SUPERVISOR'S USE ONLY

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Draw a cross through the box (☒) if you have NOT written in this booklet

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OUTSTANDING SCHOLARSHIP EXEMPLAR

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.

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 (DO NOT WRITE IN THIS AREA). This area may be cut off when the booklet is marked.

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.

Both phytoplankton and plants play an important role in the Earth's carbon cycle.
~~Phytoph~~
Phytoplankton are what is part of the biological pump (which lies in addition to the physical pump), ~~as~~ with atmospheric CO_2 removed from the atmosphere by dissolving in the water where it is used in photosynthesis, by phytoplankton. This carbon used in photosynthesis is used to produce organic forms of carbon such as glucose and other sugars, useful for respiration, ~~the ocean as~~ ~~also~~ and the synthesis of other organic carbon molecules Upon death, their bodies can also fall to the bottom of the ocean, the carbon being stored in limestone which after further compression and heat, after millions of years form coal, oil, gas, etc. These sediments are also able to be ~~su~~ subducted ~~and~~ ~~a~~ ~~ag~~ with CO_2 again released into the atmosphere ~~as~~ as part of the tectonic plates ~~math~~ and the ~~formation~~ eruption of volcanos, thereby playing a part in the rock cycle. After forming sediment and rock, they can eventually become part of the crust that subducts at a tectonic plate boundary to form subduction volcanoes. In this way, the death of phytoplankton leading to the

formation of ~~sedi~~ sediment like limestone can act as a very long-term store of carbon. Similarly the carbon-rich bodies of phytoplankton (or other marine life like whales which feed on ~~the~~ phytoplankton) ~~can~~ sink to the deep ocean with their carbon sequestered. As there is very little mixing between the different layers of the ocean, this can also act as a long-term store of carbon, with this carbon ~~never ever again~~ not reaching the atmosphere for a long time as it slowly travels with the thermohaline current. This carbon will only ever reach the atmosphere ~~unti~~ until travelling to sites of upwelling, thus being able to store carbon for long periods of time. This contrasts plants which are unable to contribute as significantly to phytoplankton in this long-term storage of carbon (though their dead bodies have the potential to form fossil fuels).

Both phytoplankton and plants will remove ~~atmosph~~ CO_2 from the atmosphere, and ~~they~~ are placed at the bottom of the food web as producers. They both are able to capture energy from the sun to allow photosynthesis to be performed. In the oceans, zooplankton eat phytoplankton which use energy stored in the organic forms of carbon produced by photosynthesis to perform photosynthesis releasing carbon dioxide:

glucose + oxygen → carbon dioxide + water + energy

This CO_2 produced by respiration is then able to return to the atmosphere. The same can be said for organisms that eat zooplankton and those further up the food web — essentially the entire ~~more~~ ~~ocean~~ food web. ~~Deep~~ Dead phytoplankton whose bodies are not stored in ~~deep~~ ~~ocean~~ ~~o~~ the thermohaline currents or in limestone, along with all other ~~organ~~ ~~deep ocean~~ ~~m~~ dead marine organisms can further have their bodies decomposed by bacteria, also producing CO_2 that can return to the atmosphere. Plants, similar to phytoplankton also act as short-term stores of carbon in this way. ~~O~~ ~~A~~ Organic material formed by photosynthesis is used by other living animals for respiration, the respiration of the plants themselves, or the respiration of bacteria feeding upon the dead ~~organ~~ bodies or organic matter of organisms, all once again emitting CO_2 into the atmosphere again.

Coal, oil, gas, etc. are long-term carbon stores which ~~act~~ ~~as~~ they are formed from organic matter from millions of years ago which have undergone heat, compression, etc. As humans uncover these fossil fuels and burn them, they release carbon dioxide into the atmosphere — carbon that was previously stored. Increased carbon dioxide is ~~is~~ leading to climate change, with CO_2 acting as a greenhouse gas that is able to absorb

~~and~~ reflected long-wave IR. This is leading to increased global tempeatures. Increased CO_2 in the atmosphere may possibly also lead to more algal blooms, with large amounts of nutrients available and an excess of atmospheric CO_2 allowing large amounts of photosynthesis and further respiration which will lower O_2 contents in the water as it is used up in respiration. This, however, can block sunlight leading to the death of other marine producers who can not photosynthesise and cause the death of other marine wildlife with reduced O_2 contents for respiration.

