Build Your Own Earth: Information Sheet and Assignment
EART10111 Planet Earth: Its Climate, History and Processes
Autumn 2016

Information Sheet

Build Your Own Earth (BYOE; http://www.buildyourownearth.com) was a vision that we had to engage students in understanding the controls on Earth's climate. The vision was for you to select the features you wanted in order to build the planet of your choice: distance from the Sun, tilt of the axis, location of continents, oceans and mountains, rotation rate, atmospheric composition, etc. You would enter these characteristics on a web page, and push the "Go" button. A climate model would run in the background and produce the climate on that world for you. Sounds fun, huh?

Unfortunately, such a vision is not currently possible with the speed of today's computers. Even using a simplified climate model that is built for speed (FOAM: the Fast Ocean–Atmosphere Model), our supercomputer will only run about 480 years of model climate in one day. That's even with our model having fairly coarse grid spacing. Each atmospheric grid box is 4.5° in latitude and 7.5° in longitude (about 500 km by 800 km near the equator), which would mean that there are around 4 grid points representing all of the UK and Ireland. Even at this coarse grid spacing, you'd need about 50–300 years of simulations to obtain a stable climate! Plus, with a number of students submitting simulations in real time, our supercomputer would be inundated with requests. Instead, we preselected about 50 Earths, did the computer simulations already, and prepared plots of the simulation results for you to examine.

Our preselected Earths are in three categories: Recent, Ancient, Alien.

Recent Earths include a Current Day (2015) simulation with 400 ppm of carbon dioxide in the atmosphere. We also have a preindustrial control simulation and a simulation from 1975. And, to show you the importance of the greenhouse gases to Earth, we have one where the atmosphere has no greenhouse gases. We also have simulations where we've changed the carbon dioxide concentrations (including some from our possible future!), the amount of solar radiation received by the Earth, and orbital parameters of the Earth (axial tilt and eccentricity).

Ancient Earths include snapshots from past geologic eras such as the Last Glacial Maximum (21,000 years ago), through the Miocene, Jurassic, Triassic, Carboniferous, Cambrian, and Ediacaran. We have taken paleogeography reconstructions from Colorado Plateau Geosystems (http://cpgeosystems.com/index.html) along with atmospheric composition reconstructions from Royer et al. (2004, *GSA Today*, doi: 10.1130/1052-5173(2004)014<4:CAAPDO>2.0.CO;2). Because the atmospheric carbon dioxide and methane concentrations millions of years ago are not well constrained, we recommend that you do not read these simulations as factually accurate representations of past environments, but as a plausible estimate of what changing ocean and land configurations and atmospheric composition can do to the climate.

Alien Earths are simple climate model experiments to abstract the climate down to its essence. What is the effect of no continents on Earth (Aquaplanet)? What would the circulation look like in a Snowball Earth episode (Iceplanet, which would be very much like Hoth from *The Empire Strikes Back*)? What would happen if a single continent existed on the equator? Or on the pole? What if the whole Earth was land except for a single ocean in the middle? These are the types of questions we want you to explore.

Words of Caution: To keep the model simple and fast-running, there are some feedbacks that are not included, such as vegetation and land-surface changes. Although ice sheets will grow and snow will cover the land surface, the ice does not become kilometers deep and become part of the terrain (which would affect the atmospheric circulation). The absence of these feedbacks limits the model's ability to simulate the climate for some configurations. The model is a fully coupled atmosphere–ocean–sea-ice model, but operates at a coarse grid spacing overall, with the atmospheric model operating at 4.5° latitude by 7.5° longitude, and the ocean and sea ice models operating at 1.4° latitude by 2.8° longitude. Thus, there will be features in the real world that will be under-represented or poorly simulated in the climate model because we lack adequate resolution.

HELP! BYOE is still in development. You will undoubtedly find problems or things that could be improved with the layout of the web site or quantities that you would like to see. Please give us constructive feedback to improve BYOE in the future in question 26 of this assignment. And, feel free to share the link with your friends and family.

***Prof. David Schultz** and **Dr. Jonathan Fairman**, Centre for Atmospheric Sciences*
***Stuart Anderson** and **Sharon Gardner**, eLearning Team*

This assignment is best done in multiple sittings, with time to ponder the results in between. We estimate that the assignment should take 8–10 hours to complete and will involve research in the library or online, so do not leave it too late to start. Some figures are in color, so refer to the PDF in Blackboard if you wish to view them in color.

The answer sheet at the end of this assignment should be detached and turned in separately from the assignment. You may either (1) edit this Word document with your answers then print it out or (2) print it out first then write in your answers by hand. In either case, submit a paper copy of your answers by **9 a.m. Thursday 10 November** at the time-stamp submission area on the first-floor coffee area of the Williamson Building.

Questions 1–23 and 26 will be marked based on the stated number of points on the answer sheet (usually 2–5 points). Incorrect answers or absent answers will receive 0. A full-credit answer will be correct, insightful, and well written (when a short-answer is requested). Partial credit will be awarded for partially correct answers. Question 24 will be worth 10 points and question 25 will be worth 25 points. Both will be marked according to the British system (First is 70% and greater, 2i is 60 to 69, etc.).

Videos to Help You Getting Started

Go to the Build Your Own Earth section of the Planet Earth Blackboard site and watch the four uploaded videos. The videos are also available on YouTube, if you prefer (links below). These videos will introduce you to the Build Your Own Earth website, show you how to interpret the graphics, and walk you through some paleoclimates.

Introduction to Build Your Own Earth:	http://bit.ly/BYOE-Video1
How to Use Build Your Own Earth:	http://bit.ly/BYOE-Video2
How to Interpret Climate Parameters:	http://bit.ly/BYOE-Video3
Exploring Earth's Paleoclimates:	http://bit.ly/BYOE-Video4

Rules on Citing and Referencing Source Material

As part of this assignment, you will be asked to find source material to compare to the simulations or to support your arguments. To receive full credit for your answers to questions, you must provide a citation, reference, or both, for any information that you find externally. You must use a consistent and standard format for full credit. Please use what is referred to as *Harvard-style referencing*. Below is a basic guide, but google it to find more information. Use "et al." in your citation if there are three or more authors. (e.g., "Smith et al. (2013)"), whereas you should list all authors in the reference list. Some examples are shown below.

If the source is a peer-reviewed journal article:

In-text citation at end of sentence or within sentence:

"…(Hume 2012)." or "Hume (2012) said…."

Reference list:

Hume, J. P., 2012: The dodo: From extinction to the fossil record. *Geology Today,* **28,** 147–151.

If the source is a book:

In-text citation at end of sentence or within sentence:

"…(Erwin and Valentine 2013, p. 141)." or "Erwin and Valentine (2013, p. 141) said…."

