MODIS Atmosphere Products: The Importance of Record Quality and Length in Quantifying Trends and Correlations

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and the entire MODIS Aerosol and Cloud Algorithm Team

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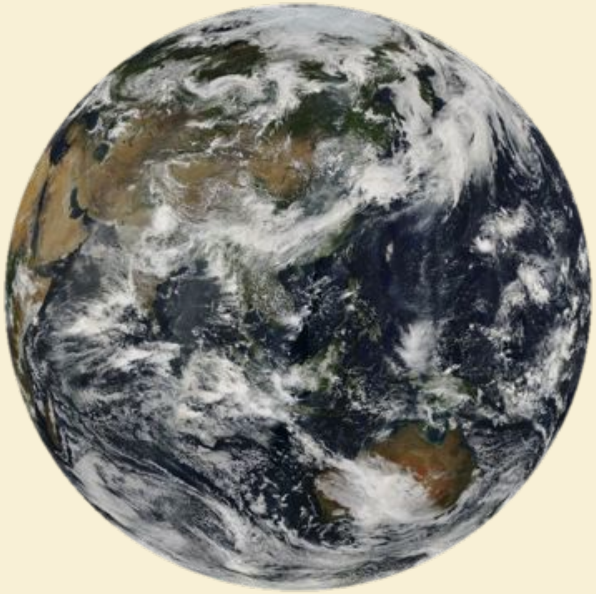
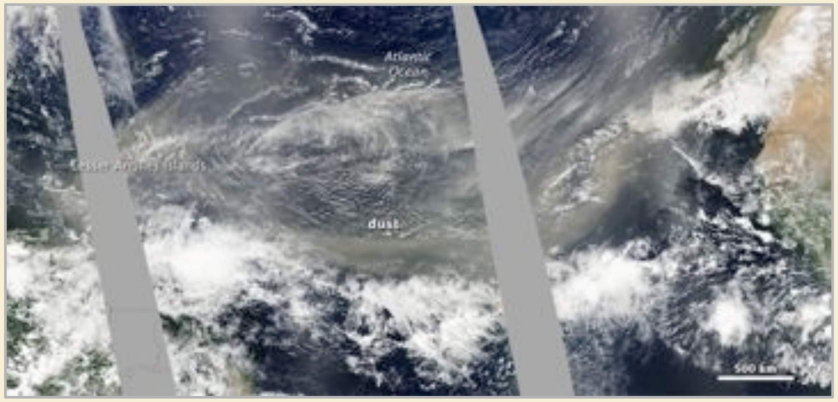
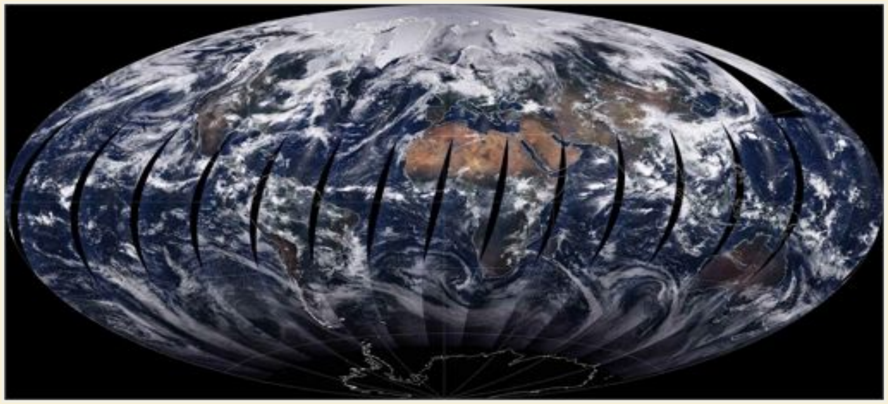


MODIS STM, 19 May 2011





Outline:

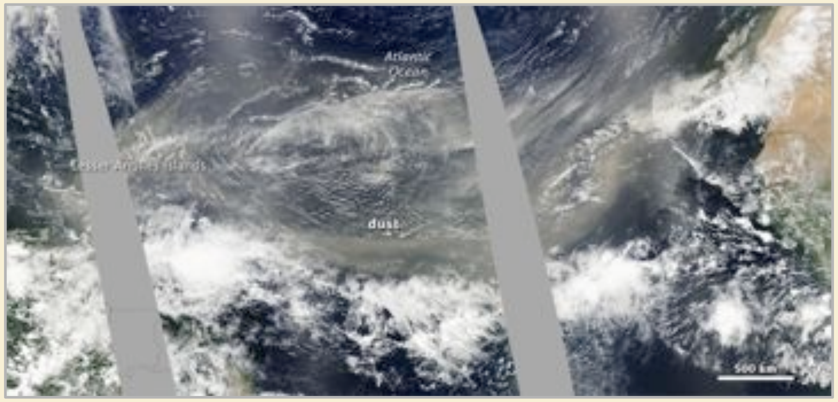
- Motivation
- Trends and Time-to-Detection
- ENSO Correlations

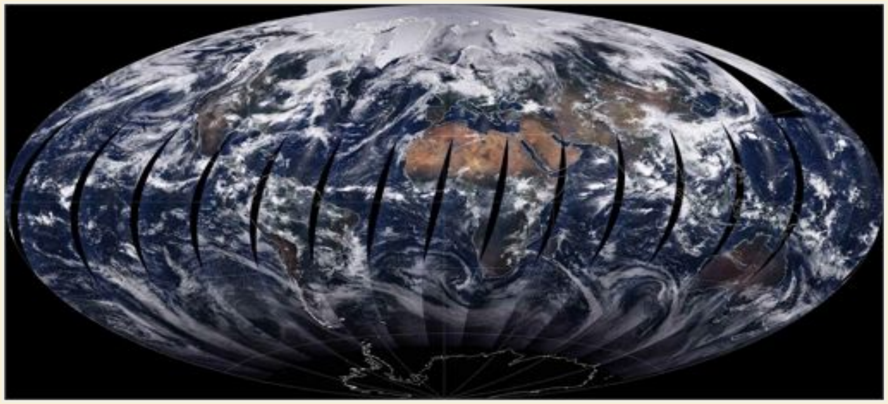
Motivation

- Trends
  - For observed temporal variability in a MODIS data set, what is the expected “time to detection” for a given trend? Can address even with “short” data records.
  - Are statistically significant trends observed for the limited MODIS time record and what are their regional distributions? Consistency between Terra and Aqua MODIS? Lack of consistency traced to instrument differences?
- Sensitivity of retrieved products to interannual (low frequency) climate variability, e.g., ENSO
  - Correlation of atmosphere properties to ENSO phase useful for climate model evaluation (e.g., GFDL AM3 cloud fields)
  - To what extent can ENSO responses alias into trend observations?
- Challenges
  - MODIS data records are only now beginning to be useful for such studies. Much longer time series are required for climate studies.
  - Continuity into VIIRS time frame?

Data Set Used in Study

- Atmosphere Team Level-3 Product
  - Daily, Eight-day, Monthly
  - 1° × 1° equal angle grid
  - Statistics: scalar (mean, standard deviation, …), 1D and 2D probability distributions
- Trends and ENSO correlation analysis using monthly mean anomaly time series
- Current production stream is Collection 5.1





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- Motivation
- Trends and Time-to-Detection
    - The role of natural variability and the need for long time records
    - Examples
    - Instrumental artifacts?
- ENSO Correlations

Evaluating Temporal Trends: Overview

Hypothesis: $y = \beta_0 + \beta_1 x$, 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:

