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NZQA

Mana Tohu Mātauranga o Aotearoa
New Zealand Qualifications Authority

Level 3 Earth and Space Science 2025

91413 Demonstrate understanding of processes in the ocean system

Credits: Four

Achievement	Achievement with Merit	Achievement with Excellence
Demonstrate understanding of processes in the ocean system.	Demonstrate in-depth understanding of processes in the ocean system.	Demonstrate comprehensive understanding of processes in the ocean system.

Check that the National Student Number (NSN) on your admission slip is the same as the number at the top of this page.

You should attempt ALL the questions in this booklet.

If you need more room for any answer, use the extra space provided at the back of this booklet.

Check that this booklet has pages 2–16 in the correct order and that none of these pages is blank.

Do not write in any cross-hatched area (////). This area will be cut off when the booklet is marked.

YOU MUST HAND THIS BOOKLET TO THE SUPERVISOR AT THE END OF THE EXAMINATION.

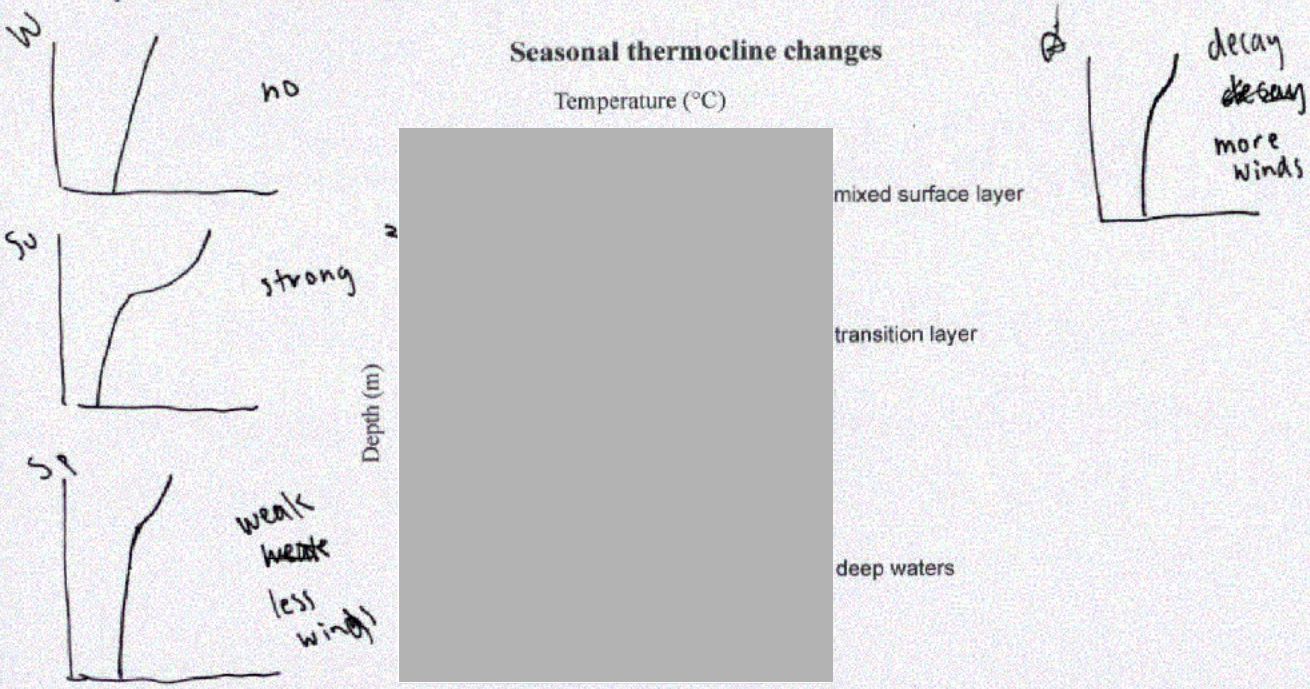
Excellence

TOTAL 24

QUESTION ONE: NEW ZEALAND'S THERMOCLINE

New Zealand is in the mid-latitudes, where surface ocean temperatures vary widely between seasons. The gradient of the thermocline changes as surface temperature changes during the year. This also impacts formation of the pycnocline, which reflects changes in density of ocean water.

Seasonal thermocline changes



Adapted from: www.sciencedirect.com/topics/agricultural-and-biological-sciences/thermocline

Discuss seasonal changes in the thermocline and pycnocline near New Zealand.

