Lab Title	**Microclimates and their link to vegetation in the Grand Canyon**  *Courtesy of the National Park Service (NPS), a helicopter view of mixed Ponderosa Pine – Oak forest on the rim transitioning toward desert scrub vegetation near the bottom of the Grand Canyon.*
What is this lab all about?	Arizona is the "Grand Canyon State." From the perspective of climate and its associated biota, this is especially true. The full range of Arizona's climates and ecoregions is on display. The highest elevations on the Kaibab Plateau's north rim host spruce-fir-aspen forest, while Mojave and Sonoran desert plants pepper its lowest elevations. This lab tasks you with analyzing how the Grand Canyon's topography influences its climate and vegetation patterns. The goal is for you to better understand basic concepts of physical geography science by interrogating the sorts of data used in scientific research – but all in a 100-level class (no prerequisites).
Lab Worth	The points you accumulate for correct answers count towards your grade. Incorrect answers do not hurt your grade.
Computer program used in this	**You will be given instructions in a canvas module page on how to download virtual world of Grand Canyon microclimatology and vegetation**. In this program, you are a virtual character able to wander

lab	around the Grand Canyon's landscape, summer temperatures, winter temperatures, and vegetation. WARNING: There are two different Grand Canyon geovisualizations – this one and one focusing on Geology-Topography. They are different video games with different data. You must use the microclimate game to complete this lab.
Interesting maps to download – not necessary to do the labs, but helpful to some students	National Park Service map of Grand Canyon National Park: https://www.nps.gov/carto/hfc/carto/media/GRCAmap1.jpg NPS 3D map of the Grand Canyon https://www.nps.gov/carto/hfc/carto/media/GRCA3DMap.jpg Shaded relief map of the Grand Canyon area: https://legacy.lib.utexas.edu/maps/national_parks/grand_canyon_map.jpg Vegetation Map of the Grand Canyon (23.4 MB) https://irma.nps.gov/DataStore/Reference/Profile/2221240
SQ general studies criteria	Students analyze geographical data using the scientific method, keeping in mind scientific uncertainty. Students also use mathematics in analyzing physical geography processes and patterns.
Lab Sections	Section 1. Preface Section 2. Overview of the lab CANVAS MODULES: Section A: Exploration Section B: Background in microclimate and vegetation patterns of the Grand Canyon Section B: Detailed Analysis Section C: Synthesis Essay

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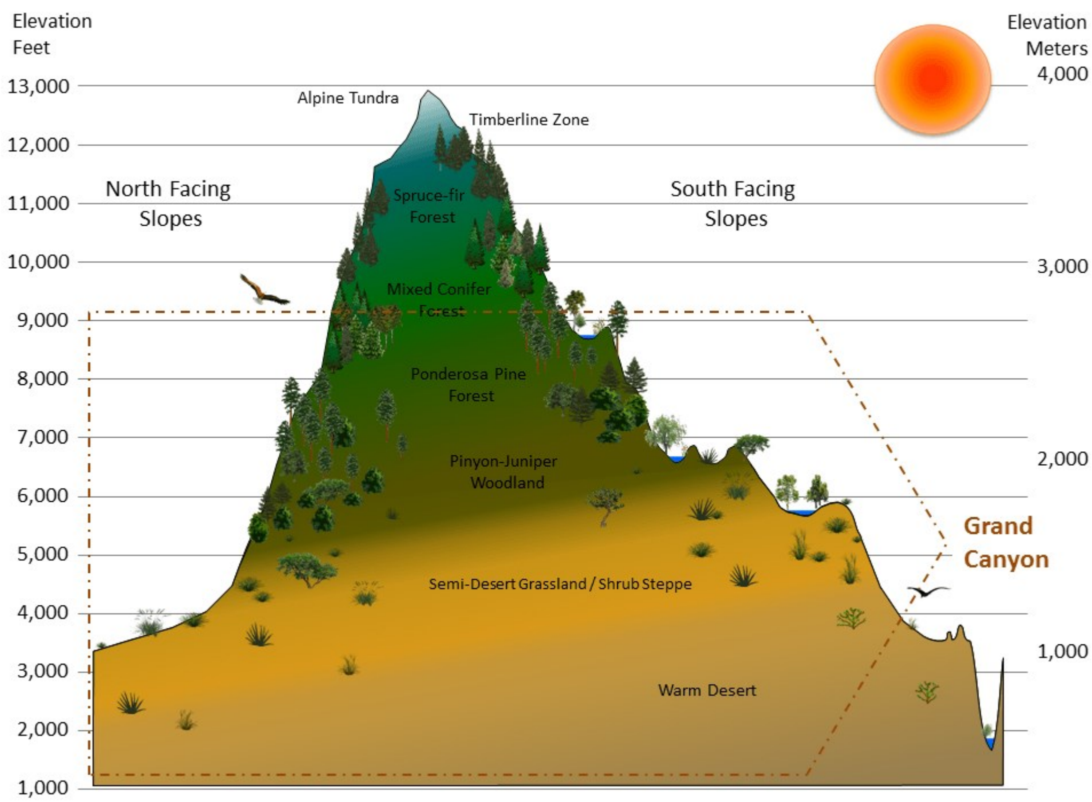
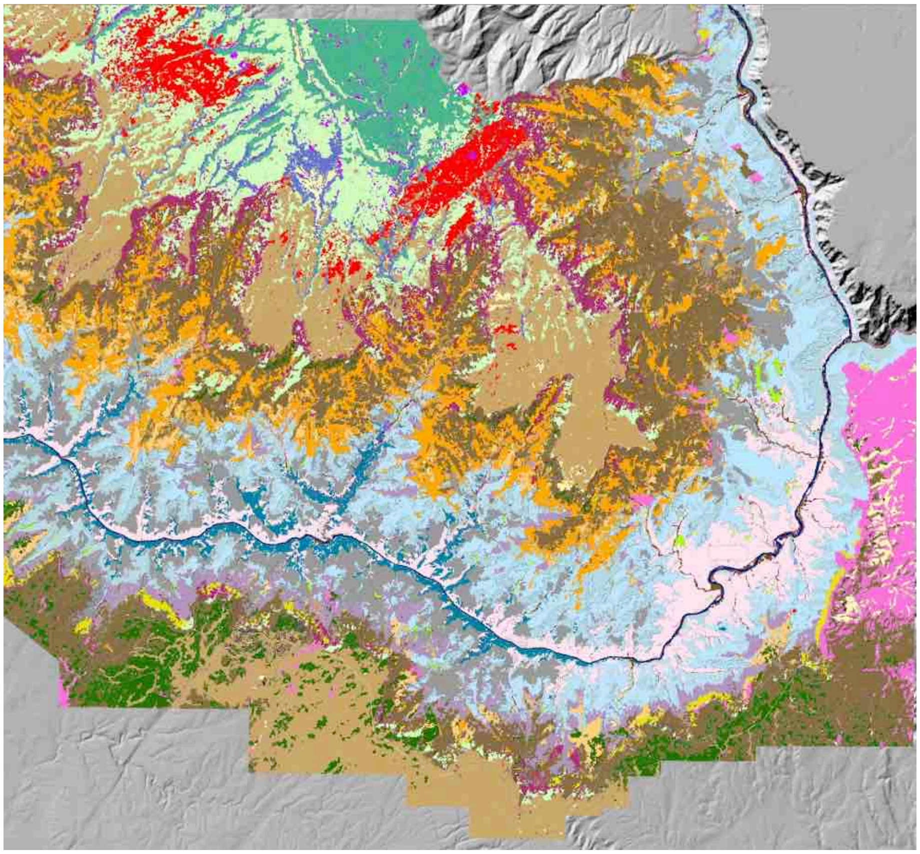
1. Preface: How do you begin to understand the complexity of microclimate and its role on vegetation?

The Grand Canyon is famous for many reasons, primarily its stunning landscape. Part of that landscape involves diverse ecoregions. The diagram below is famous for portraying this diversity, and it was redrawn by the National Park Service (with the elevations higher than the dashed-line Grand Canyon found in the nearby San Francisco Peaks).

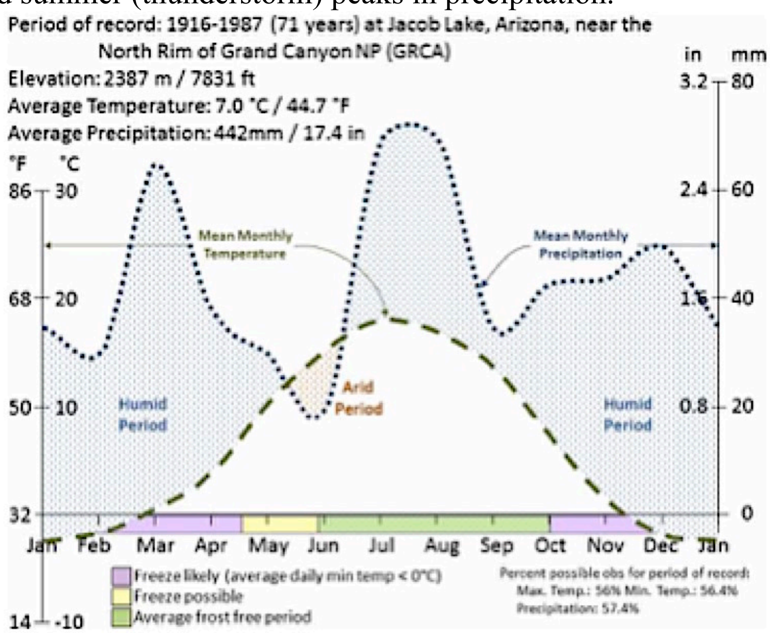
The idea conveyed so cleanly and so neatly in this diagram is that higher locations are cooler and wetter, with north-facing slopes being protected from solar radiation more than south-facing slopes. This one diagram does a nice of idea of communicating the basic idea of microclimate influencing these ecoregions (sometimes called life zones).



When the National Park Service tried to create a more realistic mapping of plant types in the Grand Canyon, a very complicated map was produced: Vegetation Map of the Grand Canyon (23.4 MB) https://irma.nps.gov/DataStore/Reference/Profile/2221240 . In this map below, you can see a bewildering complexity of plant associations displayed by different colors. In all, there are over 30 groups presented. This map is a generalization of reality found in the field. It is a product of a mixture of a lot of fieldwork and study of remotely sensed imagery.



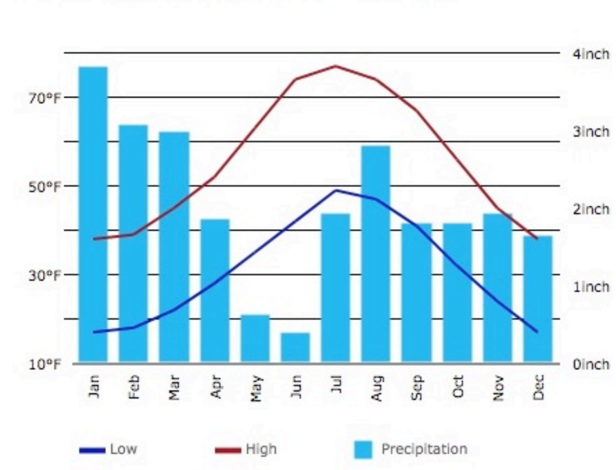
These plant associations are intimately connected with climate, and the climograph below summarizes the sort of decadal conditions that promote a Ponderosa Pine forest (tan color in the above map) on the rims of the Grand Canyon: cool winters, and both winter (snow) and summer (thunderstorm) peaks in precipitation.



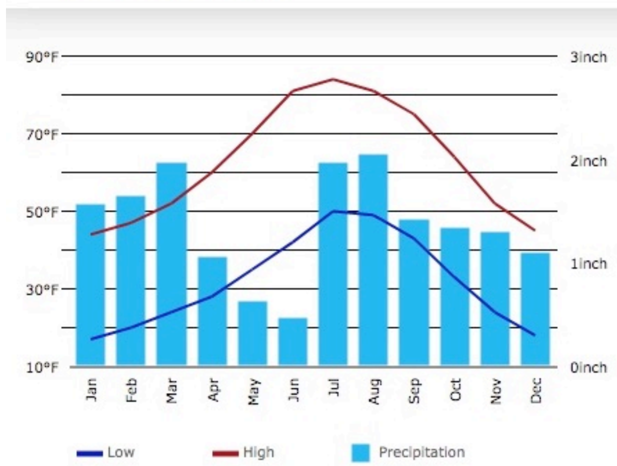
Even in the same sort of Ponderosa Pine forest, there are differences. On the North Rim of the Grand Canyon the Ponderosa Pine is mixed with some fir and other sorts of cool-loving plants that require more precipitation. On the South Rim, the Ponderosa Pine tends to be mixed with oak and needs less precipitation and can tolerate warmer temperatures.

These sorts of plots below are also called climographs, and they portray both temperature and precipitation information throughout the year. Note the warmer summer highs on the South Rim and the higher January-March precipitation (as snow) bars on the North Rim.

North Rim Climate Graph - Arizona Climate Chart



South Rim Climate Graph



Before this lab, flat maps and climographs formed the basis of student learning of this material. Everything was generalized for the student. The vegetation maps and diagrams are either extremely complicated or too general, and both are frustrating for introductory students.

That is why we turned to video game technology and geovisualization of climate and plants in and around the Grand Canyon. You can explore these relationships, and our job as laboratory builders is to try to do justice to the change in educational technology. I hope you think we did an okay job with this lab.

2. Overview of Laboratory Activities

You are undoubtedly familiar with the key scientific concepts that this lab covers, based on your life experiences (see the left column). The different stages of this laboratory delve deeper into these experiences by linking them to core aspects of physical geography.

