Determining Aerosol Indirect Effects from Satellite Data

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Outline

Aerosol – cloud interactions are difficult to study for a *variety of reasons*.

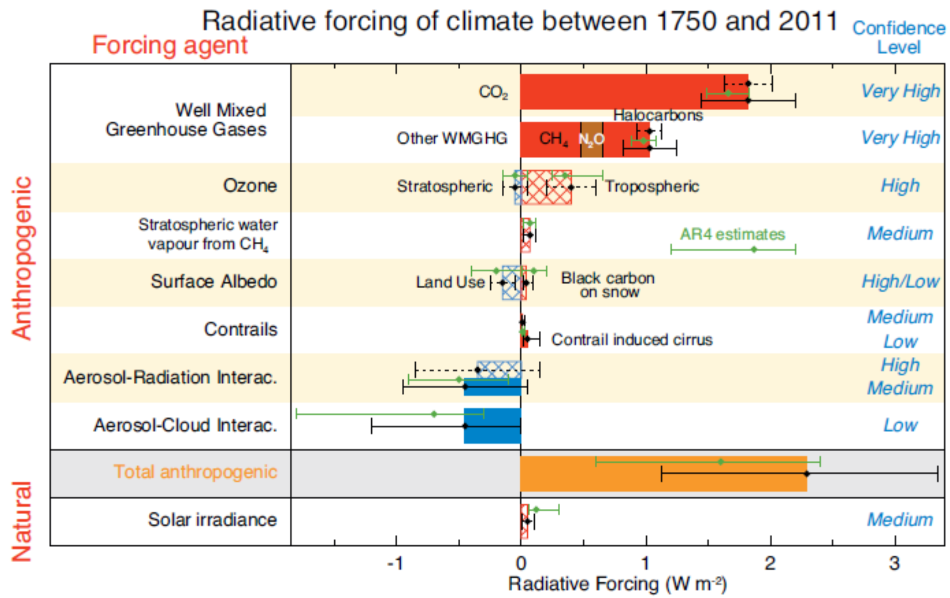
Will address this *theme* by way of a *specific calculation*

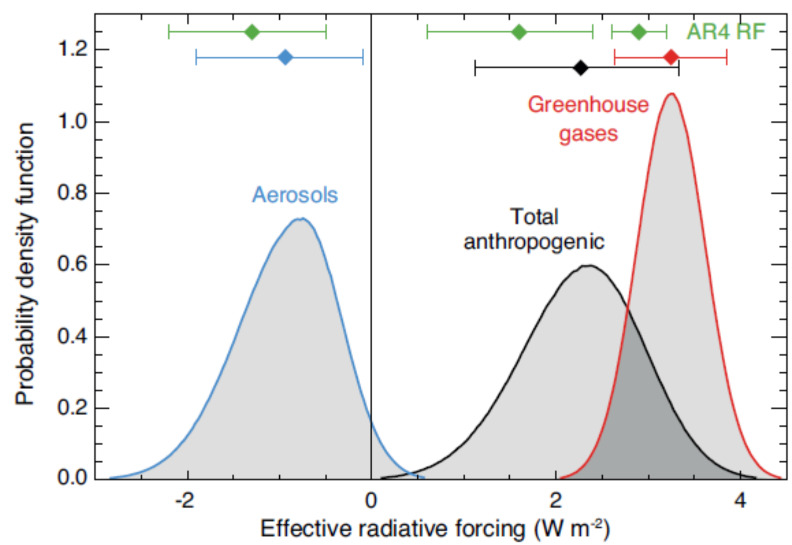
Changes in deep convective *cloud structure* in the tropics due to changes in aerosol

Why is there such a variety of results?

