

Geoengineering: Plan B Remedy for Global Warming

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Aerosol Working Group

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Some Radiative Aspects of Proposed Geoengineering Countermeasures to Global Warming (submitted to PNAS)

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Accelerated melting of Greenland ice due to global warming . . .

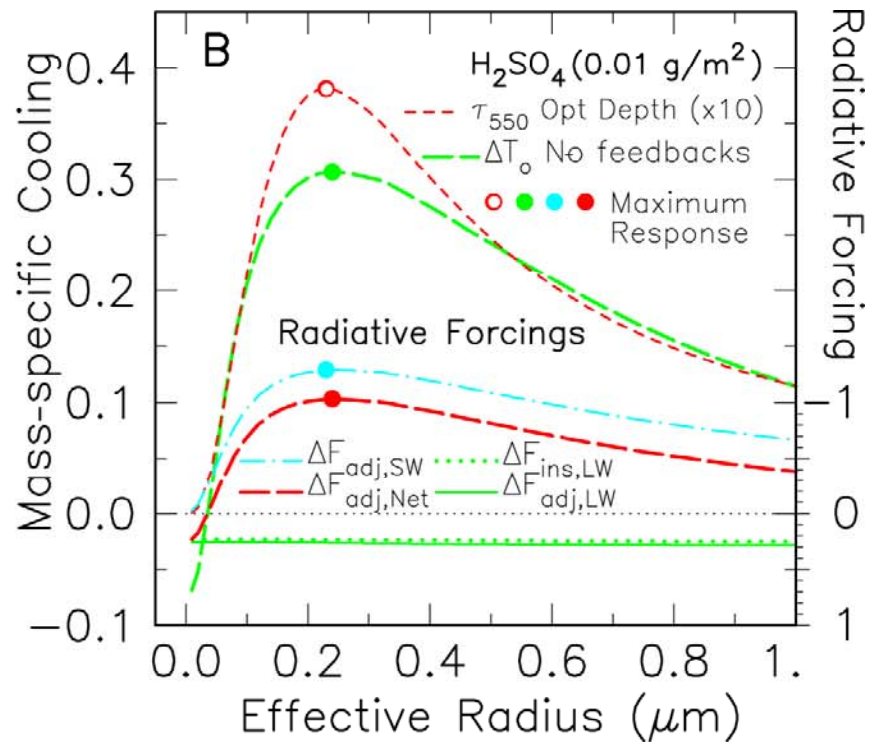
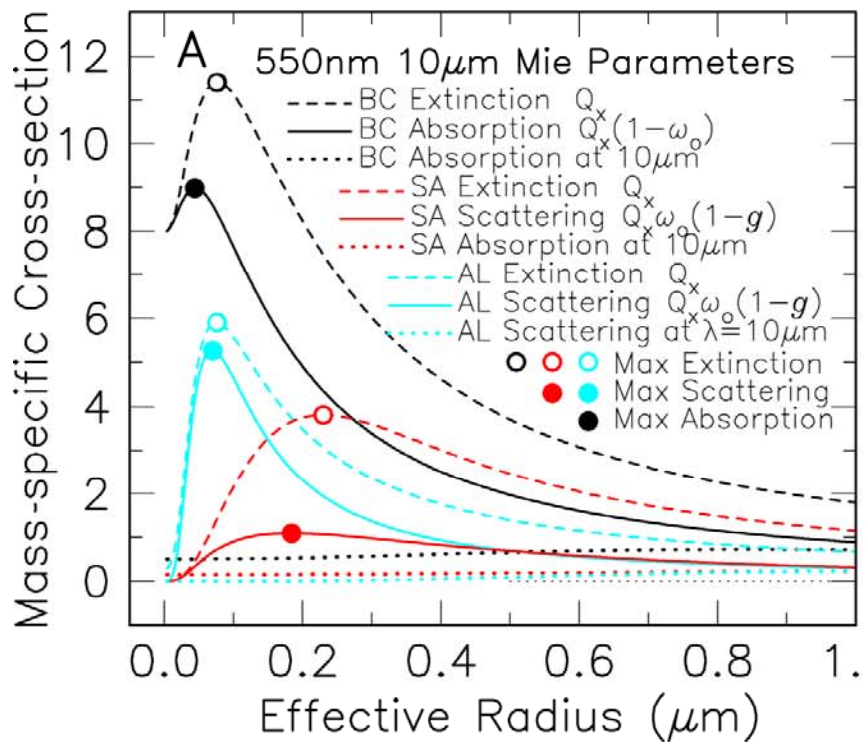
How can aerosols be used to counteract global warming?

- Injection of sulfur into the lower stratosphere . . .
- Aluminum aerosol can scatter solar radiation efficiently, but . . .
- Black carbon (soot) aerosol - a very effective control knob . . .

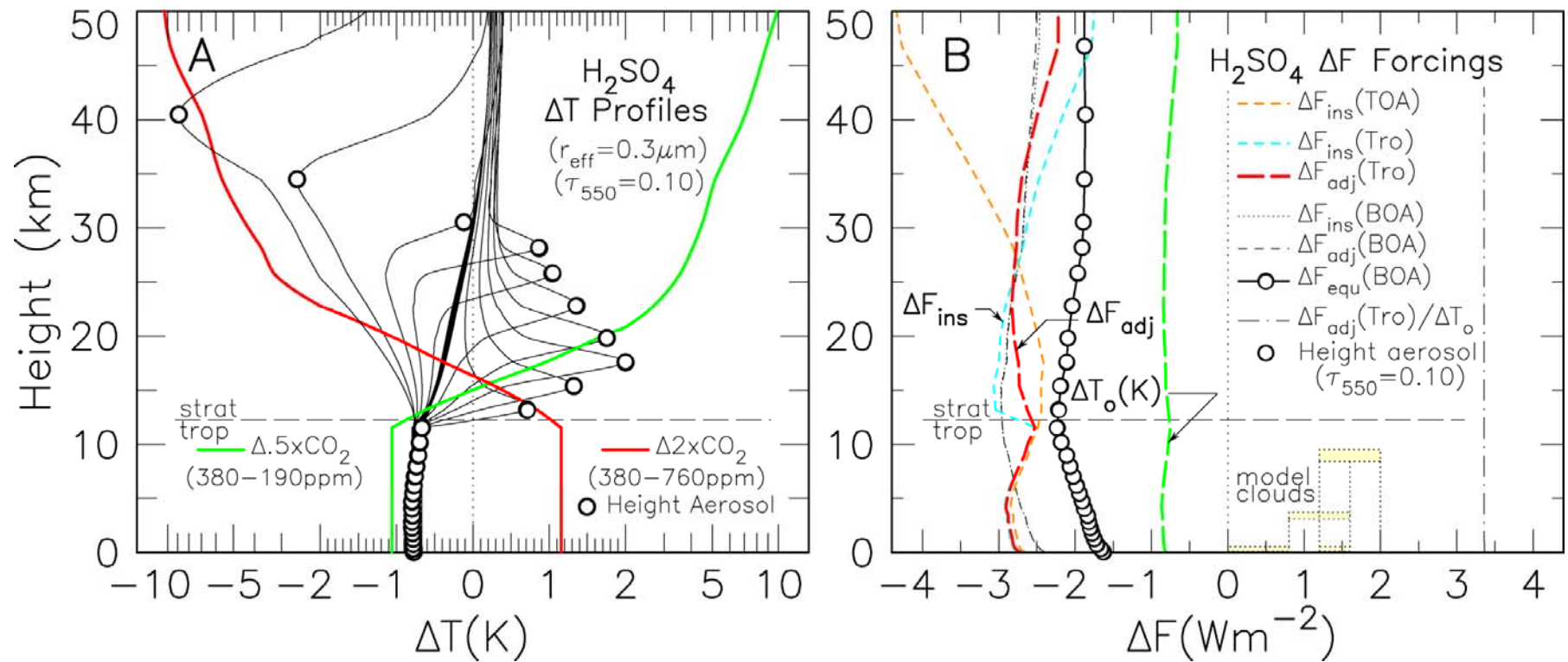
At 40 - 50 km altitude, soot can cool the ground surface . . .

Proposed countermeasures are not a cure . . .

. . . but can serve as temporary “life support” while atmospheric
greenhouse gas concentrations are brought under control . . .