For example, the idea of Stage A is for you to translate the prior knowledge of life experience into what you encounter in the geovisualization. The hopefully easier questions in Stage A provide background for later parts of the lab.

Life Experience of Students	Stage A – Videogame exploration	Stage B- presentation of academic concepts (lecture, reading, or both) that are a review of GPH 111
• the sun rises in the east, reaching its highest point at noon, and sets in the west	Surface temperatures are acquired at 10am and can be interpreted from life experience.	Understanding diurnal temperature variations are a core concept in physical geography
• in the coterminous USA, the sun is always in the south part of the sky	North-facing slopes receive less solar radiation and tend to be cooler than south-facing slopes	Seasonal temperature fluctuations and seasonal radiation balances are greatly influenced by the location of the sun and how it varies annually.
• wintertime sun angles are much lower than summertime sun angles	The steepest slopes facing north might not receive any (or very little) winter insolation	Noon sun angle calculations help explain local radiation balances
• precipitation (both rain and snow) increases with higher elevations	More precipitation helps increase biomass (more plant material) and influences type of plants	The bimodal precipitation of winter high elevation snows and summer thunderstorms is vital to explaining Grand Canyon biogeography
• temperature decreases with higher elevations	Hotter temperatures help decrease biomass and promote more xeric (dry-loving) plants	Lower temperatures reduce evapotranspiration stresses on plants, while higher temperatures limit plants severely
Different life zones exist, such as deserts, rainforests, conifer forests, and others.	Ecoregions consist of different assemblages of plants that combine together to produce a biomass signal recorded by satellites.	By taking ratios of different parts of the electromagnetic spectrum, its possible to calculate a NDVI (normalized difference vegetation index) that can be used to interpret plant types

The “rules” governing SQ laboratory science courses indicate that students practice the scientific process of gathering and interpreting data, given the prior understanding of a field of study (Stage B). The lecture in Stage B (or reading material; they are the same) reinforces and elaborates on basic concepts from GPH 111, but in the context of the Grand Canyon:

• Diurnal (temperature) variation is driven by solar radiation that peaks at noon, but there is a lag when the warmest temperatures are felt (mid-afternoon). Thus, there is a radiation balance of incoming solar radiation and outgoing terrestrial radiation with a diurnal cycle

• There are also annual changes in the radiation balance, driven mostly by seasonal changes in the amount of solar radiation. This is heavily influenced by the angle of the sun.

• Lapse rates are another way of saying how temperature changes with elevation (both on the ground, and up into the atmosphere).

• Precipitation varies seasonally, and in the case of the Grand Canyon, there exists a winter-time peak with snow at higher elevations and a summer-time peak with thunderstorms during Arizona's monsoon season.

• All of the above creates a complex fabric of daily, seasonal, and annual changes in temperature and precipitation that influences the amount of biomass (all plant and animal material) and the type of plants/animals living at different locations.

The hope is that by gathering and interpreting these sorts of data in Stage C, the science becomes more powerful and enjoyable for you. Then, you are challenged (without any grade penalty) to synthesize ideas for yourself (and also earn additional points) by writing a 4 paragraph essay in Stage D.

3. The video game geovisualization of the Grand Canyon for this lab: purchasing, downloading, and playing.

WARNING: There is another Grand Canyon geovisualization focused on the link between topography and geology. Make sure that you download the OTHER Grand Canyon microclimate geovisualization to do this lab.

All of the instructions you will need to purchase and download are found on a Canvas page in the Welcome section of the course.

There is another page on hints about playing the game in the Canvas Welcome module.

These two items are often glossed over by students, but can solve a lot of frustrations.

Escape Key – hitting the escape key will enable you to move the rabbit, or alternatively access the features of the game

How to play and game and also use other programs

	Mac	Windows
Before you open the game, access the Unity presets to make the game windowed and also lower the resolution	Hold down the OPTION key when you open the game. Then, click on windowed and any lower resolution will make the game be a window on your desktop.	Hold down the SHIFT key, when you double click on the application. Then, click on windowed and any lower resolution will make the game be a window on your desktop.
While the game is already open	Holding down the apple command button, hit tab	Holding down the windows icon key, hit tab

STAGE A:
EXPLORING THE GRAND CANYON MICROCLIMATE AND VEGETATION GEOVISUALIZATION

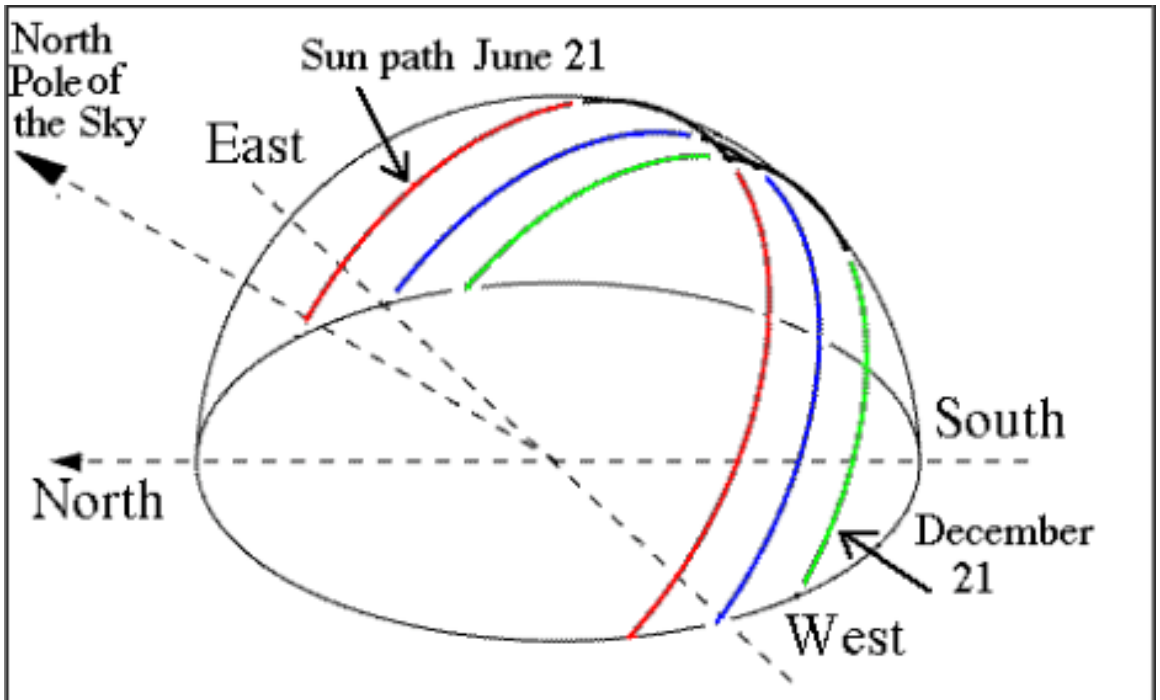
The idea of this stage is for you to explore some of patterns observed in physical geography data on climate and its connection to vegetation. Use these questions to decide if the information is of enough interest to warrant a deeper investigation in Stage B.

This section explains each type of question and gives you an example. Then, when you take the quiz on Stage A in canvas, you will see questions very similar to the examples presented here; however, the questions will not be identical. In fact, different students will be presented slightly different questions.

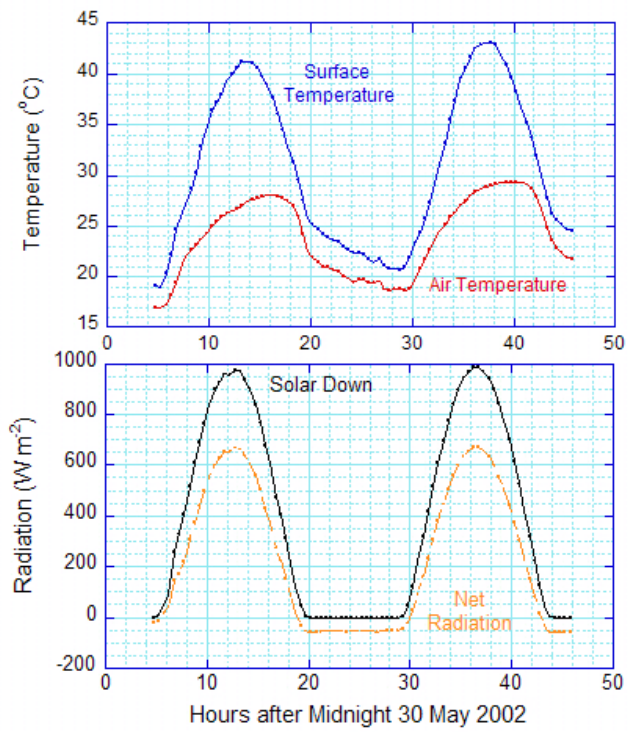
A1. QUESTION ON INTERPRETING SURFACE TEMPERATURES

Background for A1: Diurnal temperature cycle and movement of the sun

In the area of the Grand Canyon, this diagram shows the path of the sun throughout the day at winter solstice and summer solstice. The sun rises in the east, reaches its highest point at noon, and sets in the west. The amount of solar radiation received at Earth's surface is greatest when the sun is highest in the sky.



The apparent path of the Sun across the sky.
In summer, the Sun's path is longest, and so are the days.
In winter, the Sun's path is shortest, and so are the days.



This diagram would be pretty similar to what would be experienced at the Grand Canyon on bare-rock surface at the end of may. Two diurnal cycles are portrayed.

The bottom graph shows the amount of solar radiation that is being sent by the sun at the top of Earth's atmosphere (Solar Down), and then also the insolation (solar radiation) received at the surface (Net Radiation). Notice how solar radiation peaks at noon (12 hours after midnight and then 36 hours after midnight) on both days.

The top graph shows how surface temperature reflects the same pattern of solar radiation – highest at noon. However, air temperature does something different. The peak in air temperature lags behind surface temperature by about 4 hours at about 4pm.

The reason for the lag in air temperature is that the air is being heated by both reflected solar radiation and also the infrared radiation that is coming from the Earth (as it heats up). At about 4pm on both days, the incoming energy from the sun (net radiation) balances the net outgoing energy, and the air temperature reaches its maximum.

It is the emission of that long-wave radiation that cools the surface throughout the night-time hours.

A1 EXAMPLE QUESTION:

Fast Travel to the South Rim meteorological station (**36.0443° -112.0586°**). Then, display the summer surface temperatures. Look around the area just off the rim, into the Grand Canyon. These are the steep slopes that have different temperatures. One slope beneath this station faces towards the east. The other slope faces towards the northwest.

Question: What is the best explanation for what you see?

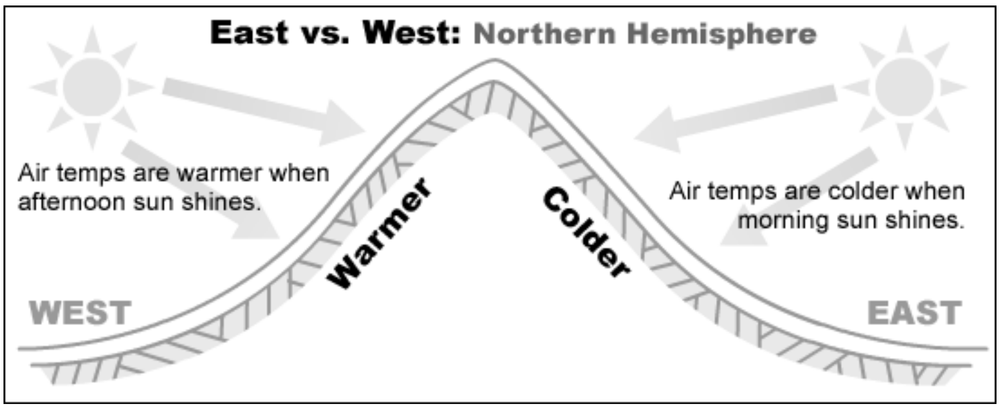
Hint: The surface temperature data were acquired about 10am in the morning, and think about the diurnal temperature cycle and how the sun travels through the sky during the day.
Correct Answer: East-facing slopes are exposed to morning insolation.

Incorrect Answer: East-facing slopes have a greater cover of vegetation, and this vegetation absorbs incoming sunlight more effectively than bare rock on the northwest-facing slopes. Thus, surface temperatures are warmer on the East-facing slopes.

