

## Air Pollutant Climate Forcings within the Big Climate Picture\*

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### Summary

We note that it will be exceedingly difficult to determine the aerosol climate forcing relative to pre-industrial climate. However, for policy purposes it may be sufficient to start with the present situation and consider climate forcing changes relative to today. The planet’s present energy imbalance, at least to first order, determines the change of climate forcings needed to stabilize climate. Climate models, using typical presumed scenarios of climate forcings for the past century, suggest that the planet should be out of energy balance by  $+0.75 \pm 0.25 \text{ W/m}^2$ , but observations of ocean heat content change (averaged over the 11-year solar cycle) suggest an imbalance of only  $+0.5 \pm 0.25 \text{ W/m}^2$  (absorbed solar energy exceeding heat radiation to space).

If all other forcings were fixed, a reduction of CO<sub>2</sub> amount to 350 ppm would restore the planet’s energy balance, assuming that the present imbalance is  $0.5 \text{ W/m}^2$ . If fossil fuel emissions continue at anything approaching “business-as-usual” scenarios, it is not feasible to restore planetary energy balance and stabilize climate. However, stabilization of climate becomes a realistic objective if coal emissions are phased out and unconventional fossil fuels (such as tar sands and oil shale) are not developed as substitutes for oil and gas as the oil and gas resources decline. With these assumptions, the non-CO<sub>2</sub> forcings become an important factor in stabilizing climate.

Of course, all other forcings are not fixed, but with appropriate directed efforts it is realistic to keep the net future change of non-CO<sub>2</sub> forcings near zero. N<sub>2</sub>O will continue to increase, at least in the near future, but its growth could be slowed with improved fertilization techniques. An N<sub>2</sub>O increase could be compensated by a decrease of CH<sub>4</sub>. There is a realistic possibility of decreasing the source strength of CH<sub>4</sub> emissions, and thus CH<sub>4</sub> atmospheric amount. However, if global warming continues, the CH<sub>4</sub> source from melting of methane hydrates could increase. Thus there is a coupling between the need to reduce CO<sub>2</sub> and the possibility of reducing CH<sub>4</sub>. Reflective aerosols are likely to decrease, thus adding a warming effect, but that warming effect may be compensated via an emphasis on reducing black soot aerosols.

The following charts (from the powerpoint presentation) include an accurate status report on climate forcings by greenhouse gases. Unfortunately, such data are not available for aerosols, but the NASA Glory mission, planned for launch late this year, promises to provide the first accurate global aerosol measurements. Comments that accompany the powerpoint charts are included below.

**Air Pollutant Climate Forcings  
within the Big Climate Picture\***

**Jim Hansen**

**March 11, 2009**

**Climate Change Congress  
*Global Risks, Challenges & Decisions*  
Copenhagen, Denmark**

**\*Any statements relating to policy are personal opinion**

Chart 1

I will discuss non-CO<sub>2</sub> human-made climate forcings, especially those that damage human-health, but in the context of what needs to be done to stabilize climate, including CO<sub>2</sub>.

**Air Pollutant Climate Forcings  
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Chart 2

Most of the data for changing greenhouse gas amounts comes from the NOAA Earth System Research Laboratory in Boulder, Colorado.

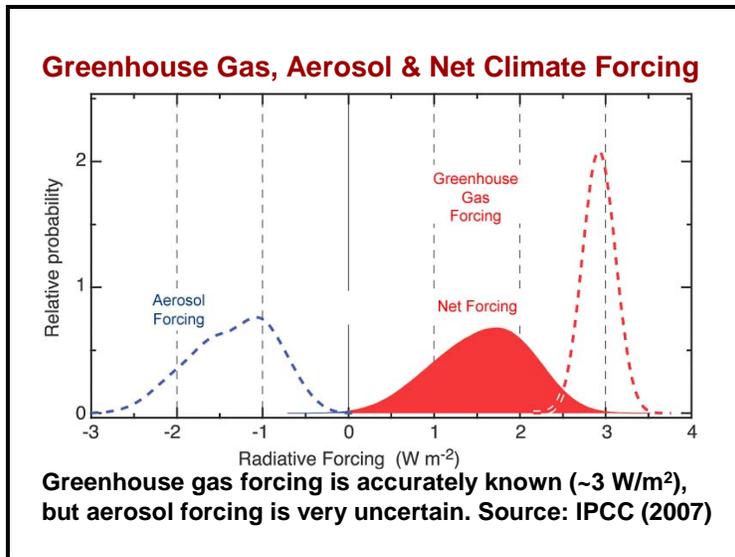


Chart 3

The two dominant human-made climate forcings are greenhouse gases and aerosols.

The greenhouse gas forcing is a sharp function, well-known at about  $3 W/m^2$ .

The aerosol forcing is negative and substantial, but the truth is that, based only on first principles, we do not know the aerosol forcing as well as indicated.

Nevertheless, we have reasons to believe that the net forcing is in the red range, which implies that the aerosol forcing is in the indicated range.

I will return to the sordid aerosol tale later.

