Response of Cloud Water Path To Aerosol Loading in Different Aerosol Regimes Over the Atlantic Ocean

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Introduction

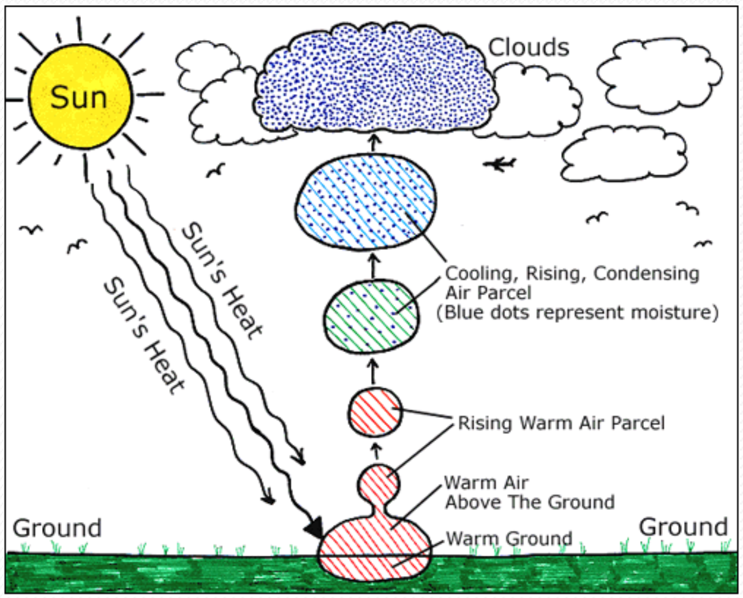
Aerosol-Cloud interaction remains the most uncertain factor in the context of global climate change because the chain of events that link aerosol to the change of cloud proprieties are carried out through processes not quite understood(Breon et al ; Science ,**295**,834-838 ,2002). As consequence various investigators have found positive, negative or no correlation at all between aerosol loading and change in cloud water path.

Objectives

Assess the response of Cloud Liquid Water Path to aerosol induced perturbation
For different aerosol regime using observational data

Why Aerosols are Important ?

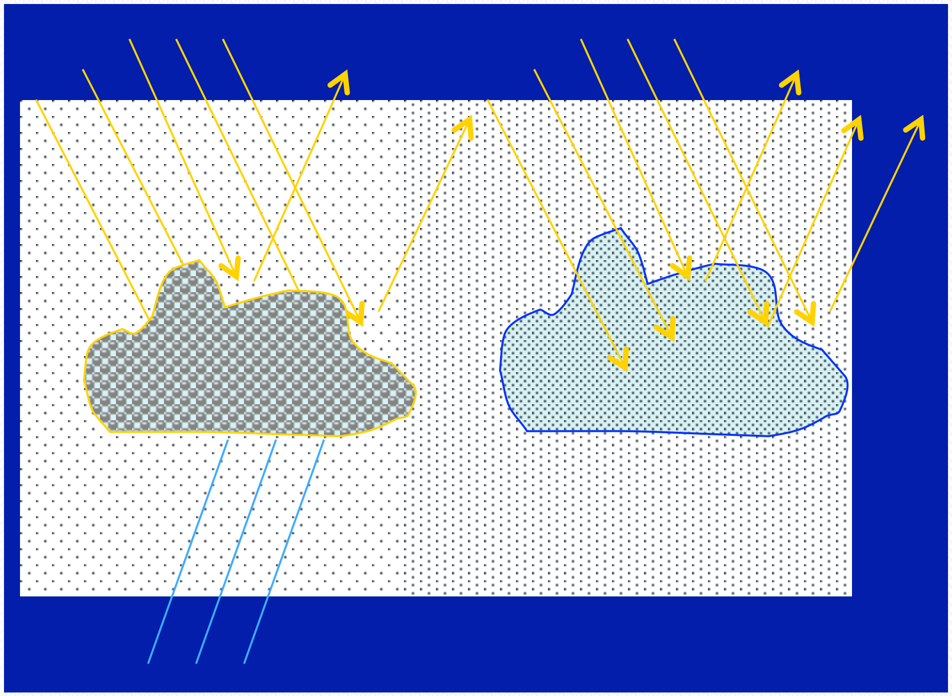
Cloud Formation



Air Parcel Model

Cloud Condensation Nuclei(CCN)
Without aerosol, cloud formation will necessitate a supersaturated environment which can only be achieved in a laboratory conditions

Twomey Effect



•Smaller, numerous droplets
=> greater reflectivity
(Twomey effect)

