Time Series Analysis of the NASA MODIS and VIIRS Cloud Products

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Sun-Climate Symposium
Madison, WI 18 May 2022

Topics

- Key Challenges to Achieving an Imager Climate Data Record
- MODIS/VIIRS Imager Cloud Products
- Example Time Series Analysis
  - MODIS Standard Cloud Products (MOD06, MYD06) & ENSO Correlations
    - How long a time series is enough?
  - MODIS/VIIRS Continuity Products (CLDMSK, CLDPROP)
    - Is continuity achievable? Does it matter for trend studies?

Challenges

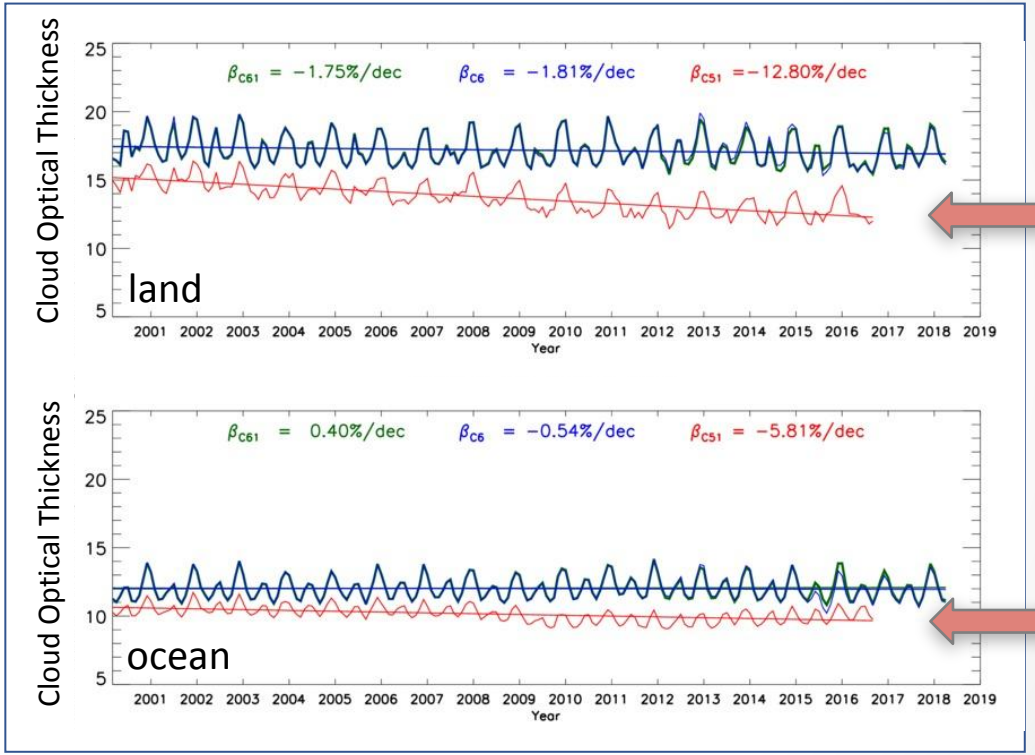
1. Radiometry
   - Single sensor: stability
   - Multiple sensors: stability and (relative) accuracy
     - LEO: MODIS Aqua and Terra, VIIRS Suomi NPP, NOAA-20, …
     - GEO ring: ABI, AHI, …
2. Information Content Across Different Sensors
   - MODIS v. VIIRS: using common algorithms to better account for:
     - VIIRS missing IR CO_2 and IR/SWIR H_2O absorption channels present on MODIS => impacts Cloud Top Pressure (CTP), cloud masking, multilayer cloud detection
     - VIIRS 2.25 µm vs. MODIS 2.13 µm channel => impacts Cloud Effective Radius (CER), thermodynamic phase
     - Spatial resolution (Nadir VIIRS 750m M-bands v. MODIS 1km native/aggregated bands, pixel growth v. scan angle)

MODIS L1B Radiometric Stability: key events

- Collection 5.1 => C6.0 (2013/2014)
  - **Terra VNIR/SWIR:** radiometric corrections (RVS), corrected significant Cloud Optical Thickness (COT) trend artifacts
- Collection 6.0 => C6.1 (2017)
  - **Aqua and Terra VNIR/SWIR:** Further RVS corrections (primarily COT trends)
  - **Terra IR:** cross-talk corrections (8.5 µm), corrected significant trends in cloud amount and cloud top height trends

MODIS Terra Radiometric Stability Example: VNIR Response v. Scan Angle

Cloud Optical Thickness
liquid water clouds,
18-yr time series,
±60° zonal mean

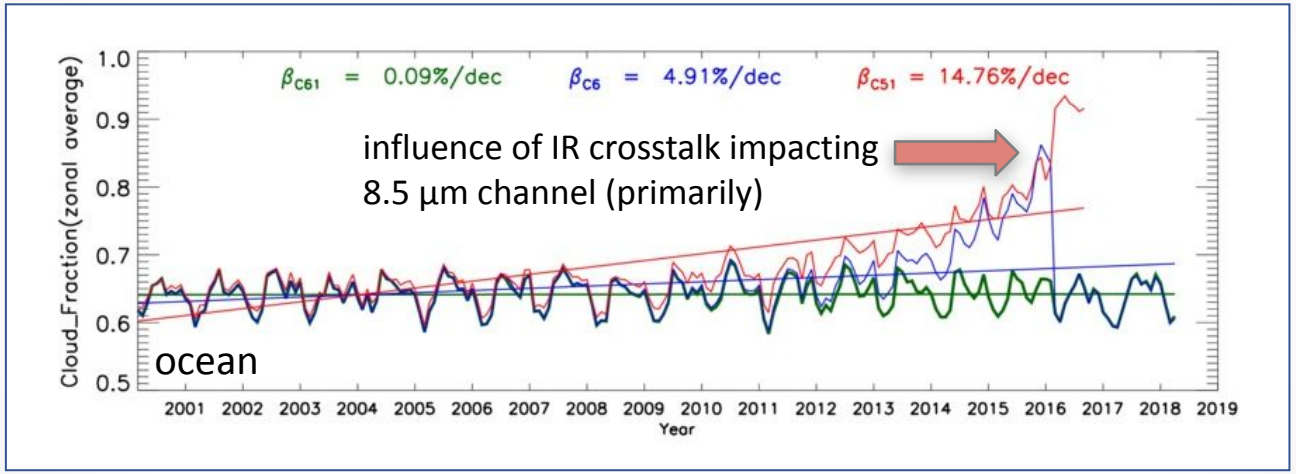


influence of
0.67 µm RVS drift
(-13%/dec)

0.86 µm RVS drift
(-6%/dec)

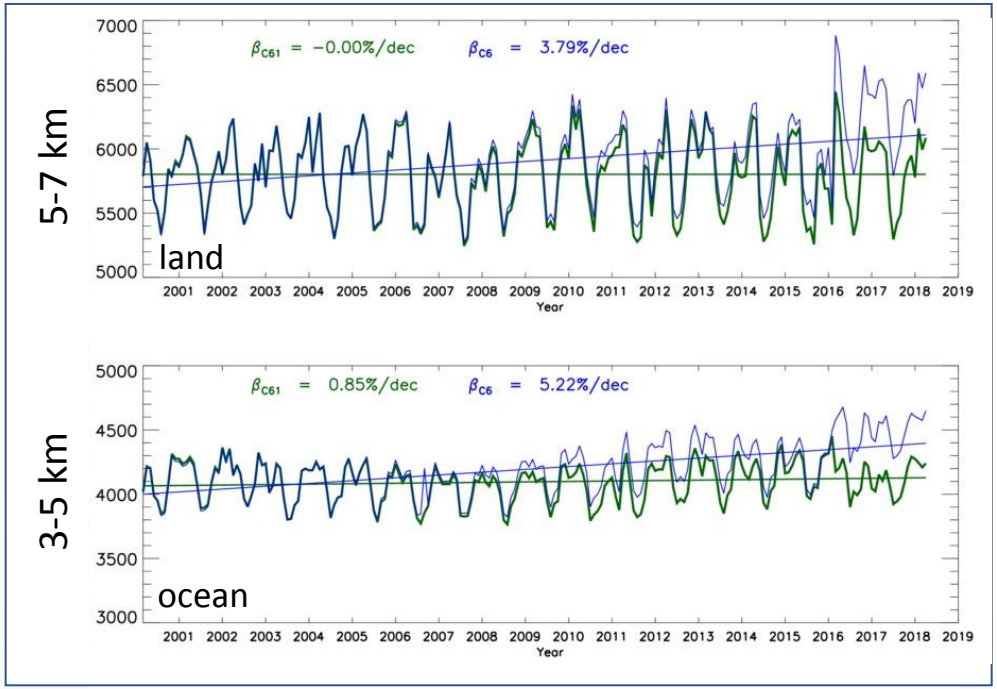
MODIS Terra Radiometric Stability: IR Crosstalk

Cloud Fraction, Terra 18-yr time series, ±25° zonal mean over ocean



MODIS Terra Radiometric Stability: IR Crosstalk

Cloud Top Height, Terra 18-yr time series, ±25° zonal mean



influence of IR crosstalk

Relative Calibration: MODIS Aqua v. SNPP and N20 VIIRS

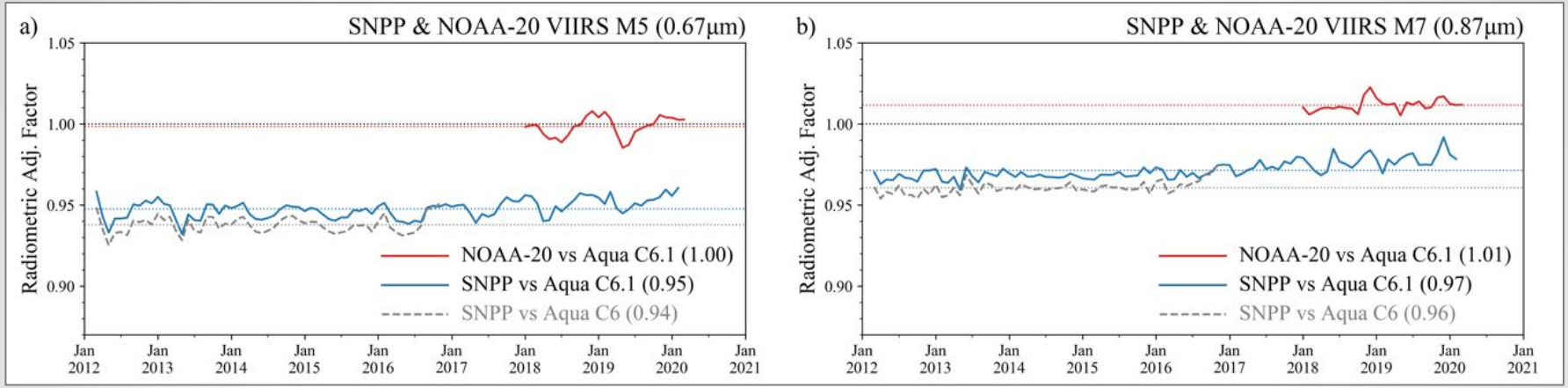
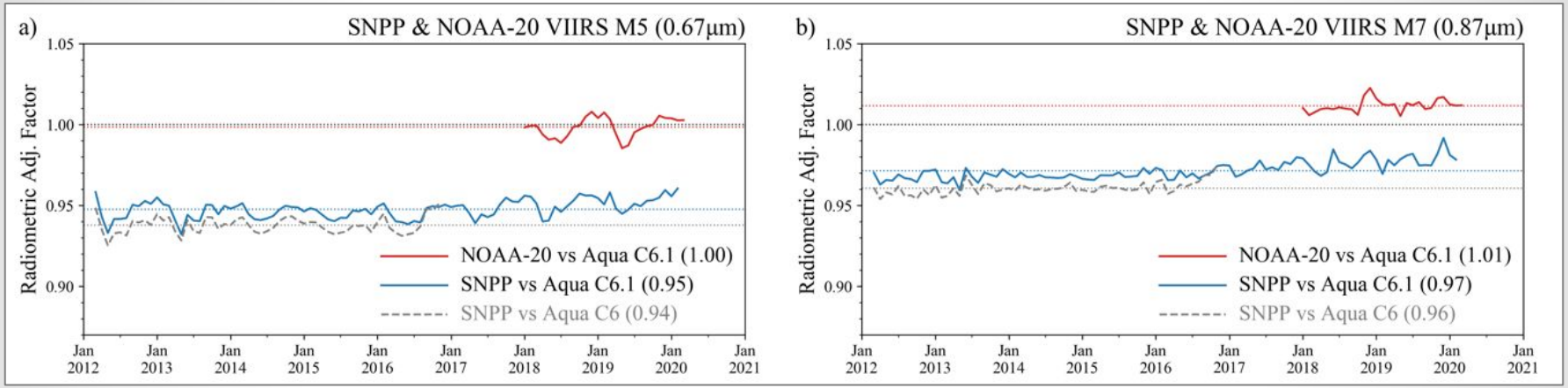


