Constraining Indirect Effects on the Process Level

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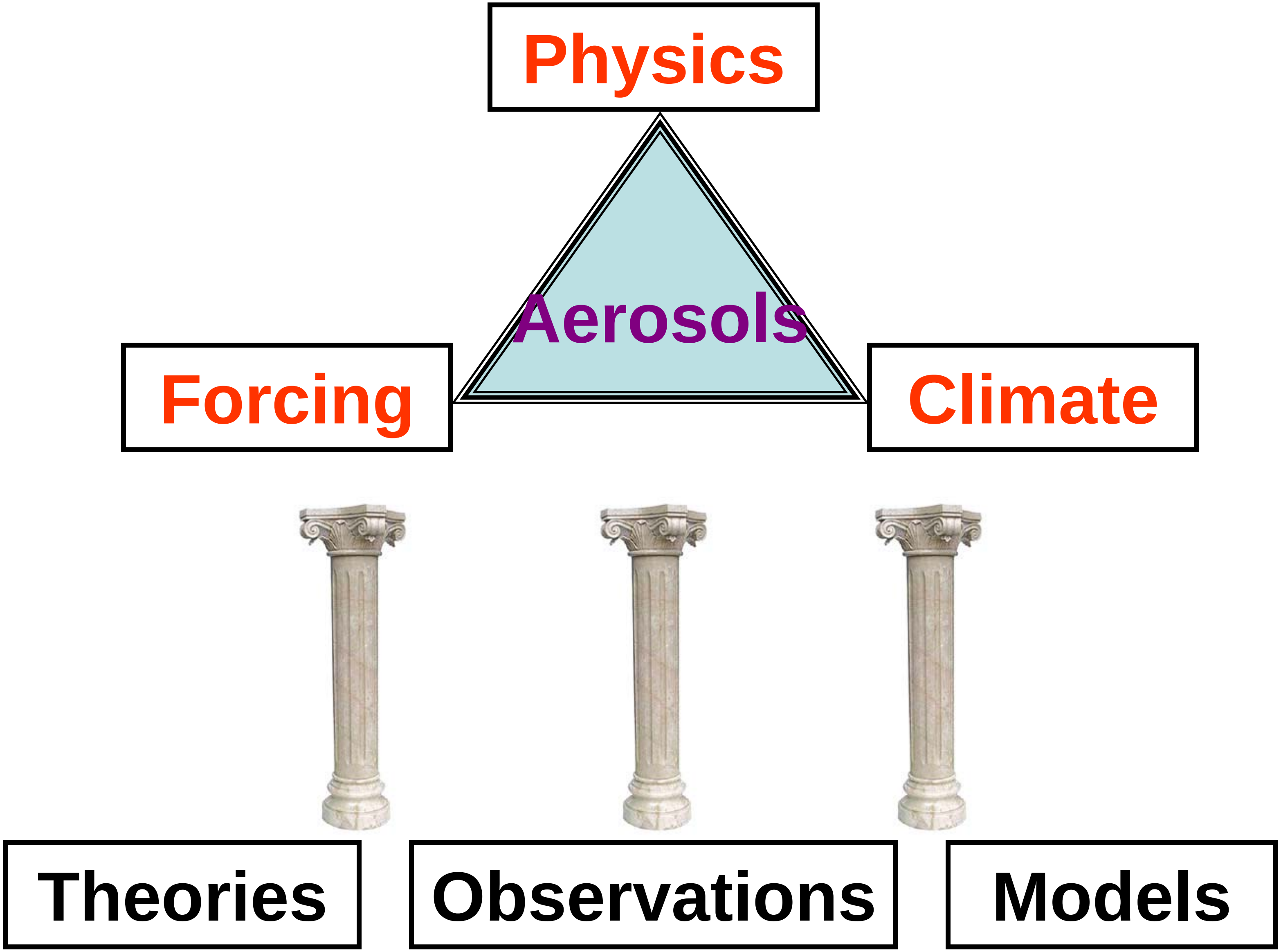
On the eve of a Nobel cause's V quest, a mysterious code offers a glimpse into the long road ahead . . .

Outline


Physics
Aerosols
Forcing
Climate
Theories
Observations
Models

Model physics and chemistry in the GFDL AM3 Model (to be used for AR5)

- **Aerosol-Liquid Cloud Interactions**

A prognostic scheme of cloud droplet number concentration (Ming et al., 2007) with an explicit treatment of aerosol activation at cloud base (Ming et al., 2006).

- **Convection Parameterization**

Move from the relaxed Arakawa-Schubert (RAS) in AM2 to the Donner deep convection scheme (Donner, 1993) and the University of Washington (UW) shallow convection scheme (Bretherton et al., 2003). By providing in-plume updraft velocity, the latter two are ideal for implementing aerosol/cloud microphysics.

- **Online aerosol transport and tropospheric and stratospheric chemistry**

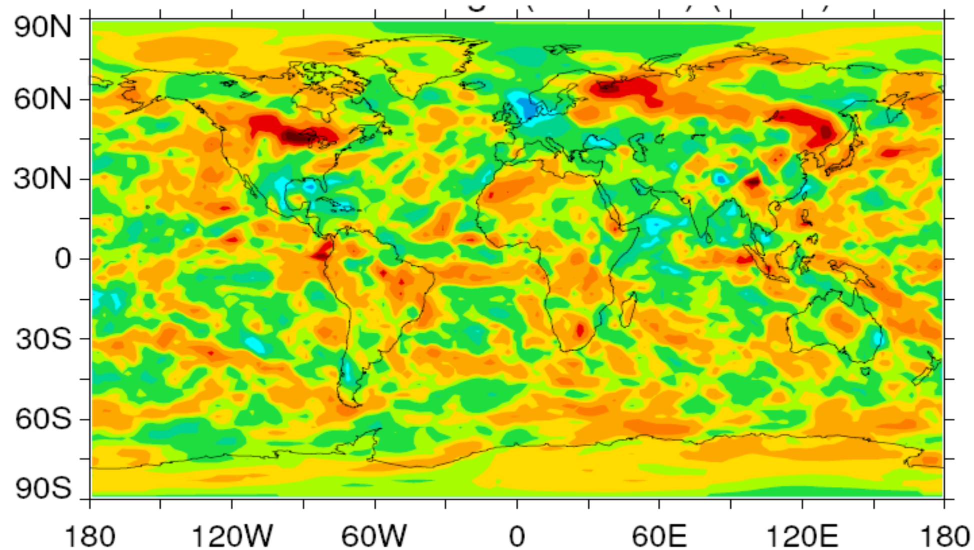
Anthropogenic aerosol radiative flux perturbation (RFP, W m^{-2}) at TOA from pre-industrial to present-day