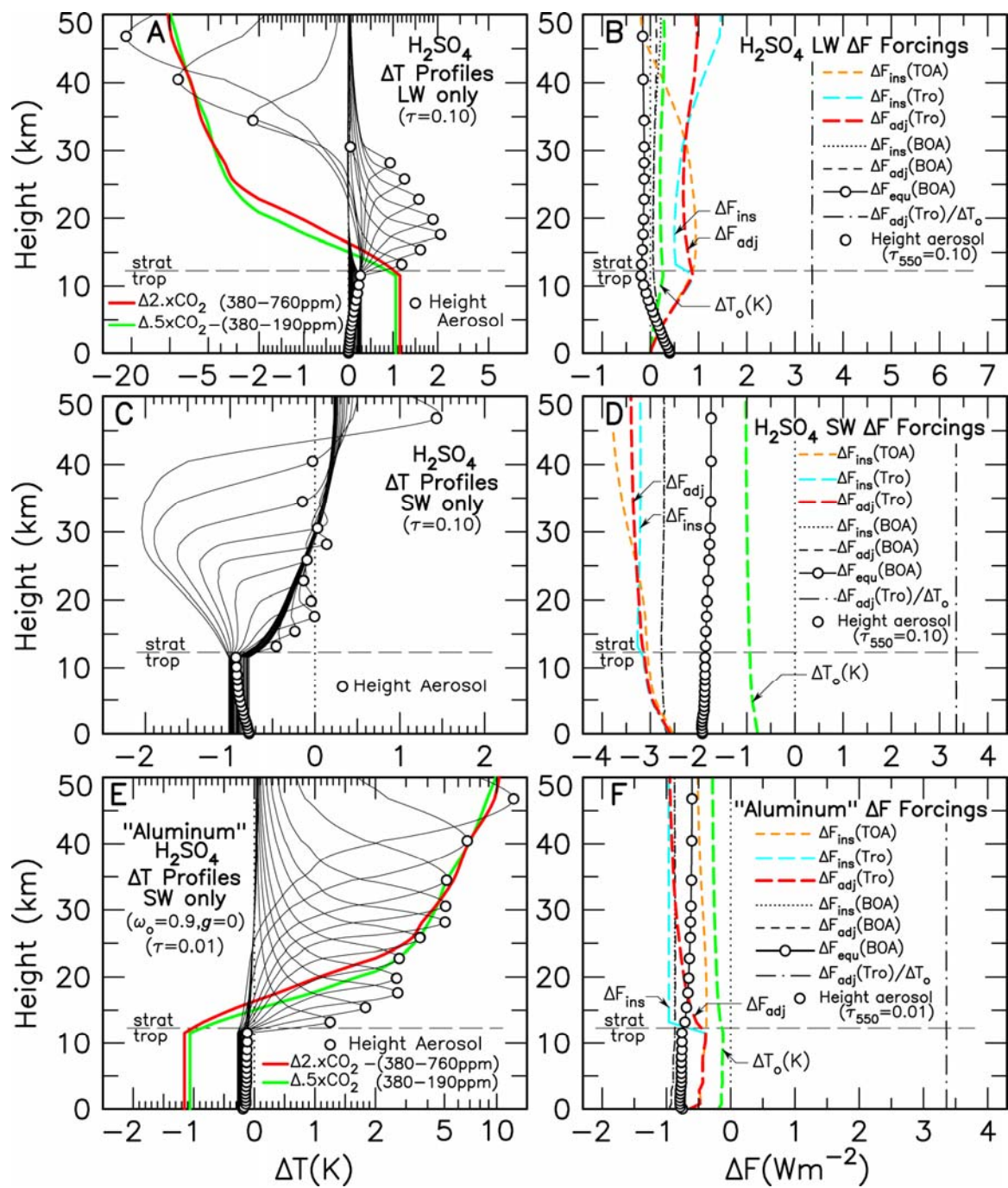


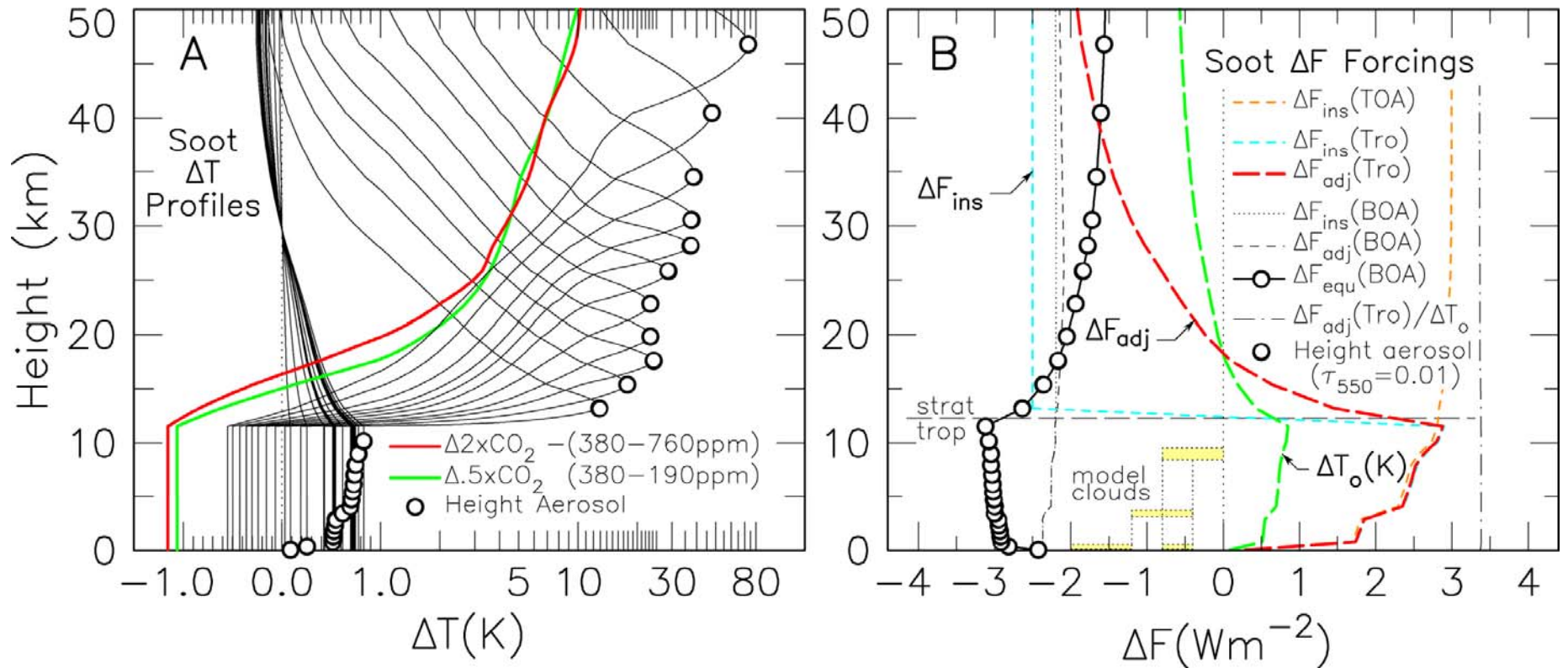
Mie Scattering Constraints



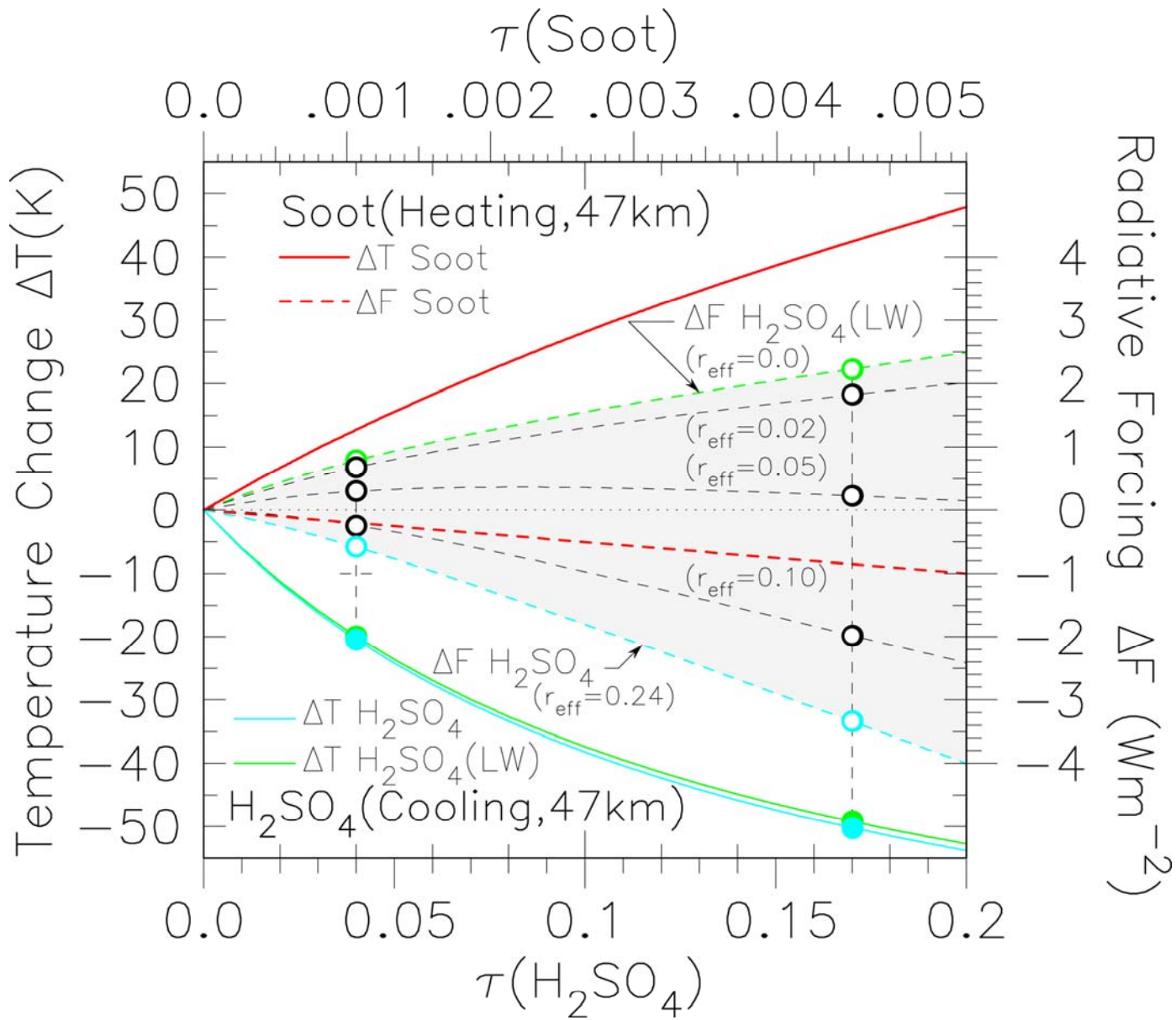
Sulfuric Acid Aerosol

(Heating/Cooling, Radiative Forcing Height Dependence)

