Moderating Climate Change by Limiting Emissions of Both Short- and Long-Lived Greenhouse Gases

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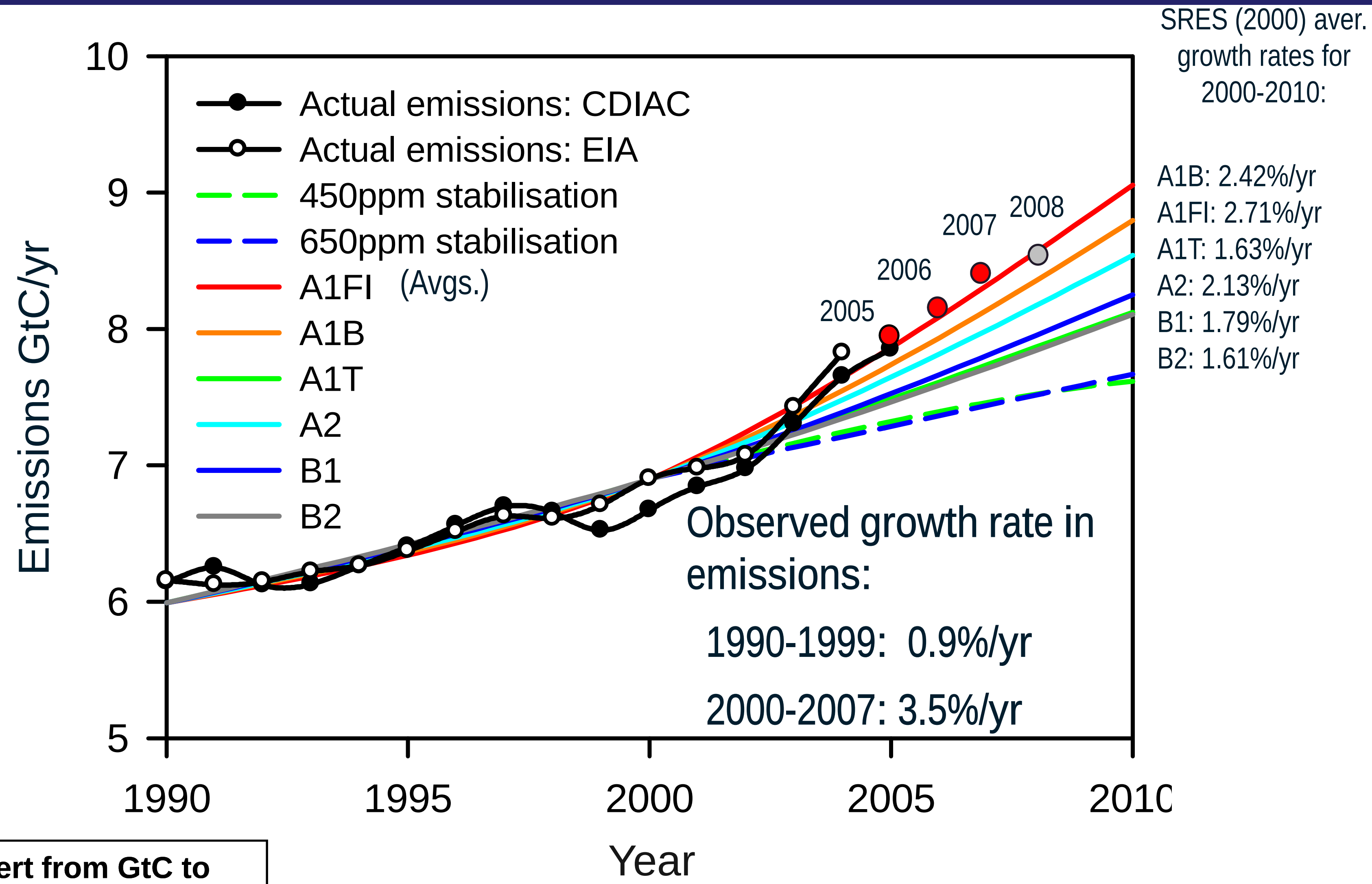
The 15th 'Science in Japan' Forum
Washington, DC
June 15, 2010

Fossil fuel emissions have been rising as rapidly as the highest IPCC scenario proposed in 2000

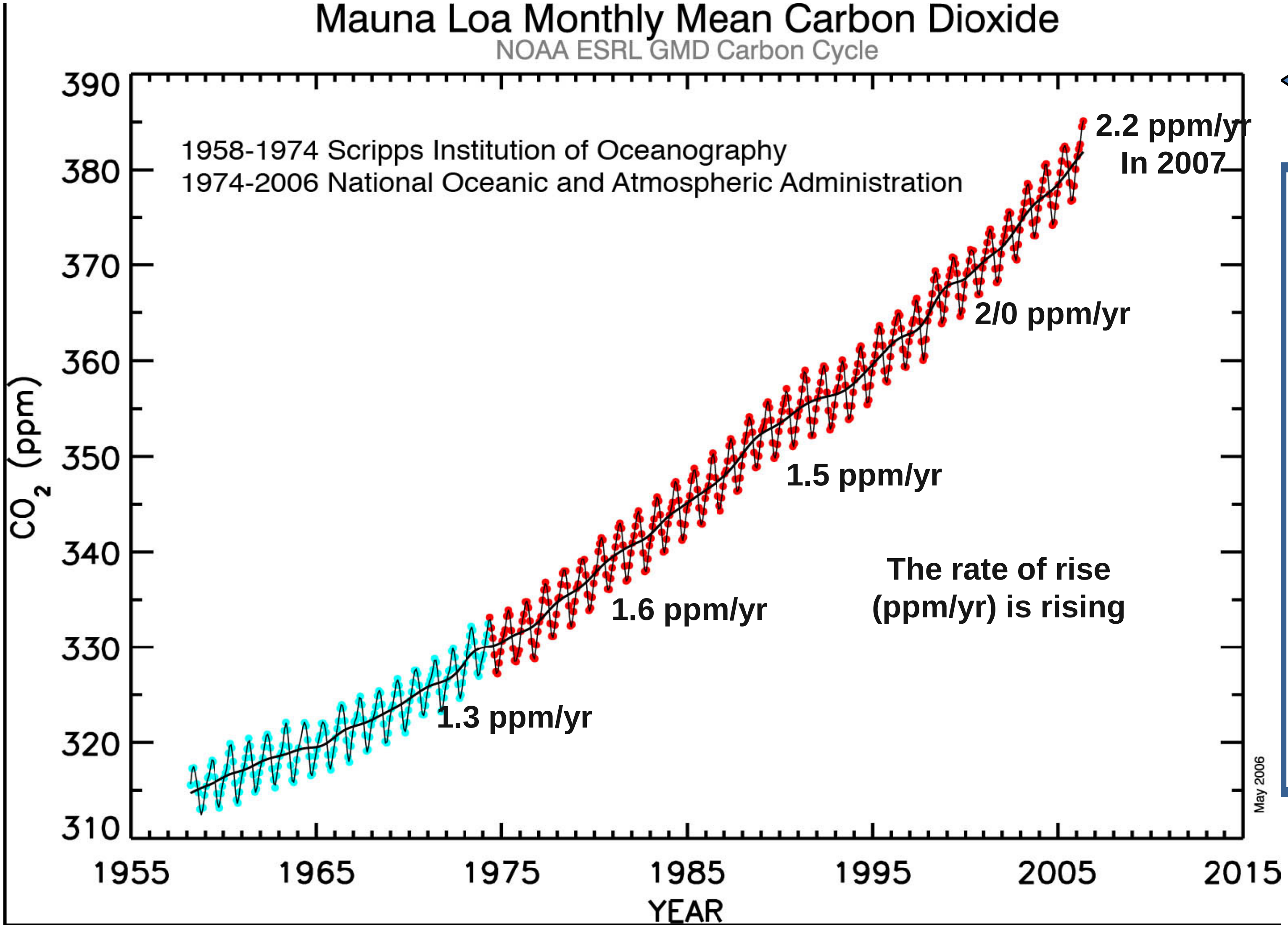


To convert from GtC to $GtCO_2$ used in negotiations, multiply by 3.67

Raupach et al 2007, PNAS; Global Carbon Project 2009, update

Slide from Canadell, 2009

Increasing emissions are increasing the rate of increase of the atmospheric CO_2 concentration

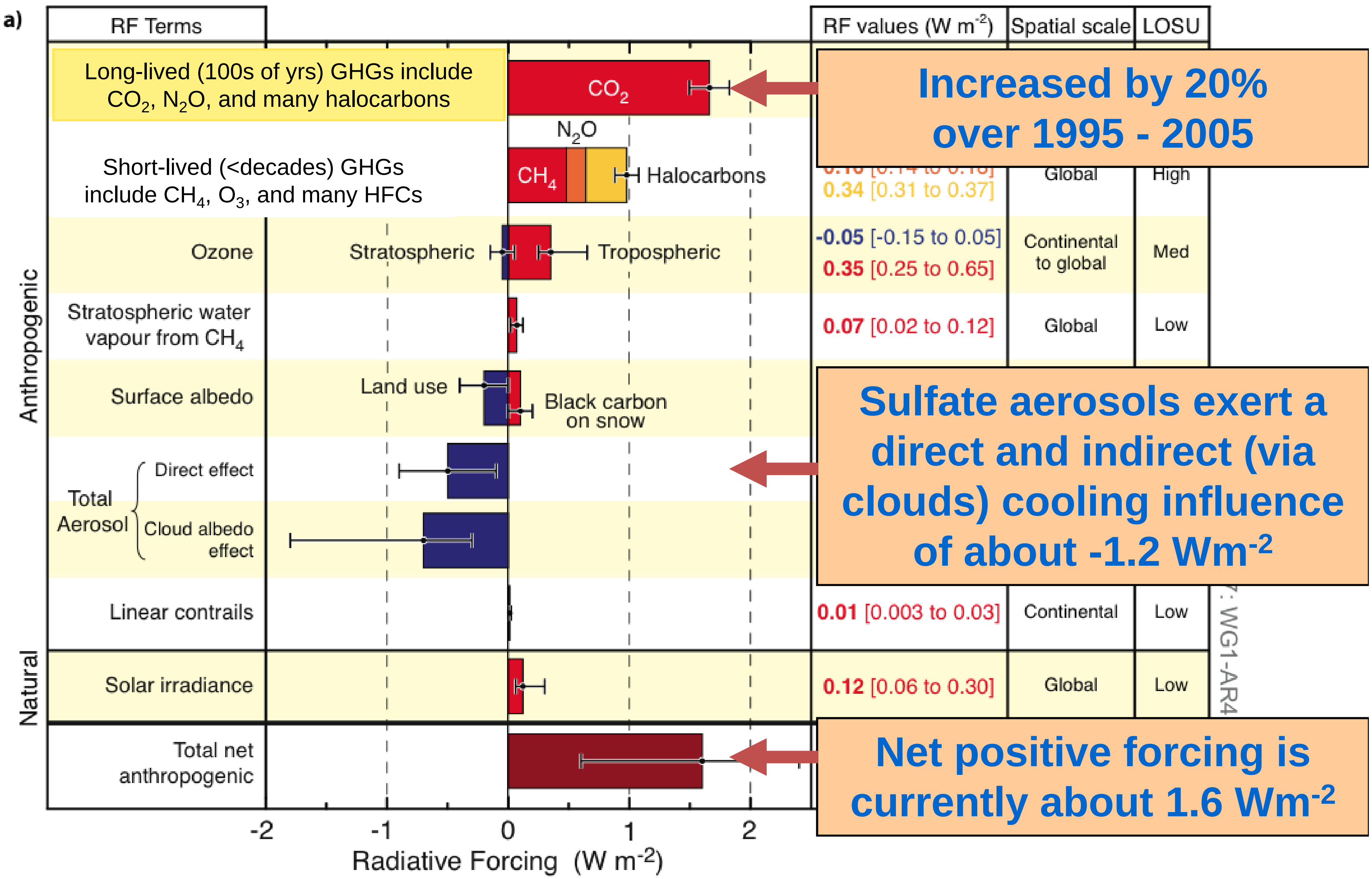


The present concentration is ~390 ppm, about 24% above the value of 315 ppm in 1957 when C. David Keeling began very careful measurements and about 40% over the preindustrial concentration

Source: NOAA

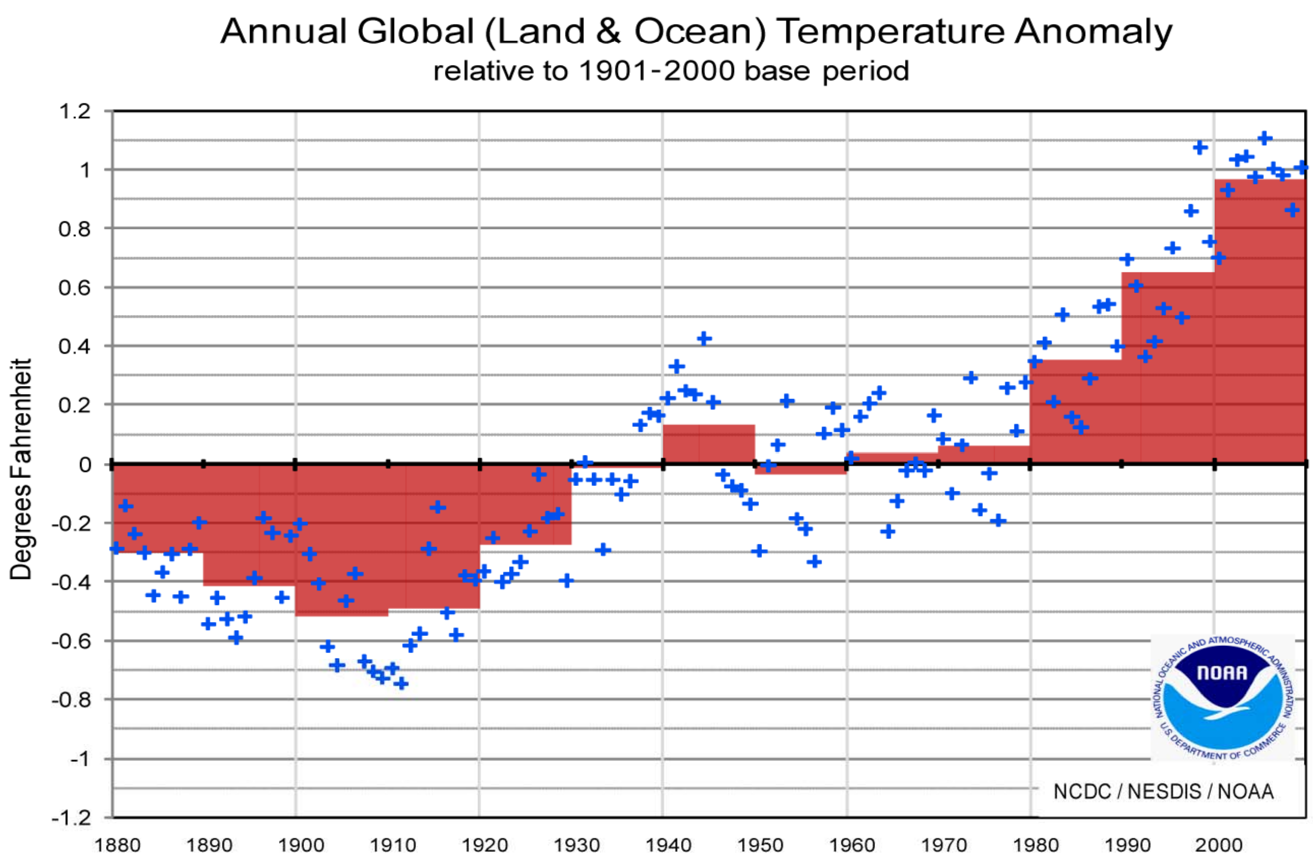
That the magnitude of the seasonal cycle has increased suggests that, even with a reduced amount of vegetation, the higher CO_2 concentration is enhancing the seasonal growth of global vegetation

Increasing concentrations of radiatively active gases and aerosols are affecting the fluxes of visible and infrared radiation, exerting a "radiative forcing" on climate



On a decadal-average basis, the world has experienced relatively steadily warming over the last few decades