Reference list:

Erwin, D. H., and J. W. Valentine, 2013: *The Cambrian Explosion: The Construction of Animal Biodiversity.* Roberts and Company, Greenwood Village, Colorado, 406 pp.

If the source is a web page and its origin does not correspond to a journal article:

In-text citation:

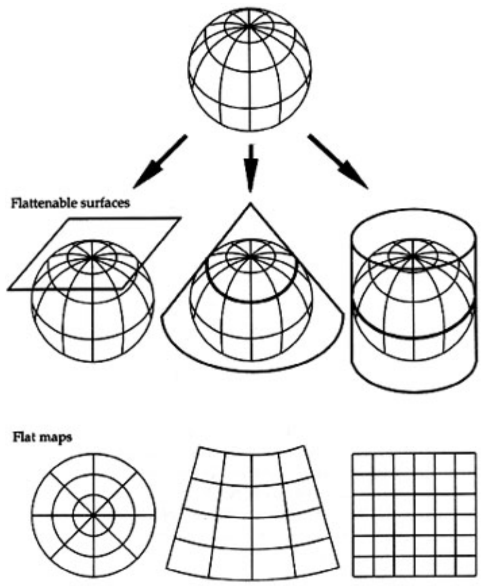
"…(University of Kansas Division of Invertebrate Paleontology 2008)." or "University of Kansas Division of Invertebrate Paleontology (2008) said…."

Reference list:

University of Kansas Division of Invertebrate Paleontology, 2008: Utah's Cambrian life, accessed 7 September 2016, http://kumip.res.ku.edu/cambrianlife/Utah-Lobopods.html.

Basic Map Projections

How to plot a spherical surface on a flat map has confounded mapmakers for a long time. Many solutions have been proposed, including some rather creative ones (e.g., google "weird map projections"). Below are three of the most common types.



How polar stereographic, conic, and cylindrical equidistant map projections are created by placing a plane, cone, or cylinder around the Earth and projecting points from the Earth onto that surface. (Source: http://krygier.owu.edu/krygier_html/geog_222/geog_222_lo/geog_222_lo13_gr/develsurfaces.jpg)

Build Your Own Earth uses two different map projections from four different perspectives. The default is called *cylindrical equidistant*, which presents the whole world on a flat rectangle. The cylindrical equidistant map treats every degree latitude and every degree longitude as having an equal area. Thus, the North and South Poles are actually represented as lines, not points on these maps. The cylindrical equidistant map in BYOE can be viewed with the Prime Meridian (0° longitude) at the center or with the International Dateline (180°) at the center.

The other projection used in BYOE is called *polar stereographic*, which presents just one hemisphere on a flat rectangle. The polar stereographic map is a circle with either the North Pole or the South Pole in the center as a point, but the equator as a circle surrounding the pole.

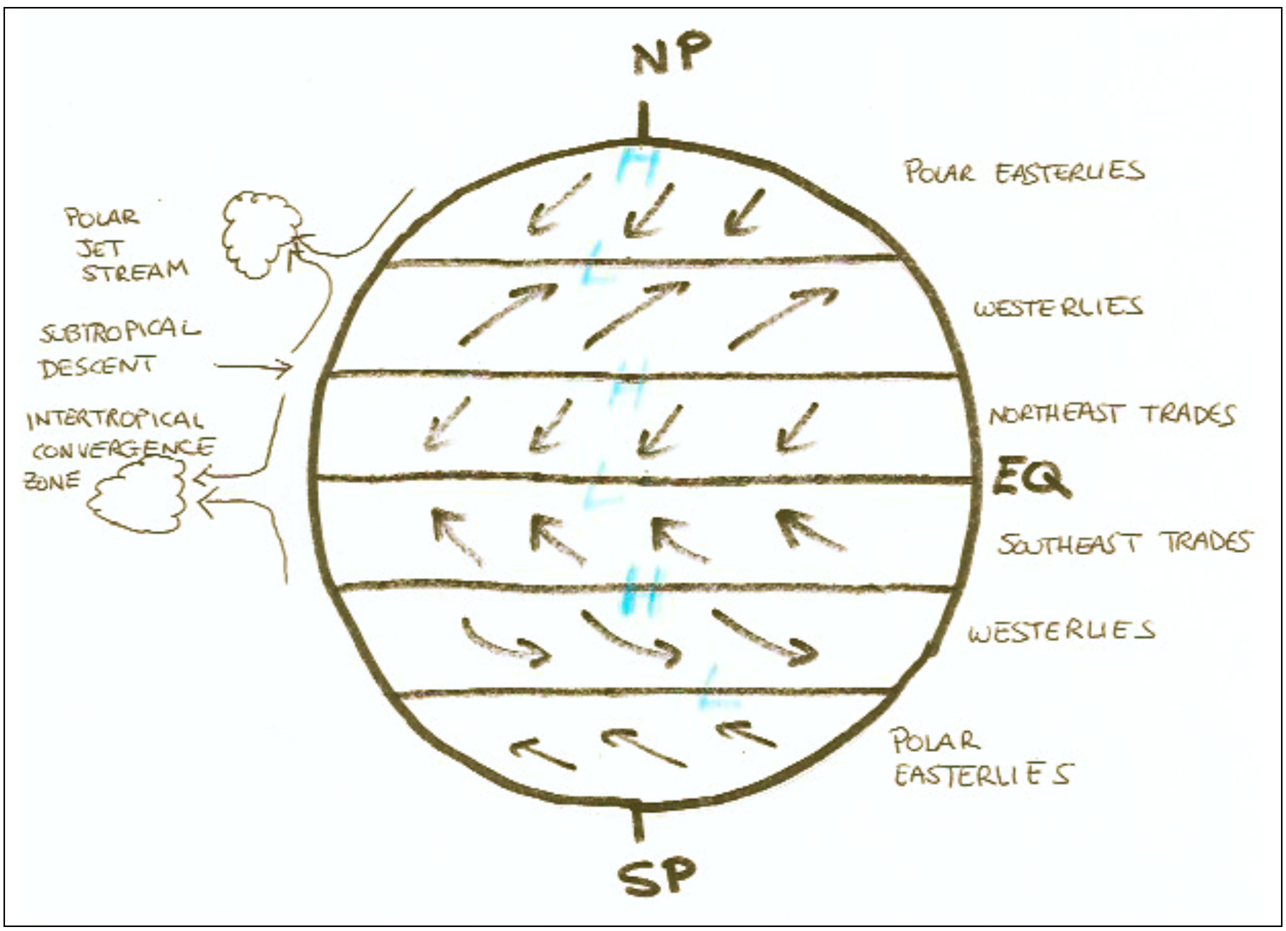
Unfortunately, both of these projections distort the Earth. **Areas near the poles are larger than areas near the equator on the cylindrical equidistant projection, whereas areas near the poles are smaller than areas near the equator on the polar stereographic projection.** Understanding map projections is important because of the distortion that it brings to our perspective. For example, see how big Africa really is because of the lens we view the world through in cylindrical map projections: http://io9.gizmodo.com/africas-true-size-will-blow-you-away-1441076531.

