EXERCISE 4 (15 POINTS): VIEWING MARS FROM ORBIT (AND THE GROUND):
BACKGROUND HANDOUT

The Exercise is Due Monday, November 2nd, 2015
You only need to turn in the exercise portion.

This exercise requires Google Earth. Download instructions and hints were included with the first Google Earth exercise. As in earlier exercises, please make sure all your measurements and answers are in the metric system (kilometers, meters, or centimeters) [If elevations are not showing up as metric, look under Tools-Options-3D View]. There are occasionally specific instructions regarding which layers should be turned on and off with each question. Following the instructions will make this exercise easier.

You will need the file “exercise4.kmz”, which was sent to you via e-mail and is also available on the class website. All of the questions using Google Mars require looking at Mars. To do this, use the 🌌 icon, and pull down the menu to select Mars.

Background

Here we give brief descriptions of the most useful layers of the Mars “Primary Database” may help you navigate the planet:

• **Featured Satellite Images**: This layer shows the location of particular images or observations.
  - The orange icons are from a camera called CTX, the ‘context imager’ on the Mars Reconnaissance Orbiter (MRO). If you click on most of these orange icons, there is an option to ‘load this image’, which will allows you to look at the full resolution image in Google Earth.
  - The red icons are from the HiRISE camera. Many of these HiRISE images are already loaded into Google Earth if the “Visible Imagery Layer” is on (which is the default, but see “Global Maps”, below). If you zoom in on these HiRISE images, it might take a second to load the image at reasonable resolution. This should not be surprising since the camera has ~30 cm per pixel resolution, which is capable of seeing a remarkable amount of detail on the surface, including landers, rovers, and Martians (if they are there). Many HiRISE images are annotated, so if you click on the icon and then the link for “See this image’s observation information page,” it will often tell you something about the image.
  - The blue icons are annotated MRO CRISM images; CRISM takes observations of Mars at many wavelengths of light from the visible to the infrared part of the electromagnetic spectrum, which provides information about the minerals exposed at the surface.

• **Place Names**: This layer shows named features

• **Global Maps**: The Global Maps layer has six datasets. If you have it turned off, it defaults to “Visible Imagery”.
  - **Visible Imagery**: This is a mosaic of observations of Mars at wavelengths close to what we would see with the human eye. Observations from HiRISE are also observable in this layer (high resolution data that cover a small footprint).
  - **Colorized Terrain**: This is the topography of Mars measured by the MOLA instrument that was onboard the Mars Global Surveyor spacecraft. MOLA worked by shooting a laser at the surface from orbit and timing how long it takes for the light to return to the spacecraft (called ‘laser altimetry’). The elevations reported at the bottom of Google Earth are mostly from this topographic data.
- **CTX Mosaic.** This is a mosaic of all Mars Reconnaissance Orbiter (MRO) Context Camera (CTX) data that were available in the fall of 2011. This provides high-resolution imagery (~6 m/px) over large swaths of the planet, enabling detailed observations within the broader geomorphologic context.

- **Daytime Infrared.** This layer shows the thermal emission (a proxy for the surface temperature) measured by the THEMIS instrument onboard the Mars Odyssey spacecraft. This can be a very valuable dataset for discerning geology because slopes that are more directly illuminated by the Sun are warmer (brighter), and those that are shadowed or less illuminated areas are cooler (darker). This tends to highlight the surface morphology. However, there sometimes are also temperature differences between different regions that are a function of surface thermal properties, particularly how fast the materials warms up (‘thermal inertia’). (The solid black areas are image gaps where the THEMIS data in Google Earth has not been updated).

- **Nighttime Infrared.** This layer is akin to the daytime infrared layer, except it is observations of thermal emission at night. At night, solar illumination is obviously not important (!), so nighttime thermal emission is a function of how fast the surface cools off, which depends mostly on its thermal inertia. Areas that are bright in this dataset are warmer at night, meaning that they have higher thermal inertia (typically this means rockier or more like bedrock).

- **Viking Color Imagery and MDIM2.1 Image Map.** These are relatively old, moderate resolution visible image products from the Viking Orbiter. The Color Imagery mosaic gives an excellent sense of dusty (brighter or higher albedo) parts of Mars and less dusty (darker or lower albedo) parts of Mars, but it is at a low-resolution, so details are difficult to discern. The MDIM2.1 mosaic provides more detail of the surface but has been largely supplanted by the other “Visible image” datasets. This can be used when the object of interest is hard to see in the “Visible Imagery” or “Daytime infrared” layers.