Radiative Forcing - Uncertainty

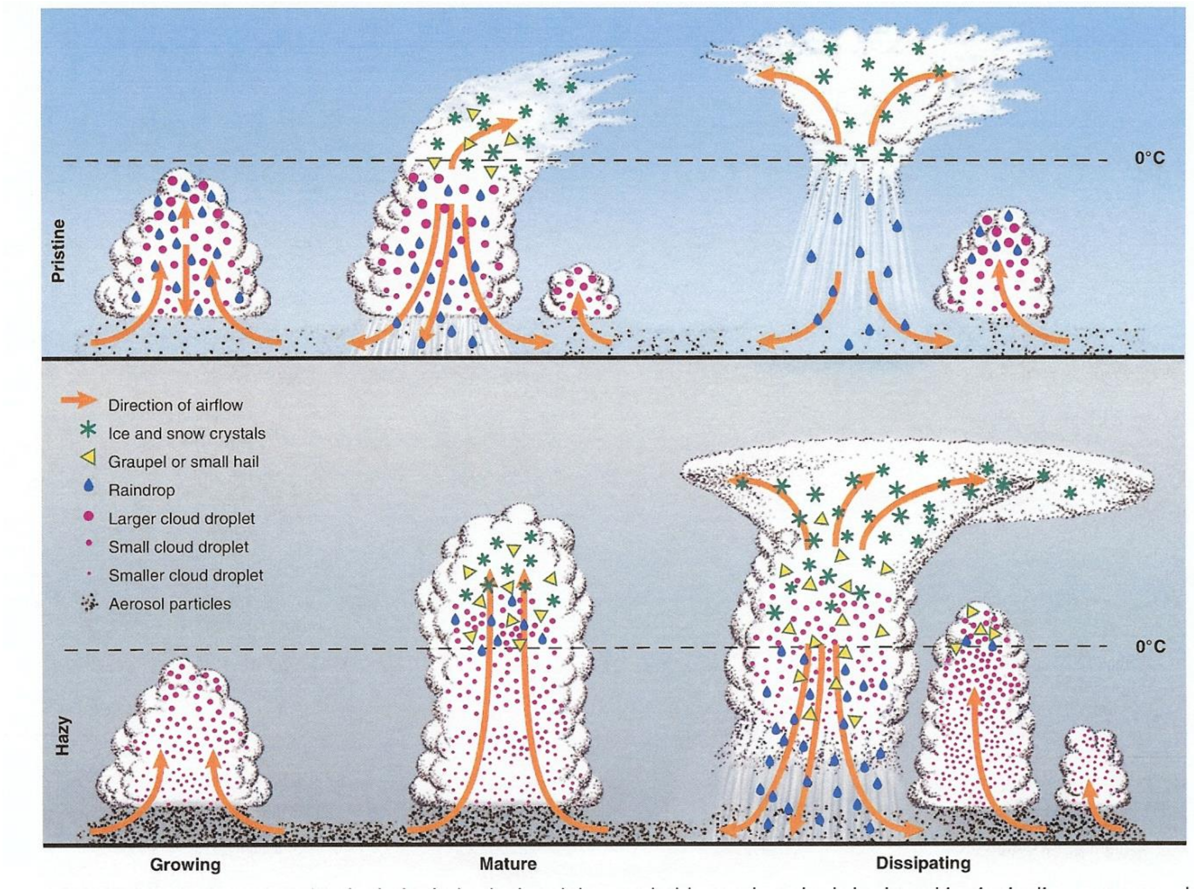
IPCC WG1 AR5-TS





Aerosol-Cloud Interactions: Low Confidence Level

Cloud Invigoration



More CCN changes liquid droplet, ice, and latent heat release profiles

Rosenfeld et al. (Science, 2008)

Conclusions of Different *Signed* Outcomes

Koren et al (2010): MODIS aerosol and cloud top pressure data for the equatorial Atlantic, July – August 2007

Cloud top heights *increased* as AODs *increased*

Wall, Zipser, Liu (2014): *14 years* of TRMM reflectivity and MODIS Aerosol-index (i.e. AOD x Ängstrom exponent) data

Echo-top heights *decreased* as the aerosol index *increased* over the equatorial Atlantic

<u>Calculations</u>

Calculate changes in *<u>cloud structure</u>* (Ice Water Content, IWC)

Regional basis (12 Tropical regions)

Each Season, 2007 - 2010

Use MODIS Aerosol Optical Depths (AODs)

***Proxy* for Cloud Condensation Nuclei (CCN)**

Look at Deep Convection, 5 – 15 km altitude range

Bin IWC average profiles (*Altitude*, AOD, Season, Region)