Assignment

What are the basic properties of the Earth's climate?

Build Your Own Earth currently has 50 different climate quantities that can be viewed for each simulation. Many are ones that you can relate to when you think of weather or climate (e.g., air temperature at the Earth's surface, wind speed and direction at the Earth's surface, sea-surface temperature, precipitation amount). Others you may not be familiar with, but are useful (e.g., dewpoint temperature, cloud fraction, winds at 250 hPa, sea-level pressure, ocean salinity, sea-ice depth). Still others are useful only to specialized research scientists (e.g., land surface albedo, surface latent heat flux, geopotential height). For this assignment, you can stick mostly to the first group.

One of the goals of this assignment is to help you visualize the relationship between the configuration of planet Earth and the resulting climate. An idealized schematic of the atmospheric circulation is below. (Here, I've only drawn the vertical circulation above the Earth's surface on the left side of the globe in the Northern Hemisphere to keep the diagram from getting too cluttered. For a nice video and animation of the atmospheric global circulation, see https://youtu.be/Ye45DGkqUkE.

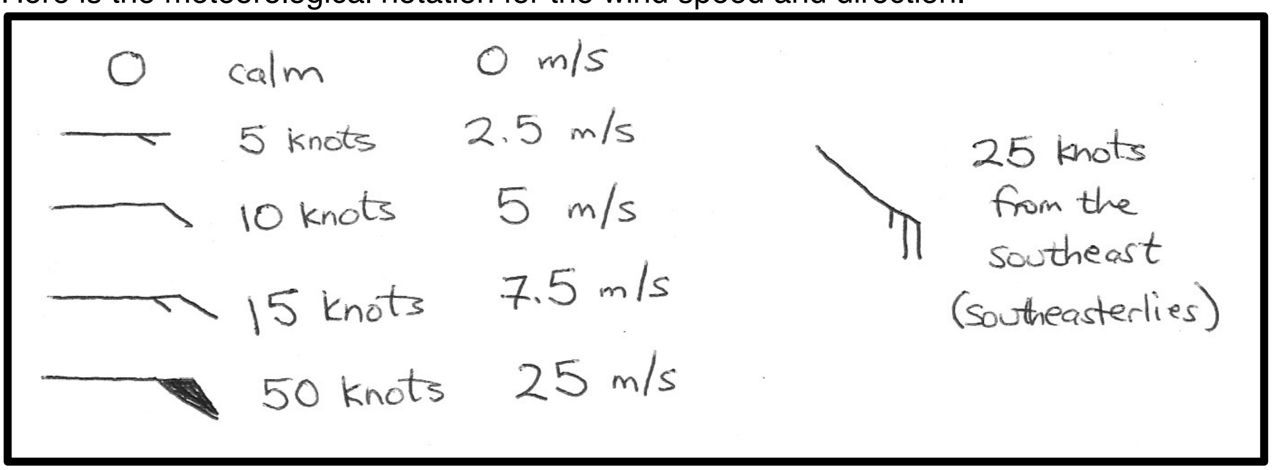


Three features are most important to you on this simplified schematic: the *Intertropical Convergence Zone* (often abbreviated ITCZ), the regions of *subtropical descent associated with the subtropical high-pressure systems* (also called the subtropical anticyclones) at the surface, and the *polar jet streams*. These three features are robust features of Earth's atmosphere, despite drastic differences in the planet's configuration, as you will see from the BYOE simulations.

The ITCZ is a region of heavy precipitation near the equator due to the converging of the northeast and southeast trade winds. The ITCZ "follows the sun", meaning it's not perfectly aligned along the equator; it moves over the course of the year, primarily occurring within the summer hemisphere. Both the Amazon and the dense forests of southeast Asia occur underneath the heavy rains of the ITCZ. Poleward of the ITCZ are drier regions associated with descent in the subtropical anticyclones of the atmosphere. The regions of subtropical descent are associated with deserts: the Sahara, the Middle East, and the southwest United States. You can best view these two features by plotting the total precipitation field or mean sea-level pressure, under Atmosphere.

Poleward of the deserts lay the midlatitudes, which are associated with flows of strong winds 5–15 km above the surface called the polar jet streams. The polar jet streams also separate warm tropical air from cooler polar air, creating the fronts you hear about on the weather reports. You can best view the polar jet stream from plotting the wind speeds at 500 hPa (about 5.5 km above the Earth's surface) or 250 hPa (about 11 km).

Here is the meteorological notation for the wind speed and direction.



The idealized schematic of the atmospheric circulation on the previous page can be compared to the atmospheric wind field in the simulation called Aquaplanet under Alien Earths. Aquaplanet is a planet similar in every respect to our present Earth except there are no continents and only a global ocean. The Aquaplanet simulation can also be used to show what the ocean circulation would be like in the absence of continents. The ocean currents are driven by the winds and the differences in density (mostly due to salinity and temperature). Specifically, choose "ocean currents – high vectors" and "surface". A strong current of surface water flows from the east to the west within the tropics, and is driven by the convergence of air along the ITCZ, thus illustrating how the wind field drives the ocean currents.

What determines the climate of Earth?

An almost uncountable number of planets are hypothesized to exist in the universe. Each one would have its own climate and possibly be favorable for life. **Is there a way to think about the question of climate more generally, perhaps by identifying a set of characteristics that determine the type of climate that such a planet would have?** Below, we present one way to think about this question, starting from the most important or most fundamental properties of the planet and ordering them in decreasing importance.

Ia. Astronomical controls on the Earth's climate: Solar constant

The first set of properties is astronomically determined and control the amount and distribution of solar energy received by the Earth. Obviously, the more solar energy that the Earth receives the warmer it would be, all other things being equal. The amount of energy received by a unit area at the top of the atmosphere is called the *solar constant*. It's not a physical constant like Newton's gravitational constant or the speed of light, but the mean of a nearly constant quantity. The currently accepted value of the solar constant is 1367 W m^{-2}, which is the value used in Build Your Own Earth.

