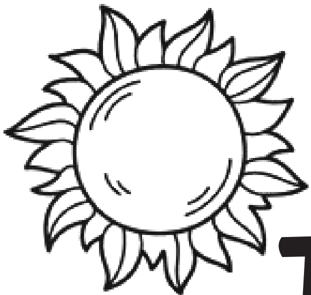


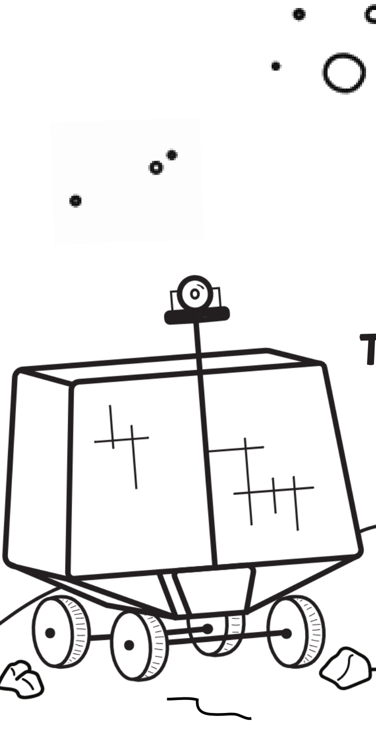
THE MYSTERY OF LUNAR WATER

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).

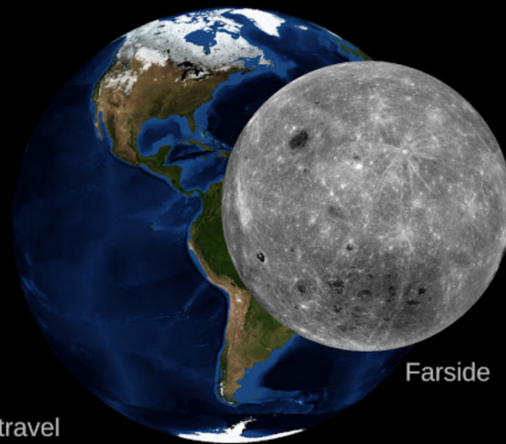
Abundant Sunlight for Power

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.