Table 2. Shortwave radiometric adjustment factors derived for SNPP and NOAA-20 VIIRS, derived against the Aqua MODIS C6.1 L1B. Adjustment factors derived against the Aqua MODIS C6 L1B following the current approach and those found by [20] are also shown for SNPP VIIRS derived for clear sky ocean scenes for the Deep Blue aerosol product.

	VIIRS Wavelength (Band Designation)		0.67 μm (M5)	0.87 μm (M7)	1.24 μm (M8)	1.61 μm (M10)	2.25 μm (M11)
Radiometric Adjustment Factor	NOAA-20	vs. MODIS C6.1	1.0	1.01	1.02	1.02	0.99
	SNPP	vs. MODIS C6.1	0.95	0.97	0.99	0.98	0.97
		vs. MODIS C6	0.94	0.96	0.98	0.98	0.97
		Deep Blue Gain Factors	0.941	0.963	1.011	0.981	0.931

K. Meyer et al., *Rem. Sens.*, 2020

Relative Calibration: MODIS Aqua v. SNPP and N20 VIIRS



K. Meyer et al., *Rem. Sens.*, 2020

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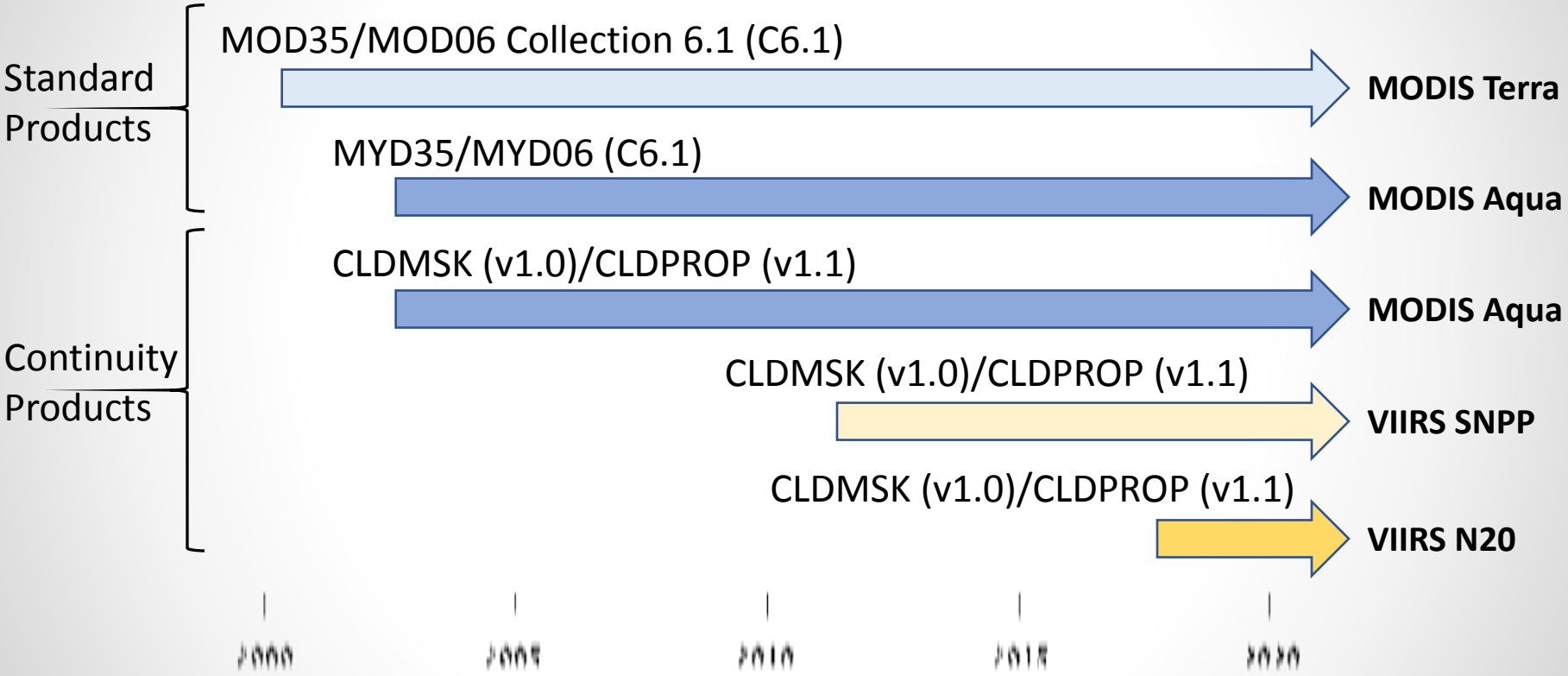
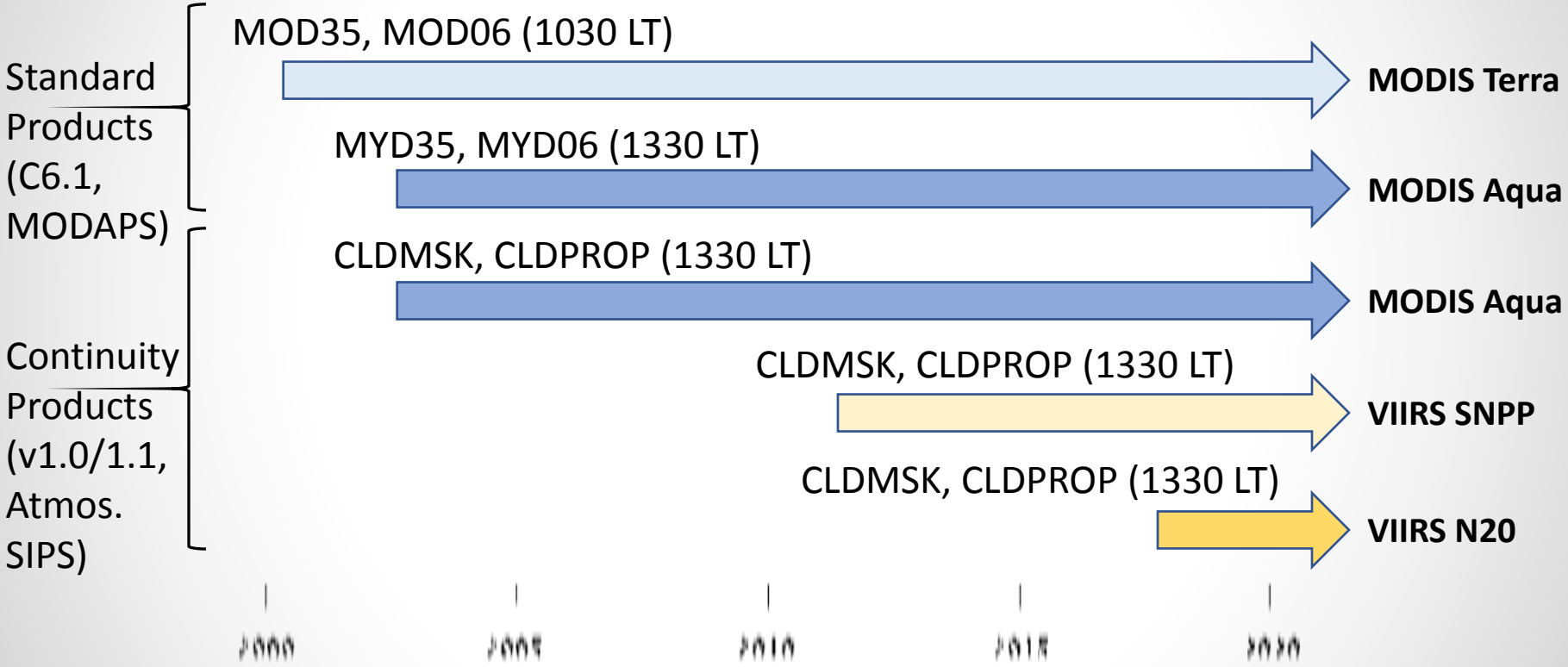
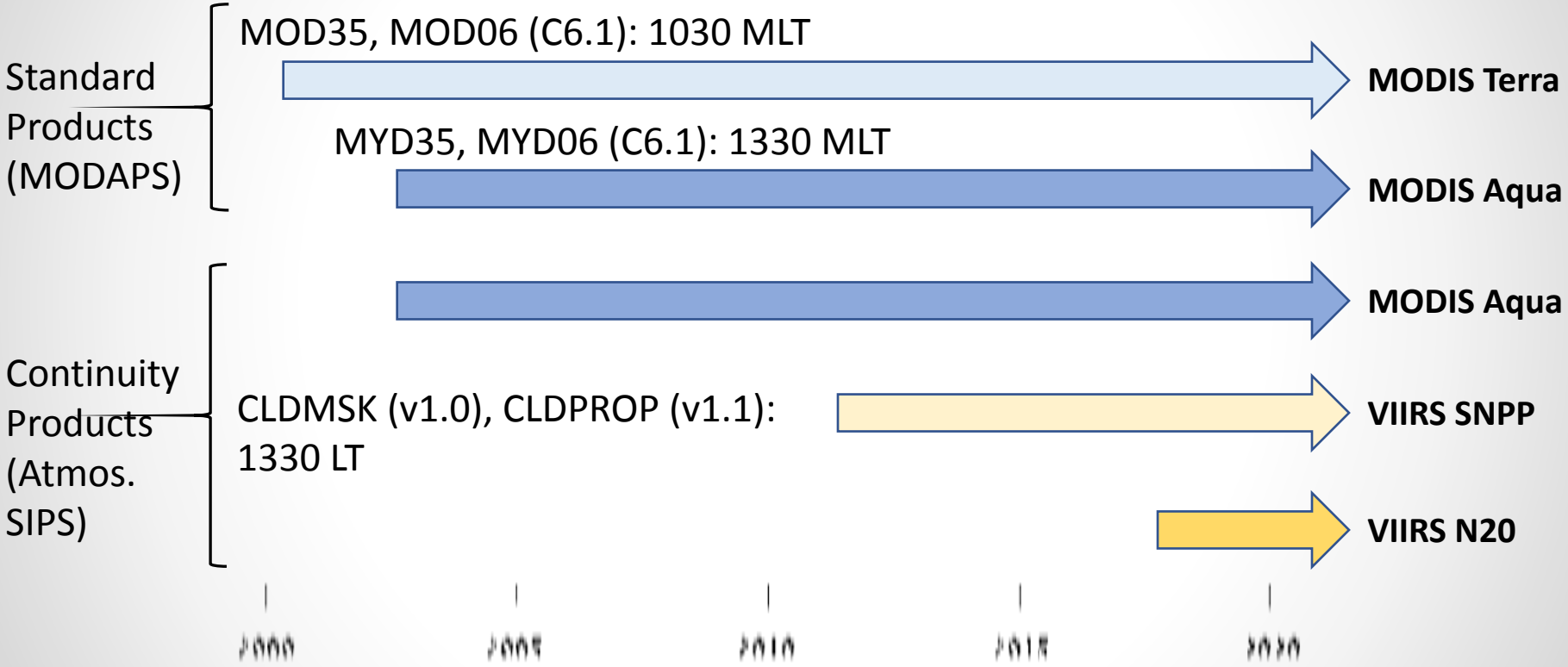
MODIS/VIIRS Current Product Summary



