THE MYSTERY OF LUNAR WATER

HELP SCIENTISTS UNCOVER WATER ICE ON THE MOON

PART 1

INSTRUCTOR GUIDE
AGES 9 AND UP.

INSTRUCTOR GUIDE

INTRODUCTION

We want to send astronauts back to the Moon to areas near the south pole that have water in the form of ice. But first, we need to discover where water, or water ice, is the most plentiful. To do this, we need to compare information from many of the instruments on the Lunar Reconnaissance Orbiter (LRO) to find out which areas show water ice in all the datasets. Scientists are doing analyses very similar to this 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 that are buried beneath the surface.

BACKGROUND INFORMATION

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

There are regions near the Moon's poles that never receive sunlight because the poles are not tilted directly towards the Sun. On Earth, we experience seasons (where each pole experiences six months of daylight during its summer and six months of darkness during its winter) because of Earth's tilt (23.5°) on its axis of rotation.

Because the Moon is only tilted 1.5°, there is little seasonal change and some craters at the poles remain in permanent shadow (Figure 1). Permanent darkness means that such regions can maintain very cold temperatures (down to -415°F or -248°C!). As such, frozen materials such as water can be captured for billions of years. At these cold temperatures, there can be ice made from many other frozen substances, which is why we refer to frozen water as water ice in this guide.

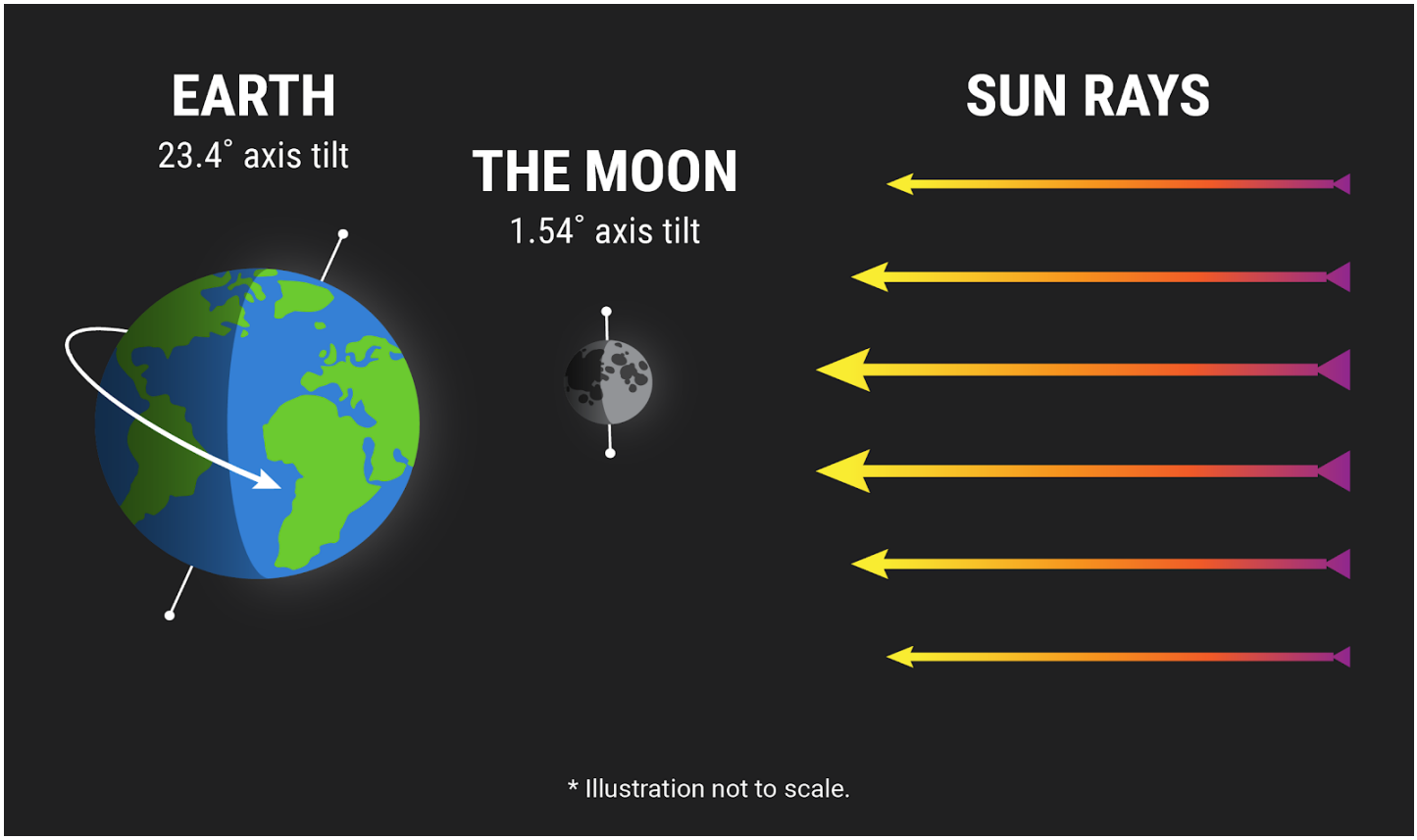


Figure 1: Image showing how the Sun's rays illuminate the Earth and the Moon. The small tilt of the Moon means there are some areas near the poles that never receive direct sunlight.

