

US EPA ARCHIVE DOCUMENT

Emission metrics, especially for BC

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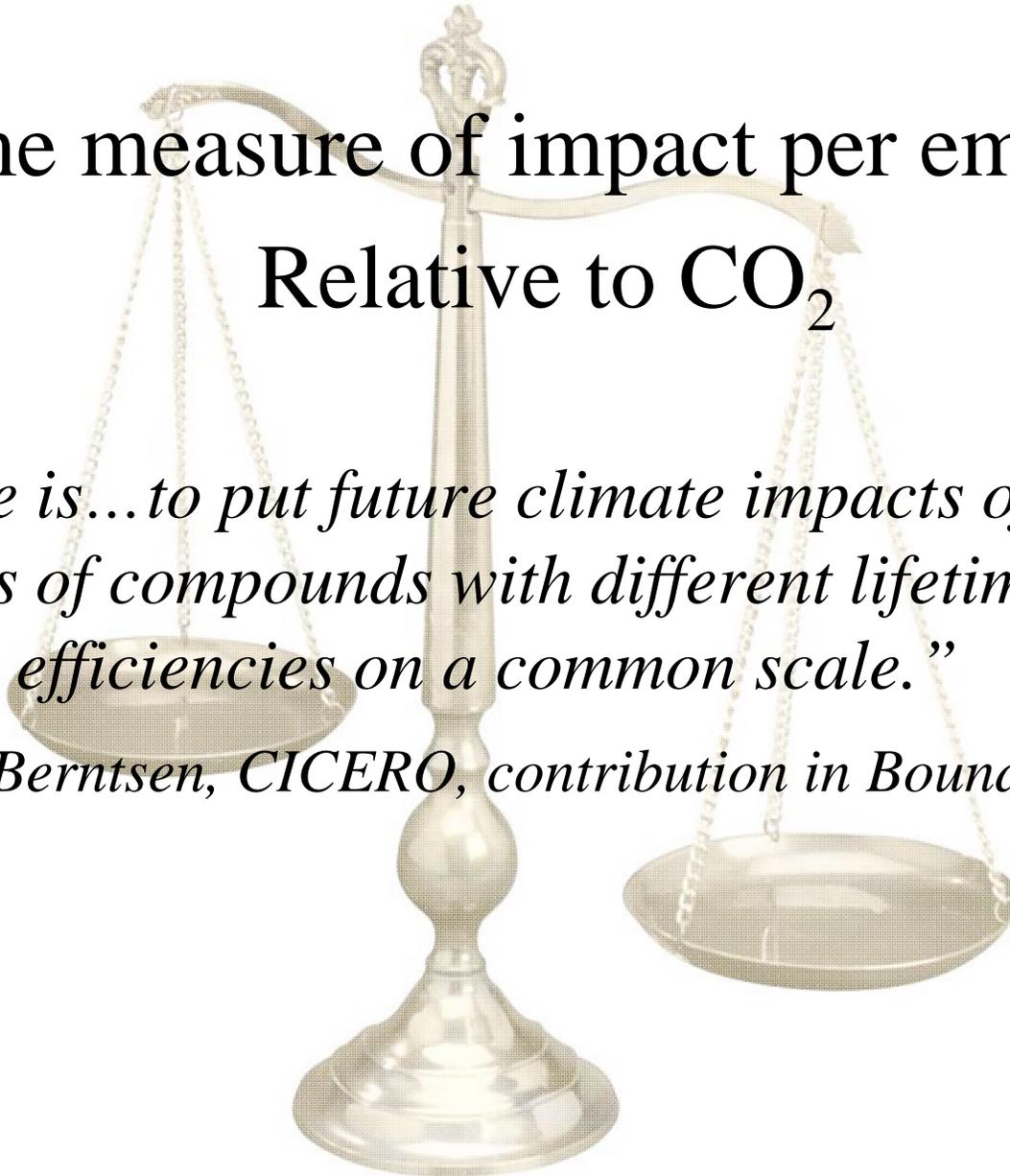
1. What we learned from “Bounding-BC”
2. Review of emission metrics
3. Proposal and exploration

Definition of emission metrics

Some measure of impact per emission
Relative to CO₂

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

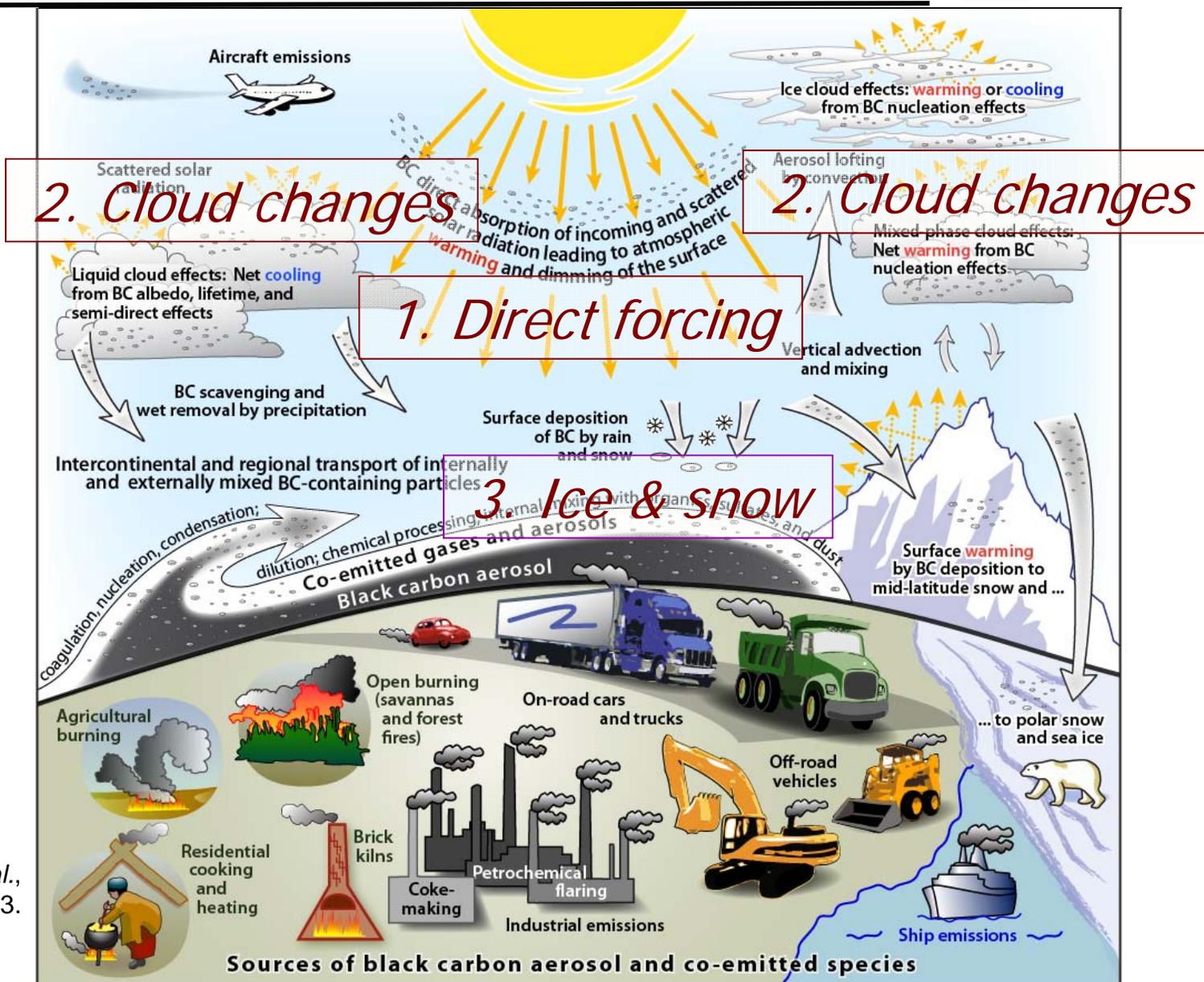
T. Berntsen, CICERO, contribution in Bounding-BC



WHAT WE LEARNED FROM “BOUNDING-BC”...

“BOUNDING-BC”...
WHAT WE LEARNED FROM

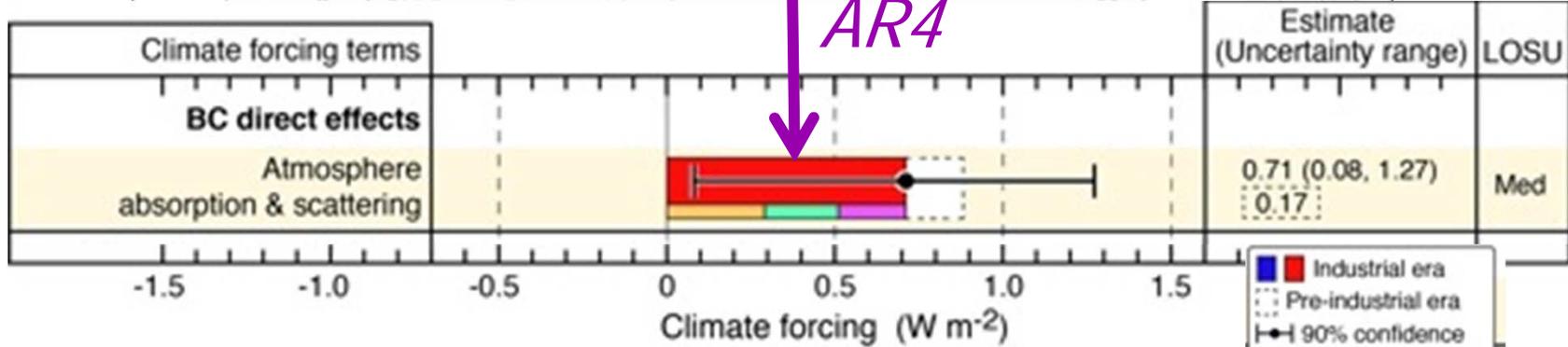
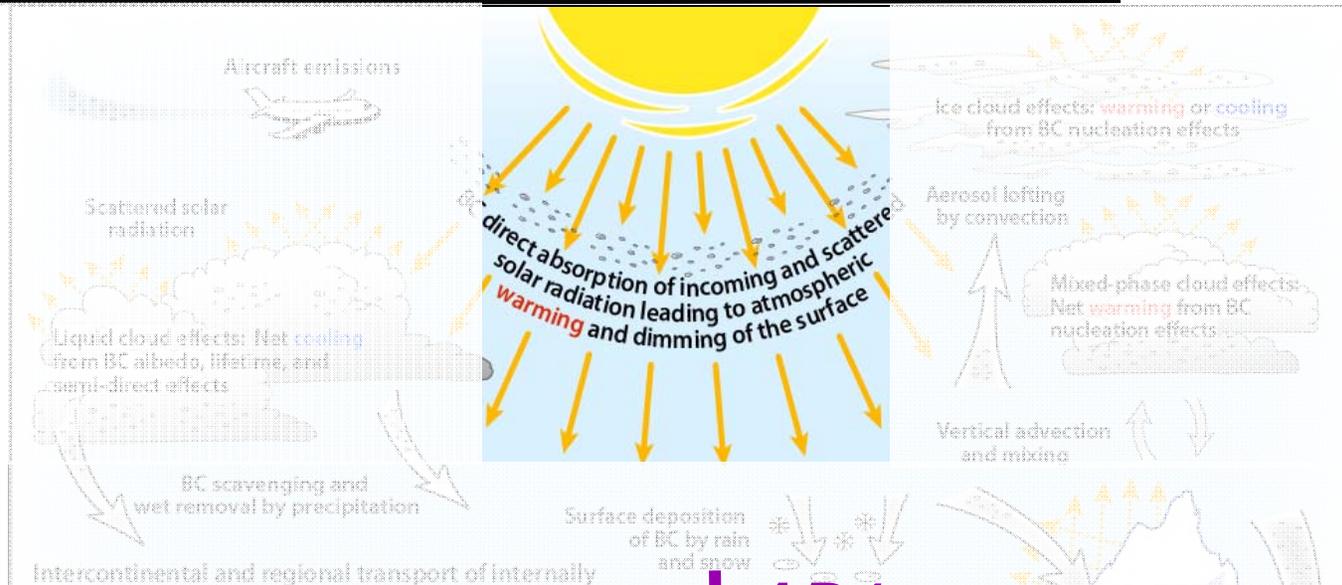
“Comprehensive” with regard to climate effects



