An Integrated View of Climate and Air Pollution:
Climate Stabilization in the 21st Century

Steven Smith

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ssmith@pnl.gov

Battelle

Pacific Northwest
National Laboratory

UNIVERSITY OF MARYLAND

The Joint Global Change
Research Institute

Pollutants and Climate Change

–Emissions of local air pollutants and precursor compounds contribute to climate change primarily through the following mechanisms:

- Tropospheric Ozone (positive forcing)
- Sulfate aerosols (negative forcing)
- Carbonaceous Aerosols (positive or negative)

–Climate policies will tend to reduce emissions of air pollutants as energy production and consumption shifts to different technologies.

–Climate change can also alter the relationship between emissions and pollutant impacts. *(not considered here)*

Key Question: Can a focus on reductions in air pollution reduce near-term climate change?

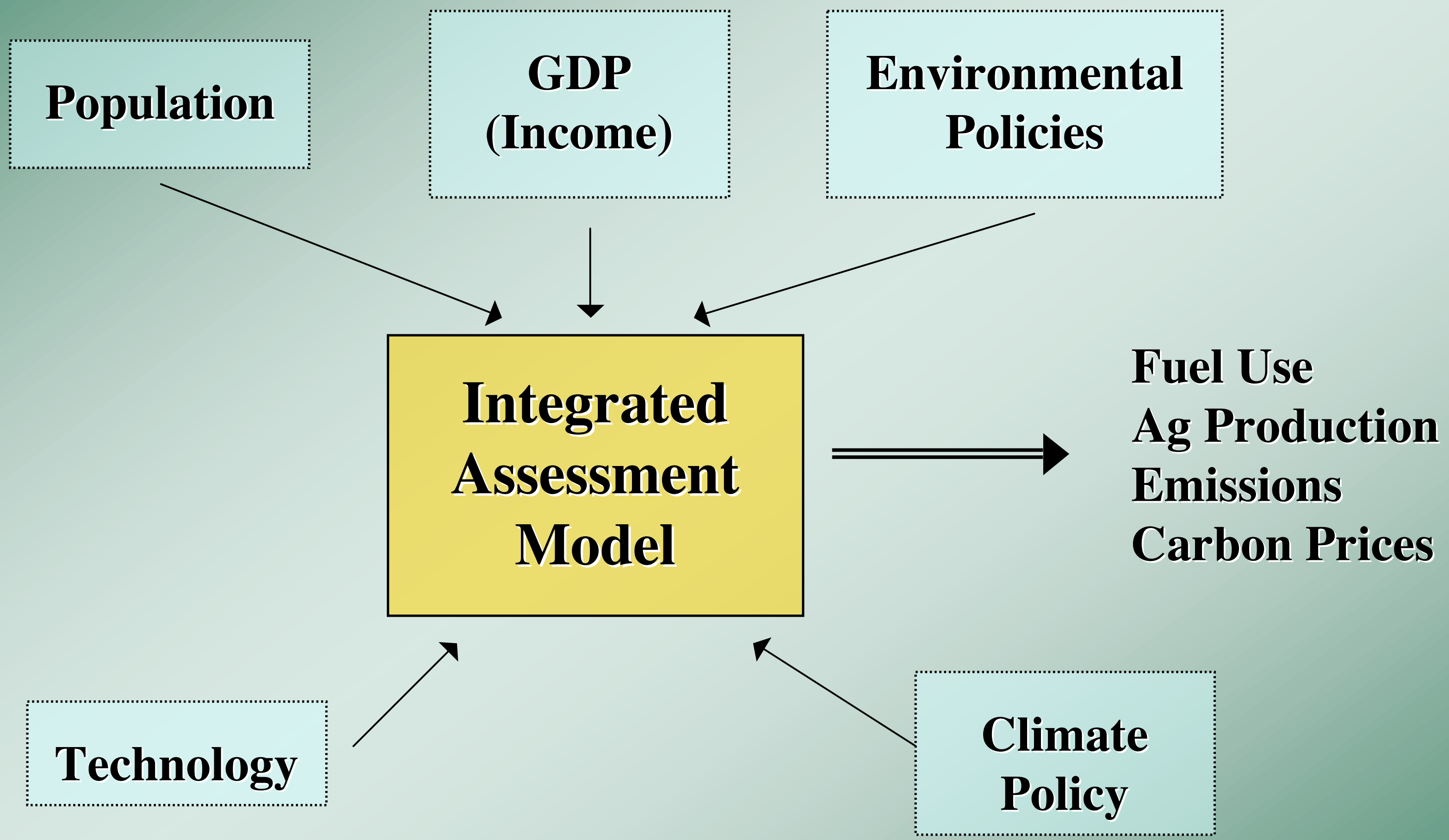
Outline

This talk will present an integrated analysis of radiative forcing over the next century, discussing the role of multiple forcing agents in both “reference” and climate policy cases.

- Integrated Assessment Models and Scenarios
- IPCC SRES Pollutant Emissions
- Forcing in a reference scenario
- Forcing in a policy scenario
- A look at aerosols
- Conclusions

Using an integrated assessment model we can present a self-consistent picture of future socio-economic developments, energy supply & demand technologies, greenhouse gas & aerosol emissions, and global climate change.

Integrated Assessment Modeling



The combination of input assumptions and output values constitutes a scenario

IAM's: Tools for Long-Term Analysis

Integrated assessment models (IAMs)

- Combine information from numerous disciplines into one framework.
- Each model makes different tradeoffs between completeness and complexity, depending on its purpose.