	AM3 (to be used for AR5)	**AM2** (used for AR4)
Direct effects – Sulfate and organic carbon	0 (assuming internal mixing of sulfate and black carbon)	-1.3 (external mixing)
Direct effects - Black carbon		0.5 (external mixing)
Indirect effects	-1.3	Not included

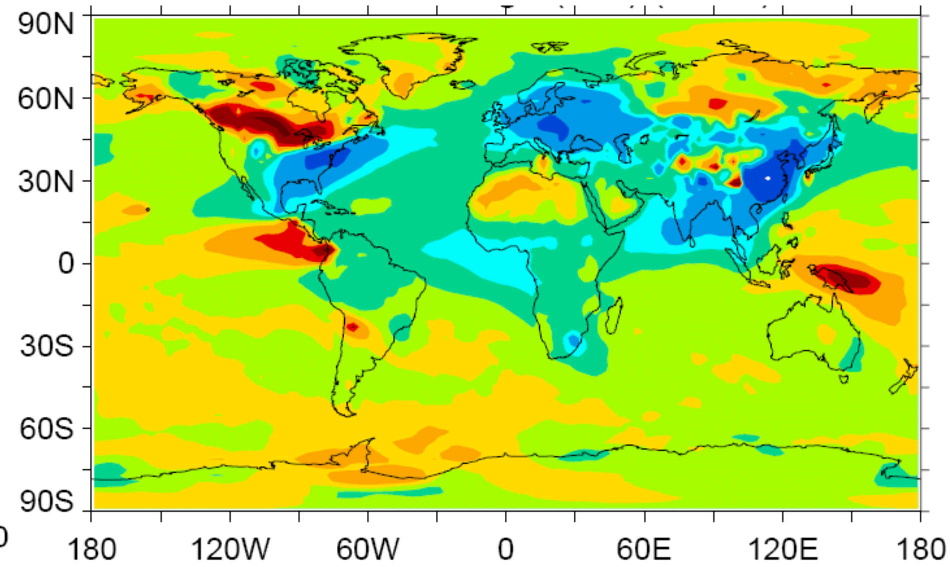
Aerosol direct effects

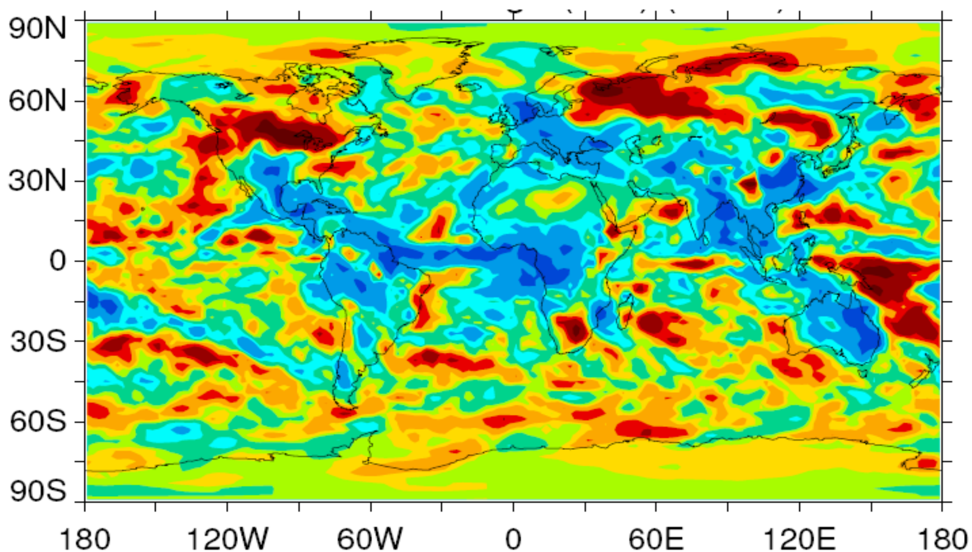
Importance of atmospheric absorption

TOA – all-sky ***0 W m^{-2}***



TOA – clear-sky ***-1.0 W m^{-2}***





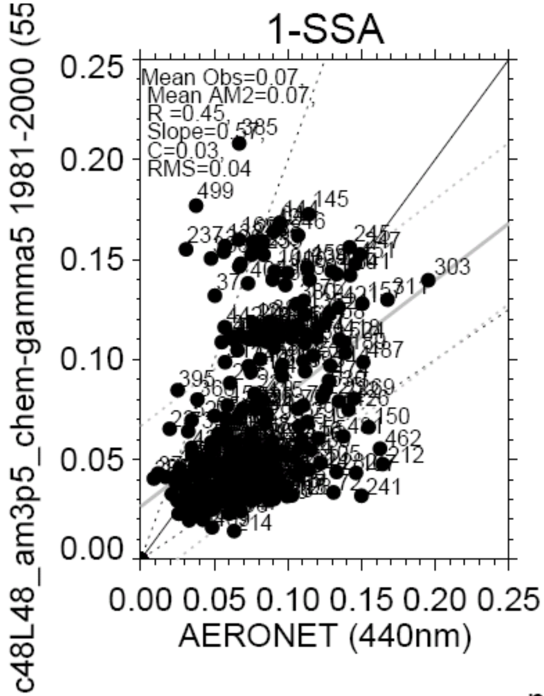
Surface – all-sky

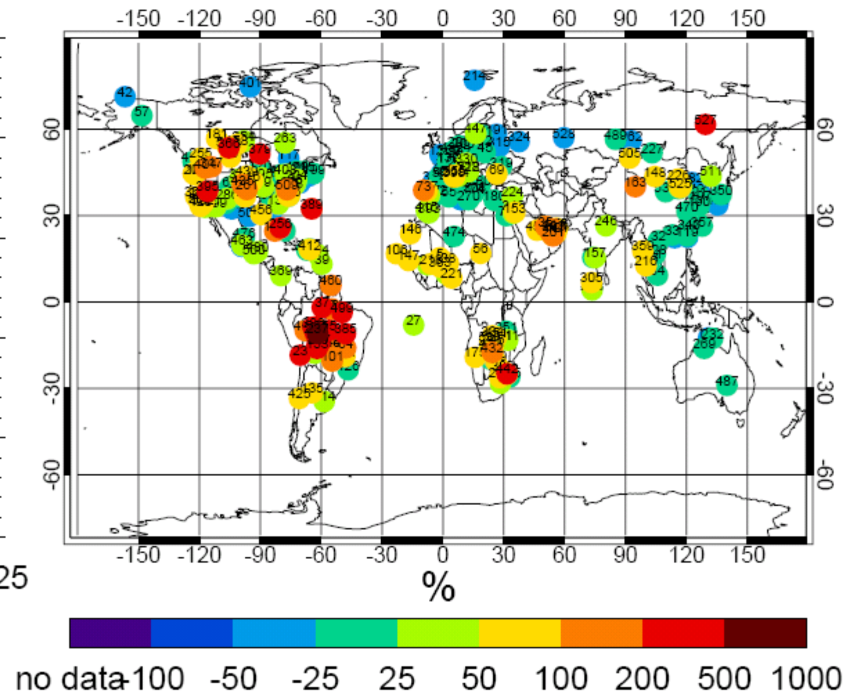
-1.3 W m^{-2}

A sanity check on aerosol absorption

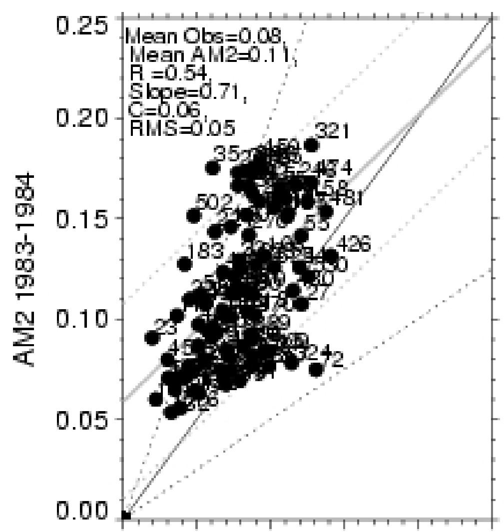
Comparison with AERONET measurements of co-albedo