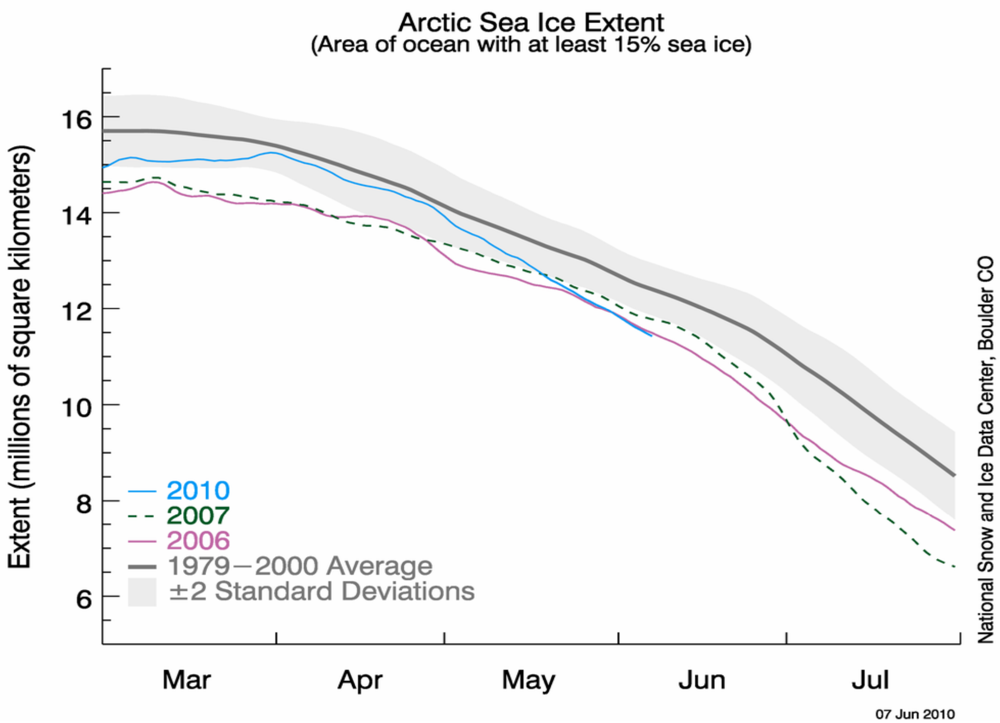
Global Temperature Anomalies

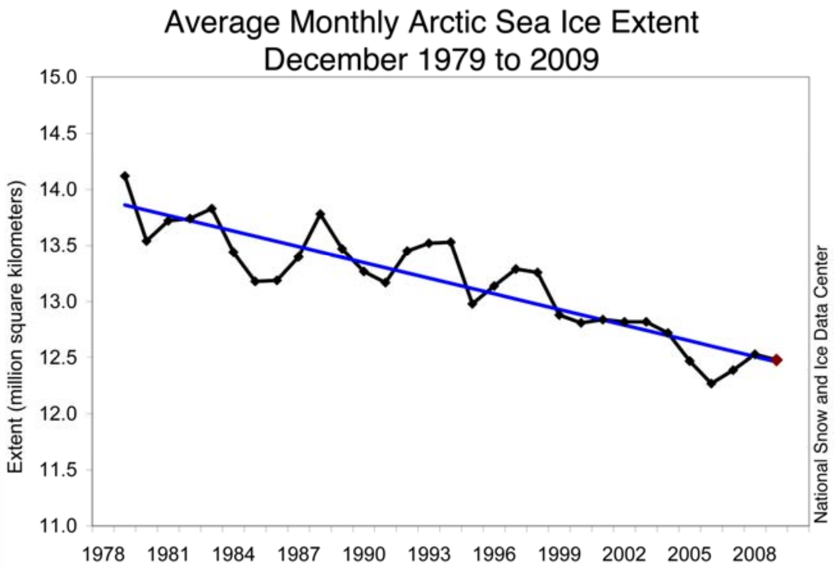


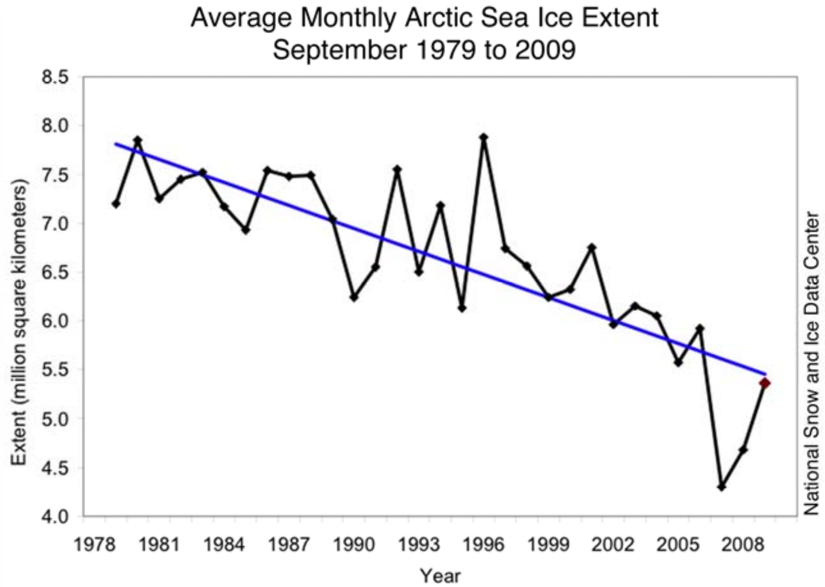
Blue dots—annual global anomalies
Red bars—decadal-average anomalies

Arctic sea ice has been retreating significantly—then came March 2010—and then May 2010

Arctic sea ice is disappearing at a more rapid rate than global climate models have been projecting. We need to determine if the acceleration is due to a general model shortcoming, under-estimated responsiveness to GHG-induced warming, increased deposition of soot, or reduced sulfate loading due to reductions in SO_2 emissions from Russia and Europe

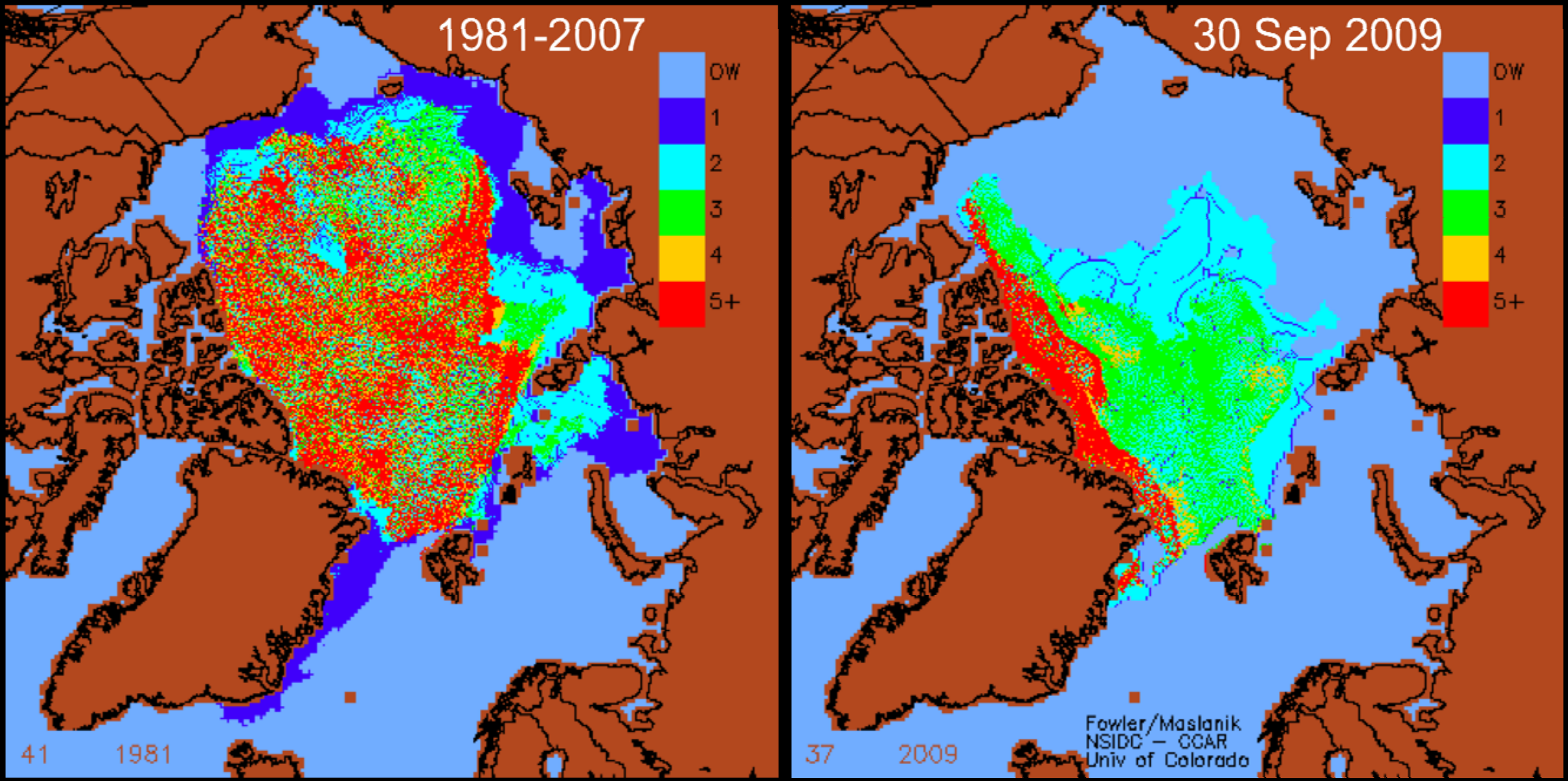






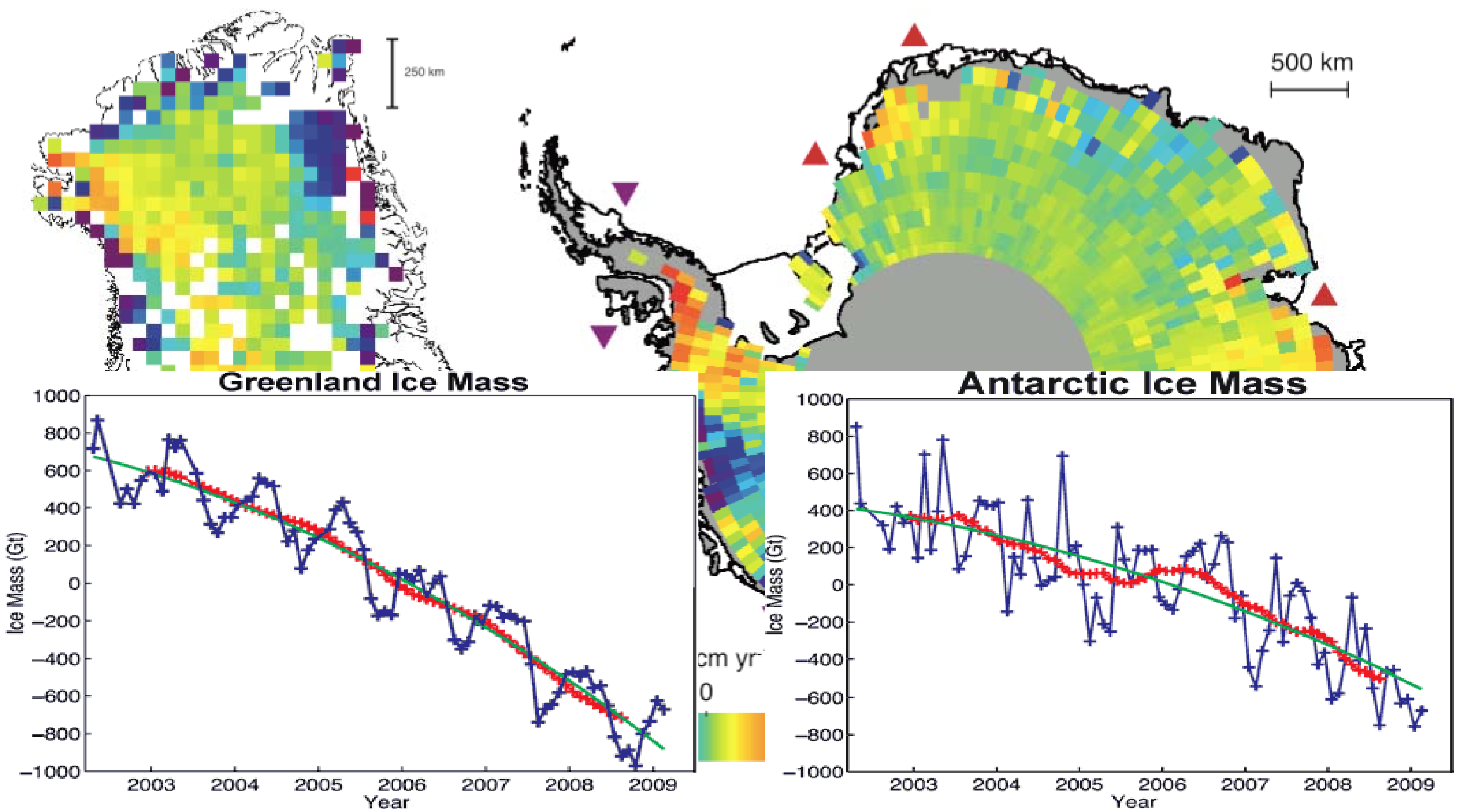
Arctic sea ice has become younger and thinner—

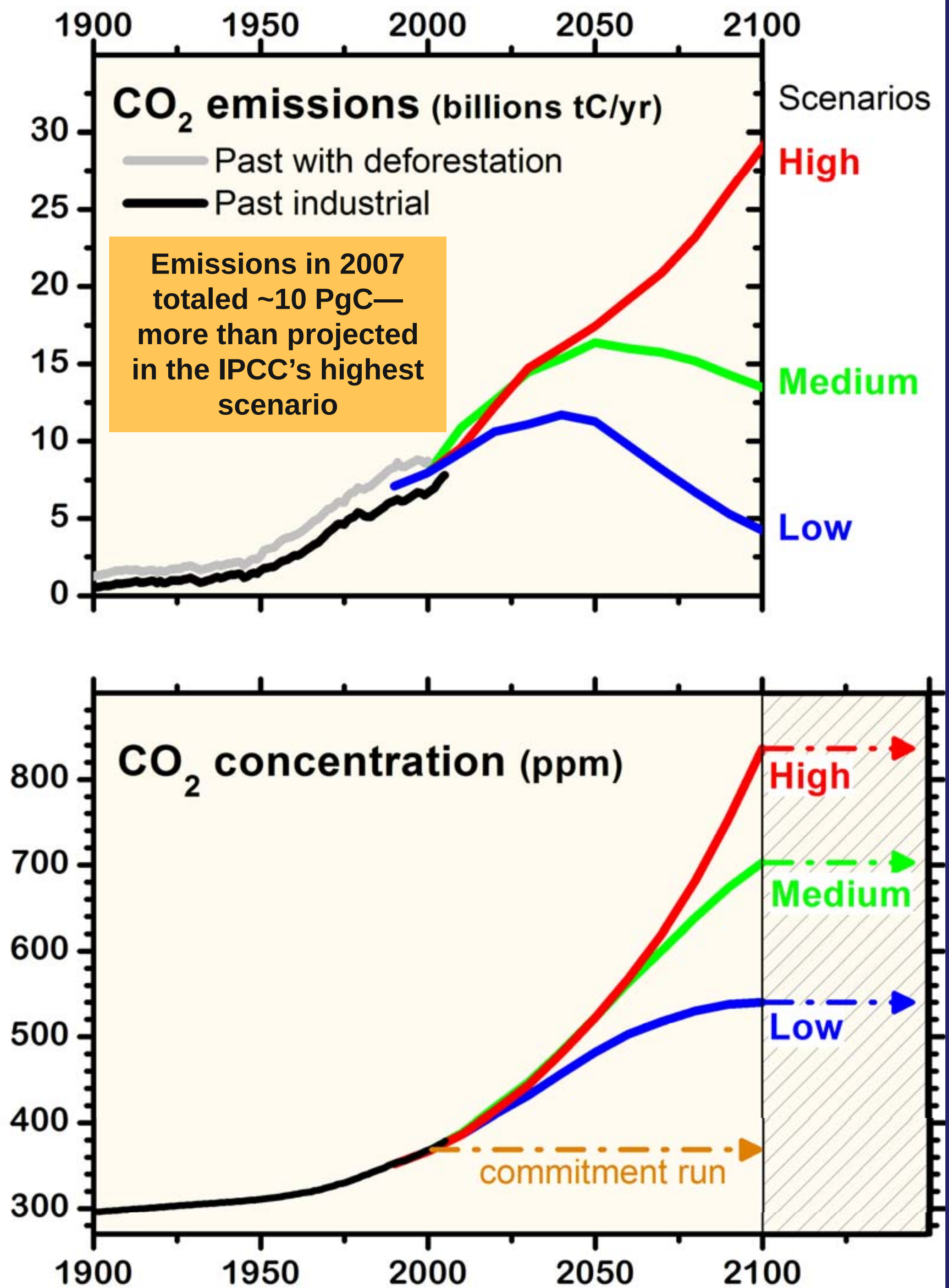
Thick ice used to cover most of the central Arctic, but now in summer is limited to a narrow band along Greenland and the Canadian Archipelago



From J. Maslanik, C. Fowler, Univ. Colorado

The Greenland and Antarctic Ice Sheets are both losing ice, around the edges and through ice streams, somewhat offset by interior thickening

