Anthropogenic Influence on Decadal Aerosol Trends and Aerosol-Cloud Interactions Over the Western North Atlantic Ocean

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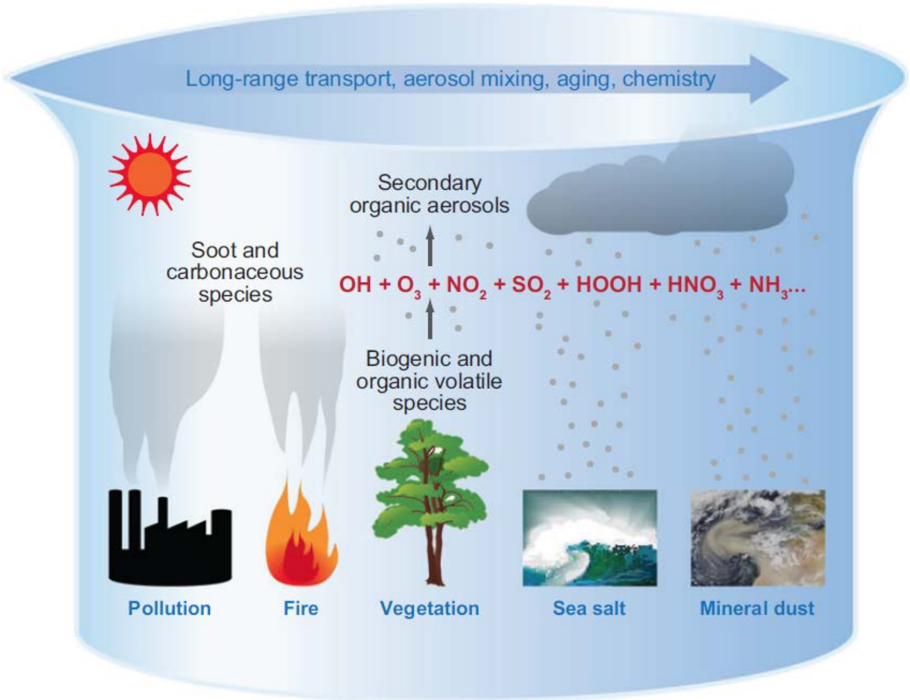
Brief Overview

Aerosols: what are they?

- Small (<<10μm) suspended particles
- Natural: dust, sea salt, smoke, volcanic, vegetation
- Anthropogenic: pollution, soot, sulfate/nitrate, smoke, organic



(Prather et al., 2008)

Aerosols: why do we care?

- Human activities during the last 100 years have increased anthropogenic aerosol species
- More recently, policies aimed at reducing air pollutants have seen success at improving local/regional air quality (Eg. U.S. EPA NAAQS)
- Eg: East U.S.: decrease emission, AOD; increase surface clear-sky SW radiation 1995-2010 from surface observations (Gan et al., 2014)

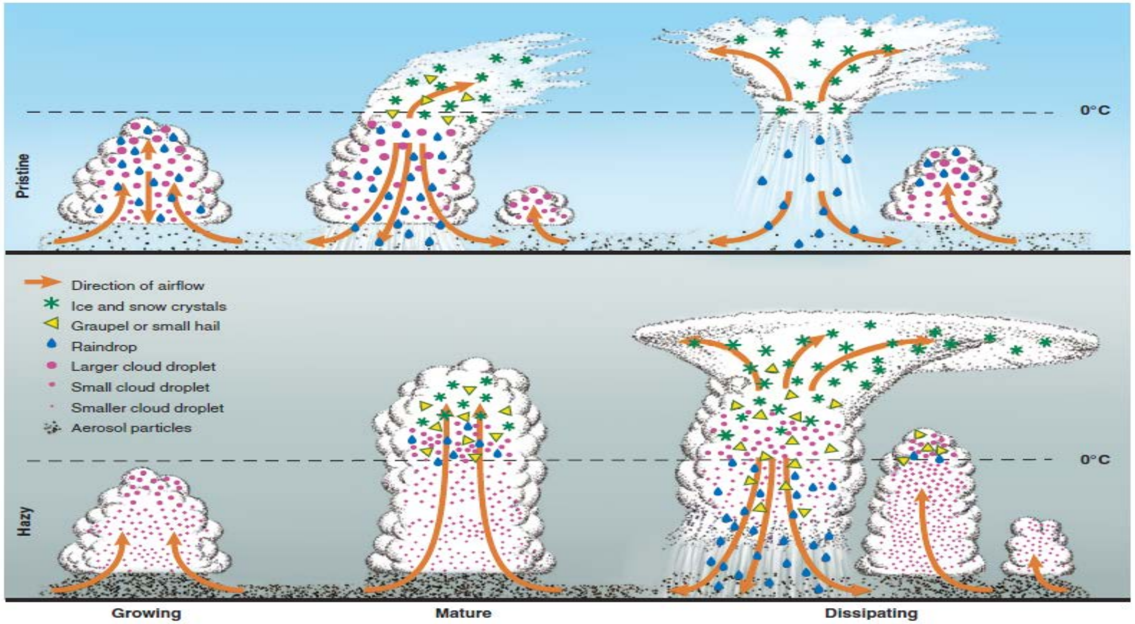
Brief Overview

Aerosols: what are their climate impacts?

- Interaction with radiation (direct effect)

Shenandoah NP, New Market Gap (IMPROVE; http://vista.cira.colostate.edu)

- Interaction with clouds (indirect effects)



(Rosenfeld et al., 2008)

- **Are there noticeable aerosol changes over the North Atlantic? … are they anthropogenic? … do they alter clouds? … how?**

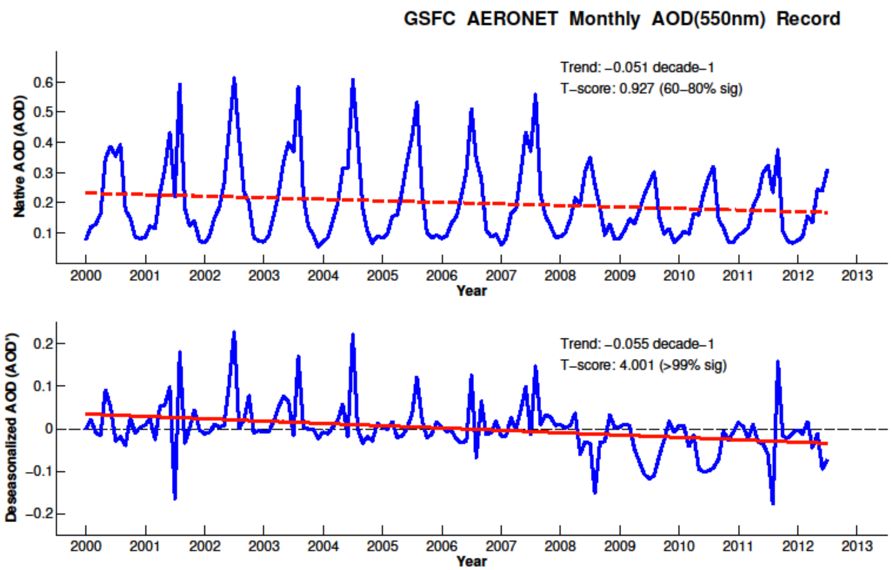
Data Sources

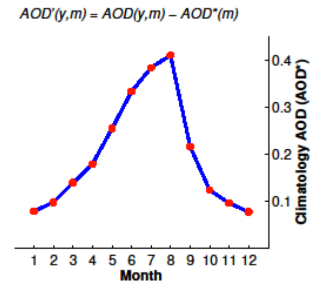
(ALL data are monthly means)