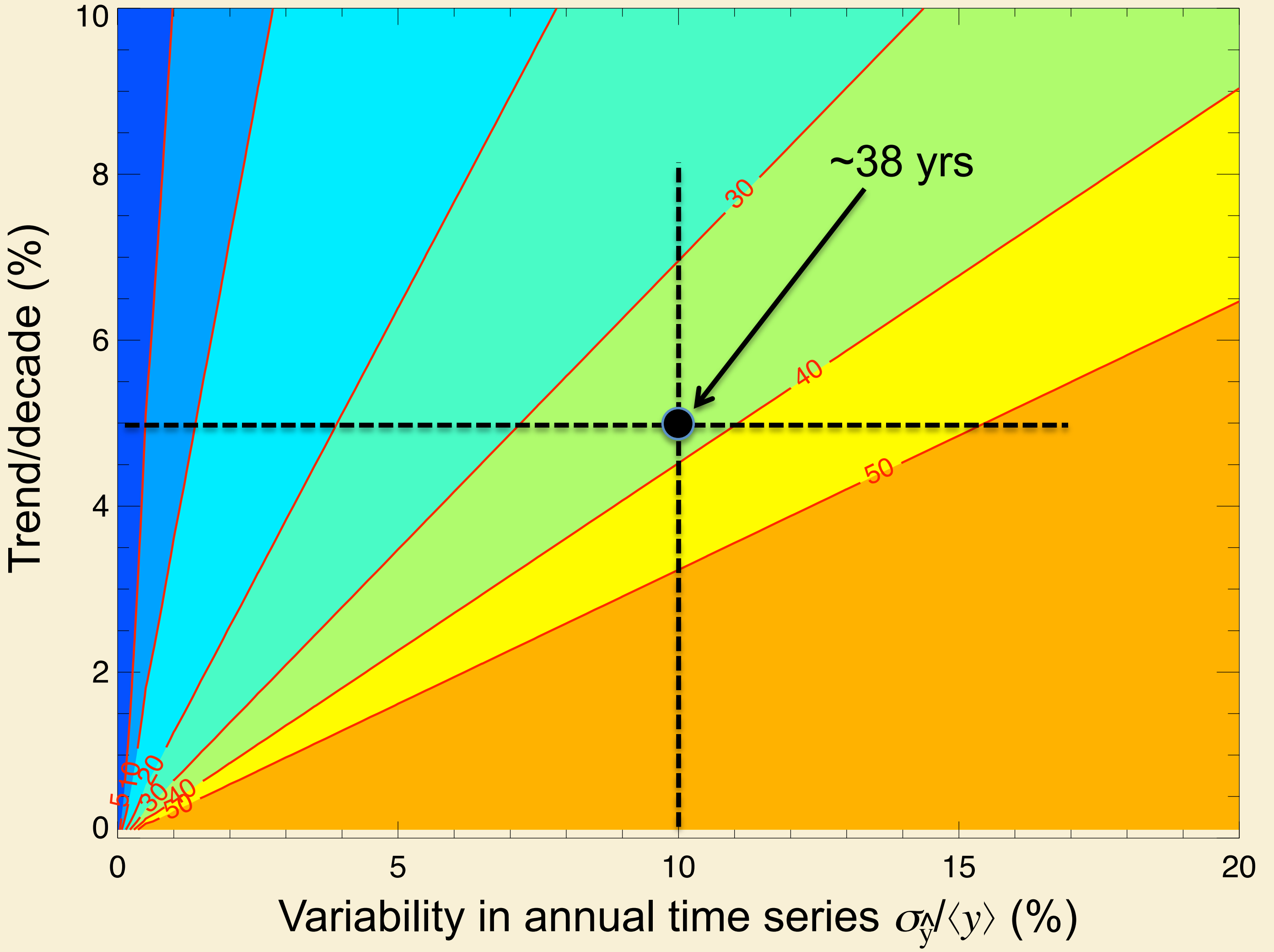
natural variability
(+ retrieval + instrument uncertainty)

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

degrees of freedom (n =number of pts)

Number of Years Required to Detect a Trend

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



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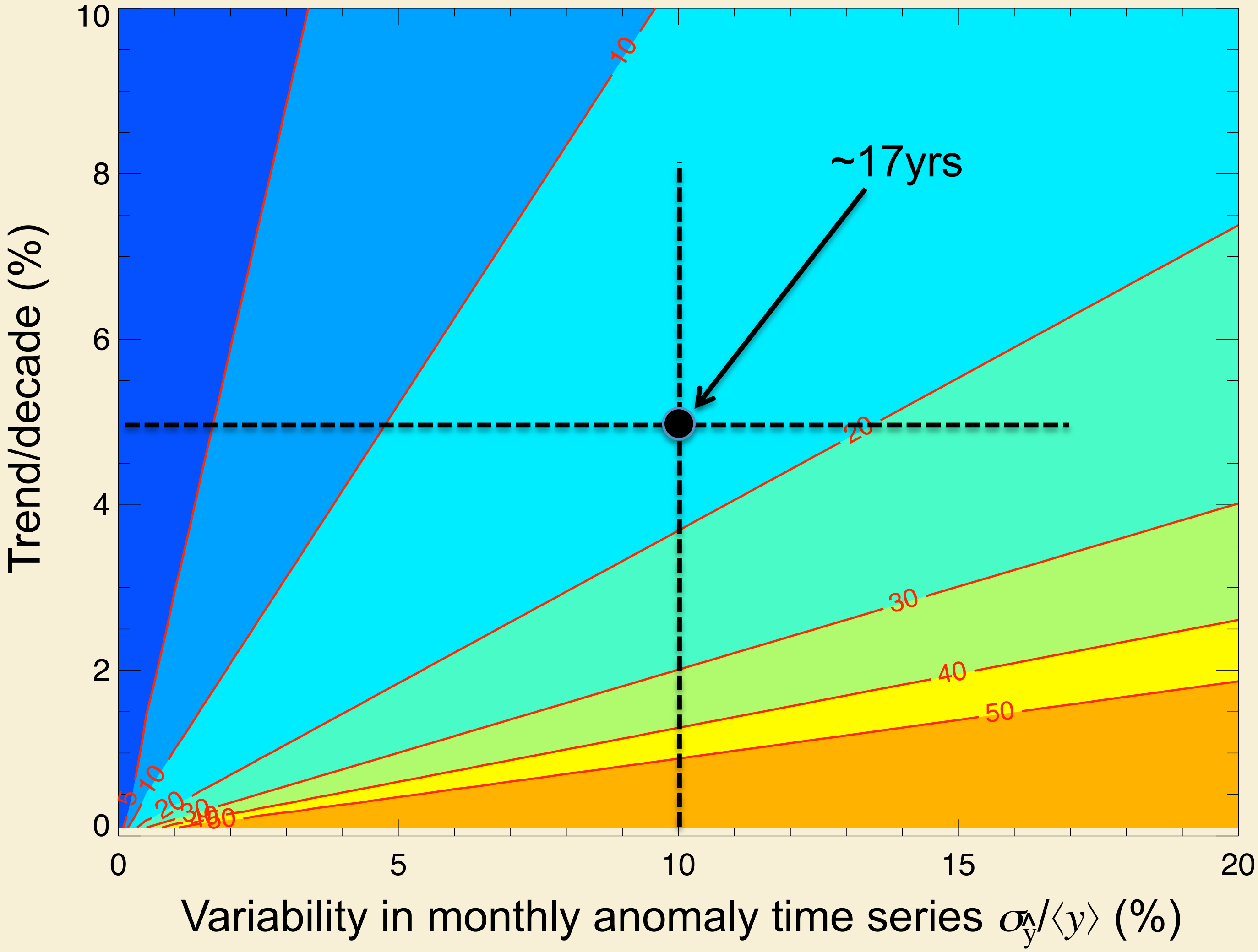

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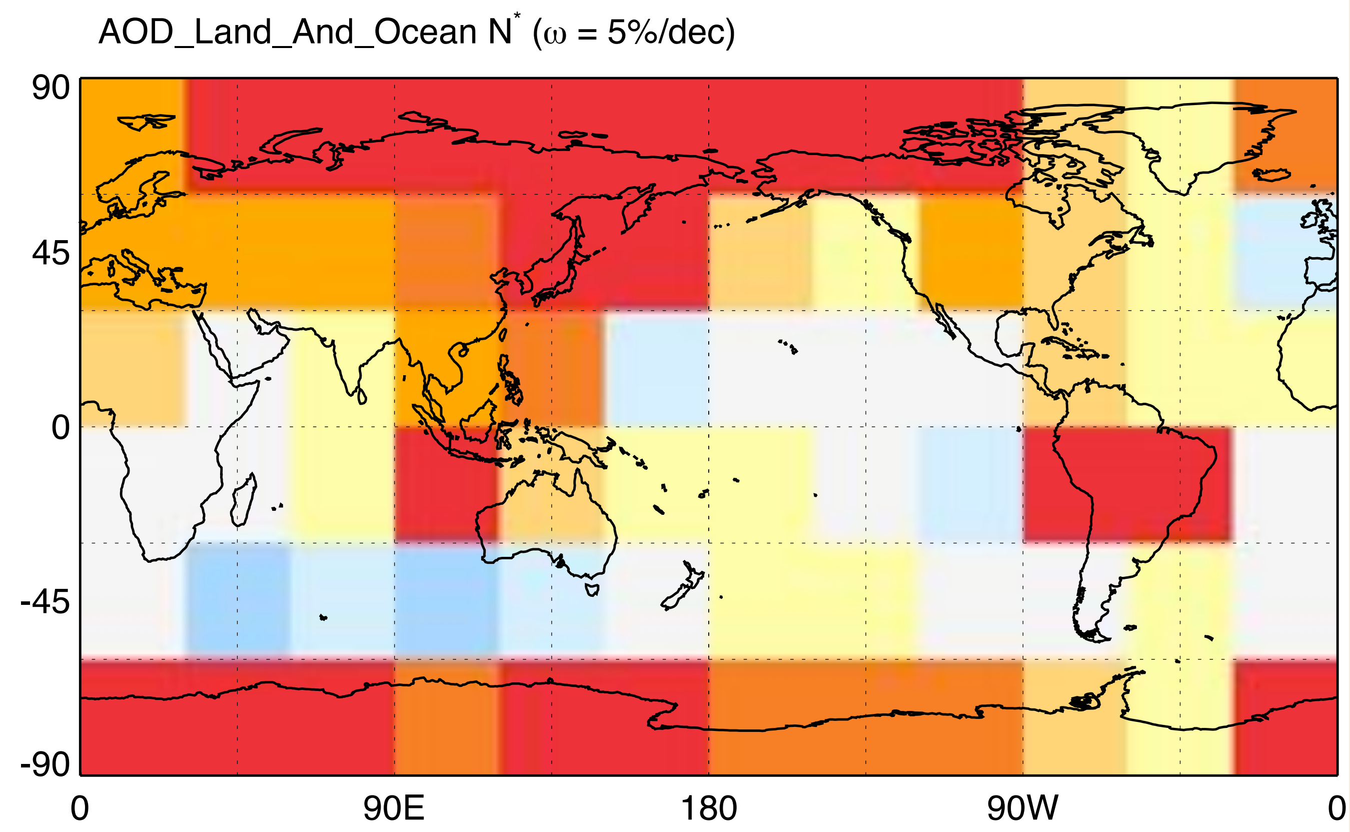
Time Required for Detection of 5%/decade Trend

