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

Tami C. Bond, Yanju Chen, and Kevin Hade

University of Illinois at Urbana-Champaign

Xin-Zhong Liang & Hao He

University of Maryland

David G. Streets, Ekbordin Winijkul, and Fang Yan

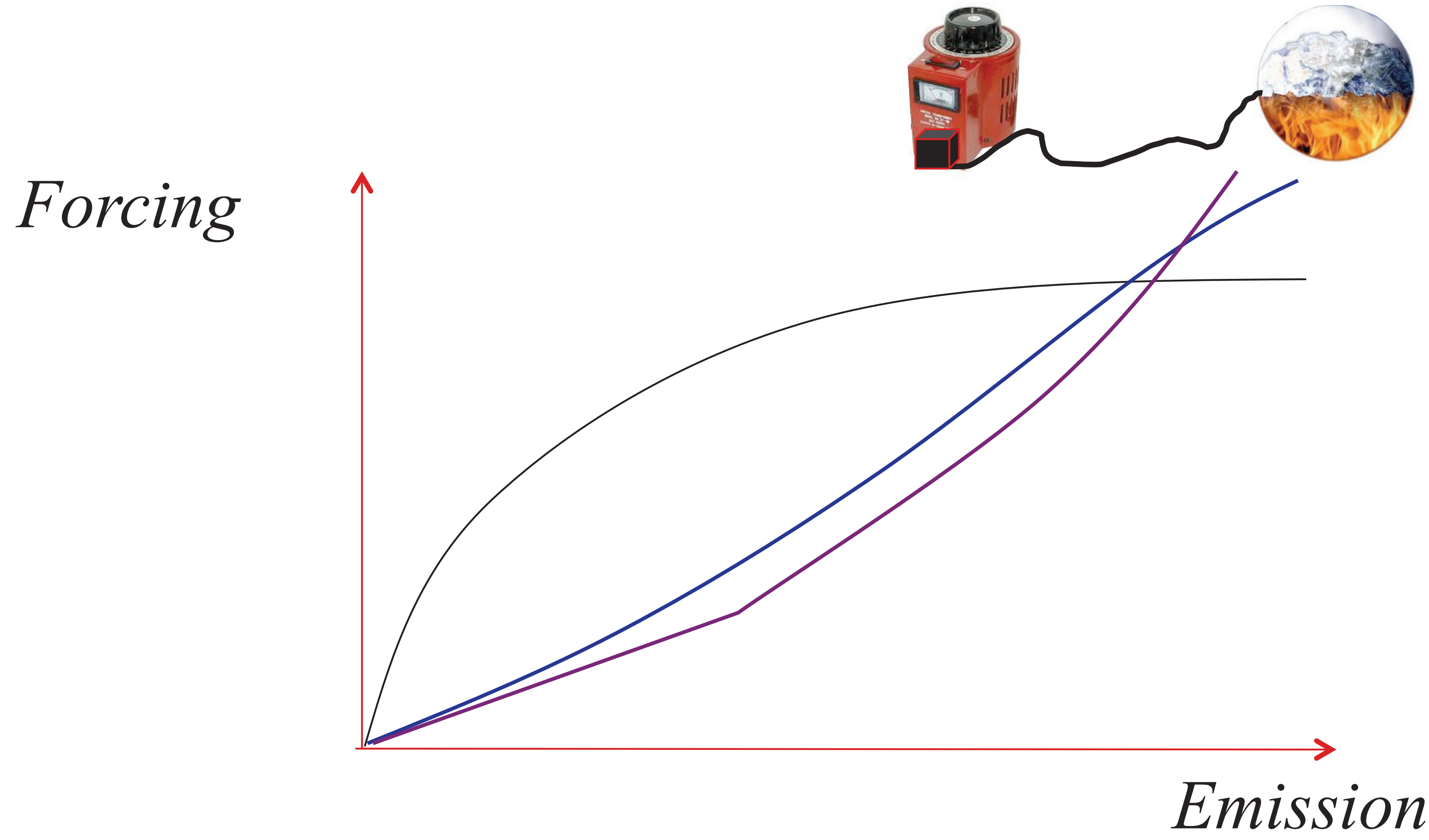
Argonne National Laboratory

Praveen Amar, Danielle Meitiv

Clean Air Task Force

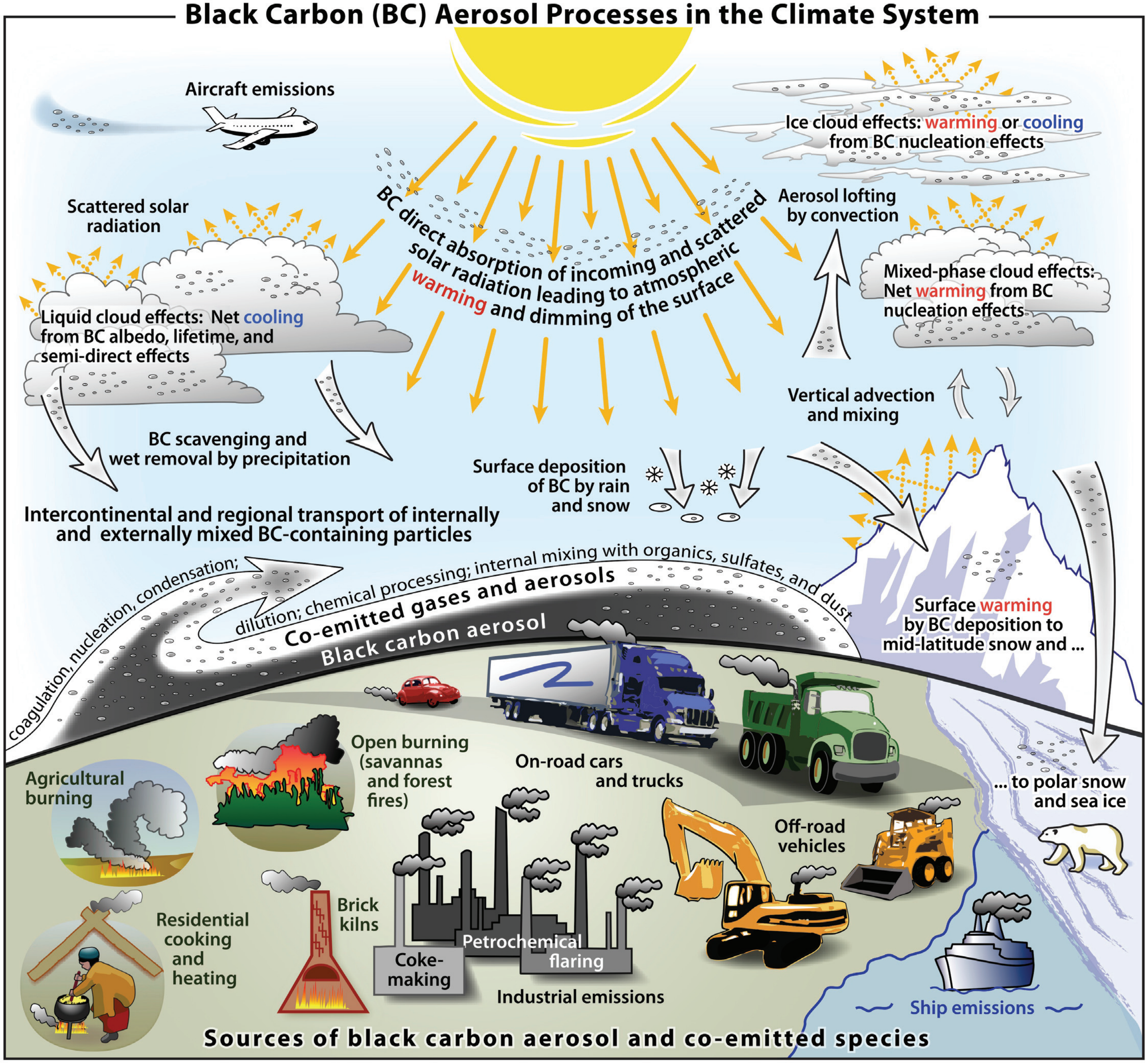
Project Design

The initial project concept remains: Find a dose-response curve for the atmosphere.



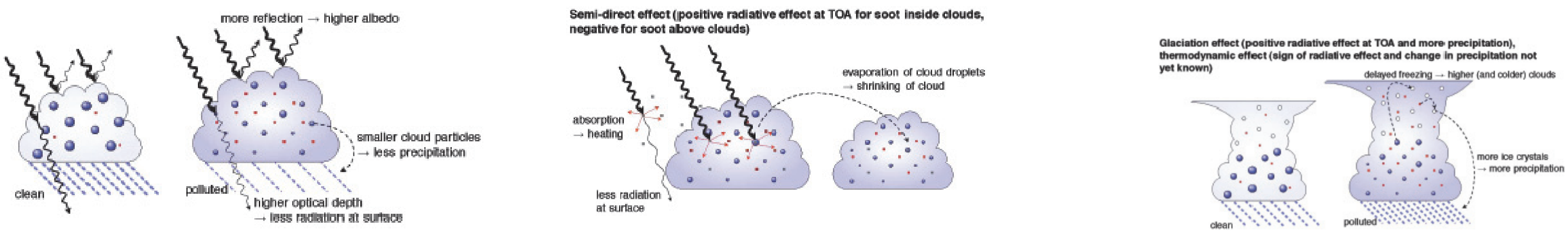
As shown in May 2012, Nov 2014

The project period kicked off by finishing “Bounding-BC”



Bond et al.
JGR 2013
Figure by D. Fahey

Bounding-BC fingered 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 __indirect__ effects of __co-emitted__ species that cause big questions about immediate forcing

Review from May 2012, Nov 2014

Despite all the scientific complexity, policy discussions need simplicity

So you got [*some scientific thing*] right. Who cares? Tell me if I should turn this off!

Can you wait 6 months? I have to run my model…

This simplicity is distilled into climate “metrics”

Normal people think:
A metric is something you can measure, and report

The climate policy community says:
A metric is a well-defined calculation that can be used to *equate impact of* a mass emission of some species to a mass emission of the big bear, CO_2

Climate metrics for short-lived species can be calculated from a single measure

Absolute global warming potential

Global warming potential

Global temperature potential

Specific forcing pulse

ENF

$$ENF = \frac{forcing}{emission}$$

For short-lived species (τ<4 mo), Emission-Normalized Forcing is the *only* model output required to calculate *any* of these metrics.

Other considerations affect the values of emission metrics, but they all come from models of the carbon cycle or Earth's heat capacity, NOT from models of aerosols

Thought process for project design

For use in climate metrics, we need emission-normalized forcing for:

-black & organic carbon
- direct & cloud-related forcing

And the aerosol-cloud interactions aren't any good if the aerosol size and number isn't right.

The cloud-related forcing isn't any good if the clouds aren't right.

Also, we should check with policy-makers if we are making this too complicated to understand.

Project objectives reflected those considerations

For use in climate metrics, we need emission-normalized forcing for:

-black & organic carbon
- direct & cloud-related forcing

And the aerosol-cloud interactions aren't any good if the aerosol size and number isn't right.

Also, we should check with policy-makers if we are making this too complicated to understand.

Objective 2: Employ an ensemble of parameterizations in regional-scale models to identify best estimates and uncertainties for direct and cloud-related forcing

Project objectives reflected those considerations

For use in climate metrics, we need emission-normalized forcing for:

-black & organic carbon
- direct & cloud-related forcing

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

Also, we should check with policy-makers if we are making this too complicated to understand.

Objective 2: Employ an ensemble of parameterizations in regional-scale models to identify best estimates and uncertainties for direct and cloud-related forcing

Project objectives reflected those considerations

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

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

Also, we should check with policy-makers if we are making this too complicated to understand.

Objective 2: Employ an ensemble of parameterizations in regional-scale models to identify best estimates and uncertainties for direct and cloud-related forcing

Project objectives reflected those considerations

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

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

Objective 2: Employ an ensemble of parameterizations in regional-scale models to identify best estimates and uncertainties for direct and cloud-related forcing