Bond *et al.*, JGR, 2013.



Direct forcing (the usual)

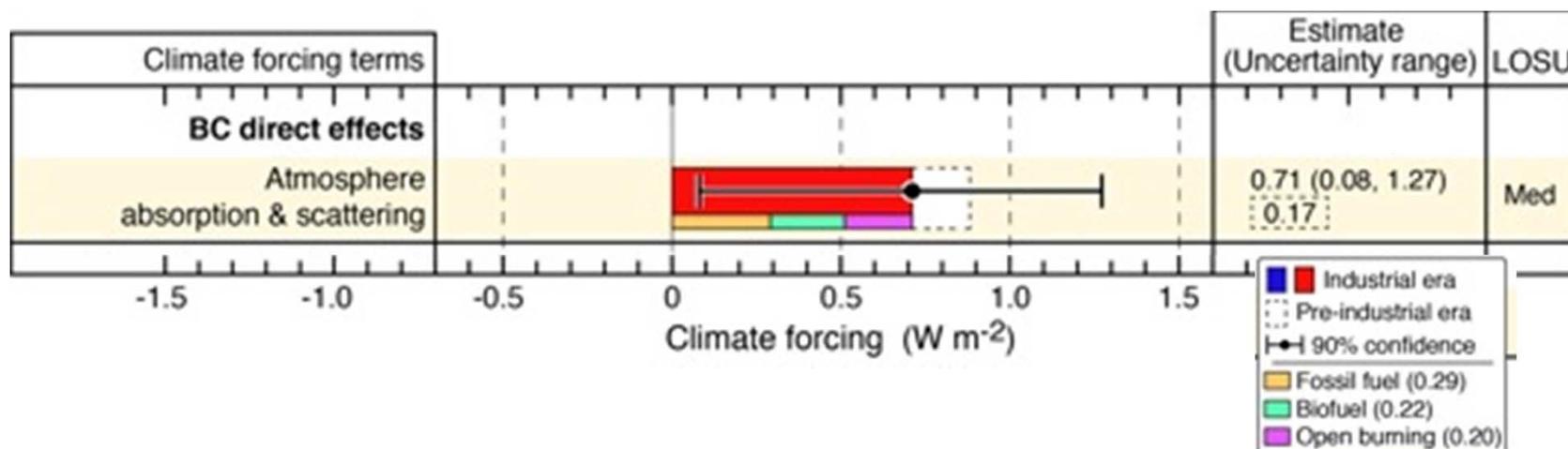


Bond *et al.*, JGR, 2013.



Bounding → Metrics → Proposal

Direct forcing



Forcing was assessed to be higher than many previous estimates.

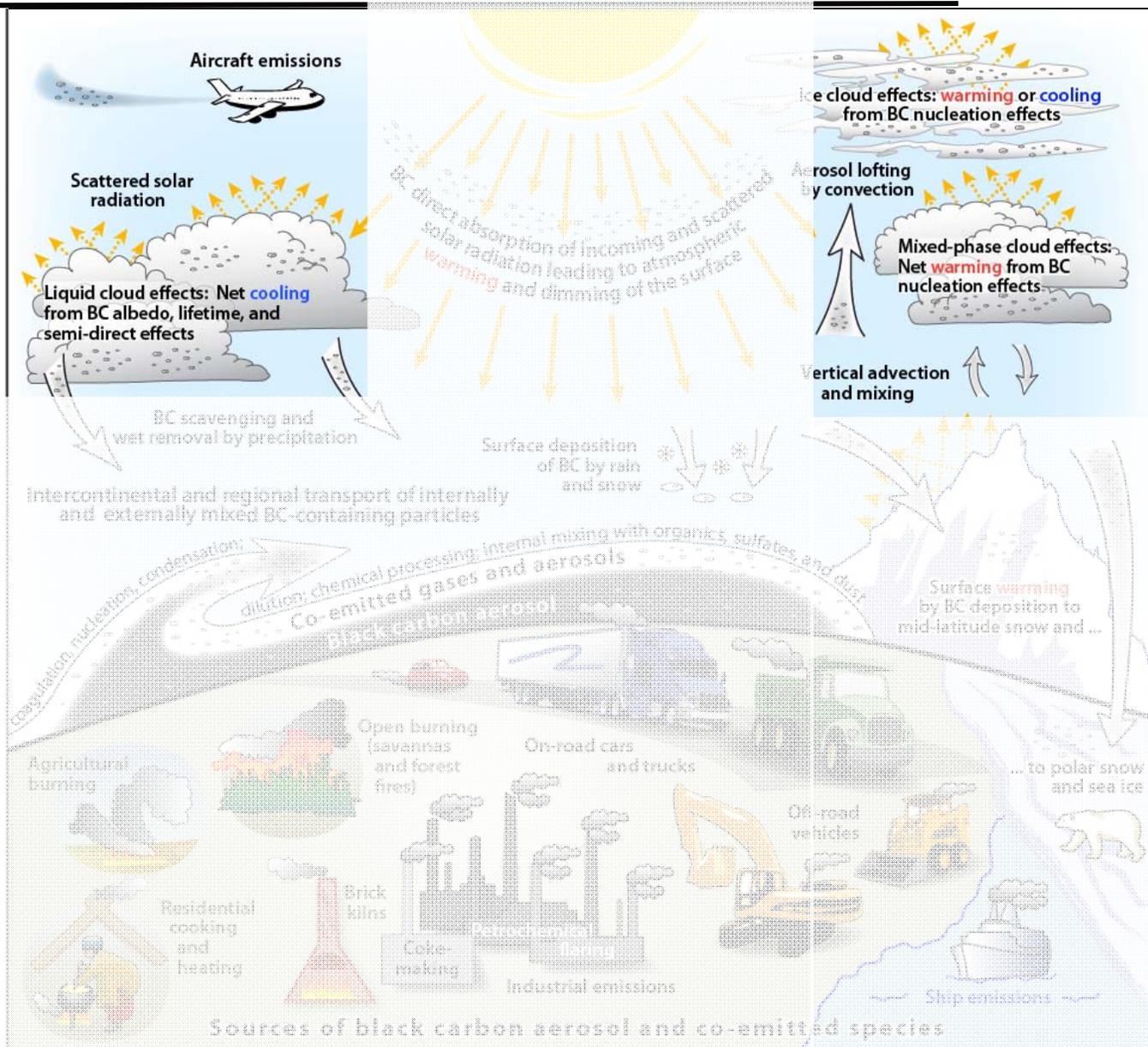
More absorption in the atmosphere than in models

But this was attributed to higher emissions.

Emission-per-forcing didn't change much.

Bounding → Metrics → Proposal

“Indirect” effect



Bond *et al.*, JGR, 2013.

Bounding

Metrics

Proposal

What do you mean, "THE" indirect effect?