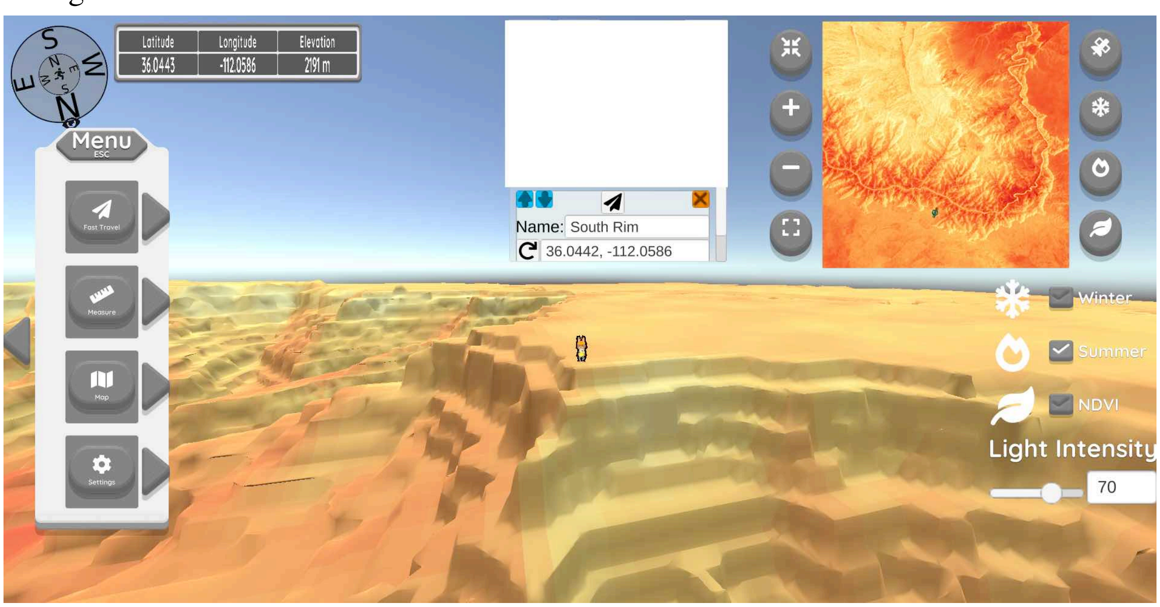
Explanation: The sun rises in the east and so the east-facing slopes receive solar radiation from sunrise until the time when data were collected at 10am, so most of the morning. Thus, these east-facing slopes heat up faster than the slopes facing away from the sun (northwest in the scene below).

WHAT ABOUT DURING THE WHOLE DAY?

Please realize that the surface temperatures shown can only be a snapshot when the sensor is collecting data. If the sensor acquired data in the afternoon, the story would be the opposite. West-facing slopes are MUCH WARMER than east-facing slopes when you consider the whole day.



GAME PLAY NOTE ABOUT INTERPRETING THE COMPASS: If you are not familiar with interpreting the compass, please study the scene below. The outer ring shows the direction in the real world. The inner ring shows the direction that the avatar is facing.



A2. QUESTION ON NORTH VS. SOUTH EXPOSURES IN DIFFERENT SEASONS

Background for A2: How noon sun angle changes throughout the year

Look at the diagram of the "Apparent Path of the Sun Across the Sky" in the background for A1 on a previous page. Notice that at the latitude of the Grand Canyon, the angle of the sun at noon is much lower at winter solstice than summer solstice.

The reason is that Earth is tilted 23.5º on its axis. As a result, as it orbits around the sun throughout the year, the northern and southern hemispheres are either tilted towards the sun (summer) or away (winter). This results in the sun appearing lower or higher in the sky depending on the season. The angle the sun makes from directly overhead to its location is called the zenith angle, while from the horizon is called the solar angle.

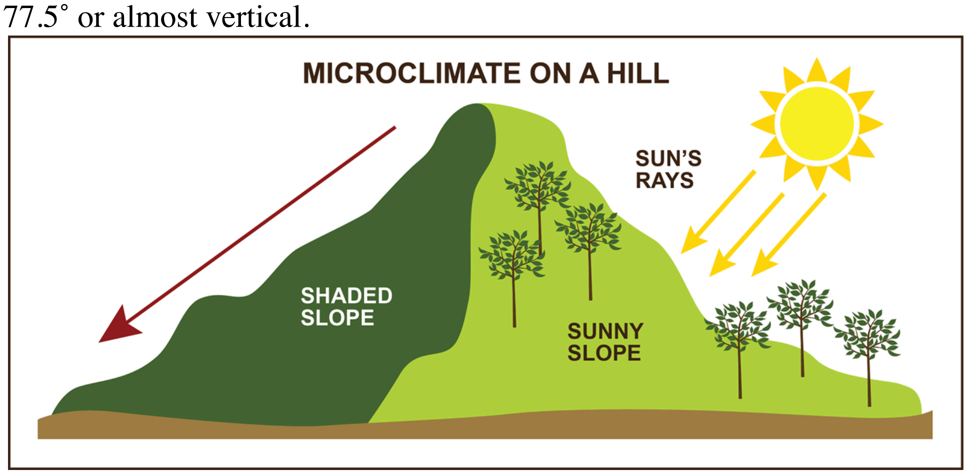
We can calculate the zenith angle if we know the latitude of the location we're interested in and latitude of the subsolar point, or where the sun is directly overhead on a given day. For this section, we'll use the summer and winter solstices for the northern hemisphere, around June 21 and December 21, respectively.

Summer Solstice: subsolar point is at the Tropic of Cancer (23.5º)
Winter Solstice: subsolar point is at the Tropic of Capricorn (-23.5º)

Try to calculate the noon solar angle for the Colorado River (Latitude: 36ºN) station using the following equation:

Noon solar angle = 90 – [Number of degrees of latitude between your site and the location of the subsolar point]
Winter solstice noon sun angle = 90 – [36+23.5 or 59.5] = 30.5˚ above the south horizon
Summer solstice noon sun angle= 90 – [12.5] = 77.5˚ above the south horizon

Now, think about how much sun a south-facing slope would receive vs. a north-facing slope in winter. North-facing slopes would receive little to no sunlight at winter solstice, and only the steepest north-facing slopes would be shaded (slopes greater than 77.5˚ or almost vertical.



A2 EXAMPLE QUESTION:

Fast Travel to the South Rim meteorological station (**36.0443° -112.0586°**). Then, display the winter surface temperatures. Look around the area just off the rim, into the Grand Canyon. Compare the slope that faces north (and a little west) to the slope that faces to the east.

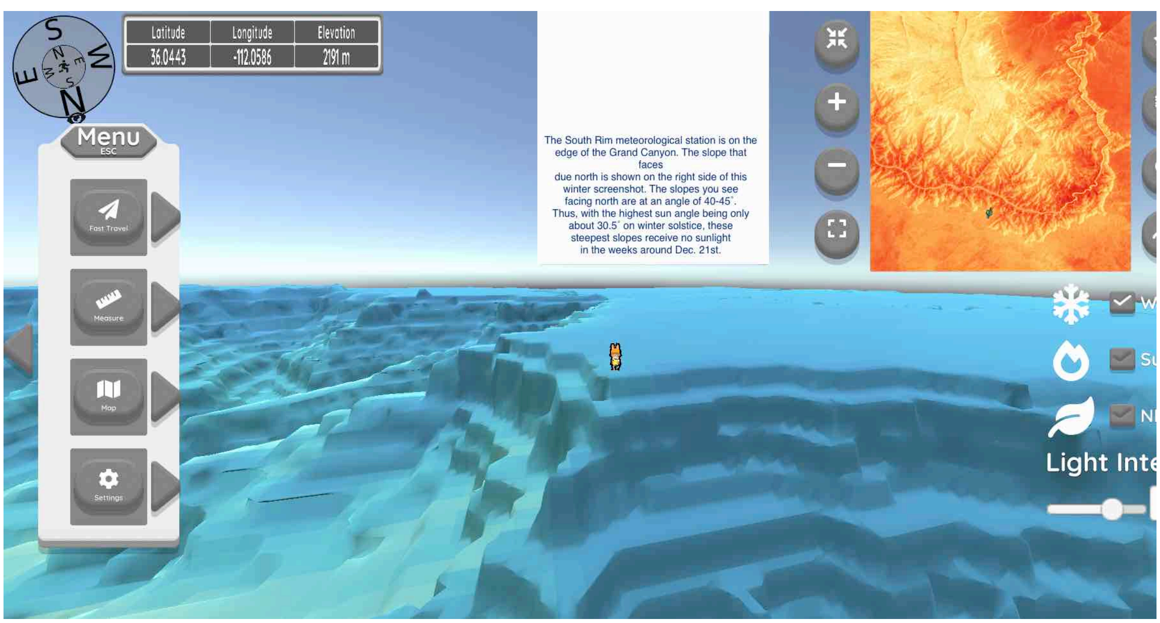
Question: What is the best explanation for what you see?

Hint: Think about the angle of the sun and how it changes throughout the day and also how it changes throughout the year.

Correct Answer: In winter, at the latitude of the Grand Canyon, the slopes that face north receive almost no sunlight.

Incorrect Answer: North-facing slopes have a greater cover of vegetation, and this blocks the incoming sunlight more effectively than bare rock on the southeast facing slopes. Thus, surface temperatures are warmer on the east-facing slopes that have less plant cover.

Explanation: The sun rises in the east and so the east-facing slopes receive solar radiation from sunrise until the time when data were collected at 10am. This explain why they are relatively warmer. However, the key aspect of this winter scene is that reality that north-facing slopes that are steep (like those shown here) receive no sunlight near winter solstice (the weeks around Dec. 21st). South-facing slopes are not present in this scene, but if they were, they would be much warmer than the north-facing slopes because they would receive sunlight (look at the diagram above this example question).

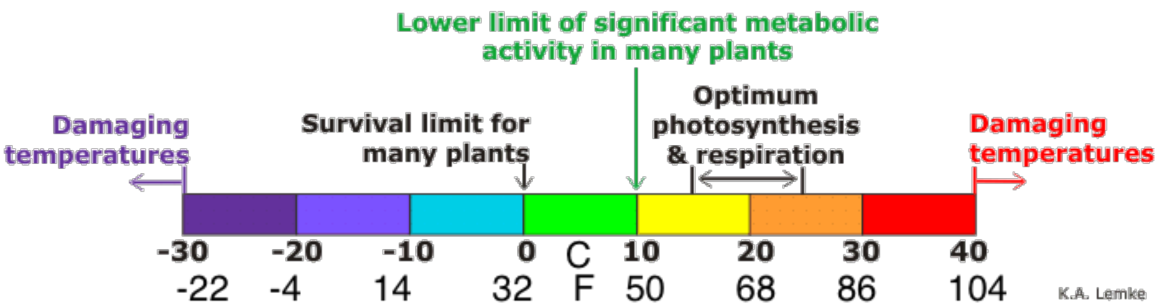


A3. QUESTION ON TEMPERATURE CONTROLS ON PLANTS

Background for A3: Factors that influence plant distribution, focusing on temperature and key plants in and near the Grand Canyon

Many factors influence the biogeography of plants. Plants have ecological niches (the combination of conditions required for reproduction). They need energy and nutrients. The need to be able to disperse and colonize new locations, and disturbances like fire influence their distribution.

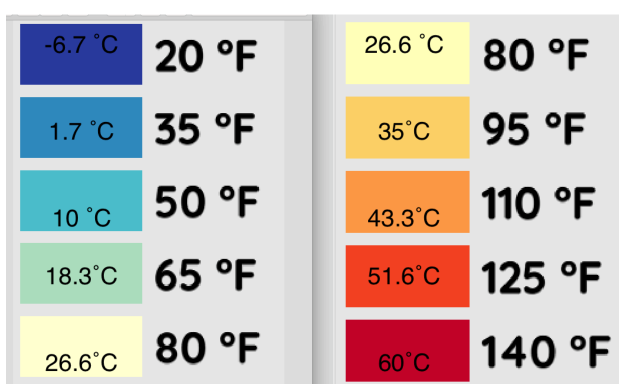
In this lab, the focus will be on the abiotic controls on plant distributions, such as moisture (precipitation), temperature (winter lows and summer highs), and sunlight. In particular, this lab focuses on temperature influences at the low (winter) end and also the high (summer end). The in-game temperatures are displayed in Fahrenheit (since the USA is one of only three countries that have not adopted the metric system), but some of the typical temperature limitations are shown in this graph by Professor Karen Lemke.



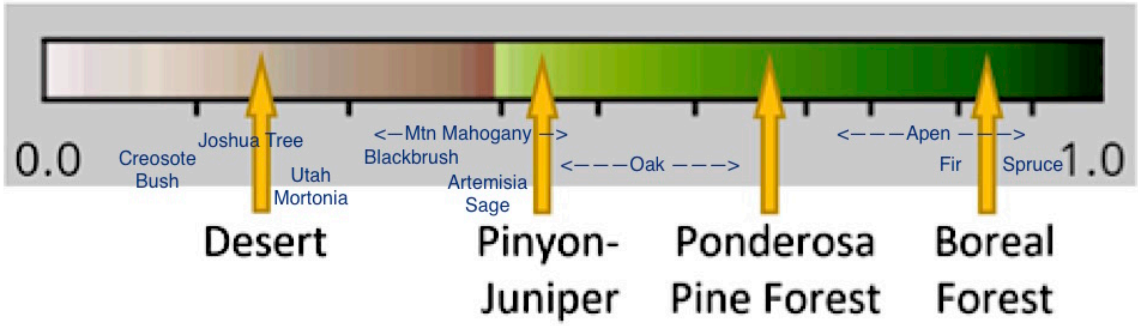
At the higher elevations of the geovisualizations on the North Rim's Kaibab Plateau, spruce is found with its ability to tolerate extreme low temperatures (e.g. -40˚ F) and its preference for lower summer temperatures (e.g. 60-76˚ F).

At the lower elevations where trees are found (typically Juniper trees, such as Utah Juniper). These junipers often live to be hundreds of years old, and they are in mean annual temperatures that range from below freezing to 104˚ F. However, if it is much hotter for a prolonged period of time, they are not usually found.

