Arctic Amplification

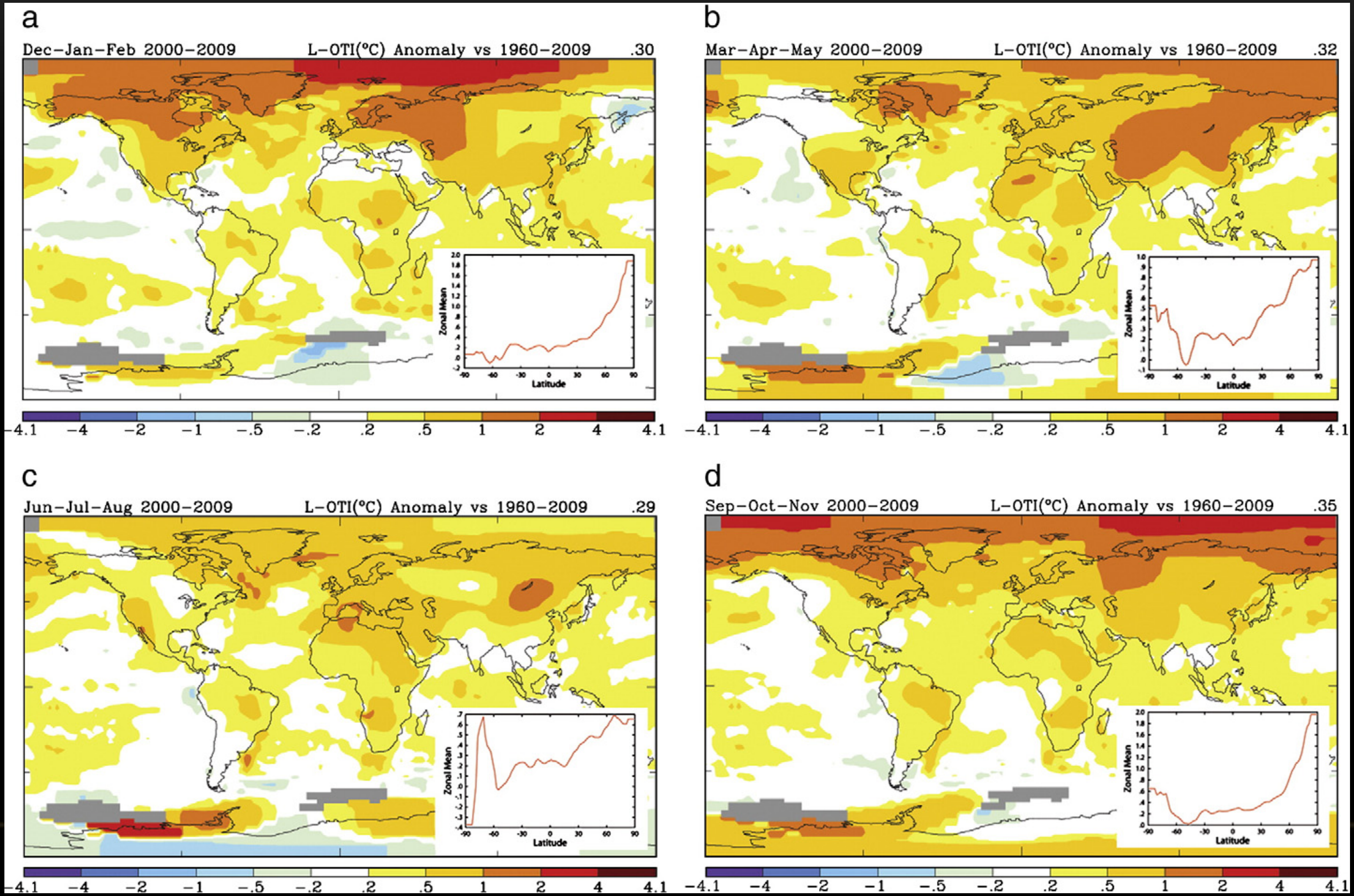
Outline

- What is the Arctic amplification?
- What are the mechanisms of the Arctic amplification?