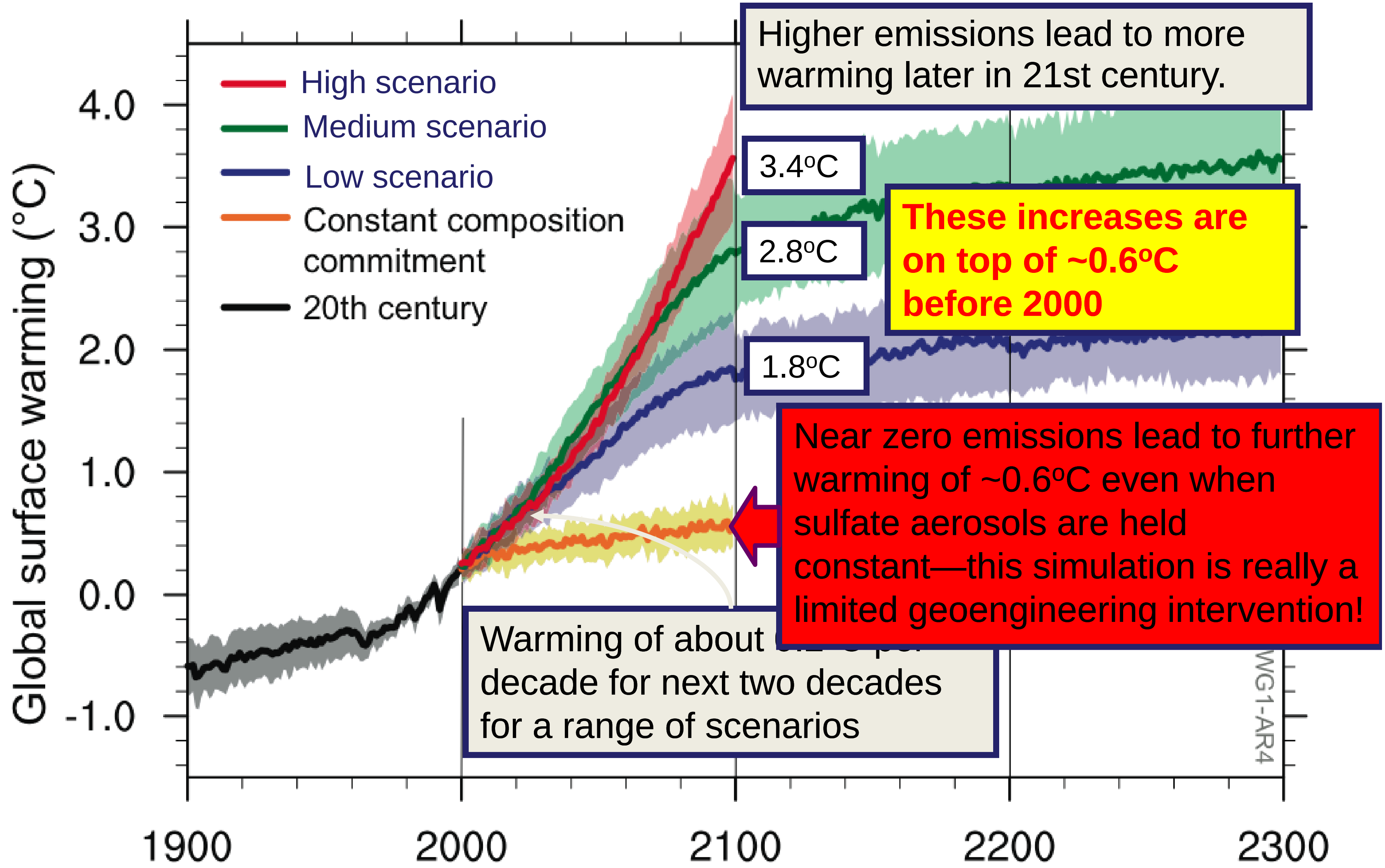




Without policies to limit emissions, the continued increase in global population and rising standard of living are projected to lead to substantial increases in global CO_2 emissions

As a result, the atmospheric CO_2 concentration is projected to rise from its current value of ~385 ppm to at least 2 to 3 times the preindustrial value by 2100, and possibly higher thereafter

Projections of global average warming after 2000 for different assumptions about emissions of GHGs



The prevailing view has been that limiting CO_2 emissions is the key to limiting climate change in the 21st century

Climate Changing Gas/Aerosol	Forcing (1750-2000) (W/m^2)	BAU Forcing (2100) (TAR, Table 6.14; etc.)
Carbon dioxide (CO_2)	1.66	~5.1
Methane (CH_4)	0.48	~0.9
Nitrous oxide (N_2O)	0.16	~0.4
Halocarbons	0.34	~0.4
Tropospheric ozone (O_3)	0.35	~0.65
Black soot	~0.4	~0.4
Sulfate direct (SO_4)	-0.4	-0.4
Cloud forcing	-0.7	-0.7
TOTAL	~2.3	~6.75

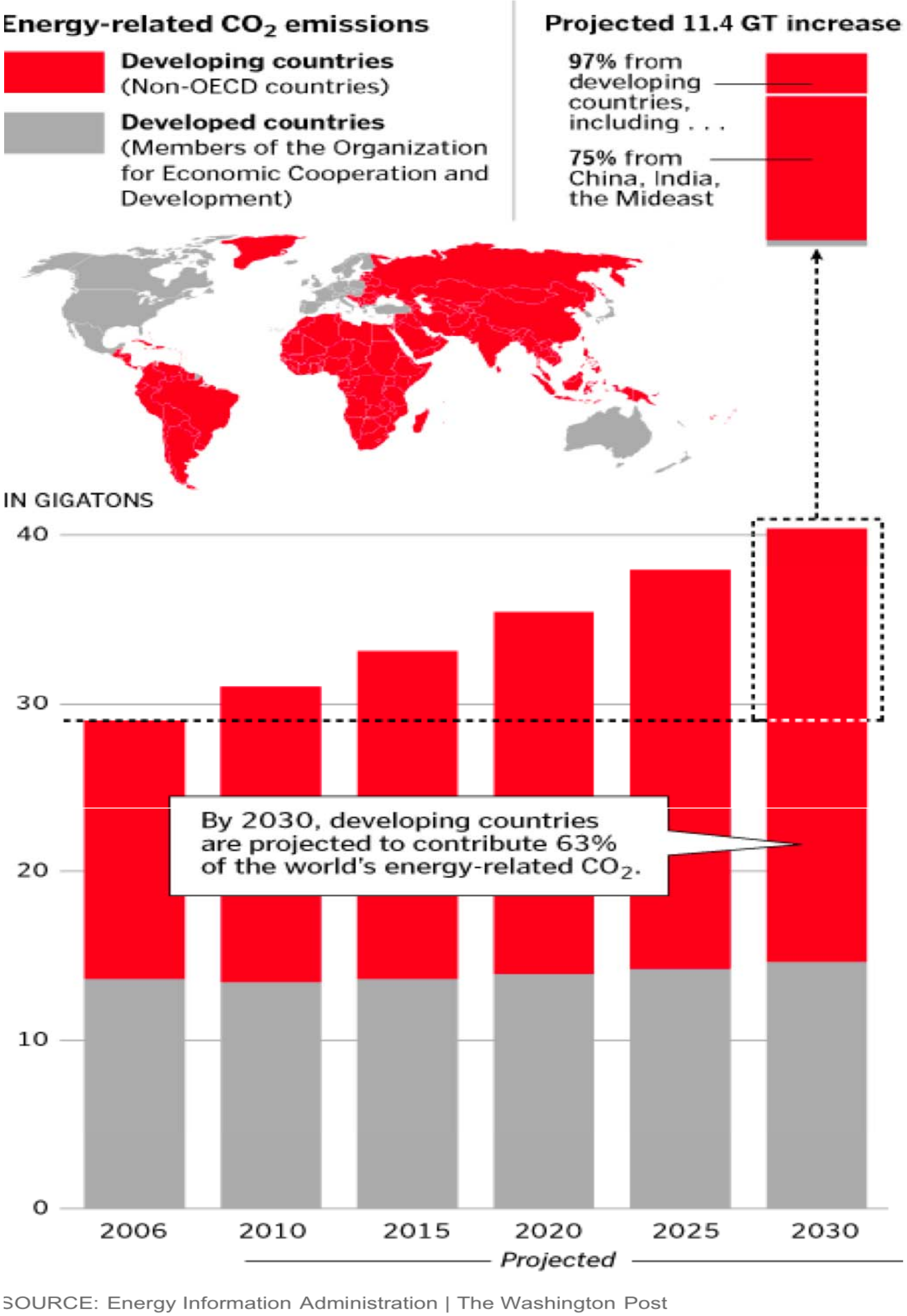
Sources: Current forcing from IPCC (2007); BAU Scenario from UN Sci. Experts Group (2007)

The largest change in forcing from 2000 to 2100 is projected to result from the higher CO_2 level – Contributions from other gases appear to be minor

Climate Changing Gas/Aerosol	TAR *Change* in BAU Forcing during 21st Century	AR4 *Change* in Forcing during 21st Century
Carbon dioxide (CO_2)	~3.4	2.06 to 5.15
Methane (CH_4)	~0.4	-0.7 to 0.59
Nitrous oxide (N_2O)	~0.25	0.11 to 0.40
Halocarbons	~0.05	~0.1
Tropospheric ozone (O_3)	~0.5	-0.16 to 0.89
Black soot	~0	-0.2 to 0.6
Sulfate direct (SO_4)	~0	0.12 to 0.24
Cloud forcing	~0	-0.56 to 0.1

CO_2 forcing is dominant

Non-CO_2 short-lived GHGs are estimated to be responsible for ~1.15 W/m^2 --or ~25% of positive forcing over the 21st century

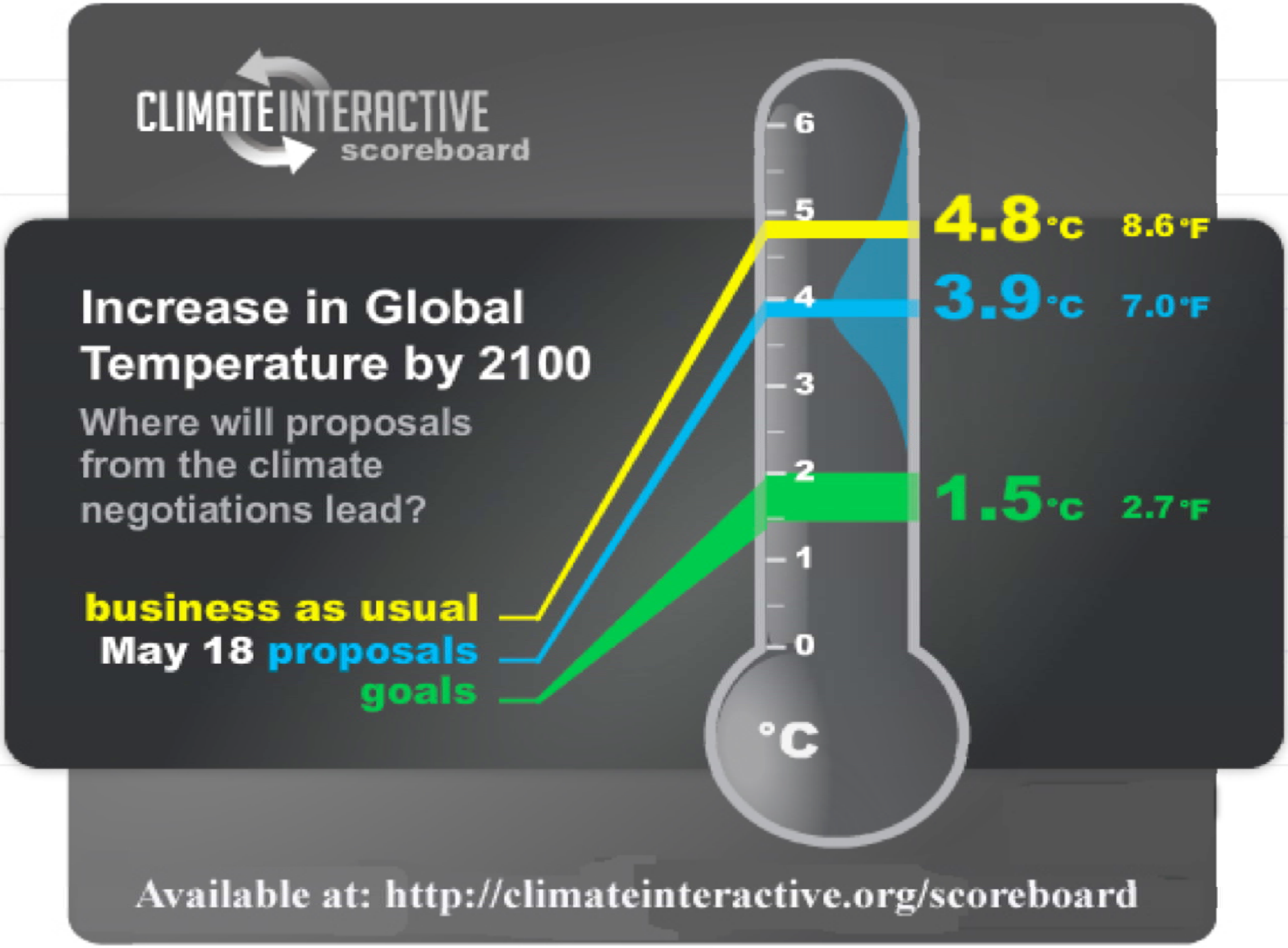


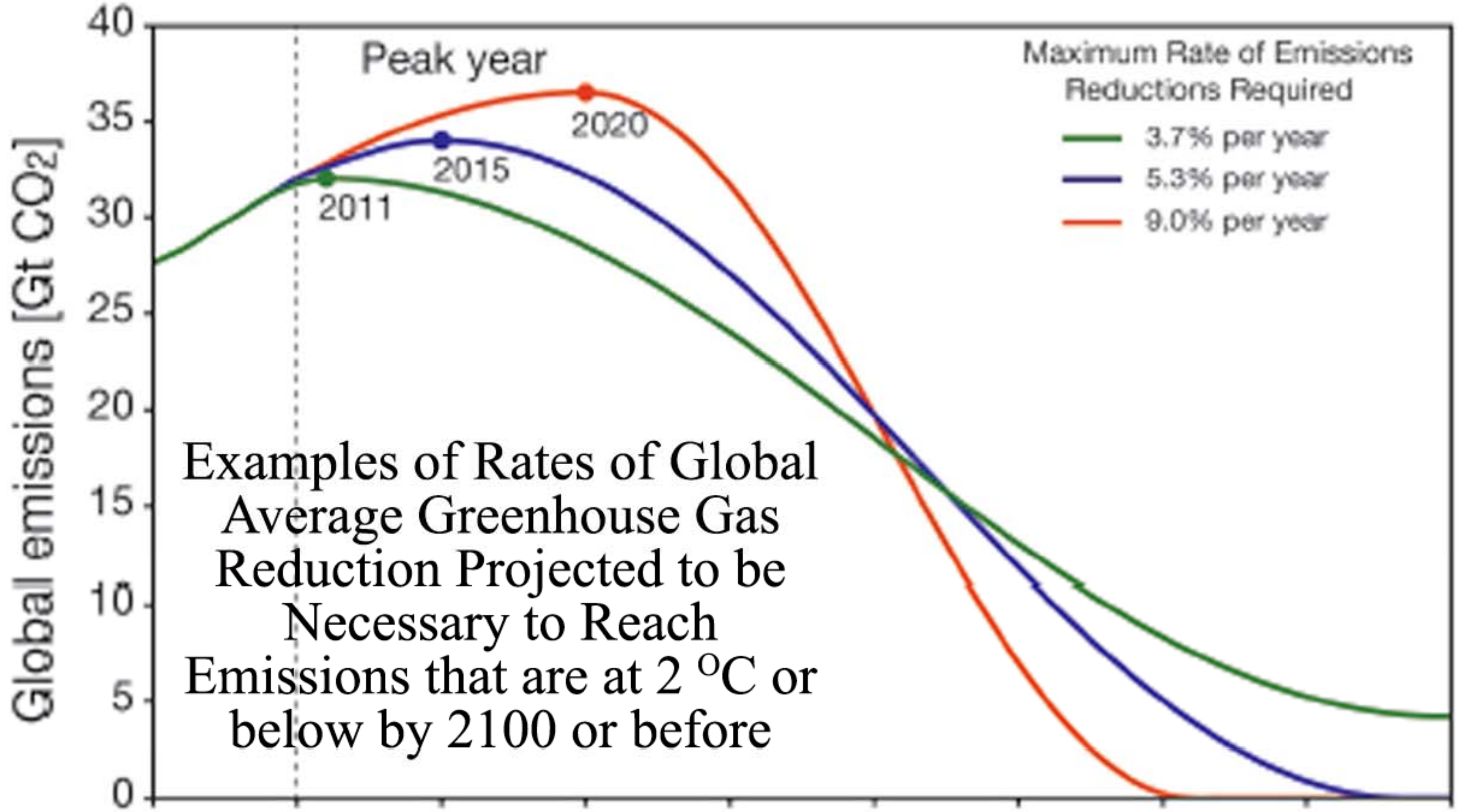
Fossil fuel emissions trends for developed and developing nations

(Washington Post, Oct. 5, 2009)

The message conveyed to readers was that the climate problem is a result of growing developing nation emissions

Schematic of effect of Copenhagen Accord *pledges* on increase in global average temperature





Limiting the increase in global average temperature to 2° C will require sharp reductions in emissions of CO_2 over the next several decades:

- **For emissions peak in 2011, reduction in CO_2e emissions of ~3% per year**
- **For emissions peak in 2015, reduction in CO_2e emissions of ~4% per year**
- **For emissions peak in 2020, reduction in CO_2e emissions of ~5% per year**

