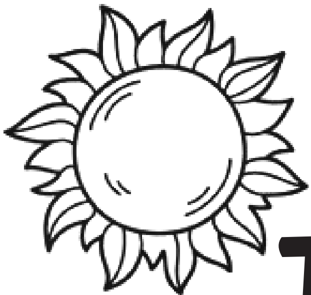


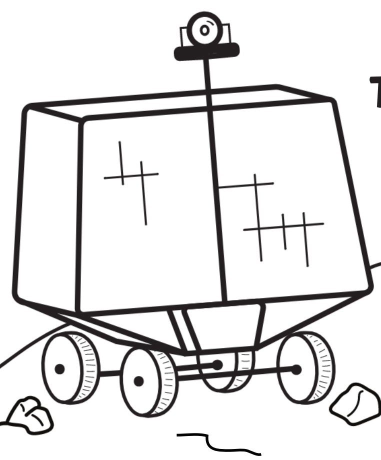
THE MYSTERY OF LUNAR WATER

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° 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°) 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°F or -248°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.

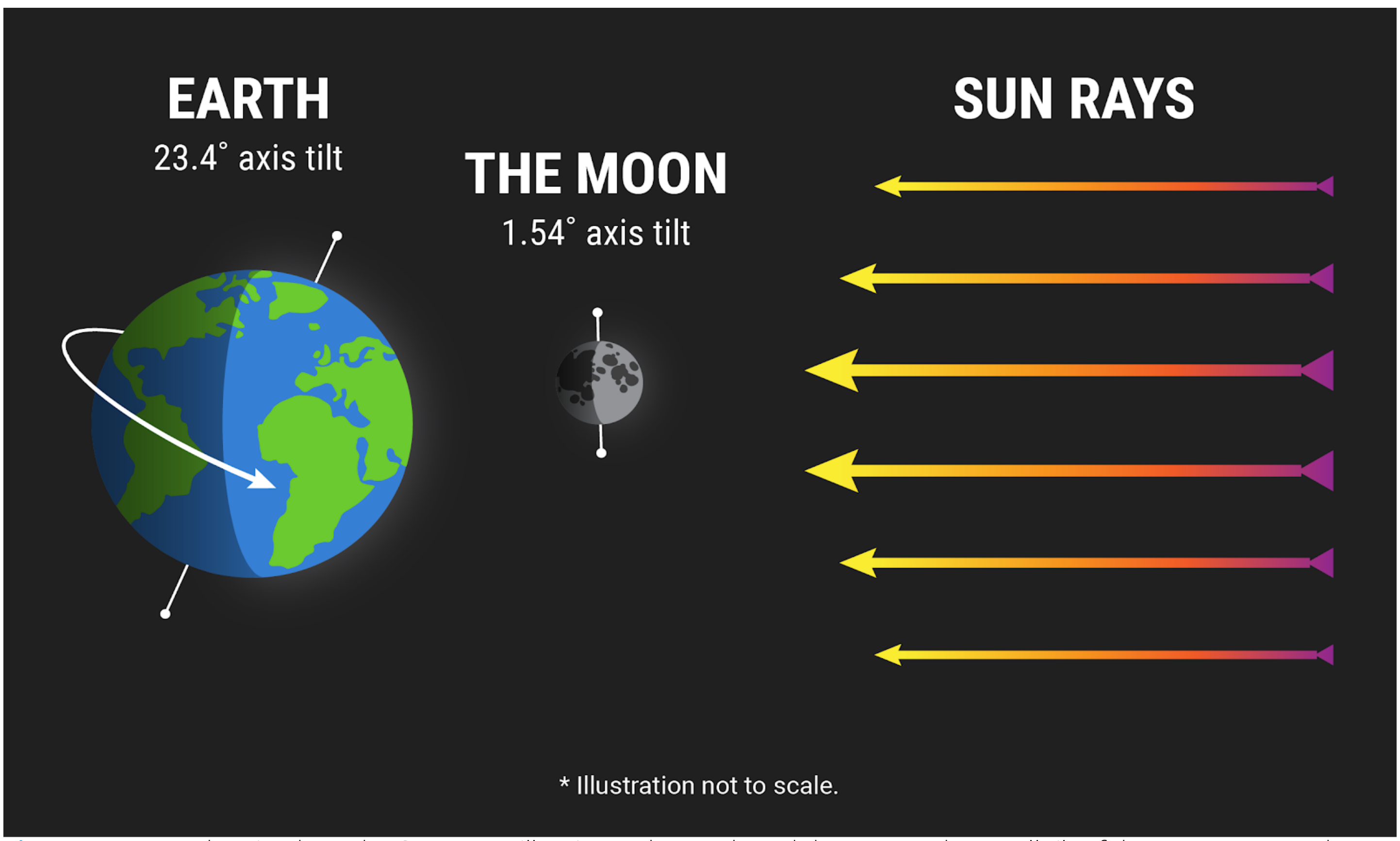


Figure 1: Image showing how the Sun's rays illuminate the Earth and the Moon. The small tilt of the Moon means there are some areas near the poles that never receive direct sunlight.

