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TOP SCHOLAR

Mana Tohu Mātauranga o Aotearoa
New Zealand Qualifications Authority

Scholarship 2023
Earth and Space Science

Time allowed: Three hours
Total score: 24

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 answer ALL the questions in this booklet.

Pull out Resource Booklet 93104R from the centre of this booklet.

Show ALL working.

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

QUESTION ONE: PHYTOPLANKTON AND THE CARBON CYCLE

Discuss the significance of phytoplankton compared to plants in the global carbon budget.

In your answer, include how it could be affected by climate change, and how it could be enhanced using human intervention. 2

Phytoplankton and plants are similar in that both consume CO_2 in their ~~photosynthesis~~ photosynthesis to produce glucose, important for supplying them with energy through respiration. Although during respiration the opposite reaction occurs (oxygen + glucose → $CO_2 + H_2O$) both still produce a net decrease in carbon dioxide. This makes both a carbon sink, which stores carbon in their bodies as they ~~use~~ convert CO_2 to form organic structures.

When carbon dioxide exchange occurs, CO_2 diffuses from the atmosphere into the ocean, and is stored in the ocean surface. This process removes CO_2 from atmosphere so it is a carbon sink (ocean surface). However, the CO_2 at ocean surface can easily ~~be~~ escape back into the atmosphere especially when the water becomes saturated with CO_2. Hence for an effective carbon sink, the CO_2 must be stored in deep ocean where it can be sequestered for long time periods. This is where phytoplankton is important. As they inhabit the surface sunlight layer (photic zone), they have abundant light energy as well as the highest CO_2 concentration from diffusion from the atmosphere, allowing photosynthetic rate ~~to~~ be very high. They hence grow very quickly, and being the producers at the bottom trophic level of the ~~foodchain~~, foodweb, they are consumed by ~~a range of cons~~ zooplankton, which can then be consumed by krill & whales etc. In this way, carbon is formed into organic matter, glucose which is consumed by ~~organic~~ ~~m~~ organisms further up in the food chain, ~~is~~ storing carbon in their bodies too. This is how organisms in the foodweb act as carbon sinks, storing glucose.

Yet this is very similar to onland ecosystems, with plants creating glucose from CO_2 then proceeding to pass it ~~to~~ on to foodweb by ~~eat~~ herbivores, which similarly act as carbon sinks in same manner. How is this in any way different? Importantly, in the oceans, when organisms die, they would begin sinking down to the ocean floor, while decomposing and emitting CO_2. This is called "marine snow". However, as they sink the water becomes colder as it is ~~more~~ further distance from the sun, the heating element, which means that the bacterial respiration slows down due to this temperature decrease. This increases the chance that ~~smaller~~ plankton can sink down to deep ocean where it can ~~be~~ be sequestered for long time, ~~x~~ storing ~~CO_2~~ carbon away, rather than decomposing back to CO_2 and increasing chance of it releasing back to atmosphere. This is different from plants as for plants onland, almost all organisms will decompose fully when they die ~~under~~ to act as carbon source, unless they were trapped in an anaerobic peat swamp and subsequently formed to fossil fuel by heat & pressure, sequestering it, or if it were trapped in ice or permafrost. This means that phytoplankton is a much better way of removing CO_2 from atmosphere than plants. Additionally, they can be consumed by ~~z~~ zooplankton, then by whales, which would then create waste that is nutritious for phytoplankton, which then means that this food-chain leads to positive feedback cycle where all 3 levels