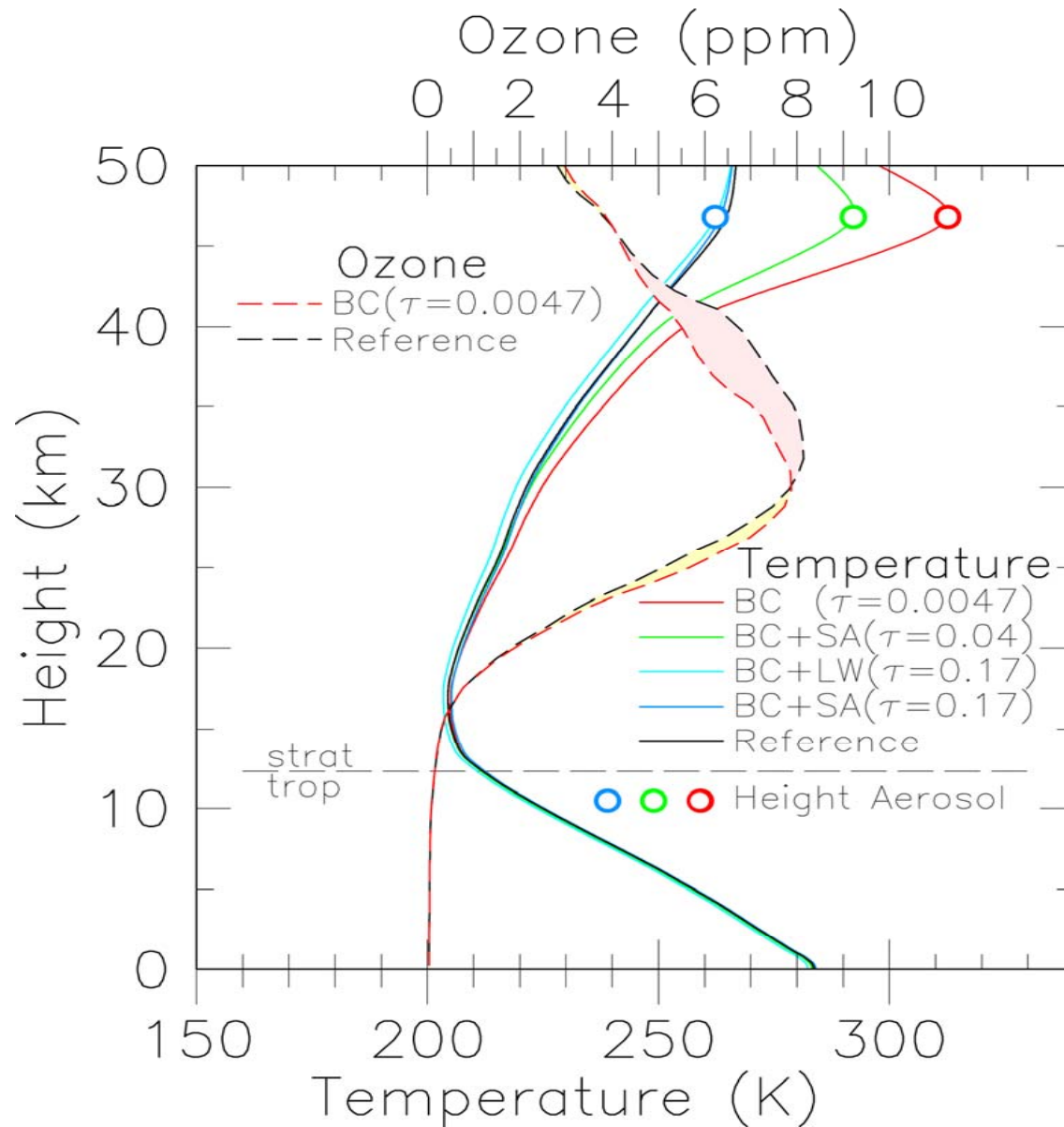




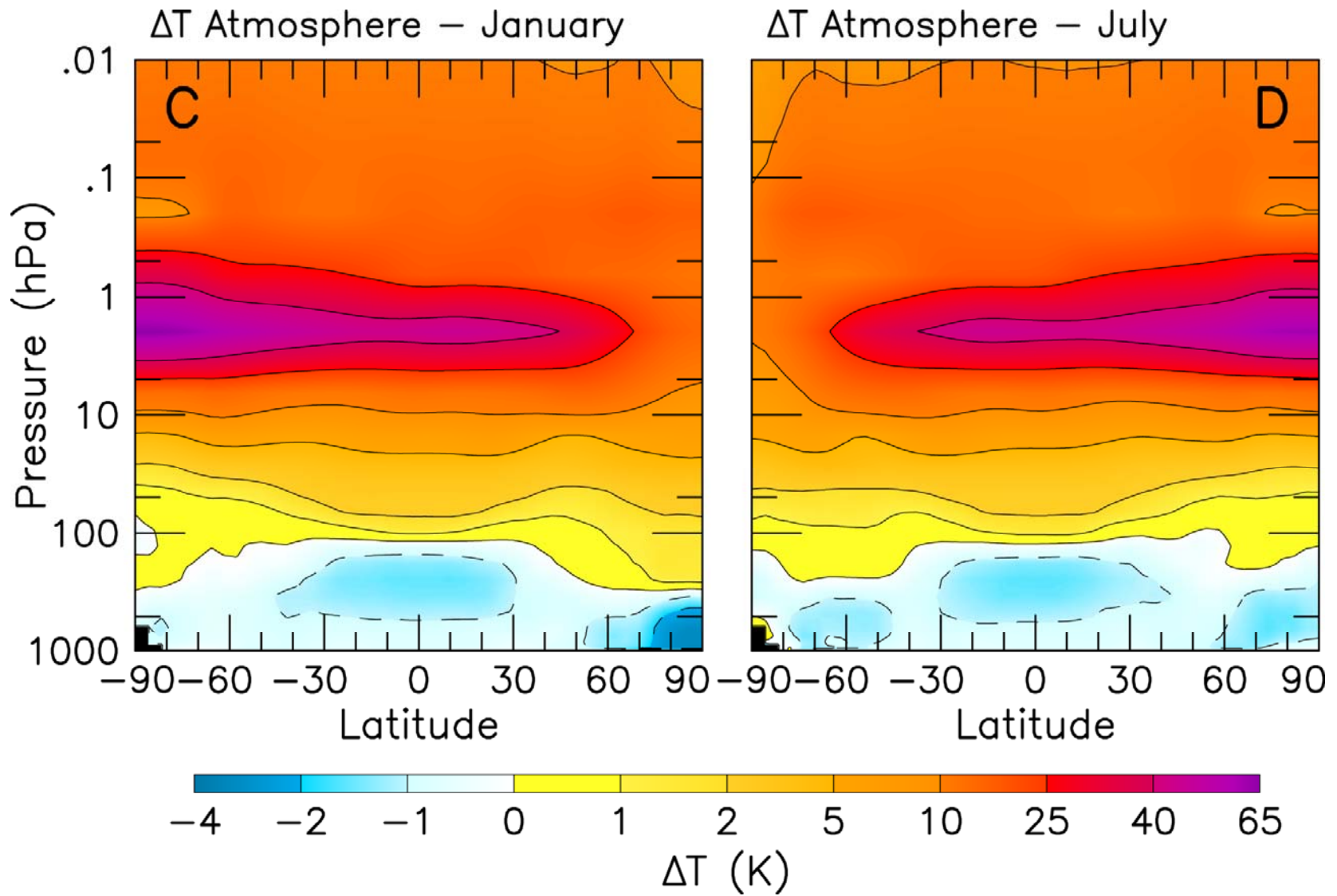
Black Carbon (Soot) Aerosol
(Heating/Cooling, Radiative Forcing)