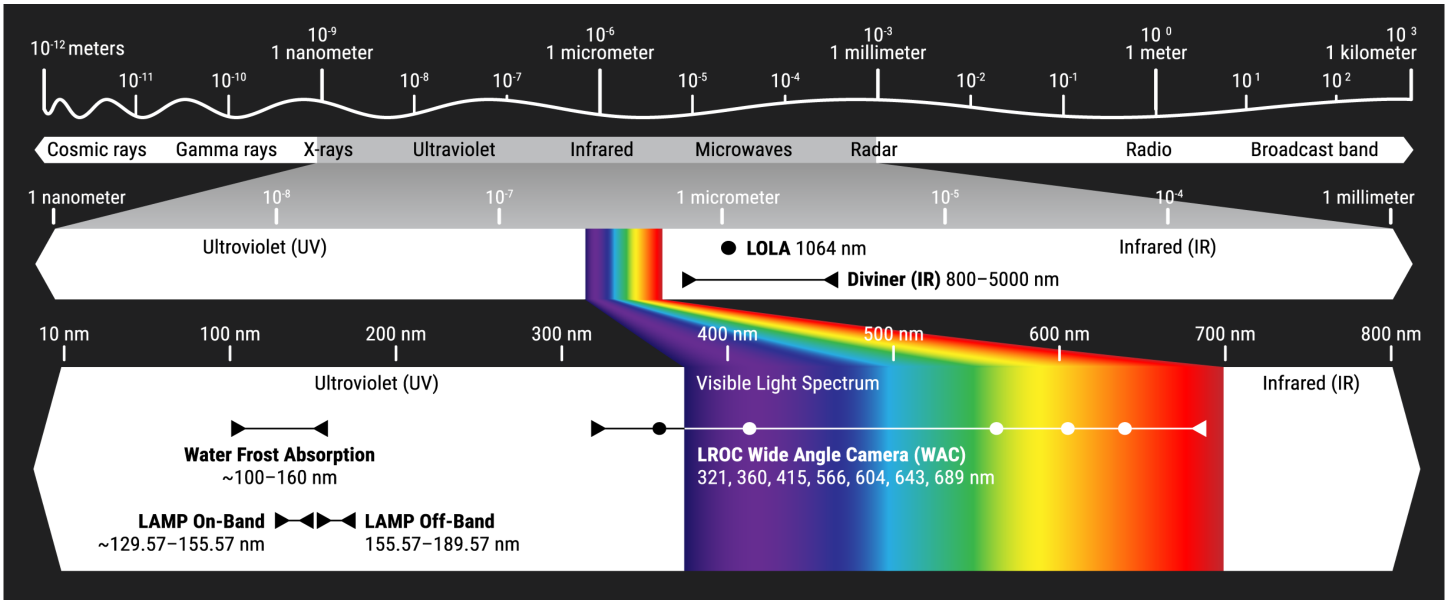


Figure 2: Electromagnetic (EM) spectrum showing the various wavelengths of light detected by instruments on-board the Lunar Reconnaissance Orbiter. Each instrument can only measure a specific wavelength range, and each provides a different type of information: Diviner measures surface temperature using 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 (H2O) 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