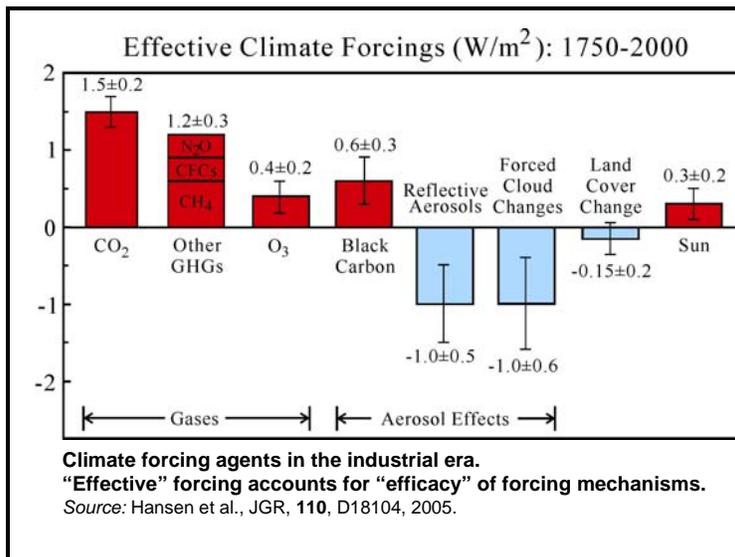


Chart 4

The non-CO<sub>2</sub> GHGs, methane, CFCs, N<sub>2</sub>O and ozone, added up are about the same as the CO<sub>2</sub> forcing – so the non-CO<sub>2</sub> GHGs are very important.

The aerosol forcings are very uncertain, and their effect on clouds even more uncertain – the error bars are subjective and may be too small.

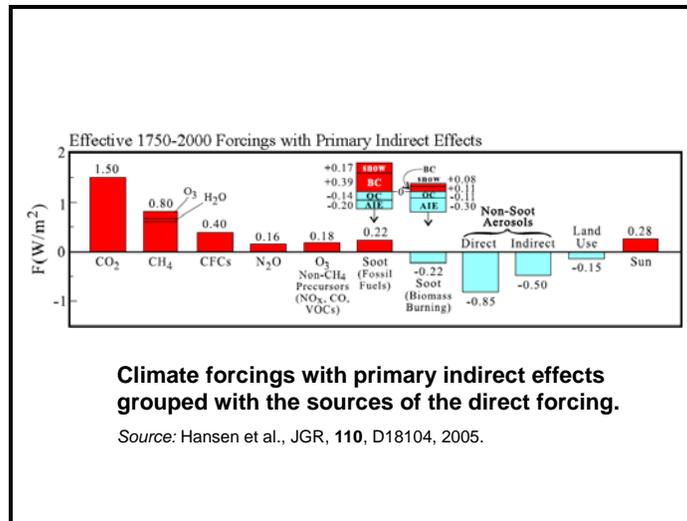


Chart 5

Here the forcings have been rearranged so that more-or-less well-understood indirect effects are included with the primary forcing. For example, if methane increases it causes tropospheric ozone and stratospheric water vapor to increase, so those indirect effects should be included with the methane forcing.

Soot I have defined as the carbonaceous aerosol product of incomplete combustion – black carbon and organic carbon.

The non-soot aerosols are mainly sulfate and nitrate. These estimates are, of course, very uncertain.

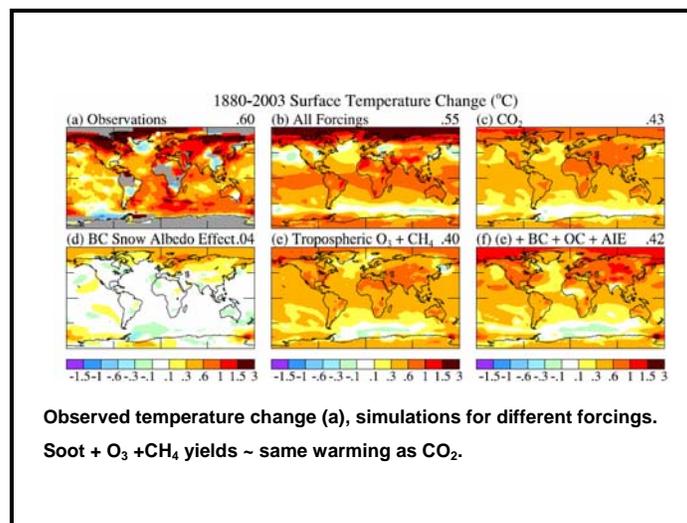


Chart 6

When we use all of these forcings for climate simulations of the past century the calculated warming is comparable to that observed.

What I want to do here is compare the warming calculated by CO<sub>2</sub> alone, upper right corner, with the warming due to the air pollutants, tropospheric ozone, methane, and the soot aerosols, including the aerosol indirect effect – you see that the pollutants yield about the same response as the CO<sub>2</sub>, supporting the contention that pollutants are important.

## Inference

- 1. Non-CO<sub>2</sub> Forcings Substantial**  
Comparable to CO<sub>2</sub> forcing today
- 2. Strategic Mitigation Role**  
If coal phased out, non-CO<sub>2</sub> important
- 3. Aerosols Complicate the Story**  
If all pollution is reduced, how much will aerosol cooling effect be altered?

### Chart 7

It follows that the non-CO<sub>2</sub> forcings are important, and because of the difficulty of turning CO<sub>2</sub> around, they may play a strategic role in the next several decades.

But aerosols are a double-edged sword.

