Montogue

Quiz GY201
Atmospheric *and* Oceanic Science

Basic Problems

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Note: Use Ω = 7.3×10^{-5} rad/s as the rotational frequency of the Earth, unless stated otherwise.

PROBLEMS

Problem 1

Which of the following alternatives lists global atmospheric cells in order of increasing latitude?

A) Polar → Ferrel → Hadley
B) Hadley → Ferrel → Polar
C) Ferrell → Hadley → Polar
D) Hadley → Polar → Ferrel

Problem 2

The Kuroshio current and Gulf Stream:

A) are both western boundary currents.
B) The former is a western boundary current and the latter is an eastern boundary current.
C) The former is an eastern boundary current and the latter is a western boundary current.
D) are both eastern boundary currents.

Problem 3

Equatorial Kelvin and Rossby waves propagate, respectively:

A) westward, westward
B) eastward, westward
C) westward, eastward
D) eastward, westward

Problem 4

What is the geostrophic wind speed for a pressure gradient of 1.3 hPa/100 km and density of 1.2 kg/m^3 at a latitude of 20°?

A) V_g = 2.70 m/s
B) V_g = 5.40 m/s
C) V_g = 10.8 m/s
D) V_g = 15.3 m/s

Problem 5

A cylindrical column of air at 40°N with radius 80 km expands to twice its original radius. If the air is initially at rest, what is the mean tangential velocity (absolute value) at the perimeter after expansion?

A) $|V|$ = 4.38 m/s
B) $|V|$ = 8.21 m/s
C) $|V|$ = 12.5 m/s
D) $|V|$ = 16.7 m/s

▶ Problem 6

In a cylindrical annulus of inner radius 200 km and outer radius 400 km, the tangential velocity distribution is given by $V = A/r$, where A is a constant equal to 10^6 m^2s^{-1} and r is in meters. Find the average vorticity within the inner circle of radius 200 km.

A) $\zeta_m = 1.25\times10^{-6}$ s^{-1}
B) $\zeta_m = 6.25\times10^{-6}$ s^{-1}
C) $\zeta_m = 1.25\times10^{-5}$ s^{-1}
D) $\zeta_m = 5.0\times10^{-5}$ s^{-1}

▶ Problem 7

The depth-integrated Ekman transport velocity for an oceanic flow at 45°N with surface shear stress equal to 0.25 Pa is, most nearly:

A) $U_{Ek} = 1.22$ m^2s^{-1}
B) $U_{Ek} = 2.44$ m^2s^{-1}
C) $U_{Ek} = 4.05$ m^2s^{-1}
D) $U_{Ek} = 6.23$ m^2s^{-1}

▶ Problem 8

Regarding the theories of atmospheric and oceanic dynamics, are the following statements true or false?

1.( ) Suppose that a parcel of air A is mixed with another parcel B. Before mixing, parcel A had temperature of 30°C and vapor pressure of 3.4 kPa, whereas parcel B had temperature of −4°C and vapor pressure of 0.2 kPa. Initially, both parcels were at 100 kPa and each had a mass of air equal to 1 kg. We can surmise that, once the parcels are mixed, the resulting mixture will be saturated.

2.( ) The f-plane and β-plane approximations are used to accommodate the sphericity of the Earth in Cartesian representations of rotating flows. In the β-plane approximation, the Coriolis parameter is written as $f = f_0 + \beta y$, in which $\beta = 2\Omega sin\theta_0/r_0$, where Ω is the rotational frequency of the Earth, θ_0 is latitude, and r_0 is the radius of the Earth.

3.( ) A measure of the Coriolis force per unit mass can be taken as the product of the Coriolis parameter f at a given latitude and the wind speed at the direction of interest. For a region at 50°N with a zonal wind of 12 m/s, the CFUM has absolute value greater than 1.5×10^{-3} m/s^2.

4.( ) Surface Ekman layer theory indicates that wind-driven horizontal transport is oriented perpendicular to the wind stress, to the right in the Northern Hemisphere and to the left in the Southern Hemisphere.

5.( ) An easterly (that is, westward flowing) square-shaped airmass of side equal to 1200 km decreases in magnitude toward the north at a rate of 20 m/s per 400 km. The corresponding circulation is greater (absolute value) than 7.5×10^{-7} m^2s^{-1}.