Satellite	**MODIS**	*MxD08_M3 (C5/6)*	*(03-2000/07-2002 – 12-2012)*
	Aerosol: optical depth (AOD), fine-mode fraction (FMF)		
	Cloud: effective radius (CRE), water path (LWP), optical thickness (COT)		
Surface	**AERONET**	*L2 v2*	*(01-2000 – 12-2012)*
	Goddard (GSFC) / Cape Verde (CPVD) AOD from sun photometer		
	IMPROVE	*IMPRHR2*	*(01-2000 – 12-2012)*
	24-hr every 3 day aerosol/PM speciation (AS, AN, POM, LAC, SOIL, SS)		
Model	**GOCART**	*g5e520m0c_2HINST*	*(01-2001 – 12-2009)*
	Total and five species AOD (SU, DU, SS, OC, BC)		
	MERRA	*instU_3d_asm_Cp*	*(07-2002 – 12-2012)*
	Horizontal winds (u and v) at 1000, 850, and 700 hPa		

Spatial Domain: [-80^0 -30^0] lonE [20^0 50^0] latN

Analysis Methods

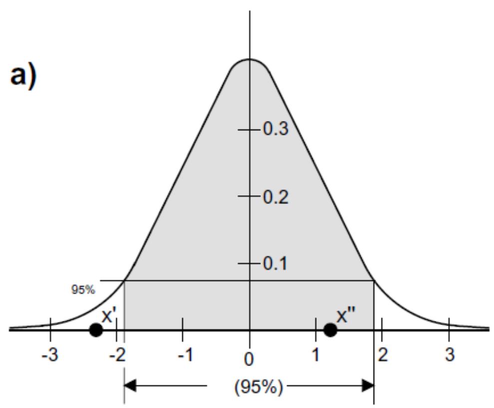




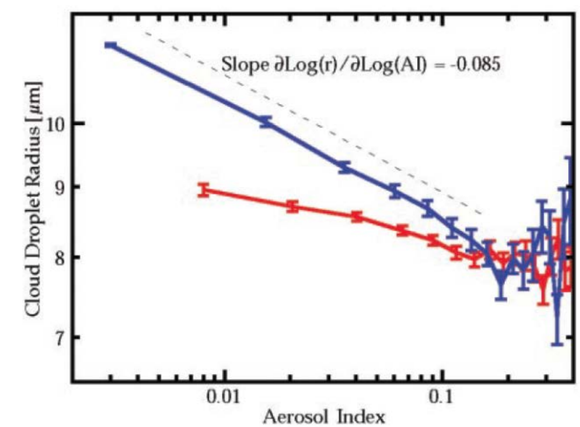
- **Deseasonalizing**
  (for trend determination)

- **T-testing**
  (for statistical significance)
  (.) = 90%   (+) = 95%

- **Binned A-C scatterplots**
  (for ACI at constant LWP)

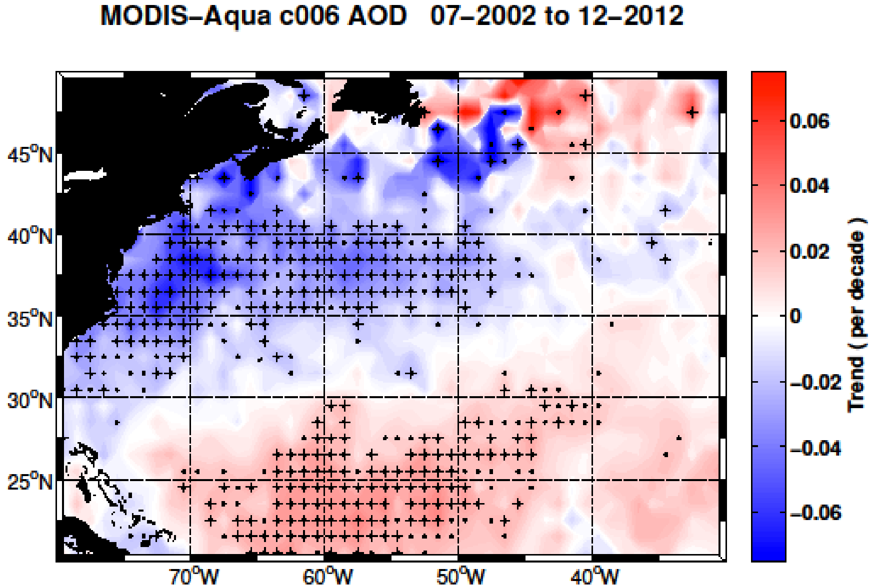


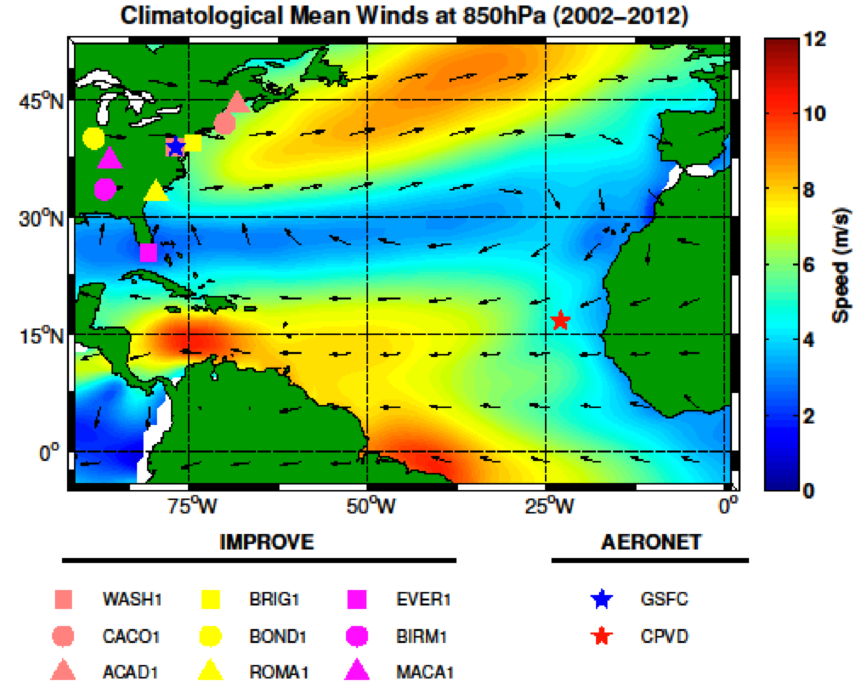
(von Storch and Zwiers, 1999)