proliferate and increase, leading to more CO_2 being taken, ~~in~~ incorporated into foodweb. Particularly, whales are large, so when they die and sink, little is decomposed by bacteria, and large amounts of carbon enters deep oceans. ~~The~~ Such carbon from marine snow can also be compressed to limestone as the sediments compress each other and mix with minerals to result in cementation. This would make the carbon part of the geosphere, and it would be sequestered from atmosphere for ~~too~~ thousands of years. Or, if it were stored in the deep sea current, it would take hundreds of years for the slow moving THC to move it to the surface where it can be re-emitted as CO_2 in outgassing. Overall, phytoplankton can much more effectively store Carbon away from atmosphere than onland plants do, as such storage could occur any where in the oceans whereas land ecosystems require very special, ~~con~~ rare conditions for carbon to be sequestered as fossil fuels. (both undergo respiration & decomposition which release some CO_2 back to atmosphere which would counteract their role as carbon sinks as short term storage is not enough: hence I compare them on which achieves better long term storage).
* Ocean surface & biomass are very short term carbon sinks.

A ~~much smaller~~ (100 times) smaller biomass of phytoplankton can carry out same ~~store same amount of~~ ~~of~~ CO_2 amount of photosynthesis as plants, which means the same unit mass is more efficient at carbon fixation. Why? Phytoplankton have a much shorter life cycle which mean they are constantly growing, but also constantly dying & being consumed. This means never at one stage is carbon ~~to~~ accumulated in the biomass greatly, as it is constly passed to higher trophic levels, yet the rate of growth is rapid. This causes a much more high-functioning ~~CO_2~~ Carbon fixation in phytoplankton than in plants, and have much more capacity to decrease global CO_2 levels in atmosphere. This means human intervention in this sector may be promising: currently, ~~on~~ the amount of carbon entering deep ocean varies from 10% to 50% based on phytoplankton concentration, the latter being the result of algae blooms, very high concentrations of algae & phytoplankton resulting in very high carbon fixation & storage in deep ocean. We must figure out how to induce ~~ph~~ such algal blooms, and as phytoplankton ~~grow~~ proliferation depends on temperature, and sunlight, and for example Iron - a limiting factor as its an important mineral for their growth, we can artificially improve these conditions. Currently, iron comes from dust-blown land winds, but we could place lots of iron dust in the water to increase phytoplankton growth, to remove this limiting factor and increase the amount of ~~carb~~ ~~phytop~~ ~~to~~ photosynthesis here, enabling more CO_2 to be removed. However, excessive algae blooms would make water toxic and deoxygenated, which means other higher trophic organisms would likely die, which reduces the biodiversity of ecosystem, and means more decomposition will counteract our efforts, emitting more CO_2. An unhealthy ecosystem is also less able to store carbon given the process works best when there is not just a lot of phytoplankton, but a fully functional foodweb. Hence, caution must be taken.

As increasing CO_2 levels cause increased global temperature, and as more CO_2 enters the ocean, which produces carbonic acid

More.

QUESTION TWO: SLOW-SLIP EVENTS

Explore the differences between earthquakes and slow-slip events, referring to the Eketāhuna and Kaikōura earthquakes.

In your answer, include how the information collected by geologists can help further their understanding of slow-slip events, and the difficulties with monitoring on land, and at sea.

1 2

As plates ~~move~~ push ~~past~~ past each other, a lot of elastic potential energy and stress builds up within it. This causes the ~~the~~ plate to crack and fracture in various places, producing faults. As tension continues to build up, the energy can suddenly release in the form of an Earthquake (EQ).

Slow slips are different from EQ as they ~~are~~ are the slow movement of plates pushing against each other and building up stress in the first place, whereas EQ is the sudden movement which releases this stress in kinetic energy. Slow slips are due to the convection currents from the magma in the Mantle, as they rise when heated and sink when cooled, moving plates against each other and at a very slow rate. It in fact relieves the built up tectonic stress from when the plates are locked together in the locked zone as seen in Fig 1, where a locked zone between Pacific and Australian plate occurs in ~~Sea~~ Wellington region. Without the slow slip, what would happen is that stress builds up but isn't relieved over time, resulting in a local Earthquake exactly where the subducting Pacific Plate locked ~~to~~ with the Australian plate. The slow slip allowed energy to relieve over a much wider area, increasing the stress in plates and faults in other regions rather than being built up in the one locked region. This is why slow slip can cause EQ in a place far away from the actual locked plate interface where friction locks plates together.

