Linking Regional Aerosol Emission Changes with Multiple Impact Measures through Direct and Cloud-Related Forcing Estimates

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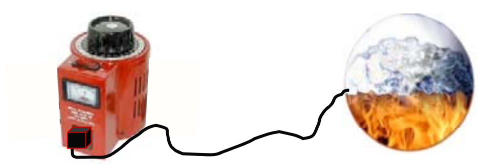
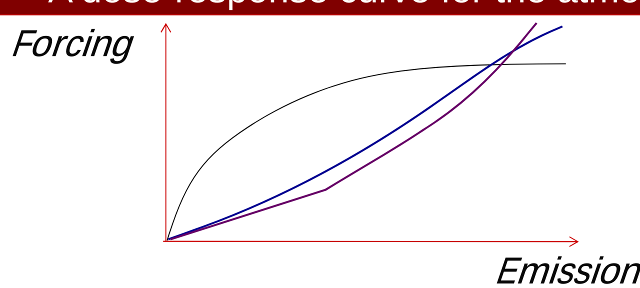
The simple view



A dose-response curve for the atmosphere



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this presentation will contain a small discussion on

What we learned from "Bounding-BC"

"Bounding the Role of Black Carbon in the Climate System" (32 co-authors)

was submitted to J.Geophys.Res. on March 28, 2012

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If accepted,

it will be about 200 journal pages including 28 tables & 43 figures

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Initiative of IGBP-IGAC/WCRP-SPARC

Atmospheric Chemistry and Climate Initiative (AC&C)

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"Bounding BC" goals

- Comprehensive
  - Examine all effects
  - Consider all models
- Quantitative (as far as possible)
  - Estimate forcing *per emission* and then forcing *per action*
  - Provide uncertainties
- Diagnostic
  - Identify reasons for differences

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Principle 1

There is no BC, but only "BC-rich sources"

- Realistic **source changes** may alter emissions of all these species.

  source changes = mitigation, economic change

- Short-lived, co-emitted species include: BC, organic matter (OM), sulfur dioxide (SO_2), NOx, and ozone precursors

Implication: we cannot focus only on BC

Principle 2

Direct forcing is only the beginning

Implication: We cannot focus only on direct forcing

source: IPCC AR4, ch7

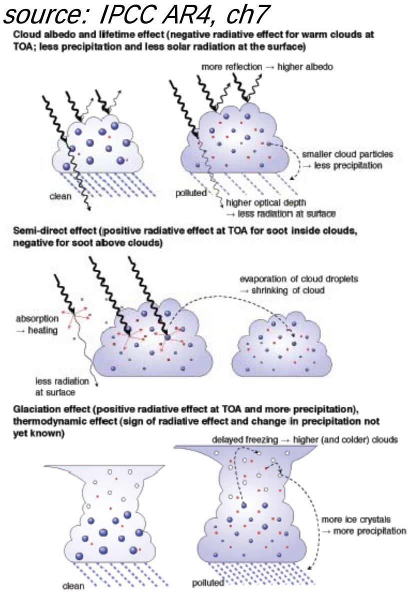


Figure 7.20. *Schematic diagram of the aerosol effects discussed in Table 7.10. TOA refers to the top-of-the-atmosphere.*

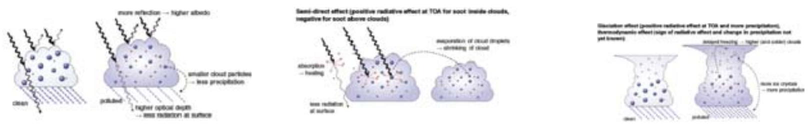
Liquid clouds: "indirect" effect

Liquid clouds: "semi-direct" effect

Ice and mixed clouds

Bounding-BC lesson

The big uncertainty in BC-rich sources



- BC → direct forcing ~ bounded
- BC → cloud forcing
  ~ large uncertainties – especially in ice/mixed
- OC + SO_4 → direct forcing
  ~ small for BC-rich sources
- OC + SO_4 → cloud forcing
  ~ large and probably negative

