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TOP SCHOLAR

NEW ZEALAND QUALIFICATIONS AUTHORITY
MANA TOHU MĀTAURANGA O AOTEAROA

QUALIFY FOR THE FUTURE WORLD
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Scholarship 2015
Earth and Space Science

2.00 p.m. Tuesday 1 December 2015
Time allowed: Three hours
Total marks: 24

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

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

You should answer 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 2–15 in the correct order and that none of these pages is blank.

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

Question	Mark
ONE	
TWO	
THREE	
TOTAL	/24

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QUESTION ONE: RECORDS OF THE PAST IN OCEAN SEDIMENTS

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Use the information provided on page 2 of your resource booklet to answer this question.

Discuss fully how the detailed analysis of sediment cores can be used to interpret and understand past events that happened in or around New Zealand over many thousands of years.

Consider in your answer: ~~Mountain building, Oligocene sea level changes + glaciations~~

- major geological events, including the effects of erosion and weathering ~~Plate boundary?~~
- changes in ocean circulation and temperature
- changes in the type and distribution of marine and land-based species ~~Volcanoes~~
- changes in climate.

You may assume, for the purposes of this question, that the sediment core record is unbroken.

Well labelled diagrams may assist your answer.

Events would be dated based on the law of superposition (older layers at the bottom since sediment would not be folded at the bottom of the ocean) for relative dating, and biological correlation for absolute dating.

Volcanic events would be fairly easy to interpret as there would be layers of ash in the sediment core when eruptions occurred.

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Sediment cores from the deep ocean can be used to interpret past events and natural history ~~by~~ through the reference frame of interactions between hydrological, geological, biological and atmospheric systems.

Major events in New Zealand over ~~the~~ the past thousands of years have included ~~over~~ significant orogeny (including uplift of the Southern Alps), volcanic ~~and~~ activity, and also climate changes and associated sea level changes. These factors have also influenced life both on land and in the sea.

Interpreting geological events such as volcanism, orogeny and tectonic uplift would be done through investigating the composition of sediment as well as sediment thickness. Increasing Uplift of mountain ranges increases the erosive forces they are subject to, through greater freeze-thaw cycles, ~~and~~ mass wasting from increasingly steep and unstable slopes, and greater orographic rainfall causing increased ~~fluvi~~ ~~hydration~~ erosion directly from rain as ~~as~~ well as fluvial processes. ~~More sediment~~ Streams and rivers draining catchments ~~areas~~ where significant uplift and therefore erosion occured would be expected to have greater sediment loads, and would thus deposit more sediment offshore on the continental shelf. Parts of the sediment core corresponding to a time period where significant uplift and erosion was occuring would be expected to ~~have~~ be thicker, and have a greater proportion of sediment that was of terrigenous origin rather than biogenous or hydrological (ie. more ~~sandstone~~ sand, clay and gravel particles rather than minerals precipitates or organic sediment, compared to the ratio of these types of sediment during other time periods). The ~~s~~ exact type of terrigenous sediment could provide evidence regarding where specifically uplift was occuring, if a particular kind of terrigenous sediment was dominant. However, as well as rates of uplift, rates of erosion would be also influenced by climate, which as stated previously may be linked to the actual uplift itself (orographic rainfall), or due to more wider-scale climatic changes. During the Oligocene, During glacials, the climate was much cooler and glaciers extended across greater areas. More water was locked up as ice so sea levels were lower. During interglacials the climate was warmer, so there was less ice and sea levels were higher.

fluctuations in climate caused alternating cycles of glacials and interglacials, which would be expected to leave a clear record in sediment cores.