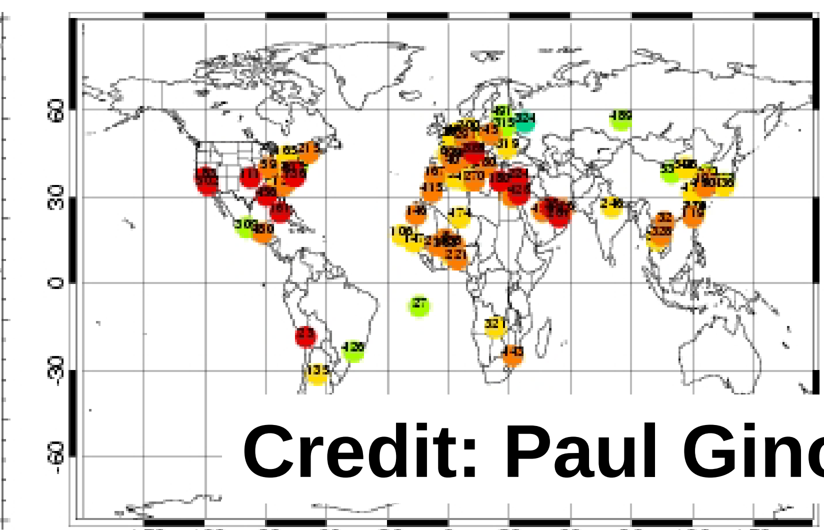
AM3





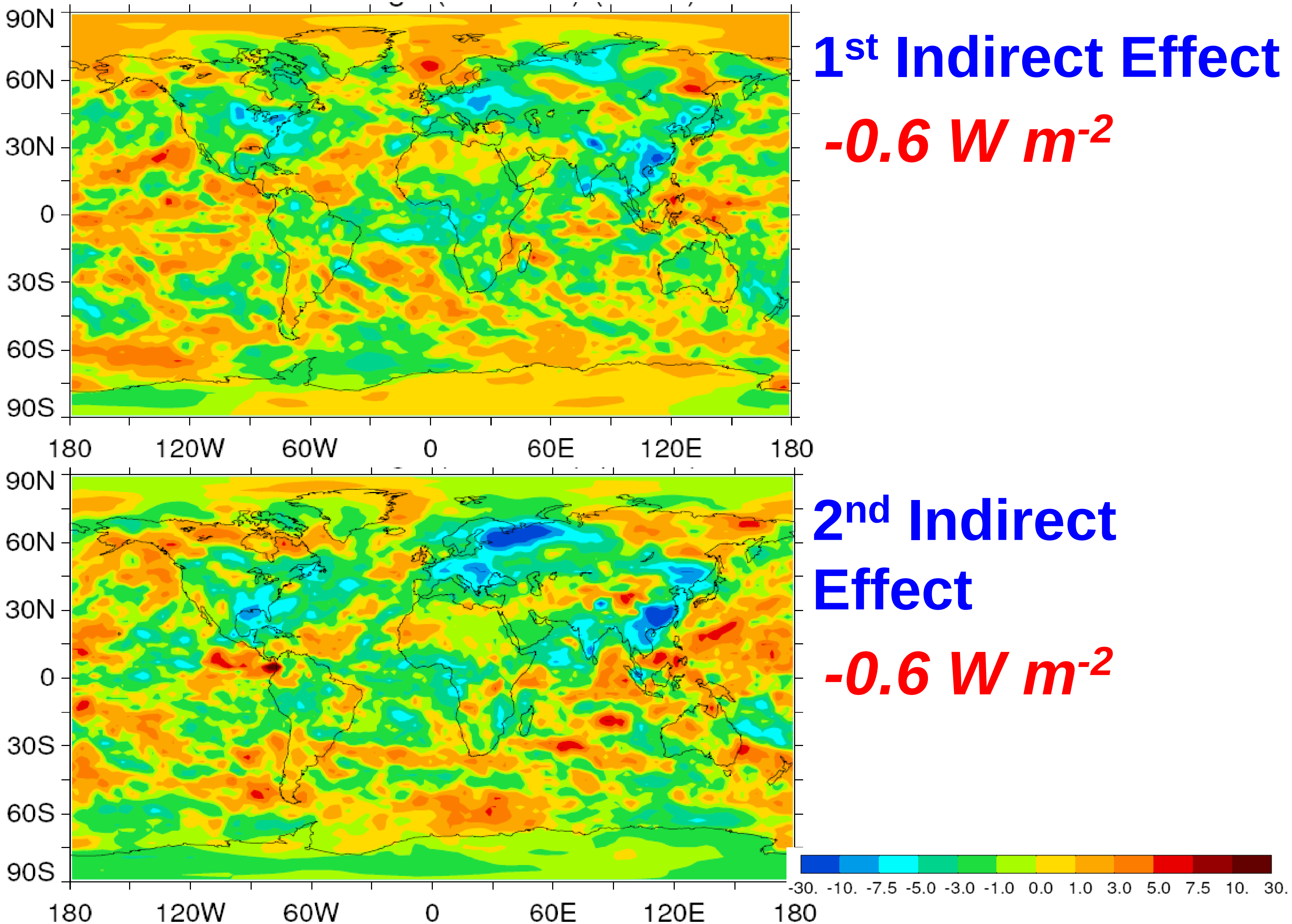
AM2





Credit: Paul Ginoux

1st and 2nd aerosol indirect effects



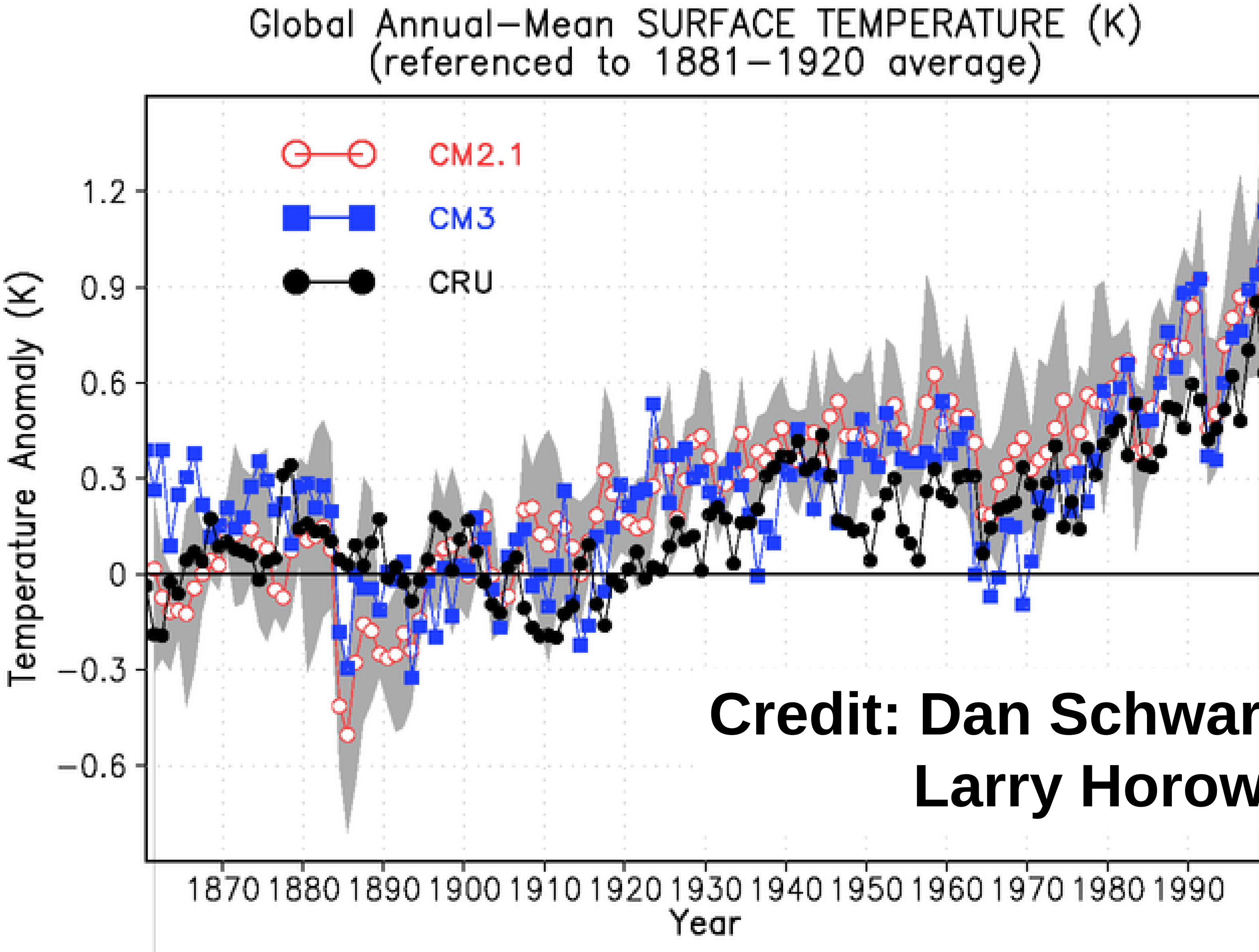
1st Indirect Effect

-0.6 W m^{-2}

2nd Indirect Effect

-0.6 W m^{-2}

A preliminary simulation of the 20th century climate using the IPCC emissions

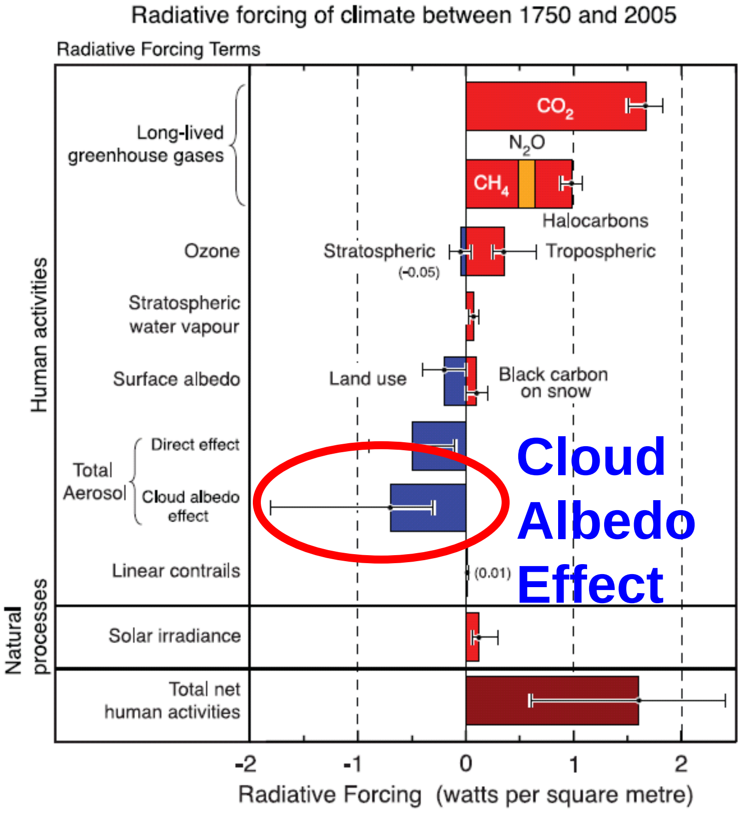