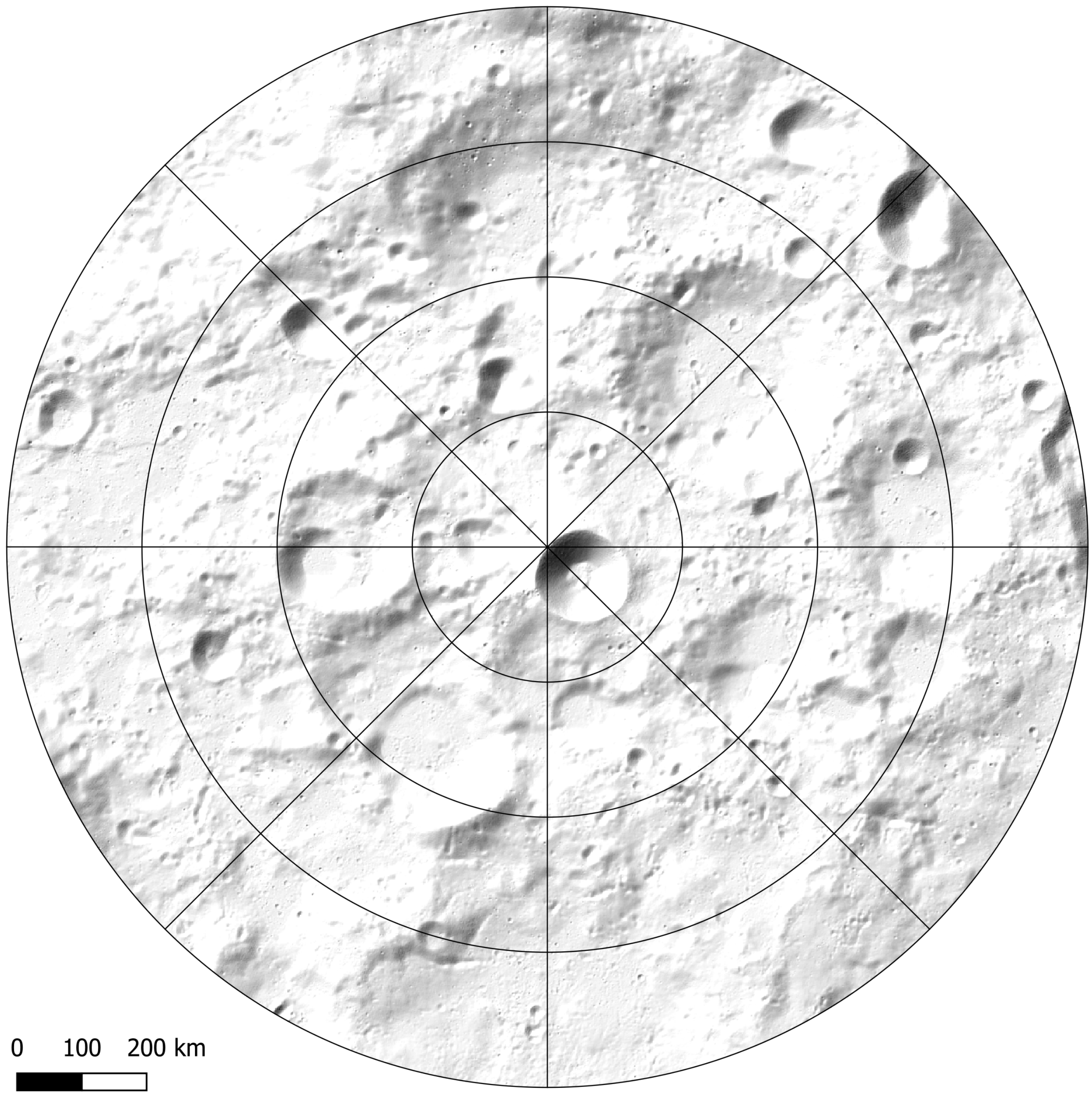
This LAMP ratio mapshows reflectance (or albedo) in the ultraviolet (UV) spectrum, measured by the Lyman-Alpha Mapping Project (LAMP) instrument at a pixel scale of 250 m. Water ice would show up in this map as having high values. Water ice reflects nearly all the light in the he "Off-band" (155.57-189.57 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)

