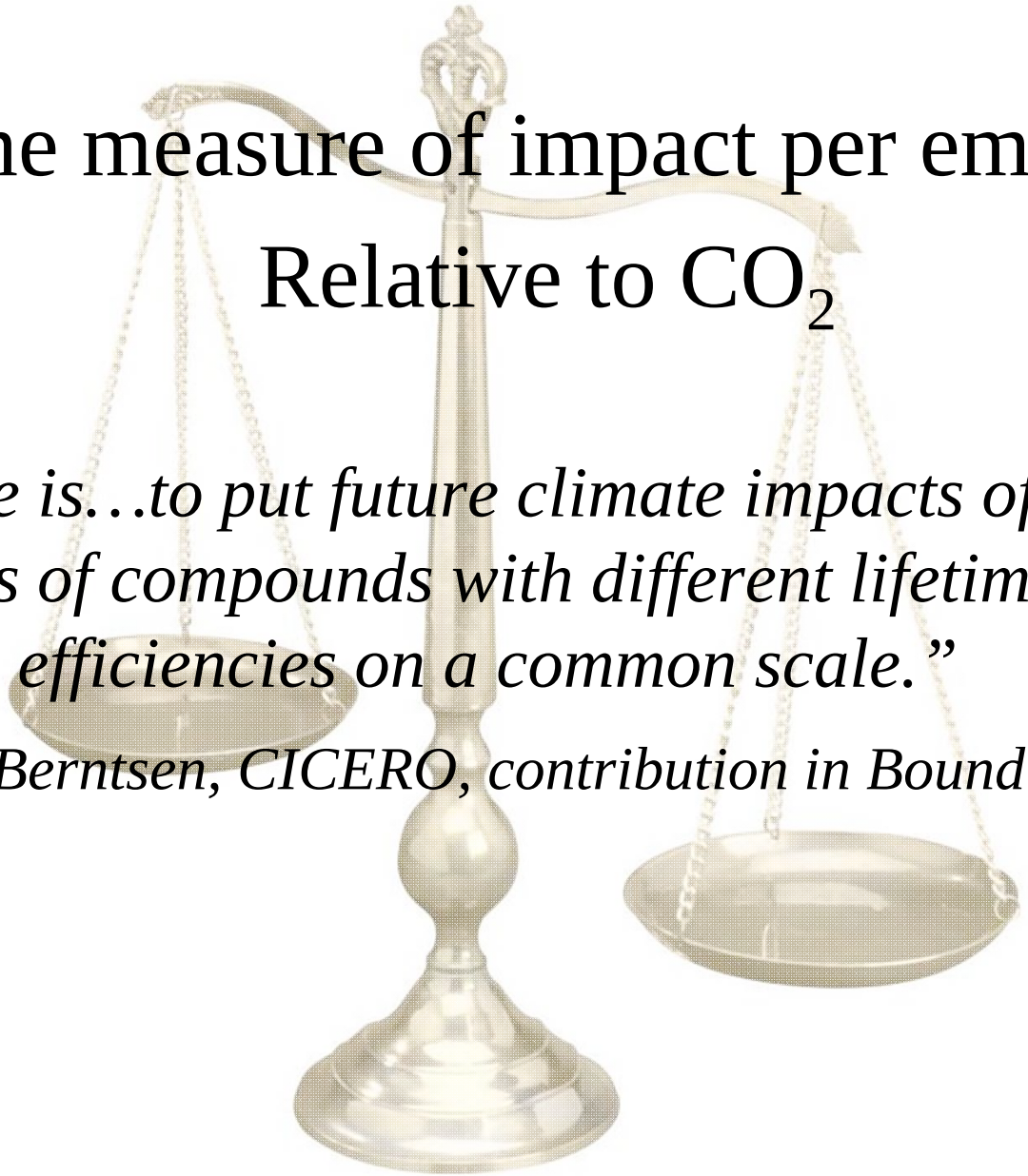
Emission metrics, especially for BC

Tami C. Bond and Yanju Chen
University of Illinois at Urbana-Champaign
March 4, 2014

1. What we learned from “Bounding-BC”
2. Review of emission metrics
3. Proposal and exploration

Definition of emission metrics



Some measure of impact per emission

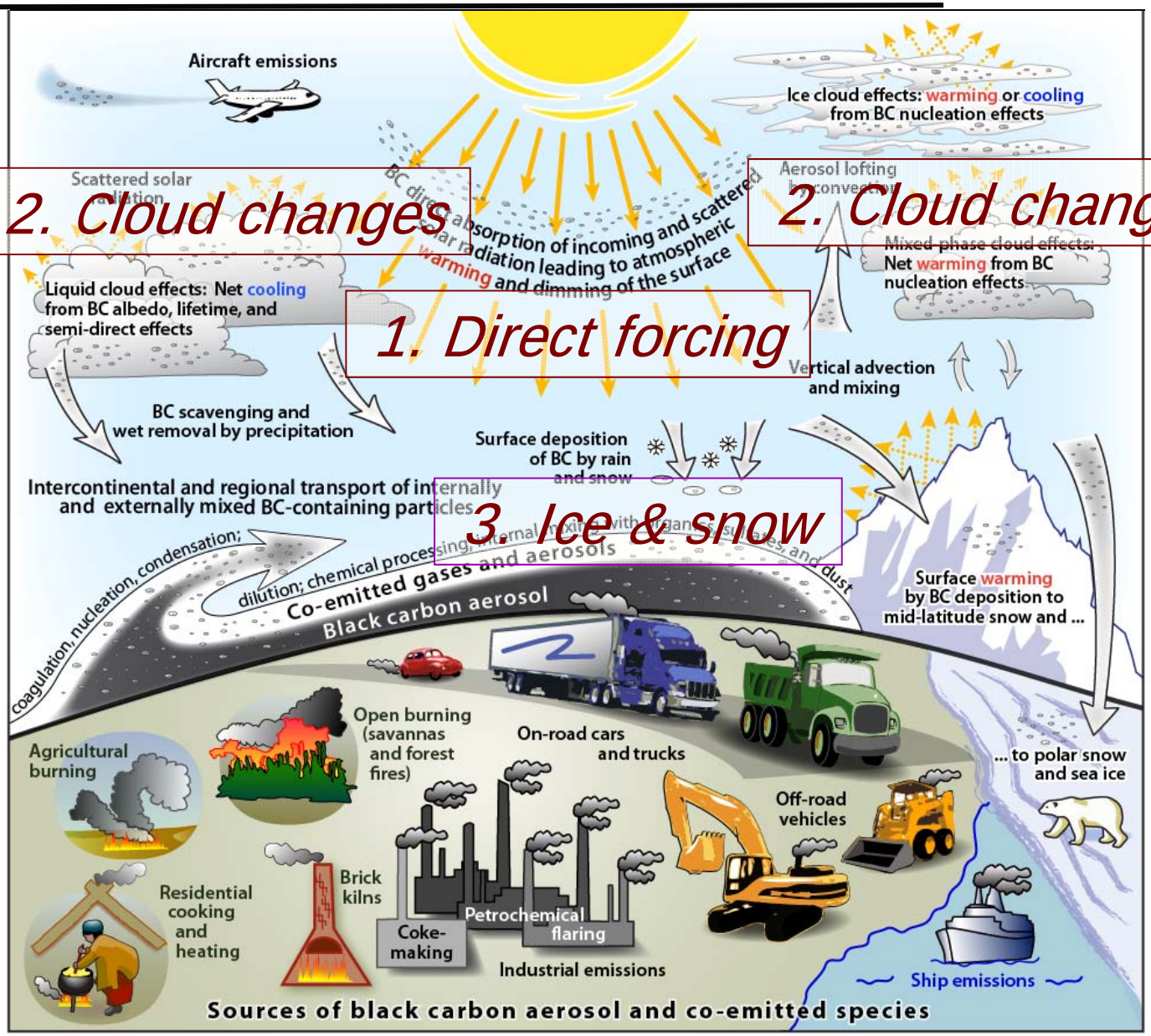
Relative to CO_2

"Purpose is…to put future climate impacts of unit emissions of compounds with different lifetimes and radiative efficiencies on a common scale."

T. Berntsen, CICERO, contribution in Bounding-BC

What we Learned from "Bounding-BC"…

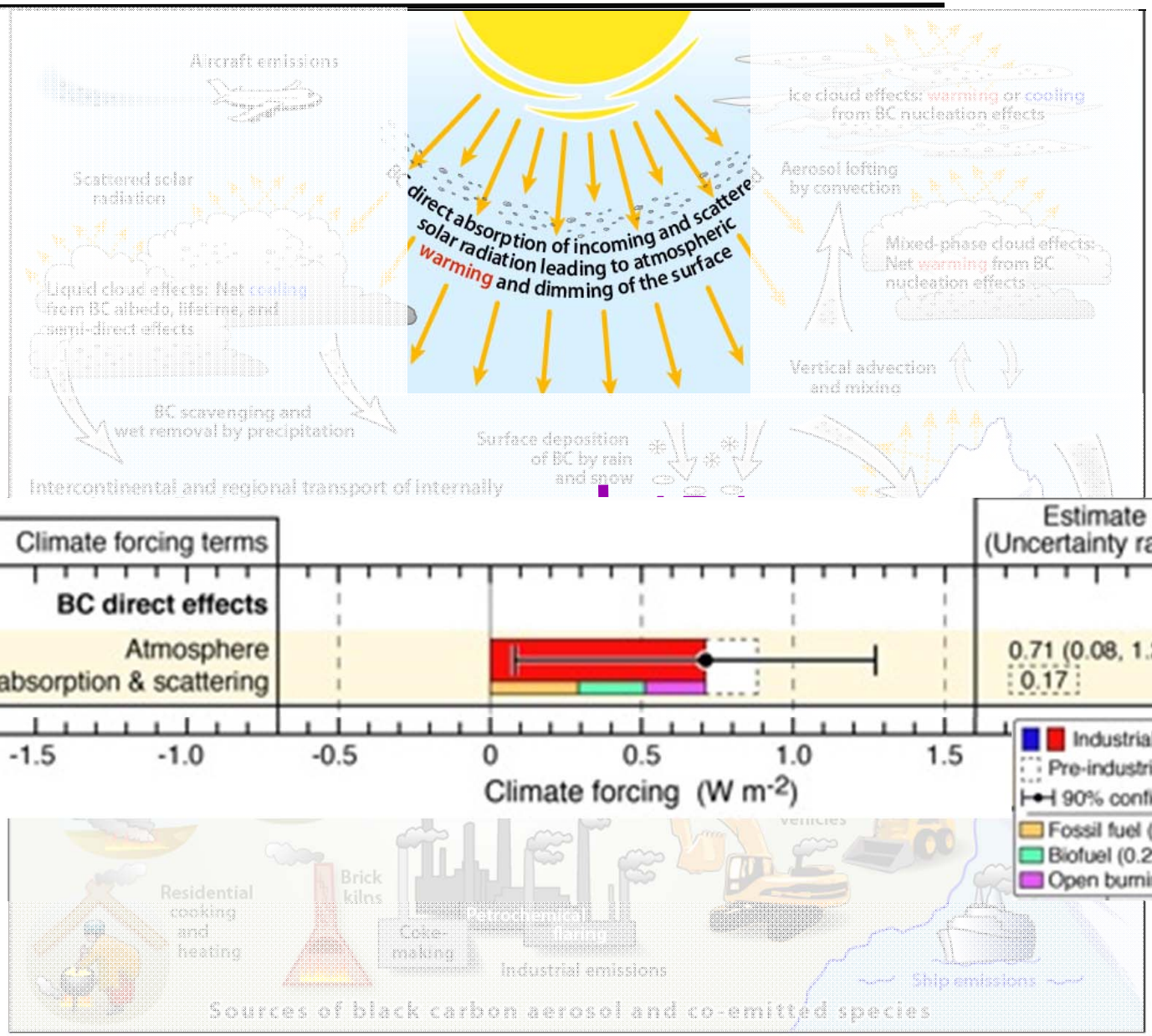
“Comprehensive” with regard to climate effects