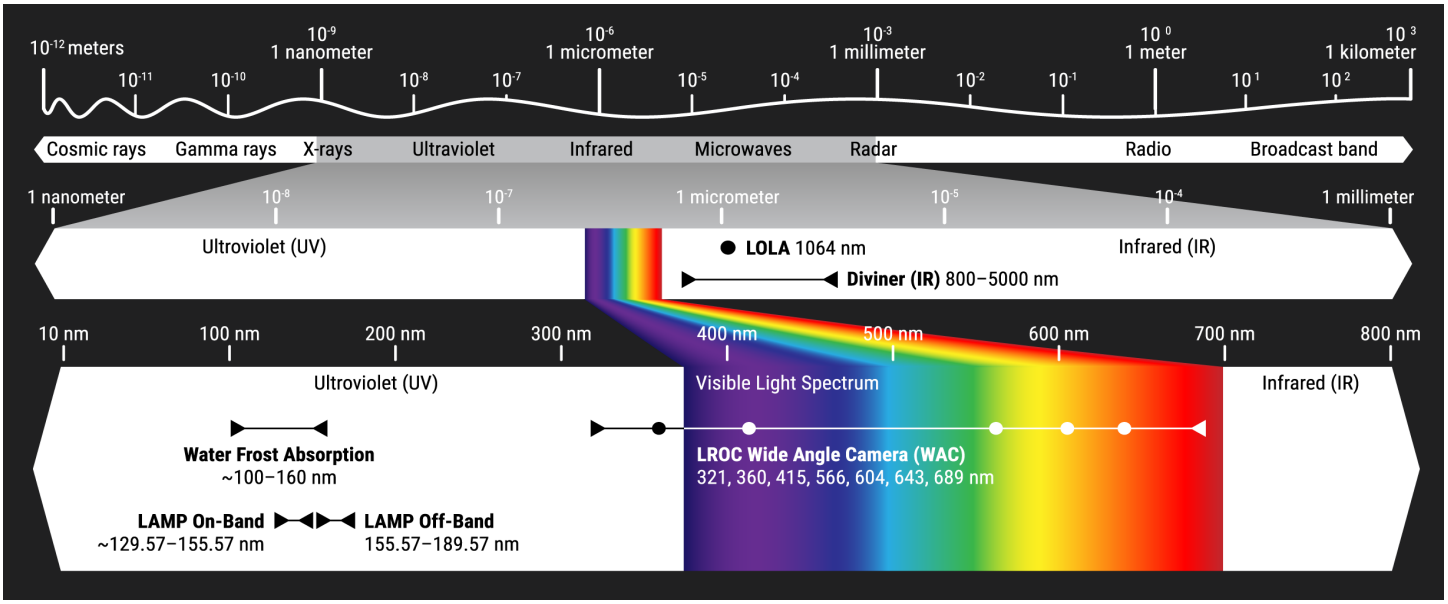


Figure 2: Electromagnetic (EM) spectrum showing the various wavelengths of light detected by instruments on-board the Lunar Reconnaissance Orbiter. Each instrument can only measure a specific wavelength range, and each provides a different type of information: Diviner measures surface temperature using 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 the Moon is gravitationally bound to Earth, a human-made spacecraft, the Lunar Reconnaissance Orbiter, is in orbit around the Moon. Onboard the spacecraft are multiple instruments that act as camera lenses that can "see" in various waves that make up the electromagnetic spectrum (Figure 2). Observations from these instruments tell us that frozen elements, such as hydrogen and oxygen in the form of water, likely exist in some of the Moon's permanently shadowed craters. Even with the variety of data available, determining how much water ice is present, what other frozen resources exist, and the exact locations and depths of the frozen materials remain uncertain.

Water is important for future space exploration because water (H_2O) can be broken apart into hydrogen and oxygen, which can be used as 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?

However, to choose a landing site for future missions additional observations are needed to interpret where the water ice actually is, particularly in the subsurface, and how much of it can be used 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).