Credit: Dan Schwarzkopf
Larry Horowitz

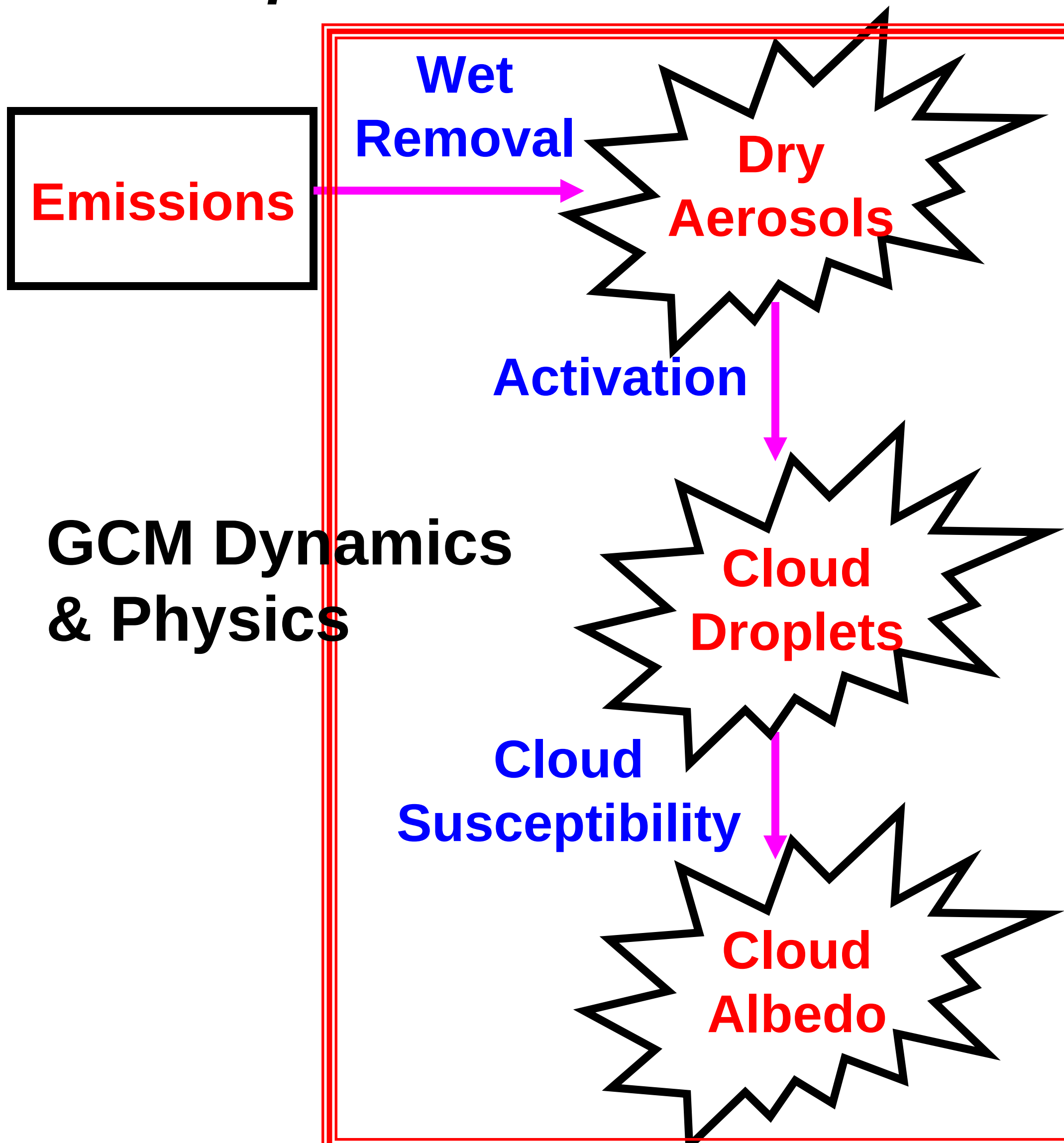
An approach to narrowing down the uncertainties in aerosol indirect effects

Dissecting indirect effects on the process level

Forcing estimates in AR4



Foster et al. (2007)



A theoretical constraint on cloud susceptibility

Revisiting Twomey's Cloud Susceptibility:

$$\left.\frac{\partial R}{\partial N}\right|_{l} = \frac{R(1-R)}{3N}$$

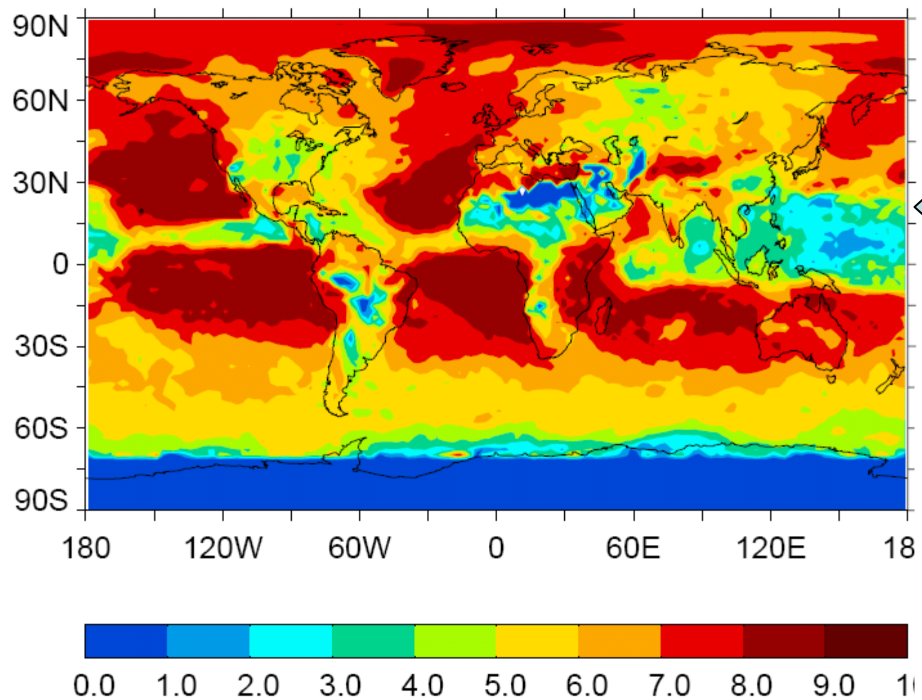
In discrete form, the <u>relative cloud susceptibility</u> can be written as:

$$\left.\frac{\Delta R}{\left(\frac{\Delta N}{N}\right)}\right|_{l} = \frac{R(1-R)}{3} \rightarrow \left.\frac{\Delta R}{\left(\frac{\Delta N}{N}\right)}\right|_{l,\max} = \frac{1}{12} = 8.3\%$$