## Nasty Aerosol Problem

- 1. Aerosol Forcing Not Measured**  
Based in good part on presumptions
- 2. Aerosol Data Include Feedbacks**  
Aerosols decrease in warming climate
- 3. Aerosol Cloud Effects Complex**  
Aerosol forcing practically unknown

### Chart 8

We do not have measurements of aerosols going back to the 1800s – we don't even have global measurements today.

Any measurements that exist incorporate both forcing and feedback.

Aerosol effects on clouds are very uncertain.

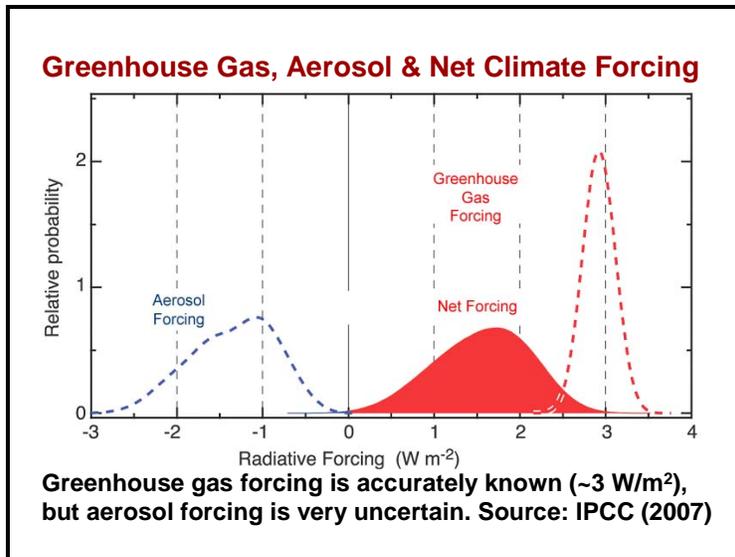


Chart 9

Even if we accept the IPCC aerosol estimate, which was pretty much pulled out of a hat, it leaves the net forcing almost anywhere between zero and 3 watts.

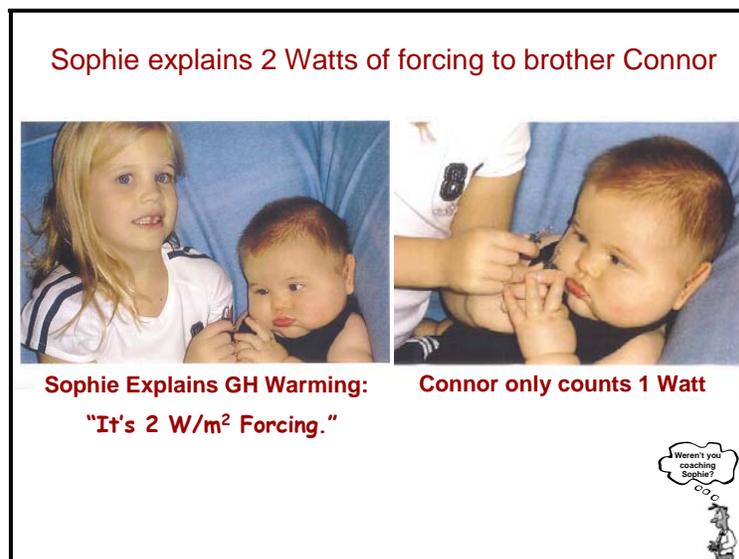


Chart 10

I didn't know what forcing to use when we started our IPCC runs 4 years ago, so I went to my grandchildren and asked them "What is the net forcing?"

Sophie explained that it was 2 watts, but her well-fed baby brother could only count 1 watt.

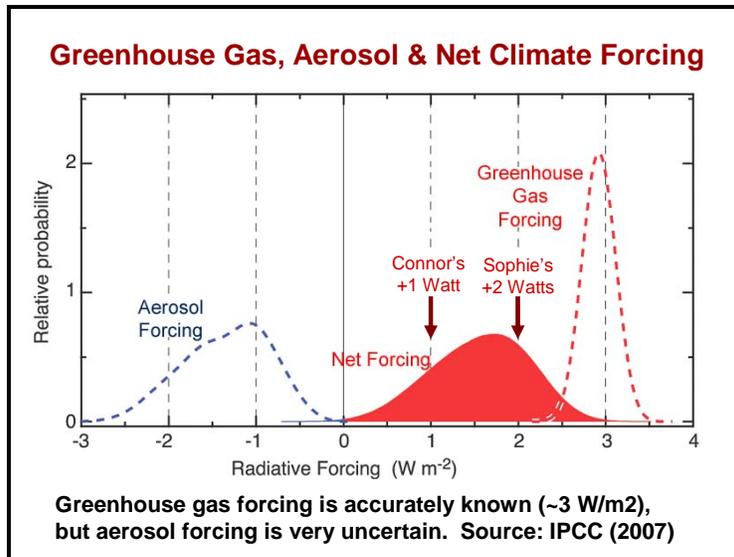


Chart 11

Sophie was older and pretty smart so we used 1.8 watts.

But now I'm not sure Sophie was right, and for various reasons I began to think that conceivably Connor was closer.



Chart 12

So I decided to go back and ask them again, because they are four years older, and should be smarter.

