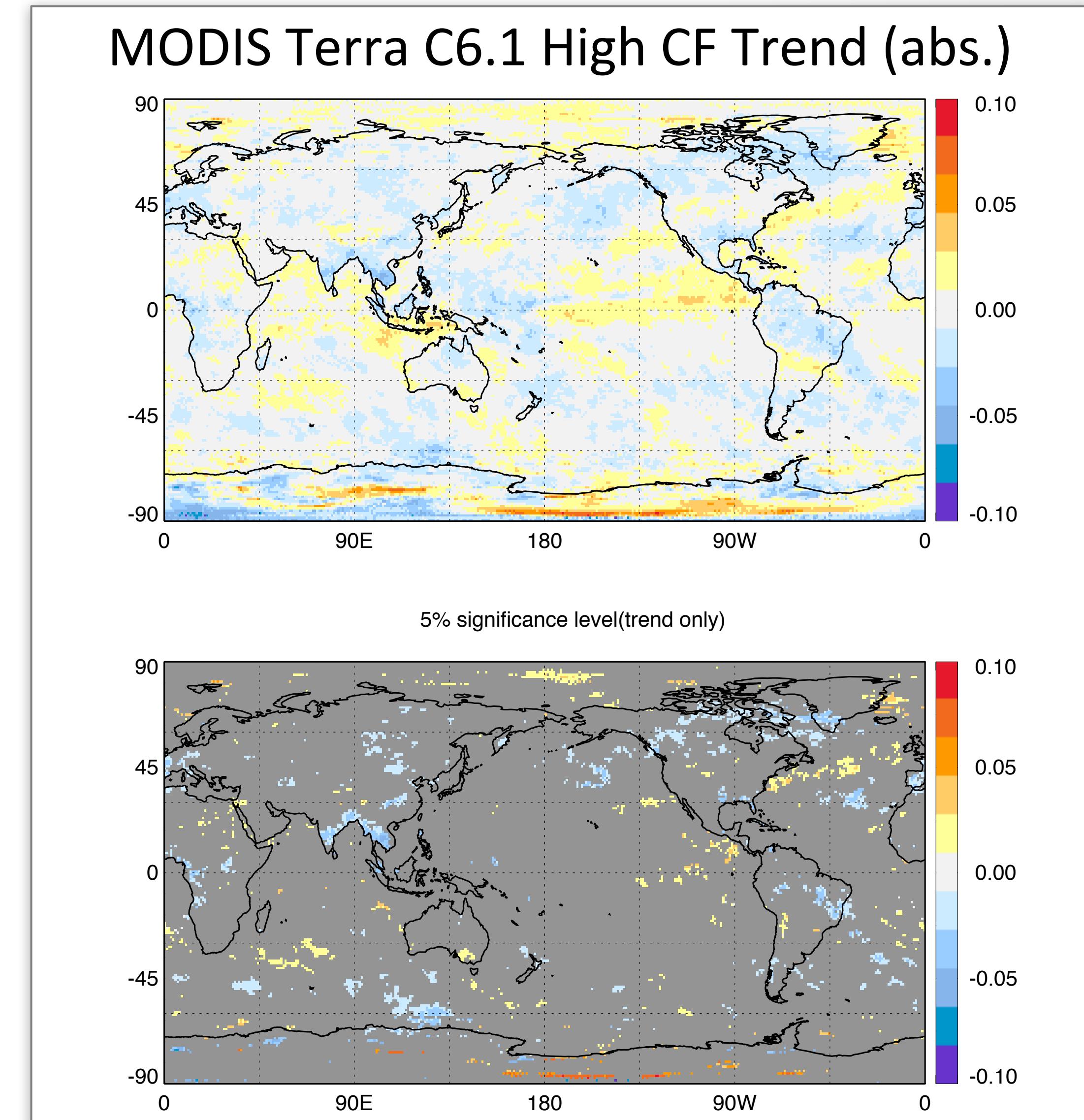


# C6.1 MODIS Terra Trends: High Cloud Fraction

**19 year record**  
Jul 2000–June 2012  
time series

trend per  
decade

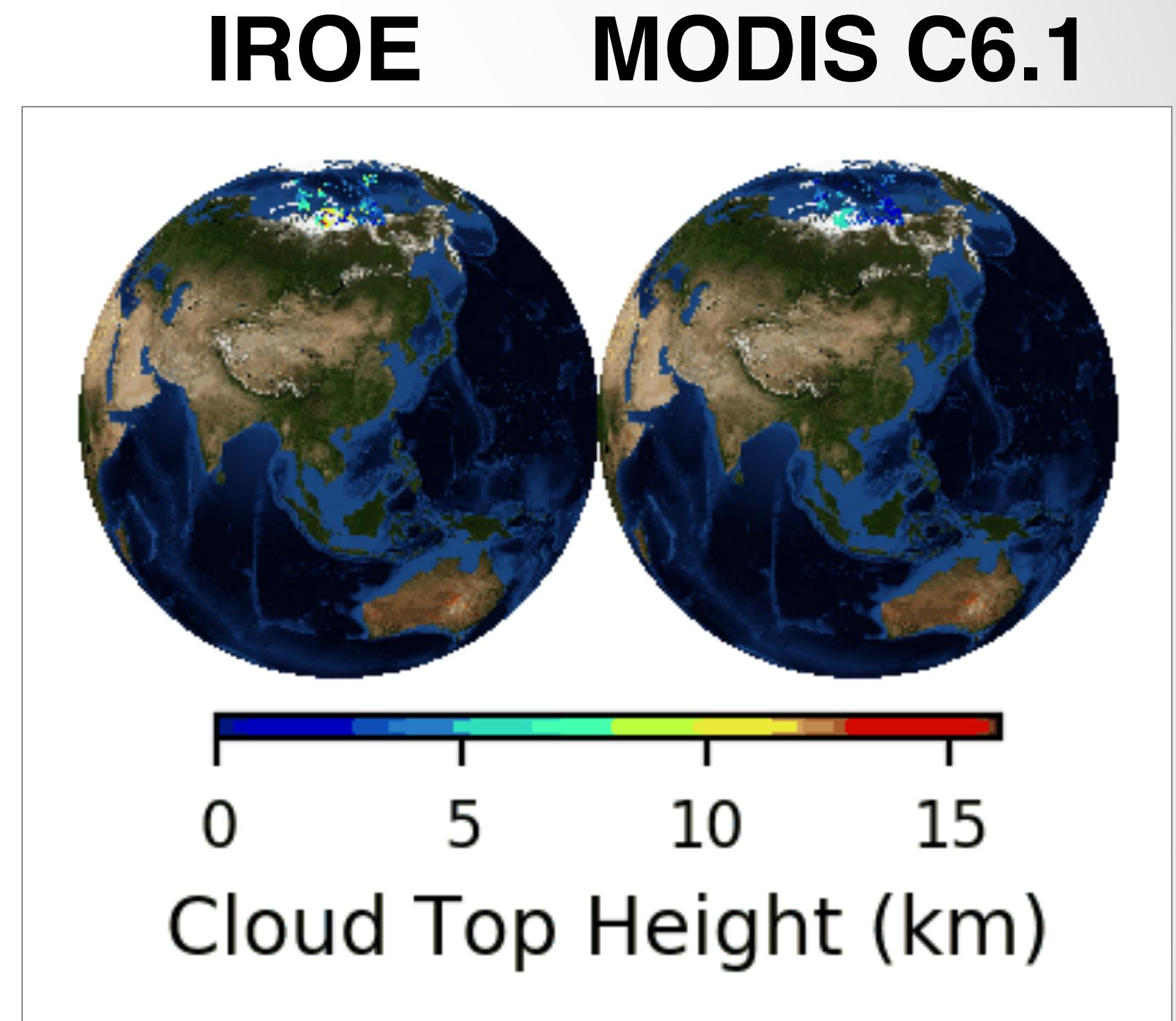
trend  
masked by  
**5% sig.**  
**level**



# C7 IR Optimal Estimation (IROE) 1km Cloud Top/Optical Properties

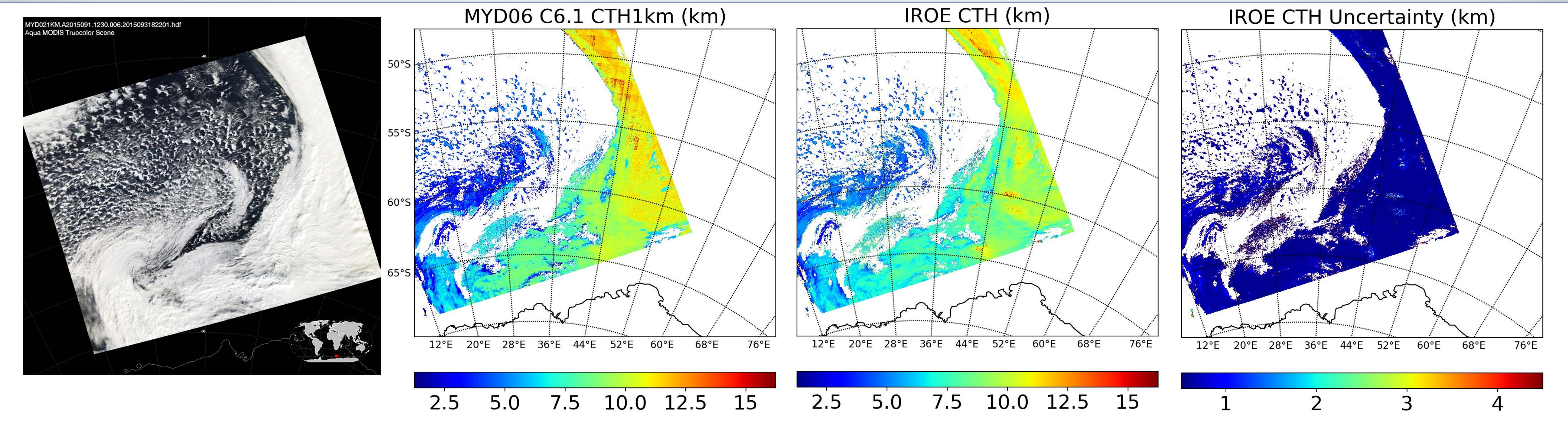
## ► Features

- Instantaneous 1-km ice cloud optical thickness, effective radius, and cloud-top height retrievals, with uncertainties
- Consistent day/night optical retrieval algorithm
- Designed for ice cloud retrievals using MODIS IR bands (3.7-14  $\mu\text{m}$ ), but can use other IR band combinations (e.g., VIIRS)
- Computationally efficient: comparable to current MOD06 COP algorithm
- Awaiting MODAPS science testing



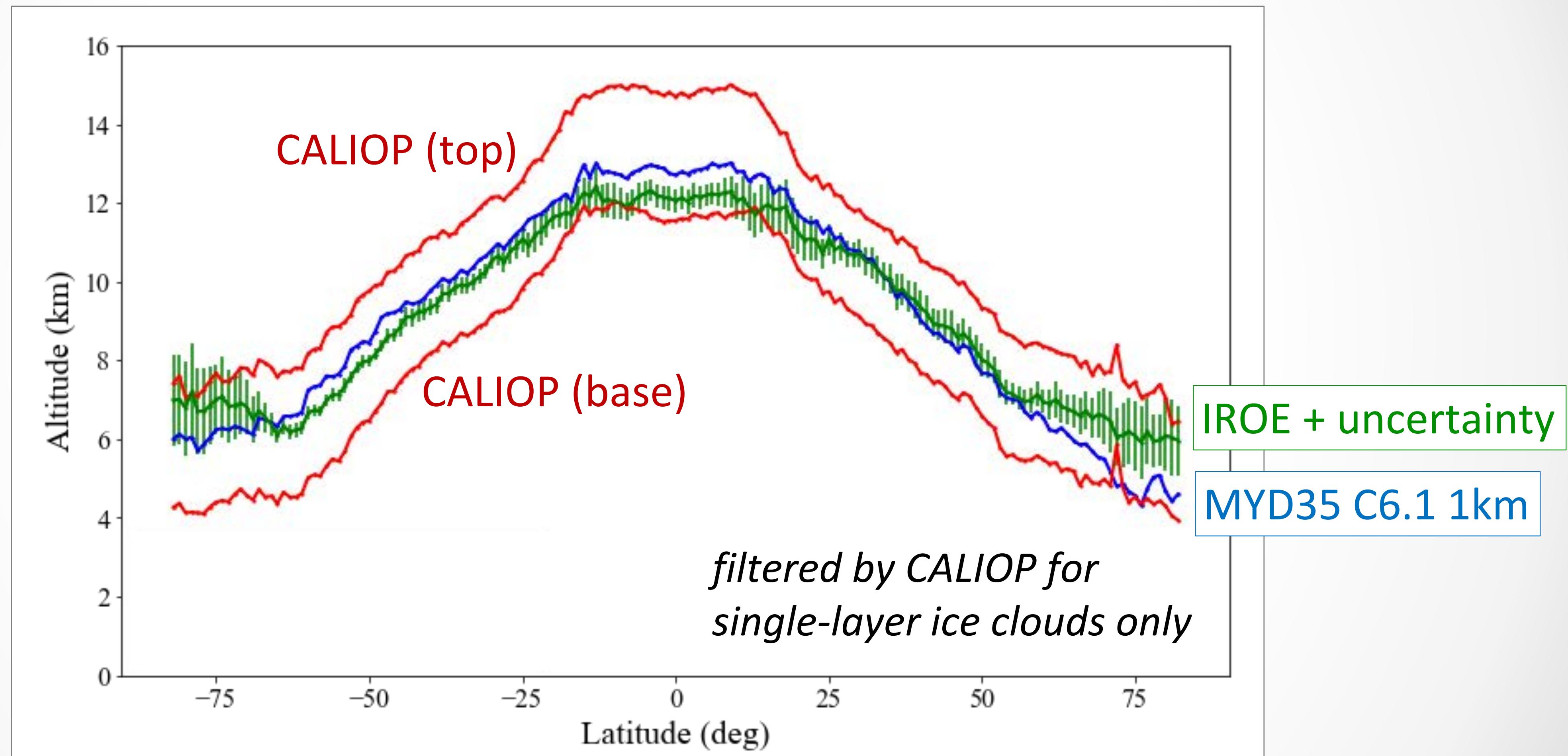
*Chenxi Wang et al., JGR, 2016a,b;  
also see poster*

