Oceanic phytoplankton, atmospheric sulfur, cloud albedo and climate

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Presented By

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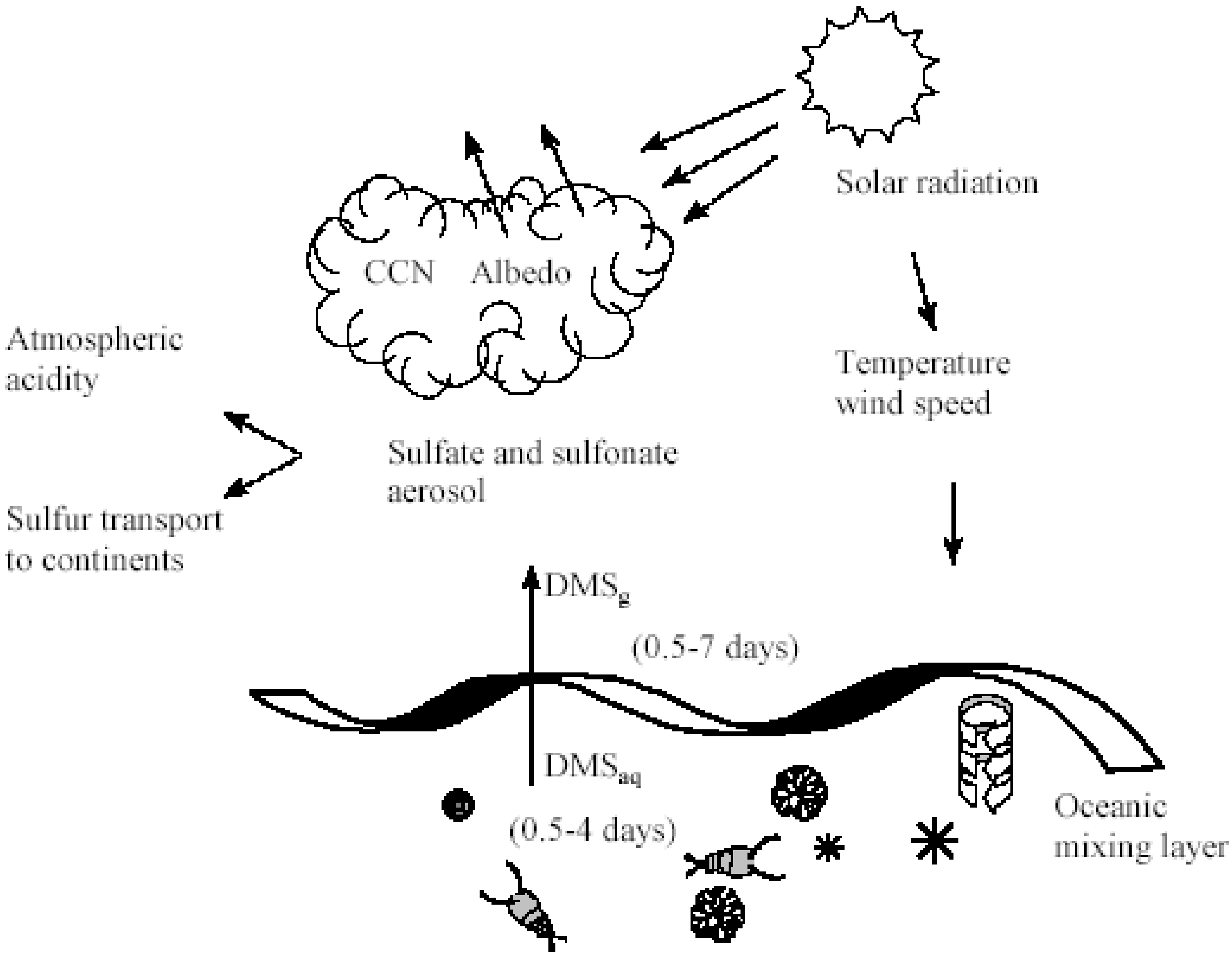
Major significance

- Proposal that biota could regulate climate
  - Hypothesized possible mechanisms
  - More data was needed to support theory
- Stimulated a great deal of scientific interest
- Cited 1203 times!
- Many assumptions made

What we knew before

- Radiation—Twomey 1977, indirect effect
- Gaia hypothesis – Lovelock 1974
- Aerosols (SO_4^{2-}) as CCN
- Global sulfur budget – Andreae 1985


