

# **THE MYSTERY OF LUNAR WATER**



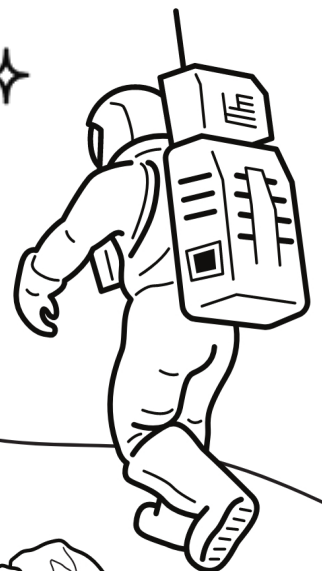
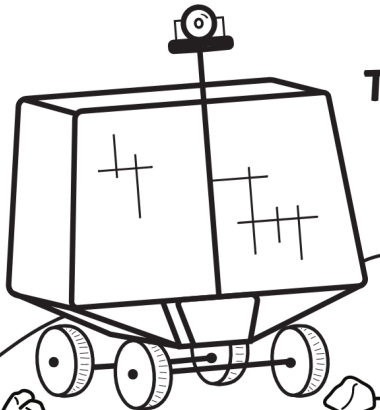
## **HELP SCIENTISTS UNCOVER WATER ICE ON THE MOON**



### **PART 1**

#### **INSTRUCTOR GUIDE**

**THIS ACTIVITY IS DESIGNED FOR  
AGES 9 AND UP.**



## INSTRUCTOR GUIDE

### INTRODUCTION

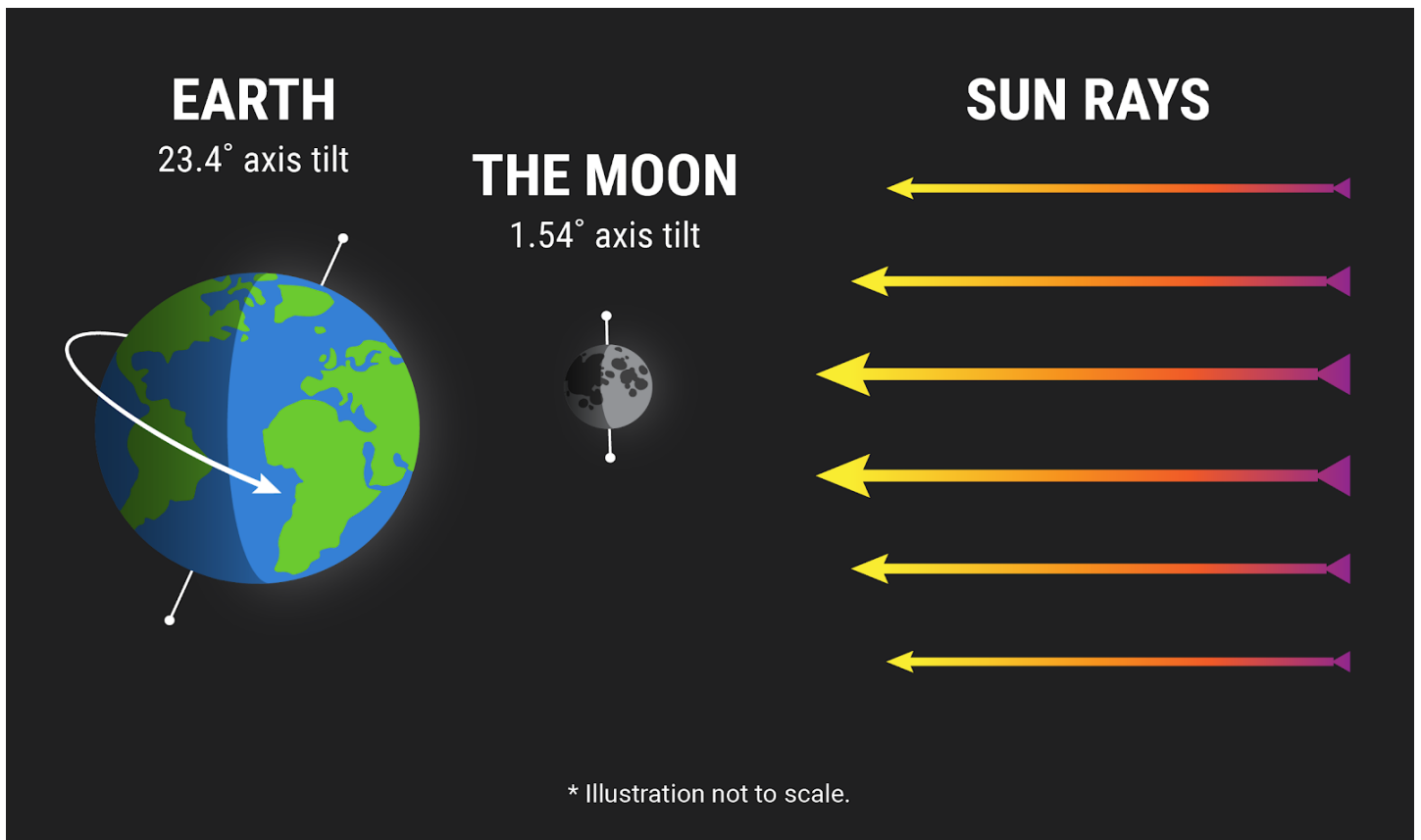
NASA astronauts are headed back to the Moon! They plan to land near the south pole, in areas where scientists have found evidence of frozen water deposits, or water ice. The big question is: where is the best place to go? Where might we find the most ice? To choose the best location, we need to compare all available data from the Lunar Reconnaissance Orbiter (LRO) to see which areas show water ice across multiple kinds of observation. Scientists are undertaking these analyses right now! Your students can join the search for water ice by finding surface frost, which is a strong indicator of water ice and other frozen resources buried beneath the moon's surface.

### BACKGROUND INFORMATION

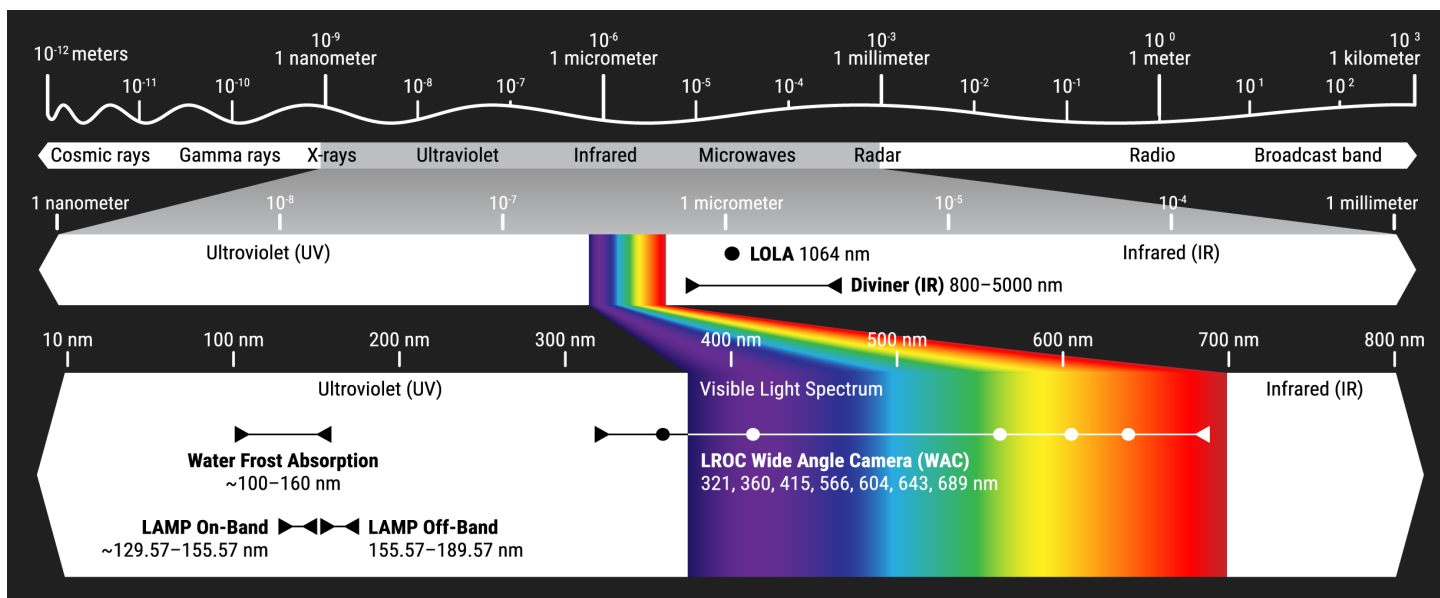
#### Do craters at the Moon's poles hold water ice?

Because the Moon is tilted only  $1.5^\circ$  towards the Sun, there are regions near the lunar poles that never receive any sunlight. On Earth, we experience seasons because the Earth is much more tilted ( $23.5^\circ$ ) on its axis of rotation. The Earth's poles each experience six months of daylight during summer and six months of darkness during winter. The Moon's small tilt, however, means that there is little seasonal change, and the interiors of some polar craters remain in permanent shadow (Figure 1).

Permanent shadow means that these regions can maintain extremely cold temperatures (down to  $-415^\circ\text{F}$  or  $-248^\circ\text{C}$ !). This is so cold that frozen materials like water can be captured for billions of years. Other forms of ice (methane, ammonia) can also occur at these cold temperatures, which is why we refer to frozen water as water ice in this guide. These other ices, delivered by comets to the Moon, are also valuable resources.



**Figure 1:** Image showing how the Sun's rays illuminate the Earth and the Moon. The small tilt of the Moon means there are some areas near the poles that never receive direct sunlight.



**Figure 2:** Electromagnetic (EM) spectrum showing the various wavelengths of light detected by instruments on-board the Lunar Reconnaissance Orbiter. Each instrument can only measure a specific wavelength range, and each provides a different type of information: Diviner measures surface temperature using infrared emission (from 2500 to 4000 nm), the Lyman-Alpha Mapping Project (LAMP) identifies water frost using far-ultraviolet reflectance (from 130 to 190 nm), and the Lunar Reconnaissance Orbiter Camera (LROC) takes pictures of the land around PSRs in visible light (400 nm to 689 nm) with the Wide Angle Camera (WAC). The Lunar Orbiter Laser Altimeter (LOLA) uses a laser to measure the height of the ground, and how reflective it is at the near-infrared wavelength of the laser (1064 nm).

### Seeing in the dark

Much like how the Moon is gravitationally bound to Earth, the Lunar Reconnaissance Orbiter, a human-made spacecraft, is in orbit around the Moon. Onboard the spacecraft are multiple instruments that act as camera lenses that can “see” various wavelengths of light across the electromagnetic spectrum (Figure 2). Observations from these instruments tell us that frozen elements, such as water ice, likely exist in some of the Moon’s permanently shadowed craters. Even with the variety of data available, though, there’s still uncertainty about how much water ice is present, what other frozen resources exist, and the exact locations and depths of the frozen materials.

Water (H<sub>2</sub>O) is essential for future space exploration because it can be broken apart into hydrogen and oxygen, both of which are used in rocket fuel. Rocket fuel mined from space would enable the development of a space “highway” between the Earth and Moon, and possibly beyond. And, of course, water could quench the thirst of space travelers!

### Next Steps?

In order to choose the best landing sites for future missions, additional observations are needed to clarify where the water ice actually is -- both on the surface and buried in the subsurface -- and how much of it will be usable for rocket fuel.

ShadowCam, set to launch in 2022, will map terrain and search for features on the surface that may be related to water ice. ShadowCam will be 800 times more sensitive than the camera it is modeled after (the Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Camera (NAC)), and will

identify features on the ground that are > 1.7 m (5.6 feet) (or objects the size of a small car).

This improved imaging of the surfaces inside permanently shadowed craters will enable scientists to map obstacles like boulders and craters, reducing travel risk for future landers and rovers. Comparing ShadowCam images of the surface with data from instruments that probe the subsurface will help us interpret water ice locations more precisely.

At the current pace of scientific invention, humankind could be visiting the Moon’s south pole in as little as a decade. But for now, mysteries remain frozen right in our celestial backyard.

## INSTRUCTIONS

### Supplies:

- **Colored pencils or other colored writing implements.**
- **Printouts of the Coloring Page (hillshade) to color on for each participant**
- **Digital or Printouts of the maps**

The goal of this activity is for students to identify the most likely locations of water ice on the lunar surface. They should compare each of the provided maps to find locations where all four maps (WAC Summer Mosaic with permanently shadowed regions (PSRs), Diviner Maximum temperature, LOLA 1064 nm albedo, and LAMP UV off/on-band ratio albedo) show results consistent with surface water ice.

Each map has a different legend, but the dark blue color in each map indicates results consistent with water ice. The PSRs are also outlined in dark blue.

Students should try to find at least one location where astronauts should go to search for water ice. To make the activity more challenging, they can identify all the locations where scientists suspect water ice. They can use colored pencils (or any other method you would like) to shade in the area(s) most likely to have water ice on the Coloring Page.

An answer sheet is provided to check their work.

## MAP DESCRIPTIONS

- *Each map represents a different dataset from LRO, including some from instruments other than LROC.*
- *Each map extends from 86°S to 90°S.*
- *Latitude lines are at 1° increments and Longitude lines are at 45° increments.*

### LOLA DTM Hillshade - Coloring Page

This is the coloring sheet. It is a “hillshade” created from a 150 meter pixel scale Lunar Orbiter Laser Altimeter (LOLA) digital terrain model (DTM). LOLA is the instrument on-board LRO that measures elevation by shining a laser at a spot on the surface and recording how long it takes for the reflected light to return. By combining all the measurements of reflected light the LOLA team made maps of the Moon’s topography, like this hillshade.

### LROC WAC Summer Mosaic with PSRs

This mosaic is composed of images from the Lunar Reconnaissance Orbiter Camera (LROC) Wide Angle Camera (WAC) (about 100 m pixel scale) taken during the summer from 21 September 2010 to 23 October 2010. The summer is when the south pole receives the maximum amount of sunlight. Overlaid on this mosaic are outlines of the permanently shadowed regions. Because these areas never receive direct sunlight, they may contain water in the form of ice.

### Diviner Annual Maximum Temperature

This map shows maximum temperature over the entire year in degrees Kelvin (K), as measured by the Diviner Lunar Radiometer Experiment (Diviner, for short) at 250 m pixel scale. Water ice evaporates into a gas at warm temperatures, so ice can only exist in regions that stay very, very cold. In order to trap water ice without it evaporating, a vacuum on Earth must be kept at temperatures < 110 K (< -262°F; **dark blue on the map**). For comparison, the coldest temperature ever recorded on Earth’s surface, at Vostok Station, Antarctica, was ~184K (-128°F or -89°C).

### LOLA 1064 nm Albedo Map

A color-coded version of the albedo map from the Lunar Orbiter Laser Altimeter (LOLA) instrument at a 500 m pixel scale. Albedo is a measure of how much a material reflects light. So, a surface that appears brighter has a higher albedo than one that appears darker. One material that is very reflective and can appear bright is water ice in the form of surface frost, so this map can help us tell where surface water ice might be located. **Values of >0.37 (dark blue)** are bright enough to indicate surface water ice.

Another kind of surface that appears bright is the walls of steep craters. So to help with interpretation, steep crater walls have been removed from this map (**white**).

There is some striping at the edges of this image. These are artifacts (errors) in the data. While we try very hard to understand and correct for all the factors that affect the data (like where the spacecraft is during observations) when producing maps like this, there is still sometimes uncertainty in the data that isn’t yet understood, and this can show up as minor glitches in the final product.

### LAMP UV Off/On-Band Albedo Ratio Map

This LAMP ratio map shows reflectance (or albedo) in the ultraviolet (UV) spectrum, measured by the Lyman-Alpha Mapping Project (LAMP) instrument at a pixel scale of 250 m. Water ice would show up in this map as having high values. Water ice reflects nearly all the light in the “Off-band” (155.57-189.57 nm) wavelength range, while it absorbs (rather than reflects) much of the light in the “On-band” (129.57-155.57 nm) wavelength range. The LAMP team divided the values in the Off-band map by the values in the On-band map to make a ratio map. High values in the ratio map show where there is increased reflectance in the Off-band and increased absorption in the On-band. The ratio map shows that at temperatures below 110 K PSRs increase in UV reflectance. Water ice is not the only highly reflective feature within PSRs, though, so bright features like crater rims have been removed from the ratio map in areas where temperatures are too high for ice to be stable on the surface. **Values >1.2 (dark blue)** indicate water ice.

