AEROSOLS:
Non-CO_2, Non-Greenhouse, Non-Gas Forcing

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Symposium on

Controlling Emissions of Non-CO_2 Greenhouse Gases and Aerosols:

Scientific and Policy Challenges

http://www.ecd.bnl.gov/steve/schwartz.html

IMPORTANCE OF ACCURATE KNOWLEDGE OF RADIATIVE FORCING BY ANTHROPOGENIC AEROSOLS

- Determining ***climate sensitivity*** from observed temperature change.
- Input to ***transient climate models***.
- Evaluating alternative strategies to reducing CO_2 emissions for ***mitigating climate change***.

  Remove black carbon (absorbing warming aerosol).

  Add sulfate (scattering, cooling aerosol).
- Implications on ***committed warming issue***.

KEY POLICY QUESTION

per

What is the ***benefit*** to society that would result from an activity having a given ***cost*** to society.

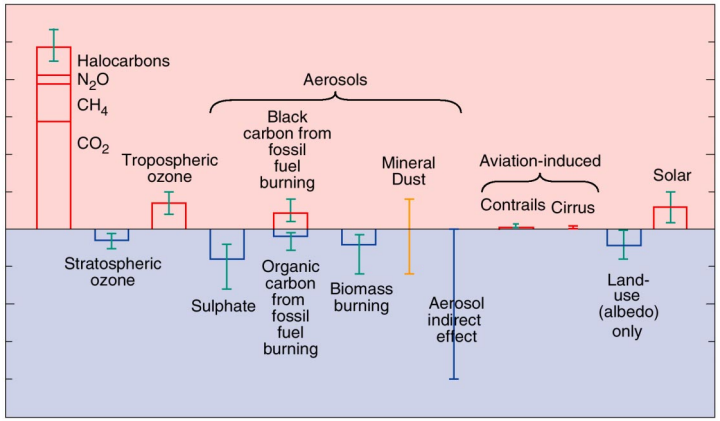
COST

Cost to not emit a specified amount of material M_0 (g) or *initial column burden* b_0 (emitted mass per area of Earth, g m^{-2}).

$$b_0 = M_0 / A_E$$

Area of Earth, $A_E = 5 \times 10^{14}$ m^2.

HOW TO MEASURE BENEFIT?



Forcing, *F*: Change in global-average top-of-atmosphere net irradiance associated with a unit amount of material.

[Benefit of not emitting taken as negative of forcing.]

But, must account for how long this benefit lasts.

HOW LONG DOES THE BENEFIT LAST?

Integrated forcing over time horizon T : $I(T) = \int_0^T F(t)dt.$

F(t) is forcing as a function of time after impulse release.

[Recall *global warming potential*.]

Total integrated forcing: $I \equiv I(\infty) = \int_0^\infty F(t)dt.$

Normalized forcing: $F_N \equiv \left(\frac{F}{b}\right)$, $(\mathrm{W\,m^{-2}})/(\mathrm{g\,m^{-2}})$ or $\mathrm{W\,g^{-1}}$

$$I(T) = \int_0^T F_N b(t)dt \approx F_N \int_0^T b(t)dt$$

Schwartz, Energy, 1993

INTEGRATED FORCING

Define *impulse response function*: $y(t) = M(t) / M_0$

Integrated forcing: $I(T) = b_0 F_N \int_0^T y(t)dt = b_0 F_N \tau(T)$

where *effective time* $\tau(T) = \int_0^T y(t)dt;$

$$\tau(\infty) \equiv \tau = \int_0^\infty y(t)dt$$

For exponential decay with lifetime τ,

Total integrated forcing: $I = b_0 F_N \tau$.

Integrated Forcing (W m^{-2} yr) =

Initial column burden × *Normalized forcing* × *Effective time*.

EXAMPLE: BLACK CARBON VS. CO_2

It has been suggested that eliminating fossil fuel BC emissions might "***buy time***" to institute fossil fuel CO_2 emissions control.