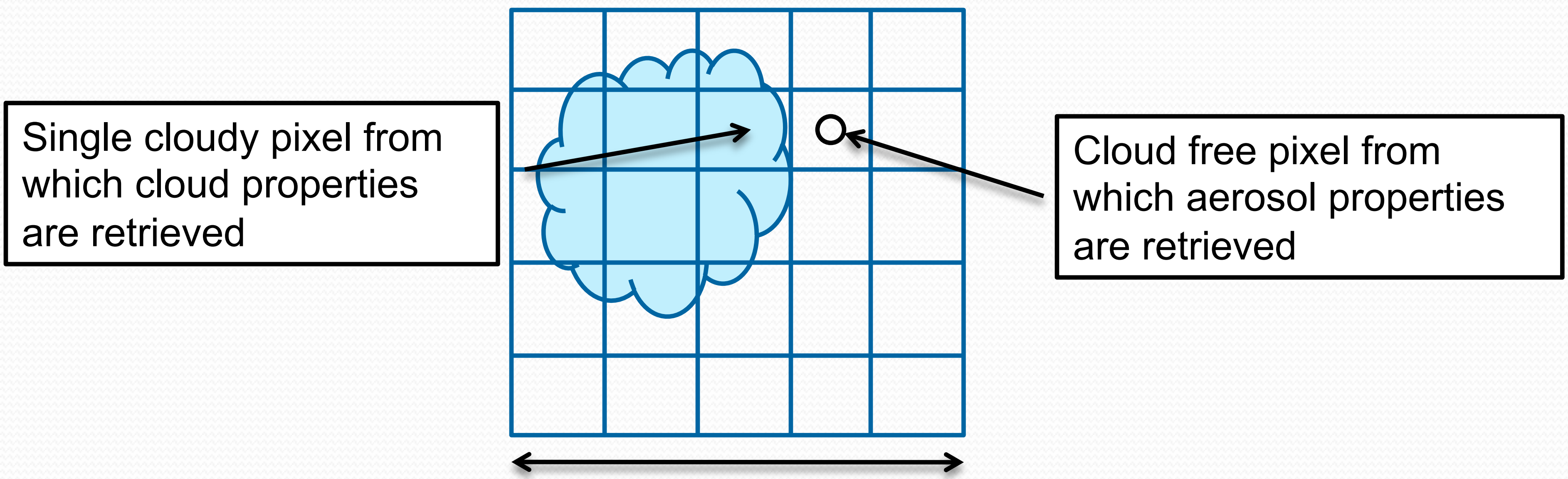
•Smaller droplets
=> lower precipitation
=> longer lifetime

Cooling Effect

Greater reflectivity of clouds produces a cooling effect that is believed to offset out some of the warming induced by anthropogenic green house gases(Ackerman, A. S., Nature, **432,** 1014–1017, 2004)

Data

- **Modis** (Moderate Imaging Spectroradiometer) **Joint Atmospheric Product level 2** retrieved from June through August 2005 between 14:00 and 22:00 GMT on board of Aqua Platform.

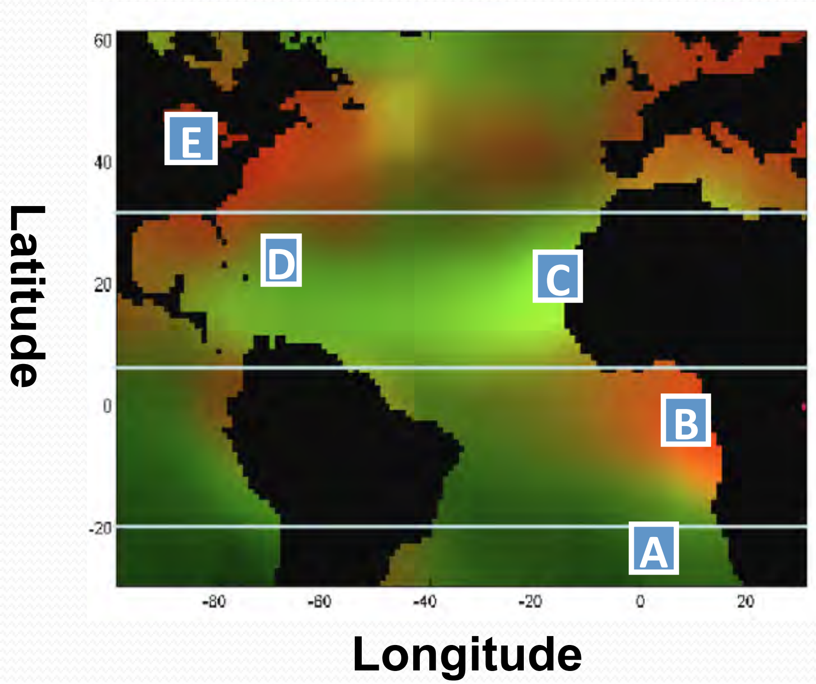


5 km grid box

- The MODIS level 2 joint atmospheric product features 5 km grids for which **Aerosol Optical Depth (AOD)** is calculated from an average of **cloud –free pixels**.