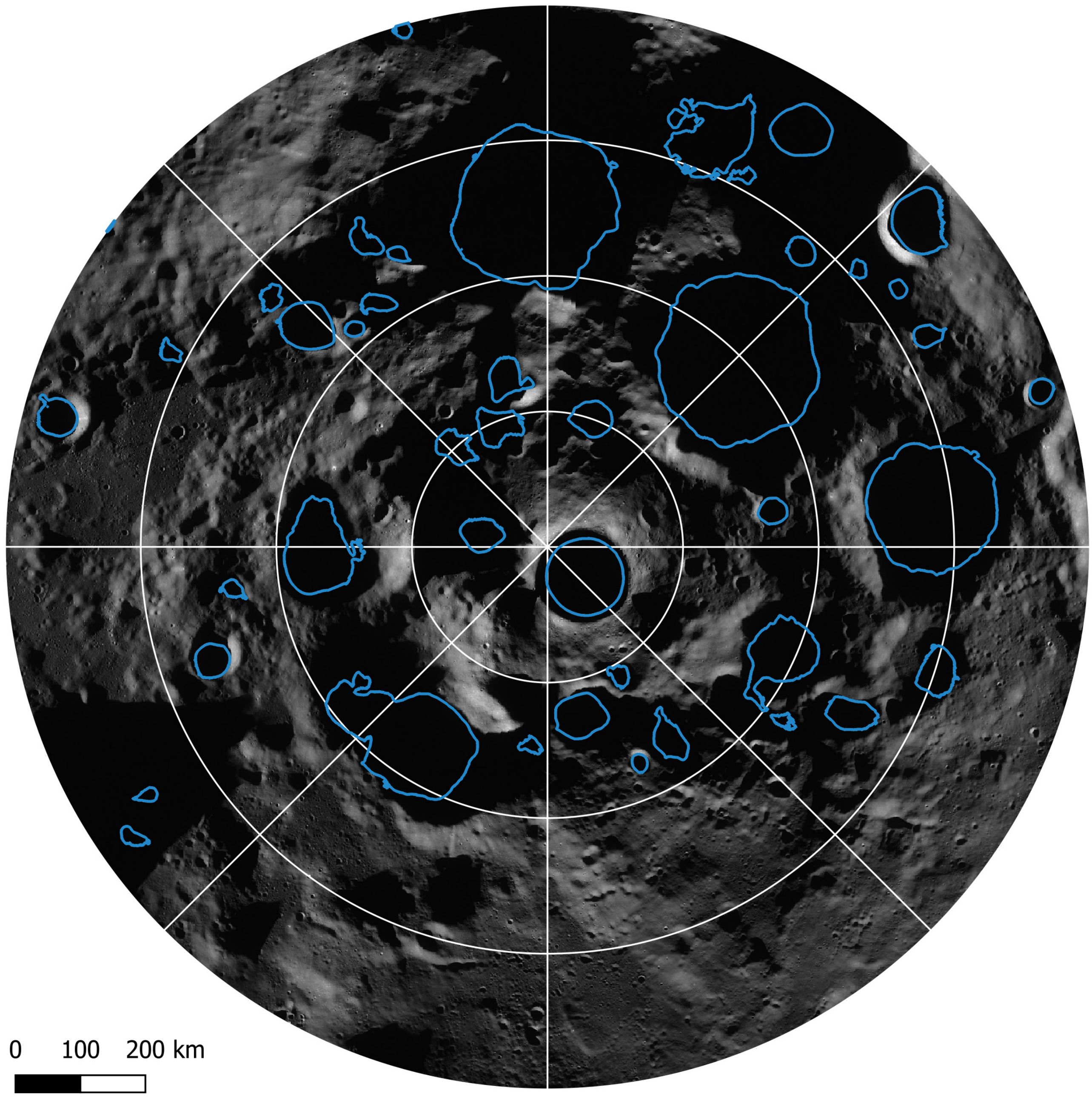
Surface water ice locations. Dark blue indicates locations where LAMP UV albedo (values >= 1.2) and LOLA albedo (values >= 0.37) intersect in craters where average annual maximum temperatures never exceed 110 K.

