# Answers to Questions

## Chapter 1

1.9 23.7 day

1.11 10 m

1.12 $-1°C\ m^{-1} = -1,000°C\ km^{-1}$, a very strong inversion!!

1.13 $p \simeq 800$ hPa and $\rho \simeq 1.00$ kg $m^{-3}$.

1.16 $\simeq$20%

1.17 8 km

1.18 The average mass per unit area of water vapor is $\sim$30 kg $m^{-3}$ rather than 100 kg $m^{-3}$ as stated in the text. Using this more realistic value yields a depth of $\sim$3 cm.

1.19 8 km

1.20 $1.18\times10^{11}$ kg $s^{-1}$

1.21 2.46 mm $s^{-1}$

## Chapter 2

2.8 1.5 $\times10^{11}$ kg $s^{-1}$ for the Gulf stream versus $1.18\times10^{11}$ kg $s^{-1}$ for the Hadley cell

2.9 1.7 mm day

2.10 78 m

2.15 (a) $\sim$700 years, (b) $\sim$300 years

2.16 The concentration of $CO_2$ would increase to 1567 ppm, roughly 4 times its current value. The concentration of $O_2$ would drop by $\sim$ 1%.

2.18 $2.36 \times 10^{-3} \times c_0$

2.19 $37 \times 10^5$ Pa; $\sim$3%

2.20 $\sim$0.1 kg $m^{-2}$

2.21 The present mass is $\sim$39% of the mass at the time of the LGM

# Chapter 3

3.19 43.2; 192 J $kg^{-1}$ $K^{-1}$

3.20 $T_v - T \simeq 1°C$

3.22 87.4°C

3.23 3377 $m^3$

3.25 ∼4 m too high

3.26 ∼ 12°C

3.27 5654 m

3.28 0.98°C; 20 m

3.29 A rise of 8.9°C

3.31 1064 m

3.32 $3.8 \times 10$ J

3.33 −86.2°C; 643 hPa

3.34 5.23 kg

3.35 $1.51 \times 10^6$ J

3.37 66°C from the chart versus 64.5 from Eq. (3.54) with $R_d/c_p = 0.286$. The difference is due to the fact that the xhart is based on $R_d/c_p = 0.288$. The actual values of $c_p$ and $c_v$ for dry air are known only within an accuracy of around ±2.5 J $kg^{-1}$ $K^{-1}$.

3.38 (a) $K_m = 0.20H$; (b) $\frac{1}{c_s}\frac{dc_s}{dT} = 0.20\frac{c_v}{R_d T}$

3.39 0.84%

3.40 0.14 g

3.41 33.7°C; 1.15 kg $m^{-3}$

3.42 2.81 hPa; 15.3°C

3.43 6.0 g $kg^{-1}$

3.45 ∼2.5°C

3.46 (a) 5.1 g $kg^{-1}$, 47%, 9.3°C; (b) 5.1 g $kg^{-1}$, 75%, 4.5°C, 288 K, 9.3°C; (c) 4.3 g $kg^{-1}$, 100%, -1.1°C, 290 K, 9.3°C; (d) 847 hPa

3.47 (a) 18°C; (b) 62°C; (c) the equivalent potential temperature ($\theta_e$); (d) ∼20°C

3.48 14°C; 19.8°C

3.53 (a) AB unstable; BC neutral; CD neutral; DE stable; EF stable; FG stable. (b) All layers are convectively unstable except CD, which is convectively neutral.

3.54 (b) 1.17 kg $m^{-3}$

3.58 53.6 J; 146.4 J

3.59 6.93 min

3.60 (a) $K(T_o - T_i)^2/T_i$ (b) 125%

3.61 An increase of 17.3 J $kg^{-1}$.

3.62 An increase of 2.0 J $kg^{-1}$.

3.64 88.7°C

3.65 A decrease of 0.0074°C.

# Chapter 4

4.12 5450 $\mu$m

4.14 0.31 W $m^{-2}$

4.15 0.25 W $m^{-2}$ and 0.06 W $m^{-2}$ reflected

4.16 (a) 0.84 (b) 0.74

4.17 537 W $m^{-2}$; 46.4 MJ $m^{-2}$ $day^{-1}$

4.18 440 W $m^{-2}$; 38.0 MJ $m^{-2}$ $day^{-1}$

4.19 Answer not available yet

4.20 1.4 $\times 10^{-10}$

4.21 (a) 1.7°C (b) 0.91°C

4.23 $3.85 \times 10^{26}$ W

4.27 87 W $m^{-2}$. In contrast, the geothermal energy emitted by the earth is estimated to be $\sim$0.06 W $m^{-2}$.

