1. The upper panel of Fig. 1 shows annual-mean SST (black contours at 1°C intervals; contours of SST greater than 27°C thickened) and precipitation (white contours at 2 mm day^{-1}; shade > 4 mm day^{-1}); the lower panel shows surface wind stress vectors (N m^{-2}) and the 20°C isothermal depth (contours at 20 m intervals; shade < 100 m). Based on Fig. 1 and dynamics, describe **concisely** the **main features** and **primary causes** of the following: [total 30 points]

a. the heating (radiative and latent) and circulation in the tropical atmosphere [10pt]

b. the SST distribution (equatorial warm pool and cold tongue, coastal water in the eastern and western boundary of Pacific) [10pt]

c. the thermocline (D20) distribution [5pt]

d. the upper ocean circulation (Ekman and geostrophic currents) [5pt]

2. Figure 2 shows the sea-level pressure in the El Nino condition. [total 20 points]

a. Mark on Fig. 2 where convergence and divergence occurs and describe concisely the Walker and Hadley circulation based on the figure and dynamic arguments. [10pt]

b. Describe qualitatively the changes in SST, wind, D20, and precipitation from the climatology shown in Fig. 1 [10pt]

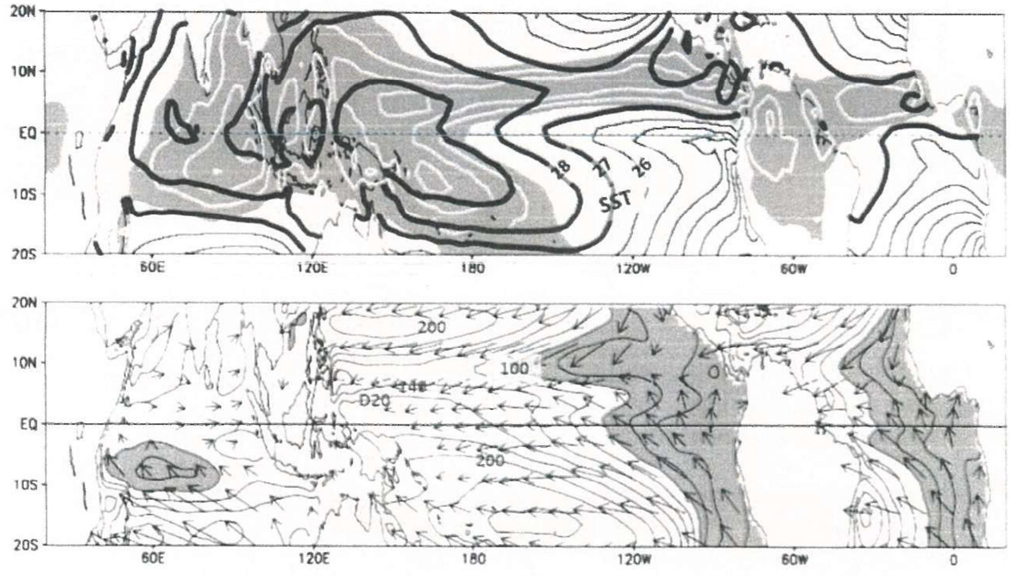

Fig. 1

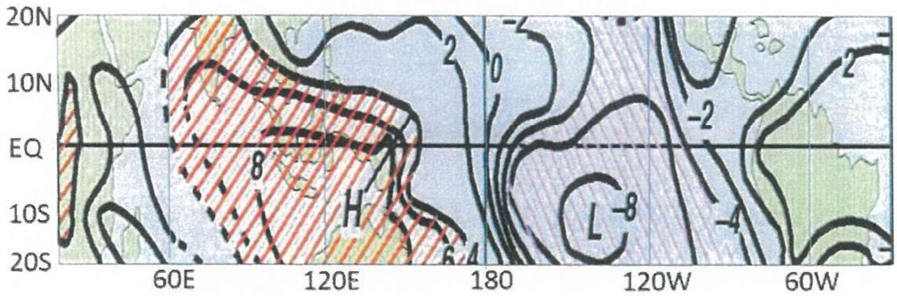

Fig. 2

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3. Consider the physical processes in the Hadley circulation. [total 25 points]

a. Sketch the vertical structure that represents the environment of the **deep convection region** in terms of moist static energy (h), saturation moist static energy (h*), and dry static energy (s) from the surface to the bottom of the stratosphere. Be careful about the detailed relationship between the state variables and their quantitative values (in terms of temperature [K]). [10pt]

b. Same as a), sketch the vertical structure for the environment of the **shallow convection region**. [10pt]

c. Please discuss how convection may change under the global warming scenario. (Discuss one potential mechanism in detail). [5pt]