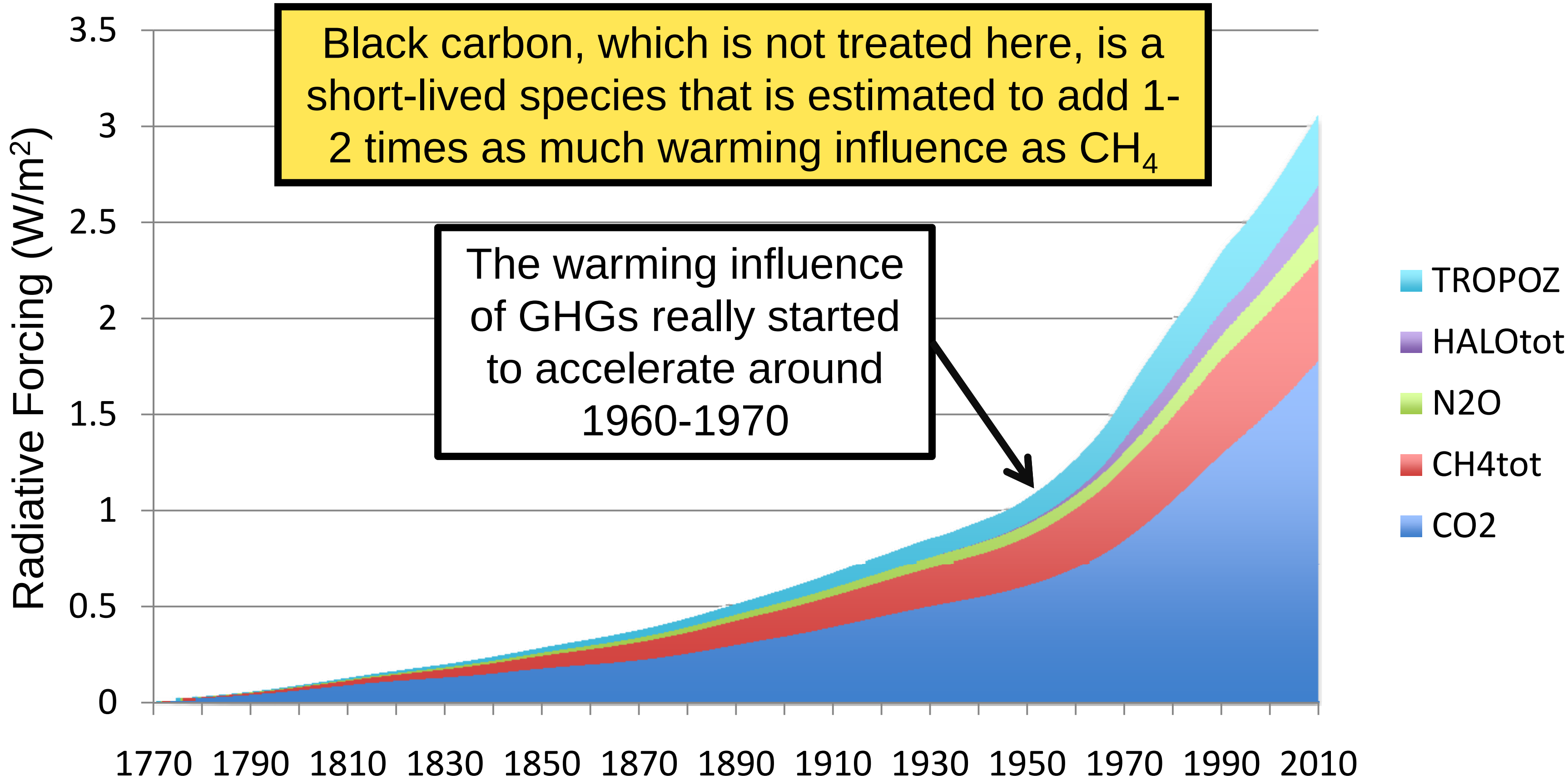
Use of the CO_2e (the CO_2 equivalent) concentration incorporates the influences of non-CO_2 greenhouse gases by scaling using their 100-year Global Warming Potentials (GWP), thus focusing attention on centennial scale climate change

We cannot take away their hope!

So, is there a feasible path forward, or is climate catastrophe inevitable, almost no matter what we do?

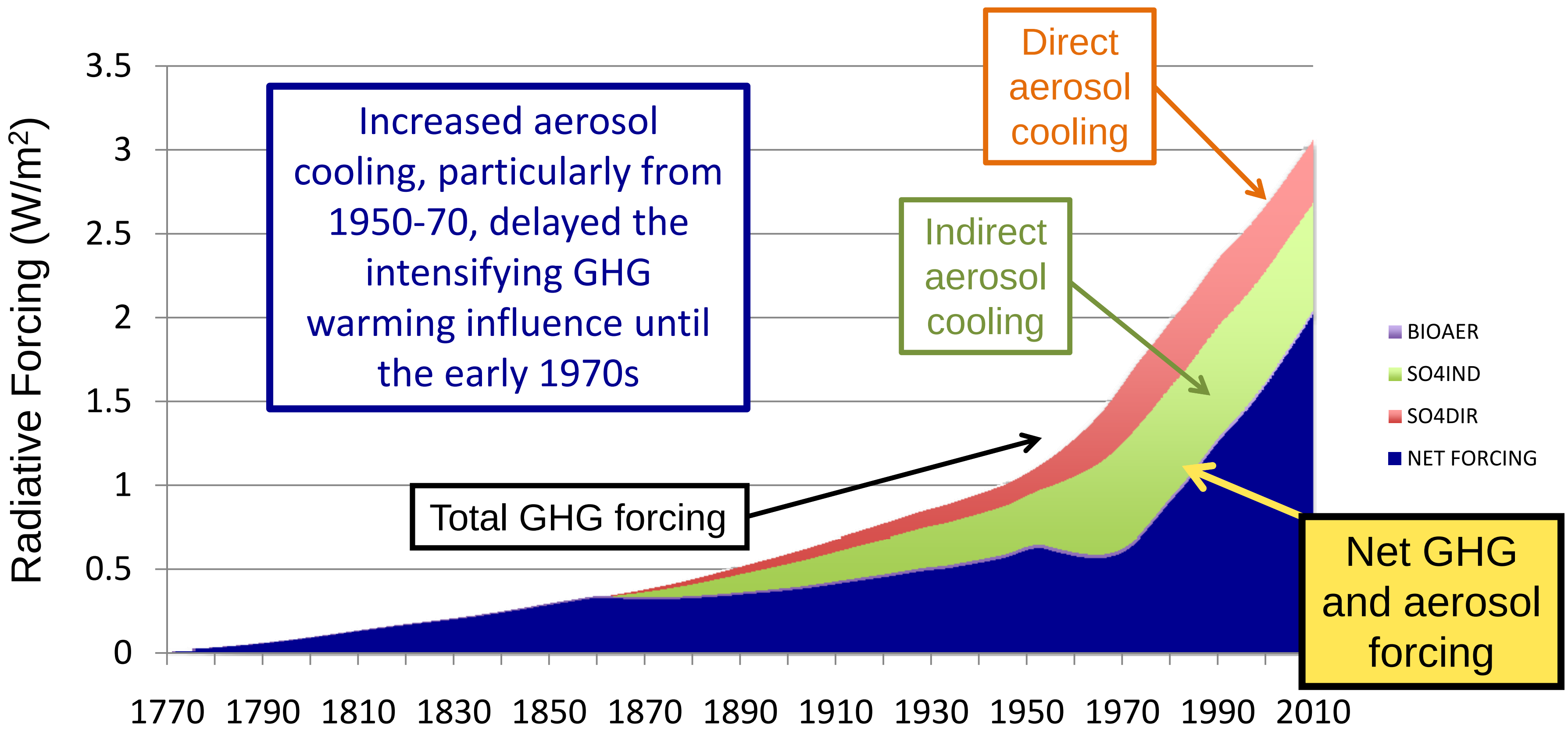
Radiative forcing due to GHG emissions from 1750 to present—

long-lived CO_2 increase contributes ~60%, whereas short-lived species contribute ~30%



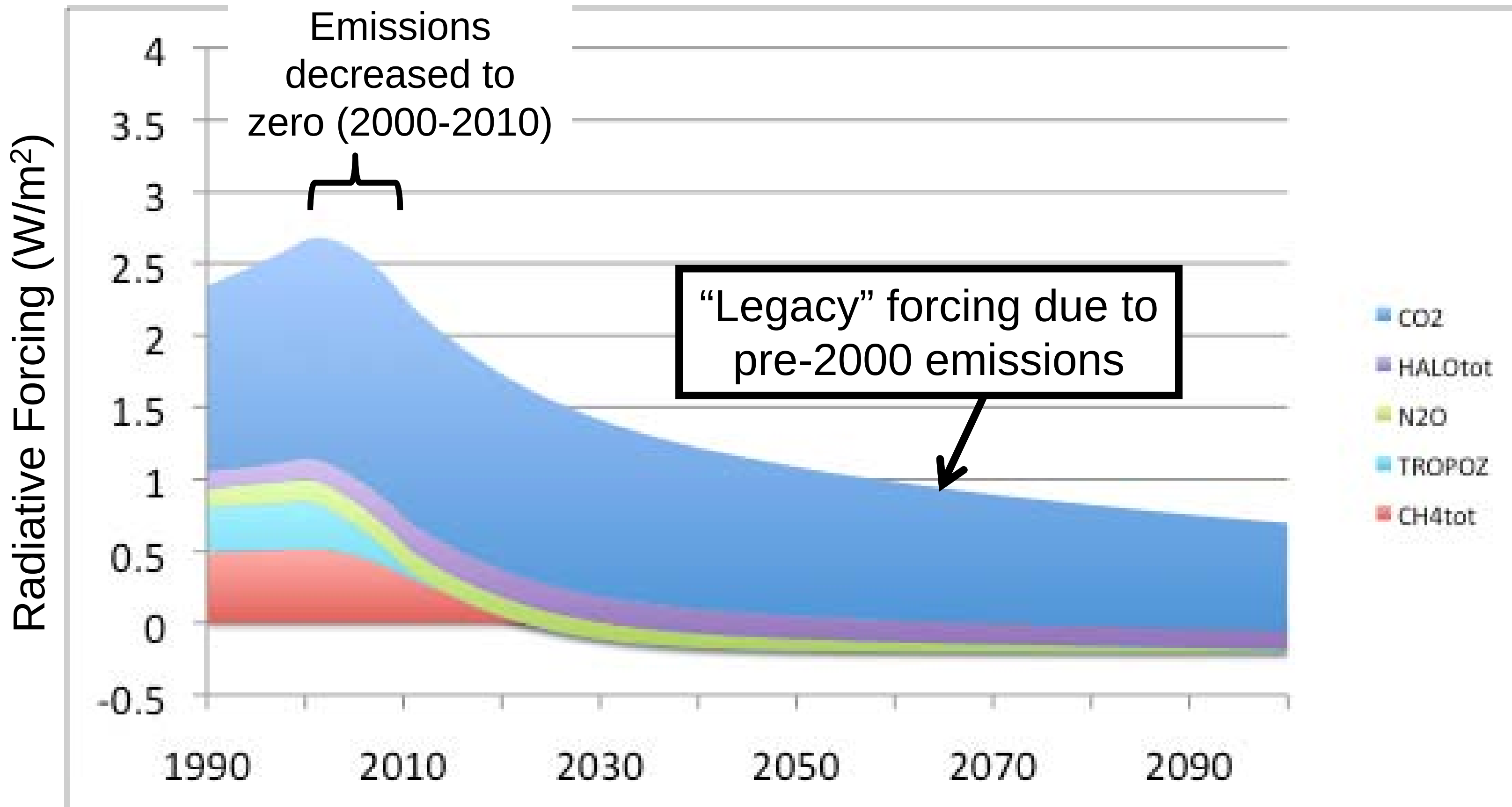
Results from MAGICC code of Wigley and Raper, 2005, updated 2008

The direct (clear sky) and indirect (cloud modifying) influences of sulfate aerosols (coming from SO_2 emissions) are estimated to reduce the recent warming influence of GHGs by about one-third



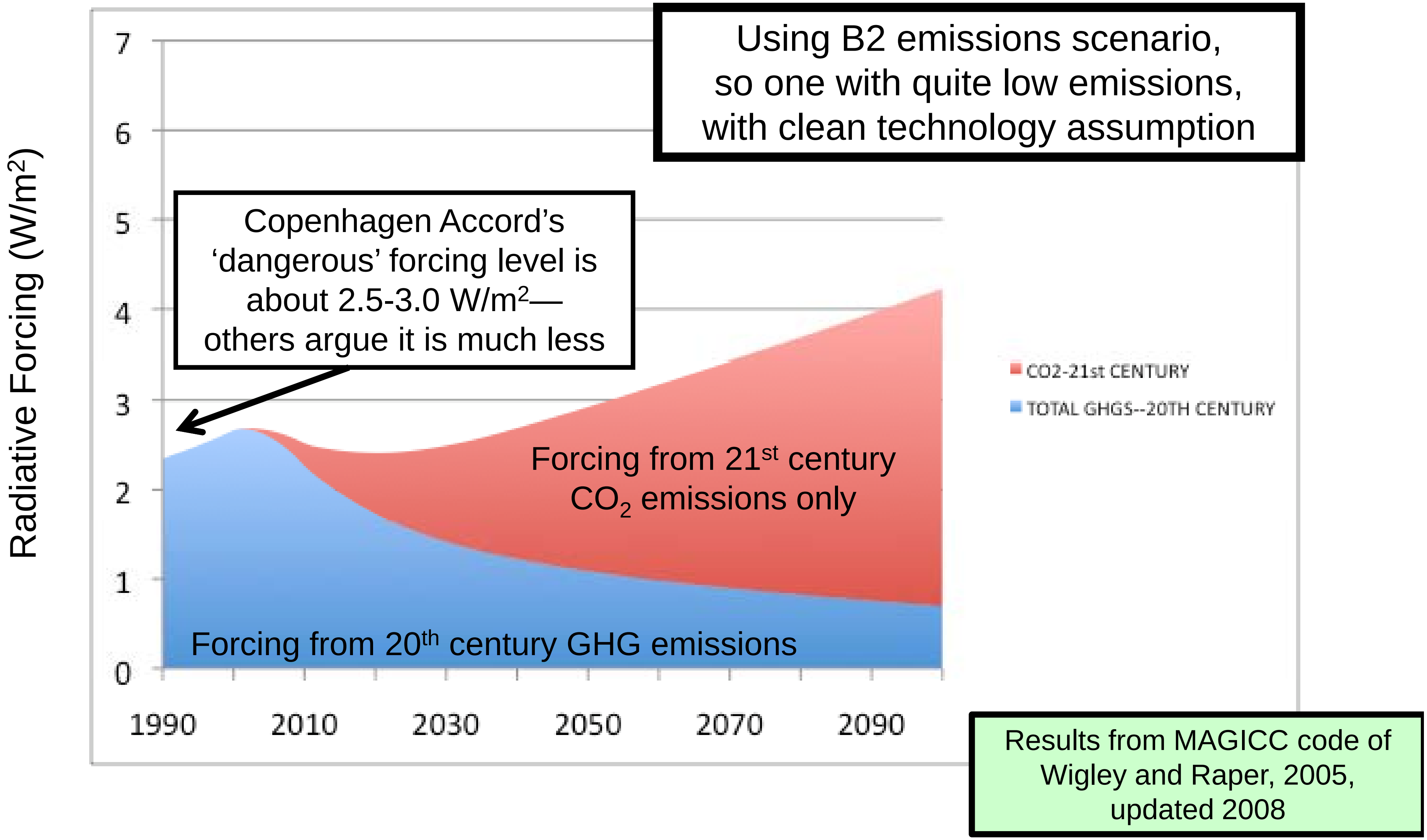
The climate responds to changes in all influences, not just the change in the CO_2 concentration

Over the 21st century, if all emissions went to zero, net forcing due to pre-2000 GHG emissions would drop from peak value by ~2/3, especially because of non-CO_2 GHGs