IA Models Are Not "Truth Machines"

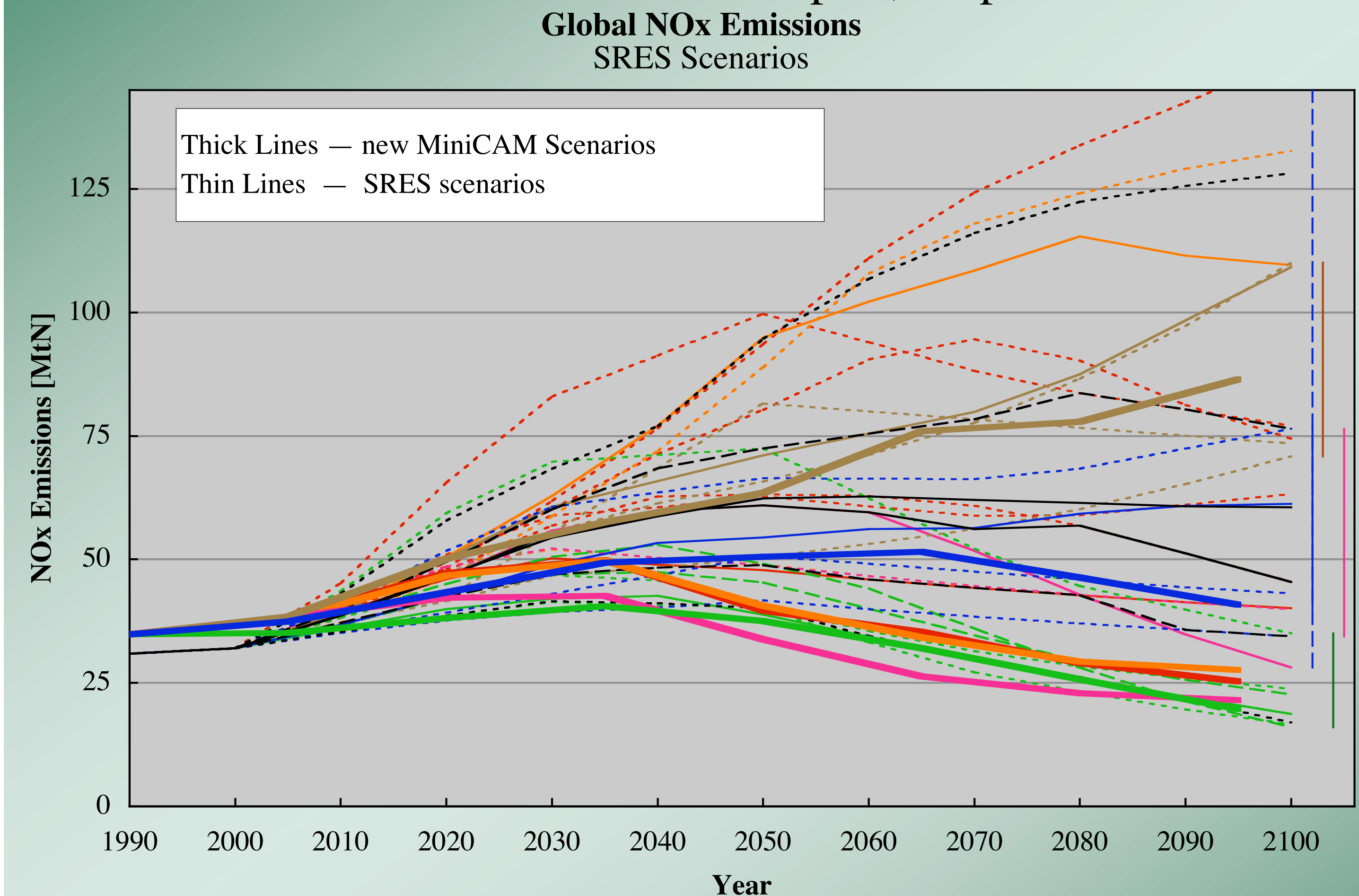
- IA models are not predictive — we can't "forecast" many of the most important factors such as technology or human socio-economic developments.

IA Models Are Tools, useful to examine:

- possible futures with different assumptions for energy technologies, economic growth rates, etc. *(thereby producing emission scenarios)*
- the relative costs of GHG emissions reductions under different scenarios for technology and policy assumptions
- what are the important linkages?
- where are the lever points?

SRES Emissions – NO_x

SRES emissions scenarios included reactive gases, which were a relatively new addition to the models. For the most part, air pollution controls were not included.



As compared with newer scenarios from the MiniCAM model (thick lines), SRES reactive gas emissions are too high for many scenarios.

The A2 Scenario is an outlier in terms of pollutant emissions

Global tropospheric ozone levels for the new scenarios are lower

SRES Emissions Scenarios

The range in forcing from ozone in particular is significantly lower if air pollution controls are included in the modeling projection.

"Greenhouse" Gas	SRES Forcing range (W/m^2)	Modeling Consistency	New MiniCAM Forcing Range (W/m^2)
Methane (CH_4)	0.4 – 1.4 W/m^2	Low	0.5 – 0.7 W/m^2
Nitrous Oxide (N_2O)	0.3 – 0.6 W/m^2	Very Low	0.3 W/m^2
Sulfate Aerosols (SO_4)	-1.5 – -0.1 W/m^2	Good	-1.8 – -0.2 W/m^2
Tropospheric Ozone (O_3)	0.2 – 1.5 W/m^2	Moderate	0.2 – 0.7 W/m^2
Halocarbons	0.3 – 0.4 W/m^2	NA	0.3 – 0.4 W/m^2

Forcing range for the entire SRES scenario set as compared to the range in new MiniCAM scenarios with pollution controls

Note: the consistency between IA models for many of these emissions is low — defined as emissions that depend more on model than scenario assumptions.

Source: Smith & Wigley (2006)

Integrated Assessment With MiniCAM

Put all this together using an integrated assessment model.

The MiniCAM is a long-term partial equilibrium model with 14 regions with markets for energy and agricultural goods and coupled sub-models for energy supply, demand, land-use, and global climate.