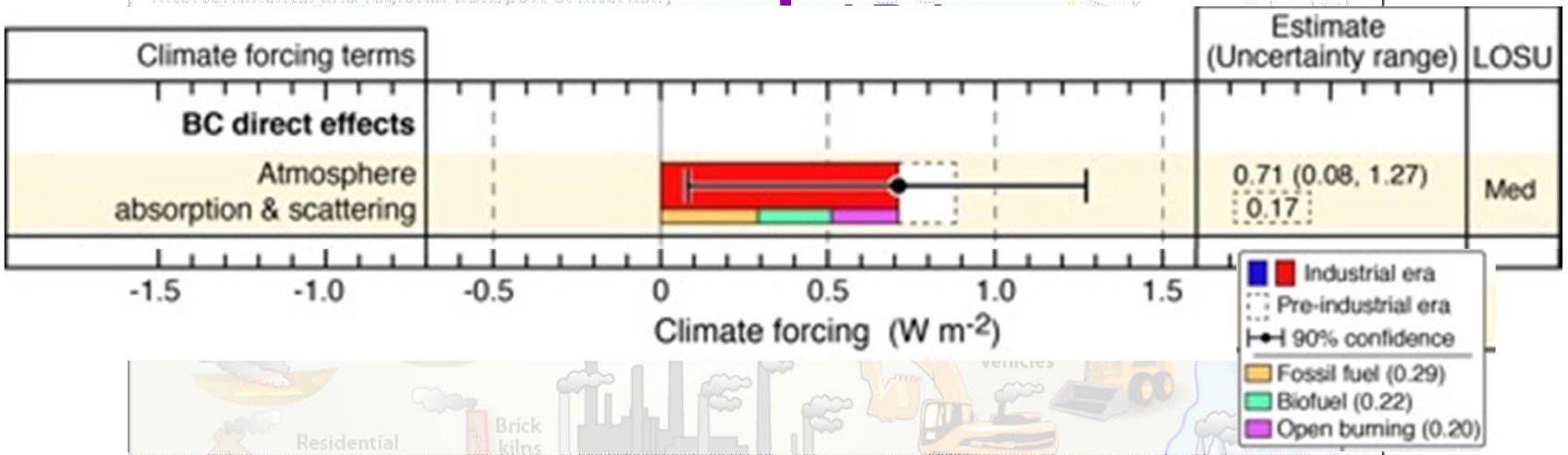


Bond *et al.*, JGR, 2013.

Bounding → Metrics → Proposal

Direct forcing (the usual)

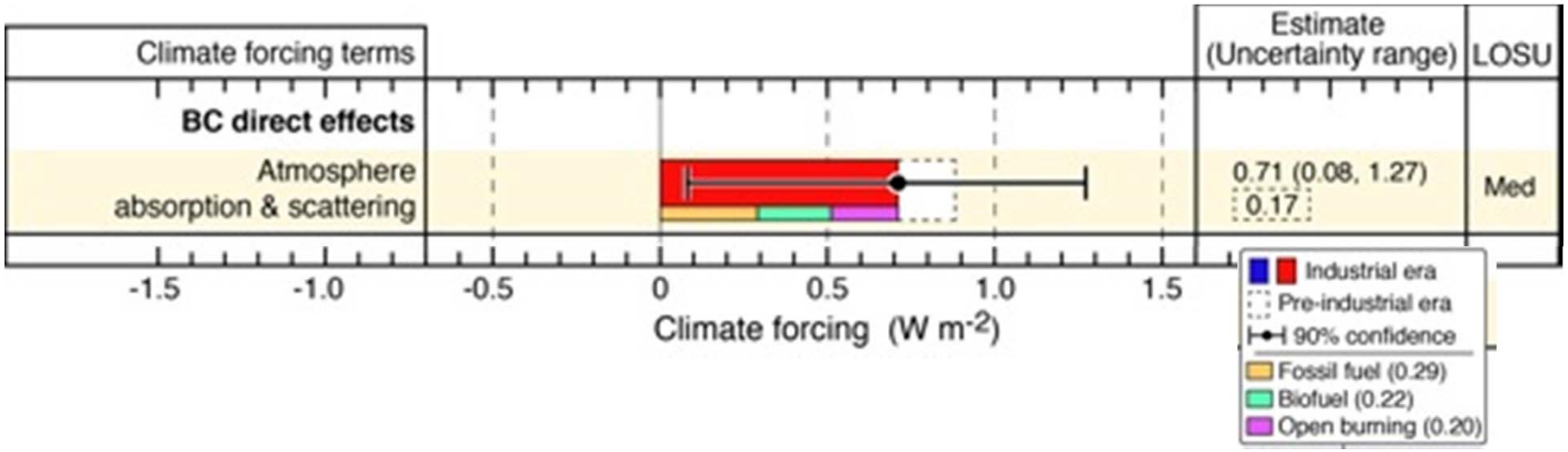




Bond *et al.*, JGR, 2013.

Bounding → Metrics → Proposal

Direct forcing



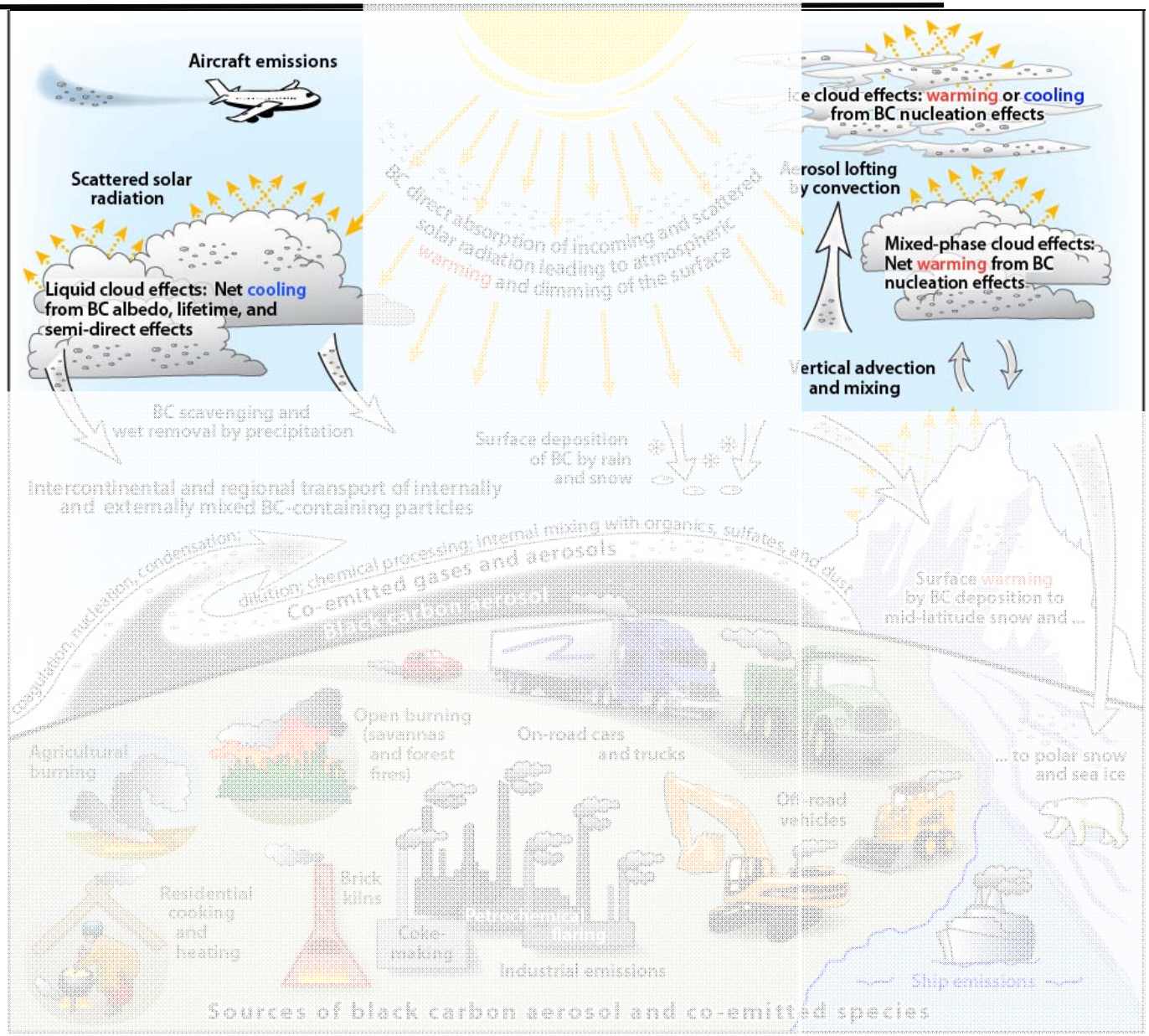
Forcing was assessed to be higher than many previous estimates.

More absorption in the atmosphere than in models

But this was attributed to higher emissions.

Emission-per-forcing didn't change much.

“Indirect” effect



Bond *et al.*, JGR, 2013.

Bounding → Metrics → Proposal

What do you mean, “THE” indirect effect?

