Changing Clouds in a Changing Climate: Anthropogenic Influences

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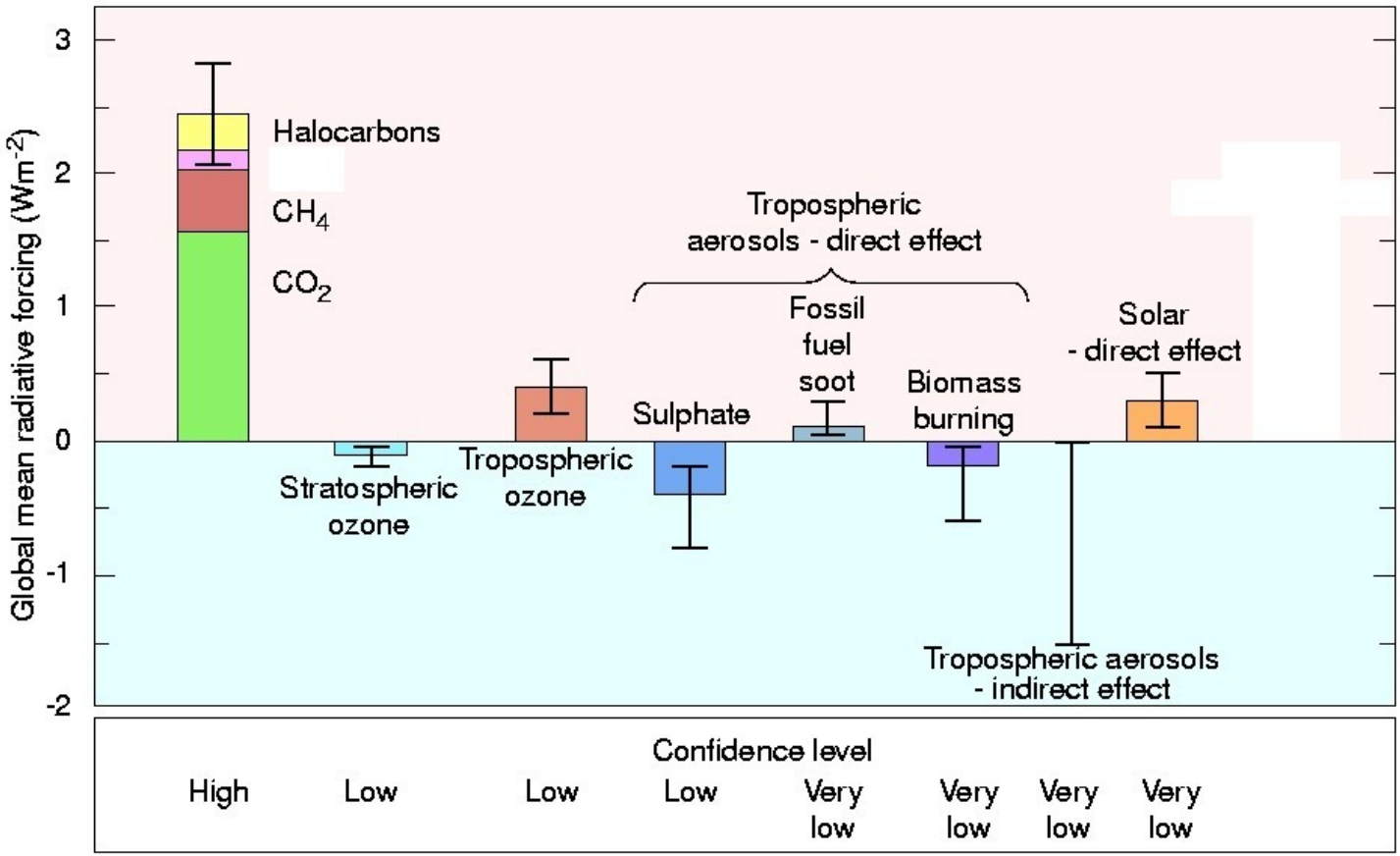
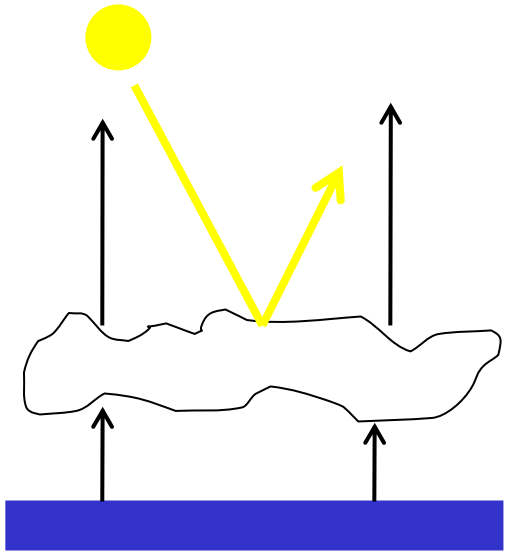
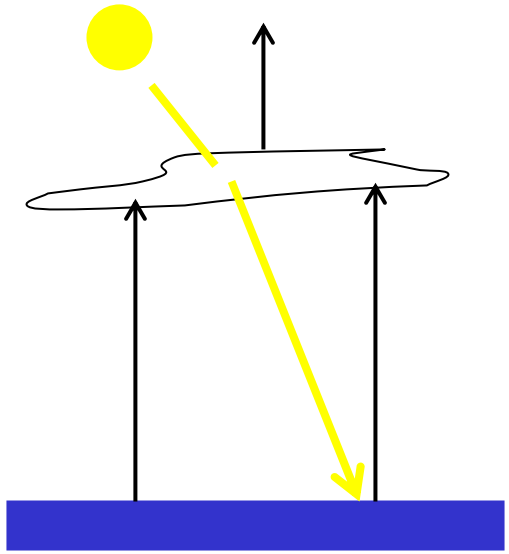
Global mean radiative forcing of the climate system for the year 2000 relative to 1750



