

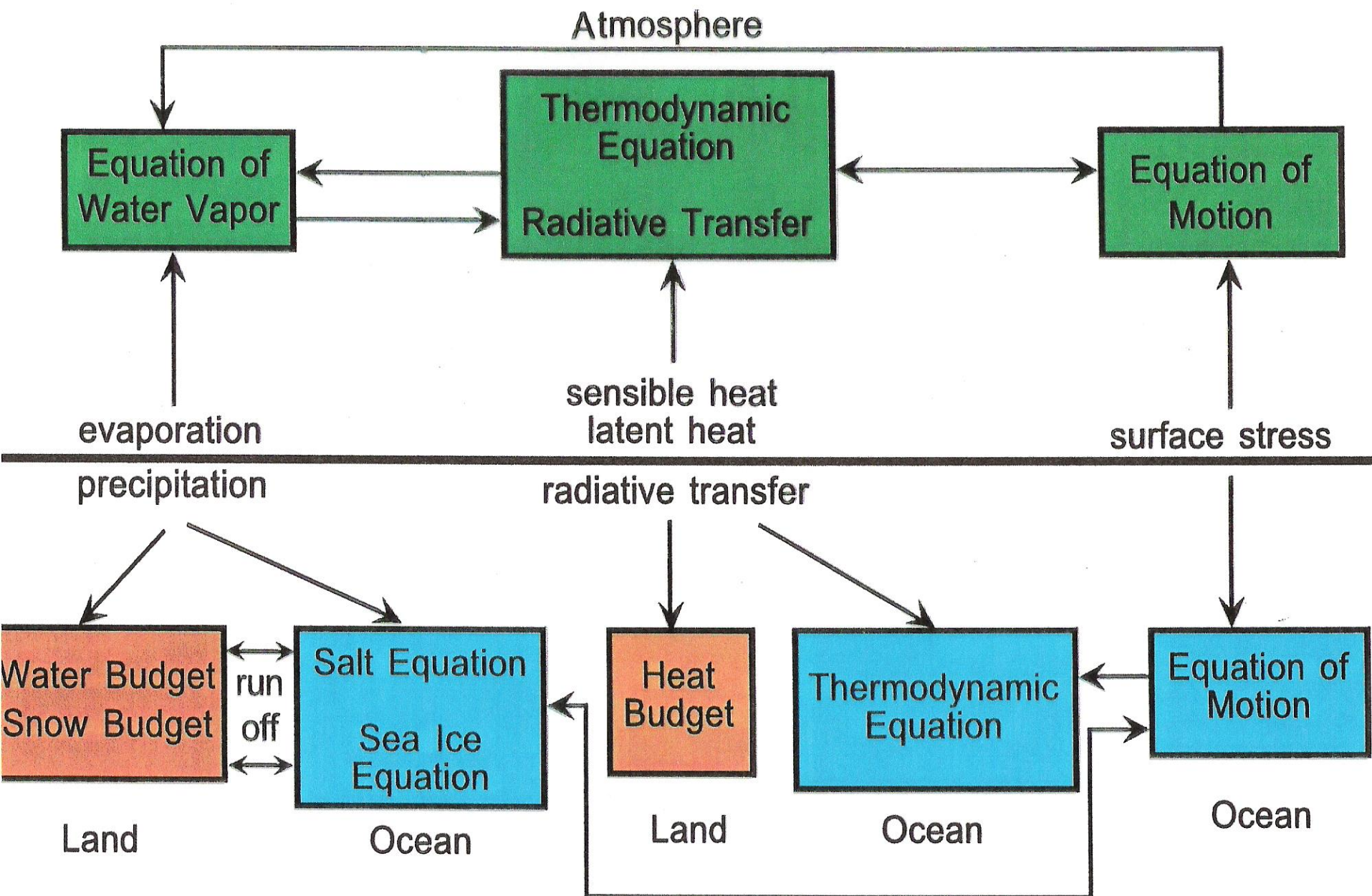
Role of Ocean in Global Warming

Stouffer, Manabe, and Bryan, Nature, 1989

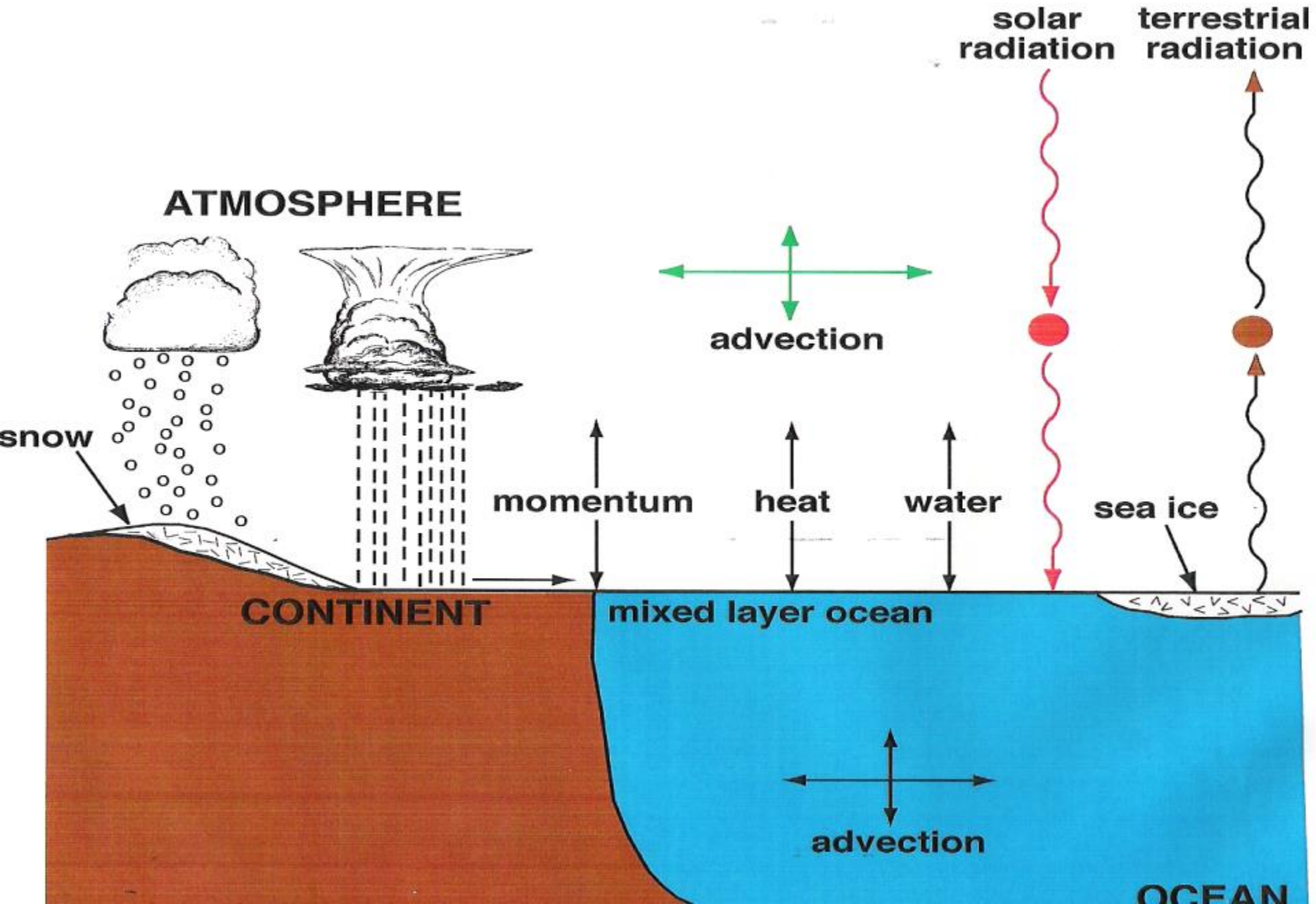
Manabe et al., J. Climate, 1991, 1992

Stouffer & Manabe, Nature Climate Change, 2017