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

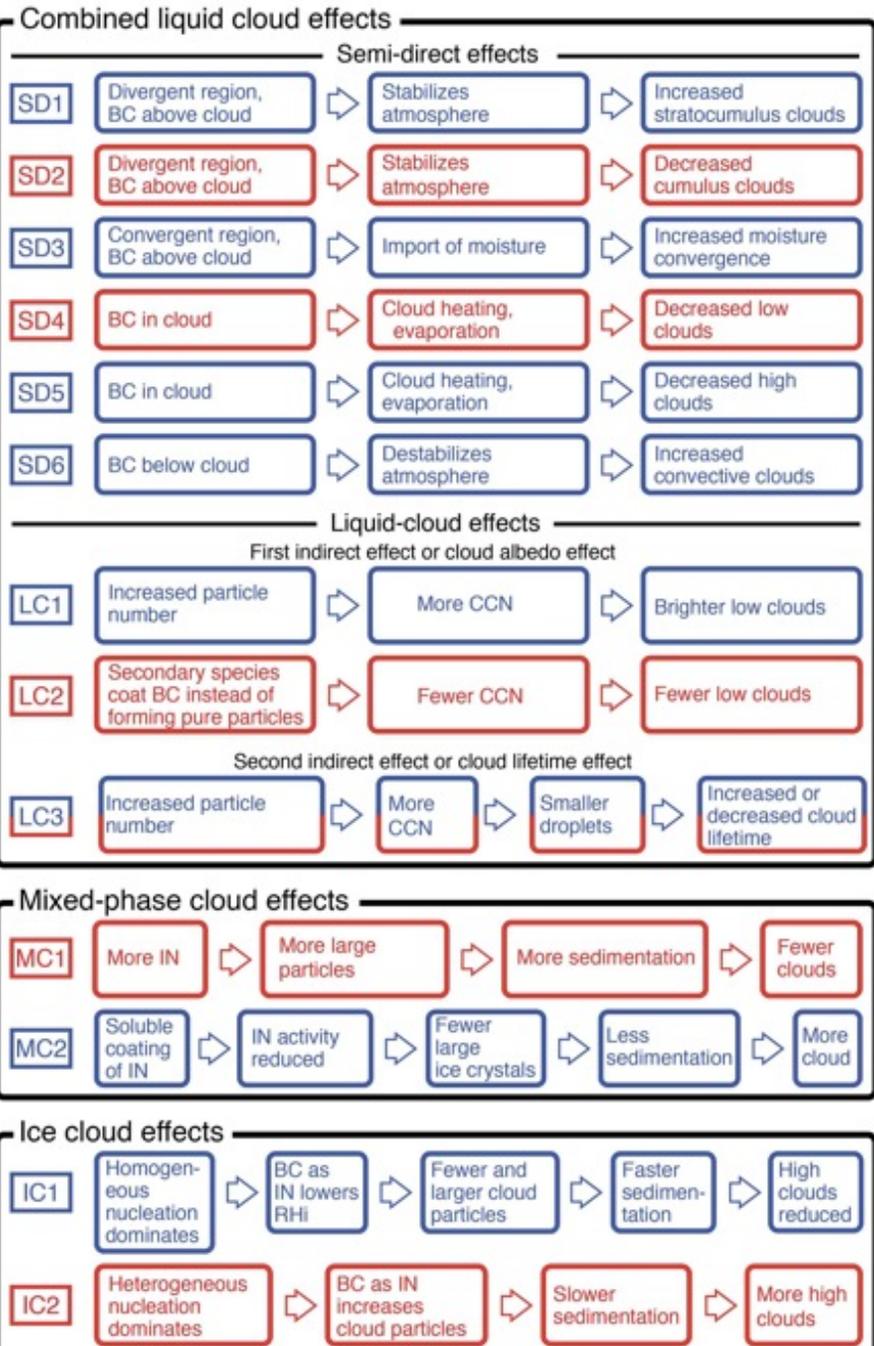
Semi-direct (-)
 but depends on BC location

Liquid indirect (-)
 but small

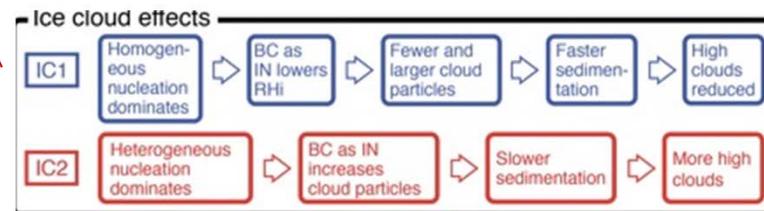
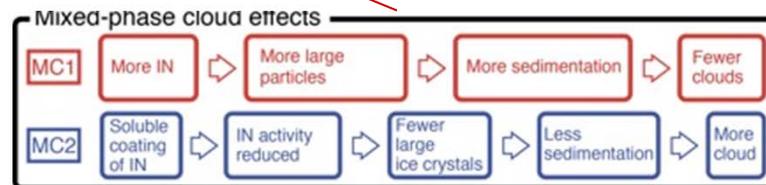
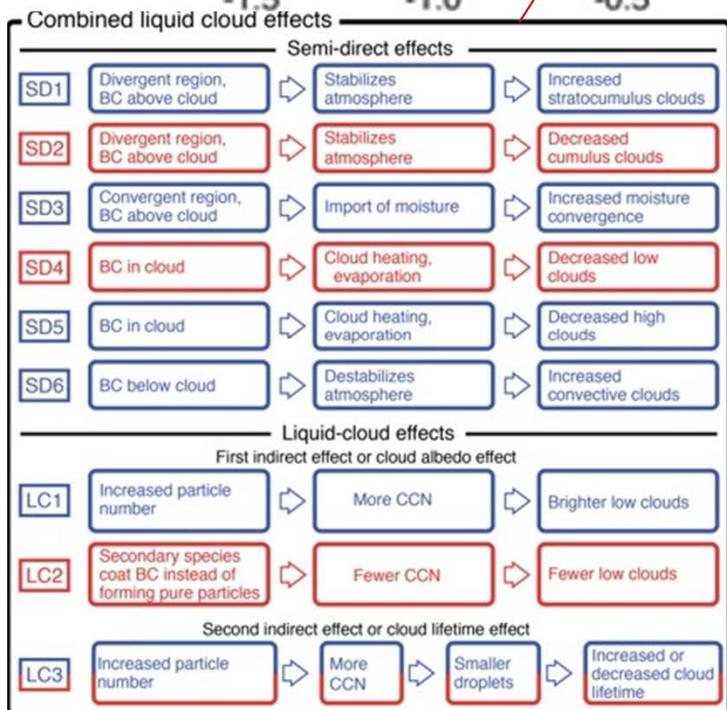
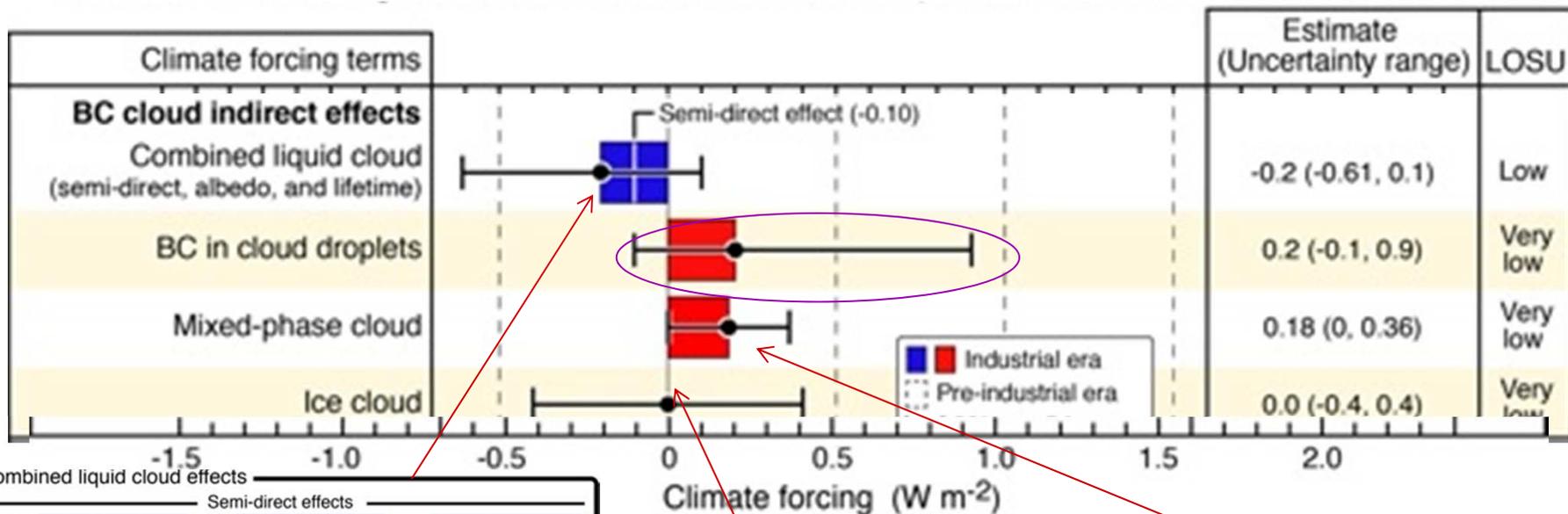
Mixed (water-ice) clouds (+)
Ice clouds +/-



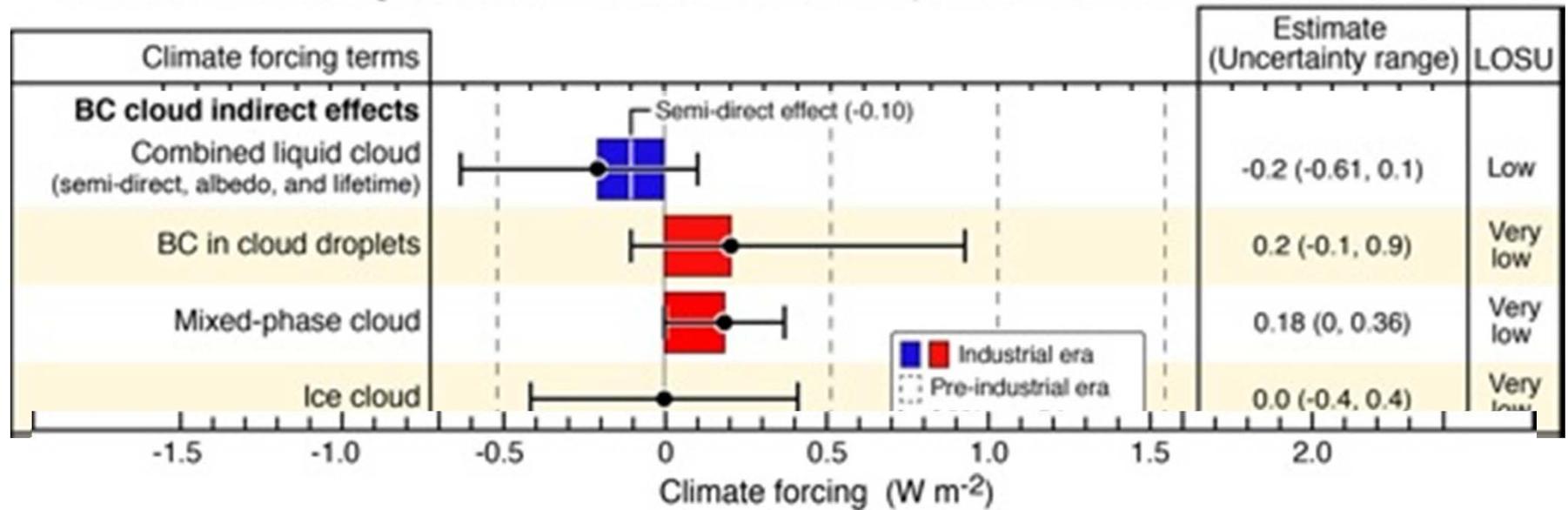
BC cloud indirect effects Climate warming and cooling effects