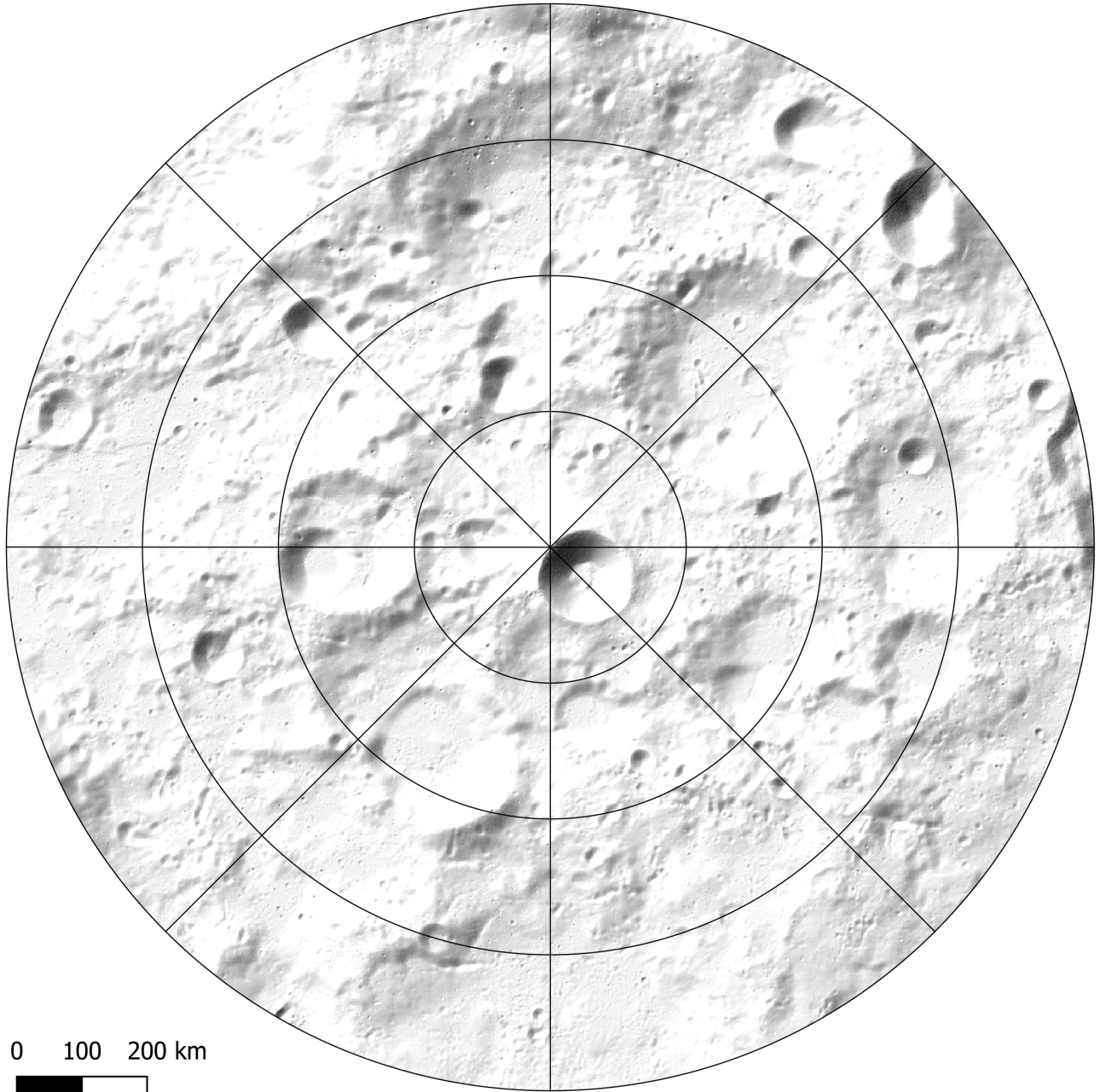
### Water Ice Map (Answer Sheet)

**Surface water ice locations.** Dark blue indicates locations where LAMP UV albedo (values  $\geq 1.2$ ) and LOLA albedo (values  $\geq 0.37$ ) intersect in craters where average annual maximum temperatures never exceed 110 K.

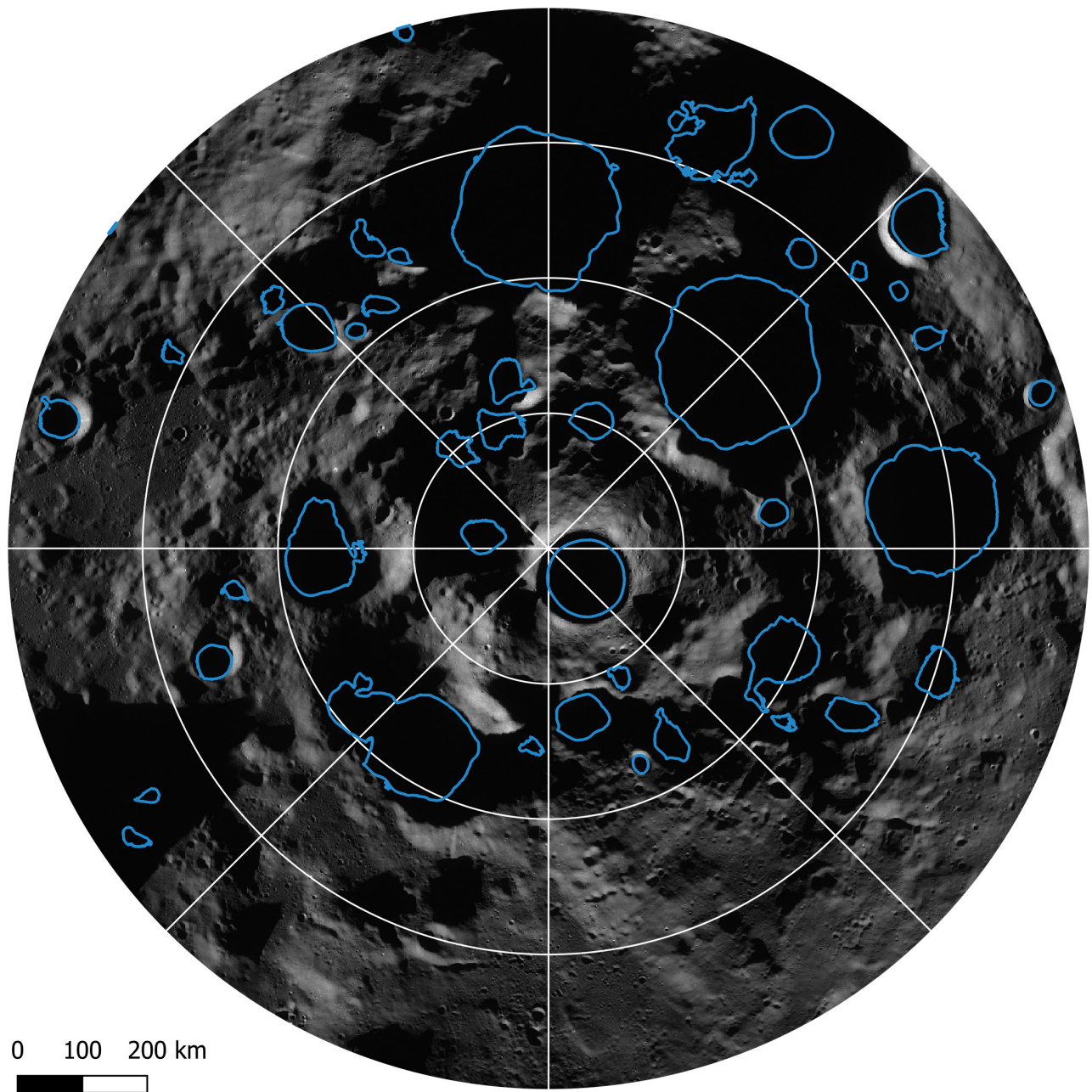
The distribution of water ice in the subsurface is still unclear to scientists!



# COLORING PAGE - HILLSHADE



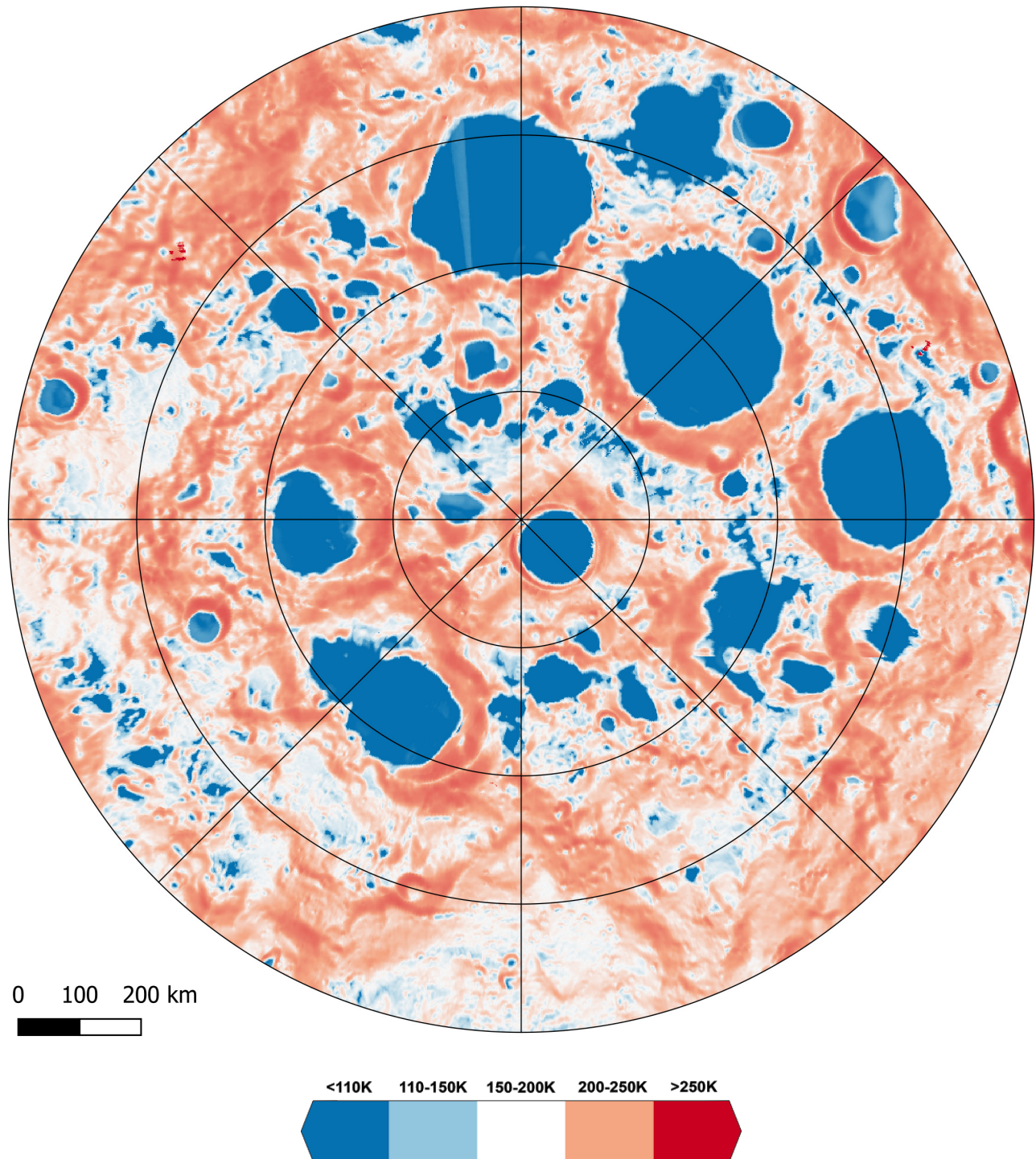
# LROC WAC SUMMER MOSAIC WITH PSRs



The WAC south pole summer mosaic is composed of images from the Lunar Reconnaissance Orbiter Camera (LROC) Wide Angle Camera (WAC) taken during the summer (from 21 September 2010 to 23 October 2010). The summer is when the south pole receives the maximum amount of sunlight, although not enough to light up the insides of most craters. Outlined in **dark blue** are the permanently shadowed regions. Because these areas never receive direct sunlight, it is possible that they contain water in the form of ice.

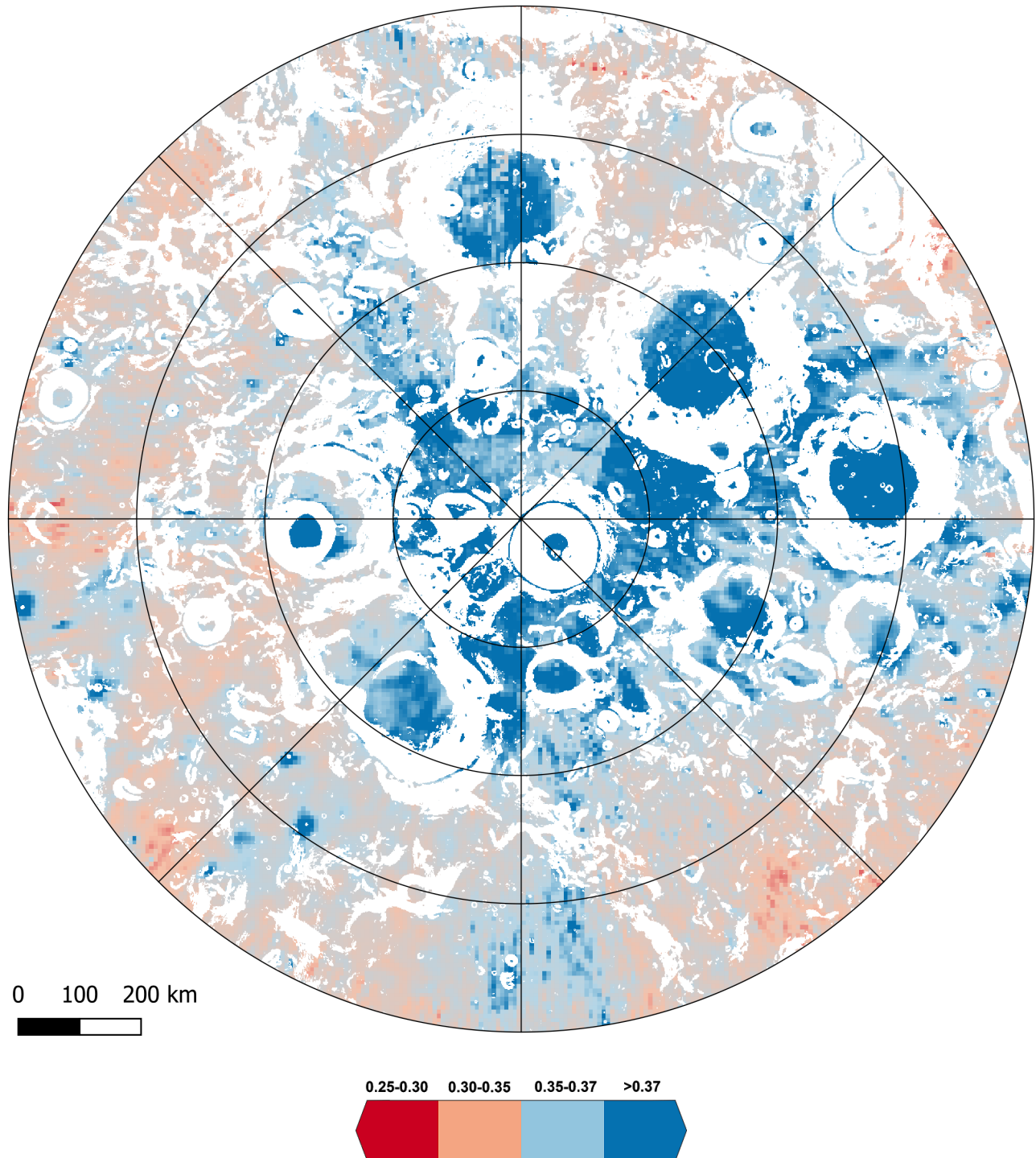


# DIVINER MAXIMUM TEMPERATURE



The maximum temperature in degrees Kelvin (K) over an entire year was measured by the Diviner Lunar Radiometer Experiment (Diviner, for short). **Values < 110 K (-262° F; dark blue)** are cold enough to trap water ice.