# IR Optimal Estimation (IROE) Granule Example

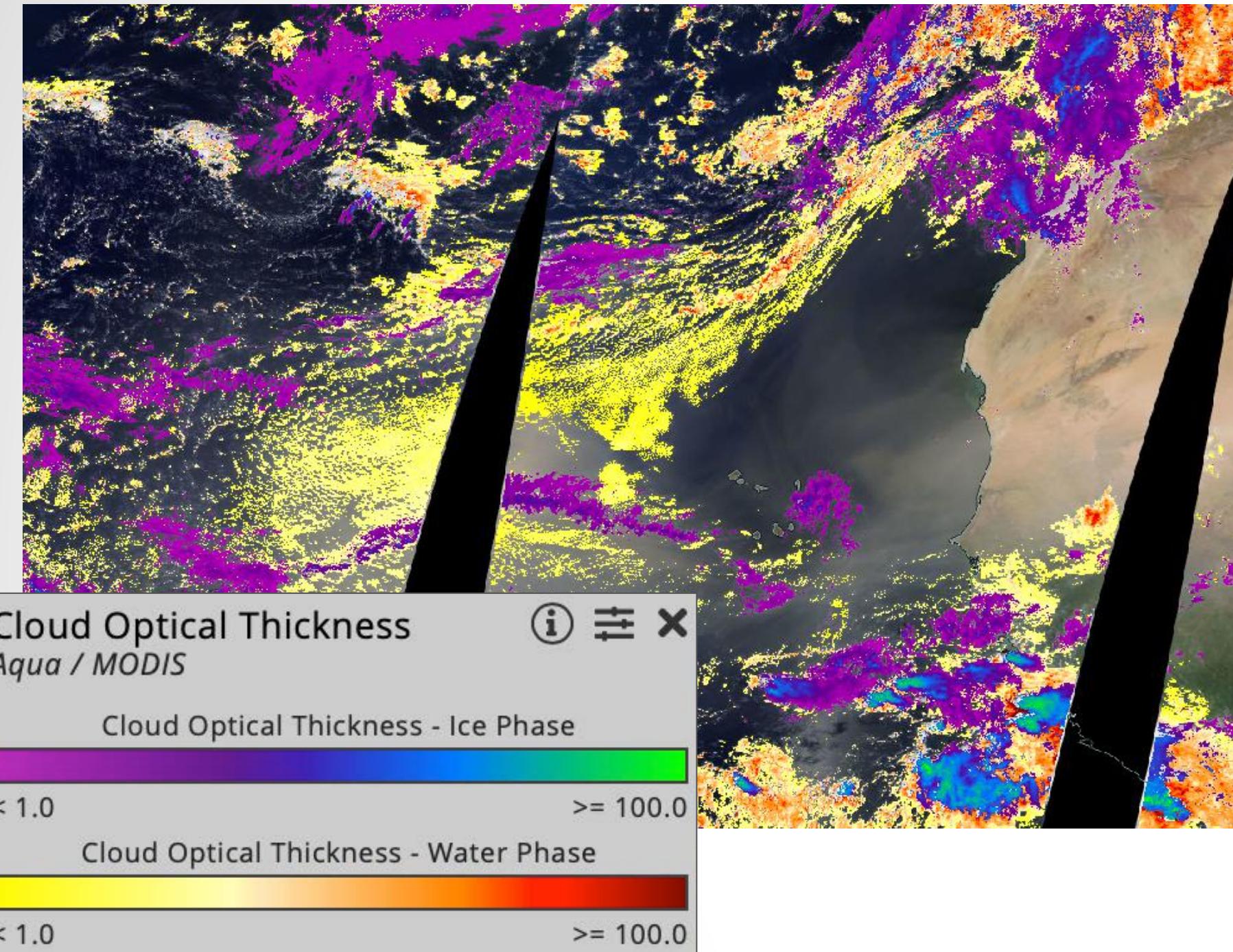


# IR Optimal Estimation (IROE) Global Evaluation

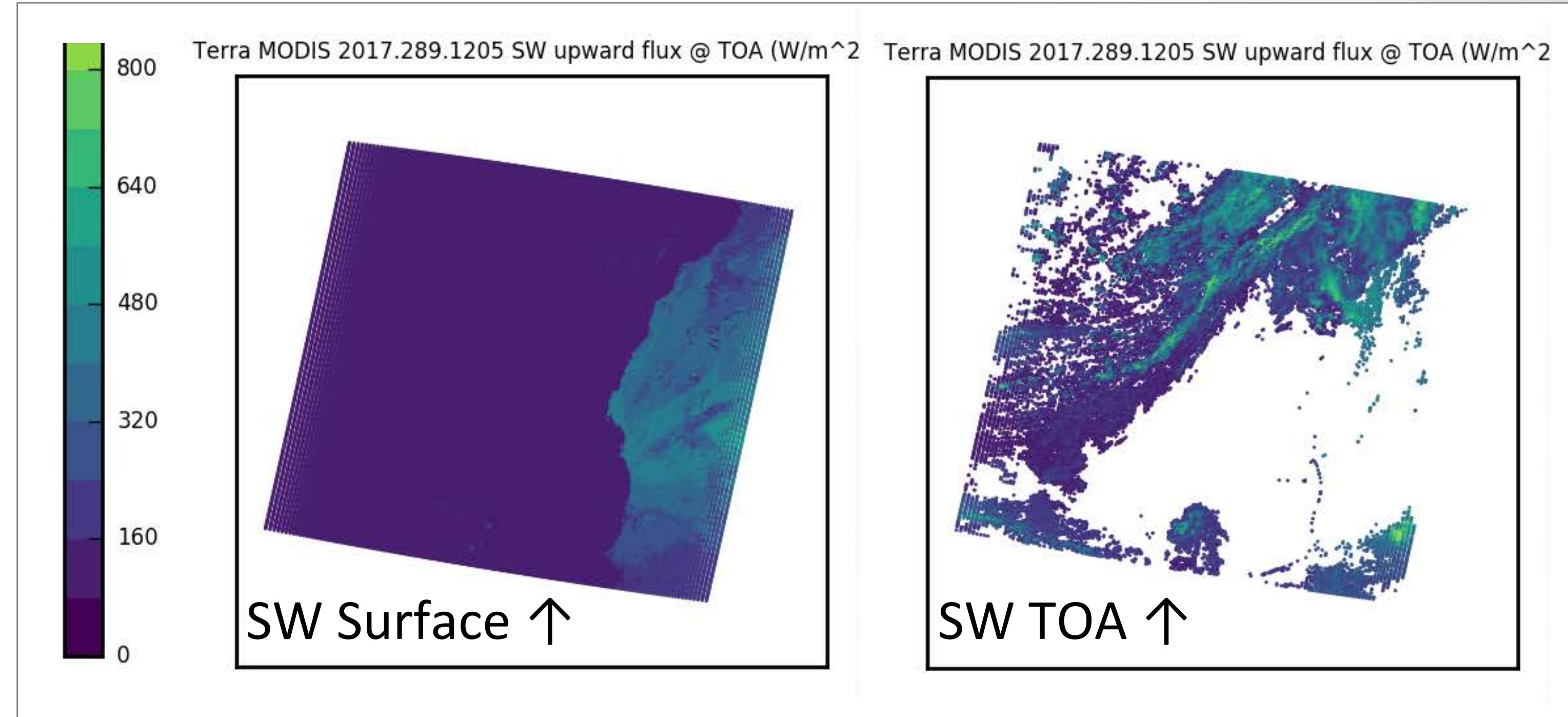
April 2015 Zonal Mean Ice Cloud Top Height (km) comparisons



# C7 Radiative Flux Example Calculation



MODIS Terra, 16 Oct. 2017



for liquid water cloud scenes:  
TOA SW + LW upwelling “clear” – cloudy TOA  $\approx -136 \text{ W/m}^2$

*Gala Wind, Dongmin Lee, Lazaros Oreopoulos, Ping Yang, et al.*

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- ▶ MODIS/VIIRS Continuity Product Status (**CLDMSK, CLDPROP**)
  - Continuity paradigm overview
  - Example results (L2 and L3)
  - Ongoing efforts
- ▶ New “atmosphere imager” web site, documentation, etc.

# Challenges for MODIS/VIIRS Cloud Product Continuity: Reminder

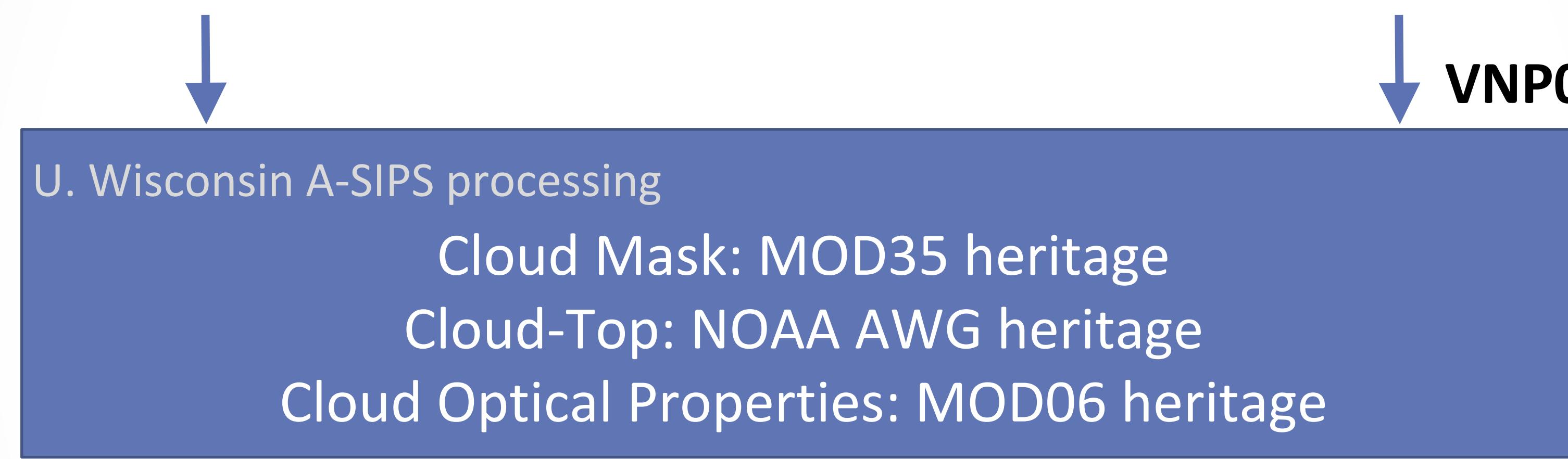
- ▶ Spectral coverage (most direct challenge)
  - 2  $\mu\text{m}$  window channels: VIIRS 2.25  $\mu\text{m}$  vs. MODIS 2.13  $\mu\text{m}$
  - VIIRS missing MODIS CO<sub>2</sub> and H<sub>2</sub>O absorption channels
- ▶ Relative radiometric calibration in solar reflectance channels
  - Spectral bias adjustments made to SNPP VIIRS using *homogenous* liquid water clouds (*Meyer et al.* using A-SIPS match files)
- ▶ Spatial resolution and spatial/temporal sampling
  - VIIRS (750, 375 m) vs. MODIS (1000, 500, 250 m) at nadir
  - VIIRS pixel size DOES NOT increase as substantially with scan angle as MODIS
  - Missing M-band bow-tie pixels “added” by A-SIPS for following results

# Strategy for Spectral Differences: Common MODIS & VIIRS Algorithm

MODIS Aqua L1B + Geolocation  
**MYD02, MYD03**  
(channel subset common w/VIIRS)

NASA VIIRS L1B intermediate product\*  
(w/restored bow-tie pixel deletions +  
VNIR/SWIR radiometric adjustments) +

Geolocation  
**VNP02MOD, VGEOM**

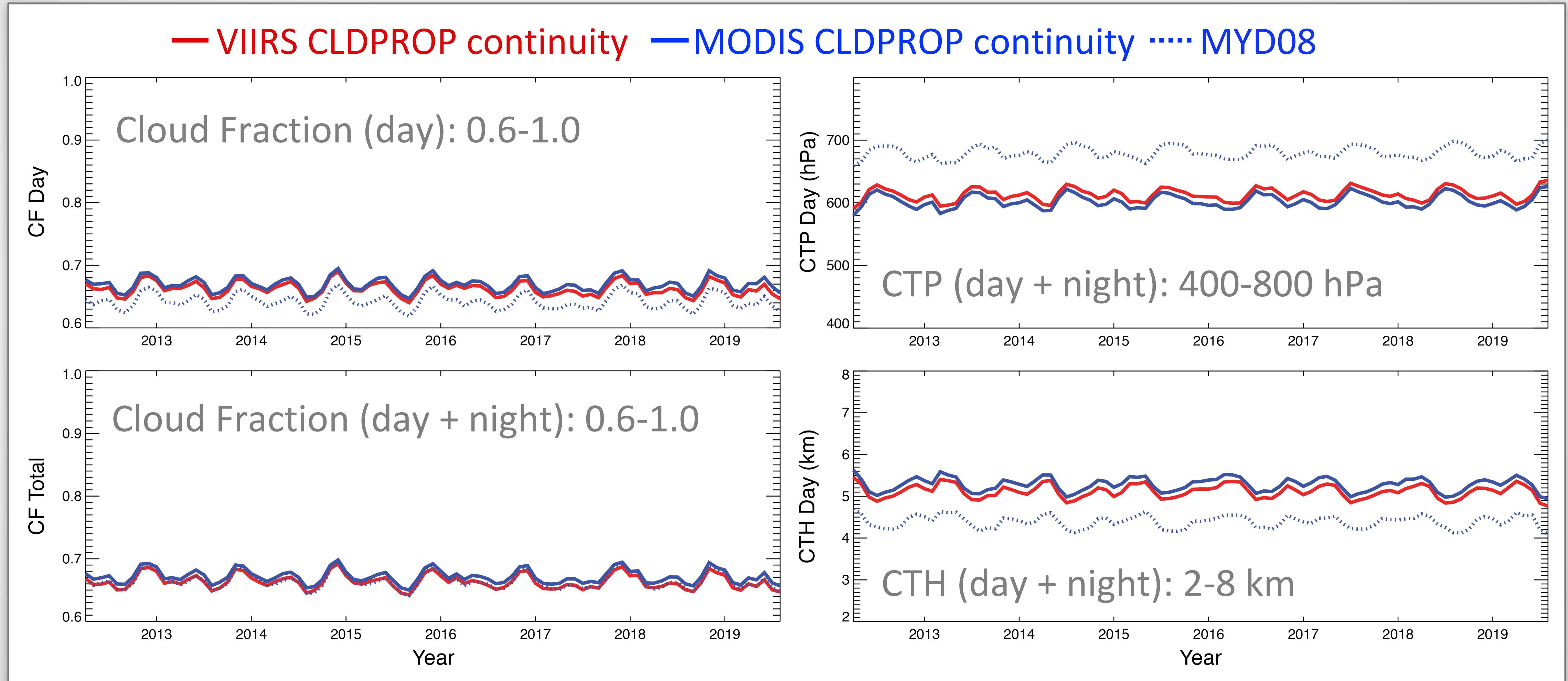


MODIS Continuity Products  
**CLDMSK\_L2\_MODIS\_Aqua**  
**CLDPROP\_L2\_MODIS\_Aqua**

L3 Continuity Products ("Yori")  
**CLDPROP\_D/M3\_VIIRS\_SNPP**  
**CLDPROP\_D/M3\_MODIS\_Aqua**

VIIRS Continuity Products  
**CLDMSK\_L2\_VIIRS\_SNPP**  
**CLDPROP\_L2\_VIIRS\_SNPP**

# Cloud Mask and Cloud Top Pressure (CTP)/Height (CTH)

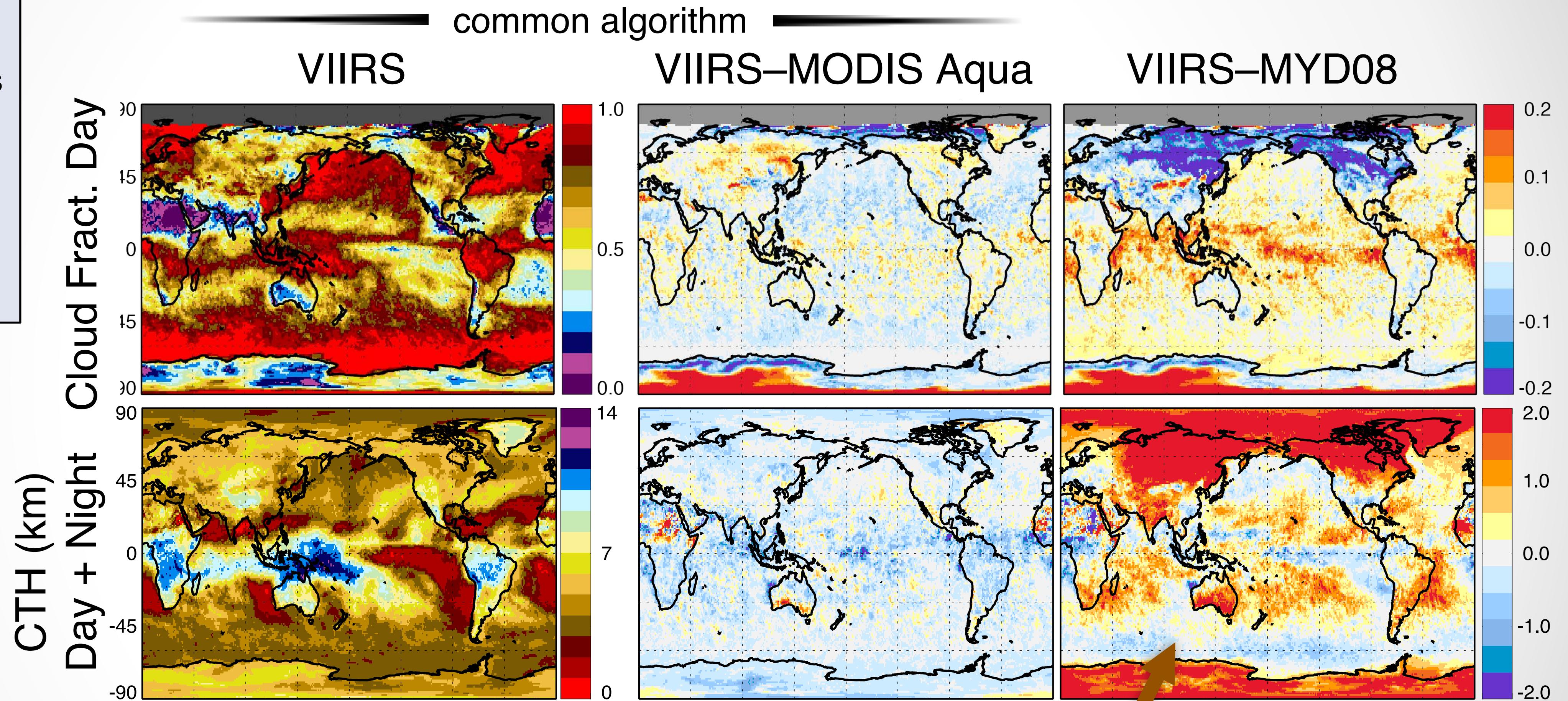


CLDPROP v1.1,  $\pm 60^\circ$  latitude, ocean + land

## Monthly Means Feb 2014 (v1.1)

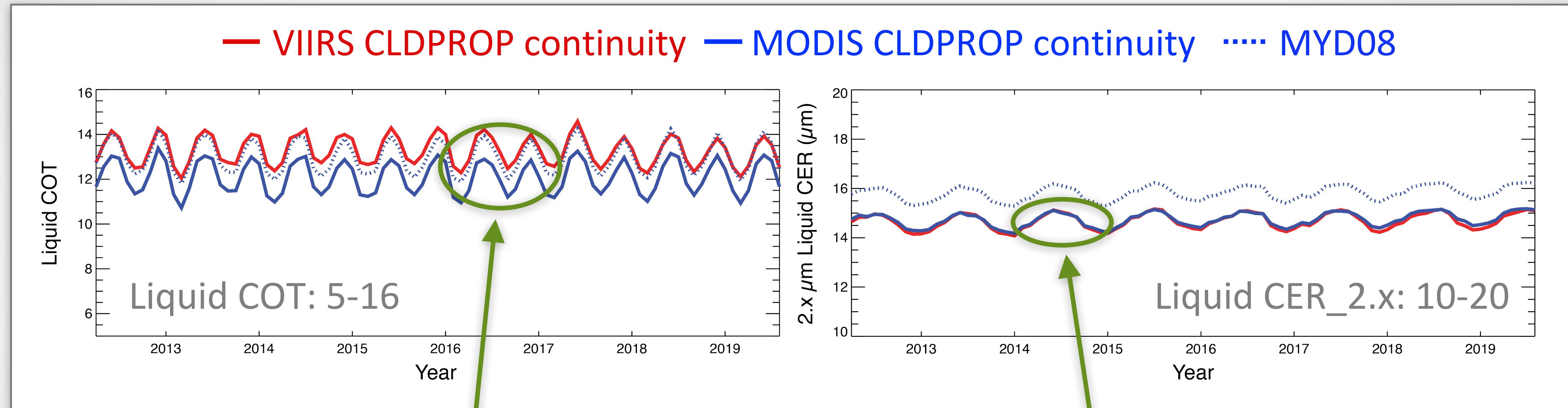
- Production version of common algorithm, includes SW Radiometric Bias Correction
- Pixel-weighted aggregation over common swath

Cloud Fraction and Cloud Top Height Comparisons



a separate MODIS product run with the common algorithm is required for continuity

# Daytime Cloud Optical Properties Liquid Clouds



why the sig. difference?!