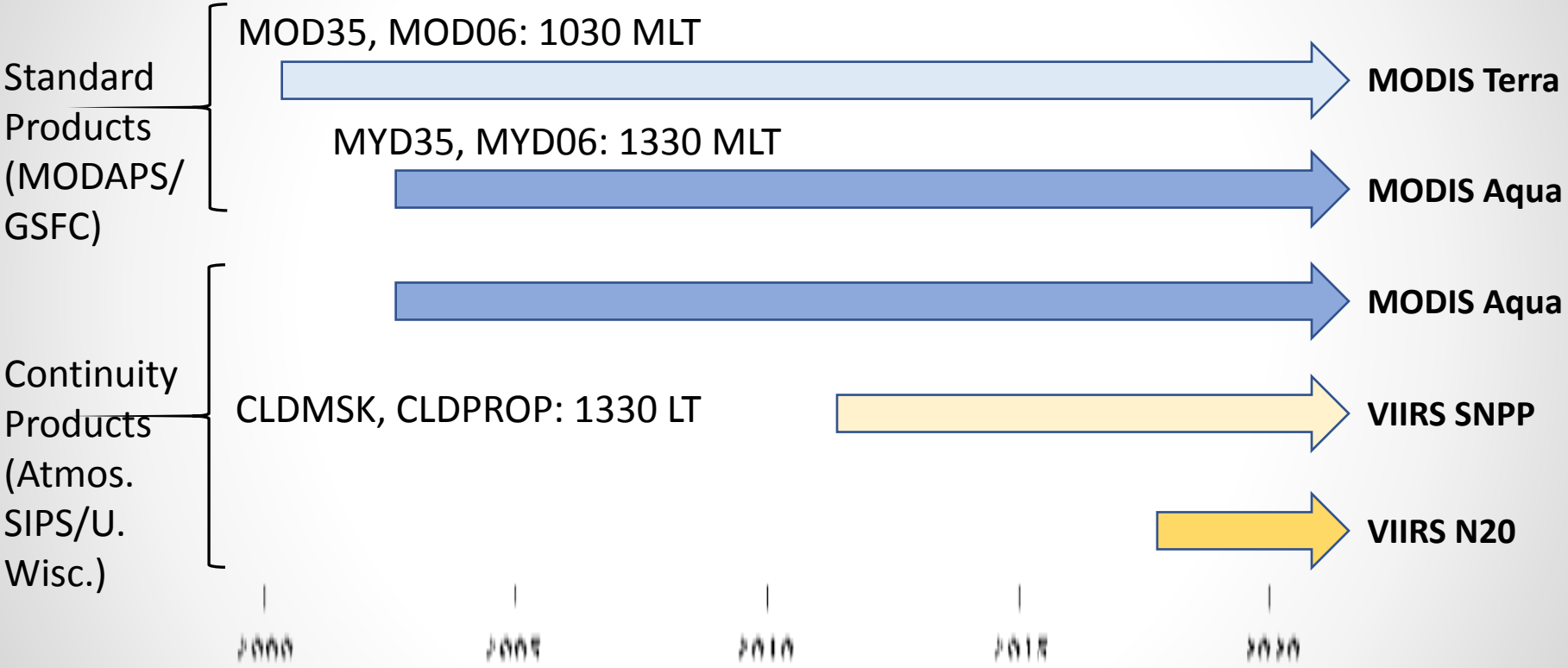
MODIS/VIIRS Current Product Summary



MODIS/VIIRS Current Product Summary



MODIS/VIIRS Current Product Summary



MODIS/VIIRS Algorithm Continuity: CLDMSK, CLDPROP

MODIS Aqua L1B
(channel subset common with VIIRS)

VIIRS SNPP & N20 L1B
(w/restored bow-tie pixel deletions + radiometric adjustments)

Common L2 Algorithm
Cloud Mask (MOD35 heritage)
Cloud Top Properties (NOAA AWG heritage)
Cloud Optical Properties (MOD06 heritage)
U. Wisconsin A-SIPS processing

MODIS L2 Continuity Products
CLDMSK_L2_MODIS_Aqua
CLDPROP_L2_MODIS_Aqua

VIIRS L2 Continuity Products
CLDMSK_L2_VIIRS_SNPP
CLDMSK_L2_VIIRS_N20
CLDPROP_L2_VIIRS_SNPP
CLDPROP_L2_VIIRS_N20

L3 Continuity Products
CLDMSK_D/M3_sensor_platform
CLDPROP_D/M3_sensor_platform

MODIS/VIIRS Algorithm Continuity: CLDMSK, CLDPROP

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

U. Wisconsin A-SIPS processing

Cloud Mask: MOD35 heritage
Cloud-Top: NOAA AWG heritage
Cloud Optical Properties: MOD06 heritage

MODIS Continuity Products
CLDMSK_L2_MODIS_Aqua
CLDPROP_L2_MODIS_Aqua

VIIRS Continuity Products
CLDMSK_L2_VIIRS_SNPP
CLDPROP_L2_VIIRS_SNPP

L3 Continuity Products ("Yori")
CLDPROP_D/M3_VIIRS_SNPP
CLDPROP_D/M3_MODIS_Aqua

** Atmosphere SIPS*

MODIS/VIIRS Products: Standard & Continuity

MODIS Terra, Aqua Standard Products

- MOD35 (Terra), MDY35 (Aqua):
  cloud mask (1 km)
- MOD06 (Terra), MYD06 (Aqua):
  cloud top (1, 5 km), optical properties (1 km)
- MOD08 (Terra), MYD08 (Aqua):
  1° gridded statistics (daily, 8-day, monthly)

VIIRS/MODIS Continuity Products

- CLDMSK_L2_*sensor_platform*:
  cloud mask (0.75 km)
- CLDPROP_L2_*sensor_platform*:
  cloud top (0.75 km), opt. properties (0.75 km)
- CLDPROP_M3_*sensor_platform*:
  1° gridded monthly statistics (also D3 daily aggregation)

Collection/Version History

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

Collection	MODIS Terra Reprocessing start	MODIS Aqua Reprocessing start
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	–

Continuity Products (CLDMSK, CLDPROP)

Version	A-SIPS delivery to LAADS: SNPP, NOAA 20
1.1 (CLDPROP)	Jan. 2020, Dec. 2020
1.0	Dec. 2018–Feb. 2020, Dec. 2020

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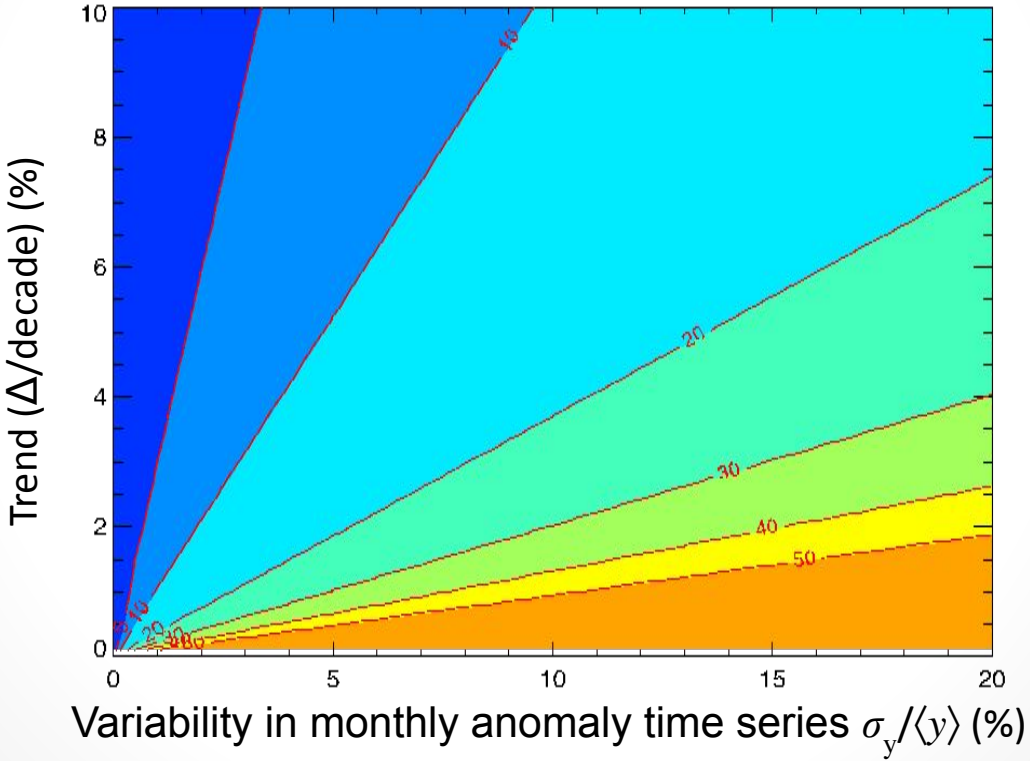
MODIS Terra C6.1 Time Series: How Long is enough?

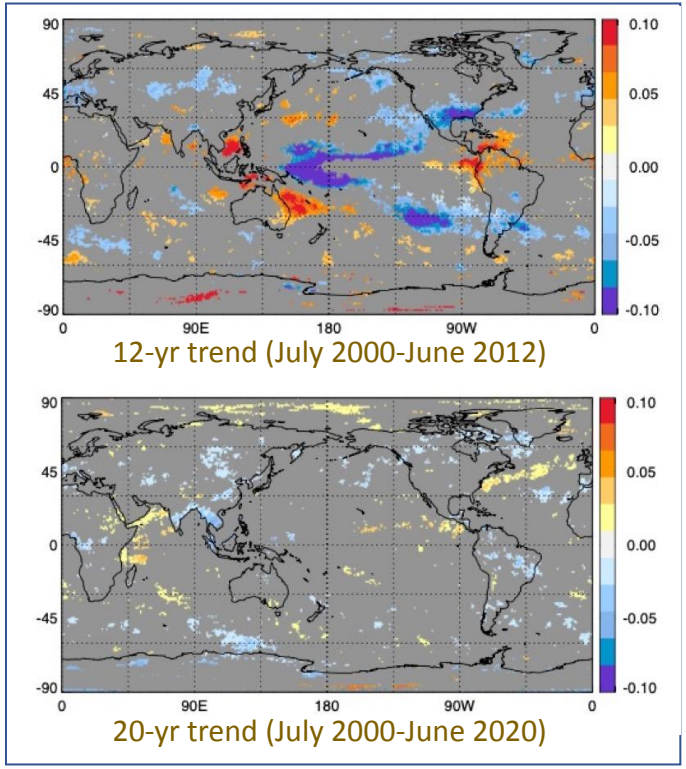
Number of Years Required to Detect a Trend

(90% prob. of detecting a trend to a 0.05 statistical level, no autocorrelation)



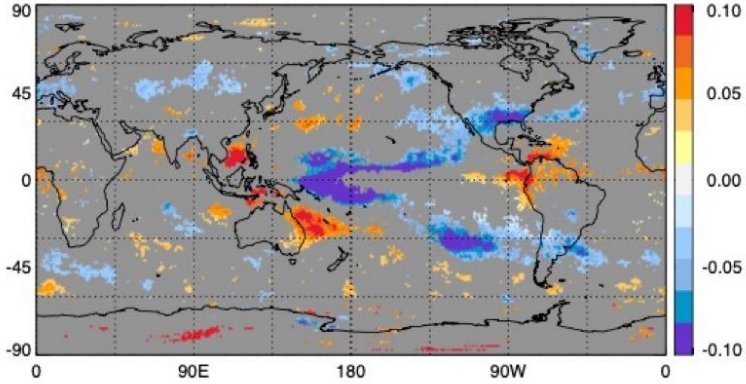
MODIS Terra C6.1 Standard Product Anomaly Time Series

High CF (p_c<440 hPa) Anomaly Trend/decade (absolute) masked by 5% statistical sig.