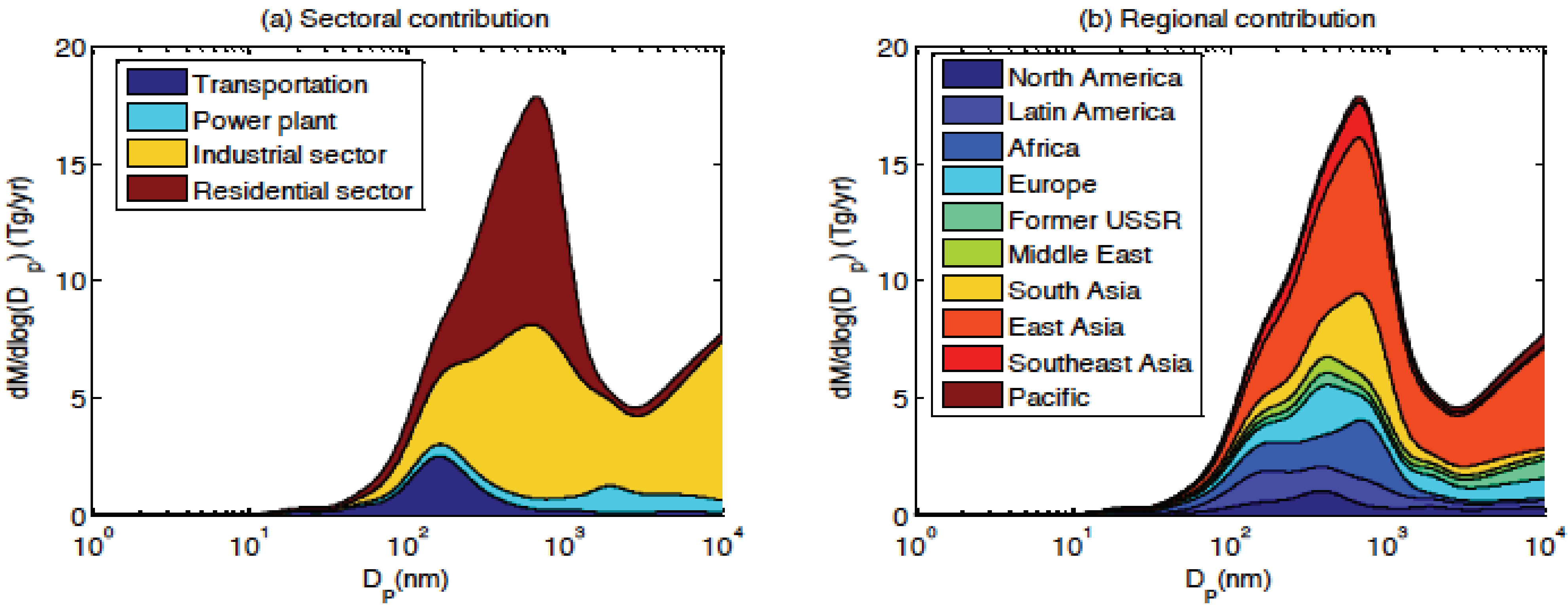
Objective 4: Iterate emission-to-forcing measures as communication tools between decision makers and climate scientists

Size-resolved inventories

Objective 1: Get the size right

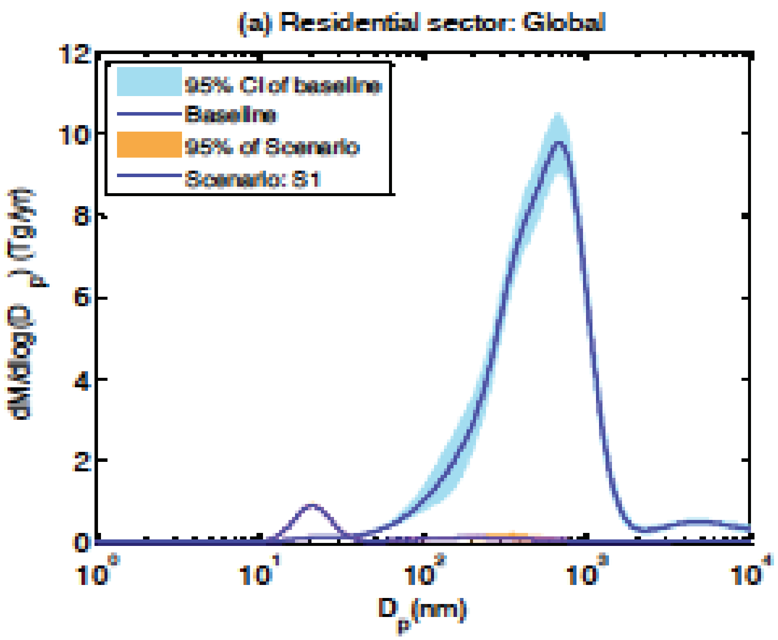
(David Streets, Ekbordin Winijkul – Argonne)

Global size-resolved emission inventory has been produced.

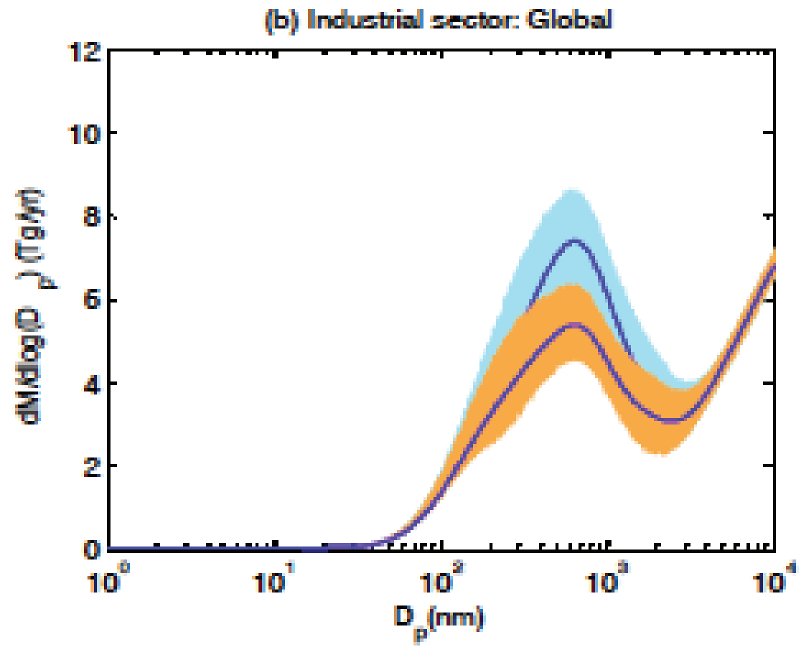


Size-resolved global emission inventory of primary particulate matter (PM) from energy-related combustion sources
E. Winijkul, F. Yan, Z. Lu, D. G. Streets, T. C. Bond, Y. Zhao
Atmos Env, 28 August 2015