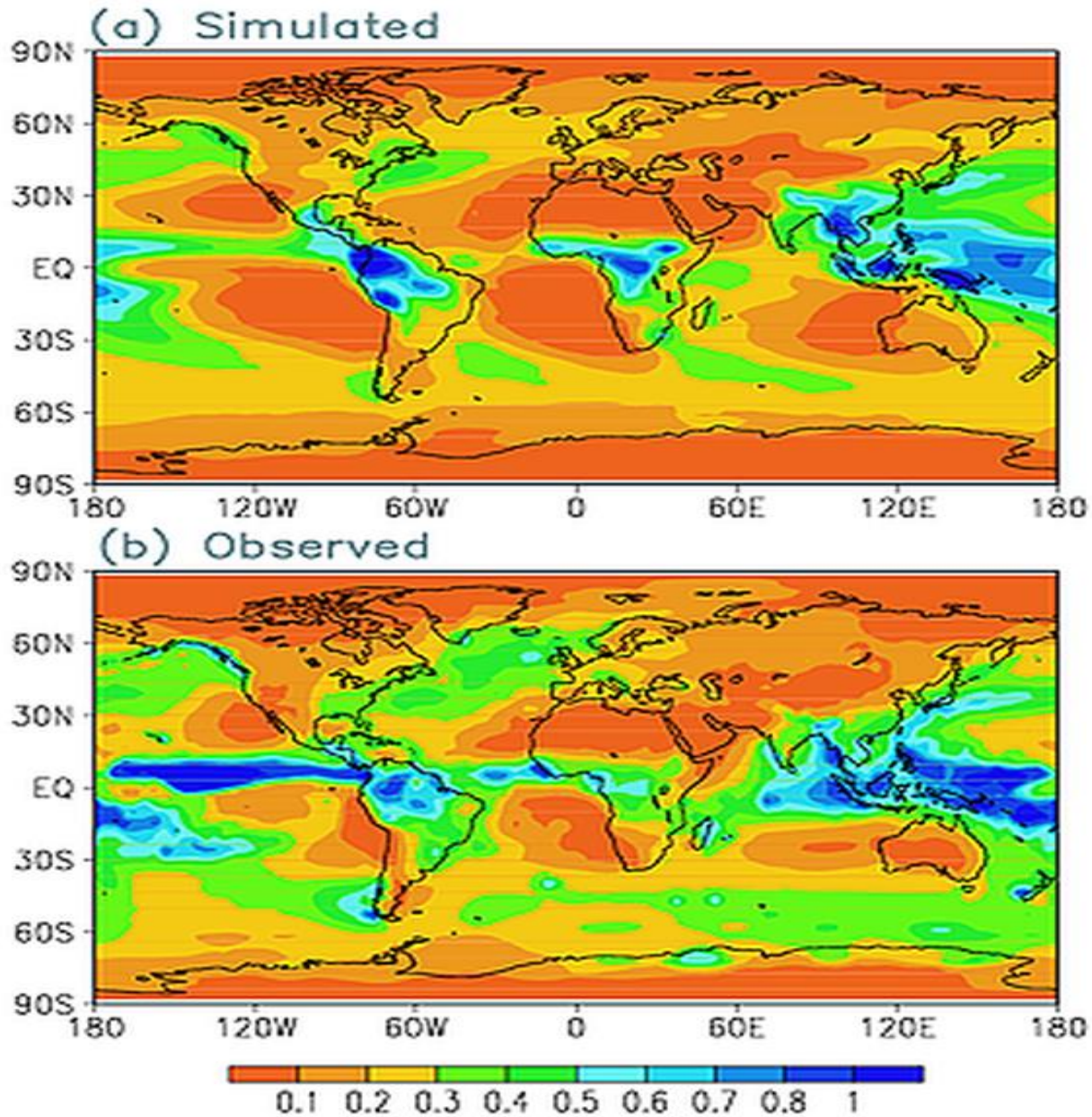
Coupled Ocean-Atmosphere-Land Model



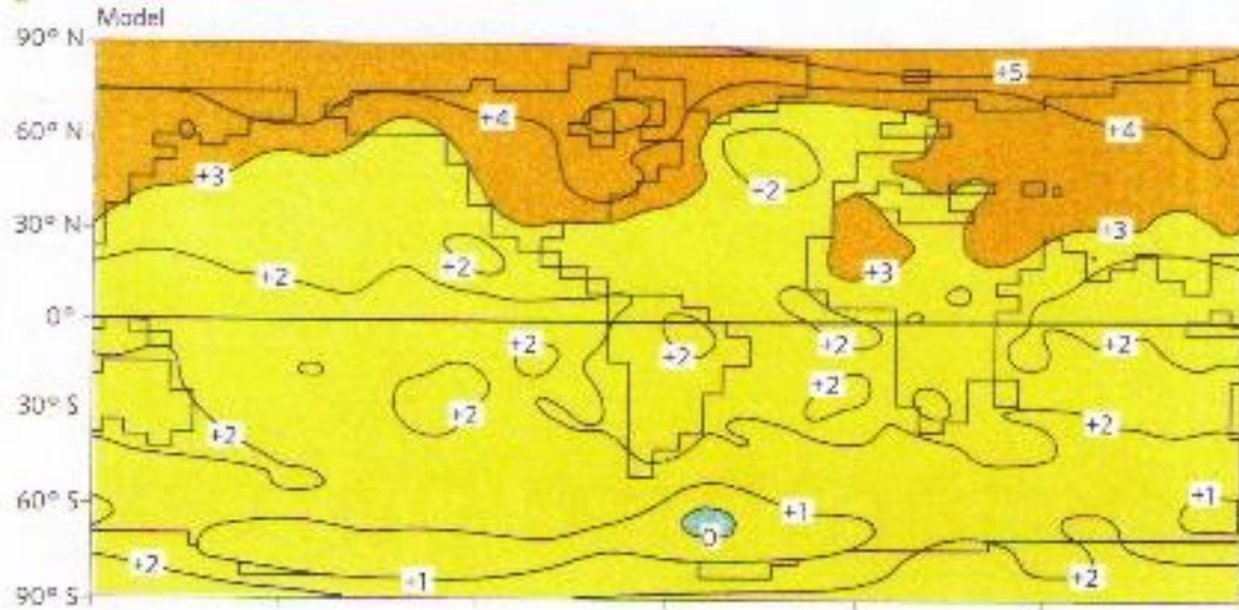
Physical Processes in a Model



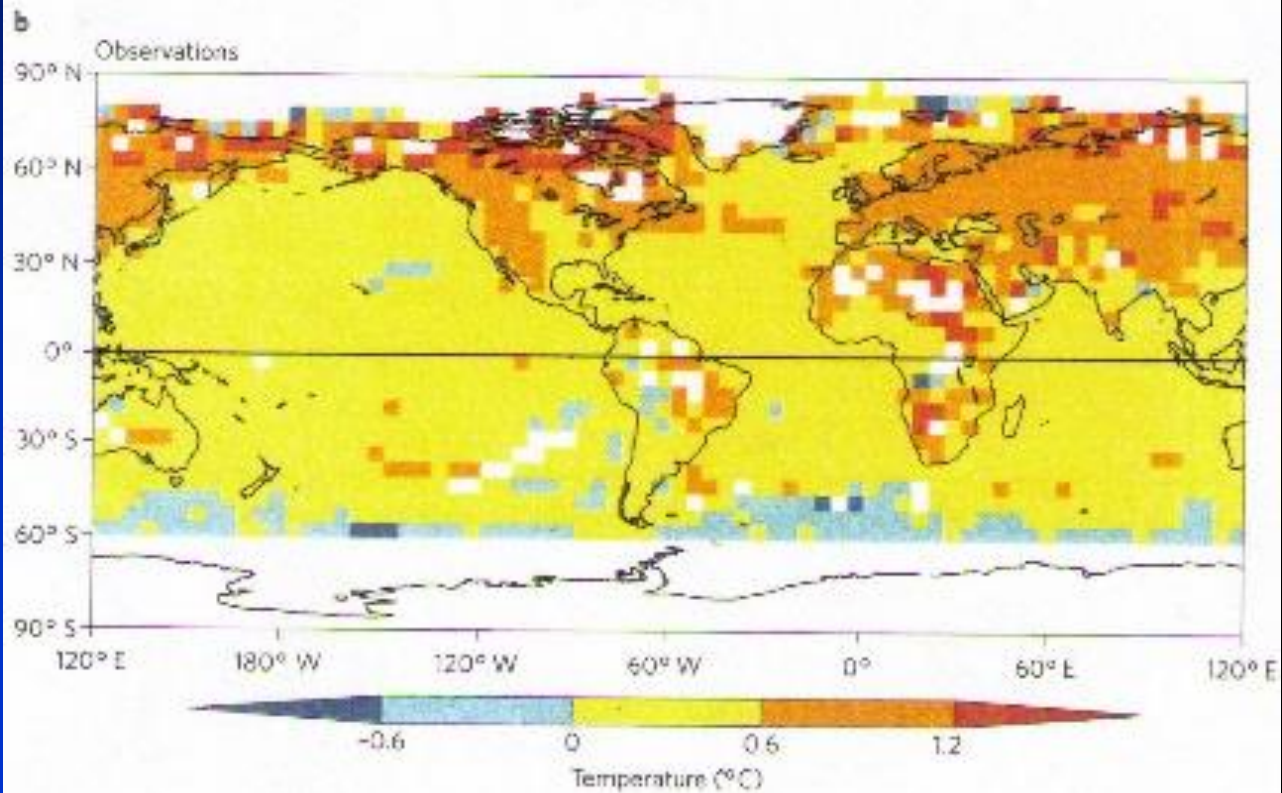
Annual Mean Rate of Precipitation, cm/day