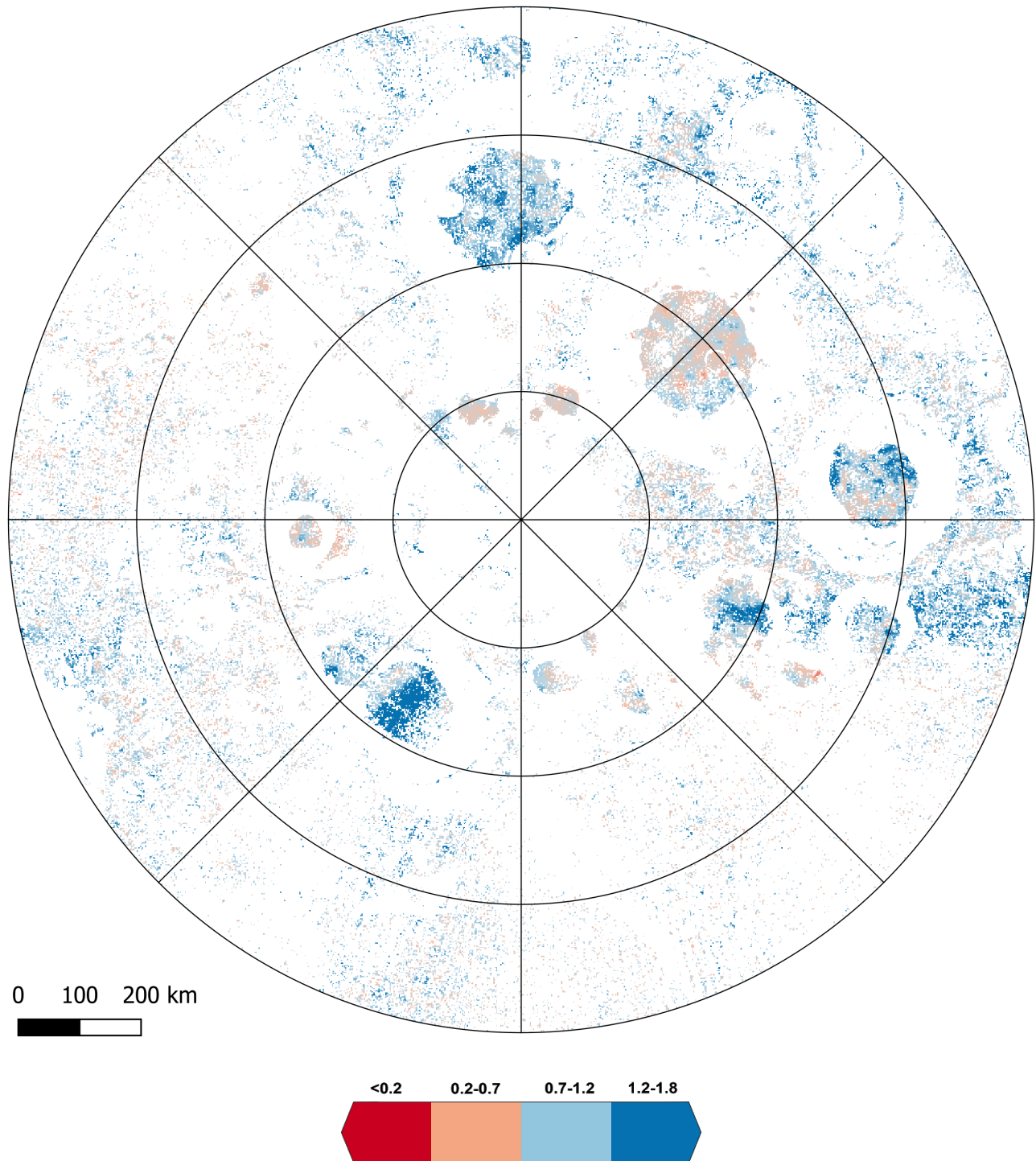
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This albedo map was created by the Lunar Orbiter Laser Altimeter (LOLA) instrument team. Albedo is a measure of how much a material reflects light. So, a surface that appears brighter has a higher albedo than one that appears darker. One material that is reflective and can appear bright is water ice in the form of surface frost, so this map can help us tell where surface water ice might be located. **Values of >0.37 (dark blue)** are bright enough to indicate surface water ice. Another kind of surface that appears bright is the walls of steep craters. So to help with interpretation, steep crater walls have been removed from this map (**white**).



# LAMP UV OFF ON-BAND RATIO UV ALBEDO MAP



This map of the reflectance (or albedo) in the ultraviolet (UV) spectrum was measured by the LAMP instrument. LAMP's Off-band is a near-perfect reflector of water ice, so the LAMP team took the ratio of the 'On-Band' and 'Off-Band' maps to more easily detect water ice. **Values >1.2 (dark blue)** are consistent with surface water ice.





# **THE MYSTERY OF LUNAR WATER**

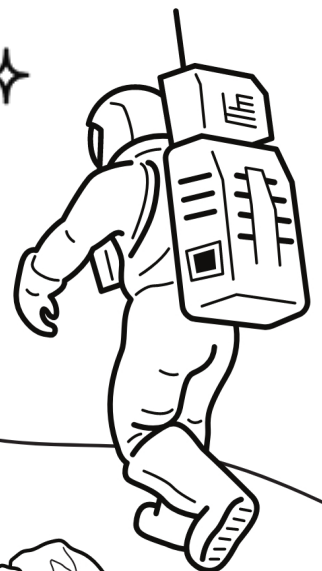
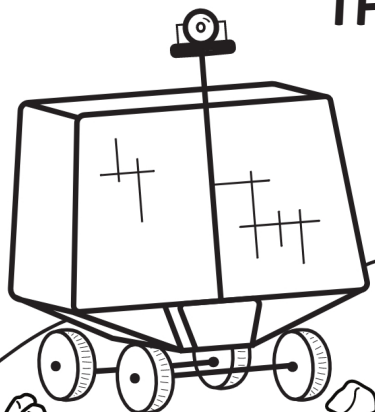


## **HELP SCIENTISTS UNCOVER WATER ICE ON THE MOON**



### **PART 1**

**THIS ACTIVITY IS DESIGNED FOR  
AGES 9 AND UP.**





## STUDENT GUIDE

### INTRODUCTION



We want to send astronauts back to the Moon to areas near the south pole that contain frozen water (referred to as water ice in this guide). But first, you need to discover where water ice is the most plentiful. To do this, you need to compare data from many of the instruments on the Lunar Reconnaissance Orbiter (LRO) satellite to find areas that show water ice in all the datasets. Scientists are doing similar studies right now to answer the same question! Help scientists locate where water ice exists on the surface in the form of surface frost. Locations of surface frost will help scientists search for water ice and other frozen resources buried beneath the surface.



### BACKGROUND INFORMATION



There are regions near the Moon's north and south poles that never receive sunlight (**Figure 1**). Such regions, known as permanently shadowed regions (PSRs), can maintain very cold temperatures (down to  $-415^{\circ}\text{F}$  or  $-248^{\circ}\text{C}$ !). At these cold temperatures, ice can be made from many frozen substances, including water, carbon dioxide ( $\text{CO}_2$ ), sulfur, and hydrogen.



### INSTRUCTIONS



#### Supplies:

- **Colored pencils, markers, or other writing tools.**
- **Printouts of the Coloring Page (Hillshade) to color on for each student**
- **Digital or Printouts of the maps**

The goal of this activity is to find at least one location where astronauts should go to search for water ice. To do this, compare each of the provided maps to find locations where all four maps (WAC Summer Mosaic with PSRs, Diviner Maximum Temperature, LOLA 1064 nm albedo, and LAMP UV off/on-band ratio albedo) show results consistent with surface water ice.

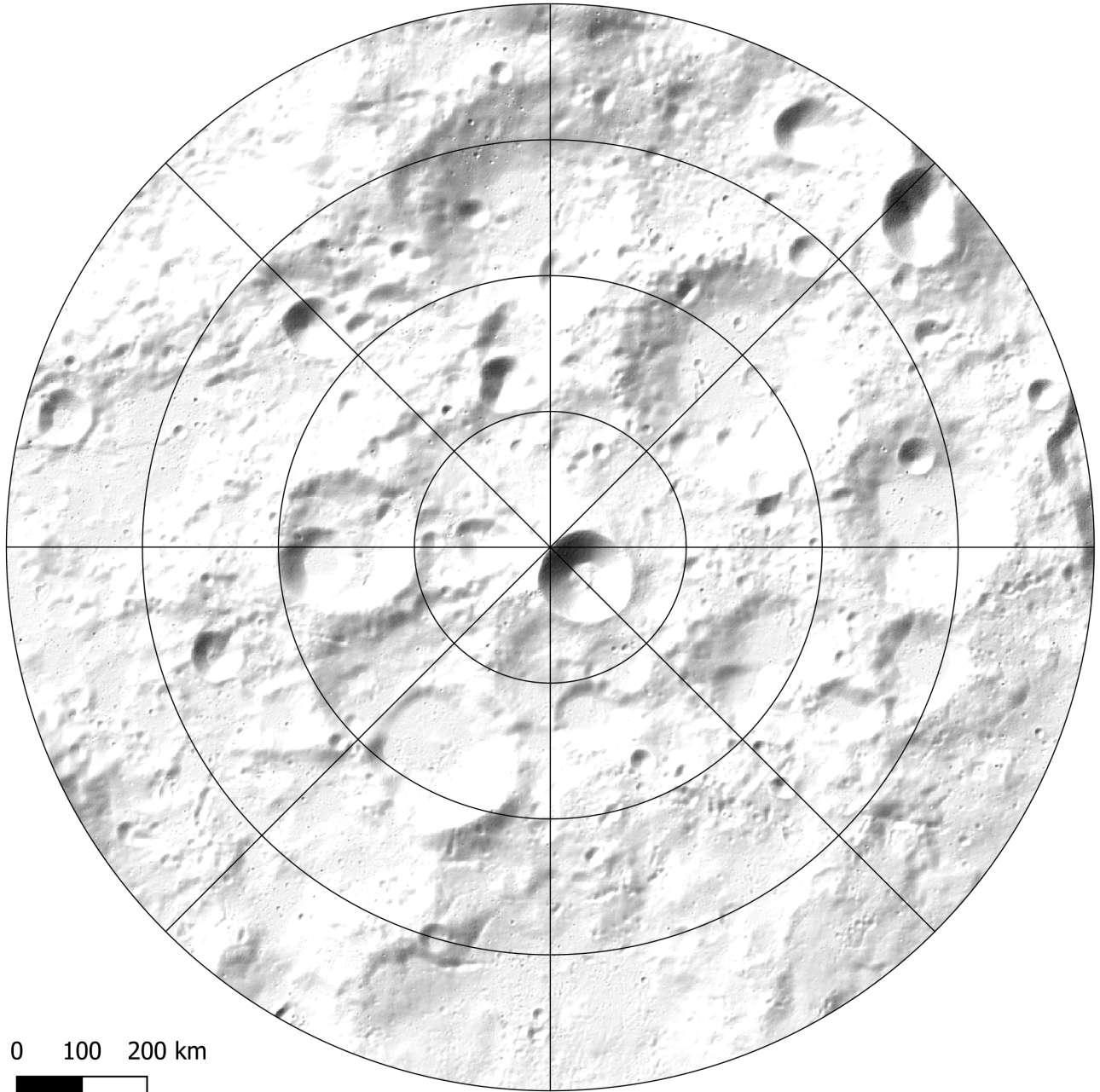
Each map has a different legend, but results that are consistent with surface water ice are indicated by the dark blue color in each map. The PSRs are also outlined in dark blue.

There are several locations that might contain water ice, so to make the activity more challenging, identify multiple locations where scientists suspect water ice may be found. Colored pencils can be used to shade in the area(s) most likely to have water ice on the Coloring Page.

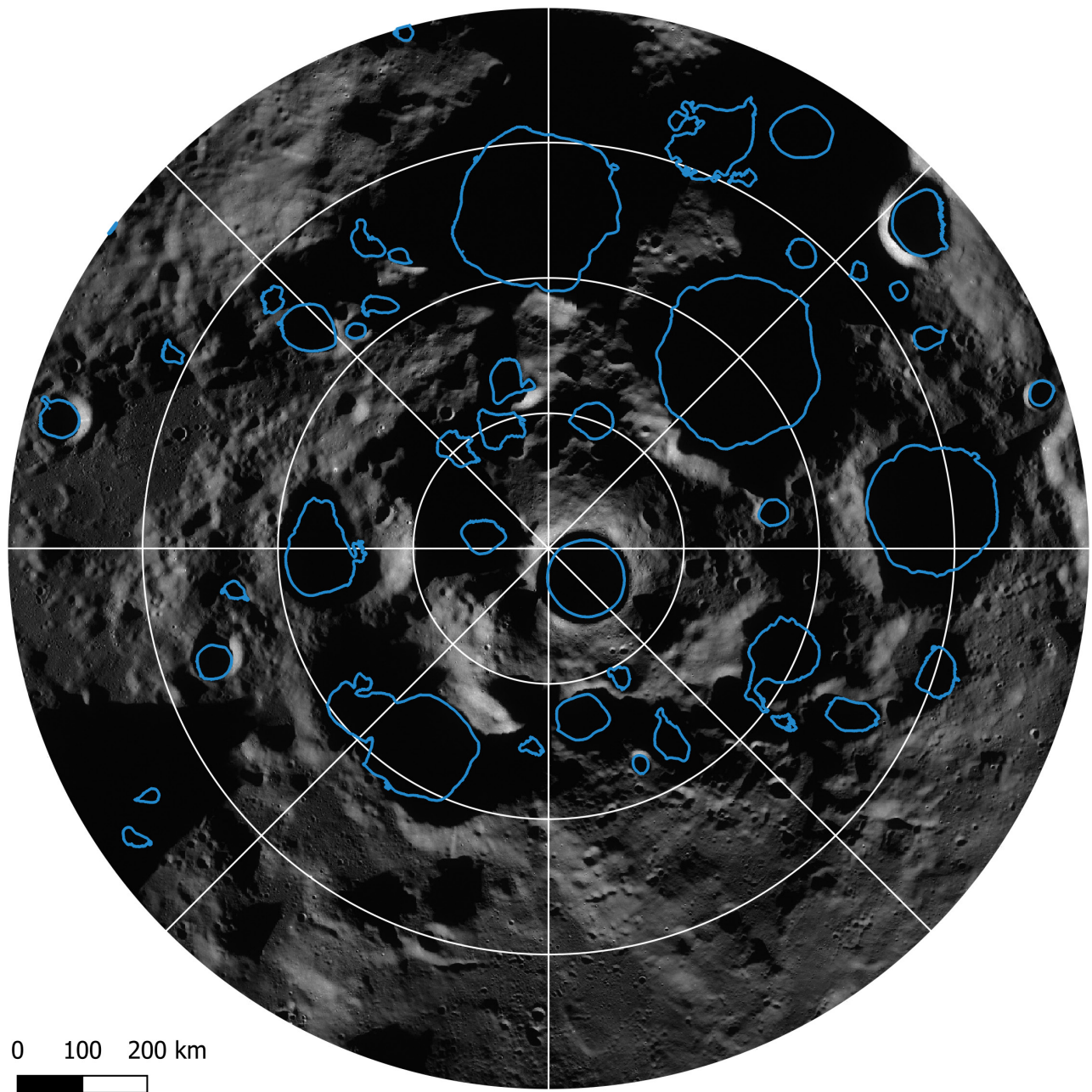
answer sheet is provided in the instructor packet so you can check your work.