This work includes uncertainty and illustrative reduction scenarios



Residential:
Switching from
solid fuel to LPG



Industrial:
Baghouses on cement kilns

Winijkul et al., Atmos Env., 2015

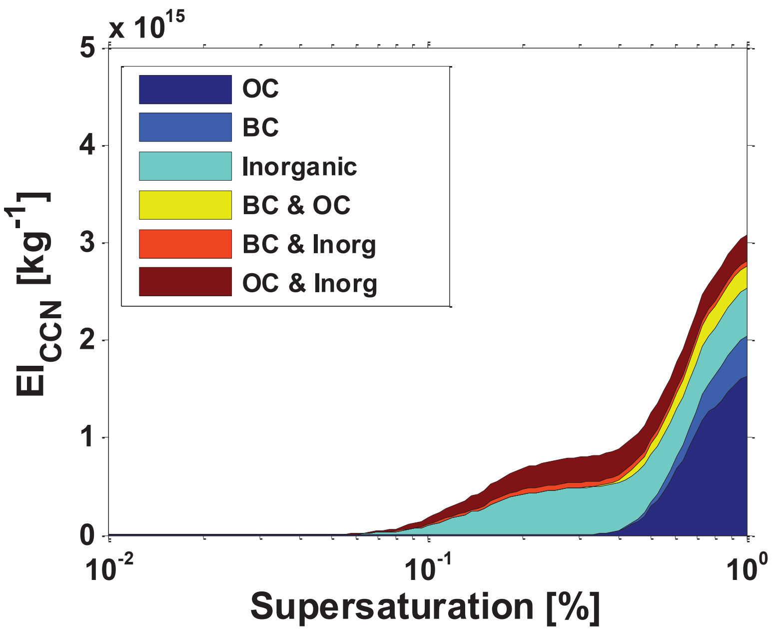
The connections still need work.

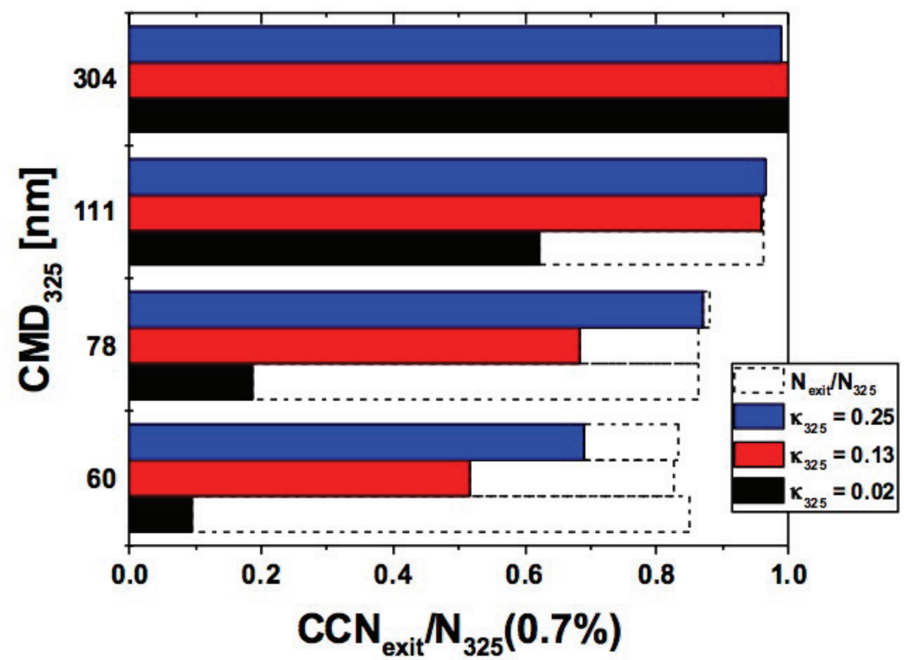
Objective 3: Determine functional relationships that express changes in direct and cloud radiative forcing as a function of emission changes in particular locations

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

Disconnect:
Most models are not ready to accept spatially-dependent, size-resolved emissions.

Teaser: We are now using aerosol-resolved models to estimate plume-exit composition and CCN.





There's a limit on CCN emission.

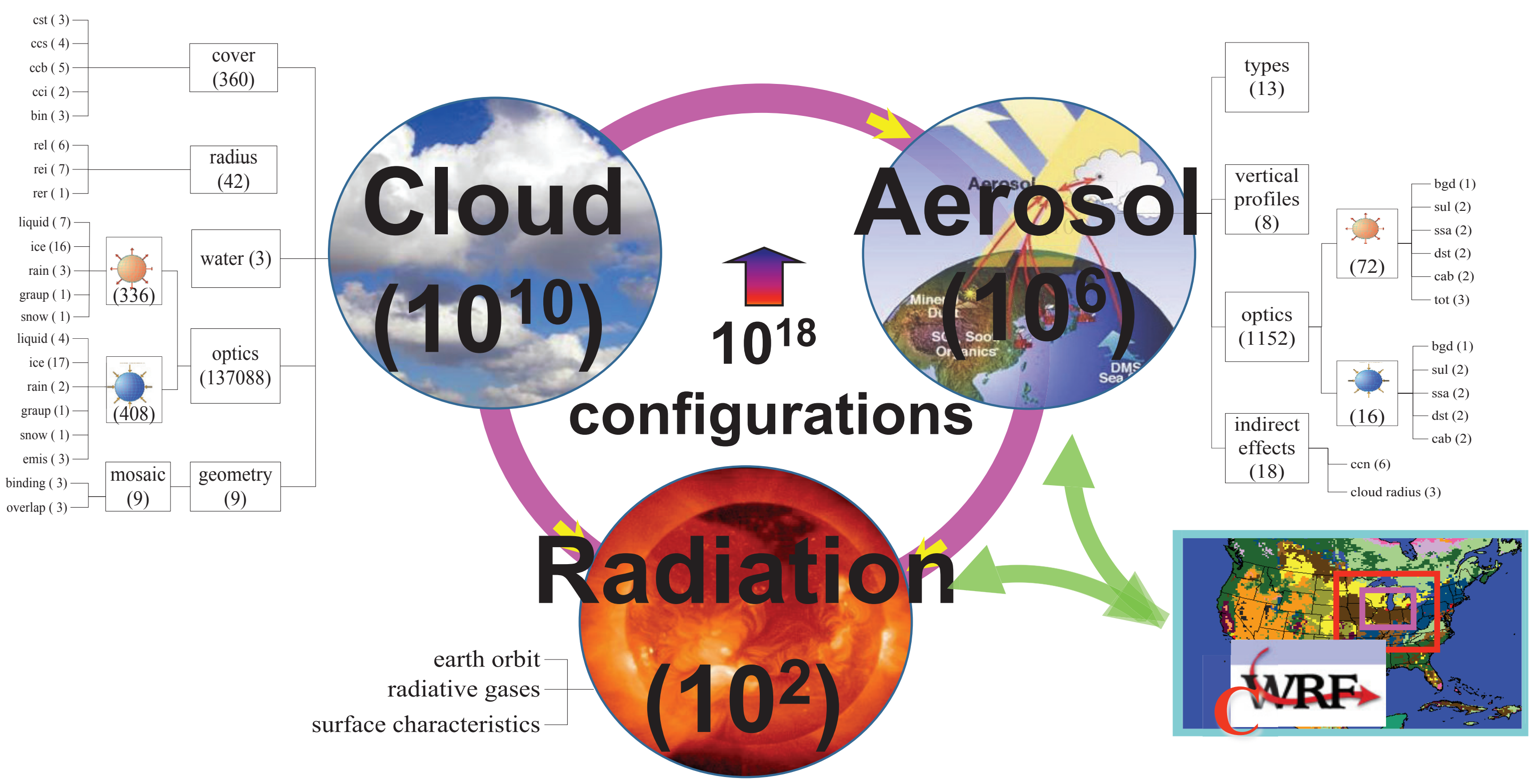
Mena, Fierce, Bond & Riemer, in prep for ACP