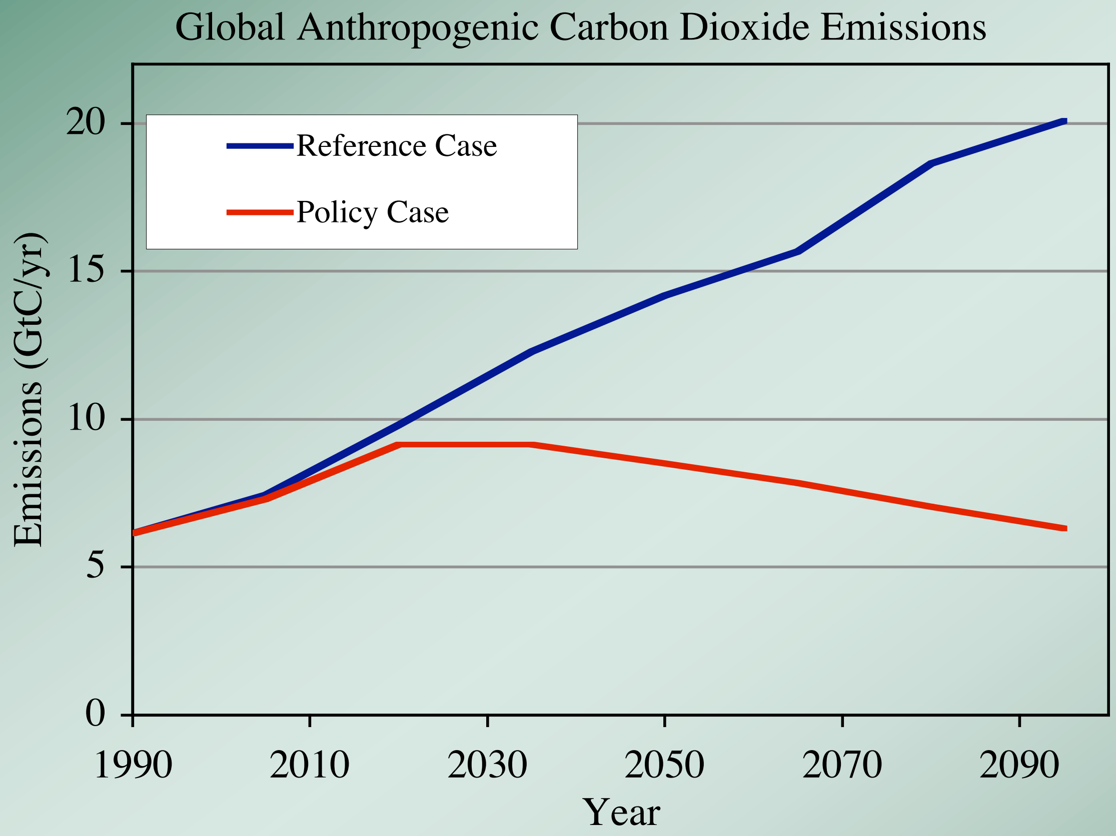
Emissions are calculated for:

- Carbon Dioxide
- Methane
  - 15 Source Sectors (Energy, Human Wastes, Agriculture, Land-Use)
- Nitrous Oxide
  - 12 Source Sectors (Energy, Human, Industrial, Agriculture, Land-Use)
- Halocarbons, etc.
  - 15 Source Sectors (7 gases)
- Carbonaceous aerosols (Black Carbon & Organic Carbon)
  - 19 Source Sectors each (Energy & Land-Use Combustion)
- Reactive Gases
  - NO_x, VOC, CO
- Sulfur Dioxide

GHG concentrations and radiative forcing calculated using MAGICC (Wigley *et al.*)

Setup: Reference and Policy Scenarios

Stabilizing radiative forcing is likely to require global, large changes in the energy system



Stabilizing radiative forcing requires a substantial change from most reference case trajectories.

In order to stabilize carbon dioxide concentrations, emissions must eventually start a continuous decline.

Radiative forcing measures the change in radiant energy balance of the Earth system. It is a common metric for comparing the long-term effect of different perturbations.

These are new realizations of the B2 scenario

Scenario Assumptions

Reference scenario - SRES B2 “innovation as usual”.

- Incomes in developing countries increase

  Most can be considered “developed” by the end of the century, but incomes still lag as compared to current higher income countries.

- Substantial innovation occurs

  More efficient energy supply and service technologies are deployed. Agricultural productivity continues to increase. No transformative technologies (H_2 economy).

  Energy systems in less affluent regions evolve toward modern structures.

- Air pollutant emissions are controlled as incomes increase

  Emissions in many “developing” regions increase in the short term, but decrease as resources become available.