4.28 Answer not available yet.

4.29 $2.72 \times 10^6$ s (or 31.5 days)

4.30 2.21 sr

4.31 166 K

4.33 289 K

4.34 0.043 °C $s^{-1}$

4.40 $\sim$0.4 $\mu$m

4.41 $\sim$400 m

4.42 (a) 0.054; (b) 0.014; (c) The planetary albedo is 0.163, an increase of 8.9% due to the presence of the aerosol layer.

4.43 1%; 69.4 kg

4.46 46 km

4.47 (a) 80%; (b) 80%; (c) 3.00$H$

4.48 $\theta = 30°$: 8.66 hPa, 47.4 km. $\theta = 60°$: 5.00 hPa, 53.0 km

4.56 2.07

# Chapter 5

5.13 An increase of 4. Oxidized.

5.14 0.600 ppbv

5.15 $\sim$230%

5.17 $v = v_o \exp(-6\pi\eta RT/m)$ The stop distance is $v_o m/6\pi\eta r$

5.18 4 days, 150 years and 9 years

5.19 $\sim$14 days

5.20 (c) $[O_3] = \frac{j[NO_2]}{k_1[NO]}$

5.23 (a) $\frac{1}{2}\frac{d[NO_2]}{dt} = k_1\,[NO]^2\,[O_2]$. Yes, because production of $NO_2$ varies as $[NO]^2$. (b) Reaction (5.17) produces $NO_2$ at a rate $5.8 \times 10^4$ faster than reaction (5.36).

5.24 9 years

5.25 (a) 19 days; (b) NMHC; (c) Because of its long residence time in the troposphere.

5.26 (a) $2O_3 \rightarrow 3O_2$; (b) O (g); (c) $k_1$ for step (i), and $k_2\,[O_3]\,[O]$ for step (ii); (d) Step (ii); (e) $[O] \propto [O_3]\,[O_2]^{-1}$

5.27 $\sim$30% decrease

5.29 (a) If (iia) dominates the net effect is

$$2O_3 + h\nu = 3O_2$$

If (iib) dominates, there is no net effect (the Cl atom in ClO never gets liberated).

(b)

$$\begin{aligned}\frac{d[O_3]}{dt} &= -k_4[Cl][O_3] \\ \frac{d[Cl]}{dt} &= j_2[(ClO)_2] + k_3[ClOO][M] - k_4[Cl][O_3] \\ \frac{d[(ClO)_2]}{dt} &= k_1[ClO]^2[M] - j_2[(ClO)_2] \\ \frac{d[ClOO]}{dt} &= j_2[(ClO)_2] - k_3[ClOO][M]\end{aligned}$$

(c) $[Cl] = \frac{2k_1[M][ClO]^2}{k_4[O_3]}$

(d) $\frac{d[O_3]}{dt} = -2k_1[M][ClO]^2$

(e) $[O_3] \propto t^3$???

5.31 2057

# Chapter 6

6.10 100.6%

6.11 (a) 0.45$\mu$m; (b) 90%; (c) ~0.47$\mu$m

6.13 15 h

6.14 (a) 3.5%; (b) 2.75 cm

6.15 0.0461 N kg$^{-1}$; (b) 1.28°C

6.16 (a) LWC $= 4\pi\rho_l r_e^3 N/3$; (b) LWC $= 2\rho_l r_e \tau_C/3h$; LWP $= \frac{2}{3}\rho_l r_e \tau_C$

6.17 −22.5°C, 12°C; 19°C

6.20 (b) $Q_2 = \rho\left[\frac{R_d T}{\varepsilon e_s} + \frac{\varepsilon L_v^2}{pTc_p}\right]$

6.21 $h = wt - 2g\rho_l SG_l t^2/9\eta$

6.22 1.8 g kg$^{-1}$

6.23 76.3 min

6.24 0.67 mm; 16.4 min

6.25 $\ln\left[1-p\left(V,t\right)\right]=-\frac{V}{\beta}\int_0^{T_t} J_{LS}dT$

6.26 $3\times10^{13}$; 2 mg; 6 mm

6.27 0.5 mm; 7.2 $\mu$g

6.28 2.8 min

6.29 30 min

6.30 1558 J

6.31 $4\times10^{-3}$ mm

6.32 Factors of $10^3$ and $2\times10^6$, respectively

6.33 0.5 mm

6.34 $c\triangle T=w_l\left(10^{-3}L_f\right)+\left(w_s-w_i\right)\left(10^{-3}L_d\right)$

6.35 0.7°C

6.36 ∼480 m

6.38 25.3 km

6.39 3.4 km; 2.72 km

6.40 An increase from 4 to 6. (b) Both increase from 4 to 6.

## Chapter 7

7.7 2.42 cm day$^{-1}$

7.16 (a) $3.11\times10^{-4}$ m s$^{-2}$ and $0.627\times10^{-4}$ m s$^{-2}$. Both are directed upward, radially outward from the axis of rotation. (b) $29.1\times10^{-4}$ m s$^{-2}$ directed downward toward the center of the Earth.