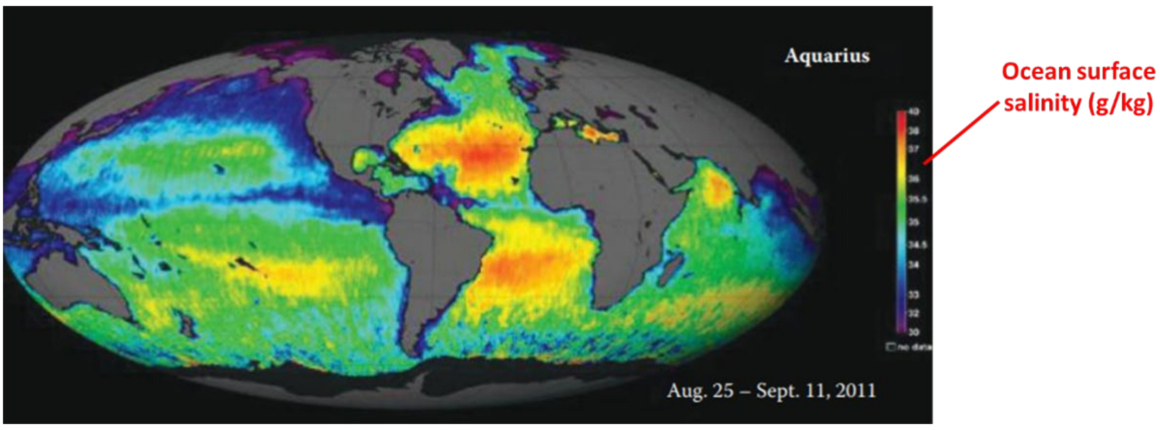
6.( ) An air parcel at 30°N moves northward while conserving absolute vorticity. If its initial relative vorticity is 6.8×10^{-5} s^{-1}, its relative vorticity upon reaching 90°N has absolute value greater than 4×10^{-6} s^{-1}.

7.( ) In a simple scaling scheme, hydrostatic balance is valid if the squared product of depth Froude number, Fr, and aspect ratio, α, is much less than unity; that is, $Fr^2 \times \alpha^2 \ll 1$. For an arbitrary atmospheric system, the buoyancy frequency is 0.02 s^{-1}, the average horizontal flow velocity is 13 m/s, the vertical length scale is 2 km, and the horizontal length scale is 400 km. We can surmise that hydrostatic balance is valid for this system, because $Fr^2 \times \alpha^2 < 1$.

8.( ) A hypothetical ocean current has 40 km width and depth of 200 m. Assuming that the current flows at an average speed of 60 cm/s, we conclude that the current has a flow rate greater than 5.0 Sv (sverdrups).

9.( ) Oceanic water flow in the Kuroshio current in a given time of year has speed of the order of 1.2 m/s and encompasses the region bounded by latitudes 30°N and 33°N. The dynamic viscosity coefficient and the density of seawater in the relevant values of temperature and salinity ($T \approx 25$°C and $S \approx 35$ ppm) are respectively equal to $\mu = 9\times10^{-4}$ Pa·s and $\rho = 1025$ kg/m^3. With these values in mind, we expect flow in the Kuroshio current to be predominantly laminar.

10.( ) The following map shows the global distribution of ocean surface salinity as sensed by the Aquarius satellite in the period of August 25 to September 11, 2011. As can be seen, surface waters in the North Atlantic are generally more saline than those in the North Pacific.



11.( ) The bulk Richardson number and the gradient Richardson number can be used to describe the nature of vertical flow of air in the atmosphere. Specifically, an atmosphere in which flow is predominantly laminar should have negative and large (absolute value) values of Ri_b and Ri_g.

12.( ) The following weather map symbol is used to indicate stationary fronts.

13.( ) In the cloud science community, so-called thunderclouds are usually classified as cumulonimbus clouds.

14.( ) A simplified form of Stokes' law can be used to compute the terminal velocity of a small spherical droplet of radius a,

$$u_\infty \approx \frac{2}{9}\eta_a a^2 \rho_p g$$

where ρ_p is the particle density, $g \approx 9.81$ m/s^2, and η_a is dynamic viscosity. Using this relation, we may conclude that a 50-μm radius particle of water at 25°C will settle at a rate of more than 0.35 millimeters per day. The density of water is approximately 1000 kg/m^3, and the viscosity of water at the temperature of interest is about 0.91 centipoise (1 cP = 10^{-3} Pa·s).

