



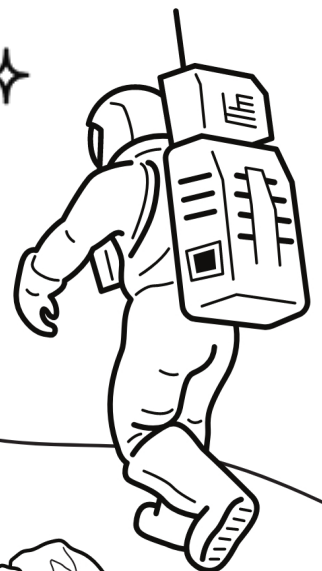
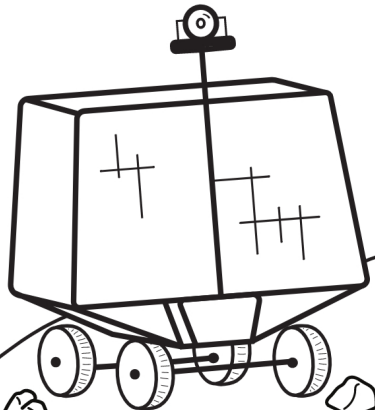
THE MYSTERY OF LUNAR WATER

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:

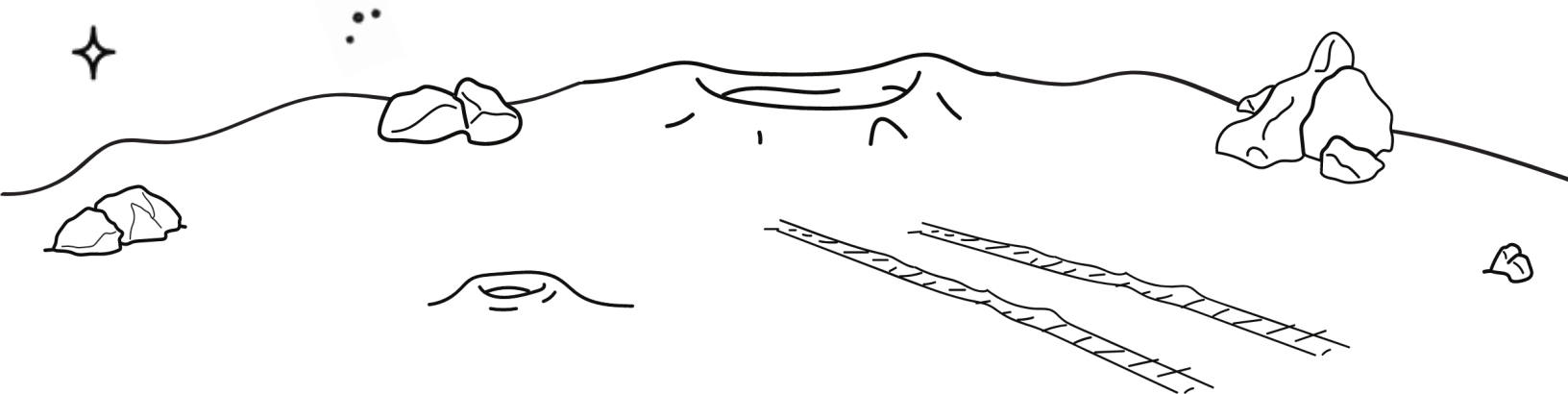
- The rover can travel 60 km on a full battery charge.
- The rover travels at up to 15 km/h
- The rover can operate for 78 hours before needing to recharge.
- The rover may survive longer and have extended missions, but has been designed to operate for a minimum of 1 lunar cycle (27.5 earth days).