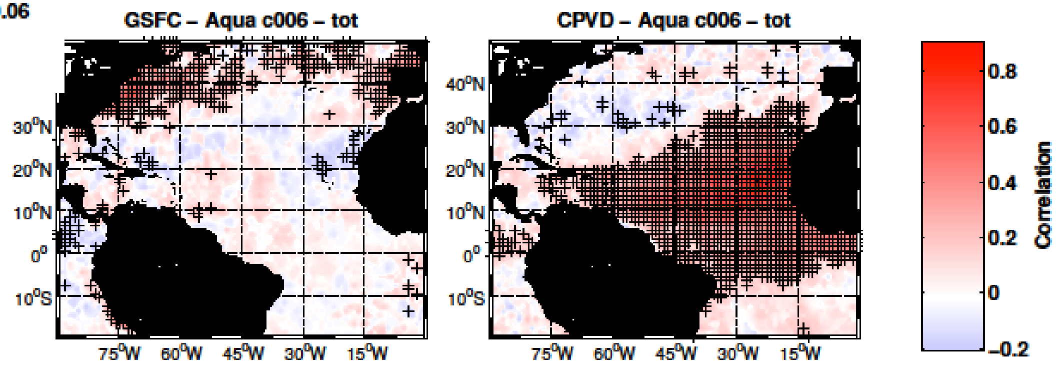
(Breon et al., 2002)

MODIS AOD Trends





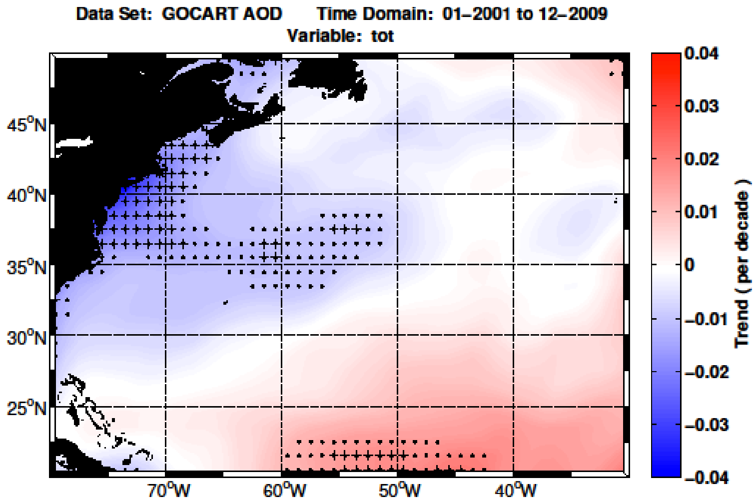
- - 0.040 AOD/da trend in mid-lats
- 0.020 AOD/da trend in sub-trop

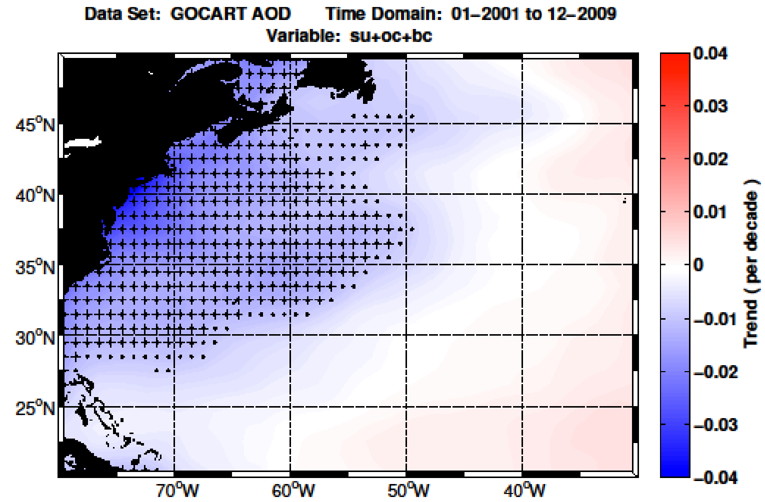


AERONET -- MODIS Correlation

- Can either be further attributed natural/anthropogenic?