Warming of the ~~oceans will also lead~~ Earth in climate change may also lead to the poles becoming significantly warmer, with the melting of sea ice further meaning ~~on~~ less ~~the~~ short wave light is reflected from the sun as sea ice has a greater albedo than ~~ocean~~ darker ocean water, ~~a~~ forming a positive feedback loop. ~~At~~ The melting of sea ice and increase in ~~sea~~ temperature may all contribute to less downwelling of cold, saline water which could slow the deep thermohaline current. The true effects, however, are unknown, and this could possibly ~~then lead to no~~ effect the deep ocean currents as a store of carbon. Warmer oceans may also lead to faster interactions in the marine ecosystem. A warmer ocean could mean ~~more photosynthesis and~~ the faster break down of ~~dead~~ organic matter with a greater rate of photosynthesis, accelerating the release of CO_2 into

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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.

In the North Island, as the denser, older oceanic crust of the Pacific Plate subducts under the less dense, newer, continental crust of the Australian plate, friction between the two plates causes the build-up of elastic potential energy ~~in~~ along faults along the overlying Australian plate. It is the sudden release of this elastic potential energy that results in the formation of an ~~Ean~~ earthquake with this energy ~~released~~ released all at once, whilst the gradual release is a slow-slip event.

Slow slip events occur when the ~~A~~ Australian and Pacific plates move past each other slowly, releasing the elastic potential energy built up through friction over a longer period and larger area. This contrasts earthquakes which are moreso the sudden release of energy ~~over a~~ in a short amount of time over a smaller area. Slow-slip events also occur at regular intervals. ~~which contrasts Earthquakes. Th~~ During slow-slip events, the land moves very slowly as it slowly ~~releasing~~ releases the elastic potential energy built up from friction in the areas that have locked the tectonic plates together, and this can take large amounts of time and be extremely slow moving as evidenced by the 2cm movement of the land. Because energy is released over a longer time period and much greater areas compared to Earthquakes, they are unlikely to cause much damage.

Yet ~~a~~ slow-slip events have also been linked to earthquakes. Earthquakes are likely to occur more in the locked plate interface zones with the plates locked by friction ~~preventing slow slipping~~, preventing slow-slip events and rather having large sudden fault movements. ~~the~~ ~~a~~ There are 3 types of faults: normal faults where crust is stretched, reverse where crust is ~~[illegible]~~ compressed, and slip-strike which involve more lateral ~~faults where~~ sideways movements of the faults.

~~A slip strike~~ Slow-slip ~~events may result from Earthquakes as it causes disor~~ Earthquakes such as the Eketāhuna ~~North~~ earthquake are thought to be the ~~cause of~~ result of ~~slip-strike~~ slow-slip events such as the Kāpiti slow-slip. This ~~and Earthquake~~ earthquake lies on the boundary of the locked plate interface and slow slip zones, and may of caused further stretching and build-up of elastic potential energy in the crust which ~~cause~~ defined the fault and thus resulted in the Eketāhuna earthquake, ~~#~~ with the "plates snapping back into place" releasing significant amounts of energy. The 2016 Kaikōura earthquake has also been linked to slow-slip events that occured after. For a similar reason, as the fault moves resulting in ~~an~~ the earthquake, this could of ~~a~~ caused a slow-slip events with the ~~energy held in the plates~~ deformation along the fault causing ~~a~~ a slow-slip event to release energy on this part of the crust. All of this friction and energy will build up on the overlying Australian plate as it rubs against the subducting Pacific Plate.

~~She Unlike Earthquakes, the slow~~ Unlike earthquakes, as slow-slip events do not release large amounts of concentrated energy, they are unable to be able to be detected by seismometers with no noticeable shake in the ground. Therefore, they must be measured using GPS stations which will track the displacement of land. ~~These~~ However, as the movement in land is ~~seen~~ often extremely small, such as the 2cm displacement off the east coast near Pōrangahau, these GPS stations are required to be extremely ~~[illegible]~~ precise and accurate, making taking measurements difficult. ~~Similarly, it may be difficult to~~ ~~due~~ However, it is shown that slow-slip events occur at regular intervals, like that off the east coast near Pōrangahau with an event in 2006, 2011, 2016, and 2021 — an interval of every 5 years. Equipment can theche be prepared to measure these slow-slip events in advance unlike with ~~Earthquakes which~~ earthquakes which seemingly occur at more random intervals. ~~...~~ To monitor land displacements accurately, numerous GPS stations will ~~b~~ be needed and over a large area to measure the full extent of the slow-slip, ~~also ...~~ with the slow slip zones comprising a large ~~...~~ proportion of New Zealand.

