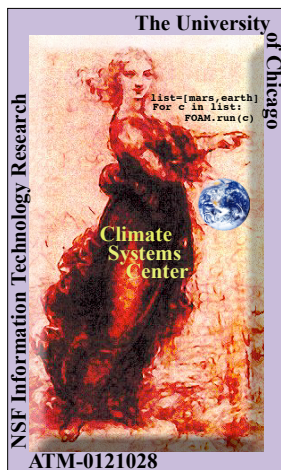


Kavli Institute, 2008

## Perils of the Sulfate Sunshield

Raymond T. Pierrehumbert  
*The University of Chicago*



## The Sword of Damocles

Raymond T. Pierrehumbert

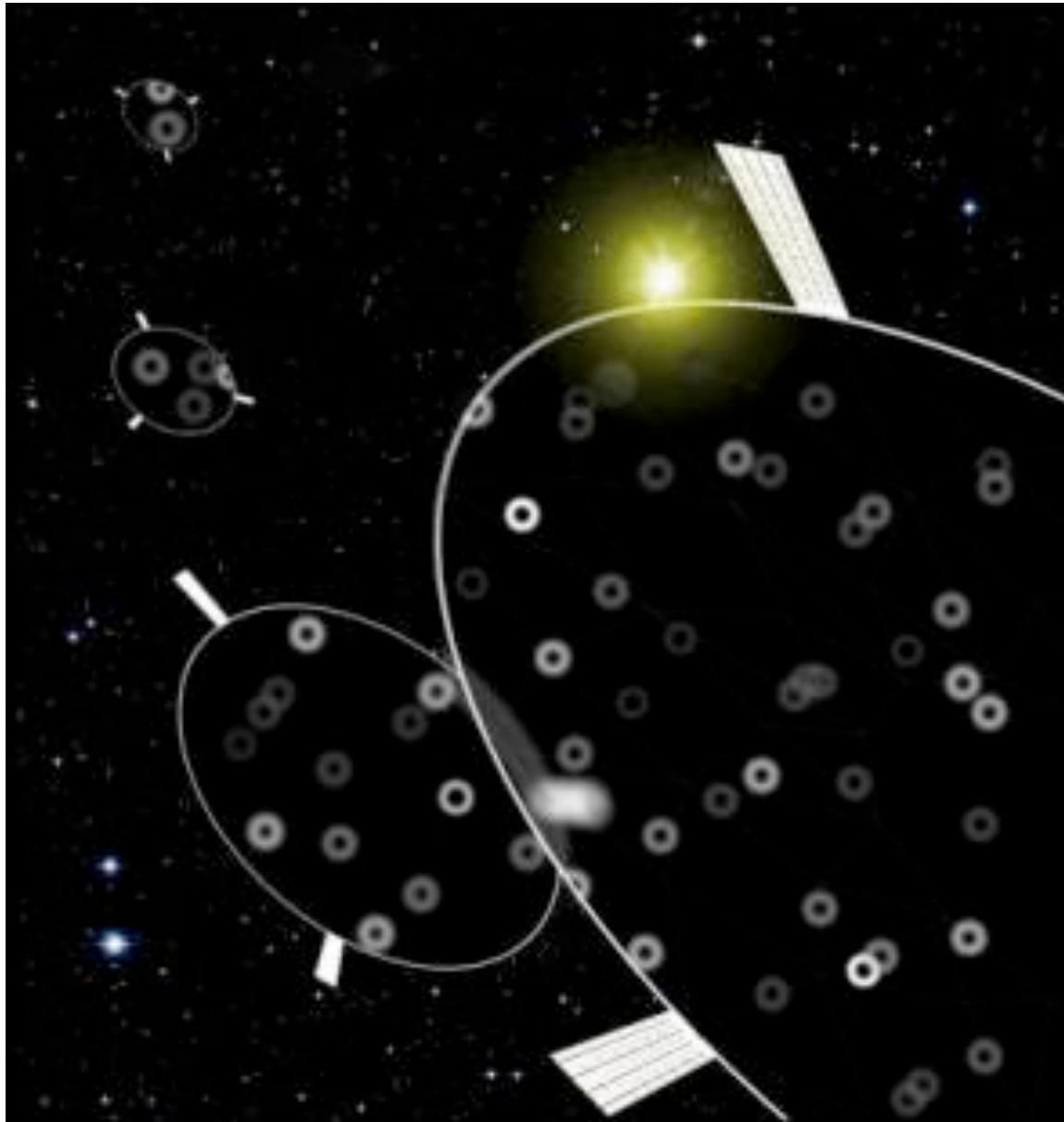
*The University of Chicago*



## The idea...

- Increased  $CO_2$  warms the Earth by trapping infrared
- Proposal is to cool the earth back down by reflecting back some sunlight
- Emphasize sulfates, but most of what I say applies to other stratospheric particles

## Space-based mirrors



*Tech barriers; High launch cost. Won't happen*

Kavli Institute, 2008

**Use stratospheric sulfate particles instead**



### Geoengineering methods to reduce global warming

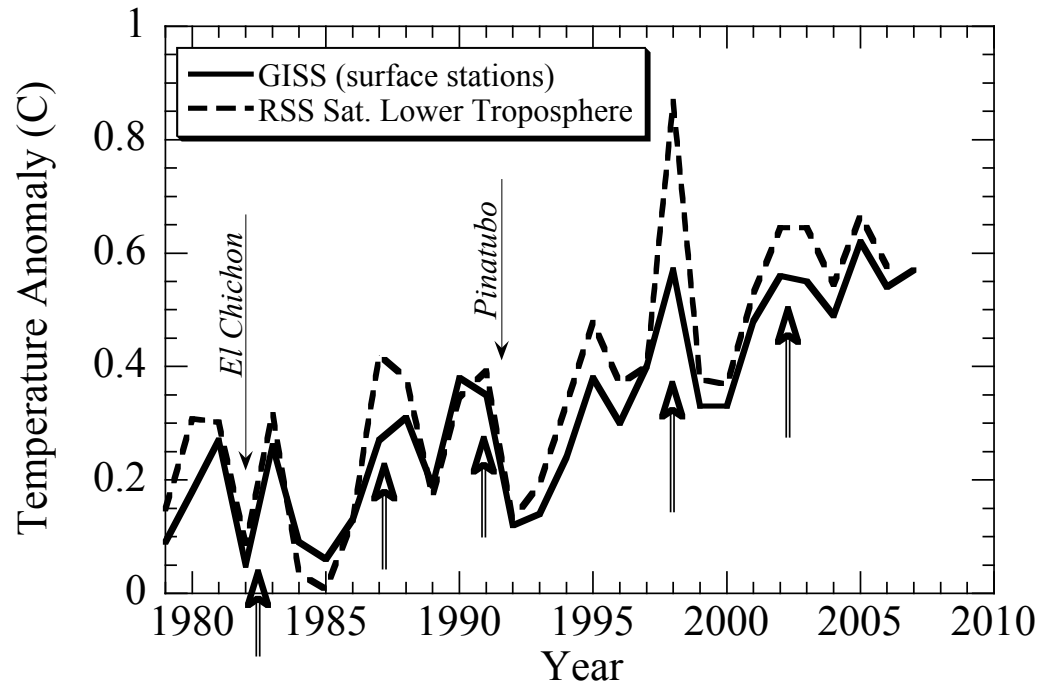
- reforestation, greening of deserts, creation of algae lakes to convert CO<sub>2</sub> to oxygen.
- sequestering of CO<sub>2</sub> in deep ocean trenches as dry ice slurry.
- space based mirror arrays
- dust and soot dust delivered into atmosphere with high-altitude balloons and large guns.
- aluminum powder and barium

## **Cheap enough for a nation or multinational to go it alone**

- Reflection proportional to total area of particles
- Use many small particles (each one millionth of a meter)
- To offset  $8xCO_2$ , need under 820 tonnes per day



## Like an artificial permanent volcano



## The marketing



"Kind sir, *please* save me."