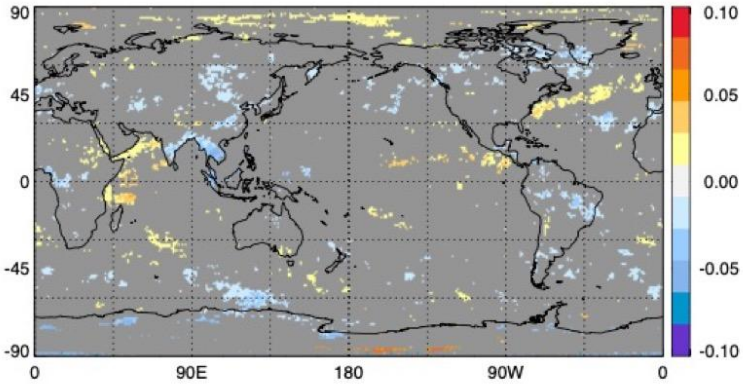


MODIS Terra C6.1 Standard Product Time Series

High Cloud Fraction (p_c<440 hPa): Absolute Trend/decade in Monthly Anomaly, masked by 5% statistical sig.



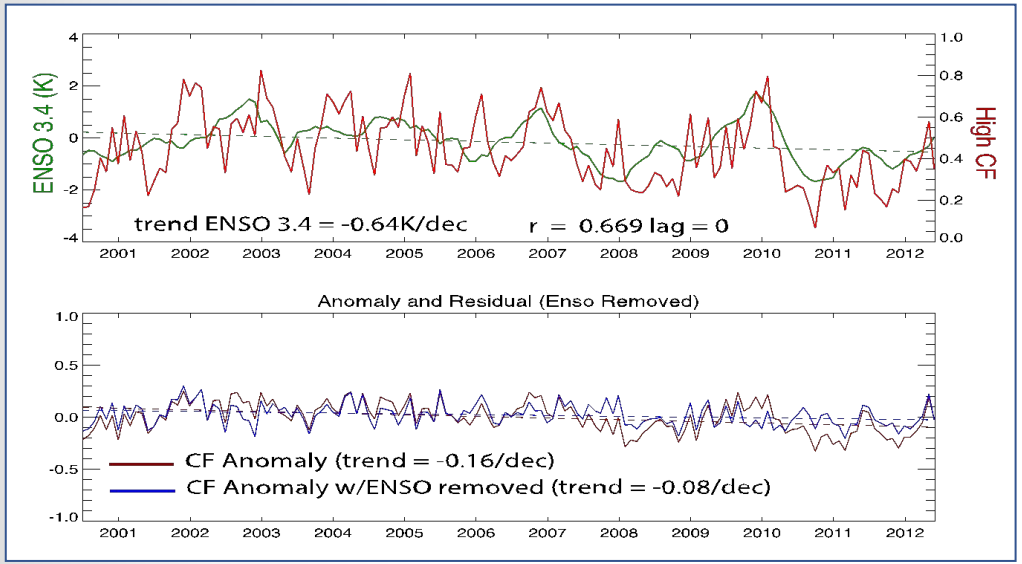
12-yr trend (July 2000-June 2012)



20-yr trend (July 2000-June 2020)

MODIS Terra C6.1 Standard Product Time Series

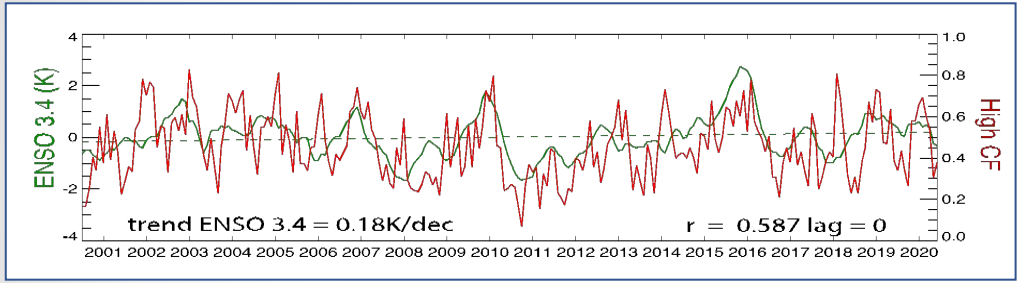
High Cloud Fraction Time Series for a 1° grid box in western equatorial Pacific



July 2000-June 2012

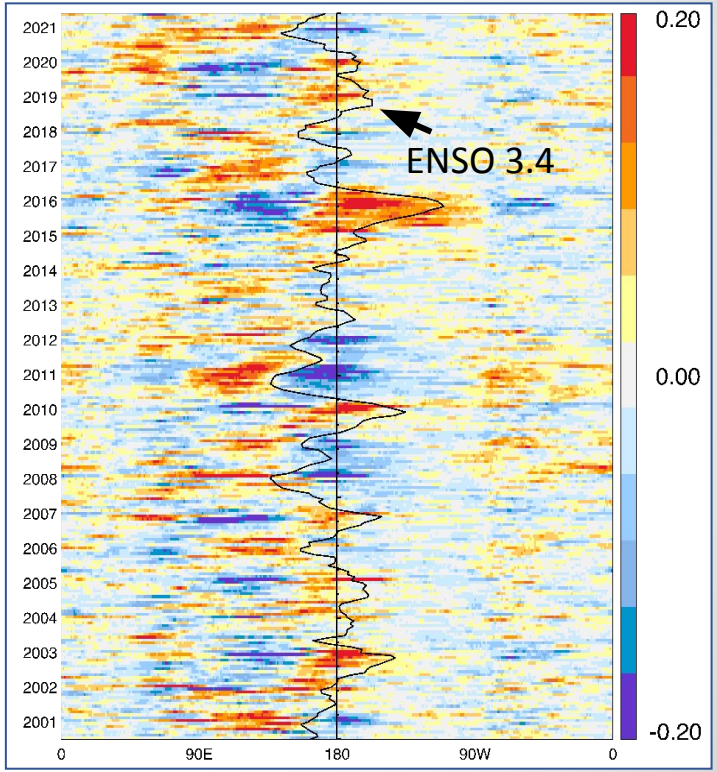
MODIS Terra C6.1 Standard Product Time Series

High Cloud Fraction Time Series for a 1° grid box in equatorial Pacific



July 2000-June 2020

High CF Anomaly (p_c<440 hPa) correlation with ENSO 3.4, ±15° lat

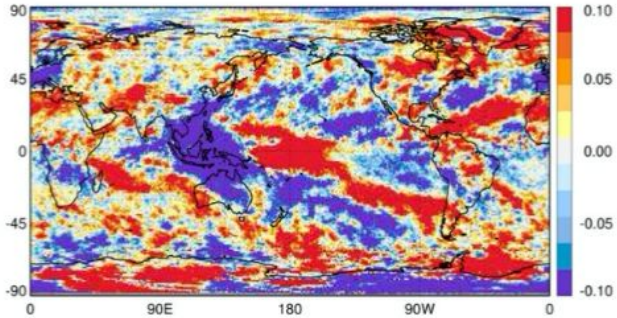


Tropical Pacific

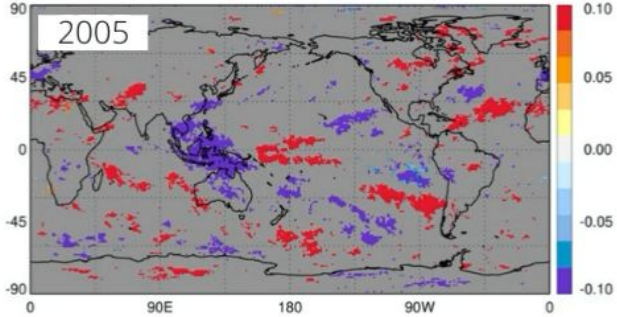
MODIS Terra C6.1 Time Series: How Long is enough?

High Cloud Fraction, Anomaly Trend from June 2000 – July of Year Indicated

Trend



Trend masked by 5% statistical significance

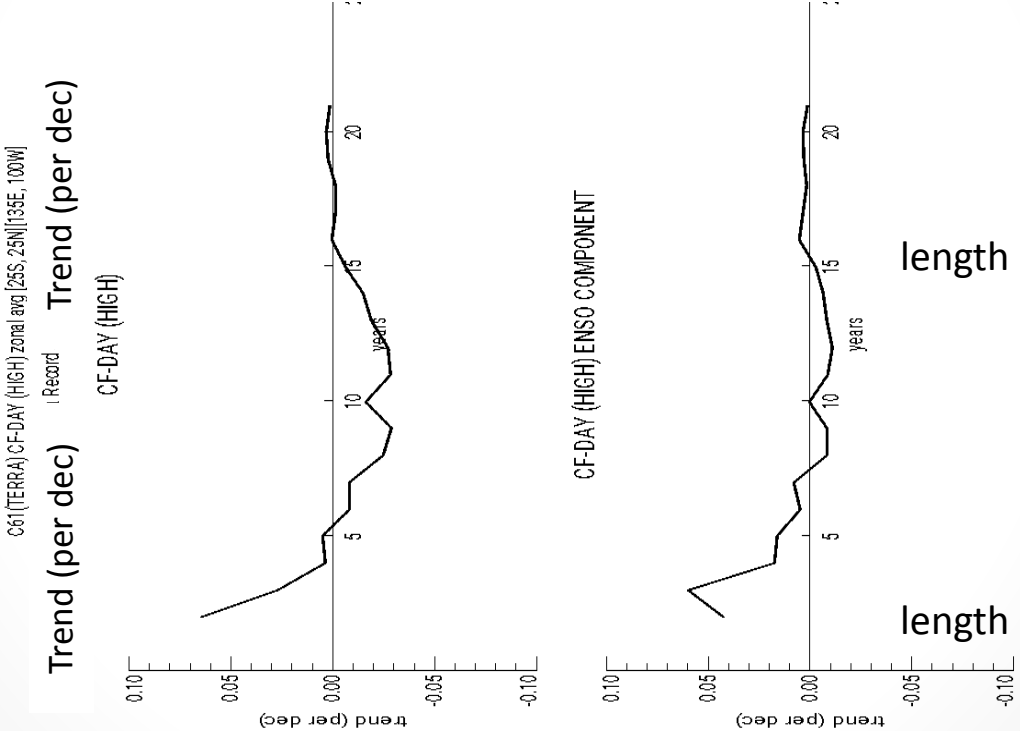


MODIS Terra C6.1 Time Series: How Long is enough?