In your answer, you should consider:

- how the thermocline forms
- formation of the three ocean layers
- reasons for seasonal variation in the thermocline at mid-latitudes
- how changes in the thermocline impact pycnocline formation.

An annotated diagram may assist your answer.

The thermocline is where temperature of the ocean rapidly changes with depth. It is a vertical zone in the oceanic water column that separates warmer surface waters from the colder deep waters. ~~A~~ The thermocline is formed by the heating of the surface waters and the amount of mixing there is of the water layers.

The ocean has 3 layers : mixed surface layer, transition layer, and deep ocean layer. The deep ocean layer is found at the bottom of the ocean, temperatures are cold and the water is dense. There is little to no mixing in the deep ocean layer. The transition layer is a barrier of water that separates the mixed surface layer and the deep ocean layer. this is where the thermocline and pycnocline is formed. The mixed surface layer is formed from the Sun heating the surface waters. The Sun can only penetrate ~ 200m into the ocean, warming this water up, and winds and currents ensure that heat is well distributed within this layer.

At mid-latitudes, the thermocline changes seasonally. During Summer, ~~the sur~~ there is the most heating from the Sun, with the surface being heated up to ~ 18°C. There is little ~~to no~~ wind during Summer at the mid-latitudes, so there is little mixing of the waters. The lack of mixing means that heat is not well distributed, so there is a strong thermocline during Summer. During Autumn, the thermocline that forms is relatively weak. During Autumn, the Sun's heating effect is less so surface waters are only heated to ~ 14°C. There is some winds that form, so there is some mixing of the waters. This mixing of waters ensures that heat is more evenly distributed, so there is a weak thermocline

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during Autumn. During Winter, the Sun's heating effect is the smallest (due to Earth's ~~%~~ tilt), so surface waters are only heated to ~ 11°C. Winter bring strong winds and stormy conditions, so that the waters are all well mixed together. Hence there is no rapid change in temperature with depth, so no thermocline during Winter. Instead, the water becomes cold at ~~to~~ a constant gradient.
During Spring, there is some heating effect from the Sun so surface waters are heated to ~ 14°C. The transition from Winter to Spring results in less winds ~~beco~~ being formed, so there is less mixing of waters. A weak thermocline begins to form after there being no thermocline ~~is~~ in Winter. Spring and Autumn thermoclines are very similar, they both form weak thermoclines. Autumn thermocline is weak due to the decay of the Summer thermocline with increasing winds, while Spring thermocline is weak due to the ~~there~~ decreasing winds and stormy conditions and the increasing sunlight as there is transition from Winter to Spring.

The pycnocline is the area where density rapidly changes with depth in the ocean. It is a vertical zone in the oceanic water column that separates ~~te~~ less dense surface waters from the more dense deep waters.
Density of water is dependent on temperature, salinity, and pressure. Pressure occurs at a constant increasing gradient of 1 atmosphere pressure for every 10m depth down the ocean. Temperature affects density in that with increase in temperature density is decreased. When water temperatures are high, this means that water molecules ~~are~~ have higher average kinetic

energy, so move with more energy and expand to take up more volume. This is thermal expansion. Density is $\frac{\text{mass}}{\text{volume}}$, and as the warmer water particles increase volume, density is decreased. When ~~temperature~~ water temperature is low, the water ~~pa~~ molecules move with less kinetic energy so are closer together, decreasing volume. ~~Since the volume of wate~~ Since the water molecules are more closely packed together, the volume decreases and so density increases with cold waters.

The pycnocline is dependent on ~~both~~ the thermocline (temperature) and halocline (salinity). If these 2 factors change, then the pycnocline will change accordingly. It can be ~~said~~ shown by the equation

pycnocline = ~~thermoh~~ thermocline + halocline.

If the thermocline increases or decreases, this will affect pycnocline formation. In the Winter where there is no thermocline, the pycnocline ~~formed~~ will be very weak or none due to the well mixed waters. In the Summer, ~~the~~ the thermocline is very strong, as ~~salin~~ halocline is also quite strong, so we could expect a strong pycnocline to be formed. In the Spring and Autumn where there is a weak thermocline, the pycnocline formed will also be very weak, as salinity is also decreased due to less evaporation.

Overall, ~~the~~ New Zealand being located in the mid-latitudes results in seasonal variations in the thermocline and pycnocline in the waters.

QUESTION TWO: SOUTHERN OCEAN CARBON SINK

The Southern Ocean plays a central role in moderating the rate of climate change, absorbing approximately 40% of the carbon dioxide (CO_2) that has been produced by humans until now.