(90% prob. of detecting a 0.05 statistical level,
based on yr-to-yr variability from July 2000 – June 2010, various binning)



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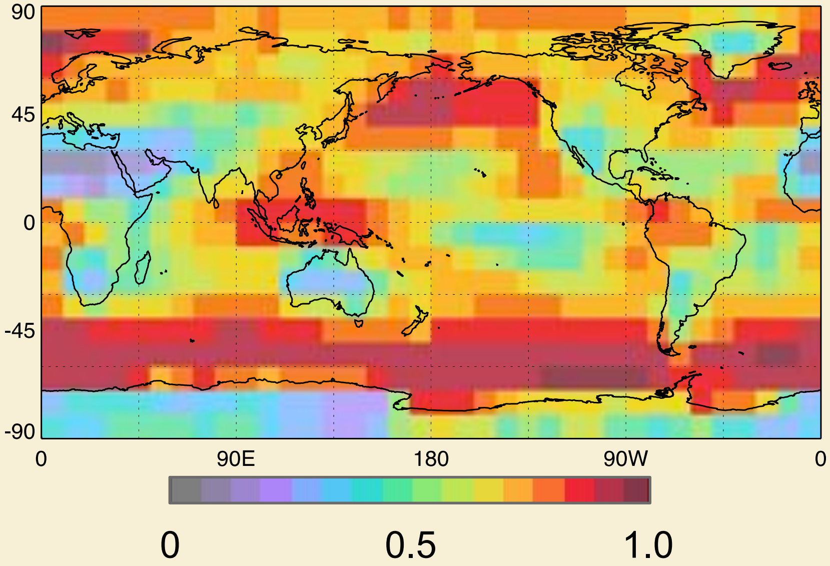
Annual Mean Fraction (July 2000 – June 2001)

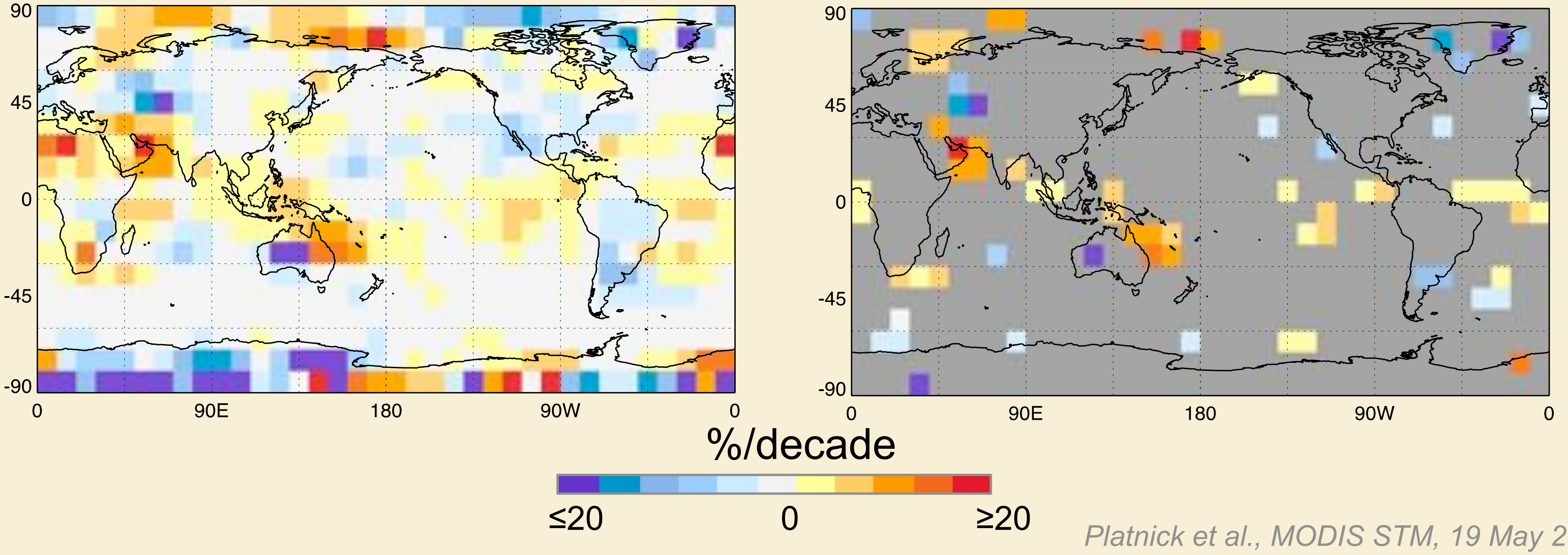


Cloud Fraction from MODIS mask, Terra (10° binning, daytime observations only)

Cloud Fraction Trends

(monthly anomalies, July 2000 – June 2010)

Trends Masked by Significance Level <0.05



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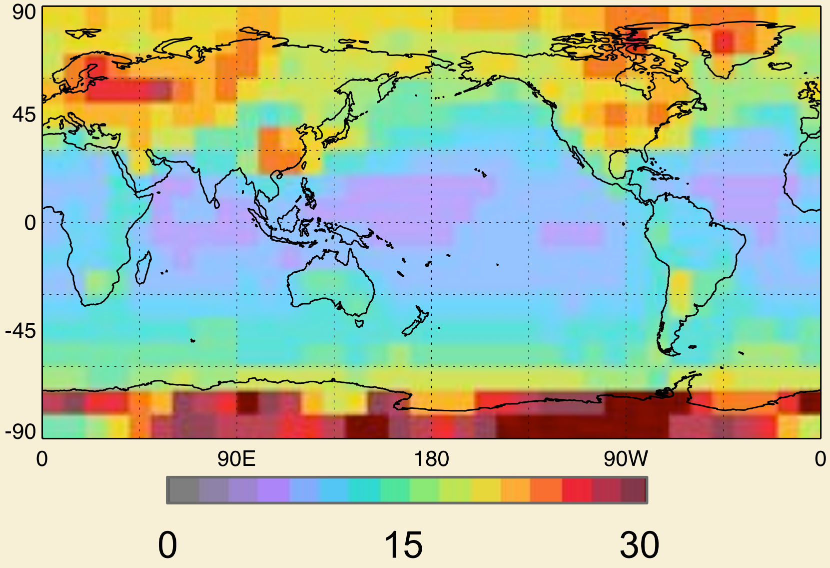
Annual Mean (July 2000 – June 2001)