when $R = 0.5$

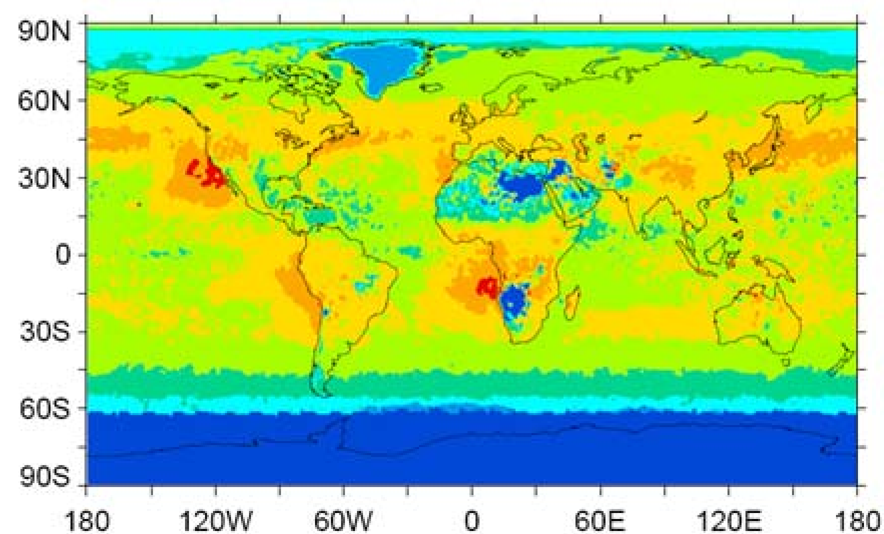
Comparison of AM3-simulated cloud albedo susceptibility with satellite data

Difference in cloud albedo (x1000) caused by a uniform 10% increase in droplet number in July.



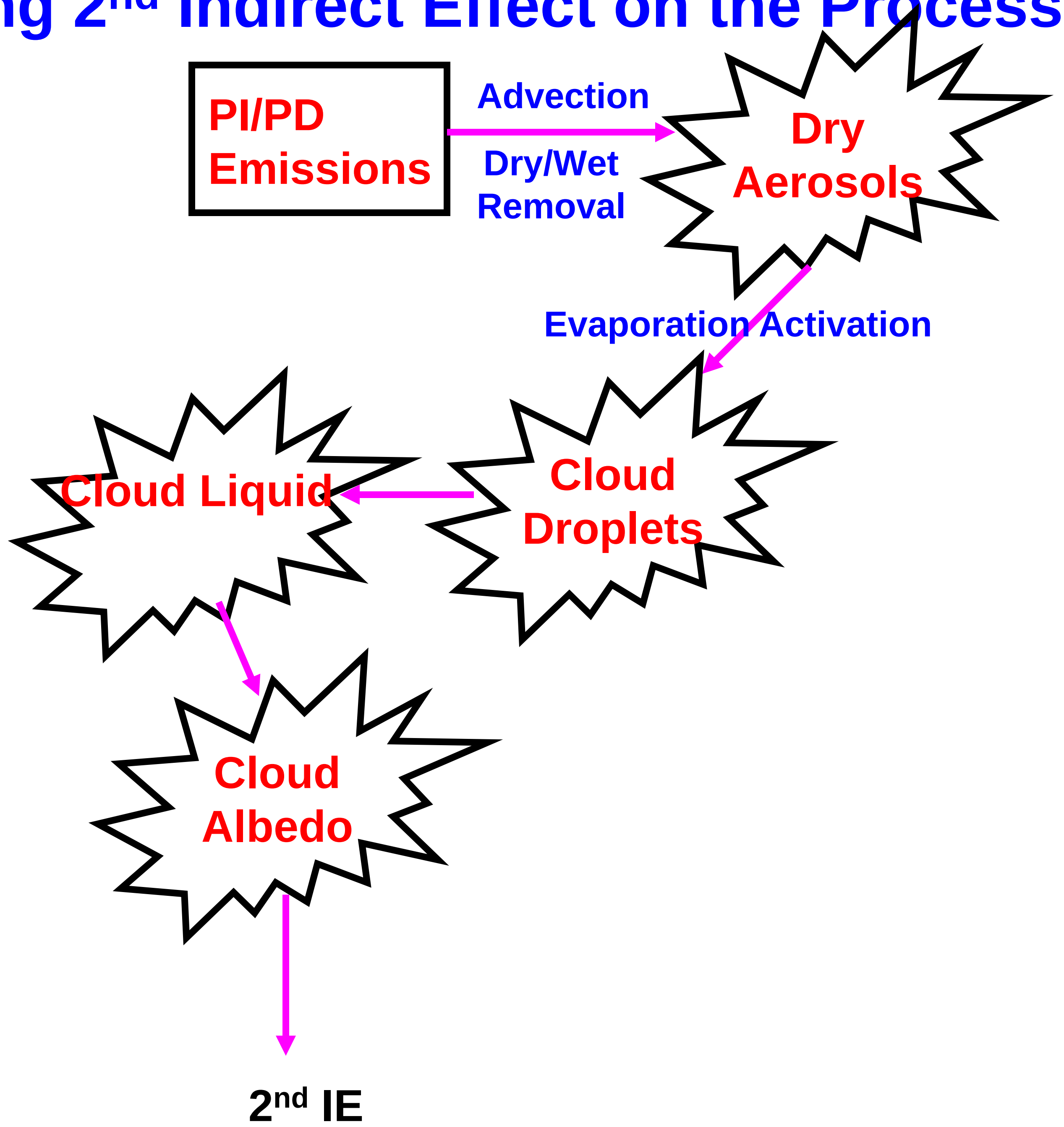
AM3

MODIS



Oreopoulos and Platnick (2008)

Dissecting 2nd Indirect Effect on the Process Level



How Droplet Number Affects Cloud Liquid?

The governing equation for cloud liquid can be simplified into

$$\frac{\partial l}{\partial t} = S - \frac{\partial l}{\partial t}_{auto} = S - a\frac{l^m}{N^n}$$

Sources/Sinks except autoconversion; assumed to be constant w.r.t. droplet number (?).