- **A single suitable cloudy pixel** for each grid is chosen for the variables of **Cloud Optical Thickness (COT) and Cloud Effective Radius (CER)**, from which the cloud **Liquid Path (CWP)** is calculated. Spatial Resolution:1Km

Study Area



Red Area :
Dominance by submicron particles
(smoke from central Africa **[B]** and sulfates from Europe and North America**[E]**)

Green Area:
Dominance by dust from Africa **[C],[D]** or sea salt in regions with high winds**[A]**

Latudinal distribution of aerosol type by color over the Atlantic Ocean from MODIS data for June-August 2005.(Credit to Kaufman et al)
Blue rectangles represent the regions of interest.

Methodology

The unique elements of this study are:

1) Data Restrictions

Maximize the amount of data and improve the data quality(Brian Vant-Hull et al 2007)

Cloud Fraction less than 0.6 ;

Cloud Top Temperature above 265 degrees;

Solar Zenith between 30 and 65 degrees(over land); between 35 and 70 degrees(over ocean)

Viewing angle less than 60 degrees.

2) Binning:

The data was sorted into aerosol bins (size 0.05), the Mean CWP(MCWP) corresponding to each bin was calculated and plotted against the bin Mean AOD (MAOD) a proxy for aerosols loading.

Methodology Continued

The magnitude of the hypothetical mechanisms was measured by the change they Produce in liquid water path in terms of aerosol loading

3) Magnitude of hypothetical mechanism producing change in CLWP

a)Assumption: $CLWP = k\ AOD^{n}$

b)Plot lognormal (Mean CLWP) vs. lognormal (Mean AOD)

Calculated **slopes** representing the **magnitudes** of hypothetical mechanisms.

$$\text{Slope} = \frac{\Delta \log(\text{Mean CLWP})}{\Delta \log(\text{Mean AOD})} \qquad \text{(Magnitude of hypothetical mechanisms)}$$

4)The t-test Used to estimate on one hand the degree of the correlation between the mean CWP and mean AOD and on the other hand to compare the regional mean to the mean AOD at the peak.