15.( ) For calculation purposes, it is convenient to have simple mathematical equations that describe the droplet spectra of clouds. One of the simplest such models is the Khrgian-Mazin (KM) distribution, which is in fact a special version of the lognormal distribution.

16.( ) Assume the probability distribution of mean wind speeds M can be described by a Weibull distribution,

$$\mathrm{Pr} = \frac{\alpha \times \Delta M \times M^{\alpha-1}}{M_0^\alpha}\exp\left[-\left(\frac{M}{M_o}\right)^\alpha\right]$$

where Pr denotes the probability (or relative frequency) of registering a wind speed $M \pm 0.5\Delta M$. For M_0 = 4 m/s and Weibull modulus $\alpha = 2$, the probability that the wind speed will be between 4.5 and 5.5 m/s is greater than 12%.

17.( ) In an arbitrary location of the northern hemisphere, a wind has just undergone a counterclockwise shift in the compass direction. We can state that the wind has *veered*.

18.( ) The Beaufort scale wind force scale is an empirical classification of wind speed that has found widespread use in practical applications, especially shipping, since it was proposed in the early 19th century. In its most recent version, the Beaufort scale classifies winds in categories (or "Beaufort numbers") 0 to 10. In one extreme, category 0 indicates a windless environment or a very mild breeze; in the other, category 10 indicates hurricane-force windstorms.

19.( ) The International Civil Aviation Organization (ICAO) has adopted a simple standard atmosphere model, known as the International Standard Atmosphere, for use in aeronautical applications. In the ISA framework, the standard mean sea-level temperature is 15°C and decreases linearly with altitude up to 11,000 m. At altitudes greater than 11,000 m, the air temperature is considered constant.

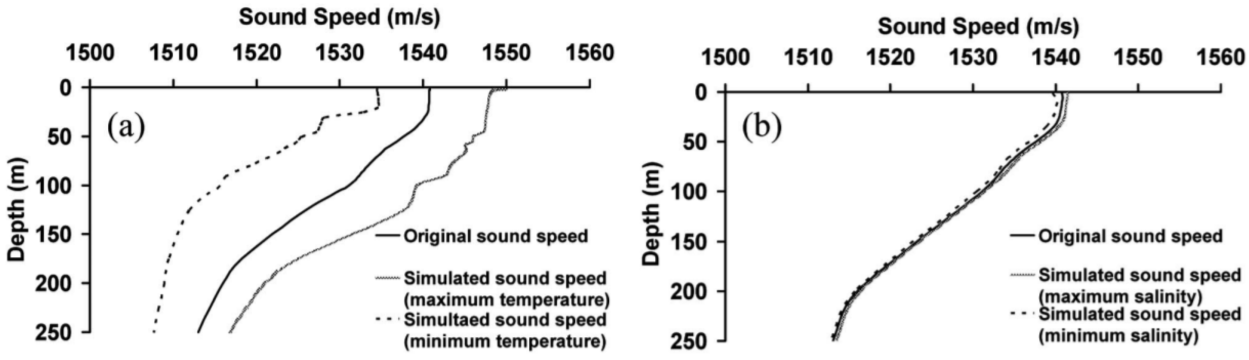
20.( ) Carbon dioxide occupies about 354 parts per million by volume (ppmv) of air. The number of CO_2 molecules in 1 m^3 of air at 1 atm and 0°C is greater than 5.0×10^{21}.

21.( ) The temperatures at the surface of the Earth and the Sun have average values of 288 and 5800 K, respectively. Assuming Wien's displacement law to be valid, the ratio of peak wavelength of emission on the surface of the Earth to that on the surface of the Sun is greater than 15.

22.( ) Observations made over the course of many years have shown that the intensity of solar radiation has not changed substantially with time, at least not in the short- to medium-scale periods employed in applications such as solar energy. For this reason, a quantity known as the *solar constant*, *S*, has been introduced as an approximation for the flux density associated with Sun's electromagnetic radiation. The solar constant is the amount of solar radiation incident per unit area and per unit time on a surface normal to the direction of propagation; the surface is arbitrarily situated at the Earth's mean distance from the Sun. The value of the solar constant is about 3610 W/m^2.

