1. Short answer questions about tides, for each mark the most nearly correct answer. (If you would like to illustrate your answers with small sketches, or explain your answer very briefly, please feel free to do so.)

a. Spring tides (times of large semidiurnal tidal range) occur twice a month
   a. when the moon is in the earth's equatorial plane,
   b. when the moon is out of the earth's equatorial plane,
   c. at full or new moon,
   d. at the quarter moons,
   e. at lunar perigee.

b. The daily inequality (elevation difference between a high tide and its immediate successor) vanishes for lunar tides
   a. when the moon is in the earth's equatorial plane,
   b. when the moon is out of the earth's equatorial plane,
   c. at full or new moon,
   d. at the quarter moons,
   e. at lunar perigee.

d. The tidal range at times when lunar perigee and full/new moon occur together
   a. is unusually large,
   b. is unusually small,
   c. is nothing special.

e. Spring tides
   a. may occur near the times of an eclipse of the sun or of the moon,
   b. never occur near the times of an eclipse,
   c. ONLY occur at the times of an eclipse.

f. Neap tides
   a. occur near the times of an eclipse of the sun or of the moon,
   b. never occur near the times of an eclipse,
   c. ONLY occur at the times of an eclipse.

g. The earth rotates on its axis once every 24 hours, and the strongest tides are semidiurnal (one high water about every 12 hrs). If the earth rotated on its axis once every 36 hours but the orbital motions of earth and moon were not changed, then at most locations there would be one high water about every
   a. 6 hrs,  b. 9 hrs,  c. 12 hrs,  d. 18 hrs,  e. 36 hrs

2. The phenomenon of refraction is important both in gravity waves that enter shallow water on the way to the beach and in sound waves that travel vertically in the ocean.
(a) In the ocean, sound waves originating at the depth of the sound speed minimum...
SOFAR channel) are generally refracted
i. back towards the center of the SOFAR channel, OR
ii. up or down away from the center of the SOFAR channel.

Explain your answer.

Best to think of a sound wave moving obliquely upwards (or downwards) through the ocean towards the SOFAR channel (sound speed minimum). The crests of the sound wave are perpendicular to the direction of wave. Consider one crest: the part that is closer to the sound speed minimum will move slower than the part that is farthest from the sound speed minimum. Therefore the crest will rotate so it is “flatter”. As the wave moves upward past the sound speed minimum, the part of the crest that is in the higher sound speed will speed up and so the whole crest will rotate back to its original angle. Keep on following this and the crest will rotate until the wave is moving horizontally and then keep on rotating until it moves back down into the SOFAR channel. Thus the waves are “trapped” by the SOFAR channel – they refract back towards the center.

(b) Consider gravity waves that enter shallow water on the way to the beach. They are refracted as they pass over variable bottom relief. Which feature of bottom relief is analogous to the SOFAR channel in the tendency of refraction to direct gravity waves relative to the center of the relief feature in the same sense that refraction directs sound waves relative to the center of the SOFAR channel?
   i. a submarine canyon OR
   ii. a submarine ridge (the opposite of a canyon).

Explain your answer.

Surface wave phase speed for shallow water is $\sqrt{gH}$. Therefore it is higher for deeper water and lower for shallower water. Thus a submarine ridge acts the same way as the SOFAR channel, with a minimum phase speed in the middle. Refraction works the same way as described for the surface gravity wave.

Change to 1,000 m to get reasonable answers

3. The Pacific Ocean is approximately 10,000 km wide and approximately 5,000 m deep. Consider a west-to-east cross-section across the whole width of the Pacific, from Japan to California (at, say, 25°N). Assume that there is a narrow western boundary current and a very broad interior flow across most of the section.

(a) If the water in that cross-section is moving southward at 1 cm/sec, calculate the total southward volume transport, in MKS units. (Ignore the western boundary current for this calculation.)

Volume transport $V$ is the integral of $v$ over the cross-sectional area. With constant $v = 1$ cm/sec, and an area of (1000 m) x (10,000 km), making sure units are all converted to meters, the result is

$V = 0.01 \text{ m/sec x 1000 m x } 10^7\text{m} = 10^{-2} \times 10^3 \times 10^7 \text{m}^3/\text{sec} = 10^8 \text{m}^3/\text{sec} = 100 \text{ Sv}$

(b) If this same amount of water is returning northward in a western boundary current that is 100 km wide (and still 5 km deep), calculate the average northward velocity of the western boundary current. (Ignore the small transport described next in part c.)
I’ll use 5 km depth for this current, since the Kuroshio does extend to the ocean bottom and returns the southward flow.

\[ \text{Area} = 5000 \text{ m} \times 100 \text{ km} = (5 \times 10^3 \text{ m}) \times 10^5 \text{ m} = 5 \times 10^8 \text{ m}^2 \]

\[ \nu_{wb} = \frac{V}{\text{Area}} = \frac{10^8 \text{ m}^3/\text{sec}}{5 \times 10^8 \text{ m}^2} = 0.2 \text{ m/sec} = 20 \text{ cm/sec} \]

(c) If the average oxygen content of the northward flow in the western boundary current is 150 µmol/kg, calculate the net northward transport of oxygen in the western boundary current, in units of µmol/sec. Use the information from (b) to calculate.