Cumulative ocean CO_2 uptake since 1850

Adapted from: https://scx2.b-cdn.net/gfx/news/hires/2022/improving-climate-mode.jpg

Explain how the Southern Ocean absorbs large amounts of carbon dioxide from the atmosphere.

In your answer, you should consider:

- the biological and physical pumps that take CO_2 into the ocean
- the effects that storing increased amounts of CO_2 may have on ocean chemistry
- reasons why the Southern Ocean can absorb such large quantities of CO_2.

The Southern Ocean is located in the Southern Hemisphere ~~and is~~ where Antarctica is. The Southern Ocean is able to absorb carbon dioxide CO_2 from the atmosphere through 2 ways; the biological & carbon pump and the physical carbon pump.

The physical carbon pump is based on the gas exchange of atmospheric CO_2 & with the ocean surface. ~~The ocean~~ The physical carbon pump is also called the solubility pump. Atmospheric CO_2 dissolves into the ocean, reacting with water

to form carbonic acid. $CO_2 + H_2O \rightleftharpoons H_2CO_3$. Carbonic acid is a weak acid so it partially dissociates. $H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$. This produces hydrogen ions and hydrogen carbonate ions. Hydrogen carbonate can further react to produce hydrogen ions and carbonate ions. $HCO_3^- \rightleftharpoons H^+ + CO_3^{2-}$. Carbonate ions further react in equilibrium reaction $CO_3^{2-} + Ca^{2+} \rightleftharpoons CaCO_3$

The biological carbon pump also begins with atmospheric CO_2 dissolving into the ocean. Phytoplankton in the ocean use this dissolved CO_2 for photosynthesis. Photosynthesis is the process where plants make their own food through raw materials. $CO_2 + H_2O \longrightarrow C_6H_{12}O_6 + O_2$. Glucose, $C_6H_{12}O_6$ is then used to undergo respiration to produce energy for the phytoplankton. $C_6H_{12}O_6 + O_2 \longrightarrow CO_2 + H_2O +$ ATP energy. This energy is then used by phytoplankton for activity, including the building of their calcium carbonate shells $CaCO_3$. Phytoplankton can then be eaten by zooplankton and other high level consumers in the marine food web, causing carbon to be stored in their bodies. When phytoplankton and high level consumers die, their remanents sink to the bottom of the ocean floor, this is known as marine snow. These remanents contain the $CaCO_3$ platelets of the phytoplankton as well as any other organic or inorganic carbon from high level consumers. Some of these remanents may be decomposed by bacteria in the ocean, releasing CO_2, while some sinks to the ocean floor to form sediments or join the thermohaline circulation in the deep ocean. The $CaCO_3$ remanents that form sediments on the ocean floor

There is more space for your answer to this question on the following pages.

will gradually build up over time, and after even longer periods of time with compactation and cementation, ~~a~~ limestone rock is formed, which contains carbon. This way, carbon is stored in the deep ocean for thousands of years, making it a carbon sink. ~~Via other Biological~~ When marine organisms respire, they release CO_2 back into the atmosphere.

CO_2 is also released back into the atmosphere at areas of upwelling of the thermohaline ~~circ~~ circulation. Upwelling brings deep ocean waters to the surface, which also includes CO_2 that has been stored for the long-term. During this upwelling process, the CO_2 is outgassed as solubility decreases.

Storing increased amounts of CO_2 may alter ~~carbon~~ ocean chemistry. As the CO_2 is absorbed into the ocean, more hydrogen ions (H^+) are being produced.

$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$
$$H_2CO_3 \rightleftharpoons \underline{H^+} + HCO_3^-$$
$$HCO_3^- \rightleftharpoons \underline{H^+} + CO_3^{2-}$$
$$CaCO_3 \rightleftharpoons Ca^{2+} + CO_3^{2-}$$

Hydrogen ions are acidic, which means that they lower the pH of the oceans. Over long periods of time, this ~~bei~~ results in the ocean becoming more acidic, or less alkaline, as the current ocean pH is around 8.1. The increased hydrogen ions lead to ocean acidification. Ocean acidification is harmful to calcifers which use $CaCO_3$ to make their shells and structures to ensure their survival. With increased H^+, more $CaCO_3$ will dissolve and these calcifers will suffer. As more of the dissolved CO_2 is turned into H_2CO_3, then $H^+ + HCO_3^-$ then $H^+ + CO_3^{2-}$ as shown in the equations before, this allows the ocean to absorb even more ~~CO~~ atmospheric CO_2 into its waters, further altering the chemistry of the oceans and producing more H^+ which makes the ocean acidic.