Summary of cloud effects: *net positive*



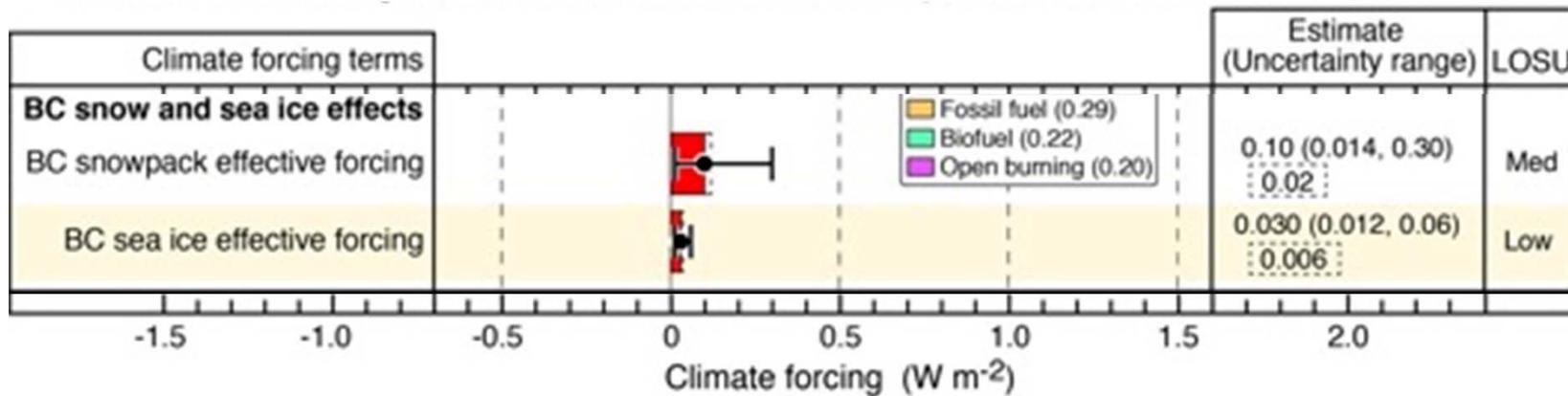
Summary of cloud effects: *net positive*



Attribution (to particular sources) is a major problem



Snow-albedo effect

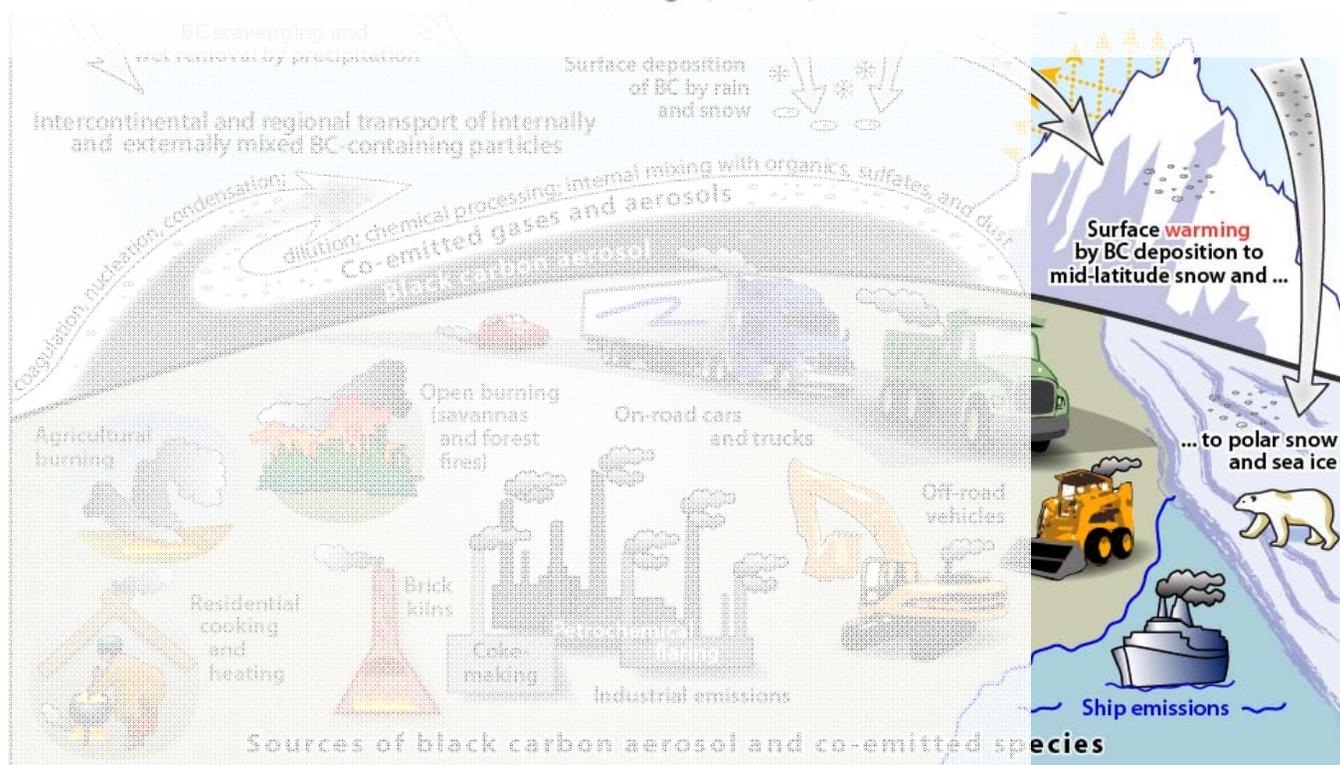
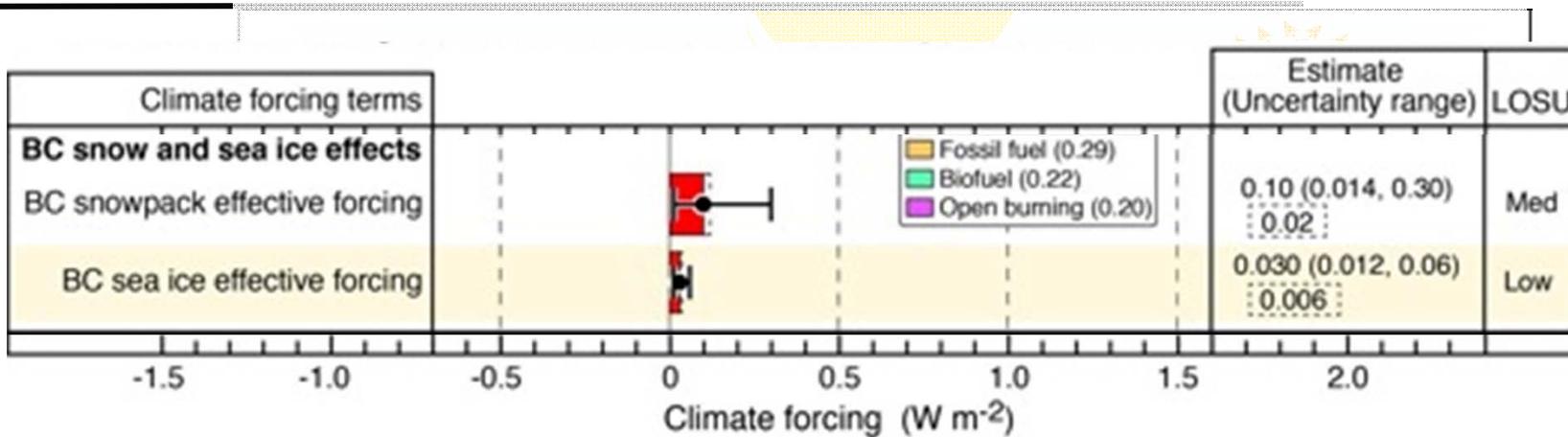


Attribution (to particular sources) is not TOO hard...

