A climate model study of indirect radiative forcing by anthropogenic sulfate aerosols

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Nature Vol 370 08/11/1994

Reviewed by James Everett and Nicole Mabante

Affects of Sulfate Aerosols

- Anthropogenic sulfate aerosols affect the Earth's radiation budget in 2 ways:

  - <u>Direct effect</u>
    - scatter solar radiation back to space
    - radiative forcing of –0.3 to -0.9 Wm^{-2}
    - significant in comparison to longwave forcing +2 to +2.5 Wm^{-2}

  - <u>Indirect effect</u>
    - alters distribution and concentration of CCN
      - Changes cloud lifetime and extent
    - effects solar radiative characteristics of clouds
    - quantification depends on poorly understood aerosol interactions (CCN and cloud properties)

Jones' Indirect Radiative Forcing Estimate

- General Circulation Model (GCM)
- Langner & Rodhe Model

Cloud Content Instrumentation

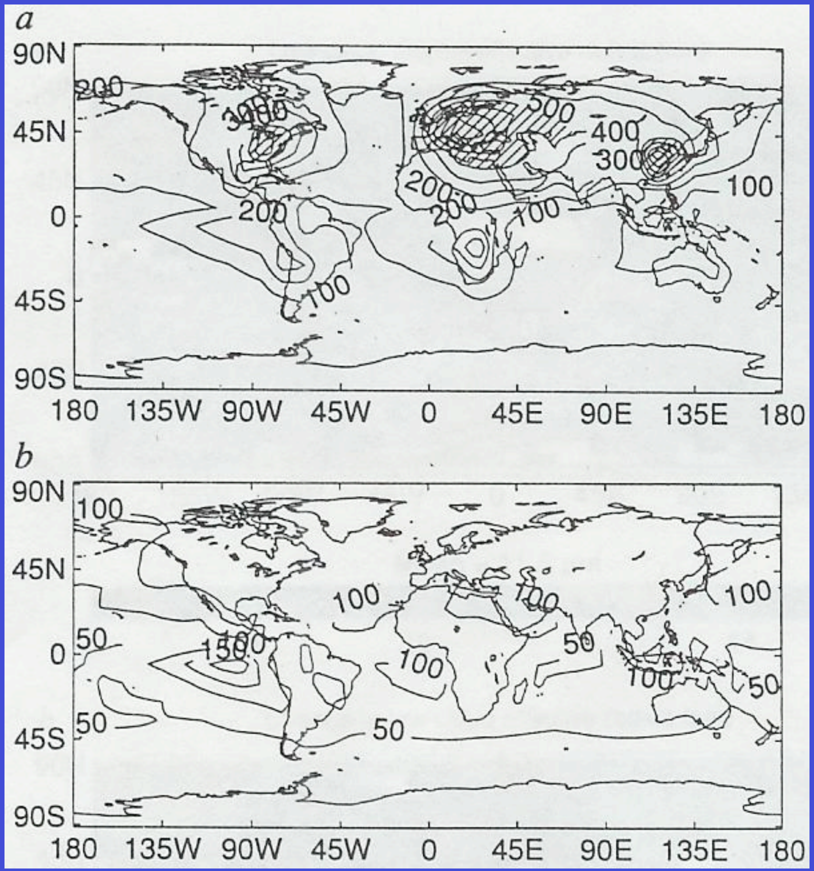
- General circulation model
  - computer model that solves equations within atmospheric gridboxes, noting transfer of mass, energy, momentum, etc. for each (1)
  - prognostic cloud scheme to predict cloud liquid/ice-water content
  - Parametization of radius cloud water droplets, linking to cloud type, aerosol concentration and cloud liquid-water content
  - Radiation scheme calculates radiative properties of clouds
  - Clouds warmer than 0°C were entirely water
  - Clouds colder than –15°C assumed to be entirely ice