Slow slips and earthquakes can interact with each other, cause each other to occur. Fig 2 shows the Kapiti slow slip event, with a moderate slip which is 10 - 20 cm for the most part, ~~a~~ but being surrounded with a yellow margin which indicates a low slip of less than 10 cm around the edges. It appears as if it were moving towards ~~E~~ Eketahuna, and indeed it is: the slow slip is caused by a strike and slip Wellington fault where lateral movement of land on both sides occurred gradually to relieve stress built up by the ~~p~~ ~~subd~~ subducting Pacific Plate. Once the slow slip reached Eketahuna, it also brought stress to the Wellington Fault in that region, which ~~triggered~~ build up to the point of triggering an EQ of 6.2 magnitude in 2014. The process was slow, taking place from 2013 - 2014.

~~Earth~~ EQ can also induce slow slip events, as seen in Kaikoura 2016 EQ. This created a post-Earthquake Marlborough slip, and the slip is very great at over ~~3~~ 30cm, which can be attributed to the recent occurrence of the EQ which would have completely eliminated any built up friction and potential energy, meaning the slip could occur more rapidly with little impedance. Why does this afterslip occur? Because of its position on the Wellington fault, which is a strike & slip fault that is constantly pushing laterally, and ~~t~~ when the subducting plate was "locked", the slip was slower, but now it is faster as the ~~EQ had~~ the stress had dissipated in the form of EQ (Kaikoura).

The East Coast shallow slip is a relatively slow slip 600km away from the Kapiti slip. It is also induced ~~by~~ by 2016 Kaikoura EQ, which would have released so much kinetic energy that this distant slip started to occur which previously experienced very little movement. It could also be that it sat ~~on~~ close to a fault, close to the Kermadec Trench area, which also facilitated to the development of this slow slip.

Slow slips are too gradual for seismometers to detect any vibration waves. Hence GPS have been placed in key slow slipping locations to measure the displacement of land. This would allow us to understand ~~how~~ where slow slip is occurring in NZ, as well as how fast the slip is. It would also allow us to understand the nature of the slip e.g. due to strike and slip fault in Kapiti slow slip for example. Furthermore, placing pressure sensors on seafloor would mean that if the slip were to cause any the sea floor to sink or uplift, the water pressure above it would change. This allows understanding of whether slow slips would be able to change the ocean profile by changing its depth, and understand whether it has the potential to increase NZ's land area over time by ~~pushing~~ uplift the Zealandia continent which is mostly submerged, or decrease our land if any increace pressure is detected, indicating a ~~lowering~~ subsidence in the seafloor. ~~If such~~ These are expected for a subduction slow slip, but if neither is observed, we can conclude that it is due to a lateral movement of ~~fat~~ faults, or plates. hence a strike and slip fault, or a transform plate boundary - which is indeed observed between AP and PP near the middle region of New Zealand. Such slow slip itself, due to its lateral slow movement rather than up or down, shouldn't change the height of water collumn above the sensors, so no change in pressure. Data showing slow slip occurring further away from NZ indicates that such events are likely generalizable to many countries across the world, or at least for similar Pacific Island contries like Tonga, and ~~this~~ as they are poor and likely won't develop such research themselves, this ~~&~~ info could be very beneficial for them, especially as understanding slow ~~-~~ slips can allow us to ~~detect~~ predict where EQs occur, allowing us to take precautions before it actually happens (especially as we found slow - slips to happen at regular intervals, and are typically accompanied by EQ).

However, many difficulties of monitoring the slip is present. At sea, it all relies on change in water pressure. ~~This~~ As slow slip is very gradual, this change is gradual, so the detector must be delicately calibrated to detect the change, which is very difficult. Plus, they would have to be made to sustain the great undersea water pressure, Each 10m of water = 1 atmosphere, and any subsidence of the seafloor further increase pressure, which may crush the plates, ~~and~~ destroying our research equipment.