- GHG emissions are reduced as it becomes economic to do so

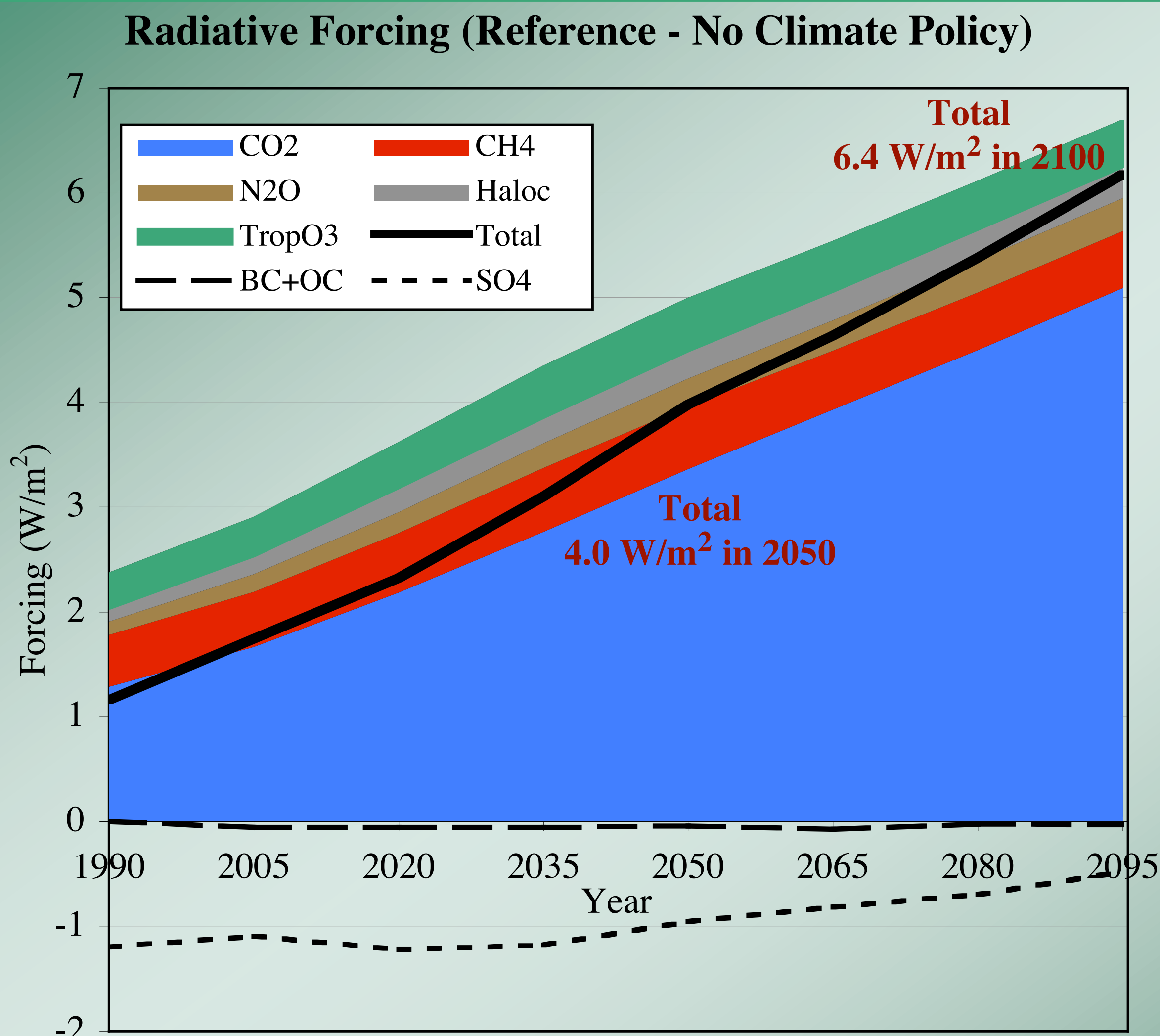
  EMF-21 MACs

  Some reductions assumed in base case (methane recovery for energy use, fertilizer use efficiency improvements). In policy case energy-use and emissions reductions respond to a carbon price.

- Aerosol forcing assumptions take “central” values

  In 1990: Sulfate direct -0.4; Sulfate indirect -0.8; BC+OC fossil 0.16; BC+OC land-use burning -0.16 (all global average W/m^2).

Radiative Forcing — Ref Case (no policy)



Total Forcing increases as GHG emissions continue and aerosol cooling decreases.

The fraction of non-CO_2 GHG forcing decreases relative to CO_2 forcing.

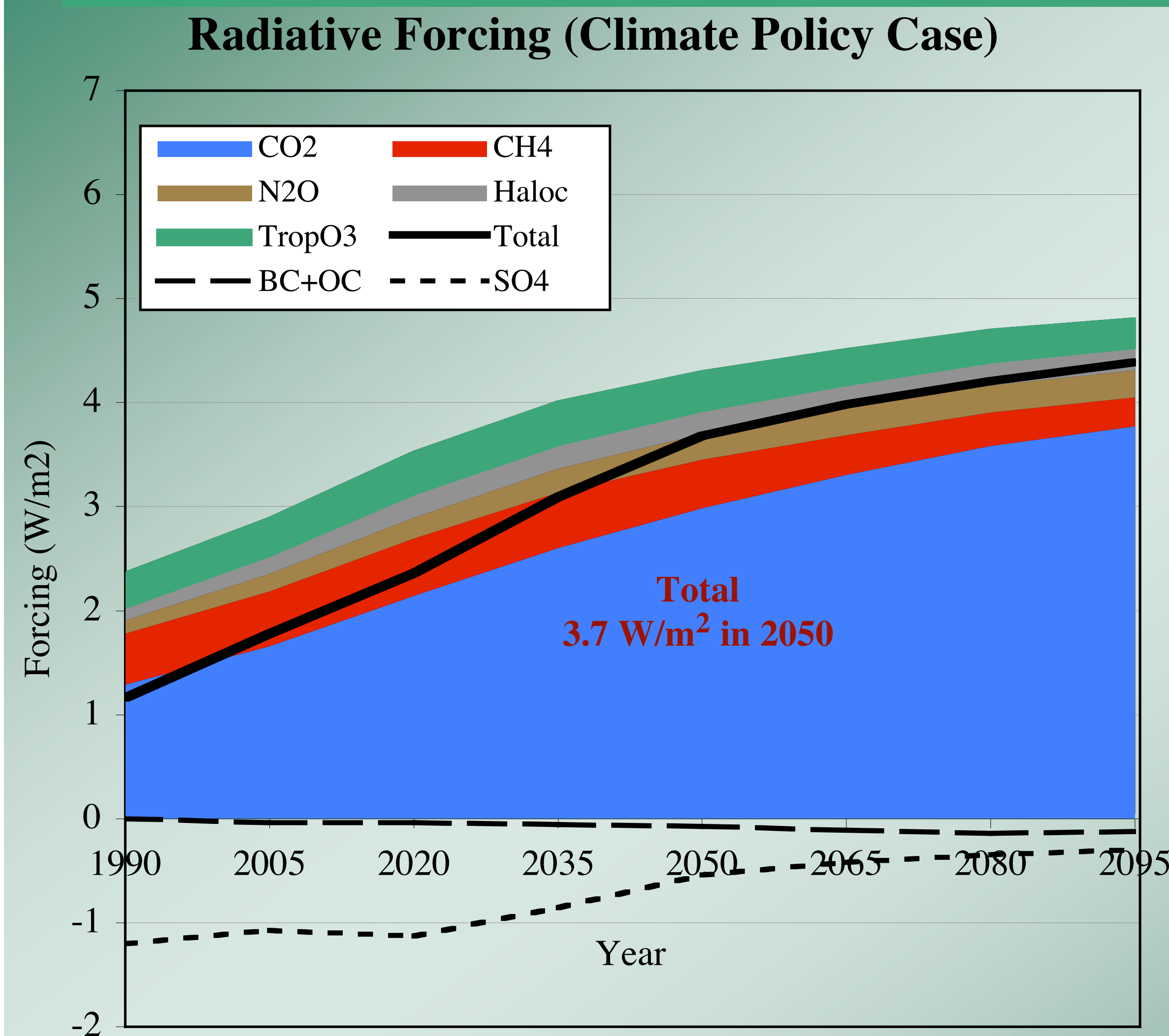
Aerosol forcing is small by the end of the century.