(1) http://www.giss.nasa.gov/research/modeling/gcms.html

Sulfate Mass Instrumentation

- Two-dimensional distributions of sulfate mass obtained from Langner and Rodhe slow oxidation model
- Difference between total sulfur and sulfur of natural sources was anthropogenic emissions
- Assumed aerosol sulphur was ammonium sulphate
- Log-normal size distrib assumed, using 0.05 um particle radius and stand dev of 2 to calc distrib aerosol particle numb conc
- Vertical distrib of aerosol approximated by assuming that _ of column-integrated mass located in lowest 1.5 km of atm; this yields annual avg total sulphate aerosol number conc ranging from <100 cm^{-3} over remote oceans to >800 cm over central Europe; only nat sources, max conc over E.Pacific

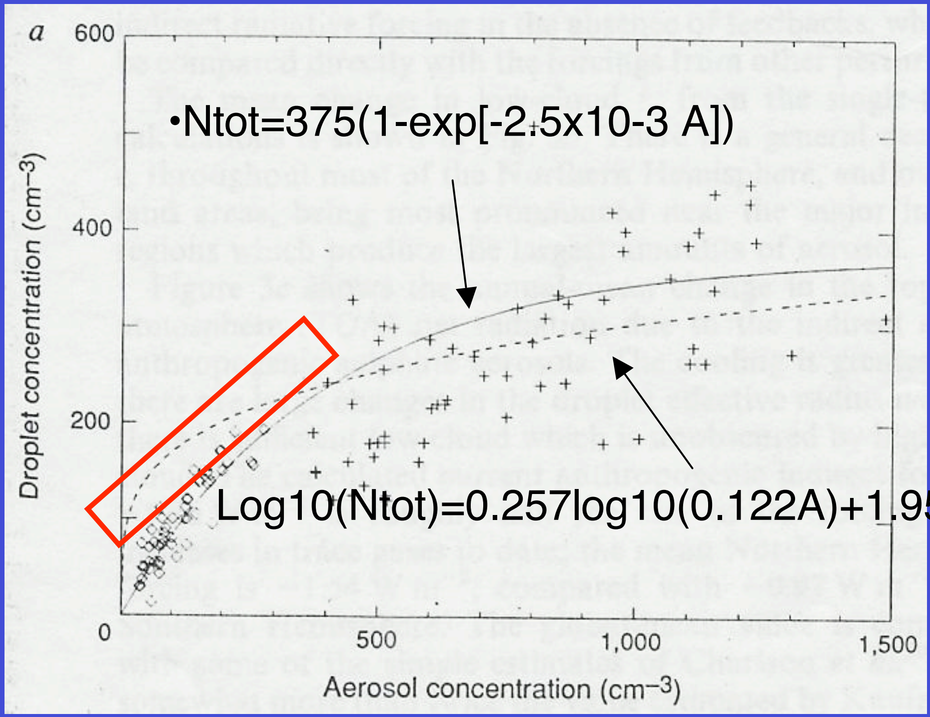
Total Sulfate Aerosol Concentration Inferred from Langner and Rodhe Data