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

COLORING PAGE - HILLSHADE

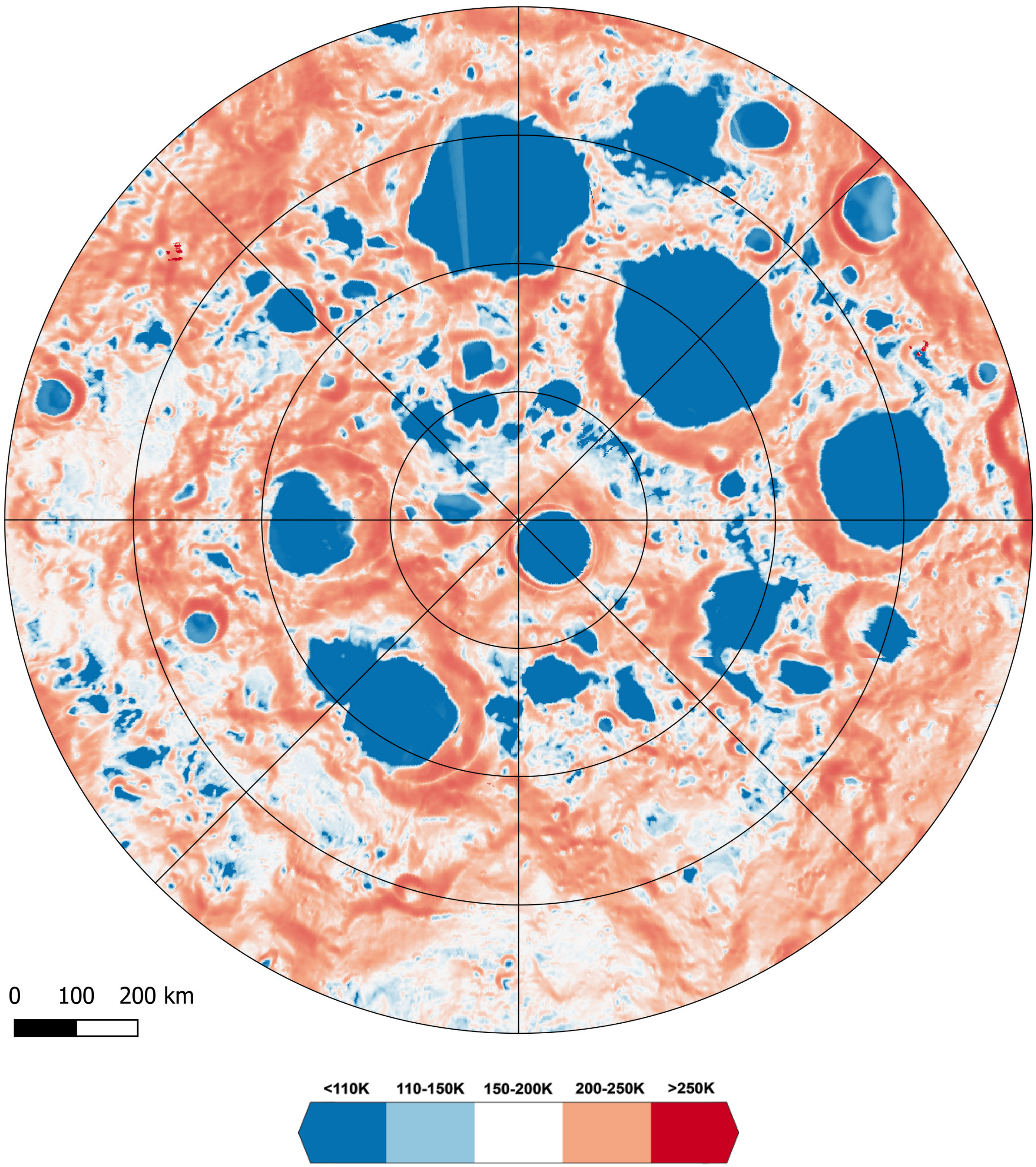


LROC WAC SUMMER MOSAIC WITH PSRs



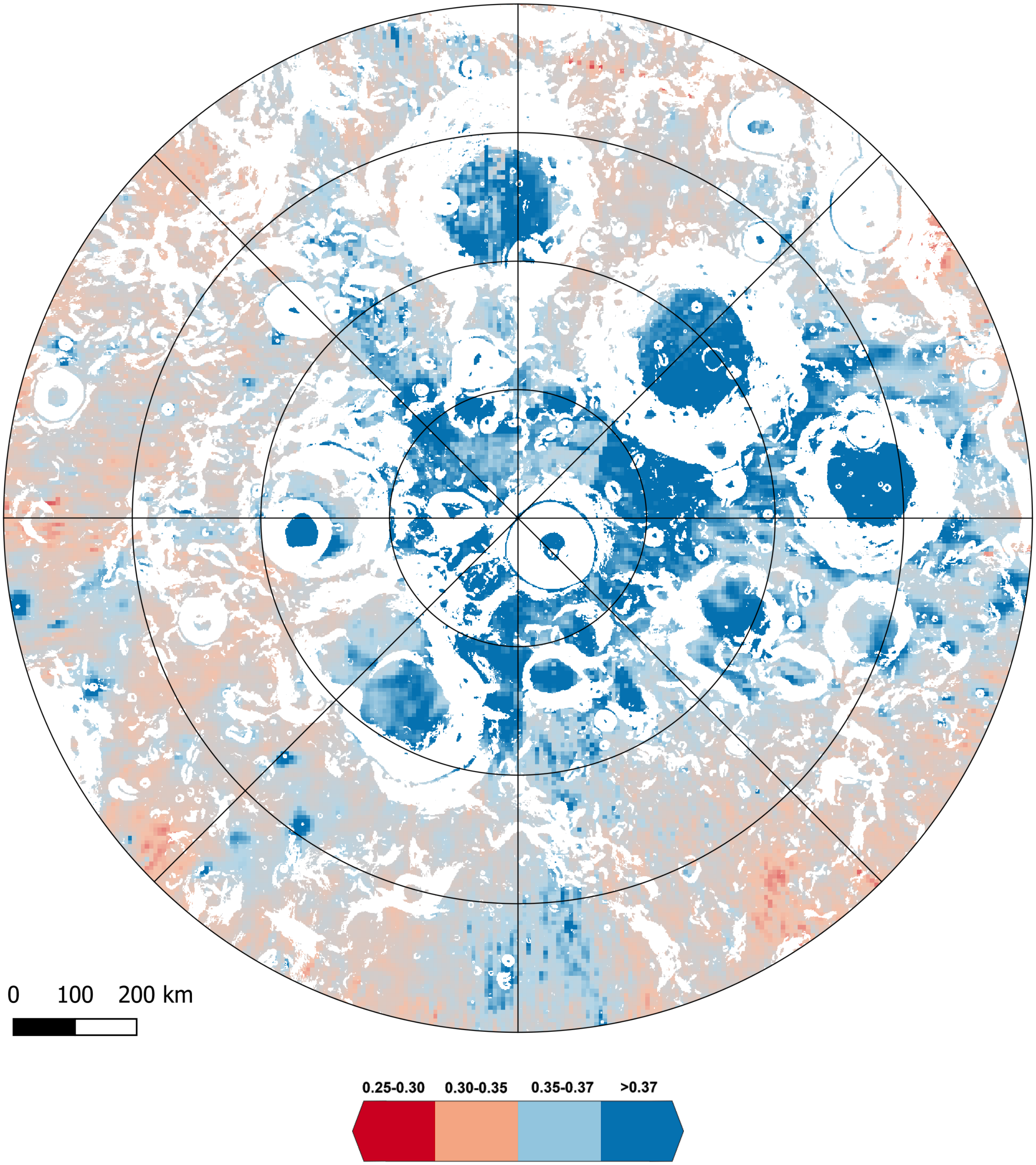
The WAC south pole summer mosaic is composed of images from the Lunar Reconnaissance Orbiter Camera (LROC) Wide Angle Camera (WAC) taken during the summer (from 21 September 2010 to 23 October 2010). The summer is when the south pole receives the maximum amount of sunlight, although not enough to light 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