Also calculate the *<u>Shapes</u>* of the IWC average profiles

Normalize to unity at 5 km

Calculate 100 (d IWC / d AOD)/ IWC *derivatives*

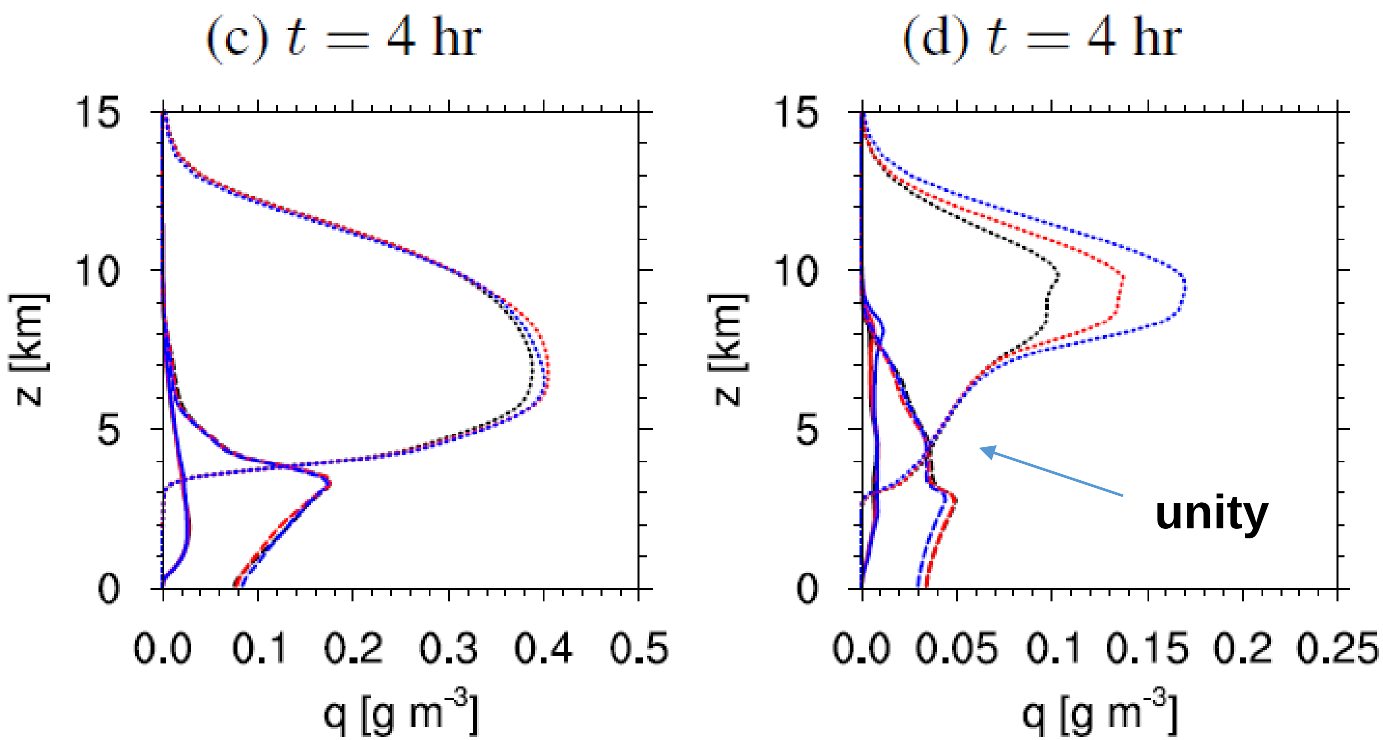
% change / 0.1 AOD units

Aggregate regional calculations into Land only, Ocean only, and Tropical averages

Profiles of derivatives (2 km vertical steps)