Regional Cloud Modeling

Objective 2: Get the Clouds Right

(Hao He, Xin-Zhong Liang – Univ of Maryland)

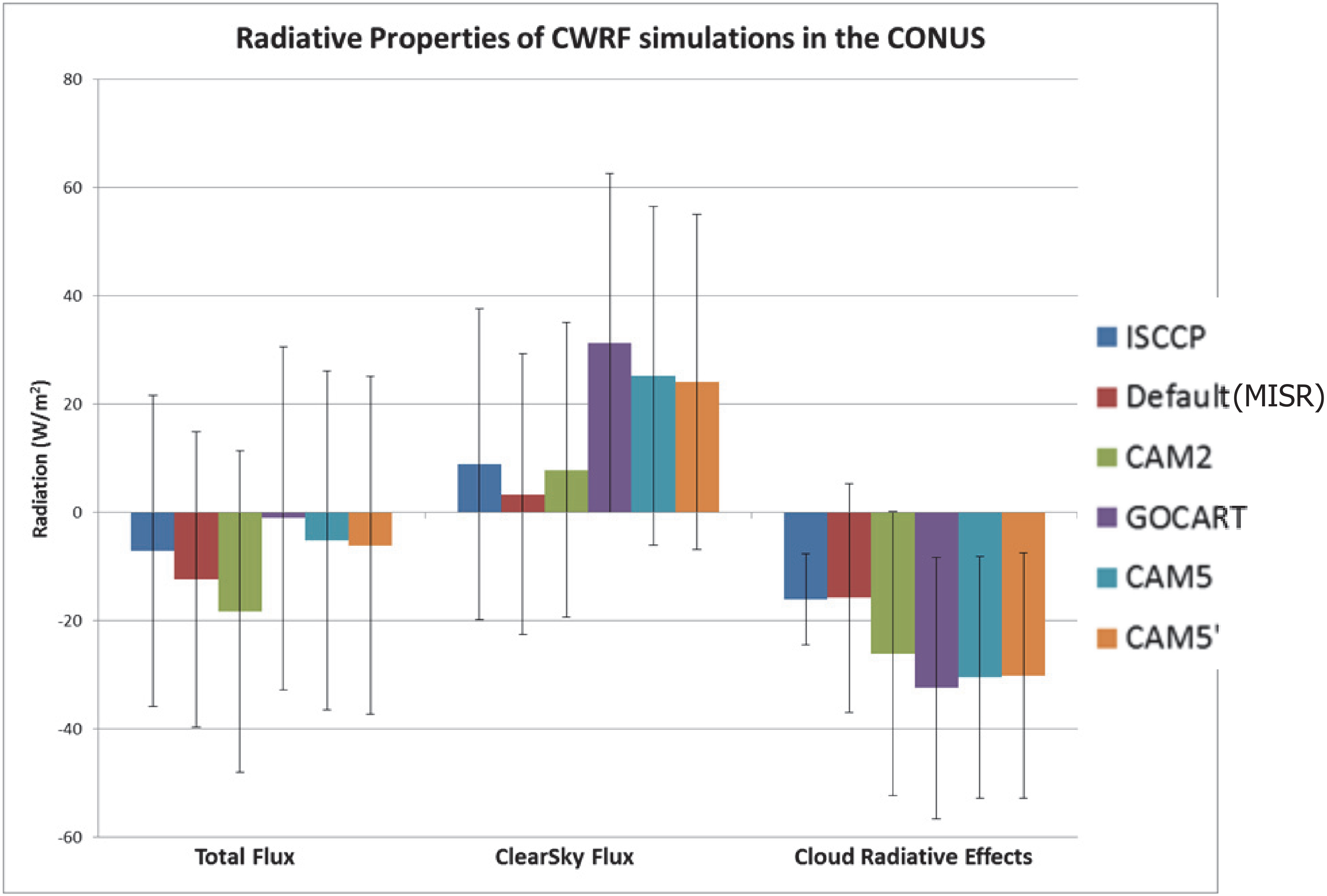
We used CWRF with an ensemble model to choose one combination of cloud-aerosol-radiation.



However, when clouds were right, aerosol wasn't, so we used offline aerosol fields (not ideal).