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.*
- 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.*

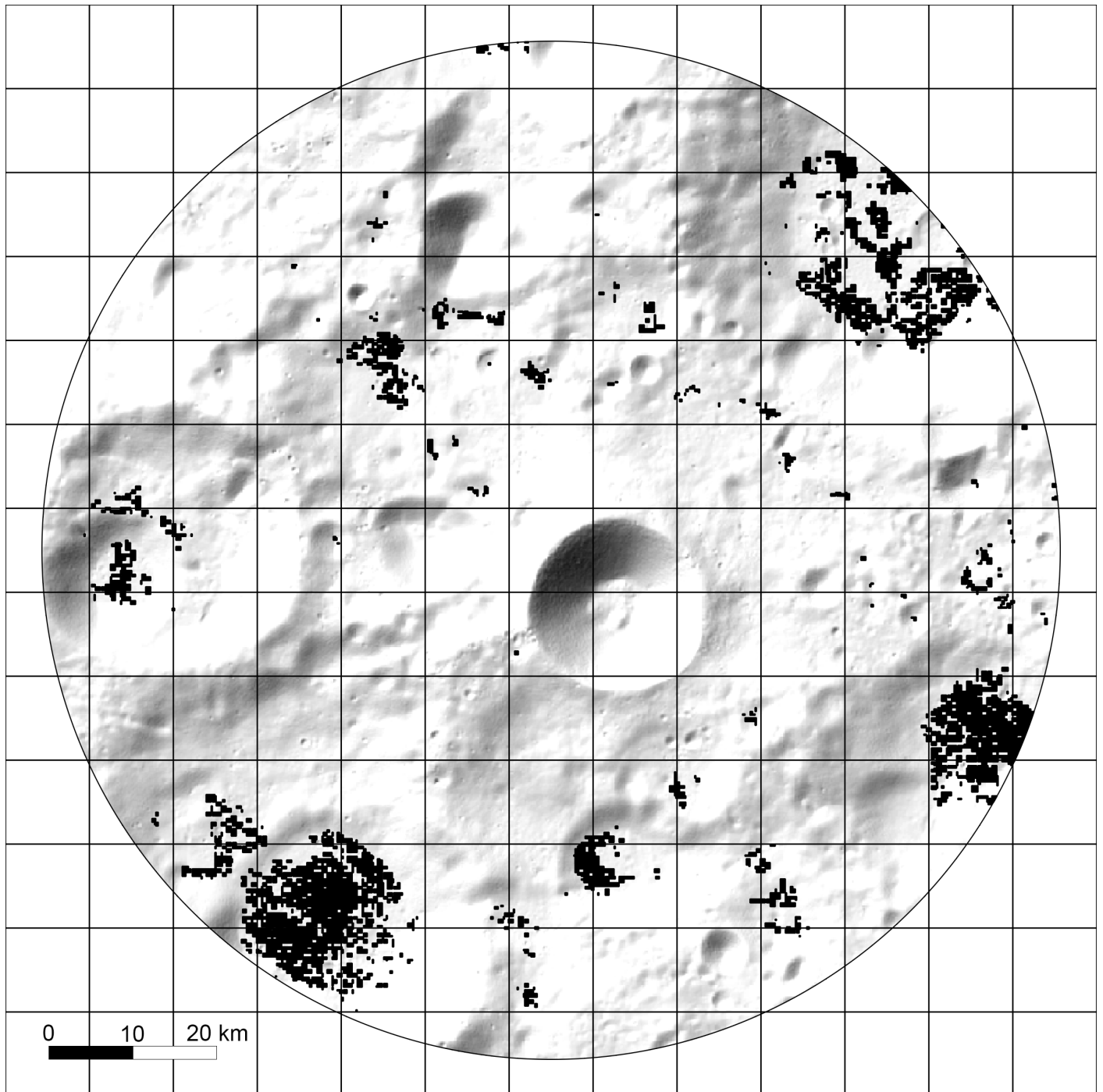
Slope (°)	Speed	Power Requirements (Watts)
Relatively flat (+/- 2°)	15 km/hr	646 W
5°	15 km/hr	893 W
10°	15 km/hr	1303 W
15°	15 km/hr	1693 W

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

Supplies:

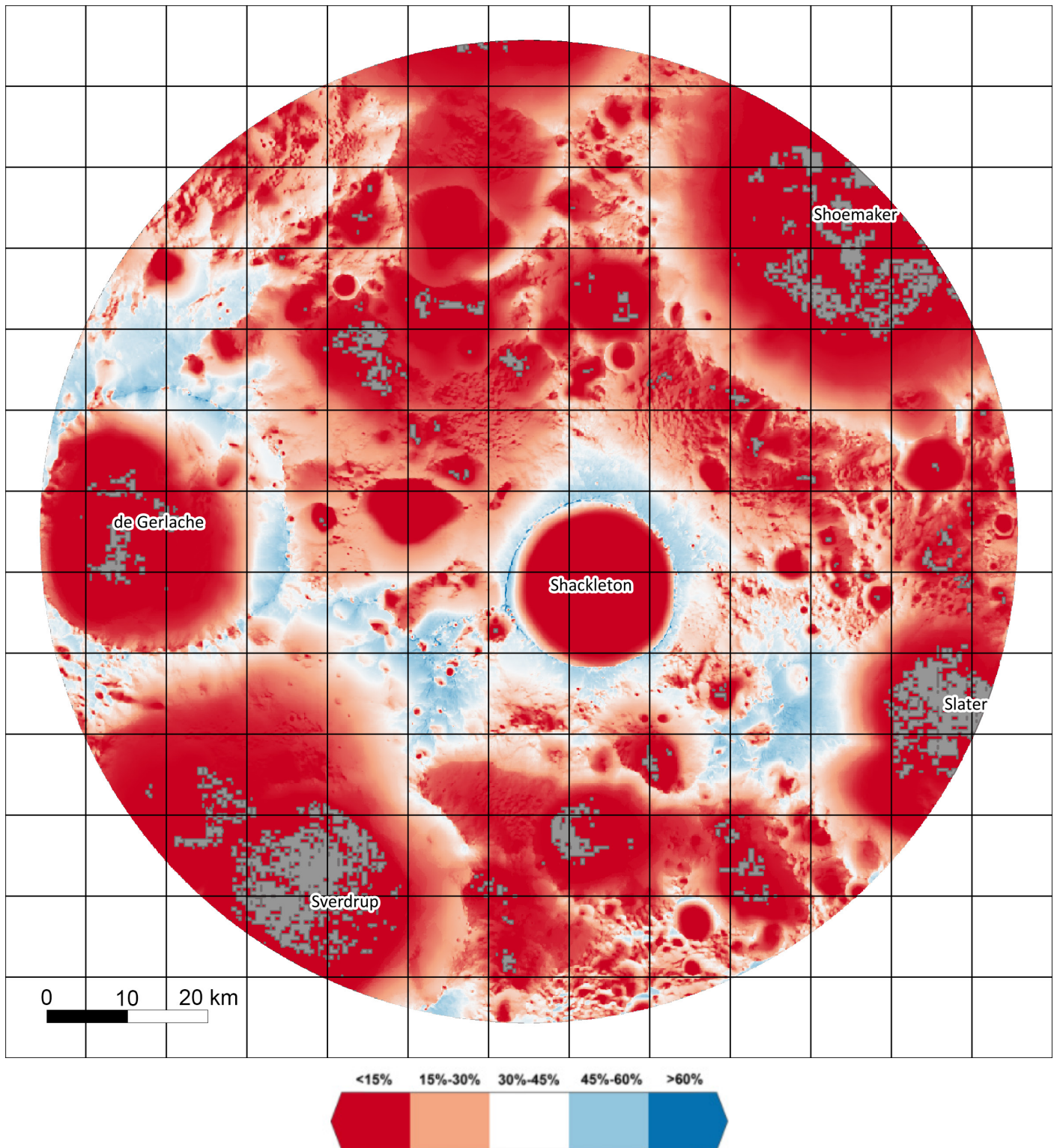
- Something to write with: pencil, pen, markers, colored pencils, etc.*
- Printouts of the Planning Sheet (Hillshade) to write on for each student.*
- Digital or Printouts of the maps.*
- (Optional) Ruler to help more accurately measure distances. There are many free, printable rulers online and they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