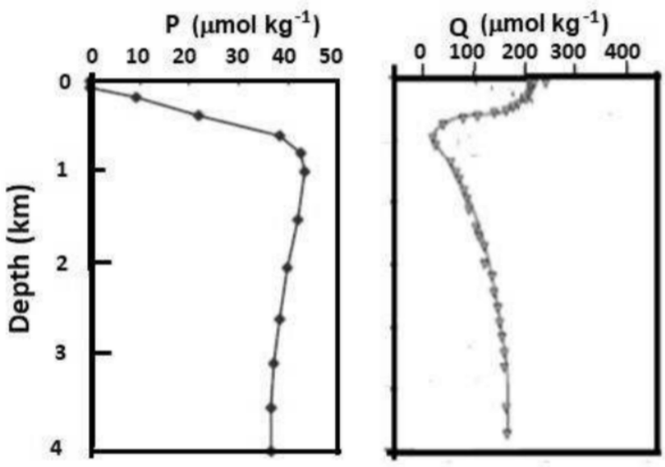
23.( ) It has long been known that halocarbons are harmful to atmospheric ozone, but the efficacy with which a compound destroys natural O_3 varies from one molecule to another. As a general rule, more heavily fluorinated halocarbons are more efficient at ozone destruction than heavily chlorinated halocarbons.

24.( ) In an article published in *The Open Ocean Engineering Journal*, a group of authors measured the effect of temperature and salinity on sound speed in a region of the Arabian Sea. Using the UNESCO algorithm, sound speeds were measured at depths ranging from 0 to 250 m. Shown below are the profiles for simulated speeds as functions of depth with temperature as a parameter, in (*a*), or salinity as a parameter, in (*b*). Profiles were simulated for the minimum, average, and maximum temperature/salinity values measured in the observation site over the course of a year; these are represented by the dashed, thick, and thin lines, respectively. With reference to these plots, it is clear that the effect of salinity on subaquatic sound speed is much more pronounced than that of temperature.



▶ Problem 9

The following graphs show the concentrations of two chemicals, *P* and *Q*, as functions of depth in a region of the Pacific Ocean. With reference to these plots, identify chemicals *P* and *Q*.



A) Oxygen, nitrate
B) Oxygen, neon
C) Nitrate, oxygen
D) Neon, nitrate

▶ Problem 10

The relative molar abundance of carbon, nitrogen and phosphorus in marine phytoplankton is expressed by the so-called Redfield ratio. Analysis of the composition of siliceous marine organisms makes it possible to write a Redfield ratio that includes silicon as well. Which of the following alternatives contains the correct molar abundance ratio C:Si:N:P in seawater?

A) 140:60:16:1
B) 106:40:16:1
C) 160:61:46:1
D) 106:60:36:1

▶ Problem 11

Associate the figures with the corresponding cloud types.

P. 	**I.** Altostratus
Q. 	**II.** Altocumulus
R. 	**III.** Cirrocumulus

A) P.III; Q.II; R.I;
B) P.I; Q.III; R.II;
C) P.III; Q.I; R.II;
D) P.II; Q.I; R.III;

ADDITIONAL INFORMATION

Table 1. A table for (1) saturation values of humidity *vs.* actual air temperature (T); or (2) actual humidities *vs.* dew-point temperature (T_d)