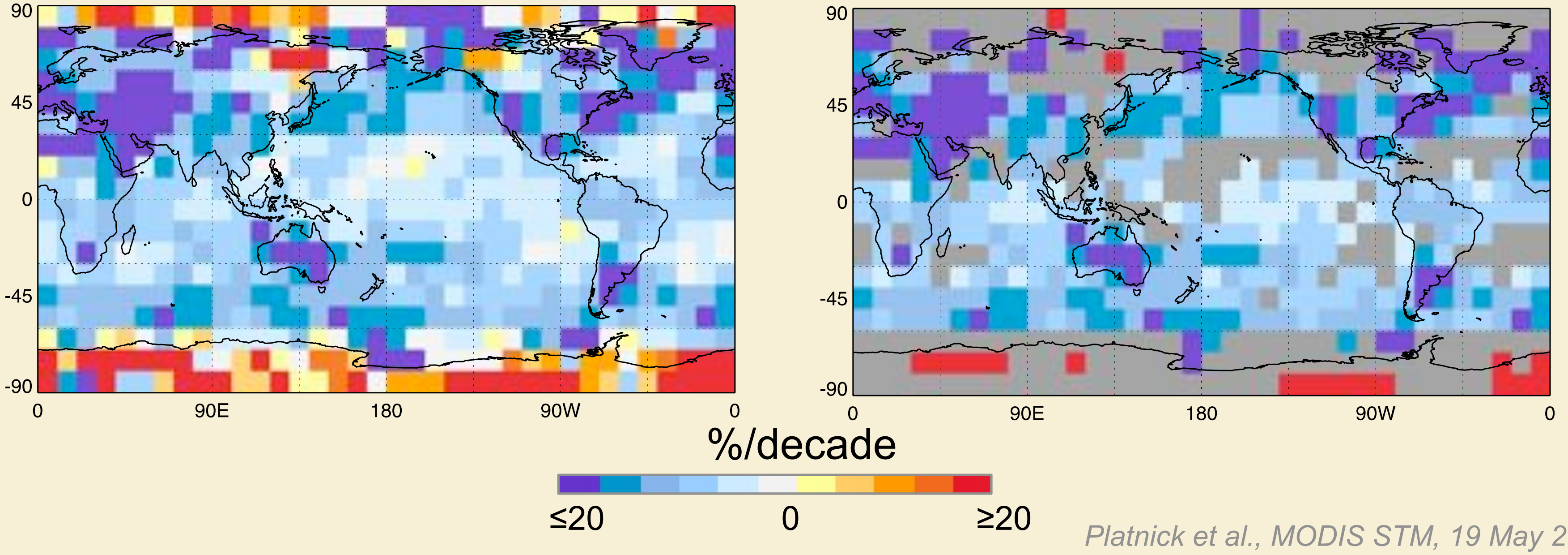


Cloud Optical Thickness, water clouds, Terra (10° binning, daytime observations only)

Optical Thickness Trends

(monthly anomalies, July 2000 – June 2010)

Trends Masked by Significance Level <0.05



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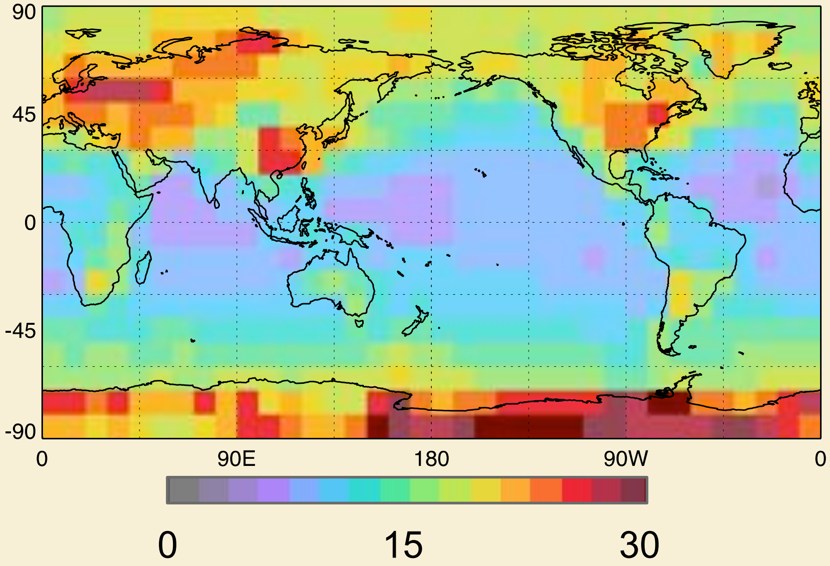
Annual Mean (July 2002 – June 2001)

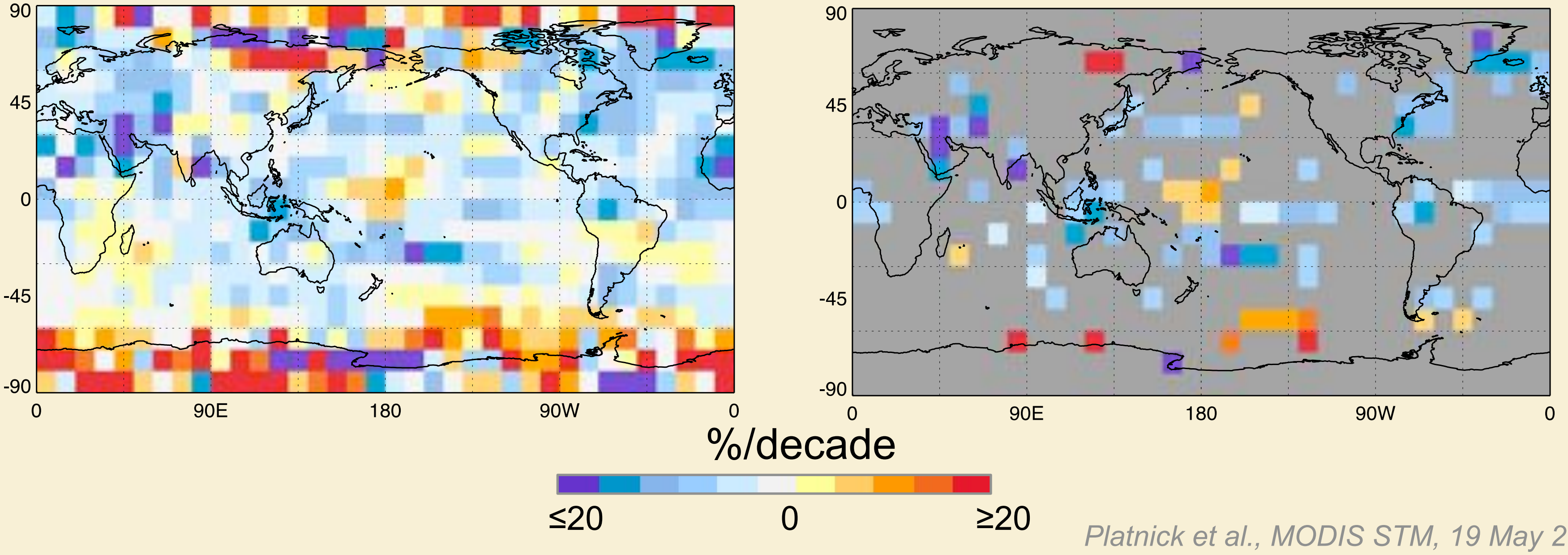


Cloud Optical Thickness, water clouds, Aqua (10° binning, daytime observations only)

Optical Thickness Trends

(monthly anomalies, July 2002 – June 2010)

Trends Masked by Significance Level <0.05



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Instrument Artifacts?

Trends (%/decade), ±60° latitude, areal averaging

Cloud Optical Thickness, Land (~ band 1)

	Aqua (8 yrs)	Terra (8 yrs)	Terra (10 yrs)
τ_{liquid}	-3.44	-15.62	-14.56
τ_{ice}	-0.98	-11.20	-10.71

Cloud Optical Thickness, Ocean (~ band 2)

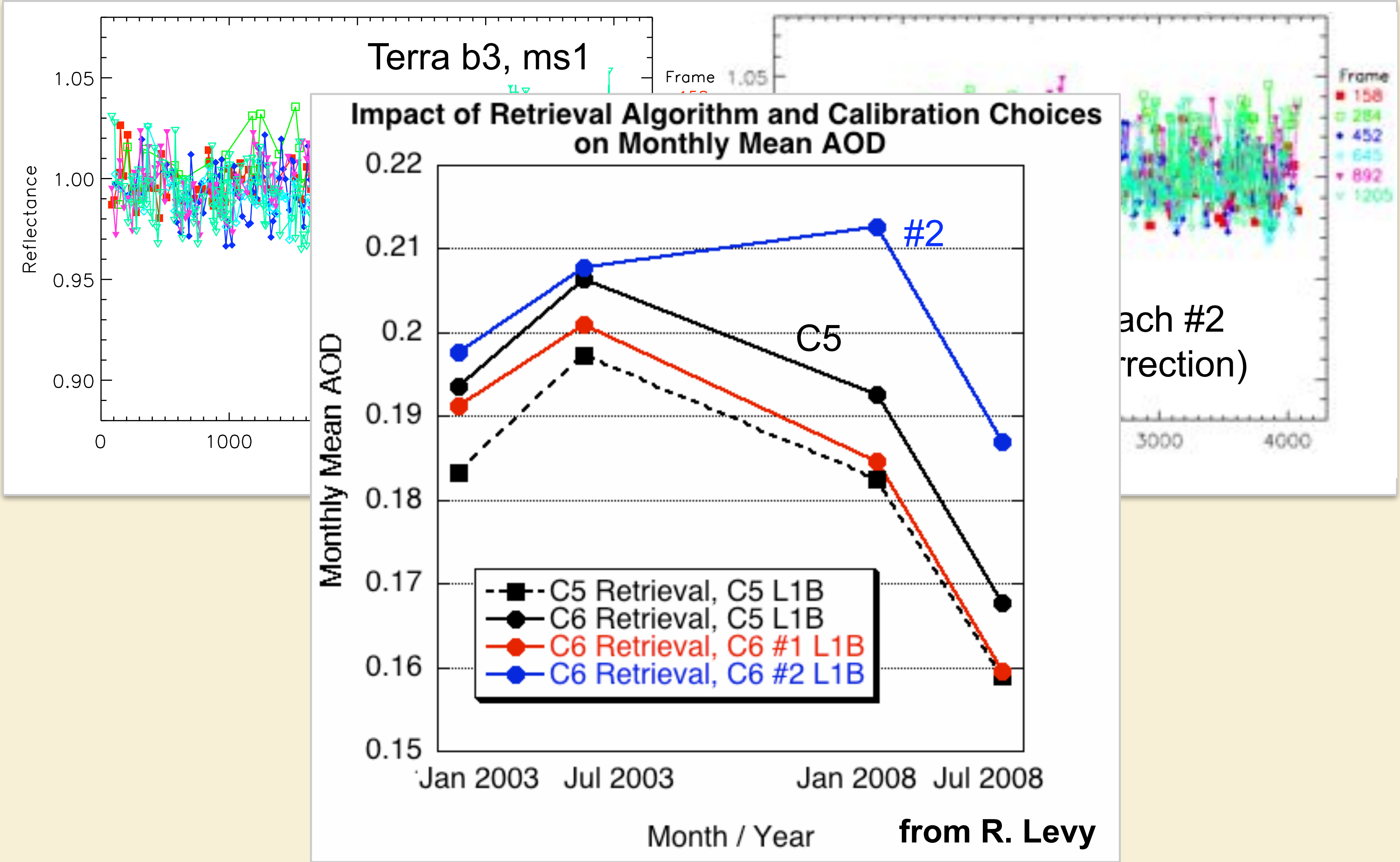
	Aqua (8 yrs)	Terra (8 yrs)	Terra (10 yrs)
τ_{liquid}	-2.6	-12.6	-10.0
τ_{ice}	-1.4	-13.1	-10.5