# COLORING PAGE - HILLSHADE



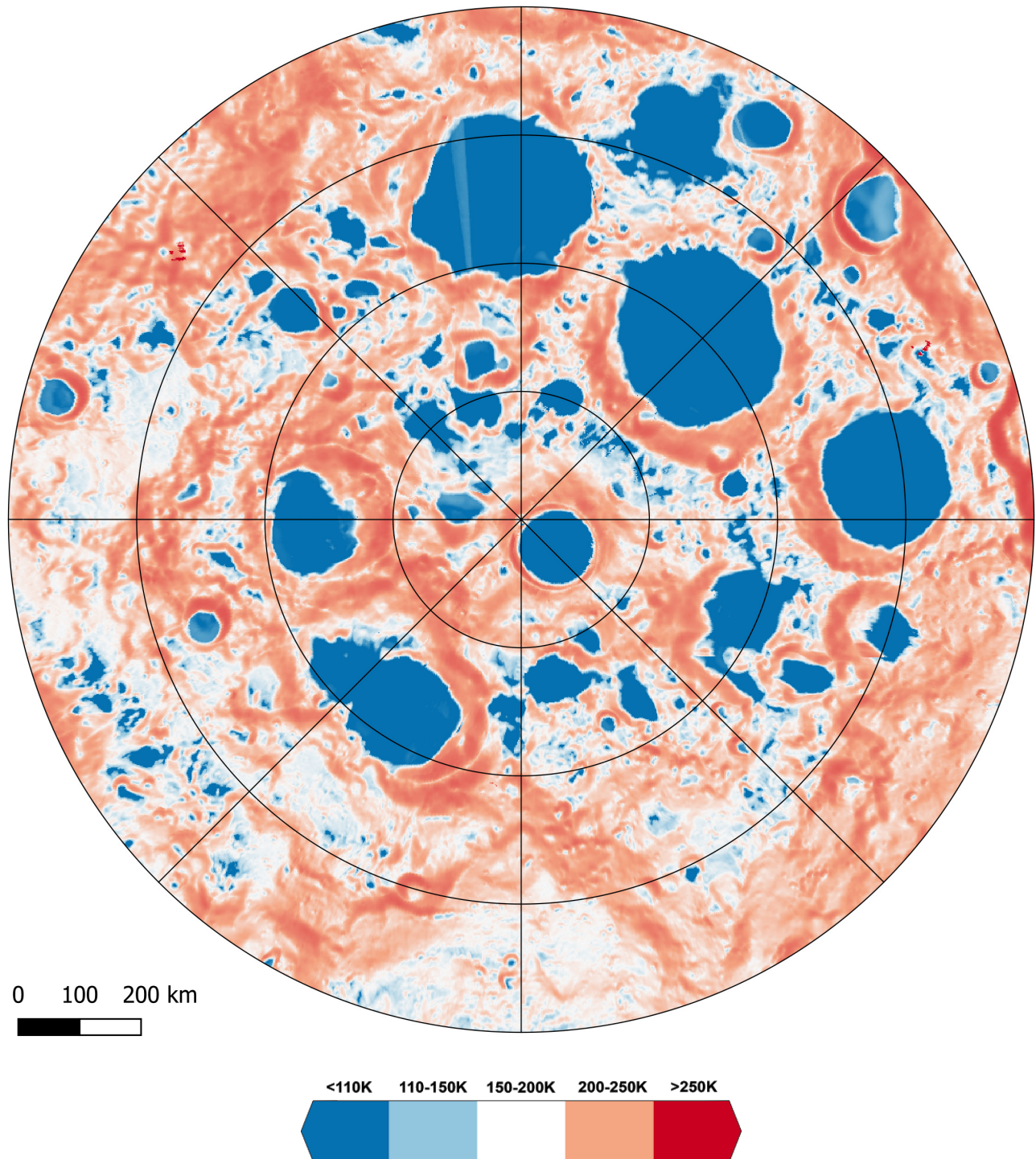
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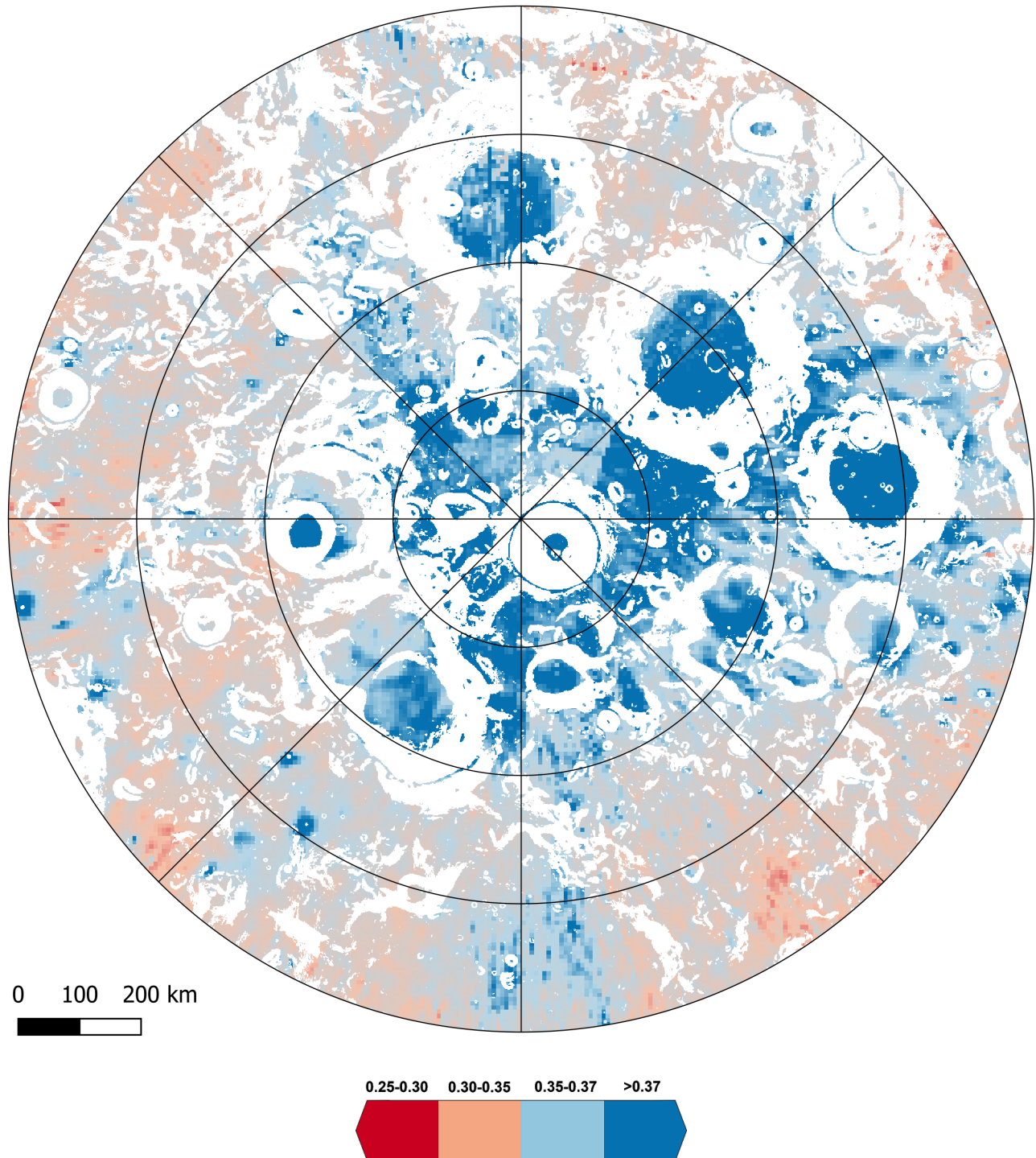
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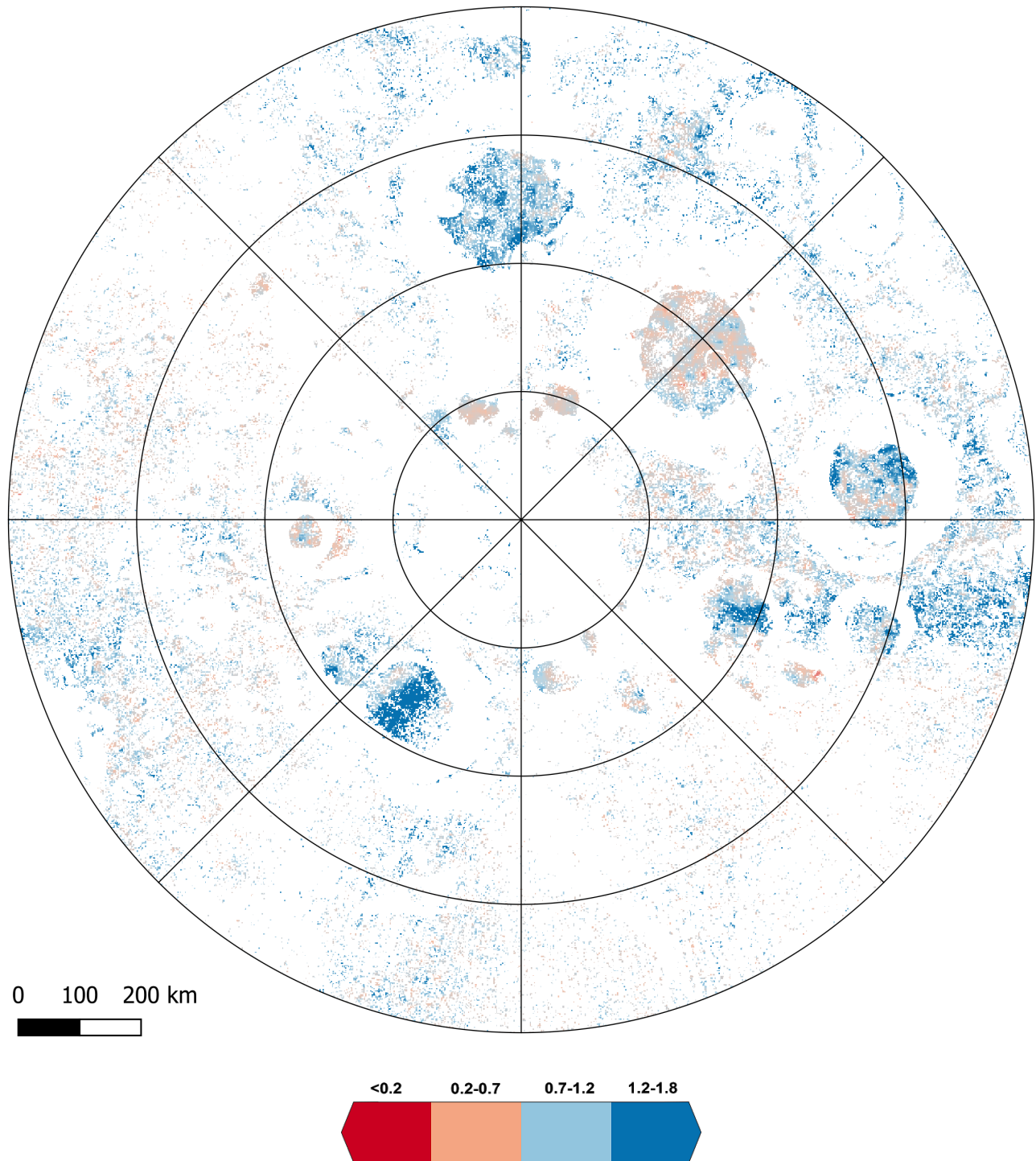


# LOLA 1064 NM ALBEDO MAP

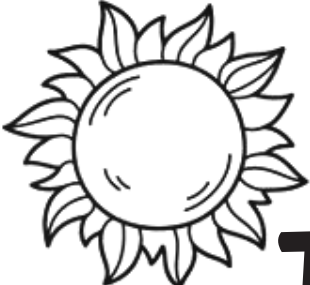


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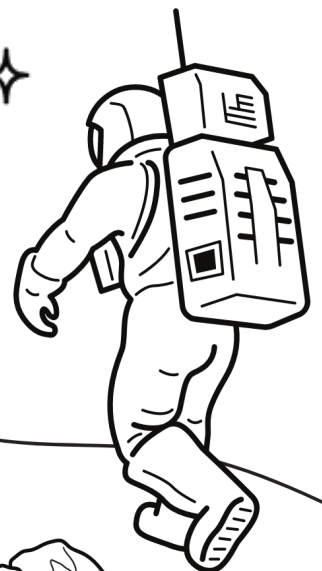
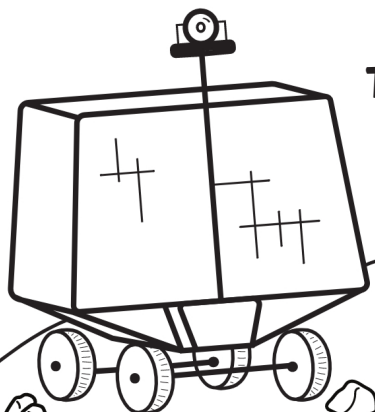
# **THE MYSTERY OF LUNAR WATER**

## **HELP SCIENTISTS UNCOVER WATER ICE ON THE MOON**

### **PART 2**

**INSTRUCTOR GUIDE**

**THIS ACTIVITY IS DESIGNED FOR  
AGES 11 AND UP.**



# INSTRUCTOR GUIDE

## INTRODUCTION

Identifying locations of water ice on the Moon's surface is only part of the puzzle scientists and engineers are trying to solve. Many of the conditions that are ideal for preserving water ice are not very safe for human exploration. Ideal exploration conditions involve relatively flat surfaces (<15 degrees), plenty of sunlight for power, and good line-of-sight communication with Earth. To safely find and use any water ice resources on the Moon, we need to plan a mission that lands somewhere safe, then traverses with a rover to the water ice. Scientists and engineers at NASA, commercial spaceflight organizations, and non-NASA governmental organizations are currently examining datasets like the ones in this activity to plan future missions to the lunar south pole! Students will help them plan a mission by choosing a safe landing site, then planning a traverse that takes the rover and its crew to a surface water ice location identified in Part 1 of this activity.

## BACKGROUND INFORMATION

### Mission Requirements

Robotic missions to the Moon require a combination of engineering and science considerations. From an engineering point of view, flat areas with a clear view of the Earth for communications and abundant energy from the sun are an ideal place to be. However, scientists want data from under boulders, inside craters, and along boulder-strewn debris paths. The job of mission planners is to reconcile these differing requirements to accomplish the maximum possible science with a realistic and safe rover design.

### Communication with Earth

The Moon is tidally locked with Earth, which means that the same side of the Moon always faces the Earth (we call this the nearside). This creates a challenge when planning a rover mission at the pole, because about one half of the pole does not have a direct line of communication with Earth. Rovers need to communicate with Earth to upload all the data they collect on the surface. Without direct communication, operations teams on Earth cannot support the astronauts on crewed missions, and rovers cannot receive any commands on uncrewed missions.

To overcome this challenge, NASA could put a communications satellite into orbit. China used this solution for Chang'e 4, the first lander on the far side of the Moon, which communicates via a satellite called Queqiao. NASA is also developing the Lunar Gateway, a deep space habitat that will serve as a base and communications hub for lunar missions as well as a science lab.

Direct communication with Earth during and immediately after landing is especially important so that the rover team can monitor the spacecraft's data and send commands if needed during touch-down. Also, the rover will need to communicate with Earth during its initial start-up and testing. The lag time for radio signals from a lunar rover to reach engineers on Earth (called latency) is about three seconds for a round-trip from the Earth to the Moon and back. When engineers send a rover to Mars the lag in communication time will be even greater (minimum of three minutes).

### Abundant Sunlight for Power

Lunar rovers will likely be solar-powered, as sunlight is, in general, a readily available and reliable power source on the Moon. However, solar energy becomes more difficult at the poles, as the shadowed regions that allow ice to exist also prevent solar panels from charging the batteries. Traverses will need to be carefully planned and rovers carefully designed with solar power constraints in mind. When scientists plan missions to the south pole, they will pay close attention to the available light and how it changes every day over the entire mission. For a 30 day mission, like the one the students are planning here, just over one day will happen on the Moon.

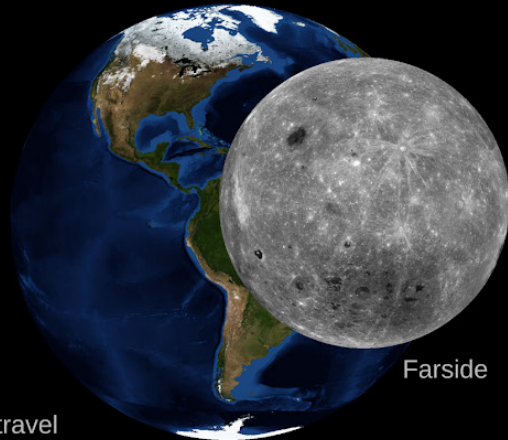
Since available light will change throughout one lunar day, a successful mission would land in terrain that stays consistently illuminated throughout the year. Once the rover has landed, direct sunlight is essential to power the rover through its initial checks, allowing engineers to make sure the rover is healthy. Additionally, having access to lots of solar power ensures that the rover does not unexpectedly run out of power and can begin its traverse with full batteries.