T	e_s	For P = 101.325 kPa		ρ_{vs}
		r_s	q_s	
or				
T_d	e	r	q	ρ_v
(°C)	(kPa)	(g/kg)	(g/kg)	(g/m^3)
−20	0.127	0.78	0.78	1.09
−18	0.150	0.92	0.92	1.28
−16	0.177	1.09	1.09	1.50
−14	0.209	1.28	1.28	1.75
−12	0.245	1.51	1.51	2.04
−10	0.287	1.77	1.76	2.37
−8	0.335	2.07	2.06	2.75
−6	0.391	2.41	2.40	3.18
−4	0.455	2.80	2.80	3.67
−2	0.528	3.26	3.25	4.22
0	0.611	3.77	3.76	4.85
2	0.706	4.37	4.35	5.57
4	0.814	5.04	5.01	6.37
6	0.937	5.80	5.77	7.28
8	1.076	6.68	6.63	8.30
10	1.233	7.66	7.60	9.45
12	1.410	8.78	8.70	10.73
14	1.610	10.05	9.95	12.17
16	1.835	11.48	11.35	13.77
18	2.088	13.09	12.92	15.56
20	2.371	14.91	14.69	17.55
22	2.688	16.95	16.67	19.76
24	3.042	19.26	18.89	22.22
26	3.437	21.85	21.38	24.94
28	3.878	24.76	24.16	27.94
30	4.367	28.02	27.26	31.27
32	4.911	31.69	30.72	34.93
34	5.514	35.81	34.57	38.96
36	6.182	40.43	38.86	43.40
38	6.921	45.61	43.62	48.27
40	7.736	51.43	48.91	53.62
42	8.636	57.97	54.79	59.47
44	9.627	65.32	61.31	65.88
46	10.717	73.59	68.54	72.87
48	11.914	82.91	76.56	80.51
50	13.228	93.42	85.44	88.84

Variables: T → Temperature, T_d → Dew point temperature, e_s → Saturation water-vapor pressure, e → Water-vapor pressure, r_s → Saturation mixing ratio, r → Mixing ratio, q_s → Saturation specific humidity, q → Specific humidity, ρ_{vs} → Saturation absolute humidity, ρ_s → Absolute humidity.

SOLUTIONS

P.1 ➡ *Solution*

In order of increasing latitude, we have the sequence Hadley cells → Ferrel cells → Polar cells.

♦ The correct answer is **B**.

P.2 ➡ *Solution*

The Kuroshio is a western boundary current in the North Pacific. The Gulf Stream is a western boundary current in the North Atlantic.

♦ The correct answer is **A**.

P.3 ➡ Solution

Equatorial Kelvin waves propagate toward the east. Equatorial Rossby waves propagate in the opposite direction of equatorial Kelvin waves – that is, westward.

♦ The correct answer is **D**.

P.4 ➡ Solution

Noting that $\Delta p/\Delta z$ = $(1.3\times10^2)/(100\times10^3)$ = 1.3×10^{-3} Pa/m, the speed we aim for is

$$V_g = \frac{1}{\rho f}\frac{\Delta p}{\Delta z} = \frac{1}{1.2\times10^{-4}}\times\left(1.3\times10^{-3}\right) = \boxed{10.8\,\text{m/s}}$$

♦ The correct answer is **C**.

P.5 ➡ Solution

Assuming circulation is conserved, we may write

$$\Gamma + 2\Omega\sin\theta A = \text{Constant}$$

Let subscripts *i* and *f* denote conditions before and after the cylindrical column has expanded, respectively. Solving for Γ_f, we have

$$\Gamma_f = 2\Omega\sin\theta\left(A_i - A_f\right) + \Gamma_i \quad \text{(I)}$$

Noting that radius $r_f = 2r_i$, we may write

$$A_i = \pi r_i^2 \;\;;\;\; A_f = \pi r_f^2 = \pi\times\left(2r_i\right)^2 = 4\pi r_i^2$$

so that, substituting in (I),

$$\Gamma_f = 2\Omega\sin\theta\left(\pi r_i^2 - 4\pi r_i^2\right) + \cancel{\Gamma_i} = 2\Omega\sin\theta\left(-3\pi r_i^2\right)$$

where we have cancelled Γ_i because the air was initially at rest. Now, from the equation for circulation,

$$\Gamma_f = 2\pi r_f V \rightarrow V = \frac{\Gamma_f}{2\pi r_f}$$

$$\therefore V = \frac{2\Omega\sin\theta\left(-3\pi r_i^2\right)}{2\pi\times 2r_i} = -\frac{3\Omega\sin\theta r_i}{2}$$

$$\therefore V = -\frac{3\times\left(7.3\times10^{-5}\right)\times\sin 30^\circ\times\left(80\times10^3\right)}{2} = \boxed{-4.38\,\text{m/s}}$$

After doubling its radius, the air column will achieve a tangential velocity of about 4.4 m/s. The negative sign indicates that motion is anticyclonic.

♦ The correct answer is **A**.