The fraction of non-CO_2 GHG forcing decreases relative to CO_2 forcing.

Total radiative forcing increases throughout the century

Total radiative forcing stabilized at 4.5 W/m²

Radiative Forcing — Climate Policy Case



Some difficult to mitigate sources of non-CO_2 GHGs remain.

About 75% of the 2100 forcing reduction comes from carbon dioxide.

Some methane and most ozone reductions are indirect effects of the CO_2 reductions.

About 2/3 of the non-CO_2 forcing reductions are due to direct actions to reduce forcing from GHGs.

Note that forcing stabilization does not equal climate stabilization

Radiative Forcing Changes

Changes in radiative forcing (relative to preindustrial):

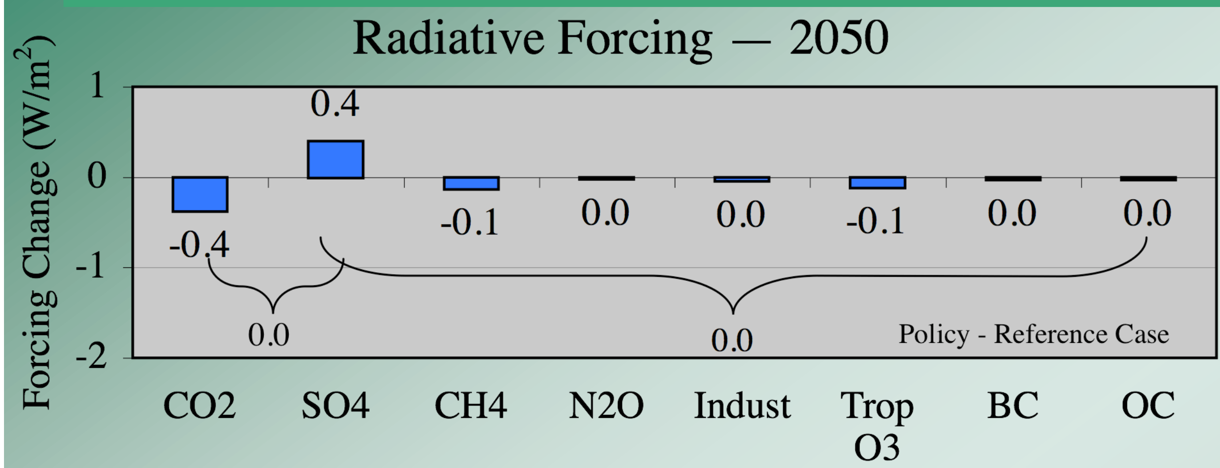
	2000			2050			2100		
	CO2	**non-CO2 GHG**	**Aerosols**	**CO2**	**non-CO2 GHG**	**Aerosols**	**CO2**	**non-CO2 GHG**	**Aerosols**
Ref (no Clim Policy)	1.5	1.2	-1.2	3.4	1.6	-1.0	5.3	1.6	-0.4
Stab at 4.5 W/m^2	1.5	1.2	-1.2	3.0	1.3	-0.6	3.8	1.0	-0.4
Stab at 3.5 W/m^2	1.5	1.2	-1.2	2.6	1.2	-0.4	2.7	1.1	-0.3

Total Forcing	2000	2050	2100
Ref (no Clim Policy)	1.6	4.0	6.4
Stab at 4.5 W/m^2	1.6	3.7	4.4
Stab at 3.5 W/m^2	1.6	3.4	3.4

For illustration, in addition to the previous scenario, a more aggressive policy case where forcing is stabilized at 3.5 W/m^2 is also shown.

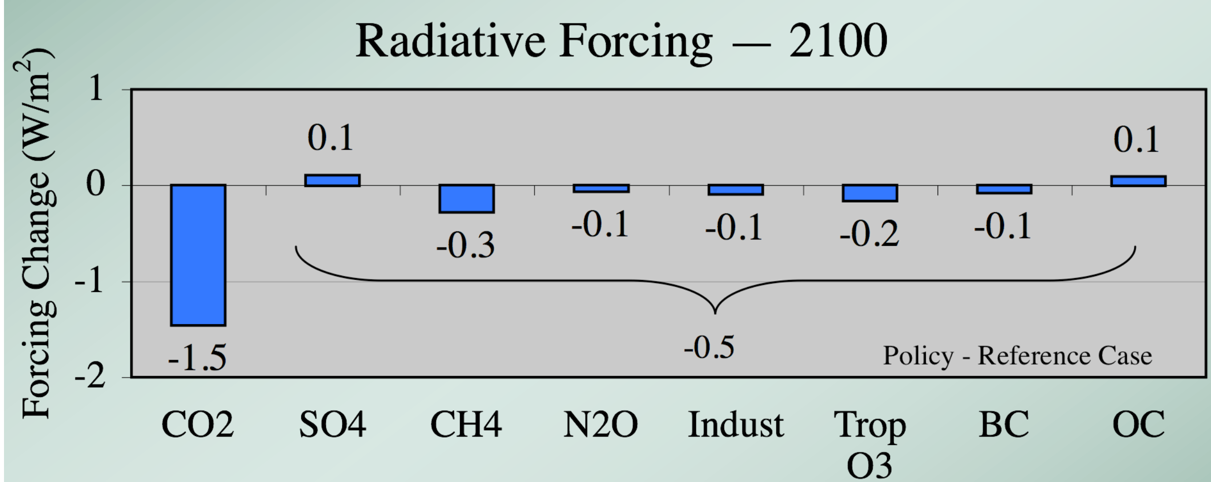
Stabilization of non-CO2 GHG forcing seems possible by 2050, but including aerosols gives a net positive non-CO2 GHG + Aerosol forcing in all cases.

Comparison of Policy and Reference Cases



In the first half of the century, decreasing sulfate emissions offsets much of the forcing reduction.