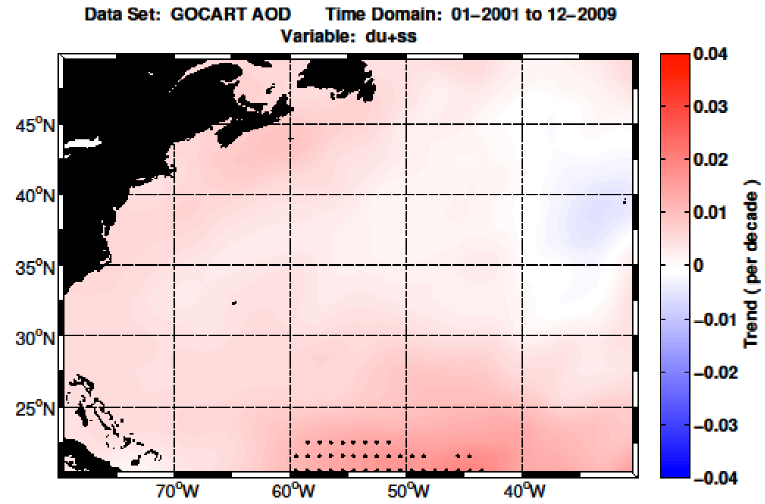
GOCART Trends



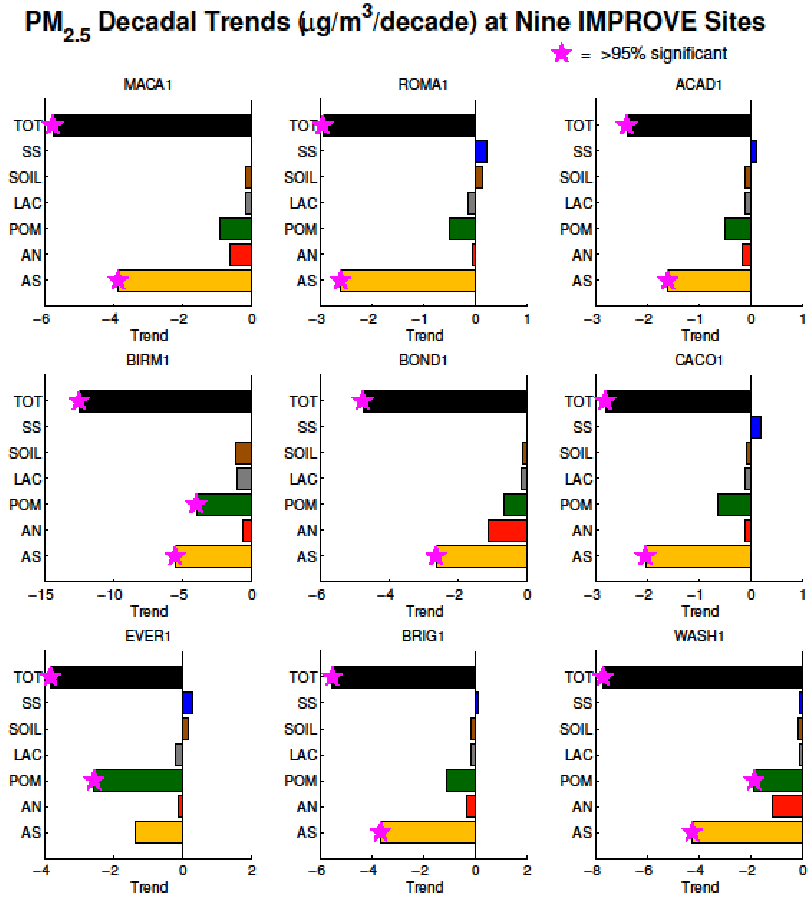


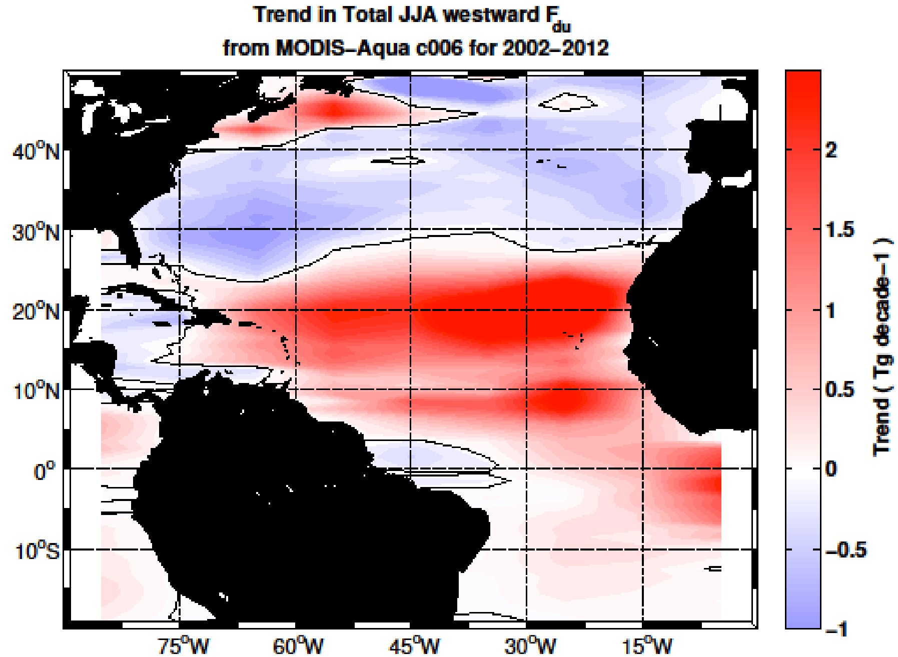
- Total reflects trends seen from MODIS
- Anthro. trends only seen near N.Am coast
- Natural trends only seen in sub-tropics

- GOCART model can aid in separating aerosol species responsible for regional trends



Additional Support





Method developed in Kaufman et al. (2005)

- Significant TOT and ammonium sulfate (AS; anthropogenic) $PM_{2.5}$ decreases at sites in East U.S.
- Increased JJA F_{du} is plausible as cause for sub-tropical (+) AOD trend

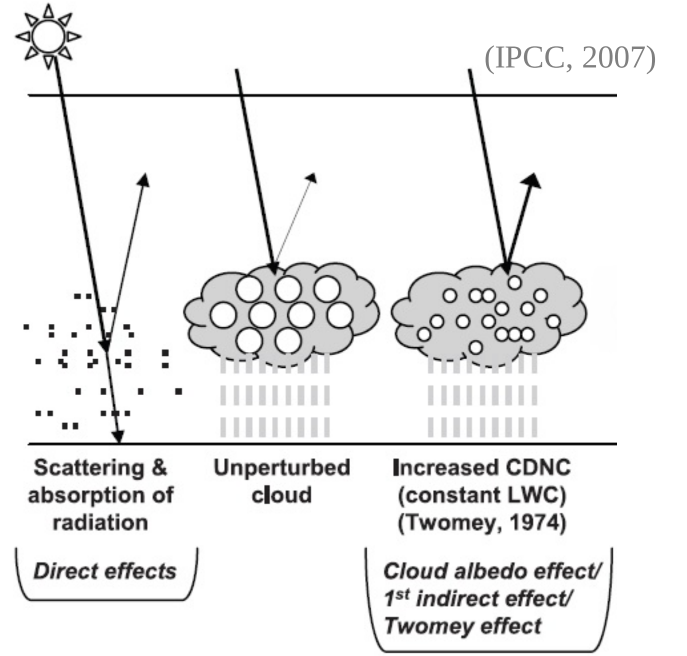
AOD Trend Summary

- MODIS reveals two opposite and separated trends in AOD
- AERONET correlation links with upwind regions
- GOCART further separates anthropogenic/natural species responsible
- IMPROVE provides ground-based confirmation of (-) mid-latitude anthropogenic AOD trend
- JJA F_{du} estimation supports (+) sub-tropical natural AOD trend