P.6 ➡ Solution

The circulation at any radial distance *r* from the center of the annulus is $\Gamma = 2\pi rV$, where tangential velocity *V* can be determined from the expression we were given,

$$V = \frac{A}{r} = \frac{10^6}{200\times10^3} = 5\,\text{m/s}$$

so that

$$\Gamma = 2\pi rV = 2\pi\times\left(200\times10^3\right)\times5 = 6.28\times10^6\ \text{m}^2\text{s}^{-1}$$

Dividing Γ by the cylinder cross-section *S* gives the average vorticity,

$$\zeta_m = \frac{\Gamma}{S} = \frac{6.28\times10^6}{\pi\times\left(200\times10^3\right)^2} = \boxed{5.0\times10^{-5}\ \text{s}^{-1}}$$

♦ The correct answer is **D**.

P.7 ➡ ***Solution***

Simply apply the formula

$$U_{Ek} = \frac{\tau_s^y}{\rho_0 f} = \frac{0.25}{\left(1.025\times10^3\right)\times10^{-4}} = \boxed{2.44\,\text{m}^2\,\text{s}^{-1}}$$

♦ The correct answer is **B**.

P.8 ➡ ***Solution***

1.True. The total mass of the mixture, *M*, is 1 + 1 = 2 kg. The temperature *T* of the mixture is

$$T = \frac{m_A T_A + m_B T_B}{M} = \frac{1.0\times30+1.0\times(-4)}{2.0} = 13^\circ\text{C}$$

and the vapor pressure is

$$e_{\text{mix}} = \frac{m_A e_A + m_B e_B}{M} = \frac{1.0\times3.4+1.0\times0.2}{2.0} = 1.8\,\text{kPa}$$

Referring to Table 1, we see that at *T* = 13°C the saturation vapor pressure of air is 1.5 kPa. Since e_{mix} = 1.8 > 1.5 kPa, we conclude that the mixture in question is saturated.

2.False. While it is true that in the β-plane framework the Coriolis parameter is written as $f = f_0 + \beta y$, the actual definition of β is

$$\beta = \frac{\partial f}{\partial y} = \frac{2\Omega\cos\theta_0}{r_0}$$

3.False. We first compute the Coriolis parameter *f*,

$$f = 2\Omega\sin\theta_0 = 2\times\left(7.3\times10^{-5}\right)\times\sin50^\circ = 1.12\times10^{-4}\,\text{s}^{-1}$$

Then, we multiply it by the zonal wind speed,

$$-f\bar{u} = \left(1.12\times10^{-4}\right)\times12 = \boxed{-1.34\times10^{-3}\,\text{m/s}^2}$$

The negative sign indicates that the force is from north to south.

4.True. This has been known since Ekman published his results in the 1900s, and helped explain Nansen's observation that icebergs, which float mostly underwater, systematically drift to the right of the wind in the North Atlantic.

5.False. We first compute the vorticity ζ,

$$\zeta = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} = 0 - \frac{20}{400\times10^3} = -5.0\times10^{-5}\,\text{s}^{-1}$$

and then the circulation Γ,

$$|\Gamma| = \int_A |\zeta|\,dA = |\zeta_m|\,A = \left(5.0\times10^{-5}\right)\times\left(1200\times10^3\right)^2 = \boxed{7.2\times10^7\,\text{m}^2\,\text{s}^{-1}}$$

6.True. If absolute vorticity is conserved, the sum of relative vorticity and Coriolis parameter must remain constant. That is,

$$\zeta + f = \text{Constant} \rightarrow \zeta_i + f_i = \zeta_f + f_f$$

Note that the Coriolis parameter at 30°N is $f_i = 2\Omega \sin 30^\circ = \Omega$, whereas at 90°N, $f_f = 2\Omega \sin 90^\circ = 2\Omega$. Relative vorticity ζ_f is calculated to be

$$\zeta_i + f_i = \zeta_f + f_f \rightarrow 6.8\times10^{-5} + \Omega = \zeta_f + 2\Omega$$

$$\therefore \zeta_f = 6.8\times10^{-5} - \Omega = +6.8\times10^{-5} - 7.3\times10^{-5} = \boxed{-5.0\times10^{-6}\,\text{s}^{-1}}$$

7.True. We first compute the Froude number,

$$\text{Fr} = \frac{U}{\bar{N}H} = \frac{13}{0.02\times2000} = 0.325$$

and then the aspect ratio,

$$\alpha = \frac{H}{L} = \frac{2}{400} = 0.005$$

so that

$$\text{Fr}^2 \times \alpha^2 = 0.325^2 \times 0.005^2 = \underline{2.64 \times 10^{-6}}$$

Thus, hydrostatic balance surely applies to this system.