Empirical answer: for ±25° latitude, 135E–100W, ocean

July 2000 – June 2021

High Cloud Fraction,
p_c < 440 hPa,
daytime



length of record (yrs)

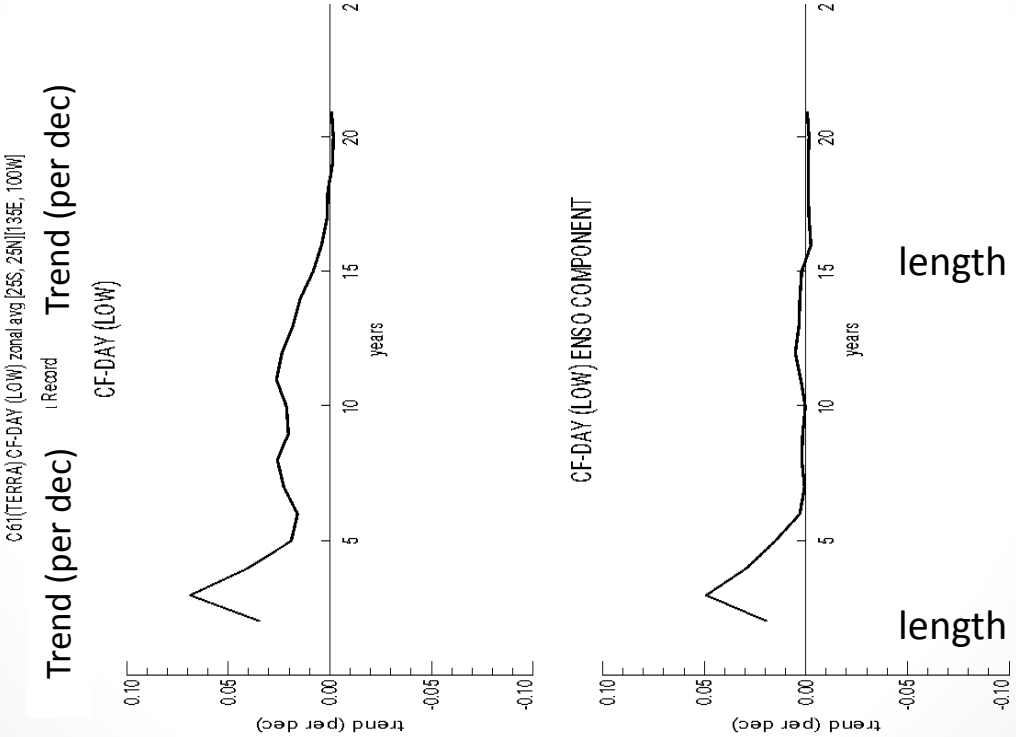
length of record (yrs)

MODIS Terra C6.1 Time Series: How Long is enough?

Empirical answer: for ±25° latitude, 135E–100W, ocean

July 2000 – June 2021

Low Cloud Fraction,
p_c > 680 hPa,
daytime



length of record (yrs)

length of record (yrs)

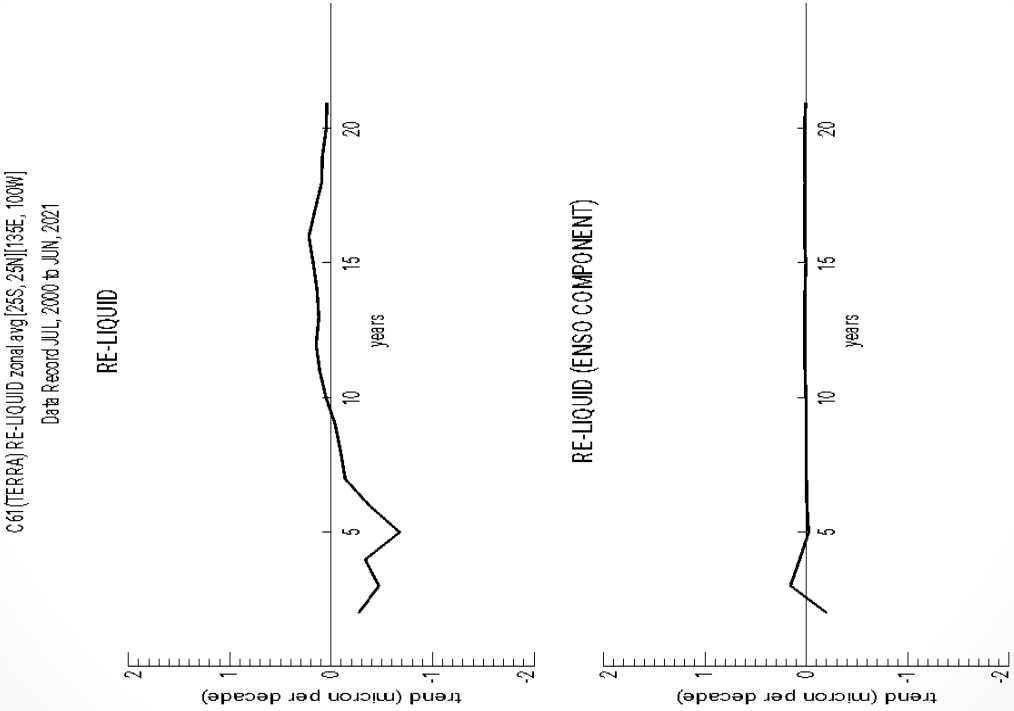
MODIS Terra C6.1 Time Series: How Long is enough?

Empirical answer: for ±25° latitude, 135E–100W, ocean

July 2000 – June 2021

Liq. Cloud CER

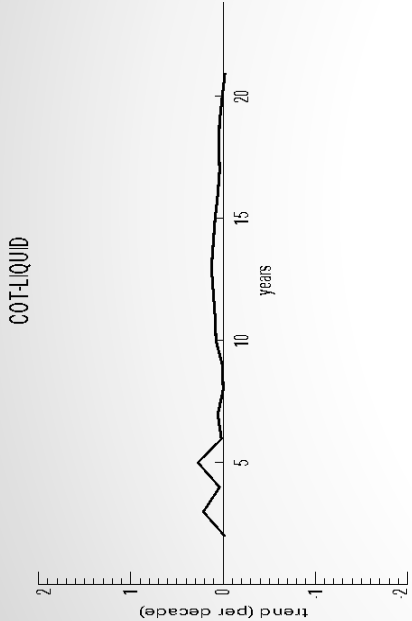
[2.13 µm retrieval]

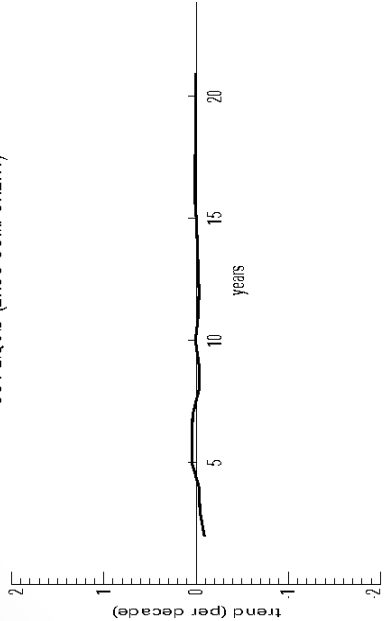


MODIS Terra C6.1 Time Series: How Long is enough?

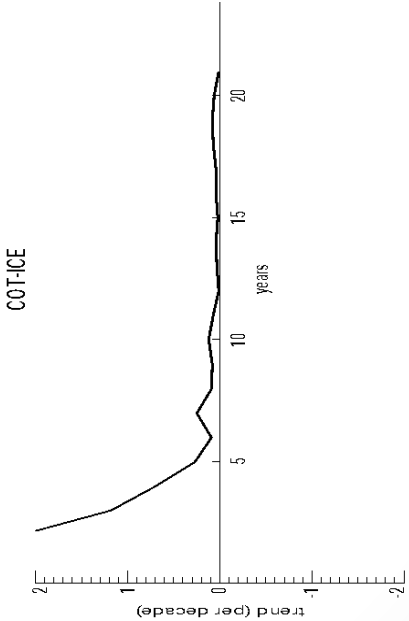
Empirical answer: for ±25° latitude, 135E–100W, ocean
July 2000 – June 2021

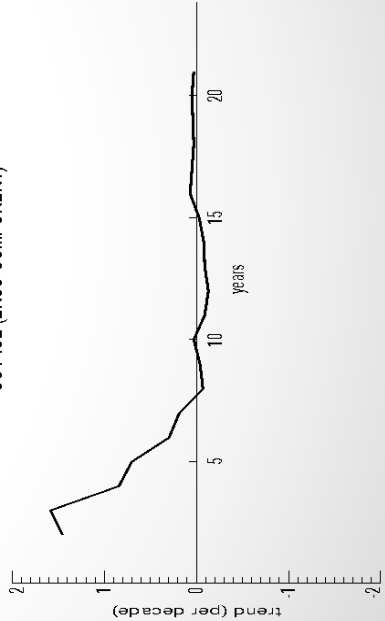
Liq. Cloud Optical Thickness





Ice Cloud Optical Thickness

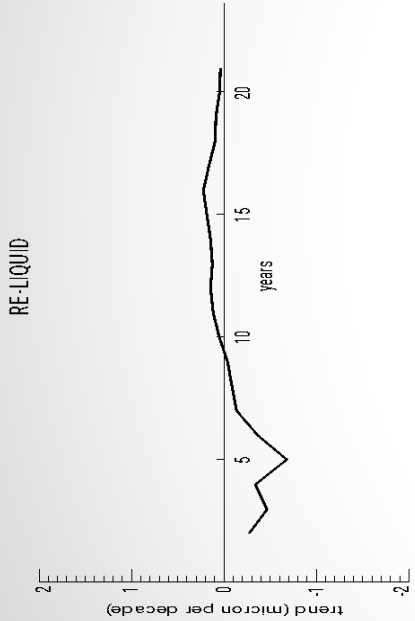


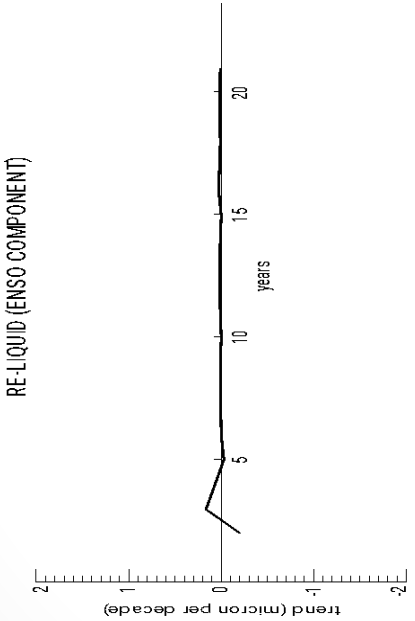


MODIS Terra C6.1 Time Series: How Long is enough?