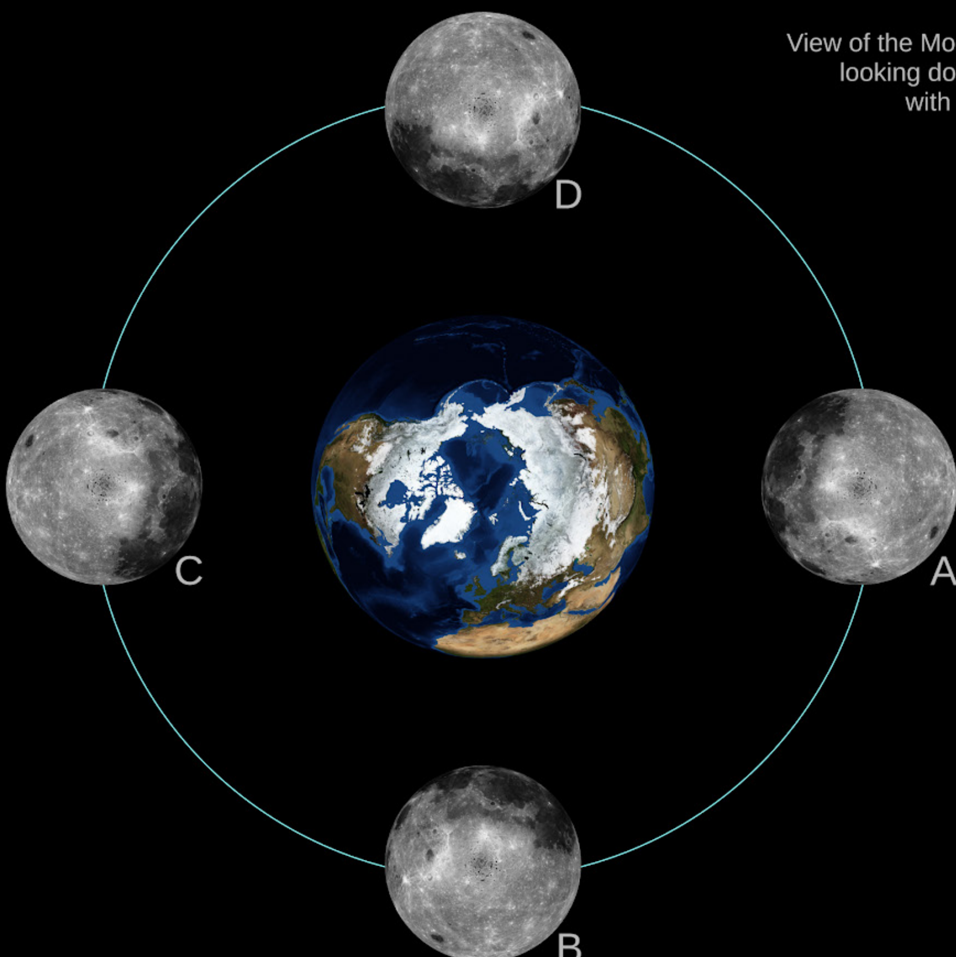
Nearside

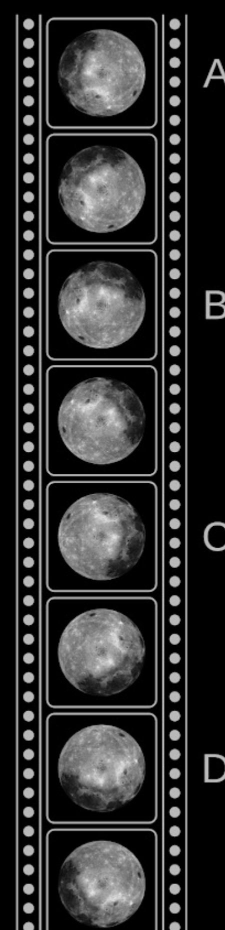


Farside

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° 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 <u>suspension</u> and <u>drive systems</u>. The <u>suspension system</u> 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 (Watts)
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 onboard 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.