Aerosol AOD, Land (~ band 3)

	Aqua (8 yrs)	Terra (8 yrs)	Terra (10 yrs)
τ_a (pixel-weighing of grids)	-1.0	-24.0	-12.4
τ_a (no weighting)	-0.9	-25.9	-15.3

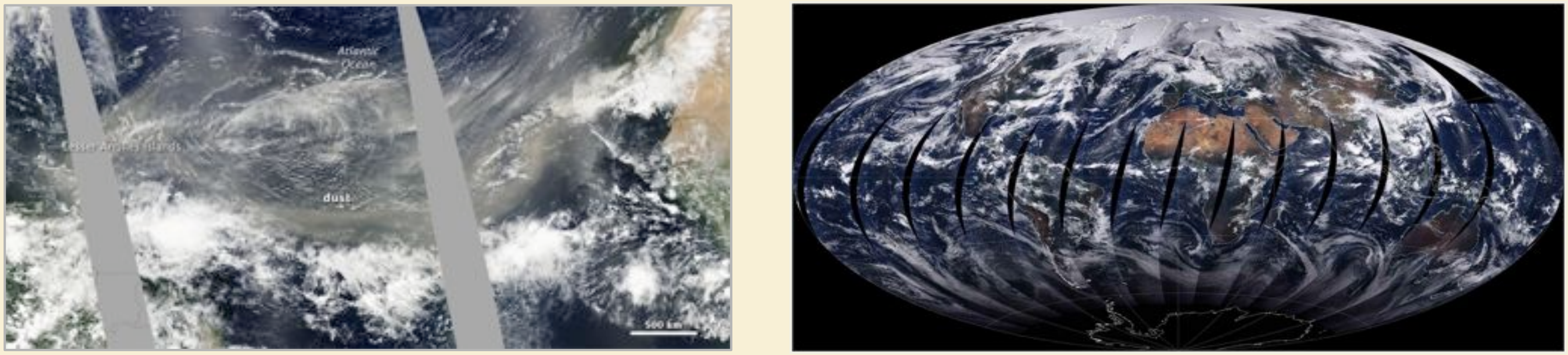
Instrument Artifacts? C5 Aqua & Terra Band 2 Trends vs. AOI (frame #)

MCST evaluation via desert ground targets (from Junqiang Sun)



Impact of Retrieval Algorithm and Calibration Choices on Monthly Mean AOD

from R. Levy



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- ▶ Motivation
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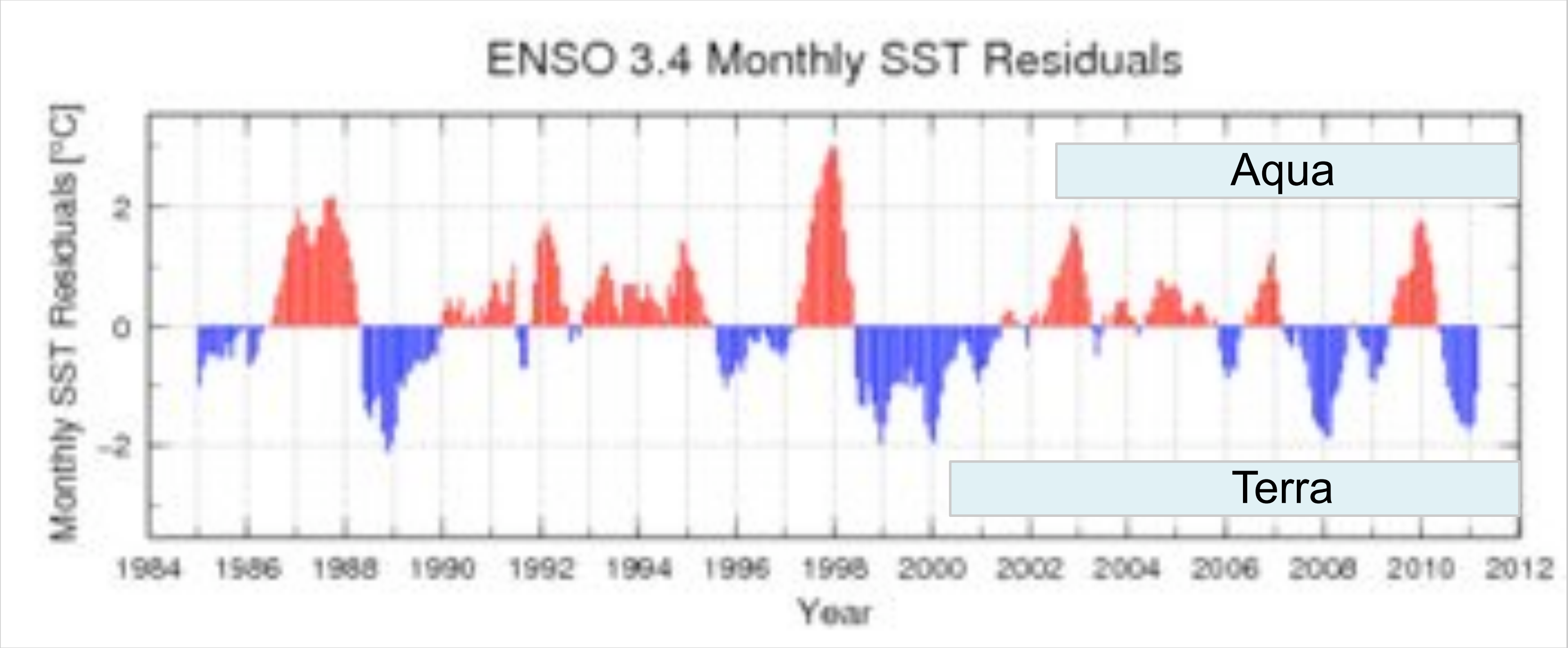
- ▼ ENSO Correlations
  - ❑ The role of natural variability and the need for long time records
  - ❑ Examples
  - ❑ Aliasing into trends?