Empirical answer: for ±25° latitude, 135E–100W, ocean
July 2000 – June 2021

Liq. Cloud Eff. Radius





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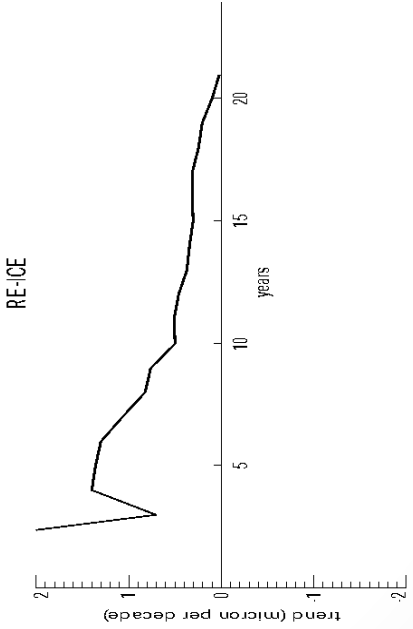
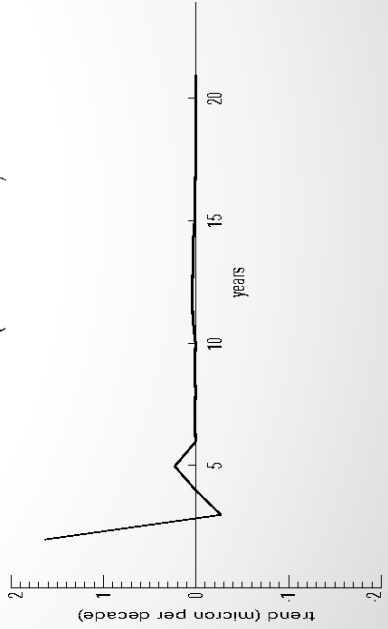
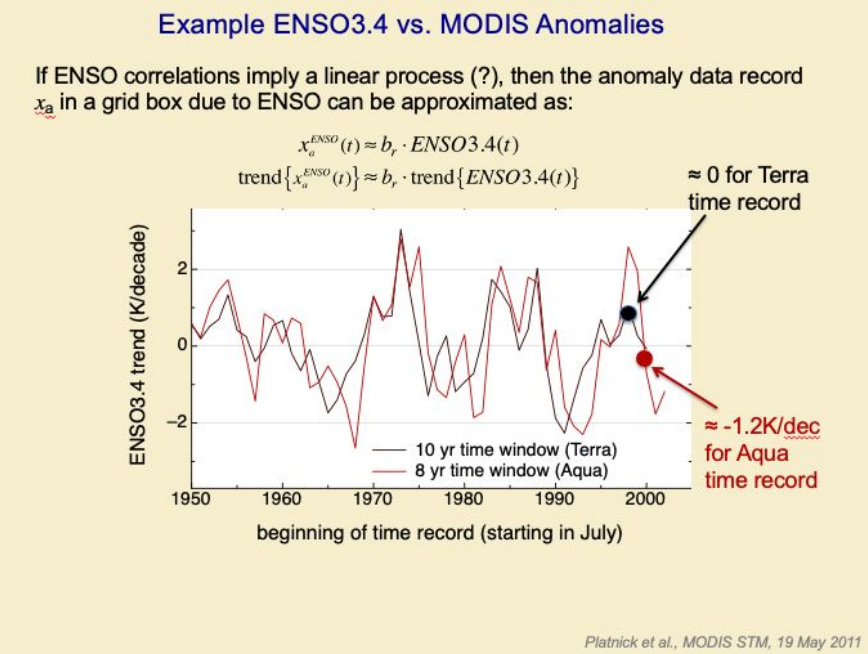




MODIS Terra C6.1 Time Series: How Long is enough?

ENSO correlation previous work: just as a reminder, the plots below were rolling 8-yr and 10-yr time windows of ENSO3.4 trends used to demonstrate the sensitivity of 8/10-yr retrieval trends to the phasing of observations with the ESNO index. Might want to redo plots.



MODIS Terra C6.1 Time Series: How Long is enough?

Hypothesis: $y = {}_0 + {}_1 x$, e.g., y = cloud fraction, x = time (month, season, yr

Linear Fit: $\hat{y} = b_0 + b_1 x$

Measures of significance: F-test, T-test on b_1, Var(b_1), R^2. All four are related for an OLS of this form.

Ignoring temporal autocorrelation:

natural variability
(+ retrieval + instrument uncertainty)

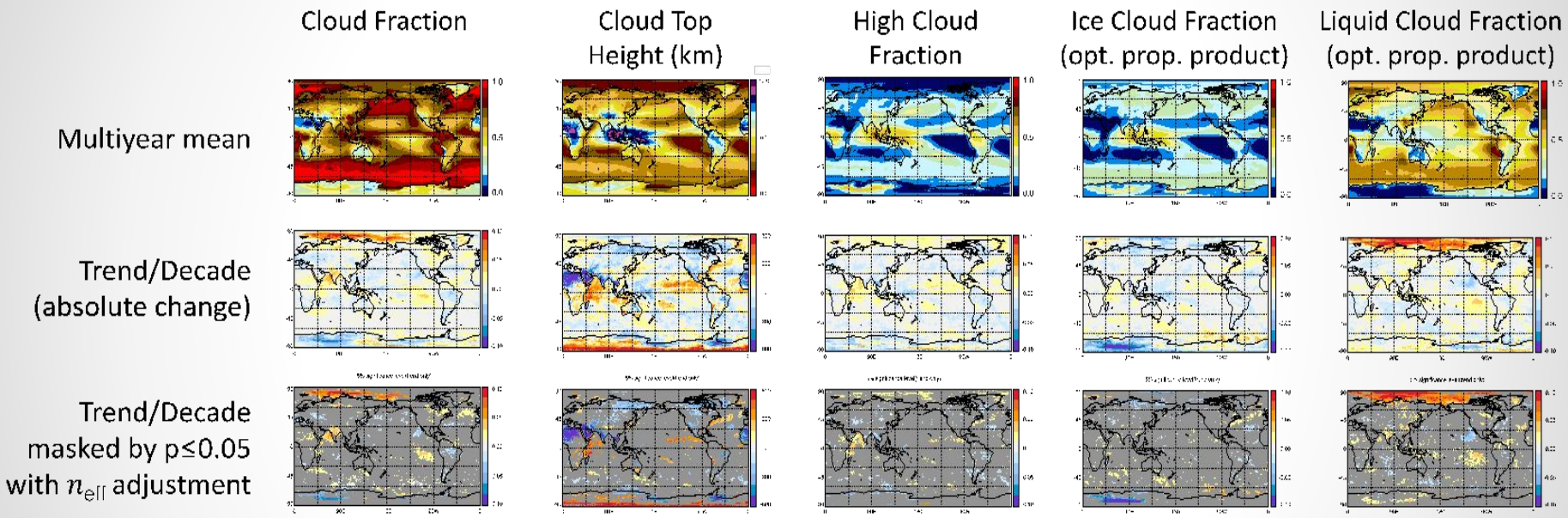
$$\mathrm{Var}(b_1) = \frac{\sum\left(y_i - \hat{y}_i\right)^2}{n-2} \frac{1}{\sum\left(x_i - \langle x_i \rangle\right)^2}$$

degrees of freedom (n =number of pts)

Time record required for 90% probability in detecting a trend at the 0.05 statistical significance level (Tiao et al., 1990; Weatherhead et al., 1998):

$$n^*(\mathrm{yrs}) \approx \left[\frac{3.3 \dfrac{100\ \hat{y}}{\langle y \rangle}}{\mathrm{trend}\ (\%/\mathrm{yr})}\right]^{2/3}$$

MODIS Terra C6.1 Standard Product Time Series



21-yr trend (July 2000-June 2021)

MODIS Terra C6.1 Standard Product Time Series

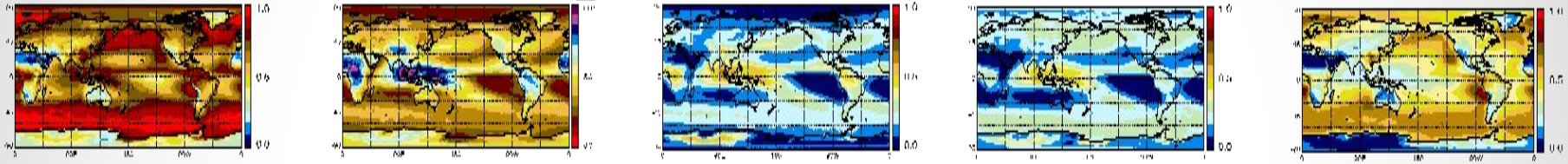
Cloud Fraction

Cloud Top Height (km)

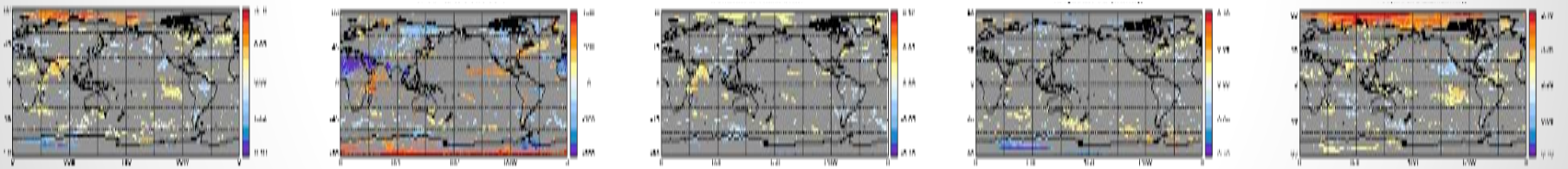
High Cloud Fraction

Ice Cloud Fraction (opt. prop. product)

Liquid Cloud Fraction (opt. prop. product)



Multiyear mean



Trend/dec masked by p≤0.05
(July 2000-June 2021)

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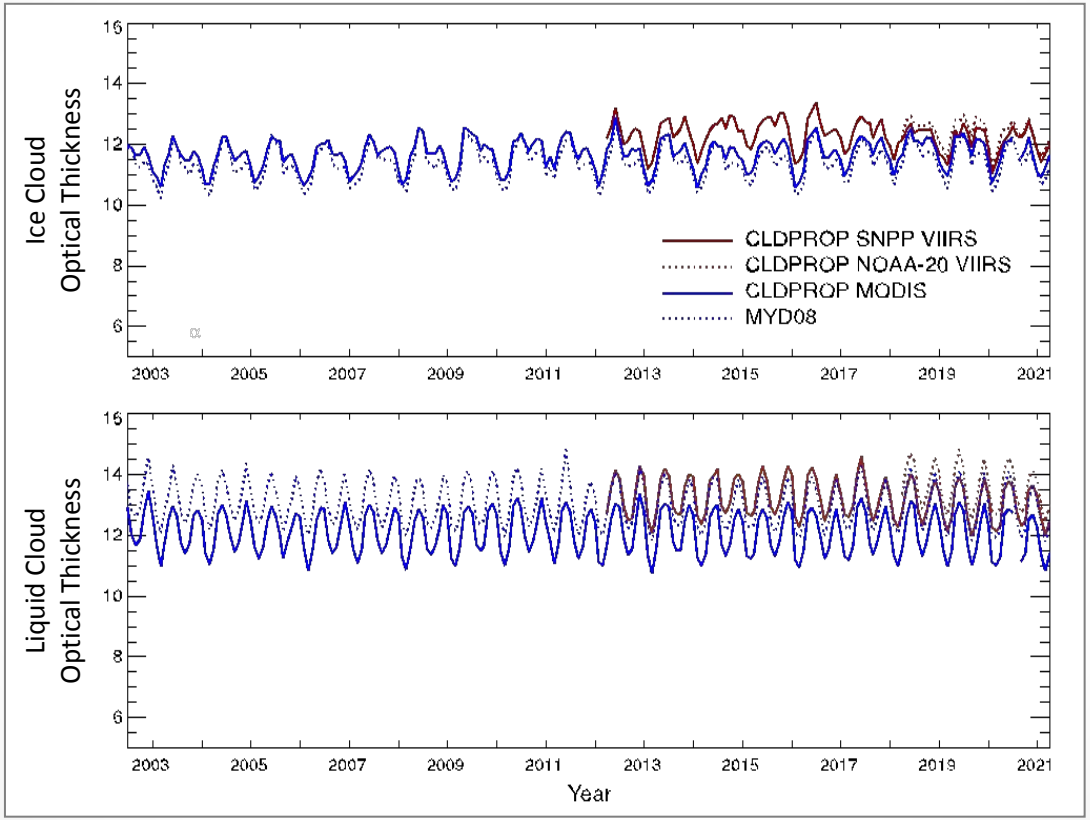
MODIS Aqua Standard v. CLDPROP Time Series