Results

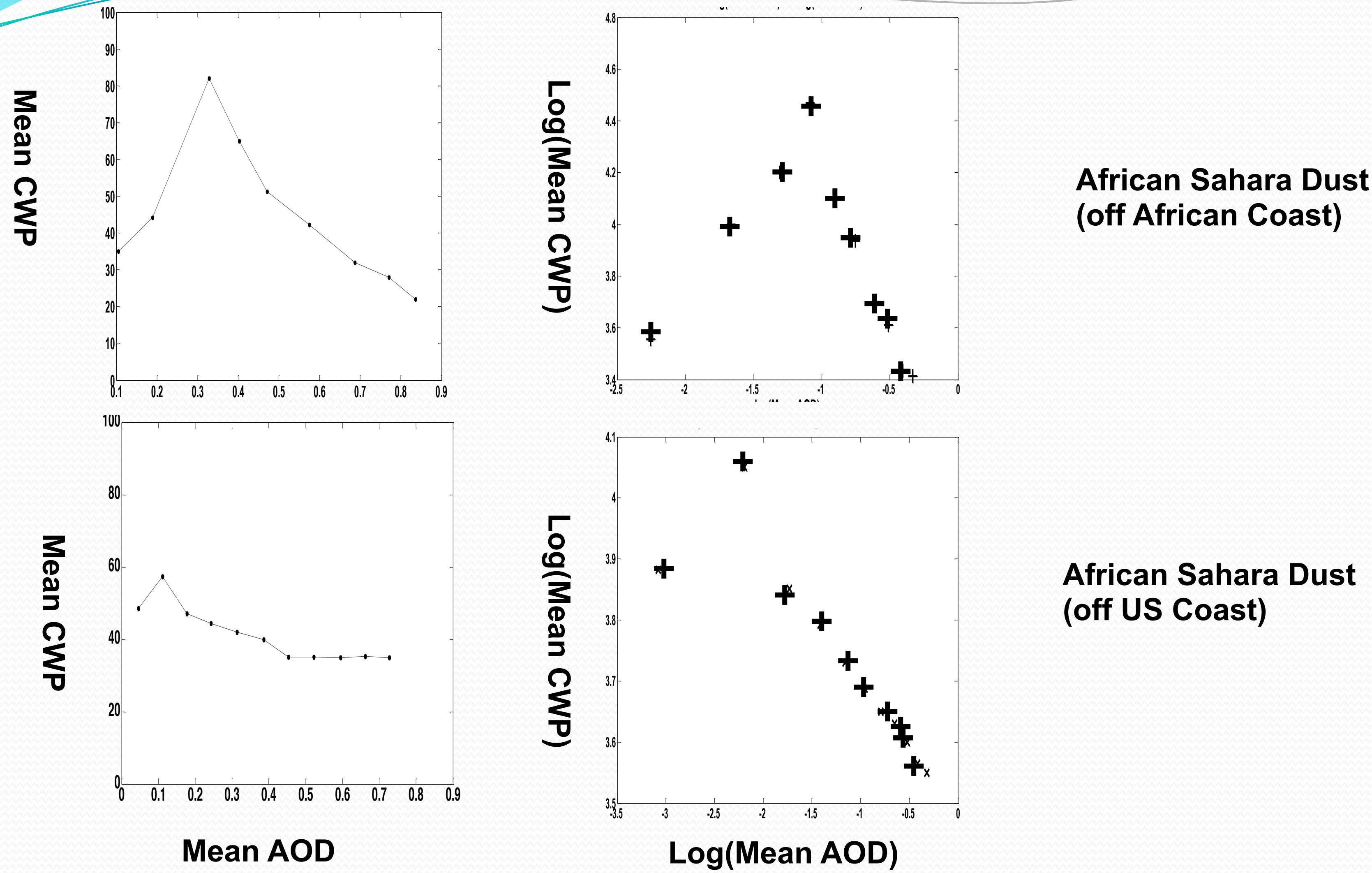
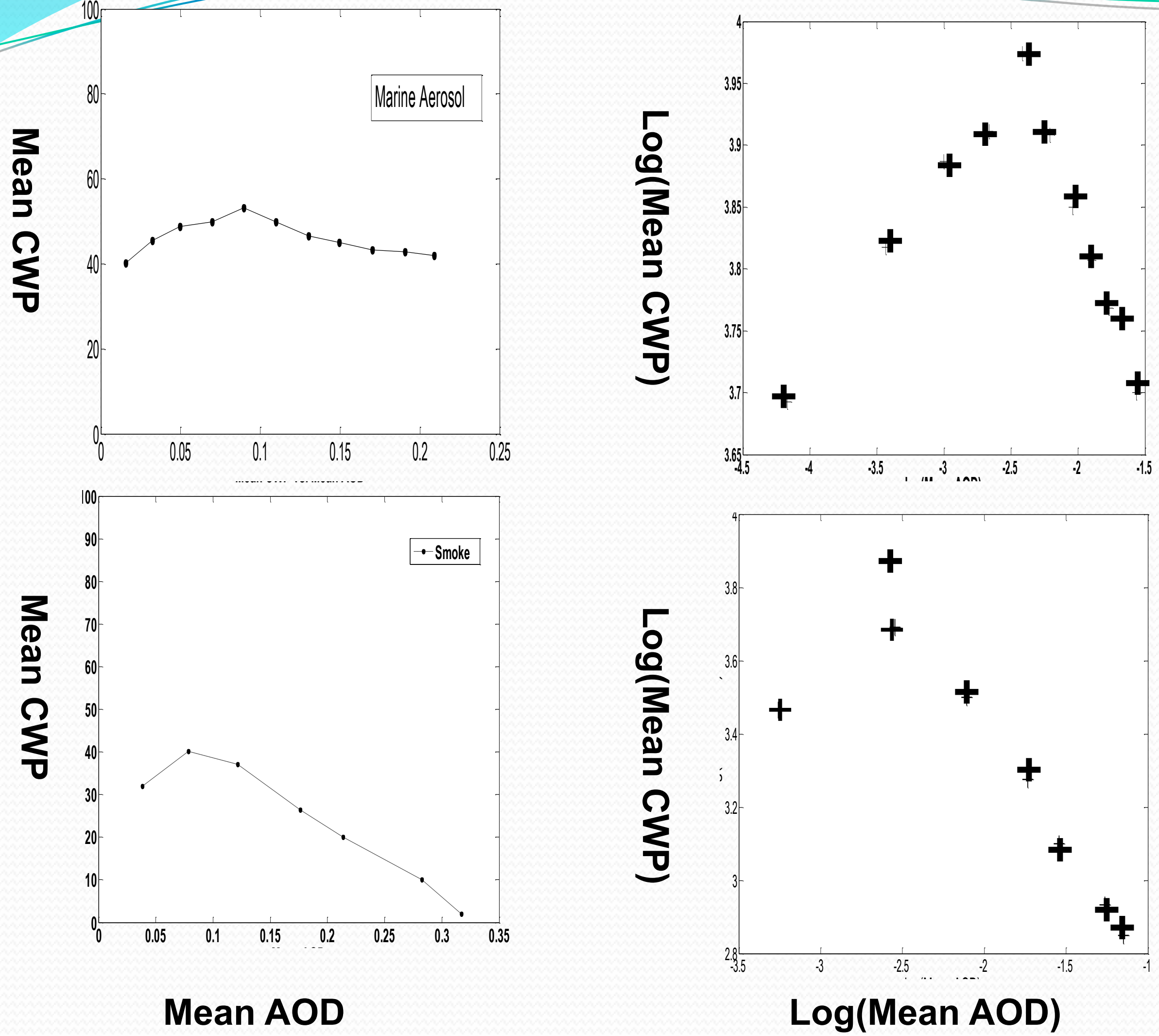