Improved imaging of what the surface looks like inside permanently shadowed craters will enable scientists to map obstacles such as boulders and craters, reducing travel risk for future landers and rovers. ShadowCam images of the surface will also be compared with instruments that probe the subsurface, helping scientists to interpret the locations of water ice 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 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 surface. Compare each of the provided maps to find 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 results that are consistent with water ice are indicated by the Dark Blue color in each map. The PSRs are 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, students can identify multiple locations where scientists suspect water ice may be. Colored pencils can be used to shade in the area(s) most likely to have water ice on the Coloring Page.

There is an answer sheet 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 image for the coloring sheet. It is a hillshade created from a 150 m 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 some spot on the surface and recording how long it takes for the reflected light to return. By combining all the measurements of reflected light, we can make maps of the Moon's topography, such as a Hillshade.

LROC WAC Summer Mosaic with PSRs

This is a mosaic 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 areas which are permanently shadowed. Because these areas never receive direct sunlight, it is possible that there might be water in the form of ice there.

Diviner Annual Maximum Temperature

This map shows the maximum temperature in degrees Kelvin (K) over the entire year as measured by the Diviner Lunar Radiometer Experiment (Diviner, for short) at a pixel scale of 250 m. Water ice evaporates into gas at warm temperatures, so ice can only exist in regions that stay very, very cold. In the vacuum on the Earth's surface, it takes temperatures < 110 K (< -262°F; dark blue on the map) to trap water ice and keep it from evaporating. 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

This map is 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 ice in the form of surface frost, so this map can help us tell where surface frost might be located. Values of >0.37 (dark blue) are bright enough to indicate surface frost.

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

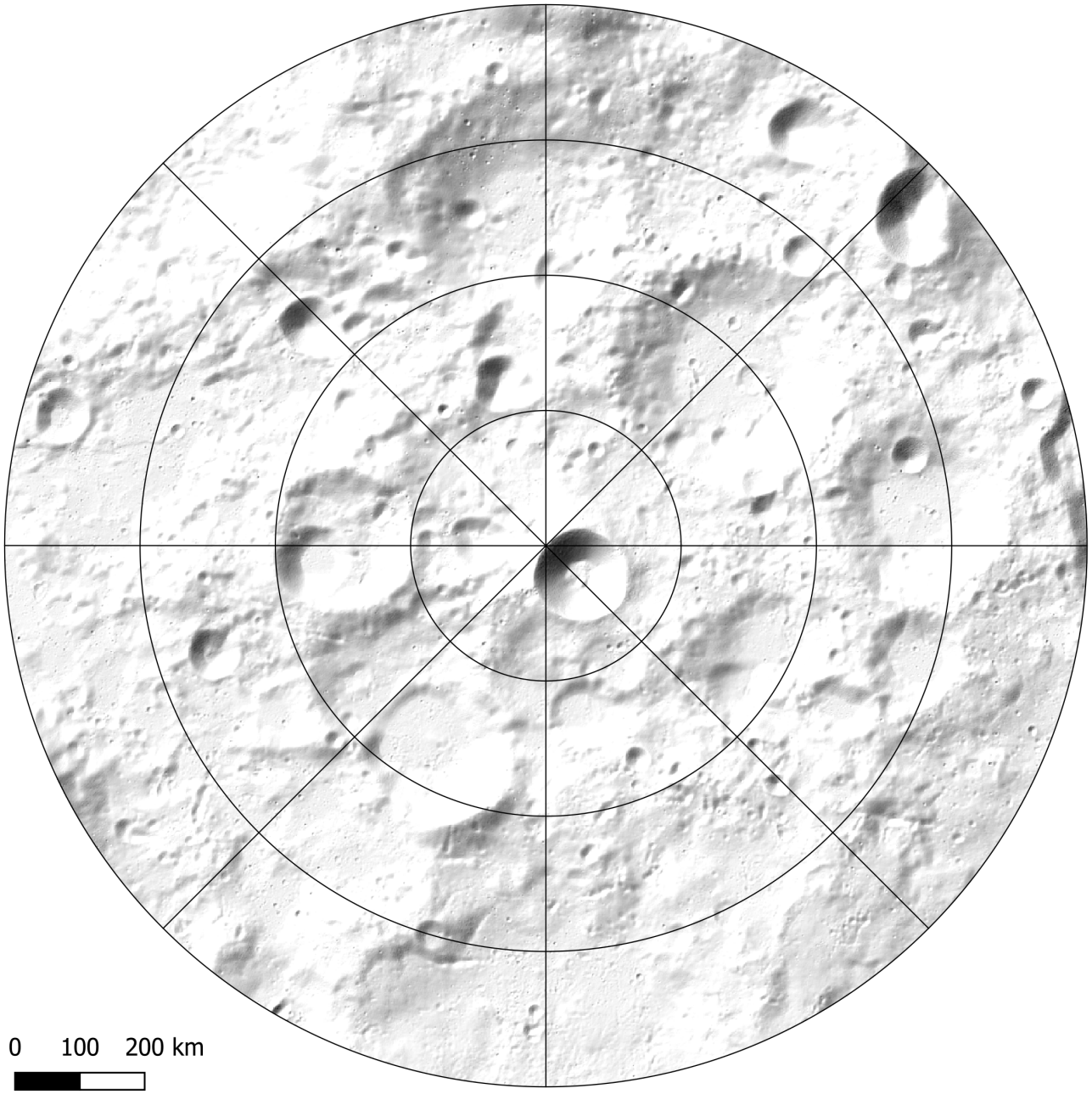
This map shows the reflectance (or albedo) in the ultraviolet (UV) spectrum, measured by the Lyman-Alpha Mapping Project (LAMP) instrument at a pixel scale of 250 m. The 155.57-189.57 nm wavelength range (also called the "Off-band) is a near-perfect reflector of water ice, while the 129.57-155.57 nm wavelength range ("On-band") is not. To see the differences between the two wavelengths, the LAMP team divided the values in the Off-band map by the values in the On-band map to make a ratio map. The Off/On-band ratio map is used to easily detect water frost absorption, which occurs at ~100 -160 nm. 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 are removed from the ratio map where temperatures are too high for ice to be stable on the surface.