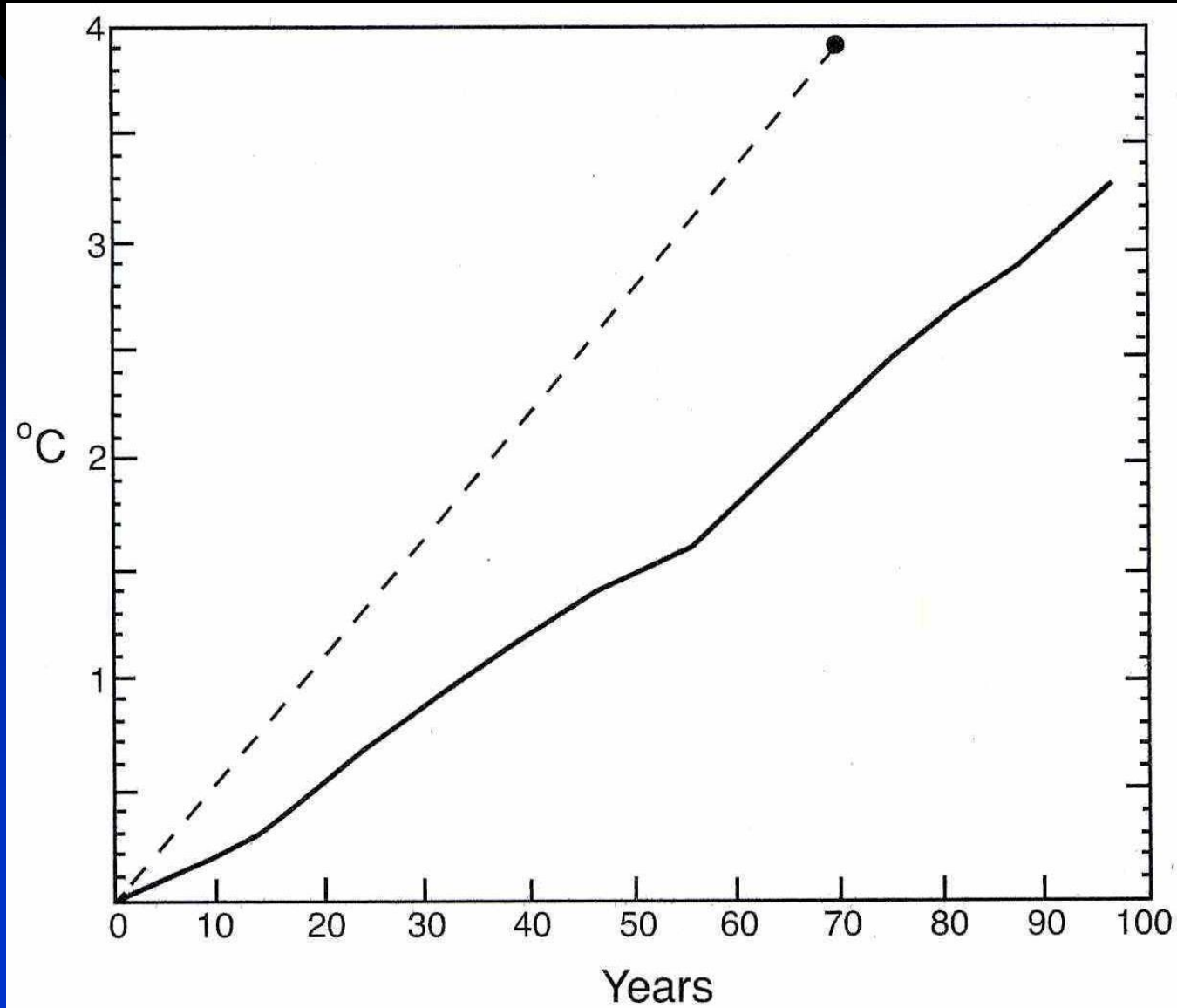
Simulated



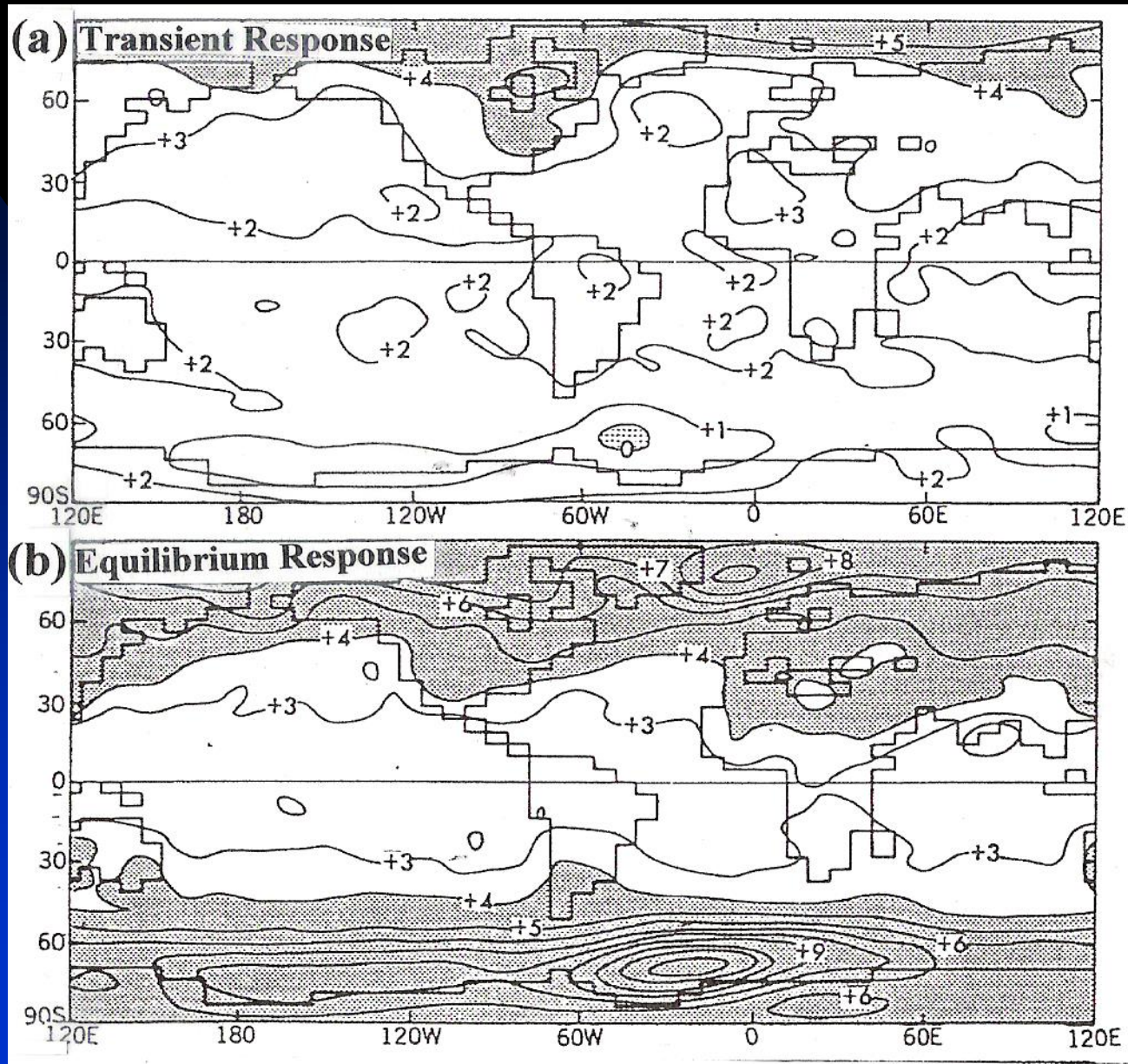