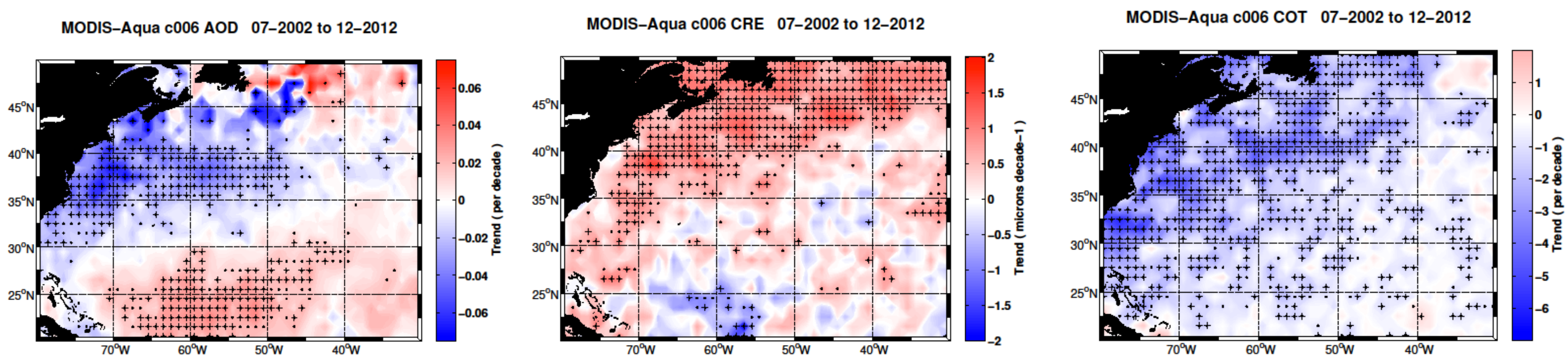
- **Given the changing AOD loading, are there related changes in clouds?**

ACI – Twomey Effect

- Formed in a dirtier environment, with increased aerosol loading, CN, and CCN -- means cloud droplets will be more numerous but with smaller radii, provided Δ LWP = 0



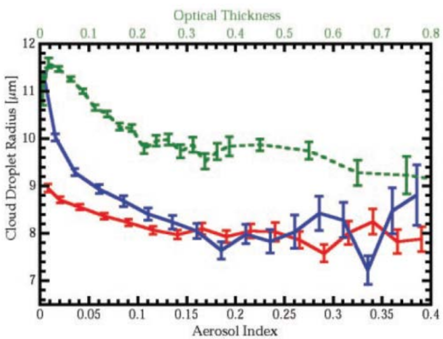
- Does this make sense on the first order?



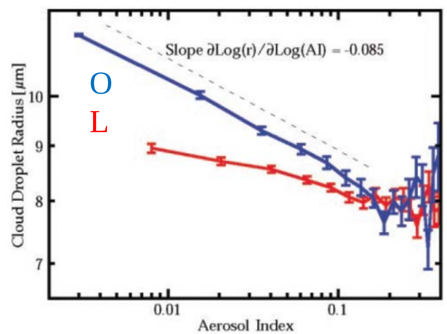
note: LWP **NOT constrained*

ACI – Twomey Effect

- To better quantify this, the slope of a log-log linear fit in aerosol-cloud parameter space gives the ACI



(Breon et al., 2002)



wavelength and particle composition.) For a homogeneous cloud with drop number concentration N_d and constant cloud liquid water content LWC, (3) reduces to

$$\tau_d \propto N_d^{1/3} \quad (4)$$

[*Twomey*, 1977]. Assuming that N_d obeys

$$N_d \propto N_a^{a_1}, \quad (5)$$

where N_a is the aerosol number concentration [*Twomey*, 1977], and using (4) and (5) yields

$$r_e \propto \tau_a^{-a_1/3}, \quad (6)$$

$$-\frac{d \ln r_e}{d \ln \tau_a} = \frac{a_1}{3}. \quad (7)$$

A characteristic value of a_1 is 0.7 [e.g., *Pruppacher and Klett*, 1997; *Charlson et al.*, 1987], yielding IE = 0.23. Note that since $a_1 \leq 1$, we obtain $0 \leq \text{IE} \leq 0.33$.

(Feingold et al., 2001)

$$ACI = \frac{d\, ln\tau_c}{d\, ln\tau_a} = -\frac{d\, lnr_e}{d\, ln\tau_a} \leq \frac{1}{3}$$

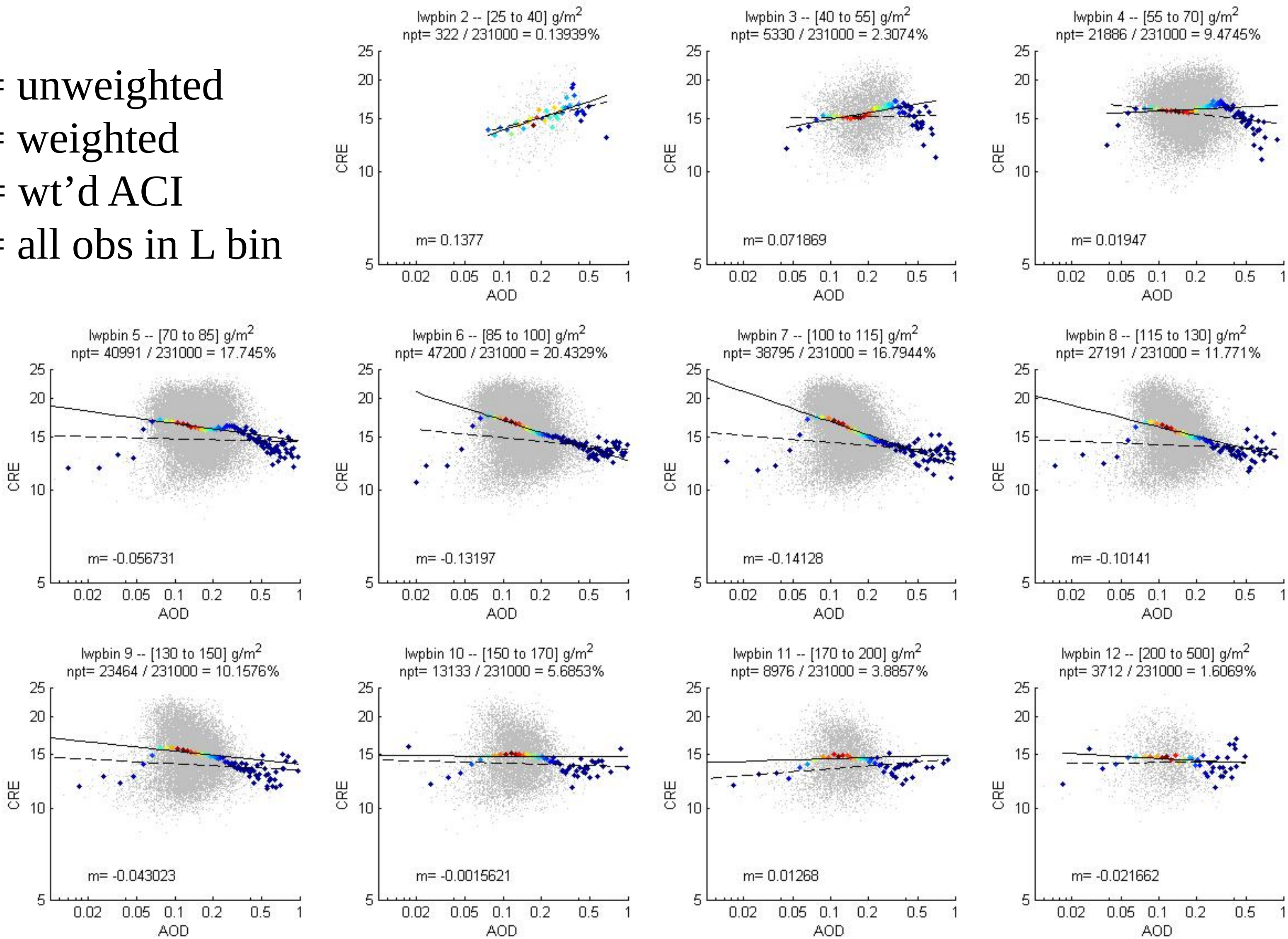
note: the following are for **MODc051 and are in the process of being updated to c006; MYD shows similar; LWP bins = [0 25, 25:15:130, 130:20:170, 170 200, 200 500]; AOD bins = [0.00:0.01:1.00]*