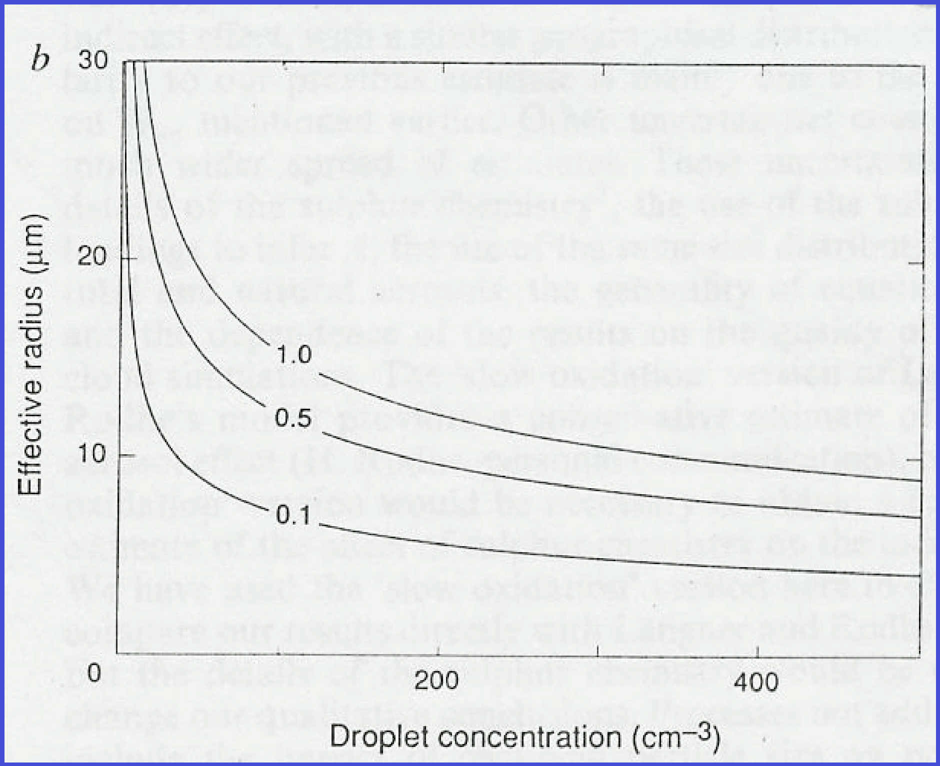
- Fig. A
  - Total sulfate aerosol concentration (anthropogenic and natural)
- Fig. B
  - Total natural
- A - B = anthropogenic

Aerosol Concentration Functions

- N_{tot}=375(1-exp[-2.5x10^{-3} A])
  - A is aerosol concentration
  - N_{tot} is the number of cloud droplets formed on the aerosols acting as CCN
  - Continuous function of the aerosol concentration
- $Log_{10}(N_{tot})$=0.257log10(0.122A)+1.95
  - Relation between cloud water sulfate and N_{tot} deduced from N.Am. Data
  - Assume same aerosol comp. And size distrib., and cloudwater and particulate sulfate conc are equal
  - Low values of A (N_{tot}>A) – unrealistic as #CCN cannot exceed total #aerosol