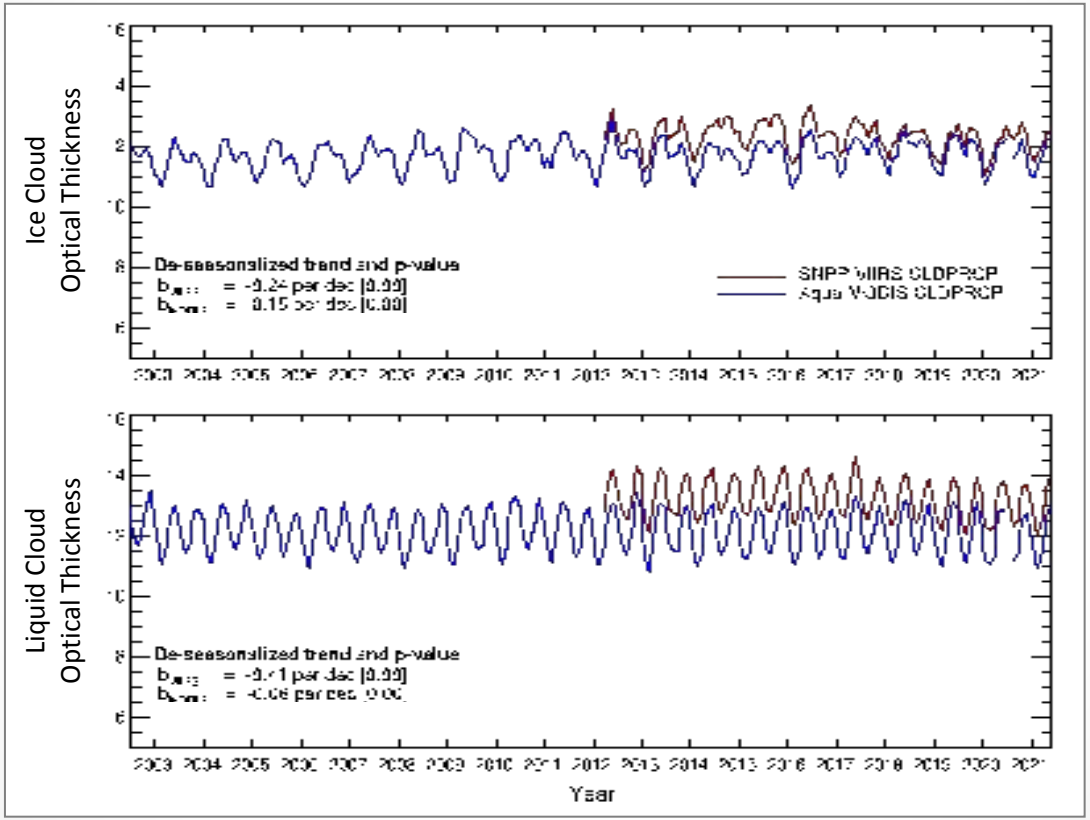
±60° latitude for all surface types, daytime observations only



Platnick et al., Sun-Climate Symposium, 18 May 2022

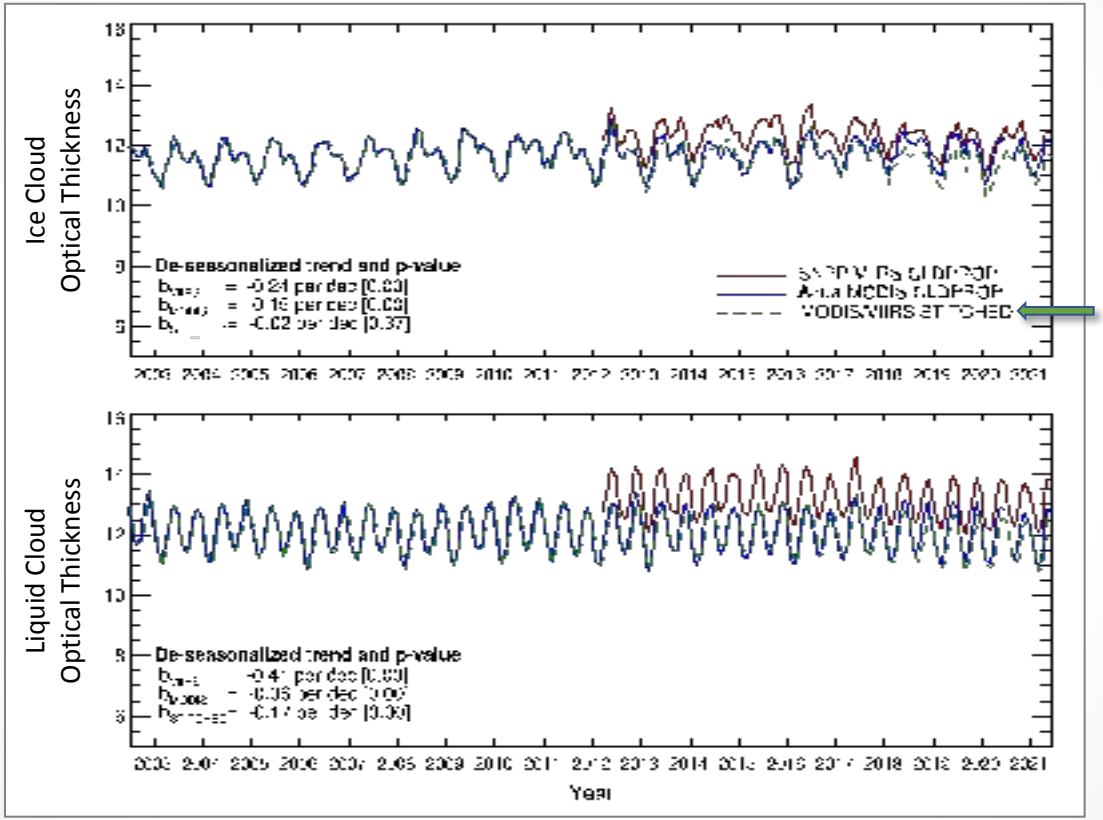
CLDPROP: MODIS Aqua + VIIRS "Stitched" Trends

±60° latitude for all surface types, daytime observations only



CLDPROP: MODIS Aqua + VIIRS "Stitched" Trends

±60° latitude for all surface types, daytime observations only



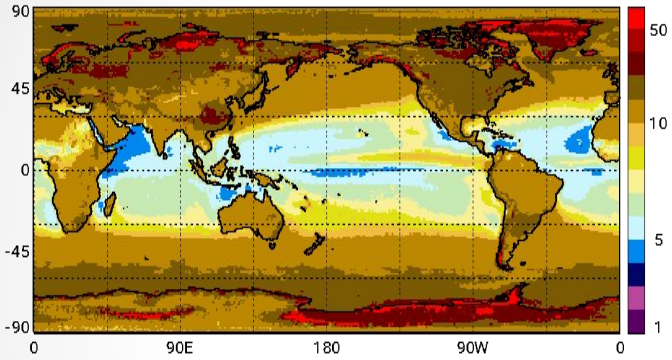
MODIS/VIIRS 'stitched' time series

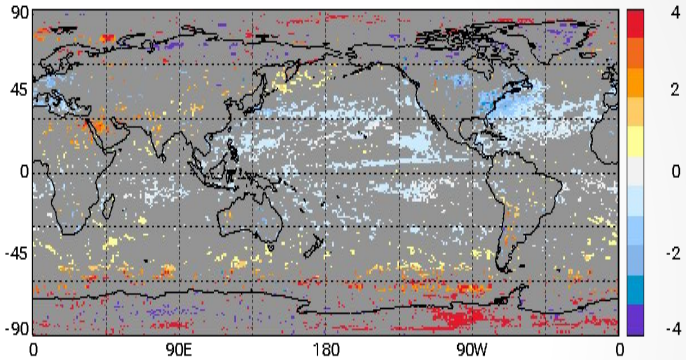
- Offset SNPP VIIRS to match 2-yr overlapping MODIS avg.

CLDPROP: MODIS Aqua + VIIRS "Stitched" Trends

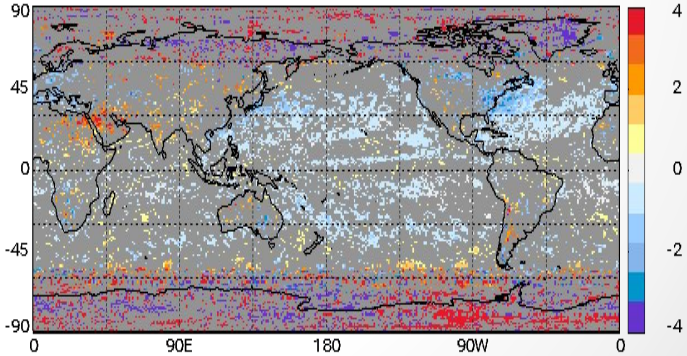
Liquid Cloud Optical Thickness (COT)

MODIS Multiyear Mean





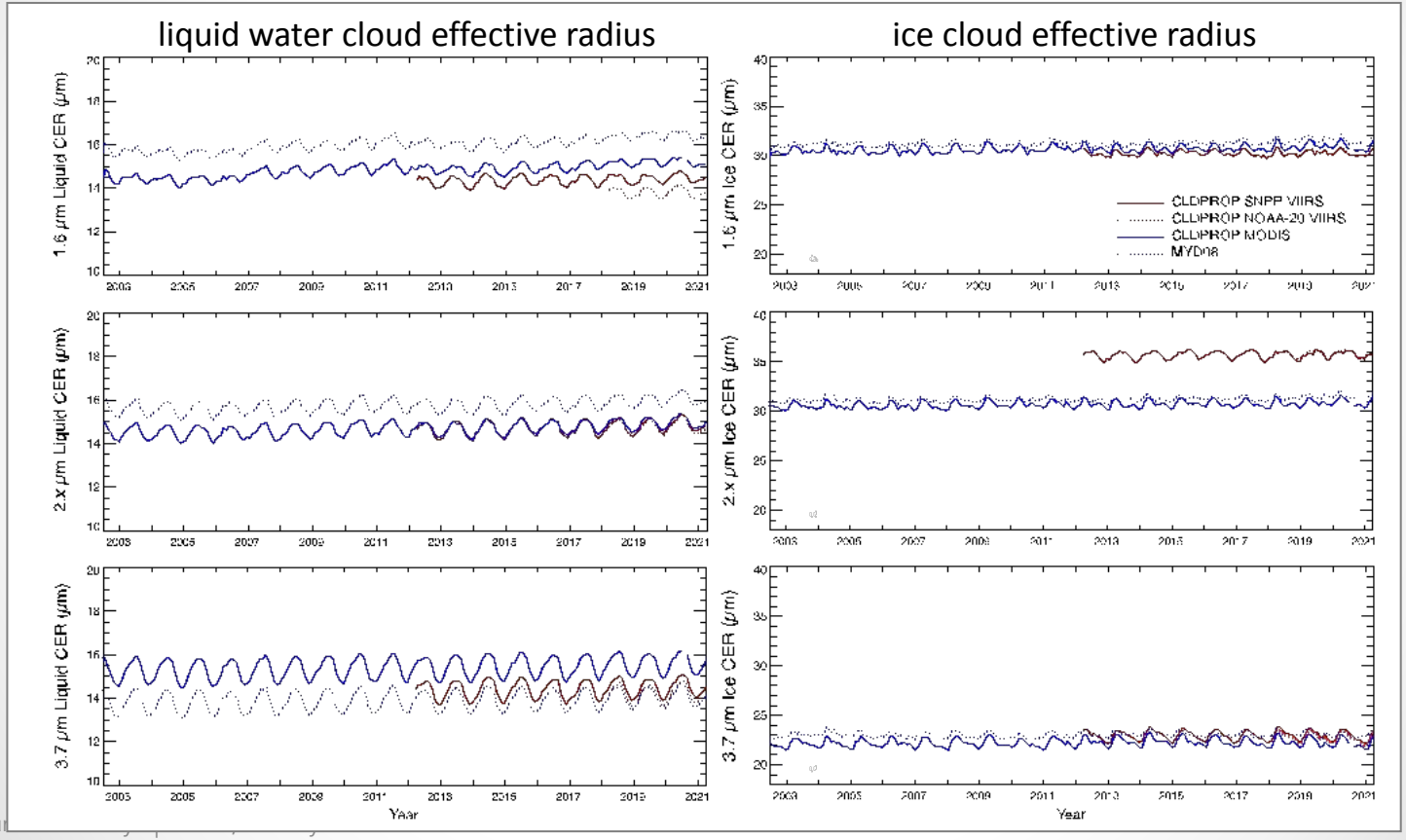
MODIS COT/dec ($p \leq 0.05$)