Motivation for *Shape* Normalization

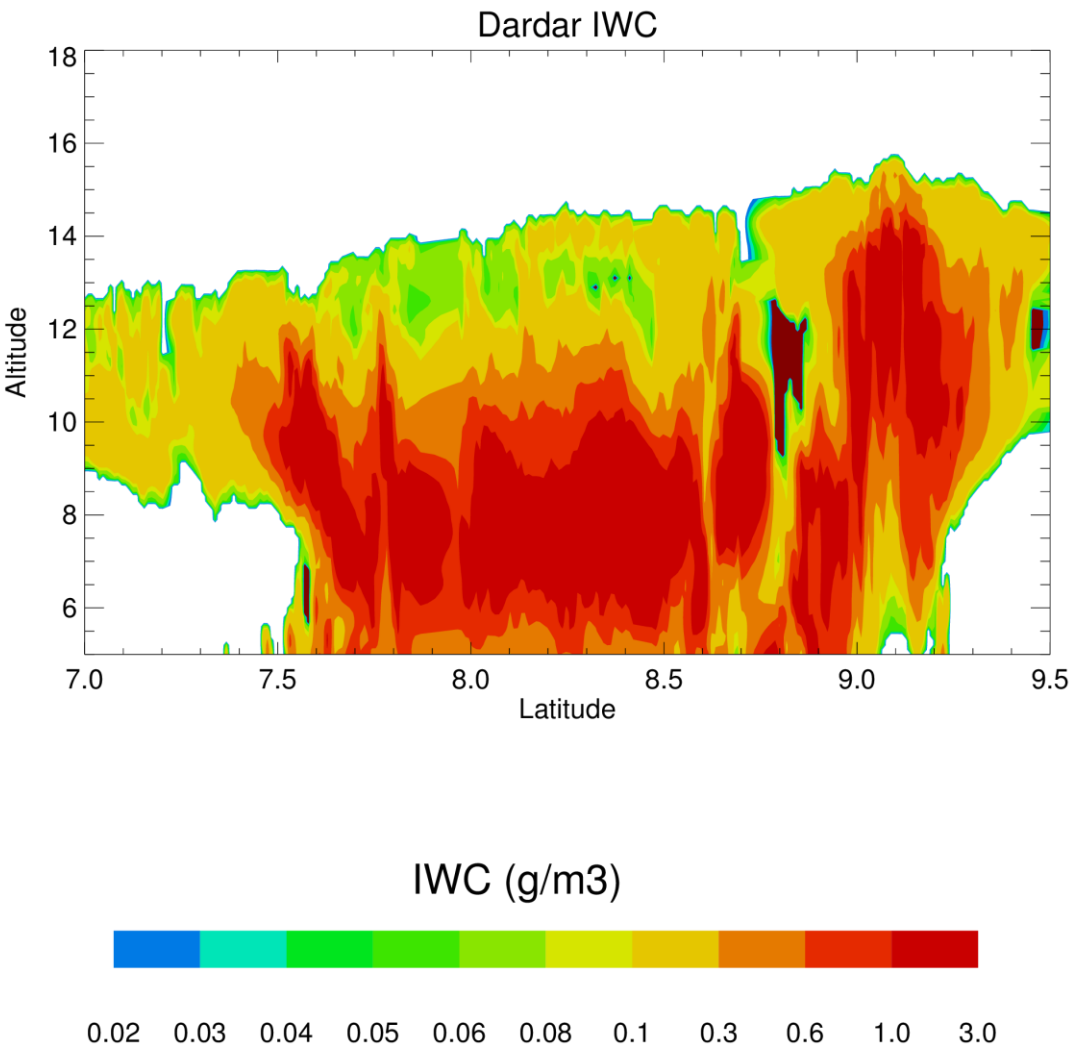
Bulk Microphysics **Bin microphysics**



ICE - - - Polluted - - - Semi–Polluted - - - Clean

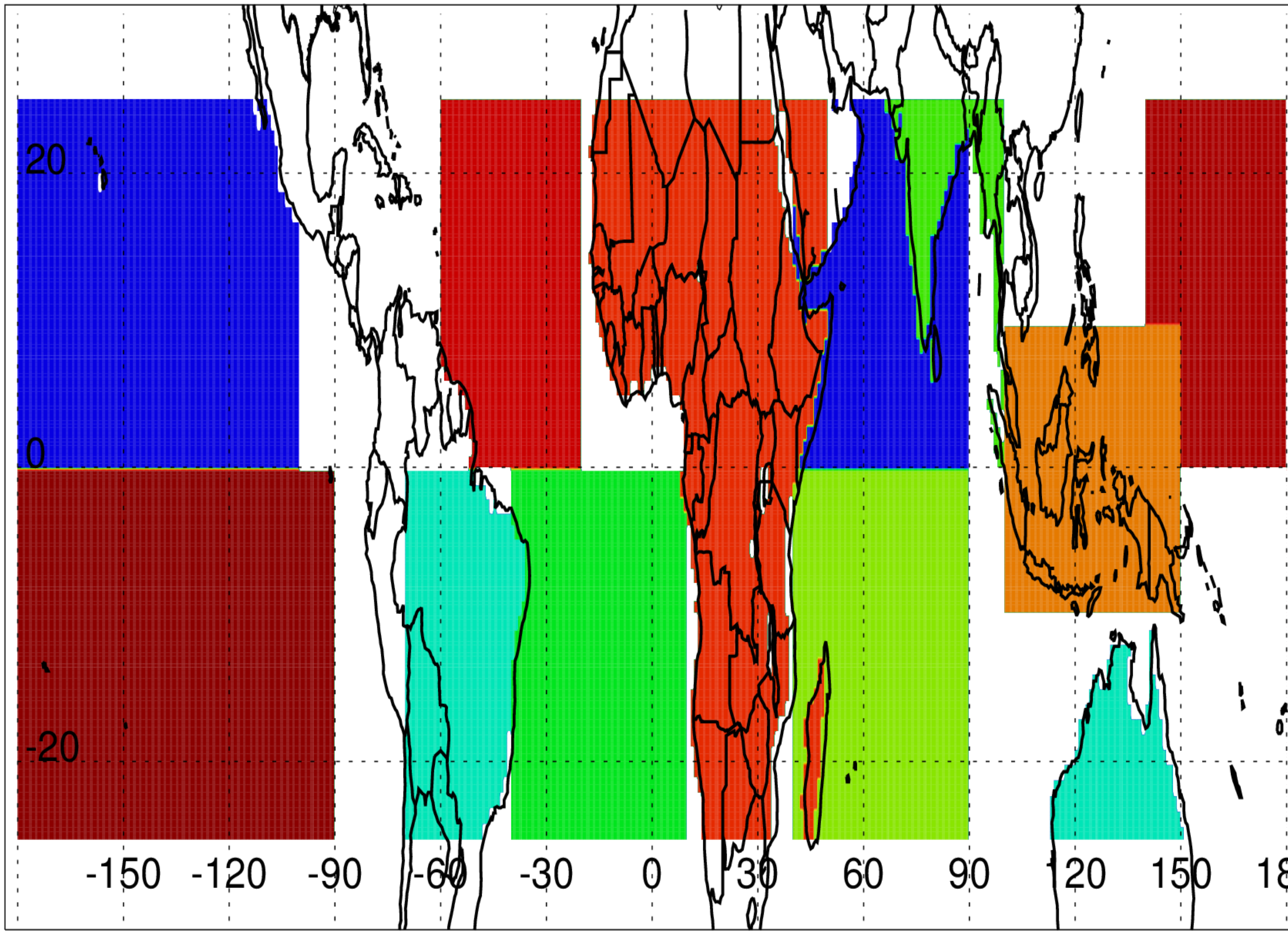