Water Ice Map (Answer Sheet)

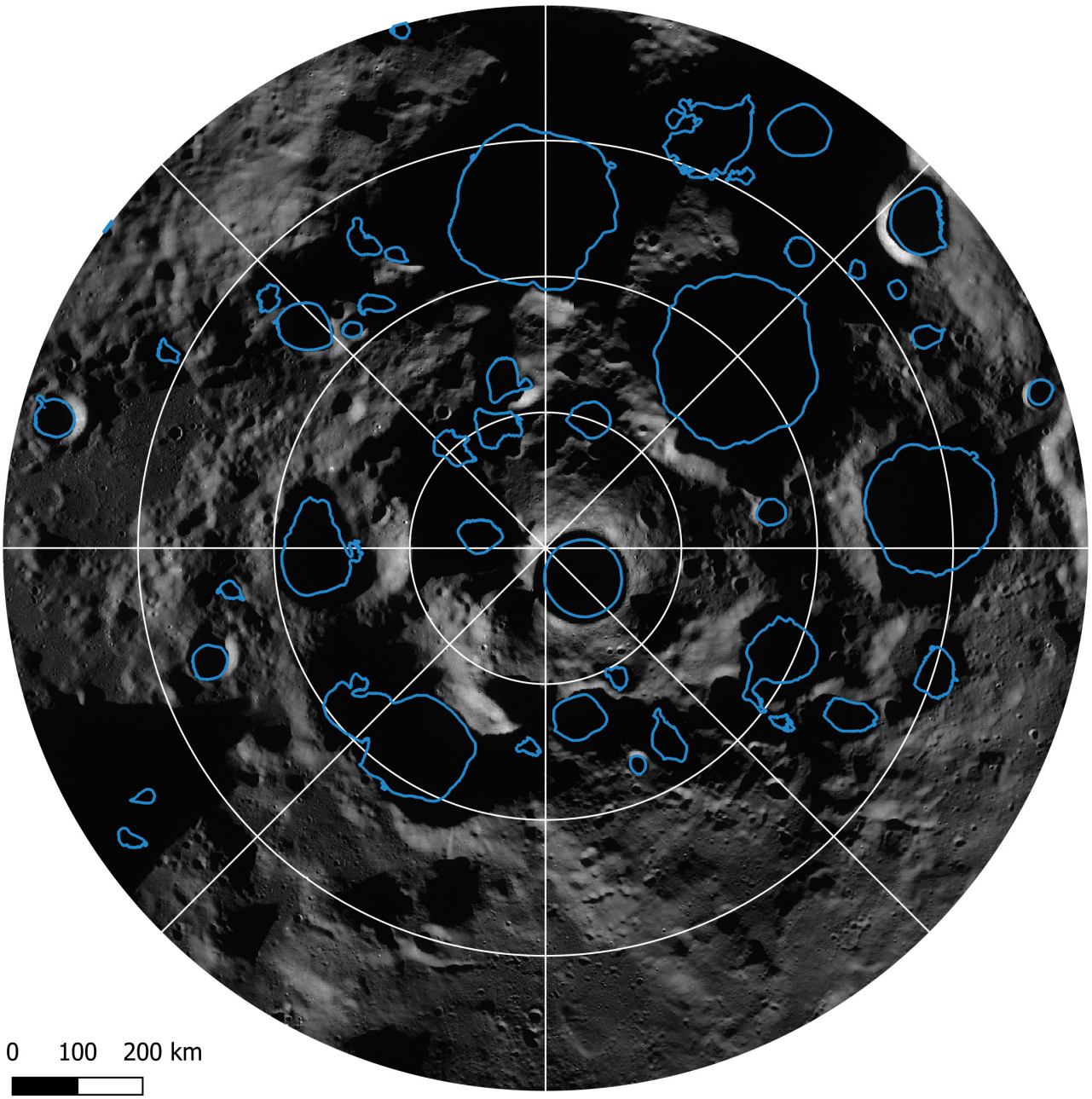
Surface frost extents. dark blue indicates locations where LAMP UV albedo (values >= 1.2) and LOLA albedo (values >= 0.35) intersect in craters where average annual maximum temperatures never exceed 110 K.

