

1. Please consider global water volumes and global water cycle of Earth in Table 1 and Fig. 1 to answer the following questions (20 points)
- (a) Estimate the recycling rate of atmospheric moisture.
 (b) Estimate the residence time of oceans, atmospheric water, and river.

Figure 1 Schematic diagram showing the fluxes of water in the global hydrological cycle. Units are cm/year over the area of the land or ocean. Note the land-ocean water exchanges by atmospheric transport and river runoff have different values depending on the reference area, as indicated by the parentheses.

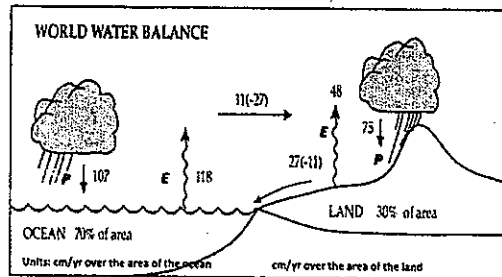


Table 1 Water volumes of Earth

Category	Volume (10^6 km^3)	Percent
Oceans	1348.0	97.39
Polar ice caps, icebergs, glaciers	227.8	2.010
Groundwater, soil moisture	8.062	0.580 ^a
Lakes and rivers	0.225	0.020
Atmosphere	0.013	0.001
Total water amount	1384.0	100.0
Freshwater	36.00	2.60

2. From the global mean energy balance shown in Fig. 2 below, (20 points)

- (a) estimate the radiative heating of the TOA, surface, and the atmosphere;
 (b) with additional measurements of the global mean OLR and absorbed solar radiation over cloud free areas (266 and 288 Wm^{-2} , respectively), estimate the planetary albedos for the global mean and global cloud free areas, cloud forcing in OLR and SW, and the atmospheric greenhouse effect;
 (c) discuss how diurnal variations contribute to the time mean energetic.

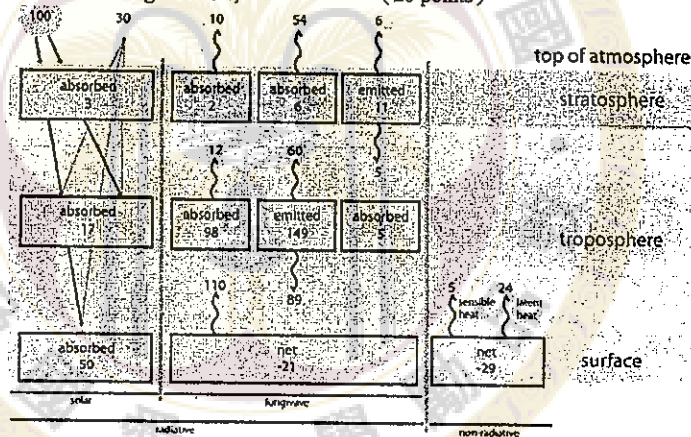


Figure 2 Radiative and nonradiative energy flow diagram for Earth and its atmosphere. Units are percentages of the global-mean insolation ($100 \text{ units} = 342 \text{ Wm}^{-2}$)

3. From the observed zonal-mean flow in the troposphere (Fig. 3) and your knowledge of atmospheric general circulation, (20 points)

- (a) discuss the flow of angular momentum from Earth through the atmosphere and back to Earth;
 (b) The tropical easterlies and mid-latitude westerlies occupy about the same surface area of Earth. Would you expect the surface westerly winds to be stronger, weaker, or about the same as the surface easterlies? Explain your answer with physical arguments.

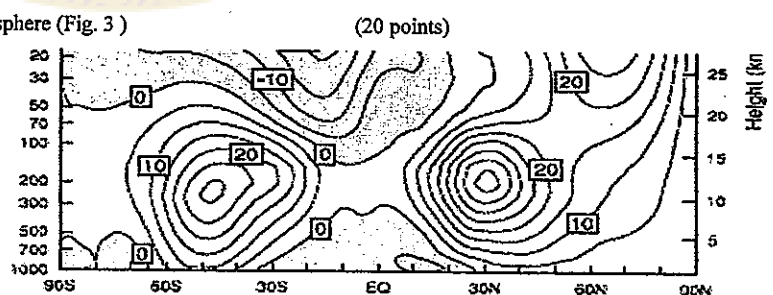


Figure 3 Latitude-height cross section of zonal-average wind speed for DJF. Contour interval is 5 m s^{-1} . Easterly values are shaded

4. Consider the wind-driven overturning circulation that occurs mostly in the thermocline or above it in global oceans, (20 points)
- (a) describe the common features of the circulation, and the responsible dynamics;
 (b) discuss the role of the circulation in global energy balance.
5. Climate oscillates at various time scales. Coupled ocean-atmosphere processes are known to cause interannual to interdecadal climate variability. Please describe the key processes in the ocean and atmosphere that are central to produce the long time scales in the coupled ocean-atmosphere. (20 points)