Lebo and Seinfeld, ACP, 2011

A 2D slice samples a *portion* of the 3D cloud field

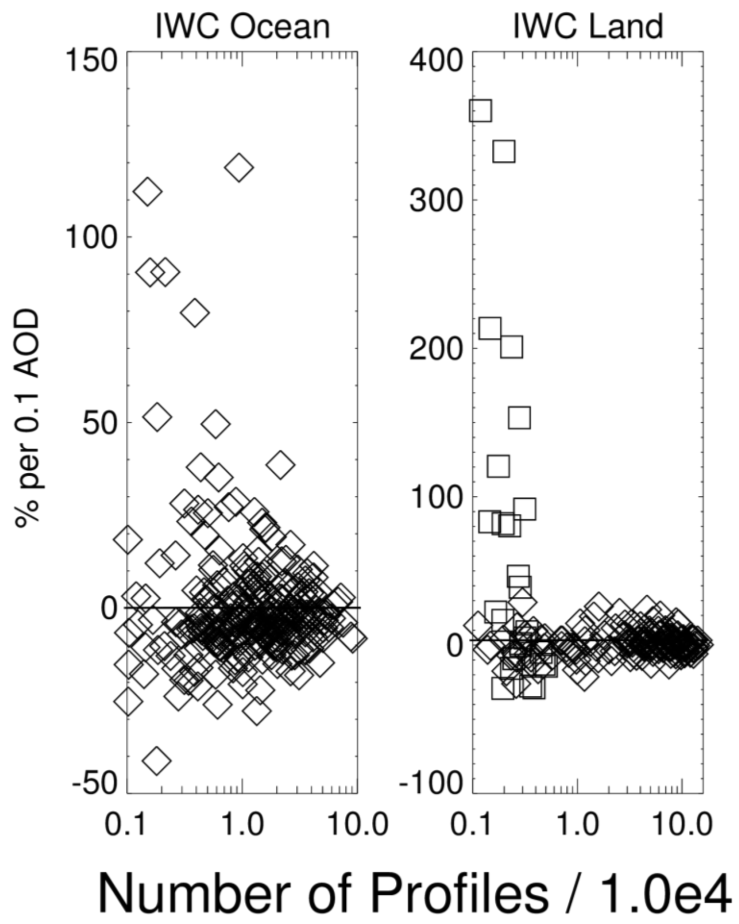


July 10, 2010 Example

Geographical Regions

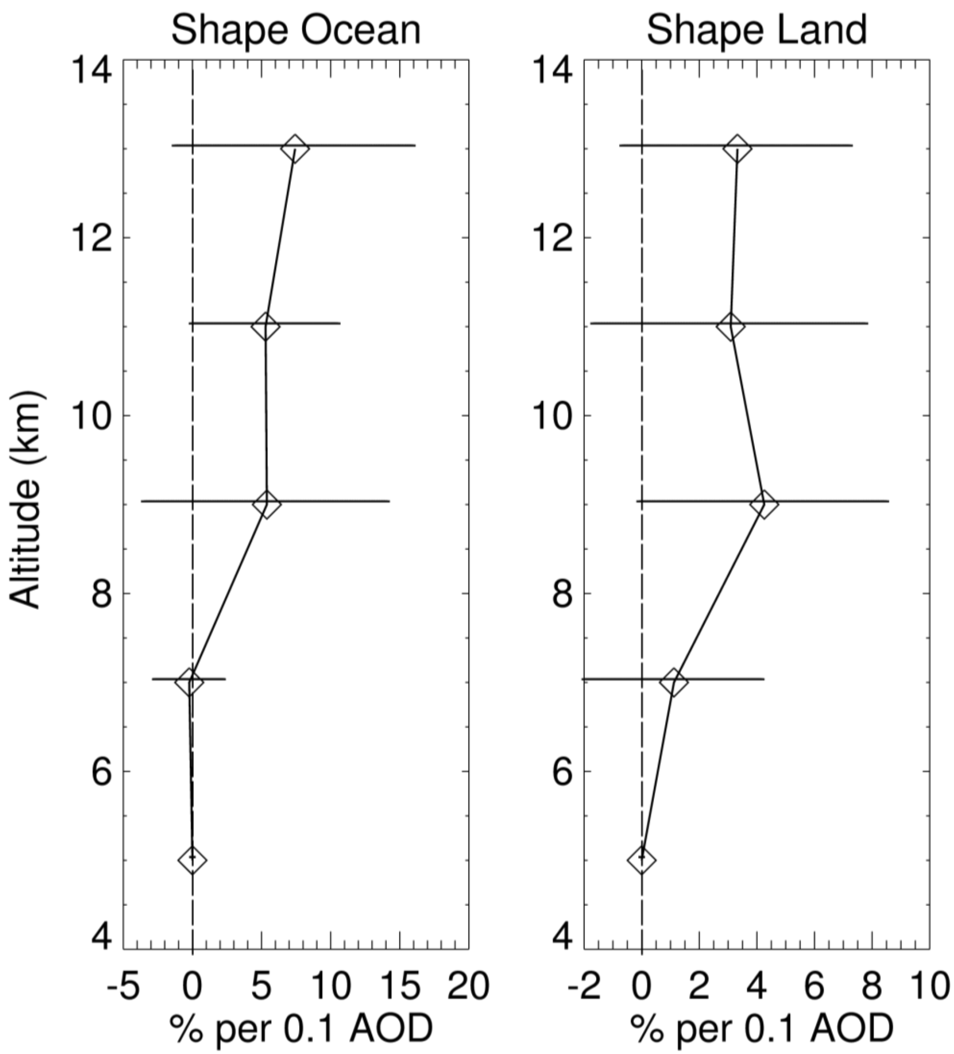