8.False. The flow rate is given by the product *width* × *depth* × *velocity*, which in the present case yields 40,000 × 200 × 0.6 = 4.8×10^6 m^3/s. Noting that 1 Sv = 10^6 m^3/s, the flow rate in the current at hand is 4.8 sverdrups.

9.False. Whether the flow is turbulent or not can be assessed if we compute the Reynolds number $Re = \rho VL/\mu$. We have all necessary variables except for the length scale L, which can be determined if we note that the radius of the Earth is ~6400 km and the variation in latitude from 30°N to 33°N is 3 degrees or $\pi/60$ radians, giving

$$L = \lambda R = \frac{\pi}{60} \times \left(6.4 \times 10^6\right) = 3.35 \times 10^5 \text{ m}$$

so that

$$\text{Re} = \frac{1025 \times 1.2 \times \left(3.35 \times 10^5\right)}{9 \times 10^{-4}} = 4.58 \times 10^{11}$$

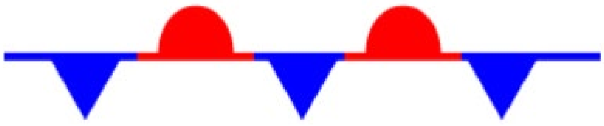
An external flow is turbulent if $Re \gtrsim 200{,}000$. Our result is well above this threshold, which indicates that flow in the Kuroshio current, as in most oceanic current systems, is largely turbulent.

10.True. The salinity of the North Atlantic surface waters is about 37.3 g/kg, whereas that of North Pacific averages at 35.5 g/kg. The higher salinity of the North Atlantic surface waters is important because it leads to a higher density when waters are colder.

11.False. Negative and large Richardson numbers are indicative of highly turbulent flow, with contribution to turbulence mostly associated with buoyancy instead of shear. A laminar flow should have large and positive Ri_b, Ri_g, as summarized in the following table.

Ri_b or Ri_g	Type of flow	Level of turbulence due to buoyancy	Level of turbulence due to shear
Large, negative	Turbulent	Large	Small
Small, negative	Turbulent	Small	Large
Small, positive	Turbulent	None (weakly stable)	Large
Large, positive	Laminar	None (strongly stable)	Small

12.False. The symbol given is actually used to indicate occluded fronts. The actual symbol for stationary fronts is shown below.



13.True. Nothing to add here!

14.True. Substituting in the equation for fall velocity gives

$$u_\infty = \frac{2}{9}\eta_a a^2 \rho_p g = \frac{2}{9} \times \left(0.91 \times 10^{-3}\right) \times \left(50 \times 10^{-6}\right)^2 \times 1000 \times 9.81 = 4.96 \times 10^{-9} \text{ m/s}$$

$$\therefore u_\infty = 4.96 \times 10^{-9} \frac{\text{m}}{\text{s}} \times 1000 \frac{\text{mm}}{\text{m}} \times 86{,}400 \frac{\text{s}}{\text{day}} = \boxed{0.429 \text{ mm/day}}$$

15.False. The KM distribution is actually a special case of the gamma distribution.

16.True. Simply substitute $\alpha = 2$, $M_0 = 4$ m/s, $\Delta M = 4.5 - 3.5 = 1.0$ m/s and $M = 5$ m/s, giving

$$\text{Pr} = \frac{\alpha \times \Delta M \times M^{\alpha - 1}}{M_0^\alpha} \exp\left[-\left(\frac{M}{M_o}\right)^\alpha\right]$$

$$\text{Pr} = \frac{2 \times 1.0 \times 5^{2-1}}{4^2} \exp\left[-\left(\frac{5}{4}\right)^2\right] = 0.131 = \boxed{13.1\%}$$

17.False. In the northern hemisphere, a wind undergoes is said to *veer* when it undergoes a clockwise shift relatively to the compass direction. A wind that undergoes a counterclockwise shift is said to be *backing*.