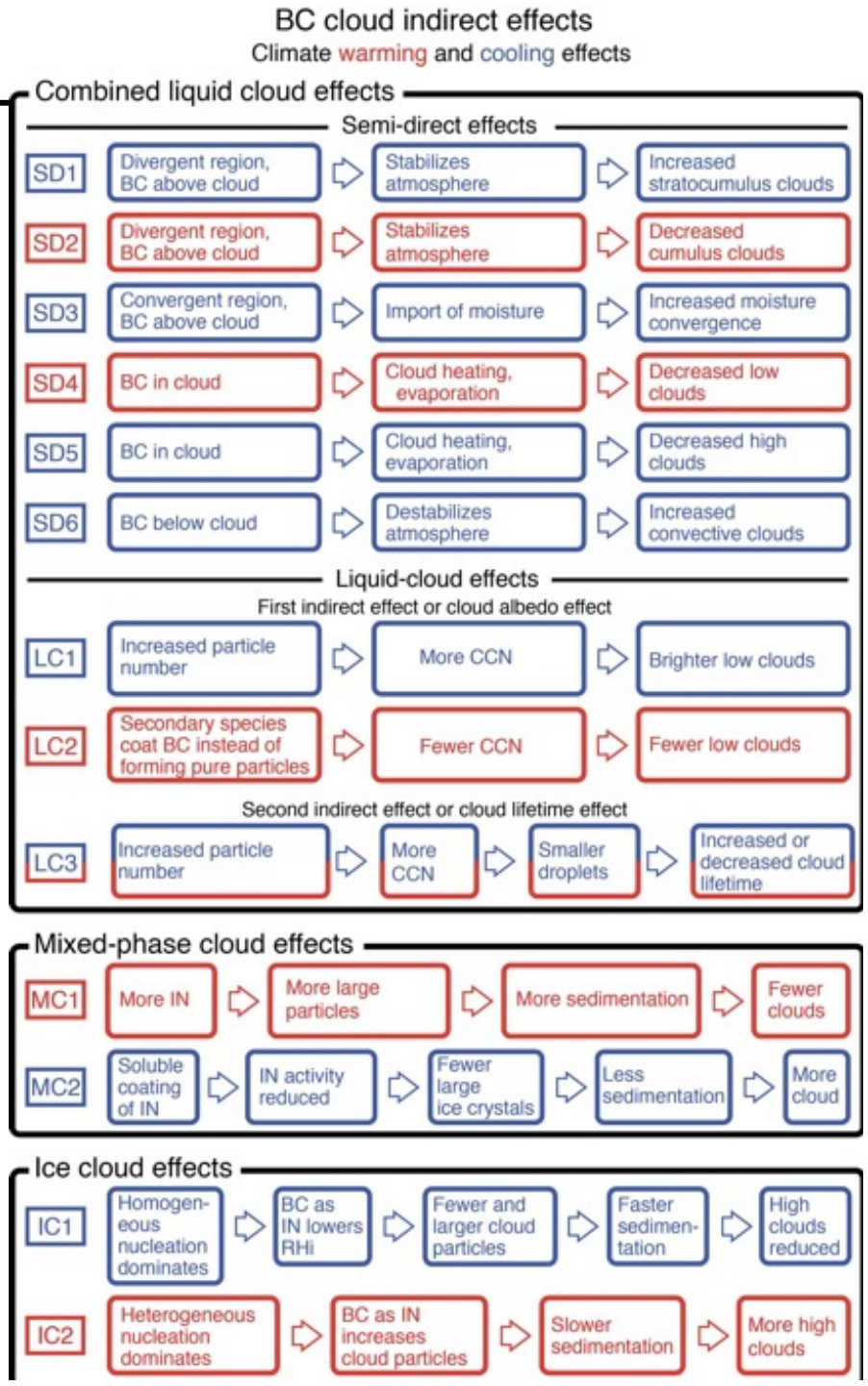
Semi-direct **(-)**
but depends on BC location

Cloud absorption **(+)**
(like burnoff but including BC in cloud droplets)