ENSO3.4 SST Anomaly Index

(avg. temperature in a box in east-central equatorial Pacific)



Evaluating Correlations: Overview

Correlation w/zero lag: $r = \dfrac{\sigma_{xy}}{\sigma_x \sigma_y}$, e.g., x = ENSO3.4(t, $grid_{i,j}$), y = obs(t, $grid_{i,j}$)

Correlation w/lag: lag chosen with modified *Chen et al.* (2007)

Measure of significance:

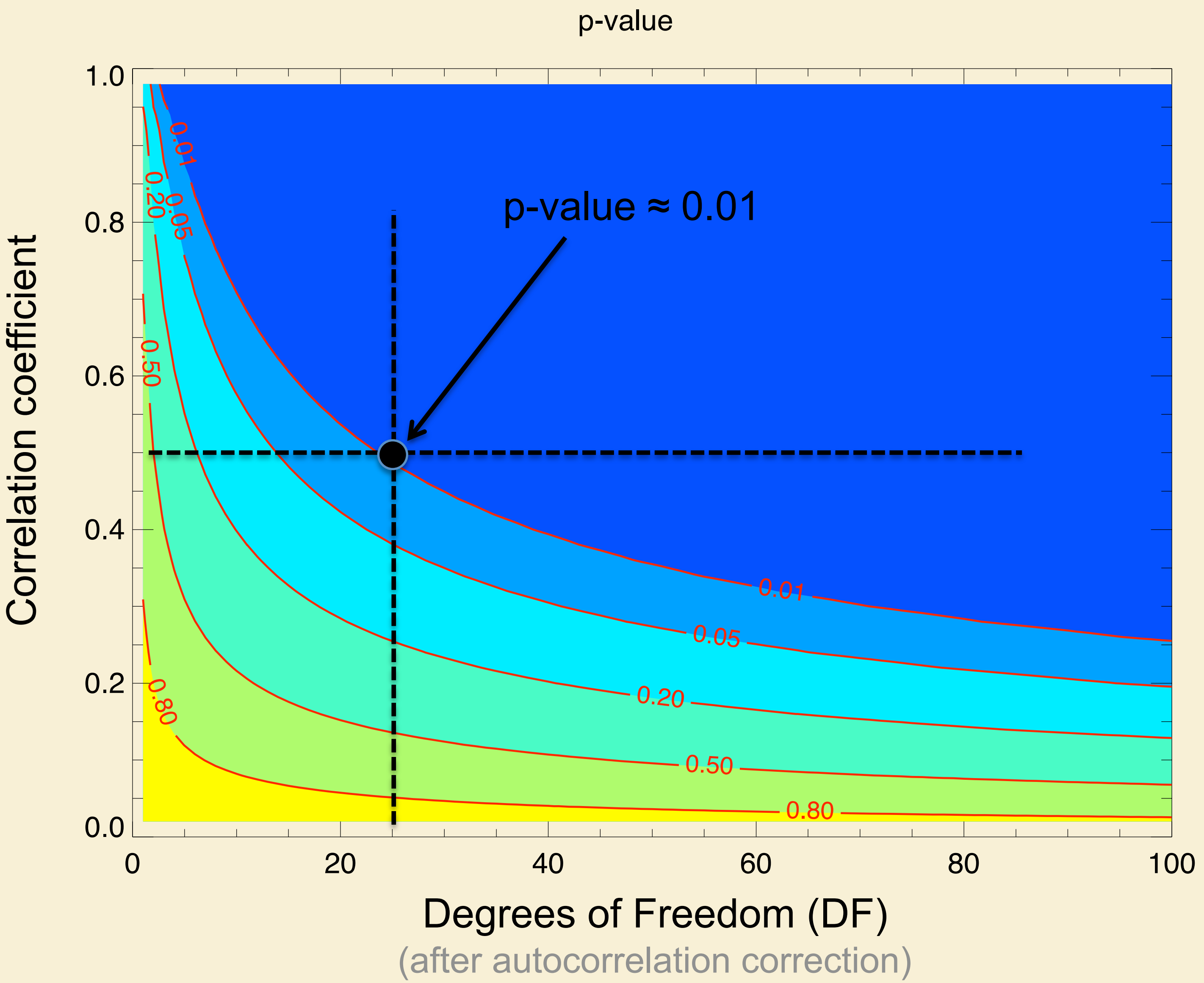
degrees of freedom ≈ record length

$$t = \frac{r\sqrt{DF}}{\sqrt{1 - r^2}}, \quad DF = N - 2$$

natural variability decreases w/grid size,
covariance may also decreases w/grid size
(significance may increase or decrease)

Statistical Significance (p-value) vs. Correlation & DF

(90% prob. of detecting a trend to a 0.05 statistical level)



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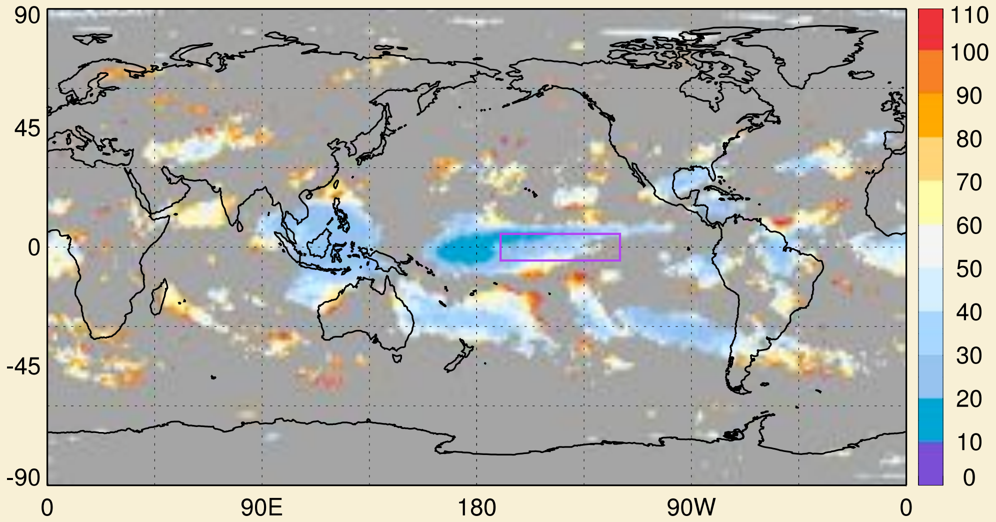
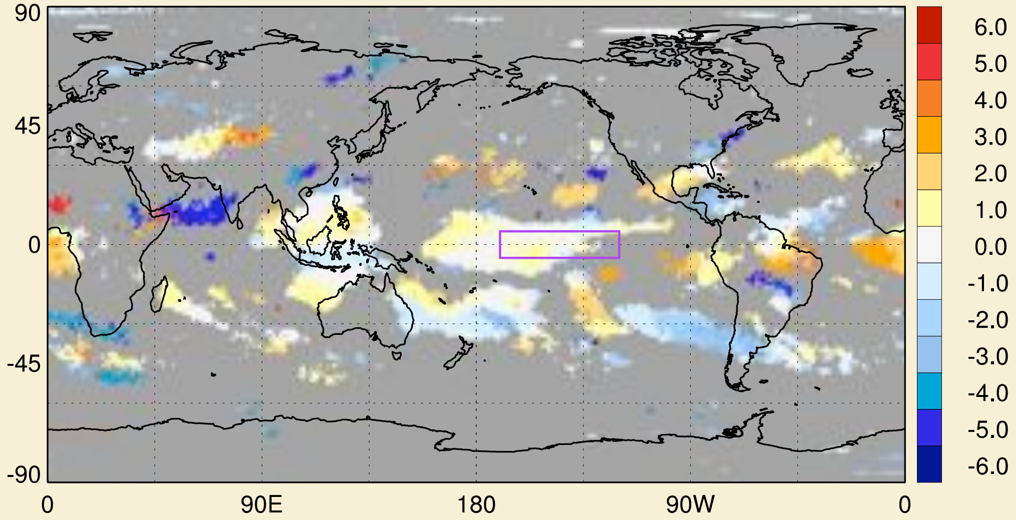
Example ENSO3.4 vs. MODIS Anomalies

1° bins, masked by 1% statistical sig., July 2002–Jan 2011

High Cloud Amount



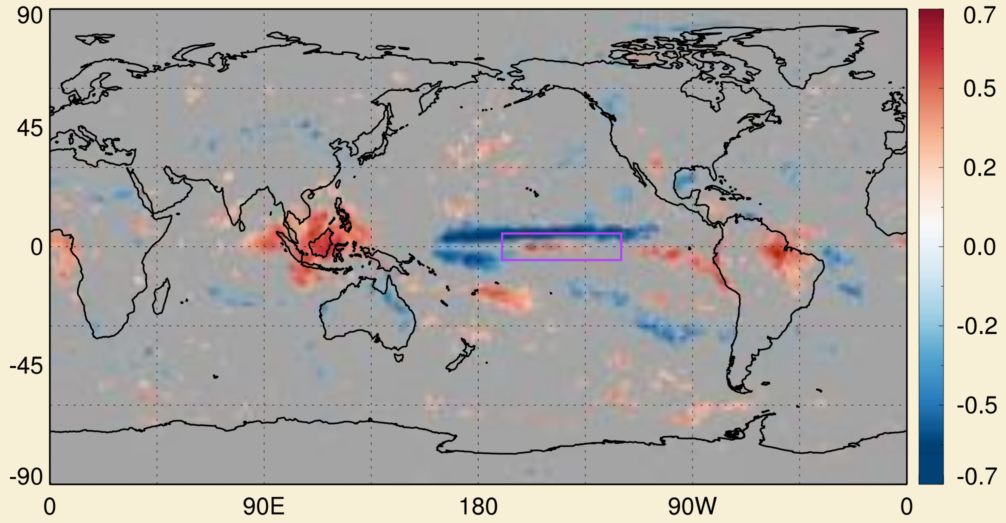
Degrees of Freedom
(max=108)