But now when I ask them, "What is the forcing?", they say that they don't know. Maybe this is scientific reticence creeping in already.

## Conclusion re Aerosols

### 1. Sophie & Connor are right

- Don't know forcing re pre-industrial
- Probably never will; Is it essential?
- Use Forcing Changes re "Now"

### 2. Planetary Energy Imbalance

- Ocean Heat + Ice Sheet Mass +...

### 3. Measure Aerosol Changes

- Glory mission initiates aerosol data

#### Chart 13

Sophie and Connor are probably right, and we may never know the aerosol forcing relative to pre-industrial.

But perhaps that is not so essential – because we can measure the planet's energy imbalance.

And, to first order, if we want climate to stabilize we must reduce the net climate forcing enough to restore the planet's energy balance.

We are measuring greenhouse gas changes very accurately, and, beginning with the Glory satellite mission at about the end of this year, we will be able to measure aerosols well enough to define aerosol properties and their change with time. That mission will look at a given piece of real estate from all angles as the satellite flies over, it will measure from the UV to the near IR, and it will measure the polarization to about a tenth of a percent accuracy, a factor of 10 better than POLDER.

## How Can Climate be Stabilized?

### Must Restore Planet's Energy Balance

**Modeled Imbalance:  $+0.75 \pm 0.25 \text{ W/m}^2$**

**Ocean Data Suggest:  $+0.5 \pm 0.25 \text{ W/m}^2$**

#### Chart 14

Now, the ultimate question: can we stabilize climate?

We would need to restore the planet's energy balance. The underlying imbalance (averaging over short-term fluctuations) is probably close to  $0.5 \text{ W/m}^2$ .

Of course if fossil fuel use continues to increase as in business-as-usual, we probably need to look for another planet.

But let's say we phase out coal, and, with the help of improved agricultural and forestry practices, plus ocean uptake of  $\text{CO}_2$ , we get back to 350 ppm – that would decrease forcing by about  $0.5 \text{ W/m}^2$  (see chart 16 –  $\text{CO}_2$  was 350 ppm in 1988).

Can we get a net decrease from the non- $\text{CO}_2$  forcings, or, at worst, avoid any increase?

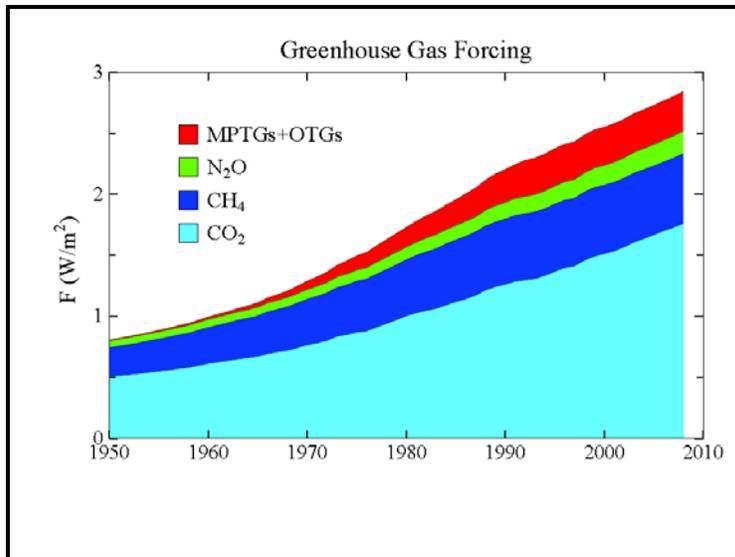


Chart 15

$N_2O$ , because of its long time constant, will continue to increase, although we could get its growth rate to slow via better fertilization practices.

However, if we pay attention to HCFC-22 and 134a (see chart 23), we should be able to get a small decrease of MPTGs + OTGs so as to offset the  $N_2O$  increase.

The best opportunity for a decrease is in methane, and thus also tropospheric ozone and stratospheric water vapor, which are not shown on this chart.

If coal mining is phased out (a big methane source), and venting at oil mining declines, and if other methane sources such as land fills and waste management facilities are addressed, it may be possible to decrease the present forcing by of the order of  $0.25 W/m^2$ .

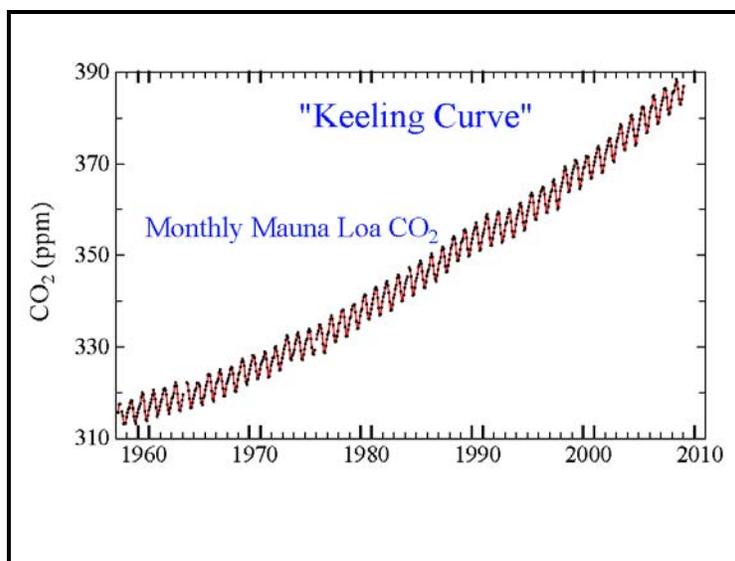


Chart 16

Now let's put pollution climate forcing in the context of the total climate forcing, including  $CO_2$ , which we know is increasing more and more rapidly.