Solar radiation
CCN
Albedo
Atmospheric acidity
Temperature wind speed
Sulfate and sulfonate aerosol
Sulfur transport to continents
DMS_g
(0.5-7 days)
DMS_{aq}
(0.5-4 days)
Oceanic mixing layer

Global Sulfur budget

TABLE 6. Sulfur emissions from natural and anthropogenic sources expressed in 10^9 mol/a

Region	Oceanic	Terrest-rial	Vol-canic	biomass burning	Anthro-pogenic	Biogenic/ total[1]	Natural/ total[2]
80°–65°N	4	0.02	2	0.4	3	40%	62%
65°–50°N	19	0.40	43	2.3	534	3	10
50°–35°N	31	0.95	53	3.3	942	3	8
35°–20°N	46	2.05	37	7.1	598	7	12
20°–5°N	79	2.52	54	20.7	106	31	52
5°N–0°	26	1.14	17	4.2	18	41	67
0°–5°S	25	1.10	27	3.6	16	36	73
5°–20°S	82	2.11	45	17.3	47	44	67
20°–35°S	60	0.86	2	9.2	153	27	28
35°–50°S	60	0.08	8	0.7	24	65	73
50°–65°S	50	0.00	0	0.2	1	98	98
65°–80°S	4	0.00	1	0.0	0	79	100
N. Hemisphere	200	7.1	210	38	2200	8	16
S. Hemisphere	280	4.1	83	31	240	45	58
Global	480	11.	290	69	2400	15	24

1 (Marine + Terrestrial)*100/(Marine + Terrestrial + Volcanic + Anthropogenic + Biomass burning).

2 (Marine + Terrestrial + Volcanic)*100/(Marine + Terrestrial + Volcanic + Anthropogenic +

Bates, T. S., Lamb, B.K., Guenther, A., Dignon, J., Stoiber, R.E. (1992). "Sulfur emissions to the atmosphere from natural sources." J. Atmos. Chem. **14**: 315-327