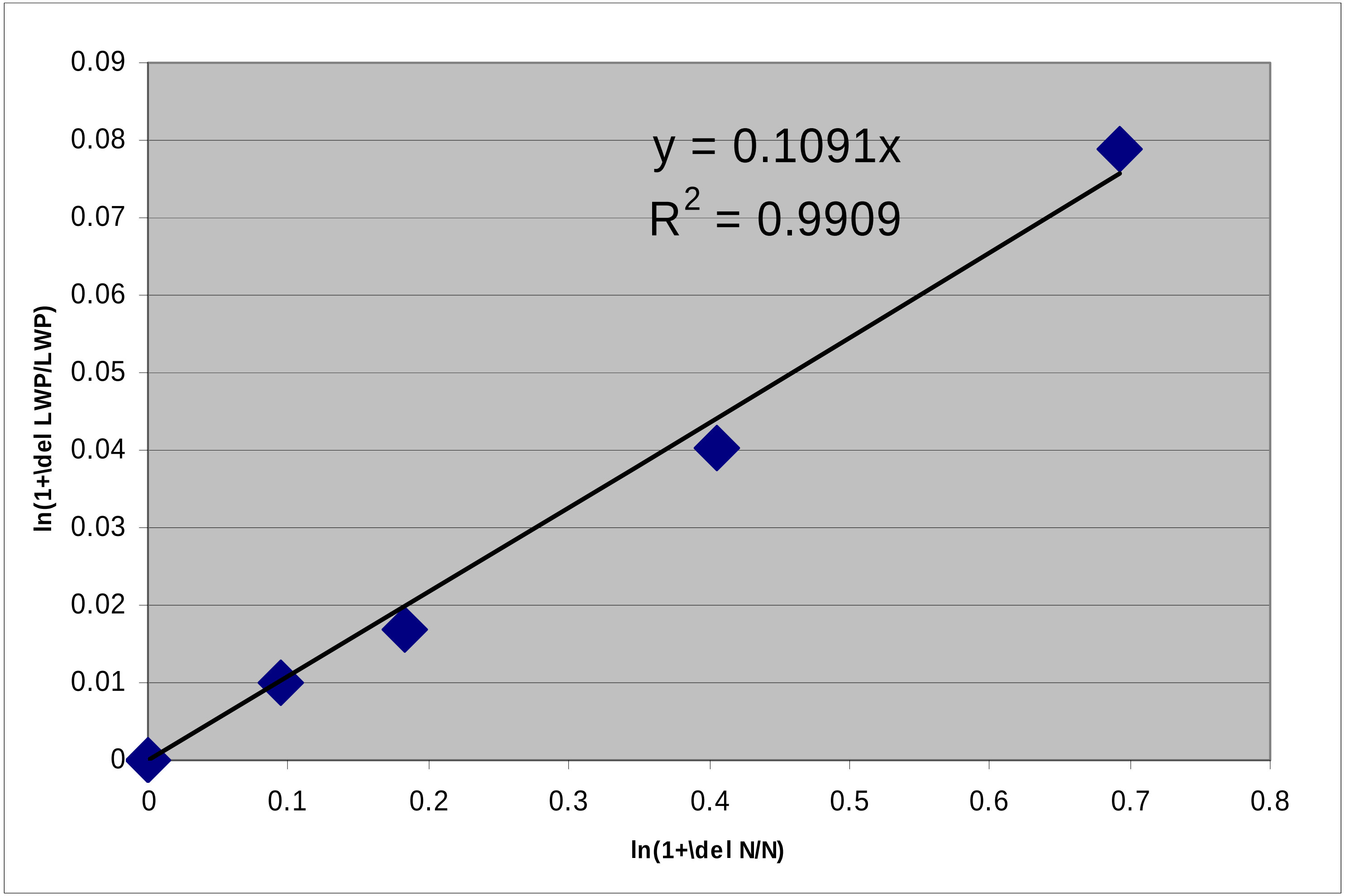
At steady state, $\frac{\partial l}{\partial t} = 0$

Then,

$$\ln\left(1 + \frac{\Delta l}{l}\right) = \frac{n}{m}\ln\left(1 + \frac{\Delta N}{N}\right)$$

In this model configuration, n/m is less than 1/7 (0.14).

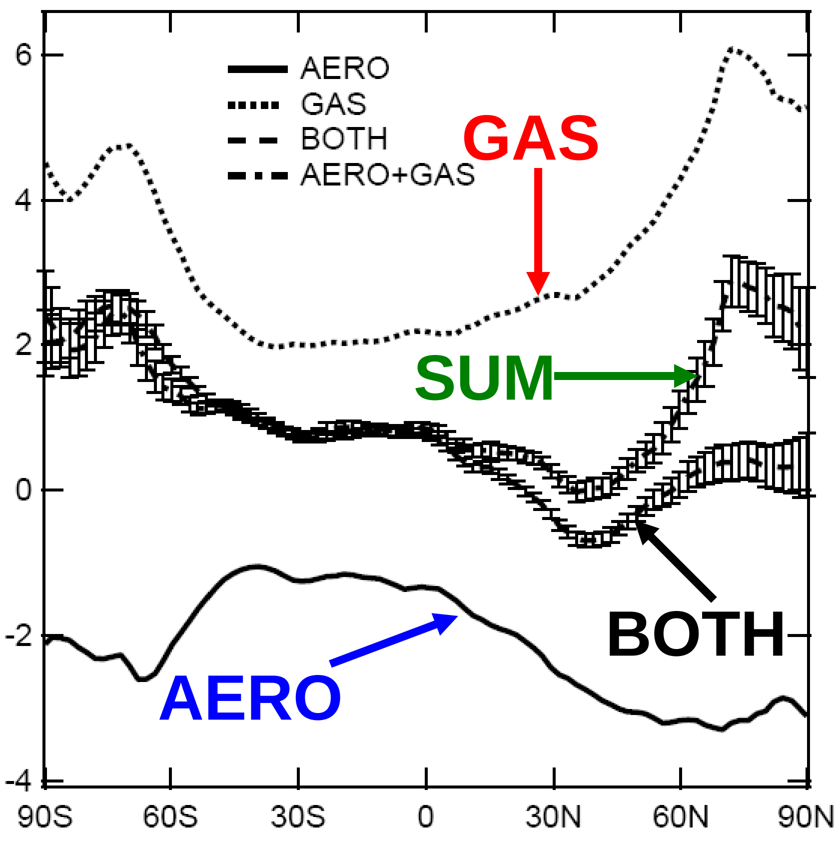
Model-Simulated Dependence of Cloud Liquid on Droplet Number