Liquid indirect **(-)**
but small

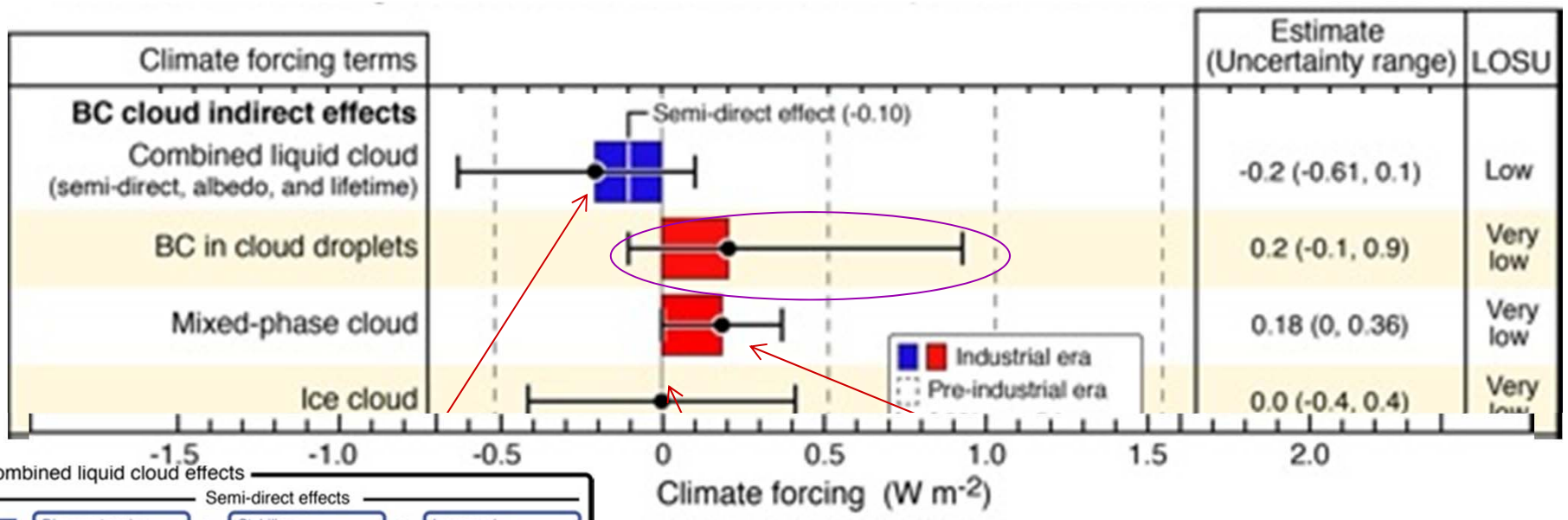
Mixed (water-ice) clouds **(+)**

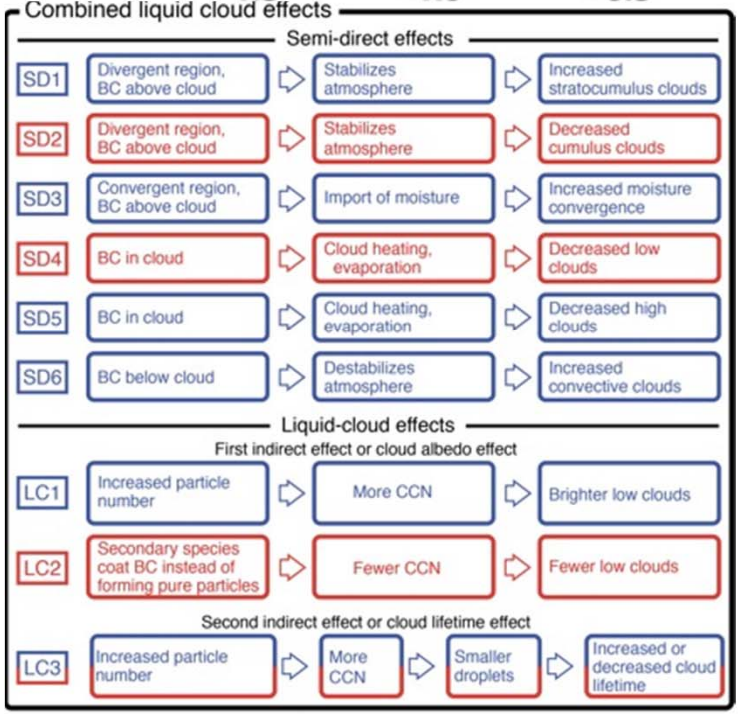
Ice clouds **+ / -**

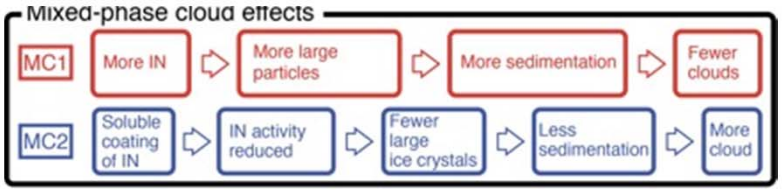


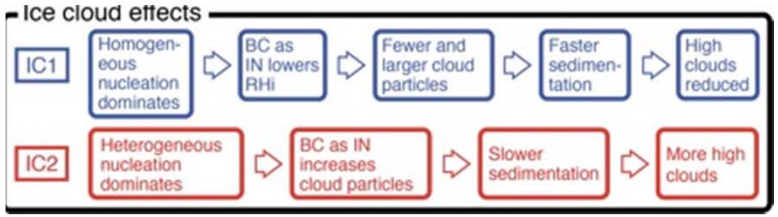
Bounding → Metrics → Proposal

Summary of cloud effects: *net positive*

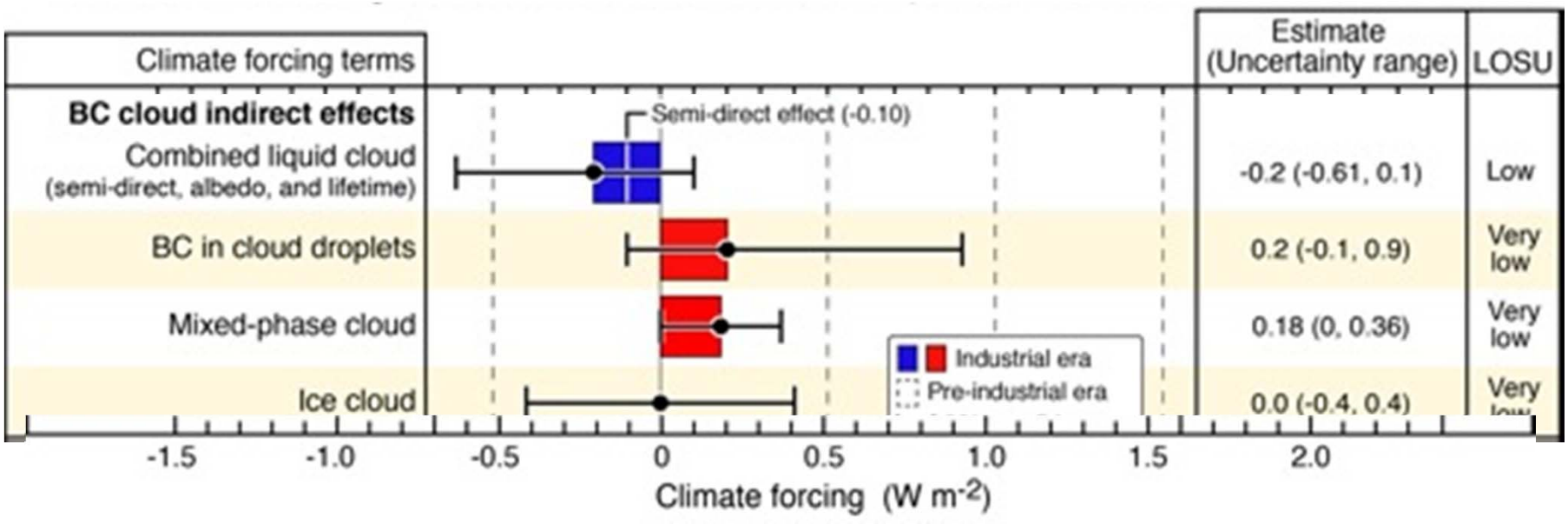






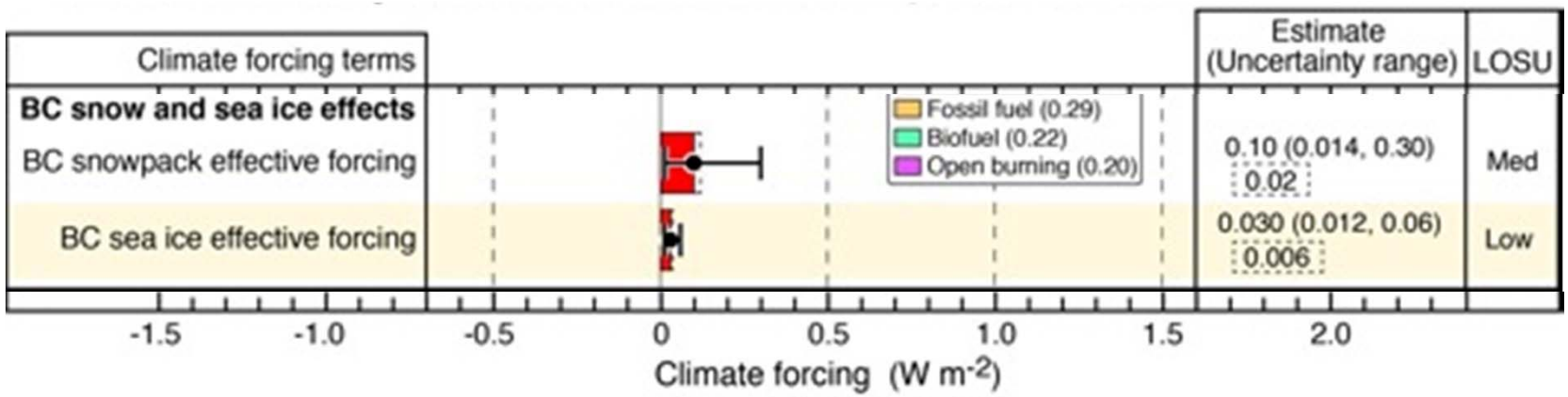


Summary of cloud effects: *net positive*



<u>Attribution</u> (to particular sources) is a major problem

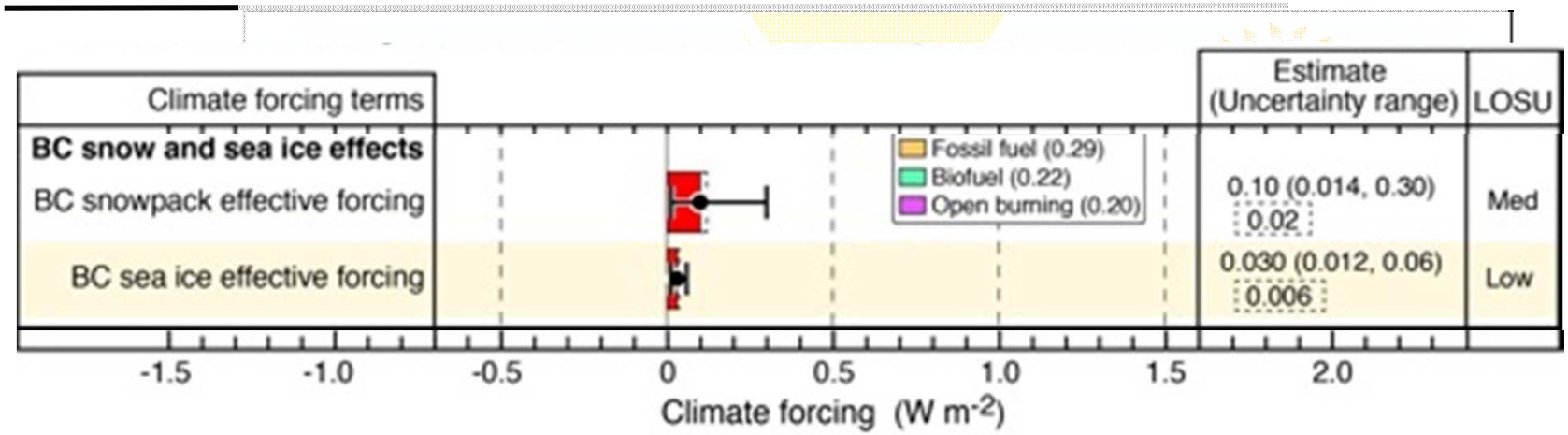
Snow-albedo effect

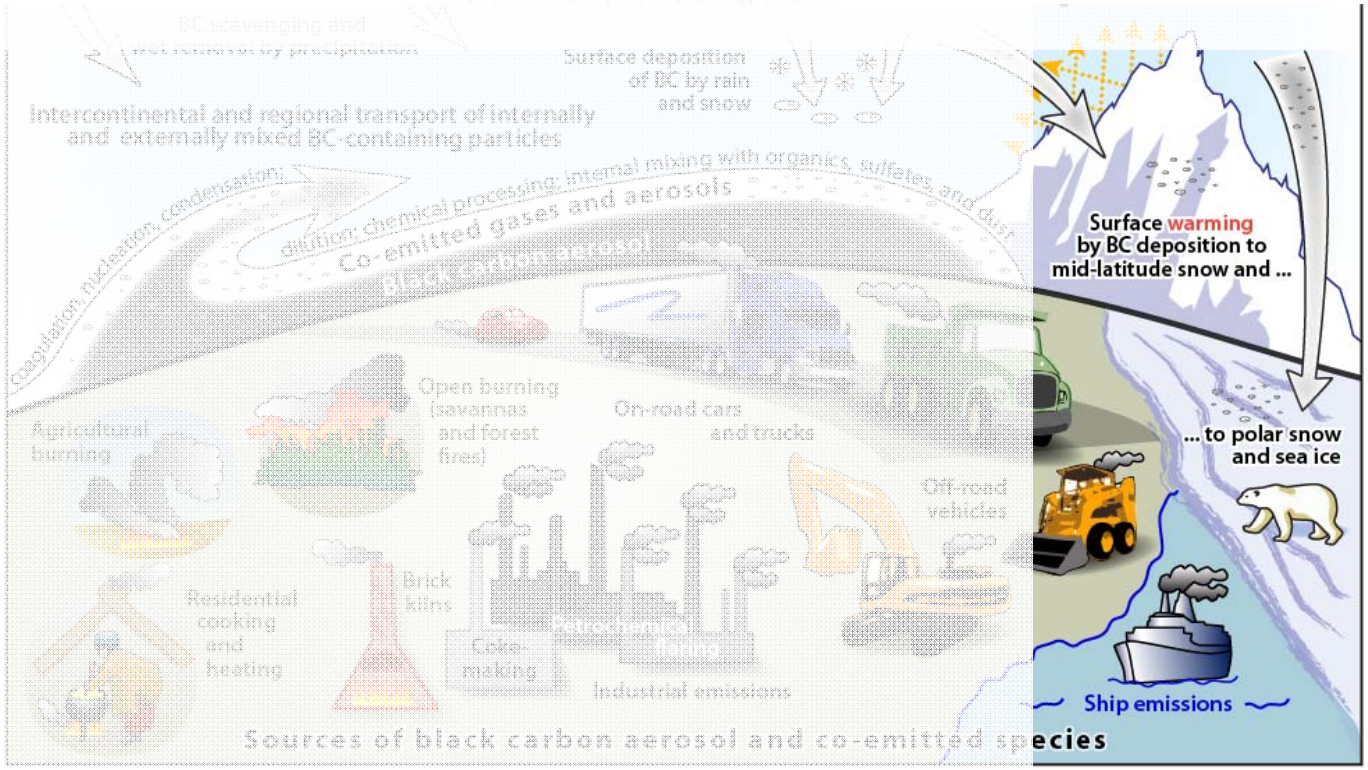


<u>Attribution</u> (to particular sources) is not TOO hard…

although there is still a lot we don't know about transport
(More distant = More uncertain)

Snow-albedo effect



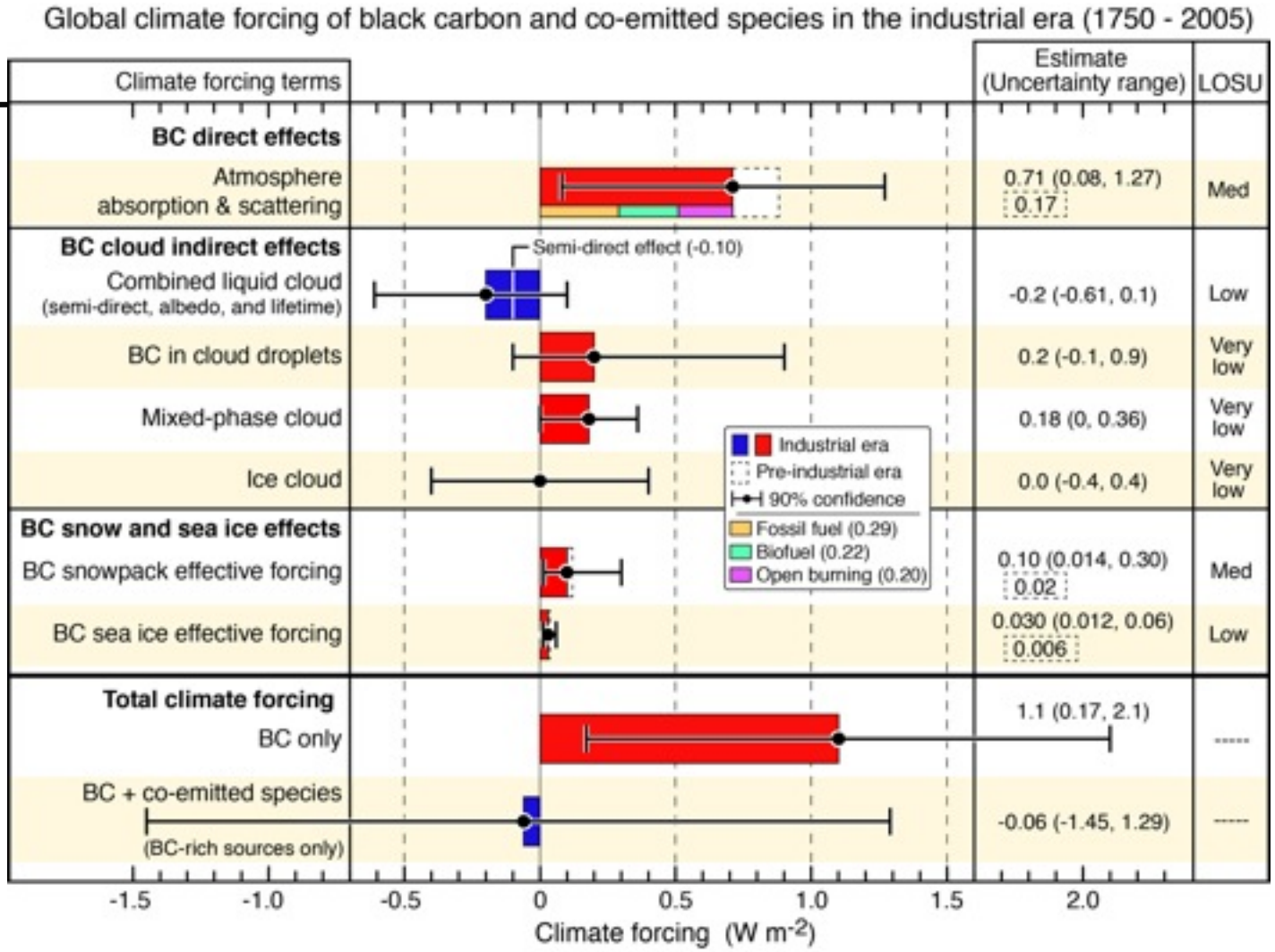


Bond *et al.*, JGR, 2013.