The amount of solar energy received by the Earth is a function of two things: how bright the sun is and how far the Earth is away from the Sun. Under Recent Earths, select "Solar Constant". Five different simulations exist. The Control simulation uses the present value of the solar constant for the Earth. Two additional simulations Faint Sun and Warm Sun represent climate simulations if the Sun had a cooler or warmer surface. The temperature of the photosphere of the Sun is currently about 5800 K. The Faint Sun has a temperature of 5700 K (resulting in a solar constant of 1123 W m^{-2}), and the Warm Sun has a temperature of 5900 K (resulting in a solar constant of 1590 W m^{-2}). Alternatively, we can move the Earth away from the Sun, to the orbit of Mars, resulting in a solar constant of 585 W m^{-2}. Or, we can move the Earth closer to the Sun, to 87.3% the Earth–Sun distance, resulting in a solar constant of 1800 W m^{-2}.

By keeping everything else about the Earth fixed (e.g., continental configuration, greenhouse gas concentrations) and only varying the solar constant, we have what is called a *controlled experiment*. When testing a scientific hypothesis, using controlled experiments are essential because we can precisely determine what was responsible for any change. The simulation referred to as the *control* is the one that everything else is compared to. Were both the solar constant and the composition of the atmosphere changed, we would have no way of knowing what might be responsible for any changes in the resulting simulation from the control simulation.

First, convince yourself that as the solar constant increases, the temperature throughout the Earth's atmosphere increases throughout the year. Select from among the five different simulations varying the solar constant. Select climate property group "Atmosphere", "Mean Temperature", and "Surface" (for example). Then, change the Earth 2 simulation from "Control" to "Warm Sun" or "Faint Sun". Slide the bar left and right or up and down to compare the two simulations.

Second, change the climate property from “Mean Temperature” to “Total Precipitation”. Select from among the five different simulations varying the solar constant.

1. How does the amount of precipitation across the Earth change as the solar constant changes among these five simulations? Why might this be the case?

II. Astronomical controls on the Earth’s climate: Earth’s orbital properties

The second set of properties that control Earth’s climate are those that relate to the Earth’s orbit around the Sun. These properties include the rotation rate of the Earth, the tilt of the Earth’s axis of rotation (also called the obliquity), the eccentricity (how elliptical the orbit is), and day of the year when the Earth is closest to the Sun (called perihelion day). For this assignment, we’ll focus on tilt and eccentricity.

IIa. Astronomical controls on the Earth’s climate: Axial tilt (Obliquity)

Go to BYOE. Click “Get Started”, and go to Recent -> Axial Tilt. Set the obliquity to its current value of 23.44°. Change the climate property to “Atmosphere” -> Mean Temperature -> Surface, and click “View Model”. Click “Add Earth 2”, and select Axial Tilt again, this time setting the obliquity to 0°. Select “view climate model”. You can compare the two simulations by moving the slider left and right across the screen. Click on “view properties” of either Earth 1 or Earth 2 to see what the Earth would look like from space.

2. What do you notice about the changes in temperature over the course of the year in the 0°-tilted Earth compared to the 23.44°-tilted Earth?

Look at the 0°-tilted Earth. The amount of area with a temperature higher than 25°C in the tropics changes during the year.

3. What month has the largest area above 25ºC in the tropics? What month has the smallest area above 25ºC in the tropics? Why is there this difference?

From the drop-down menu, explore the other obliquity values (10º–90º).

4. Which obliquity value produces the highest January temperature on Earth? Where? Why might that be?

Explore other climate variables, such as sea-surface temperature, cloud cover, sea-ice fraction, and 250-hPa mean winds (jet streams, about 11 km above the Earth’s surface).

5. Which obliquity value produces the most consistent sea ice fields over the course of the year?

6. Which obliquity value produces the strongest jet stream? What month and where?

7. Generally speaking, conventional wisdom says that more tilt in the Earth's axis (i.e., higher obliquity) will lead to a larger difference between summer and winter temperatures (also referred to as larger *seasonality*). Based on what you have seen with the BYOE experiments, would you agree with this statement? Defend your answer.

IIb. Astronomical controls on the Earth's climate: Eccentricity

Eccentricity is a measure of how elliptical the orbit is. A perfect circle would have an eccentricity of 0. The current value for Earth is 0.016724. If you don't have a sense for the shape of an ellipse with this eccentricity is, check out this web page:
http://people.bridgewater.edu/~rbowman/ISAW/PlanetOrbit.html [An axis length of 1.0 AU means one astronomical unit, or the mean distance between the Earth and the Sun.]

Under Recent Earths, select "Eccentricity". Five different simulations exist. The Current simulation has the present value of the eccentricity, and there are two simulations with smaller eccentricity (more circular orbits) and two simulations with larger eccentricity (more elliptical orbits).

8. Examine the surface temperature for these simulations. Describe how the temperature on Earth changes as eccentricity increases. Why is this happening?

IIc. Orbital changes during Pleistocene glacials and interglacials

Under Recent Earths, select "Orbital Parameters". Seven different simulations exist: Current, 3, 6, 8, 11, 21, and 126 ka (ka is an abbreviation for *kilo annum* or "thousand years"). In these sets of simulations, the current atmospheric composition, land surface, and ice sheets are fixed. In other words, the atmospheric greenhouse-gas concentrations and ice sheets – which we know changed throughout the glacial–interglacial cycle from our paleoclimate reconstructions – are not included in these simulations. The height of the ice sheets was not taken into account in changing the topography during the Last Glacial Maximum simulation. Therefore, simulations at the Last Glacial Maximum, particularly in the Southern Hemisphere, are likely to be different than what happened in reality. Instead, the only changes in these simulations are to the orbital parameters that the Earth had at those past times (tilt, eccentricity, and perihelion day, for example).

The simulation representing 21 ka is the time of the Last Glacial Maximum (the farthest equatorward advance of the ice sheets in the Northern Hemisphere). The 126-ka simulation is the time of the last interglacial warm period.

9. Examine the surface temperature and snowfall (as a proxy for the ice sheets, which are not explicitly simulated in BYOE) for this range of simulations. Describe how the temperature on the simulated Earth changes from the glacial to the interglacial. How does this compare to your expectations? Why does it conform or not conform to your expectations. Explain your answer.

III. Composition of the atmosphere

The third set of properties relate to the composition of the Earth's atmosphere. As you will see later in this course, the primary control on the near-surface temperature in the Earth's atmosphere is the concentration of greenhouse gases in the atmosphere. *Greenhouse gases* have the property that they allow visible light to pass through them (i.e., we say that they are transparent to visible light), but absorb infrared radiation (i.e., we say that they are opaque to infrared).