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

COLORING PAGE - HILLSHADE

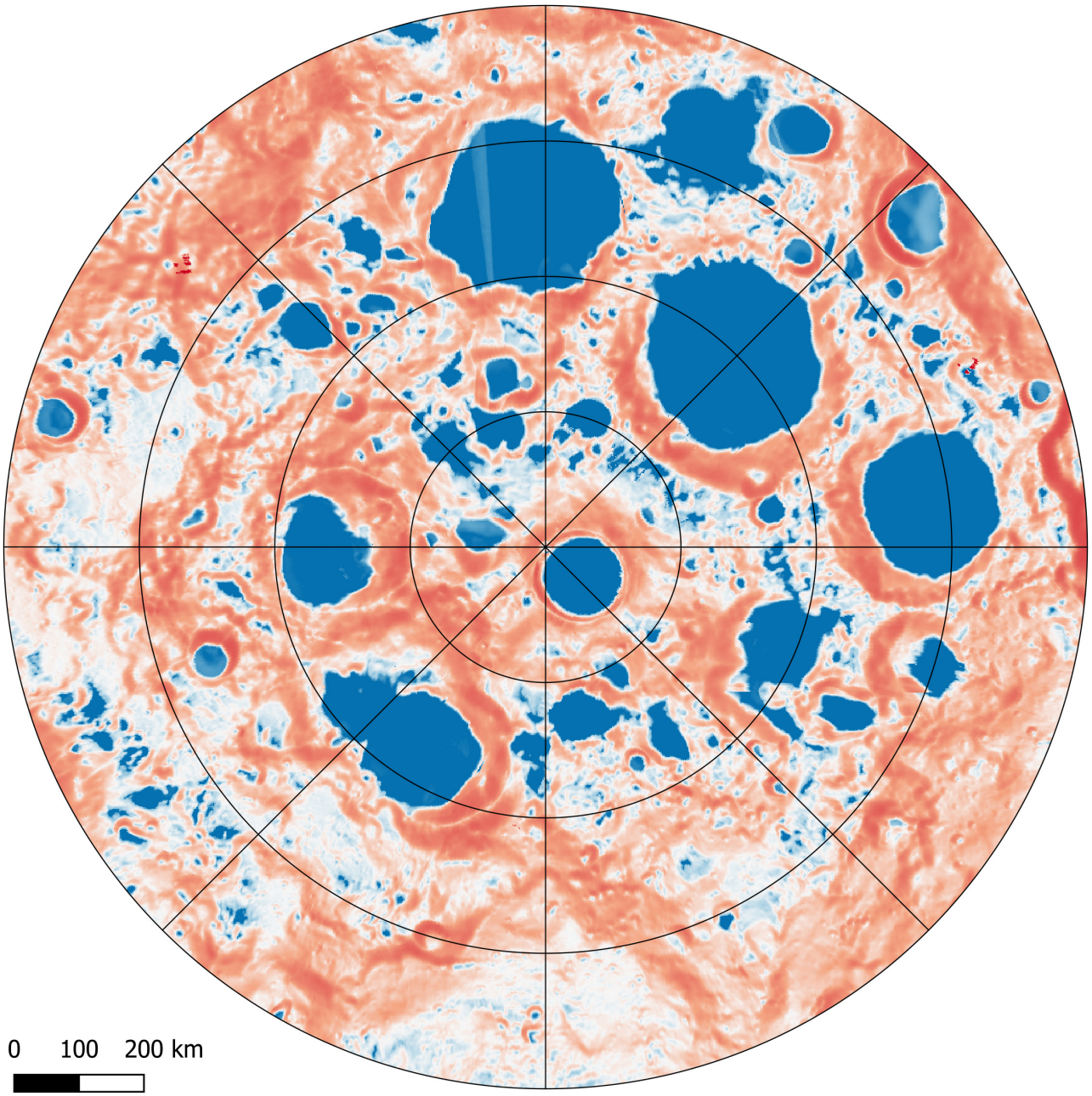


LROC WAC SUMMER MOSAIC WITH PSRs



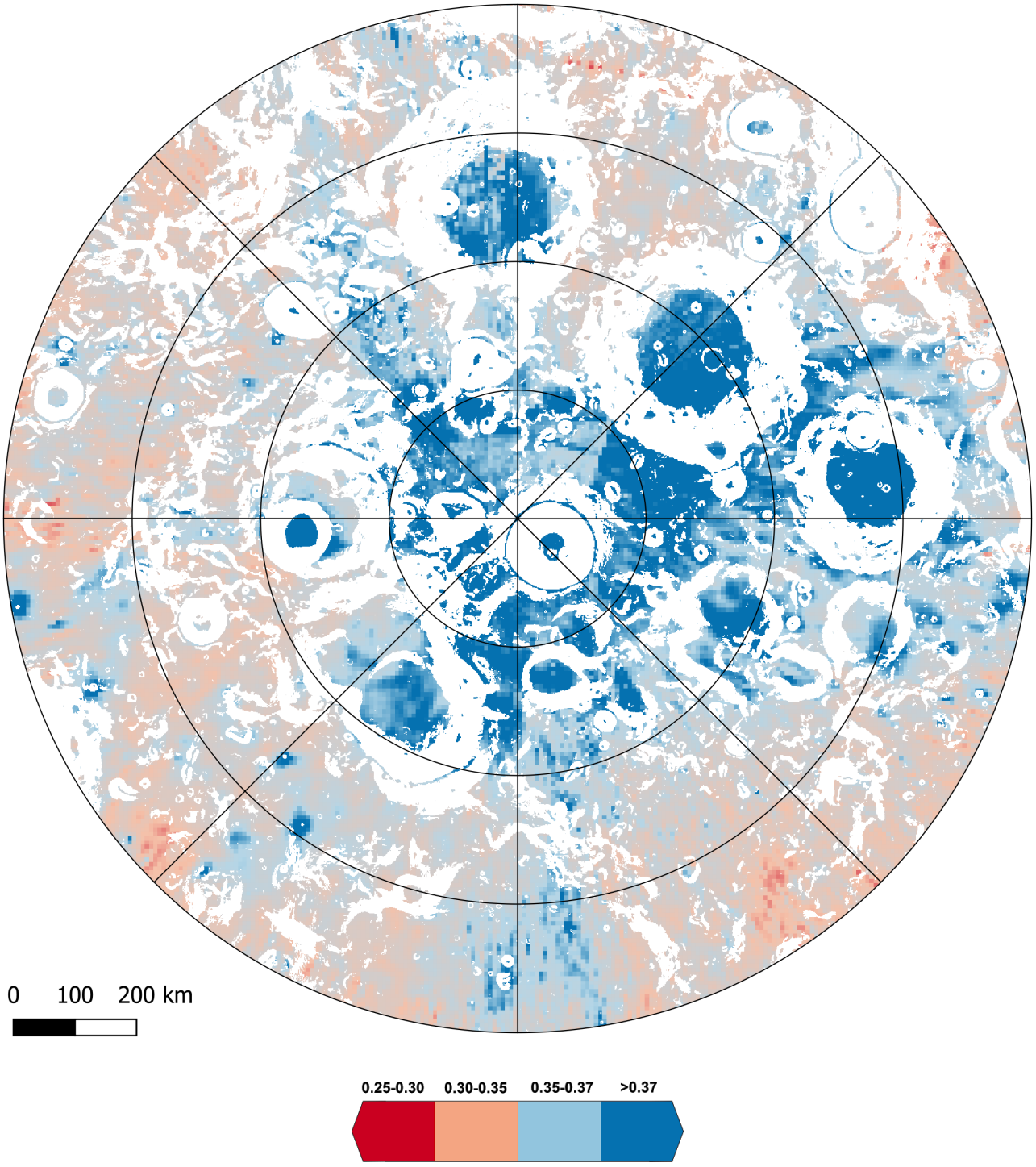
This is a mosaic of images from the Lunar Reconnaissance Orbiter Camera (LROC) Wide Angle Camera (WAC) taken during the summer (from 21 September 2010 to 23 October 2010). The summer is when the south pole receives the maximum amount of sunlight, but still not enough to light up the insides of most craters.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