"Conceivably a reduction of climate forcing by 0.5 W m^{-2} or more could be obtained by reducing black carbon emissions from diesel fuel and coal. *Hansen et al., PNAS, 2001*

"Emission reduction of fossil-fuel particulate BC plus associated organic matter may slow global warming more than may any emission reduction of CO_2 or CH_4 for a specific period . . . 25 - 100 years. *Jacobson, JGR, 2002*

Compare the ***integrated forcing*** of

1 year's BC emissions vs. 1 year's CO_2 emissions.

GLOBAL WARMING INTEGRAL OF BLACK CARBON

M_0	7×10^{12}	g	*Penner et al., IPCC, 2001*
b_0	1.4×10^{-2}	g m^{-2}	$b_0 = M_0 / A_E$
F_N	900	W g^{-1}	*Penner et al., JGR, 2003* (includes organic)
τ	0.013 (4.7)	yr day	calc. as avg. burden/emissions from *Penner et al., JGR, 2003*
I	0.17	W m^{-2} yr	$I = b_0 F_N \tau$

Bond et al., JGR, 2004, give $M_0 = 3.0 \times 10^{12}$ g yr^{-1}.

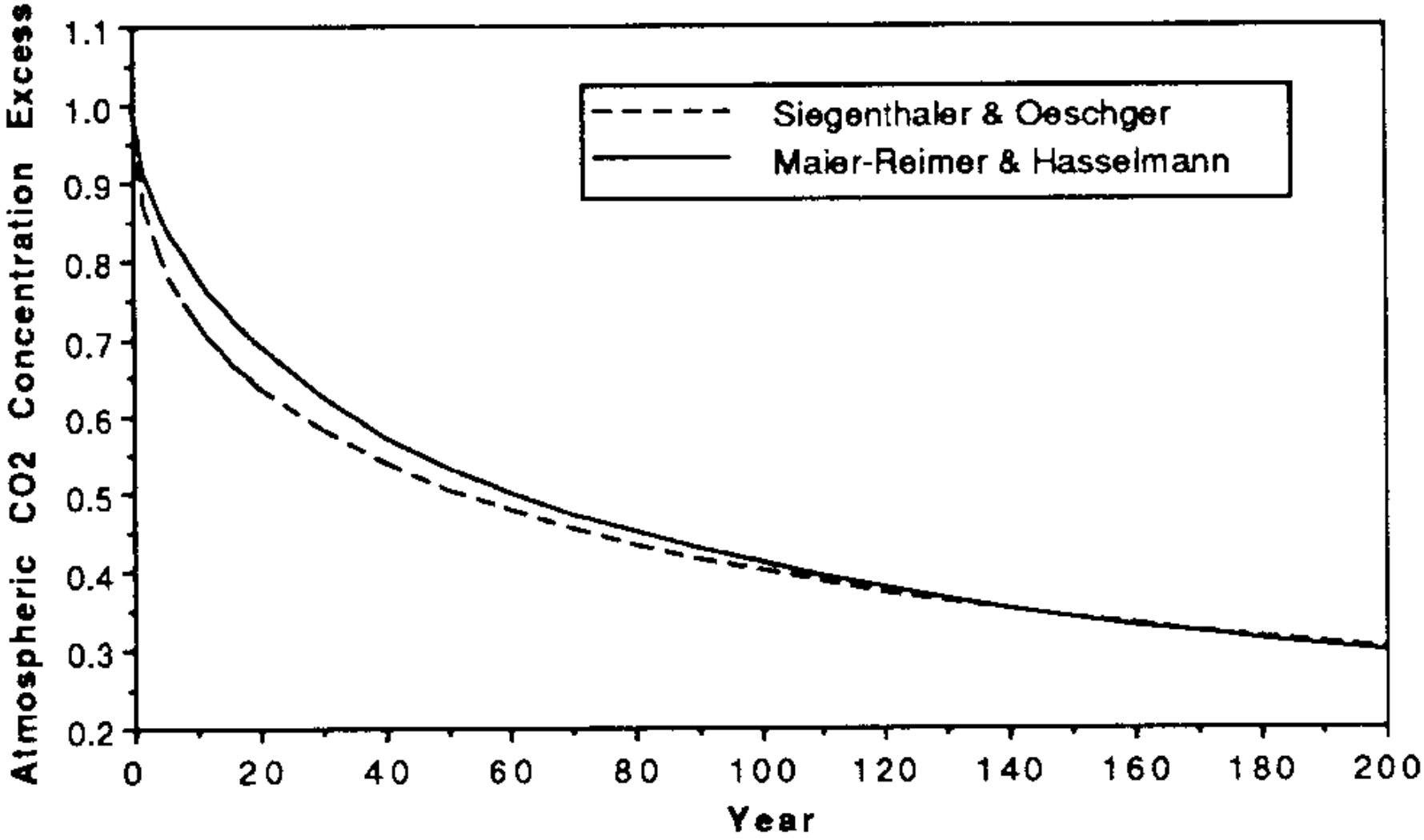
Jacobson, GRL, 2000, gives F_N = 590 - 1700 W g^{-1}.