Derivatives are Positive and Negative



Derivatives are for the 5 to 15 km altitude range
Most of the largest derivatives are over India (□ symbols)

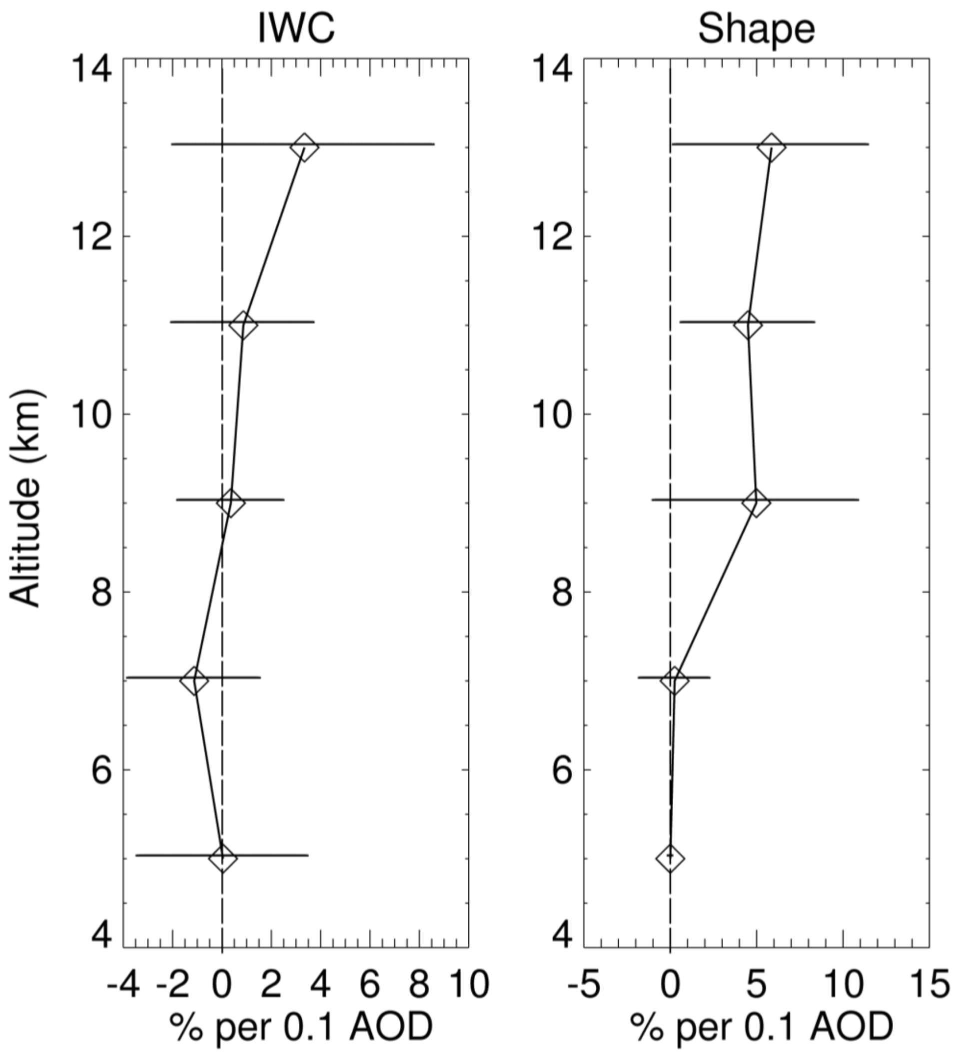
***Shape* Derivatives over Ocean and Land**