The LROC WAC Polar Illumination map provided in this activity was initially created to help scientists plan missions by finding the sites with the most sunlight year-round.



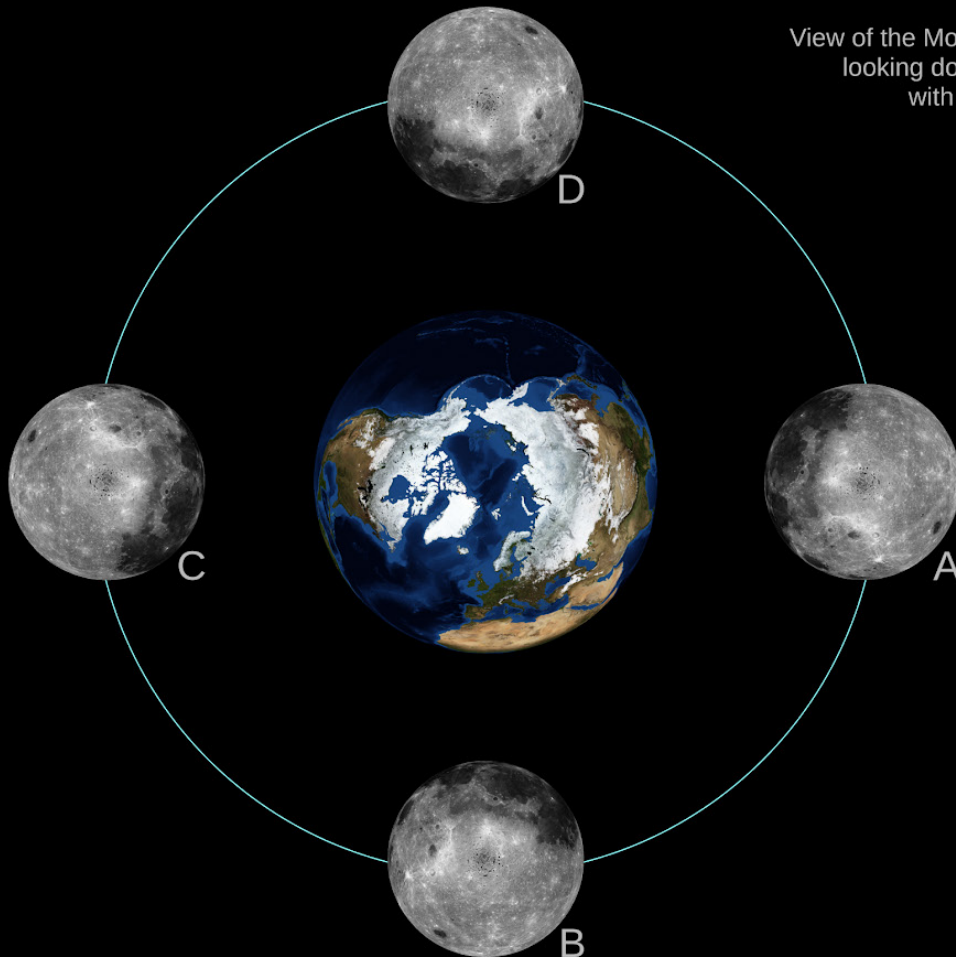


Nearside

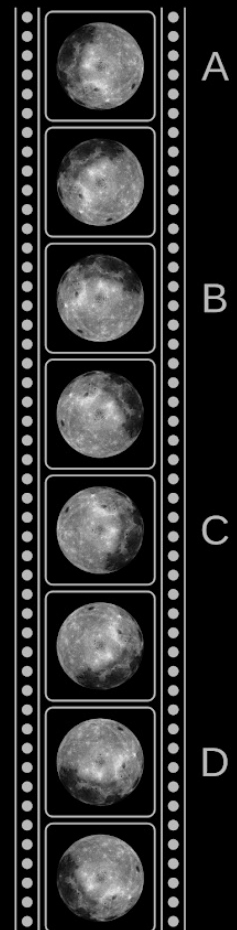


Farside

From the Earth, we can only see the nearside of the Moon.  
To see the farside of the Moon, a spacecraft would have to travel  
beyond the Moon and look back towards the Earth.



View of the Moon's orbit around the Earth  
looking down towards the North Pole  
with a "filmstrip" of the rotation.  
(Not to scale)



The Moon rotates once every orbit around the Earth.  
This is called "tidal locking" and means only the nearside of the Moon  
has a clear path for radio signals to reach the Earth.



## Hazard Avoidance

Landing site selection is one of the most critical decisions for any rover mission. During a rover mission, the rover can drive into dark areas or climb up a steep slope; however, the landing site must have direct communication with Earth, abundant sunlight for energy, and avoid surface obstructions.

The landing site must have slopes  $<5^\circ$  within an oval of space called a landing ellipse to avoid topographic hazards. For the Apollo missions to the Moon, the landing ellipse was 15 km by 5 km in diameter, which gave engineers a margin of error when landing the spacecraft. The area must be relatively free of boulders and craters. To identify potential hazards, scientists spend a lot of time looking at surface roughness maps and high-resolution images of the potential landing zones, such as those taken with the LROC Narrow Angle Cameras (about 0.5 meters per pixel at the South Pole).

## Lunar Rovers

To safely traverse the uneven lunar terrain, engineers must carefully consider a rover's suspension and drive systems. The suspension system provides control and stability, allowing the rover to drive over obstacles (such as craters and boulders) by minimizing tilt. A simple, lightweight, yet sturdy suspension system is ideal. When the rover encounters an area with obstacles its suspension is unable to handle, it must either drive around (perhaps many kilometers out of its way) or be able to maneuver carefully between the obstacles.

Older rovers such as the Apollo Lunar Roving Vehicles (LRVs) accomplished obstacle avoidance by providing car-like steering on both the front and rear ends. This steering capability allowed the LRVs to have a tight turn radius (compared to traditional vehicles that steer with the front wheels only). For future rovers, engineers are improving on this drive system design by providing independent steering to each wheel. The four-wheel steering system will allow the rover to turn in place and drive sideways.

## Successful Landed Lunar Missions

There have been seven successful landed lunar rover missions; the United State's Apollo 15, 16, and 17 missions, the Soviet Union's Lunokhod 1 & 2, and the Chinese landers Yutu and Yutu 2.

The Apollo Lunar Roving Vehicle (LRV), used during Apollo 15, 16, and 17, was used to transport astronauts, tools, scientific equipment, communications gear, and lunar samples across large distances. This allowed the crew to explore more of the Moon than on previous missions. The LRV could operate for 78 hours and travel up to 65 km (40 mi) during the lunar day. The rover is 3.1 meters long, 2.3 meters wide, and 1.14 meters tall, and was capable of carrying more than twice its weight, or 490 kg (1080 lbs).

The Lunokhod rovers were the first robotic rovers to land on the Moon. They were designed to support the planned Soviet crewed lunar missions until those missions were canceled shortly after the success of the Apollo program. Lunokhod 1 drove 10.5 km (6.5 mi), and Lunokhod 2 drove 39 km (24 mi) on the Moon.

Yutu (Jade Rabbit) and Yutu 2 landed on the lunar surface as part of China's Chang'e 3 & 4 missions. Chang'e 3 landed and deployed Yutu in 2013 and Chang'e 4 landed and deployed Yutu 2 in 2019. The objective of the Chinese Lunar Exploration Program that launched the Chang'e missions is to help pave the way for future human exploration missions.

No lunar landed missions have yet been attempted at the poles or in permanently shadowed craters. However, NASA is planning the Volatiles Investigating Polar Exploration Rover (VIPER), which will explore the south pole in late 2023 in search of water ice and other potential resources.

For a complete list of rovers, see our activity, Rovers of the Solar System!

## INSTRUCTIONS

During the first part of this activity, students identified the most interesting locations to gather scientific data for water ice on the surface. Using the rover's capabilities, how many of those areas can be visited by the rover during its limited time? Where will the rover land? Where will it go? What PSRs will it study? If students want more of a challenge, encourage them to consider possible extended missions: can the rover explore the most interesting areas and be in a good position to continue exploring other targets if it survives longer than planned?

For this exercise, a few important engineering constraints should be considered when designing the mission:

### Rover design:

- ***The rover can travel 60 km on a full battery charge.***
- ***The rover travels at up to 15 km/h***
- ***The rover can operate for 78 hours before needing to recharge.***
- ***The rover may survive longer and have extended missions, but has been designed to operate for a minimum of 1 lunar cycle (27.5 earth days).***

Landing site constraints	Traverse constraints	Associated LRO maps
The site must have exposure to Sun to maintain power during initial rover checks	Rover must be in sunlight to transmit high-speed science data and to receive battery recharge	LROC WAC Polar Illumination Map
Slope <5°; flat terrain is best	Rover can climb slopes up to 15°	LOLA Slope Map
Means of communicating with Earth	Rover must have a view of Earth to return data	LOLA Earth Visibility Map

**Table 1.** Engineering constraints for a safe landing site and successful rover traverses.

Slope (°)	Speed	Power Requirements ( <u>Watts</u> )
Relatively flat (+/- 2°)	15 km/hr	646 W
5°	15 km/hr	893 W
10°	15 km/hr	1303 W
15°	15 km/hr	1693 W

**Table 2.** Engineering constraints for how much power a rover has during its traverse based on slope of surface and speed travelled.

**Landing site constraints:**

- *The landing area must have a slope <5°*
- *The landing area must have a view of the Earth for communication during the landing sequence.*
- *The landing area must be relatively free of large boulders.*
- *The landing area must have exposure to the Sun to maintain power during initial rover checks.*

**Traverse constraints:**

- *The rover must have a view of the Earth to return data.*
- *The rover must be in sunlight to transmit high-speed science data.*
- *The rover can climb slopes up to 15°.*

If students would like more of a challenge, encourage them to consider the following questions:

- *Using the rover's capabilities, how many water ice deposits can be visited by the rover during its limited time?*
- *If the rover were on an extended mission, could it explore the most interesting areas, and be in a good position to continue exploring other targets if it survives longer than planned?*

Students can use Table 2 to consider how the slope of the surface affects the speed with which a rover can travel. Speed plays an important role in how far the rover can explore before needing a battery recharge.

*Students can consider rover power constraints, assuming that on the Moon the rover weighs 116 kg:*

- *The battery capacity of the rover is 8700 watt hours.*
- *A 1300 W load would last about 6 hours.*
- *Half the speed would use half the power.*
- *Given a solar panel that could output 300 W, the rover could recharge 300 W of battery per hour assuming full illumination.*
- *It would take the rover approximately 29 hours (or a little over one day) to fully recharge.*

**Supplies:**

- *Something to write with: pencil, pen, markers, colored pencils, etc.*
- *Printouts of the Planning Sheet (Hillshade) to write on for each student.*
- *Digital or Printouts of the maps.*
- *(Optional) Ruler to help more accurately measure distances. There are many free, printable rulers online and they are available in most graphics programs.*

### Map Descriptions:

- *Each map represents a different dataset from LRO.*
- *Each map extends from 88°S to 90°S.*
- *The grid has 10 km by 10 km squares.*

### LOLA DTM Hillshade - Planning Sheet

This is the map to print for planning the crewed rover mission. It is a hillshade created from a 150 m pixel scale Lunar Orbiter Laser Altimeter (LOLA) digital terrain model (DTM) with the results from the Activity 1 surface water ice analysis overlaid in **black**. LOLA is the instrument on-board LRO that measures elevation by recording how long it takes to bounce a laser spot to the Moon and detect it on the spacecraft. By combining all the spots, the LOLA team made maps of the Moon's topography.

### LROC WAC Polar Illumination Map

This polar illumination map is a mosaic of images from the Lunar Reconnaissance Orbiter Camera (LROC) Wide Angle Camera (WAC) taken over an entire year, and the values in it represent the percentage of time that each pixel was illuminated during that year. Areas with surface water ice are indicated by **gray**. While the slight tilt of the Moon creates areas that never see any illumination (0%), it also means there are areas that see sunlight more than half the time (up to 71.7% of the time) - more than anywhere on Earth. This is good news for polar explorers since most of the equipment sent to the Moon is solar powered. Any areas that are **blue** are illuminated more than 45% of the time, with areas that are **dark blue** having the most sunlight. Any planned traverses should try to stay in illuminated areas as much as possible, and must not be in shadowed areas for more than 30 hours.

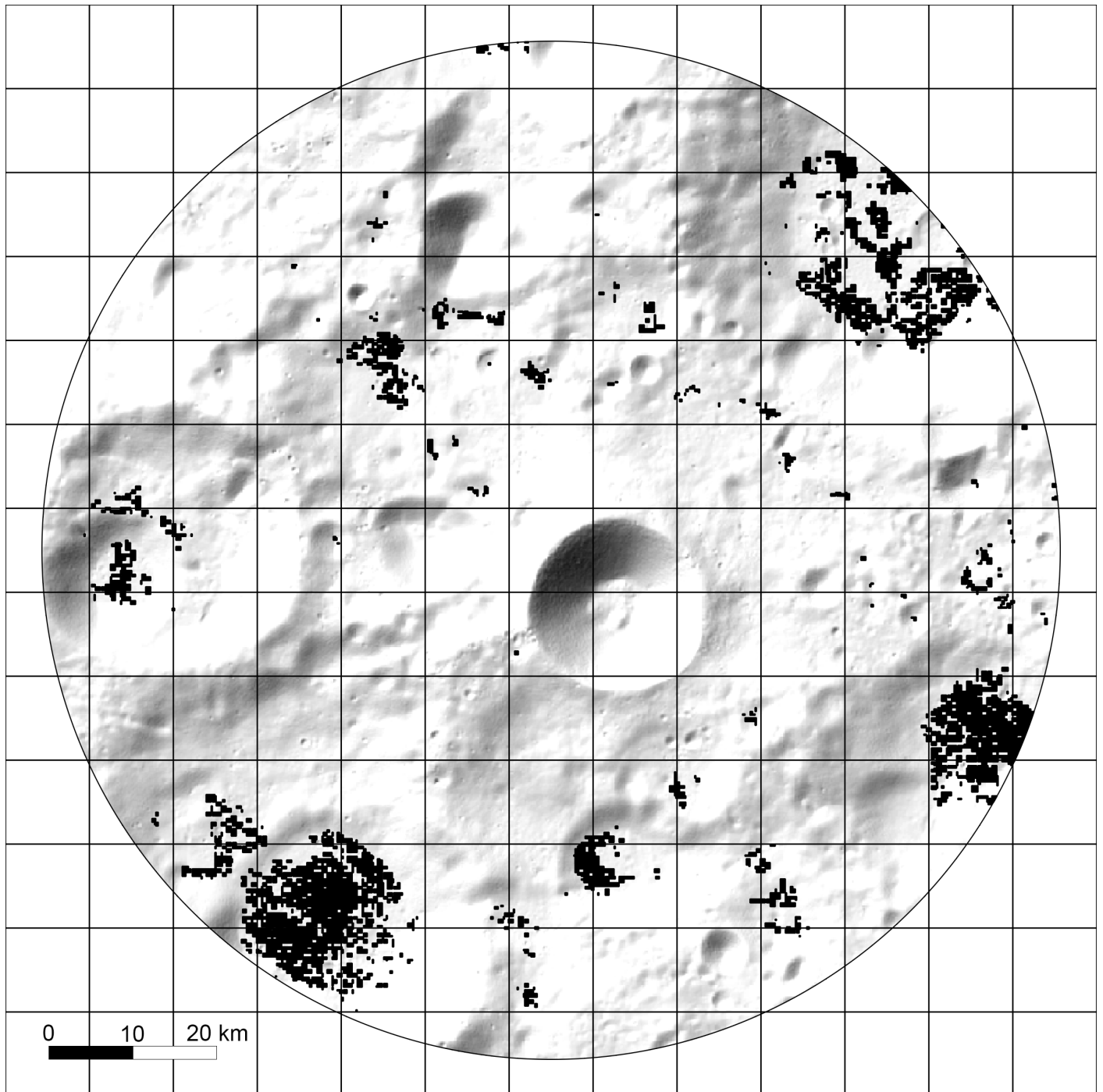
### LOLA Slope Map

This slope map shows the steepness of terrain on the lunar surface, and was created from a 25 m/px LOLA digital elevation map (similar to the one used to create the hillshade). Slope is a very important consideration when planning rover traverses, as the rover can only traverse slopes less than 15°. If slopes are 15° or larger there is a serious risk of the rover tipping or sliding downhill. Traversable slopes are indicated by shades of **blue**. Landing sites must be even flatter, with slopes <5° (indicated by **dark blue**). Areas with surface water ice are indicated by **dark gray**.