While the ocean does have its own buffering system which naturally balances out the pH of the ocean, this is very slow. Anthropogenic CO_2 is being ~~re~~ produced much quicker than the ocean's buffering system can withstand, hence the process of ocean acidification.

The Southern Ocean is able to absorb much more atmospheric CO_2 compared to the Equatorial or sub-tropical regions. This is because CO_2 is a gas, ~~and~~ which means that absorption is increased in cold temperature waters rather than warm temperature waters. The Southern ocean receives ~~very~~ little ~~sunli~~ solar radiation over a large surface area due to the tilt of the Earth, so the ~~so~~ Southern Ocean ~~does not become as ve~~ remains cold. The constantly cold waters of the Southern Ocean results in large quantities of CO_2 being able to be absorbed. High temperature waters break the intermolecular forces between CO_2 molecules, so they quickly escape back into the atmosphere. The cold Southern Ocean prevents this from happening.

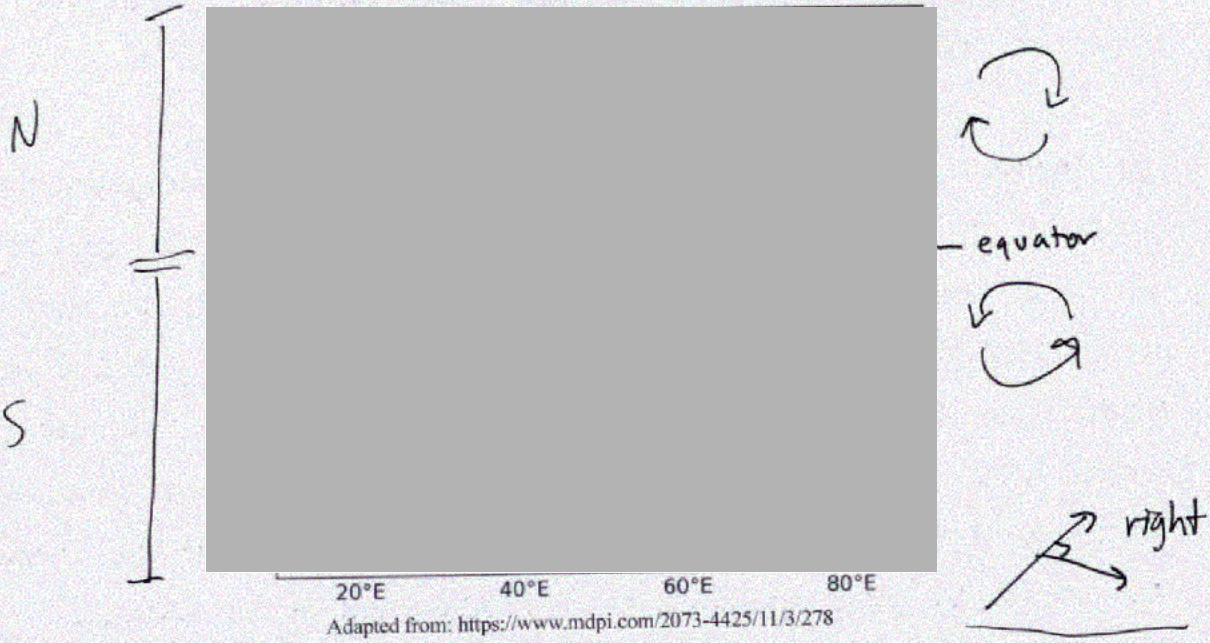
Additionally, the katabatic winds that occur due to the continental ice sheets open up polynyas, which are open areas of water, in the southern ocean. This open area of ocean allows for sunlight to reach the surface waters of the Southern Ocean during Summer, ~~and th~~ the Phytoplankton in the Southern Ocean are at the surface, and along with the cold waters that allows for more CO_2 absportion, the phytoplankton have all the materials they need for photosynthesis. The summer of the Southern Ocean means 24 hours of sunlight, so ~~photo~~ phytoplankton can continually undergo photosynthesis to use up dissolved CO_2. ~~This an~~ As the phytoplankton continually photosynthesise, to use the dissolved CO_2, this results in more CO_2 being able to be dissolved into the Southern Ocean. Hence the Southern Ocean can store large CO_2 quantities,

summer – upwelling ✓

QUESTION THREE: SOMALIA SEASONAL UPWELLING

Somalia is a country in East Africa. During the northern hemisphere summer, from June to September, a strong monsoon wind blows from the south-west along the coast. This causes upwelling and very good fishing compared to other seasons.