Firstly, during glacials, rates of deposition of eroded terrigenous sediment would be expected to slow, because while glaciers ~~[illegible]~~ may have been stronger erosional agents than rivers, the eroded sediment would have been accumulated into the glacial flow and transport of the sediment to the coasts would have been much slower. Thus rates of terrigenous sediment deposition from this time would be lower, and ~~the sediment cores would show smaller segments~~ thinner segments in the sediment cores would represent greater spans of time. Also, because sea levels were lower, in order to build up a complete picture of past events, sediment ~~[illegible]~~ cores would have to be taken further out on the continental shelf, ~~[illegible]~~ from an area that was still underwater even during glacial maximum, as ~~otherwise~~ the sediment record ~~would be disrupted~~ from an area that was exposed when sea levels fell would have a record disrupted by erosion and incomplete as deposition would not occur in a consistent way when it was exposed. ~~However,~~ However, using cores from further offshore could lead to inaccuracies in measuring rates of deposition and therefore erosion on land - ~~the further away from land, less sedime~~ most sediment is deposited by rivers very close to land and comparatively little is moved by currents further out. Thus rates of deposition ~~would~~ over time would change as the proximity of that area changed ~~[illegible]~~ in relation to the coastline, regardless of changes in erosive processes occuring on ~~[illegible]~~ land. However, the type of sediment could provide evidence as to how far a location was from the coast and therefore how high sea level was, and therefore what the climate was like. Larger particles are deposited near the coast while smaller particles, which require less energy to transport and are therefore more 'mobile', can be deposited further ~~[illegible]~~ offshore. Thus if larger particles such as sand

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dominate part of the core, it may be because the coast was closer to the site of the core sample, meaning sea levels were lower and ~~an interglac~~ a glacial period occurred at that time. Conversely, more silt or clay in the core would suggest that the core site ~~&~~ was further from the coastline at the time, and ~~in~~ that part of the core would indicate an interglacial period.

Further evidence from changing climates would come from biological factors. Firstly, different climates on land would support different kinds of species - eg. in warmer climates, kauri and podocarp forests became more extensive, while ~~the~~ cooler climates favoured species of beech. The pollen produced by land-based plants would be carried out to sea by the wind where it would eventually settle out as sediment to be incorporated into the sediment core, so different abundances of different types of pollen in different parts of the core would give evidence of what ~~the~~ plant species were dominant, and therefore what climatic conditions were like.

eg. In cooler climates, more beech pollen would be expected in sediment cores ~~taken~~ ~~from~~ from northern coasts, as the distribution of beech forests would have extended further north.

Further to this, because pollen preserves very well and is also distinctive to each species of tree (ie. can be identified when viewed under a microscope), pollen in sediment core layers can be used in a similar way to fossils in rock layers. If the dates and time periods that certain species were present in are known (eg. from land-based fossil evidence), ~~parts of~~ layers of the sediment core can be dated with an absolute date based on the types of pollen they contain. (From evidence regarding the type, abundance and distribution of plant species on land, the type and distribution of animal species could be inferred as ecosystems are based on plants, the primary producers).

Different climatic conditions would have also affected overall plant growth, with ~~plants expe~~ primary productivity expected to be greater during warmer climates (interglacial periods) because of greater CO_2 concentrations in the atmosphere (*) and warmer, more humid conditions which favoured plant growth. Greater rates of photosynthesis would have ~~increased~~ decreased the ratio of C-12 to C-13 isotopes in the atmosphere (because C-12 is used more in

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QUESTION TWO: CHANGES IN ATMOSPHERIC CIRCULATION IN THE SOUTHERN HEMISPHERE

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Use the information provided on pages 4 and 5 of your resource booklet to answer this question.

Discuss in detail the consequences of the effects that both the ozone hole over Antarctica and the increase in greenhouse gases (GHG) have had on the Southern Hemisphere's atmospheric circulation and the position of climate belts.

Consider in your answer:

- how the ozone hole has caused cooling of the stratosphere and the southwards shift of wind and climate belts
- how the ozone hole and increasing concentrations of greenhouse gases indirectly work together to enhance the depletion of ozone in the stratosphere
- the implications of the eventual recovery of the ozone layer on the Southern Hemisphere's atmospheric circulation and the position of climate belts.

Well labelled diagrams may assist your answer.

~~The~~ Both ozone depletion and increasing GHG concentration are having a significant impact on ~~the~~ atmospheric circulation and climate belts, ~~and~~ the result of complex interactions between these factors and the factors that affect the climate and atmospheric system.