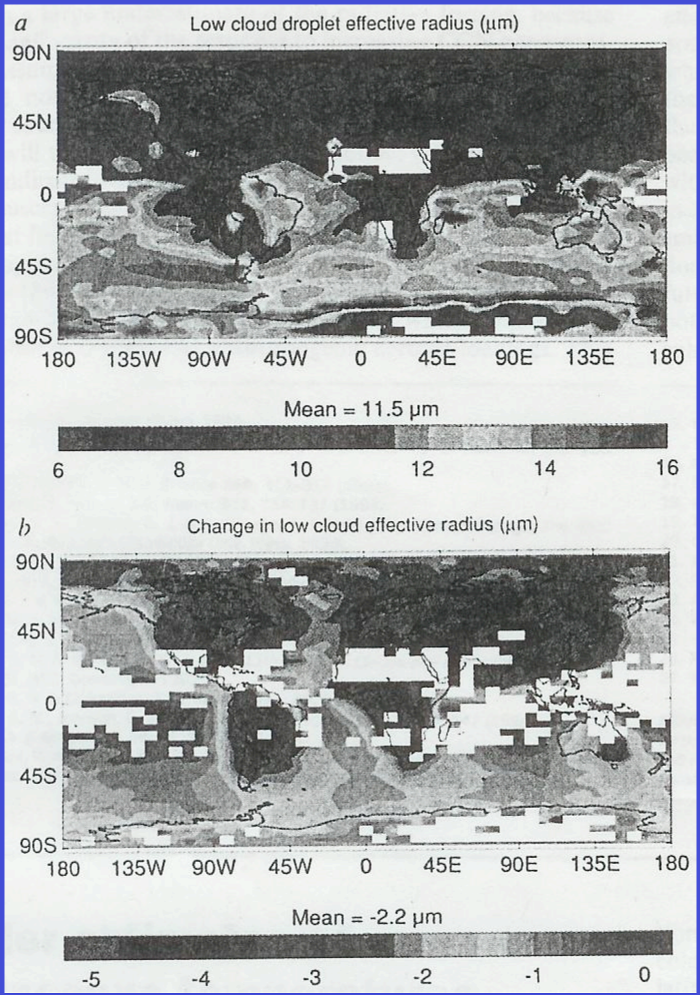
Cloud Droplet Effective Radius



- $r_e=(3L/4\pi\rho\kappa N_{tot})^{1/3}$
  - r_e is cloud droplet effective radius for stratiform and shallow (<500m) convective clouds
  - L is cloud liquid-water content
  - ρ is the density of water
  - κ is a constant that depends on maritime (0.80) or continental (0.67) clouds
- Assumed clouds over land are continental and those elsewhere are maritime
- Fig 2b: Continental clouds r_e=9.5um and maritime clouds r_e=13.5um
- Low-level layer clouds (below 750 mb) assume [dropet] constant w/height and L inc monotonically from zero at cloud base to max at cloud top
- Droplet radius inc with height according to equation