PLANNING SHEET - HILLSHADE



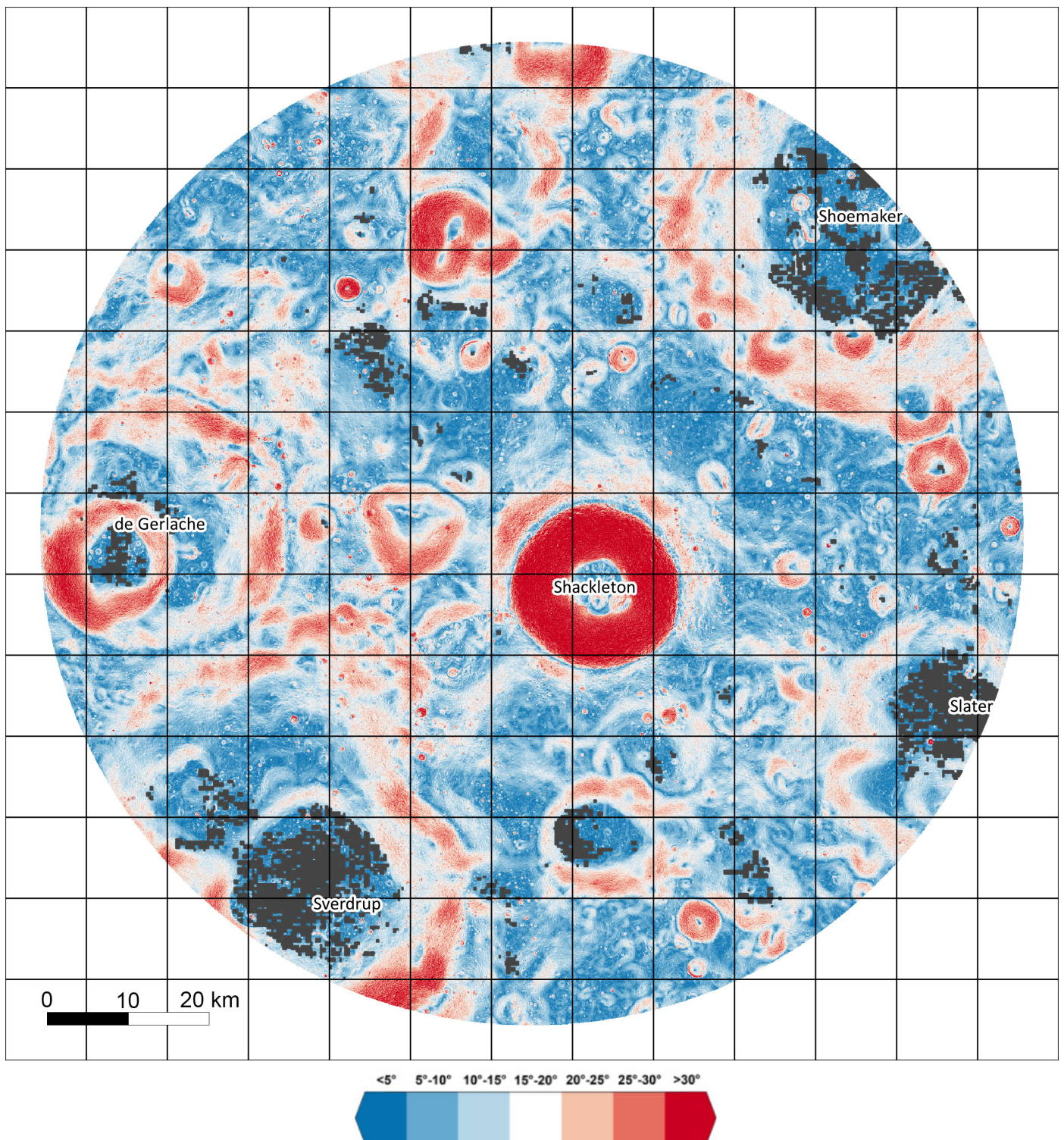
This is the map to print for planning the crewed rover mission. It is a hillshade created from a 150 m pixel scale Lunar Orbiter Laser Altimeter (LOLA) digital terrain model (DTM) with the results from the surface water ice analysis overlaid in **black**.