Keep in mind that the temperature chart above is for air temperature. Air temperature has to be measured at meteorological stations, but surface temperature can be imaged from space. Thus, the game displays surface temperatures with the following scale:



When you are playing the video game, and you click on the NDVI to show biomass, this scale will be useful in interpreting the plants that are growing:



A3 EXAMPLE QUESTION:

Fast Travel to a high point on the Kaibab Plateau, where the edge of the plateau faces northeast (**36.3186° -112.0065°**). The avatar is just off the edge of the plateau. If you change the camera angle (pull it back and high above), you can see the edge of the East Rim of the Kaibab Plateau as shown here:

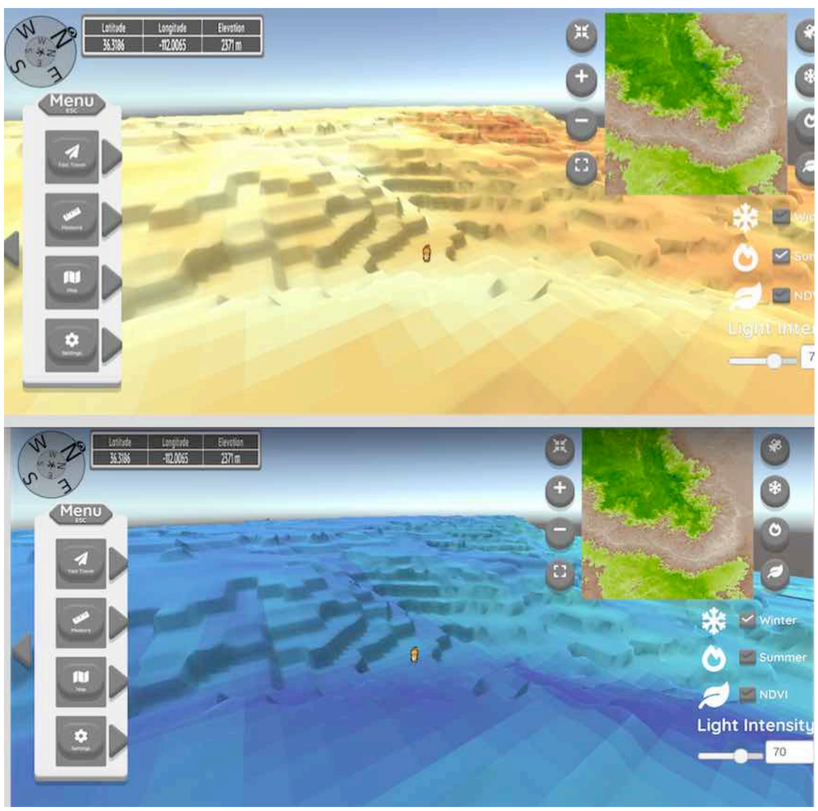
Compare the dark green color with the NDVI scale above. You can see that this area is boreal forest with a lot of spruce (genus Picea) trees and some fir (genus Abies) trees. In particular, the most common trees here are *Picea engelmannii* and *Abies lasiocarpa*. However, you do not need to know the Latin names for plants in this lab. We present just the common names as they are used in the Grand Canyon National Park.

Question: Using the temperature scale in the geovisualization (presented above for your convenient), what are the 10 am typical summer surface temperatures in this area and the typical winter surface temperatures. Select the best answer.

Hint: Do not fret much about precision. The answer will have a range of temperatures, and the different answers will vary enough so that there should not be a worry about mis-interpreting the scale.

Correct Answer: In winter, temperatures range from 20-35˚F, while in summer they are in the 80-95˚ F range

Explanation: If you examine the screenshots of this location for summer and winter, you can match the colors and estimate the range of temperatures where there's the darkest green spruce. Keep in mind that these are 10 am surface temperatures, and the air temperatures at that time will be slightly cooler at 10a,. Also, keep in mind that northeast-facing exposures like this do not get nearly as hot as west-facing exposures that really heat up in the afternoon. It is the reason why boreal plants like spruce and fir can grow here.



A4. QUESTION ON ELEVATION'S INFLUENCE ON TEMPERATURE

Background for A4: Different types of Lapse Rates

Lapse rate is term used to describe how temperature changes with altitude. In this course, you will encounter lapse rates in several different labs.

The lapse rates explained below are not the focus of this laboratory. They are important and they relate to questions in other GPH 112 labs. However, this lab only touches a little bit on these ones. The reason why they are explained is to avoid confusion with what you will be studying in this lab.

Environmental Lapse Rate – imagine climbing a ladder up into the atmosphere (or floating with a rising balloon). The air temperature of the thermometer you are carrying is the environmental lapse rate. This changes every day and throughout the day. Usually, temperatures go down as you go up into the atmosphere with an average of about 6.5 ˚C per 1000 meters (a kilometer)
Dry Adiabatic Lapse Rate – imagine filling a giant balloon filled with air at the surface, and then you drag the balloon up into the atmosphere. The balloon will expand because of lower air pressure, and the molecules inside the balloon will be further apart. This results in cooling at a lapse rate of about 10 ˚C per 1000 meters when the air is "dry" (no clouds).
Moist (wet) Adiabatic Lapse Rate – imagine that your rising giant balloon cooled enough to reach the dew point (the temperature when the water vapor in the atmosphere condenses and starts to form cloud droplets). When condensation occurs, heat is released (latent heat of about 580 calories per gram of water). This latent heat release slightly offsets the dry adiabatic cooling from expansion, and so the temperature change is a bit less. Just how much less depends on how much water is condensing.

The type lapse rates explored in this question are changes in air temperature and surface temperature with elevation in the Grand Canyon. Overall, you probably already know that air temperatures on the rims of the Grand Canyon are much cooler than those at the bottom. The influence of surface heating in the canyon results in a temperature gradient that differs from the lapse rates seen above, with a seasonal fluctuation as well.

This lab refers to the **air surface lapse rate:** the change in air temperature near the surface with elevation (this is measured at a meteorological station) and **ground surface lapse rate:** the change in ground temperature with elevation (this is measured by satellite remote sensing and shown for winter and summer in this lab)

The air surface lapse rate in the Grand Canyon can be as high as 8.2 ˚C per 1000 meters (5.5˚ per 1000 feet) in summer, but in winter, the air surface lapse rate decreases a bit to around 5-6˚ C per 1000 meters. These values are just generalizations. The real air surface lapse rate depends a lot on the complex topography.

So much influences the temperature you experience when you hike in the Grand Canyon or stroll around the rim. The list of factors includes: cloud cover, surface heating that occurs, reflectivity of the surface, the moisture in the ground, how the surrounding topography and plants release or absorb heat, pooling of cold air in low spots, movement of air up and down the canyon, and movement of air upslope and downslope. These and other factors make the microclimatology of the Grand Canyon complex.

For this question and this lab, however, you will be making observations with real air temperature data measured at stations and with real surface temperature data.

A4 Example Question:

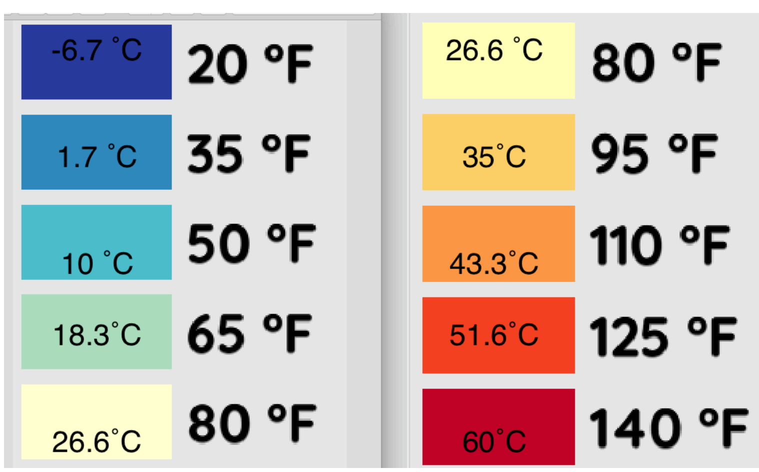
Fast Travel to the meteorological station at the bottom of the Grand Canyon, the Colorado River (**36.0976° -112.0969°**).

First, make a note of its elevation.

Then, use this table to **calculate the average air temperature in January in ˚C**. The table presents temperatures as Fahrenheit, because that is the way that it is recorded. Just average the maximum and minimum temperatures (add together and divide by 2), and then convert the ˚F to ˚C.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature Max	57.7	64.1	73.3	82.4	92.7	102.8	105.7	101.9	95.2	82.1	67.8	56.6
Temperature Min	36.2	40.2	46.1	52.9	61.7	69.9	74.8	72.3	65.7	54.9	44.0	36.6
Precipitation	0.9	1.0	0.9	0.6	0.4	0.2	0.8	1.6	1.0	1.0	0.8	0.8

Then, in the geovisualization, click on the winter surface temperatures and estimate the surface temperature where the avatar is standing. It is a square pixel about 30 m in dimension. Use the color chart below to make your estimate.



You will be using the elevation, average air temperature, and surface temperature for winter to estimate the lapse rate between the bottom of the Grand Canyon and the North Rim. Thus, you need to repeat these steps for the meteorological station on the North Rim, that you can get there via fast travel (**36.2274° -112.0296°**). Here's the meteorological station averages that you will need.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature Max	37.8	38.9	44.8	52.2	62.8	73.6	77.4	74.2	67.4	56.2	45.4	37.6
Temperature Min	17.5	18.4	22.4	28.2	35.3	42.4	48.7	47.4	41.2	32.2	23.7	17.2
Precipitation	3.8	3.1	3.0	1.8	0.6	0.4	1.9	2.8	1.8	1.8	1.9	1.7

You can use this table, if you wish, to help you organize the observations and calculations

	Elevation (meters)	Ave Jan Air Temperature from station data		Winter Surface Temperature from geovisualization	
Colorado River		˚F	˚C	˚F	˚C
North Rim		˚F	˚C	˚F	˚C
Change from bottom to top of Grand Canyon		Change in ˚C		Change in ˚C	
Air surface lapse rate in ˚C per 1000 m		Answer Part 1:			
Ground surface lapse rate in ˚C per 1000 m				Answer Part 2:	

QUESTION: WHAT IS AIR SURFACE LAPSE RATE IN JANUARY?

Remember, this **is** the change in air temperature near the surface with elevation (this is measured at a meteorological station). **Then, what is the ground surface lapse rate in winter?** This is the change you observe using the remotely sensed winter surface temperatures that can be found in the geovisualization. Select the best answer.

Answer: The lapse rate of average air temperatures from the Colorado River to the North Rim in January is about 5.7˚/1000 m, while the lapse rate of ground temperatures is relatively close, at about 4.4˚ C/1000 m.

Example of Incorrect Answer made when division is by 1890 instead of 1.89:
0. 01 ˚C/1000 m for air surface lapse rate and 0.004˚C/1000 m for ground surface lapse rate. Remember: lapse rates are temperature change over a given altitude, which is 1000 m.

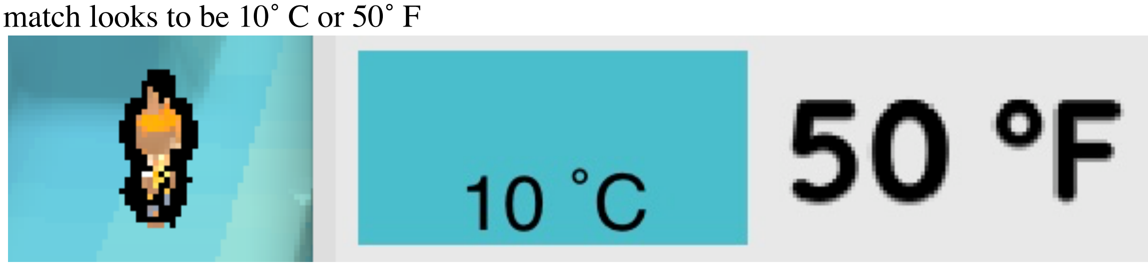
Explanation: this table shows the steps involved in obtaining the answer.

	Elevation (meters)	Ave Jan Air Temperature from station data (see notes 1 and 2 below)		Winter Surface Temperature from geovisualization (see note 3 below)	
Colorado River	721	47.0 ˚F	8.3 ˚C	50 ˚F	10 ˚C
North Rim	2611	27.7 ˚F	-2.4 ˚C	35˚ F	1.7 ˚C
Change from bottom to top of Grand Canyon	1890	Change in ˚C = 10.7		Change in ˚C = 8.3	
Air surface lapse rate in ˚C per 1000 m		5.7˚ C/ 1000 meters			
Ground surface lapse rate in ˚C per 1000 m				4.4˚ C/ 1000 meters	

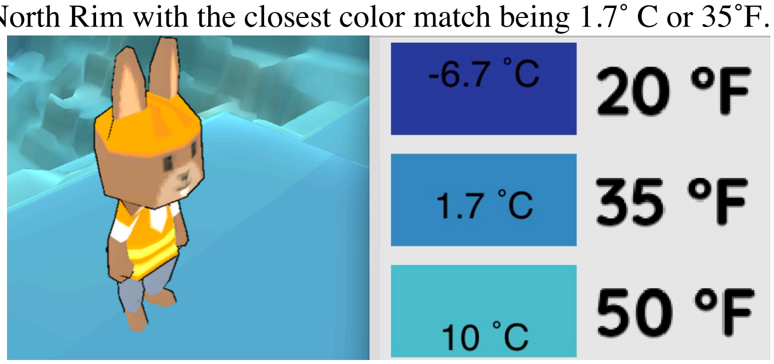
Note 1: The Colorado River's average January air temperature can be calculated by (57.5+36.2)/2 = 47.0 rounded off to the nearest tenth.
Then, the conversion to ˚C is 8.3˚ C

Note 2: The North Rim's average January air temperature can be calculated by (37.8+17.5)/2 = 27.7 rounded off to the nearest tenth.
Then, the conversion to ˚C is -2.4˚ C

Note 3: It is difficult to estimate a precise winter surface temperature with the color scale. Thus, the possible answers in a multiple-choice must be constructed so that students are not worrying about precision that is just not possible given the spatial and temperature scales involved. Examine these screenshots from the Colorado River and the closest color match looks to be 10˚ C or 50˚ F



& the North Rim with the closest color match being 1.7˚ C or 35˚F.