It's the <u>indirect</u> effects of <u>co-emitted</u> species that cause big questions about immediate forcing

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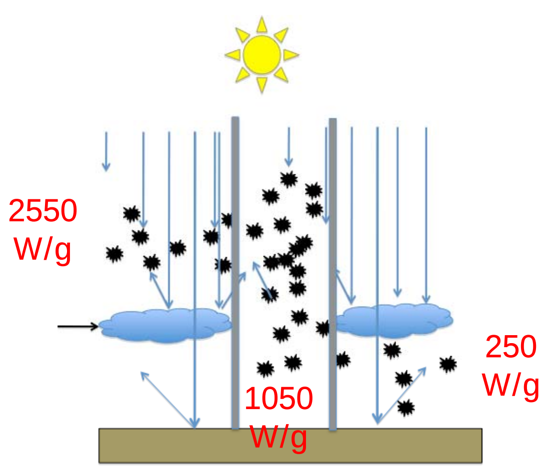
Relative location of BC and clouds affects direct forcing



Zarzycki & Bond, GRL 2010

BUT, while doing this study, we found that the modeled clouds weren't accurate
(older version of Community Atmosphere Model)

Note: Also affects semi-direct forcing; see Ban-Weiss et al, Clim Dyn, 2011

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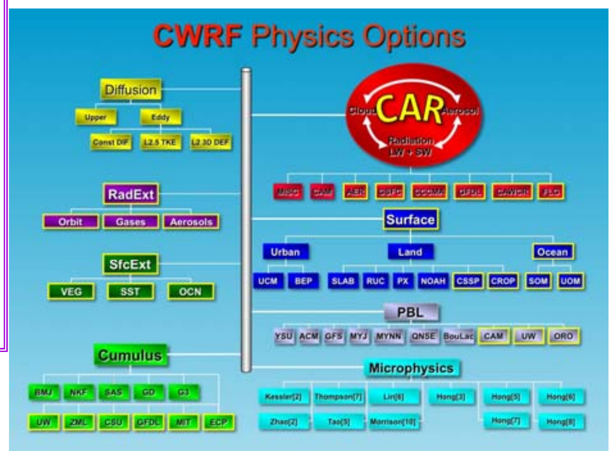
Detour: Get the clouds right first!

Objective 2: Identify best estimates and uncertainties for fields of direct and cloud-related forcing using an ensemble of parameterizations

University of Maryland

Xin-Zhong Liang & Hang Lei



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Cloud-Aerosol-Radiation Modeling System

- 7 complete packages from latest global weather forecast or climate prediction models: NCAR, GFDL, NCEP, NASA, ECMWF, CCCMA, Fu-Liou (ARM)
- 7 distinct modules to facilitate plug-and-play capability among parameterizations:
  - **3 main drivers** (*cloud, aerosol, radiation*) provide the hubs for alternative parameterizations for cloud properties (cover, water, radius, geometry), aerosol properties (type, profile), and radiation transfers (solar, infrared)
  - **3 couplers** (*cld_2_rad* for cloud optics, *aer_2_rad* for aerosol optics, *aer_2_cld* for aerosol impacts on cloud droplet nucleation) interface interactions (cloud radiative forcings, aerosol direct and indirect effects) across all spectral bands
  - **1 external** (*rad_ext*) manages all external forcings, such as solar insolation, earth orbit variations, radiative gas concentrations, aerosol loadings, surface albedo, emissivity and topographic impacts