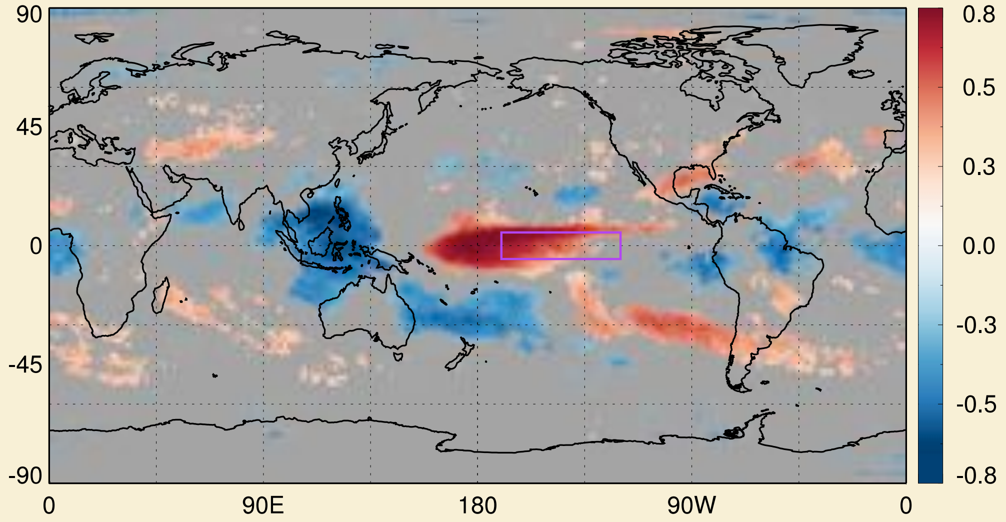
Lag (months)
[red => cloud response lags E3.4 index; blue => cloud response precedes index]

Example ENSO3.4 vs. MODIS Anomalies
1° bins, masked by 1% statistical sig., July 2002–Jan 2011

High and Low Cloud Amount Correlations



Low Cloud



High Cloud

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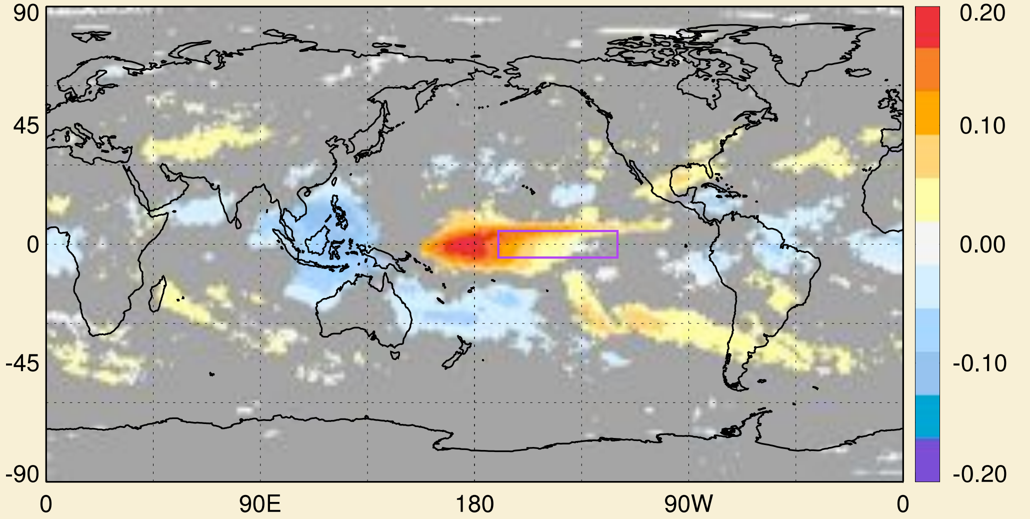
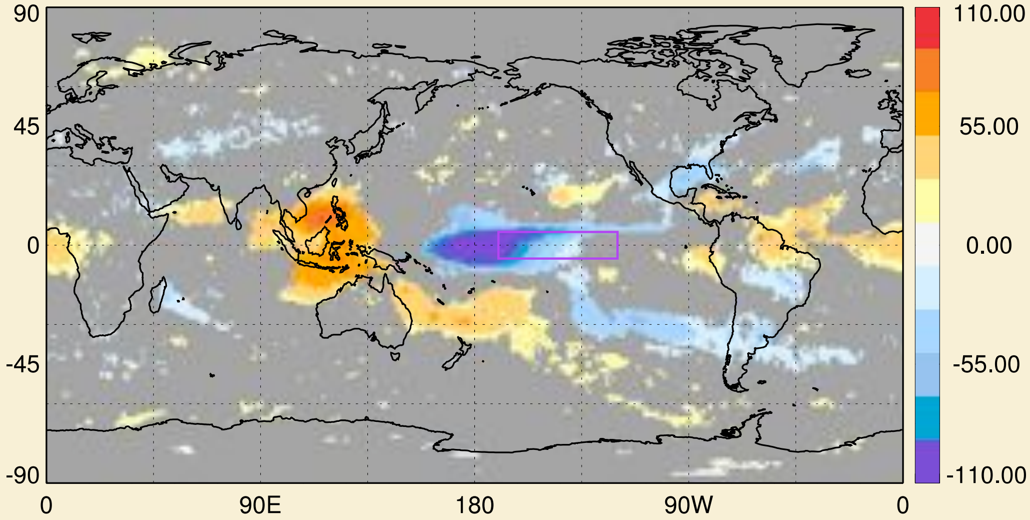
Example ENSO3.4 vs. MODIS Anomalies
1° bins, masked by 1% statistical sig., July 2002–Jan 2011

High Cloud Amount and Pressure Regression Slopes



High Cloud Amount
df_c/dT (K^{-1})



Cloud-top Pressure
dp_c/dT (hPa-K^{-1})

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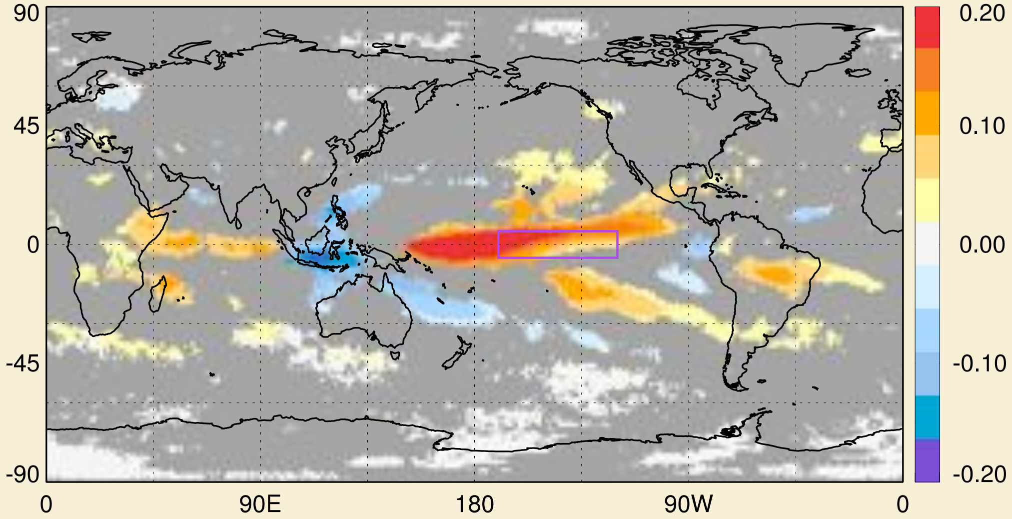
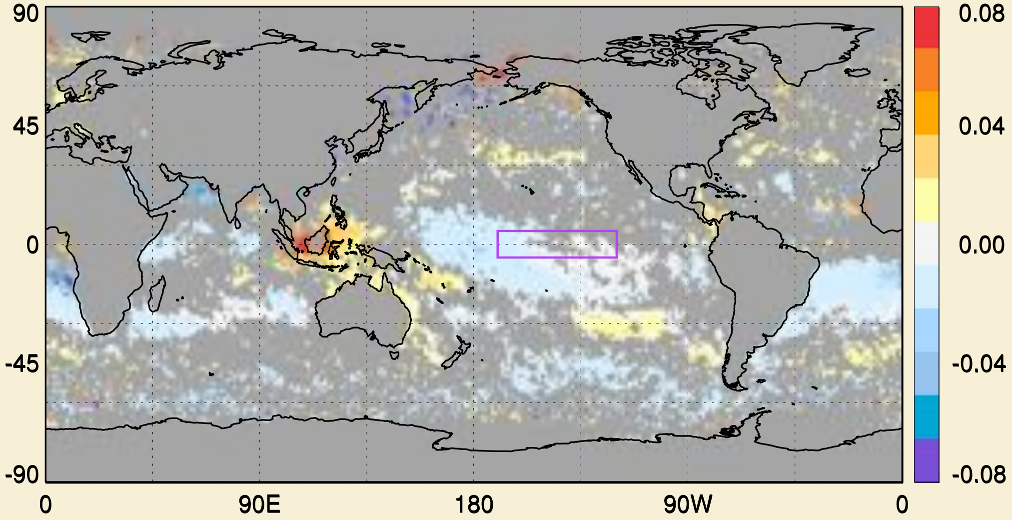
Example ENSO3.4 vs. MODIS Anomalies
1° bins, masked by 1% statistical sig., July 2002–Jan 2011

Upper Trop. Water Vapor and AOD Regression Slopes



Upper Trop. Water Vapor
(300-700 hPa)
dPW/dT (cm-K^{-1})



5% statistical sig.