2 σ error bar

Exclude India

Tropical Averages

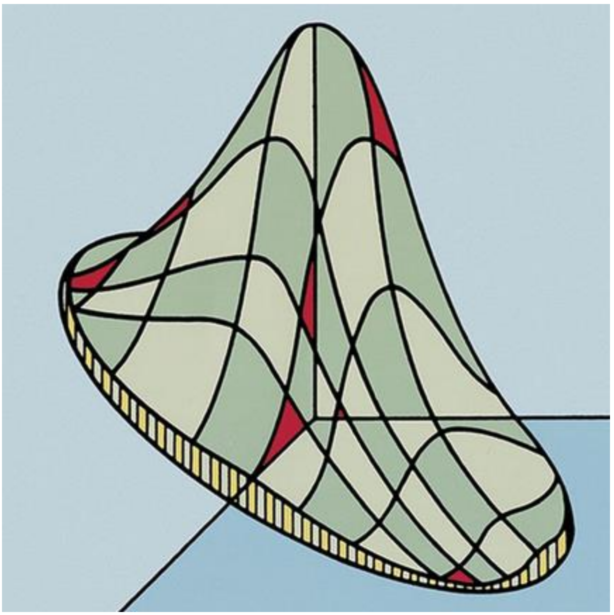


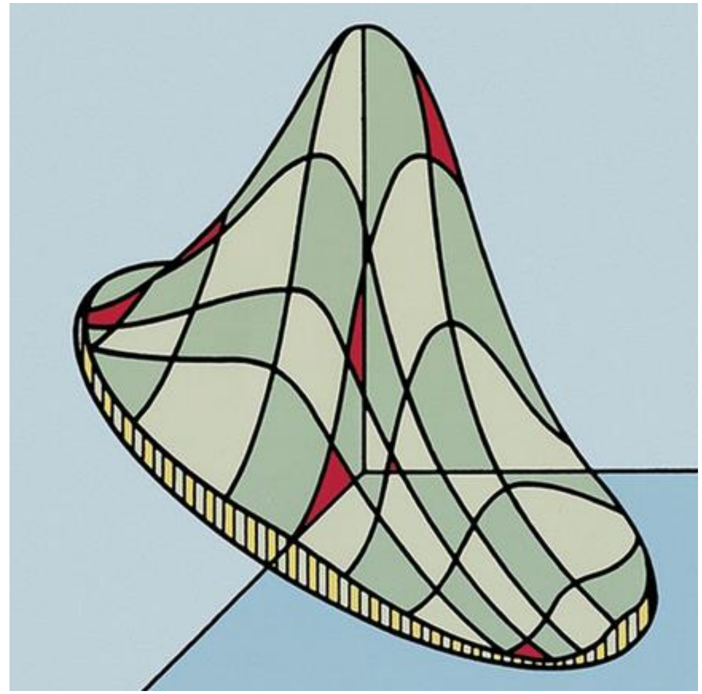
5%

Not significant **Significant (2σ)**

Microphysics – Cloud Dynamics – Time

Time →





Microphysics
AOD

E. S Keeping
Intro to Statistical Inference

Dynamics
RH – Relative Humidity

∂ IWC / ∂ AOD $_{\text{RH=const}}$

but ∂ IWC / ∂ RH and
∂ IWC / ∂ t $\neq 0$

Important life-cycle presentation by R. Fu and Sudip Chakraborty

<u>Condensate Loading Term</u>

***Lebo and Seinfeld* (2011): "The aerosol-induced effect is controlled by the balance between latent heating and the increase in condensed water aloft, each having opposing effects on buoyancy."**

Buoyancy = g [$(\theta^* / \theta_a) + (\kappa-1)(p^* / p_a) - q_H$] **Houze (2014)**