Koch & Hansen, JGR, 2005, give τ = 7.3 day.

Overall uncertainty in integrated forcing at least factor of $\div\times$ 2.

CARBON DIOXIDE IMPULSE PROFILE

Most models give long non-zero tail.



For time horizon T taken as 200 yr, $\tau(T)$ = 92 yr.

FORCING BY INCREMENTAL CO_2

Forcing is logarithmic in CO_2 column burden:

$$F_{CO_2} = \left(\frac{4 \text{ W m}^{-2}}{\ln 2} \right) \Delta \ln b_{CO_2} = \left(5.8 \text{ W m}^{-2} \right) \frac{\Delta b_{CO_2}}{b_{CO_2}}$$

Normalized forcing (forcing per incremental column burden):

$$F_N \equiv \frac{F_{CO_2}}{\Delta b_{CO_2}} = \frac{5.8 \text{ W m}^{-2}}{1600 \text{ g m}^{-2}} = 3.6 \times 10^{-3} \text{ W g}^{-1}$$

GLOBAL WARMING INTEGRAL OF CO_2

M_0	7×10^{15}	g	*Marland*
b_0	14	g m^{-2}	$b_0 = M_0 / A_E$
F_N	3.6×10^{-3}	W g^{-1}	$2 \times CO_2$ = 4 W m^{-2}
τ(200 yr)	92	yr	*Maier-Reimer & Hasselmann*
I(200 yr)	4.7	W m^{-2} yr	$I = b_0 F_N \tau$

Value of global warming integral depends strongly on choice of "***time horizon***".