Fig1: Shows respectively, Mean CWP vs. mean AOD (left) and log(mean CWP) vs. log(mean AOD)(right) profiles from which the magnitude of each effect is computed for African Sahara Dust off African and US coasts

Results Continued

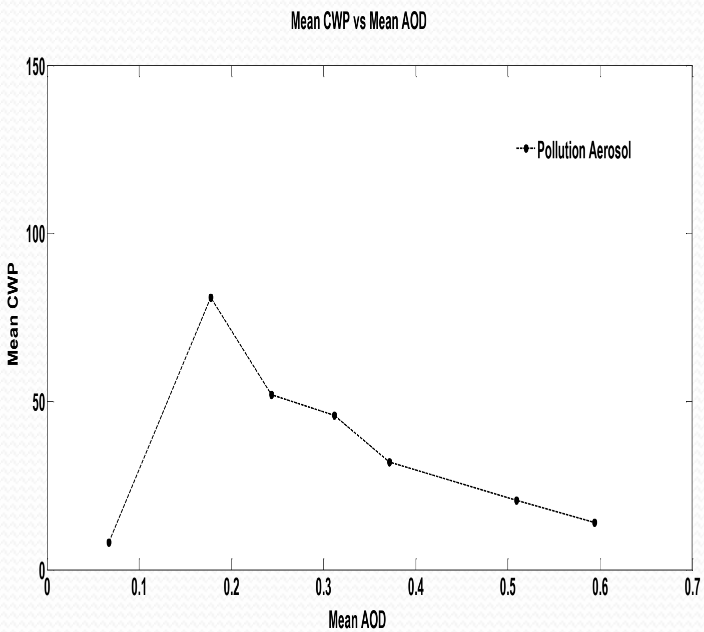


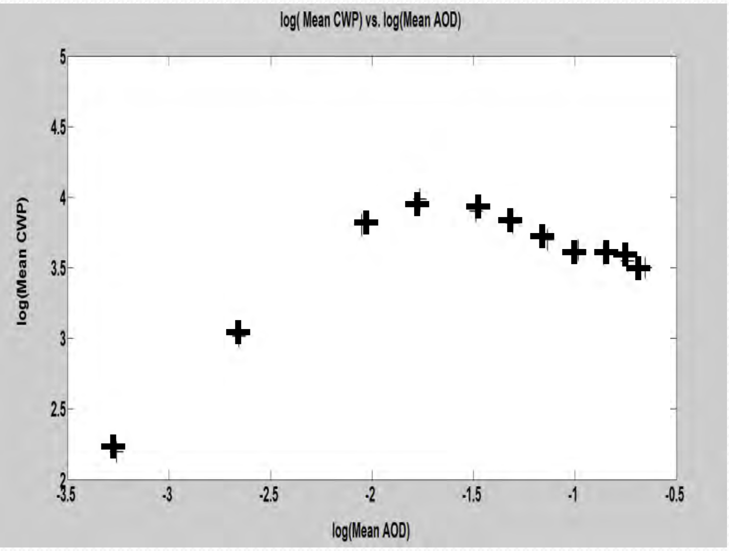
Sea salt

Smoke

Fig2: Shows respectively, Mean CWP vs. mean AOD(left) and log(mean CWP) vs. log(mean AOD)(right) profiles from which the magnitude of each competing effect is computed for sea salt and smoke dominated regions

Results Continued





Sulfates

Fig3: Shows respectively, Mean CWP vs. mean AOD(left) and log(mean CWP) vs. log(mean AOD)(right) profile from which the magnitude of each competing effect is computed for sulfates dominated regions

Theoretical Interpretation/Discussion

The response of CLWP to aerosol loading could be described as the result of **two competing effects** as the aerosol loading increases.

1)First effect resulted in the increase of the cloud liquid water path. It could have been induced by either aerosol or some meteorological conditions; maybe the combination of both. A that stage of the study we could not tell. Moving forward we will simply refer to this effect as **moistening.**

2)Second effect resulted in the reduction of cloud liquid water path. Because we could attribute this effect to either aerosol or to some meteorological conditions, it will be referred to as **drying**.

3) Magnitude of each effect seems to depend in part upon the aerosol regime.

The magnitude of both competing effects **increases** from clean <u>marine environment</u> to <u>dusty environment</u> on the Coast of Africa.