Surface currents in the western Indian Ocean



Adapted from: https://www.mdpi.com/2073-4425/11/3/278

Upwelling current at the Somali coast during southwest monsoon

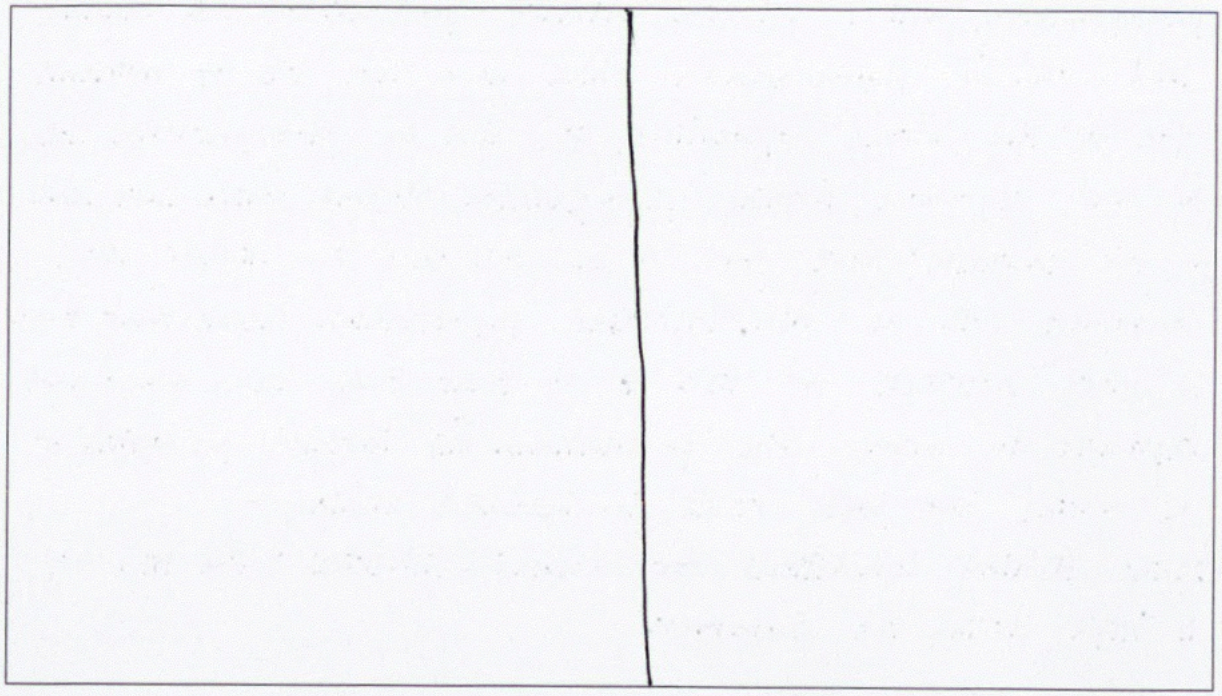
Adapted from: https://commons.wikimedia.org/wiki/File:Upwelling_current_at_the_Somali_coast_during_Southwest_Monsoon.png

Compare the seasonal fishing conditions off the coast of Somalia during the summer and winter monsoons.

In your answer, you should consider:

- the role of wind from the south-west and the Coriolis effect to create strong seasonal upwelling
- the source of nutrients
- the effect of strong seasonal upwelling in this area on productivity
- the conditions that lead to downwelling and poor fishing during the winter monsoon season.

An annotated diagram may assist your answer.



Upwelling is the process where deep ocean waters are brought to the surface. This occurs due to Ekman transport, where the net movement of water is 90° to the direction of the wind. The south-west wind and coriolis effect work together to create a strong summer ~~up~~ coastal upwelling.

The coriolis effect is the apparent deflection of objects such as currents due to the rotation of the Earth on its own axis. ~~Objects are def~~ Currents are deflected right in the Northern Hemisphere, and currents are deflected left in the Southern Hemisphere.