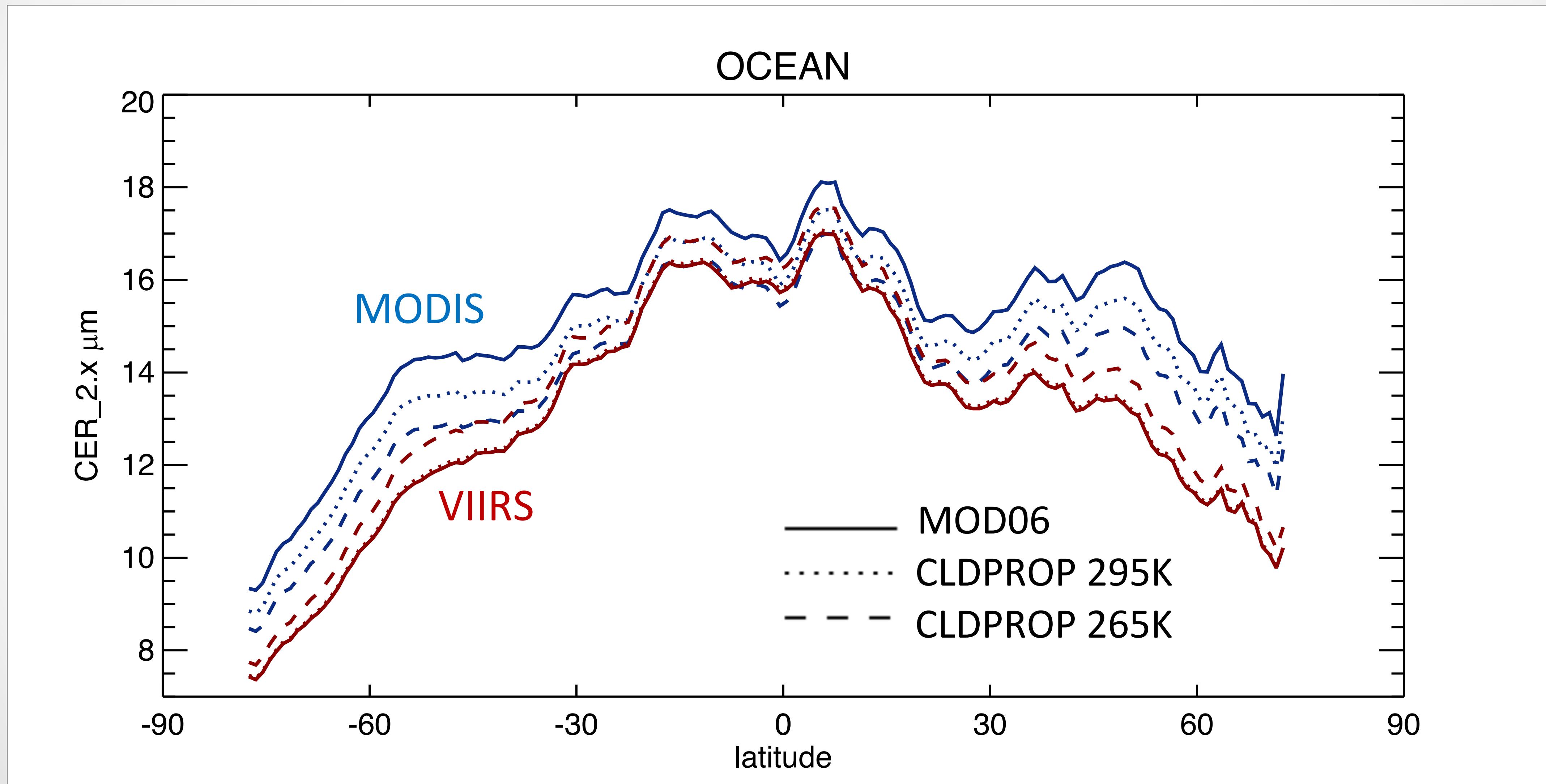
“overcast” population

required updated liquid index of  
refraction dataset improved biases  
across the  $2 \mu\text{m}$  window locations

CLDPROP v1.1,  $\pm 60^\circ$  latitude, ocean + land

# MODIS Liquid Water CER\_2.x $\mu\text{m}$ Comparisons

Feb. 2014 zonal means vs. liquid water index of refraction (LUTs)

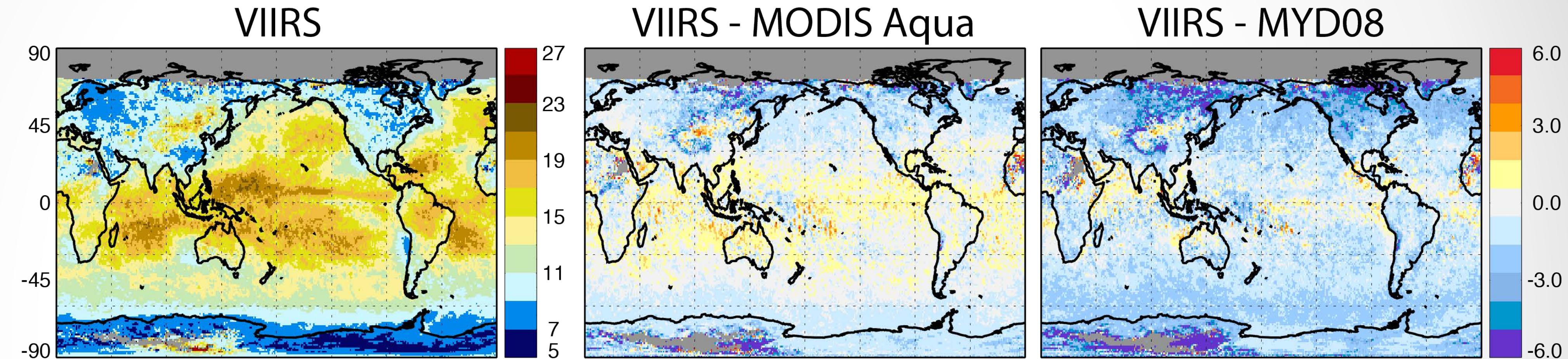


## Monthly Means Feb 2014 (v1.1)

- Production version of common algorithm, includes SW Radiometric Bias Correction
- Pixel-weighted multi-day aggregation over common MODIS swath
- Daytime only
- Highest Quality (“Overcast” pixels)

## Liquid Water CER\_2.x ( $\mu\text{m}$ ) Comparisons

common algorithm



Initial implementation of CLDPROP 2.25  $\mu\text{m}$  (VIIRS) and MYD06 (MODIS) 2.13  $\mu\text{m}$  (MODIS) effective radii revealed large biases, suggesting an inconsistency in the RT forward model.

=> Updated liquid index of refraction dataset improved biases (center panel)

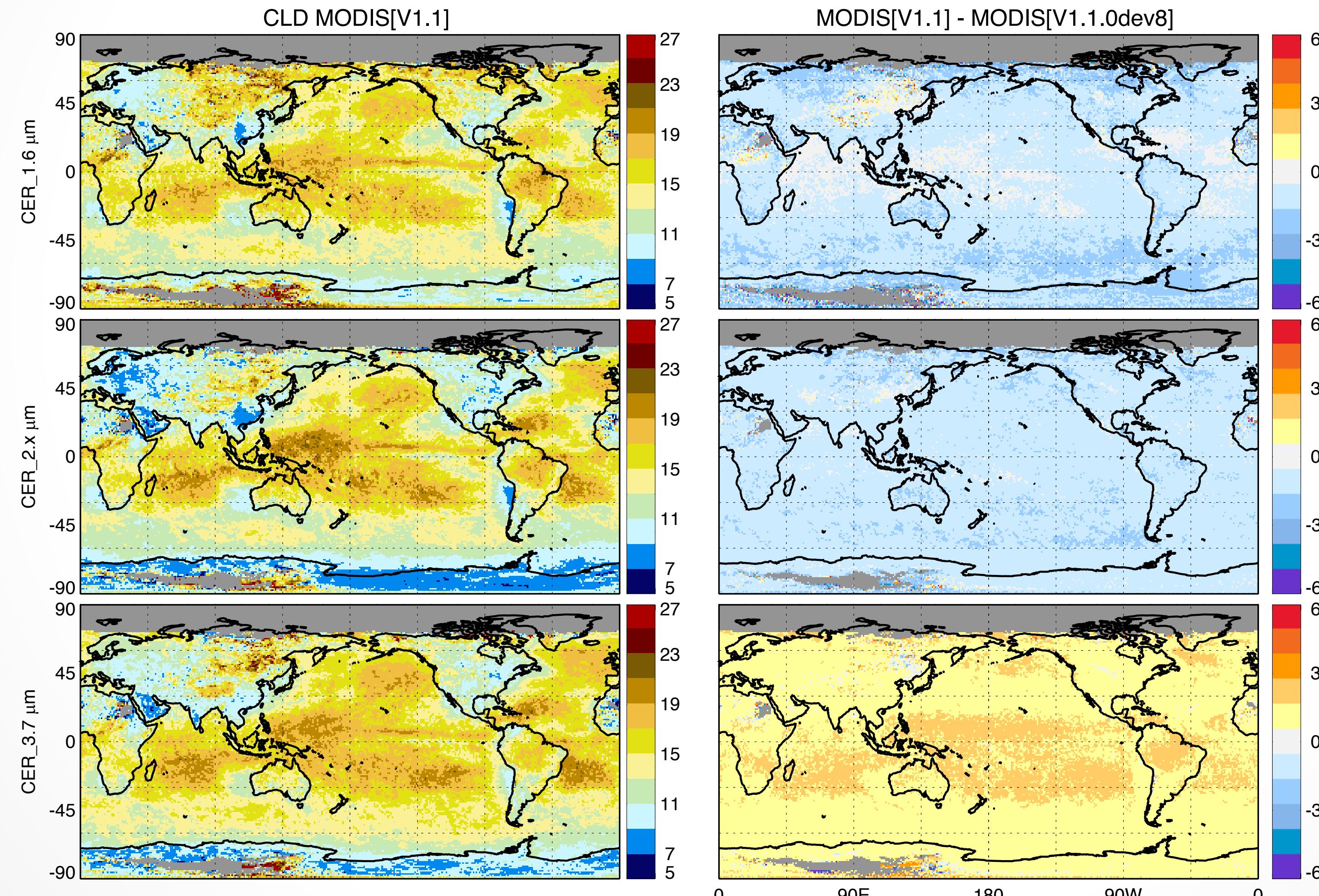
# MODIS Liquid Water CER Comparisons

2014 FEBRUARY [MODIS V1.1 (Yori) , MODIS V1.1.0dev8(Yori)]

CLDPROP\_M3\_MODIS\_Aqua.A2014032.011.2019232182026.nc CLDPROP\_M3\_MODIS\_Aqua.A2014032.300K.2019312205422.nc

Cloud\_Effective\_Radius\_Liquid, Cloud\_Effective\_Radius\_16\_Liquid, Cloud\_Effective\_Radius\_37\_Liquid

CER 1.6  $\mu\text{m}$



CER 2.x  $\mu\text{m}$

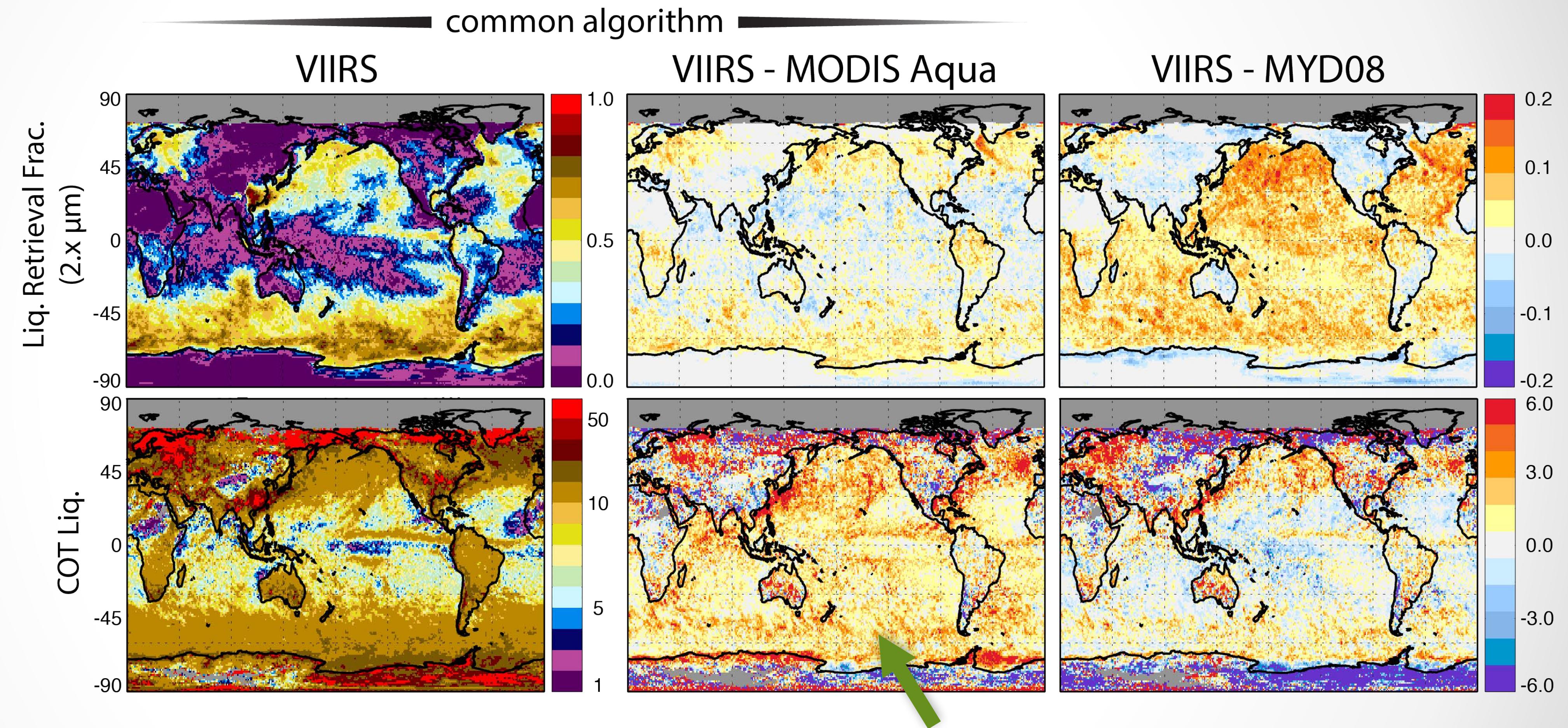
MODIS  $\Delta$ CERs  
(CLDPROP LUTs minus  
MOD06 C6.1 LUTs)