Build Your Own Earth has several simulations with various greenhouse gas concentrations. These simulations vary the amounts of carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4). All of these gases have both natural sources and sinks and anthropogenic sources. These simulations also include two manmade greenhouse gases called chlorofluorocarbons (CFC-11 and CFC-12), which are industrial products whose concentrations in the atmosphere have been declining since the 1987 Montreal Protocol banning ozone-depleting chemicals.

Open Build Your Own Earth. Under Recent Earths, select the "Preindustrial Control" simulation. If you select other simulations (such as "Control in 1975" and "Current Day 2015") from the drop down menu, you should see changes in the bar charts that indicate changes in the relative concentrations of the greenhouse gases between simulations.

Select the "Preindustrial Control" simulation, and examine some of the fields such as cloud fraction, surface temperature, 250-hPa wind speed, sea-surface temperature, and sea-ice fraction. Add in "Earth 2" as the "CO2" -> "2 X Preindustrial" simulation, and use the slider to compare and contrast the two different simulations and respond to the following questions.

10. Where on Earth do you see the largest differences between the two simulations for the "Mean Temperature at the Surface" field?

Click on "Sea Ice Fraction" as your climate property (under Ice). Then click the N button to the bottom left for a view from the North Pole and S for a view from the South Pole.

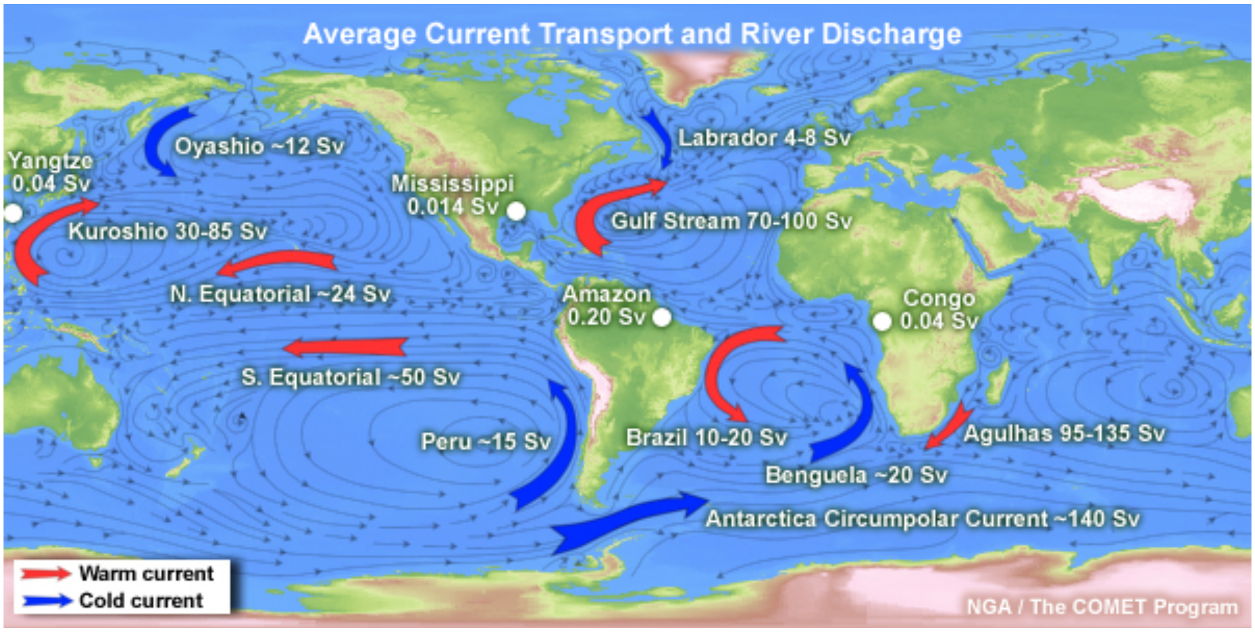
11. Describe the differences in the sea ice over the Northern Hemisphere between the two simulations. During what month(s) are the changes between the two simulations most dramatic?

IV. Configuration of the continents and terrain

The fourth set of properties relates to the configuration of the continents and their terrain. These configurations have several effects on its climate.

IVa. Changes in the oceans

First, the configuration of the continents determines the ocean currents, which enables (or disables) efficient heat transport from the tropics to the poles. The graphic below illustrates the surface ocean currents and their strengths. Sv is an abbreviation for a *Sverdrup* (named after oceanographer Harald Sverdrup) and is a unit of volume transport used in oceanography equal to one million $m^3\ s^{-1}$.



Surface ocean currents and transport. (Source: http://www.meted.ucar.edu/oceans/currents/print.htm)

Consider the Alien Earths that alter the position of the continents: Polar Supercontinent and Equator Supercontinent. Examine the quantities in the ocean: sea surface temperature, salinity, and currents. There are two graphics for the currents to highlight the weaker and stronger current directions (high vectors and low vectors).

12. Describe how the position of the supercontinent determines the climate characteristics of the ocean.

Coral reefs are found in a relatively narrow range of temperatures and salinities, and occurrences outside this narrow range prohibit their occurrence. Specifically, 95% (within two standard deviations from the mean) of coral reefs are found in ocean waters within a temperature range of 25–29°C and salinity of 32–37 parts per thousand (ppt) (Kleypas et al. 1999).

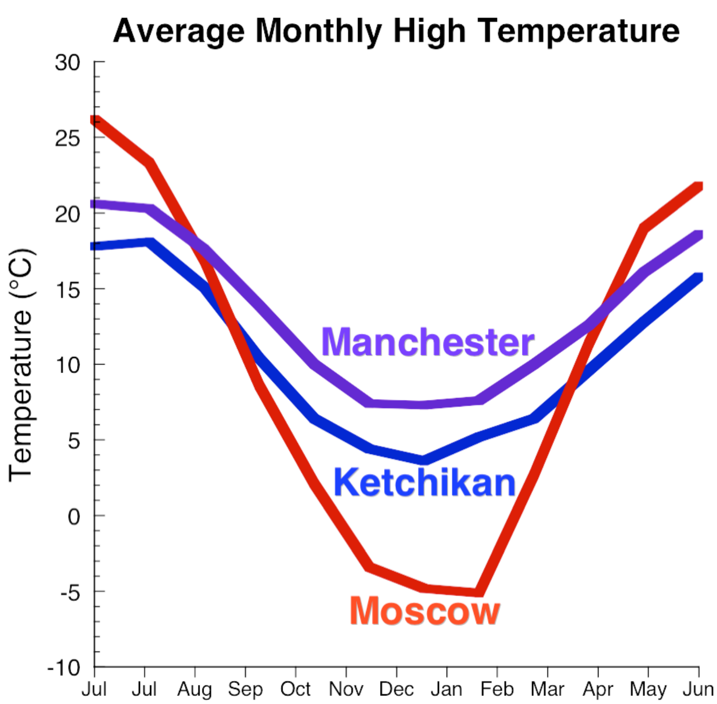
13. Using the monthly surface water conditions for the Polar Supercontinent and Equator Supercontinent, indicate the regions on the maps in the answer sheet where coral reefs would occur on these two Earths. For example, you can shade in the areas on the maps to indicate possible coral-reef locations.