DIVINER MAXIMUM TEMPERATURE



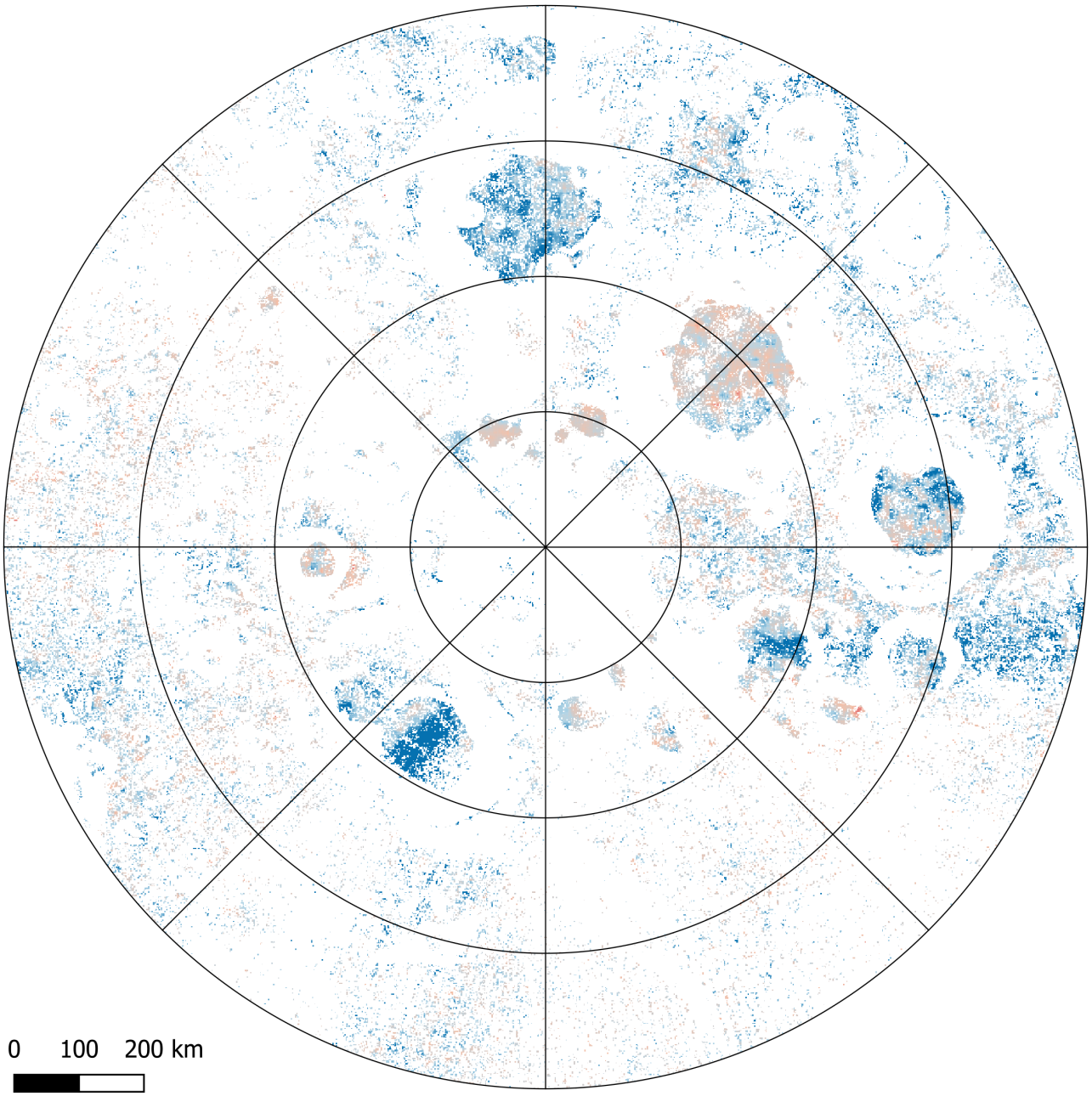
This map shows the maximum temperature in degrees Kelvin (K) over the entire year as measured by the Diviner Lunar Radiometer Experiment (Diviner, for short). Values < 110 K (Dark Blue) are cold enough to trap water ice.