- **Spacecraft Imagery:** Six layers that show footprints from various instruments. Clicking on the icons gives weblinks to the full resolution products on external websites.

- **Mars Gallery:**
  - The Live from Mars layers shows the recent orbit paths of Mars Odyssey and MRO. If you turn one of these layers on, expand it, and double click Fly Along, you can get a sense of the actual spacecraft paths for particular orbiters.
  - Guided Tours has annotated tours of Mars that might help you answer the exercise questions. [hint: For the Intro to Mars tour, make sure that you have all other layers turned off except ‘Tour Resources’. For the Nye tour, turn on the ‘Rover and Landers’ layer for the full experience].
  - Historic Maps has a few hand-drawn, historic maps of Mars from telescopic observations of the Red Planet. Note that some of these appear ‘upside-down’ because reflector telescopes flip the image in their optics as they send the planet onto the observer’s eye.
  - Rovers and Landers has locations, models, and traverses associated with the rovers and landers. Many camera mosaics are also available; if you click on the camera icon, there is a “fly into this high resolution image” link. Note that the waypoint information is now out-of-date.
  - A Traveler’s Guide To Mars; A layer with annotations about certain features from a book by Bill Hartmann, a pioneering planetary geologist.
Exercise 4 (15 points): Viewing Mars from orbit (and the ground)
Due Monday, November 2, 2015

1. Seeing Mars from the orbital perspective:
For an introduction to Mars, see Exploring the Planets, Chapter 6, http://explanet.info/Chapter06.htm. The 8-minute Guided Tour “Introduction to Mars” may also be helpful (see background for hints on what layers to turn on).

Turn on the Colorized Terrain layer under global map. Go to the Parana Region placemark by double-clicking on that layer in exercise4.kmz. This is in a region 480 km east of the failed Soviet Mars 6 lander. Look around at the Parana region. Then look at the area marked by the Arisia Mons Apron placemark. These placemarks are at the same eye elevation so you are seeing each at the same scale. Make sure you zoom in and look around to get a sense of the landscape.

1. [1 Point] After looking at the Arisia Mons apron and the Parana region, which has more superposed craters? Based on this observation, which is younger?

2. [2 Points] There have been different processes important for modifying the surface at these two locations. Fill in the following table, noting whether a particular process has been a major geologic process, minor geologic process, or a geologic process that did not occur (DNO). It may be helpful to switch to the Visible Imagery layer, or to load individual images in the Featured Satellite Image layer by turning that layer on, clicking on available icons, and selecting “load this image”.

<table>
<thead>
<tr>
<th>Location</th>
<th>Geologic Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arisia Apron</td>
<td>Volcanic Flows on the Surface</td>
</tr>
<tr>
<td>Parana Region</td>
<td></td>
</tr>
</tbody>
</table>
3. **[4 Points]** Now, pick your own region of interest on the surface to explore and analyze (some suggestions include Jezero Crater; Valles Marineris; Olympus Mons and/or Alba Patera; etc.). It is best to start with the “Visible Imagery Layer” turned on. You can use a featured satellite image if you want to pick somewhere interesting; HiRISE (red icons) are commonly among the best places to start. Using the different available datasets, make the observations that allow you to fill out the following table (make sure you zoom in to eye elevations of $< \sim 100$ km to see details):

<table>
<thead>
<tr>
<th>What location did you choose? (Use the Place Name Layer and also write down the lat and lon from the bottom of the screen)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>What major characteristics or features do you observe in the location you chose?</td>
<td></td>
</tr>
<tr>
<td>What geological process(es) do you think were particularly important for forming the characteristics you observe?</td>
<td></td>
</tr>
<tr>
<td>Now, examine different global map layers to see what different datasets say about the area you picked. What additional observations can you make from this data?</td>
<td></td>
</tr>
</tbody>
</table>

Recent years have seen a number of successful landings on the surface of Mars. Turn on the Visible Imagery layer. **Open up the Rovers and Landers tab under the Mars Gallery layer and turn on and double-click on the Mars Phoenix lander.** The 8-minute Guided Tour by Bill Nye called “Mars Exploration” may also be helpful as background for this question.