STAGE B: Lecture (or read the same content below) about microclimates and vegetation.

The idea of this section is to provide you basic background information about the interrelationships between microclimate the weather. The content in this PDF file is the same as the content in the lecture that is linked through the Canvas page for the Stage B part of this lab. There is a quiz on the information that you are welcome to take that is administered in canvas. Points from this quiz will be added to your GPH 112 point total. However, there's no penalty for incorrect answers or not taking the quiz

Introduction

Tall evergreen trees sway in the cool morning air. Below, over the cliff's edge, steep, layered and multi-colored towers of rock plunge thousands of feet. Plateaus soften out at their base, then slip into the depths below, towards the sound of cascading water. The Colorado River sits in the bottom of this landscape of earth and sky. Some of the warm, sunbathed rocks down here are 1.8 billion years old, exposed over time by the river and erosion. This is the Grand Canyon.

Several different climates exist around and within the canyon, a result of a vertical mile of elevation change from rim to river. Temperatures at the bottom of the canyon soar regularly over 100F while the North Rim sometimes sees temperatures below 0F. Over 11 feet of snow closes the North Rim every winter while the bottom of the canyon sees only 8 inches of rain annually. Locations around the Grand Canyon also have localized microclimate variations. Small changes in solar radiation, cast by shadows from the canyon walls, can have a noticeable influence on temperature within the small regions of the canyon. In this lab, we'll look closer at what influences the microclimates of the Grand Canyon and how that impacts plants and animals within its walls.

Atmosphere and Lapse Rates

If you've ever been on top of a large mountain or at a significant elevation and felt that it was harder to breath, you've noticed that higher altitudes have lower air pressure, and as a result lower oxygen for you to breath. This is because the further away from the center of the earth you are, the less gravity pulls on you and as a result, pulls on the air molecules. This leads to the atmosphere being thinner, with most of the air down closer to the surface. As a result, the air pressure is at higher altitudes. Lower air pressure means temperature also decreases. Generally, in the free atmosphere, for every kilometer ascended into the atmosphere it is 6.5C cooler (3.5F/1000feet). This is called the normal, or **environmental lapse rate**.

However, because of the complex topography and surface heating within the Grand Canyon, this air temperature lapse rate is generally greater than the environmental lapse rate, particularly in the summer where the lapse rate can approach 7.5C per kilometer. (5.5^{o}F per 1000 feet). We will call this lapse rate the **surface lapse rate** because of the influence surface variables (reflectivity, moisture, heat release/absorption, etc). This lapse rate changes seasonally; in the winter, the surface lapse rate can drop below 3C/km. This winter change is a result of multiple factors. Since cool air is denser, it sinks off the top of the rim into the canyon below, called cold air pooling. Combined with the fact that the canyon bottom gets less sunlight in the winter, resulting in less surface heating, it can remain cooler than expected at the canyon floor. On occasion, the temperature in the canyon can be lower than the temperature on the rim. This happens in the winter, especially in the morning while the sun heats up the canyon rim above. Cool, dense air has sunk into the canyon and being trapped below warmer air above. When this happens, it's called an inversion. On occasion, when the air in the canyon has reached saturation (a temperature which clouds form), a sea of clouds can form inside the canyon walls.

Radiation Balance

So why does winter see a change in this lapse rate and the presence of inversions in the Grand Canyon? That has to do with the amount of insolation, or incoming solar radiation, sunlight, received. As sunlight enters the Earth's atmosphere, some of it gets absorbed or reflected by the atmosphere, and the rest is absorbed or reflected by the surface. The earth's surface warms up and reemits this energy as longwave radiation, which helps warm the air above.

However, the amount of insolation and longwave radiation changes throughout the course of the year, as the Earth rotates on its axis around the sun. During the summer, the northern hemisphere is pointed towards the sun, causing more direct sunlight. During the winter, the opposite occurs, with the northern hemisphere pointed away. This results in the sun being lower in the sky, and insolation more spread out across Earth's surface, and an overall lower amount of insolation received. This leads to less energy being absorbed by the surface, and less warming of the air, leading to cooler temperatures. In the bottom of the canyon, this is especially true, as many deep, shadowed sections of the canyon may see little to no sunlight during the day in the winter, as high walls block the already low, shallow sunlight.

Precipitation / North American Monsoon

The Grand Canyon, along with much of the southwest United States, sees a seasonal pulse of precipitation in the winter and summer, separated by drier periods in the spring and fall. In the winter, large low-pressure storms from the Pacific sweep across the region, pulling moisture from the Pacific and bringing soaking rains and snow. The higher and colder North Rim sees the heaviest snowfall, averaging 142 inches of snow (nearly 12 feet) every winter while the South Rim sees 58 inches of snow (or a little over 6 feet). The inner canyon rarely sees snow, as any snow falling overhead melts into rain by the time it reaches the bottom. This disparity in winter precipitation is largely a product of orographic uplift, with higher regions of the park pushing air up to elevations which clouds begin to form, leading to precipitation.

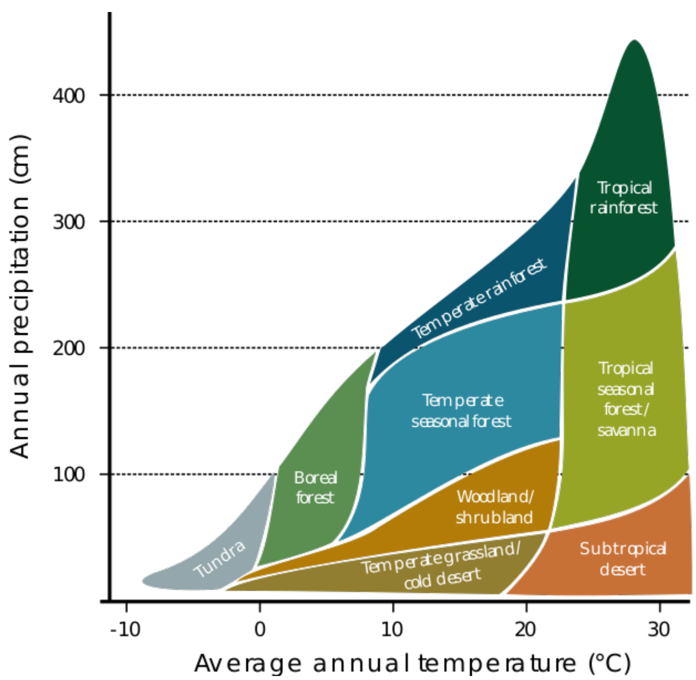
The summer precipitation pattern for the Grand Canyon is characterized by the North American Monsoon. A **monsoon** is a pronounced seasonal reversal in wind direction (N to S, E to W). The seasonal reversal of wind direction is associated with large continents. In winter, the wind blows from land to sea; in summer, it blows from sea to land as the surface pressure changes over land. The North American monsoon is a wind pattern that produces a dry spring with a relatively wet summer across the southwestern US and northwestern Mexico. In June, a high-pressure ridge in the upper atmosphere blocks moisture from moving into the Southwest. Winds during this time generally flow from the west, bringing dry continental air.

As the summer progresses, the high pressure progresses north. This causes a change in winds over the Southwest. The dry conditions combined with intense direct sunlight produce extremely hot conditions over Arizona and California. This hot air lowers the pressure over the southwestern US, creating a thermal low at the surface. By July, this thermal low, along with the high pressure aloft then begins to draw air from the south, bringing warm, moist air from the Gulf of California and even the Gulf of Mexico toward Arizona. The increase in moisture, combined with the hot conditions leads to an increase in precipitation over the southwestern US and northwestern Mexico around July and August.

Days often begin clear, but strong surface heating, results in powerful updrafts into the humid air, particularly along the rims. This is because the higher elevation North/South Rim act as focusing mechanisms for updrafts, with air over the rims exhibiting higher temperatures than air at the same elevation over the canyon. This imbalance in temperature results in air being more buoyant over the rims, causing rising updrafts and resulting in powerful thunderstorms, lightning, heavy localized precipitation, and flash flooding. Storms that move off the rim can dissipate because of the dramatic drop in precipitation and lack of rising air, and rain that does fall over the canyon floor can evaporate on its way down, called virga, leading to generally lower precipitation values over the course of the summer between rims and canyon floor.

Life Zones *(basic term used by rangers in the park) or* ***Ecoregions*** *(term more commonly used in science)*

Precipitation, and temperature, are the most relevant variables for determining the ecoregions within the Grand Canyon. Multiple ecoregions exist within certain temperature or precipitation regimes (an annual average temperature of 10C, or roughly 50F, has four different habitats that are possible, depending on the amount of annual precipitation). While the general trend for precipitation is an increase with height in the Grand Canyon, the annual temperature and other important factors influencing microclimate temperatures (such as slope or orientation) are going to determine ecoregions within the Grand Canyon.



Due to the great range in temperatures and precipitation over a relatively small area, the Grand Canyon sees an incredible diversity of plant and animal life. Five distinct biotic communities exist in the Grand Canyon's ecosystem: *boreal forest, ponderosa pine forest, pinyon-juniper woodland, desert scrub, and riparian.*

Above 2400 meters (8000 feet), the **Boreal Forest** is only found on the North Rim. This community is the coolest and wettest in the park. Life here adapts to an extreme winter climate and short, frenzied growing seasons. Here, dense dark spruce and fir forests are mixed with quaking aspen, which drop their golden leaves as winter approaches. These forests are broken by bright, open meadows filled with wildflowers and birds in the summer. Some species avoid the harsh winters through hibernation or migration, or through adaption like the evergreen trees and their tough, narrow needles that resist freezing.

Between 2100 and 2400 meters (6800-8000 feet), the **Ponderosa Pine Forest** thrives on both the North and South Rim, and act as a transition zone between the mixed conifer above, and pinyon-juniper woodlands below. Air temperatures increase and precipitation decreases slightly here. Like the mixed conifer forest, this ecosystem is specialized for fire, brought on by lightning during monsoon season. Tall ponderosa pine trees, with the thick fire-resistant bark stand tall among thickets of Gambel's oak. Naturally occurring, low intensity fires clear the forest and add crucial nutrients to the soil here. These fires reduce competition, allowing trees to grow tall and healthy.

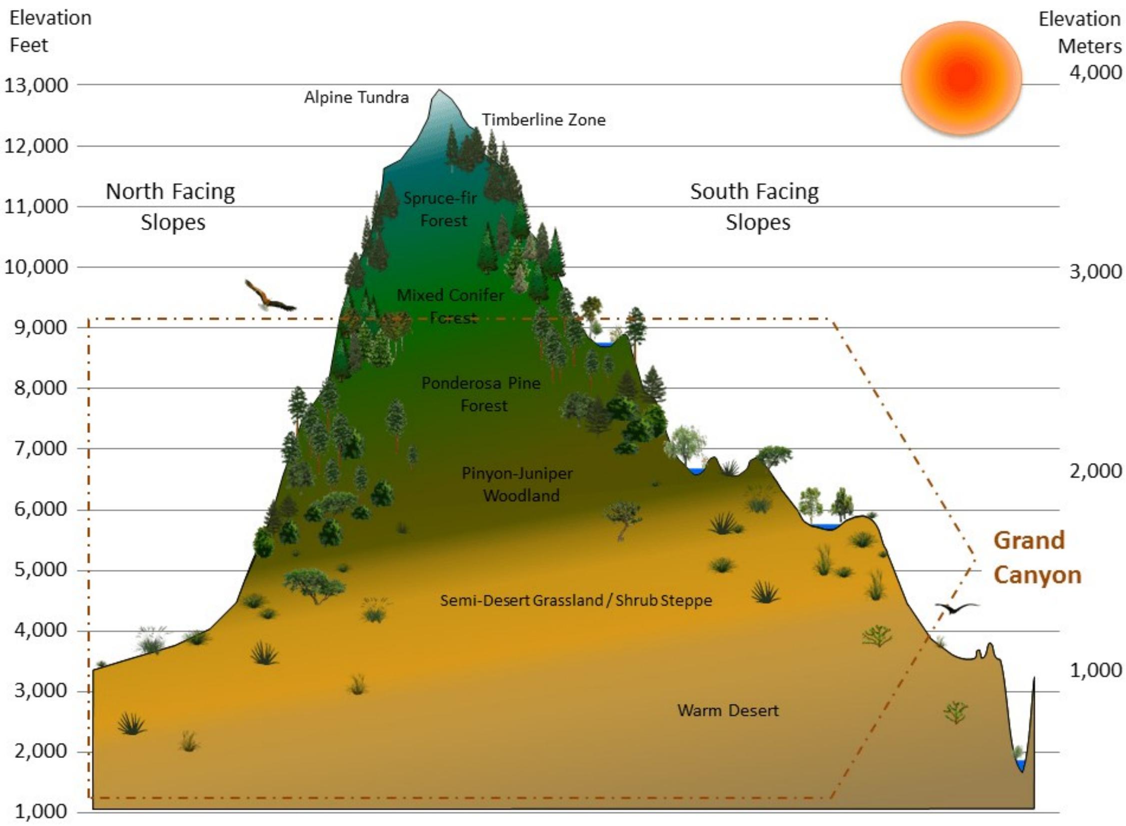
However, in the past, humans suppressed these natural wildfires, resulting in the buildup of dense debris and thick underbrush in the naturally open forests. Faster, hotter fires tore through the forests, consuming even the large trees. Thankfully, we now better understand the role of fire in these forests and fire managers work to safely restore the forests using prescribed burns and forest thinning.