CER 3.7  $\mu\text{m}$

## Monthly Means Feb 2014 (v1.1)

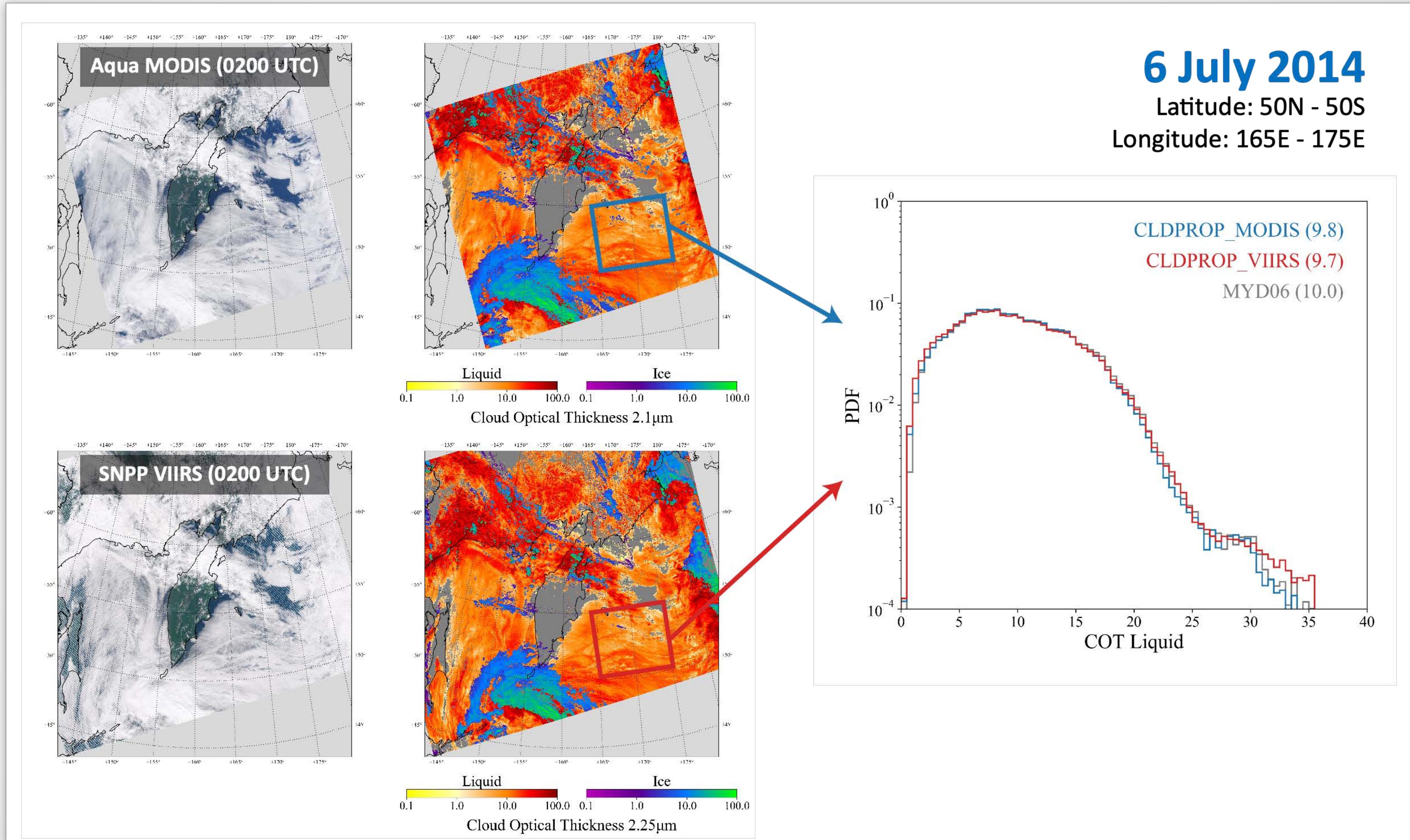
- Production version of common algorithm, includes SW Radiometric Bias Correction
- Pixel-weighted aggregation over common swath
- Daytime only
- Highest Quality (non-“Partly Cloudy” pixels)

Liquid Water Retrieval Fraction and COT Comparisons

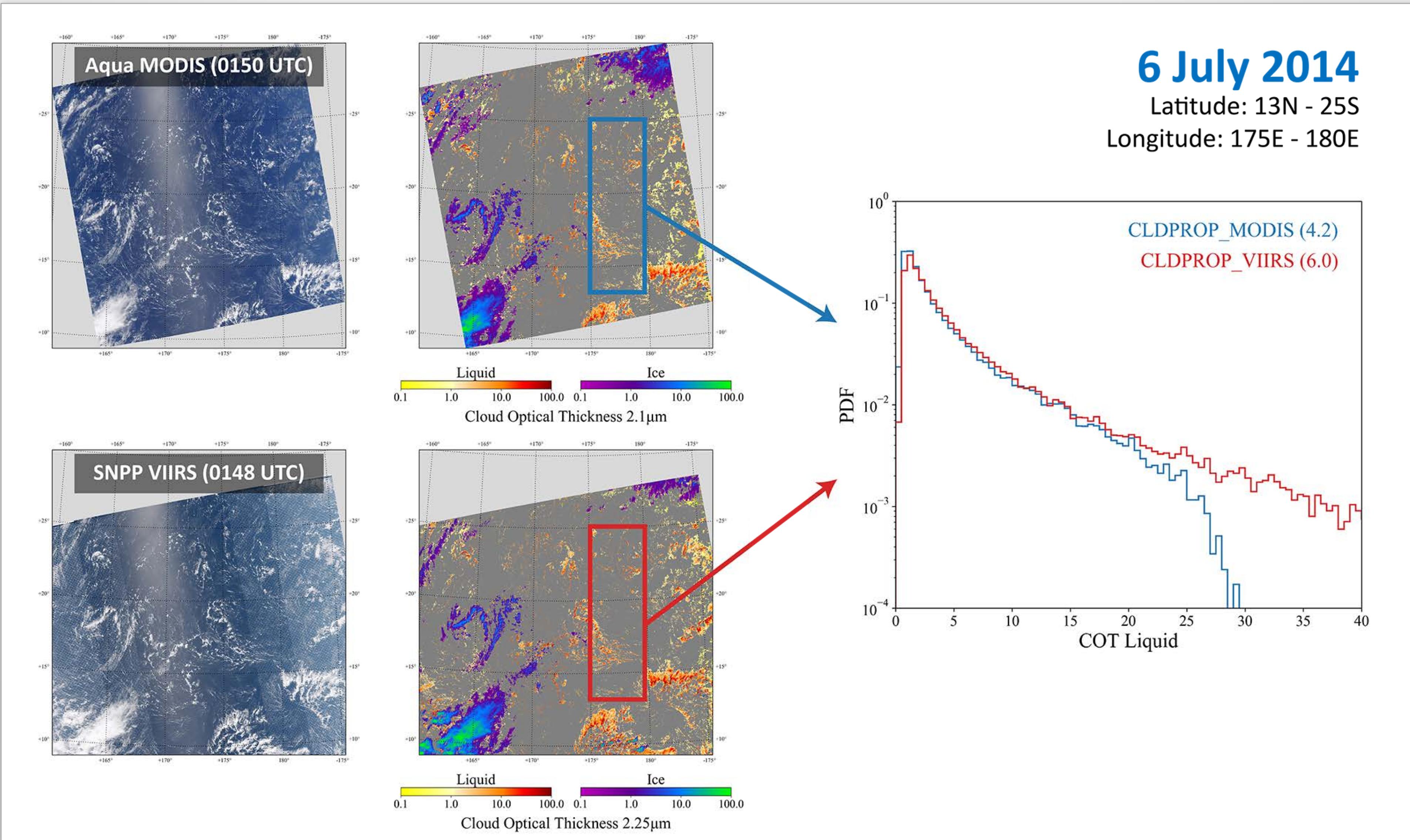


Systematic Liq. COT VIIRS > MODIS over ocean!?

# Pixel FOV: horizontally *homogeneous* liquid cloud scene

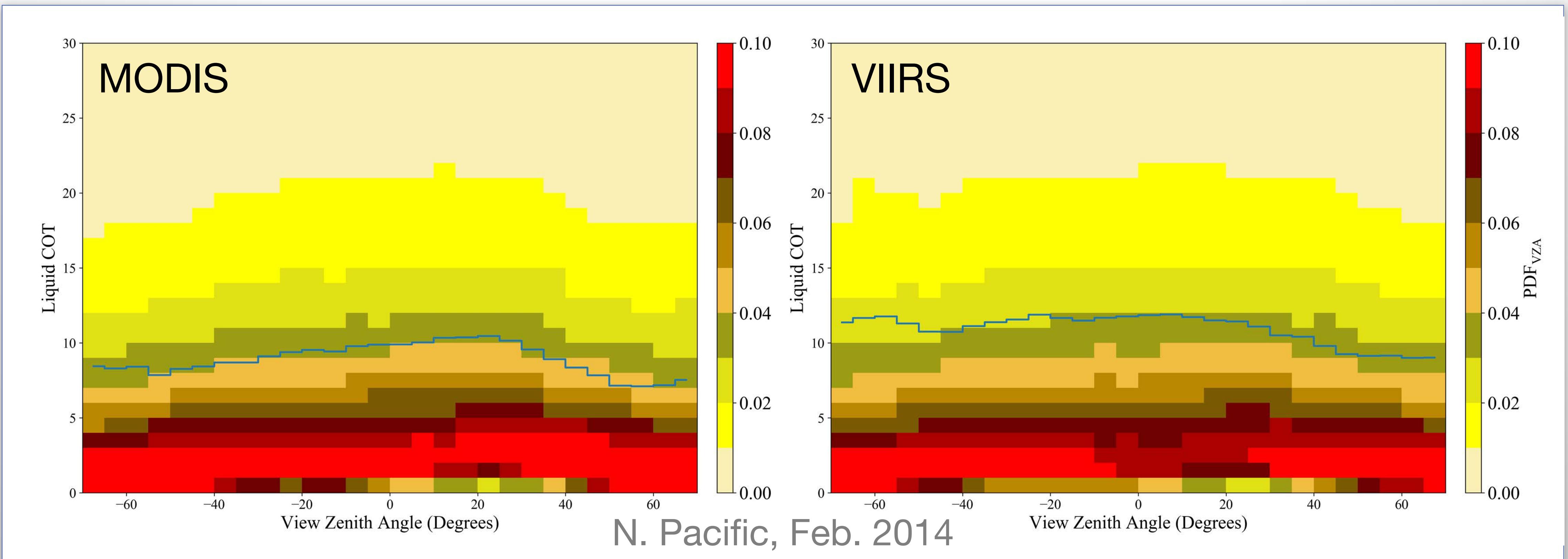


# Pixel FOV: horizontally heterogeneous liquid cloud scene



# Research L3 Product using Yori Infrastructure at A-SIPS

- Developed to understand
  - Temporal sampling differences between Aqua MODIS and SNPP VIIRS aggregations
  - Viewing geometry sensitivities



# MODIS COSP L3 Products using Yori Infrastructure at A-SIPS

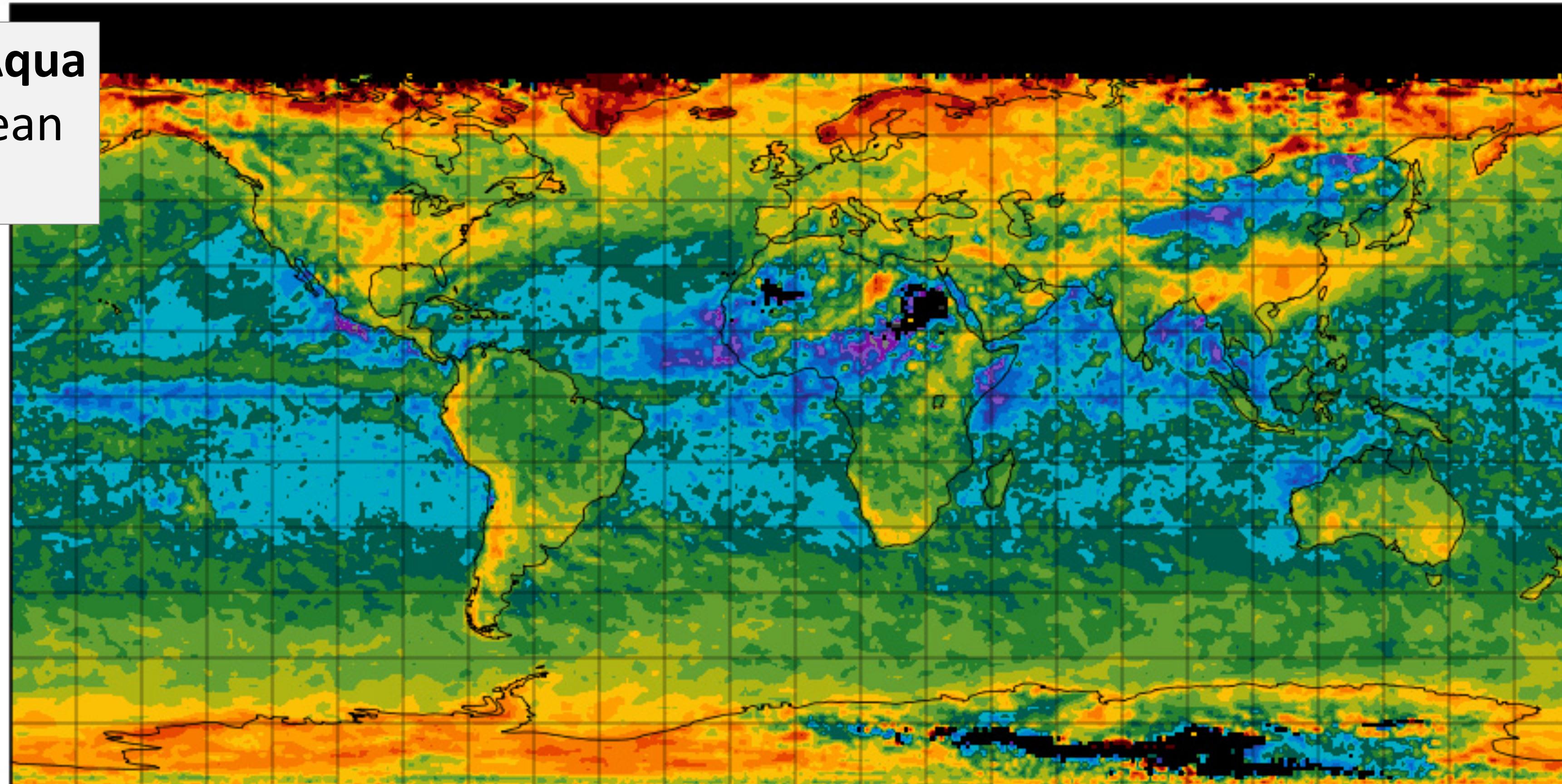
- ▶ COSP (CFMIP Observational Simulation Package)
  - MODIS C5 Cloud Simulator was initially developed for COSP as part of IPCC AR5 CFMIP5 climate model evaluation.
  - Simulates core MODIS cloud products from model output and generates L3-like statistics.
  - Separate monthly L3 file produced corresponding to simulator output only and converted to netCDF (CF compliant convention).
- ▶ MODIS C6 Cloud Simulator being updated for CFMIP6 (R. Pincus)
- ▶ Tested new COSP L3 product using Yori at A-SIPS
  - Special example  $0.25^\circ$  L3 research product produced at request of LLNL/DoE

MYD08\_M3 (1.0 degree)

Cloud Optical Thickness Liquid: Mean (3.7 microns)

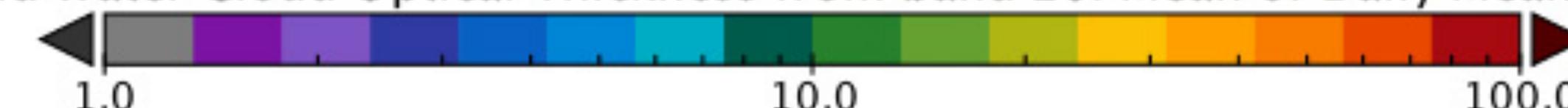
Feb 2014

**MYD08 (1°) Aqua  
COT liquid mean  
Feb 2014**



Liquid Water Cloud Optical Thickness from band 20: Mean of Daily Mean (none)

Aqua (C6.1)