O_3 is formed and destroyed in roughly equal amounts by UV radiation from the sun, so the amount of O_3 in the stratosphere is kept approximately in balance by natural processes. Human impacts have disrupted this balance. ~~Ozone~~ Man-made chemicals CFCs have been carried up into the stratosphere by upward moving air currents, from deep convection processes in the lower part of the atmosphere where air parcels have been carried up through the tropopause temperature inversion. ~~This has occurred most significantly over Antarctica because the ground surface receives little solar radiation~~ CFCs cause O_3 to break down due to complex chemical reactions, ~~which are catalysed by~~ for which polar stratospheric clouds can provide a catalytic surface. ~~[illegible]~~ As a result, during winter and spring, when PSCs are more frequently formed, more ozone is destroyed and an ozone 'hole' forms above Antarctica. Ozone absorbs incoming solar radiation, particularly high energy UV radiation. This energy is later re-radiated as heat, and this process ~~causes~~ is ~~what ma~~ the dominant process causing heating in the stratosphere. Less ozone during winter due to the hole means less heating of the stratosphere. Cooling of the stratosphere causes expansion of the troposphere, both vertically and horizontally. This means that the high pressure centre ~~of~~ over Antarctica ~~intensifies, as~~ reduces in intensity, as pressure decreases when volume increases. ~~more air is able to descend downward reduces in intensity, as the air~~ ~~This causes further cooling~~ ~~pressure is decreased. intensifies, the as more air is able to flow downwards.~~

During winter, the insolation recieved by the South Pole is negligible as there is 24hrs darkness, so the Earth's surface is very cold in that region. Overlying air is very cold as well and therefore sinks downward, due to high density, forming a zone of high pressure. This air attempts to flow out towards low and also warm ocean currents, as the winds drive the Antarctic Circumpolar Current which acts as a further barrier

pressure areas in the direction of the equator but are deflected to the left (due to the Coriolis effect - deflection is extremely strong at the poles), as a result forming intense winds that circle anticlockwise around the high pressure belt, forming the polar easterlies at surface level. These isolate the polar region from warmer air masses moving in from the north, causing temperatures to remain very low. As a result, ~~PSCs~~ conditions are very favourable for PSCs to form, ~~to cau~~ causing further depletion of ozone.

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This effect is ~~exacerbated~~ ehnanced by increasing GHG concentrations. The Earth recieves heat energy in the form of shortwave radiation from the Sun. Part of this radiation (about 30%) is reflected from the atmosphere, land and clouds. The remainder is absorbed, ~~either directly by the atmosphere (ie~~ mostly ~~by~~ at the surface because atmospheric gases/particles are relatively 'transparent' to shortwave radiation and ~~simpl~~ simply transmit most of it. The heat is then re-radiated from the surface as longer wave radiation (the frequency of radiation emitted by something is proportional to its temperature and frequency is ~~in~~ inversely proportional to wavelength). Atmospheric gases ~~and~~ in particular GHGs absorb long wave radiation very well and reradiate it back towards the Earth, rather than allowing it to escape into space. This causes the Earth to heat up. Increasing GHG concentrations cause the atmosphere to warm and therefore expand further, on top of the expansion caused by the cooling of the stratosphere (they also increase this effect as less re-radiated energy from the Earth's surface makes it to the stratosphere decreases so the stratosphere cools further). This intensifies the high pressure area in the South Pole during winter. As a result, GHGs ~~increase polar~~ cause decreases in temperatures at the poles and increase the formation of polar stratospheric clouds, and therefore ozone depletion.