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



Snow-albedo effect

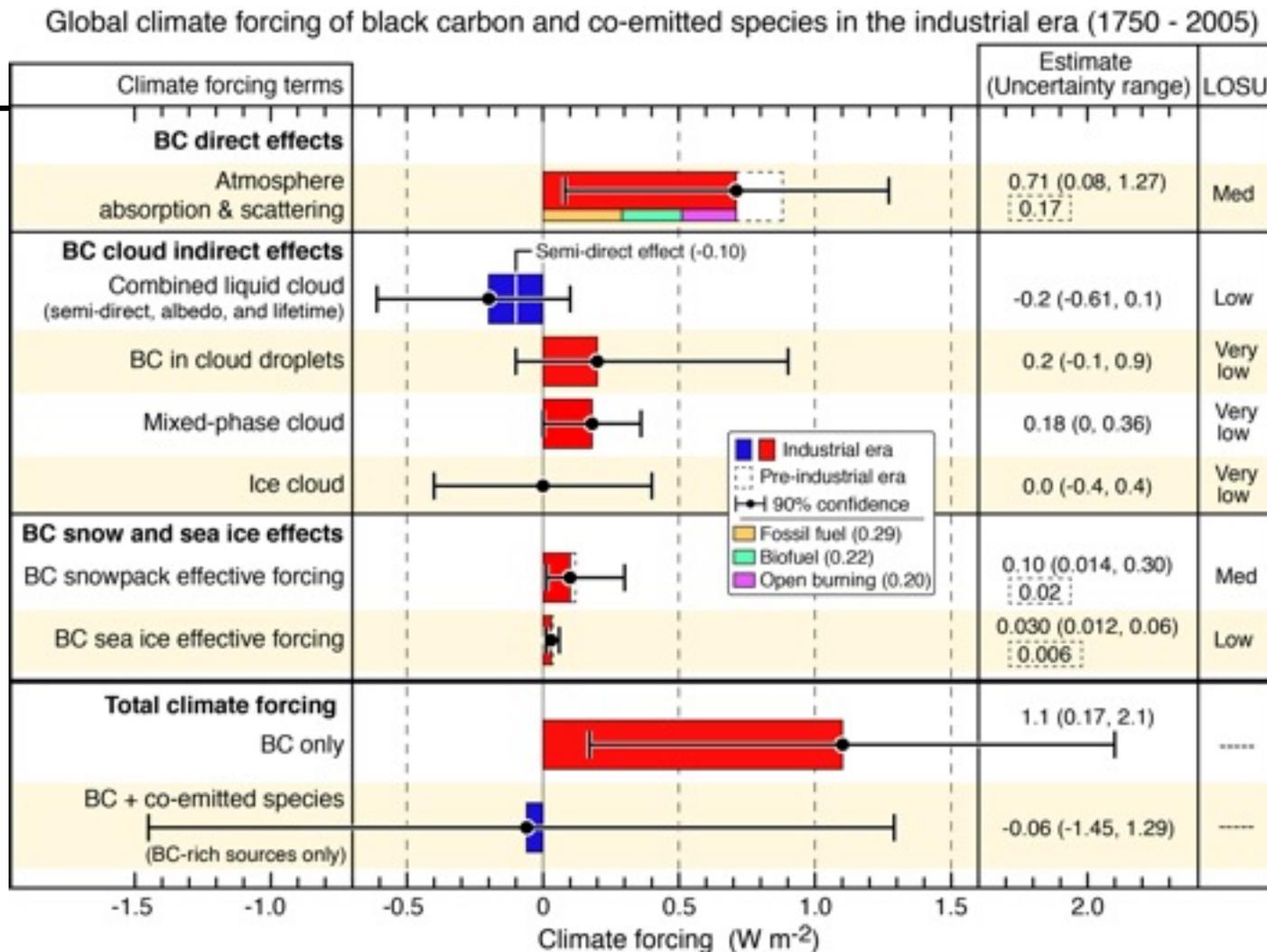


Bond *et al.*, JGR, 2013.

Bounding → Metrics → Proposal

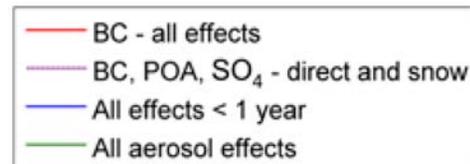
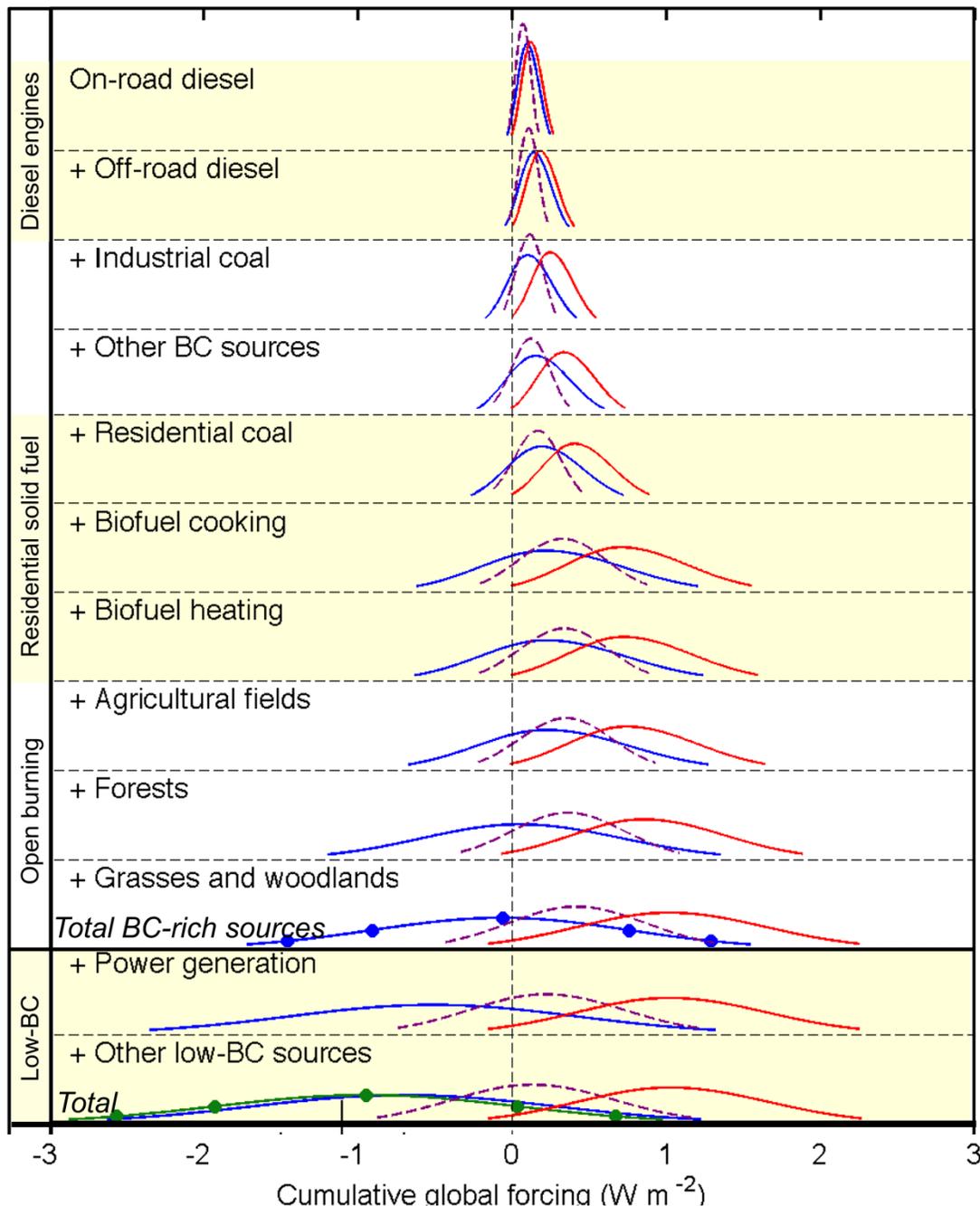
At last:

(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

NOTES ABOUT EMISSION METRICS

Each pollutant induces different response

Response to a pulse of emission

Atmospheric lifetime

$\tau \ll 1$ yr

$\tau \sim 10$ yrs

$\tau > 50$ yrs

Forcing trajectory follows atmos. concentration

Temperature lags because of Earth's heat capacity

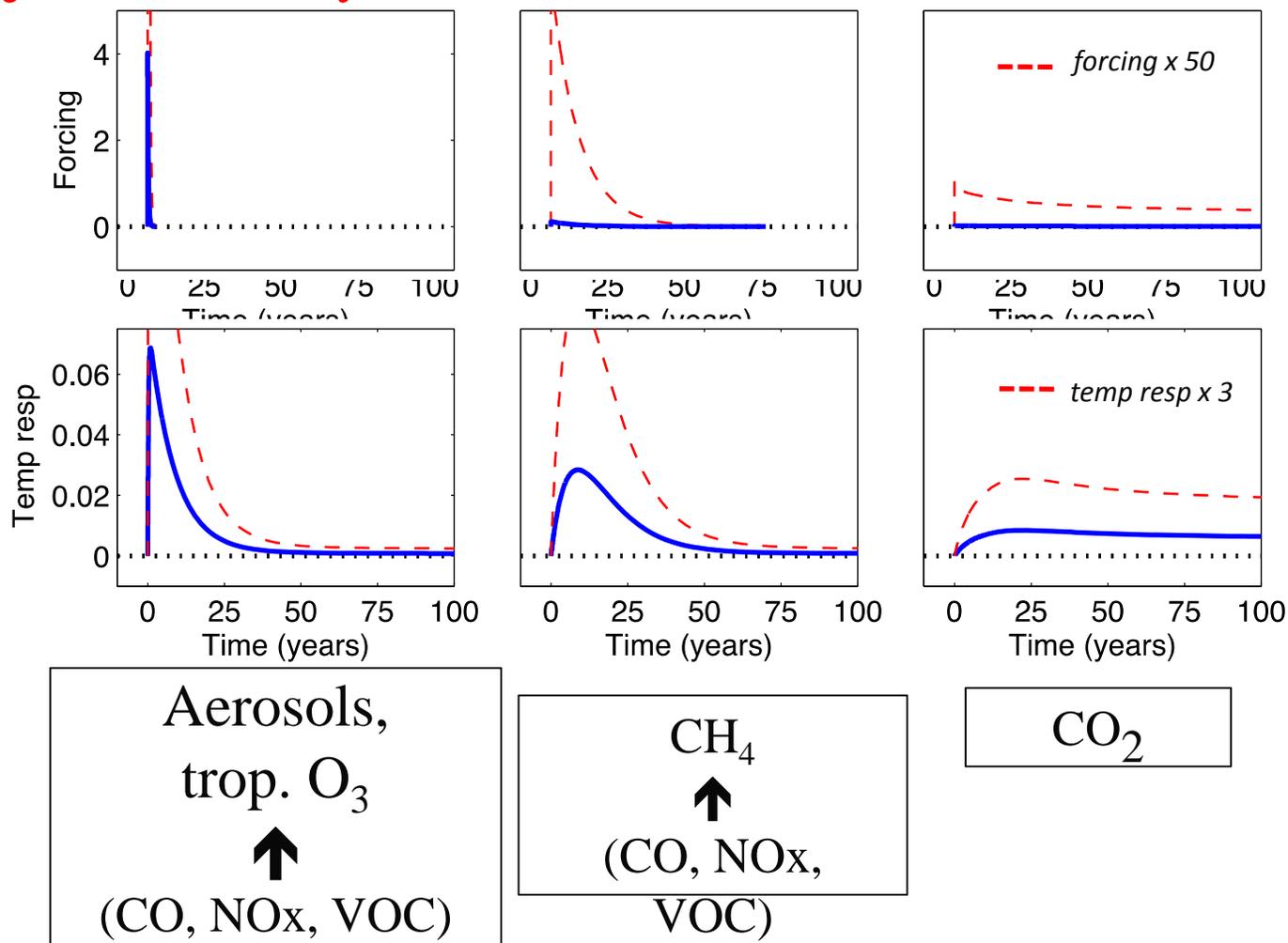


Figure from Bond et al., ACP 11, 1505 (2011)