## **Sold as insurance**

- ... but insurance is something you know will work.
- This is more like changing the engines of a fully loaded 747 in flight

## The problem of the time scale mismatch

- Carbon dioxide stays in the atmosphere for  $\approx 1000$  years
- Some of it will continue to affect climate for 10,000 years
- Stratospheric aerosols last only about a year
- We would be committing humanity to carrying out the aerosol program every year for the next millennium or more without fail

## Marcus Aurelius (169 AD) Sez...



*Things look great. The Empire is forever. Let's burn all the coal. We can always cancel it out with sulfates.*

Kavli Institute, 2008

**But along comes Alaric (410 AD)...**



Il sacco di Roma

**And *nobody* expects the Plague of Justinian (541AD)**

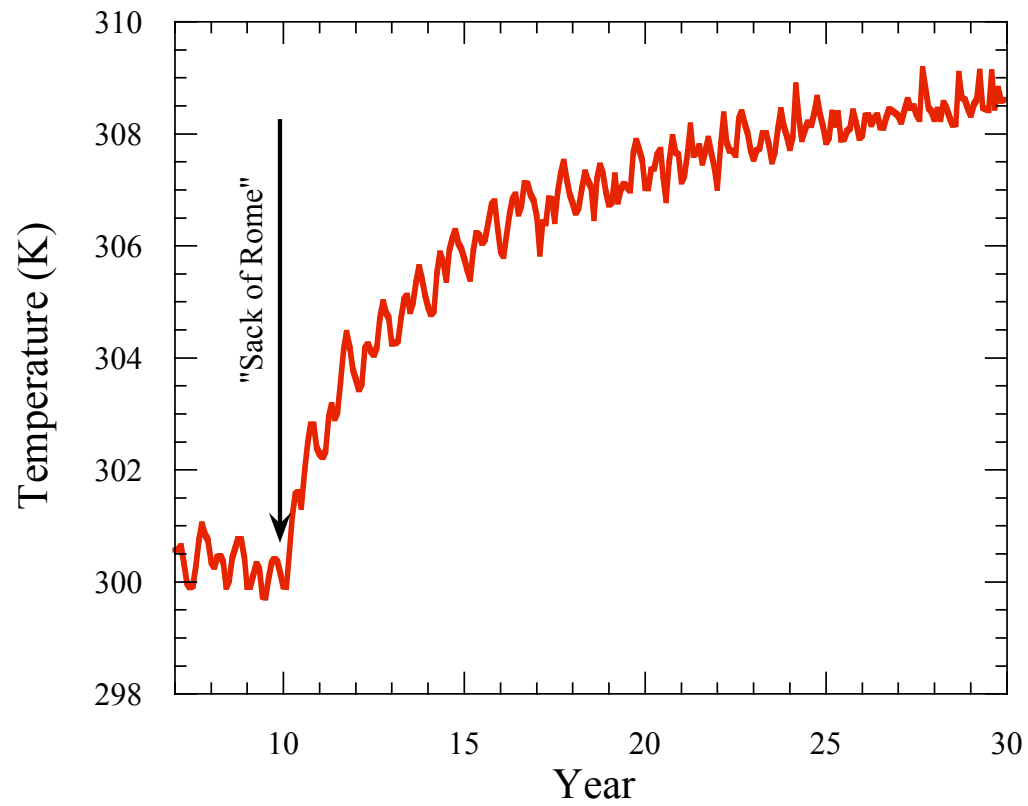




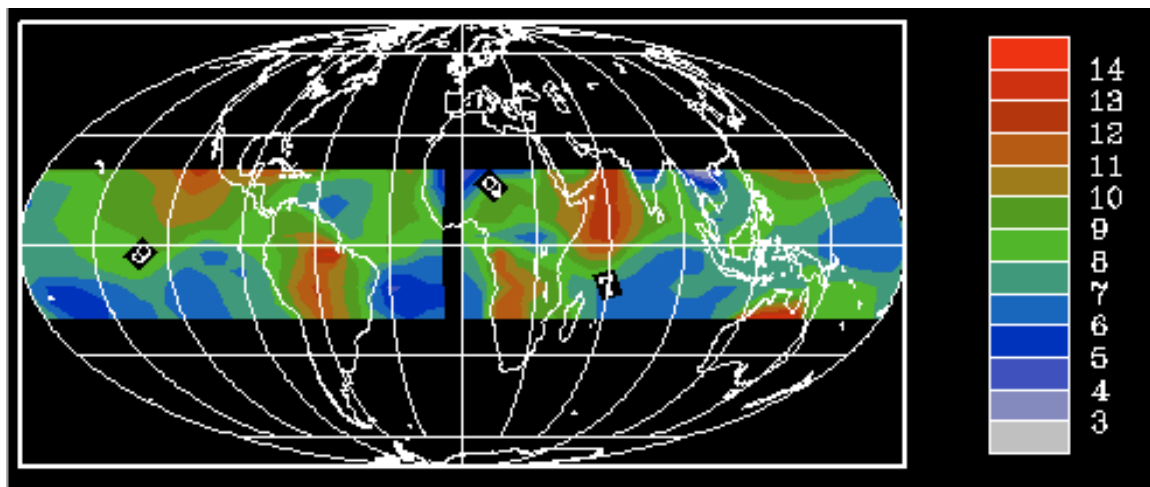
## **Simulations of sudden termination of geoengineering**

- Full climate model, simplified ocean
- 8xCO<sub>2</sub>; equiv to 4xCO<sub>2</sub> in high-sensitivity model
- Engineer tropical temperature back to normal, then shut off sulfates

## Tropical maximum temperature over time



## Tropical warming over 20 years



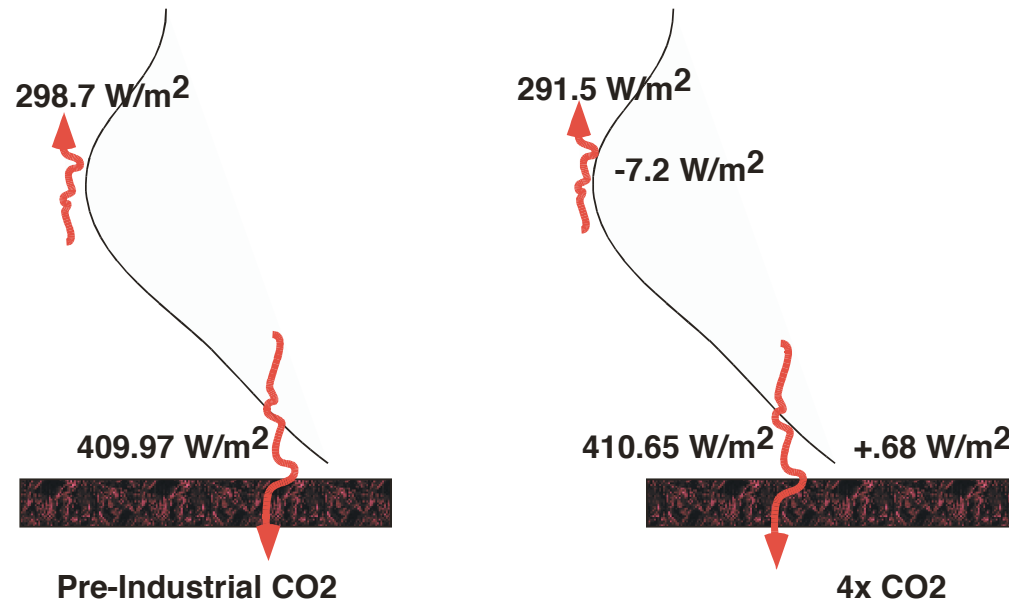
Kavli Institute, 2008

**Say, Dionysus, about that sword...**



## SulfateWorld is not like NatureWorld

Tropical Conditions (moist b.l)