Aerosol Optical Depth
$d\tau_a/dT$ (K^{-1})

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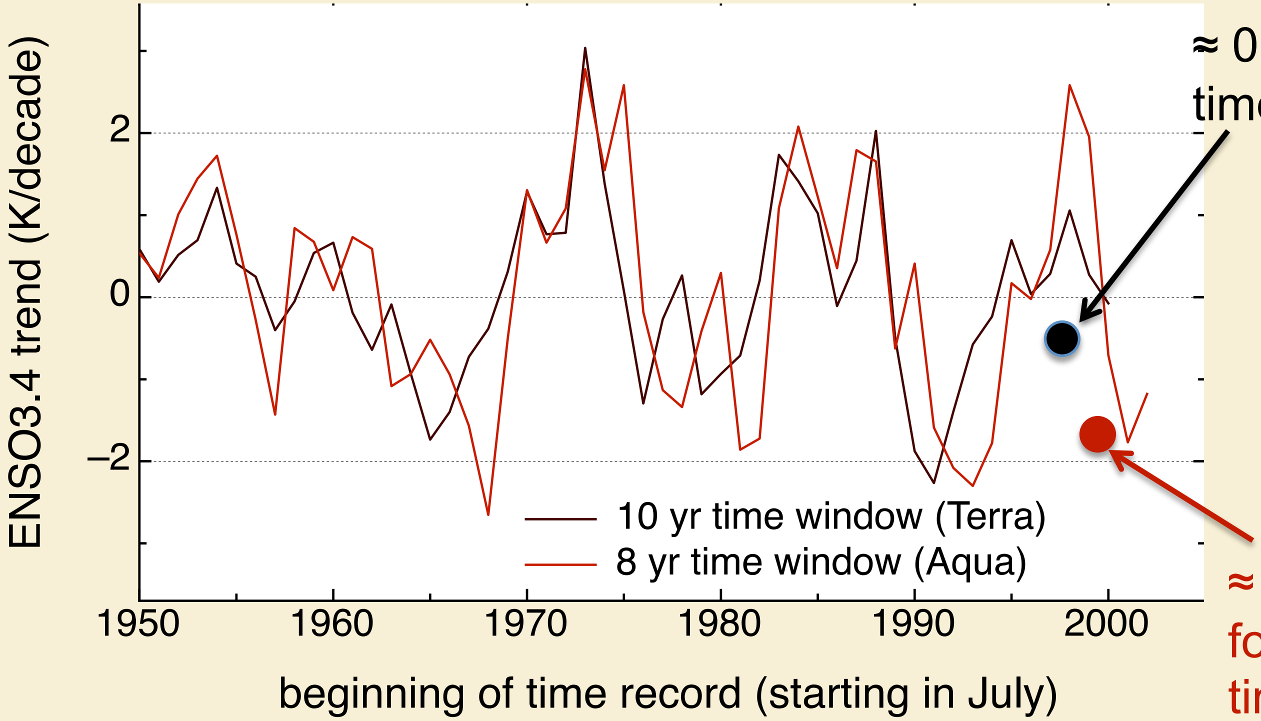
Example ENSO3.4 vs. MODIS Anomalies

If ENSO correlations imply a linear process (?), then the anomaly data record x_a in a grid box due to ENSO can be approximated as:

$$x_a^{ENSO}(t) \approx b_r \cdot ENSO3.4(t)$$

$$\text{trend}\left\{x_a^{ENSO}(t)\right\} \approx b_r \cdot \text{trend}\left\{ENSO3.4(t)\right\}$$



≈ 0 for Terra time record

≈ -1.2K/dec for Aqua time record

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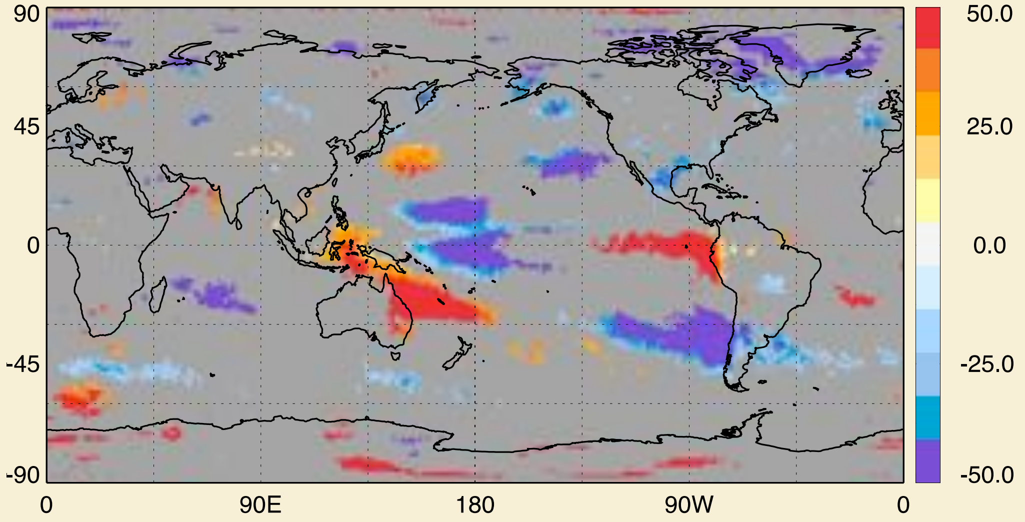
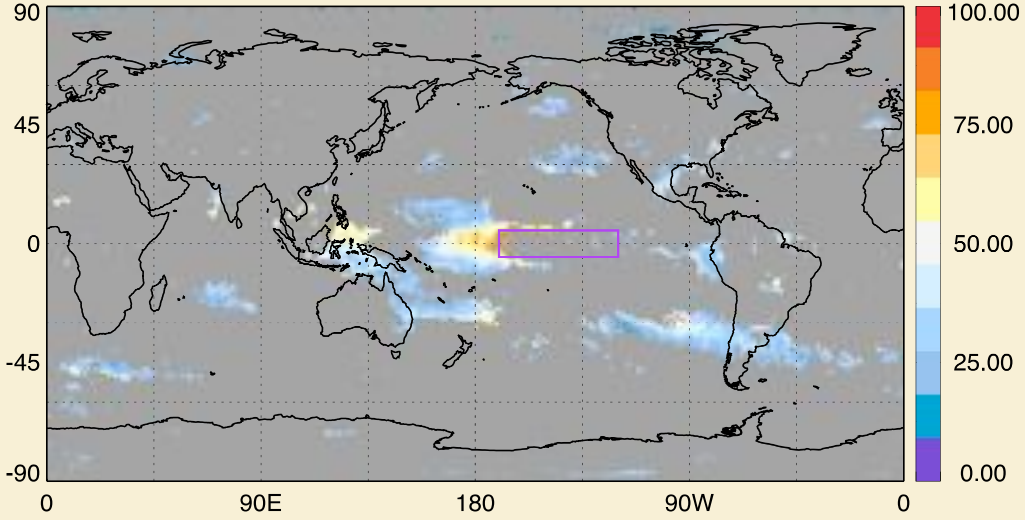
Example ENSO3.4 Component of MODIS Trend
Aqua, 1° bins, July 2002–Jan 2011

High Cloud Amount



High Cloud Trend

Masked by stat. sig. <0.05



ENSO component of trend (%)
derived from correlation
regression slope

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Closing Thoughts

- The ability to detect a trend to within some level of significance is a function of:
    - Natural variability, spatial aggregation and temporal scale (e.g., monthly, seasonal, yearly)
    - Record length (number of effective data points or degrees of freedom)
- For anticipated atmospheric changes associated with global warming, trend detection and quantification is a multi-decadal problem.
    - A decade long time series (Terra) is unlikely to have statistical significance at synoptic scales and smaller.
- Other challenges
    - Short term climate variability (e.g., ENSO) can alias into a time records complicating trend detection/interpretation.
    - Instrument trends
    - Retrieval biases that vary as the climate state changes