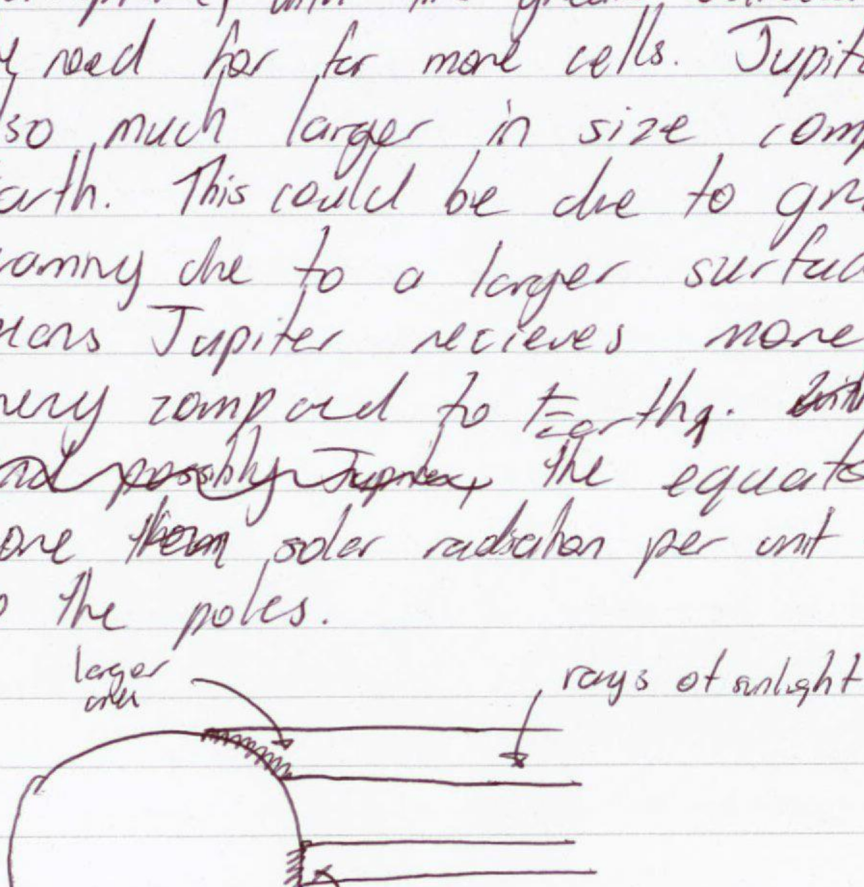
To ~~...~~ take recordings of slow-slip events at sea, pressure sensors are used to measure increases in height of the sea floor. This is as, when the Australian Plate slowly overrides the subducting ~~...~~ Pacific Plate during slow-slip events, it will gradually uplift. This uplift means less water above the pressure sensor and so a lower pressure. Having to use pressure sensors, however, will come ~~...~~ with many difficulties. It is likely very expensive to transport pressure sensors to the bottom of the sea floor, and changes in water pressure could be affected by numerous other factors like winds, or La nina events for instance which would pile water on the east coast of NZ, raising the sea level and so pressure upon the sensor. ~~...~~ Differences in pressure would somehow need to be adjusted to measure only differences from the slow-slip event. Similarly, from pressure differences ~~...~~

QUESTION THREE: JUPITER'S ATMOSPHERIC CELLS

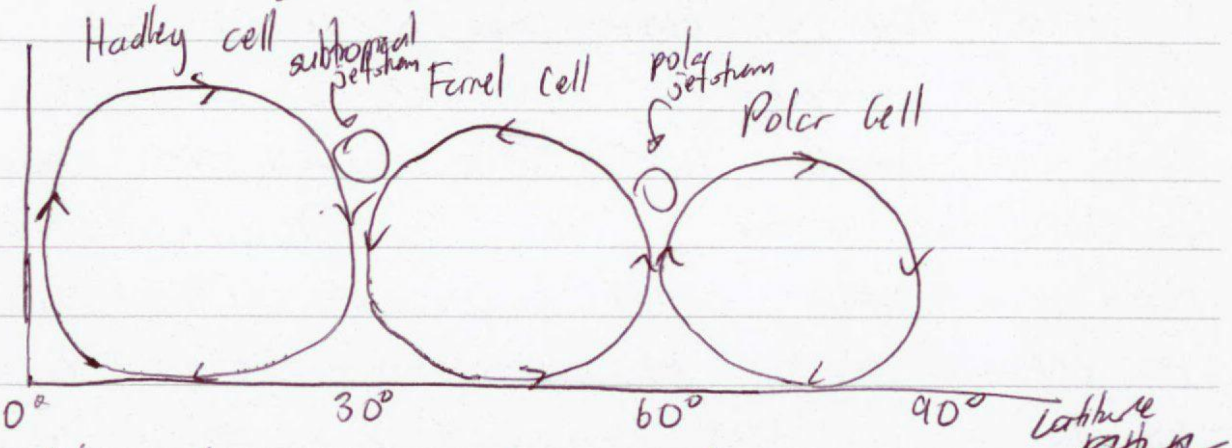
Analyse the differences between the Earth's atmospheric cells and the bands on Jupiter. Explain why these differences occur, and how these relate to the size, rotational speed, and composition of both planets.