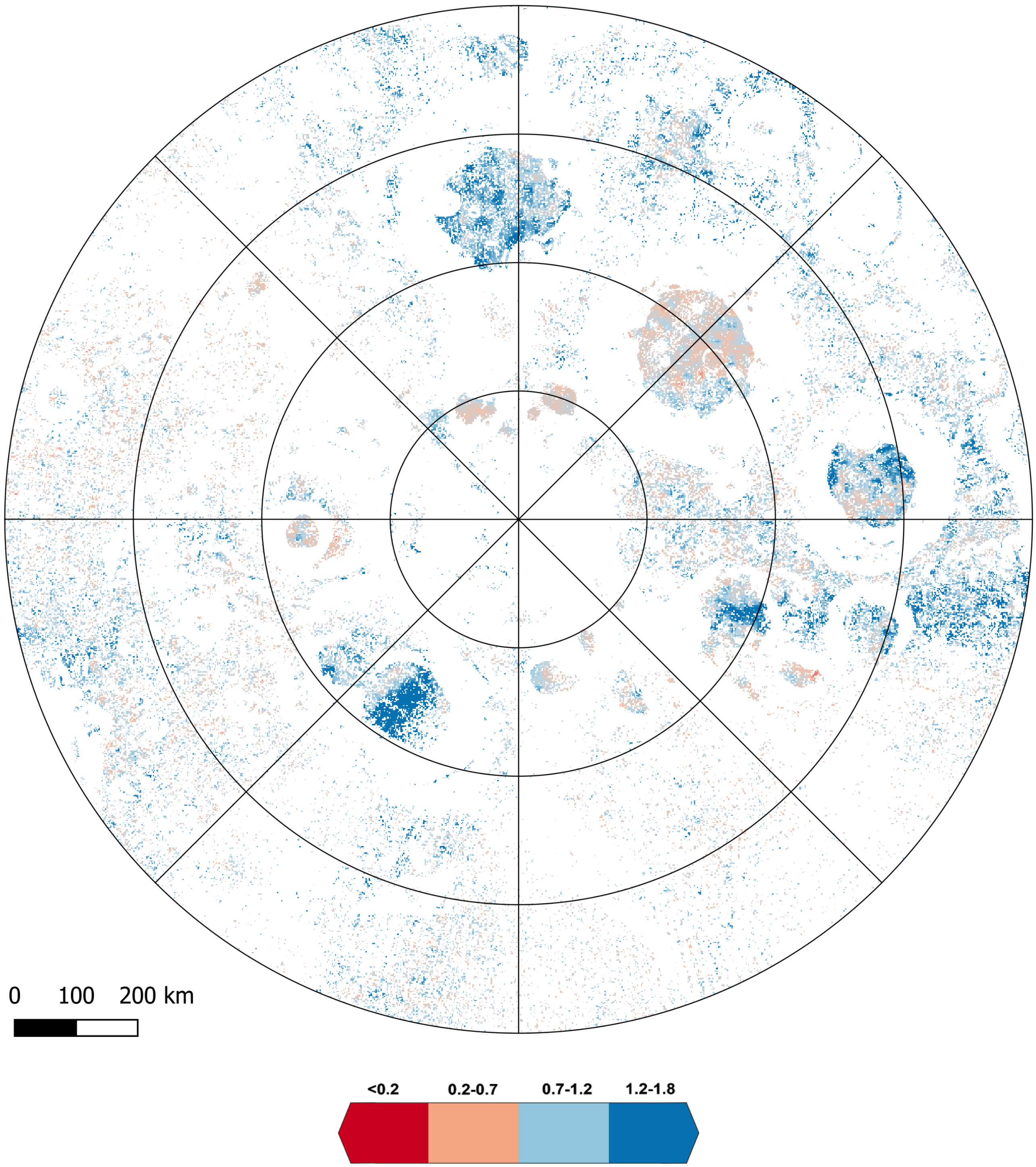
The maximum temperature in degrees Kelvin (K) over an entire year was measured by the Diviner Lunar Radiometer Experiment (Diviner, for short). **Values < 110 K (-262° F; dark blue)** are cold enough to trap water ice.