### LOLA Earth Visibility Map

The average visibility of Earth as seen from the lunar south pole. The Moon is tidally locked, so the same side, called the nearside, always faces the Earth. To communicate with Earth, rovers need direct line-of-sight communication with Earth. This map shows the average percent of the Earth visible to direct line-of-sight communication. Areas that are **blue** have enough visibility (>45%) to send data back to Earth. It is safer to stay as much as possible in areas with line-of-sight communication with Earth. Areas with surface water ice are indicated by **gray**.

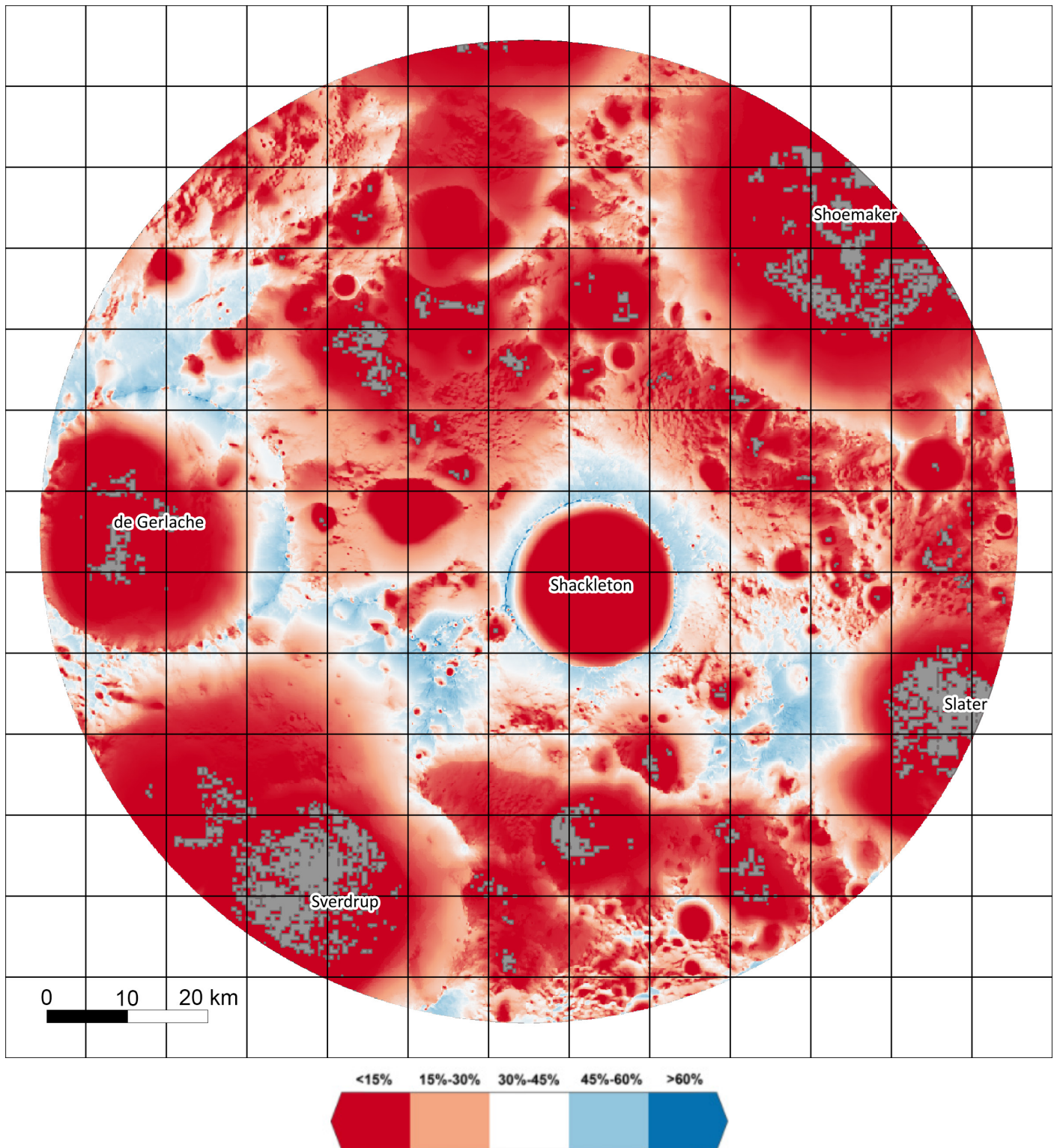
# PLANNING SHEET - HILLSHADE



This is the map to print for planning the crewed rover mission. It is a hillshade created from a 150 m pixel scale Lunar Orbiter Laser Altimeter (LOLA) digital terrain model (DTM) with the results from the surface water ice analysis overlaid in **black**.



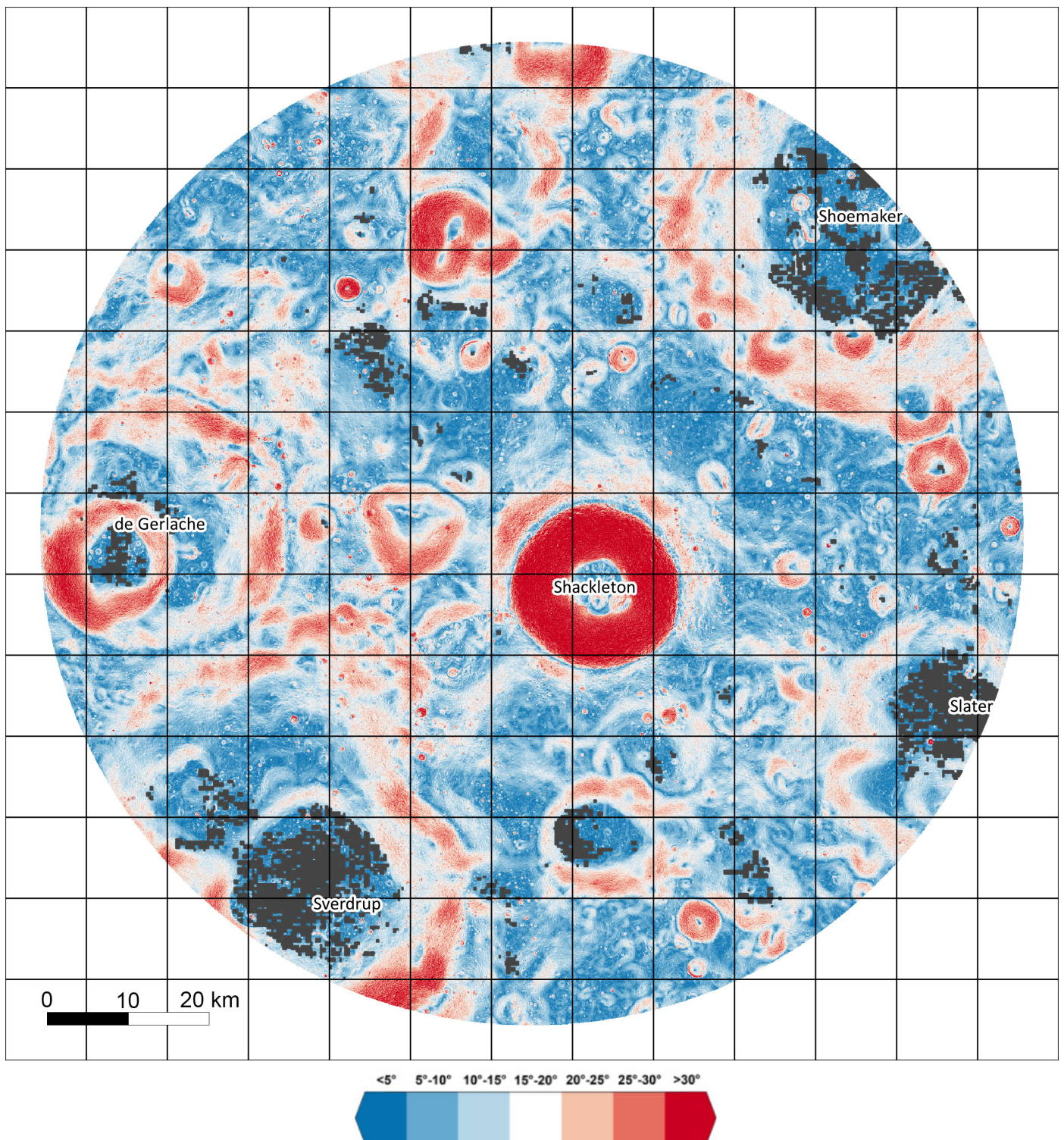
# LROC WAC POLAR ILLUMINATION MAP



This mosaic was created from images taken by the Lunar Reconnaissance Orbiter Camera (LROC) Wide Angle Camera (WAC) over an entire year. Map values represent the percentage of time that each pixel was illuminated during that year. Areas with surface water ice are indicated by **gray**. Any areas that are **blue** are illuminated more than 45% of the time, with areas that are **dark blue** having the most sunlight.



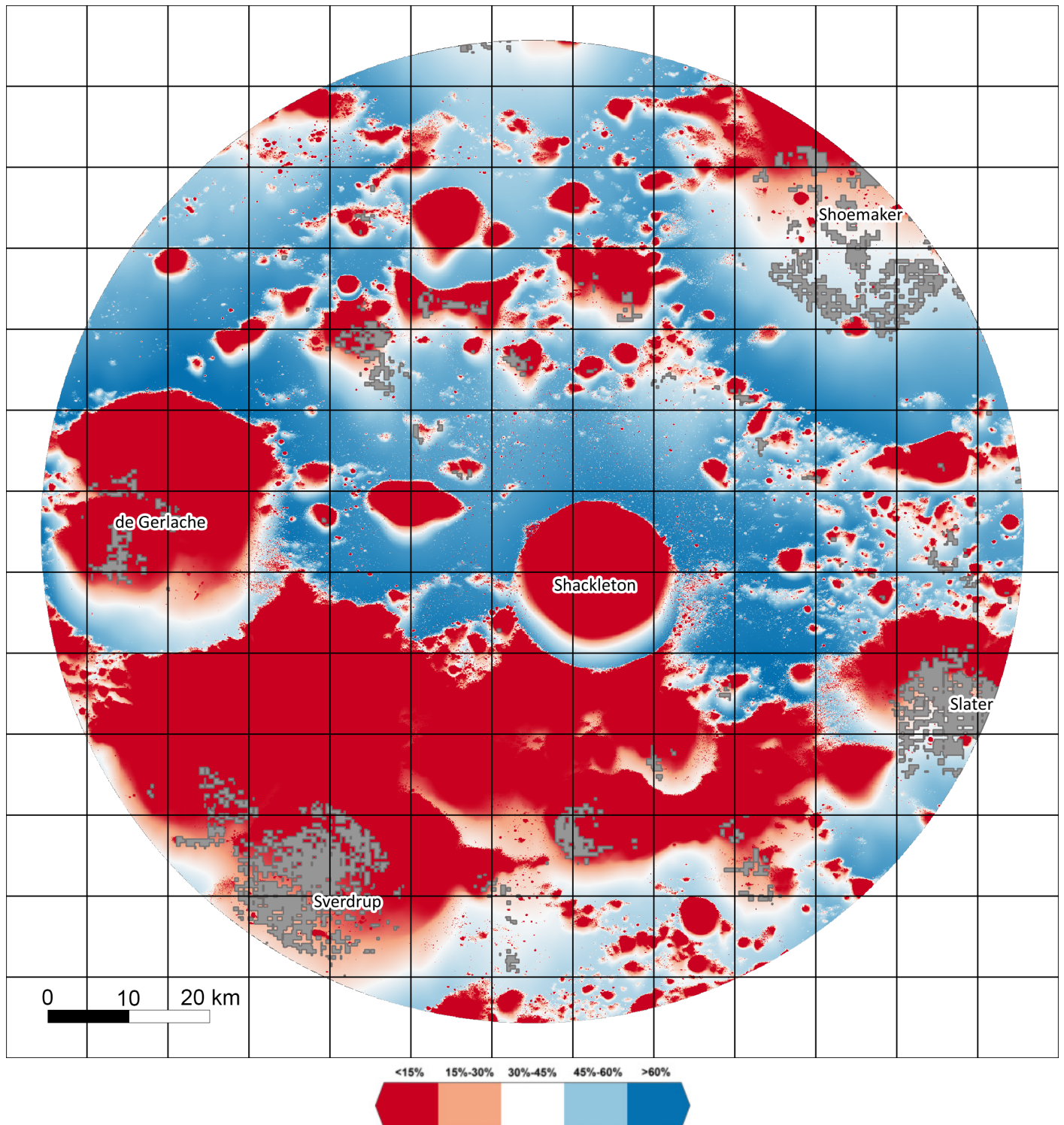
# LOLA SLOPE MAP



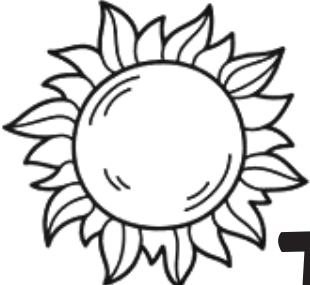
This slope map shows the steepness of terrain on the lunar surface. The rover can only traverse slopes less than 15°. Traversable slopes are indicated by shades of blue. Landing sites must be even flatter, with slopes <5° (indicated by **dark blue**). Areas with surface water ice are indicated by **dark gray**.



# LOLA POLAR EARTH VISIBILITY MAP



The average visibility of Earth as seen from the lunar south pole map was created from LOLA data. The Moon is tidally locked, so the same side, called the nearside, always faces the Earth. To communicate with Earth, rovers need direct line-of-sight communication with Earth. This map shows the average percent of the Earth that is visible with direct line-of-sight communication. Areas that are **blue** (>45%) have enough visibility to send data back to Earth. Areas with surface water ice are indicated by **gray**.



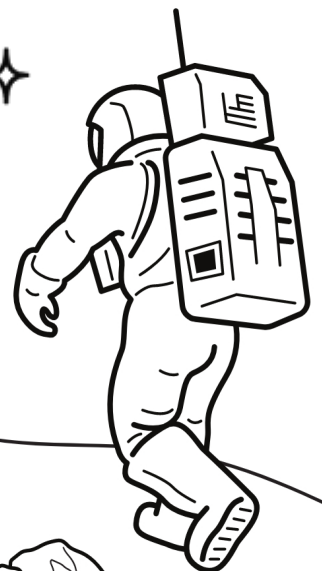
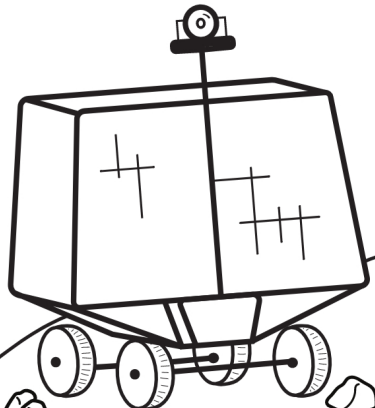
# **THE MYSTERY OF LUNAR WATER**

## **HELP SCIENTISTS UNCOVER WATER ICE ON THE MOON**



### **PART 2**

#### **STUDENT GUIDE**







# STUDENT GUIDE

## INTRODUCTION

Identifying locations of water ice on the Moon's surface is only part of the puzzle scientists and engineers are trying to solve. The harsh environments that contain water ice are not very safe for human exploration. Robots and humans have to find a way to survive missions with no sunlight, extremely cold temperatures, and hazardous travel kilometers deep in a steep, rocky crater. A safe and successful mission needs plenty of sunlight for power, relatively flat surfaces (<15 degrees slope), and to be able to see and communicate with Earth (good line-of-sight communication).

To safely find and use any water ice resources on the Moon, we need to plan a mission that first lands somewhere safe and sets up a lunar outpost, then travels with a rover to the water ice. Scientists and engineers at NASA, as well as other commercial spaceflight organizations, are currently using datasets like the ones in this activity to plan future missions to the lunar south pole! Help them to plan a mission by choosing a safe landing site, then planning a traverse that takes them to a surface water ice location identified in Part 1 of this activity.