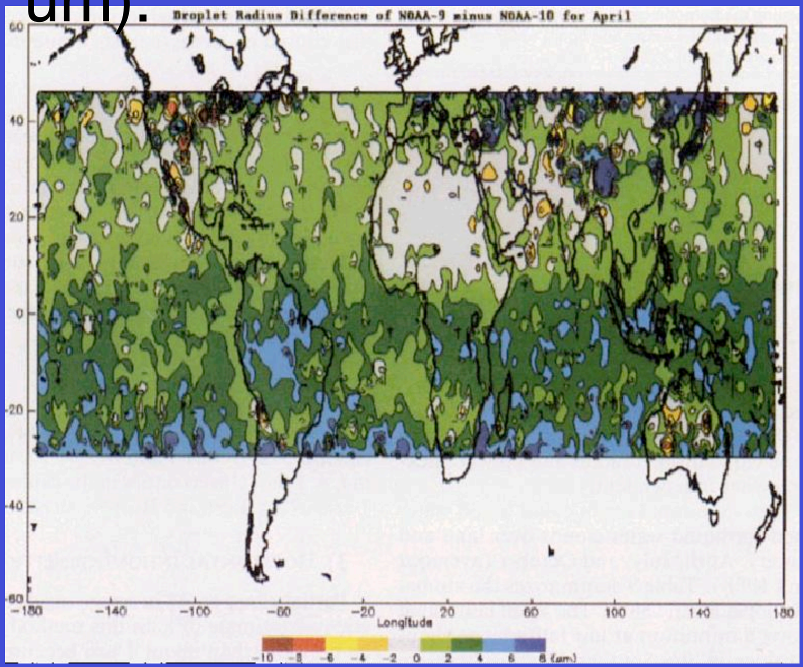
GCM Simulation

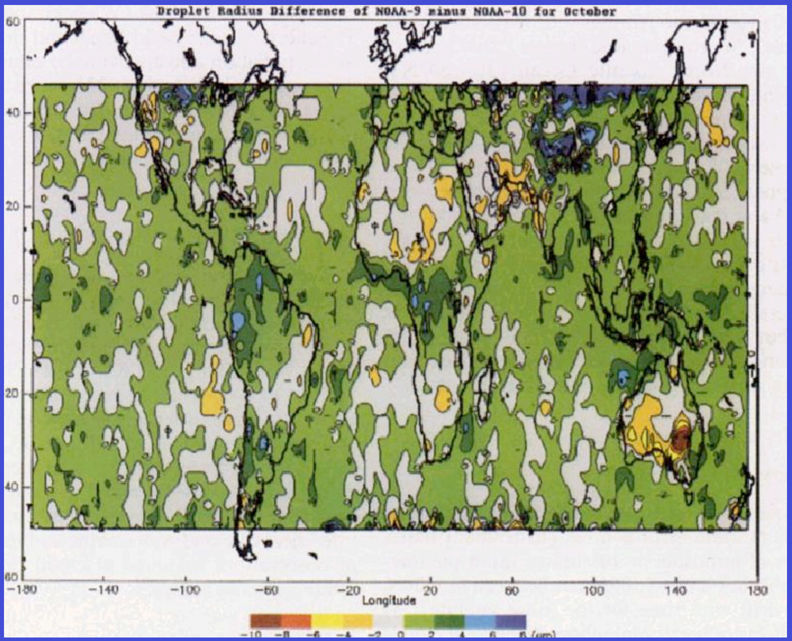
- Fig A
  - Simulated annual-mean re distribution for low-level water clouds
  - Mean values 1.3um larger over oceans than land & 2.4um larger in S.Hemisphere than N.Hemisphere
- Fig B
  - Decrease in re N.Hemisphere and land areas, most pronounced major industrial regions which produce largest amounts of aerosol



Jones:Han Comparison

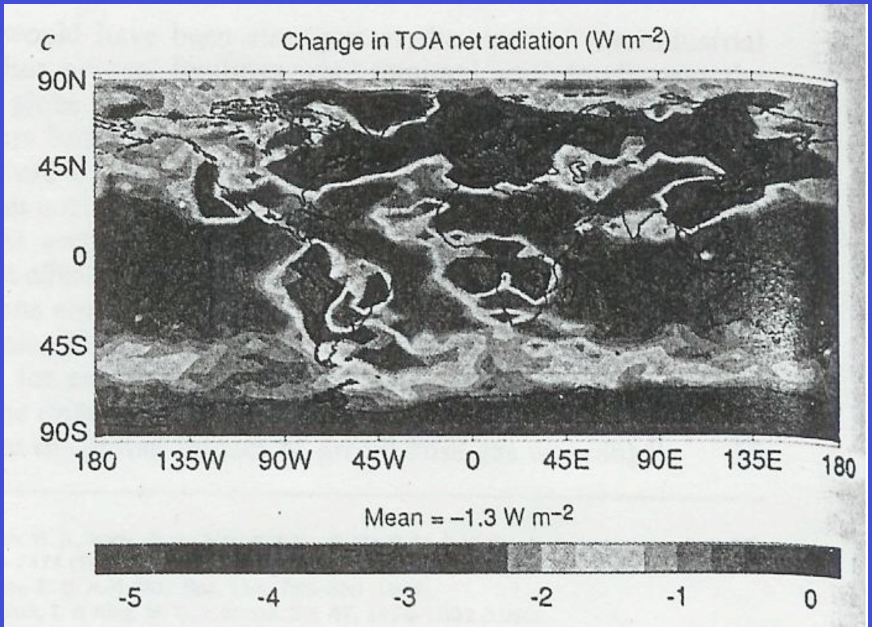
Jones claims differences are same as satellite retrievals of Han et al., although they found bigger ocean/land contrast (3.3 um) and smaller hemispheric contrast (0.7 um).





Cooling Effects

- Cooling is greatest where there are large changes in droplet effective radius and sufficient low cloud unobscured by higher-level cloud.



Summary

- Calculated current anthropogenic indirect forcing is -1.26 Wm^{-2}
- Mean N.Hemisphere forcing is -1.54 Wm^{-2} and S.Hemisphere forcing is -0.97 Wm^{-2}
- Global-mean comparable with Charlson et al.
- More than twice that estimated by Kaufman and Chou which used a two-dimensional model
- Combination of direct and indirect effects, suggest that aerosol have overall cooling effect.

Things to consider…

- Sulfur chemistry details
- Same-size distribution for both total and natural aerosols
- Equation generalities (1-3)
- Slow oxidation verses fast oxidation versions
  - Jones used slow for comparison to Langner
- Future work
  - Changing particle on precipitation development and cloud evolution