These factors also influence climate belts. Earth's climate is driven by

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air pressure differences between the poles and the equator, caused by differences in the temperatures there. At the equator and ~~to~~ within the tropics, the sun is close to overhead for a greater proportion of the year, so solar intensity (radiation per unit area) is greater than at the poles, where the angle of sunlight means intensity is less, and ~~the absence of~~ radiation is absent for half of the year during winter in ~~the polar night~~, the "polar night". Thus the Earth's surface re-radiates more heat at the equator, which heats the over-lying air and causes strong convection, forming a low pressure belt (Inter Tropical Convergence Zone) around the equator. The rising air cools but cannot sink down directly due to continuing rising air below, and cannot spread directly to the poles because of the Coriolis Effect. As a result, it sinks back down at about 30° latitude north and south, forming high pressure areas in these latitudes. These are where the world's desert climates are located, as the air is very warm (heating as it descends due to increased pressure) and dry (having lost most of the moisture as rainfall in the tropics, during convective rising). Some of the air returns towards the equator (to complete the Hadley cell), while some flows poleward along the surface to eventually meet cold air flowing out from high pressure areas at the poles. ~~B~~ The converging air masses rise and spread north and south again, forming the Ferrell and Polar cells. Thus atmospheric circulation is driven by differences in air pressure. ~~Kave~~ The tropopsphere is typically higher at the equator because the air there is hotter and air pressure is therefore lower. ~~This~~ Air pressure is higher at the poles as the air is colder and the troposphere ~~i~~ smaller in height. The effect of the ozone depletion (causing stratosphere cooling at the South Pole, and therefore expansion of the troposphere) combined with GHGs (warming and expansion of the troposphere) causes this net pressure gradient between the poles and the equator to decrease. As a result, atmospheric circulation is weakened and climate belts are shifted further south, as air flowing from the equator can penetrate further south before being sufficiently denser relative to surrounding air to sink, and also before meeting cold polar air flowing out of the Polar High and then rising (ie. previous downward convection at about 30° latitude and upward convection at about 60° latitude would shift further south). This affects the portions

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QUESTION THREE: HABITABLE ZONES AROUND RED DWARF STARS

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Use the information provided on pages 6 and 7 of your resource booklet to answer this question.

The search is on for rocky planets around red dwarf stars, that may have life on them. One of the key requirements is a liquid medium, such as water. Therefore astronomers have been looking for planets in an area the right distance away from a star for liquid water to be present – the habitable zone.

There is gathering evidence that liquid methane could also be a suitable medium for life. If this is shown to be true, there may be a second habitable zone around some stars.

Discuss in detail the possibility of TWO habitable zones around red dwarf stars as they form and age.

Consider in your answer:

- the relative positions of two habitable zones around red dwarf stars
- the most likely zone for life to evolve
- the implications for evolving life in both zones as a red dwarf star forms and ages.

Well labelled diagrams may assist your answer.

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One of the key requirements for life is liquid water, or potentially, ~~as~~ a substitute liquid medium such as methane. The habitable zone where life could potentially evolve therefore depends on the zone where liquid H_2O or CH_4 could exist, as well as other factors.

For a red dwarf star, the habitable zone for a planet with liquid water would be close to the star ~~than to~~ compared to the distance between Earth and the Sun, because red dwarf stars are smaller than the sun and have cooler surface temperatures, so energy output as EM radiation is lower and a planet needs to be closer to recieve enough energy to maintain water in ~~the~~ its liquid form (EM radiation intensity is inverse square proportional to distance from the source). The smaller the star, the closer the habitable zone is to it. ~~For methane~~ If CH_4 was a suitable ~~so~~ medium for life, a second potential habitable zone can exist ~~wher~~ at a distance where solar radiation/energy is sufficient to maintain methane in its liquid state - further than for water, because methane has a much lower ~~to~~ melting point (-183°C compared to 0°C). However the planet cannot be too close in either case as the star-ward edge of the habitable zone is where energy is great enough to boil the water or methane instead of maintaining it in liquid state. Thus temperature requirements determine the general ~~[illegible]~~ ~~[illegible]~~ zones of where planets would need to be found for life to develop. However, there are other significant factors. Planets that are located very close to the star would become tidally locked, so ~~they~~ ~~tat~~ the period of rotation is the same as the period of revolution. This means only one face of the planet ever faces the star, and one is constantly in darkness. This would set up extremes in climate on the surface of the planet, and it may cause all liquid on one side to eventually boil away and all liquid on the other side to freeze. Even if the whole planet remained liquid, the extreme temperature differences would cause extremely strong ~~[illegible]~~ convection currents that may be disruptive to life, carrying

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it away from the lit side of the planet (presumably they would need sunlight for photosynthesis) to the dark side, unless they were somehow anchored, in which case shallow seas would be required. ~~As~~ a result, the nearer habitable zone, of H_2O, cannot be too near the star, otherwise tidal locking will probably cause unsuitable conditions for life. Around ~~smaller +~~ very small stars therefore, the methane zone (further away), might be the only habitable zone.