Below the canyon edge, between 1500 – 2100 meters (5200-6800 feet), hot dry breezes rise from inside the canyon in the **Pinyon-Juniper Woodland**. Thin soils here hold little water, and with less precipitation (between 10 and 15 inches annually) and warmer temperatures than along the canyon rim, the pinyon and juniper trees here grow short and gnarled. To conserve water, these trees have developed waxy coatings on their needles and leaves. Around five feet of snow still falls in this ecosystem in the winter while summers are very warm.

The hottest and driest community, the **Desert Scrub**, is found between 700 and 1500 meters (2000 and 5200 feet). Life here adapts to extreme heat and a very dry climate. Limited precipitation, less than 10 inches annually, comes in the form of cool, gentle winter rains and violent, localized summer monsoon thunderstorms. Drought tolerant desert plants thrive down here, like yucca, creosote, and ocotillo. Nocturnal animals like bats, ringtails, and owls avoid the heat of the day.

Generally sharing the same dry and hot climatic conditions as the desert scrub community, the **riparian** habitat is found along the Colorado River at the bottom of the canyon, around 700 to 800 meters (2000-2500 feet). This ecosystem can also be found higher in the canyon wherever water can be found, in hanging springs or creeks located among canyon walls. This habitat is the smallest in the Grand Canyon but supports the greatest biodiversity. Cottonwood trees, ferns, willows, frogs, and other unique plants and animals found nowhere else thrive in these small corridors where water is in constant supply.

The following PDF from the National Park Service gives some more information and background on these ecoregions in the Grand Canyon if you are interested: https://www.nps.gov/grca/planyourvisit/upload/grca_ecology.pdf

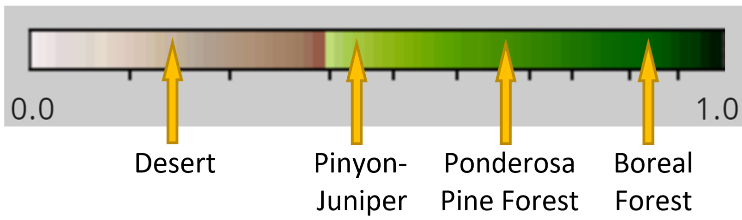


It's a bit more complicated than that though. These habitat zones cover a wide elevation gradient, a result of the north/south facing slopes of the canyon walls. Locations on the south facing walls receive more direct sunlight and encounter higher temperatures and greater evaporation than north facing locations. This allows for cooler habitat zones to exist lower in elevation on north facing walls of the canyon, while habitat zones on the south face exist at a higher elevation. For example, on the south facing side of the canyon, the pinyon-juniper woodland's range is between roughly 1800 – 2100 meters (6800-6000 feet), while on the north face, this habitat zone extends from roughly 1500 – 1900 meters (6200-5000 feet).

Remote Sensing and NDVI

Remote sensing is a way of observing the Earth without making physical contact with it. In the case of this lab, remote sensing will be using imagery created by satellites. These satellites generally rely on energy coming off the Earth's surface, such as heat (infrared wavelengths) and color (visible wavelengths).

The NDVI layer in the geovisualization represents the Normalized Difference Vegetation Index (NDVI) layer. It is a measure of the greenness and health of vegetation. The index is calculated based on how much red and near-infrared light is reflected by plant leaves. The index values range from 0 to 1 where higher values (0.3 to 1) indicate areas covered by green, leafy vegetation and lower values (0 to 0.3) indicate areas where there is little or no vegetation. Areas with a lot of green leaf growth, indicates the presence of chlorophyll which reflects more infrared light and less visible light, are depicted in dark green colors, areas with some green leaf growth are in light greens, and areas with little to no vegetation growth are depicted in tan colors.



Within the Grand Canyon, these are going to generally be related to the life zones found within the park. Boreal forests represent dark green, and light green represents Pinyon-Juniper, with Ponderosa Pine forests in between. Low-hot deserts are light brown/gray colored.

STAGE C: More detailed investigation of the geovisualization of the Grand Canyon's microclimate and vegetation

The idea of this stage is for you to explore some patterns observed in physical geography data on climate and its connection to vegetation. However, you are the one who decides if the topic is of enough interest to warrant a deeper investigation in Stage B.

This section goes over each type of question administered by canvas and gives you an example. Then, when you take the quiz on Stage C in canvas, you will see questions very similar to the examples presented here; however, the questions will not be identical. In fact, different students will be presented slightly different questions.

The detailed investigation is broken into several sorts of tasks:

1st Task: Using meteorological stations data and the geovisualization, investigate the connections between precipitation, elevation in the canyon, and the types of plants that are growing.

2nd Task: Investigate precipitation trends across the Grand Canyon, looking at seasonality and elevation.

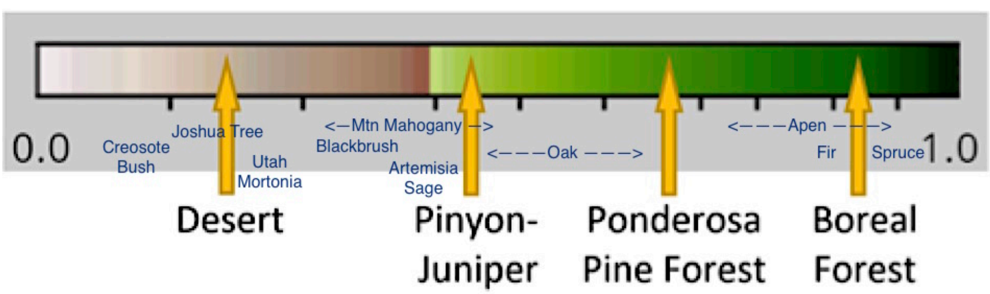
3rd Task: Investigate microclimates within the canyon caused by elevation, slope, orientation, surface cover, and other factors.

4th Task: Investigate the elevation of treelines in the Grand Canyon (where juniper trees no longer grow) on different exposures (north-facing and south-facing)

1st Task: Using meteorological stations data and the geovisualization, investigate the connections between precipitation, elevation in the canyon, and the types of plants that are growing.

Question Overview For 1st Task

There are meteorological stations in and just above the Grand Canyon used in this lab. You will be supplied randomly generated questions that task you with analyzing the information from different stations. Some of the information will come from the geovisualization (bold font in table below). Some will come from information supplied to you in a question. You may find this table useful in compiling your observations of a forested station site (1st question, Task 1) and a non-forested station site (2nd question, Task 1).

<table>
<tr><td>Station Name:</td><td>Geographic Coordinates:</td><td>Elevation:</td></tr>
<tr><td>Annual Precipitation:</td><td>% Precip During Summer Monsoon (Jul-Sep):</td><td>June-Aug Summer Max Temps</td></tr>
<tr><td>Summer Ground Temp</td><td>Winter Ground Temp</td><td>Months Min Temp Freezing:</td></tr>
<tr><td colspan="3">NDVI Estimate Using This Scale

</td></tr>
<tr><td colspan="3">Grand Canyon Vegetation Map Information Summary:</td></tr>
</table>

You will be asked three questions in canvas related to this task. One question will ask for an analysis of a station with trees nearby. Another question will ask for an analysis of a station without trees. The third question will ask a comparison question.

Example Material for Questions 1 and 2 for Task 1: Cedar Ridge

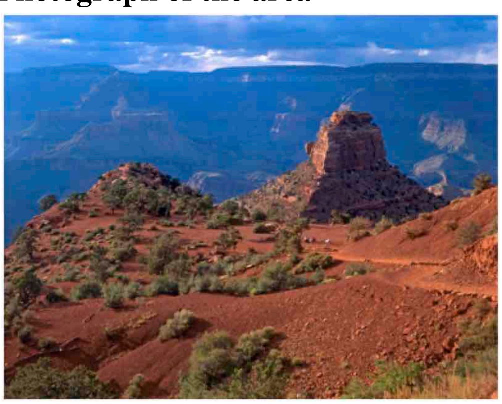
What are the basic climate-vegetation relationships that you can observe at the Cedar Ridge station from the geovisualization and information supplied in the question? Select answer that best matches the available information.

THIS WOULD BE AN EXAMPLE OF A CORRECT ANSWER:

At an elevation of 1621 m, precipitation averages 14 inches at the station. About a third of the precipitation falls during the monsoon summer thunderstorm season (July-September) with the remaining coming during the cooler months of October through April. May and June are the driest months. Maximum temperatures range from the upper 40s ˚F around winter solstice to the upper 80s-low 90s ˚F around summer solstice. However, these are air temperatures. The ground temperatures experienced even in the late morning about 10 am in summer can be considerably hotter than the air temperature. Minimum temperatures do typically fall below freezing, both recorded at the meteorological station and seen areas shaded from the sun. These conditions have led to the growth of small trees (e.g. oak, ash, juniper) and shrubs (e.g. mountain mahogany).

THE INCORRECT CHOICES would have false information mixed in. They may have the elevation wrong. They may have a temperature range wrong. They may have the wrong mix of summer and winter presentation. **The intent is not to trick you, but to promote careful observations on your part.** The hope is that you gather in a file on your computer the sorts of information you see here.

Location: 36.0646° -112.0738°
Photograph of the area

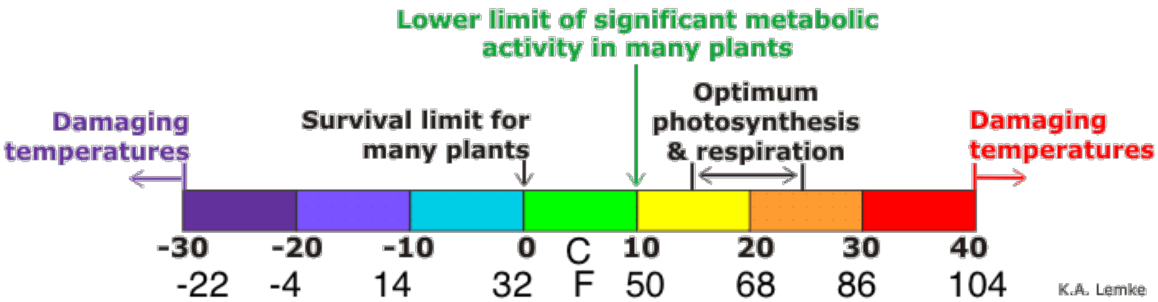



Elevation as determined in the geovisualization: 1620m

Monthly Averages from the meteorological station

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature Max	46.8	50.4	57.8	65.9	76.4	86.9	90.3	86.8	80.0	68.0	55.6	46.2
Temperature Min	26.0	28.3	33.2	39.4	47.3	54.9	60.6	58.7	52.3	42.5	32.9	26.0
Precipitation	1.3	1.3	1.5	0.9	0.5	0.3	1.5	2.1	1.3	1.2	1.0	1.1

This graphic from Professor Karen Lemke indicates that the freezing temperatures experienced in December through February can limit many plants, but that the maximum temperatures typically do not exceed damaging temperatures. **This graphic will not be supplied in the question. You can use this one.**



Grand Canyon Plant Inventory Study

This is the mapped area, about 100 square meters where the center of this square is the center of the station location. The NDVI pixel sizes are such that this area could have influenced the biomass pixels surrounding the avatar in the game view screenshot below.

The colors correspond with the key information blow. Common names are as follows:
Quercus gambelii - Juniperus osteosperma – Gambel Oak and Juniper
Faxinus-Thus-Fedlera- single leaf ash – three leaf sumac – cliff fendlerbush
Cercocarpus montanus – mountain mahaogany

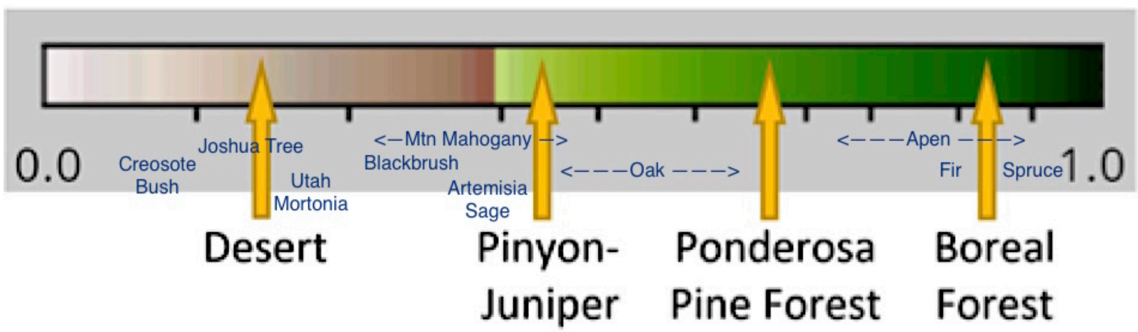
The photograph of the area above shows the general sort of vegetation structure you would encounter in this area.