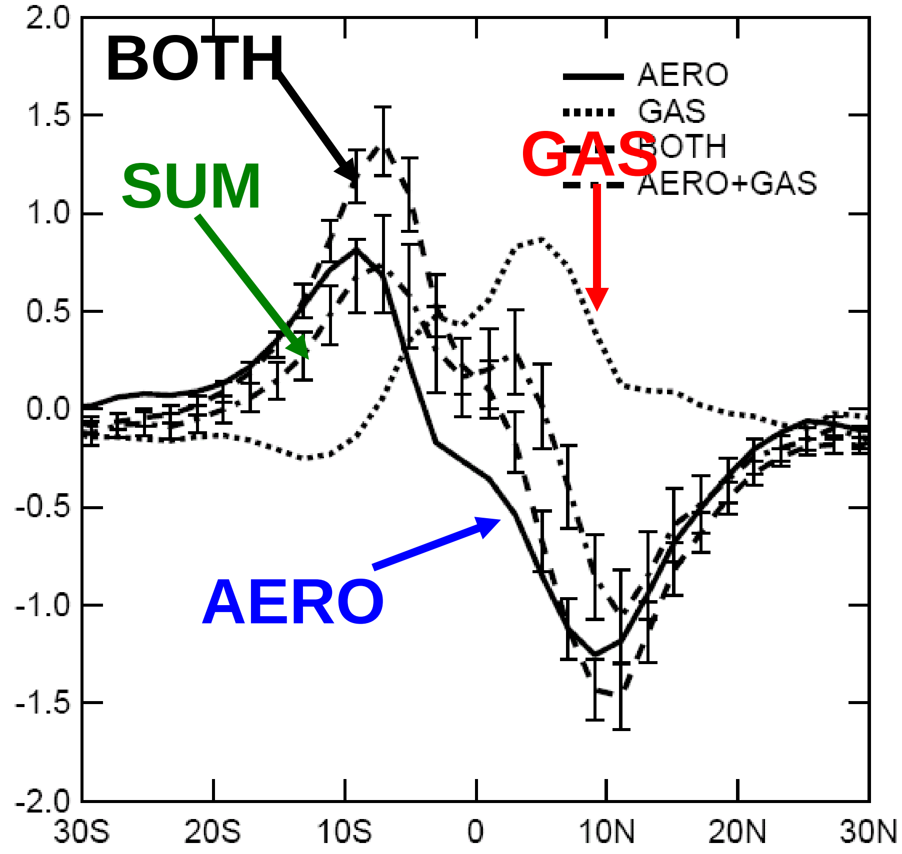
Aerosols are important for understanding regional climate change

Zonal-mean responses to <u>aerosol direct and indirect effects</u> simulated with a slab ocean model

Surface temperature (K)



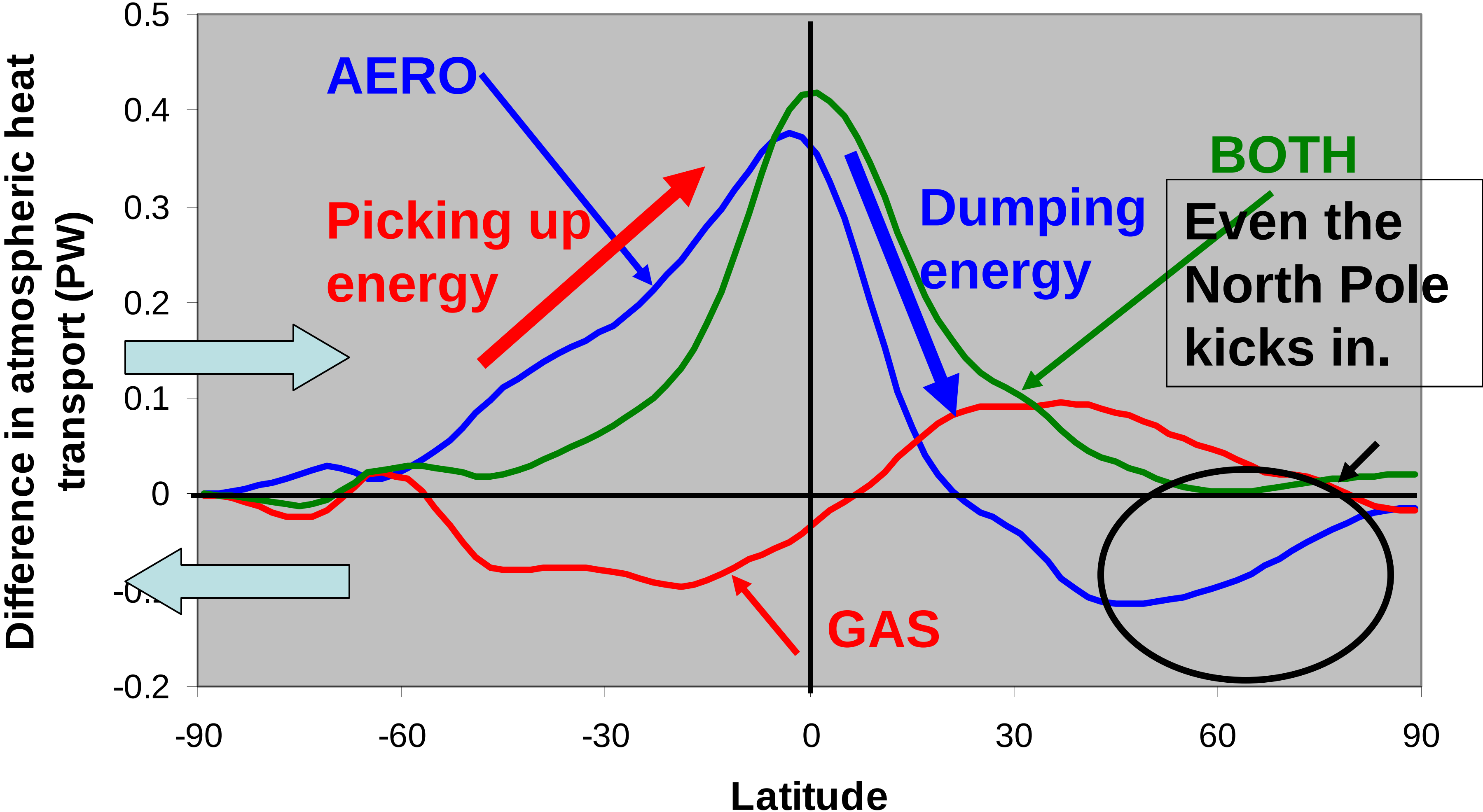
Precipitation (mm day^{-1})



Ming and Ramaswamy (2009)

How does the tropical heat engine response to aerosol forcing, and why?

From the viewpoint of atmospheric energy transport, the response gives rise to a cross-equatorial heat flux from SH to NH.



Concluding remarks

- **In AM3, a prognostic scheme of droplet number establishes a physical link between aerosols and clouds;**

- **Theories, models and measurements are used to better constrain indirect effects;**

- **Aerosol-induced circulation changes need to be studied more thoroughly.**

The End