Arctic Amplification

- Arctic amplification — temperature variability and trends in the Arctic region tend to be larger than trends and variability in the rest of the northern hemisphere or the globe.
  - In 1896, the Swedish scientist Svante Arrhenius suggested that changes in the concentration of carbon dioxide in the atmosphere could alter the earth's surface temperature and that the temperature change would be especially large in polar latitudes (Arrhenius, 1896). This appears to be the first formal recognition of AA.
- More recent studies have shown that there were periods of strong Arctic warming or cooling throughout the 20th century. Arctic amplification is prominent in annual surface air temperature trends for the past 50 years.

Surface Air Temperature Anomalies in 2000-2009 with respect to the period 1960–2009



The inset shows linear trends over the 50-year analysis period averaged by latitude.

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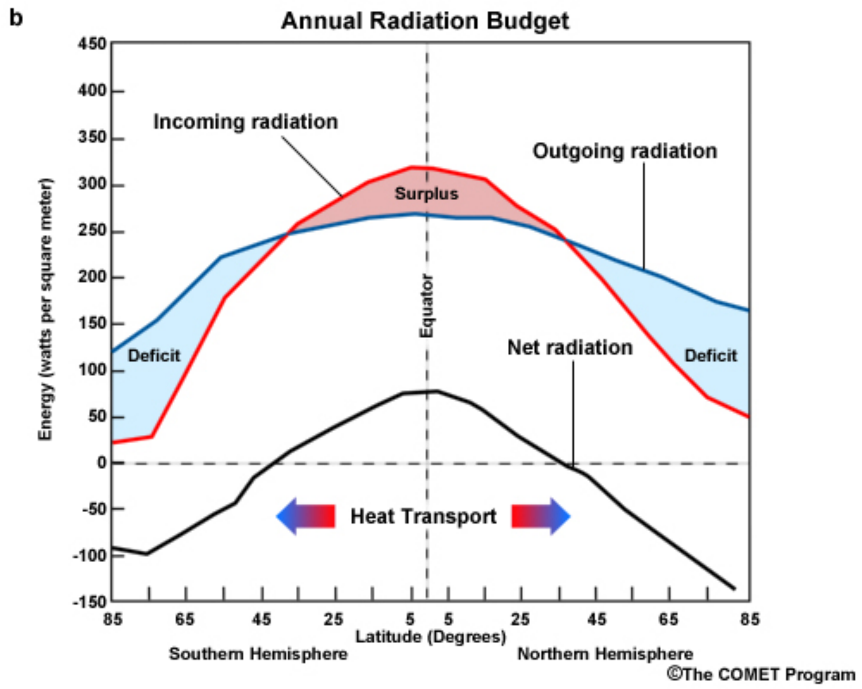
Mechanism I: Albedo Feedback

- Albedo feedback related to snow: warming → earlier melt of the snow → earlier exposure of the dark snow free surface → stronger absorption of solar radiation → higher surface air temperature
- A similar mechanism with sea ice loss:
  - The sea ice melt season will lengthen and intensify in a warmer Arctic
  - →dark open ocean leads to increased solar radiation absorption and higher ocean heat content in the mixed layer
  - → larger heat transfer from the open, warm ocean to the atmosphere in the low sun season
  - → warmer surface air temperature
  - → thinner sea ice in spring
  - → more readily sea ice melt in summer

Mechanism II: Changes in heat flux convergence

- Although albedo feedback seems an effective mechanism, it can not explain some observed features of Arctic warming.
- Another process that may contribute to Arctic warming is the poleward energy transport from lower latitudes.
- Some studies suggested that advection of relatively warm air from the southern Barents Sea to the Kara Sea and the associated increase in wind-driven oceanic inflow can induce warming, which can lead to reduced sea ice extent in the area. (Bengtsson et al. 2004; Wood and Overland 2010). In this mechanism, sea ice loss is the consequence instead of an active player of Arctic warming.

The Arctic region is characterized by both an atmosphere and oceanic heat flux convergence; in the annual mean, this convergence is primarily balanced by longwave radiation loss to space



Mechanism III: Cloud radiation feedback

- *How do clouds affect shortwave and longwave radiative fluxes to the surface?*
  - While clouds reduce the shortwave flux to the surface through their high albedo, cloud cover (especially low-level Arctic stratus) augments the downward longwave flux to the surface
- *Then what does this mean for the Arctic?*
  - Clouds warm the Arctic surface except for a brief period in summer, i.e., the surface net all-wave radiative flux is larger in the presence of cloud cover as compared to clear sky conditions.
  - The net surface warming effect of clouds in the Arctic for most of the year is due to the absence of solar radiation during polar nights and the high albedo of the sea ice surface. The shortwave cloud forcing and thus the net forcing are strongly sensitive the surface albedo (Curry and Ebert, 1992).
  - The warming effect of clouds at the surface of the Arctic averaged over the year contrasts with lower latitudes, where clouds have a net cooling effect
- An increase in atmospheric water vapor and total cloud cover leads to greenhouse effects larger in the Arctic than at lower latitudes.