## INSTRUCTIONS

Now that you have found at least one location where you think astronauts should go to find water ice, help scientists plan a mission to send a crewed rover to confirm the findings! Where will the rover land? Where will it go? Using the three maps provided (WAC Polar illumination, LOLA slope, and LOLA earth visibility), identify the safest landing site and traverse path for the rover to travel to find water ice. Use the LOLA DTM hillshade map to plan your mission!

To choose a safe landing site and plan a traverse path for your rover, the following engineering limitations must be considered:

### Rover Design:

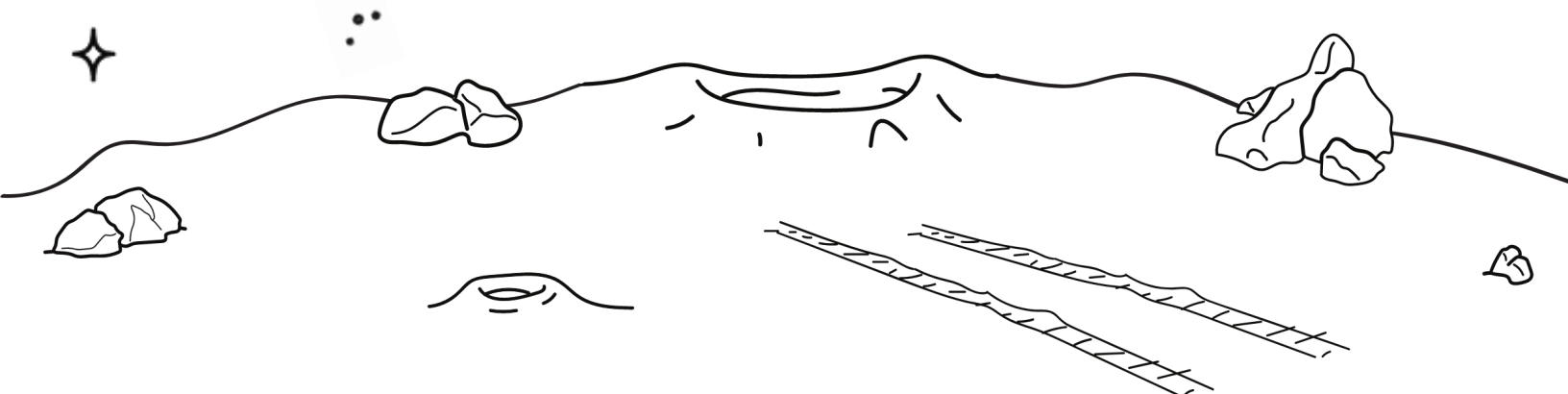
- The rover can travel 60 km on a full battery charge.
- The rover travels at up to 15 km/h
- The rover can operate for 78 hours before needing to recharge.
- The rover may survive longer and have extended missions, but has been designed to operate for a minimum of 1 lunar cycle (27.5 earth days).

### Landing site constraints:

- The landing area must have a slope <5°
- The landing area must have a view of the Earth for communication during the landing sequence.
- The landing area must have exposure to the Sun to maintain power during initial rover checks.

### Traverse constraints:

- The rover must have a view of the Earth to return data.
- The rover must be in sunlight to transmit high-speed science data.
- The rover can climb slopes up to 15°.



- Use the table below to help you design a safe and successful mission to search for water ice and other resources:

Landing site constraints	Traverse constraints	Associated LRO maps
The site must have exposure to Sun to maintain power during initial rover checks	Rover must be in sunlight to transmit high-speed science data and to receive battery recharge	LROC WAC Polar Illumination Map
Slope <5°; flat terrain is best	Rover can climb slopes up to 15°	LOLA Slope Map
Means of communicating with Earth	Rover must have a view of Earth to return data	LOLA Earth Visibility Map

**Table 1.** Engineering constraints for a safe landing site and successful rover traverses.

*If you would like more of a challenge, consider the following questions using table 1 and 2:*

- Using the rover's capabilities, how many water ice deposits can be visited by the rover during its limited time?*
- If the rover were on an extended mission, could it explore the most interesting areas, and be in a good position to continue exploring other targets if it survives longer than planned?*

*Power constraints, assuming that on the Moon the rover weighs 116 kg:*

- The battery capacity of the rover is 8700 watt hours.*
- A 1300 W load would last about 6 hours.*
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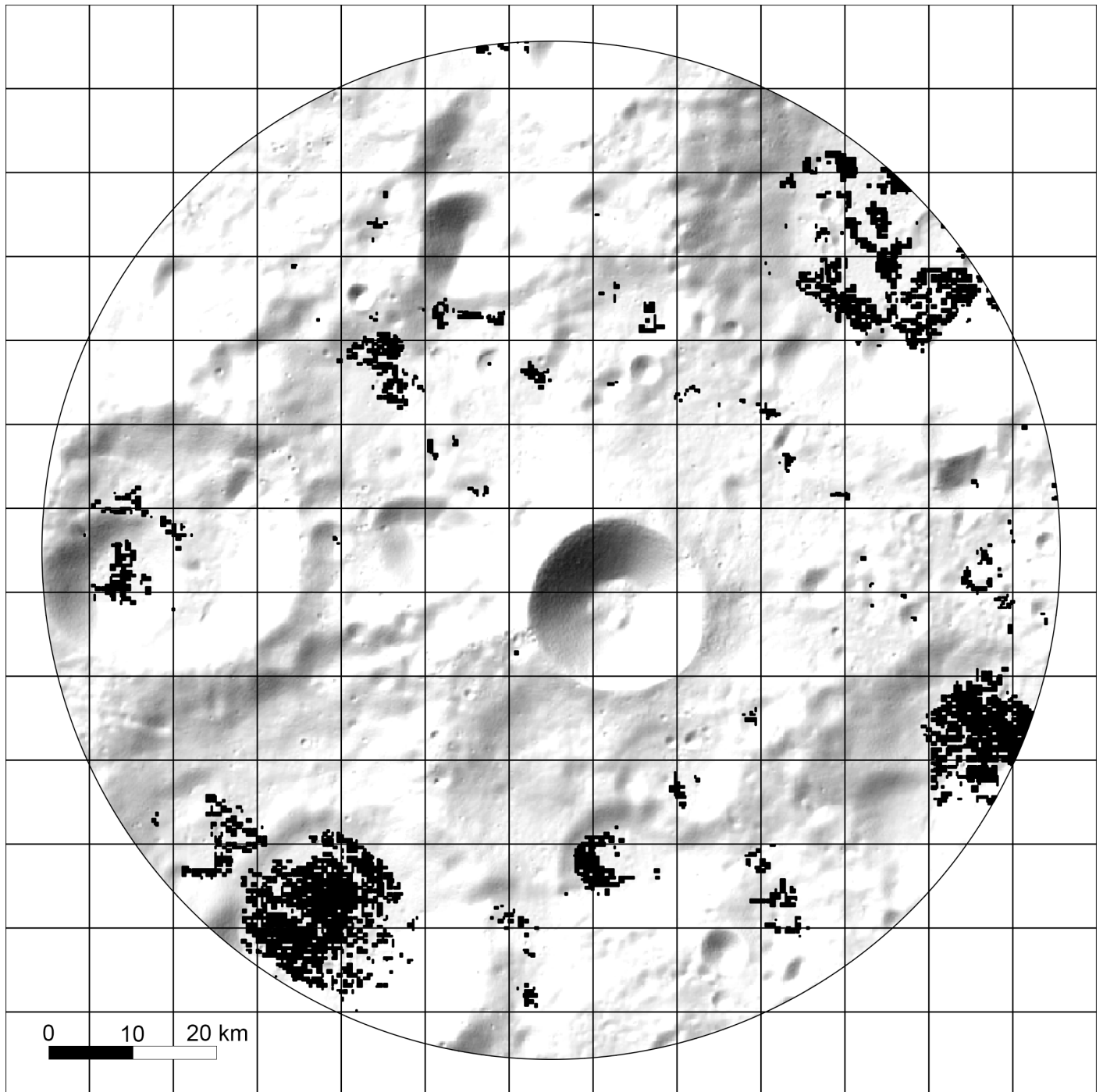
Slope (°)	Speed	Power Requirements (Watts)
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**Table 2.** Engineering constraints for how much power a rover has during its traverse based on slope of surface and speed travelled.

**Supplies:**

- Something to write with: pencil, pen, markers, colored pencils, etc.*
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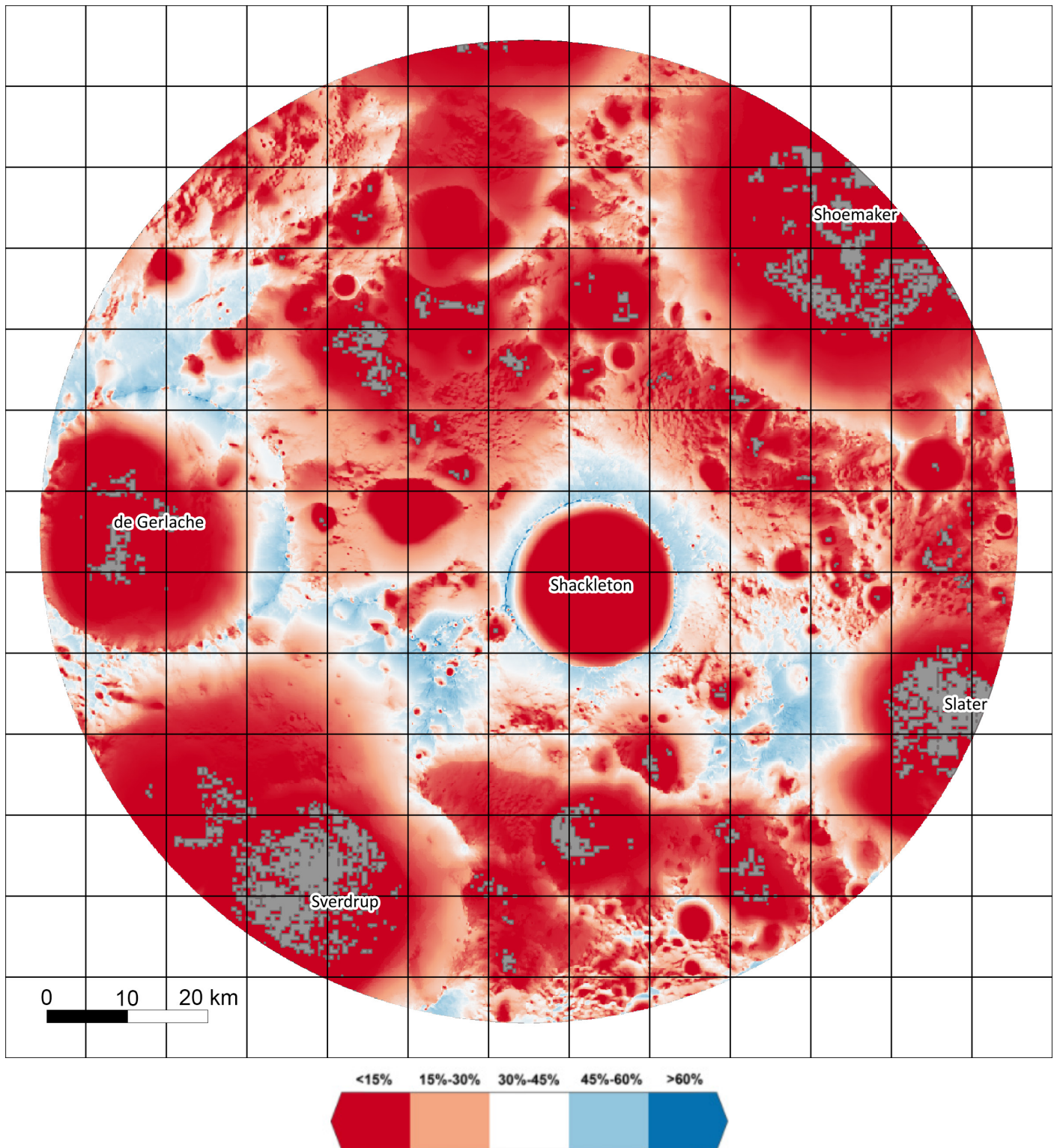
# PLANNING SHEET - HILLSHADE



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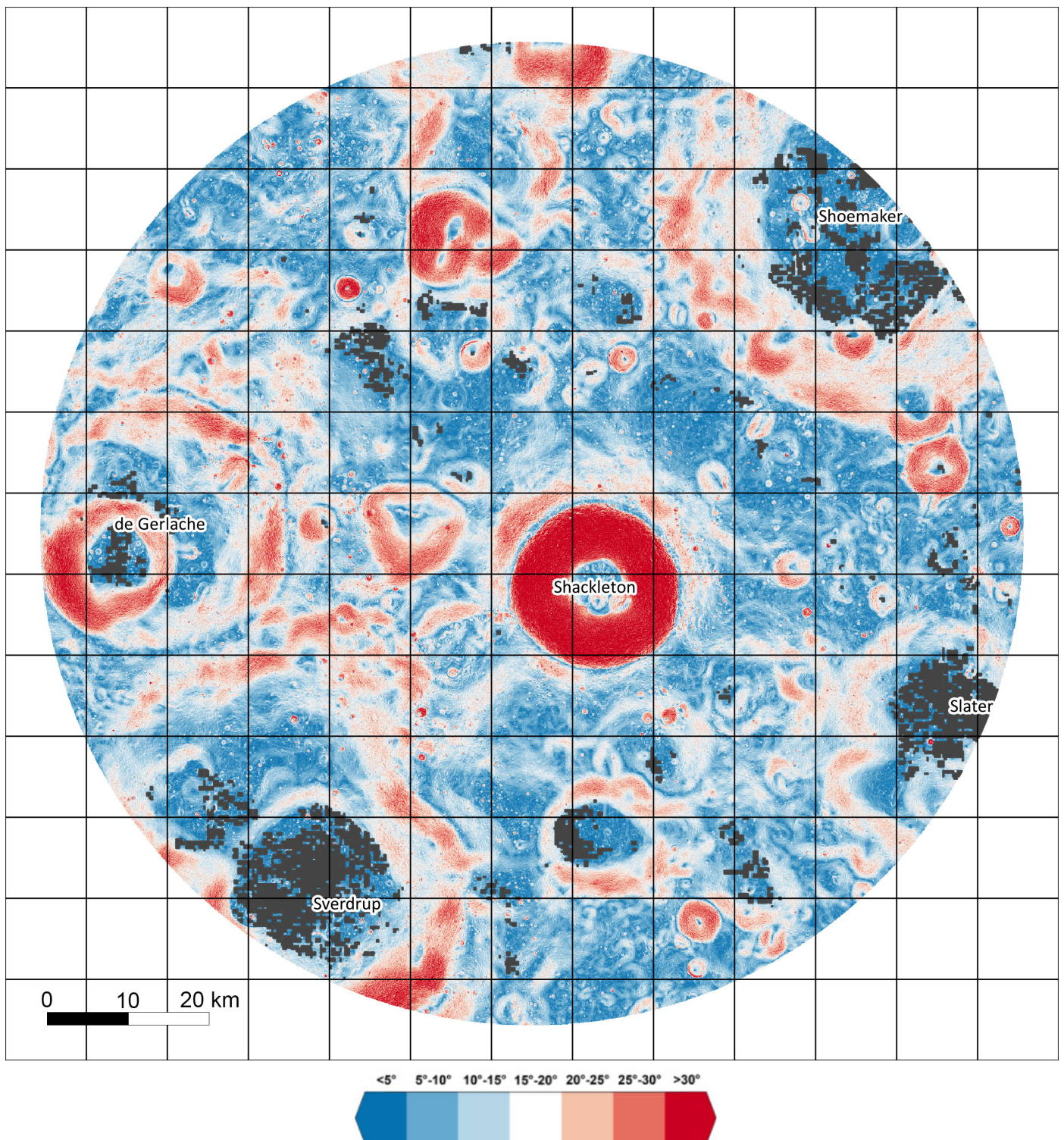
# LROC WAC POLAR ILLUMINATION MAP



This mosaic was created from images taken by the Lunar Reconnaissance Orbiter Camera (LROC) Wide Angle Camera (WAC) over an entire year. Map values represent the percentage of time that each pixel was illuminated during that year. Areas with surface water ice are indicated by **gray**. Any areas that are **blue** are illuminated more than 45% of the time, with areas that are **dark blue** having the most sunlight.