Cercocarpus montanus - Amelanchier utahensis Shrubland Alliance
Fraxinus anomala - Rhus trilobata - Fendlera rupicola Talus Shrubland Alliance
Quercus gambelii Shrubland Alliance

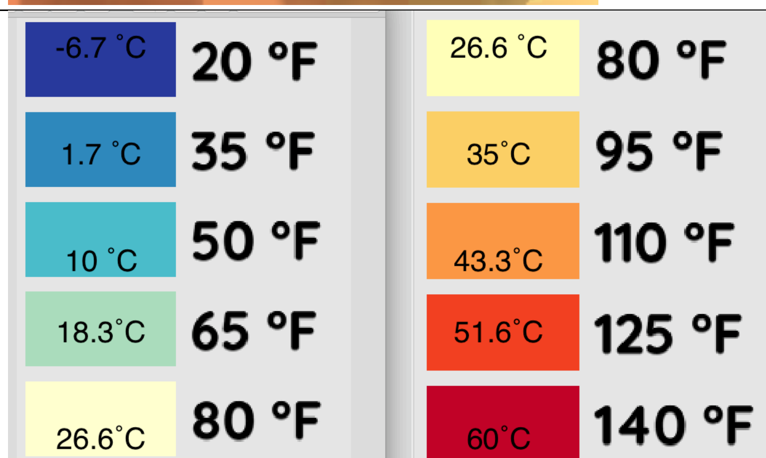
NOTE: None of the information seen below will be found in the question. You will need to extract this information in observations make in the video game. The material presented in a question in canvas will just be (1) the geographical coordinates you can use to Fast Travel to the station, (2) a photograph of the site, (3) the weather station information, and (4) the National Park Service vegetation survey information for the area right around the weather station.

Station Elevation: you will get this from the geovisualzation

NDVI INTERPRETATION: The biomass scale (NDVI) in the game screenshot below matches the vegetation survey information. The color is not a dark green of a dense forest. Neither is it a brown of no trees. The site is near the lower elevation where you would find trees on the south rim.



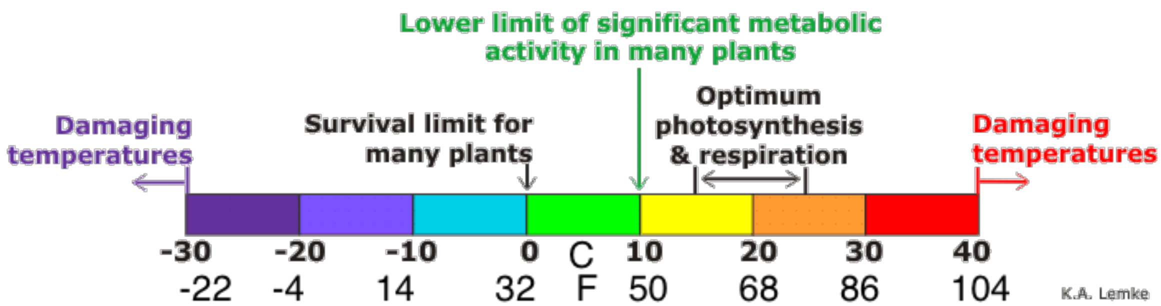
NDVI with compass orientation for all of the game screenshots	

Summer Surface Temperature at 10am. The reason why the east-facing slopes are warmer is because the surface temperature data are gathered about 10am	
Temperature scale from the game	
Winter Surface Temperature at 10am Note that the slopes that are shaded at 10am (west facing) are probably at or below the freezing mark.	

The third question for Task 1 asks you to compare your observations for the forest site (question 1) and a desert site (question 2). The questions in the pool will have slightly different wording, but this is a typical one.

QUESTION: Match the microclimate information to the impact on vegetation at forested and desert sites in and around the Grand Canyon. Select the best matches.

QUESTION SETTING: You analyzed microclimatology and vegetation information from a site in and around the Grand Canyon with trees (mostly forested) and without trees (desert). You compiled the annual precipitation values and the seasonality of this precipitation. You observed the extremes of ground surface temperatures found in winter at 10am and in summer at 10am. You analyzed air temperatures extremes of the coldest minimums and the hottest maximums, and you tabulated precipitation totals and seasonality, and thought about the issue in terms of the impact of these temperatures on plants contextualized by this diagram:



2nd Task: How does elevation impact precipitation?

Even though the Grand Canyon is roughly 10 miles wide, the change in elevation causes dramatic fluctuations in precipitation. First, we'll look at the basic relationship between precipitation and elevation in the Grand Canyon.

Using the images below, calculate the annual precipitation gradient per kilometer between Cedar Ridge and the South Rim weather station. [There will be another question in canvas about calculating between the location and the Rim weather station].

EXAMPLE: What is the precipitation gradient per kilometer between the Cedar Ridge climate station (36.0646°, -112.0738°) and the South Rim Station (36.0442, -112.0586) annually?

First, calculate the annual precipitation for both locations. Cedar Ridge has an annual precipitation of 14 inches, while the South Rim has an annual precipitation of 15.9 inches. To find the kilometer rate of change, you would find the change in elevation between two locations (South Rim: 2191m , Cedar Ridge: 1620m) and divide that by 1000 (.571).

The precipitation gradient will be the difference in annual precipitation divided by the 100 m change
GRADIENT = (15.9 – 14in) / (.571km) = 3.4 inches per kilometer.

Your calculations will look at gradients over larger distances into the canyon, and you'll compare the North Rim gradient to the South Rim gradient.

CEDAR RIDGE
36.0646°, -112.0738°

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature Max	46.8	50.4	57.8	65.9	76.4	86.9	90.3	86.8	80.0	68.0	55.6	46.2
Temperature Min	26.0	28.3	33.2	39.4	47.3	54.9	60.6	58.7	52.3	42.5	32.9	26.0
Precipitation	1.3	1.3	1.5	0.9	0.5	0.3	1.5	2.1	1.3	1.2	1.0	1.1

SOUTH RIM
36.0442, -112.0586

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature Max	41.4	43.5	50.0	57.7	68.2	78.9	82.5	79.2	72.5	60.9	49.5	41.1
Temperature Min	20.9	22.4	26.7	32.7	40.1	47.4	53.4	51.9	45.7	36.3	27.4	20.7
Precipitation	1.5	1.4	1.7	1.0	0.5	0.3	1.9	2.4	1.4	1.3	1.1	1.3

2^{ND} TASK QUESTION: Analyze the Lapse Rate in the Winter

You should have observed a strong gradient between canyon bottom and rims, as well as a change in gradients between South/North rim. The next task will be to understand why this gradient exists as well as why there is a difference in precipitation between North and South Rims.

In the summer, precipitation is generally higher on the rims compared to the canyon floor due multiple factors. Higher elevation locations are typically the starting locations for monsoon season thunderstorms. Storms that move over the canyon often dissipate as well, and any rain that falls over the canyon has a chance of evaporating before the rain hits the canyon floor. Lastly, the high elevation of the North/South Rims can influence orographic lifting, which is particularly prevalent in winter precipitation, which we'll look at next.

HOW TO THINK ABOUT THIS QUESTION:

When air lifts up above the surface, it cools at what is called the **dry adiabatic lapse rate**, or roughly 10C per 1000m (1C per 100m). This cooling will eventually lead to the air reaching its dew point temperature.

Then, when an air parcel reaches dew point, clouds begin to form, and with enough uplift, precipitation can occur. If the air continues to rise, it will cool off at the **wet adiabatic lapse rate**. The exact wet adiabatic lapse rate will vary depending on how much water vapor is in the atmosphere.

For this lab, you will use the rate of 6C per 1000m (.6C per 100m). This is because as water vapor (a gas) condenses into a cloud (liquid), it gives off a bit of heat during the change between gas and liquid. This heat slightly warms the air parcel, which is still cooling as it rises, leading it to cool at a slower rate (10 vs 6) compared to the dry adiabatic lapse rate.

Please use the elevations found in the earlier sections of the lab and round them to the closest 100m value. The North Rim has an elevation of roughly 2600 meters, and the Colorado River has an elevation of roughly 700 meters, while the South Rim has an elevation of 2200 meters

Locations in the Grand Canyon experience significant winter precipitation brought by strong mid-latitude cyclones pulling moisture from the Pacific Ocean. The dramatic changes in elevation mean different types of precipitation fall at different locations within the park. Even if there is no precipitation at the South Rim, there still might be precipitation at the North Rim, simply because it's pushing the air mass moving over the Grand Canyon up higher into the atmosphere.

Think about an air mass south of the Grand Canyon, at an elevation of 1500 meters and it is pushed up by the motion of the atmosphere onto the South Rim, at 2200 meters in elevation. You have the knowledge now to estimate if there would be clouds/precipitation if you just knew the air temperature/dew point of that air mass when it started..

EXAMPLE: Consider an air mass with a temperature of 7˚ C and a dew point of 3˚ C to start with. The air miss is then lifted from 1500m up to the South Rim at 2200m.
It will first cool off at 10˚ C/km (1C/100m). When it reaches dew point at 1900m, clouds begin to form, and precipitation can begin occurring if the cloud is lifted further.
Since clouds have started to form, = it has reached dew point. The parcel if aur is saturated, so you now use the wet adiabatic lapse rate (6˚ C/km or 0.6˚/100m). Continuing at this rate, the temperature of the air parcel at the South Rim is 1.2C and if the parcel is lifted up even more the height of the North Rim, the temperature drops to -1.2˚C. This means that if precipitation is falling, the South Rim will have rain, while the North Rim will have snow (since -1.2˚ C is belowf reezing).

ELEVATION	TEMPERATURE	CONDITION
2600 (North Rim)	-1.2	SNOW
2500	-0.6	SNOW
2400	0.0	SNOW
2300	0.6	RAIN
2200 (South Rim)	1.2	RAIN
2100	1.8	RAIN
2000	2.4	RAIN
1900	3.0	DEWPOINT – clouds form
1800	4.0	Not saturated
1700	5.0	Not saturated
1600	6.0	Not saturated
1500 (Start)	7.0	Not saturated

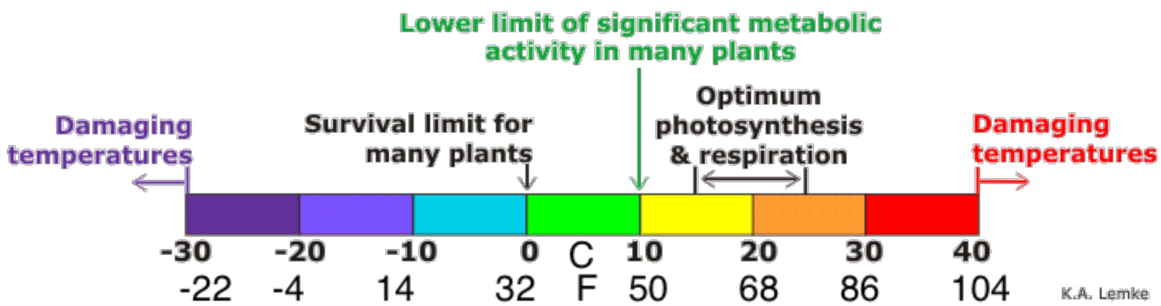
3rd Task: Investigate Temperature Stresses for plants in and around the Grand

Brief Review of the Importance of Temperatures on Plants

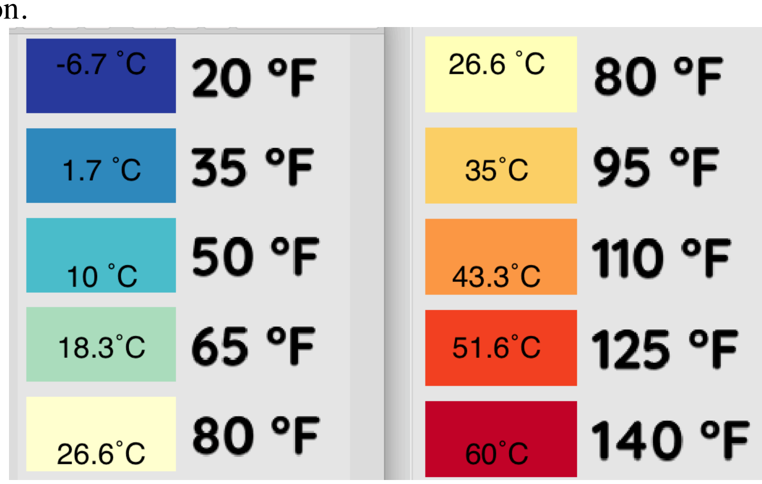
In the exploratory Stage A of this lab, the third question examines the role of temperatures on trees. The highest elevations around the Grand Canyon have spruce trees that are not very sensitive to very cold temperatures. They have the ability to survive at temperatures of -22˚ F (-30˚C) where other plants cannot.

Juniper trees (e.g. Utah Juniper), in contrast, cannot survive super cold temperatures. They also cannot survive super hot temperatures for very long. Still, they very hardy. They can tolerate freezing and 100˚ F temperatures- just not the extremes found around the Grand Canyon.

This graphic made by Professor Lemke gives a snapshot of some of the **temperature** issues associated with different types of plants.



While the graphic above was made for air temperature measurements (e.g. meteorological stations), the ground temperature information in the geovisualization still applies. Extreme cold and extreme heat can influence whether a particular type of plant can survive. For your reference, this is the key for ground temperatures seen in the geovisualization.



3rd Task questions related to temperature differences in and around the Grand Canyon

There are dozens of ways that microclimates can develop and influence plants. The ways vary at different spatial scales. For example, on the scale of tens of centimeters, the orientation of a boulder can influence whether precipitation is channeled to a spot where a tree might or might not germinate.

The temperature data in the geovisualization is at the highest resolution available at the present time – at least for the coverage of the entire Grand Canyon. Thus, this investigation is limited to the resolution of about a 30 m pixel. Those are the squares seen in the geovisualization for winter and summer ground temperatures. At this scale, you can investigate/analyze six connections between topography and temperature that are presented below.