The habitable zone positions would also change over time as the star develops. Proto-stars are larger and young, newly formed stars are much more active. Firstly this means more radiation would be emitted, so the habitable zones for liquid state H_2O and CH_4 would both shift back initially, with respect to their positions when each star is in the main sequence stage. As the star ages, the zone shifts forward as the star becomes less active and releases less energy. Therefore, a habitable zone for a planet where life would be likely to evolve would have to be where habitable zones from the early stages and main/later stages of the star's lifecycle overlap - ie. where it is not too 'hot' when the star is young and active, but not too 'cold' when the star is older and smaller and less active. As a red dwarf star ages, it continuously shrinks, so the habitable zone would be continously changing. As a planet remains in orbit at a fixed distance, it must have started out at a distance that remains in the habitable zone for as long of the star's lifecycle as possible, to give the greatest chance / time for life to evolve.

Further to this, factors regarding the planet itself are significant. ~~The planet~~ ~~to~~ To increase chances of life evolving and being able to survive, the planet ~~wet~~ needs to have a sufficient atmosphere, or some other way of protecting organisms from harmful ~~electroradiation~~ ionizing solar wind, which damages DNA (presumably extraterrestrial life would similarly have some sort of biochemical genetic material that would also be vulnerable to ionising radiation). ~~Thus~~ In the case of Earth, ~~the~~ its mass is sufficient to have a strong enough gravitational pull to retain an atmosphere, but not too strong so that the atmosphere is too thick and dense and surface pressure is too high (alternatively, the habitable zones for liquid to be present could be wider as planets could be located further from the star as long as the surface pressure was sufficient to maintain H_2O or CH_4 in liquid state. However colder temperatures and high pressures ~~we~~ would still be detrimental to life as it would be harder to carry out life processes, and biochemical reactions would be slower). An atmosphere would protect life from extremes in climate (the atmosphere on Earth ensures temperatures do not vary by hundreds of degrees between day and night, as occurs on Mercury and the Moon), and to ionising radiation to a degree (although a magnetic field, ~~wat~~ from convection currents in a molten iron core would be needed to properly achieve this). Alternatively, it is possible that a frozen outer layer (possibly from internal heating) of ice could serve a similar role, ~~as~~ if pressure and temperature at depth was sufficient to maintain liquid (as occurs on the moon Enceledus). This would again extend habitable zones for a planet to be located, if the other characteristics of the planet were suitable.

Overall, searching for life around red dwarf stars seems reasonable, given the number of red dwarf stars (70% of stars in the universe) and their relative stability with a lifespan in the main sequence ~~of up to 2.5 bn years~~ of trillions of years (compared to red giants, which quickly consume all fuel and become unstable, ejecting outer layers and exploding in supernovae after a few hundred million years, which is less than the amount of time life would need to evolve). ~~However,~~

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~~their lifespans are still reasonably shorter for. Life on Earth has been evolving for 3.5 4bn years, although it may have arisen first arose 0.5-1 bn years after Earth formed. Thus it is more reasonably likely that some form of life may evolve on a planet orbiting a red dwarf, but not necessarily have time to develop into intelligent or even multi-celled life (which is less likely anyway given the range of other conditions required for this, such as protection from climate extremes and radiation, suitable habitat, atmosphere, etc).~~

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photosynthesis). Since CO_2 dissolves into the ocean in the C-12 to C-13 ratio present in the atmosphere at the time, and photosynthetic marine organisms use dissolved CO_2 to produce sugars and organic matter, organic matter contained in layers of the sediment cores that were deposited when the climate was warmer would be expected to have greater C-13 to C-12 ratios. (These ratios would not change after deposition because the isotopes are stable and do not decay). Further to this, marine organisms themselves would provide further evidence of different climatic conditions. Similarly to land based organisms, different species are more abundant in different climatic conditions, so species of microscopic organisms such as foraminifera, coccolithophores and diatoms (distinct species have distinct shapes) that had settled out as sediment after death could be used to date layers of sediment as a 'fossil record', as well as provide evidence of past climates based on which species were abundant. For instance, in warmer climates, calcareous rather than silaceous ~~organic~~ plankton species are more common, and would be expected to be more dominant in layers of sediment deposited during different climates.