For each aerosol regime the magnitude of **drying** outweights by far that of **moistening** except for the sulfates over land

Summary of the data statistic of the five study regions

	Sulfates	Sea salt	Smoke	Fine Dust (US Coast)	Dust (Africa Coast)
Reg. mean AOD	0.275	0.11	0.175	0.385	0.485
Mean AOD@ peak	0.172	0.089	0.078	0.11	0.33
Standard Dev.	0.164	0.065	0.103	0.228	0.255
Moistening (S_r)	1.20	0.16	0.318	0.190	0.78
Drying (S_d)	-0.159	-0.283	-1.660	-0.272	-2.168
Mean AOD Range	0- 0.6	0-0.25	0-0.35	0-0.9	0-0.9

Focus on Summary Table

Sulfates dominated region of the East coast of the US

Conversely to the case of the ocean, the moistening magnitude (**S_m = 1.196**) of land outweighted by far the drying (**S_d = -0.159**). The study region is near the gulf of Mexico a major source of moisture in the US. Abundant moisture and aerosol coupled with strong convection could partly explain higher moistening rate; far higher than the magnitude observed in any other four regions.

Saharan Dust regions off the coast of Africa

Drying magnitude(**S_d = -2.1677)** much higher than moistening**(S_m = 0.78**). These regions are close to the source , relatively dry and have a high aerosol concentration . High drying rate could possibly be explained in part by the continental dry dust plume flowing offshore .Another possible, dust aerosols can absorb solar radiation , heat the atmosphere and increase the evaporation rate hence inhibit cloud formation.

smoke region

In this region, a remarkable fact is the high drying magnitude**(S_d = -1.660)** which not only exceeded by far the moistening (**S_m = 0.318**), it appeared to be comparable with highest drying (S_d = -2.168) observed in dusty region off the coast of Africa. This observation is consistent with the conventional wisdom. An increase in absorbing aerosols(smoke) heats up the atmosphere and increases cloud evaporation rate or absorbing aerosol can reduce surface evaporation by reducing energy that feed the convection