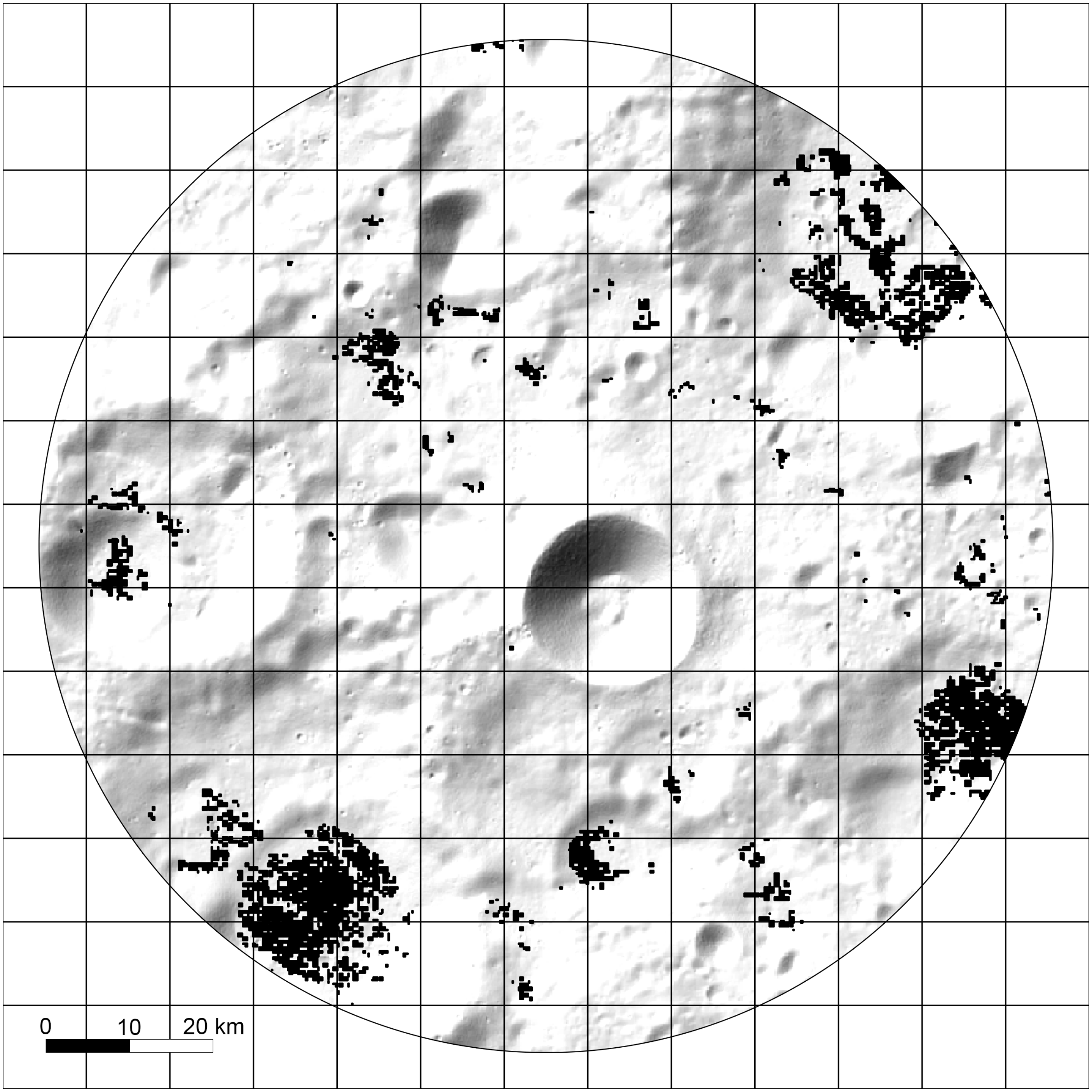
LOLA Slope Map

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

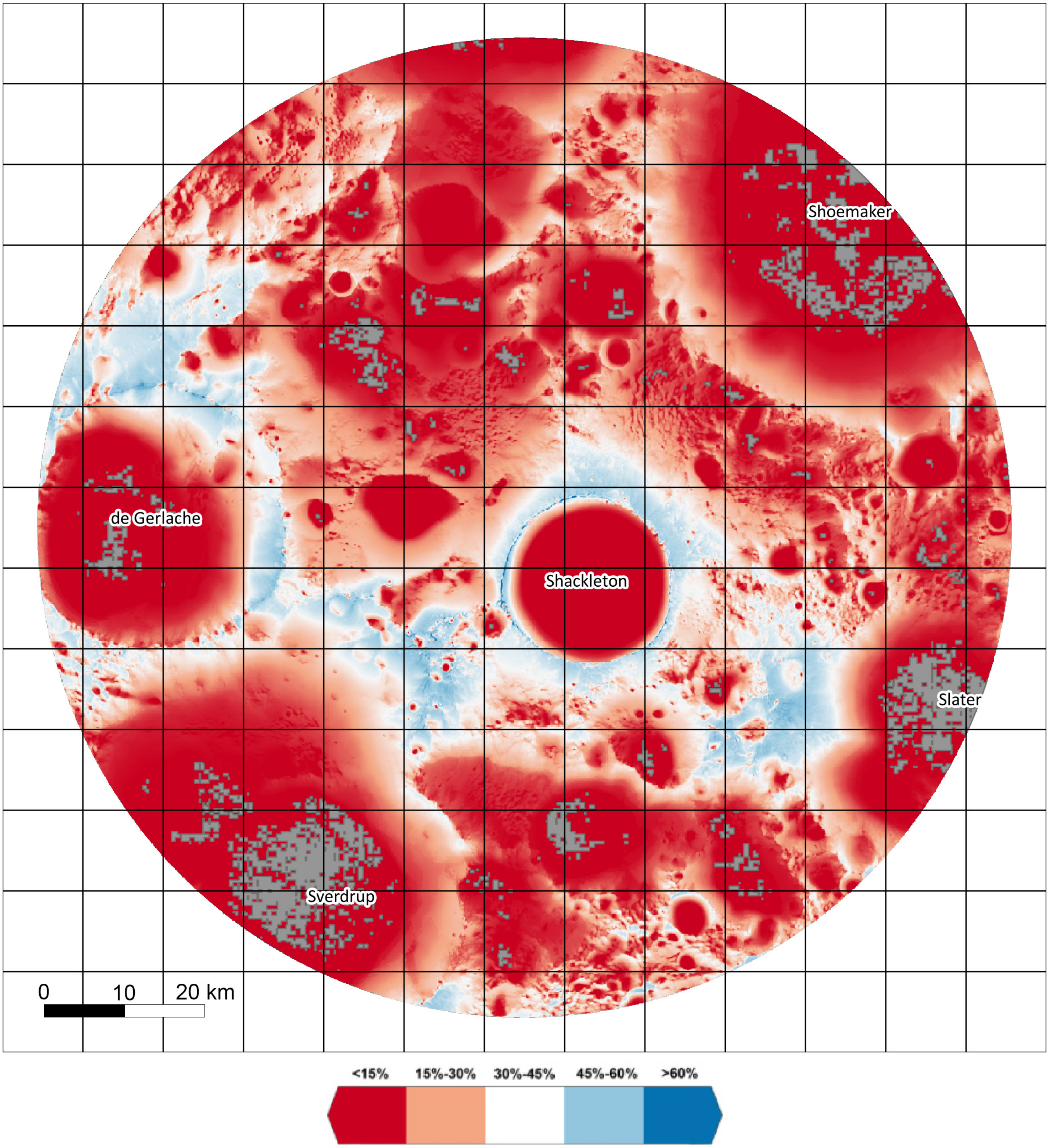
The average visibility of Earth as seen from the lunar south pole. The Moon is <u>tidally locked,</u> so the same side, called the nearside, always faces the Earth. To communicate with Earth, rovers need direct <u>line-of-sight communication</u> with Earth. This map shows the average percent of the Earth 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