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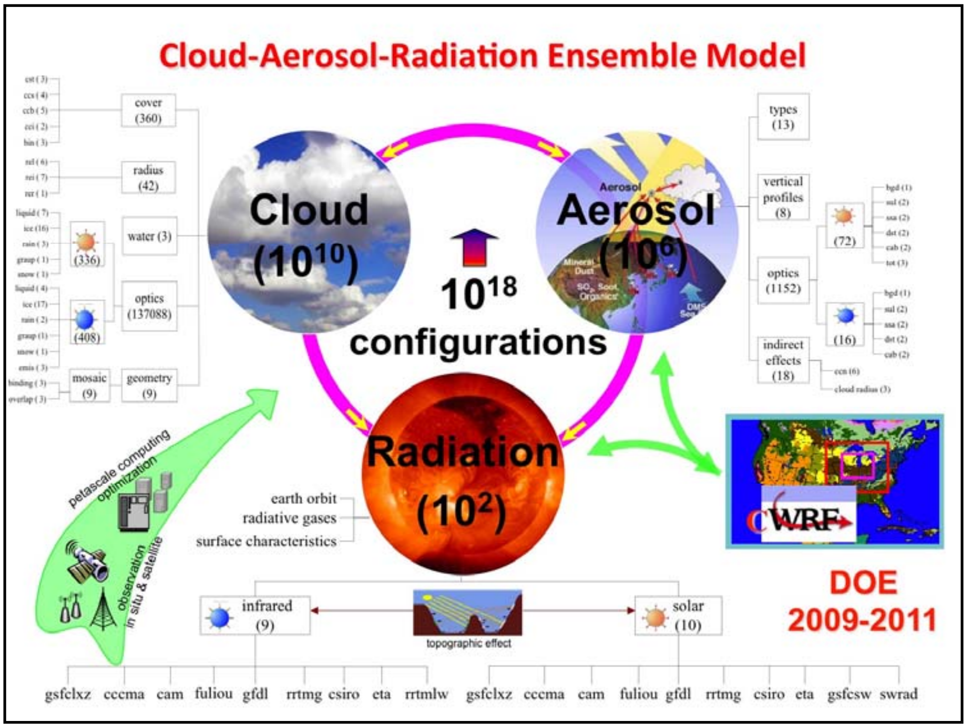
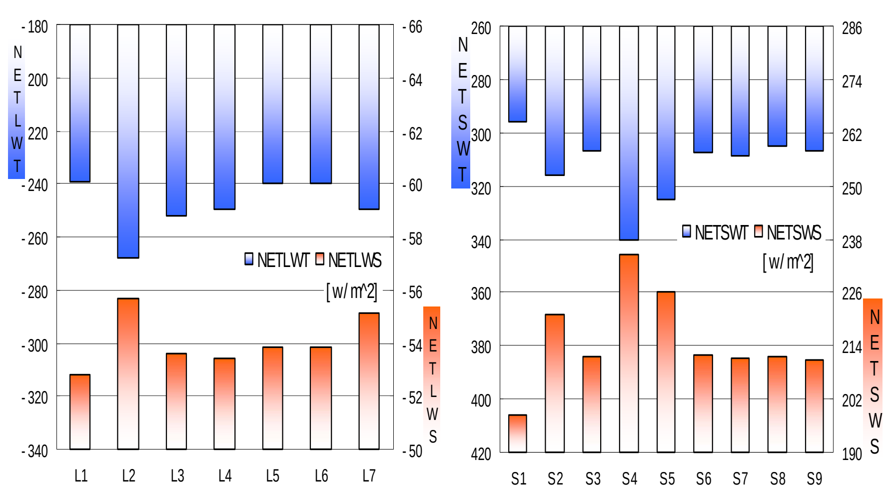


CAR: Differences among cloud optical schemes



Net TOA & Surface Radiation over USA Midwest in July 2000 (NARR)