18.False. In the most recent Beaufort scale, wind categories range from 0 to 12, with Beaufort number 12 representing hurricane-force winds.

19.True. Indeed, in the ISA atmospheric temperature decreases linearly with a lapse rate of 6.5°C/km, so that, at some altitude z, we may write $T[°\text{C}] = 15 - 0.0065z[\text{m}]$. At altitudes greater than 11,000 m, temperature is assumed constant at about −56.5°C.

20.True. We begin by calculating the number of molecules in 1 m³ of any ideal gas at 1 atm and 0°C, which is known as the Loschmidt number,

$$p = n_0 k_B T \rightarrow n_0 = \frac{p}{k_B T}$$

$$\therefore n_0 = \frac{1.01\times10^5}{\left(1.38\times10^{-23}\right)\times273} = 2.68\times10^{25}\text{ molecules m}^{-3}$$

Since, at the same temperature and pressure, the volumes occupied by ideal gases are proportional to the numbers of molecules in each gas, we may write the linear proportion

$$\frac{\text{Volume occupied by CO}_2\text{ molec. in air}}{\text{Volume occupied by air}} = \frac{\text{No. of CO}_2\text{ molec. in 1 m}^3\text{ of air}}{\text{Total No. of molecules in 1 m}^3\text{ of air}}$$

$$\therefore \frac{354\times10^{-6}}{1.0} = \frac{\text{No. of CO}_2\text{ molec. in 1 m}^3\text{ of air}}{2.68\times10^{25}}$$

$$\therefore \text{No. of CO}_2\text{ molec. in 1 m}^3\text{ of air} = \left(354\times10^{-6}\right)\times\left(2.68\times10^{25}\right) = \boxed{9.49\times10^{21}}$$

21.True. For the Earth,

$$\lambda_{p,\text{earth}}\left[\mu\text{m}\right] = \frac{2897}{T\left[K\right]} = \frac{2897}{288} = 10.1\,\mu\text{m}$$

whereas for the Sun,

$$\lambda_{p,\text{sun}}\left[\mu\text{m}\right] = \frac{2897}{T\left[K\right]} = \frac{2897}{5800} = 0.499\,\mu\text{m}$$

so that

$$\frac{\lambda_{p,\text{earth}}}{\lambda_{p,\text{sun}}} = \frac{10.1}{0.499} = \boxed{20.2}$$

22.False. The statement correctly defines the solar constant, but the value quoted for it is false; S is actually approximately equal to 1360 W/m².

23.True. Chlorinated halocarbons such as $CHCl_3$ (chloroform) are more powerful ozone-depleting agents than similar fluorinated halocarbons such as CHF_3. (We have not mentioned brominated halocarbons, which tend to be even stronger at ozone depletion than both their chlorinated and fluorinated counterparts.)

24.False. This is a simple observational exercise; inspecting the graphs, we see that the profiles simulated with temperature as a parameter deviate much more pronouncedly from each other than do the equivalent profiles produced with salinity as a parameter. This indicates that, at least in the region of the Arabian Sea explored by those authors in that particular seawater, variations in temperature affect subaquatic sound speeds much more expressively than changes in salinity.

P.9 ➡ *Solution*

Curve *P* likely represents the concentration of nitrate as a function of depth, in that this ion is depleted near the surface due to phytoplankton activity and increases substantially with depth before achieving a somewhat steady value at lower levels. Curve *Q*, in turn, is compatible with the concentration profile of oxygen, which has a maximum at the surface, decreases precipitously at moderate depths – the so-called *oxygen minimum layer* – and then increases somewhat at the greatest depths because higher pressures and lower temperatures raise the solubility of gaseous solutes. Neon, a noble gas, is virtually nonexistent in seawater and was included in two of the alternatives merely for confusion.

♦ The correct answer is **C**.

P.10 ➡ *Solution*

The Redfield ratio with silicon included is C:Si:N:P = 106:40:16:1.

- The correct answer is **B**.

P.11 ➡ *Solution*

Alternative C contains the correct associations.

- The correct answer is **C**.

ANSWER SUMMARY

Problem 1	B
Problem 2	A
Problem 3	D
Problem 4	C
Problem 5	A
Problem 6	D
Problem 7	B
Problem 8	T/F
Problem 9	C
Problem 10	B
Problem 11	C

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