Observed



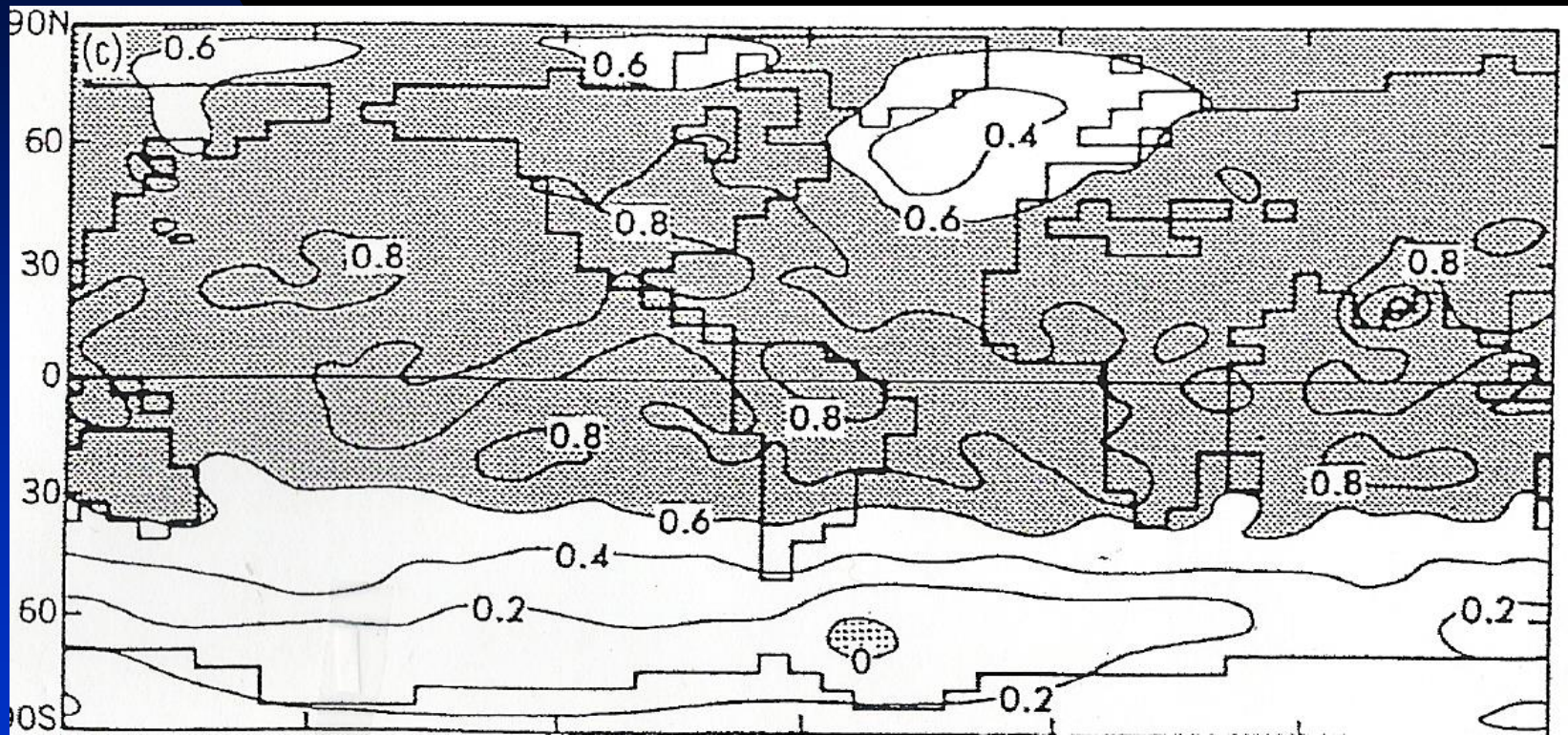
Change in Global Mean Surface Temperature (°C)