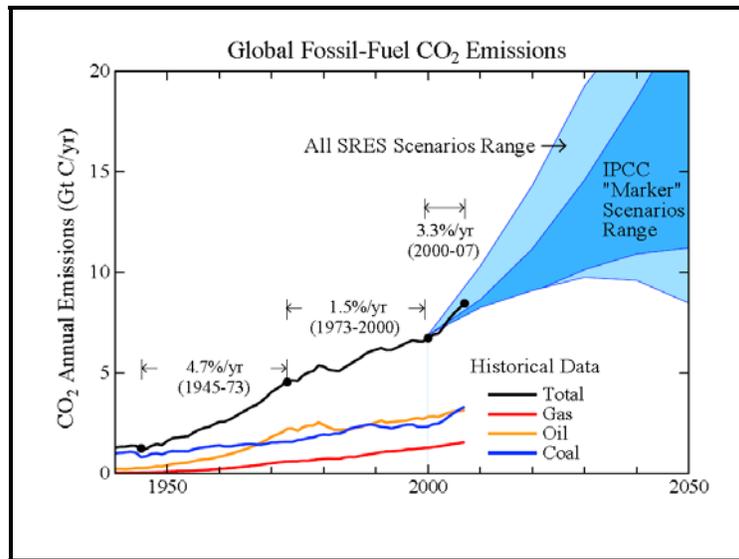
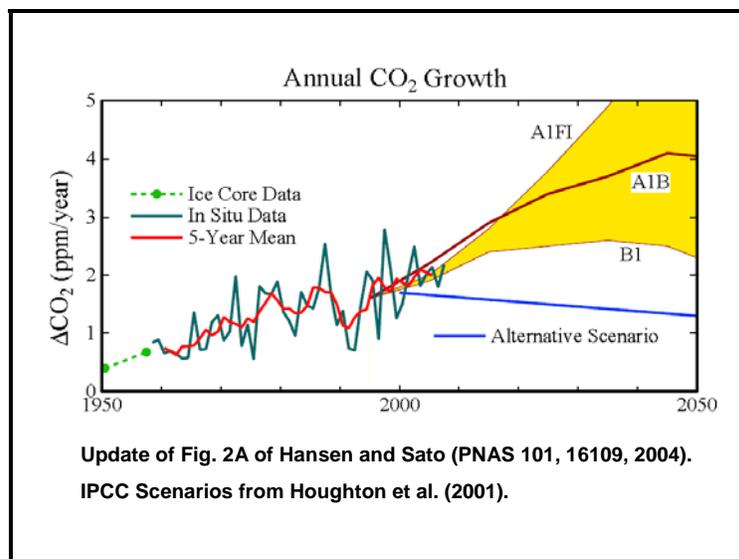


Chart 17

Fossil fuel emissions will need to decrease, if we want to stabilize atmospheric CO<sub>2</sub>, or get it to decline, but in fact the emissions have been increasing, at least through 2007.



Update of Fig. 2A of Hansen and Sato (PNAS 101, 16109, 2004).  
 IPCC Scenarios from Houghton et al. (2001).

Chart 18

The amount of CO<sub>2</sub> in the air is increasing about 2 ppm per year, similar to IPCC scenarios.

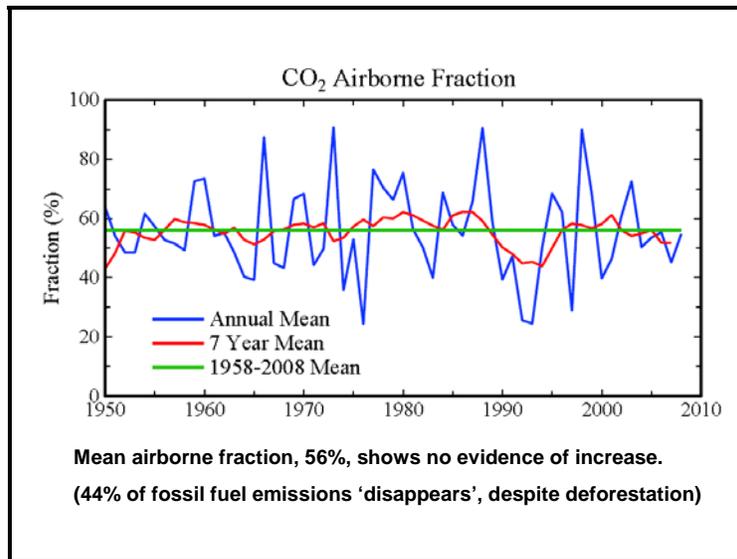


Chart 19

Contrary to what you read in the newspaper, the sinks of CO<sub>2</sub> are not decreasing. On the contrary they are increasing as fast as the CO<sub>2</sub> emissions have increased.

The fraction of CO<sub>2</sub> emissions that disappears annually continues to average 44%.

