APPENDIX

E

Answers to Selected Exercises

CHAPTER 1

2. For a mean temperature of 260 K, 69% is below you.
3. If $T_s = 288\text{K}$, $\overline{T} = 260\,\text{K}$, p_s =1013.25 hPa, $\Gamma = 6.5$ K km^{-1}, then $T = 223$ K and $p = 272$ hPa.
4. If H increases from 7.6 km to 7.76 km, then p increases by ~6.9 hPa.
5. 6.11 hPa at 273 K for both. At 30°C = 303 K. 13.4 hPa for (1.10) and 43.7 hPa for (1.11). The linearization is not so good for such a big temperature change.

CHAPTER 2

1. For Jupiter, $S_0 = 1361\,\text{W m}^{-2} \times (150/778)^2 = 50.6\,\text{W m}^{-2}$, and $T_e = 101.7$ K. Since the observed emission from Jupiter is greater than this, it must have an internal heat source.
2. 233 K.
3. 271 K.
4. 255 K.
6. 42.8° summer, 81.3° winter at 47°N; 40.75° summer, 65.88° winter at 26°N.
7. $\theta_s = \varphi - \delta \pm 15°$ at noon: 1098 W m^{-2} (38.55°) North face, 1358 W m^{-2} (8.55°); South face in summer, 156 W m^{-2} (85.45°); North face, 814 W m^{-2} (55.45°); South face in winter.
8. 303 K conducting, 361 K nonconducting. For the nonconducting case, you need to move the ring out to a distance that is $\sqrt{4}$ times its current distance to get the same emission temperature of 255 K on the inside of the ring.

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CHAPTER 3

1. 30 km.
2. 2.7 K day^{-1}, 5.1 K day^{-1} above, and 0.48 K day^{-1} below.
5. $T_s = \sqrt[4]{2.1}\,T_e$, $T_2 = \sqrt[4]{1.7}\,T_e$.
6. The model convective adjustment flux is 159 W m^{-2} from surface to the lower layer, 172 W m^{-2} from lower layer to the upper layer; net surface longwave loss is 80.5 W m^{-2}.
8. 194 K, 21 km.

CHAPTER 4

1. 270 W m^{-2}, 26 W m^{-2}.
2. For an isothermal hydrostatic atmosphere to warm at constant pressure requires $c_p \Delta T (p_s/g)$ J m^{-2}. To raise it up requires $R\Delta T(p_s/g)$, so the ratio is R/c_p. To show this, start from $PE = \int_0^\infty gz\,\rho\,dp$ and use the fact that the atmosphere is assumed isothermal and hydrostatic. You might also need to know that $\int_0^1 \ln p\,dp = -1$.
4. 5.4 W m^{-2} K^{-1} longwave; 12 W m^{-2} K^{-1} sensible flux.
5. 50.5°C asphalt, 43.5°C concrete.
6. 50.5°C dry asphalt; 33°C wet asphalt for $B_e = 0.25$.

CHAPTER 5

1. The average depth of groundwater on land is a whopping 52.7 m. For a land precipitation rate of 0.75 m year^{-1} it takes 69 years; if only 10% of the runoff is available (0.027 m year^{-1}) it takes 1952 years.
2. (a) 1.2 mm day^{-1}, (b) 0.3 mm day^{-1}, (c) 7.8 mm day^{-1}, (d) 1.7 mm day^{-1}
3. B_e(0°C) = 0.48, B_e(15°C) = 0.20, B_e(30°C) = 0.07.

CHAPTER 6

4. −54 m s^{-1} (Easterly).
5. OK you need to use the fact that the total amount of angular momentum transferred between the Earth and the atmosphere must be zero and that the moment arm is larger in the tropics. It is given that the area over which the wind stress is applied is the same for easterly and westerly and you can assume that the transfer coefficient is about the same.

6. $w = -2 \times 10^{-4}$ m s^{-1}.
7. To increase the net radiation from −20 to +20 W m^{-2} requires an albedo decrease of about 0.1 if the insolation is 400 W m^{-2}. If the surface warms up, you can use the Stefan–Boltzmann emission law to estimate how much more outgoing longwave radiation (OLR) you will lose, but if the air also moistens once you switch on the precipitation, you might get a stronger greenhouse effect and evaporation can help to cool the surface.