DMS oxidation by OH

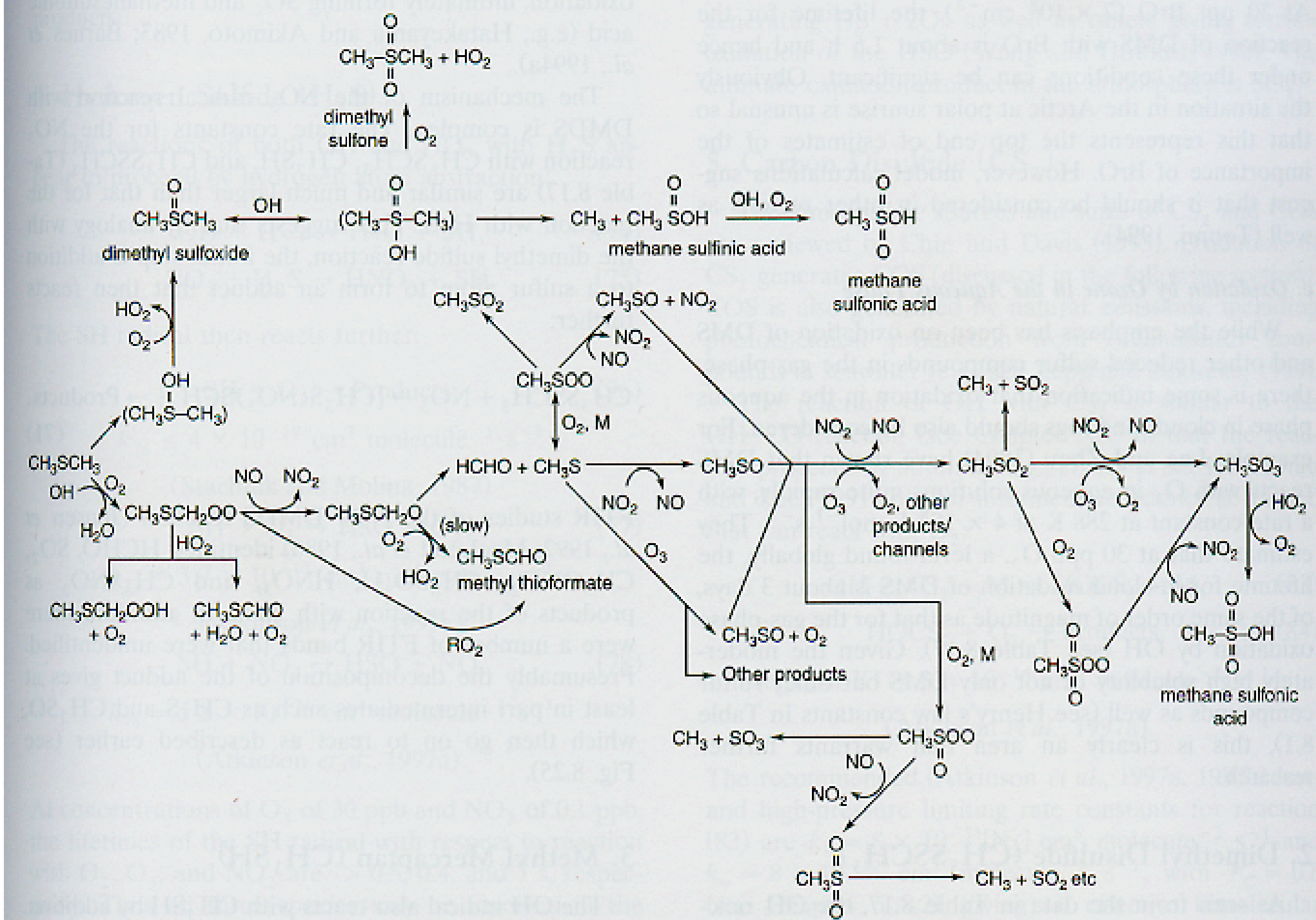


FIGURE 8.25 Overview of oxidation of DMS by OH in the troposphere (note that many of the reactions after the first step are the