Kleypas, J. A., J. W. McManus, and L. A. B. Meñez, 1999: Environmental limits to coral reef development: Where do we draw the line? *American Zoologist,* **39,** 146–159.

IVb. Different thermal properties of land versus ocean

Second, land and water have different thermal properties, and this can change how energy is stored and released, affecting the climate. Land heats up faster and cools down quicker than the oceans. Thus, land areas that are far from the ocean or are isolated from a marine influence (such as being blocked from prevailing winds arriving from over the ocean) have climates that have more extreme seasonal variation. Such a climate is called a *continental climate* and is characterized by hot summers and cold winters. In contrast, land areas that are affected by the oceans in the midlatitudes (30–70° latitude) have climates that are moderated by the more slowly evolving and subdued range in ocean temperature. Such a climate is called a *maritime climate* and is characterized by milder, more temperate seasons. These differences in how energy is absorbed and emitted by land and water mean that the distribution of the continents on the planet can influence the climate.

Consider the following example. Manchester, Moscow, and Ketchikan (Alaska) are all roughly at the same latitude (about 53°N), so all receive about the same amount of incoming solar radiation over the course of the year (aside from reflection by clouds). The graphs of the monthly-average high temperature (the average of the 30 daily maximum temperatures for 30 years) for the three cities are shown below. Moscow is interior to the continent with cold winters and hot summers, illustrated by a large annual cycle in monthly-average high temperature (32°C difference between summer and winter). Moscow definitely has a continental climate and large seasonality. On the other hand, Manchester and Ketchikan are both coastal or near-coastal locations and have similar annual cycles: relatively mild summers and mild winters (about a 15°C difference between summer and winter). We would say that Manchester and Ketchikan have maritime climates and less seasonality.



Now, examine some of the Alien Earths to consider the role of continental configuration on climate.

14. Rank Aquaplanet, Terraplanet, and Ice Planet from the largest range in temperature between summer and winter to the smallest range? Explain why your ranking is in this order.

15. One hypothesis that has been proposed is that extensive glaciation occurs when a large land mass lies on the polar region. Discuss the evidence in support of this hypothesis and counter to this hypothesis. Use present-day climate, paleoclimate simulations in BYOE, and other geological evidence. Cite your sources properly.

IVc. Locations of mountains affect the climate

A third effect on the climate is the location of the mountains. For the next few questions, look at the Single Midlatitude Continent simulations. If you select "180°" as your map view and select Land -> Surface Topography, then you can look at the differing mountain positions for the three different simulations (Western, Central, and Eastern). Look through some climate variables for these three simulations and answer the following questions.

16. Comparing these three simulations, the greatest differences in surface temperature downstream of the mountains occurs in which month? Why?
    January, April, July, October

17. Describe how the shape and strength of the jet stream (mean winds at 250 hPa) changes relative to the location of the mountains in these three simulations.

V. Rapid external forcings to the climate

The fifth set of properties relate to external forcings on the Earth's climate system. These include emissions of greenhouse gases by volcanic eruptions and flood basalts (eruptions of basalt that cover large areas of land or ocean), and impacts by asteroids or comets. Although the current configuration of the climate model used in BYOE doesn't allow us to insert such an event, we can run two sets of experiments at the end-Cretaceous (66 Ma): one before the asteroid impact at Chicxulub that is believed to have facilitated the extinction of the dinosaurs and one after the impact. The effect of the impact is simulated in BYOE indirectly by increasing the concentration of particles in the atmosphere through an increase in the *aerosol optical depth* (AOD, a measure of how far radiation travels through the atmosphere before being absorbed or scattered), keeping everything else the same.

The global-averaged temperature for the pre-asteroid simulation was 287.9 K (14.8°C), whereas it was 279.3 K for the post-asteroid simulation. For comparison, the Current Day simulation has a global-averaged temperature of 286.2 K.

Under Ancient Earth, compare the two end-Cretaceous simulations to see the effects of the asteroid.

18. Consider "Atmosphere" -> "Mean Temperature" at the surface. The change in temperature after the impact is greatest in what region on Earth?
    Tropics, Subtropics, Midlatitudes, Polar regions

VI. Exploring Ancient Earths: Last Glacial Maximum

Go to the BYOE website and select the "Ancient" category. Compare the Current Day 2015 simulation to the Last Glacial Maximum (21 ka) simulation.

19. Consider "Atmosphere" -> "Total Precipitation". Which simulation produces less precipitation over the Earth: the Last Glacial Maximum or Current Day 2015?

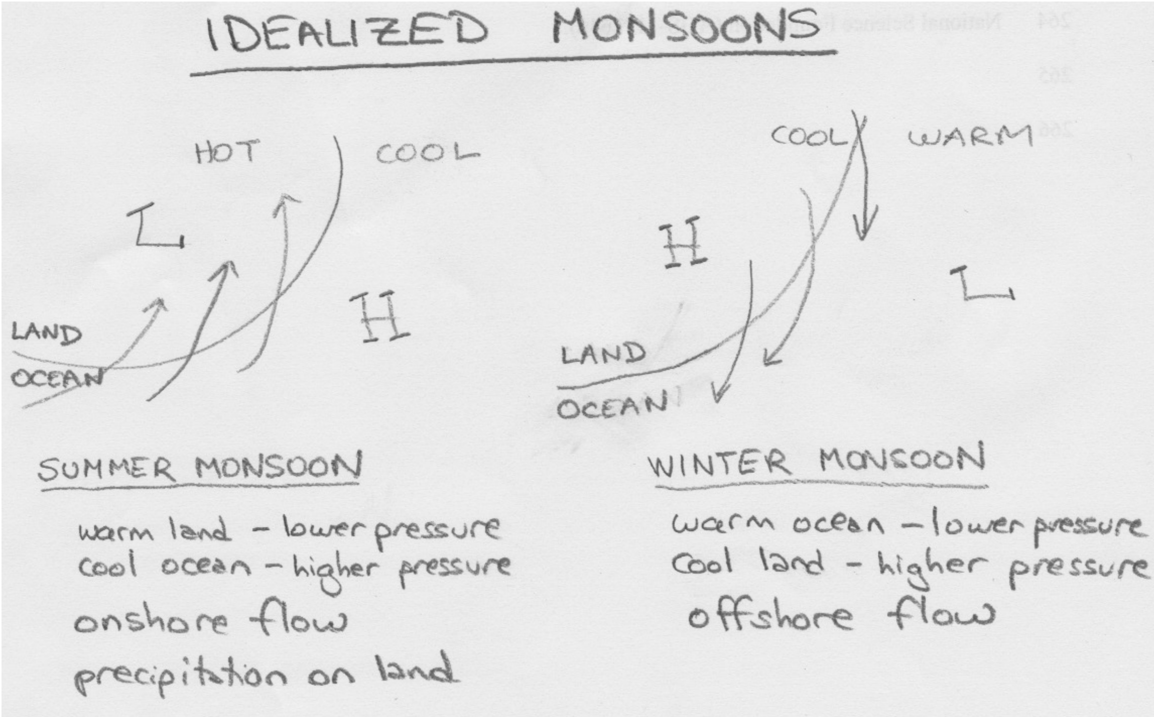
20. Describe the effect that this change in the hydrological cycle would mean for the types of vegetation living during the Last Glacial Maximum. Can you find some reconstructions of the vegetation at that time from the scientific literature? How is that determined? Cite the source or sources of your reconstructions to receive full credit.