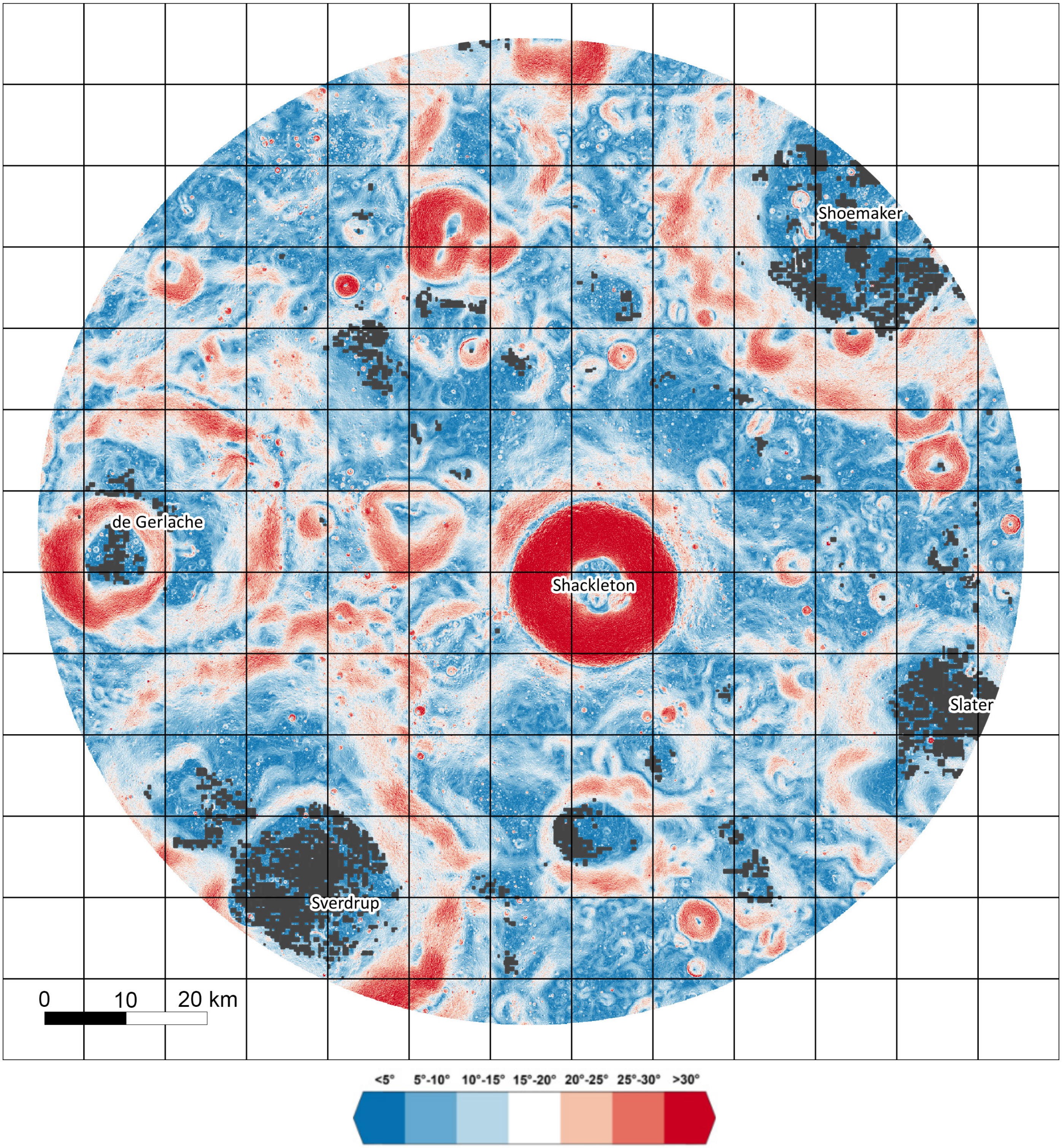
This is the map to print for planning the crewed rover mission. It is a hillshade created from a 150 m pixel scale Lunar Orbiter Laser Altimeter (LOLA) digital terrain model (DTM) with the results from the surface water ice analysis overlaid in **black**.