LROC WAC POLAR ILLUMINATION MAP



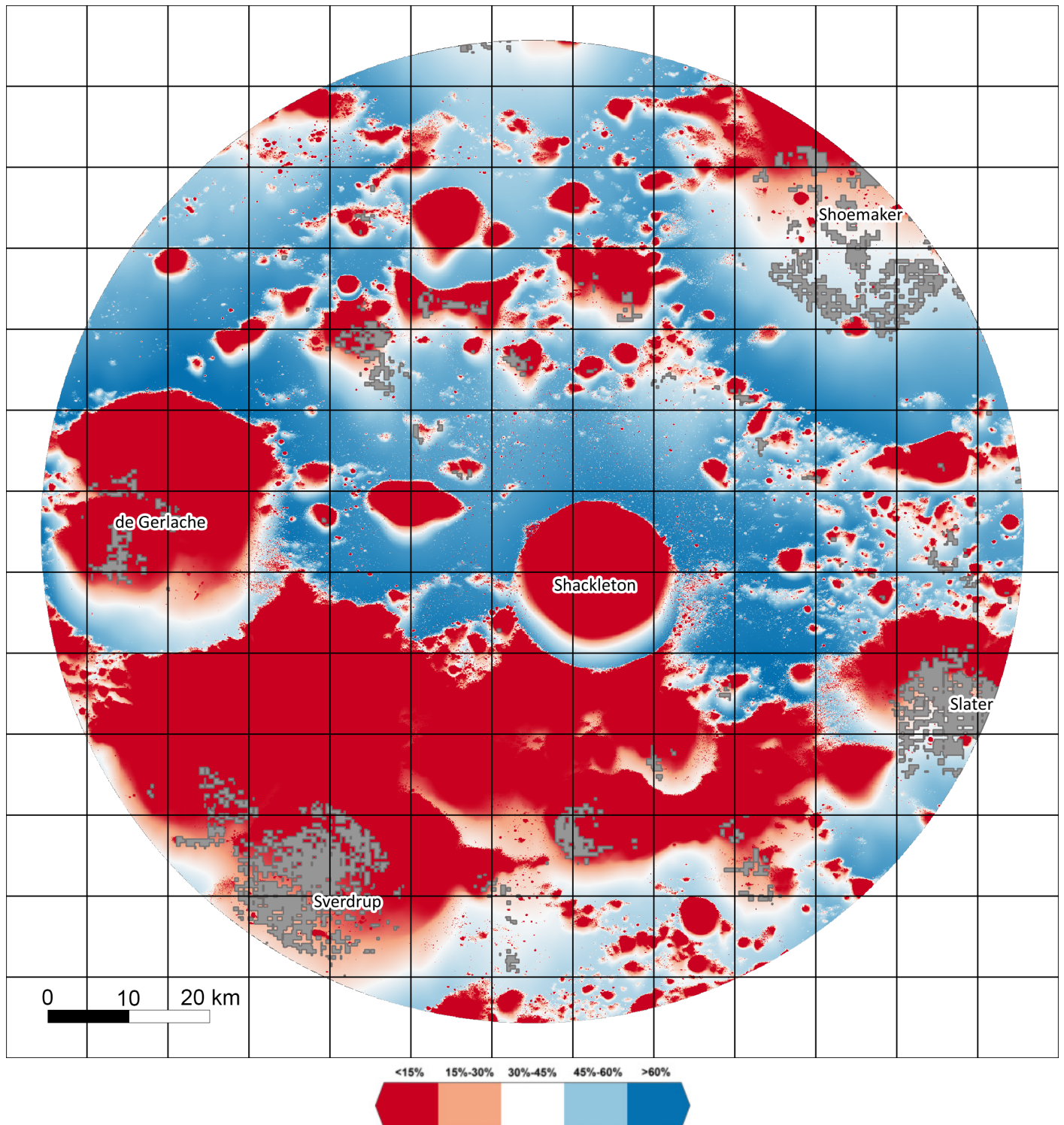
This mosaic was created from images taken by the Lunar Reconnaissance Orbiter Camera (LROC) Wide Angle Camera (WAC) over an entire year. Map values represent the percentage of time that each pixel was illuminated during that year. Areas with surface water ice are indicated by **gray**. Any areas that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

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 (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.