Comparison between modeled and observed fluxes (*average over Continental US)*

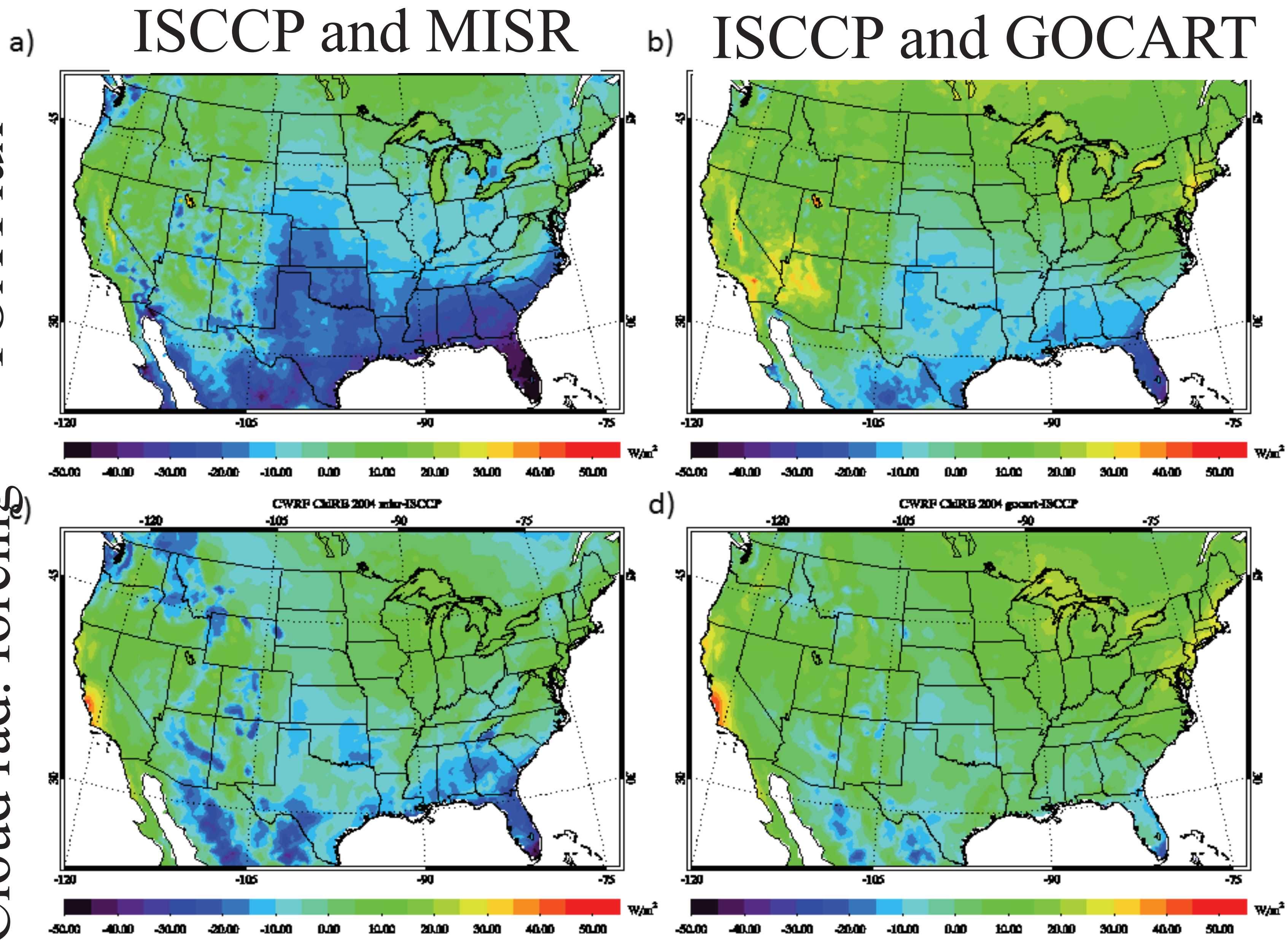
Error bars are std dev of all grid boxes



Biases appear lower (but not perfect) with GOCART fields

TOA Flux

Cloud rad. forcing



The connections still need work.

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

Disconnect:
Model components are getting *more* rigid– difficult to switch in components that work best

Objective 2: Employ an ensemble of parameterizations in regional-scale models to identify best estimates and uncertainties for direct and cloud-related forcing

Emission-to-forcing measures

Objective 3: Model Interpretation for Policy Relevance

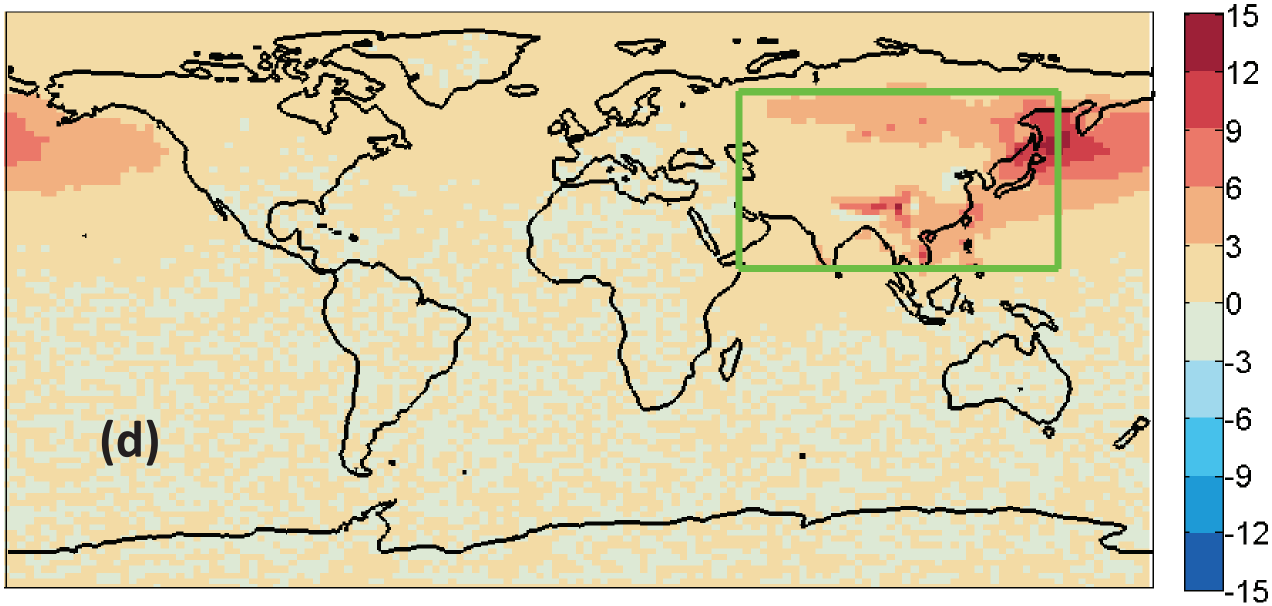
(Yanju Chen– Univ of Illinois)

Basic approach: Global model, regional reductions

Reported previously:

- Used Community Atmosphere Model (CAM), version modified for polar transport
- Determined that 30°x30° is optimum aggregation region