same in DMS reactions with SO_3, Cl, etc.).

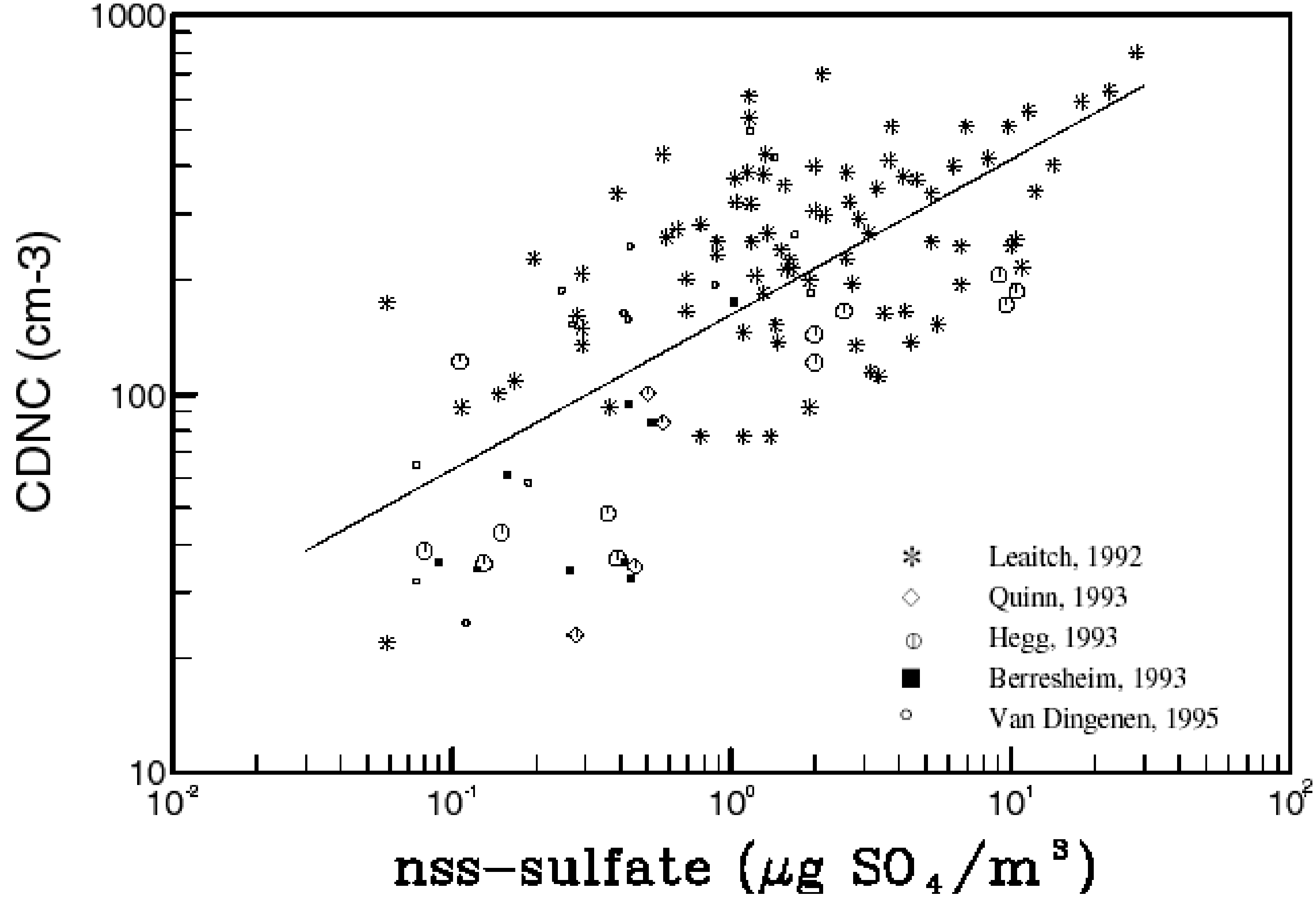
Finlayson-Pitts, B. F., Pitts, J.N. (2000). Chemistry of the upper and lower atmosphere. San Diego, Academic