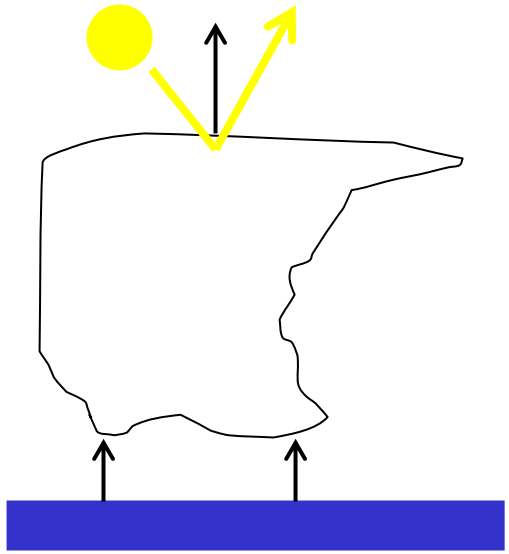
Cloud Radiative Forcing



low-level clouds strongly reflect sunlight back to space *(negative cloud radiative forcing)*



high-level clouds strongly restrict emission out to space *(positive cloud radiative forcing)*



thick clouds strongly reflect and restrict emission *(net zero cloud radiative forcing)*

Cloud Radiative Feedbacks

Remember, forcing is not the same as feedback

Positive cloud feedbacks if these occur with global warming:

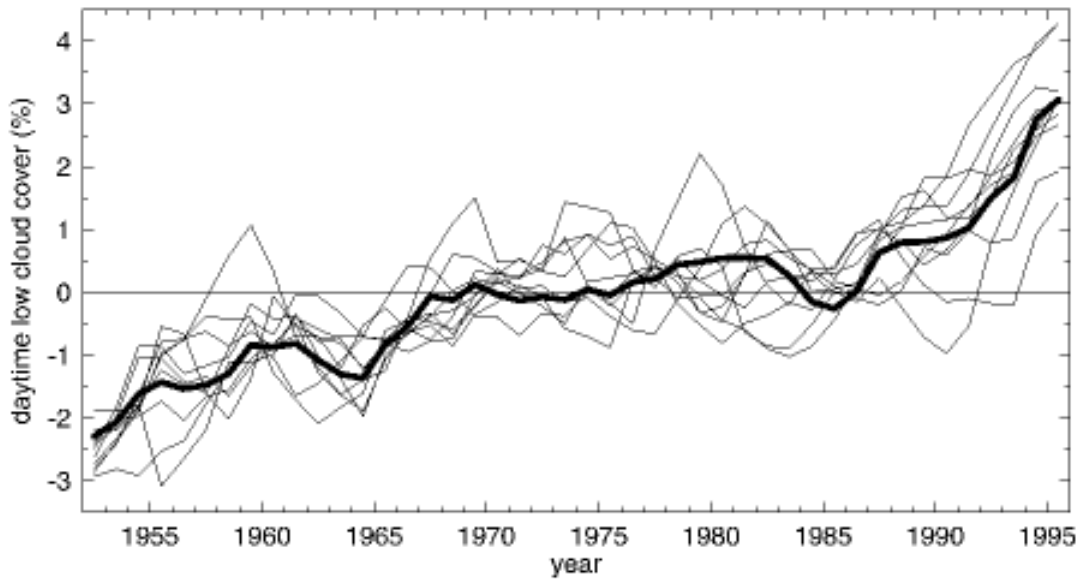
- decreased low-level cloud cover
- decreased low-level cloud reflectivity
- increased high-level cloud cover
- increased height of high-level cloud cover