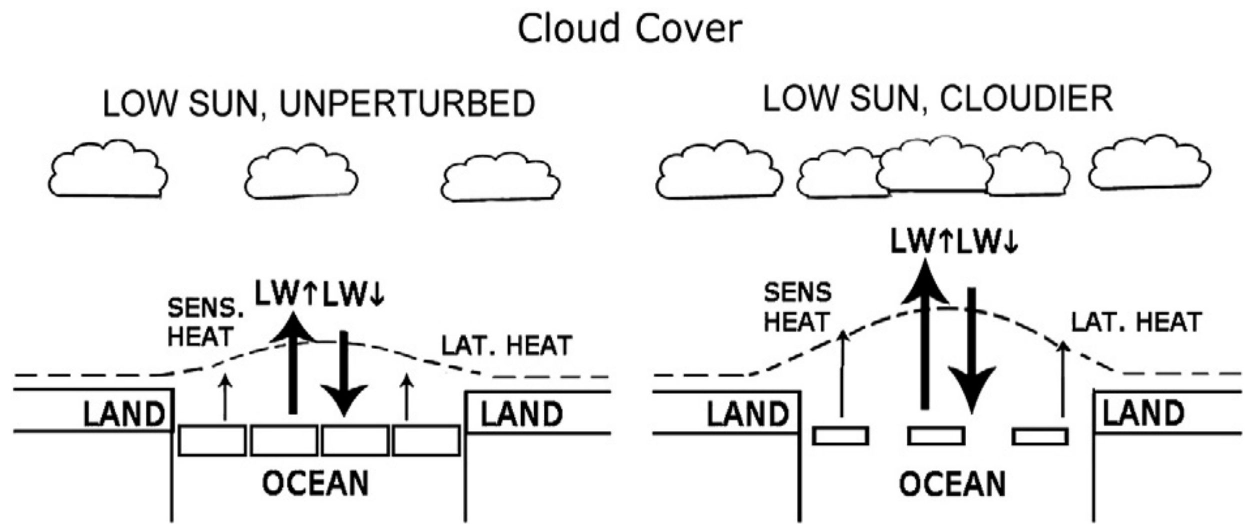


Fig. 7. Schematics of the surface energy budget of the Arctic Ocean, contrasting the situation during the low sun period for (left) an unperturbed Arctic and (right) in response to a forcing that results in more extensive and/or thicker cloud cover. The dotted line is an arbitrary isotherm in the lower troposphere; warming over the Arctic Ocean bows the isotherm upward. Changes in water vapor content linked to changes in open water fraction may contribute to temperature change. SW = shortwave radiation flux, LW = longwave radiation flux, Sens. Heat = sensible heat flux, Lat. Heat = latent heat flux.

- Model simulations (e.g., Abbot et al. 2009) suggest that if high concentration of the atmospheric carbon dioxide (i.e., quadrupled) can lead to a reduction in winter sea ice and a large increase in heat and moisture fluxes from the ocean surface. This may destabilize the atmosphere, promote atmospheric convection and produce more clouds and higher column water vapor content, leading to a stronger longwave radiation flux to the surface, initiating further sea ice loss and, in some models, an ice-free state.
- Loss of the winter ice cover linked to the convective cloud feedback would lead to a very strong warming of the Arctic.