VII. Exploring Ancient Earths: Pangaea

BYOE offers two simulations from Pangaea: Triassic (240 Ma) and Jurassic (170 Ma). The Triassic climate of Pangaea is often referred to as having megamonsoons (e.g., Kutzbach and Gallimore 1989; Parrish 1993).

Kutzbach, J. E., and R. G. Gallimore, 1989: Pangaean climates: Megamonsoons of the megacontinent. *Journal of Geophysical Research,* **94,** 3341–3357.
Parrish, J. T., 1993: Climate of the supercontinent Pangea. *Journal of Geology,* **10,** 215–233.

A *monsoon* is a large-scale atmospheric circulation that results from intense heating contrasts between land and water over the course of a year. As discussed before, the land heats up and cools down more quickly than the ocean. During the summer, the land will be warmer than the ocean, leading to relatively lower pressure over the land and relatively higher pressure over the ocean. Although the wind does not necessarily flow straight from high to low pressure because of deflection by the rotation of the Earth (i.e., the Coriolis force), there is some truth to this generalization. Thus, the *summer monsoon* is characterized by warm moist air flowing onshore, rising, cooling, forming clouds, and leading to precipitation. In the winter, the reverse happens with relatively cooler land and relatively warmer ocean. The *winter monsoon* happens when cooler dry air from land blows offshore, leading to subsidence over the land and the dry season. Although the Indian monsoon on our current Earth is best known, North America (southwest United States and northwest Mexico), southeast Asia, and northern Australia have well-defined monsoons that result from the differences in heating between land and ocean.



In contrast, other sources refer to Pangaea having an extremely arid climate.

"Much of the inland area was isolated from the cooling and moist effects of the ocean. The result was a globally arid and dry climate, though regions near the coast most likely experienced seasonal monsoons" (Asaravala et al. 2000).

"Climate was generally very dry over much of Pangaea with very hot summers and cold winters in the continental interior" (Bagley 2014).

Asaravala, M., H. Lam, S. Litty, J. Phillips, and T.-T. Wu, 2000: Triassic period: Tectonics and paleoclimate, accessed 7 September 2016, http://www.ucmp.berkeley.edu/mesozoic/triassic/triassictect.html.

Bagley, M., 2014: Triassic period facts: Climate, animals & plants, accessed 7 September 2016, http://www.livescience.com/43295-triassic-period.html.

Explore the Triassic and Jurassic simulations, and then answer the questions below.

21. Given your experience with these two simulations, how would you characterize its climate? Monsoonal? Very arid? Both? Neither? Depends? Construct an organized argument to advance your arguments. Make reference to specific plots from BYOE to support your argument.

22. Of these Alien Earth simulations, which has the best example of a monsoon circulation? Explain your answer. [Hint: you will have to pick one or more fields and incorporate them as part of your answer.]
Central Ocean, Polar Seaway, Tropical Seaway, Equatorial Supercontinent, Polar Supercontinent

23. Ninety-five percent of all tropical storms in the present climate form over sea-surface temperatures higher than 26ºC. Assuming that this condition also held in the past, which of the Alien Earths above could potentially have tropical storms?
    Central Ocean, Polar Seaway, Tropical Seaway, Equatorial Supercontinent, Polar Supercontinent

VIII. Comparing a paleoclimate model simulation to a paleoreconstruction

Pick one of the Ancient Earths that has not been discussed in this assignment so far. Find at least one reconstruction of some aspect of paleoclimate (e.g., sea-surface temperature, temperature, vegetation, climate type) from source material. If you can't find a reconstruction for the exact time (say, 170 Ma), then use a reconstruction within the same geologic time period.

24. How does the reconstruction compare to the simulation in BYOE? What are the similarities and differences? If you have found more than one reconstruction, are there differences between the two reconstructions? Remember to cite your sources.

IX. Asking Your Own Research Question

25. Pick a scientific question that you could answer with simulations that are not currently in BYOE. Design a simulation or series of simulations that you would like to perform. To best answer your question, design a controlled series of simulations. Hypothesize what results that you might expect. Explain why the series of simulation is designed the way it is and the hypothesized results. Explain your answer.

    Remember that this question will be graded on the British system (First is 70 and greater, 2i is 60 to 69, etc.) and it will be worth 25% of the assignment, so a thoughtful, fact-based response – that draws, not only from this assignment, but from the lectures, your reading, and external sources – is expected. If you refer to external sources, please provide a complete citation.

    Ten points will be given to your articulation of the question and why it is an important question (i.e., the motivation for your research). Five points will be given to the design of the simulation or simulations. Ten points will be given for your hypothesis and your explanation of the possible results.

X. What to Take Away from this Assignment

I hope that you have enjoyed this assignment and have learned something from it. The content of this assessment is fair game to end up on the test. Here are three take-home messages (of many in this assignment) that I hope that you've discovered and appreciate about how the Earth's climate works.

- Although the Earth has undergone large changes over geologic time, the patterns of moist tropics and dry subtropics with polar jet streams are relatively consistent. Details about these features change and their locations may shift slightly on the planet, but the planetary-scale circulation (Hadley cells, polar jet streams) is a consistent feature throughout geologic time.
- The global average temperature is a relatively simple metric for the global climate that fails to illustrate the wonderfully rich patterns associated with the planetary-scale circulation and annual cycle.
- These rich patterns control the local climate (temperature, precipitation, wind), which then determine various ecosystems for plant and animal life.