θ virtual potential temperature
a ambient value
*** perturbed value of a parcel**
q_H <u>condensate loading</u> due to liquid water and ice

Need to consider *changes in the opposing terms*

$(\theta^* / \theta_a) + (\kappa-1)(p^* / p_a)$ due to *latent heat release*

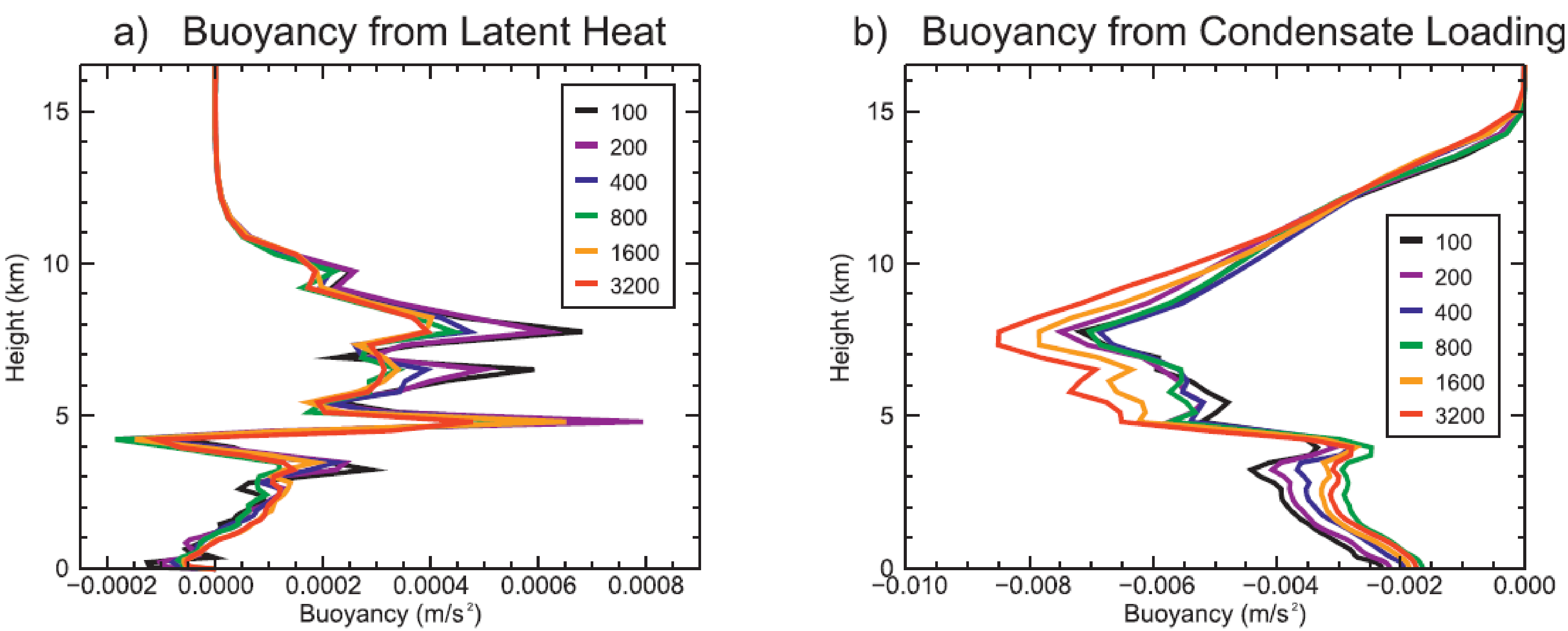
q_H due to *condensate loading*

<u>Condensate Loading Term</u>

Storer and Van Den Heever: JAS, v 70, p 430, 2013.
Cloud resolving model study of aerosol - deep convective cloud development

Figure 8 curves are for different aerosol concentrations (# / cm^3)

"Changes in *latent heating* were, on average, an <u>order of magnitude smaller</u> than those in the *condensate loading* term"



0.0008 **-0.008 m/s^2**

Conclusions

The *variance* of the *derivatives* is dependent upon the *number of profiles* used in *regional* calculations

For the specific case of *equatorial deep convection:*

∂ IWC / ∂ AOD average derivatives are *very small* if you average over 4 years time.

∂ IWC / ∂ AOD *shape* derivatives are *statistically significant* (%5 , 11 – 13 km)

There are a *variety of results* in the literature since:

a) Aerosol-cloud interactions (for deep convective clouds) are *fairly small* (the *condensate loading term* needs greater attention)

b) *Equal consideration* (and *adequate sampling*) of *microphysical* and *cloud dynamic* variables is needed

c) The *time* coordinate is important, while many of our experiments are locked into the A-train 1:30 am / pm fixed time