Change in Surface Air Temperature, °C



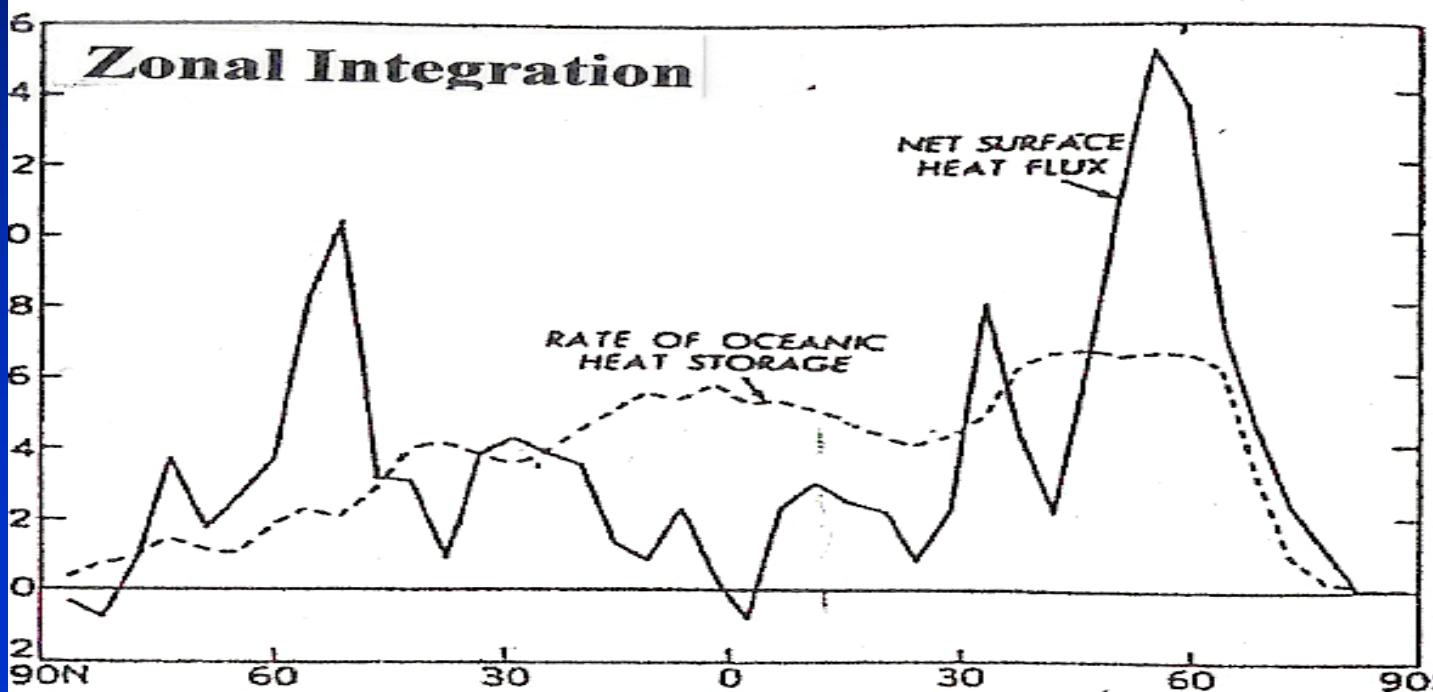
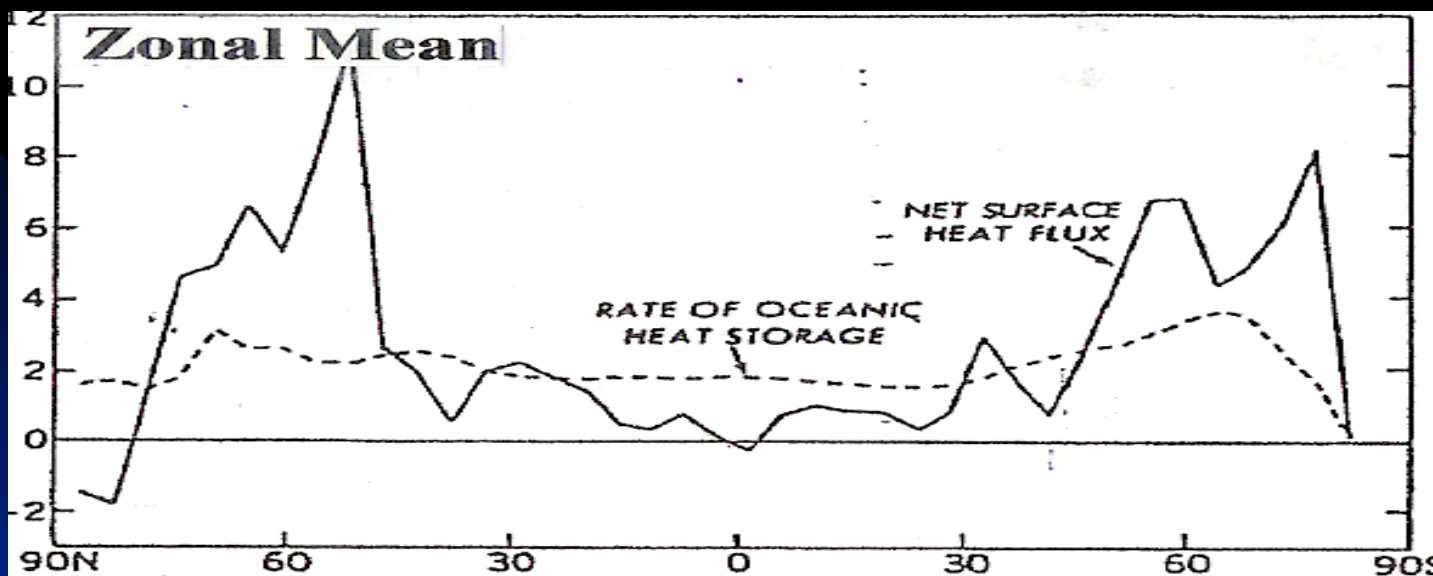
(Transient Response) / (Equilibrium Response)