Note: SW=shortwave; LW=longwave; T=ToA; S=Surface

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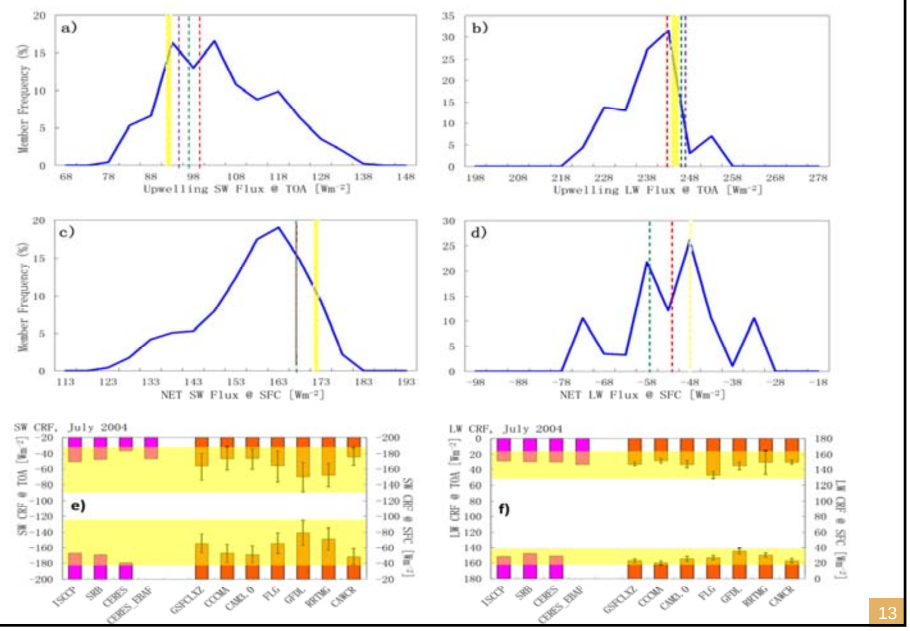
CAR ensemble flux frequency distribution



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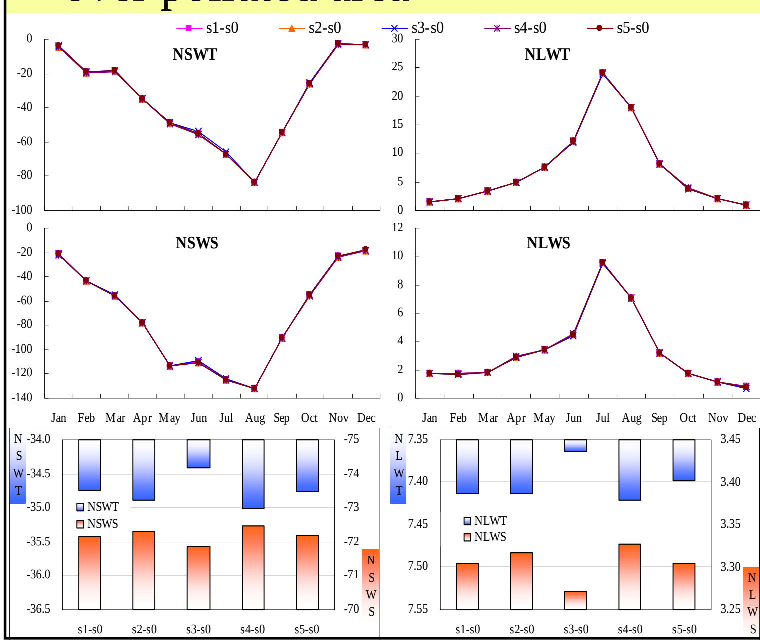
Example: first indirect effect over polluted area



Aerosol altering cloud effective radius:

s0: no aerosol effects

s1: Martin et al. (JAS 1994)

s2: Ming et al. (JAS 2006)

S3: Nenes & Seinfeld (JGR 2003)

S4: Chuang et al. (JGR 2002)

S5: Abdul & Ghan (JGR 2002)

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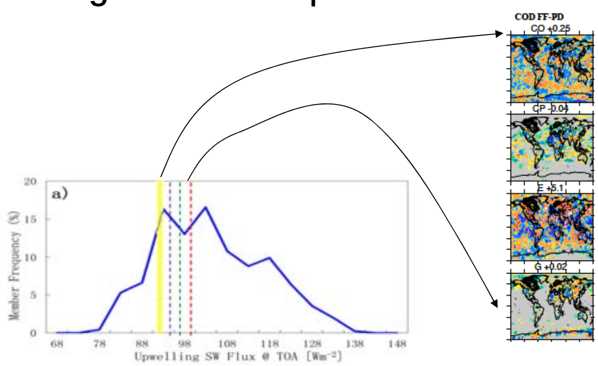
Approach to ensemble modeling