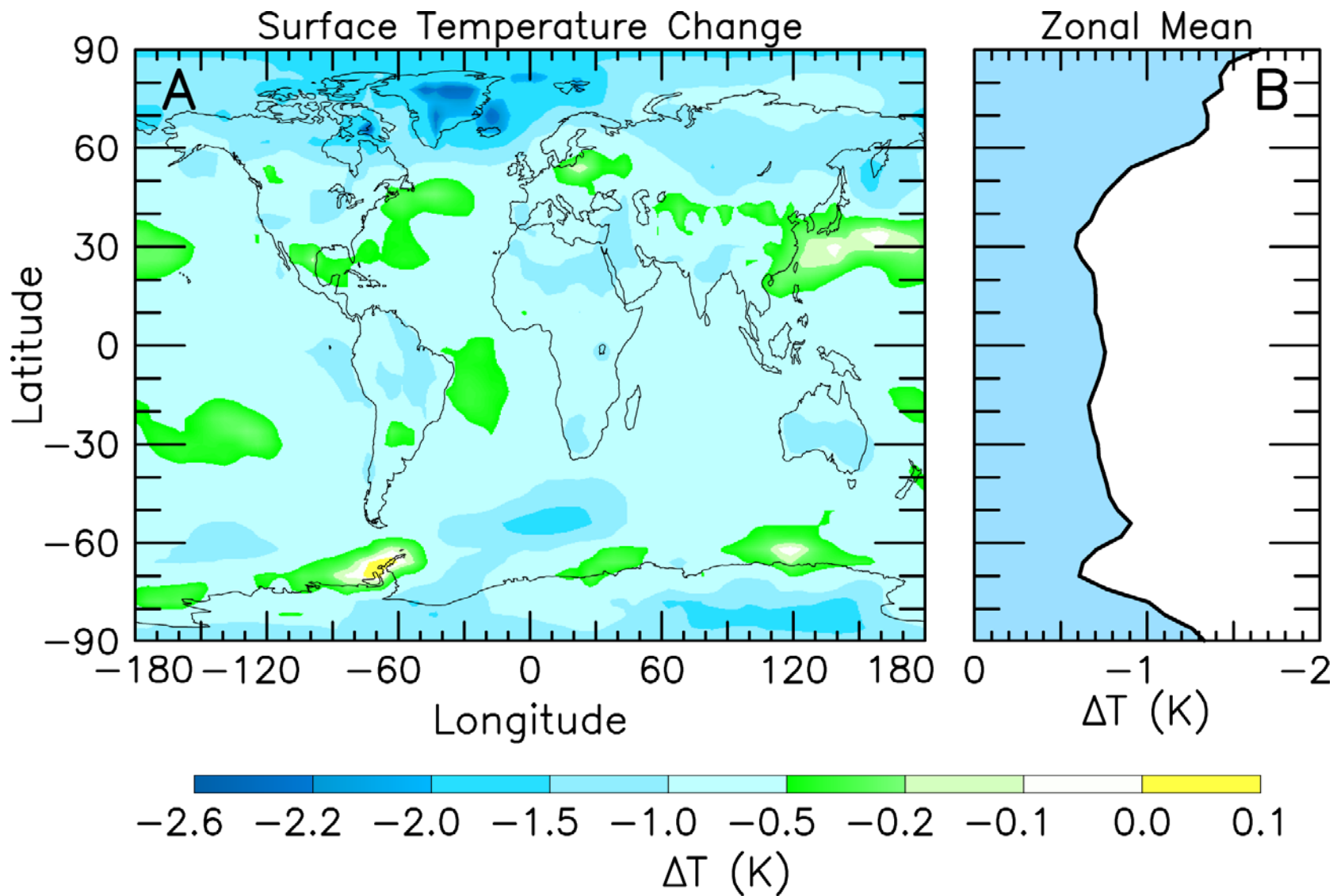
Soot + Sulfuric Acid “Designer” Aerosol”



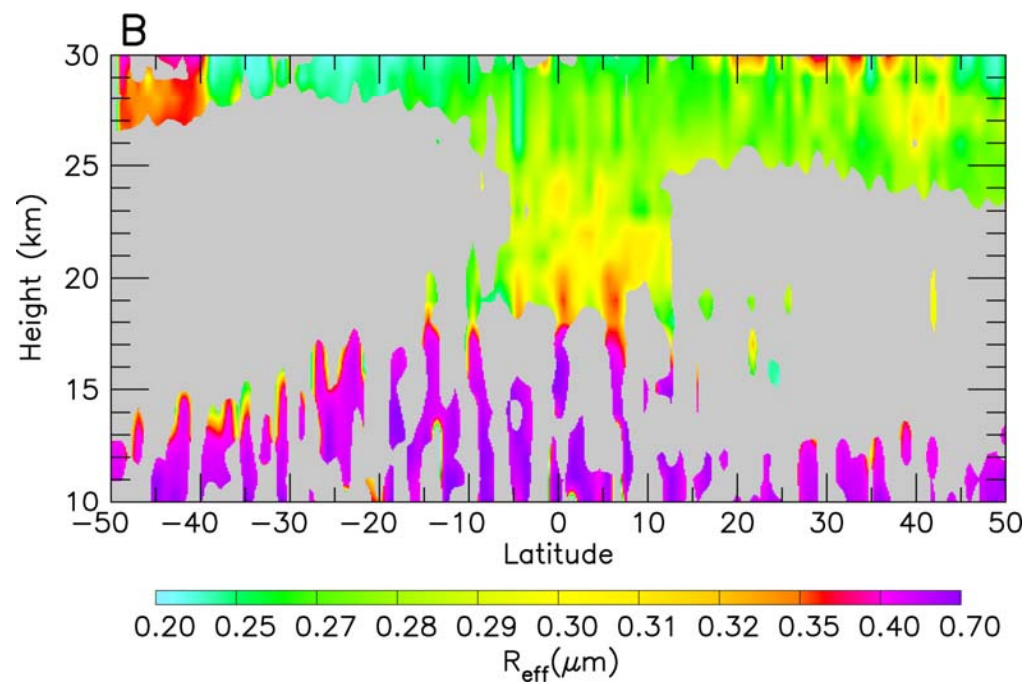
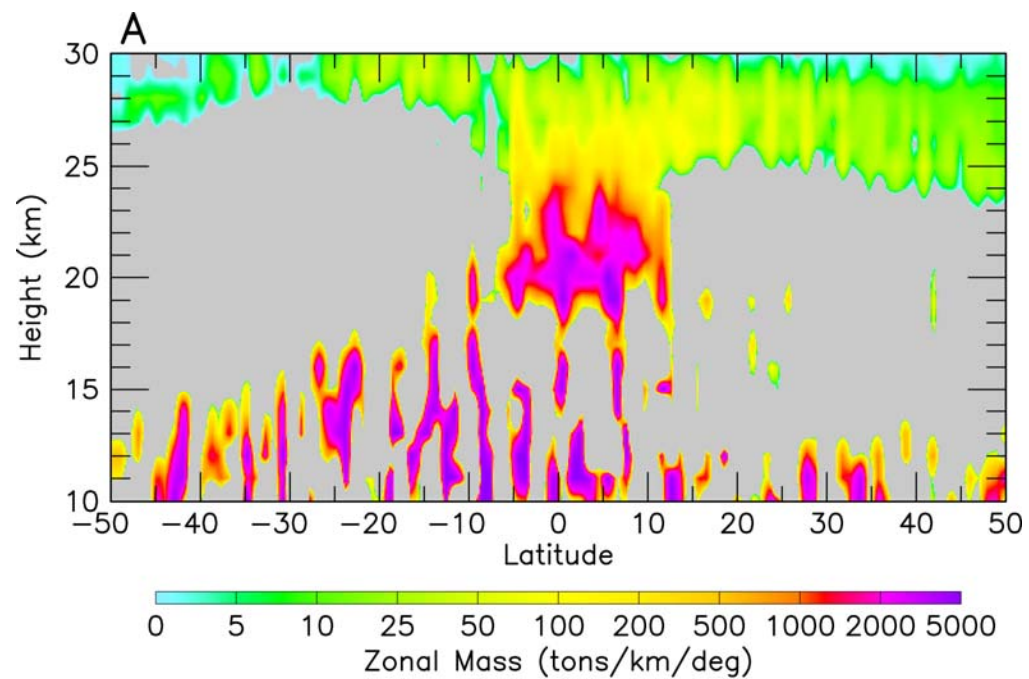
Soot Aerosol - Collateral Effects on Ozone



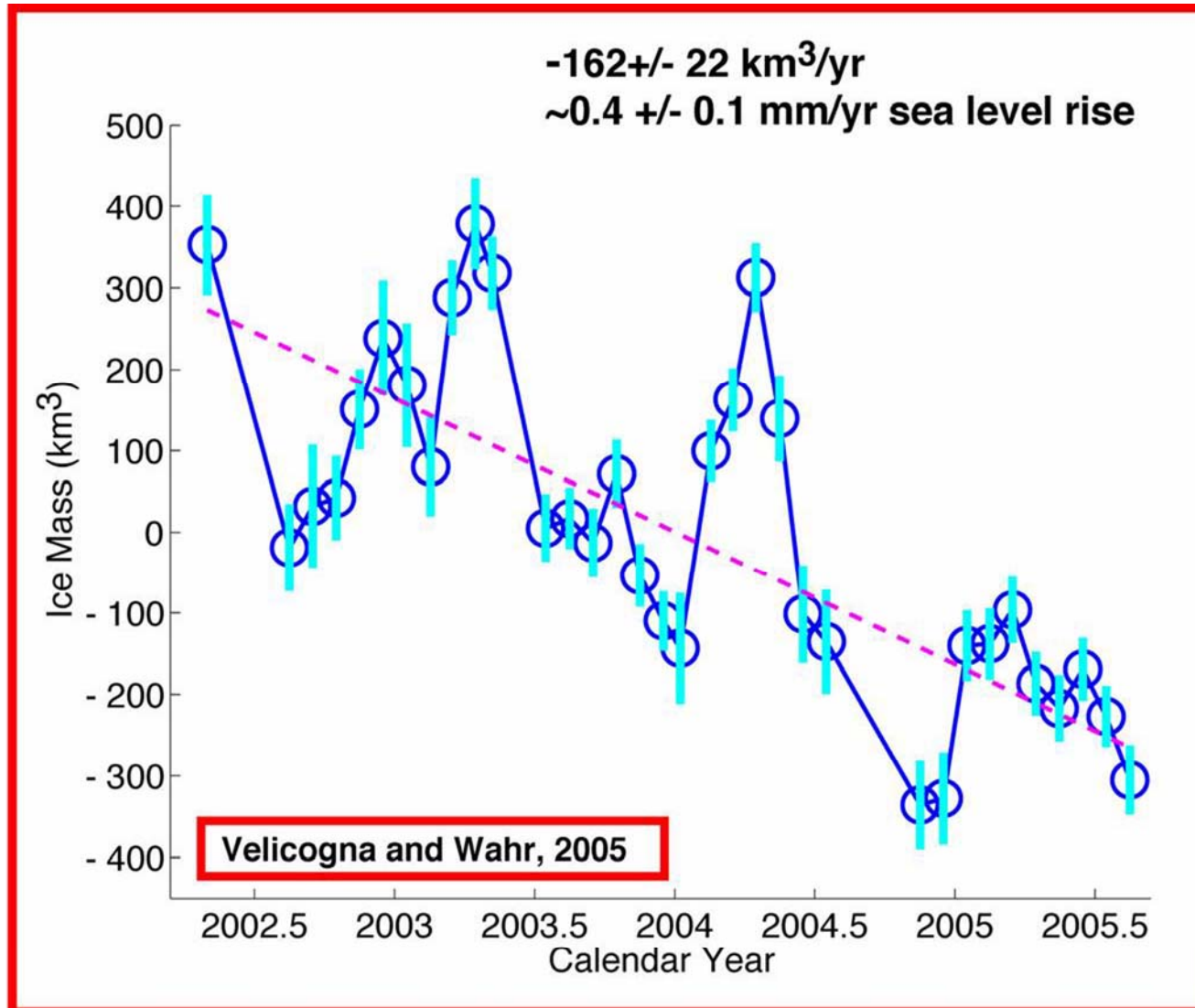
GCM Simulation of Soot Aerosol at 40-50 km Altitude



