1. **Global mean temperature**

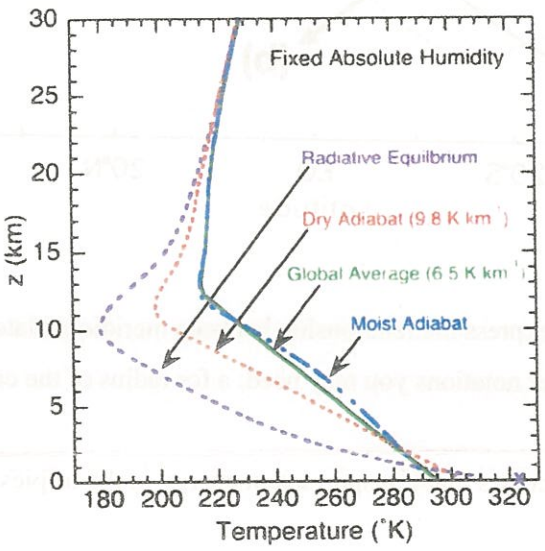
(1) Please calculate total solar irradiance (i.e. solar constant), the irradiance of the solar emission at the mean distance of the Earth from the Sun. (solar luminosity is $3.9\times10^{26}W$, the mean distance of Earth from the Sun is $1.5\times10^{11}m$) (5%)

(2) Please calculate the emission temperature of Earth. (Earth has an albedo of about 0.29, Stefan-Boltzmann constant is approximately $5.67\times10^{-8}W\cdot m^{-2}\cdot K^{-4}$) (5%)

(3) Please list out three factors that influence the emission temperature of Earth and explain how. (5%)

(4) Is the global mean surface air temperature higher or lower than the emission temperature? Why? (5%)

2. **Vertical structure of temperature**



(1) Please list out the two main factors shaping the vertical distribution of temperature in the troposphere and describe the relative mechanisms in details. (10%)

(2) Please list out the two main factors shaping the vertical distribution of temperature in the stratosphere and describe the relative mechanisms in details. (10%)

(3) How may surface temperature and vertical temperature structure change with global warming? Why? (Hint: Please discuss how may the mechanisms you describe in questions (1) and (2) change as the climate warms.) (10%)

The equation below can be obtained by Schwarzchild's equation, which is a simple model that describes longwave radiation in the atmosphere. It assumes a plane, parallel atmosphere, and the properties of the atmosphere depend only on altitude. The term on the left is upward longwave intensity at some height z, at a zenith angle defined by μ (μ= cos θ, θ is zenith angle), where the optical depth is $\tau_\nu(z)$. τ_ν' is a dummy variable of integration. $B_\nu(T)$ is black body emission for temperature T.

$$I_\nu(\tau_\nu(z),\mu)=I_\nu(0,\mu)\ e^{\{-\tau_\nu(z)/\mu\}}+\int_0^{\tau_\nu(z)}\mu^{-1}B_\nu\left(T\left(\tau_\nu'\right)\right)\ e^{\{(\tau_\nu'-\tau_\nu(z))/\mu\}}\,d\tau_\nu'$$

(4) Please describe the two terms on the right hand side with a schematic and a few words. (5%)

(5) How may clouds influence longwave radiation at the top of the atmosphere? (Please use the equation above for the explanations.) (5%)

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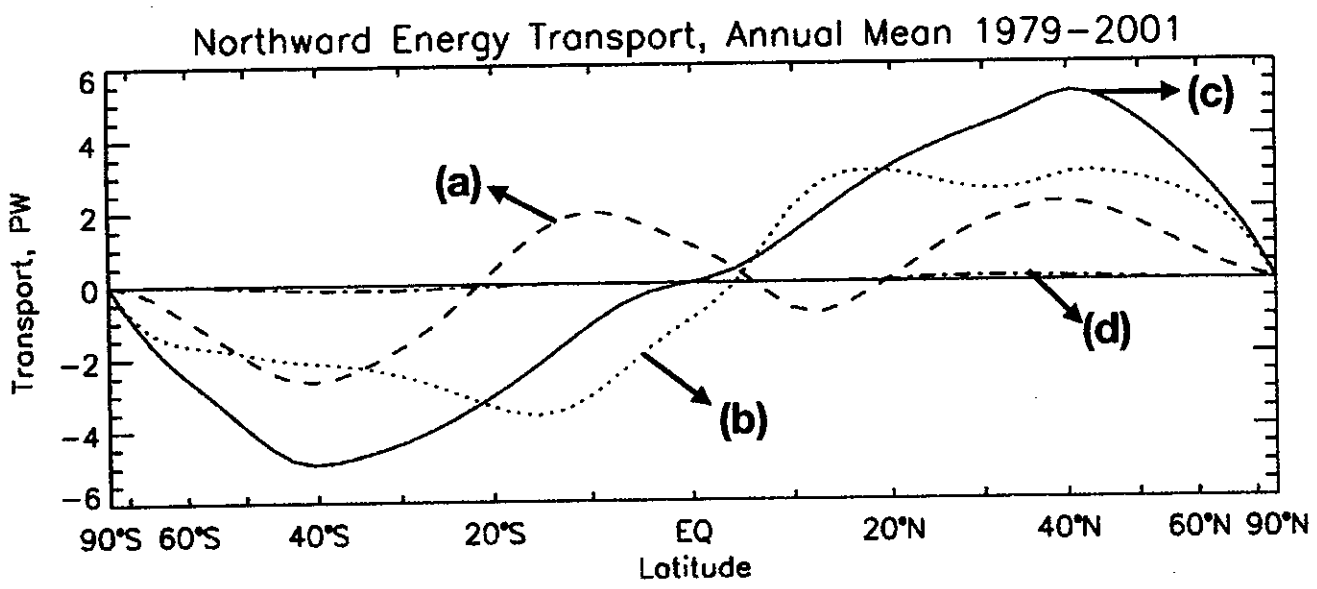
3. Meridional energy transport

(1) Which line in the figure below is northward latent heat transport? (5%)



(2) Use a mathematical equation to express the relationship between meridional latent heat transport (LHT), evaportranspiration (E), and precipitation (P). (Some other notations you may need: a for radius of the earth, Φ for latitude, and λ for longitude.)

LHT (Φ) = (5%)

(3) Describe concisely the main processes that transport latent energy in the tropics and in mid-latitudes (5%)

4. Meridional momentum transport

(1) Please sketch zonal mean zonal wind as a function of pressure and latitude. (5%)

(2) What is the latitude of subtropical jets in current climate? Why? (5%)

(3) What is the latitude of eddy-driven jets? Why? (5%)

(4) What is Northern Annular Mode (i.e. Arctic Oscillation)? Please describe the mechanisms maintaining the positive/negative phases of the mode. (5%)

(5) How may zonal mean zonal wind change as the climate warms? Why? (5%)

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