Bounding → Metrics → Proposal

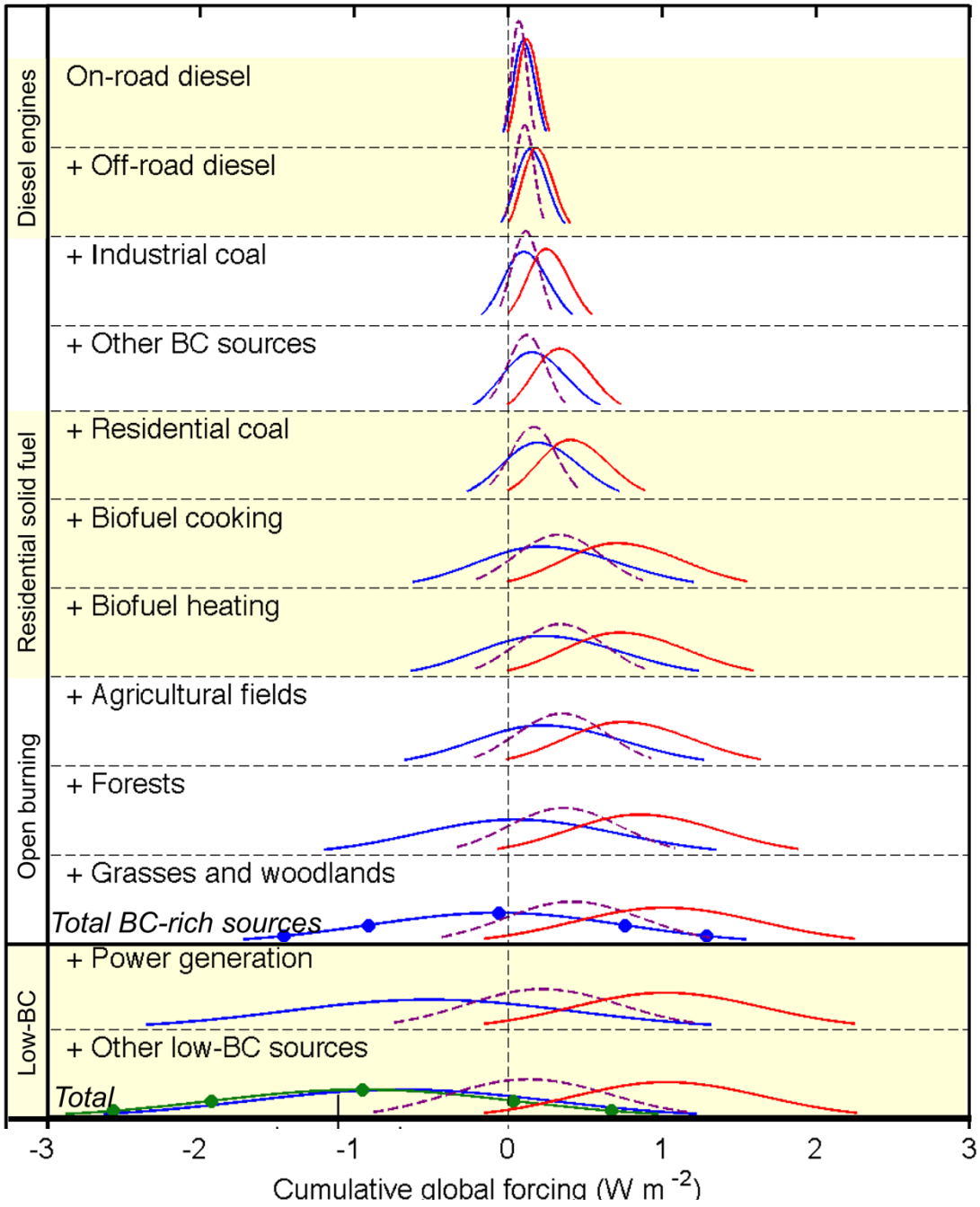
At last:

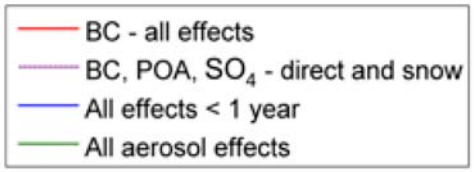
(But that's not the point of this talk.)



- Black carbon is the 2nd most important climate forcing agent in 2000-2005.

Cumulative forcing (add selected categories)





BC forcing positive (+0.33)
Total forcing positive (+0.15)

BC forcing positive (+0.72)
Total forcing still positive (+0.21)
but becoming less certainly so,
because of cloud uncertainties

BC forcing positive (+1.01)
Total forcing nearly neutral (-0.06)
because of large OC & its cloud forcing
(*note: simple sum differs from BC median produced by Monte Carlo analysis)*

Remainder of aerosol forcing
is in low-BC categories (total -0.95)

Message:

- IF we reduce aerosol concentrations *(which must happen to protect public health)*
- THEN “BC-rich sources” are the most climate-friendly targets.
- AND the sources with fewer cloud-active species are most certain to be climate-friendly.

NOTES ABOUT EMISSION METRICS

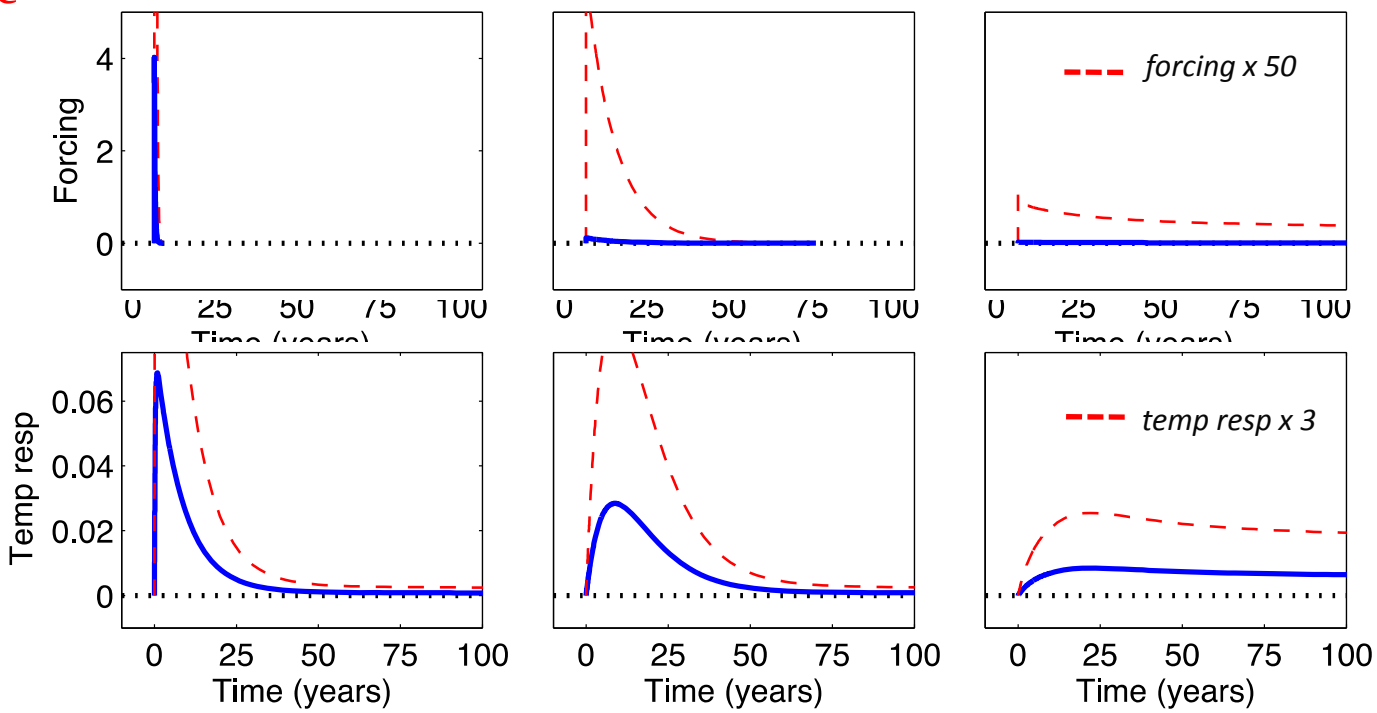
Each pollutant induces different response

Atmospheric lifetime → Response to a pulse of emission

τ<<1 yr | τ~10 yrs | τ>50 yrs

Forcing trajectory follows atmos. concentration

Temperature lags because of Earth's heat capacity



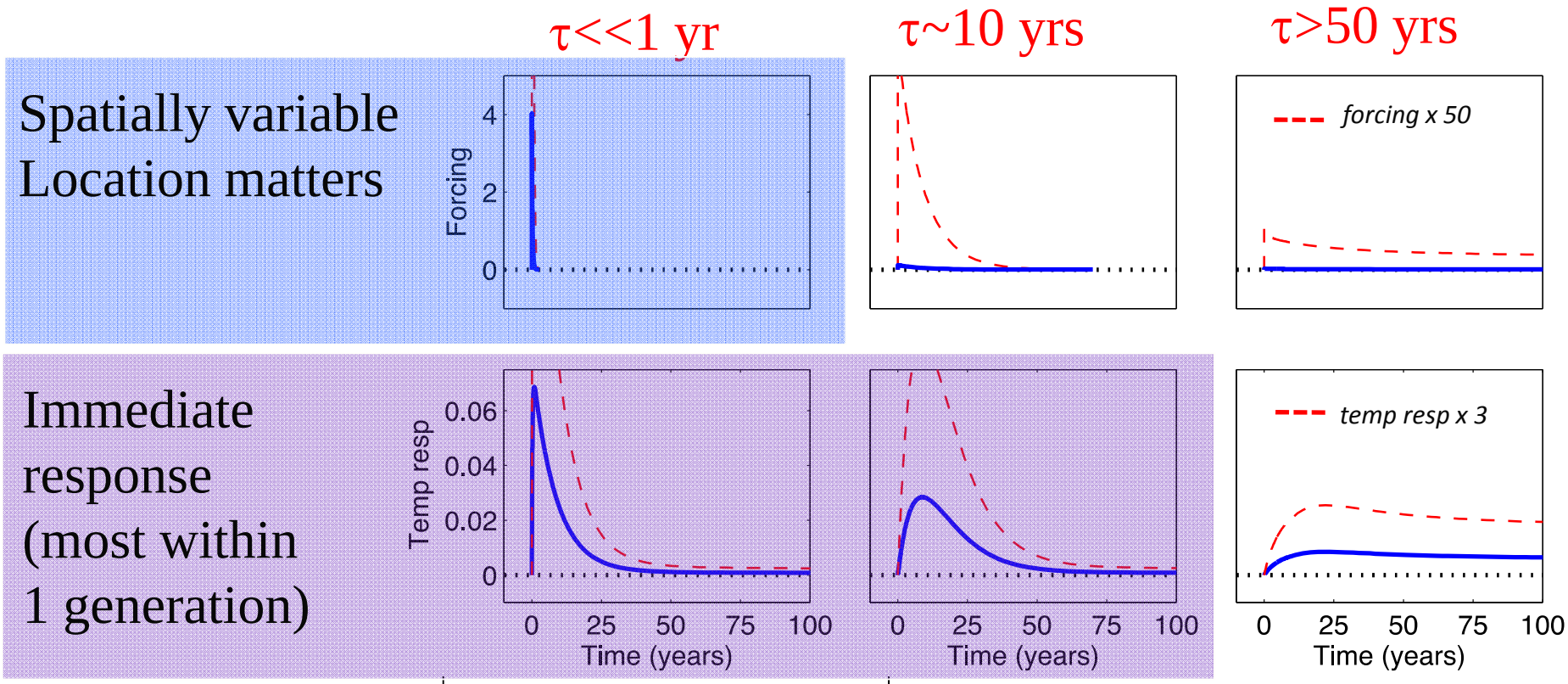
Aerosols, trop. O_3 ↑ (CO, NOx, VOC)