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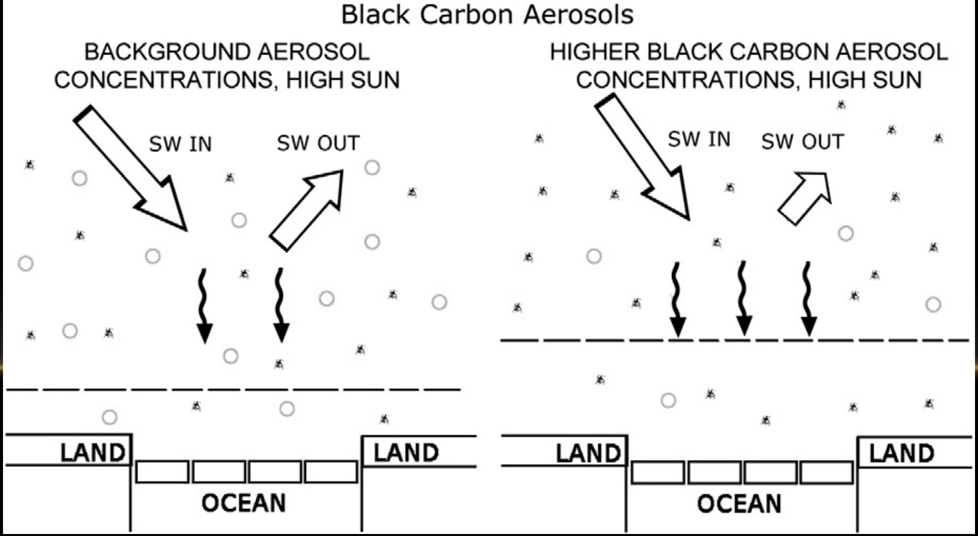
Mechanism IV: Impacts of Aerosols

- Sulfate aerosols reflect solar radiation and have a net cooling effect.
- In contrast to sulfate aerosols, black carbon aerosols strongly absorb solar radiation, and hence have a warming effect on the atmosphere.
- With the advent of cleaner combustion techniques, sulfate aerosol concentrations have declined, but black carbon aerosol concentrations have increased. Modeling study (e.g., Shindell and Faluvegi 2009) suggest that the combination of decreasing concentrations of sulfate aerosols and increasing concentrations of black carbon aerosols in the Arctic has contributed to Arctic warming over the past three decades



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Zonal Mean T2m for 2XCO2 with and without albedo feedback

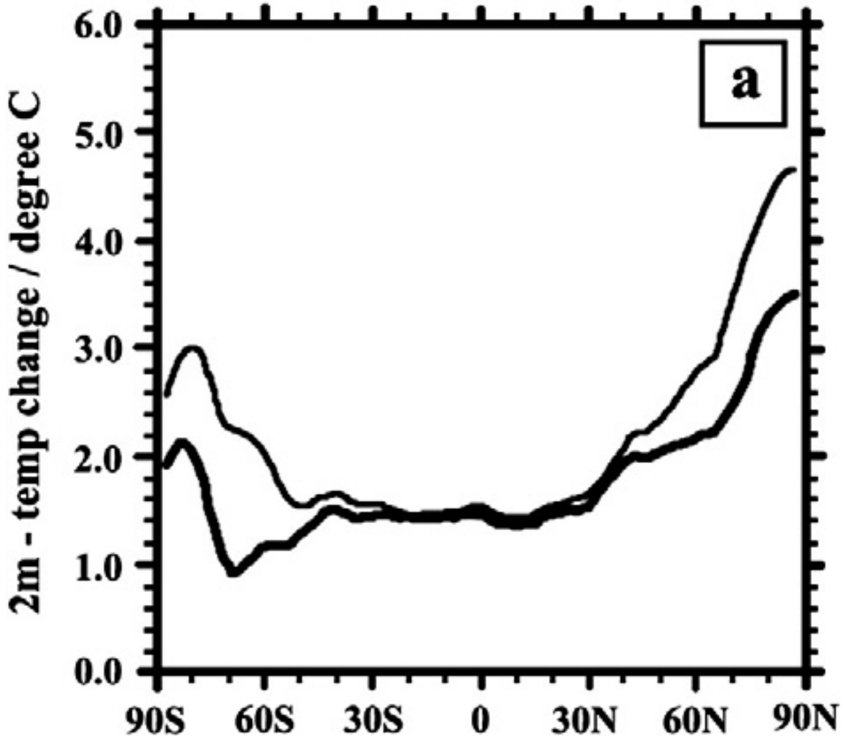

Fig. 6. Zonal mean 2-meter air temperature change with doubled carbon dioxide for experiments with locked albedo (thick line) and variable albedo (thin line) (from Graversen and Wang, 2009).

The amplification signal with variable albedo is only about 15% greater than with a fixed albedo. While albedo feedback is important, other feedback processes may collectively play a more important role.

In addition, albedo feedback can not explain some observed features of Arctic warming.

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References

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