Negative cloud feedbacks if these occur with global warming:

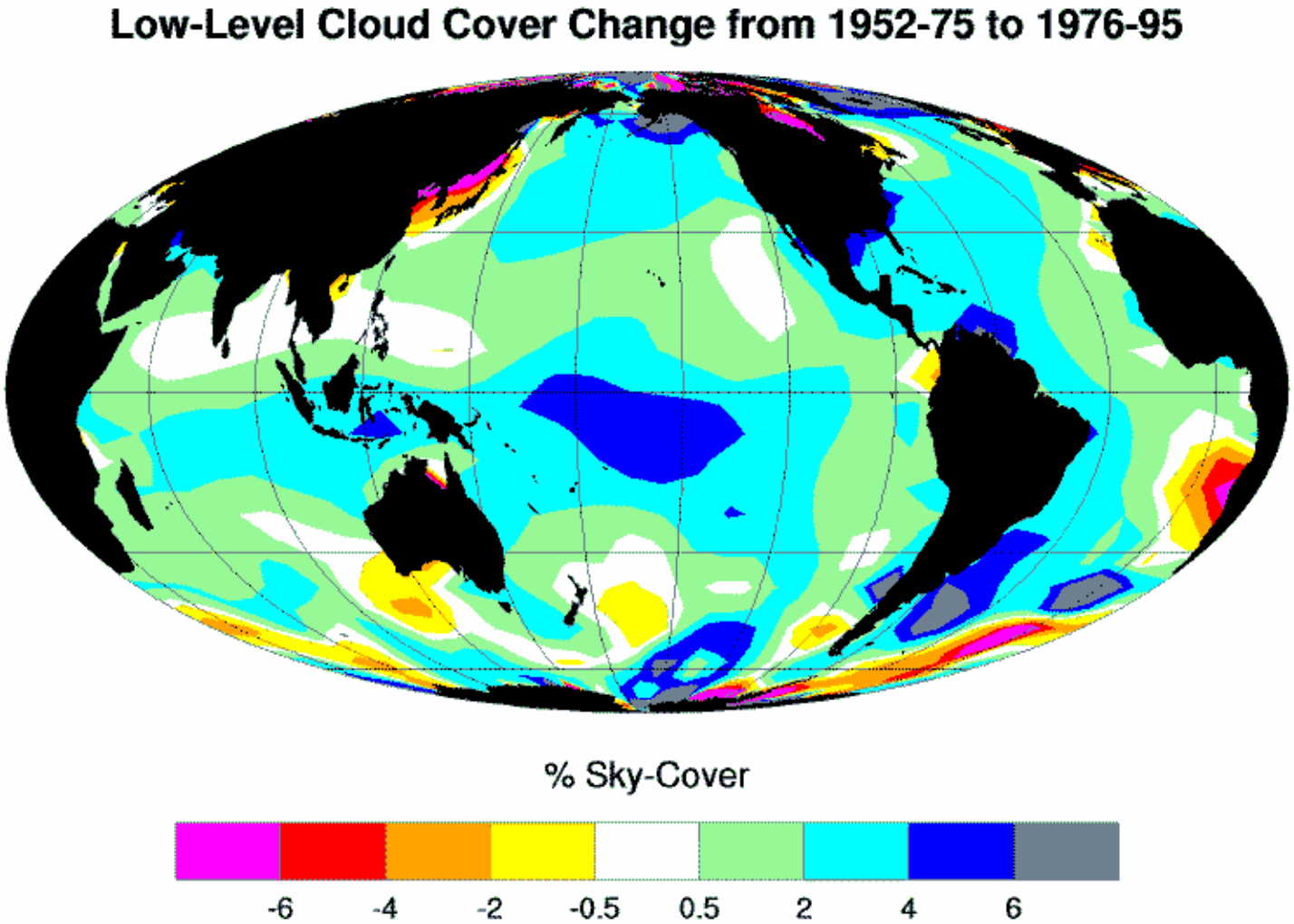
- increased low-level cloud cover
- increased low-level cloud reflectivity
- decreased high-level cloud cover
- decreased height of high-level cloud cover