Forcing timescales: eg Wild & Prather, JGR 105, 24647 (2000)¹⁷

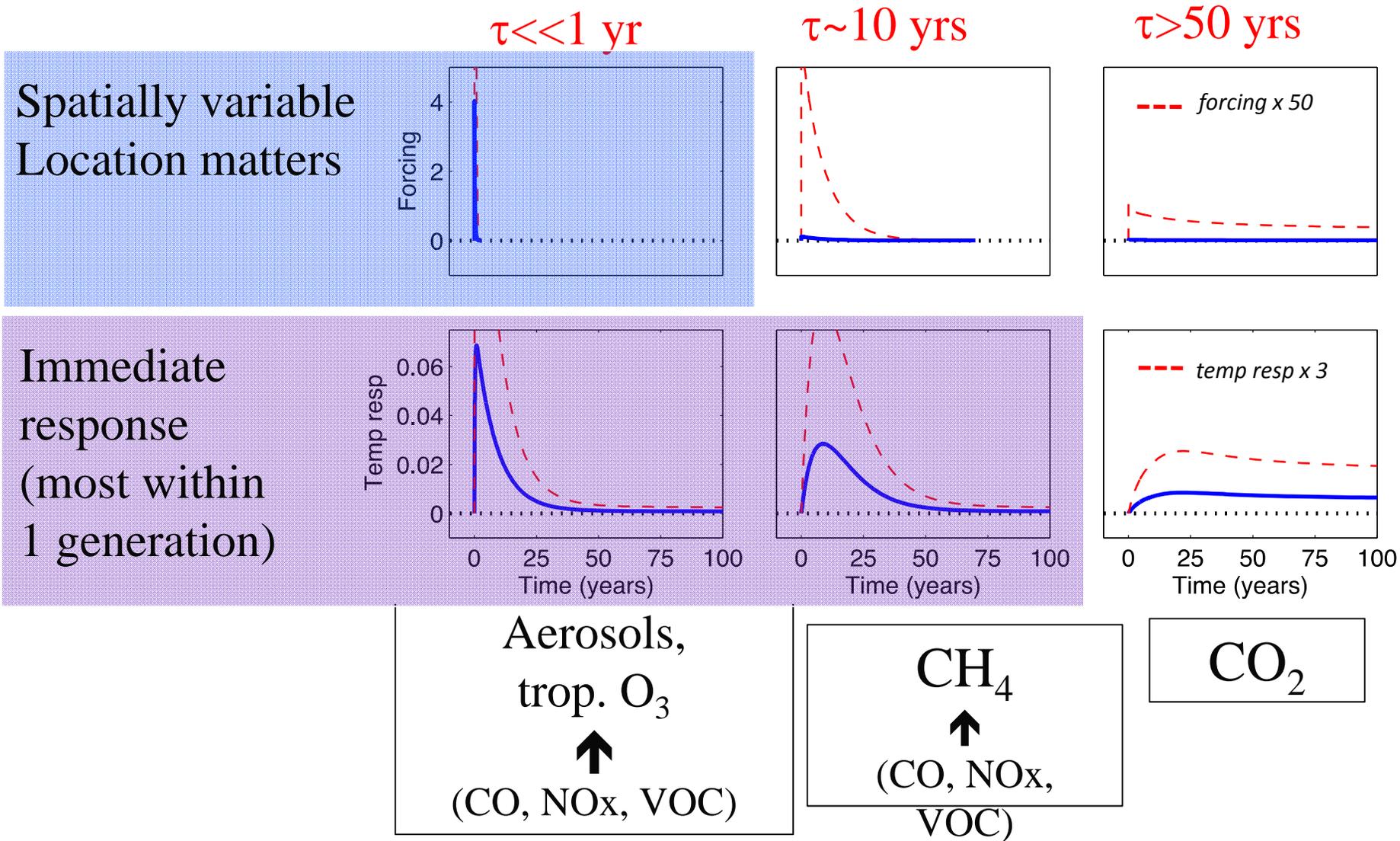
Challenge

Metrics

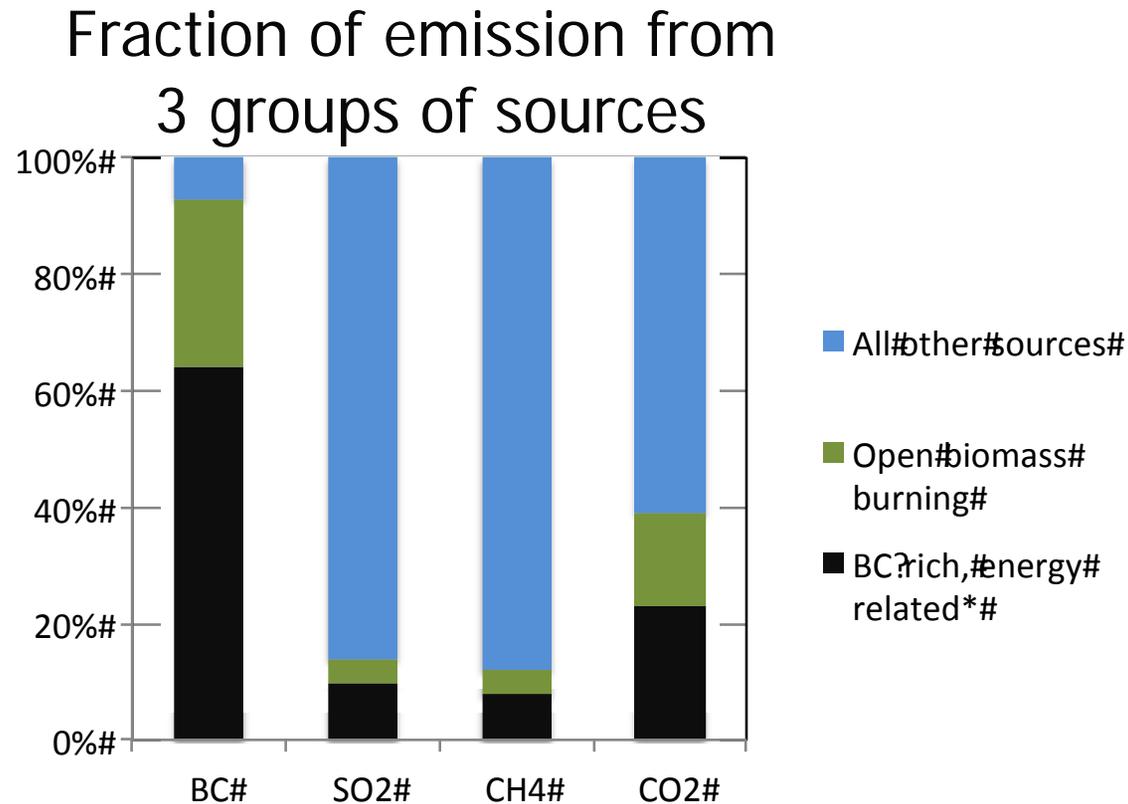
Proposal



Each pollutant induces different response



Short-lived and long-lived warming have different sources



Two-thirds of BC is associated with <25% of the CO₂ and <10% of SO₂

* 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 ?

$$GWP^S(H) = \frac{\int_0^H f^S m^S(t) dt}{\int_0^H f^{\text{CO}_2} m^{\text{CO}_2}(t) dt}$$

time horizon

forcing per mass

mass remaining in the atmosphere at time t after pulse emission of 1kg

Challenge

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 ?

$$GWP^S(H) = \frac{\int_0^H f^S m^S(t) dt}{\int_0^H f^{\text{CO}_2} m^{\text{CO}_2}(t) dt}$$

Absolute Global Warming
Potential for S

Absolute Global Warming
Potential for CO_2

Challenge → Metrics → Proposal

Global Warming Potential of BC

Time horizon, H (yr)	AGWP of BC	AGWP of CO ₂	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

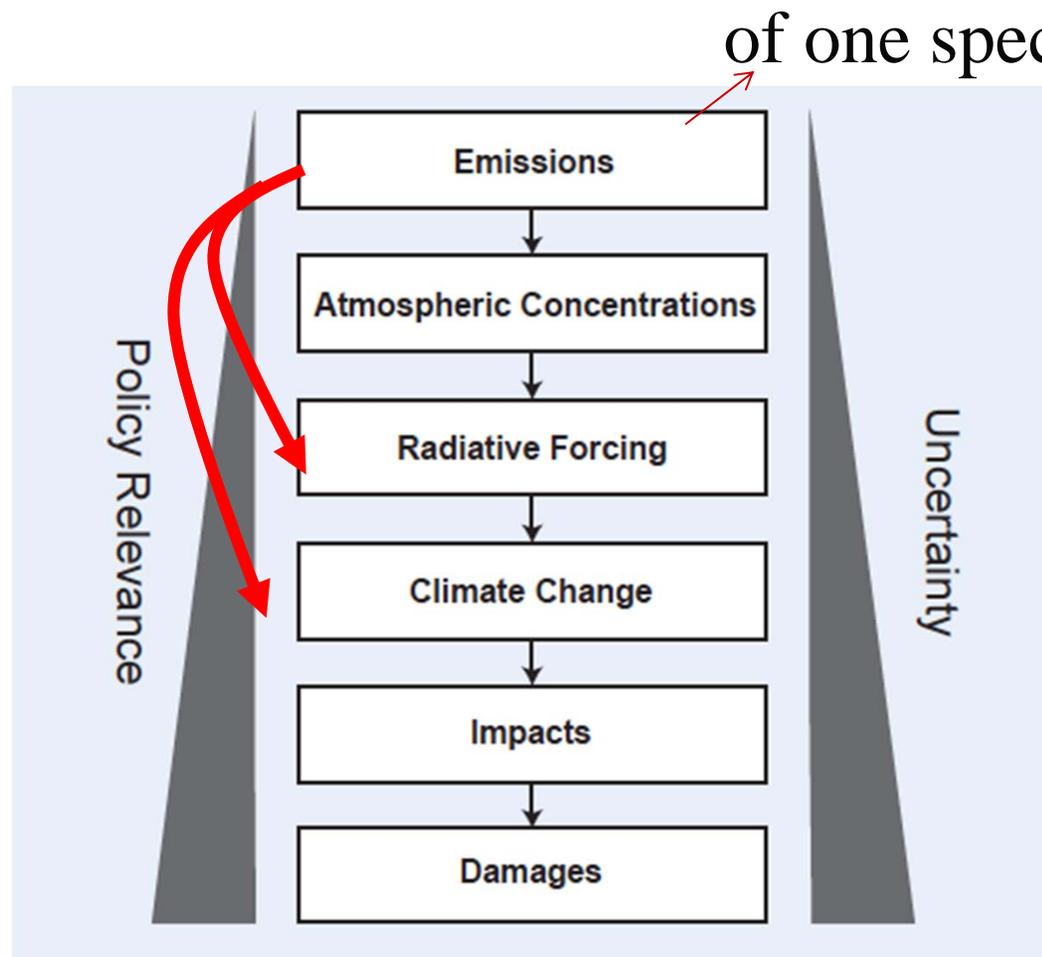


Ideal emission metrics would...