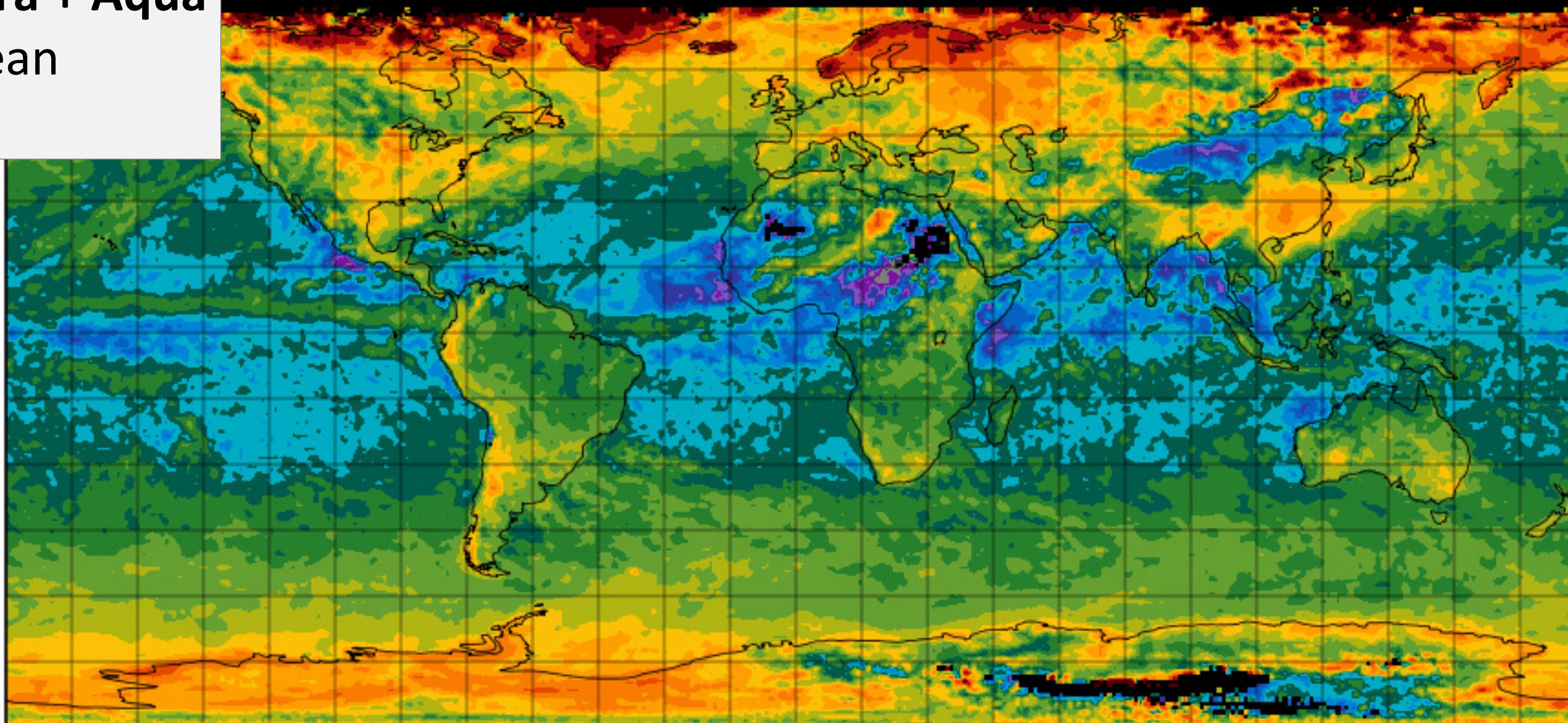
Data Min = 0.2, Max = 150.0, Mean = 14.3

COSP (1.0 degree)

Cloud Optical Thickness Liquid: Mean (3.7 microns)

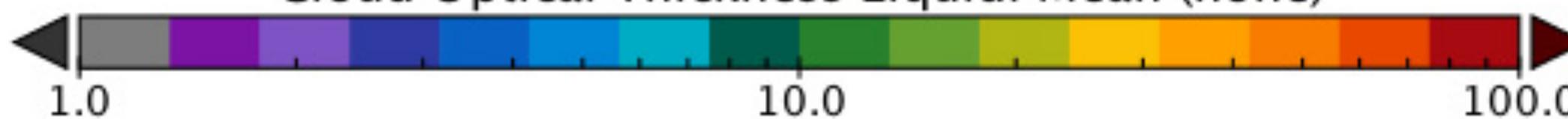
Feb 2014

**COSP (1°) Terra + Aqua  
COT liquid mean  
Feb 2014**



Terra+Aqua (C6.1)

Cloud Optical Thickness Liquid: Mean (none)



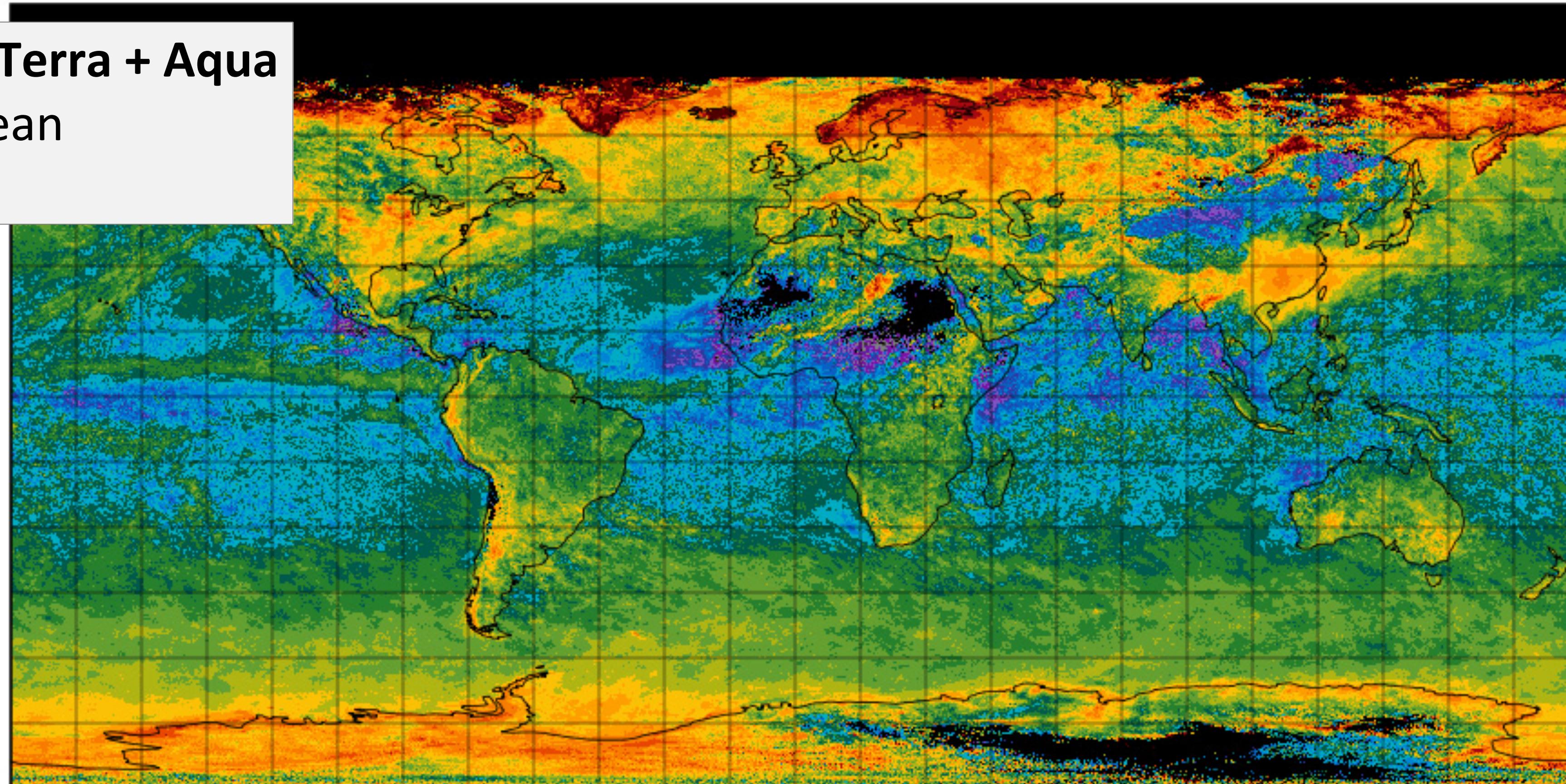
Data Min = 0.7, Max = 150.0, Mean = 14.9

QDEG (0.25 degree)

Cloud Optical Thickness Liquid: Mean (3.7 microns)

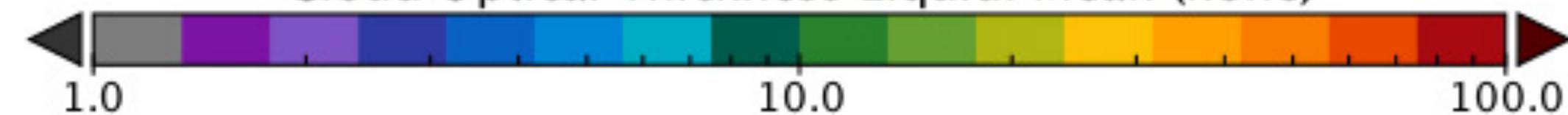
Feb 2014

**COSP (0.25°) Terra + Aqua**  
COT liquid mean  
Feb 2014



Terra+Aqua (C6.1)

Cloud Optical Thickness Liquid: Mean (none)



Data Min = 0.1, Max = 150.0, Mean = 14.7

# CLDPROP Phase with Machine Learning Random Forest (RF)

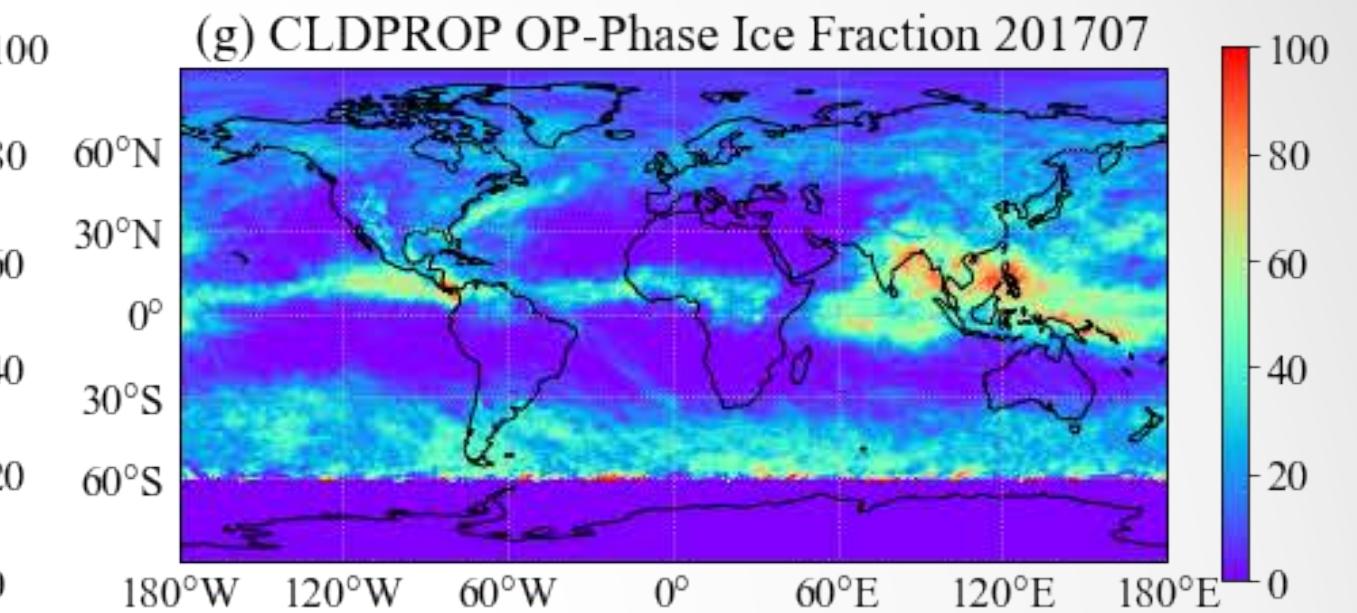
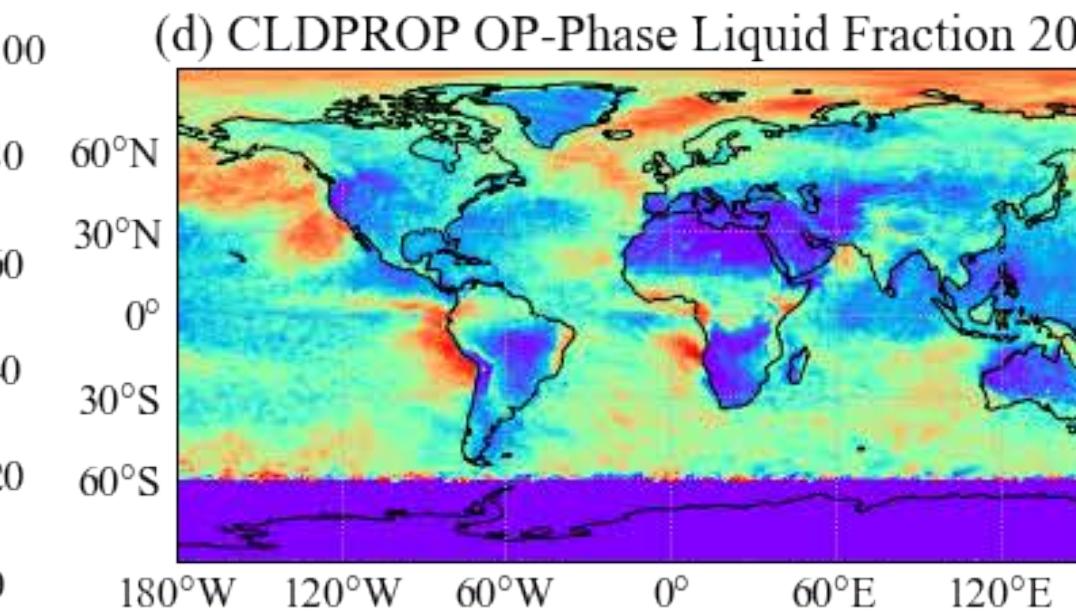
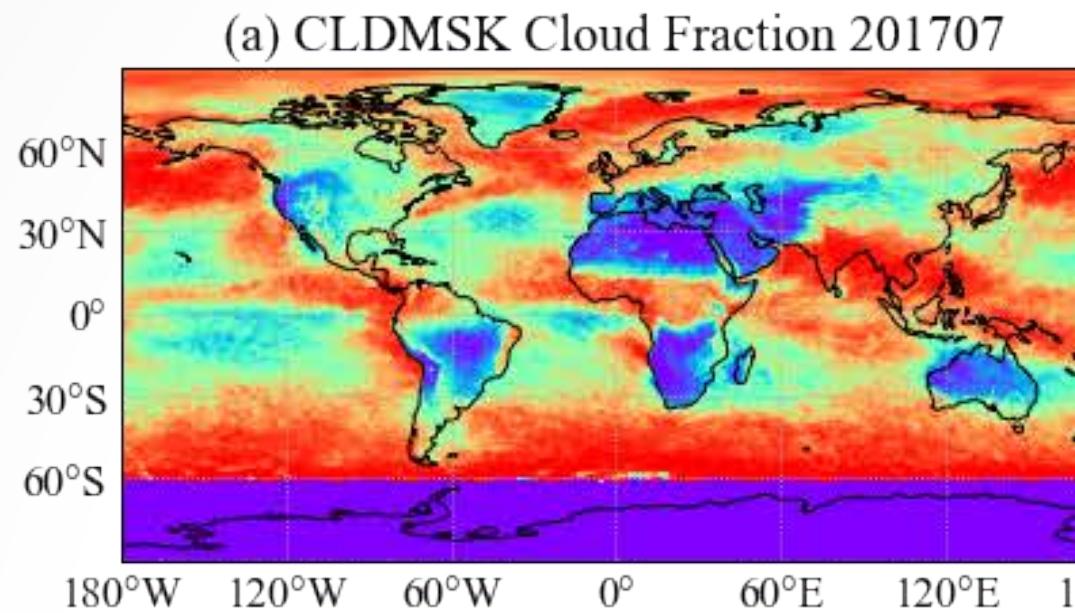
## ► Features

- Evaluates two RF tree structure for simultaneous VIIRS cloud phase/masking
  - All day (day + night): IR-only (8.6, 11, and 12  $\mu\text{m}$ )
  - Daytime only: IR + VNIR/SWIR (0.86, 1.24, 1.38, 1.64 and 2.24  $\mu\text{m}$ )
- Trained on 4-yrs of collocated VIIRS & CALIOP data (2013-2016)
- Evaluated against 1-yr (2017) of collocated VIIRS & CALIOP data