Net reduction from ref case is relatively small (0.3 W/m²).



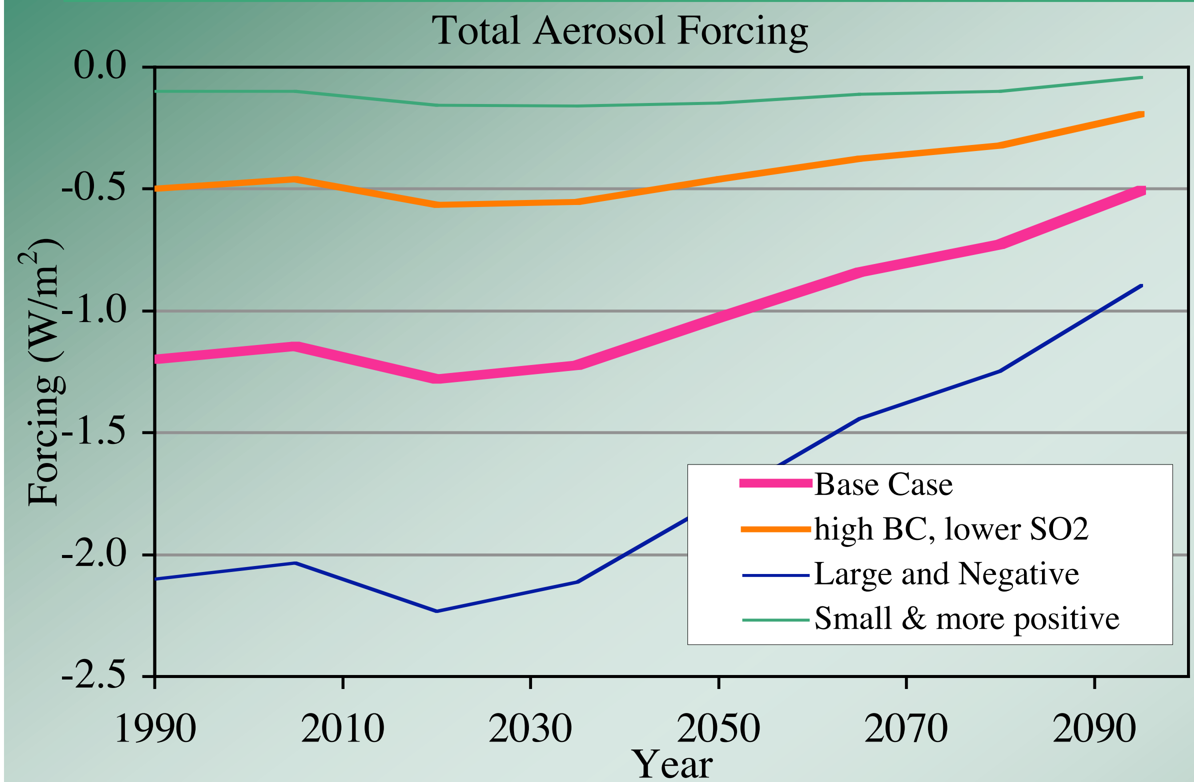
Over the entire century carbon dioxide provides the dominant forcing reduction.

Net reduction in non-CO_2 forcing is 1/3 of the CO_2 reduction.

The "un-masking" effect of sulfur reductions makes reducing forcing in the first half of the century more difficult.

Total forcing from SO_4, BC, & OC

Aerosol Uncertainties (Ref case forcing)



Assumptions about aerosol forcing are constrained by the following observations:

Net forcing from biomass burning is thought to be negative.

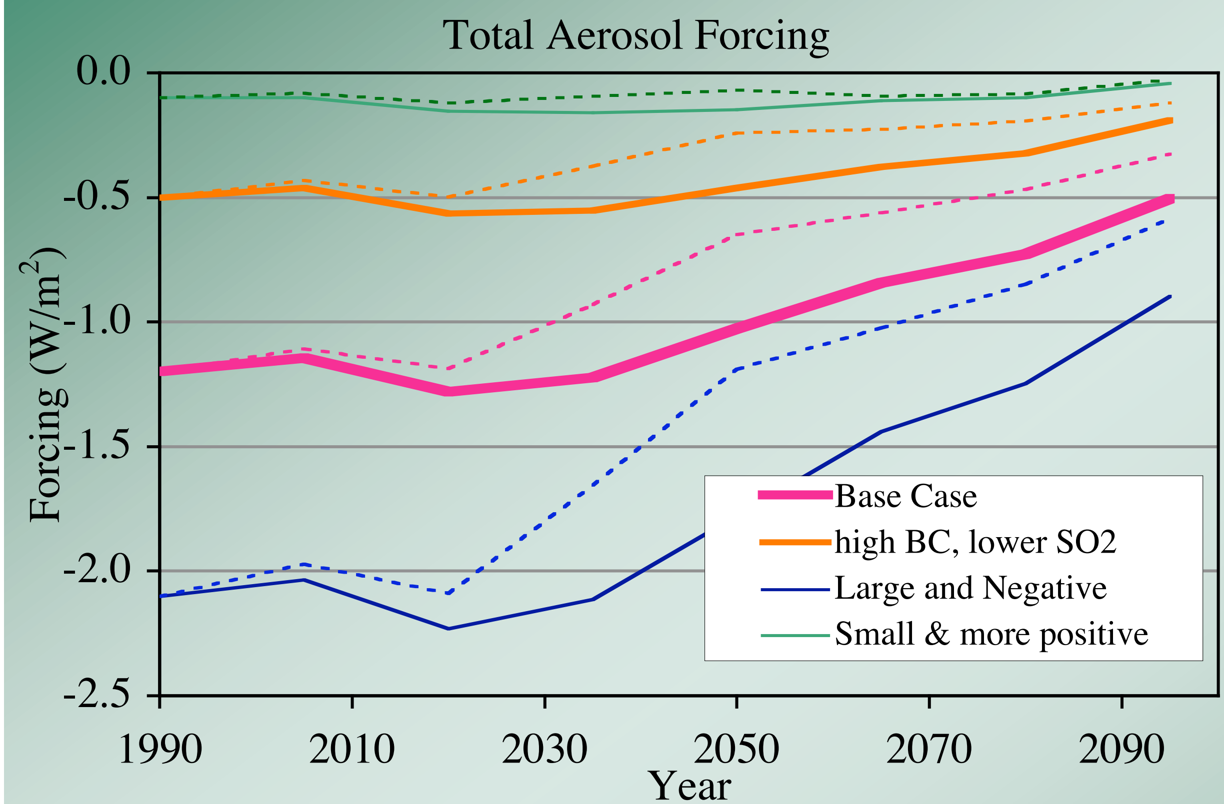
Spatial and temporal pattern matching between models and historical temperature records indicates a net negative forcing from aerosols.