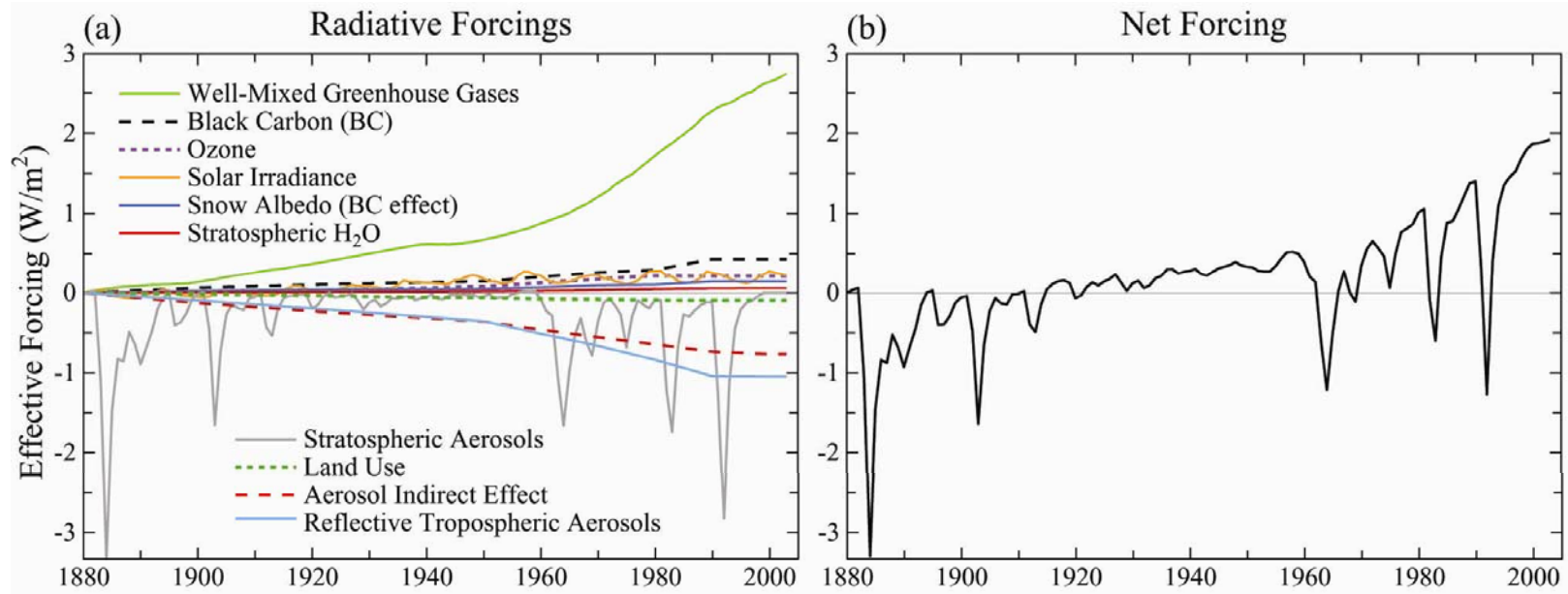
Soot Aerosol ($\tau = 0.005$) Cooling of the Ground Surface



Greenland Mass Loss – From Gravity Satellite

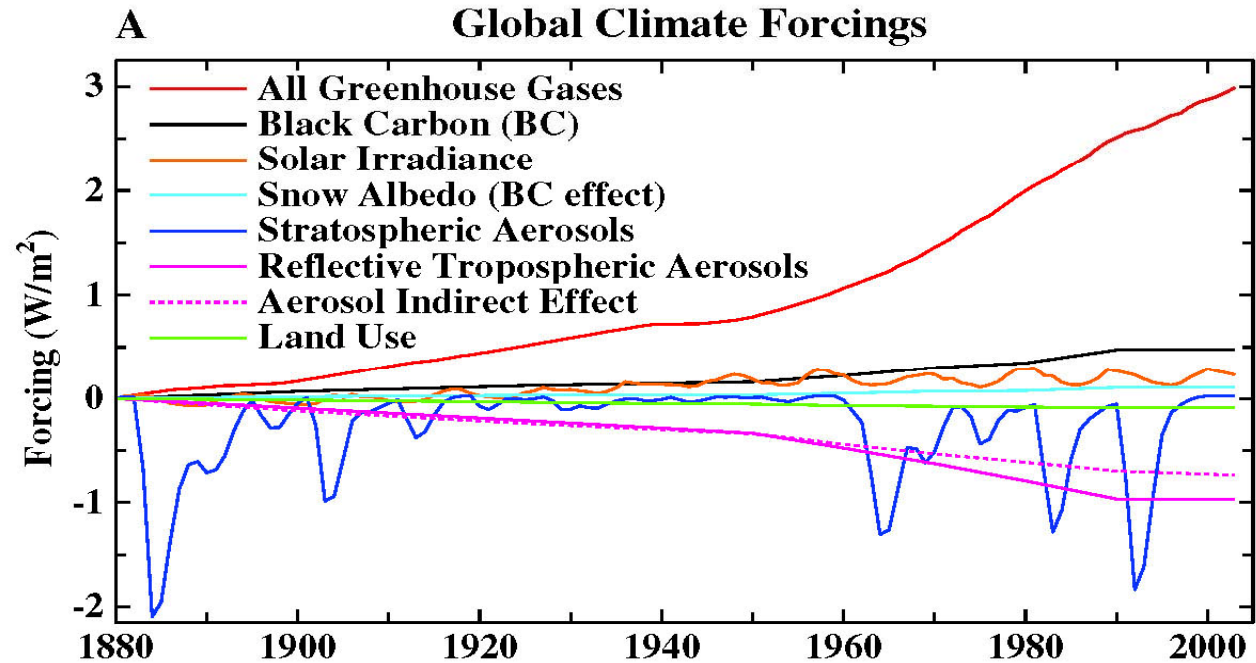


Climate Forcings Since 1880

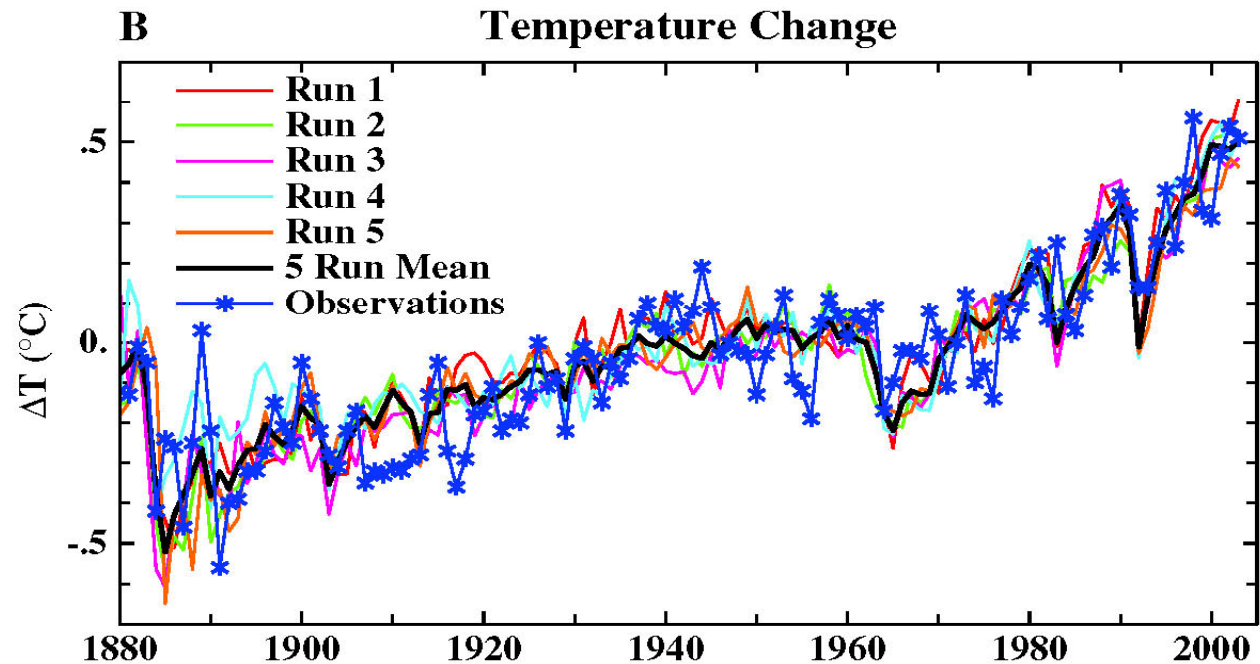


Source: "Dangerous human-made interference with climate: A GISS modelE study", submitted

(A) Forcings used to drive climate simulations.