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.

Whilst on Earth, there are only 6 cells, on Jupiter, there are 20 bands/cells which are similar to Earth's atmospheric cells. The reason for this is possibly due to the greater rotational speed of Jupiter which causes the coriolis effect to have a larger impact. This means more ~~defl~~ deflection of winds to the right in the Northern hemisphere and more deflection to the left in the Southern hemisphere, with this greater deflection resulting in the need for for more cells. Jupiter's bands are also much larger in size compared to Earth. This could be due to greater ~~energy~~ warming due to a larger surface area that means Jupiter recieves more ~~h~~ solar energy compared to Earth. ~~Both~~ On Earth, ~~and possibly Jupiter,~~ the equator exposes more ~~therm~~ solar radiation per unit area compared to the poles.



This causes an uneven heating effect that drives the polar and hadley cells whilst the ferrel cells are not so much temperature ~~dr~~ driven. At the equator, warm, less dense air rises and falls at about 30° latitude North and South to form the Hadley cells. The other cells are also shown below.



The subtropical and polar jetstreams are also labelled which are areas of fast moving winds due to large temperature gradients between the cells. As Jupiter ~~a~~ has more bands as it spins faster, it will also have more of these jet streams. ~~and possibly faster or wall~~ with a greater deflection east/west. The jet streams are also faster.

Jupiter's bands may also have a greater depth compared to Earth due to more solar radiation ~~reaching it as well as~~ as well as ~~p~~ being able to produce more thermal radiation than it recieves from the Sun. ~~As rotating~~ Unlike Earth, there is no solid rock that prevents larger convection currents being made up of mostly gas and liquid. Hence, this will allow much deeper convection currents to form with cool material sinking to the planet's centre, being warmed by the heat produced in the core as Jupiter cools from ~~radioactive~~ ~~a pmy~~ likely the heat left over when Jupiter first formed. This causes the ~~gom material~~ now heated warm material which is less dense to rise, producing these large circulation cells back compared to Earth in which these circulation cells are driven only from solar energy alone. ~~As we~~ natural ~~rises nearly~~ ~~storms on Jupiter, Moving away from the equator~~ ~~the cells may~~ Similar to Earth, Jupiter has Ferrel-like cells with circulation directions that are opposite to the temperature driven cells. ~~As its As~~ As Jupiter has more bands it makes sense it would have more of these Ferell-like cells compared to Earth, with one ~~Ferell-each~~ Ferell-like cell between each temperature driven band. On both Earth and Jupiter vertical convective motion drives the bands/cells. ~~If Air~~ Material is heated, becomes less dense and so rises, until cooling, becoming more dense and falling until becoming heated again.

The Giant Red Spot is a storm on Jupiter ~~on~~ of crimson-colored clouds spinning anticlockwise at high speeds. It shows how Jupiter has far greater pressure gradients compared to Earth which can lead to such long-lasting and significant storms. Earth for instance ~~instance~~ has very short-lived and much weaker storms. It also proves how the bands on Jupiter and ~~jets~~ wind movements are overall much faster and violent compared to Earth.

Overall, the atmospheric cells or bands on Jupiter are significantly larger with a greater depth and ~~faster than on Earth, meaning~~ are faster compared to Earth. ~~Convec~~ Vertical convection cells require fluids -liquids or gases that are free to move and make up the entirety of Jupiter, whilst only a small part of Earth which has a surface. This allows for deep vertical convection currents with material being significantly heated at the core of Jupiter, and cooling significantly as it reaches the surface and falls again. The strong temperature gradients as a result of this significant heating and cooling in addition to solar energy from the sun (though this is likely not as significant in driving the convection cells) contributes to these ~~fa~~ belts or jetstream equivalents on Earth ~~form~~ as a result of the massive pressure differences which drive these belts in a similar process to the polar or subtropical jet streams on Earth. The added 20 belts ~~and all~~ compared to Earth's 6 ~~a~~ atmospheric cells are due to a more pronounced coriolis effect with greater deflection ~~on~~ of air ~~to the right/ relative the~~ to the right in the Northern hemisphere and left in the Southern hemisphere, thus requiring more atmospheric cells, and thereby in doing so leading to more ~~stronger~~ jetstreams and intermediate Ferrel-like cells. In addition to showing how strong the temperature gradients are on Jupiter, the Great Red Spot may also demonstrate how strong the coriolis force is on ~~the~~ Jupiter, producing such a