$NSS\text{-}SO_4^{2-}$ particles are the main contributor to CCN

1) Significant fraction of submicrometer particles are active CCN
2) Most CCN are composed of water soluble materials
3) The total number-population of $NSS\text{-}SO_4^{2-}$ agrees with measured CCN population
4) Much of the light-scattering aerosol in marine air is volatile at elevated temperatures
5) The turnover time of CCN is the same order as $NSS\text{-}SO_4^{2-}$

CLOUD DROPLET NUMBER CONCENTRATION

Dependence on Non-Seasalt Sulfate



Boucher and Lohmann, 1995

Potential effects of NSS-SO_4^{2-} variations on cloud properties

Basic equation: $L = (4/3)\pi r^3 \rho N$

Three variables: L (liquid water content, gm^{-3})

N (number-density of droplets, m^{-3})

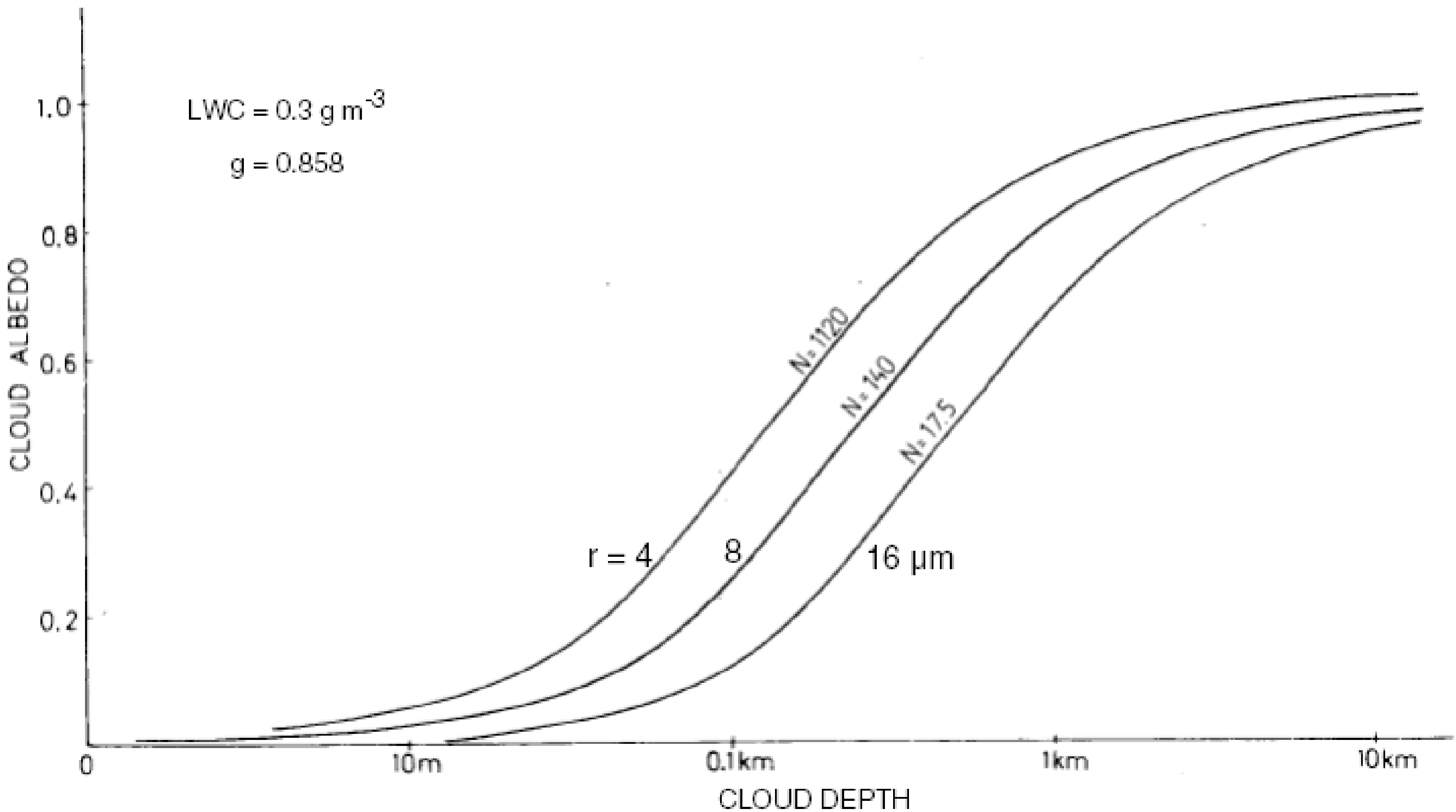
r (droplet radius, m)