Indirect radiative forcing of Asia OC



Emission region

Extensive assistance from H. Wang, P. Rasch at PNNL

We developed a "linearity diagnostic" *R*

50% present-day emission

100% present-day emission

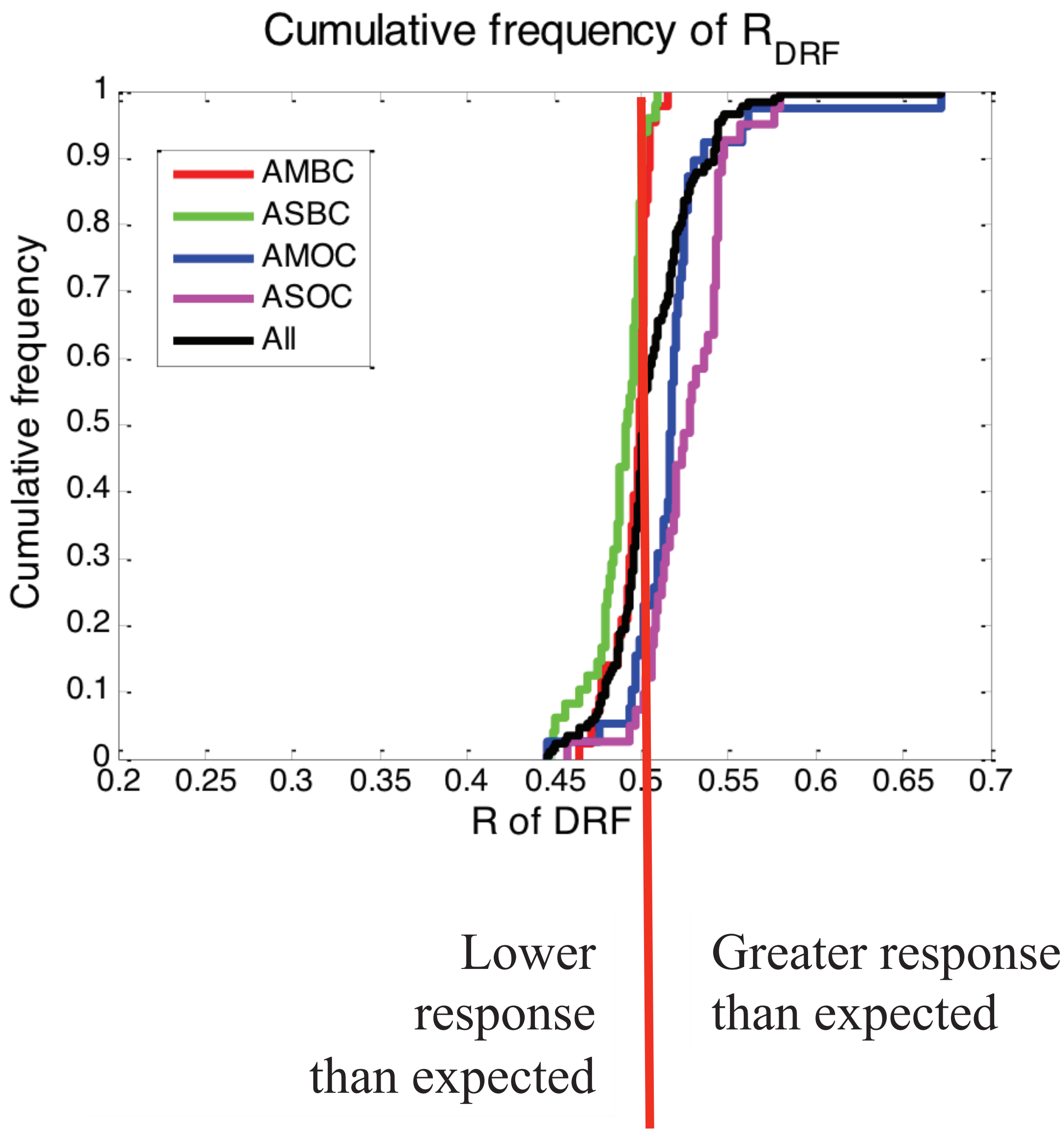
$$R = \frac{F_{100} - F_{50}}{F_{100} - F_{0}}$$

0 emission

R≅ 0.5: Forcing is linear in emission.

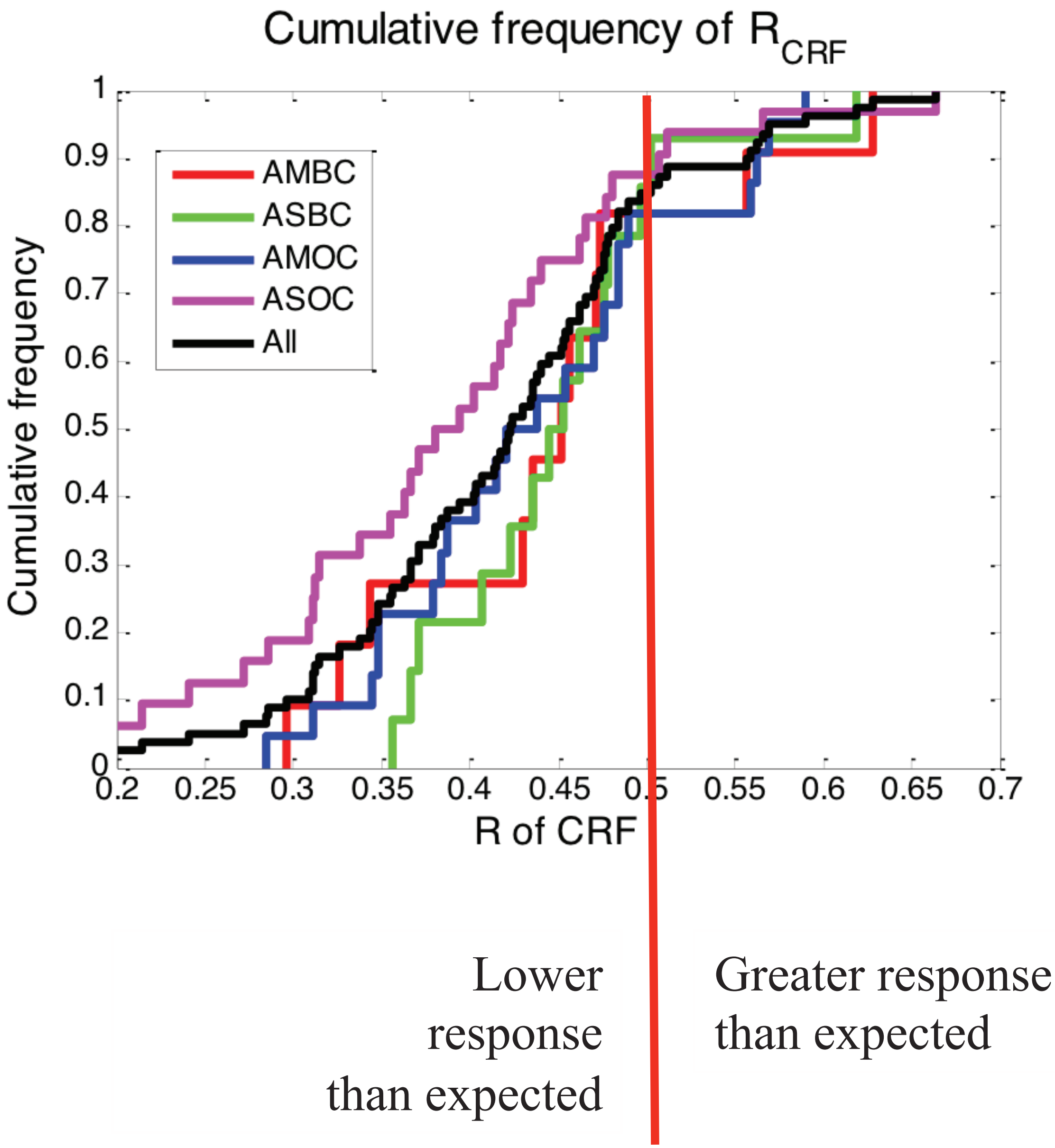
R< 0.5: Small emission change from present-day produces *less forcing change* than one would expect