Observed Cloud Changes

Low-level cloud cover has increased at every latitude



Observed Cloud Changes



Why is cloud cover observed to increase?

- Spurious data from an unknown observational problem
- Natural climate fluctuation
- Unidentified process resulting from “global warming”
- Increased anthropogenic aerosol

Cloud–Aerosol Interactions

- Aerosols are tiny particles in the atmosphere
- Natural sources are dust, sea salt, and coagulation from gases of biological origin
- Anthropogenic sources are fossil fuel and biomass combustion
- Anthropogenic sources overwhelm natural sources over much of the globe

- Aerosols can act as condensation nuclei for haze and cloud droplets to form on

Anthropogenic Aerosol Radiative Forcing

"Indirect effect"

- More cloud condensation nuclei are available so more but smaller cloud droplets form
- This can enhance cloud reflectivity by increasing scattering area *(indirect effect 1)*
- This can enhance cloud lifetime by inhibiting coalescence of droplets and thus suppressing precipitation *(indirect effect 2)*

- Absorption of solar radiation by soot can heat the atmosphere and thus evaporate clouds and prevent new cloud growth *(semi-direct effect)*

Indirect Effect One

Anthropogenic Effect

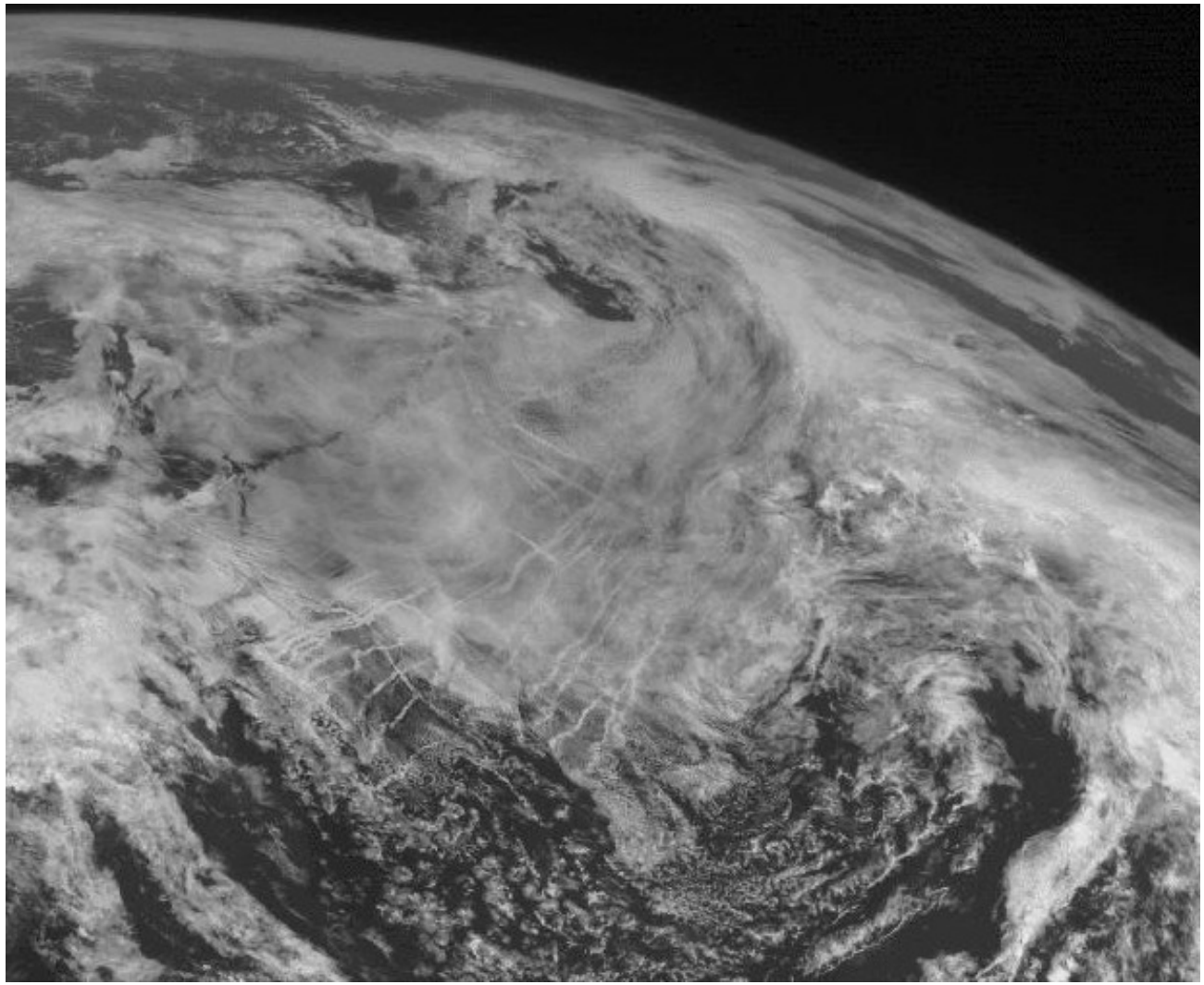
large number of cloud condensation nuclei