→ Choose members of ensemble for which radiation matches observations

→ Use these members to develop a family of forcing fields in response to aerosols



Shown here: Cloud optical depth fields from Koch et al., ACP 2011

Aerosol effects are size-dependent

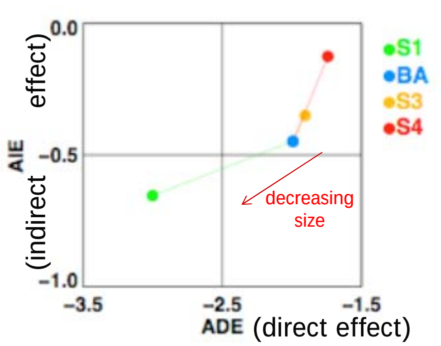


Fig. 4. Global mean AIE and ADE [W/m^2] values for all size experiments, (S1–4) and the base experiment, BA, for present day conditions.

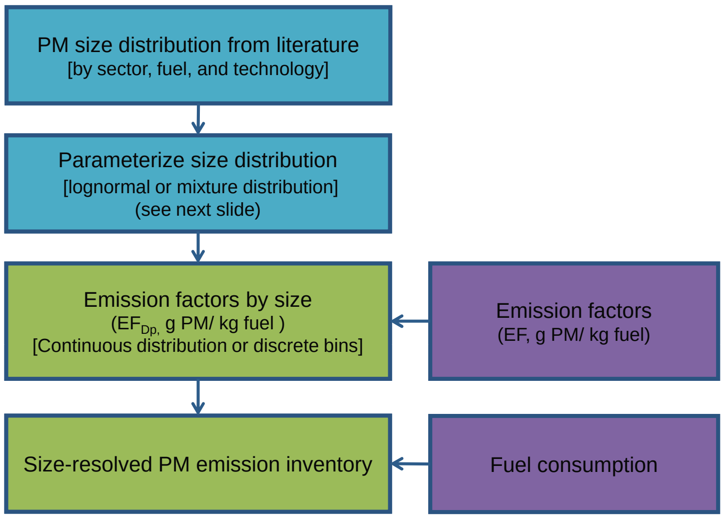
Bauer et al., ACP, 2010
for carbonaceous aerosols

Objective 1: Develop size-resolved, speciated emission inventories of aerosols & precursors

Argonne National Laboratory

David G. Streets

Size-resolved emission inventory



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Parameterize size distribution

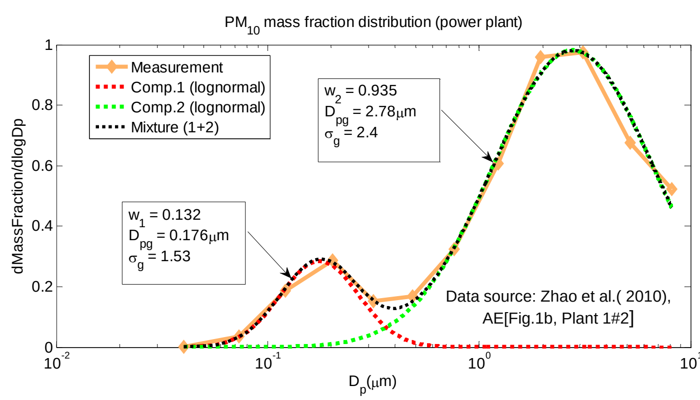
- Lognormal distribution is used to fit size distribution

$$f\left(\ln D_p\right) = \frac{1}{\sqrt{2\pi}\ln\sigma_g}\exp\left[-\frac{\left(\ln D_p - \ln \bar{D}_{pg}\right)^2}{2\ln\sigma_g^2}\right]$$