Use the total volume transport \( V \) times the amount of oxygen. Oxygen concentration is \( C = 150 \) µmol/kg, so the transport would be expressed as

\[ \text{Oxygen transport} = \rho CV = (1025 \text{ kg/m}^3)(150 \mu\text{mol/kg})x 10^8 \text{ m}^3/\text{sec} = 1.5375 \times 10^{13} \mu\text{mol/sec} = 1.5375 \times 10^7 \text{mol/sec} \]

(d) The actual flow across 24°N also contains 1 Sv of water moving northward to escape to the Arctic through Bering Strait. Adjust the western boundary current transport to account for this, and recalculate the average northward velocity from (b).

The interior is still carrying 100 Sv southward. Therefore the western boundary current must be carrying 101 Sv northward to feed both the southward transport and the Bering Strait transport. With an area of \( 5 \times 10^8 \text{ m}^2 \) and volume transport of \( 101 \times 10^6 \text{m}^3/\text{sec} \), the velocity is \( \frac{V}{\text{area}} = \frac{(101 \times 10^6 \text{m}^3/\text{sec})}{5 \times 10^8 \text{m}^2} = 0.202 \text{ m/sec} = 20.2 \text{ cm/sec} \)

(e) If the average salinity of the water leaving the Pacific through Bering Strait is 32 psu, and if the average salinity of the water at 24°N is 34.6 psu, calculate the total E-P (evaporation minus precipitation) for the northern North Pacific.

Two different approaches.
1. Most accurate, using equation 5.5. This is the best way if there is just one inflow and one outflow (as specified in the problem).

\[ V_{in}S_{in} = V_{out}S_{out} \]

\[ V_{out} = V_{in}(S_{in}/S_{out}) = 1 \times 10^6 \text{ m}^3/\text{sec} \times \frac{34.6}{32} = 1.081 \times 10^6 \text{ m}^3/\text{sec}. \]

Therefore the net amount of freshwater added through negative E-P is \( 0.081 \times 10^6 \text{ m}^3/\text{sec} \). If you want to convert this to E-P per unit area, you need the area of the N. Pacific between 24N and Bering Strait. (See below.)

2. Approximate method

Here we use a volume transport of 1 Sv into the N. Pacific at 34.6 psu, and 1 Sv out of the N. Pacific at 32.0 psu, and the formula (5.7) from Chapter 5

\[ F = V x (1-S_{out}/S_{in}) = (1 \times 10^6 \text{ m}^3/\text{sec}) \times (1 - 32/34.6) = 0.075 \times 10^6 \text{ m}^3/\text{sec} = 0.075 \text{ Sv}. \]

This is the NET loss of water from the North Pacific between 24N and Bering Strait. The sign is of course net precipitation, so \( E-P = -0.075 \text{ Sv} \). (You can see from this calculation
why we can approximate equality between the inflowing and outflowing volume transports: the inflow across 24N should be 1 Sv and the outflow across Bering Strait higher to account for the net precipitation. This calculation gives you approximately 1.075 Sv northward through Bering Strait.

To do this calculation exactly precisely, you would

If you want to calculate the average E-P per unit area (net local rainfall), you need to know the area of the N. Pacific between 24N and Bering Strait. I didn’t ask you to calculate this. However, if you want to, you would estimate the area. I happen to have a calculation (Talley, Progress in Oceanography, 2008, Table 3) that shows it is

\[(0.82 + 1.05 + 1.46) \times 10^{13} \text{ m}^2 = 3.78 \times 10^{13} \text{ m}^2\]

Therefore the average E-P per unit area is

\[(-0.075 \times 10^6 \text{ m}^3/\text{sec})/(3.78 \times 10^{13} \text{ m}^2 ) = -1.98 \times 10^{-9} \text{ m/sec}\]

We usually express E-P/Area in cm/yr because the rates are so small in m/sec. Converting this to cm/year: -6.2 cm/yr (net precipitation)

(Using the first answer of 0.081 Sv for P-E, the rate is -6.7 cm/yr (net precipitation)

4. Explore Chapter 16 (supplementary) in the online version of the DPO textbook. Choose (any) one instrument or sensor or platform from the chapter. Answer the following questions about that instrument. These answers are more in the nature of a guided very short essay, and there are no precise answers (this would not be a typical mid-term exam question!)

I’ll choose a RAFOS float.

(a) What does it measure?
Currents (direction and speed between fixes, which is about once per hour) at the depth of the float. If the floats are programmed to follow isotherms, then the current is at the depth of the isotherm.

(b) Does it provide Eulerian or Lagrangian observations or both?
RAFOS float is a Lagrangian instrument because it moves with the water.

(c) How accurate are its measurements? If it is a modern instrument, what did it replace? If it is a very old instrument, what has replaced it?
Accuracy of the velocity measurement (which means accuracy of positioning) is not reported in Chapter S16. It was developed in the 1980s, and replaced the SOFAR float (1970), which replaced the Swallow float (1950s), which was the first tracked submerged float.

(d) What kinds of science has it been used for?
For mapping ocean currents and their eddy variability. Because it is acoustically-tracked, the currents have 1-hour resolution and therefore they are good for