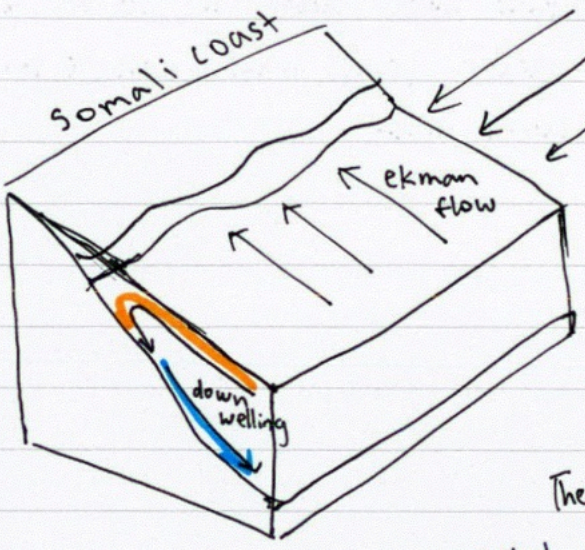
As the southwest monsoon wind blows across the Somali coast, the warm surface waters off the coast are deflected at a net 90° angle to the right (due to coriolis effect), causing these warm waters to move away from the Somali coast. This causes deep ocean water to replace the warm summer coast and rise to the surface. The deep ocean waters are rich in nutrients and CO_2, which is beneficial for the

There is more space for your answer to this question on the following pages.

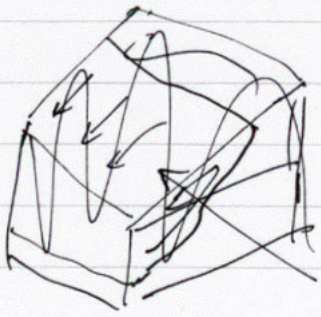
phytoplankton, which are the primary producers of the marine food web. The phytoplankton which now have lots of nutrients due to the strong upwelling, is able to photosynthesise lots & and reproduce forming phytoplankton blooms, which ~~have~~ leads to ~~the increased~~ more food to be consumed by higher level consumers such as fish. Increased phytoplankton means that there is more nutrients for fish & so that they can grow and reproduce to form large populations. This increased productivity of the marine food webs results in ~~increased fishing~~ better fishing conditions for Somali fisheries; the fish crop is high during the Summer.

Downwelling is the process where surface waters are pushed down into the deep ocean due to Ekman transport.
During the Winter monsoon season, the & ~~ear easterly~~ trade winds blow over the Somali coast. The trade winds in the Northern Hemisphere cause the winter monsoon currents to be downwelled. The trade winds blowing in a south-west direction across the Somali coast cause the surface waters to be deflected via coriolis effect to the right. The surface current waters are pushed up against the Somali coast, and with no where else to ~~gro~~ go, they are ~~pushed~~ forcefully pushed under into the deep ocean, hence downwelling. Downwelling results in a poor fishing season for the ~~people~~ fisheries of Somali, as there is a lack of nutrients at the surface for phytoplankton to grow and reproduce. Since there is a lack of nutrients, phytoplankton do not & reproduce to large numbers / no phytoplankton blooms, hence this means that the higher level consumers

have ~~less nutrients to~~ consume less nutrients and thus they will not populate into large numbers. As fish populations are low, this causes Somali fisheries to suffer.



During Winter monsoon season, the winter surface current is deflected to the right of the trade winds due to coriolis effect These surface waters are then pushed down into the deep waters of the Indian Ocean, resulting in downwelling



Extra space if required.
Write the question number(s) if applicable.

QUESTION NUMBER

as increased phytoplankton activity ~~via pho~~ due to more photosynthesis means that more carbon is stored in ~~is~~ long-term via the biological carbon pump, making the ~~S~~ Southern Ocean a massive carbon sink.

~~The~~ ~~sink~~

Excellence

Subject: L3 Earth & Space Science

Standard: 91413

Total score: 24

Q	Grade score	Marker commentary
One	8	The candidate linked multiple ideas into a comprehensive explanation of the formation of the ocean layers, thermocline and pycnocline, including how seasonal sunlight and wind strength both affect the thickness of the mixed layer, and therefore the starting depth of the thermocline and pycnocline layer.
Two	8	The candidate showed comprehensive understanding by connecting all ideas of biological and physical pumps together, with explanation of how they work together to allow the ocean to absorb even more CO_2.
Three	8	The candidate provided a logical, sequential explanation of the various processes that lead to summer upwelling in coastal waters, and applied it to the specific context of Somalia. This was then applied in reverse to comprehensively also explain the reverse effect in winter conditions.