QUESTION THREE: JUPITER'S ATMOSPHERIC CELLS.

coriolis.

Analyse the differences between the Earth's atmospheric cells and the bands on Jupiter. Explain why these differences occur, and how these relate to the size, rotational speed, and composition of both planets.

1 2 3

In your answer, include a comparison of the depth of the cells between the two planets, and discuss the significance of the Giant Red Spot. 2 1

Without coriolis effect, the ~~Ea~~ Earth would have only 2 atmospheric cells, stretching from low pressure in the equator to high pressure in the poles. It is the Earth's spin, therefore, which caused each of these hemisphere's cells to break up into Hadley, Ferrell and Polar cells, which gives a total of 6. As Jupiter spins 2.5 times faster, it would have a much ~~As~~ stronger coriolis effect, which would contribute to it having 20 atmospheric cells (bands), much more than Earth. Coriolis effect is why the winds ~~are~~ on Jupiter are much faster, and move in opposite directions as such to create many bands. Overall, greater ~~coriolis~~ c' rotation speed → stronger coriolis effect → more cells. * later point related

Jupiter, ~~is~~ being a gas giant being composed of liquid and gas, is much less dense than Earth, having 1321 times the volume but only 317 times the mass. This means that at its surface, ~~t~~ despite the much greater mass, gravitational force is not much stronger than on Earth as radius is 11 times greater, and $F_g \propto \frac{1}{r^2}$. ~~This is why the bands on Jupiter can be as high as 3000 kilometers~~ Yet it is still stronger than on Earth, meaning that ~~the~~ the larger gravity can hold a thicker atmosphere. This is why the cells on Jupiter are much deeper (3000 km) than on Earth, as Jupiter still has enough gravitational force to attract its mass back down at that height in the "zone". Another reason for the great depth is that much convection occurs inside Jupiter. Its formation, as a gas giant, produced a lot of primordial heat, as deep beneath the surface, the temp & pressure is so high that a very hot plasma substance is produced near the core. Jupiter, being much larger than Earth, would have a much greater pressure at its core from the mass above, ~~due to the~~ ~~f~~ ~~due to~~ and they would collide very frequently, causing a high temperature, and hence lots of internal primordial heat. This, as well as the fact that it receives even more thermal energy from Sun due to its large size than Earth, meant that there is ~~surface temperatures~~ a lot of temperature variation from ~~its~~ deeper in its surface, to its surface. Note, as its own thermal energy produced from hot ~~one~~ large core is greater than the thermal energy from the sun, ~~it~~ is the most significant heating element is from below. As the ~~warmed~~ gases are warmed, they rise via convection as they are now less dense, and are subsequently cooled down, sink back down again. The reason that gas particles rise up much higher before being cooled and sinking is that the heating from its primordial heat is quite significant, and would need ~~to rise up~~ the particles to rise up a long distance before it is sufficiently cooled to sink, whereas on Earth, the ~~tropos~~ air cools much more rapidly as ~~air~~ it rises due to a decrease in air pressure and the "blanket" of greenhouse gases trapping heat, meaning that gas particles don't rise up as high before cooling down and sinking. On Jupiter however,