Change in the Rate of Oceanic Heat Uptake

North

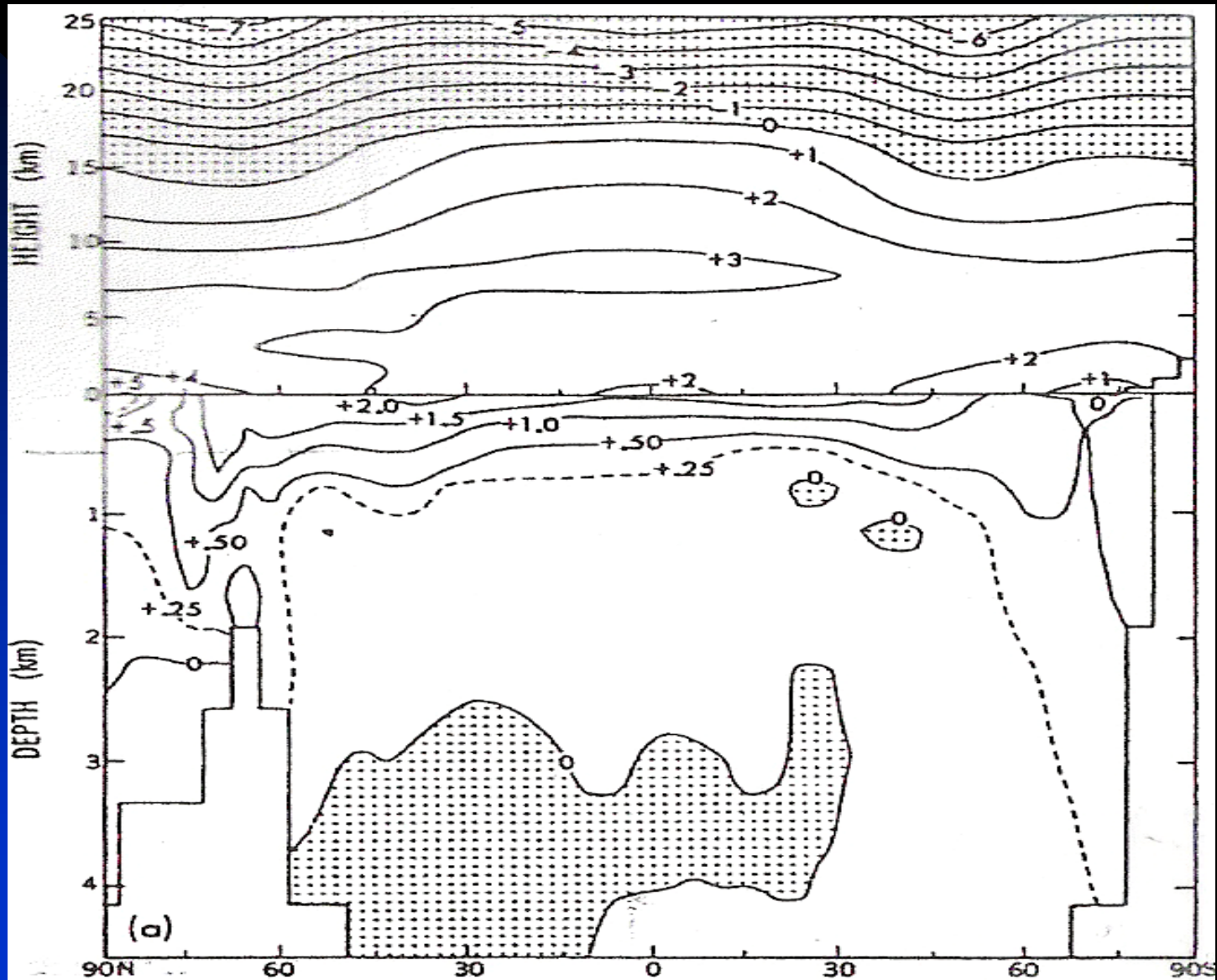
South



Zonal Mean Temperature Change, °C

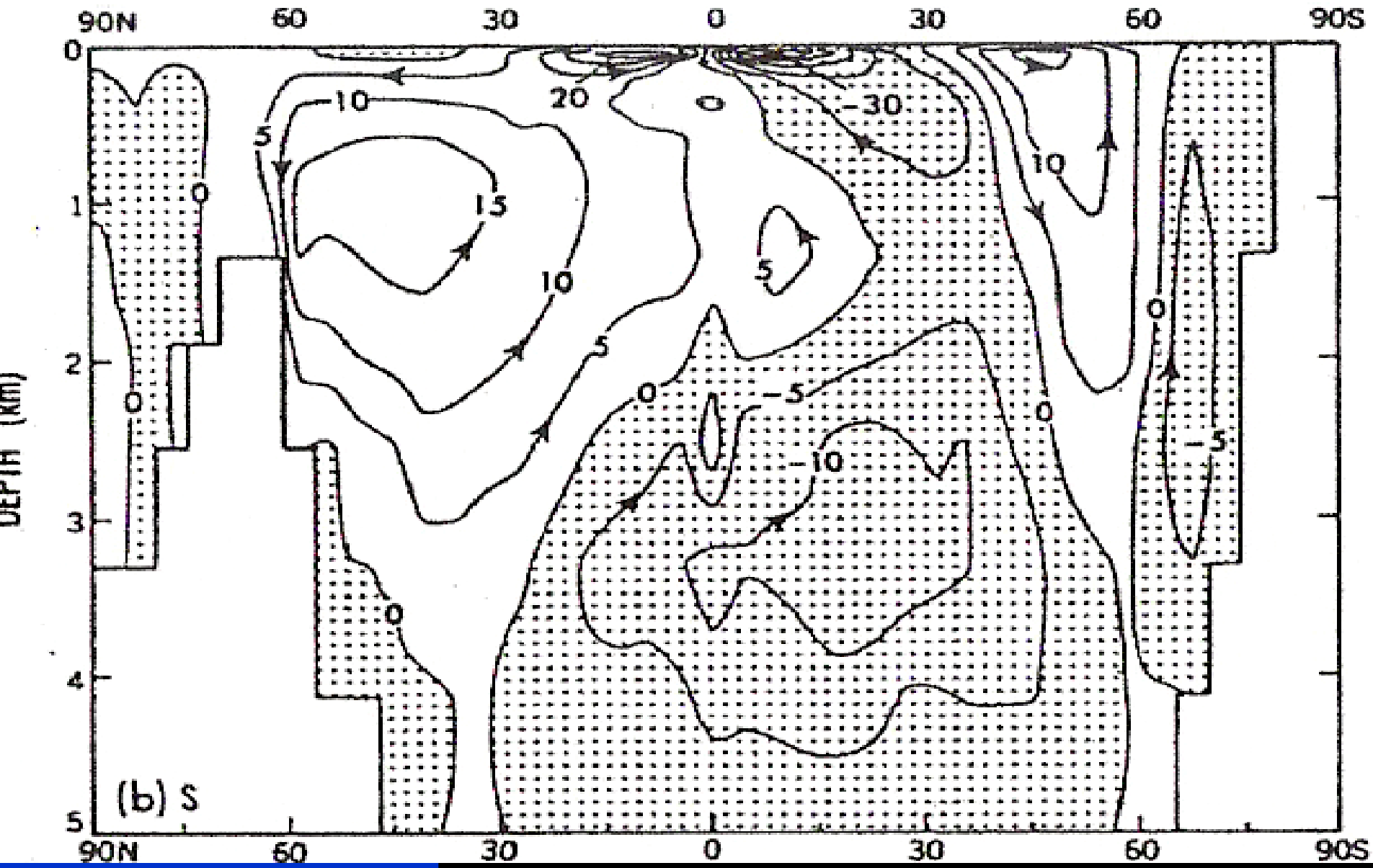
North

South

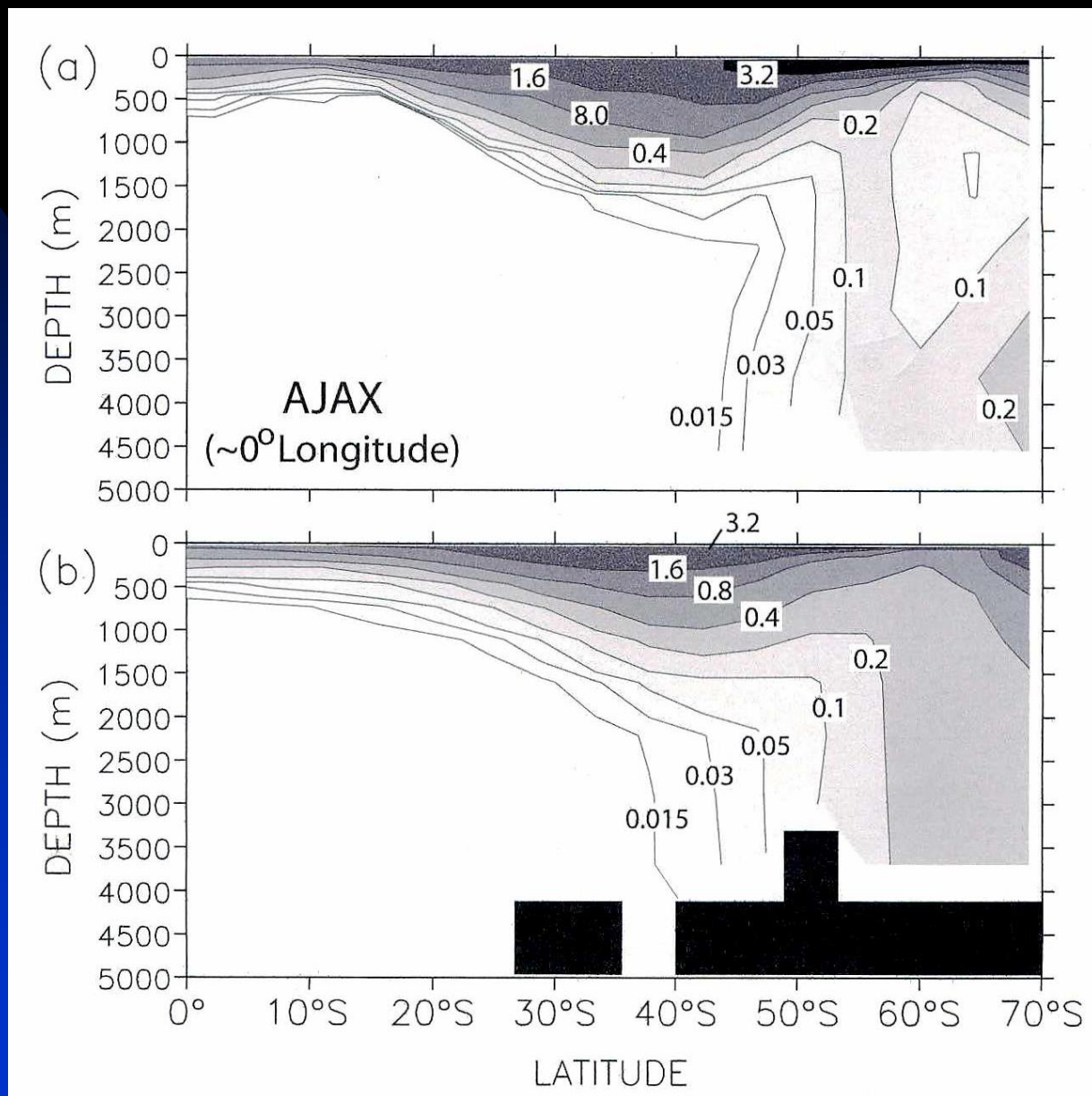


Meridional Overturing Circulation

North South

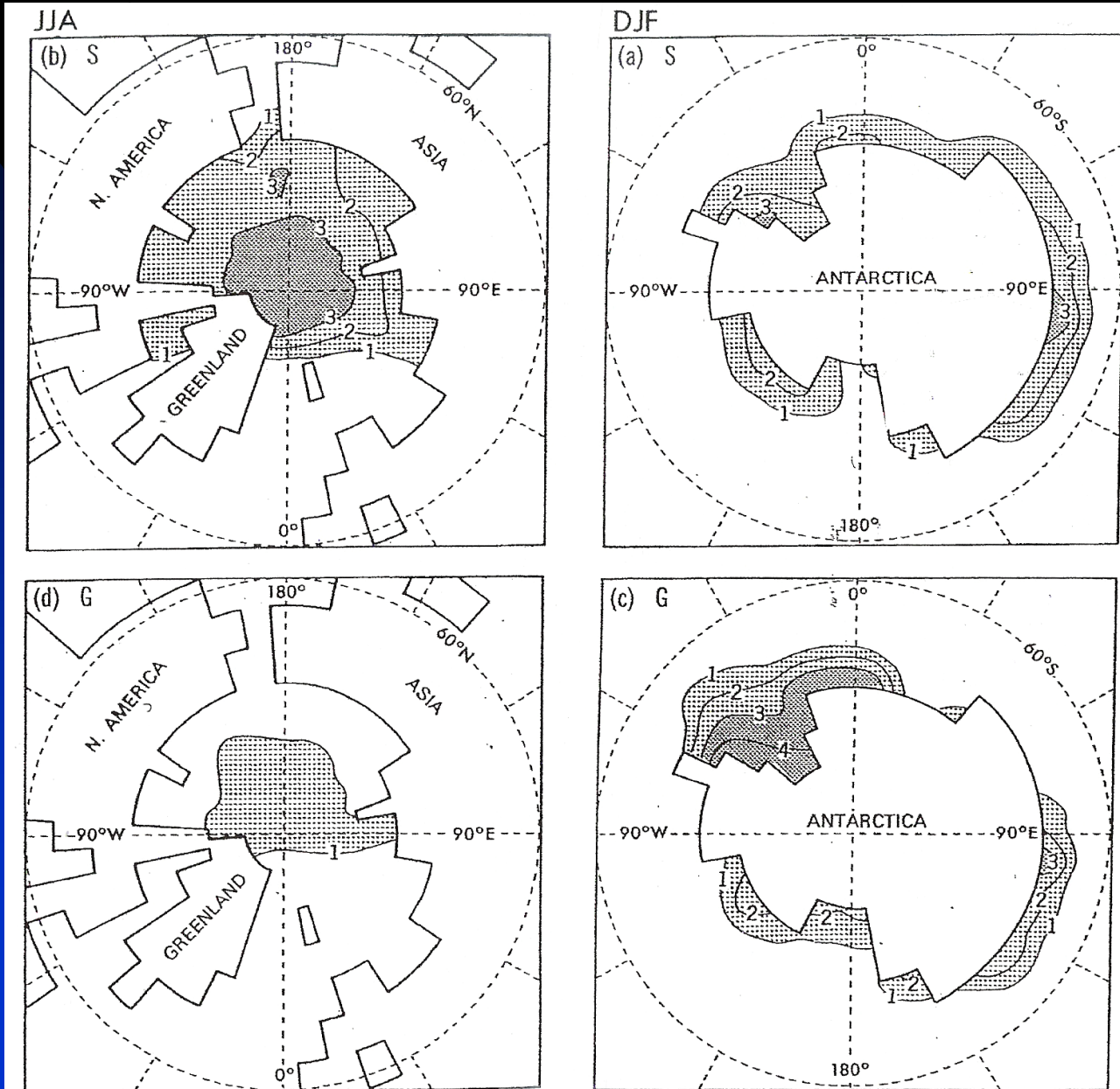