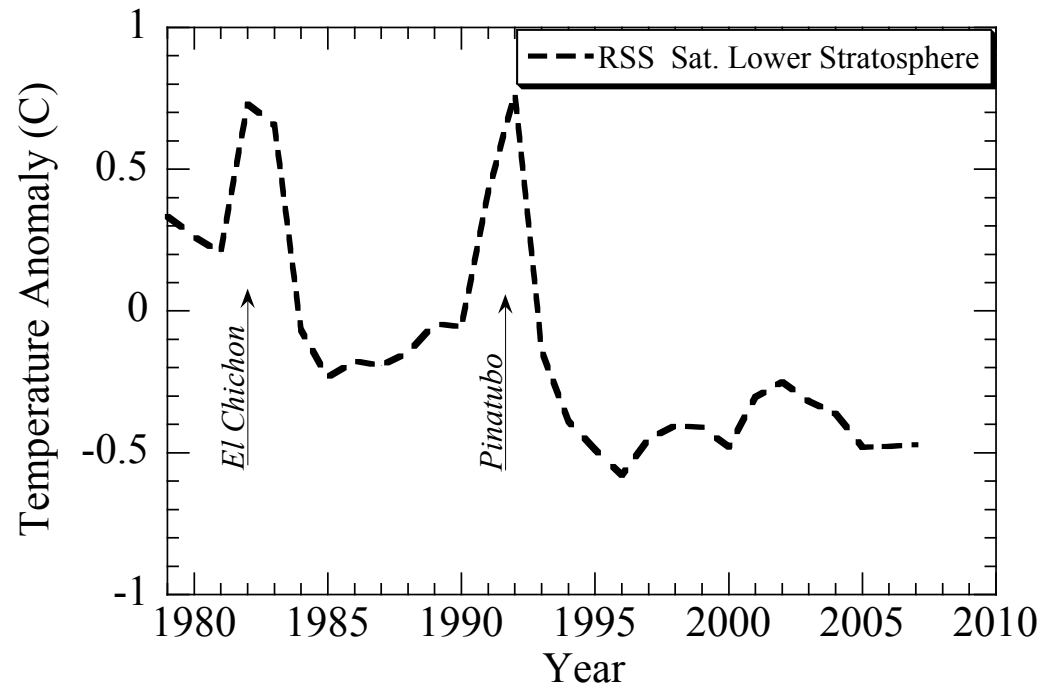


Reduces tropical precipitation

## **Problem: Ocean acidification**

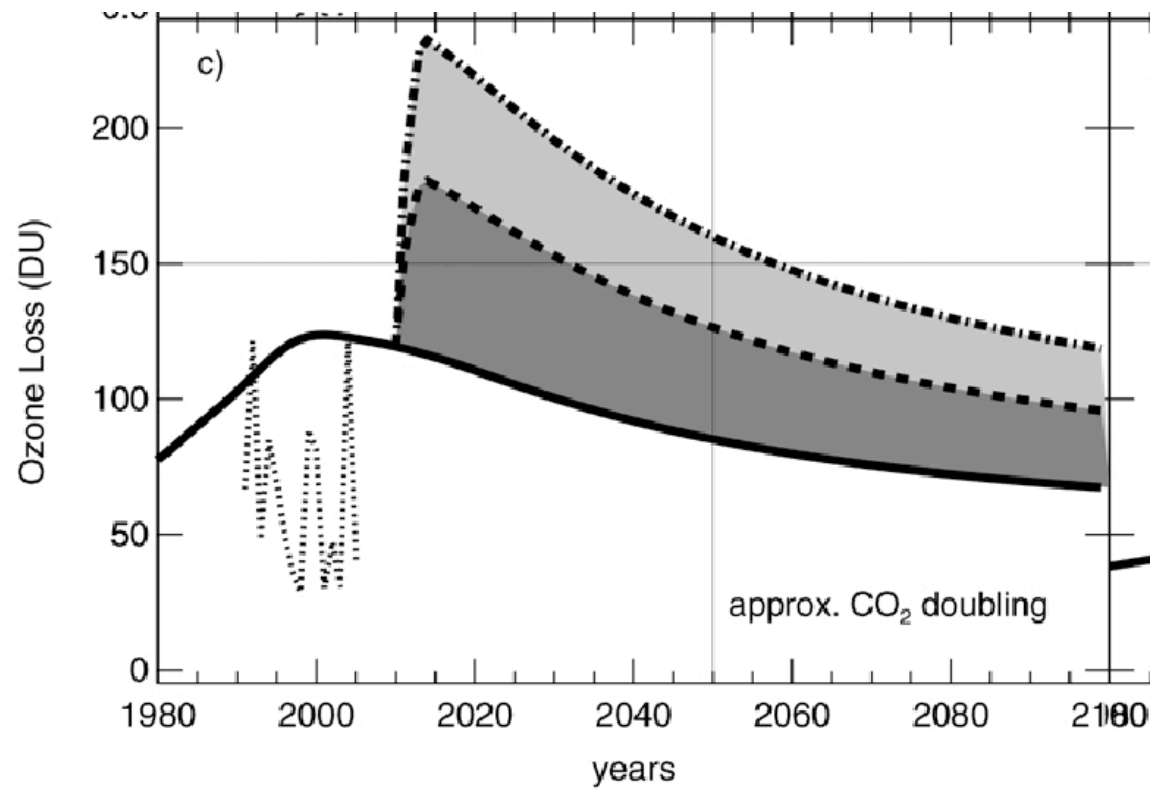
- Carbon dioxide has effects beyond warming
- Dissolves in ocean, makes it more acidic
- Causes corals and carbonate shells of micro-organisms to dissolve
- Affects the ocean food chain
- Engineering the albedo does not eliminate this problem