The sinks may begin to saturate eventually, but so far they have not.

During the next two years, however, I expect the airborne fraction will jump temporarily to higher values as an El Nino is likely to start this year, with effects extending into 2010.

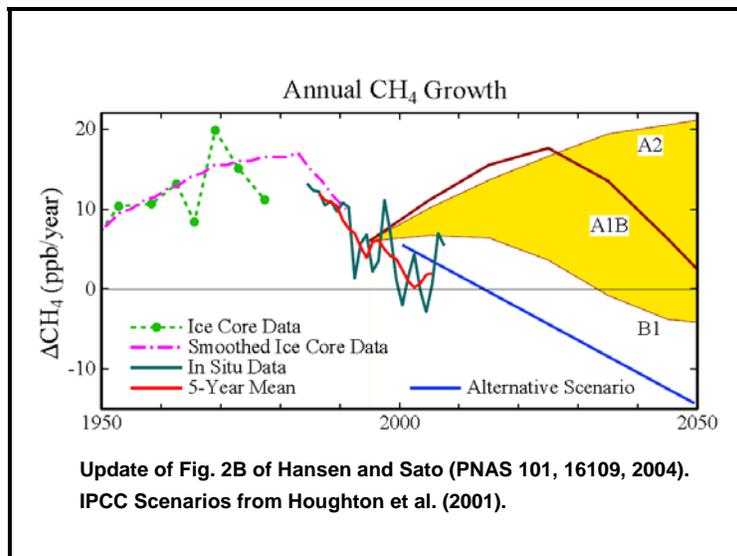


Chart 20

Methane annual growth has been well below IPCC scenarios, with atmospheric amount almost stabilizing, until the past two years, when it began to increase again.

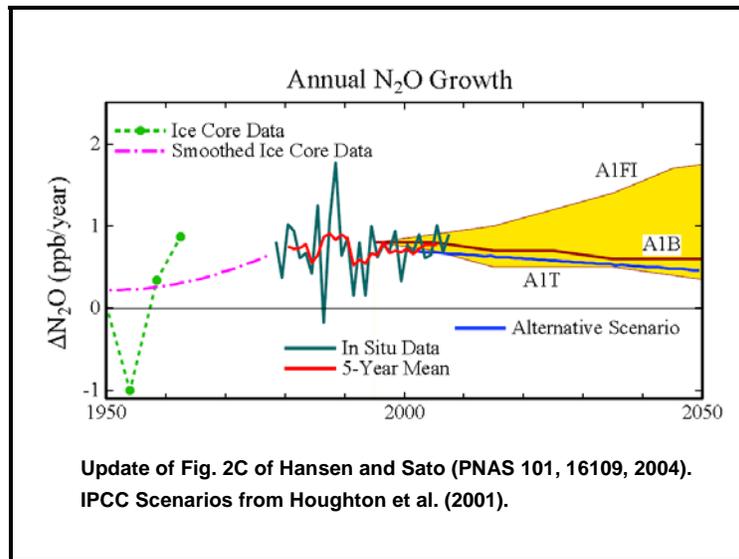


Chart 21

Nitrous oxide is continuing to increase, at an approximately constant rate, similar to IPCC scenarios.

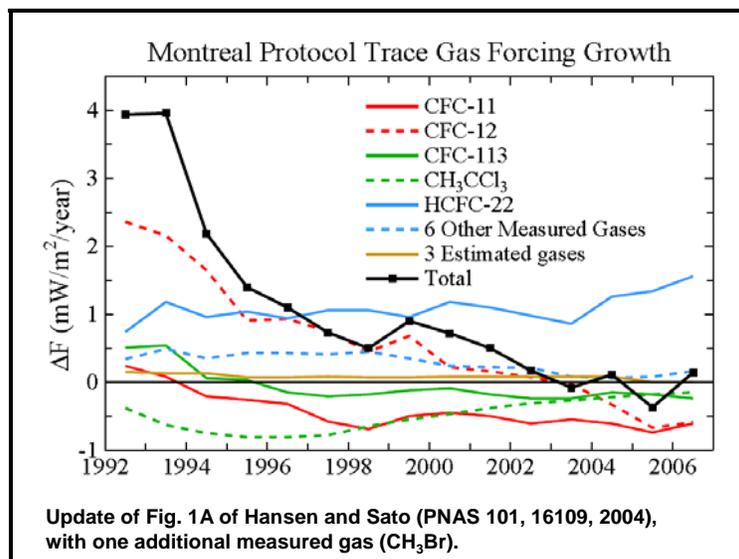


Chart 22

Here is a success story. The climate forcing by Montreal Protocol trace gases has stopped increasing. Some of the gases are decreasing in absolute amount.

The clinker is HCFC-22. Supposedly it will begin to decline within several years, so we have the potential to obtain a significant decrease in the greenhouse gas forcing by these gases, beginning within the next few years.