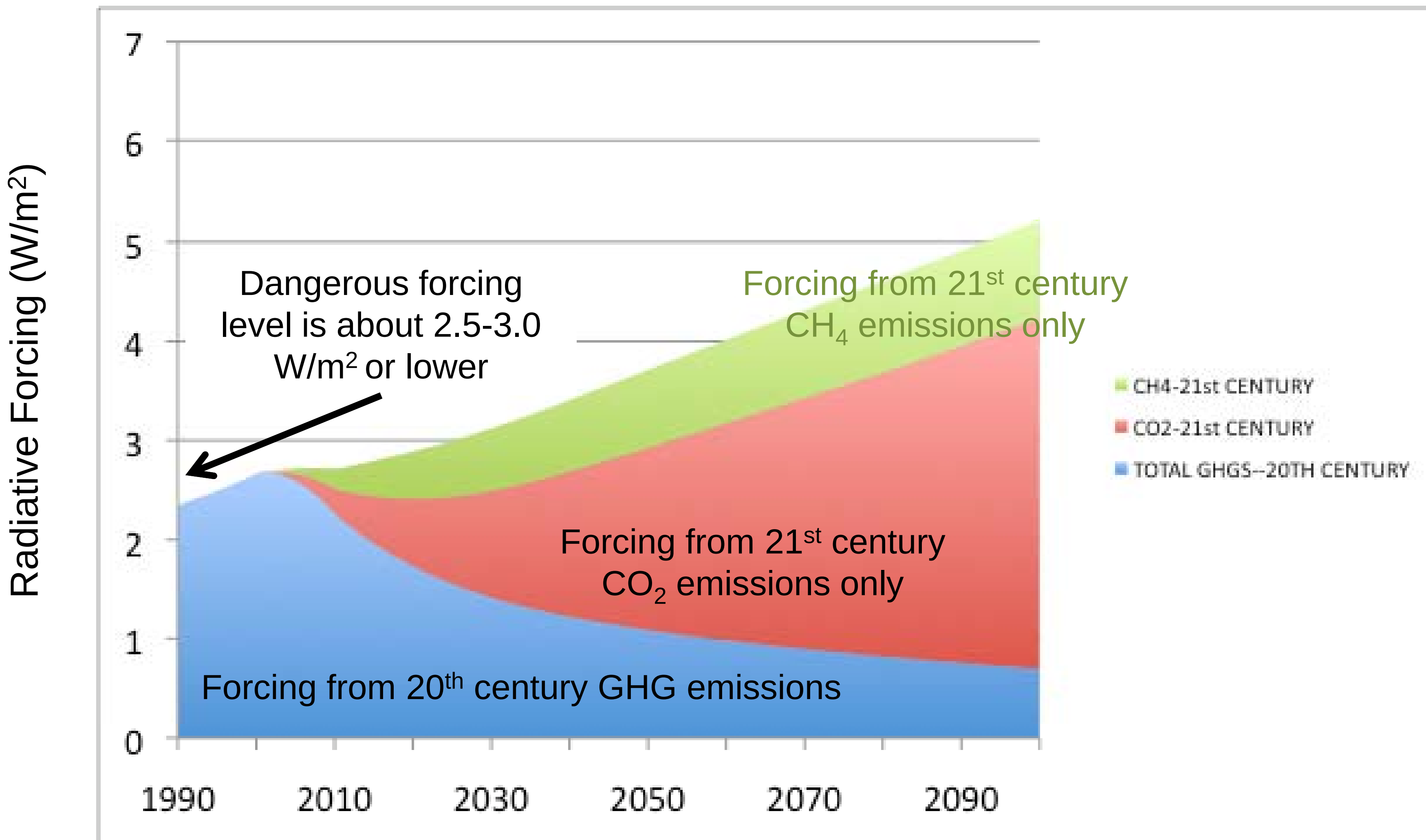


Results from MAGICC code of Wigley and Raper, 2005, updated 2008

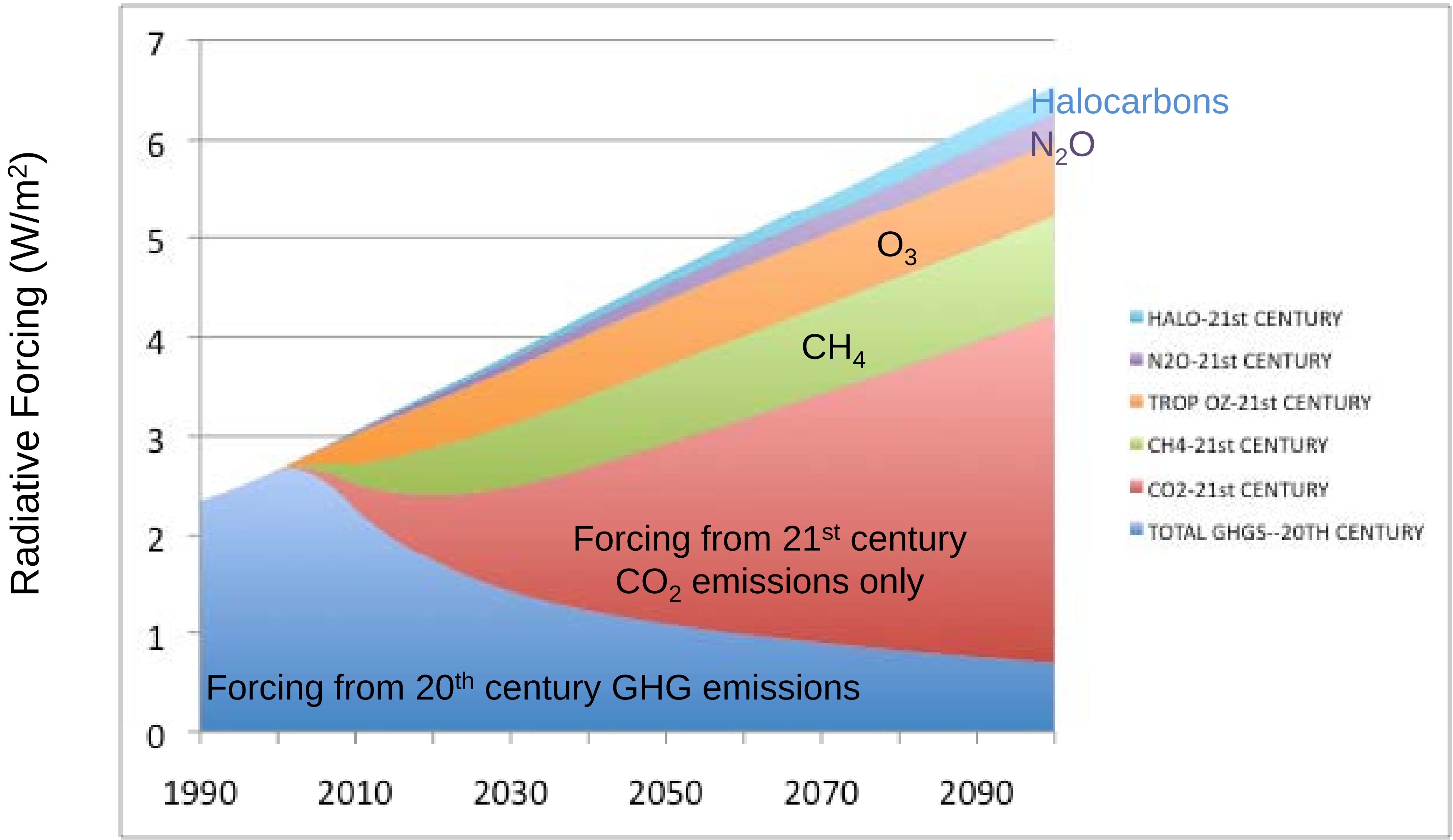
Adding forcing due to 21st century CO_2 emissions to 20th century legacy forcing would raise forcing to well above the 'dangerous level'



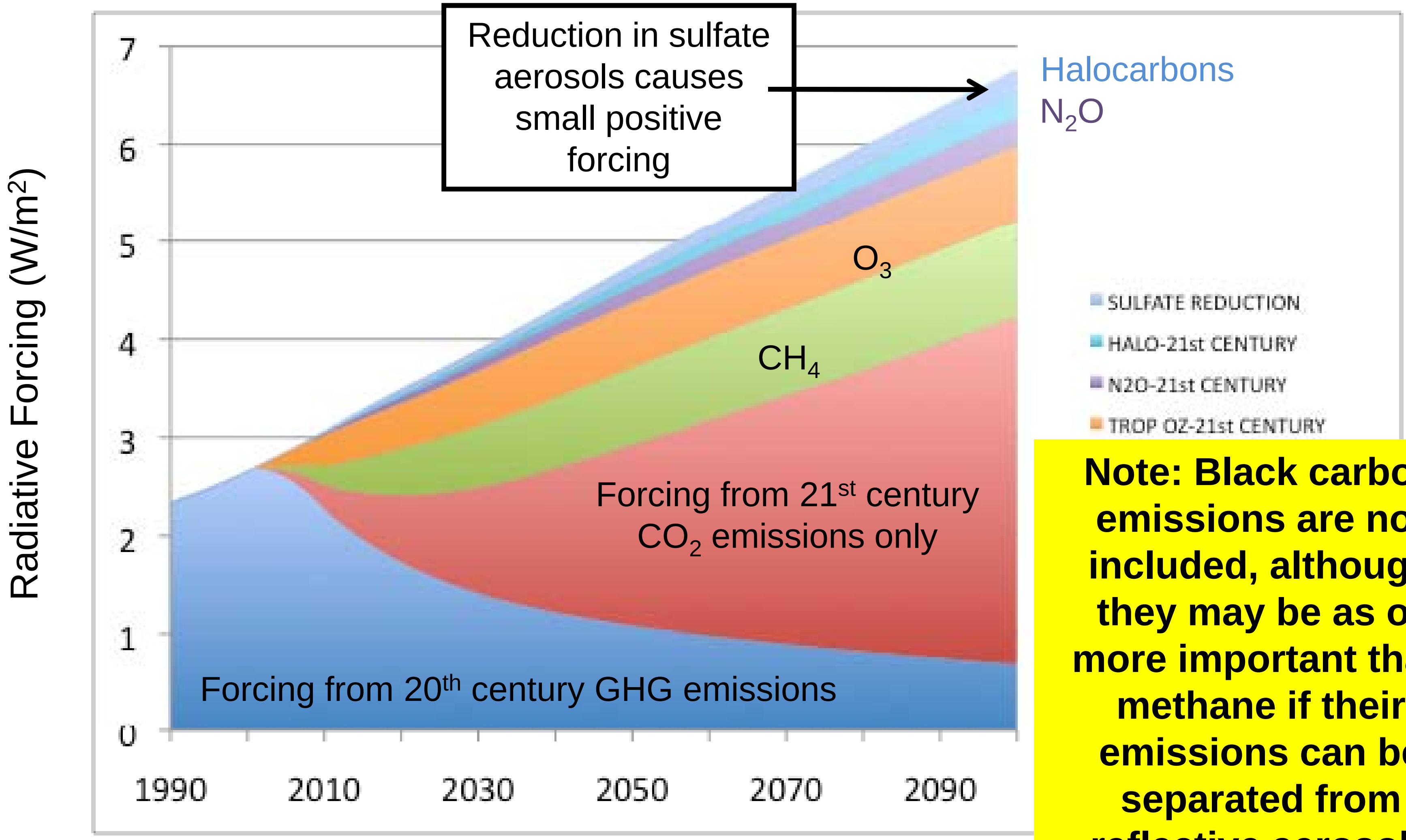
Adding CO_2 and CH_4 forcing to 20th century 'legacy' forcing takes GHG-only forcing even higher



Together, the CH_4 and tropospheric O_3 forcing increments due to 21st century emissions will be very significant, especially over the next few decades

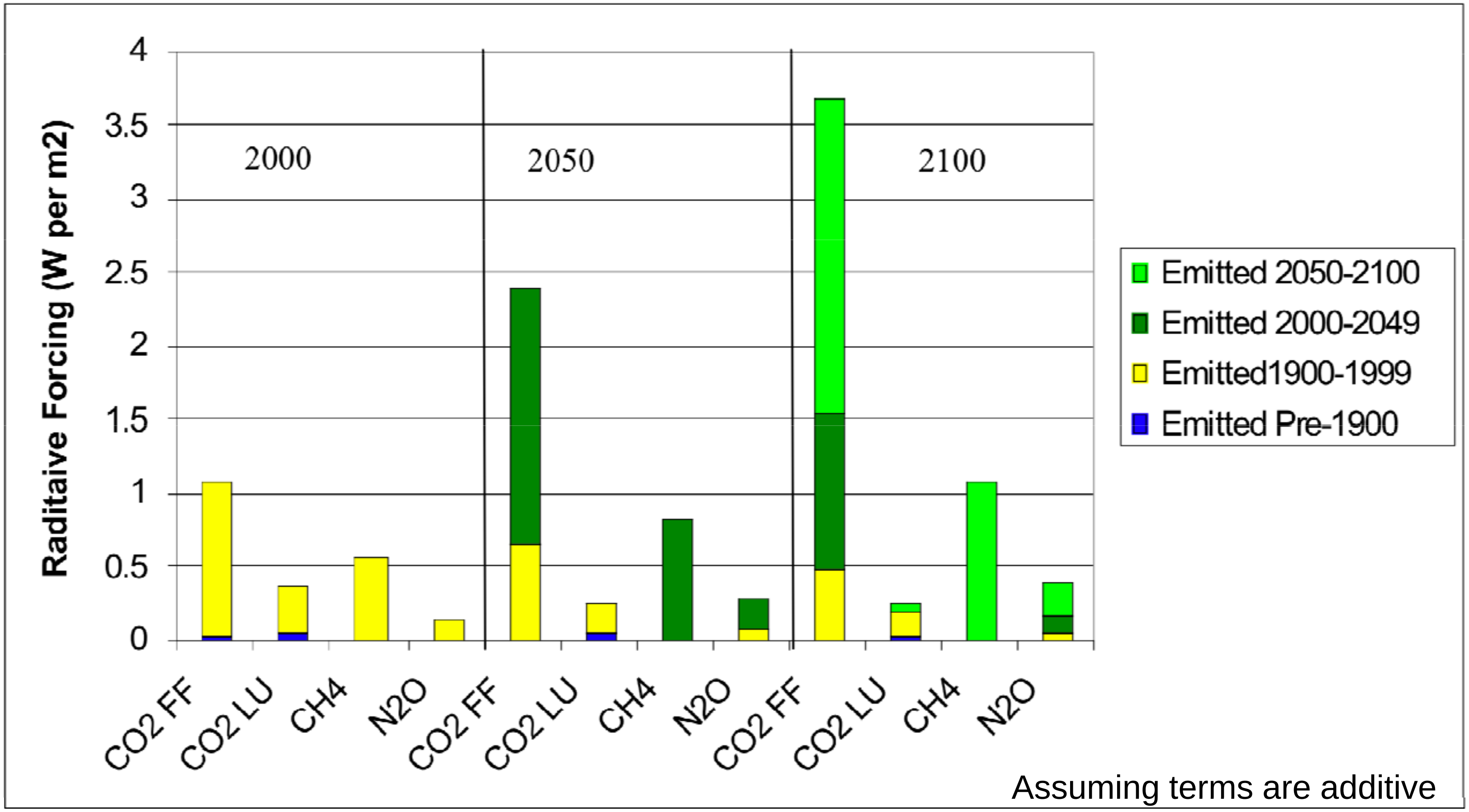


Reduction in emissions of aerosol precursors is expected to cause a small positive forcing; the cooling offset is still projected to be -0.8 W/m² in 2100—but located differently



Note: Black carbon emissions are not included, although they may be as or more important than methane if their emissions can be separated from reflective aerosols

Contribution to forcing by period of emission (for key GHGs and allowing for removal)



That methane's importance is obscured is a result of using its 100-year GWP of 22 instead of its 20-year GWP of 75

Source: Moore and MacCracken, 2009

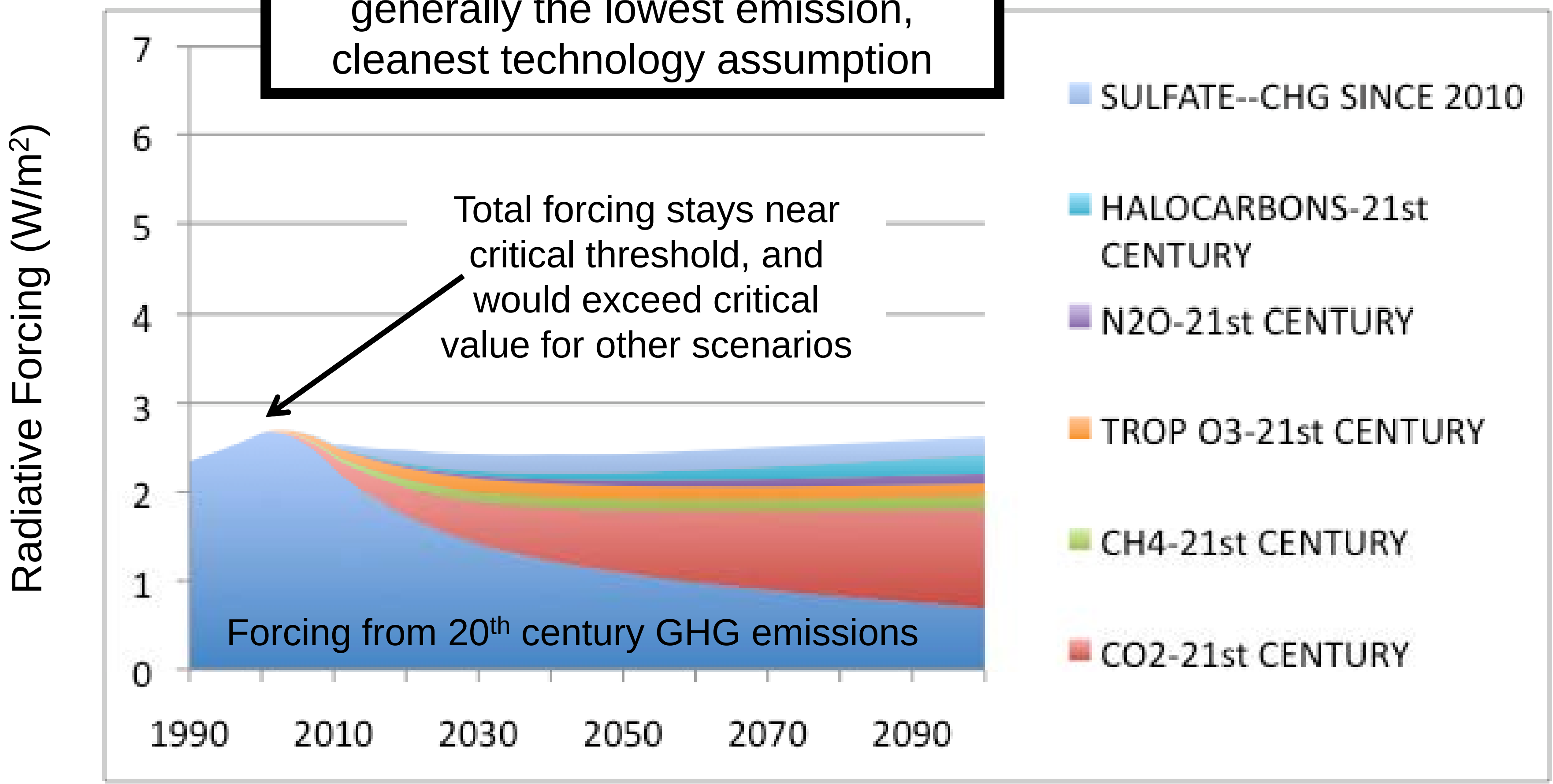
Considering species' lifetimes also makes clear the important cooling role played by sulfate aerosols

Climate Changing Gas/Aerosol	Change in BAU Forcing due to 21st Century Emissions	Change in Potential for Making a Difference
Carbon dioxide (CO_2)	~4	
Methane (CH_4)	0.9	Much larger contribution
Nitrous oxide (N_2O)	0.35	Much larger contribution
Halocarbons	~0.1	
Tropospheric ozone (O_3)	~0.65	Much larger contribution
Black soot	0.4	Much larger contribution
Sulfate direct (SO_4)	-0.4	Help to limit warming
Cloud forcing	-0.7	Help to limit warming
TOTAL	~5.3	

2. Loss of the sulfate cooling offset would, in effect, augment positive radiative forcing by about 1 W/m^2—so by roughly a degree of warming. Offsetting this is one reason that geoengineering may be needed.