1) Hold r fixed: T↑ ⟶ L↑ ⟶ N↑ ⟶ _↑
2) Hold N fixed: T↑ ⟶ L↑ ⟶ r↑ ⟶ _↓
3) Hold L fixed: T↑ ⟶ DMS↑ ⟶ N↑ ⟶ r↓ ⟶ _↑

----Twomey's effect

DEPENDENCE OF CLOUD ALBEDO ON CLOUD DEPTH

Influence of Cloud Drop Radius and Concentration



Twomey, *Atmospheric Aerosols*, 1977

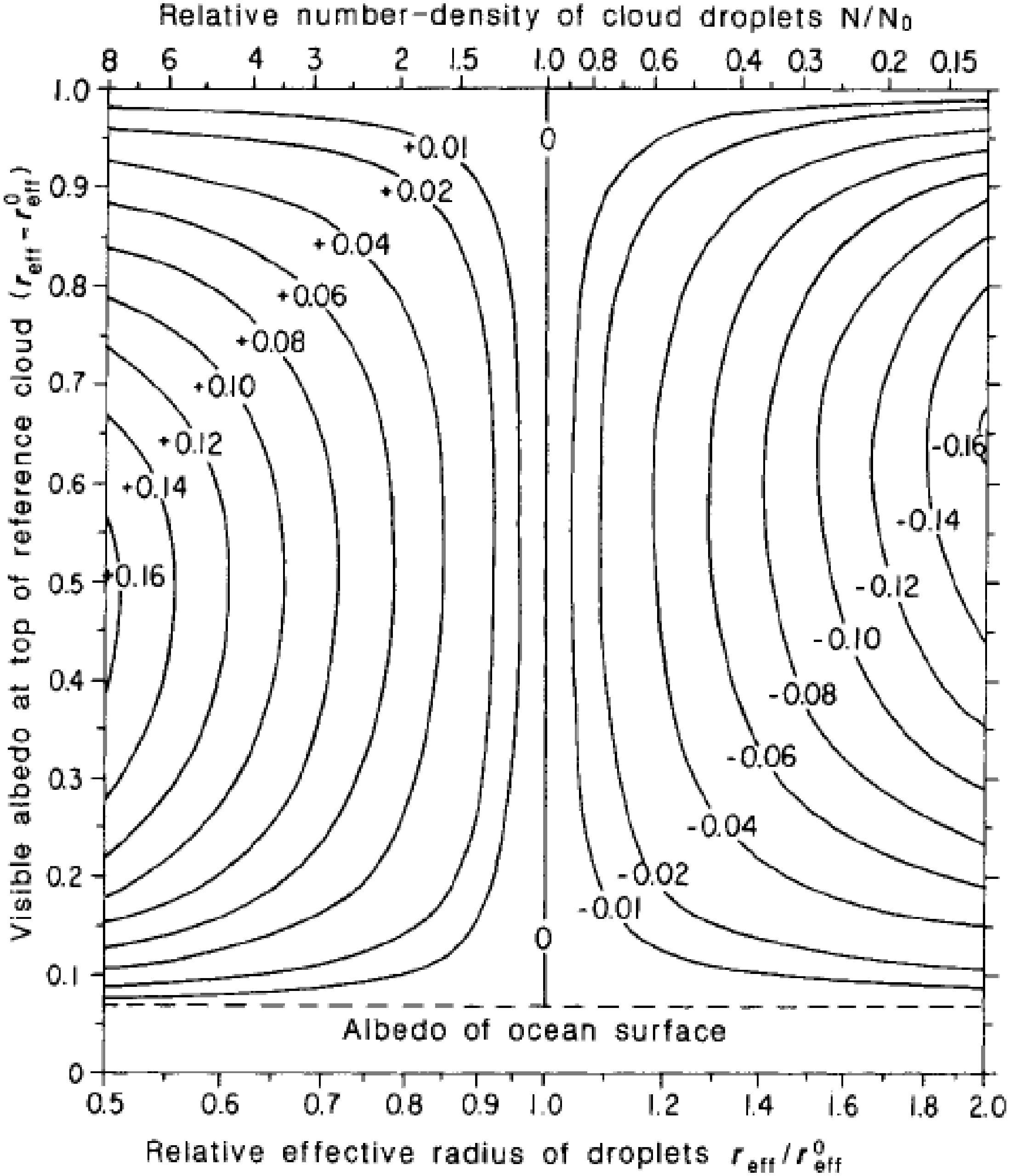

Relative number-density of cloud droplets N/N0
8 6 4 3 2 1.5 1.0 0.8 0.6 0.4 0.3 0.2 0.15
Visible albedo at top of reference cloud ($r_{eff} = r_{eff}^0$)