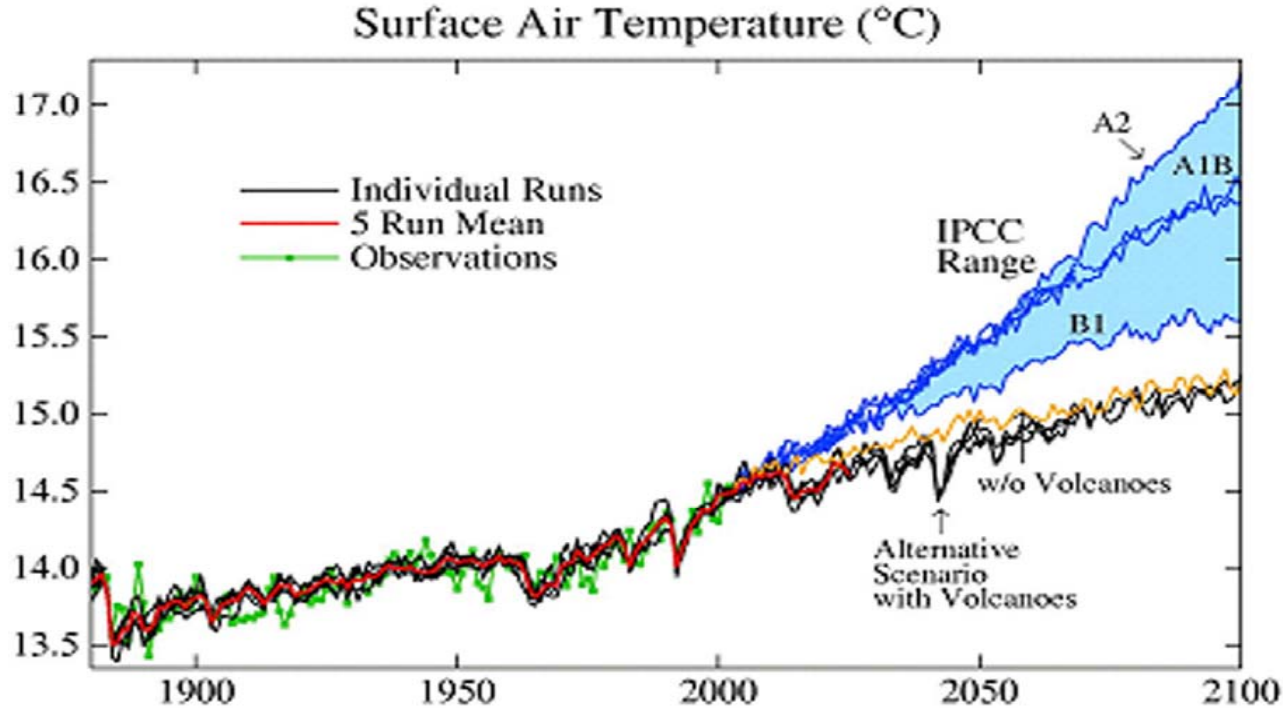


(B) Simulated and observed surface temperature change.



Source: Earth's energy imbalance: Confirmation and implications. *Science* 308, 1431, 2005.

21st Century Global Warming



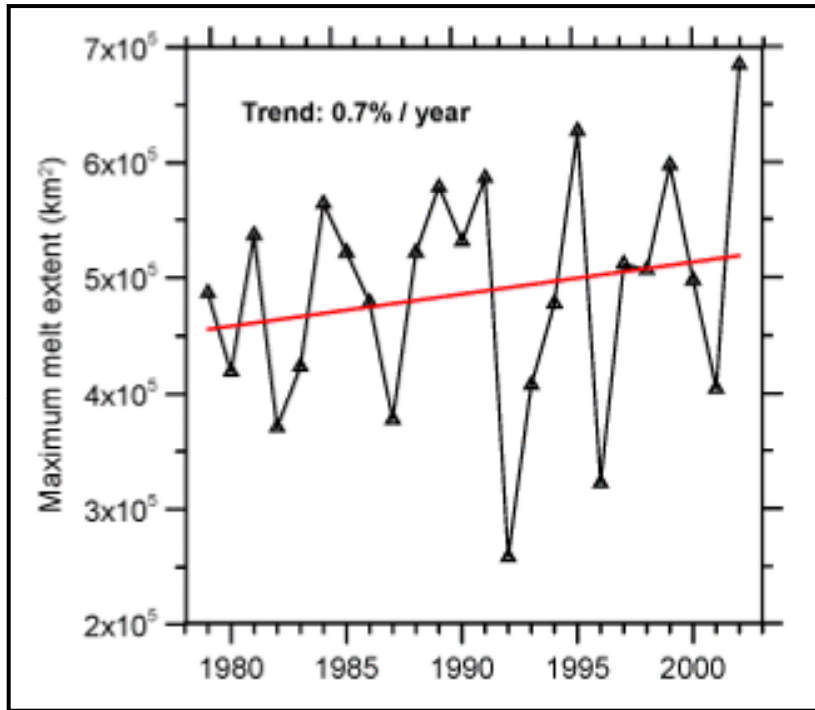
Climate Simulations for IPCC 2007 Report

- ▶ **Climate Model Sensitivity 2.7-2.9°C for 2xCO₂**
(consistent with paleoclimate data & other models)
- ▶ **Simulations Consistent with 1880-2003 Observations**
(key test = ocean heat storage)
- ▶ **Simulated Global Warming < 1°C in Alternative Scenario**

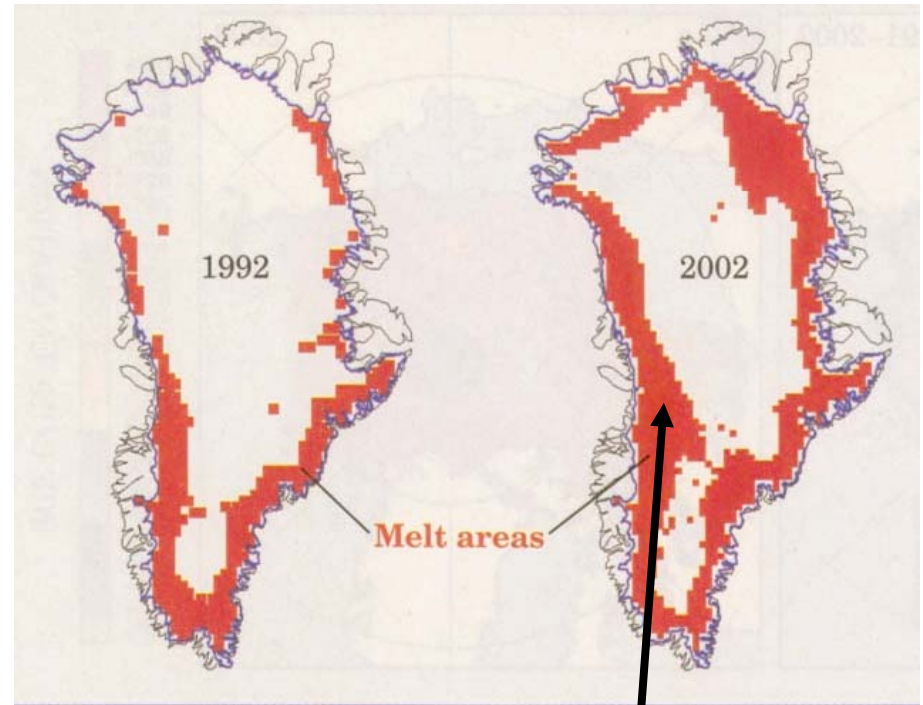
Conclusion: Warming < 1°C if additional forcing ~ 1.5 W/m²

Source: Hansen et al., to be submitted to *J. Geophys. Res.*

Increasing Melt Area on Greenland



- 2002 all-time record melt area
- Melting up to elevation of 2000 m
- 16% increase from 1979 to 2002



70 meters thinning in 5 years

Satellite-era record melt of 2002 was exceeded in 2005.

Source: Waleed Abdalati, Goddard Space Flight Center

Surface Melt on Greenland

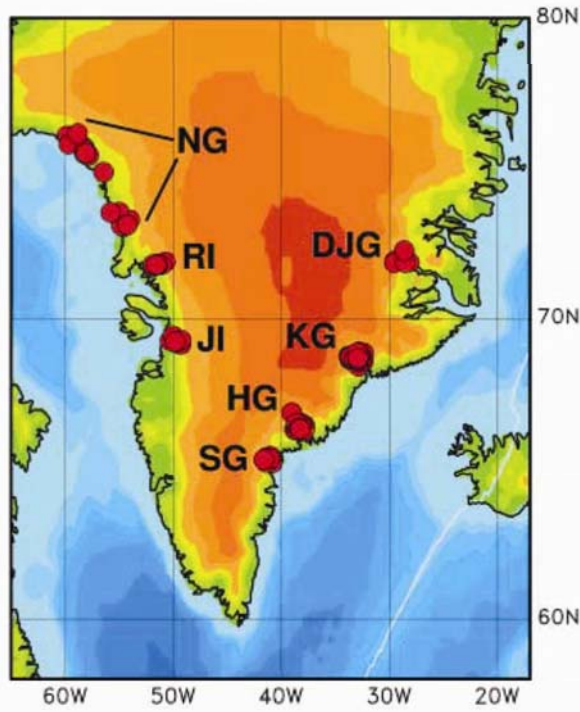
Melt descending into a moulin, a vertical shaft carrying water to ice sheet base.