Where $\ln\bar{D}_{pg}$ and $\ln\sigma_g$ are the mean and standard deviation of $\ln D_p$

- For a bimodal distribution, a mixture model with two components is applied

$$f(x) = w_1 f_1(x) + w_2 f_2(x) \qquad 0 \le w \le 1$$



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Ultimate goal of task 1 (size-resolved)

- Size-resolved emission inventory will be made available via web-based interface
- Gridded data will be requested via web form with quick turnaround

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Metric: quick 'n' dirty estimate

- A metric is a measure of climate impact per emission.
- By some definitions (but not mine) a metric must provide comparison to CO2.

Principle 3

- For species that aren't well mixed (short-lived climate forcers), impact depends on location and time of emission.

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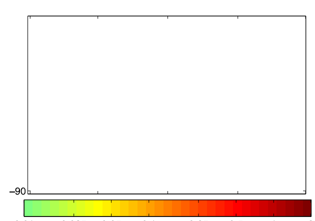
Spatial dependence of impact measures

Emission in region 1

Forcing in region 2

Response in region 3



We stop here

...assuming that the next step ought to be done by a climate model, and forcing-response depends on location but not forcing agent

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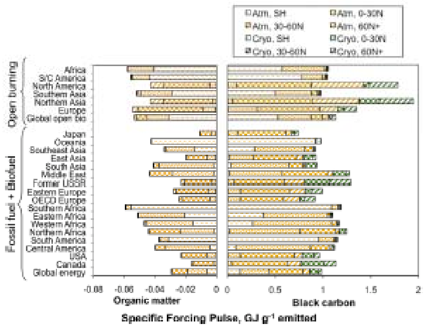
We have estimated latitude-dependent *direct forcing* by emitting region

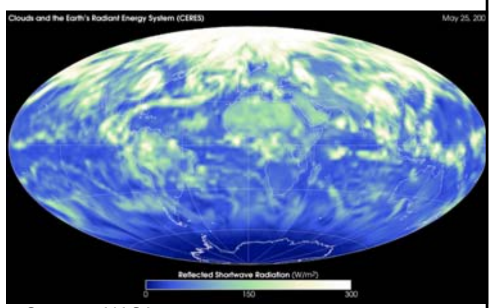


Bond et al., *ACP*, 2011

Started with Berntsen et al 2005, 2006

And more contributions will probably come soon

What about the cloud forcing?



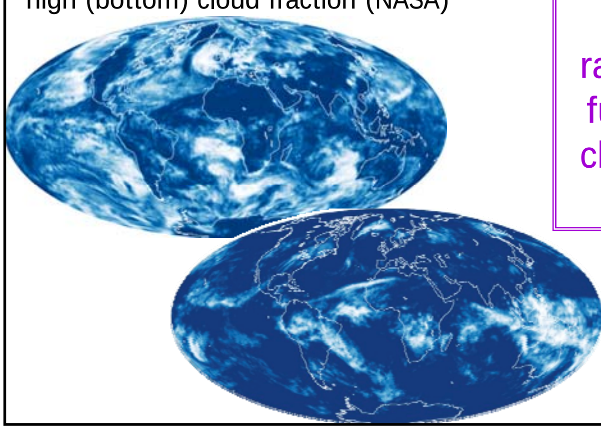
Source: NASA

Emission-to-forcing relationships

University of Illinois

Tami Bond and Yanju Chen

Shown: CERES low (top) and high (bottom) cloud fraction (NASA)



Objective 3: Determine functional relationships that express changes in direct and cloud radiative forcing as a function of emission changes in particular locations

Possible approaches

All beginning with the selected model ensemble

- Reduce emissions from regions one at a time
- Tag emissions from specific regions and apportion impact
- Philosophy: Many things are quasi-linear, or at least monotonic