large number of small cloud droplets

high reflectivity

Indirect Effect

ship tracks



Indirect Effect Two

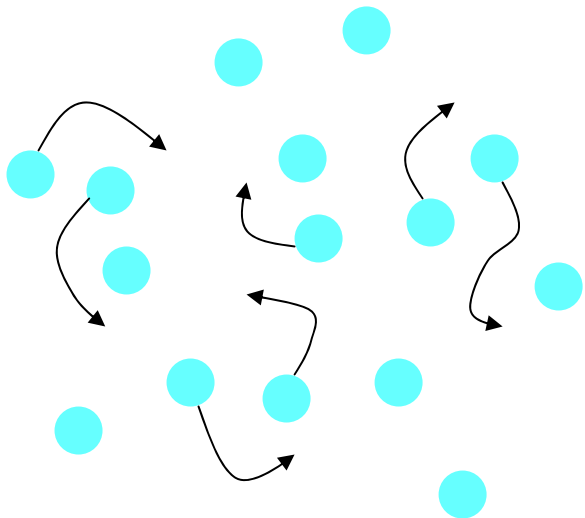
Anthropogenic Effect

large number of cloud condensation nuclei

large number of small cloud droplets

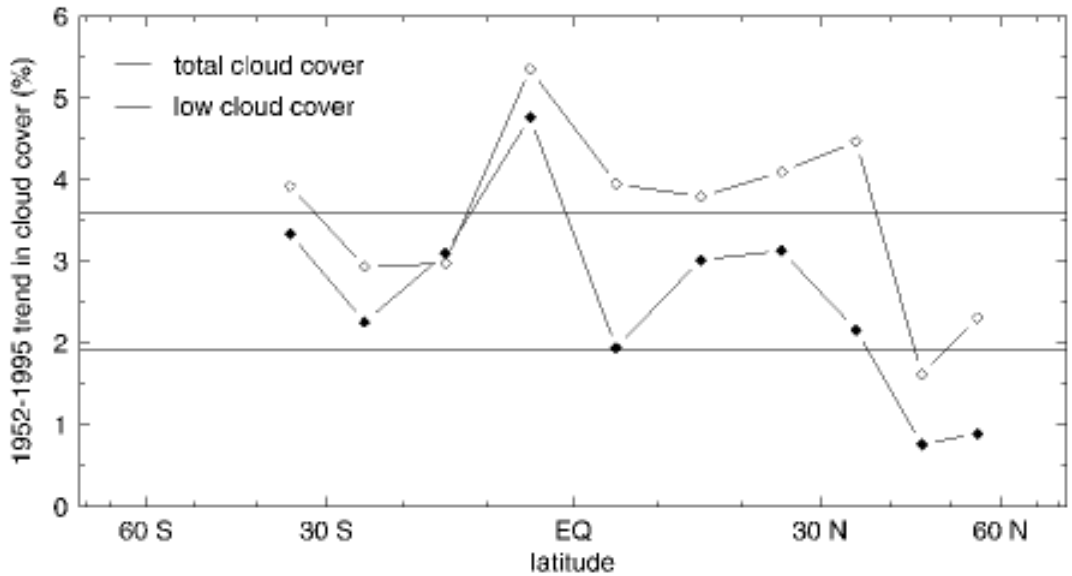
no collisions occur and droplets do not grow big and rain out