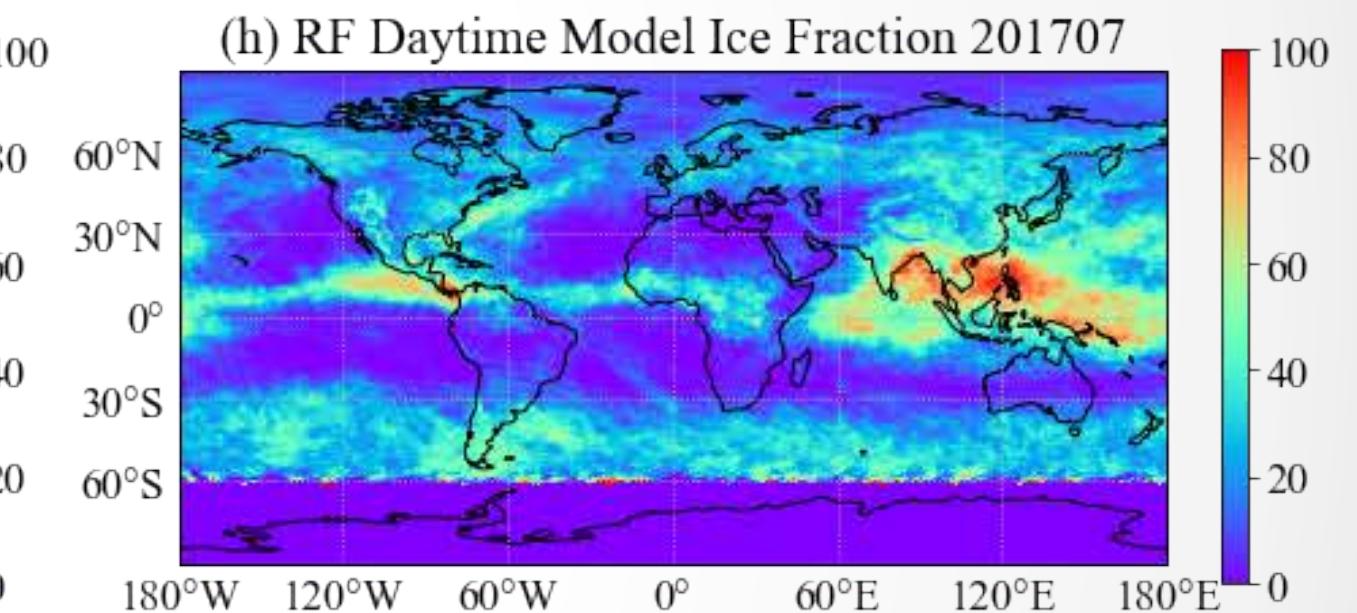
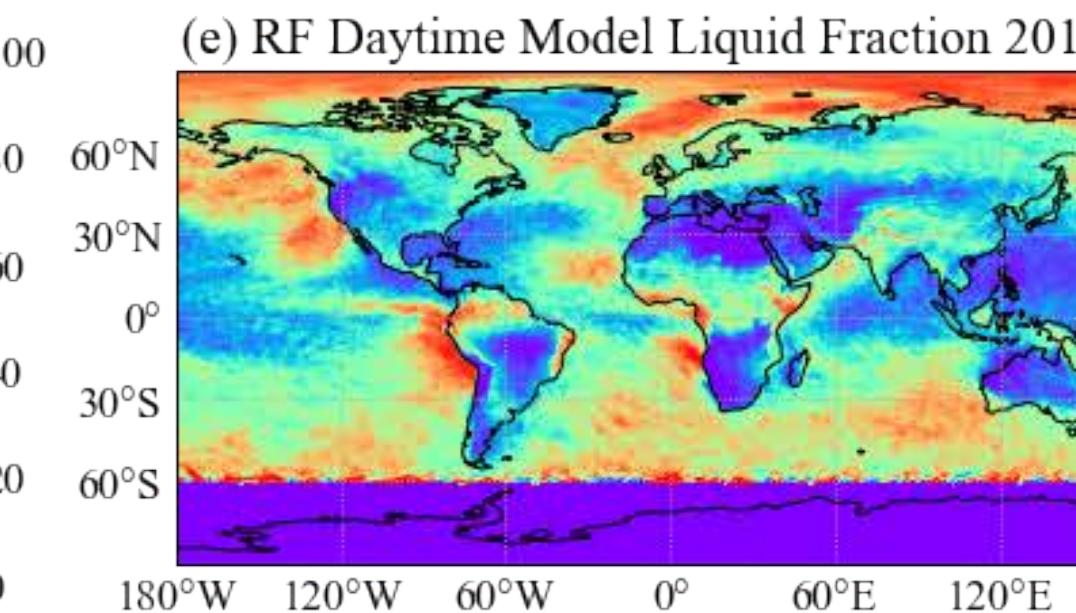
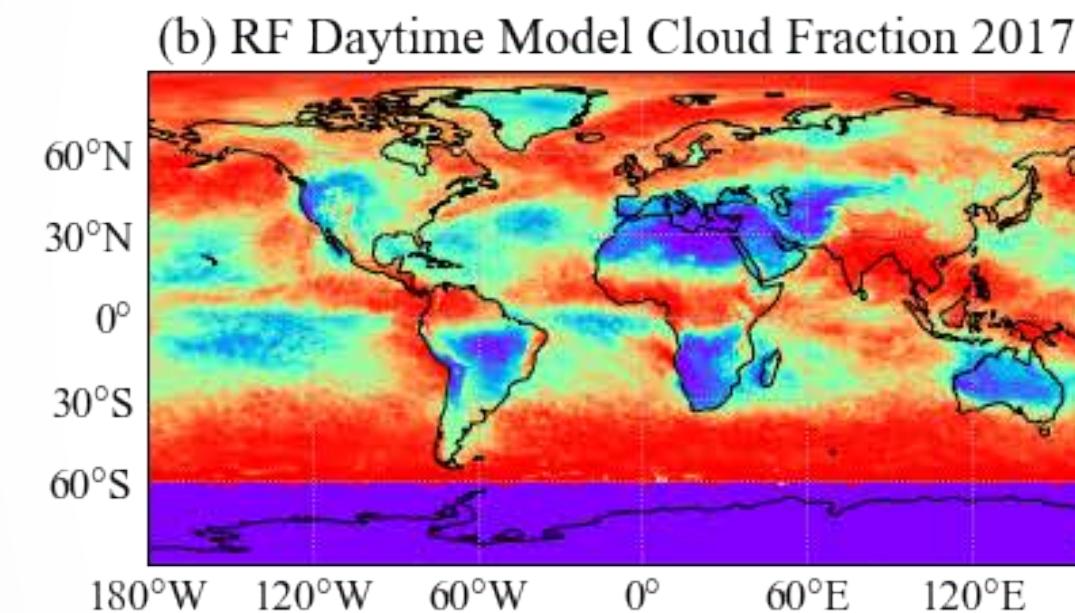
see Chenxi Wang et al. poster, manuscript submitted to *AMT*, Oct. 2019

# CLDPROP Phase with Machine Learning Random Forest (RF)

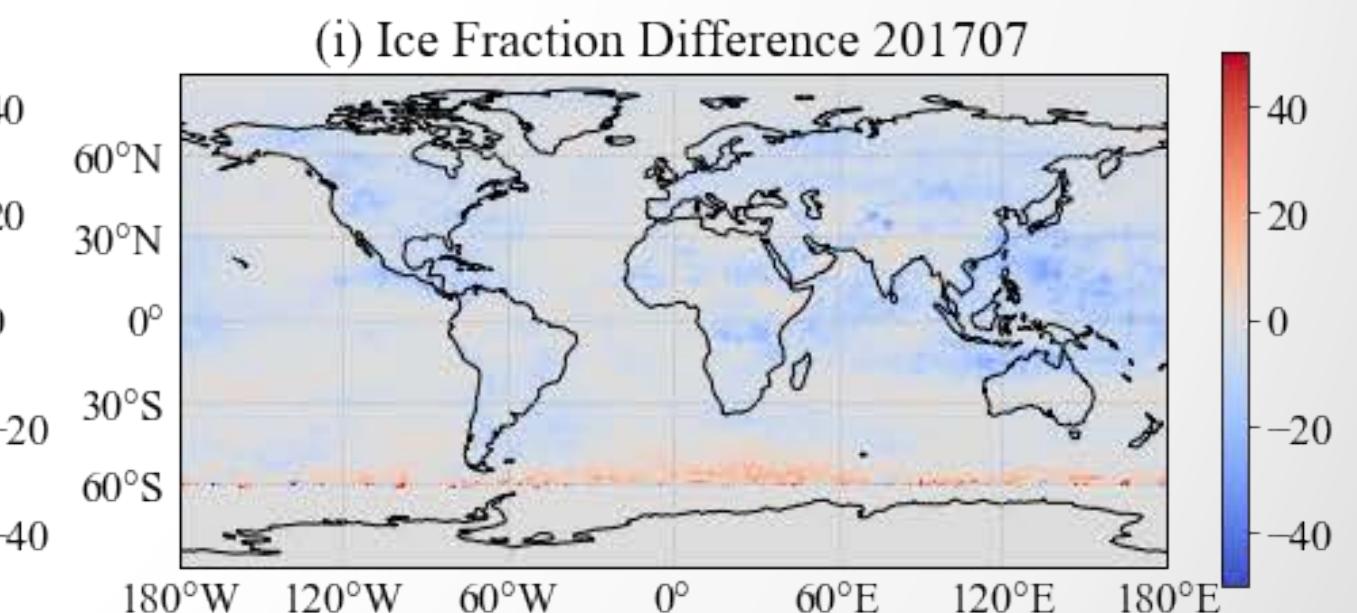
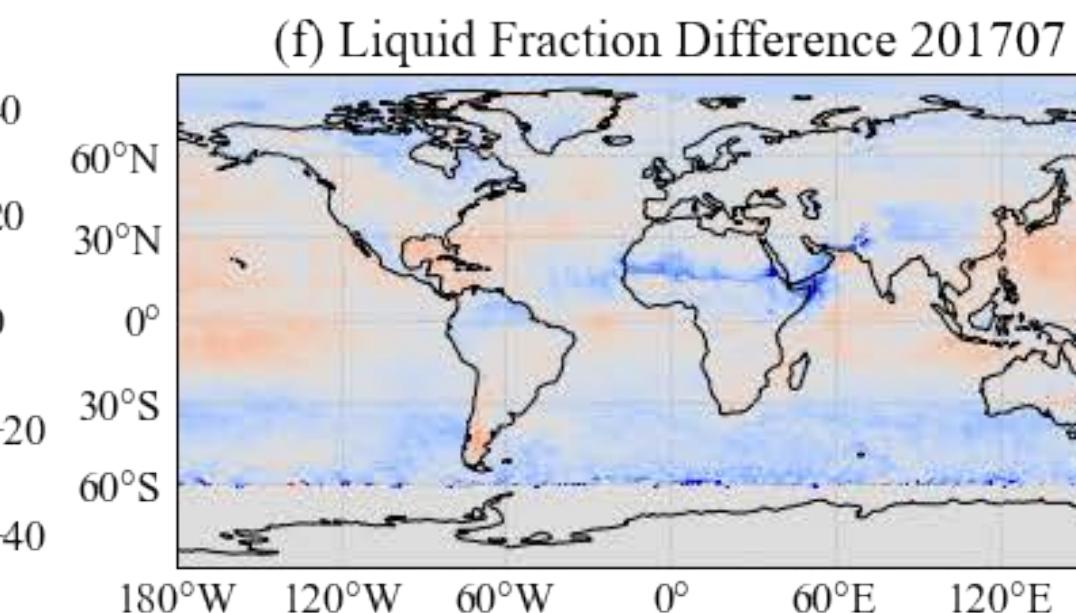
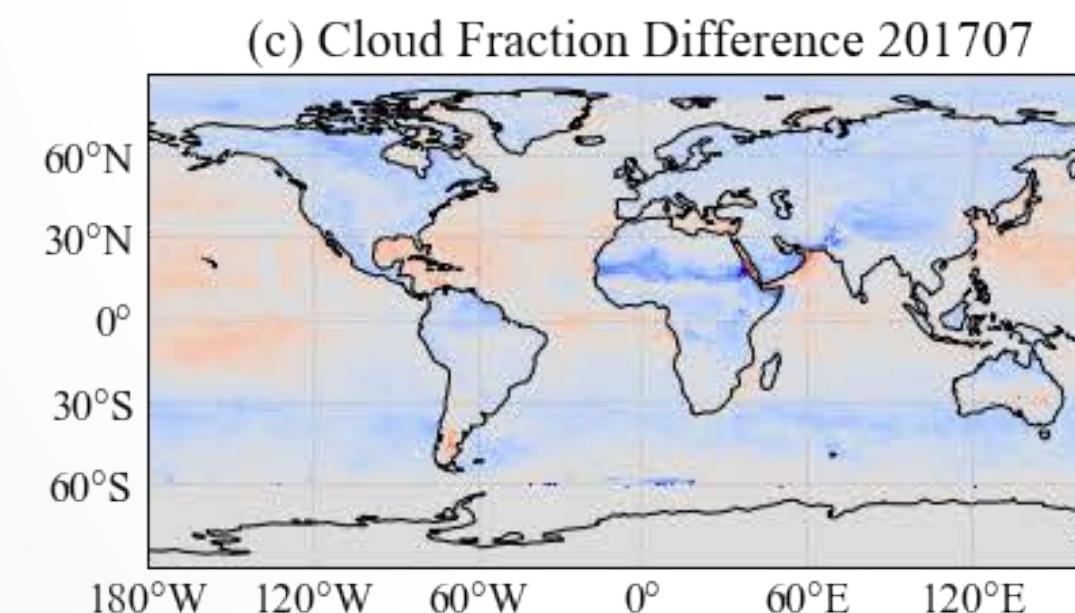
RF



CLDPROP (v1.1)

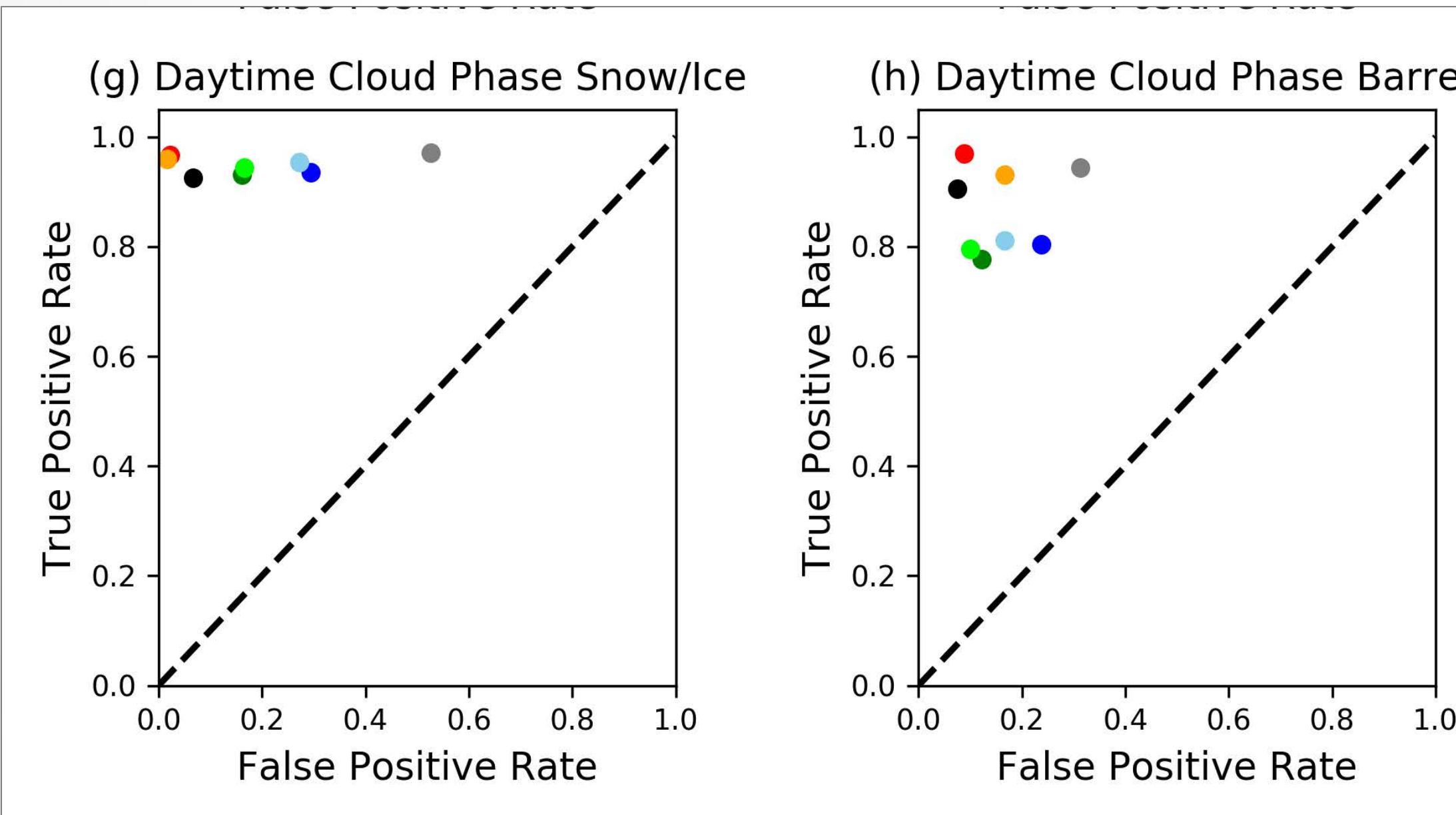
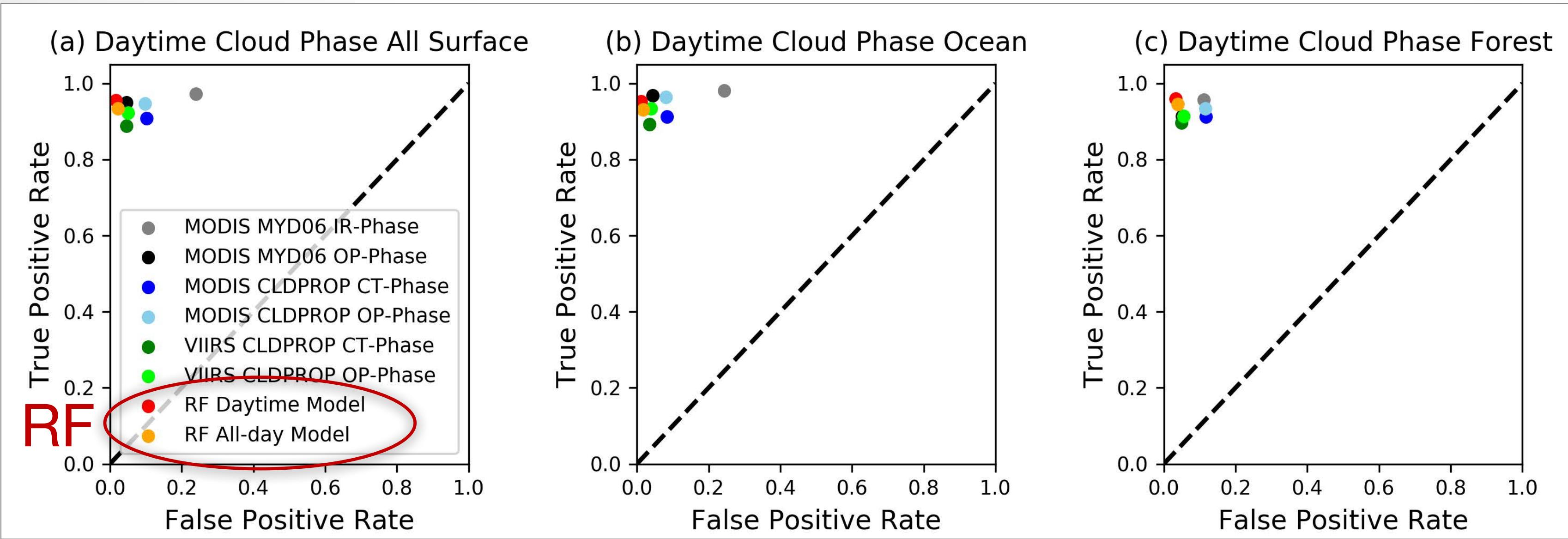