LROC WAC POLAR ILLUMINATION MAP



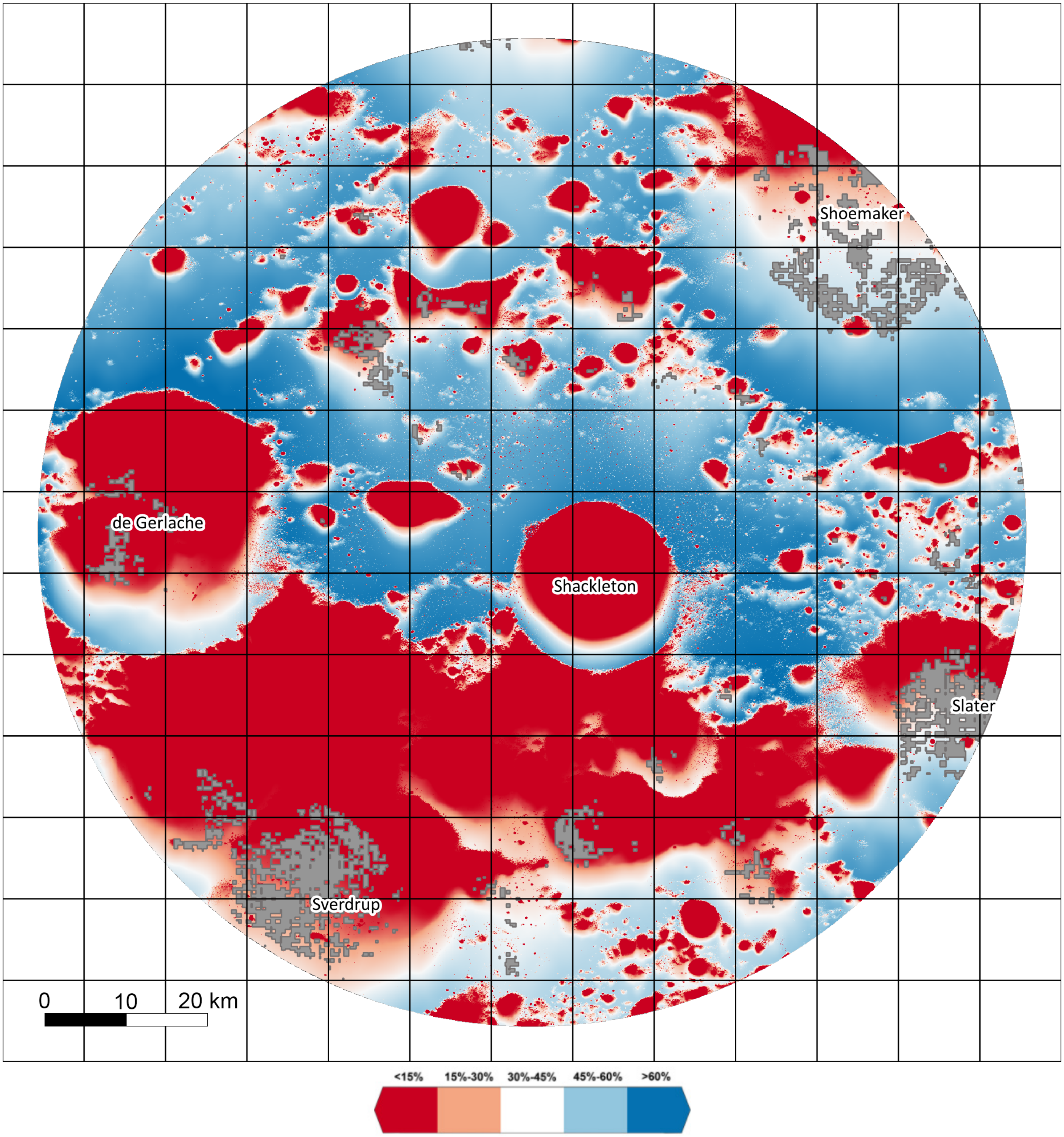
This mosaic was created from images taken by the Lunar Reconnaissance Orbiter Camera (LROC) Wide Angle Camera (WAC) over an entire year. Map values represent the percentage of time that each pixel was illuminated during that year. Areas with surface water ice are indicated by **gray**. Any areas that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