26. Now that you've had a chance to explore the different BYOE simulations and have experienced using the web site to access the plots, what did you think about BYOE and this assignment? What improvements can you suggest for BYOE simulations or the web site? Was there something that didn't work well or could have been explained better? Were there climate fields that you would have liked to have seen available for the different simulations? What kind of exercises would you like to have seen as part of this assignment?

NAME:________________________________ STUDENT NUMBER:_____________

EART10111: BUILD YOUR OWN EARTH: ANSWER SHEET AUTUMN 2016

1. (2 points)

2. (2 points)

3. (2 points)

4. (2 points)

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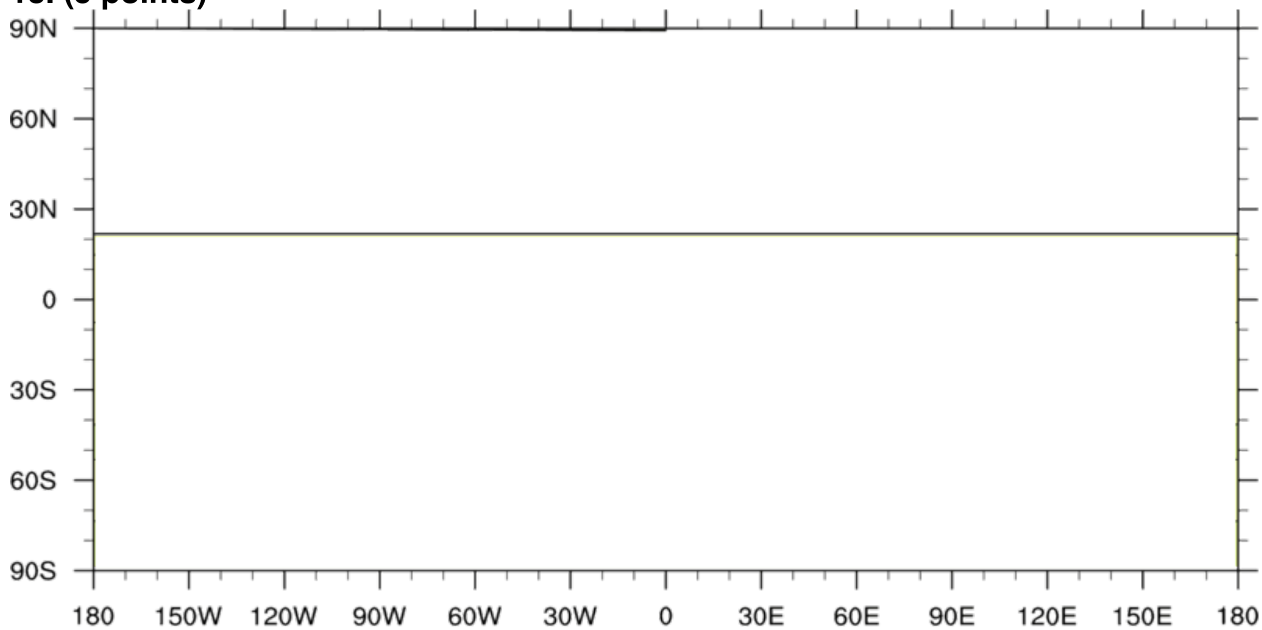
12. (3 points)

13. (5 points)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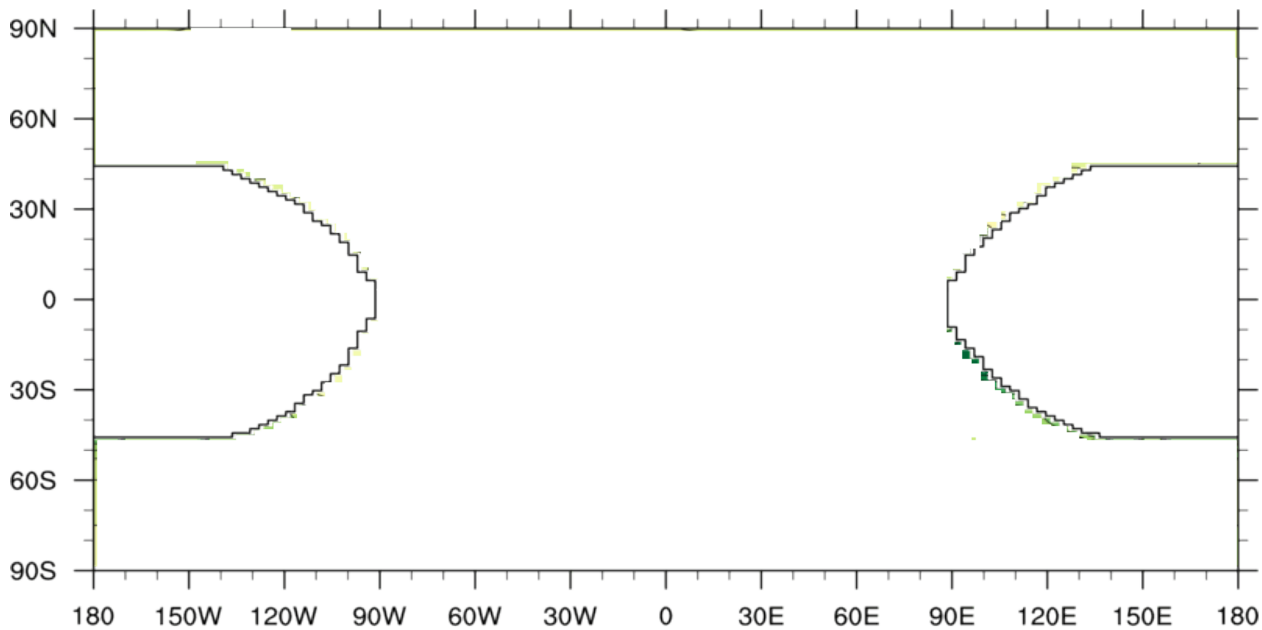
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14. (2 points)

15. (5 points)

16. (2 points)

17. (2 points)

18. (2 points) Circle one: Tropics Subtropics Midlatitudes Polar regions

19. (2 points) Circle one: Last Glacial Maximum Current Day 2015

20. (5 points)

21. (5 points)

22. (3 points) Circle one: Central Ocean Polar Seaway Tropical Seaway Equatorial Supercontinent Polar Supercontinent

Explain your answer.

23. (3 points) Circle one: Central Ocean Polar Seaway Tropical Seaway Equatorial Supercontinent Polar Supercontinent

24. (10 points)

25. (25 points) Please add additional pages, if needed.

26. (2 points)

The questions asked above are from just a sampling of the simulations in BYOE and from a very small fraction of all the available climate quantities. If you have time and the interest, please continue to experiment and explore BYOE.