1.0 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0
+0.01
+0.02
+0.04
+0.06
+0.08
+0.10
+0.12
+0.14
+0.16
0
-0.16
-0.14
-0.12
-0.10
-0.08
-0.06
-0.04
-0.02
-0.01
Albedo of ocean surface
0.5 0.6 0.7 0.8 0.9 1.0 1.2 1.4 1.6 1.8 2.0
Relative effective radius of droplets r_{eff}/r_{eff}^0

Figure 1

Table 1

Table 1 Climatic effect caused by increasing CCN concentration over the ocean

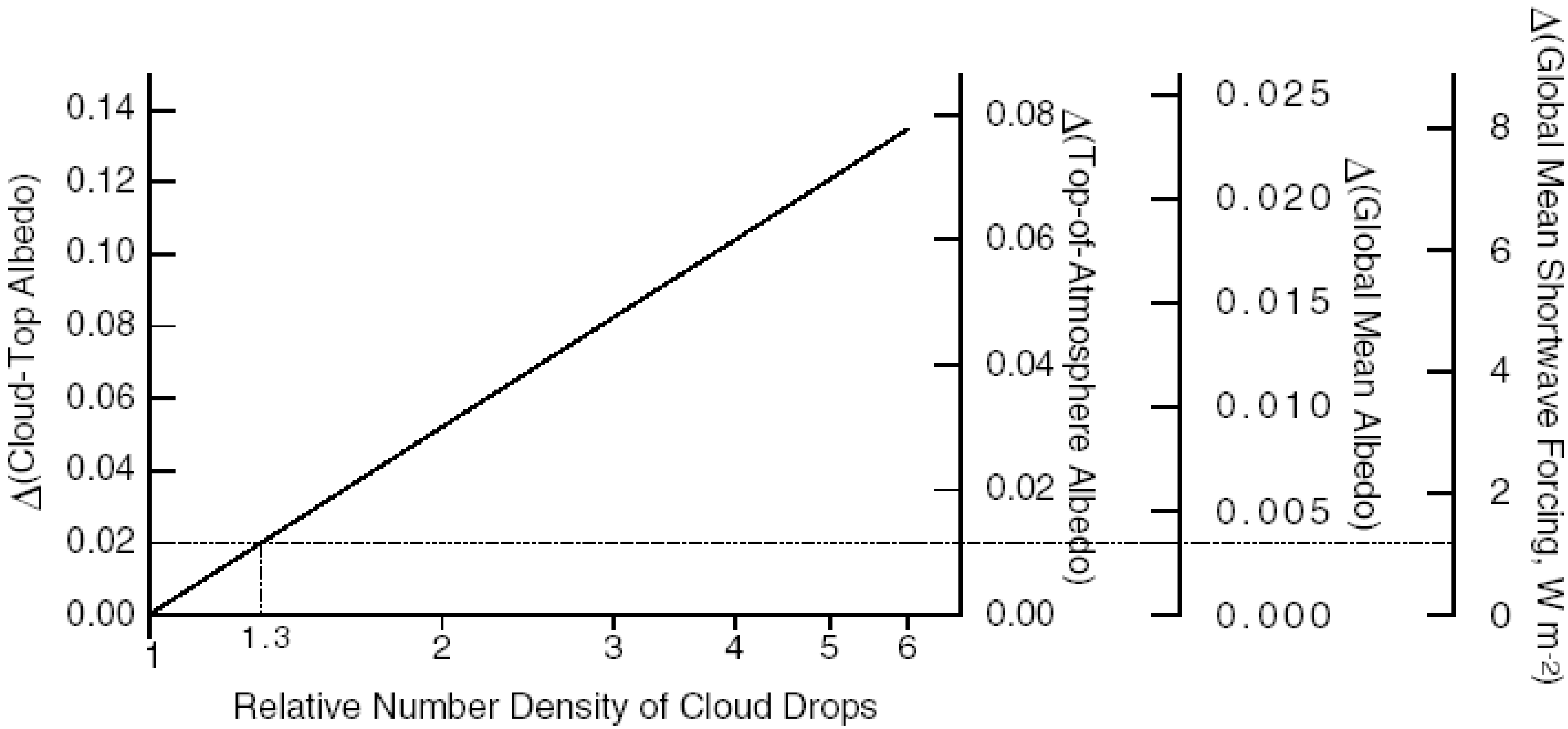
a Global annual average cloud cover (ocean areas only)