Simulation of CFC, Dixon, Bullister et al., 1996

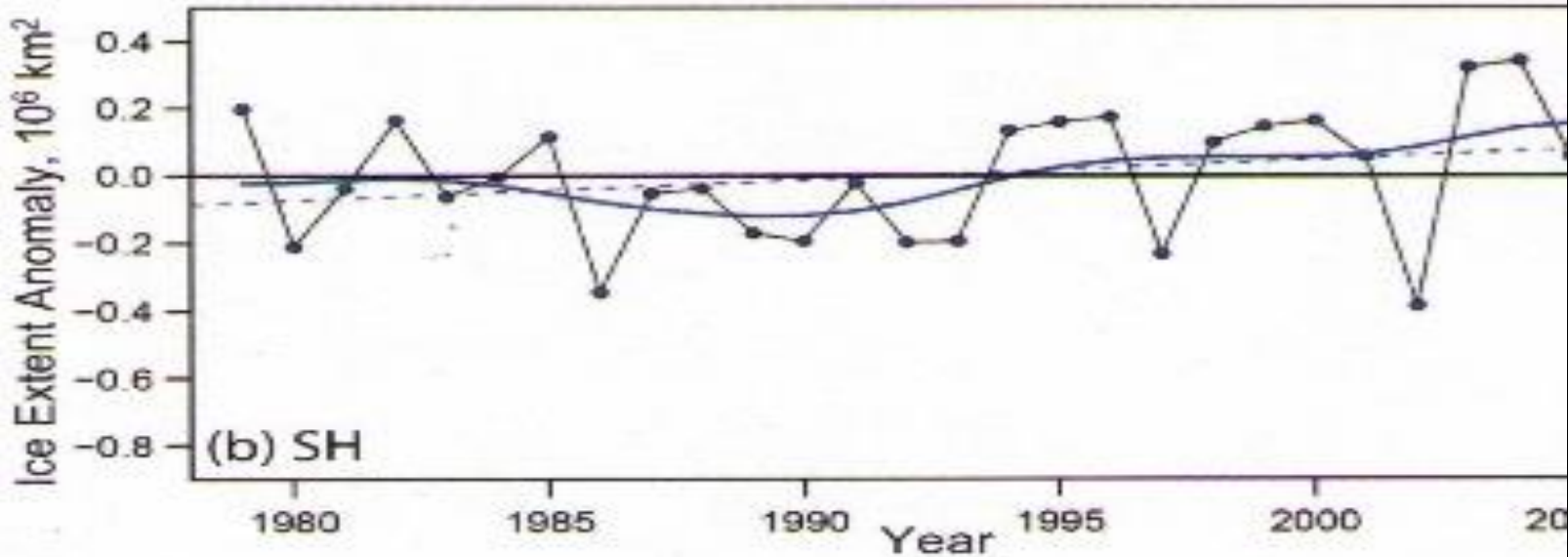
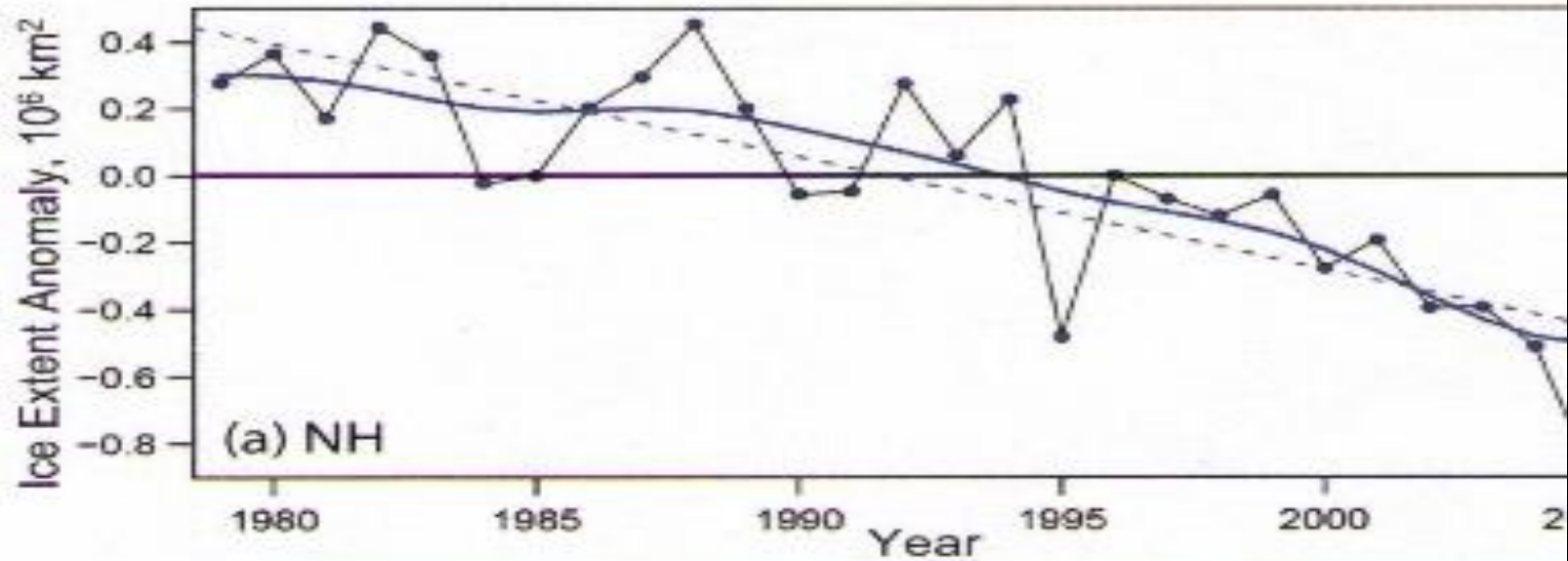


Sea Ice Thickness (m) in Summer

Arctic Ocean, JJA Antarctic Ocean, DJF



Area Coverage of Sea Ice



Conclusion

Deep penetration of heat is mainly responsible for the absence of warming poleward of 50°S in the Southern Ocean

→ Interhemispheric Asymmetry
in Global Warming

Disolution of CO₂ into Ocean

- $\text{CO}_2 + \text{H}_2\text{O} + \text{CO}_3^{-2} \rightarrow 2\text{HCO}_3^{-2}$
- $\text{CaCO}_3 \rightarrow \text{Ca}^{+2} + \text{CO}_3^{-2}$

Sarmiento et al., 1998, Nature