Direct forcing is linear, as expected



Not much to see here. Just checking.

Indirect forcing is nonlinear and lower than expected

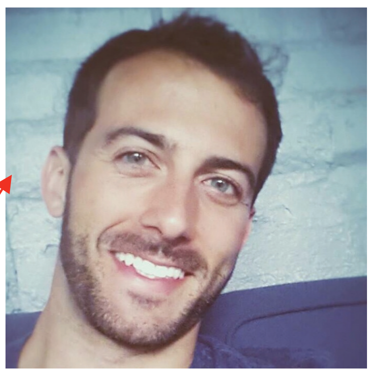


Cause: Saturation; CCN not activating

Not a new finding, but we didn't know magnitude.
Asian OC CRF is about 40% *less negative* than simple proportion would predict.

Policy-relevant metrics

Policy-relevant metrics



Objective 4: Tell the Story

Praveen Amar, Danielle Meitiv– Clean Air Task Force
Kevin Hade, Tami Bond – University of Illinois

Common metrics have common failings

- Global Warming Potential
  - Integrated forcing per emission
  - Doesn’t take Earth system inertia into account
  - Doesn’t communicate immediacy
  - Requires choice of time horizon
- Global Temperature Potential
  - Temperature change at single year in future
  - Doesn’t communicate trajectory experience
  - Doesn’t communicate immediacy
  - Requires choice of time

Two sets of surveys conducted

- Original goal: Survey state decisionmakers
- Survey 1: 35 policy-oriented people and scientists
- Survey 2: Eight city managers
  (where the climate action is now)

2 reports have been communicated to EPA

Main messages had nothing to do with metrics

- Non-specialists need simple ways to communicate black carbon's effects to non-specialists
  - Even terms like "radiative forcing" and "feedback" are not as straightforward as you think.
- People want to hear about certainty, not uncertainty.

Scientists understand the importance of GWP time horizon…

…but policymakers don't care

images: smh.com.au, dalje.com

The challenge

- Communicate immediacy

  ...without minimizing importance of CO_2
- Communicate timing
- Make it relevant

Also, scenarios & emissions should have parallel treatment?!

Our solution…

which WILL be redacted from this presentation…

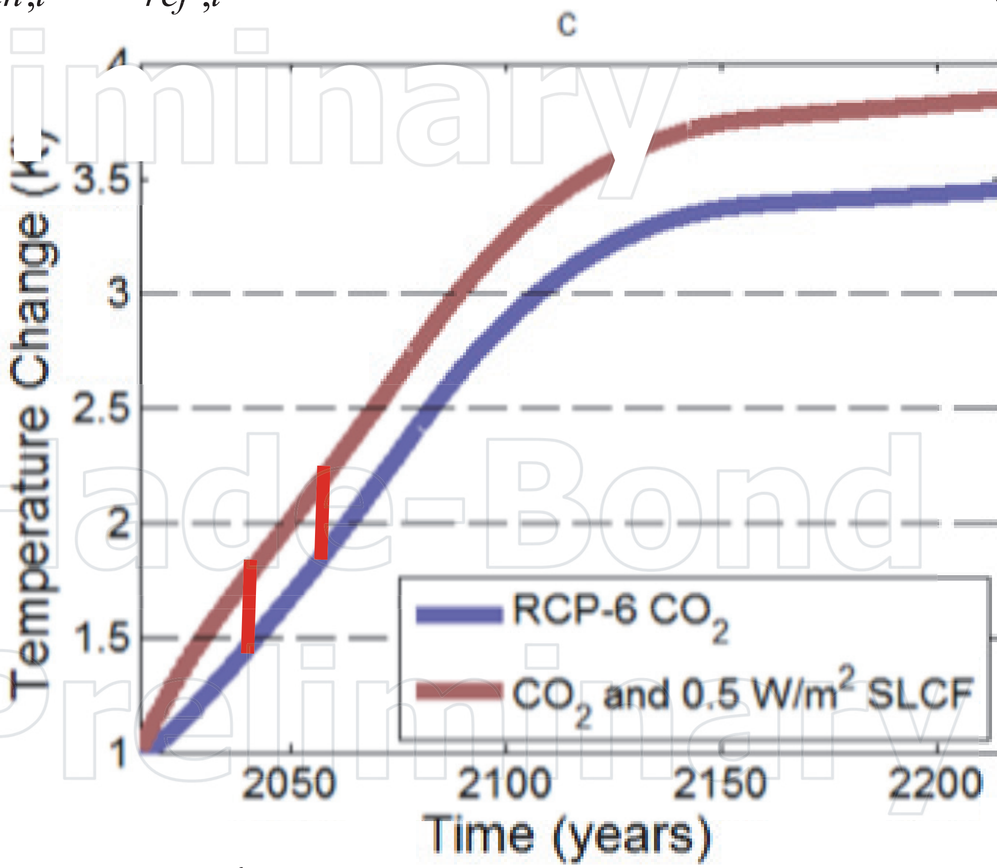
involved a simple energy-balance model that was calibrated against MAGICC

generational Integrated Temperature Perturbation

Super simple.

$$gITP = \sum_i (T_{scen,i} - T_{ref,i})$$

Sum of temp changes across 1 generation.



Following Peters et al. 2011

Can be used for both emission metrics & scenario

Avoided gITP for SLCF at different rates and CO_2