CH_4 ↑ (CO, NOx, VOC)

CO_2

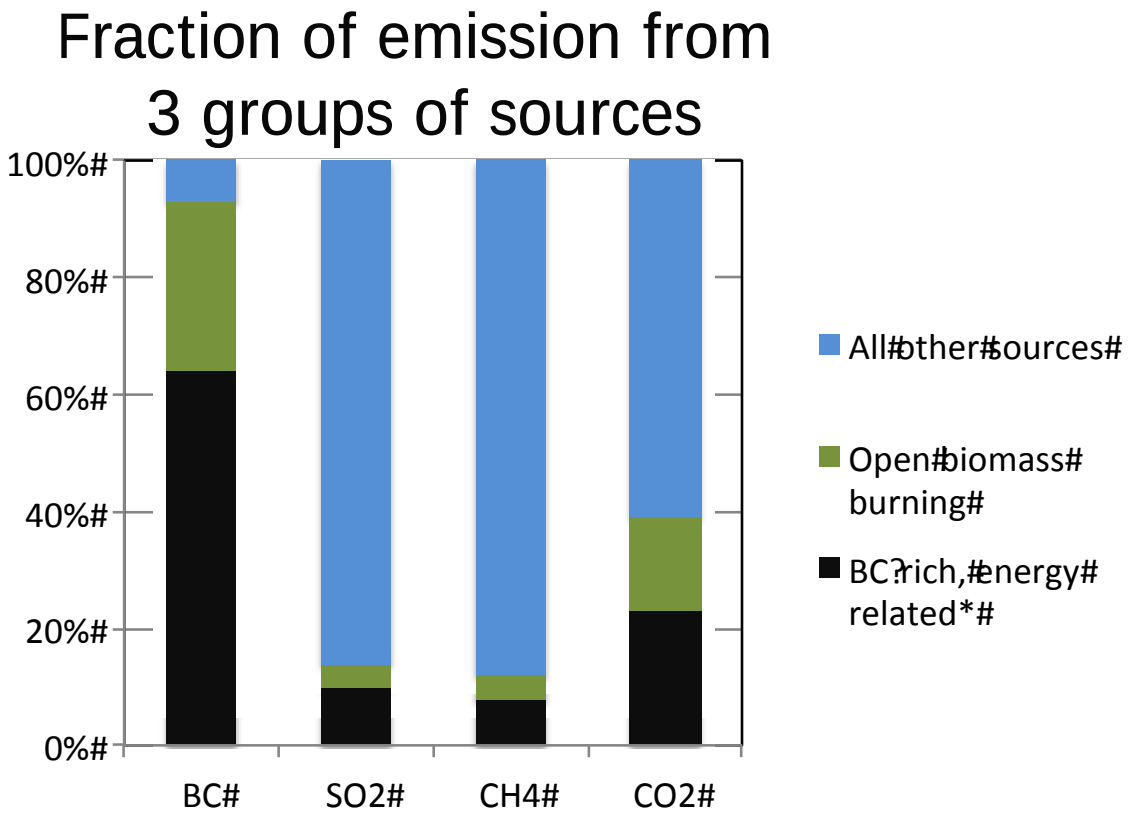
Figure from Bond et al., ACP 11, 1505 (2011)
Forcing timescales: eg Wild & Prather, JGR 105, 24647 (2000)

Each pollutant induces different response



Challenge → Metrics → Proposal

Short-lived and long-lived warming have different sources



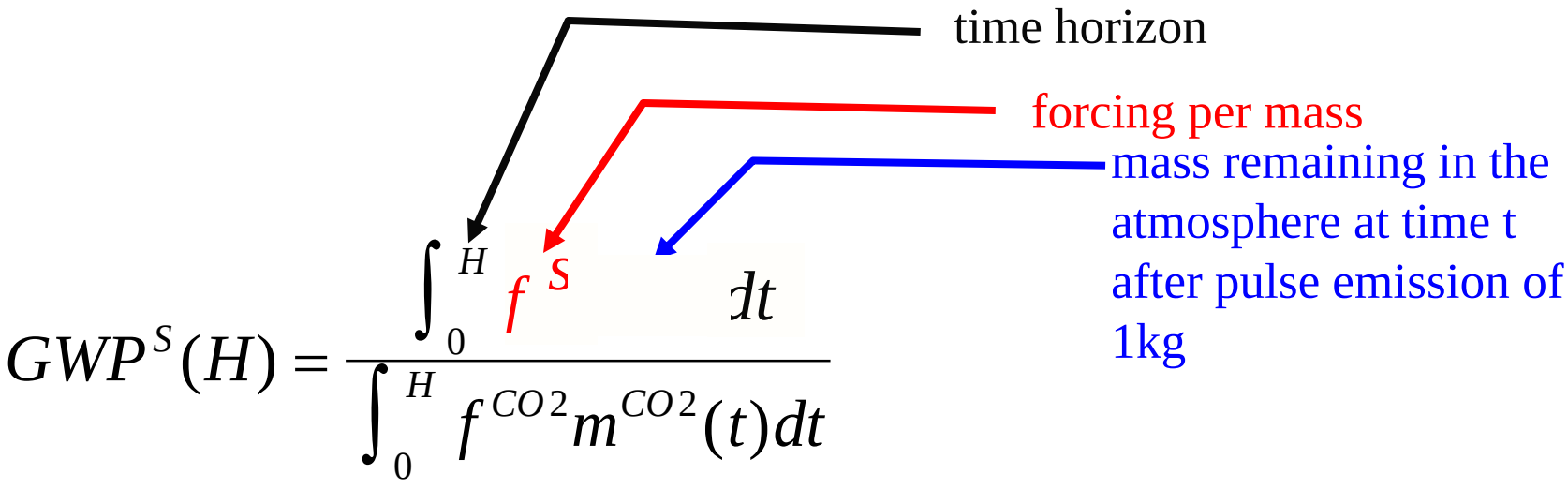
Two-thirds of BC is associated with <25% of the CO_2 and <10% of SO_2

* these are the "BC-rich" source categories identified in "Bounding-BC," Bond et al., JGR 2013

Bounding → Metrics → Proposal

Global Warming Potential: a review

Basic idea:
How much forcing is caused by
1kg of substance *S*
compared with 1kg of CO_2?



Global Warming Potential: a review

Basic idea:
How much forcing is caused by
1kg of substance *S*
compared with 1kg of CO_2?

$$GWP^S(H) = \frac{\int_0^H f^S m^S(t)dt}{\int_0^H f^{CO2} m^{CO2}(t)dt}$$

Absolute Global Warming Potential for *S*

Absolute Global Warming Potential for CO_2

Global Warming Potential of BC

Time horizon, H (yr)	AGWP of BC		AGWP of CO2		GWP of BC
20	26010	÷	13	=	2100

The BC part doesn't change

…no surprise; it occurs all in 1 year

Units above: W yr/kg

You may also see (W m-2)/(kg yr-1)

I don't use that here because global average forcing doesn't exist

Advocates' perception

*GWP 20 = 2100**

GWP 500 = 180

** direct forcing only; values from Bounding-BC*

Explaining the GWP time horizon

understand
the importance… but policymakers

could care less

images: smh.com.au, dalje.com

Where we stand

- GWP* has wildly varying values
  (despite its wide acceptance)
- Variation is caused by an arbitrary choice:
  the time horizon
- Meanwhile, GWP misses distinguishing characteristics of short-lived climate forcers:
  immediate & spatially distinct

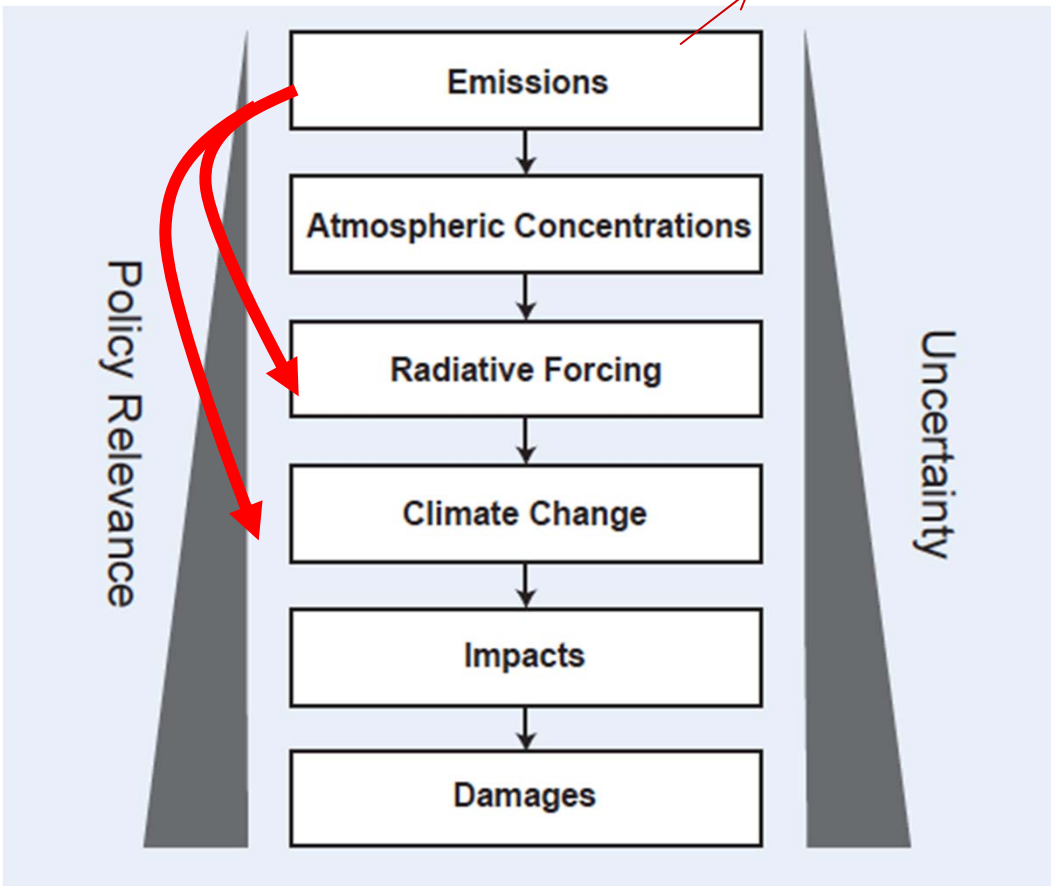
* and Global Temperature Potential, too

Ideal emission metrics would…

- capture important differences in atmospheric behavior
- enable analysis that can achieve climate targets
- minimize the “eye-glaze factor” for non-scientists
- evolve along with scientific understanding

How to evolve as understanding grows?

of one species(?)