ACI$_{CRE}$ Domain-wide

Weighted by N(obs) in bin
Point is (AOD_m,CRE_m) in bin

- - - = unweighted
—— = weighted
m = wt'd ACI
● = all obs in L bin

2/3 obs



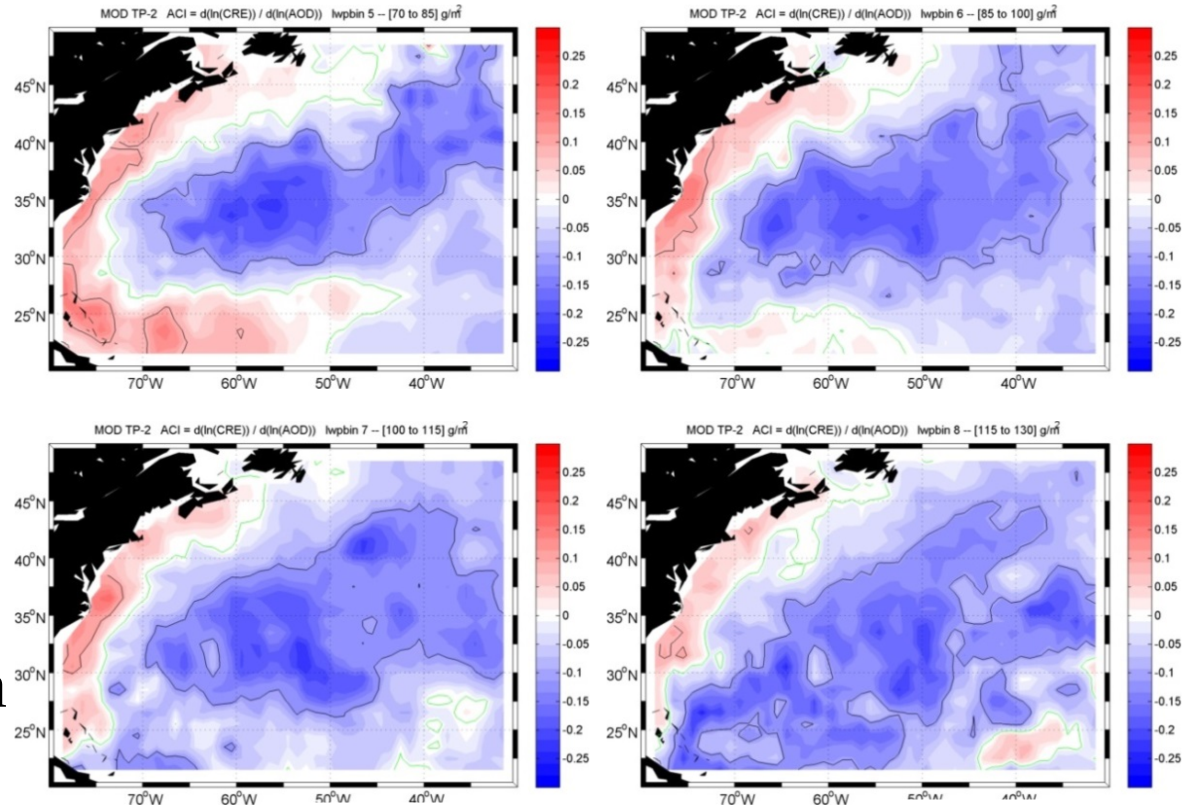
ACI_{CRE} 3x3 Analysis

Middle 4 LWP bins (2/3 obs)

(green line) = 0.00 (black line) = +/- 0.10

- **At sea:** Twomey behavior well observed
- **Near coast:** persistent behavior counter to Twomey theory
- **Western sub-tropics:** behavior transition from counter > Twomey