longer cloud lifetime



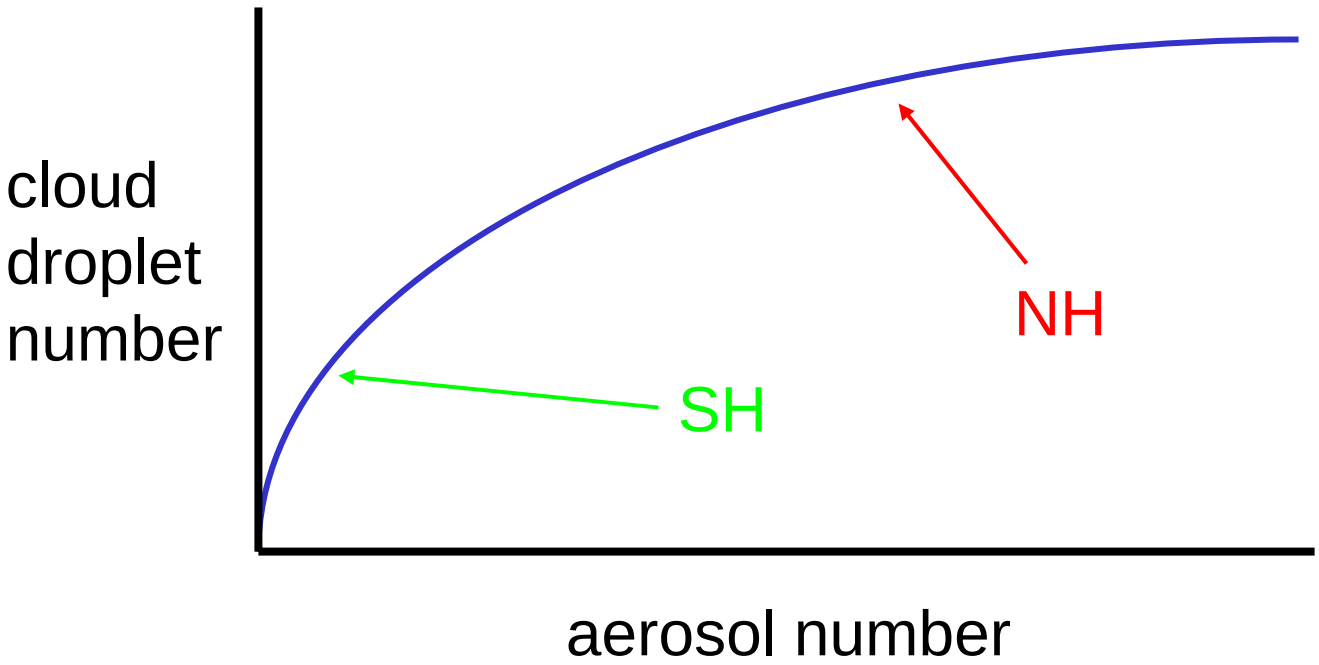
Observed Cloud Changes

If anthropogenic aerosol is greatest in the Northern Hemisphere, why are cloud increases greatest in the Tropics and Southern Hemisphere?



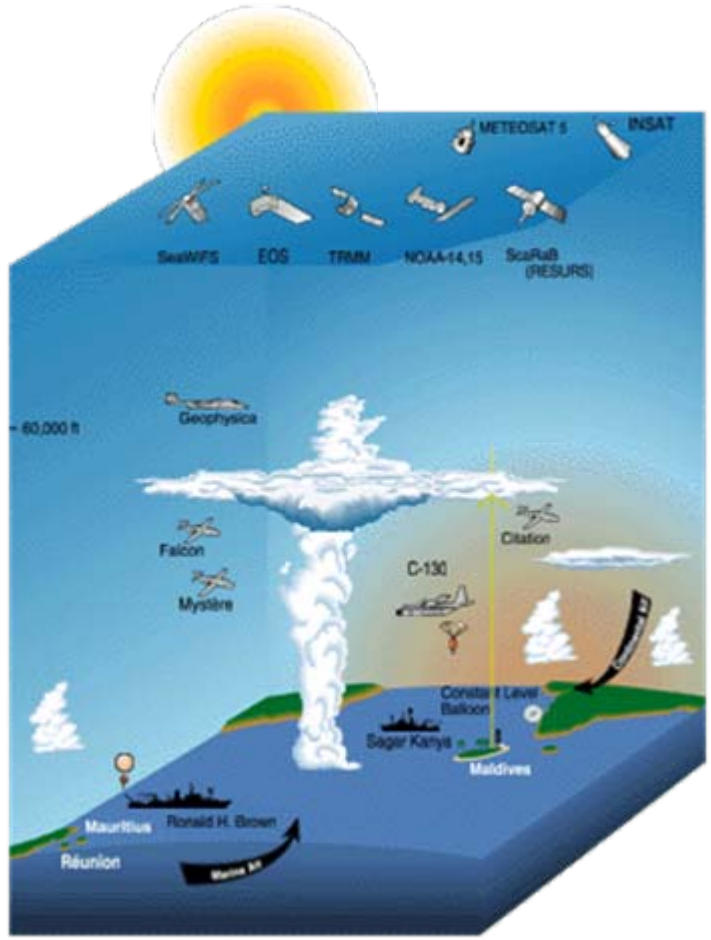
Cloud–Aerosol Interactions

Perhaps the Tropics and Southern Hemisphere have greater susceptibility to anthropogenic effects due to more pristine conditions



Indian Ocean Cloud Experiment (INDOEX)