<table>
<tr>
<td>ALREADY STUDIED IN THIS LAB: Diurnal effect of the 10am time of data acquisition – explaining why east-facing slopes are often warmer than west-facing slopes
The satellite gathering the temperature data images at about 10am in the morning. Thus, the east-facing slopes have accumulated more insolation than the west-facing slopes.
This image of the South Rim of the Grand Canyon was presented earlier in the PDF file.</td>
<td>
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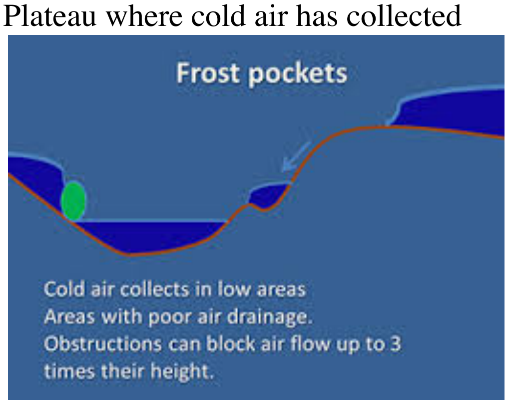
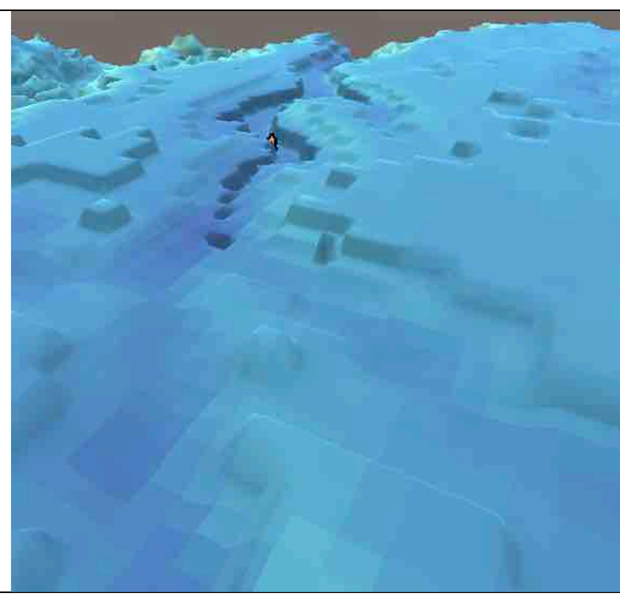
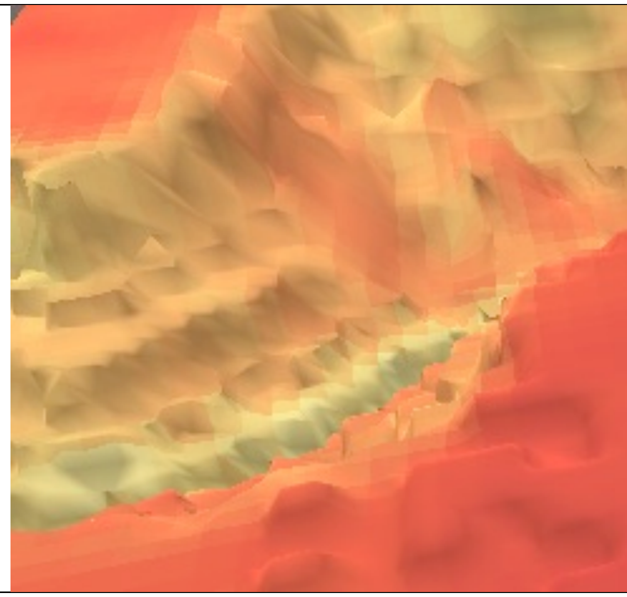
<table>
<tr>
<td>Cold Air Drainage, especially in winter. The game screen on the right shows a small drainage on the Kaibab Plateau where cold air has collected

</td>
<td></td>
</tr>
</table>

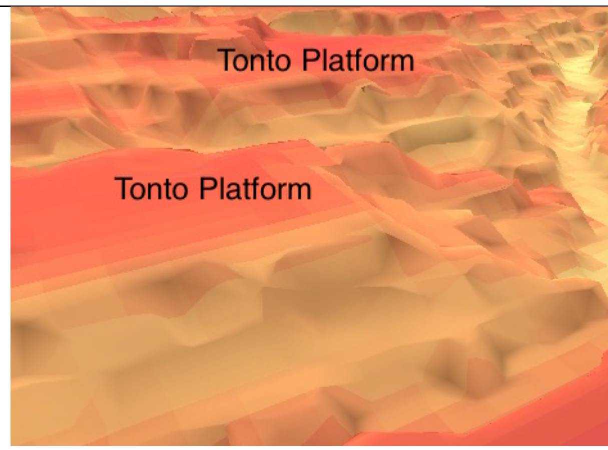
Evaporative cooling – In the summer temperature image, the Colorado River is able to exert a cooling effect on the 30 m pixels. This effect is often several pixels wide.

The effect of water evaporative cooling is not seen in the winter imagery around the Colorado River. The reason is that the surface temperatures around the river are sometimes colder or similar to the river itself.



Flat treeless surfaces as heat accumulators – Stage B has a section called "Radiation Balance", which is a significant topic in GPH 111.

Flat surfaces can accumulate a lot of energy in summer, when sun angles are high. Solar radiation starts the process. However, treeless surfaces with lots of exposed rock play a big roll in absorbing lots of the solar radiation. The result is that these are some of the hottest surfaces in and around the Grand Canyon



ALREADY STUDIED IN THIS LAB: Around the time of winter solstice, **North-facing slopes that are steeper than the angle of the sun at noon receive no solar radiation.**

This slope has an angle of 35˚, and the rabbit is facing south, so the slope is facing north. Because the noon sun angle at winter solstice is only 30.5˚, no sunlight hits this slope.

The effect on plants is greatest in winter at high elevations, because the result can be severe cold temperatures.

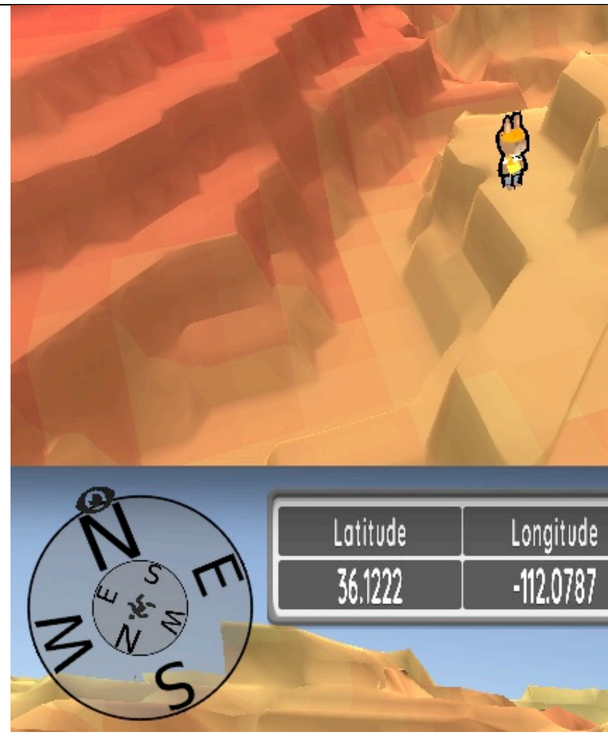
Summertime north-south exposure contrasts. Wintertime temperatures in the lower desert portions of the Grand Canyon are not severe. Freezing rarely occurs, and only for a few hours in the morning. Maximum temperatures are not extreme.

In contrast, summer temperatures can cause great stress for plants, especially when air temperatures exceed 104˚ F and ground temperatures exceed 120˚ F.

Even though sun angles are much higher in summer, the contrast of south (warmer)-facing and north (cooler)-facing slopes can influence plants.

The rabbit is standing on the side of a river canyon that has facing north, where the suns rays are not as direct.

The hotter surface temperatures on the other side of the canyon are because those surfaces are facing south, and they are getting more direct sunlight.



The questions for Task 3 will be matching. You will be given different locations in the geovisualization to "Fast Travel" to and study. Then, you will match those locations with the effect of the topography.

SUGGESTION ON WHAT YOU MIGHT DO IN TAKING THE QUIZ:

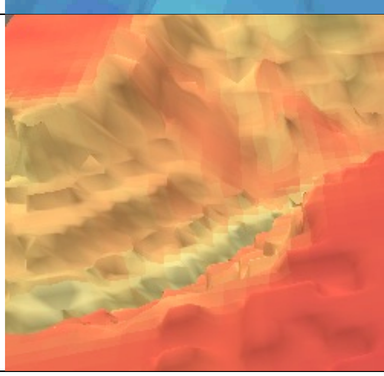
You can speed up the answering of these questions by taking full screenshots of the different locations. Try setting the default location for the screenshots to your desktop. Then, they toggled the game to your 'task bar' when you are done traveling and taking screenshots.

This will allow you to see the latitude/longitude coordinates and also the compass rose for reference in answering the matching question of the sort exemplified below.

Example Question for Task 3 (keeping mind that there are pool of questions like these in canvas).

Please fast travel to the locations presented in the question below. Each location also has the season (winter or summer) that you should investigate. Try to bring the game camera angle up higher, so that you can get an overview of the location and you can spin the view. Make the best matches between the temperatures you see for each location/season with the effect of topography on temperature.

NOTE: To save you a lot of time, screenshots are presented on the left instead of coordinates and season. However, in canvas, the left side of the matching will be the coordinates and season information

	Hotter south-facing slopes than north-facing slopes in summer
	Cold air in winter pooling (accumulating) in a low-lying area
	Evaporative cooling in the lowest location (Colorado River)

4th Task: What influences lower treeline in the Grand Canyon?

Start this task by exploring impacts of North/South facing slopes on existing vegetation. Exposure of a slope can have a dramatic impact on vegetation due to differences in surface heating and the resulting evaporation. What you'll be looking at next is how treeline varies between north versus south facing slopes on walls in the Grand Canyon. This portion of the lab will task you with finding the lowest elevation for the treeline on either north facing or south facing slopes, comparing 3 different locations.

You will have two questions like this:

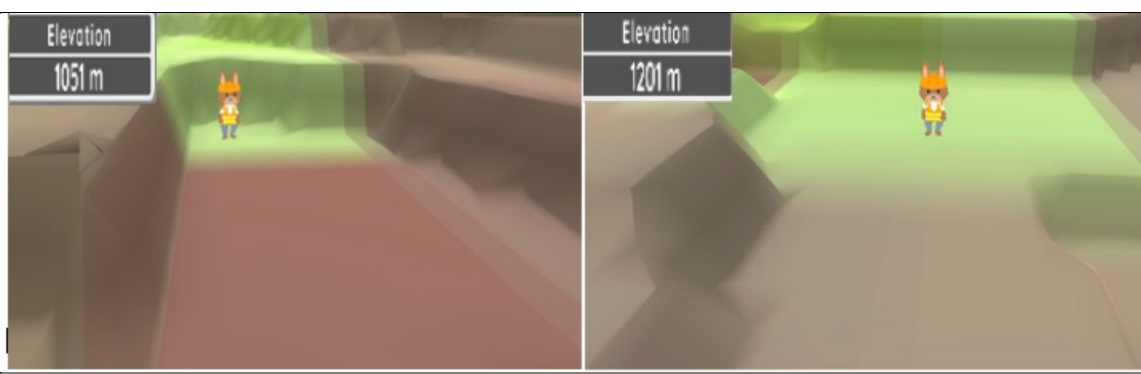
2 questions like this. One is for north-facing slopes. The other is for south facing slopes.

QUESTION: Fast travel to the three coordinate locations in the geovisualization. What is the slope orientation (north facing, south facing) and mean (average) height of the transition zone between desert (brown, no trees) and pinyon-juniper woodland (green, leafy trees) for these locations?

Part of the task has you understand the compass in the geovisualzation. What direction is the slope you are sent to facing. Then, the other part is taking the elevations and averaging them. Two examples are given below, but you'll have three spots in the question.

For this simple example, Treeline elevation = (1051 + 1201) / 2 = 1126 meters.

WARNING: the answer choice in canvas will probably not be EXACTLY what you calculated. The reason is that where you locate your avatar will be slightly different from where we put our avatar. These slight differences will mean that you should pick THE CLOSEST ANSWER. The incorrect choices will be either be far off or facing the wrong direction.



The lab does not end with this question. Hopefully, you feel empowered to try to synthesize everything you've learned in writing the essay. But there's no penalty for deciding not to participate in the next section.

Stage D: Synthesis

As with all assignments in GPH 112, there is no grade penalty for skipping this assignment. At the same time, many students have a lot of interesting thoughts about the lab that they just completed, and this essay is a great chance for you to bring these thoughts together.

The assignment is to write four paragraphs. Each paragraph is worth a maximum of 0.5 points. We are not English teachers, but proper grammar and well-composed sentences make it a lot easier for us to read your ideas. Still, our focus rests in the details that you use to support your thinking.

Paragraph 1: What is the connection between altitude, microclimate, and vegetation in and around the Grand Canyon? Please give examples from the lab, and you can also include your own observations.

Paragraph 2: What is the connection between the direction a slope faces (aspect), microclimate, and vegetation in and around the Grand Canyon? Please give examples from the lab, and you can also include your own observations.

Paragraph 3: Was there anything in particular that struck you as particularly interesting about the connection between topography, microclimates, and vegetation? Please do not simply write down a sentence. Explain your idea, and elaborate with at least a few sentences.

Paragraph 4: Please provide you thoughts on this geovisualization as a tool to investigate connections between microclimate and the biomass (abundance) of vegetation. Please do not simply write down a sentence. Explain your idea, and elaborate with at least a few sentences.