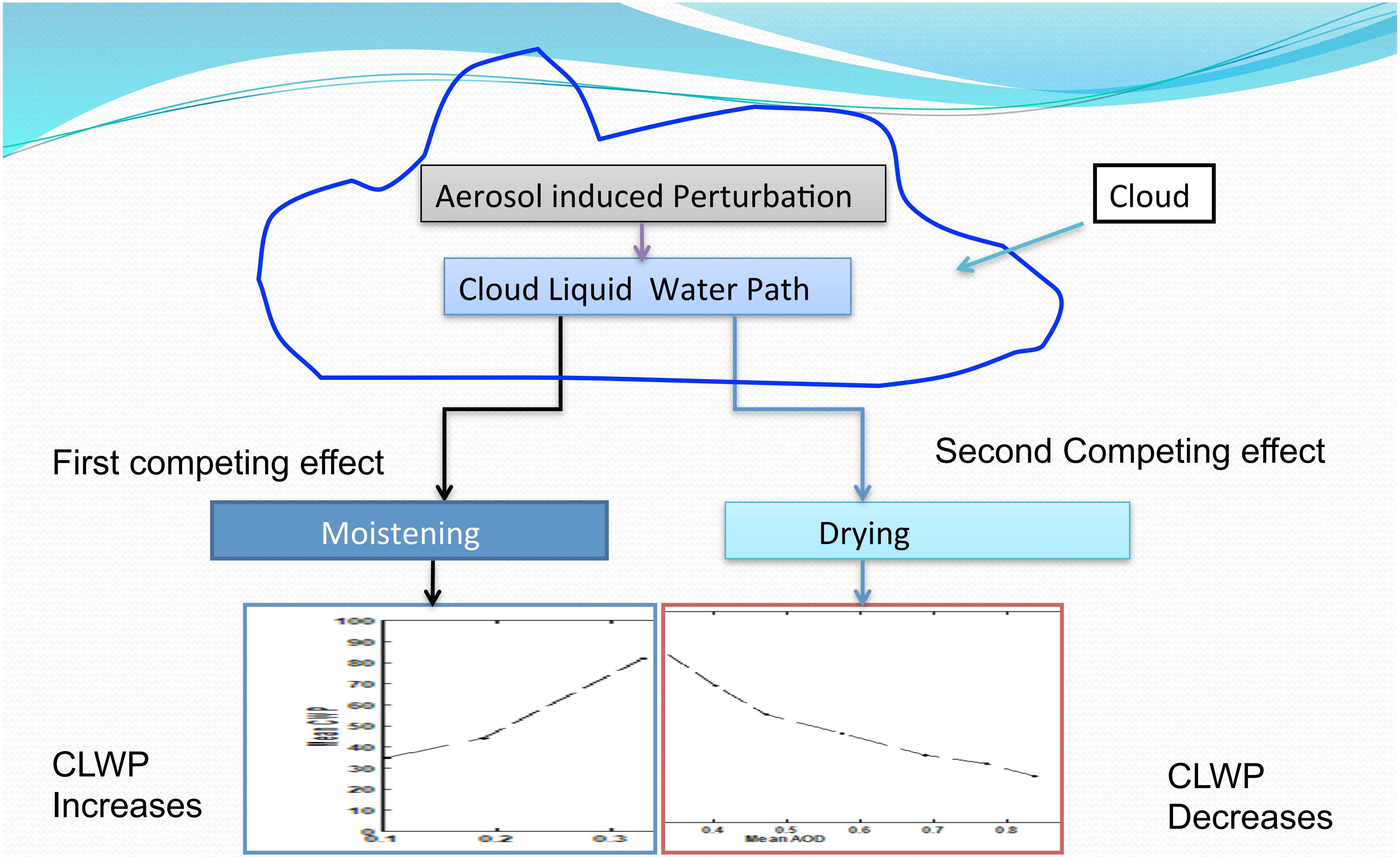
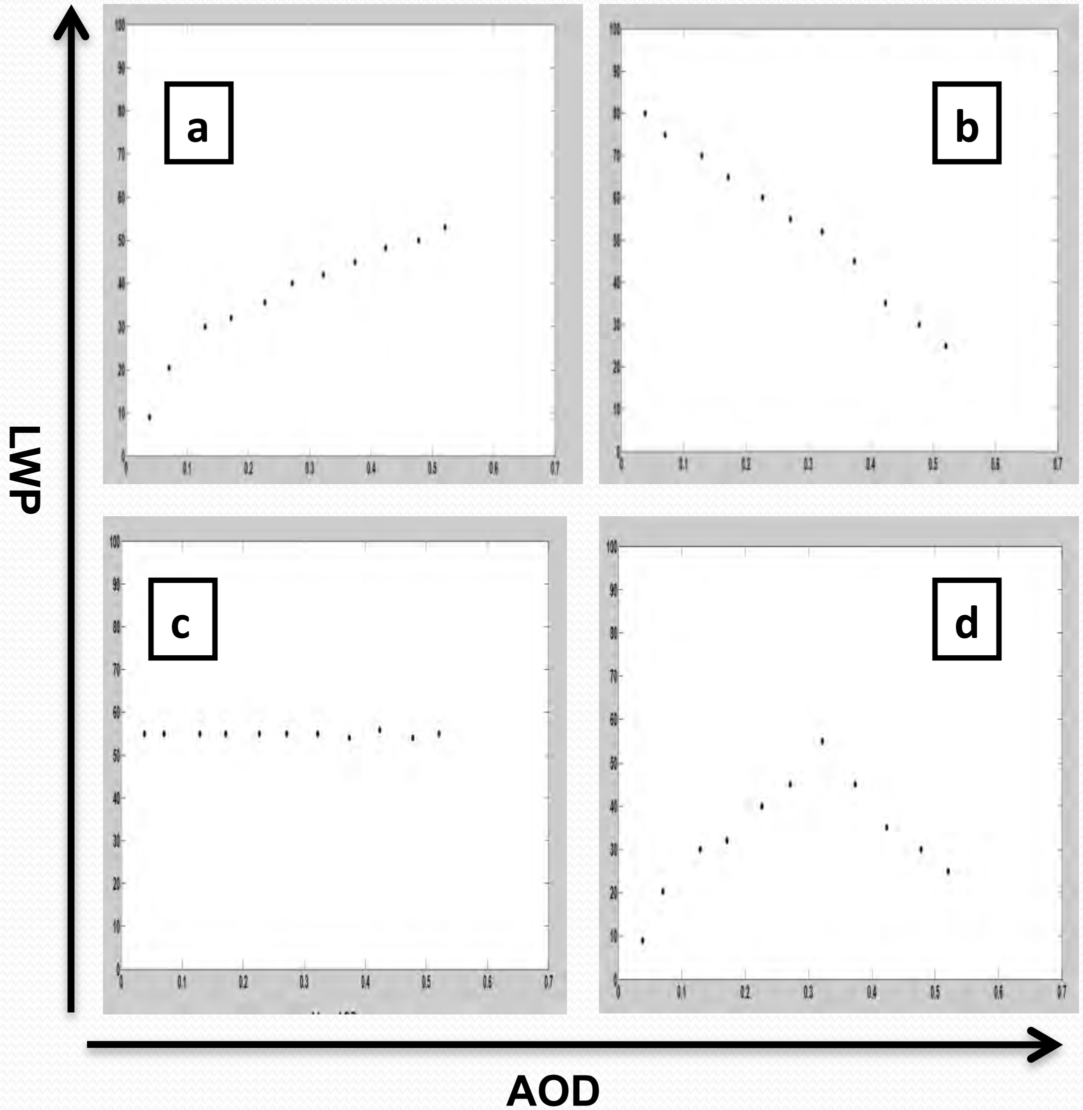