7.17 (b) 126 m

7.18 80 N

7.19 21 m s$^{-1}$ from the west

7.20 $1.57\times10^6$ s$^{-1}$

7.21 19.9 m s$^{-1}$

7.22 $|\mathbf{F}_s|=3.63\times10^{-4}$ m s$^{-2}$, and $|\mathbf{P}|=1.06\times10^{-3}$ m s$^{-2}$

7.26 $9.01\times10^{-4}$ K s$^{-1}$ or 77.8 K day$^{-1}$. The sign is positive, indicative of warm advection.

7.27 Decreasing at a rate of 140 m day$^{-1}$.

7.34 (a) 64.6 m; 1.57 $\times$ 10$^{-5}$ s$^{-1}$ (b) 1.62 $\times$ 10$^{-10}$ and 4.93 $\times$ 10$^{-10}$ s$^{-2}$, respectively; and (c) 7000 km

7.37 $2 \times 10^{-3}$

7.40 $3.02 \times 10^{-5}$ s$^{-1}$

7.43 14.7 m

7.44 120 m s$^{-1}$ from the west

7.45 About a week

## Chapter 8

8.12 62.5 hPa

8.13 25 Pa m$^{-1}$ = 250 hPa km$^{-1}$

8.14 12 m s$^{-1}$

8.15 28 m s$^{-1}$

8.16 36 K

8.17 1.103; 26 K

8.18 396 Pa km$^{-1}$

8.19 1.256°C km$^{-1}$

8.20 208 km

8.21 61 cm

## Chapter 9

9.8 ~0.2°C$^2$

9.10 *Some, but not all, of the answers*: Homogeneous for $u$ wind at 1100 UTC. Stationary for $v$ wind at location B. Isotropic at location A at 1100 UTC.

9.11

(a) 20.21 °C
(b) -0.286 m s$^{-1}$
(c) 13.9 °C$^2$
(d) 4.92 (m s$^{-1}$)$^2$
(e) -1.582 K m s$^{-1}$

9.13 $t_{\text{e-fold}} = 0.32{\cdot}L_\varepsilon{\cdot}(TKE/m)_o^{-1/2}$

9.14 ~10 cm

9.15 (a) $\Delta t = \frac{\Delta z}{2}\left[\frac{P}{\pi v_g}\right]^{1/2}$ (b) $\nu_g = 1.5 \times 10^{-6}$ m$^2$ s$^{-1}$

9.17 (a) 1.87 m s$^{-1}$; (b) −3.06 m; (c) 8.9 min; (d) ~4 m s$^{-1}$

9.19 In kinematic units: (a) 0.1 K m s$^{-1}$; (b) 0.2 K m s$^{-1}$; or in dynamic units, (a) 123 W m$^{-2}$; (b) 246 W m$^{-2}$.

9.22 (b) $z_i = \left[\frac{w_e}{\beta} - \frac{w_e}{\beta} - z_{i_o}\right] e^{-\beta t}$

9.23

$$F_{Hs} = \frac{0.9F^*}{1 + \frac{\Delta q}{\gamma{\cdot}\Delta\theta}} \text{ and } F_{Es} = \frac{0.9F^*}{1 + \frac{\gamma{\cdot}\Delta\theta}{\Delta q}}$$

9.24 513 W m$^{-2}$

9.26 (a) Stable: 0 to 0.1, 1.3 to 1.4, and 1.6 to 1.7 km ; (b) Neutral: 1.4 to 1.6 km ; (c) Unstable: 0.1 to 1.3 and 1.7 to 2.0 km.

9.27 $z_i = 1.6$ km, $\theta = 19$°C.

9.29 Use the Ball ratio, Eq. (9.25) to get the entrained heat flux, knowing $F_{Hs}$. Use Eq. (9.24) with (9.27) to get $F_{Ezi} = -0.2\ F_{Hs}{\cdot}\Delta q/\Delta\theta$.

# Chapter 10

10.7 ~150 W m$^{-2}$

10.10 4.0°C

10.12 10 8 W m$^{-2}$

10.13 355 K

10.14 $6.24 \times 10^{15}$ W

10.15 (a) 46.4 versus 38.0 MJ m$^{-2}$ day$^{-1}$(see also Fig. 10.5)

10.16 (a) 0.53 K; (b) immediately after the eruption, $dT/dt = 1.95 \times 10^{-7}$ K s$^{-1}$ or 0.0186 K day$^{-1}$

10.18 Answer not available yet.

10.19 a factor of 6

The answers to the remaining exercises in this chapter are not available yet.