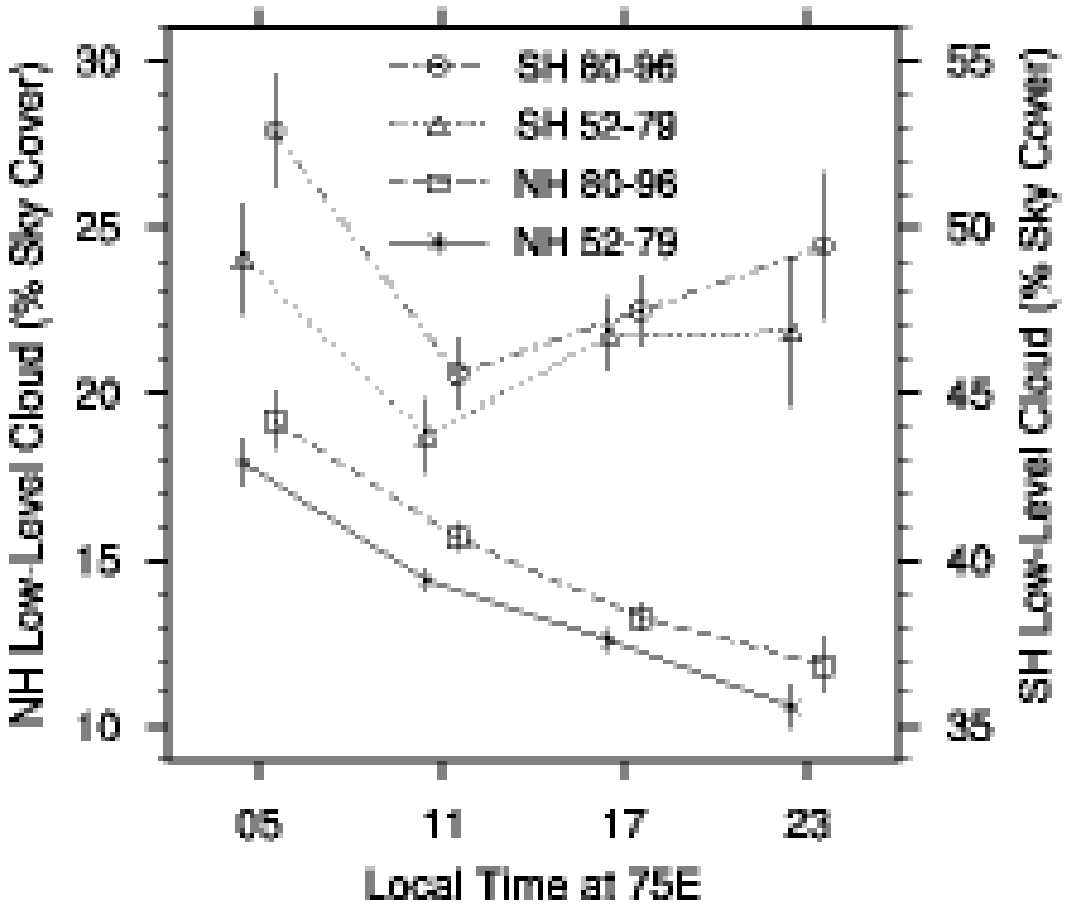
- strong offshore flow during December-April brings polluted air over Northern Indian Ocean
- Southern Indian Ocean provides “clean air” comparison
- A very heavy and dark haze layer was observed over the Northern Indian Ocean
- The haze layer strongly absorbed solar radiation



Cloud–Aerosol Interactions

Is the semi-direct effect dominating over the Northern Indian Ocean? Is low-level cloud cover decreasing?

No and No!



Indirect Effect Two

Frequency of precipitation when low-level cloud is present is negligible and suggests indirect effect two is not important for enhancing cloud

	Local time at 75°E	1952-79 period	1980-96 period
NH 10-20°N 65-90°E	11	1.8%	1.5%
	17	1.9%	1.6%
SH 20-30°S 65-90°E	11	14.4%	16.2%
	17	17.1%	16.2%

Conclusions

- clouds have strong and varying radiative impacts on the climate system
- anthropogenic aerosol might have a substantial influence on cloudiness, but the large scale impact is difficult to quantify
- observed cloud changes are often not consistent with expected anthropogenic aerosol influences
- causes for increased cloud cover have not been identified over much of the global ocean
- the observed cloud changes may not be completely reliable