Stitched MODIS/VIIRS COT/dec ($p \leq 0.05$)

MODIS Aqua Standard v. MODIS/VIIRS CLDPROP Time Series

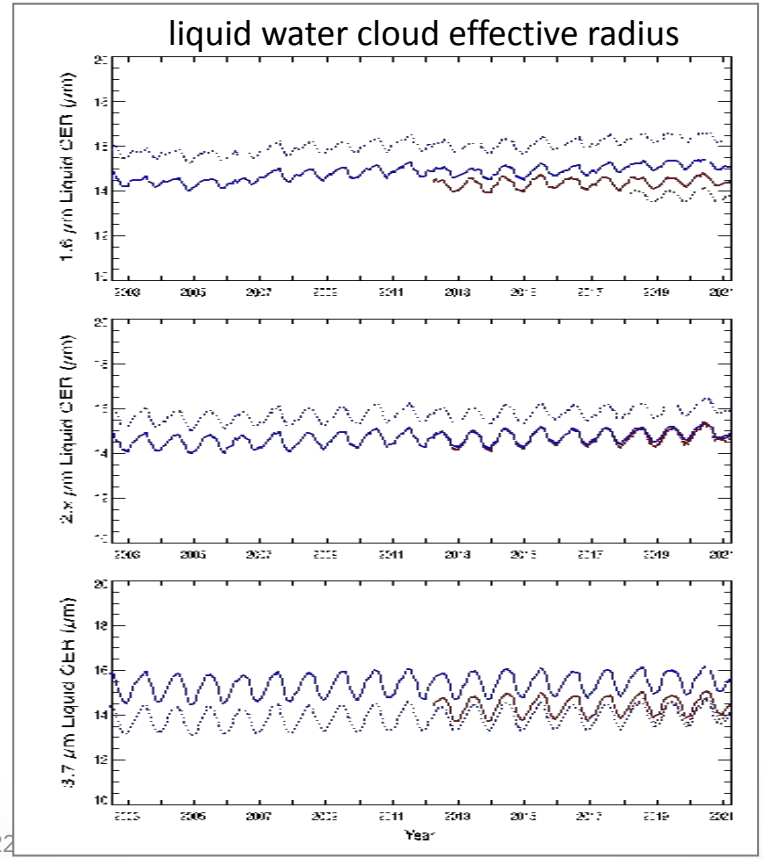
±60° latitude for all surface types, daytime observations only



Platnick et al., Su

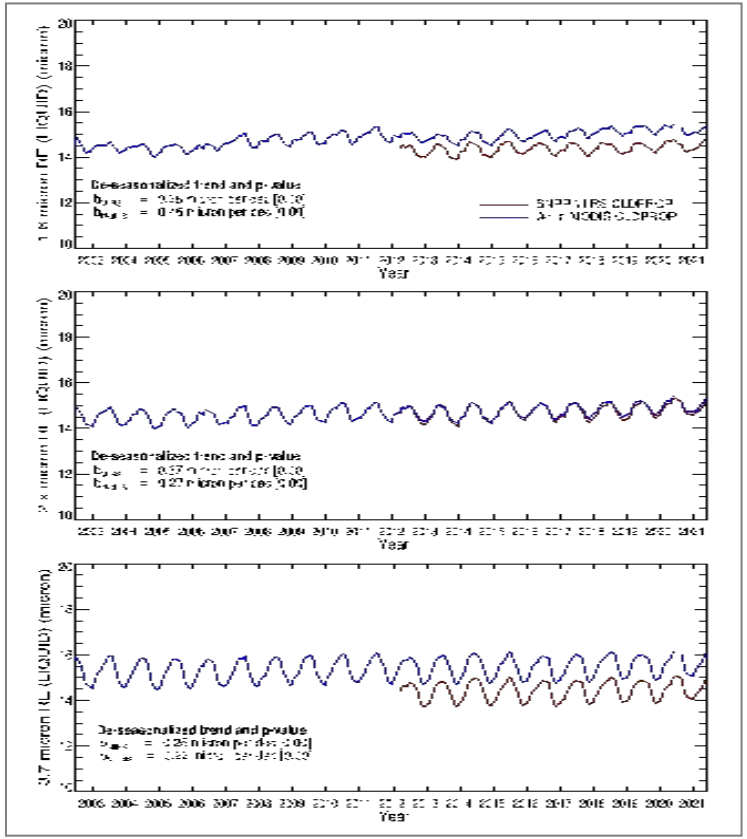
MODIS Aqua Standard v. MODIS/VIIRS CLDPROP Time Series

±60° latitude for all surface types, daytime observations only



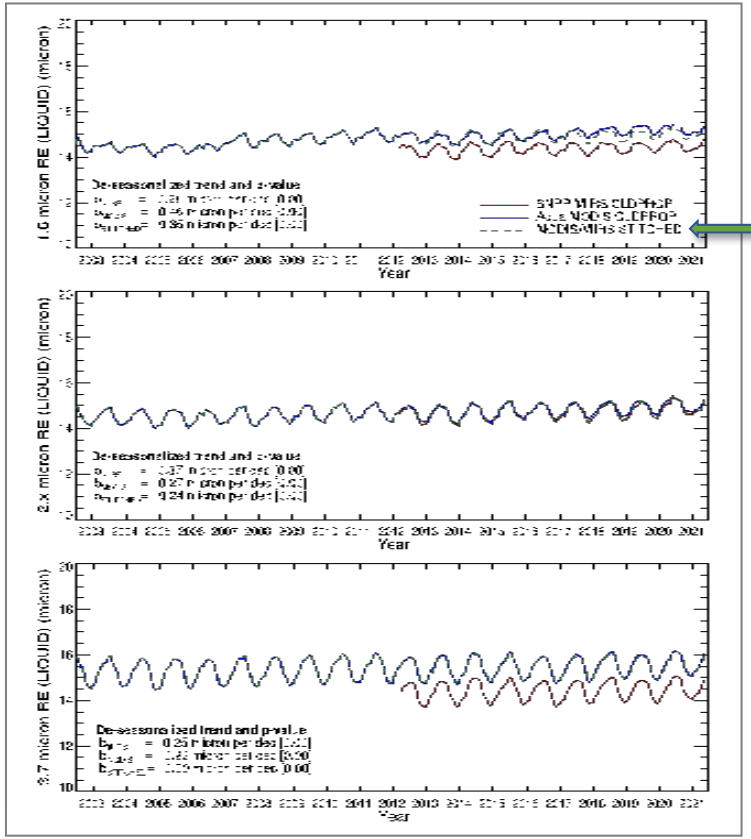
MODIS/VIIRS CLDPROP "Stitched" Time Series

Liquid Cloud Effective Droplet Radius (CER), ±60° latitude for all surface types



MODIS/VIIRS CLDPROP "Stitched" Time Series

Liquid Cloud Effective Droplet Radius (CER), ±60° latitude for all surface types



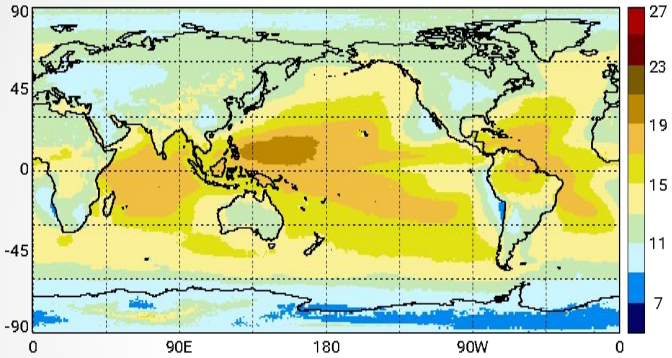
MODIS/VIIRS 'stitched' time series

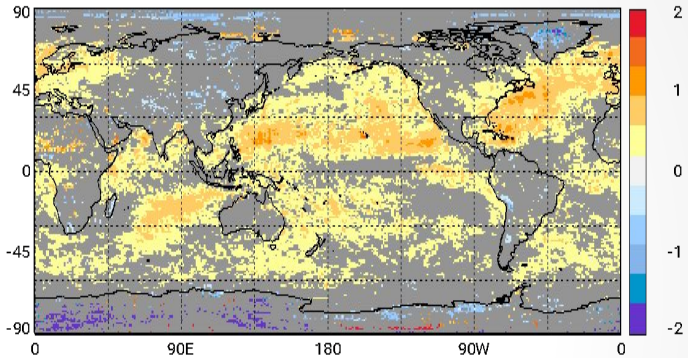
- Offset SNPP VIIRS to match 2-yr overlapping MODIS avg., 2013-2014

CLDPROP: MODIS Aqua + VIIRS "Stitched" Trends

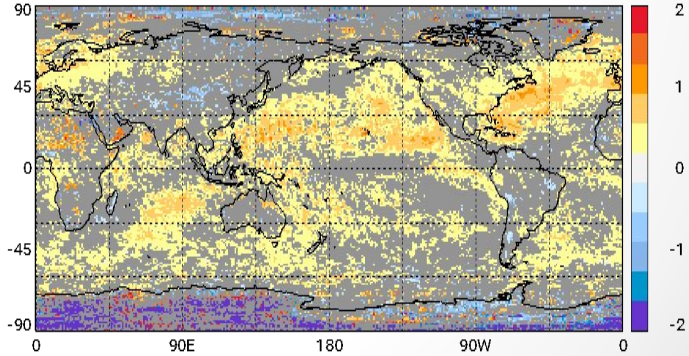
Liquid Cloud Effective Radius (CER) from 2.x µm channel

MODIS Multiyear Mean (µm)





MODIS CER (µm)/dec (p≤0.05)



Stitched MODIS/VIIRS CER (µm)/dec (p≤0.05)

Algorithm References

- **CLDMSK**: Frey et al., *Rem. Sens.* (2020)
- **MODIS/VIIRS VNIR-SWIR Radiometric Adjustments**: Meyer et al., *Rem. Sens.* (2020)
- **MODIS Standard Cloud Products**: Platnick et al., *TGRS* (2017)
- **CLDPROP Optical/Microphysical Properties**: Platnick et al., *Rem. Sens.* (2020, 2021)
- **CLDPROP Cloud Top Properties**: Heidinger et al., *J. Atmos. Ocean. Technol.* (2019)