Figure 4: Illustration of CLWP response to Aerosol induced perturbation

Possible Outcomes of Cloud Path Water Responses to Aerosol Induced Perturbation



Dominance of **moistening over the entire range** and cloud liquid water path increases continuously(**a**)

Dominance of **drying over the entire range** and LWP decreases continuously(**b**)

No one effect is prevailing over the entire range; no change in LWP as aerosol loading increases(**c**)

Existence of a peak where each effect has its AOD's interval of dominance on each side the peak(**d**)

Previous Works vs. our Results

The focus here is the statistical approach used to assess the correlation between Cloud propriety and aerosol loading

T. Storelvmo et al.: Aerosol-cloud Interactions in MODIS and CAM-Oslo(2006)

(Previous work)

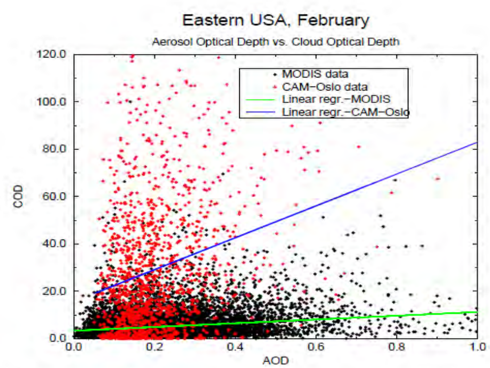
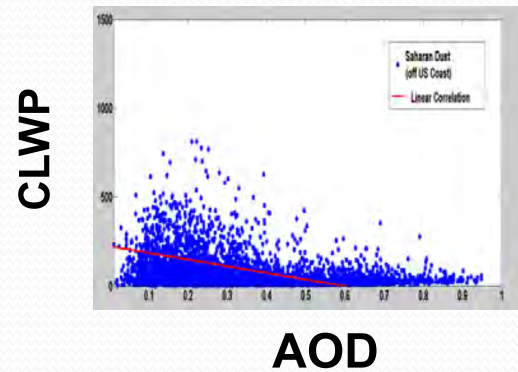


Fig. 4. Liquid Cloud Optical Depth as a function of Aerosol Optical Depth for Eastern USA in February for both MODIS and CAM-Oslo data.

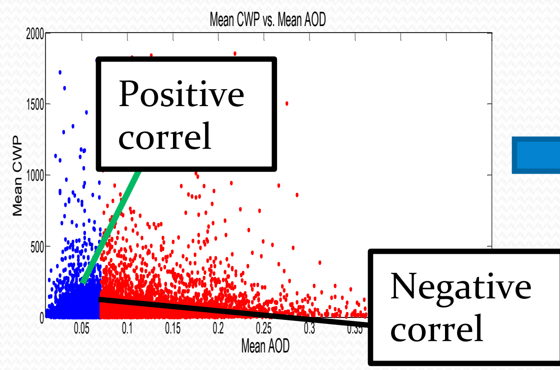
Figure 5

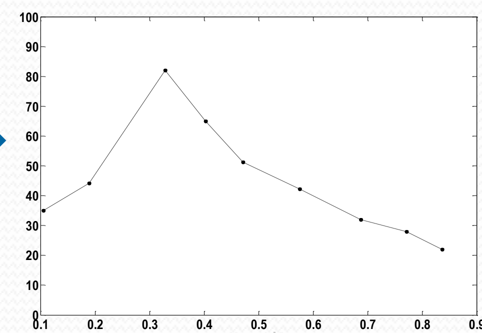


Our work

Figure 6 *shows a negative correlation between CLWP and AOD using the same statistical method as in* ***Figure 5***

Our Work





Our work

Figure 7 *shows a positive(blue) and a negative(red) correlation between CLWP and AOD*

Figure 8 *show that both tendencies coexist on either side of the peak after binning*

Summary

- Past researchers exhibit contradictory AOD vs. CLWP responses
- May be due to using linear fit to non-monotonic data
- Our method sorts data into aerosol bins
- Calculate the bin mean AOD and Mean CWP corresponding to each bin
- Plot mean CWP against the bin Mean AOD a proxy for aerosols loading.
- AOD vs. CLWP response is a combination of two opposite monotonic sub-response over two adjacent AOD interval of prevalence for either behavior of CLWP

Future Work

We will be using Lower Tropospheric Static Stability parameters and Modis Aerosol characterization to try understand mechanisms behind CLWP response

Acknowledgment

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Thank You