- ✦ 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?



Each step is
location-dependent

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

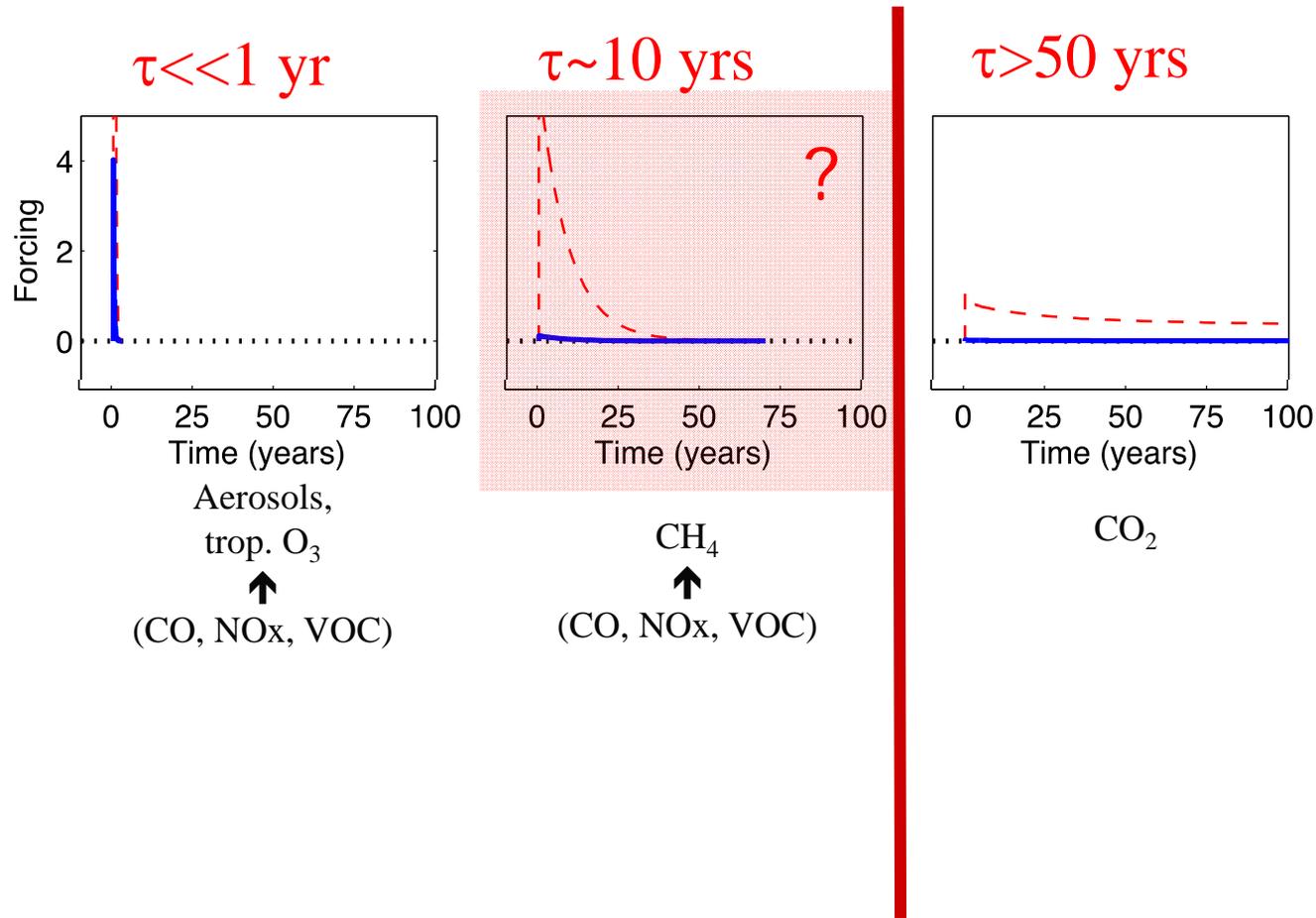
Image: Meeting Report, IPCC Expert Meeting on the Science of Alternative Metrics



PROPOSAL

ПРОПОЗАЛ

Proposal: formal separation



integrated forcing ($W \cdot \text{yr}$) is OK for now
 but use ratio (like GWP) only when it's useful or helpful

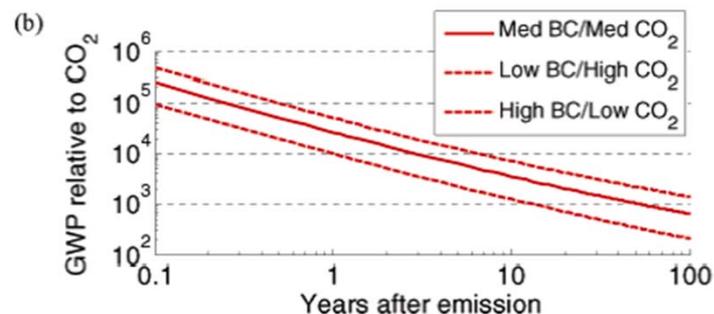


Dear GWP_{BC} : If I brought you into this world... can I take you out?

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

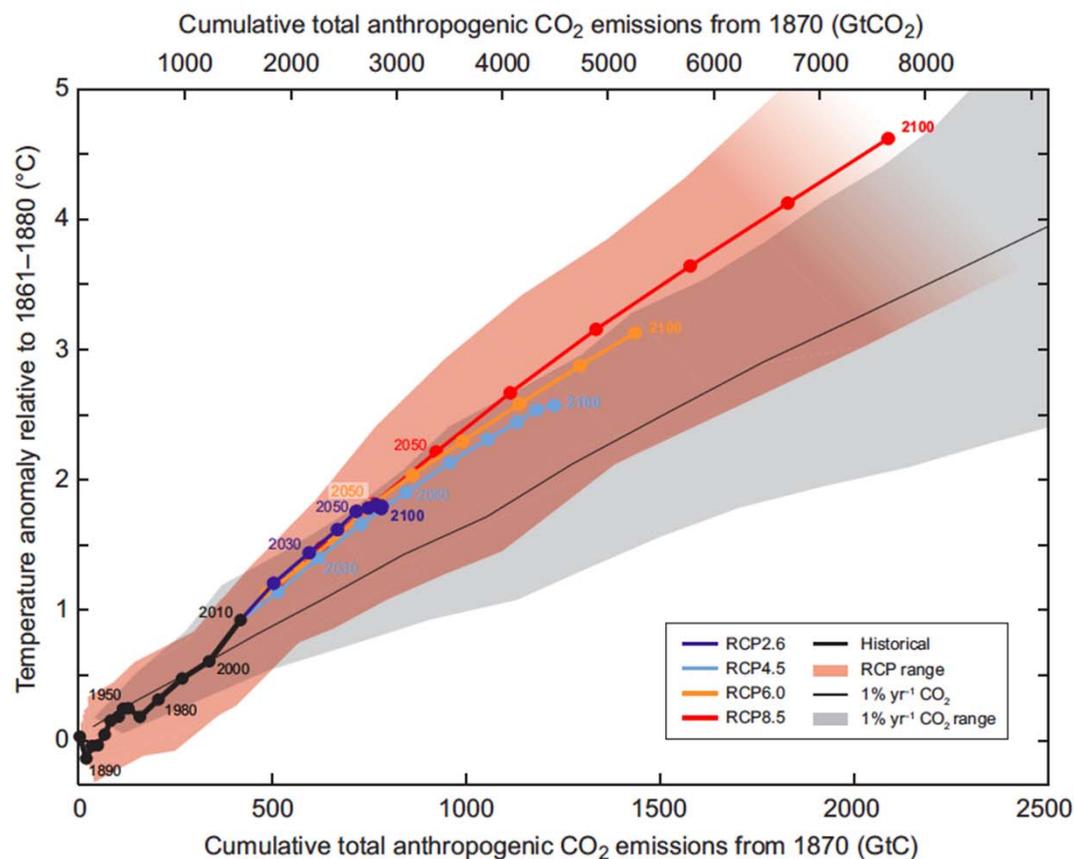
In part due to the scientific arguments against equivalence, BC reductions have not yet been assessed within a framework similar to that of CO₂. Introducing a GWP for aerosols may be controversial, but it is useful for this preliminary inquiry. Within the limitations of current uncertainty, we can inquire 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.