From 2000 through 2100, the net aerosol effect is positive.

Aerosol effect from 2000 through 2050 is positive or neutral

While the "un-masking" effect appears at this point to be unavoidable, it may be larger or smaller than the estimate used here.

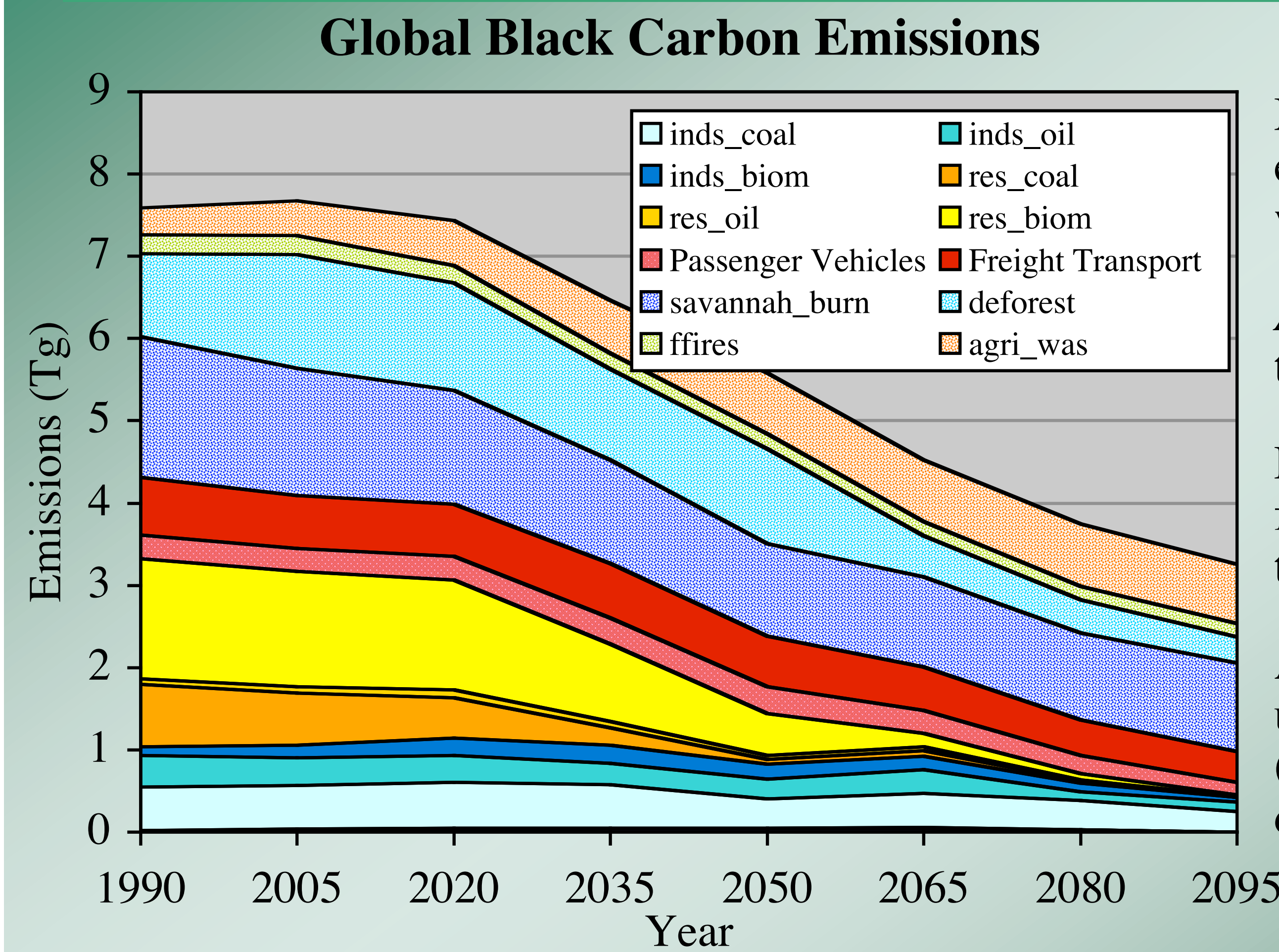
Aerosol Uncertainties (Policy case forcing)



In the policy case (dotted lines) aerosol forcing more rapidly approaches its asymptotic value.

From 2000 to 2050 the net aerosol affect is positive in a policy scenario

Black Carbon Emissions (reference case)



Many sources of pollutant emissions will decrease even without a climate policy.

Additionality: can't count these toward a climate policy goal.

For black carbon, emissions from residential uses are likely to decrease substantially.

At the end of the century, land-use and transportation (particularly freight) are dominant emissions.

May be quite difficult to make additional reductions in many of the sources

Note: reducing open biomass burning (e.g., deforestation) emissions increases net radiative forcing from aerosols.

Summary

- **Total radiative forcing at least doubles from 2000 and 2050 in these scenarios — even in policy cases** (Forcing + 2 W/m^2)
  - **Difficult to change — energy trends, carbon-cycle, and aerosol cooling**
- Non-CO_2 greenhouse gas forcing increases between 2000 and 2050
  - Stabilization of non-CO_2 GHG forcing is possible in a policy scenario — but requires global participation in a substantial climate policy.
- Net aerosol emissions contribute a net positive forcing 2000–2050.
  - Alternative results depend not on policy, but on uncertain physical parameters.
  - Limited offset: major sources are different: SO_2 (elec); BC/OC (resid/LUC).
- In the reference case, non-CO_2 GHG forcing has stabilized and aerosol forcing is insignificant by the end of the century.
  - Only cases where this is not true are those where development has failed in many regions — a global carbon policy in this case is probably not possible…
- Our reference case includes controls for local air pollution, shifts in fuel use due to development, and cost-effective reductions in CH_4.
  - These are likely to happen without a climate policy. Shouldn't "double count".