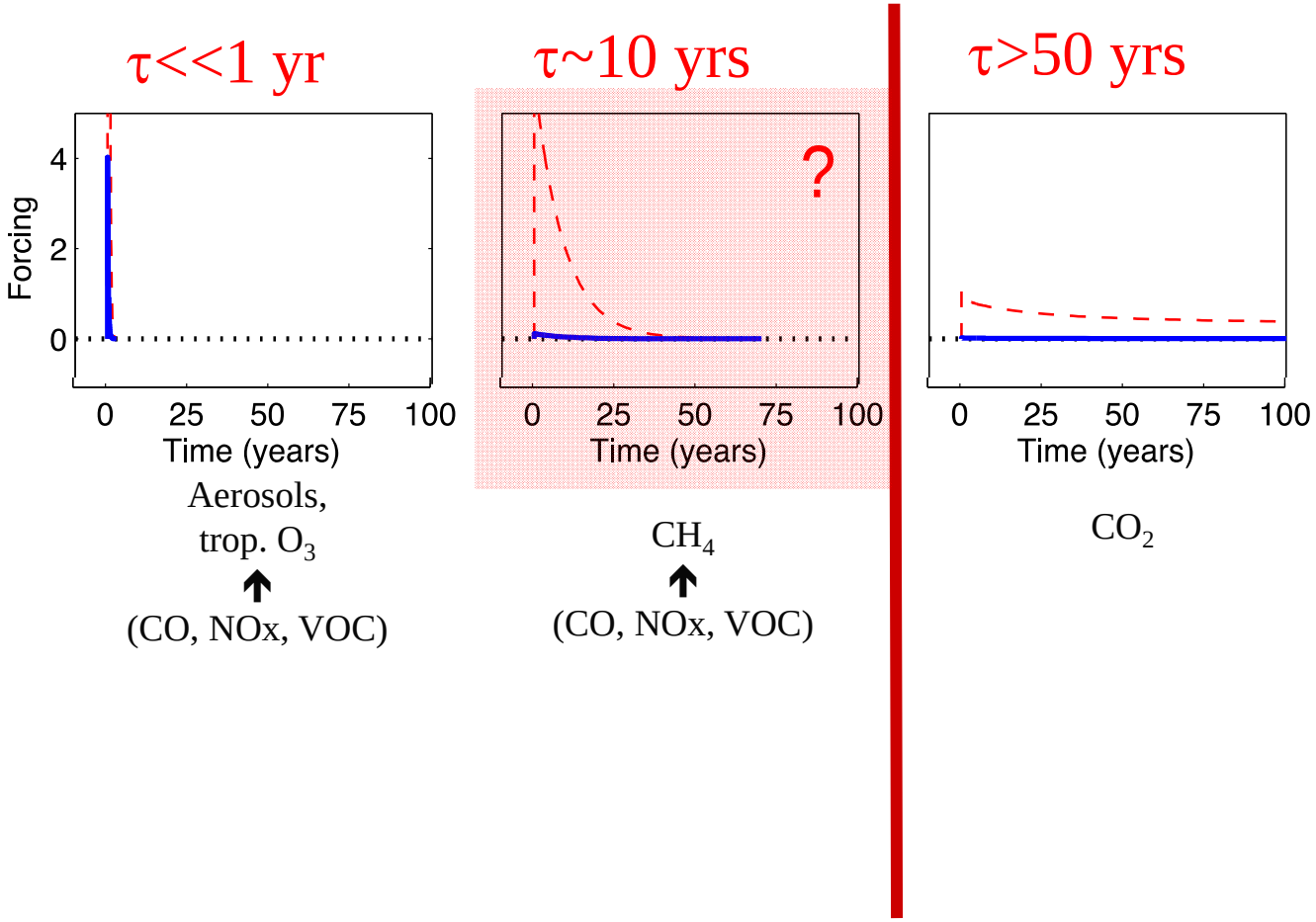
Each step is location-dependent

1) If you're modeling a big leap, save the steps in between
2) Seek observables and use them

Image: Meeting Report, IPCC Expert Meeting on the Science of Alternative Metrics

PROPOSAL

Proposal: formal separation



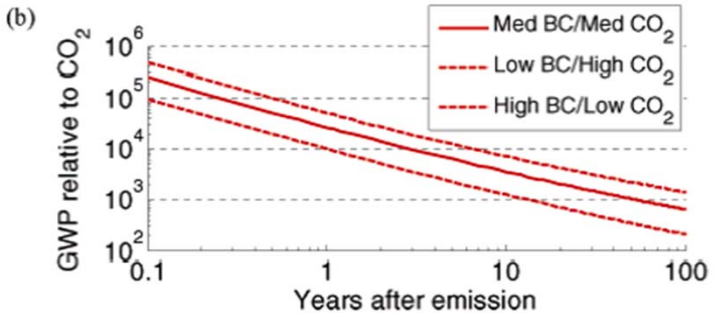
integrated forcing (W•yr) is OK for now
but use ratio (like GWP) only when it's useful or helpful

Dear GWP_{BC} :
If I brought you into this world… can I take you out?

Environ. Sci. Technol. **2005**, *39*, 5921–5926

Can Reducing Black Carbon Emissions Counteract Global Warming?

TAMI C. BOND* AND HAOLIN SUN
Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois 61801



Feasibility: Cost and Control

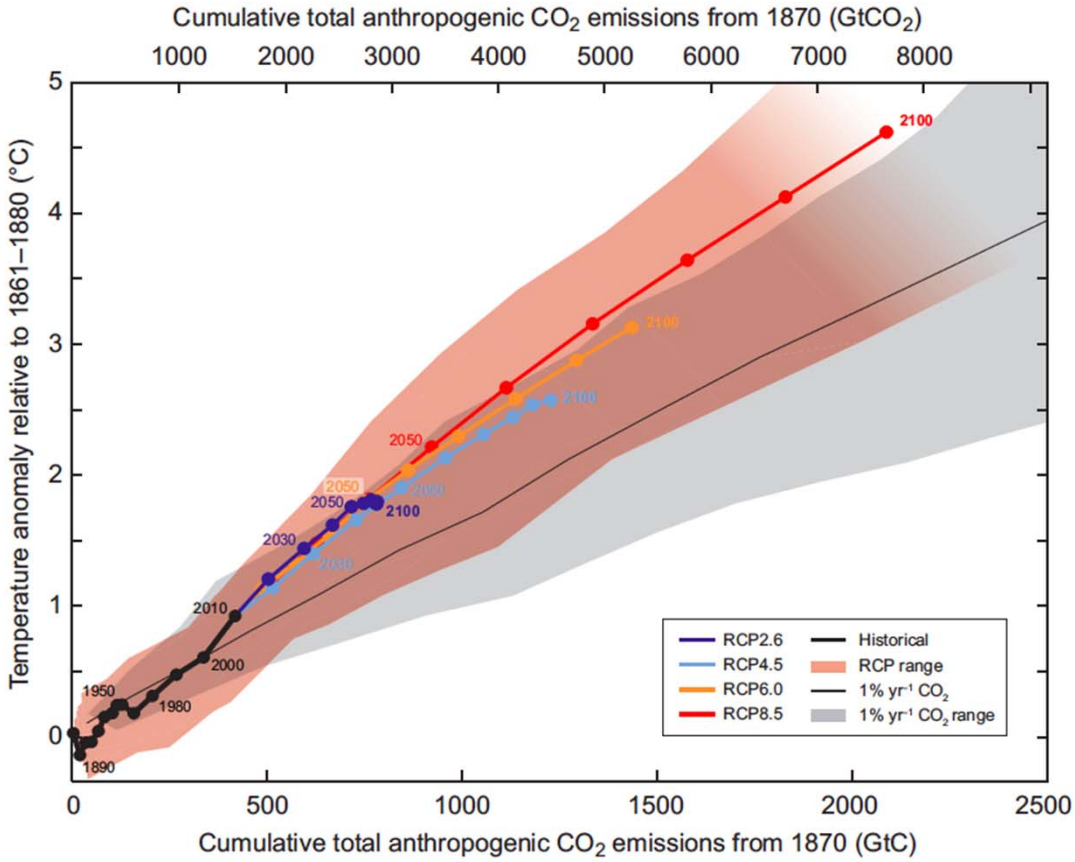
In part due to the scientific arguments against equivalence, BC reductions have not yet been assessed within a framework similar to that of CO_2. Introducing a GWP for aerosols may be controversial, but it is useful for this preliminary inquiry. Within the limitations of current uncertainty, we can inquire whether these reductions might be cost-effective for climate purposes. If BC reductions are clearly expensive in such a framework, then they are not viable alternatives to GHG mitigation and should be discussed mainly for their ancillary

AR5, 2013: IPCC reports GWP for SLCF
OK, now we can move on

The thinking about long-term carbon commitment is changing, anyway.

Peak temperature appears proportional to *cumulative* carbon emissions.

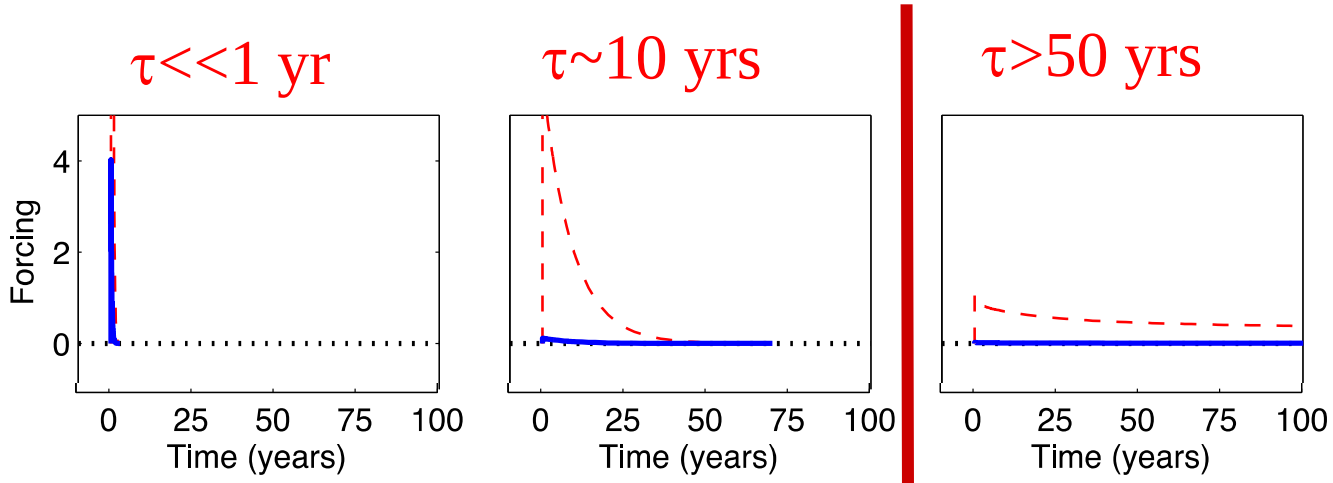
Equivalence on emission basis not possible



IPCC AR5 Fig SPM.10
Based on work since 2009 & since
See Allen et al, Nature 458, 1163;
Matthews et al, Nature 459, 829;
Zickfeld et al, PNAS 106, 16129

Challenge → Metrics → Proposal

Proposal: formal separation



Almost all forcing occurs within near future (25 years)

Contribute to peak temperature

integrated forcing (W•yr) is OK for now
use ratio (like GWP) only when it's useful or helpful

Short-term integrated forcing

$$AGWP(H) = \int_{t=0}^{H} f^S m^S(t)\,dt$$

We really really need forcing-per-emission values, please!