## Problem: Stratospheric warming





### Problem: Ozone destruction

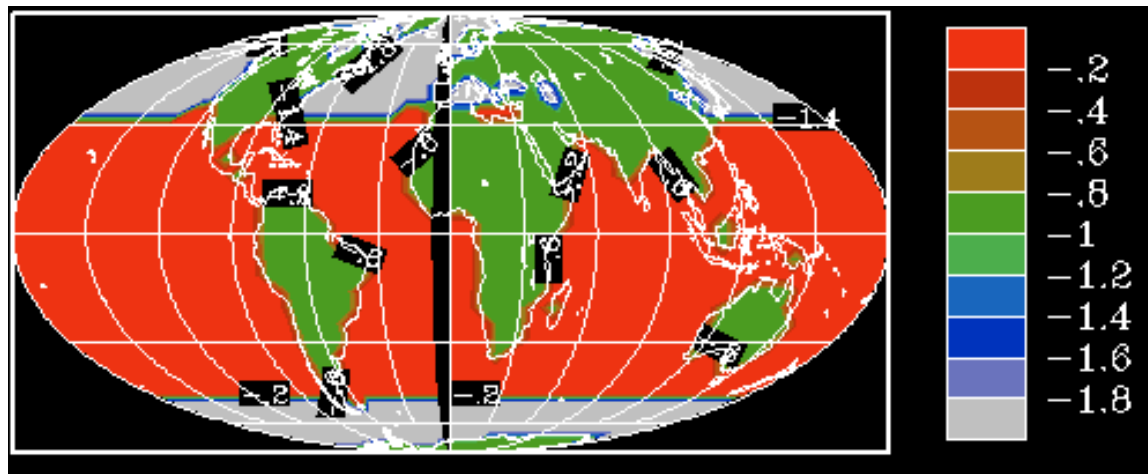


Tilmes *et al*, *Science* 2008

## Redistribution of radiative forcing?

- $CO_2$  forcing fairly uniform
- Forcing from albedo change varies greatly with lat,lon, and time
- Caldeira result: Atmospheric heat redistribution evens all this out
- Are there limits to how well this can work?
- Look at ice margin on DamoclesWorld (8xCO<sub>2</sub>, tropics engineered with sulfates)

Oops!



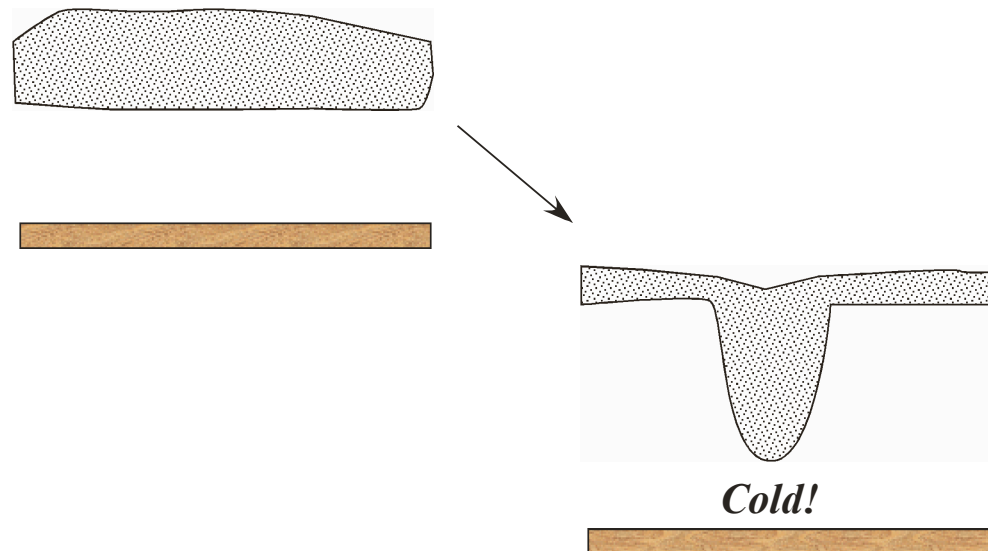


”Thanks, guys! :) ”

## **Problem: Oceans and sea ice**

- Nobody's done a calculation yet with a dynamic ocean
- This could affect response of sea ice

**Problem: Could stratospheric weather bunch up aerosols?**



## Other problems

- Interaction with soot: "Internal mixing"
- Growth of particle size (large particles could have warming effect)
- "Permanent Volcano" unlike natural episodic volcano

## **Sulfate addiction**

- Sulfate geoengineering makes a high CO2 DamoclesWorld more likely
- If we make some of the more obvious heat effects more tolerable, it make it more likely we'll just burn all the coal



## Sulfate addiction

- David Keith: " We're not sitting in 1600 deciding whether to go from 280ppm to 600ppm and cancel it with sulfates"
- ... but we *are* sitting in 2008 deciding whether to go from 390ppm to 1600ppm and cancel it with sulfates.

## Sulfate addiction

- David Keith: "We wouldn't just burn coal til it runs out and count on sulfates to save us. That would be stupid"
- ... but it's also pretty stupid to double CO<sub>2</sub>, as we are doing now
- We are quite capable of doing stupid things



## Concluding Remarks

- This is not insurance
- THIS IS NOT INSURANCE
- *THIS IS NOT INSURANCE*
- (Maybe after 100 years of intensive research we might begin to know if it's insurance)
- But if 50 years of intensive research on global warming have not narrowed the uncertainty in warming forecast, why should we expect it to be any better for sulfate geoengineering?