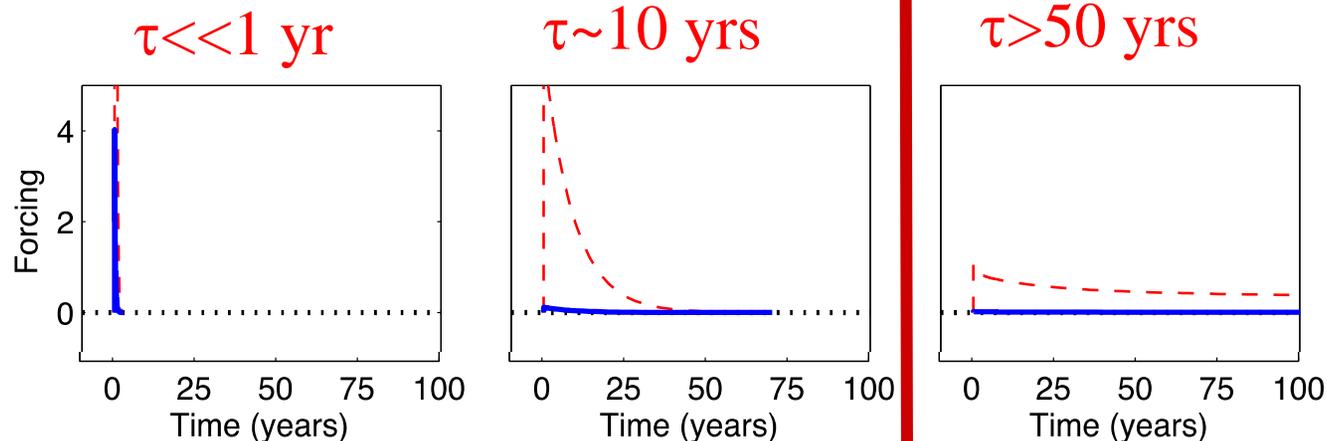
Equivalence on emission basis not possible



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



Proposal: formal separation



*Almost all
forcing occurs within
near future (25 years)*

*Contribute
to peak
temperature*

integrated forcing ($\text{W}\cdot\text{yr}$) is OK for now
use ratio (like GWP) only when it's useful or helpful

Challenge → Metrics → Proposal

Short-term integrated forcing

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

H doesn't matter, so

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

The global average is questionable, so

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

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

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

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

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

Short-term integrated forcing by one source

Short-term forcing by
a single source

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

*Sum of all the emissions
weighted by integrated
forcing of each*

Units: TW yr

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

Challenge

Metrics

Proposal

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

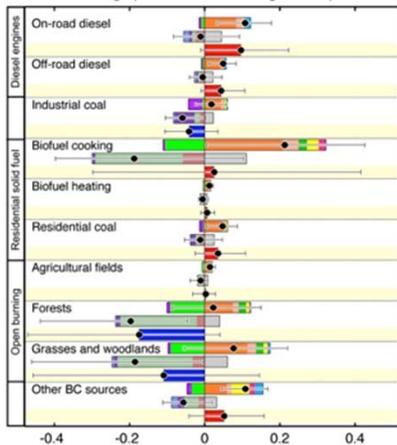
VOC, NO_x, CO

Fry et al. JGR 117, 2012
Multi-model estimates of
forcing from 4 regions

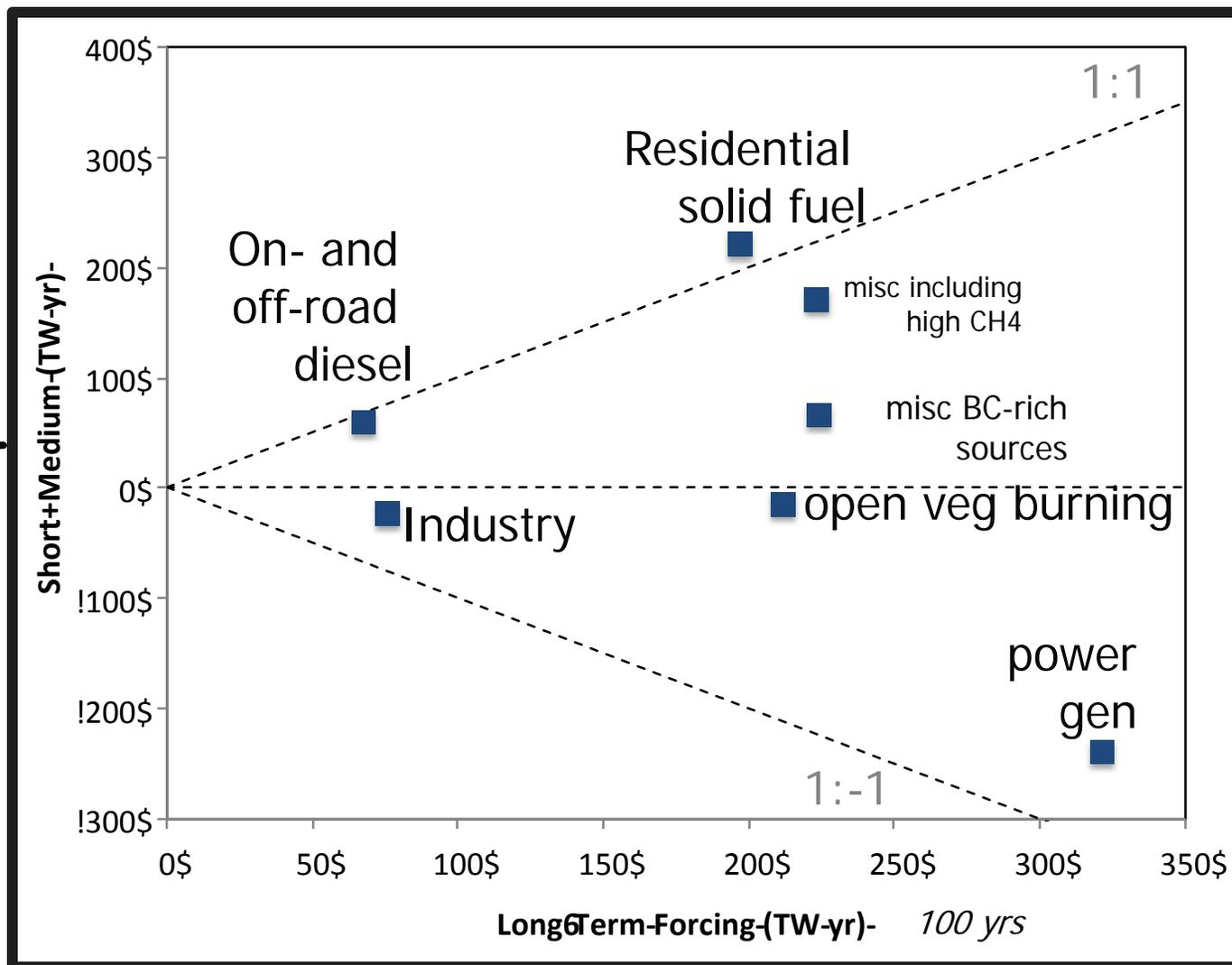
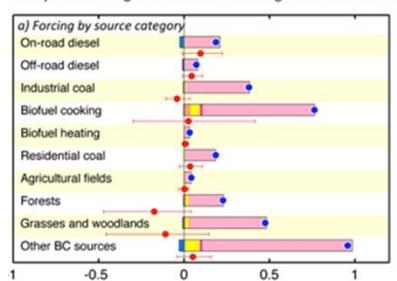
Short and long forcing often similar in magnitude

Categories from Bounding-BC

Climate forcing by BC-rich source categories in year 2005



First-year and longer-term climate forcing from BC-rich sources

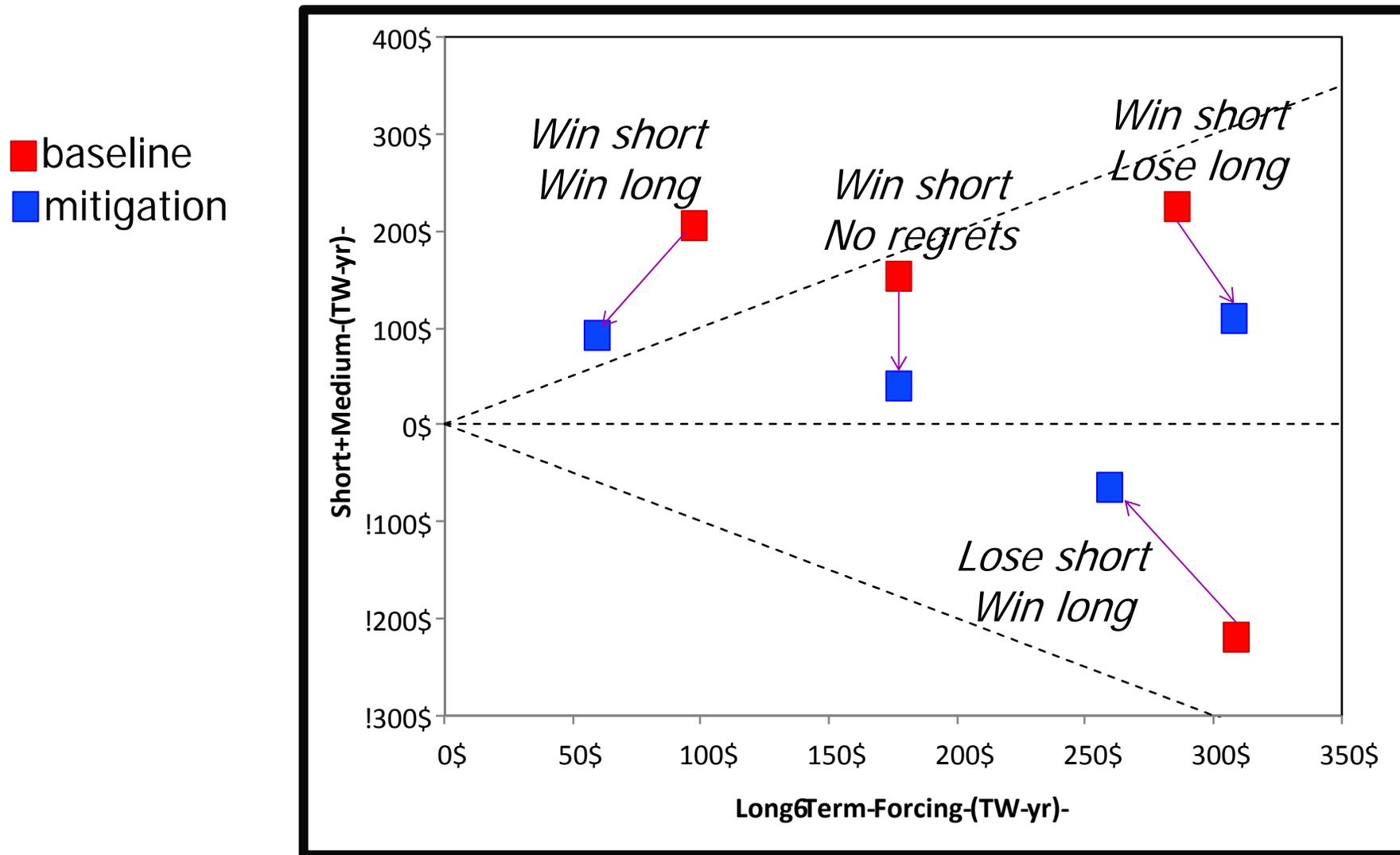


Warning 1: Left out uncertainties to achieve graph visibility

Warning 2: Depends on scaling to match atmospheric conc

Incidentally: World energy consumption is ~16 TW yr

Mitigation is the difference between measures



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.