Conclusion

Actions over the next 50 years are critical to achieving long-term stabilization of radiative forcing. Reducing CO_2 emissions is central to this effort.

Within this context, radiative forcing will almost certainly continue to increase until mid-century, by least 2 W/m^2 with central assumptions, even in a policy case.

> *This includes substantial pollution reduction due to continued control efforts and potential climate policy.*

Additional forcing reductions due to further pollution controls are likely to be small.

References (non-CO2 emissions, forcing, and policy)

The scenario results presented here were taken from:

Smith, Steven J. and T.M.L. Wigley (2006) Multi-Gas Forcing Stabilization with the MiniCAM *Energy Journal* (accepted).

Scenario results

Smith, Steven J. (2005) Income and Pollutant Emissions in the ObjECTS MiniCAM Model. *Journal of Environment and Development* ***14 (1)*** pp. 175–196.

Pollutant em & controls

Smith, Steven J., Pitcher, H., and Wigley, T.M.L. (2005) Future Sulfur Dioxide Emissions. *Climatic Change* **73(3)** pp. 267-318.

SO2 em & controls

Smith, Steven J (2003) The Evaluation of Greenhouse Gas Indices *Climatic Change* **58 (3)**, pp. 261–265.

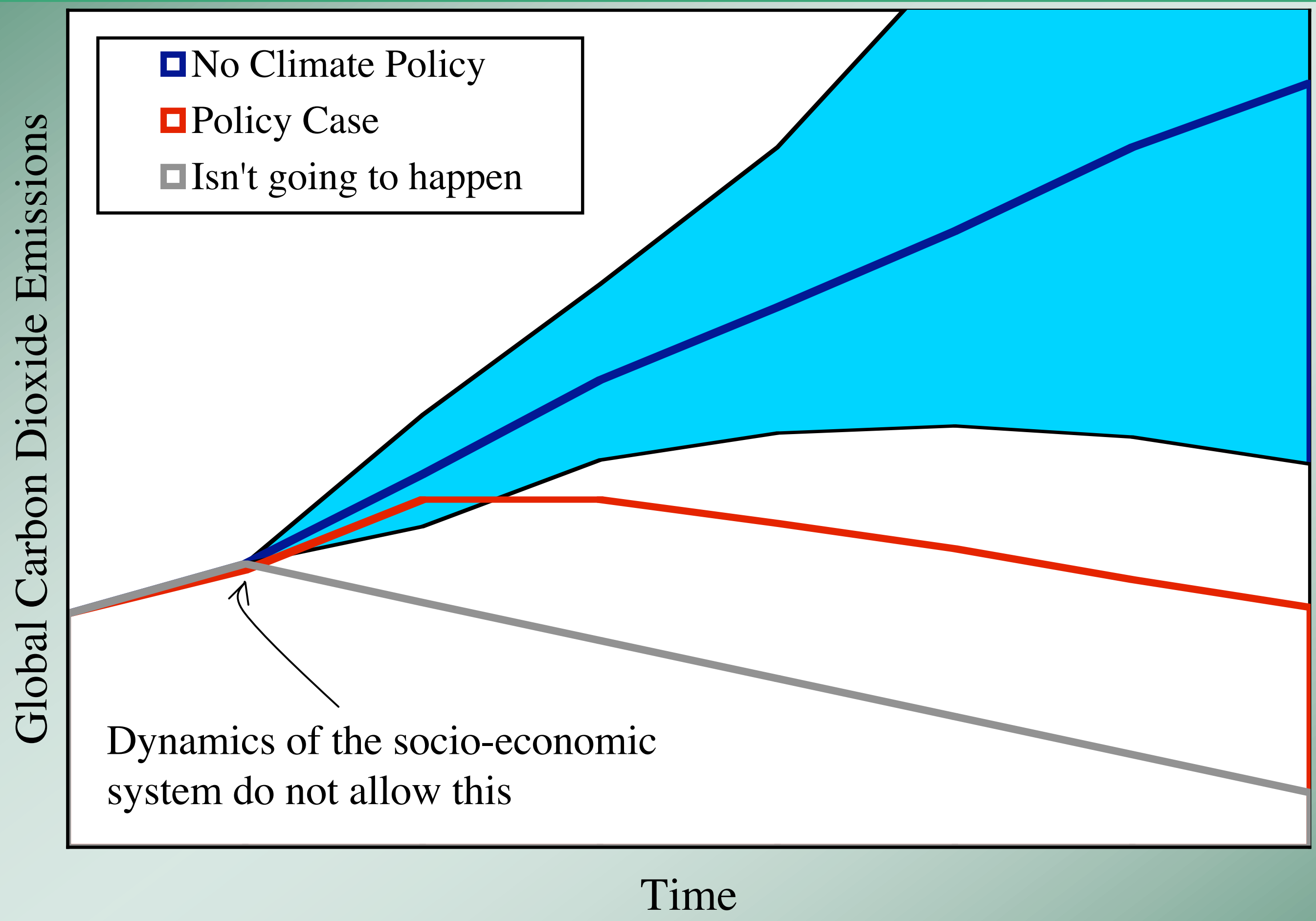
GHG indices (Pulse vs Step)

Wigley, T.M.L., Steven J. Smith, and M.J. Prather (2002) Radiative Forcing due to Reactive Gas Emissions. *Journal of Climate* **15(18),** pp. 2690–2696.

Reduced form O3 relationship

Smith, Steven J., Wigley, T.M.L., and Edmonds, J. (2000) A new route toward limiting climate change? *Science* **290:** 1109–1110.

Epilouge(Cartoon Policy)



How fast can we change the global trajectory?

(Even if we knew what it was…)