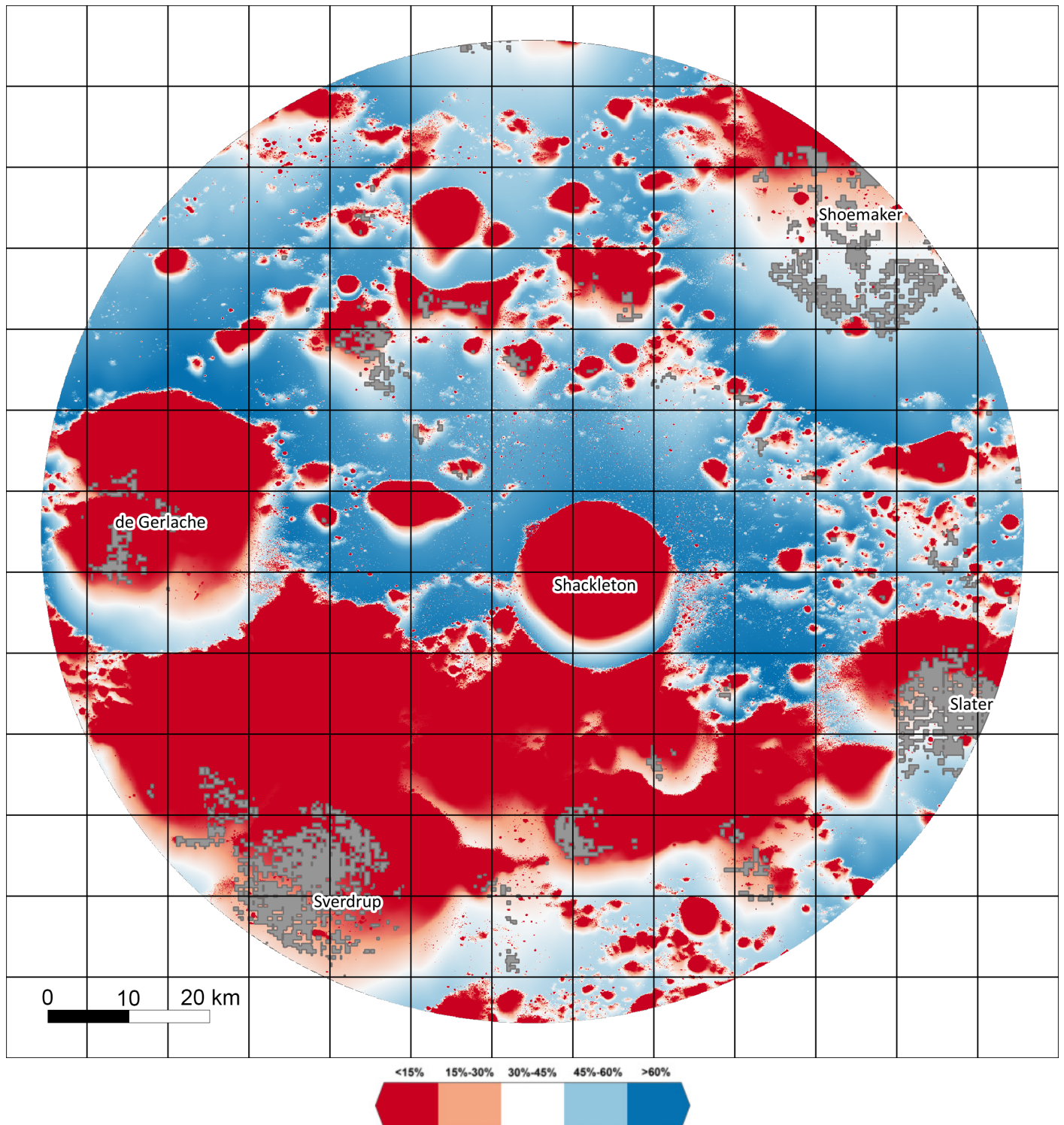
# LOLA SLOPE MAP



This slope map shows the steepness of terrain on the lunar surface. The rover can only traverse slopes less than 15°. Traversable slopes are indicated by shades of blue. Landing sites must be even flatter, with slopes <5° (indicated by **dark blue**). Areas with surface water ice are indicated by **dark gray**.



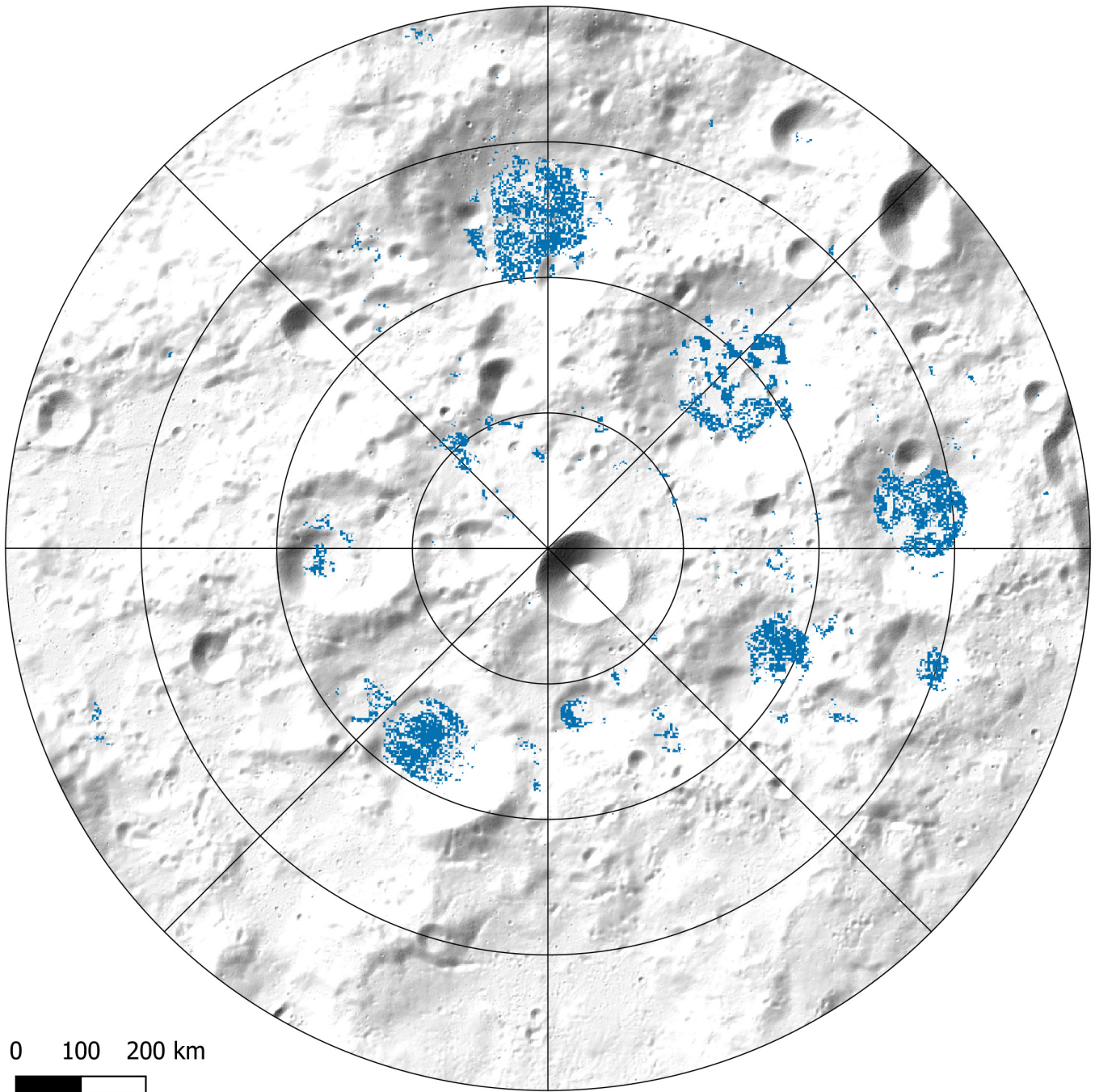
# LOLA POLAR EARTH VISIBILITY MAP



The average visibility of Earth as seen from the lunar south pole map was created from LOLA data. The Moon is tidally locked, so the same side, called the nearside, always faces the Earth. To communicate with Earth, rovers need direct line-of-sight communication with Earth. This map shows the average percent of the Earth that is visible with direct line-of-sight communication. Areas that are **blue** (>45%) have enough visibility to send data back to Earth. Areas with surface water ice are indicated by **gray**.

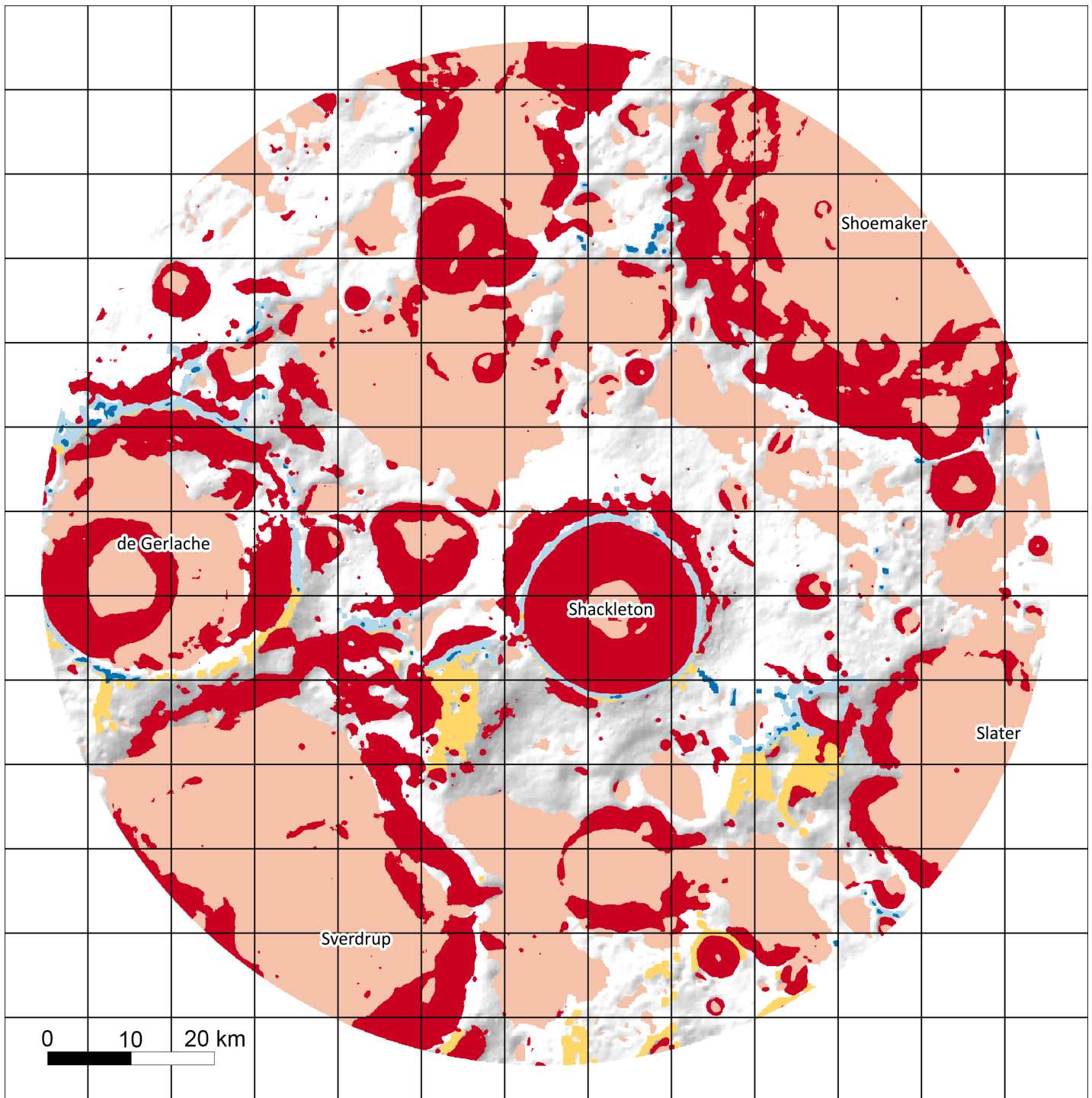


# ANSWER SHEET FOR PART 1



Surface Frost is overlaid in blue.

## ANSWER SHEET FOR PART 2



Ideal exploration conditions for sustained surface activities involve relatively flat traverse surfaces ( $<15^\circ$ ), plenty of sunlight for power ( $>45\%$ ), and good line-of-sight communication with Earth ( $>45\%$ ), all within a reasonable distance from water ice deposits. Impassable terrain ( $>15^\circ$  slope) is indicated by **red**,  $>45\%$  sunlight is indicated by **yellow**, ideal landing sites ( $<5^\circ$  slope,  $>50\%$  communication and sunlight) are shown in **dark blue**, and communication and recharge zones ( $>45\%$  sunlight and communication) are indicated by **light blue**. Surface water ice analysis is overlaid in **black**.

## GLOSSARY

**Albedo** - Albedo is a measure of how much a material reflects light. A surface that appears brighter has a higher albedo than one that appears darker.

**Commercial spaceflight organizations** - Nongovernmental companies that provide space goods, services, or activities. Some American commercial spaceflight organizations that work with NASA include Boeing and SpaceX.

**Drive system** - A system that controls speed, rotation, and direction of a motor in a machine.

**Earth line-of-sight communication** - Communications between Earth and rover are made possible because Earth is in constant view. Only the nearside of the Moon is in constant line-of-site.

**Electromagnetic spectrum** - Made up of waves (wavelengths) that travel through space at the speed of light. Waves differ in frequency (long vs. short waves).

**Elements** - Chemical elements that are matter in the universe. Elements are atoms with a specific number of protons.

**Engineering** - Designing and building new products, machines, or systems using chemistry, physics, and math to solve problems. Different kinds of engineering are often used together when designing something. Building a rover for example uses a combination of electrical engineering (designing how the machine is powered), mechanical engineering (the design, construction, and use of the machine), and materials engineering (designing and building new materials).

**Farside** - The face of the Moon that faces away from Earth. Sometimes inaccurately called the “dark side”. During a new moon on Earth, the farside is illuminated by the Sun; when we see a full moon, the farside is dark.

**Hillshade** - Hillshading is a process of adding light and dark shading to a topographical map to represent sunlight and shadow, allowing us to see surface features such as mountains and craters.

**Kelvin** - K, the abbreviation for Kelvin, is the base unit of temperature in the International System of Units. Compared to Celsius and Fahrenheit, which are most useful for taking everyday temperatures (water freezes at 0°C, 32°F), Kelvin is useful for measuring much colder material (water freezes at 273.15 K).

**Map Legend** - A key or visual explanation for how to read colors and symbols on a map.

**Nearside** - The face of the Moon that we see from Earth is called the nearside.

**Pixel scale** - A pixel (short for picture element) is one of many small squares that make up a picture. The number of small squares in a picture controls the resolution of a picture. In a satellite image, the amount of ground covered by one pixel is referred to as the pixel scale.

**Power** - In physics and science, power refers to the rate, or how fast, energy is used. Power comes from “work”, or the transfer of heat or energy to an object.

**Reflectance** - Measure of how light or dark a surface appears. See “Albedo”.

**Surface frost** - On Earth, frost is a thin layer of ice crystals formed when water vapor (a gas) comes into contact with a surface, thus changing the water vapor into ice (a solid). On the Moon, surface frost is not only water; other chemicals such as sulfur, ammonia (NH<sub>3</sub>) and methane (CH<sub>4</sub>) are thought to exist as well.

**Suspension system** - How the wheels are connected to a rover; provides control of how the rover interacts with the terrain.

**Tidal Locking** - The Moon completes a full rotation about its axis in about the same time it takes to orbit the Earth, resulting in the same side of the Moon always facing towards Earth.

**Traverse** - Planned path that rover will travel during a mission.

**Vacuum** - The vacuum of space is empty (contains almost no matter) and cold; a vacuum is a space where pressure is so low that any particles in the space do not affect processes that occur.

**Water ice** - Frozen materials such as water can be trapped in the permanently shadowed regions on the Moon because of their cold temperatures. There is no liquid water on the Moon.

**Watts** - Unit used to measure power, or the rate at which energy is used.