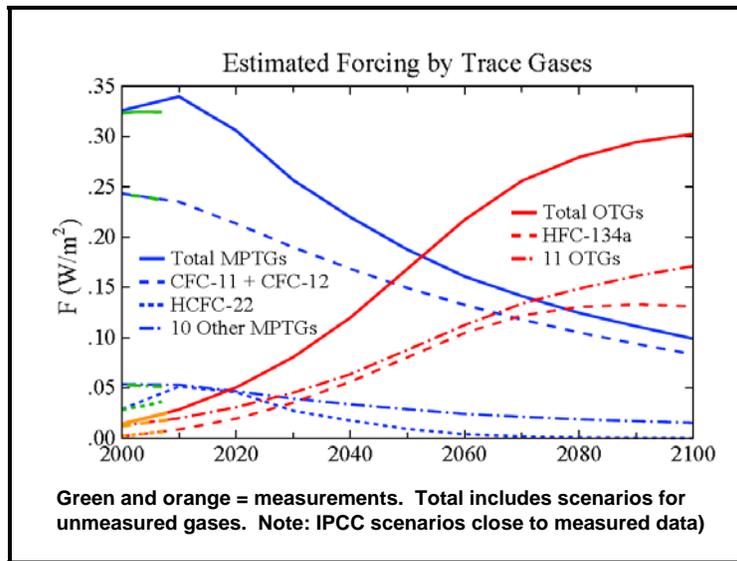


Chart 23

However, there are other minor trace gases, which could wipe out the gain from decreasing MPTGs. So we need to cut off at the pass HFC-134a and other OTGs if we want to get a net decrease in forcing by all of the minor gases.

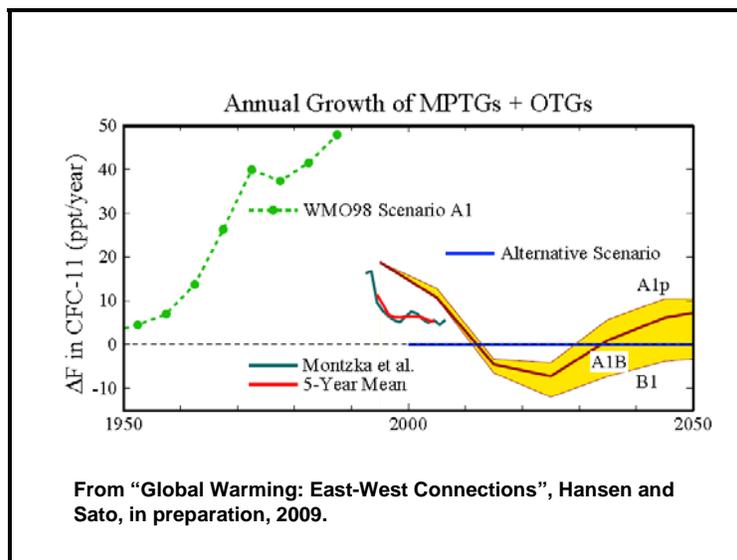


Chart 24

The sum of MPTGs and OTGs is still producing a small annual increase of GHG forcing. But it is less than in the IPCC scenarios. If we get HCFC-22 and HFC-134a under control the net annual change could become negative.

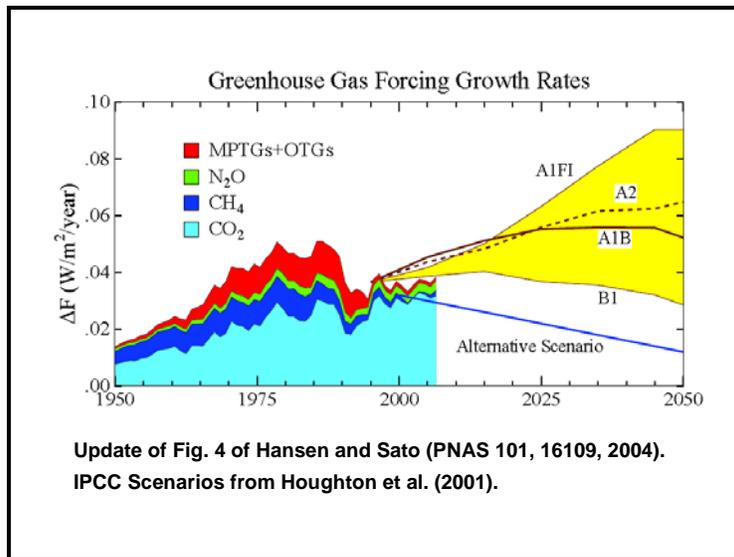


Chart 25

Here is the summary for all well-mixed GHGs, that is, excluding ozone and stratospheric water vapor. The growth rate for observed GHG changes is slightly below IPCC scenarios, but it is much higher than the “alternative scenario”, which is a scenario that was defined so as to keep additional warming after year 2000 at no more than about 1 degree Celsius. That alternative scenario had CO<sub>2</sub> reaching 450 ppm in 2050.

### Assessment of Target CO<sub>2</sub>

<u>Phenomenon</u>	<u>Target CO<sub>2</sub> (ppm)</u>
1. Arctic Sea Ice	300-325
2. Ice Sheets/Sea Level	300-350
3. Shifting Climatic Zones	300-350
4. Alpine Water Supplies	300-350
5. Avoid Ocean Acidification	300-350
<b>→ Initial Target CO<sub>2</sub> = 350* ppm</b>	
*assumes CH <sub>4</sub> , O <sub>3</sub> , Black Soot decrease	
Reference: Hansen et al. Target Atmospheric CO <sub>2</sub> , Open Atmos. Sci., 2008	

Chart 26

Moreover, it has become clear that 450 ppm CO<sub>2</sub> is well into the dangerous zone. We should be aiming for an atmospheric CO<sub>2</sub> amount of no more than 350 ppm.