There is no greenhouse effect, and the ~~core~~ centre of planet is a more significant heating source than the sun ~~and so~~ (As solar radiation is too widespread over its large surface, less intense, and solar radiation not effectively trapped by GHG). This, combines with ~~how~~ Jupiter's larger size and stronger gravity, creates ~~a much~~ deeper atmospheric cells.
* As Jupiter is a ~~giant~~ gas ~~ball~~ giant, its idea of atmosphere and core are not clear-cut: its composed of a gas layer over liquid inner parts (due to pressure), ~~and~~ as opposed to Earth, a terrestrial rocky planet holding a thin gas atmosphere. This means that atmospheric circulation on Jupiter is the movement of its own surface material from which its made, and on Earth it is due to uneven heating of the sun on the air molecules). As Jupiter is mostly made of hydrogen, which has a very low ~~melting~~ boiling point, this may also be why hydrogen powders travel a very long distance above planet before being cooled down enough to sink, leading to a deeper cell.
~~The bands act like Jetstreams likely because of the great~~
~~* coriolis effect of the ~~to~~ high speed rotation.~~ ~~It~~ ~~Uneven surface heating would cause the atmosphere ~~to~~ be of different heights, higher in equatorial region of Jupiter.~~ This Bands act like Jetstreams because ~~E~~ of the much faster rotation speed causing greater coriolis effect, which would deflect the winds of upper atmosphere of Jupiter, creating many jetstreams in the zones, many ~~most~~ more than on Earth due to coriolis effect being more significant.

The great red spot is an area of low pressure that acts as a cyclone, similar to the cyclones on Earth. The fact that it has existed for so long, fixed in place implies that the atmosphere/ beneath the surface in that region is an anomaly, perhaps an unusual convection pattern, or perhaps the ~~temperature of~~ beneath planet surface there is strangely high or low. Regardless as it is fixed there for 500 years now, it is ~~most~~ very significant of ~~a~~ an anomaly for researchers to delve into. We could link it to how cyclones like Hurricane Katrina work on Earth. Perhaps it implies that the atmospheric cells on Jupiter really are similar enough to Earth to create cyclones, albeit stationary.

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

QUESTION NUMBER

and increase the acidity, decrease pH, ~~carbon~~ phytoplankton functioning is affected. For example, warmer oceans are more suitable for phytoplankton growth, and as the whole world becomes warmer, the algal blooms could become more frequent in ~~te~~ currently temperate regions, like NZ, as waters warm up. This means that numbers would increase. More CO_2 in the atmosphere would also mean more to ~~d~~ diffuse into ocean, so more ingredient ~~fo~~ reactant for photosynthesis, causing numbers to increase and rate of photosynthesis to increase too (carrying capacity would increase). However, lower pH and warmer ocean would ~~g~~ favor smaller species of phytoplankton, ~~th~~ than larger ones. This would change the current composition of the foodweb and may have unforseen negative consequences, where species go extinct, and biodiversity is reduced, reducing the ability of food web to function, and to incorporate CO_2 and sequester it. It ~~is~~ also ~~shown~~ may ~~to~~ lead to a faster transition from organic carbon to inorganic CO_2, which also decreases its ability to act as carbon sink. Moreover, as mentioned, excessive algal blooms can be bad for biodiversity, building up toxins and harming the ecosystem, and may lead to more CO_2 release. Uniquely, ocean pH acidify → decrease can lead to the dissolving of $CaCO_3$ shells, ~~which~~ found in most phytoplankton & zooplankton species, ~~a~~ integral to their survival. This means that a decrease in pH can in fact decrease phytoplankton populations.

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QUESTION NUMBER

and vastly reduce their ability to photosynthesize and carbon storage. Climate change may lead to strengthening & changing ~~work~~ wind patterns, which would change the way iron dust is blown to ocean, and affect the abundance of this limiting factor in various locations.

2. Also, when EQs occur, it can trigger underwater landslides and volcanoes, which could easily damage our pressure sensors on the seafloor. Maintenance is also very difficult and costly, as we would have to travel very deep to fix things.

On land, we can't use a similar pressure detection as changes would be far too small, to monitor, and seismometers don't work either. Hence the only way to detect land slow-slips and their effect would be to use GPS to model the land profile & heights, to see any uplift & subsidence, as well as if the land had laterally moved in position. This is very difficult as it requires satellite accuracy, ~~and~~ which can be very hard to achieve, as it is too far away. The tech involved is very expensive, and it requires many such GPS stations to be built on ground, likely to cross-corroborate their info for accuracy. The modelling process is very difficult and costly, and could be very inaccurate.

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