We also need fast responses (within 1 year), normalized to emission or forcing, please!

H doesn't matter, so

$$AGWP = \int f^S m^S(t)\,dt$$

The global average is questionable, so

$$AGWP = \int_{surf} \int f^S m^S(t)\,dt\,dA$$

and you can do this for any area, not just the whole Earth

Now it doesn't have to be global, doesn't have to be warming, and isn't a potential (which was the point of dividing by CO2)– I would rather call it something else

Short-term integrated forcing by one source

Short-term forcing by a single source

$$\sum \mathrm{Em}_i \left[\int \int f^{Si} m^{Si}(t)\, dt dA \right]$$

Sum of all the emissions weighted by integrated forcing of each

Units: TW yr

(This is pretty standard stuff, except for the separation.)

data sources:

BC, OM

Bond et al. ACP 11, 1505, 2011

Multi-model estimates of forcing in multiple regions

"Bounding-BC" estimate of fast response

SO2

Koch et al. JGR 112, D02205, 2007

Single-model estimate of forcing in several regions

VOC, NOx, CO

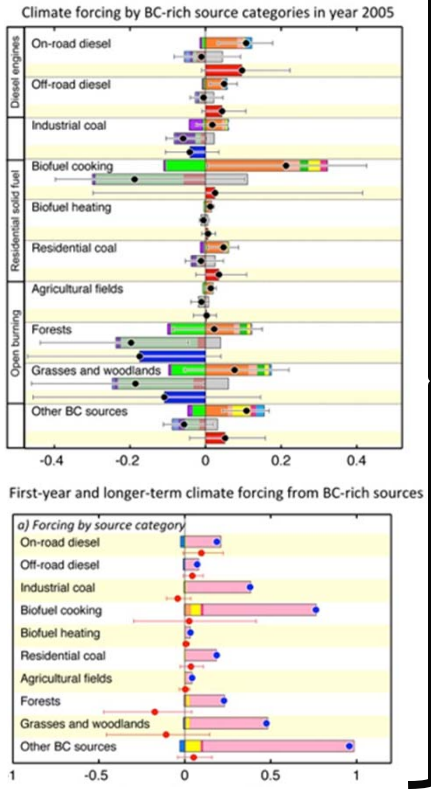
Fry et al. JGR 117, 2012

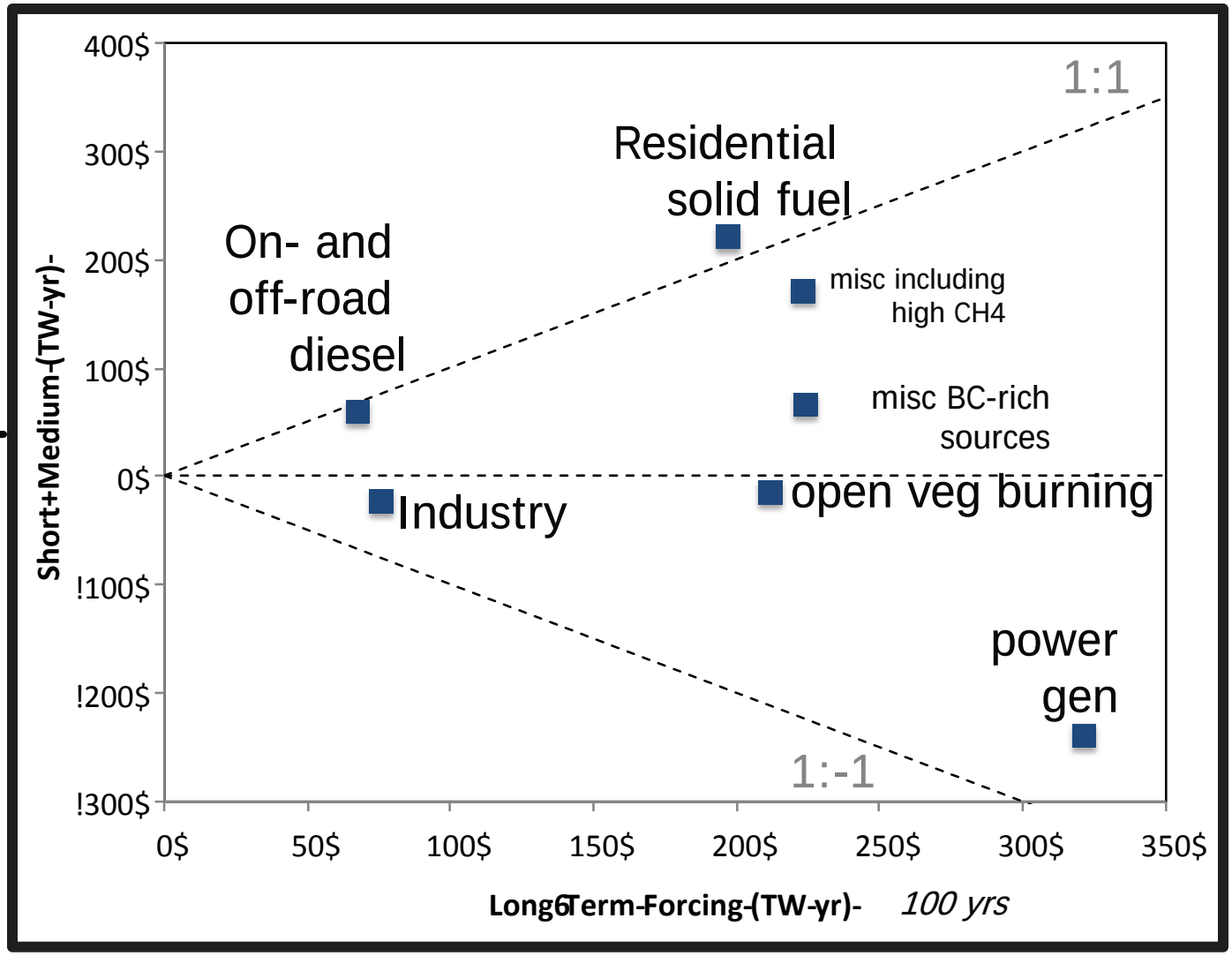
Multi-model estimates of forcing from 4 regions

Challenge → Metrics → Proposal

Short and long forcing often similar in magnitude

Categories from Bounding-BC

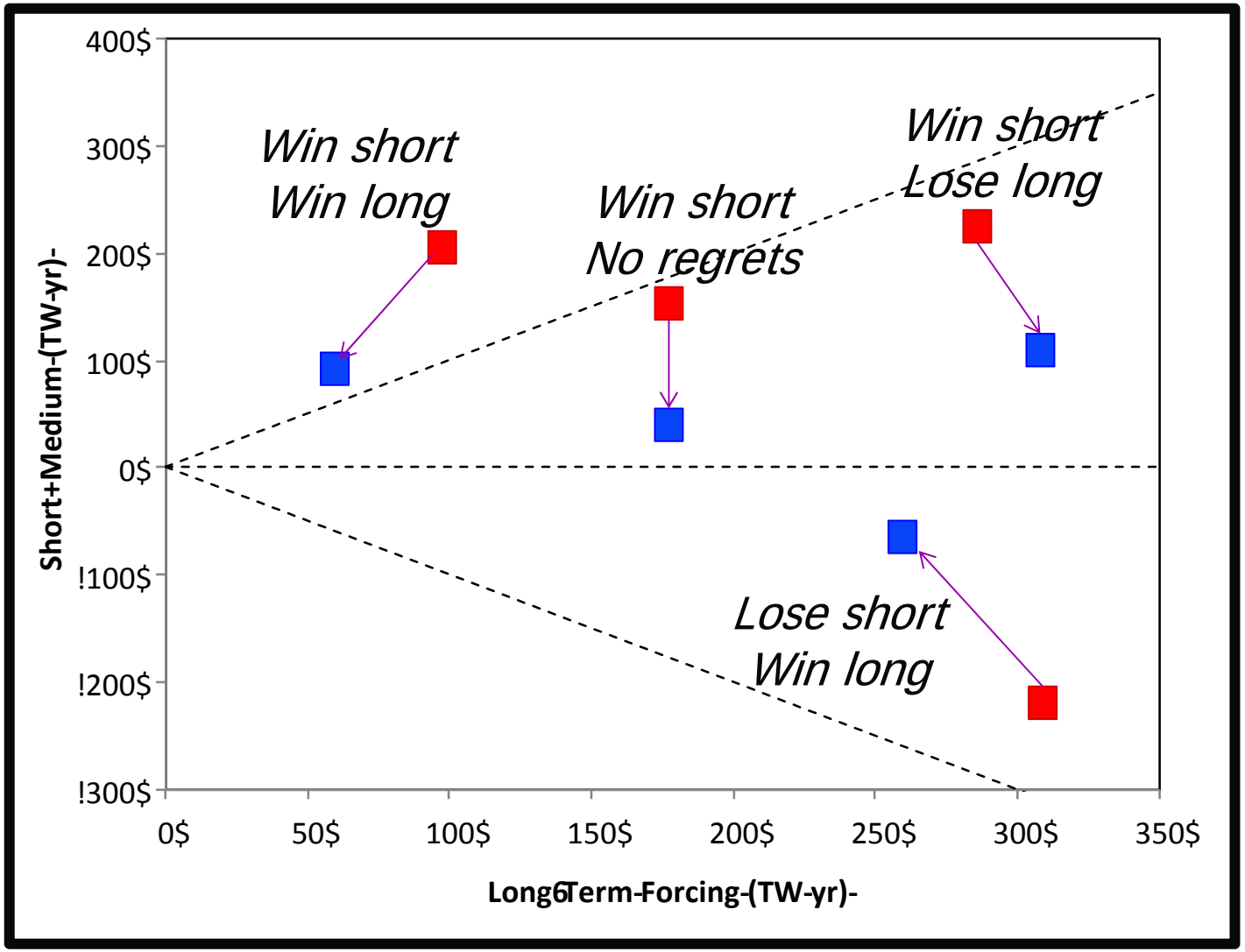




Warning 1: Left out uncertainties to achieve graph visibility
Warning 2: Depends on scaling to match atmospheric conc
Incidentally: World energy consumption is ~16 TW yr

Mitigation is the difference between measures

baseline
mitigation



No more ratio, but 1:1 lines maintain context

Recommendations

Policy picture:

- Keep it simple. Short-term and long-term.
- Provide quick, transparent evaluation of sources.

Scientific additions:

- Use integrated forcing over different areas to target desired climate change

  e.g. Absolute Regional Temperature-Change Potential (Shindell, ACP 12, 7955 [2012]; Collins *et al.*, ACP 13, 2471 [2013])

Recommendations for scientists

- Keep it simple: [Short+Medium] vs [Long]
- Keep it updatable
- Limit use of *policy* ratios (like GWP)
  - Unwarranted confusion
  - Apples/oranges comparison hides important aspects (immediacy, spatial specificity)
- Fill in the important gaps (spatial differences, cloud response) by using *physical* ratios (emission per forcing or something else)
- Provide quick, transparent evaluation of sources

Thanks. And sorry I was late.