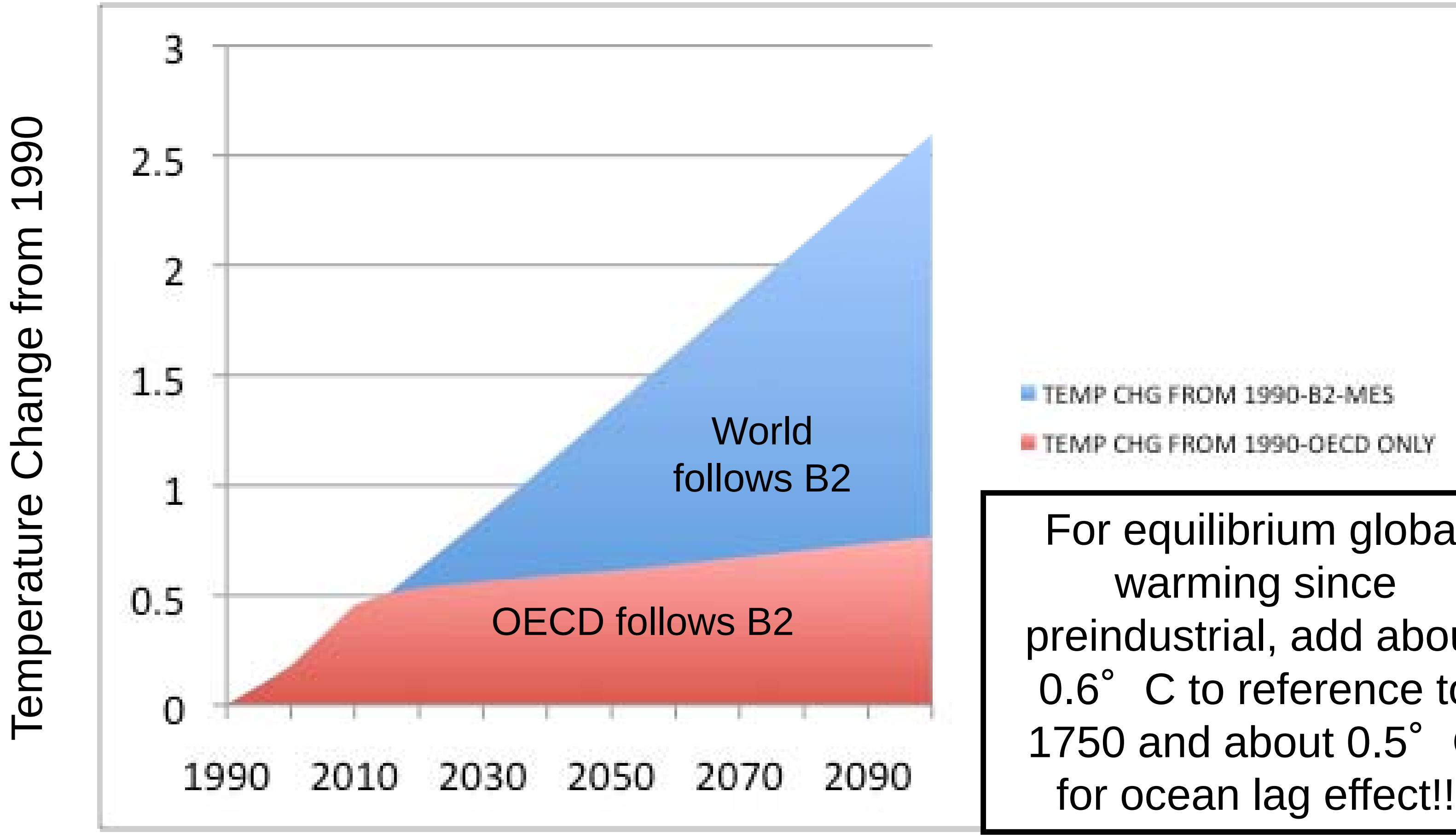
Adding the effects of B2 scenario emissions from just OECD nations to the 'legacy forcing' from the 20th century fills the 'forcing space' created by natural removal processes

Using B2 emissions scenario, so generally the lowest emission, cleanest technology assumption



Clearly, OECD nations must work to reduce contributions of multiple species, especially CO_2

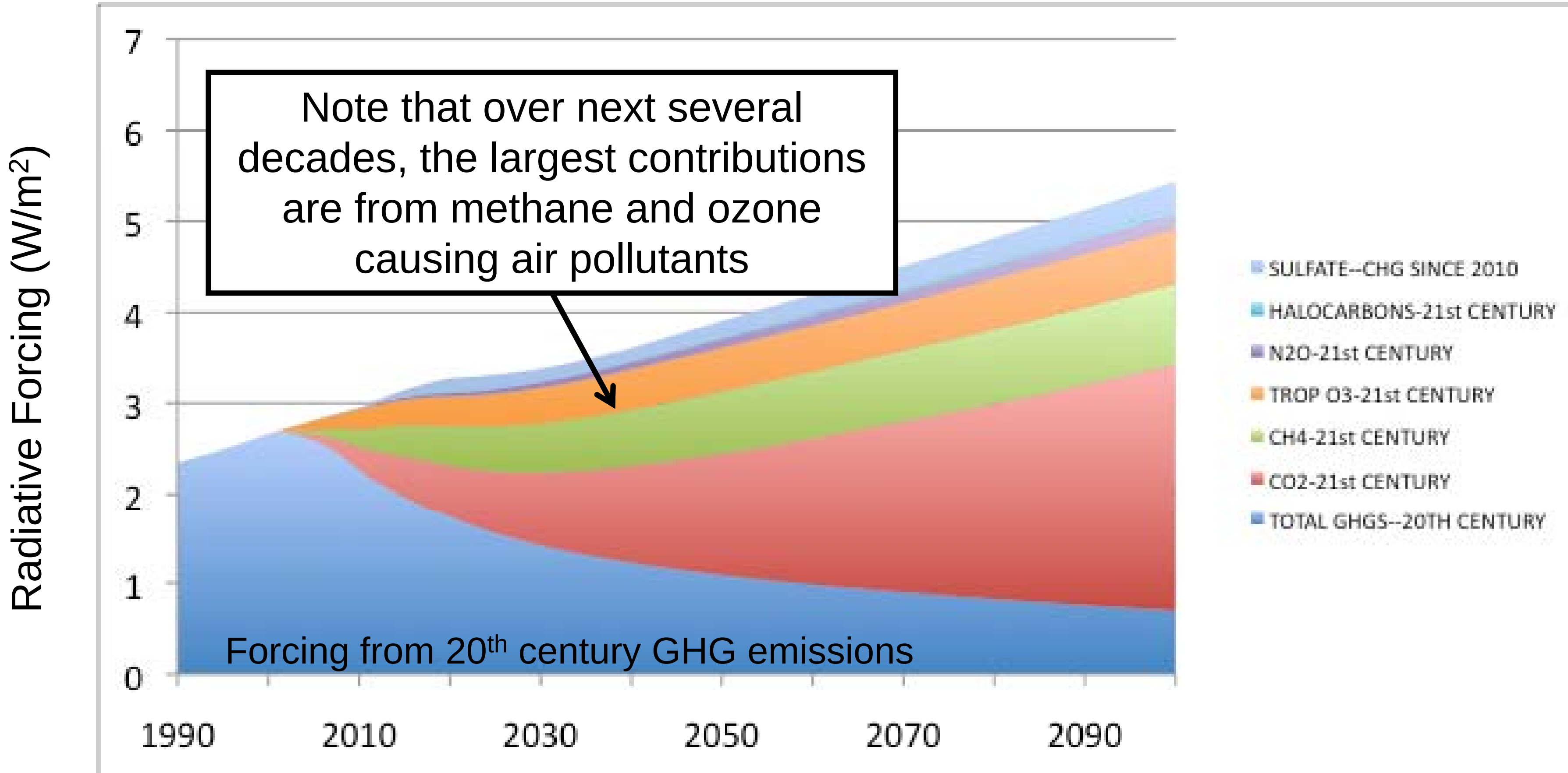
OECD-only emissions (so no CO_2 or non-CO_2 emissions from non-OECD nations) would still cause the Earth to warm, although more slowly



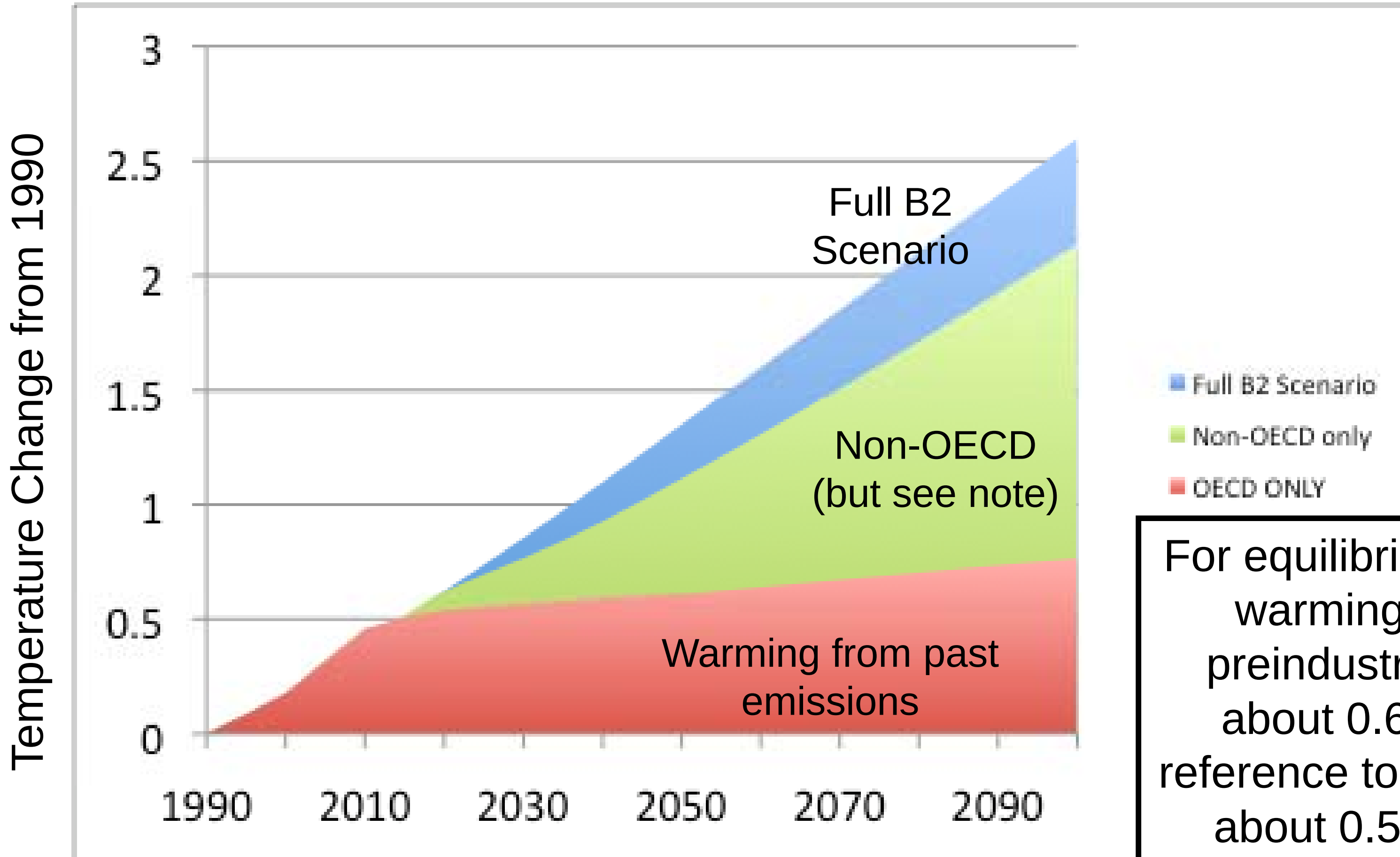
For equilibrium global warming since preindustrial, add about 0.6° C to reference to 1750 and about 0.5° C for ocean lag effect!!

Stopping global warming will require <u>the world</u> to have lower emissions than the OECD nations have now and as projected by the B2 emissions scenario

Also, in the absence of OECD emissions, projected emissions from only non-OECD nations would push forcing well above dangerous level



Temperature rise from non-OECD emissions only takes temperature well above ‘dangerous threshold’



For equilibrium global warming since preindustrial, add about 0.6° C to reference to 1750 and about 0.5° C for ocean lag effect!!

Note: This calculation of non-OECD temperature rise mistak
take out OECD contributions due to halocarbons and tropospheric ozone

These results point to three conclusions

1. **Even if the emissions from non-OECD nations went to zero tomorrow, the projected emissions from the OECD nations would cause the temperature to rise to >2° C over preindustrial.**
2. **Even if the emissions from OECD nations went to zero tomorrow, the projected emissions from the non-OECD nations would cause the temperature to rise to >2° C over preindustrial.**
3. **We are all in this together and we all must act, starting in the very near future.**

What is needed is an effective, economical, fair, and equitable basis for emissions reductions that would really limit future warming

- **Recognizing the different situations in:**
  - **per capita emissions and**
  - **economic development, and**
- **Recognizing the principles of:**
  - **equity and**
  - **differentiated responsibility,**

A fair and balanced agreement would involve OECD and non-OECD nations taking on:

- **differentiated responsibilities, but**
- **comparable challenges**

To stay below the 'dangerous forcing' level, OECD nations need to demonstrate that a modern nation can prosper with low GHG emissions

Pursue an 'aggressive' trajectory of emissions reductions for all GHG species:

- **CO_2: 80% below 2010 values by 2050; 90% by 2100**
- **CH_4: 60% below 2010 values by 2050; 80% by 2100**

(note: in US, landfill plus fossil-fuel related emissions add to 60%--and agricultural reductions are possible)

- **N_2O: 50% reduction by 2100**
- **VOC/CO/NOx: 50% by 2050 and 90% by 2100**
- **SO_2: 80% by 2050; 90% by 2100 (B2 scenario has even faster near-term cutbacks)**
- **Halocarbons: B2 scenario or better—use for tradeoffs**

Non-OECD nations must also reduce their emissions. Strong early efforts on short-lived GHGs could create room in 'forcing space,' reducing warming influence from less aggressively addressing CO_2 emissions

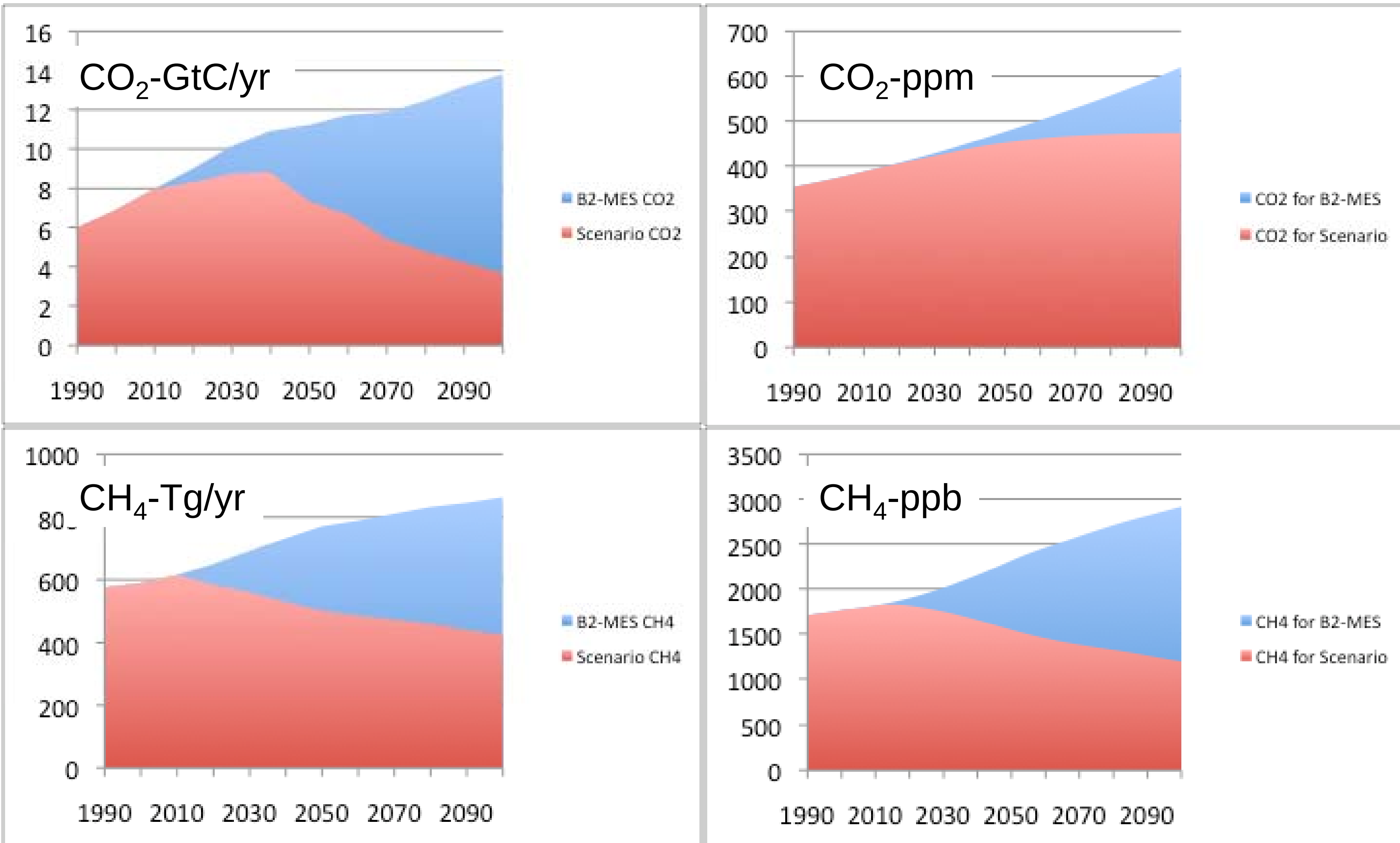
Two-phase approach for non-OECD nations*:

- **First, few-decade phase:**
  - Improve fossil fuel efficiency, without a CO_2 emissions cap
  - Best efforts on halocarbons and N_2O
  - Aggressive caps on CH_4, air pollutants, and black carbon
  - End deforestation, move to reforestation
  - Set a graduation date to second phase of reducing CO_2
- **Second phase that nations graduate into when per capita CO_2 emissions and per capita GDP exceed a specific limit:**
  - Add a cap on CO_2 emissions that collectively cuts projected 2040 non-OECD emissions in half by 2100, leading to roughly equal global per capita emissions by 2100

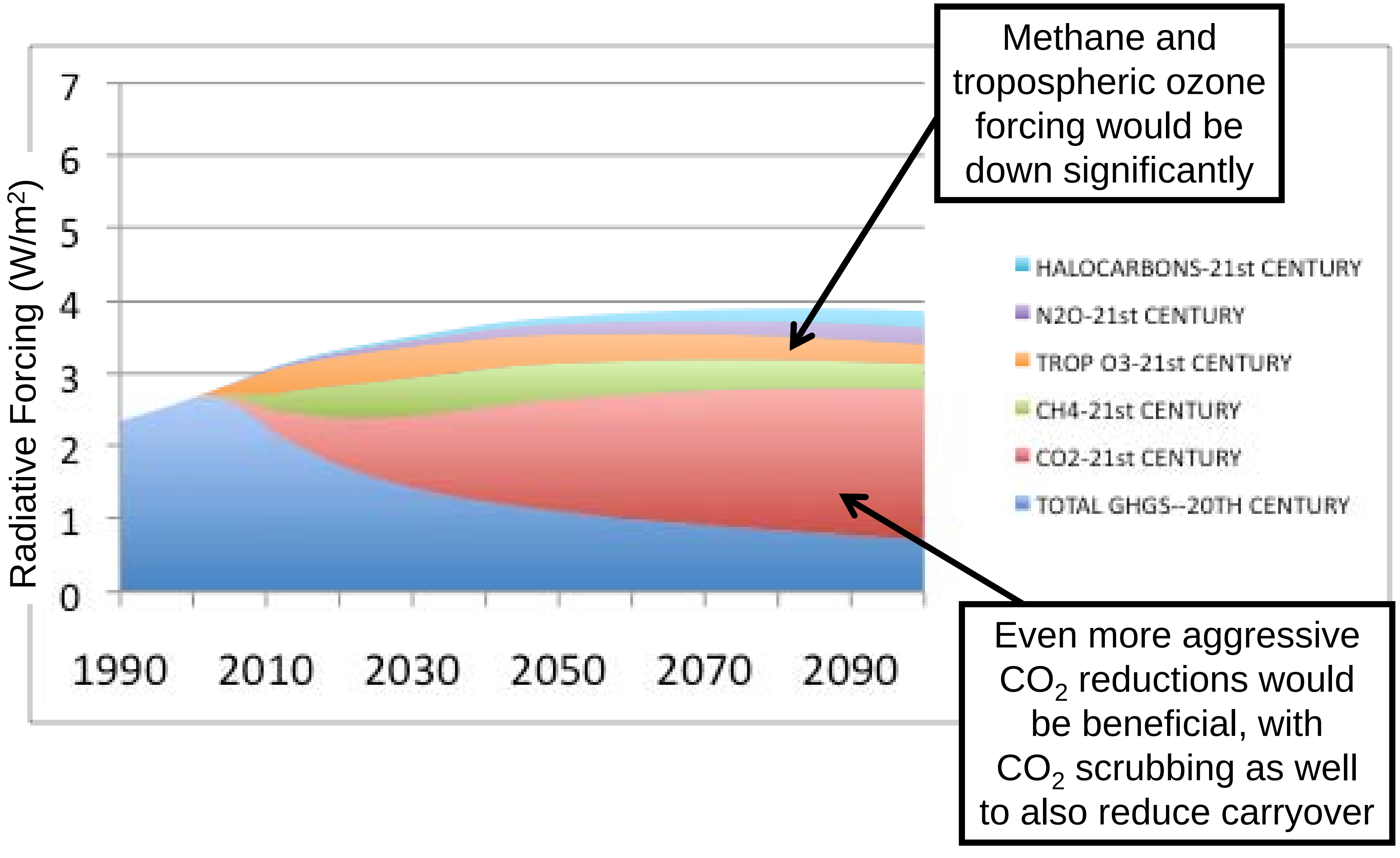
*Idea further developed in Moore and MacCracken (2009)

The ‘Comparable Challenges’ scenario would limit peak CO_2 to ~475 ppm and decrease CH_4 from ~1800 ppb to ~1200 ppb

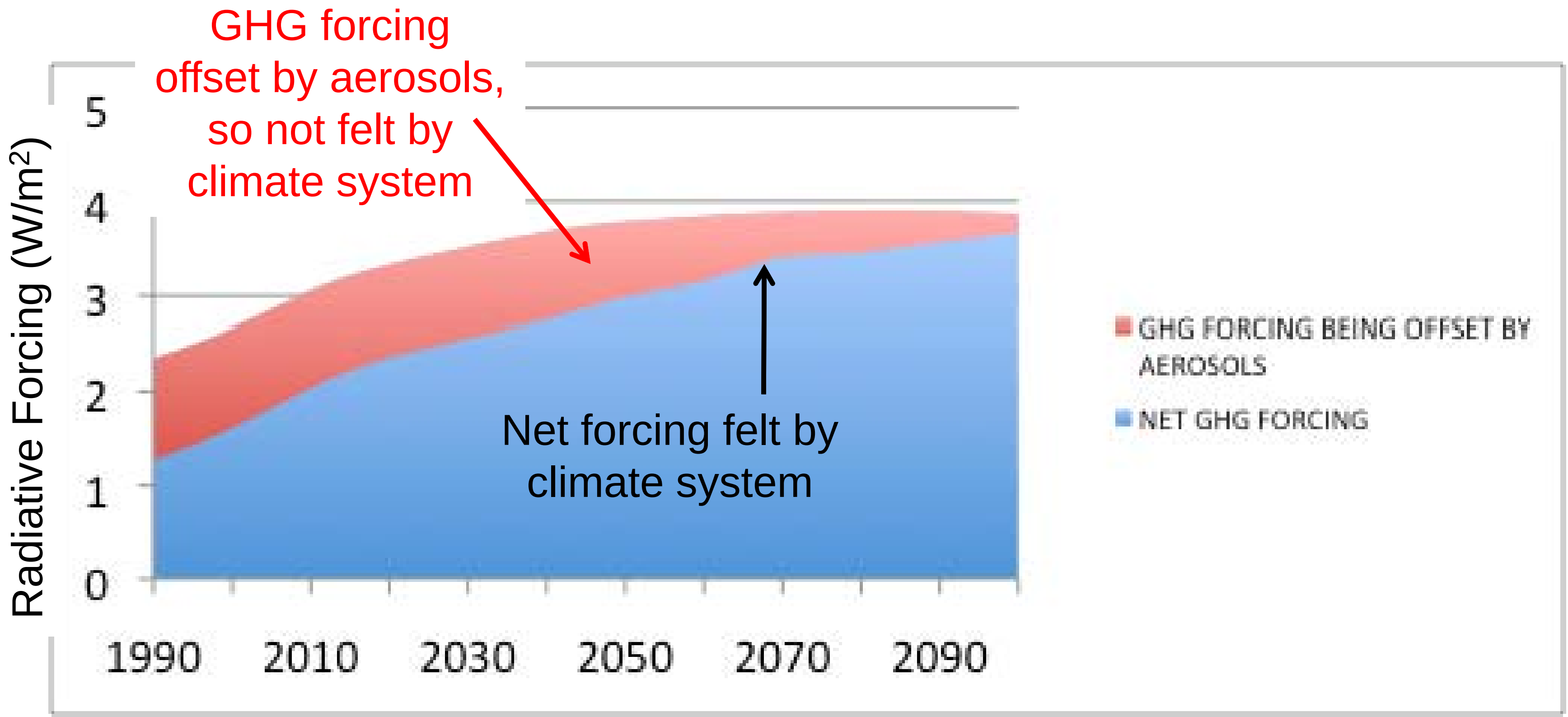
Emissions | Concentrations



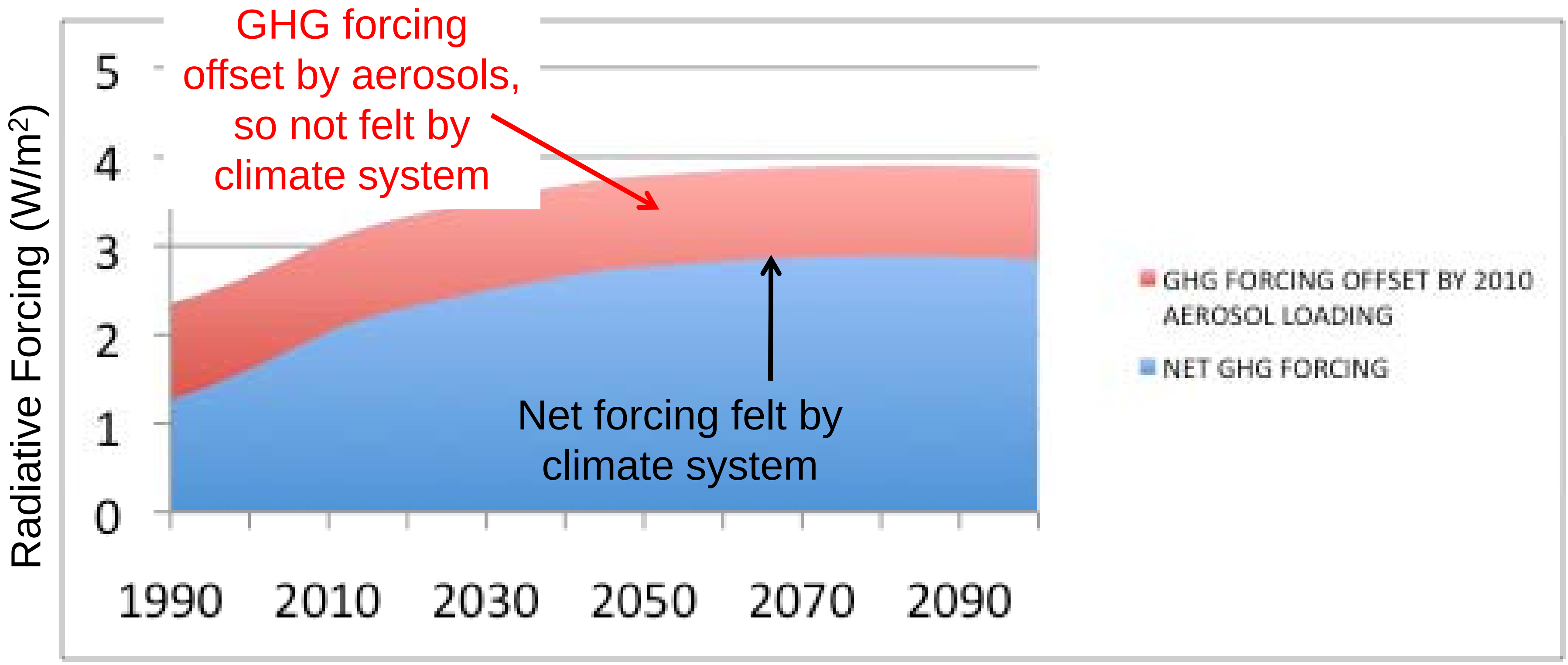
Under the Comparable Challenge scenario, GHG radiative forcing would stay below 4 W/m^2, equivalent to CO_2 doubling—but reduced by aerosol cooling



The aerosol cooling offset is projected to lessen as a result of the projected reductions of SO_2 emissions, especially after 2050, which would cause net forcing to exceed the 'dangerous' forcing level of 2.5-3 W/m^2

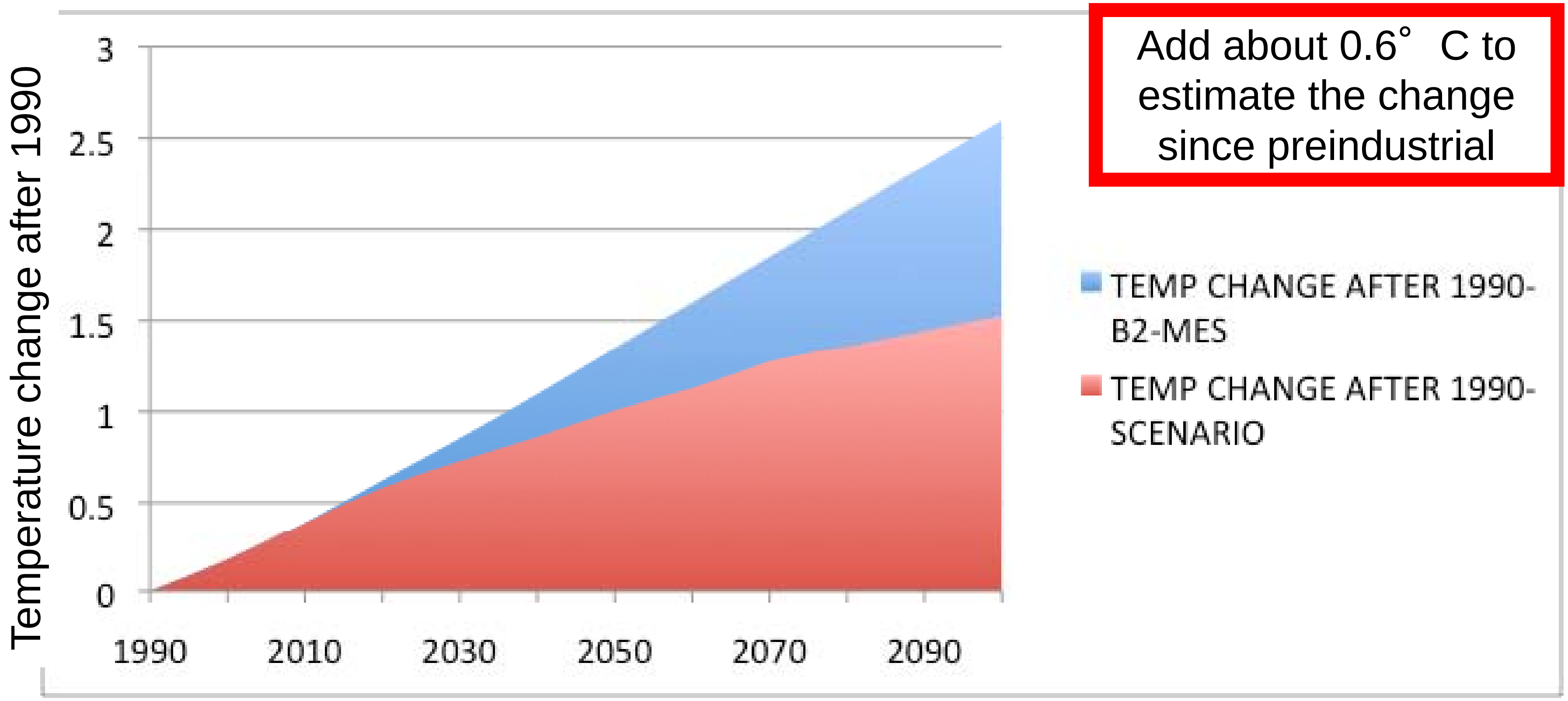


Sustaining the aerosol cooling offset at its 2010 value (perhaps intervening by geoengineering*) would limit the net forcing peak to ~2.5-3 W/m²



For example by; injecting SO_2 into the stratosphere,
cloud brightening in the troposphere, and/or distributing SO_2 emissions over ocean areas;
[see, for example, Royal Society (2009) and MacCracken (2009), Environmental Research Letters]

By focusing on short-lived species as well as CO_2, the Comparable Challenge scenario considered here would limit warming to ~2-2.5° C over preindustrial, too high for many reasons, but appears feasible



Further emissions reductions (including perhaps additional geoengineering) would be needed to further moderate the projected warming

Summary: Limiting global warming to 2-2.5° C appears possible with an aggressive approach leveraging both long- and short-lived species

The OECD (higher per capita GDP and GHG) nations:

- **have demonstrated that *short-lived* species can be economically controlled--and must move aggressively to do more**
- **must move expeditiously to show that modern societies can prosper without emitting short- or long-lived GHGs (especially CO_2)**