CLDPROP (v1.1)  
- RF



January 2017

# CLDPROP Phase with Machine Learning Random Forest (RF)



False Positive Rate (FPR) vs. True Positive Rate (TPR) for daytime results from two RF models and standard products, for collocated CALIOP L2 products from 2017.

# CLDPROP Phase with Machine Learning (Random Forest)

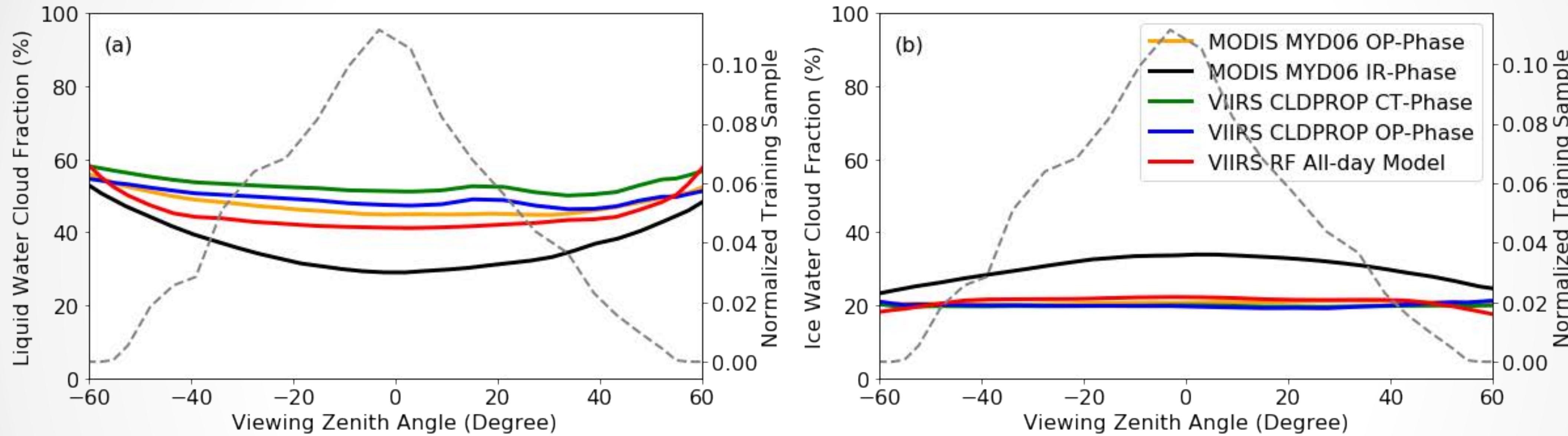


Figure 12. Liquid water (a) and ice (b) cloud fractions as a function of viewing zenith angle from the one-month daytime cloud mask/phase products in January 2017. The gray dashed curve is the probability density function of the 4-year VIIRS/CALIOP training samples (2013-2016).

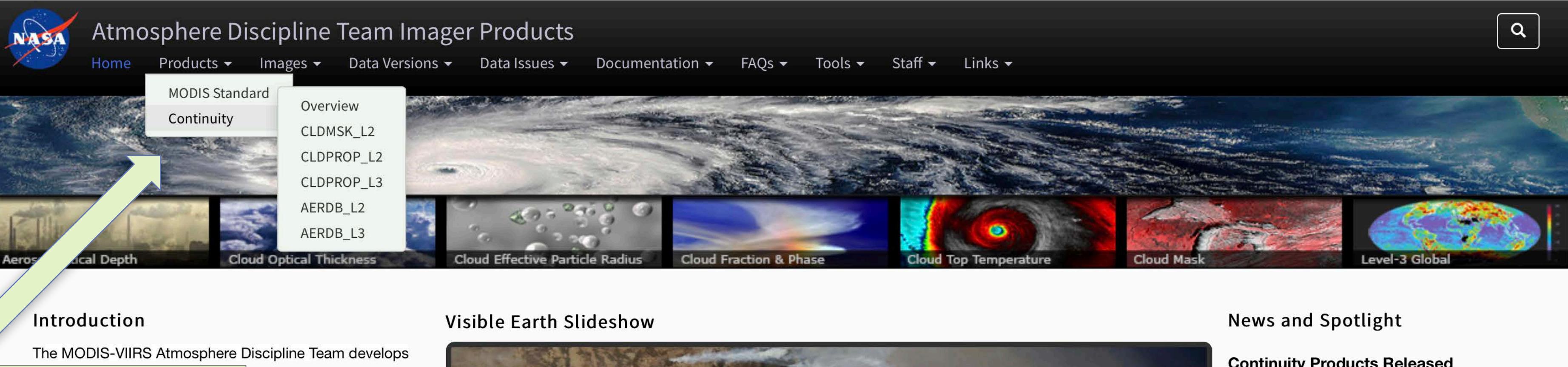
# MODIS/VIIRS Cloud Product Continuity Summary

- ▶ Shortwave radiometric data record continuity is challenging, even with the same instrument (MODIS Aqua/Terra). More so for different instruments.
- ▶ Impact of  $2.x \mu\text{m}$  window channel placement on optical properties (ice as well as liquid) requires understanding spectral imaginary index of refraction.
- ▶ Next Steps:
  - Public release: v1.1 L2 & L3 (November 2019)
  - Algorithm: Further investigation of index of refraction sensitivity (ice as well as liquid), FOV/sampling aggregation sensitivities, and use of CrIS to compensate missing VIIRS IR absorption channels (longer term).
  - Science assessment: time series analysis, include “cloud radiative effect” datasets and assess radiative continuity, user community feedback, ...

# Topics

- ▶ MODIS Standard Cloud Product Status (**MOD35, MOD06**)
  - C6.1 trend assessments
  - C7 major activities
- ▶ MODIS/VIIRS Continuity Product Status (**CLDMSK, CLDPROP**)
  - Continuity paradigm overview
  - Example results (L2 and L3)
  - Ongoing efforts
- ▶ New “atmosphere imager” web site, documentation, etc.

# New Atmospheres Imager Team Web Site



The MODIS-VIIRS Atmosphere Discipline Team develops algorithms for the data records of derived parameters (e.g., aerosols, clouds, water vapor). The team contributes to the EOS flagship Terra mission (1998) and the EOS-2 mission (2002), and provides support of the twin Suomi NPP and JPSS missions.

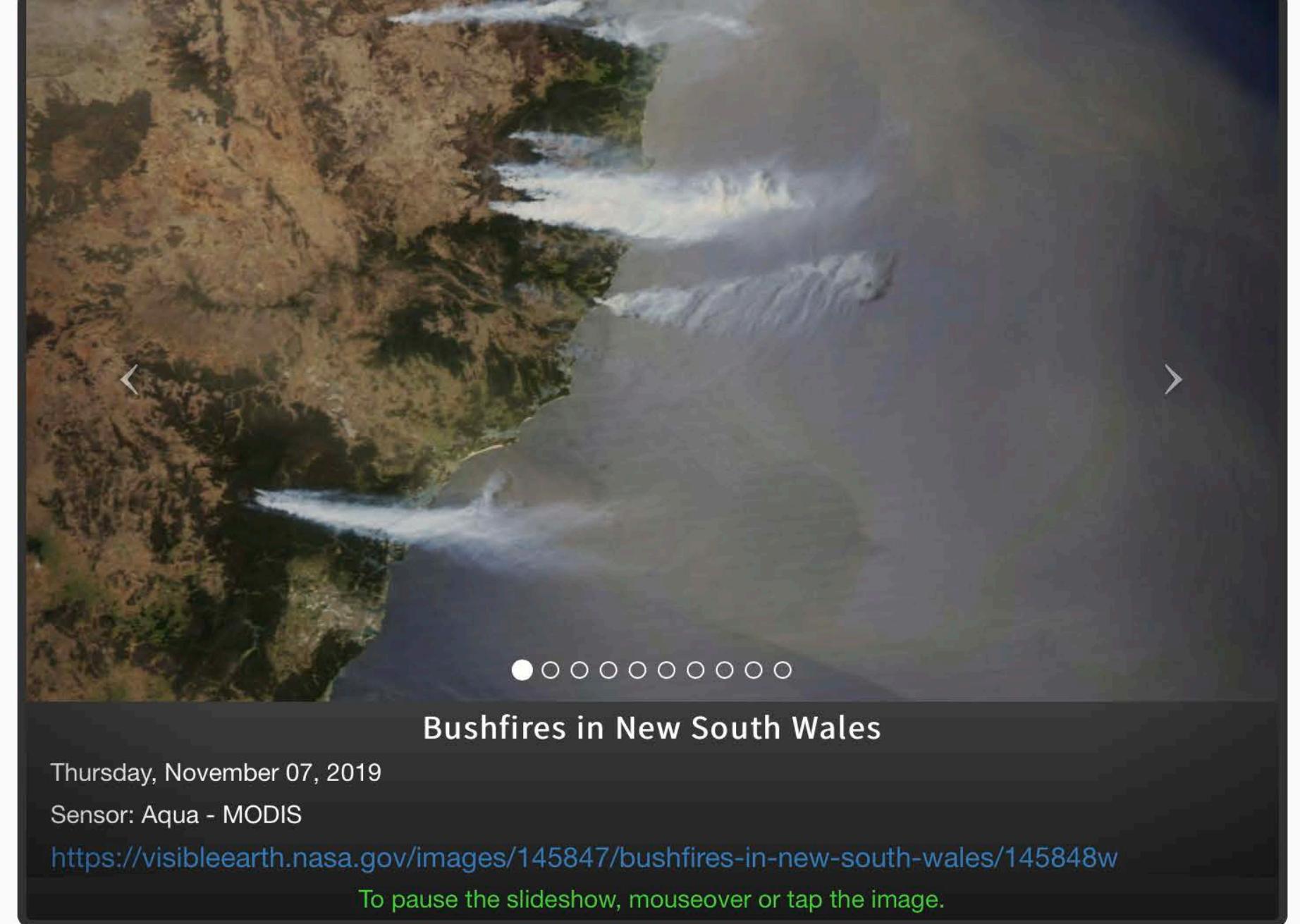
Moderate-resolution imaging Spectroradiometers (MODIS). As these missions and sensors age, NASA is supporting the extension of key EOS-era MODIS climate data records to NOAA's next-generation polar orbiting imager VIIRS, the first of which was launched on the Suomi NPP platform in 2011. Both MODIS and VIIRS provide wide spectral range (narrowband channels from visible to infrared), high spatial resolution, and near-daily to daily global coverage of the Earth and its atmosphere.

To support climate data record production from two different sensors, two product streams are available, both archived at the Level-1 and Atmosphere Archive & Distribution System (LAADS) Distributed Active Archive Center (DAAC): the EOS-heritage MODIS Standard

**Introduction**  
The MODIS-VIIRS Atmosphere Discipline Team develops algorithms for the data records of derived parameters (e.g., aerosols, clouds, water vapor). The team contributes to the EOS flagship Terra mission (1998) and the EOS-2 mission (2002), and provides support of the twin Suomi NPP and JPSS missions.

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**Visible Earth Slideshow**  


Bushfires in New South Wales  
Thursday, November 07, 2019  
Sensor: Aqua - MODIS  
<https://visibleearth.nasa.gov/images/145847/bushfires-in-new-south-wales/145848w>  
To pause the slideshow, mouseover or tap the image.

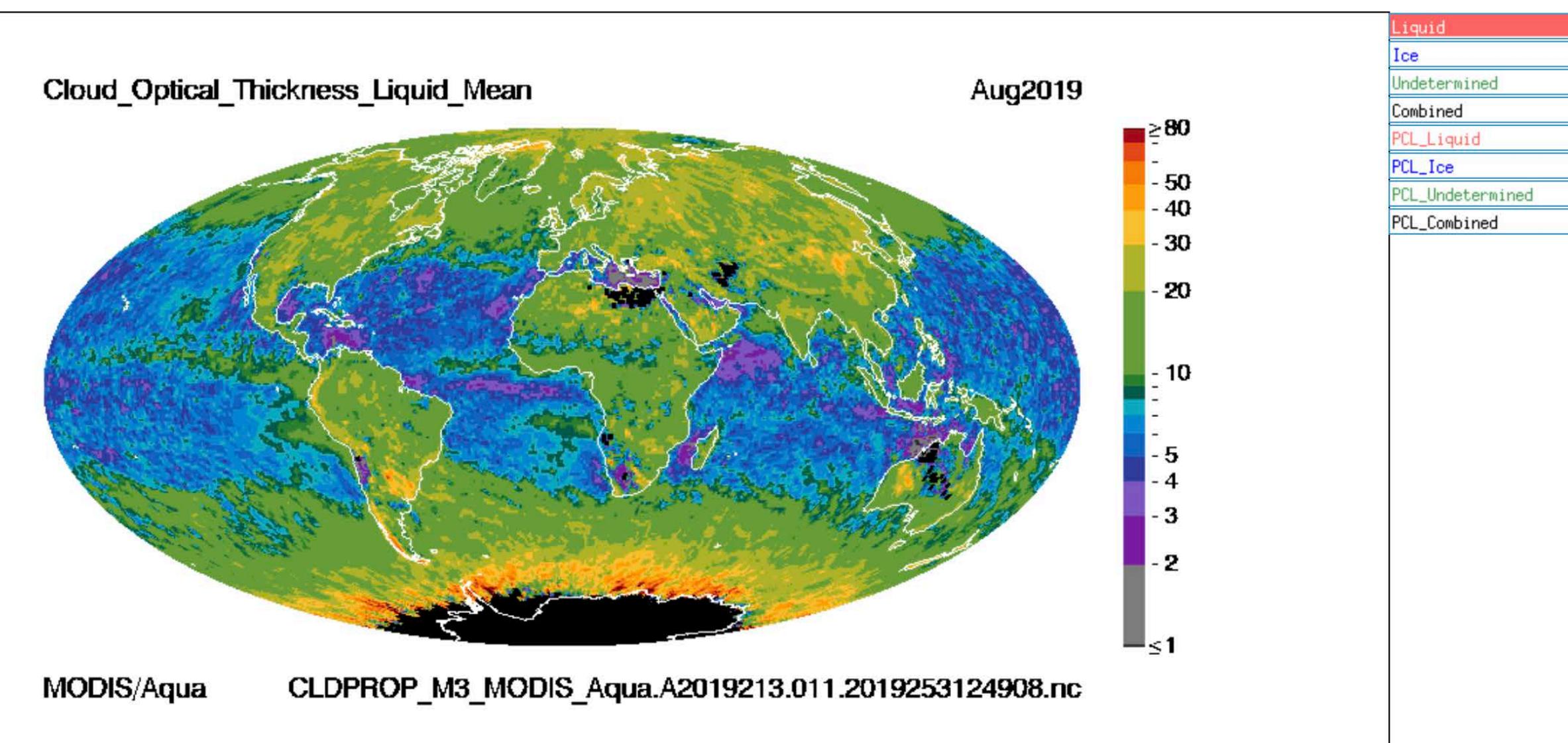
**News and Spotlight**  
**Continuity Products Released**  
Version 1.1 CLDPROP (Cloud Properties) products were released in September 2019. CLDMSK (Cloud Mask) products were released in mid March 2019. AERDB (Aerosol Deep Blue) products were released in December 2018. Product availability is from 1 March 2012 through the present for all products. For the CLDMSK and CLDPROP products, there are both SNPP-VIIRS and Aqua-MODIS streams. For the AERDB products, there is only a SNPP-VIIRS stream. Both Level-2 (L2) and Level-3 (L3) products are available for AERDB and CLDPROP. Keep up with late-breaking LAADS news and spotlight items at [LAADS Alerts and Issues](#).