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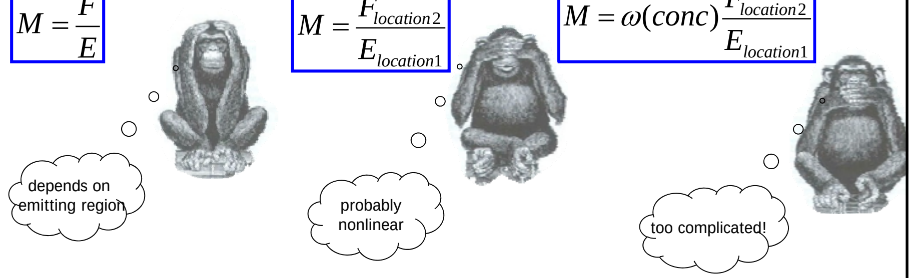
Calculation of metric *M*: "As simple as possible, but no simpler"

F=forcing
E=emission

$$\boxed{M = \frac{F}{E}}$$

$$\boxed{M = \frac{F_{location2}}{E_{location1}}}$$

$$\boxed{M = \omega(conc)\frac{F_{location2}}{E_{location1}}}$$



U of Maryland post-doc
> CAR model <

U of Illinois post-doc
> interpretation <

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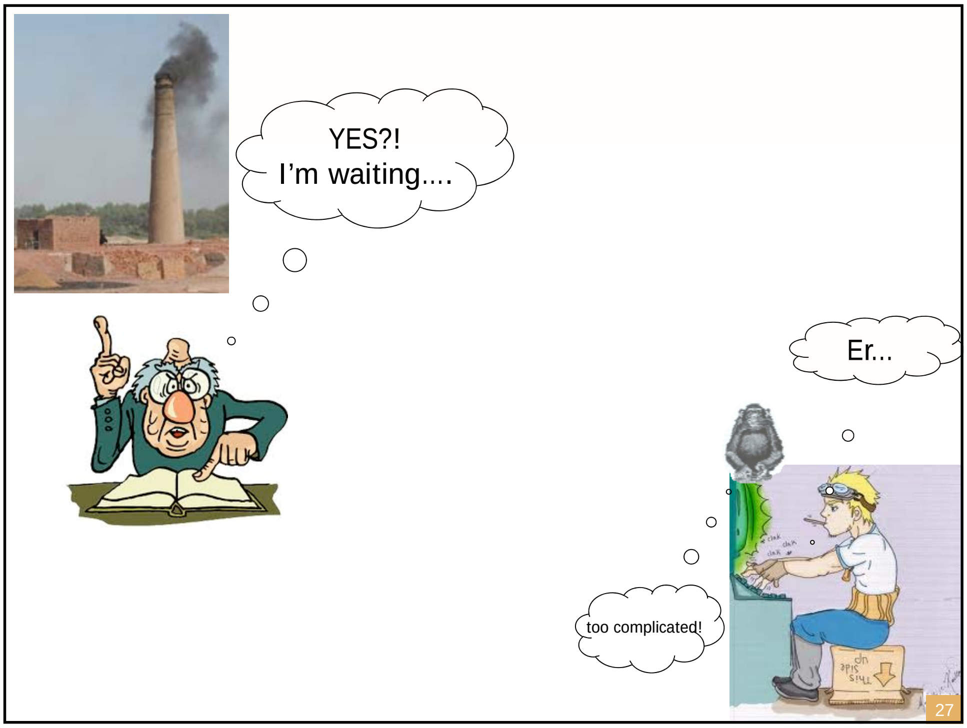

Emission-to-forcing relationships

Objective 4: Iterate emission-to-forcing measures as communication tools between decision makers and climate scientists

Clean Air Task Force

Praveen Amar

Target audience:

Northeast US state decisionmakers

Specific topics:

- Meaning of emission-to-impact
- Short vs long-lived
- Role of uncertainty

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Summary of objectives

1: Develop size-resolved, speciated emission inventories of aerosols & precursors

2: Provide best estimates and uncertainties for forcing fields using ensembles

3: Express changes in direct and cloud radiative forcing as a function of emission changes

4: Iterate emission-to-forcing measures between decision-makers and climate scientists

Questions??

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