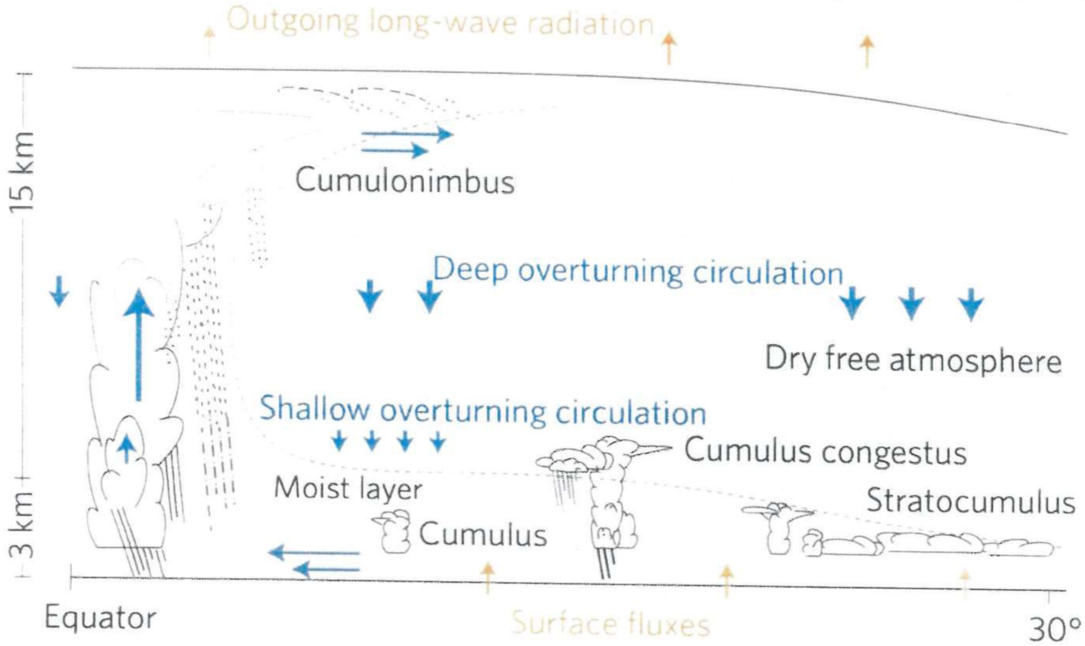

Fig. 3 Schematic diagram of convective processes associated with Hadley circulation.

4. Consider the global energy balance [total 25 points]

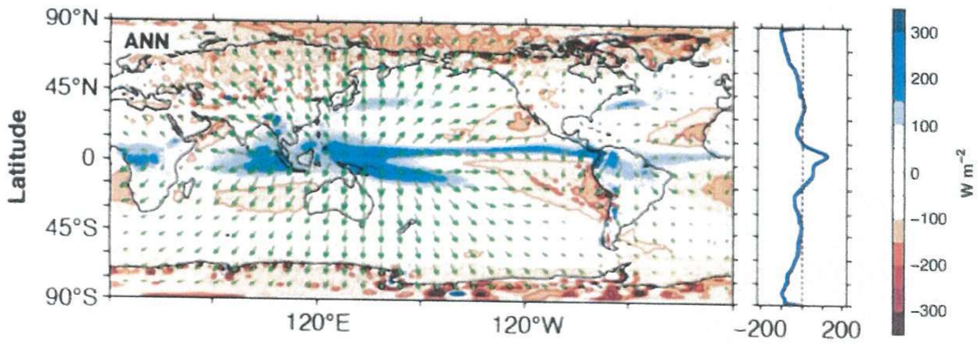

Fig. 4 The annual mean dry static energy budget.

a. Starting from the moist static energy budget and moisture budget, write down all of the energetic terms (e.g., energy fluxes) that would affect globally averaged dry static energy. Be clear about the definition of positive and negative signs. [10pt]

b. Under global warming, deep tropical high clouds tend to rise and maintain a similar temperature. With the help of a.), discussed how raising high clouds with global warming in deep tropics affects global mean precipitation. [5pt]

c. Consider the effects on the ocean, discuss how decreasing surface wind speed will modify the oceanic mixed layer depth, and why? [5pt]

d. Consider all factors listed in question a), most climate models project an increase in global mean precipitation (about 2~3% per K); however, the increase is smaller than what one would expect based on the Clausius-Clapeyron relation (about 7% per K). Due to this constraint, tropical circulation tends to slow down. Do you think the change in the mixed layer depth discussed in c.) would be positive or negative feedback for global warming, and why? [5pt]

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