LOLA SLOPE MAP



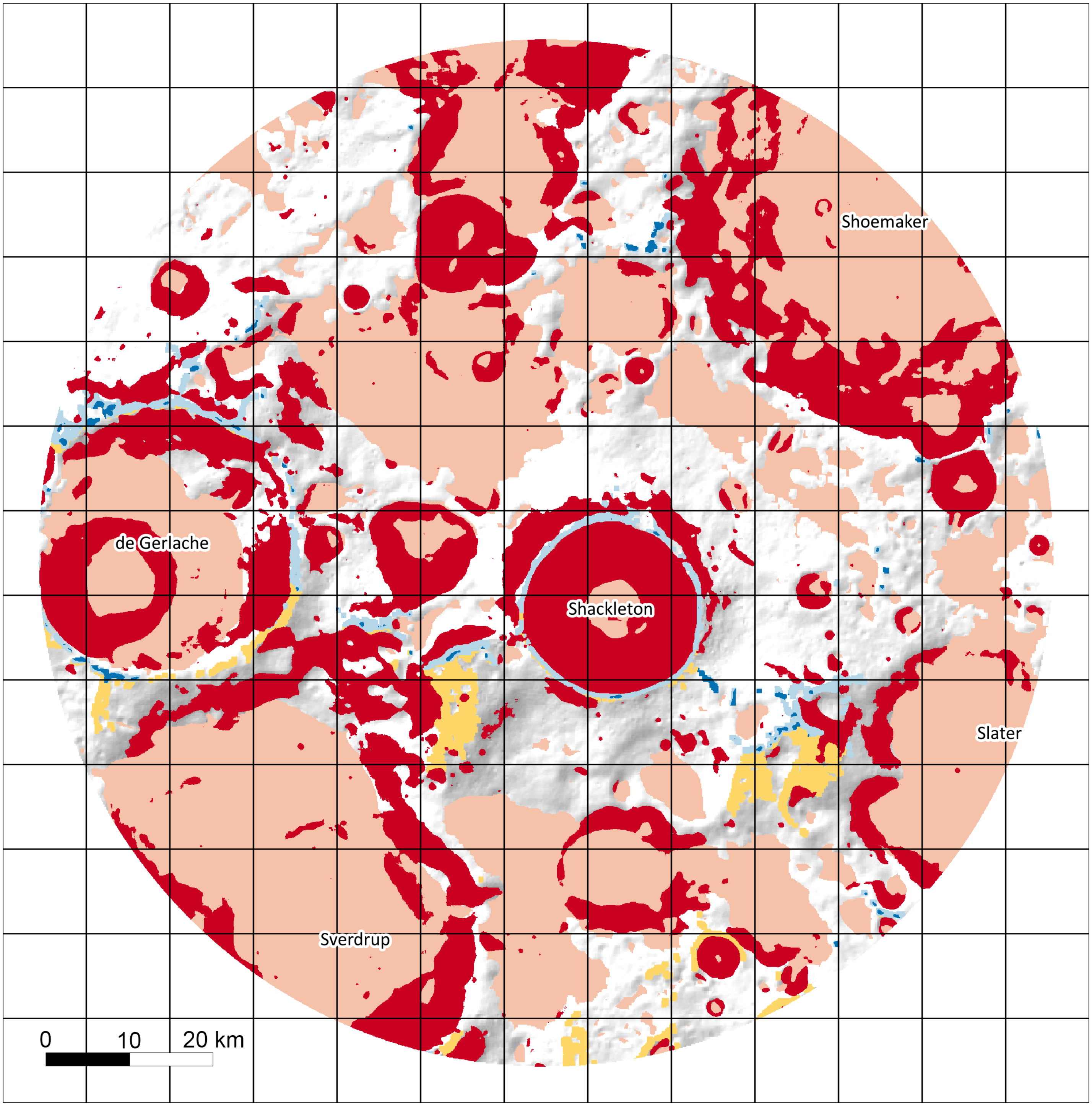
This slope map shows the steepness of terrain on the lunar surface. The rover can only traverse slopes less than 15°. Traversable slopes are indicated by shades of blue. Landing sites must be even flatter, with slopes <5° (indicated by **dark blue**). Areas with surface water ice are indicated by **dark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

ANSWER SHEET FOR PART 2



Ideal exploration conditions for sustained surface activities involve relatively flat traverse surfaces (<15°), 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° slope) is indicated by **red**, >45% sunlight is indicated by **yellow**, ideal landing sites (<5° 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 Celcius 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 (NH3)and methane (CH4) 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.