5. **[2 Points]** Water ice has also been discovered buried within or beneath thin layers of soil far from the current polar ice caps. Mars Phoenix was sent to the north arctic circle of Mars to find and explore this buried ice. Examine the “Full Circle color panorama” made by Phoenix by clicking on the camera icon and selecting “Fly into this high-resolution photo”. What evidence do you see for water ice in the subsurface at the Phoenix landing site? [It might help to quickly sketch the evidence that you observe].

The north and south polar caps are the most important surface reservoirs of water ice on the planet; the southern cap also has a small, perennial CO$_2$ ice deposit.
5. (a) [1 pt] Look at the northern and southern polar caps of Mars in Google Earth (the “Viking Color” layer has one of the best views); you can use the placemarks to navigate, if you wish. Which polar cap is larger (based on the extent of bright, exposed water ice)? Measure the diameter of each polar cap to check your answer.

(b) [2 pts] Recently, ESA (the European Space Agency) and NASA have sent detectors called MARSIS and SHARAD to Mars that can provide imaging radar through the water ice layers of the polar caps (which are more transparent to radar in these wavelengths than rock is). An example of how the North polar cap looks in its interior with the SHARAD radar instrument is shown below and in Google Earth. Notice how that internal layering in the ice is generally flat-lying, except where it is draped over preexisting topography (which has been approximately marked with pink arrows).

![Image of SHARAD profile](image.png)

Figure modified from Phillips et al., 2008.

Using the SHARAD profile above and its associated scale bar (upper right), measure a typical thickness of the north polar cap (this is easier to do on the exercise than in Google Earth). The nearly-pure ice polar deposits in the northern hemisphere have a surface area of approximately $8.1 \times 10^5$ km$^2$. Given the thickness that you can estimate from the radar profile, what is the total volume of water ice in the polar cap, in km$^3$? If this ice were somehow melted, how would the resulting volume of water compare to the total volume of water in the Earth’s oceans ($\sim 1.4 \times 10^9$ km$^3$)?

[Water ice is slightly less dense than just liquid water, but for the purposes of this question you can treat the equivalent volume of ice and water as equal. Also, keep in mind that Earth is a considerably bigger planet than Mars as you think about these numbers (e.g., the surface Area of Mars = 0.284 x surface area of Earth). If there was an early martian ocean, other sources of water might have existed].
6. [3 points] Mars Science Laboratory (MSL) Curiosity exploration of Gale crater (http://www.nasa.gov/mission_pages/msl/). The very capable Curiosity rover landed inside the crater on August 6th, 2012 and has been exploring the floor of Gale crater, working its way toward the central mound, Mount Sharp, just reaching the base on September 11, 2014.

Double-click on the “Gale Crater” placemark. With the “CTX Mosaic” layer turned on, zoom into the northwestern portion of the crater, where Curiosity landed, located inside the white oval. Click on the camera icon at the landing sight and then fly into the panorama and answer the following questions: [TIP: If you have not done so, turn off the “HiRISE” and “CTX Image Browsers” under “Spacecraft Imagery”]

6a. Describe the foreground of the panorama. What is the relative distribution of particle size of the rocks on the ground (describe qualitatively, e.g. fine-grained sand versus boulders)? How much diversity is there in the color of the rocks? Are all of rocks loose on the surface or are there some embedded at that location? Why are there gray patches of regolith near the rover while all other regolith is red in color?

6b. Describe the background of the panorama. Look towards Mount Sharp (the closest mountain to the rover). Describe the differences in color at the base of Mount Sharp (the panorama does not extend to the top of Mount Sharp). Look away from Mount Sharp and describe the mountains in the distance. Are the peaks of the mountain range isolated or generally continuous? What hypothesis do you think best explains how these mountains formed? [Hint: if you’re stumped, try exiting out of the panorama. In might help to use the tilt feature in Google Earth. Hold down the Shift key while clicking and dragging the mouse to see the landscape in a “perspective view.”]

6c. Exit the panorama by clicking “Exit Photo” in the upper-right of the scene. Now, with the “CTX Mosaic” layered activated, investigate the dark material at the base of Mount Sharp. What is this feature? If the goal of the mission is to investigate rocks at Mount Sharp, how far did Curiosity have to drive to avoid getting stuck in this unit?