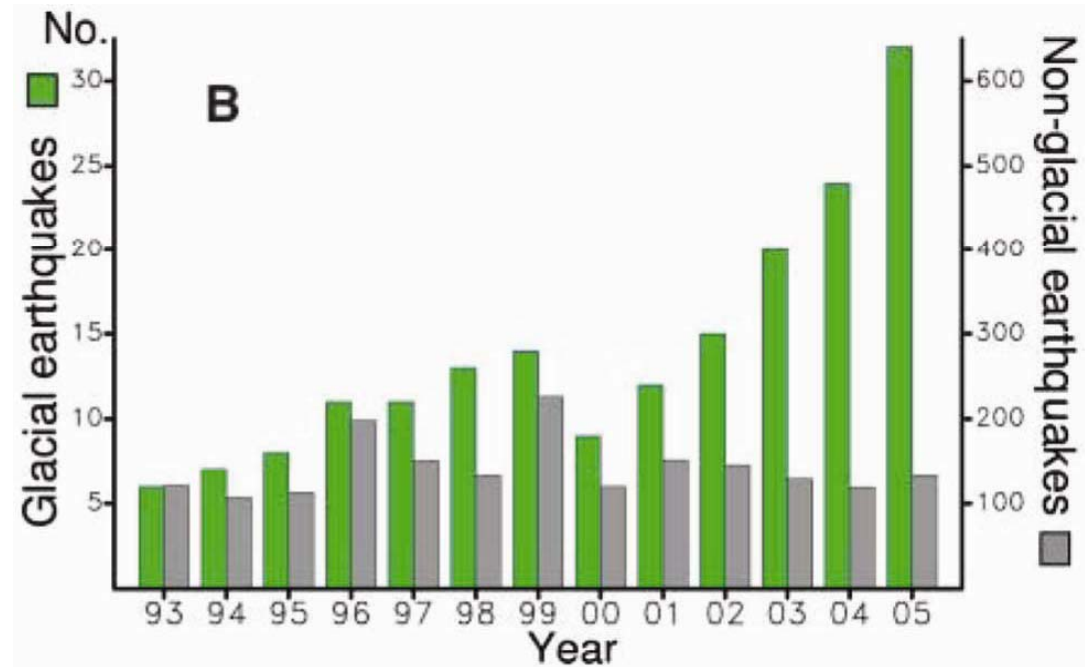
*Source: Roger Braithwaite,
University of Manchester (UK)*

Glacial Earthquakes on Greenland

Earthquake Locations



Annual Number of Quakes*



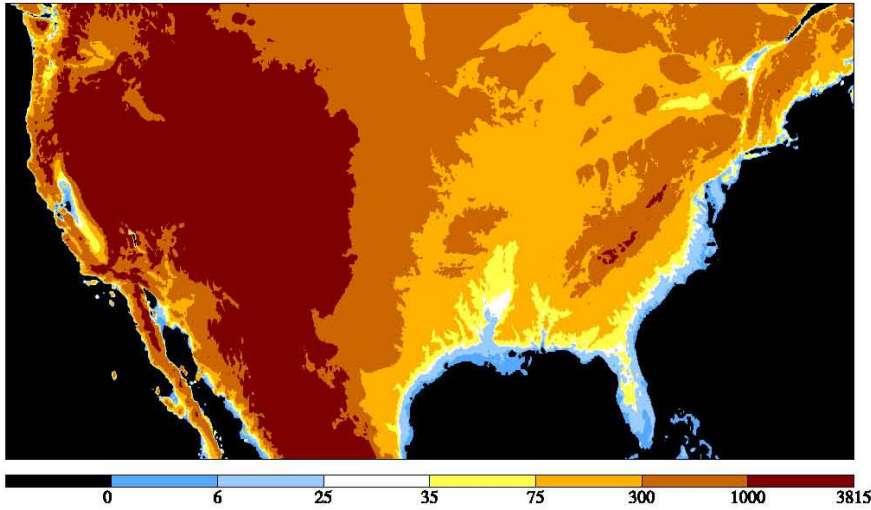
* 2005 bars capture only first 10 months of 2005

Location and frequency of glacial earthquakes on Greenland. Seismic magnitudes are in range 4.6 to 5.1.

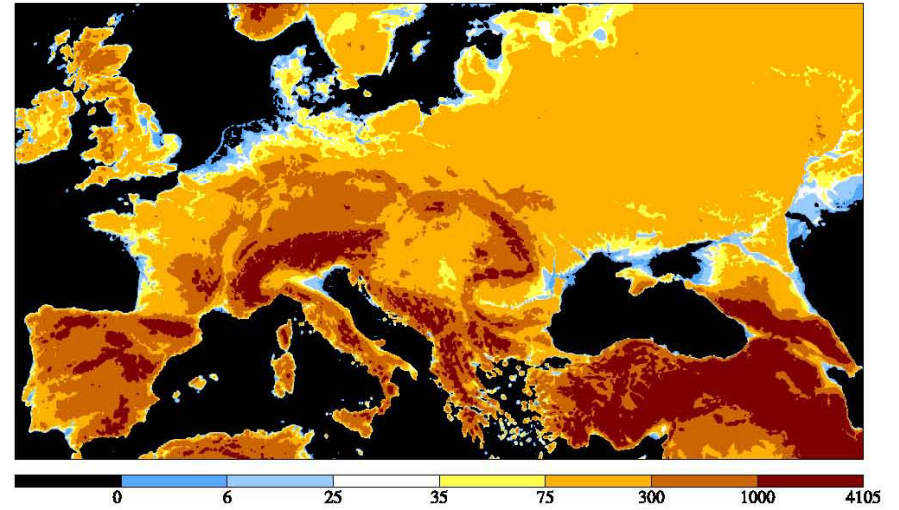
Source: Ekstrom, Nettles and Tsai, *Science*, 311, 1756, 2006.