**Continuity Product Website Expansion**  
This website has been modified to include "Continuity" Atmosphere Products. Access to information pertaining to both the old product

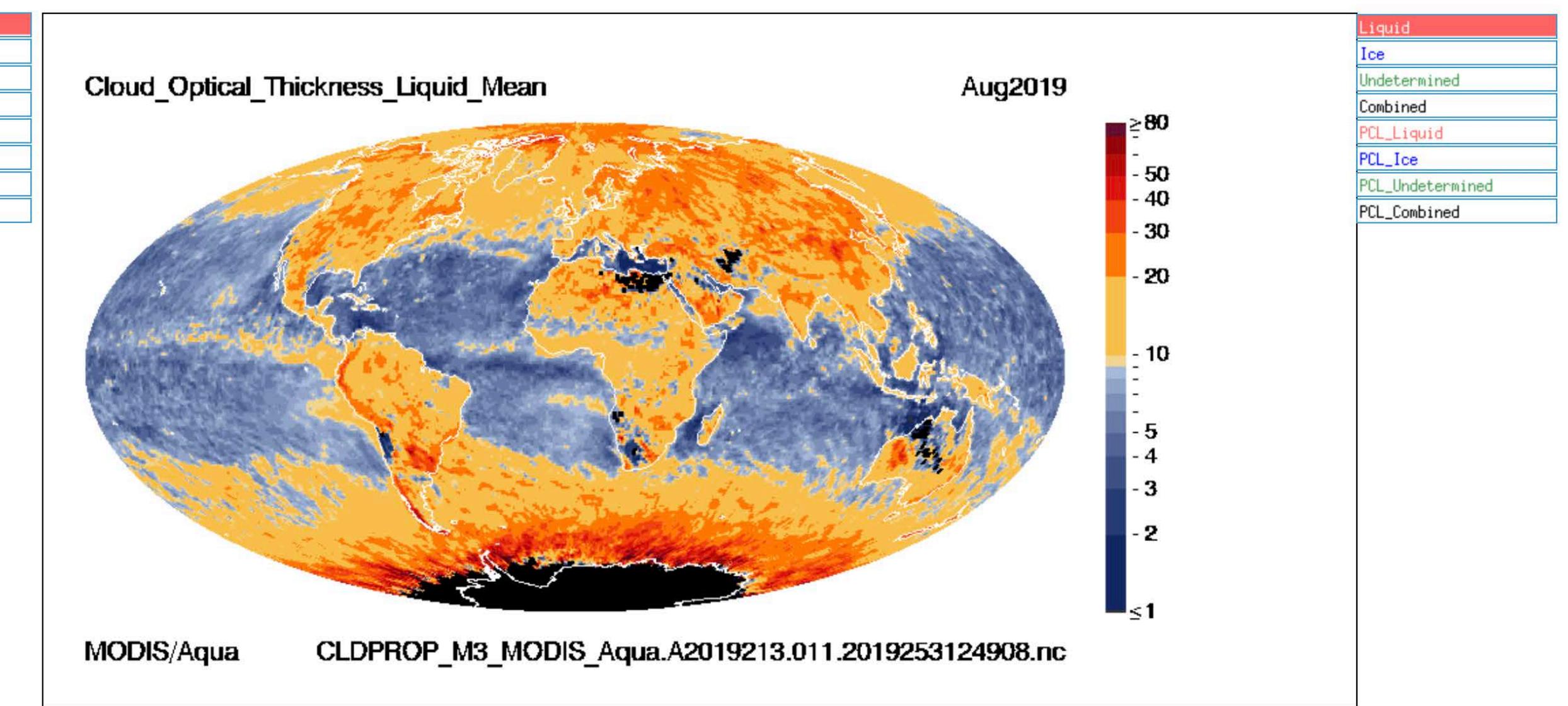
# Continuity Product L3 Browse (Currently Cloud Only)

New user interface and color bar choices

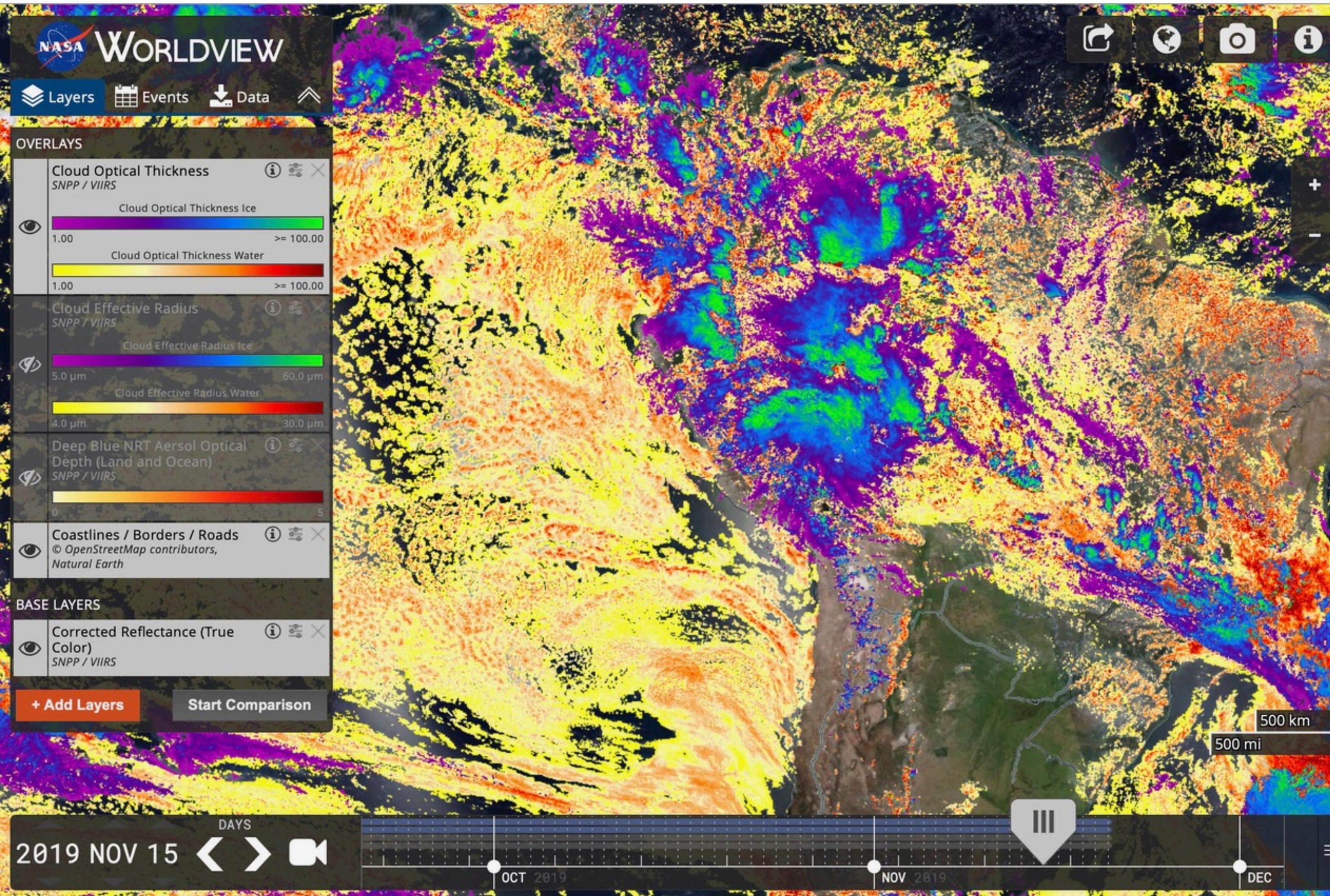
Default color bar



Colorblind friendly



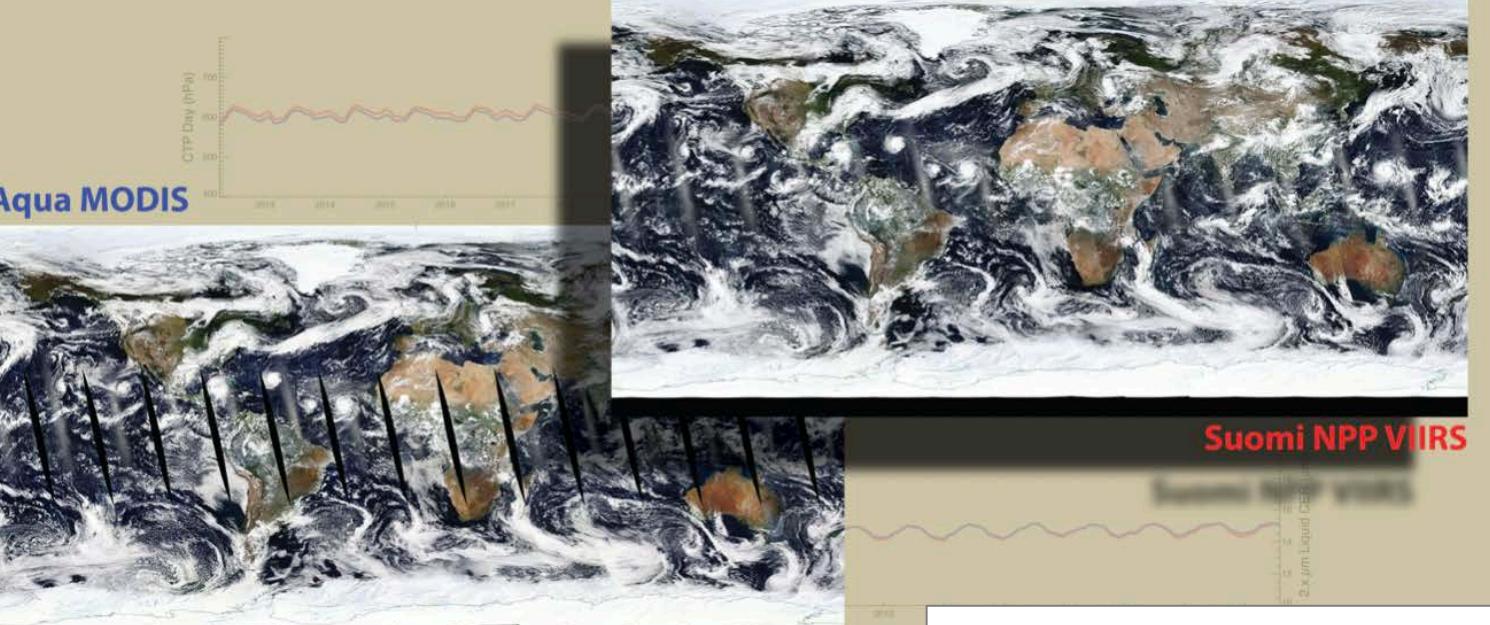
# CLDPROP in Worldview Example (VIIRS COT)



MODIS/VIIRS STM, Cloud Products, Nov. 2019

# Continuity Product User Guides

**EOS MODIS and SNPP VIIRS Cloud Properties:  
User Guide for the Climate Data Record Continuity  
Level-2 Cloud Top and Optical Properties Product  
(CLDPROP)**



**Version 1.1  
October 2019**

**CLOUD MASKING TEAM**  
STEVEN A. ACKERMAN<sup>6</sup>, RICHARD FREY<sup>6</sup>

**CLOUD TOP PROPERTY TEAM**  
ANDREW HEIDINGER<sup>2</sup>, YUE LI<sup>6</sup>, ANDI WALThER<sup>6</sup>

**CLOUD OPTICAL PROPERTY TEAM**  
STEVEN PLATNICK<sup>1</sup>, KERRY G. MEYER<sup>1</sup>, GALA WIND<sup>3,1</sup>, N  
CHENXI WANG<sup>4,1</sup>, BENJAMIN MARCHANT<sup>5,1</sup>

**PRODUCT ASSESSMENT SUPPORT**  
ROBERT E. HOLZ<sup>6</sup>, STEVEN DUTCHER<sup>6</sup>, PAUL HUBANKS<sup>7,1</sup>

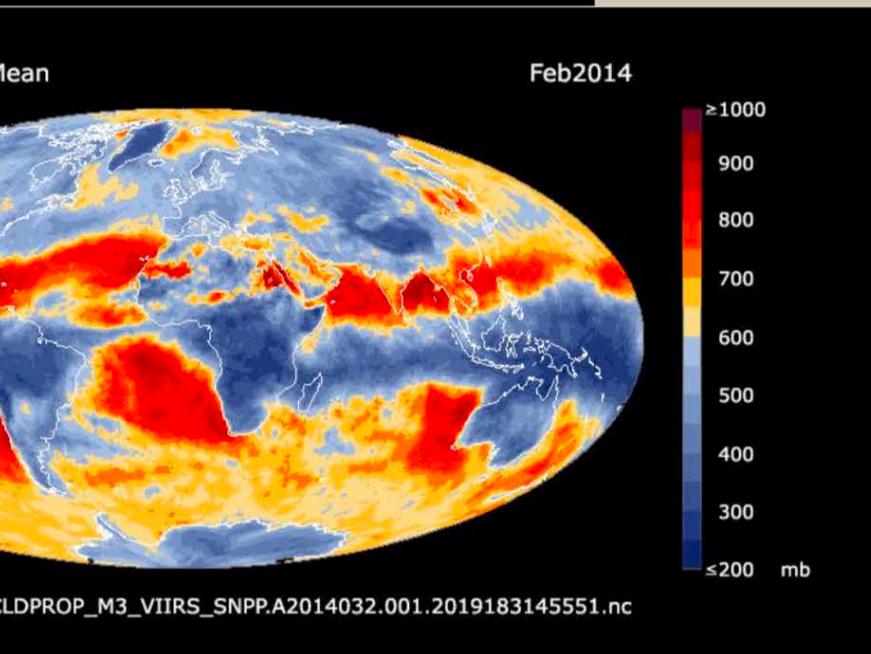
1 Earth Sciences Division, NASA Goddard Space Flight Center, Greenbelt, MD  
2 NOAA NESDIS/STAR/CIMSS, Madison, WI  
3 Science Systems and Applications, Inc., Lanham, MD  
4 Earth System Science Interdisciplinary Center, University of Maryland, College Park, MD  
5 Goddard Earth Sciences Technology and Research, Universities Space Research Association, Boulder, CO  
6 Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin-Madison, WI  
7 ADNET Systems, Inc., Bethesda, MD

## Continuity Atmosphere Products QA Plan for CLDPROP, CLDMSK, & AERDB



Version 1.1  
2 April 2019

**Level-3 Continuity Cloud Properties (CLDPROP\_L3)  
Global Gridded Product  
User Guide**



**CLDPROP\_M3\_VIIRS\_SNPP.A2014032.001.2019183145551.nc**

**Continuity Atmosphere L3 CLDPROP  
(VIIRS SNPP & MODIS Aqua)  
Global Gridded Products for Daily (D3) and Monthly (M3)  
User Guide**

**User Guide, Version 1.7, 12 September 2019**

**STEVEN PLATNICK<sup>2</sup>, KERRY MEYER<sup>2</sup>, MICHAEL KING<sup>3</sup>, STEVE ACKERMAN<sup>4</sup>, YUE LI<sup>4</sup>, RICH FREY<sup>4</sup>, ANDI WALThER<sup>4</sup>, STEVE DUTCHER<sup>6</sup>, DENIS BOTAMBEKOV<sup>4</sup>, GALA WIND<sup>5</sup>, NANDANA AMARASINGHE<sup>5</sup>, BENJAMIN MARCHANT<sup>2</sup>, BHASKAR RAMACHANDRAN<sup>5</sup>**

1 Goddard Space Flight Center, Greenbelt, MD  
2 Space Physics, University of Colorado, Boulder, CO  
3 Madison, WI

## The Continuity MODIS-VIIRS Cloud Mask (MVCm) User's Guide

Based on NASA MODIS Cloud Mask (MOD35, MYD35)  
Reprocessed Data - Version 1  
Product User's Guide Version 1.0

Richard Frey, Steve Ackerman, Robert Holz, Steve Dutcher  
Space Science and Engineering Center  
University of Wisconsin-Madison  
January 2019

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## The Deep Blue aerosol project: Aerosol retrievals from S-NPP VIIRS

Data product user guide and file specification document

This guide is specific to Version 1 of the VIIRS Deep Blue data products