LOLA 1064 NM ALBEDO MAP



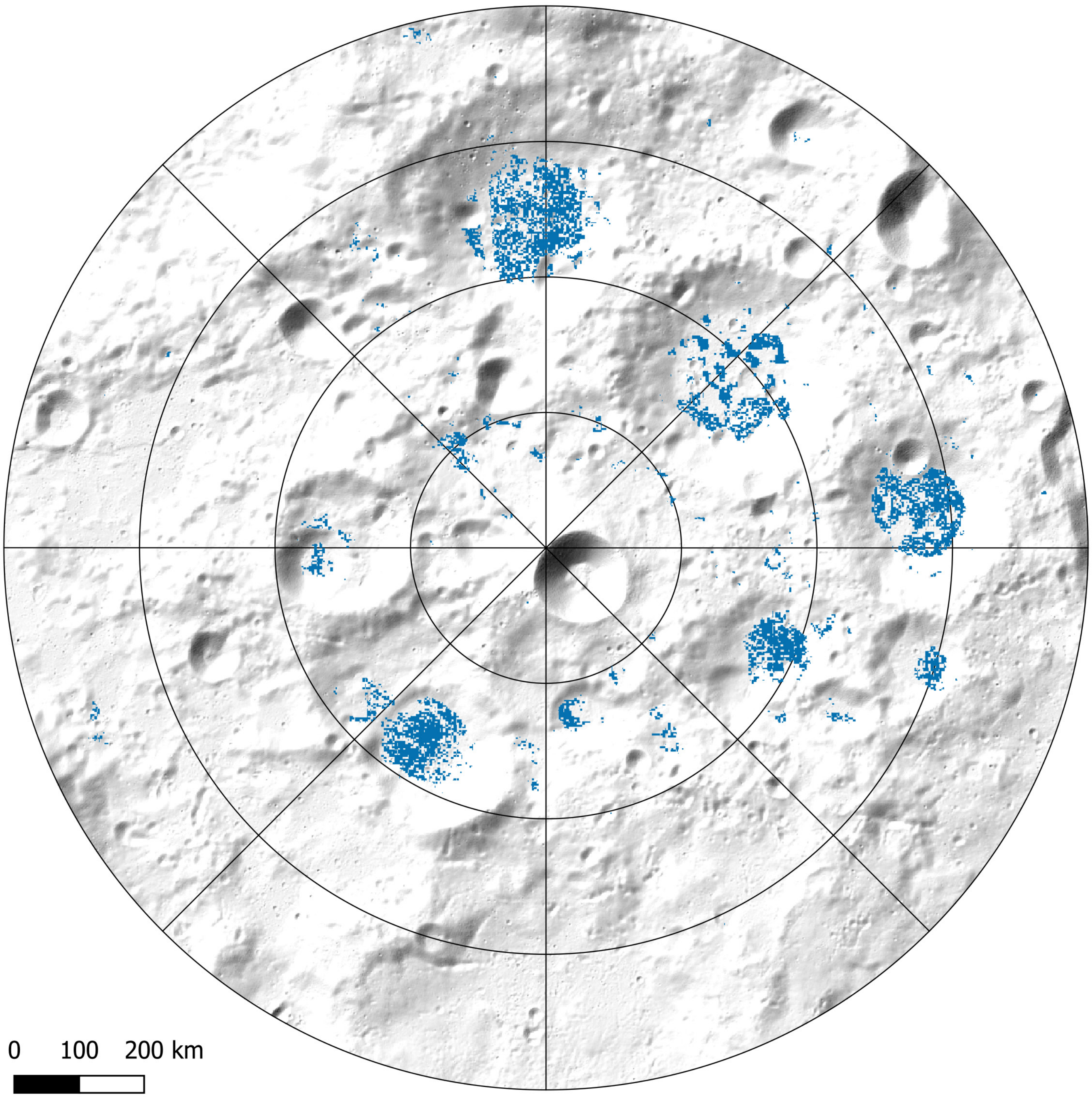
This albedo map was created by the Lunar Orbiter Laser Altimeter (LOLA) instrument team. Albedo is a measure of how much a material reflects light. So, a surface that appears brighter has a higher albedo than one that appears darker. One material that is reflective and can appear bright is water ice 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.

ANSWER SHEET FOR PART 1



Surface Frost is overlaid in blue.

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.