Cloud type*	Ocean area covered (%)	Earth covered by oceanic clouds (%)
Non-overlapped St/Sc†	25.2	17.6
Non-overlapped As/Ac‡	10.8	7.5
As/Ac overlapped with St/Sc§	8.8	6.1
Nimbostratus, cumulus, cumulonimbus	not applicable (optically thick; high albedo)	
Cirrus‖	not applicable (ice)	
Total cover of oceanic stratiform water clouds (As/Ac+St/Sc) not overlapped with cumuliform clouds	44.8¶	31.2

b Example: effect on surface climate due to increasing CCN concentration N by 30% while holding liquid water path fixed

	For area covered by oceanic stratiform water clouds	Averaged over Earth's surface area
Imposed change in N	+30%	
Change in r_{eff}	−10%	
Change in 0.5–0.7-μm albedo at TOC#	+0.02	
Change in 0.5–0.7-μm albedo at TOA**	+0.018	
Change in solar albedo at TOA**	+0.016	+0.005
Equivalent change in solar constant††		−0.7%
Change in global-average surface temperature‡‡		−1.3 K

SENSITIVITY OF ALBEDO AND FORCING TO CLOUD DROP CONCENTRATION



Schwartz and Slingo (1996)

Global climate and DMS emission

A stable negative feedback

Sea-to-air mass flux of DMS: $F = A \cdot k \cdot \Delta c$

A: total ocean surface T A F

K: transfer velocity

_C: concentration gradient across the air/sea interface

T

DMS

F

counteract

_ cooling

CCN

SO_4^{2-}

NSS-

Climatic Feedback Loop

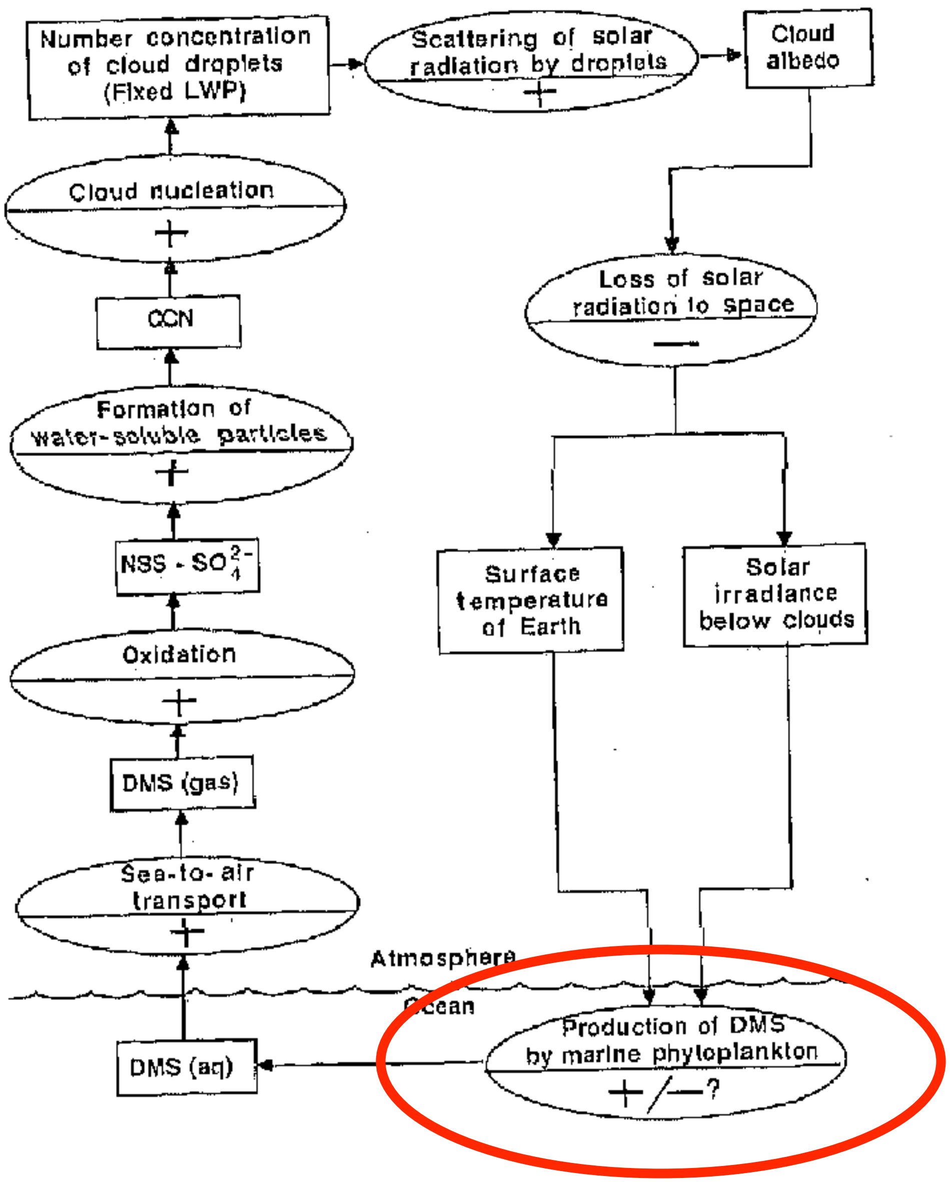


Figure 2

Atmospheric DMS concentrations

- Independent of the rate of primary production, the warmest, most saline, and most intensely illuminated regions of the oceans have the highest rate of DMS emission to the atmosphere
- Key fact when considering possible climatic feedback mechanisms

Gaia theory*

- Early after life began it acquired control of the planetary environment
- This homeostasis by and for the biosphere has persisted until the present
- Why would phytoplankton evolve to produce DMS?
  - Many theories for the mechanism, little supporting data
    - Reaction to salt stress
    - Increased rainfall leading to more nutrients from land

*Lovelock, J. E. and L. Margulis (1974). "Atmospheric homeostasis by and for the biosphere. Gaia hypothesis." Tellus **26**(1-2): 2-10.

Future work

- Intense study in many areas in attempts to support or disprove the theory
  - Biological role of DMSP & possible explanations for its evolutionary development Simo, R. (2001). "Production of atmospheric sulfur by oceanic plankton: biogeochemical, ecological and evolutionary links." Trends in Ecology & Evolution **16**(6): 287-294.
  - Understanding ocean-atmosphere DMS fluxes Kettle, A. J. and M. O. Andreae (2000). "Flux of dimethylsulfide from the oceans: A comparison of updated data sets and flux models." Journal of Geophysical Research, [Atmospheres] **105**(D22): 26793-26808.
  - Connection between DMS and CCN Pandis, S. N., L. M. Russell, et al. (1994). "The relationship between DMS flux and CCN concentration in remote marine regions." Journal of Geophysical Research, [Atmospheres] **99**(D8): 16945-57. Reasonable agreement between observations and model