LOLA 1064 NM ALBEDO MAP



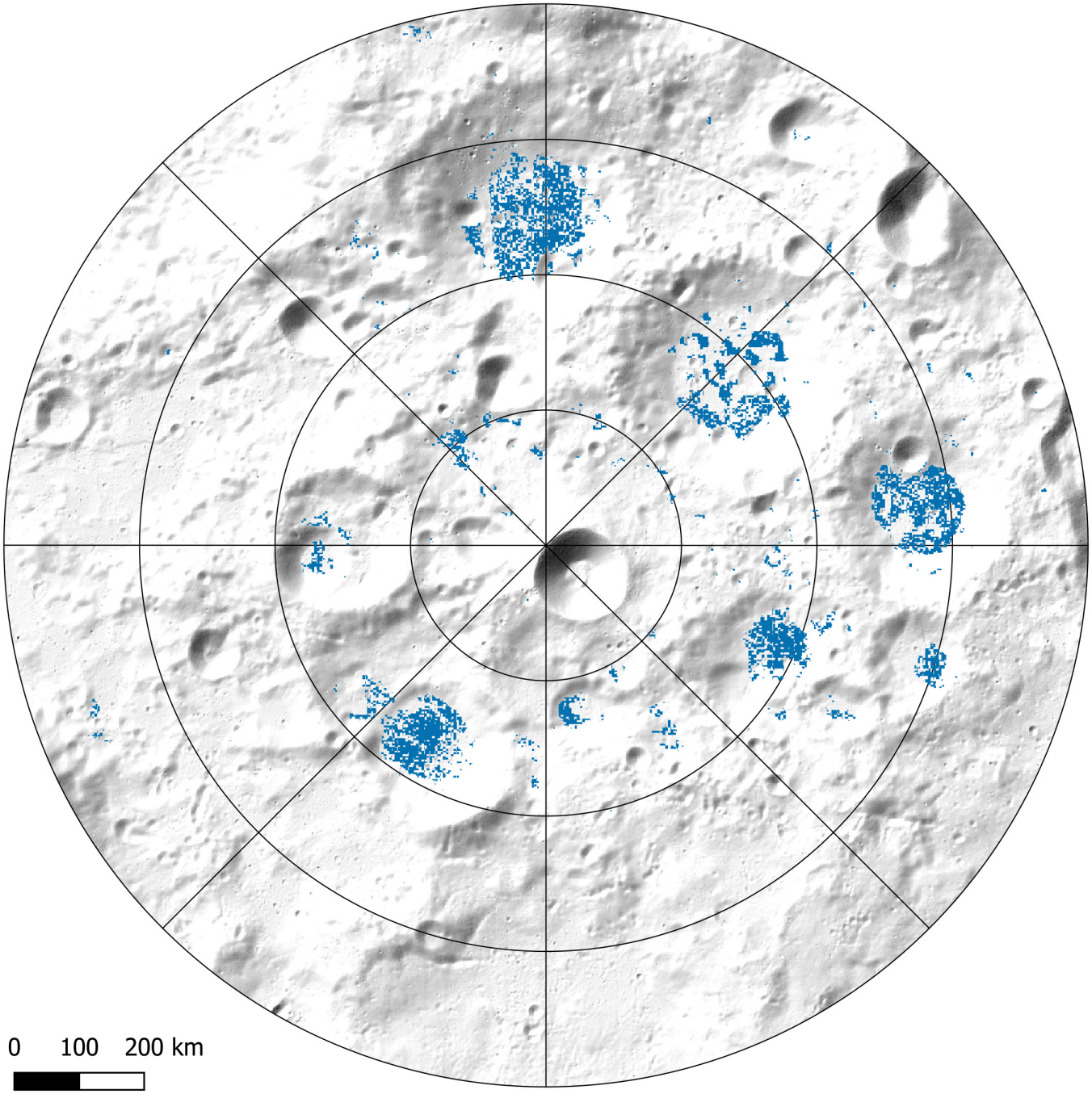
This is an albedo map from the Lunar Orbiter Laser Altimeter (LOLA) instrument. Albedo is a measure of how much a material reflects light. So, a surface that appears brighter has a higher albedo than one that appears darker. One material that is reflective and can appear bright is ice in the form of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

LAMP UV OFF ON-BAND RATIO UV ALBEDO MAP



This map shows the reflectance (or albedo) in the ultraviolet (UV) spectrum, 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 frost absorption. Values >1.2 (dark blue) are consistent with surface water ice.

ANSWER SHEET FOR PART 1



Surface Frost is overlaid in blue.

GLOSSARY

Albedo - A measure of how bright or dark materials are.

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.

Kelvin - K, the abbreviation for Kelvin, is the base unit of temperature in the International System of Units.

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 is referred to as resolution. In a satellite image, how much ground is 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 heat or energy transferring to an object.

Surface frost - On Earth, frost is a thin layer of ice on a solid surface. Frost forms when water vapor (a gas) comes into contact with a frozen surface, thus changing the water vapor into ice (a solid). On the Moon, surface frost is not only water, other elements such as sulfur and nitrogen are thought to exist as well.

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

Tidal Locking - The Moon rotates 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 mission duration.

Vacuum - The vacuum of space is empty and cold; the vacuum of space is nothing.

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

Watts - Unit used to measure how fast energy is used. Power is measured in Watts.