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Warmer water also absorbs less CO_2 than ~~wa~~ colder water, so ocean warming could lead to less CO_2 absorbed by phytoplankton leading to less big removal. and less available for photosynthesis

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

QUESTION NUMBER

1) the atmosphere. In terms of plants on land, climate change may ~~lea~~ and similarly ~~or~~ warming may lead to a greater frequency of forest fires which would release large amounts of CO_2 into the atmosphere in ~~the~~ the burning of plants, with these plants also being now unable to absorb CO_2 from the atmosphere. Usually, the carbon cycle acts as the Earth's 'thermostat', with more CO_2 ~~here~~ in the atmosphere leading to more rainfall (as warmer air can hold more water vapour) which removes CO_2 leading to ~~a~~ less atmospheric CO_2, so less rainfall, and so on. However, the burning of fossil fuels is putting large amounts of CO_2 that ~~cannot be dealt with~~ means this regulatory system is ~~th~~ no longer in action. Human intervention to reduce the burning of CO_2 ~~may great~~ and ~~Increased atmospheric CO_2 concentrations is also~~ leading to burning of fossil fuels by adopting electric vehicles, etc. may ~~th~~ reduce CO_2 in the air and allow the regulatory system to once again act.

Increased atmospheric CO_2 is also leading to ocean acidification (or rather the oceans becoming less basic). Increased atmospheric CO_2 means more

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CO_2 being absorbed to produce carbonic acid:

$$CO_2 + H_2O \rightarrow H_2CO_3$$

~~Carbonic acid~~ $H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$

H^+ produced from carbonic acid can react with CO_3^- in the ocean, reducing the CO_3^- in the ocean:

$$CO_3^{2-} + H^+ \rightleftharpoons HCO_3^-$$

~~It can~~ This makes it more difficult for carbonate shells to form with lower CO_3^{2-} concentrations and other carbonate minerals. It also reacts with $CaCO_3$ shells

$$CaCO_3 + H^+ \rightleftharpoons HCO_3^- + Ca^{2+}$$

With less shells forming, less sediment is produced which can fall to the ocean floor, so the ocean acts as a worse long-term carbon store.

In this way, human intervention to prevent further burning of fossil fuels will reduce the increase in CO_2, and both reduce the warming of oceans and ocean acidification, reducing these negative effects and allowing better storage of carbon in oceans and on land. It would allow phytoplankton to better uptake and store carbon in the oceans long-term.

2) alone, it may be difficult to get accurate cm readings of the extent of slip. Likewise, with such a large area over which slow-slips can occur, numerous pressure sensors would all be required which could be expensive.

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QUESTION NUMBER

3) large storm of circular moving clouds in an anticlockwise direction, possibly similar to the formation of gyres on Earth. As there jet streams are numerous, and the atmosphere cells massive compared to Earth, they move matter around Jupiter at significant speeds. Due to the atmospheric cells on Jupiter being much deeper compared to Earth, the jet streams are much ~~deeper~~ deeper as well – up to 3000km deep as a result of there pressure gradients extending over a massive length.

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Subject	Earth and Space Science Scholarship Outstanding	**Standard**	93104	**Total score**	20

Q	**Score**	**Annotation**
1	7	Candidate has explored the carbon cycle and related it to the context. Their answer is well structured and provides good coverage of human interventions and the effects of climate change on phytoplankton and carbon cycle. However, they have not compared the significance of plants with phytoplankton well enough to receive an 8 on this question.
2	6	Candidate has analysed the differences between earthquakes and slow-slip events. Furthermore, they have extrapolated the resource material to explain how these events are linked. They completed with examining the issues around monitoring of slow-slip events and aimed to give some ideas regarding solutions. The answer was awarded a 6 because it was well structured. However, it was not awarded a 7 because the answer required more exploration of how these events are linked for example why did the Gisborne slow slip occur after the Kaikoura earthquake.
3	7	Candidate has analysed differences between Earth and Jupiter's atmospheres as well as how they are affected by aspects of each of the planets. They were awarded a 7 because they did not fully explore the significance of the Giant Red Spot.