COMPARISON OF CO_2 VS. BLACK CARBON

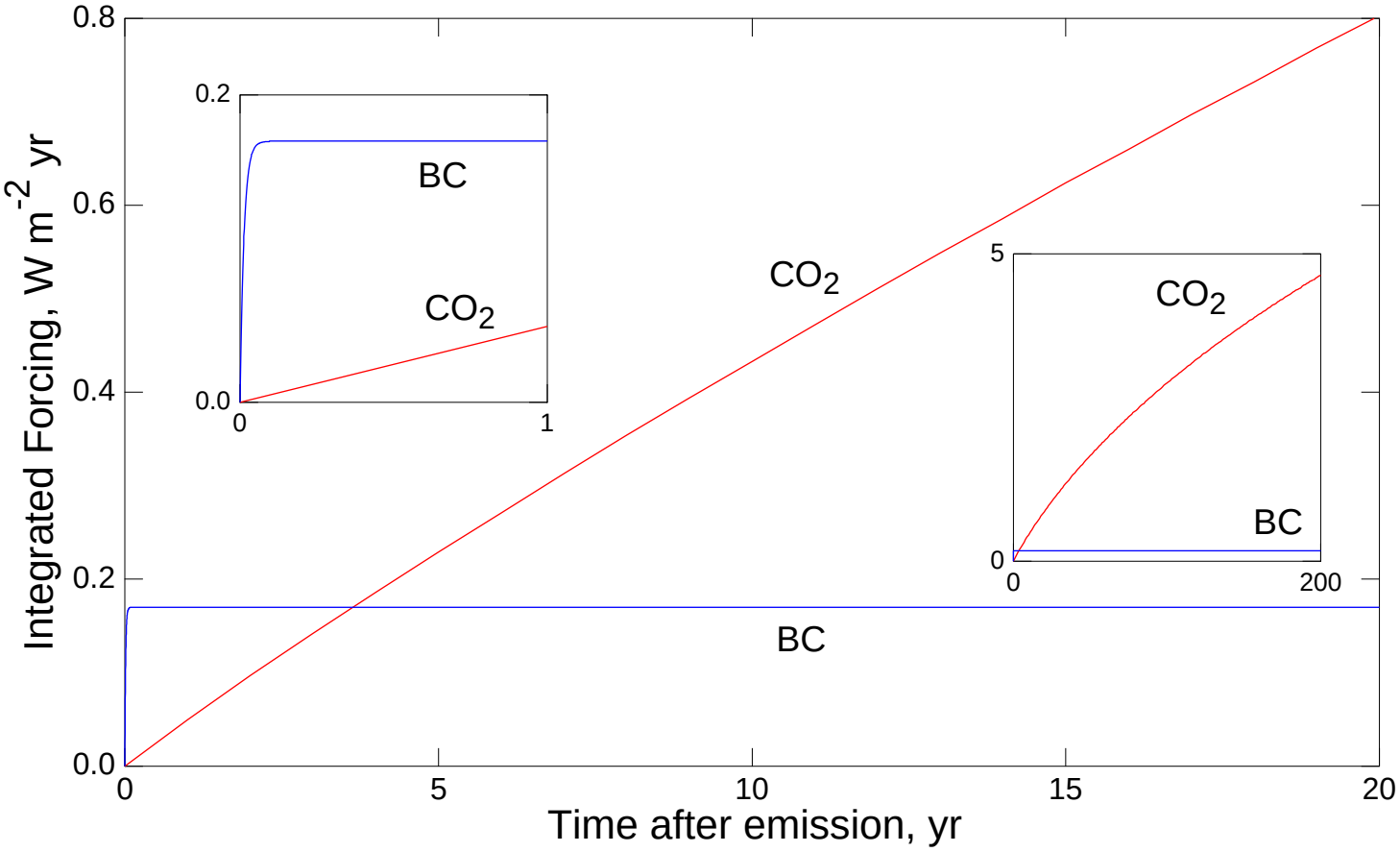
Quantity	Unit	CO_2	BC	CO_2/BC
M_0	g	7×10^{15}	7×10^{12}	1000
b_0	g m^{-2}	14	1.4×10^{-2}	1000
F_N	W g^{-1}	3.6×10^{-3}	900	3.8×10^{-6}
τ(200 yr)	yr	92	0.013	7500
I(200 yr)	W m^{-2} yr	4.7	0.17	27

Over 200 year time horizon CO_2 "wins" by ***factor of 27***.

Exact ratio is uncertain – depends on parameters – but is likely to be ***several tens***.

Ratio depends on "***time horizon***" chosen for comparison.

HOW MUCH TIME COULD YOU BUY? ?



Exact cross-over time is uncertain – depends on parameters – but is ***unlikely to be more than several years***.

CONCLUSIONS

- Evaluation of future consequences of emissions changes requires accurate knowledge of impulse profile as well as forcing.
- A ***conceptual framework*** exists to compare alternative emissions strategies.
- Comparison of 1 year's BC and CO_2 shows that ***integrated forcing of CO_2 rapidly exceeds that of BC*** because of much greater residence time.
- Details are uncertain because of uncertainty in aerosol residence time and normalized forcing.
- These considerations require ***improved understanding of aerosol processes and properties***.