That criterion comes especially from looking at the history of Earth’s climate, but also from ongoing phenomena, such as those listed here.

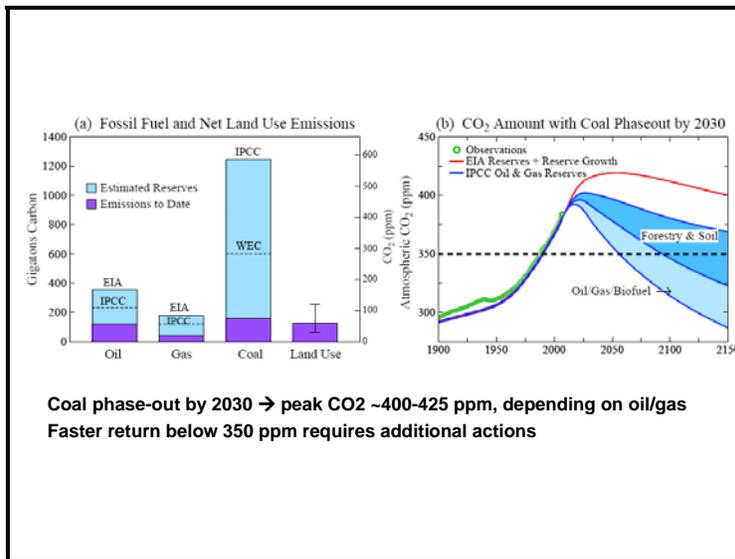


Chart 27

Such a low level of atmospheric CO<sub>2</sub> is conceivable, if we phase out coal emissions linearly between 2010 and 2030, and if we prohibit use of unconventional fossil fuels such as tar sands and oil shale.

In that case, depending upon the magnitude of undiscovered reserves of oil and gas, CO<sub>2</sub> would peak at something between 400 and 425 ppm and then begin to decline.

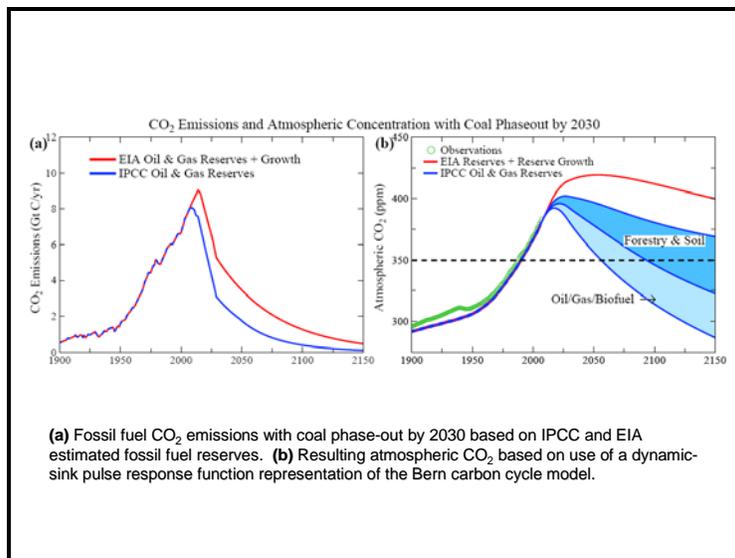


Chart 28

With coal phase-out and prohibition of unconventional fossil fuels, CO<sub>2</sub> emissions would plummet over the next few decades.

**How Can Climate be Stabilized?**

**Must Restore Planet's Energy Balance**

Modeled Imbalance:  $+0.75 \pm 0.25 \text{ W/m}^2$   
 Ocean Data Suggest:  $+0.5 \pm 0.25 \text{ W/m}^2$

**Requirement Might be Met Via:**

Reducing CO<sub>2</sub> to 350 ppm or less  
 &  
 Reducing non-CO<sub>2</sub> forcing  $\sim 0.25 \text{ W/m}^2$

Chart 29

Now, back to the ultimate question: can we stabilize climate?

If CO<sub>2</sub> were reduced to 350 ppm, that would decrease forcing by about  $0.5 \text{ W/m}^2$ . It will require some effort to keep the other forcings from increasing, but with focused efforts it is conceivable that a decrease of forcing of up to about  $0.25 \text{ W/m}^2$  could be obtained from the non-CO<sub>2</sub> greenhouse gases.

**Are Needed Actions Feasible?\***

**Coal must be phased out & Unconventional Fossil Fuels avoided**

Requires Carbon Tax & Dividend  
 'Cap & Trade' a Proven Failure

**Do not lump non-CO<sub>2</sub> forcings w CO<sub>2</sub>**

Methane + Ozone most important (reduction feasible as fossil fuel use declines)  
 Emphasize BC reductions among aerosols

\*My opinions

Chart 30

Overall, to stabilize climate, by far the most important required action is phase-out of coal emissions.

The practical implication is a need to eliminate subsidies for fossil fuels and initiate an increasing carbon price, allowing renewable energies and efficiency to grow.

Non-CO<sub>2</sub> forcings should be dealt with separately from CO<sub>2</sub> – they should not provide an escape hatch to avoid CO<sub>2</sub> emission reductions.