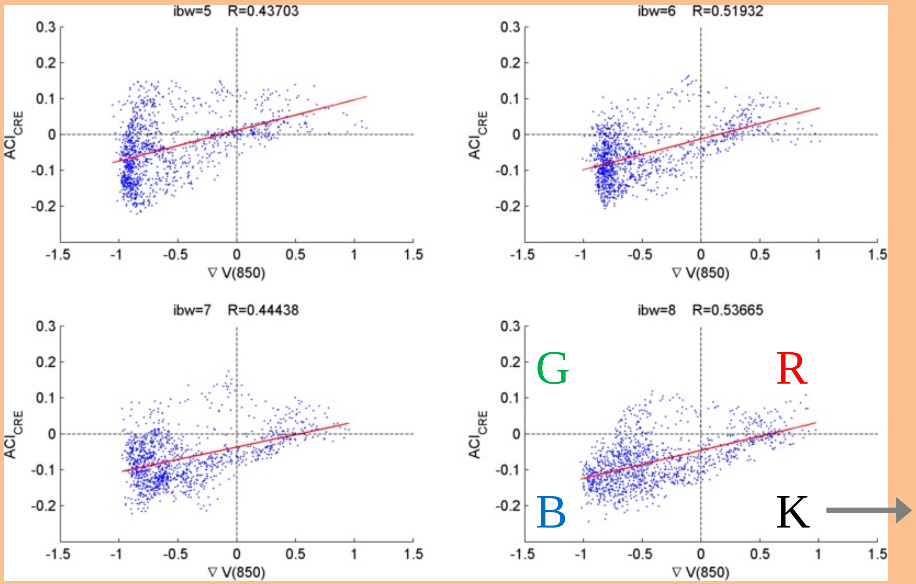
[70 85] g/m^2 [85 100] g/m^2

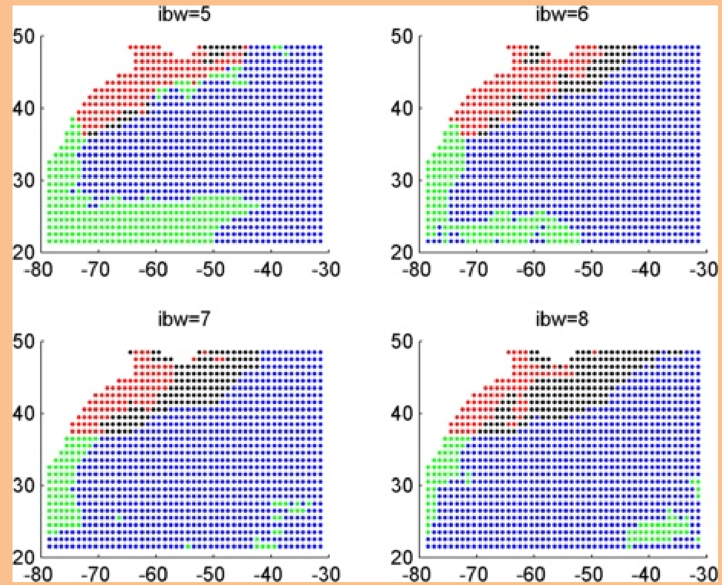


[100 115] g/m^2 [115 130] g/m^2

ACI$_{CRE}$ 3x3 – Causes?

ACI$_{CRE}$ vs mean(div($\mathbf{V}_{850}$))



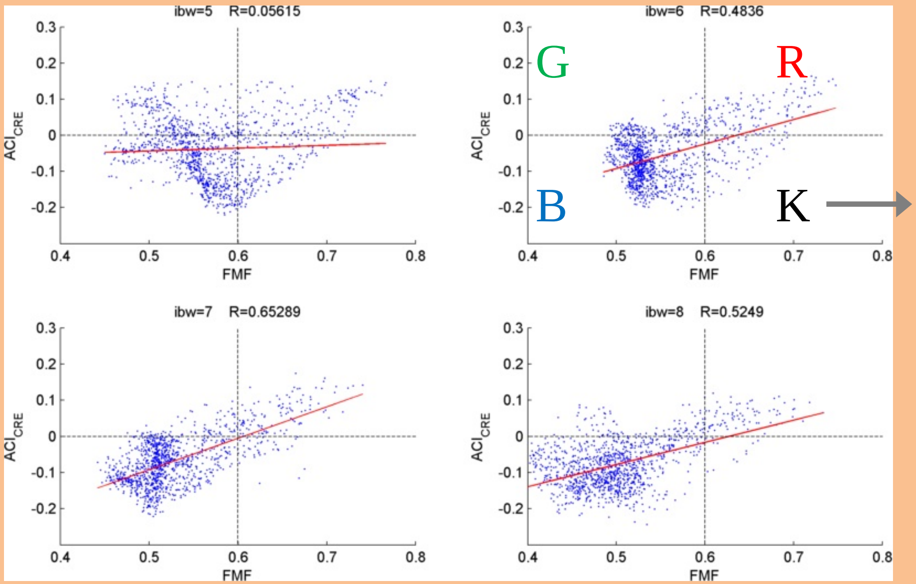


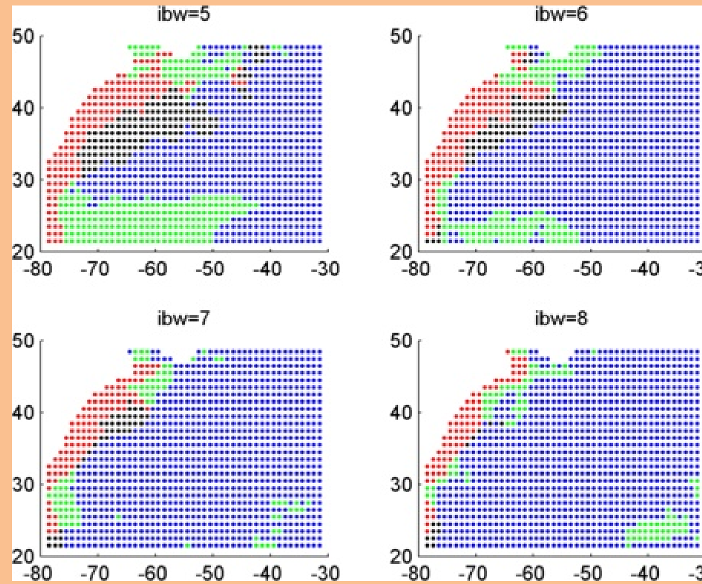
➢ Mid-latitude dynamics persistent; sub-tropics interplay between dynamics and water amount?

*(*still exploring causes)*

ACI_{CRE} 3x3 – Causes?

ACI_{CRE} vs mean(FMF)





- ➢ Influence of fine-mode along coast?

*(*still exploring causes)*

ACI Summary

- Cloud trends suggest *some* Twomey-like agreement
  - weak/no sub-tropic relation
  - cloud trends more extensive than aerosol
- 2/3 observations (4 med LWP bins; [70 130] g/m^2) in domain-wide analysis agree with Twomey theory
  - increasing to higher LWP saturates aerosol influence
- 3x3 spatial analysis reveals interesting behavior:
  - persistent counter Twomey near U.S. coast >> related to FMF?
  - transition counter > Twomey in W sub-tropics
- Other factors that may be at play as well:
  - dynamics
  - cloud/atmosphere water content
  - aerosol composition
  - wrong assumptions
  - bad/non-independent LWP

… meaning the aerosol influence may be more obscured

Wrap-Up and Moving Forward

- Anthropogenic decrease seen in MODIS AOD
- Cloud trends appear plausible with Twomey theory, but closer examination reveals inconsistencies
  - trends too broad for *just* aerosol effects
  - "interesting" coast/sub-tropic behavior
- Expand from "simple" Twomey effect to other ACIs
- Potential influence of changing aerosol make-up
- Needed:
  - independent LWP source
  - accounting for dynamic/environmental factors

Thank you for your attention!
I am happy to take any questions/continue discussion afterward

Aerosol trends paper to be submitted any day now..

Jongeward, A., Li, Z., He, H., and Xiong, X. *Natural and anthropogenic aerosol trends from satellite and surface observations and model simulations over the North Atlantic Ocean from 2002 to 2012*. In preparation for submission to the Journal of Atmospheric Sciences. 2015.

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von Storch and Zwiers. Statistical Analysis in Climate Research. Cambridge University Press. 484 pp. 1999.

