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

Low-Level Cloud Cover Change from 1952-75 to 1976-95

% Sky-Cover

-6  -4  -2  -0.5  0.5  2  4  6
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.

<table>
<thead>
<tr>
<th></th>
<th>Local time at 75°E</th>
<th>1952-79 period</th>
<th>1980-96 period</th>
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<tbody>
<tr>
<td><strong>NH</strong></td>
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<td></td>
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<tr>
<td>10-20°N</td>
<td>11</td>
<td>1.8%</td>
<td>1.5%</td>
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<tr>
<td>65-90°E</td>
<td>17</td>
<td>1.9%</td>
<td>1.6%</td>
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<tr>
<td><strong>SH</strong></td>
<td></td>
<td></td>
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<tr>
<td>20-30°S</td>
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<td>14.4%</td>
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<tr>
<td>65-90°E</td>
<td>17</td>
<td>17.1%</td>
<td>16.2%</td>
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</table>
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