CHAPTER 7

1. Need $S \approx 35‰ \approx$ average.
2. ~13 m of sea ice if you choose an initial salinity of 30.5‰.
3. Would reverse the poleward heat transport.
4. Brings salty water (mostly below the surface where it is not freshened by rainfall) to a region where it can be cooled or where sea ice can form.
5. $\rho_t = 22.5$ becomes $\rho_t = 28.2$.
6. $c_w \, \Delta T = L(d/D)$ about 4.5% of the water mass would have to evaporate (or freeze), so the salinity would increase by 4.7, to be 36.6‰, for a potential density anomaly of about 30.

CHAPTER 8

1. In each case, the intermediate variance seems to peak on the eastern, downstream part of the high-frequency variance maximum.
2. It seems likely that this is related to the topographic barrier of the Andes and the Palmer Peninsula, or perhaps also the topography of Antarctica. The convective heat source in the tropical western Pacific also sends Rossby waves in this direction.
3. The Indian Ocean is the farthest from topographic barriers and the meridional gradient of sea surface temperature (SST) is larger there, too. The NH has two oceans and two major topographic barriers, Eurasia and North America.
4. This has to do with the vorticity balance of Rossby waves. The westward propagation associated with the beta effect becomes stronger relative to the eastward advection of relative vorticity as the zonal wavelength gets longer.
5. To explain why latitude shifts are more persistent than jet strengthening and weakening is an advanced topic in atmospheric dynamics, but it has to do with how the meridional propagation of Rossby waves depends on the jet structure.

6. The heat sources are over the warmest SST, but the waves can propagate freely over a greater range of longitudes, and the biggest amplitude waves tend to be the ones with the longest zonal wavelengths that span the globe.
7. Colder, denser water of the same depth would create larger pressure at depth, so the pressure is high in the east and low in the west. If the wind stress stopped, the water at depth would want to go west and the warmer surface water would go east to weaken the pressure gradient at depth.
8. A big MJO event would create equatorial westerly wind anomalies on the equator west of the OLR anomaly. These westerlies would push the warm surface water toward the east, like what happens in an El Niño.

CHAPTER 9

3. The decreased CO_2 and CH_4 during the ice ages explains about half of the cooling then.
5. It is about 0.13 Sverdrups, or about 10% of the deep-water formation rate.
6. If you mix 2 Sverdrups of 35‰ water with 0.13 Sverdrups of fresh water, you get a salinity of 32.9‰.
7. 38% of 10^{19} kg would have to melt in 100 years.

CHAPTER 10

3. $\lambda = \sqrt[4]{N+1}/4\sigma T_e^3$.
4. The static stability will increase more than the meridional gradient.
6. The more the heat transport weakens the temperature gradient, the more sensitive the ice line position is to global mean temperature change, and the more sensitive the climate.

CHAPTER 11

1. (a) $T_s = -2°C$, SH = 230 W m^{-2}, (b) $T_s = -23.9°C$, SH = 44 W m^{-2}, (c) $T_s = -27.6°C$, SH = 17 W m^{-2}. Derive $T_s = \left[(k_I T_b / h_I) + CT\right] / \left[C + (k_I / h_I)\right]$, where $C = c_p \, \rho C_{DH} U_r$.
3. (a) 9.1 m, (b) 4.6 m.
7. Hudson's Bay is ice-free longer and stores more heat in the summer. In winter, this stored heat is released and keeps it warmer then. It is only about 100 m deep, but that is still a lot of stored heat.

CHAPTER 12

2. The emission temperature would have to be reduced by a factor of $\sqrt[4]{0.7}$ to 233 K, and the greenhouse effect increased to 222 W m^{-2}. The emission level would have to rise 3.7 km to make the emission temperature 22 K colder.
3. 2% annual mean, 40% at summer solstice.
4. The difference is about 110 W m^{-2} or 23%, with two-thirds from precession and one-third from obliquity.

CHAPTER 13

1. 1°C, 4°C, 25%.
3. About 4°C.
4. $\varepsilon = 10^{-4}$, $T_{\text{Strat}} = 275.2\,\text{K}$ when $\varepsilon = 1.12 \times 10^{-4}$.
5. Using the approximation (13.10), 32.5 years. If the forcing is held steady after that, the two cases equilibrate at 2.6 K and 1.3 K of warming.