Areas Under Water: Four Regions

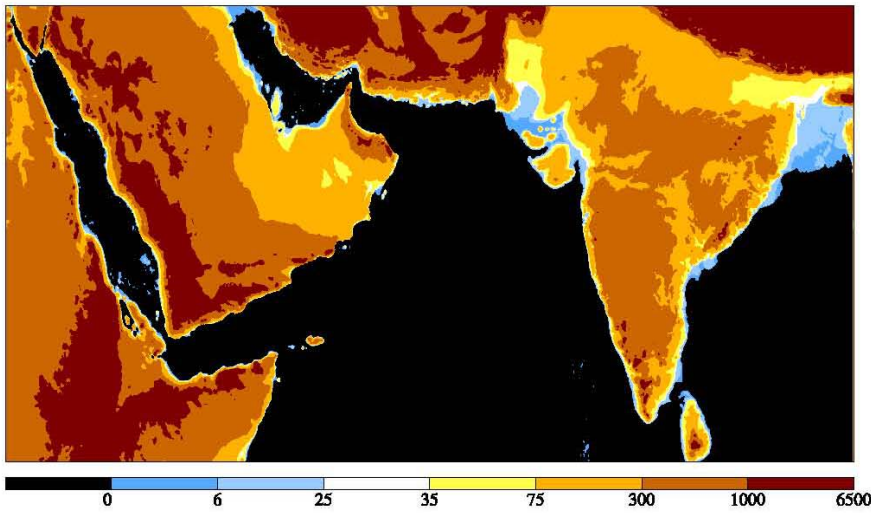
U.S. Area Under Water



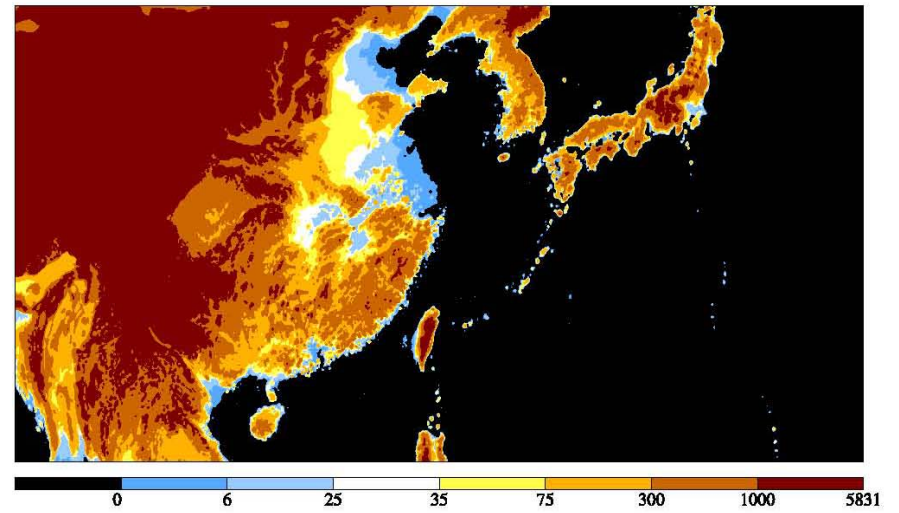
Europe Area Under Water



Central Asia: Area under Water



Far East: Area under Water



Levitation of mesospheric and stratospheric aerosols by gravitophoresis

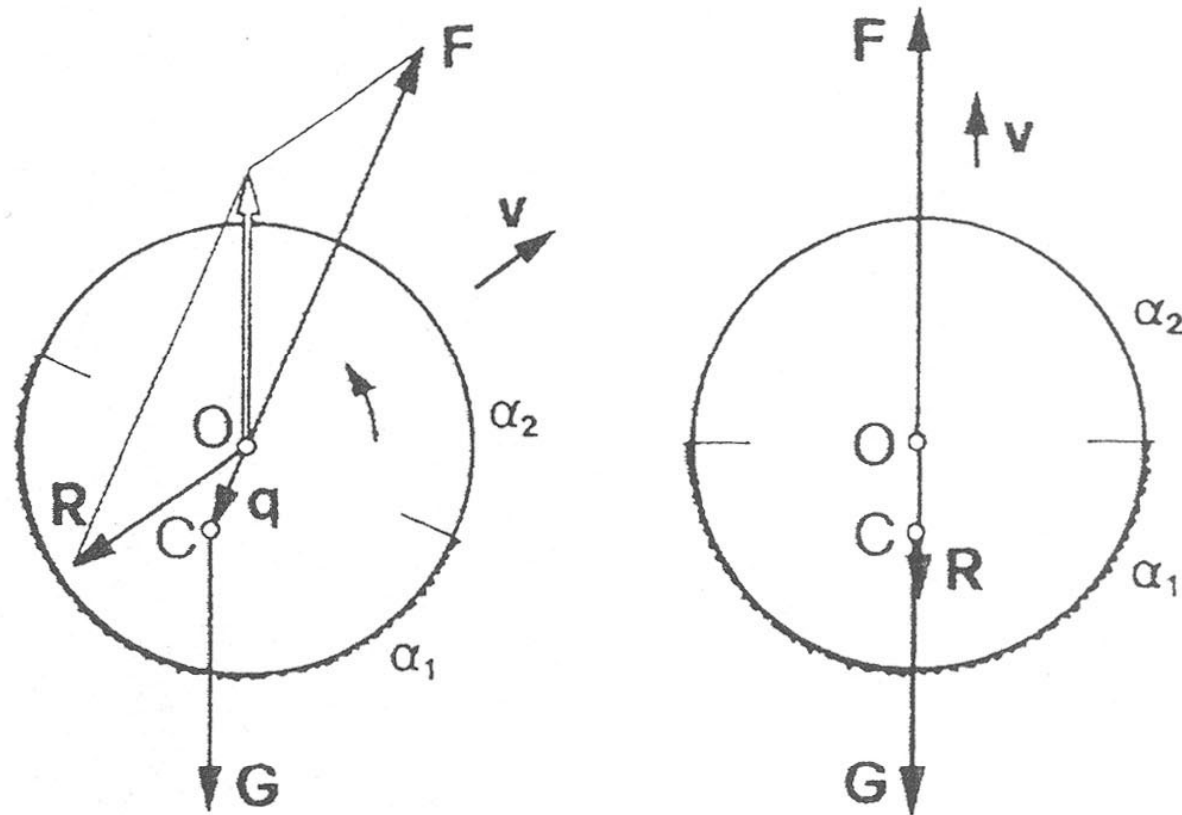
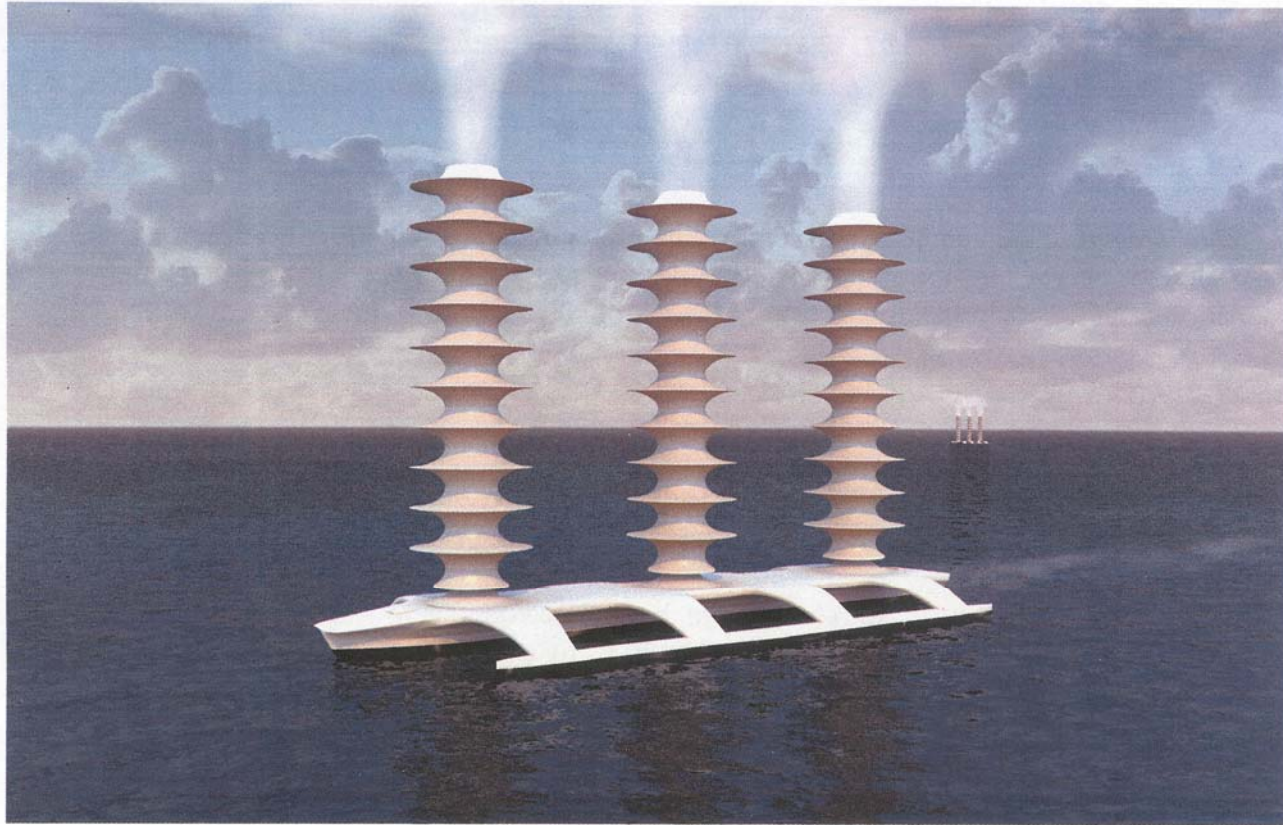
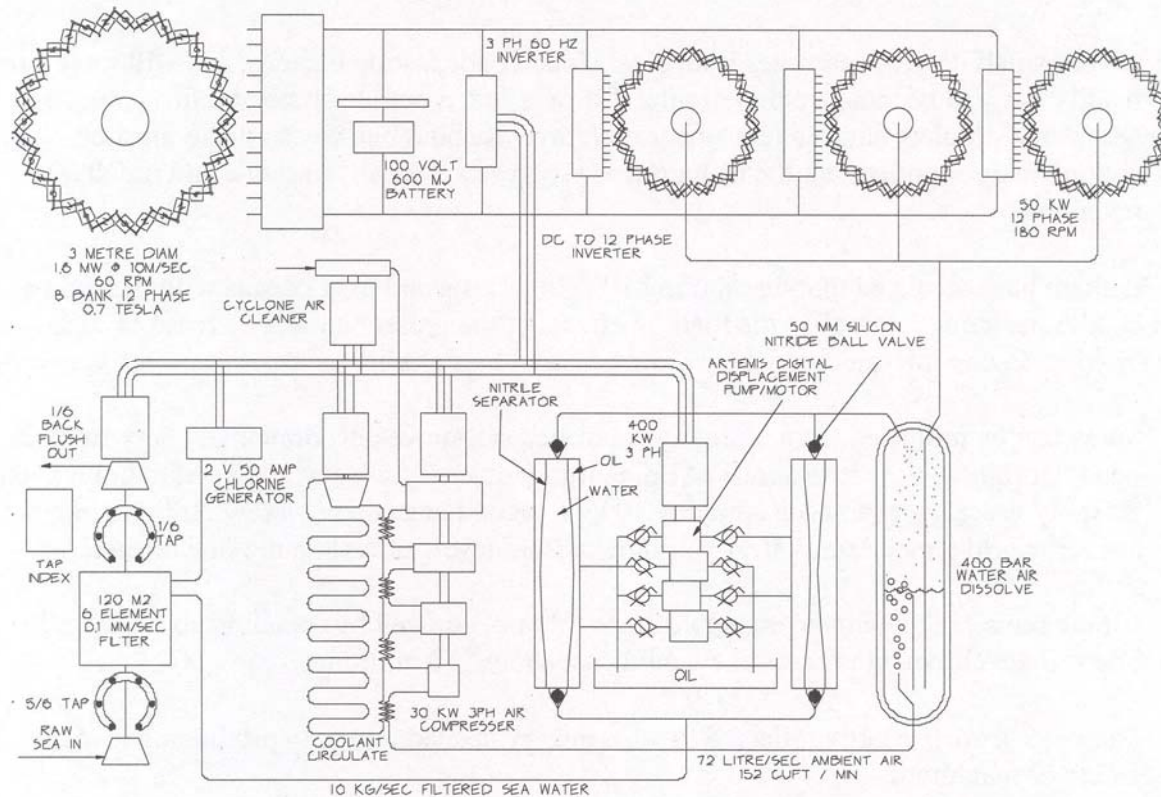


Fig. 1. Forces acting on the model particle with gravito-photophoresis: F , photophoretic $\Delta\alpha$ -force, G , weight force, R , resistance (drag) force. On the left: nonequilibrium state; the forces add up to a restoring couple, represented by the vectors G and $F + R = -G$. On the right: stable equilibrium.





An artist's impression of the spray vessel. Flettner rotors with Thom fences spin about a vertical axis and act as very high performance sails. They drive the vessel against the drag of underwater turbines which generate the energy for spraying.



The block diagram of the spray system. Filtered sea water is compressed to 400 bar in a rubber sleeve by external oil. Seven volumes of compressed air are added. The mix is discharged through face-to-face jets giving a very high Weber collision number and then directed upwards.

Jakobshavn Ice Stream in Greenland

Discharge from major Greenland ice streams is accelerating markedly.



*Source: Prof. Konrad Steffen,
Univ. of Colorado*