The non-OECD (lower per capita GDP and GHG) nations:

- **can demonstrate their legal commitment to taking action by committing to a declining cap on *short-lived* species (most of which must be and are being addressed to limit air and water pollution, increase efficiency, etc.); this could be encouraged by using the 20-year GDP for CH_4, taking strong action on black carbon, etc.**
- **commit to best practices for reducing emission of long-lived GHGs in the near-term, and then graduate to the developed nation requirements as OECD nations demonstrate that economies can prosper with low per capita emissions.**

The temperature increase could then possibly be made lower via geoengineering

Additional Information

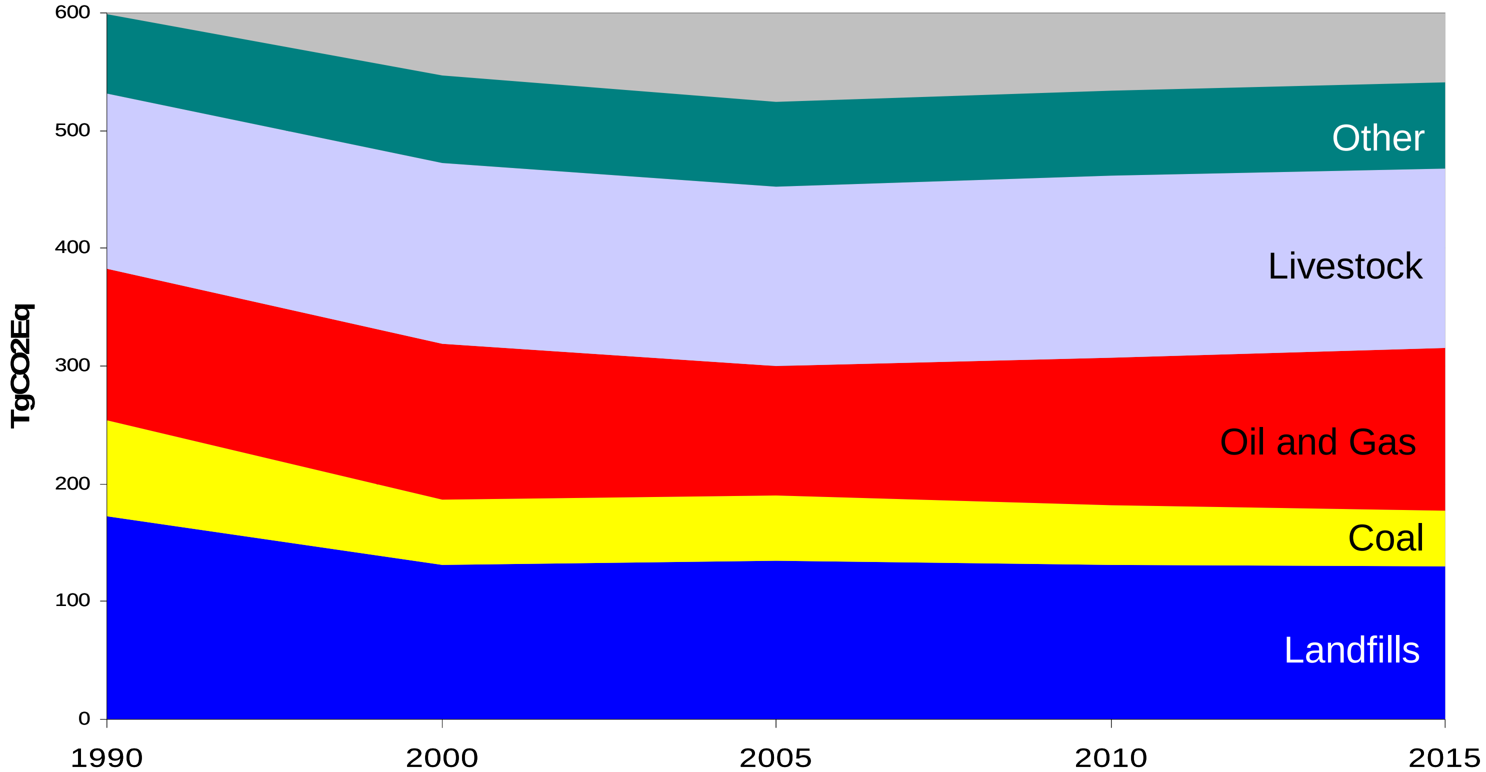
- Scientific Expert Group on Climate Change (SEG), 2007: *Confronting Climate Change: Avoiding the Unmanageable and Managing the Unavoidable*, Rosina M. Bierbaum, John P. Holdren, Michael C. MacCracken, Richard H. Moss, and Peter H. Raven (eds.), Report prepared for the United Nations Commission on Sustainable Development by Sigma Xi, Research Triangle Park, NC, and the United Nations Foundation, Washington, DC, 144 pp. [downloadable from http://www.unfoundation.org/global-issues/climate-and-energy/sigma-xi.html
- MacCracken, M. C., 2008: Prospects for future climate change and the reasons for early action, *Journal of the Air and Waste Management Association*, **58**, 735-786 [downloadable from www.climate.org].
- Moore, F. C., and M. C. MacCracken, 2009: Lifetime-leveraging: An approach to achieving international agreement and effective climate protection using mitigation of short-lived greenhouse gases, *International Journal of Climate Change Strategies and Management* **1**, 42-62.
- MacCracken, M. C., 2009: On the possible use of geoengineering to moderate specific climate change impacts, *Environmental Research Letters*, **4** (October-December 2009) 045107 doi:10.1088/1748-9326/4/4/045107 [http://www.iop.org/EJ/article/1748-9326/4/4/045107/erl9_4_045107.html].

A wide range of technologies have been demonstrated for Methane Mitigation

Source	Key Technologies
Landfills	Methane recovery and combustion (i.e., power generation, industrial uses, flaring)
Coal Mines	Methane recovery and combustion, flaring, ventilation air use
Gas/Oil Systems	Use of low-bleed equipment, and better management practices
Livestock Waste	Methane collection from anaerobic digestors and combustion (power, flaring)
Ruminant Livestock	Improved production efficiency through better nutrition and management
Rice Production	Water management, organic supplements

Source: Paul Gunning, EPA, 2010

US CH_4 emissions are dropping, and significant potential exists for further reductions

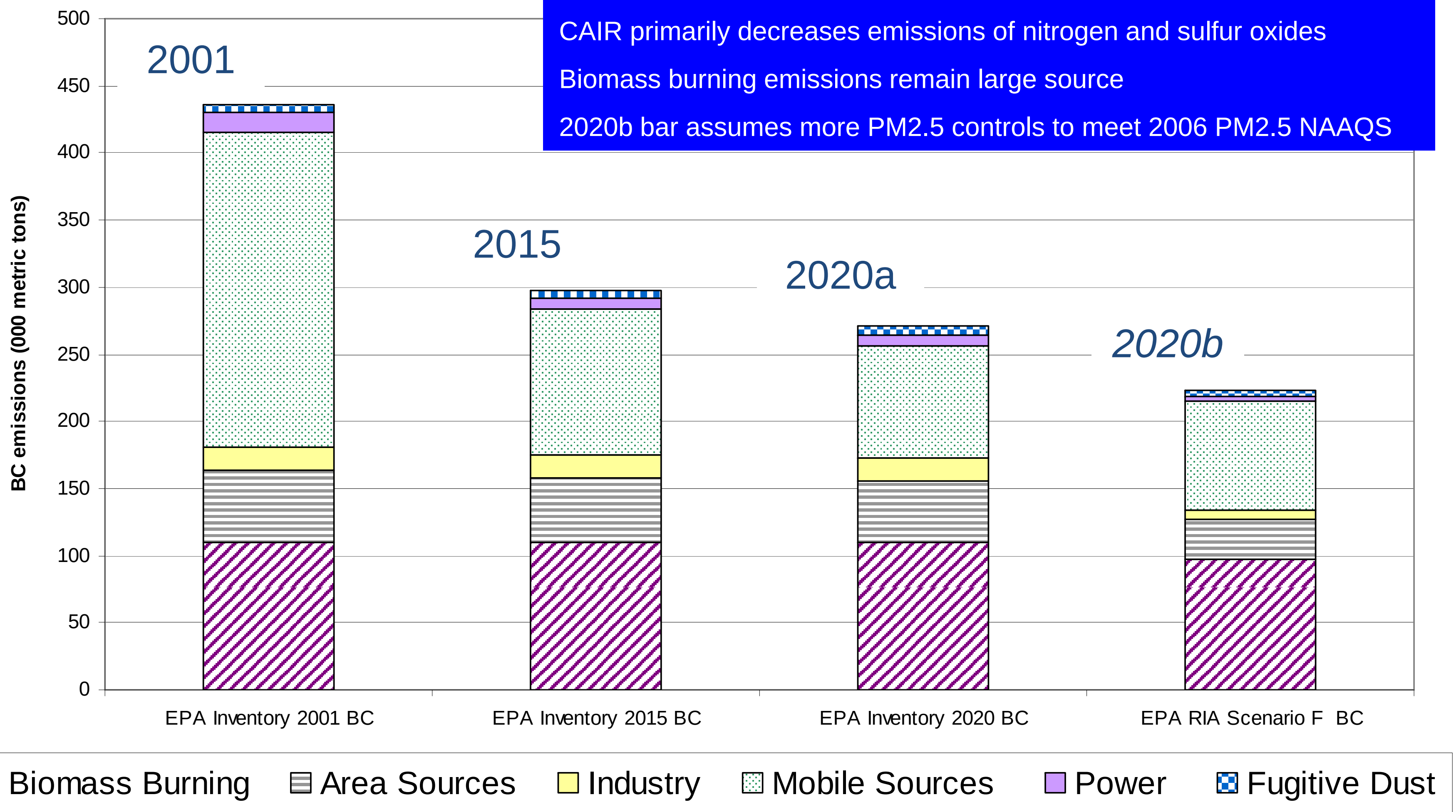


- As of 2005, the CH4 partnership programs have successfully reduced US emissions 11% below 1990 levels
- With continued efforts, emissions are expected to remain below 1990 level in spite of economic growth through 2020

Source, Paul Gunning, EPA, 2010

US Black Carbon Emissions are projected to go down

- Diesel rules are expected to decrease BC emissions **~65%** by 2020
- CAIR primarily decreases emissions of nitrogen and sulfur oxides
- Biomass burning emissions remain large source
- 2020b bar assumes more PM2.5 controls to meet 2006 PM2.5 NAAQS



Based on EPA Regulatory Impact Analysis,

Speciation of PM2.5 into carbonaceous particles,

A range of technologies exist to significantly reduce Black Carbon emissions

In most countries, black carbon is not being separately targeted, but rather addressed through particulate matter (PM) control strategies

- Mobile sources
  - Highway diesel rules significantly reduce BC with turn-over of the fleet (by ~2030)
  - Non-road diesel (e.g., farm and construction equipment) rules significantly reduce BC with turn-over of the fleet (by ~2030-2040)
  - Recent locomotive & marine diesel rule reduces BC (note that this rule does not cover ocean-going vessels)
  - Voluntary diesel retrofit program
- Point sources
  - Federal, State and Local controls over past decades have reduced much of the stationary source PM, including BC
  - Utilities: large US coal boilers have near complete combustion & high percent particle removal
- Biomass burning
  - Fires on agricultural lands are managed in many cases
  - Land clearing and construction burning are regulated in some cases
- International opportunities:
  - Address domestic fuel burning sector (e.g., cook stoves) in Asia, Africa and Latin America

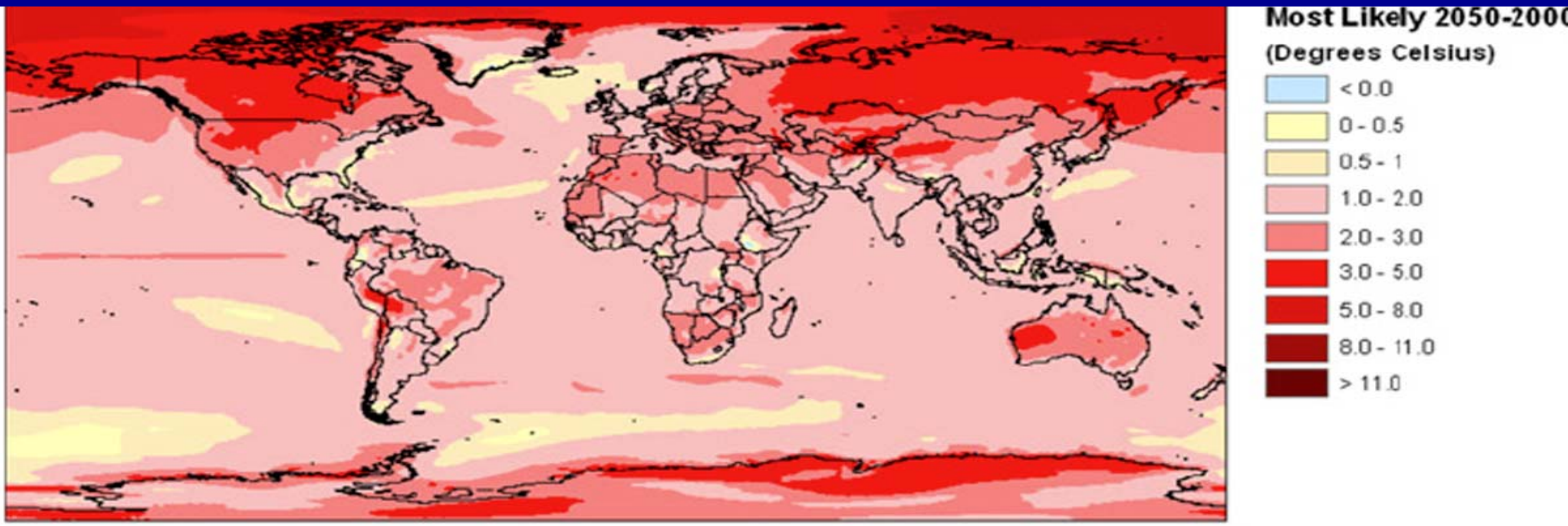
The results presented in this study are from the MAGICC model of Wigley and Raper (2005, updated to 2008)

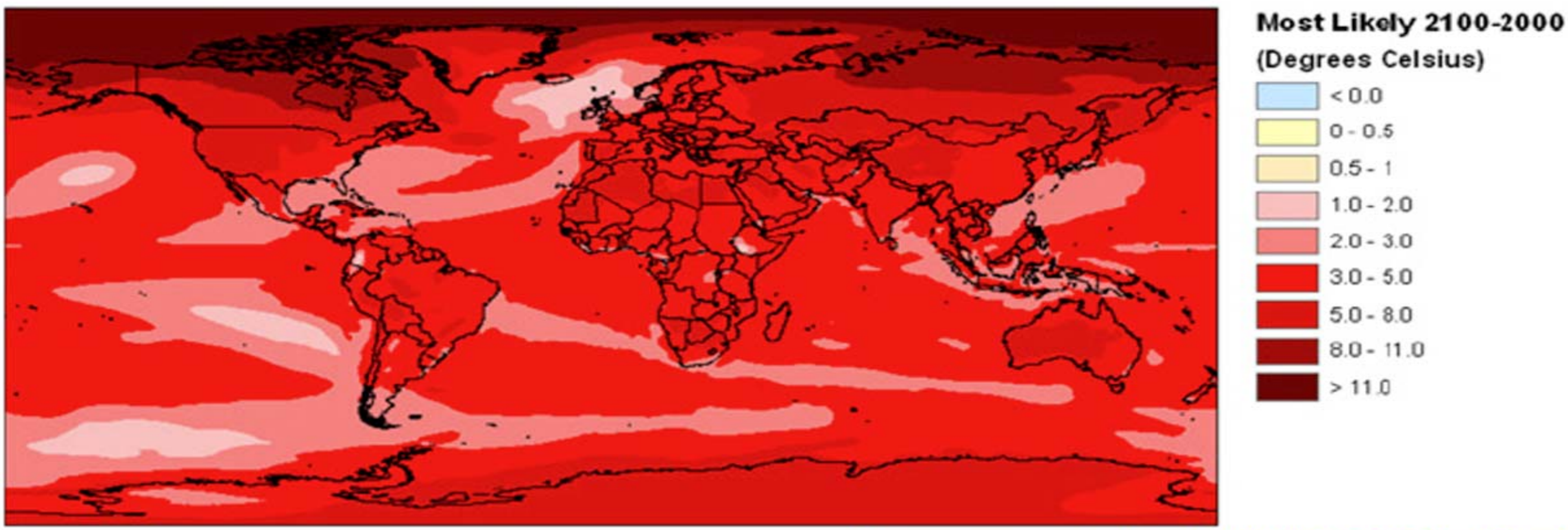
The model is an energy balance model, focused on the treatment of the thermodynamics of the climate system.

The model, used extensively in IPCC studies, includes:

- Treatment of atmospheric radiation, that calculates the changes in radiative forcing at the tropopause
- Treatment of the biogeochemical cycles affecting concentrations of CO_2, CH_4, N_2O, halocarbons, pollutant emissions leading to tropospheric ozone, etc.
- Treatment of the ocean, including an upper ocean and deep ocean that introduces a thermal lag
- Change in global average temperature is based on multiplication by a sensitivity factor, calibrated to GCMs

Projections of increase in surface air temperature for the A1FI (high) emissions scenario for CCSM3.0 (www.ccsm.ucar.edu/)





Source: www.pnas.org/content/106/37/15555.full.pdf+html