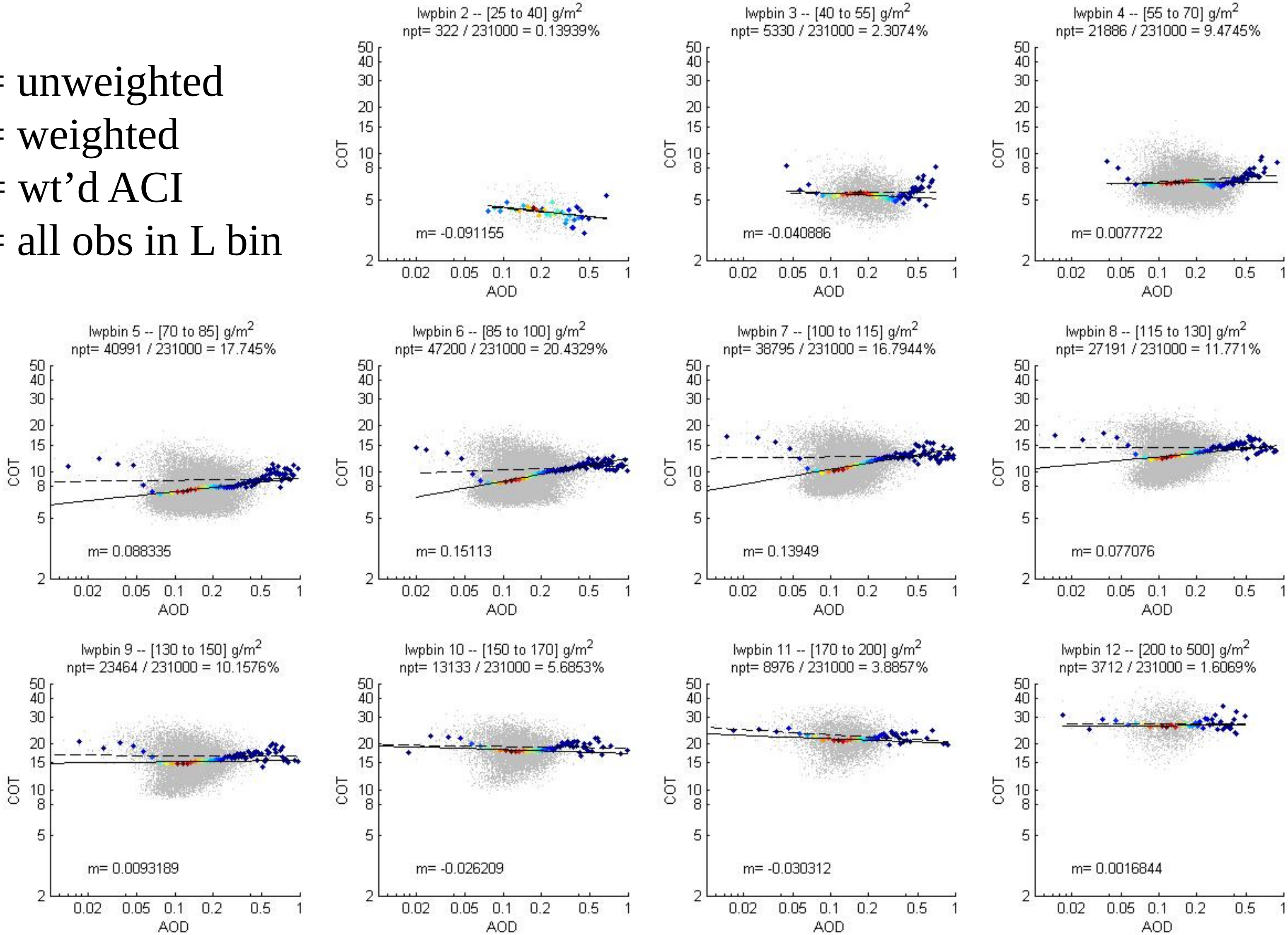
Two ACI_{COT} back-up slides follow

ACI$_{COT}$ Domain-wide

Weighted by N(obs) in bin
Point is (AOD_m,COT_m) in bin

- - - = unweighted
—— = weighted
m = wt'd ACI
● = all obs in L bin

2/3 obs



ACI_{COT} 3x3

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— = 0.00 — = +/- 0.10

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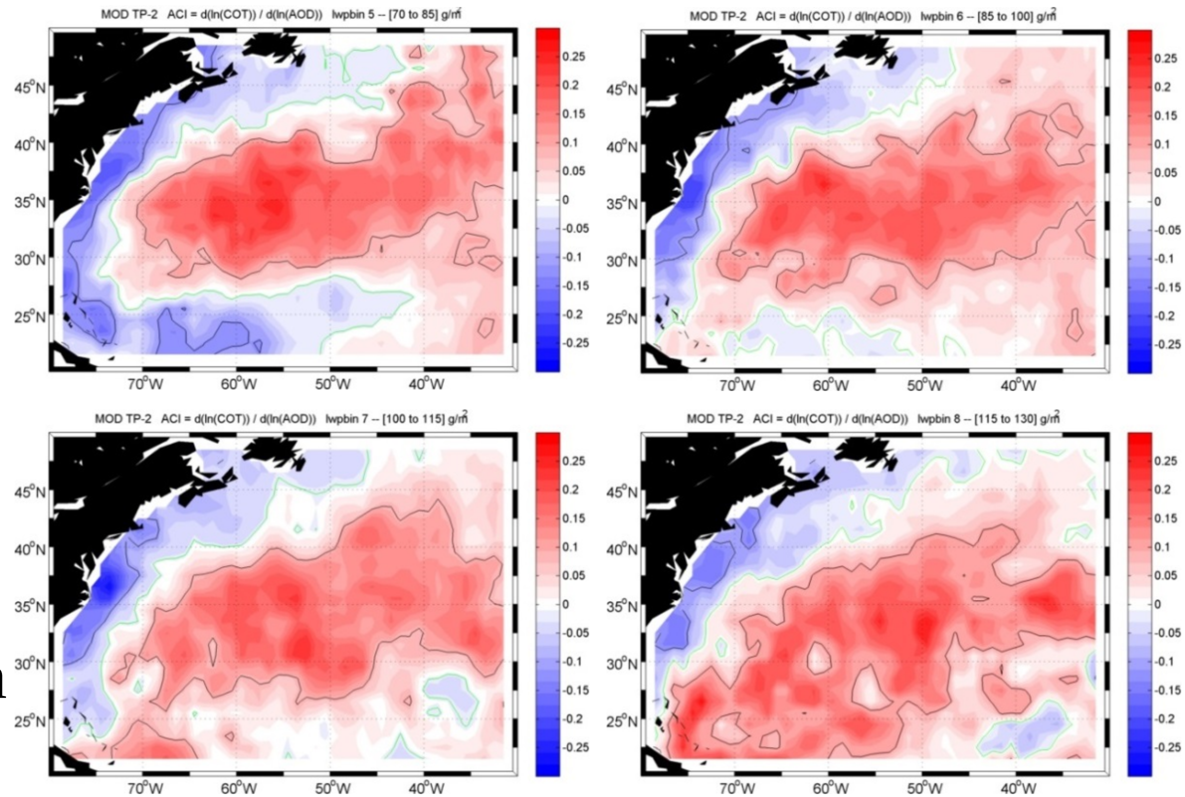

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