~~Oxygen incorporated into the organic material~~ ~~Phytoplankton~~

Different isotopes of oxygen in core samples (as determined from oxygen ~~incorporated into organic matter from respiration of~~ containing compounds such as iron oxides, produced by inorganic precipitation and then settling onto the sea floor) could be further used to support interpretations of past climates - O-18 is a heavier isotope and water molecules with this isotope are less likely to be evaporated. When evaporation rates of seawater are greater, as when the

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climate is warmer, ~~would suggest~~ the ratio of O-18 to O-16 in the water would increase and this would be shown in sediment cores. In this way, different evidence from layers of the sediment cores can reveal the climatic conditions that layer was deposited in. This can reveal changes in the type and distribution of land-based and marine species (which can also be inferred directly for some species, particularly plants with pollen and marine micro-organisms, which are preserved in the actual sediment). Changes in climate can also reveal changes in ocean circulation and temperature. Warmer climates would suggest warmer ocean temperatures, which would in turn affect global ocean circulation patterns. The ~~difference betwe~~ thermal gradient between polar and equatorial regions would be expected to be lower in warmer climates, so atmospheric circulation and the processes which drive surface water circulation would be weaker. Similarly thermohaline circulation would be affected, as it is driven by differences in water density and particularly by the sinking of cold, saline water in polar regions where sea ice forms. ~~Greater~~ Warmer temperatures would mean warmer surface waters that were less salty (from melting of ice / reduced ice formation), so polar waters would not be as dense, and thermohaline circulation would be weaker. The opposite changes in circulation would be expected to occur during cooler climates.

3 It is possible that this could occur when ~~during~~ the pre-main sequence stage, before fusion actually begins in the star. However during this time, the energy output of the star would be very low, as most of its energy comes from nuclear fusion. Once fusion starts, the change in energy output would cause the habitable zone to shift very significantly, so a planet that was in a habitable zone during the pre-main sequence stage would probably

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no longer be in it. Thus life would only have around 2.5 bn years to develop during this stage before it would go extinct - which is possible, given that life on Earth arose about 0.5 - 1 bn years after Earth formed - but it would not have much time to evolve significant complexity (multi celled organisms only arose ~~hundreds of millio~~ less than 1 bn years ago). Thus life would be more likely to ~~deve~~ develop successfully after the star is in the main sequence, when conditions are much more stable for much longer. ~~In terms of~~

In terms of which of the zones is more likely to develop life: the CH_4 zone, being further from the star relative to the H_2O zone during all stages, would be better in the sense that conditions would be more stable as the star ~~are~~ changed over ~~time~~ time - eg. less exposed to solar flares and solar radiation initially. However, whether life could actually evolve ~~in~~ using methane as a 'solvent' is questionable. H_2O is ~~a polar mo~~ so significant as a biological solvent where biochemical reactions can occur because it is polar, ~~and also acts~~ and thus has properties such as strong cohesion, high specific heat (greater stability as a solvent) and bonding /dissolution of polar molecules or ions. H_2O is also amphiprotic and is significant in a role as an acid or base in many biochemical reactions. CH_4 has neither of these characteristics. If life were to evolve using ~~it is a~~ it as a biological solvent, it would be significantly different to the life we know on Earth. It seems much more ~~probab~~ probable that if life was to be found on an exoplanet, it would be on one with water, not methane, as the solvent.

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(2) ~~and~~ Seen strengths of the westerly wind belts, which flow along the bottom of the midlatitude Ferrel cell as air tries to move from high pressure at 30° to low pressure at 60° and is deflected left by the Coriolis effect. Moving the ~~ba~~ pressure belts south would move the westerly winds south, as well as decrease their strength (since the pressure gradient that caused them is reduced). ~~These also affect the~~ This also affects the polar jet stream, which flows just beneath the tropopause along the south edge of the ~~Polar cell~~ Ferrel cell, above the westerly wind belts. When the ozone layer eventually recovers, these effects will be reversed and the climate belts will shift north again, ~~as~~ However GHGs will still be present, if emissions are not curbed very rapidly and significantly, so will continue to play a role in influencing circulation, and climate belts may not return to exactly their 'original' positions.