Planning a Mission to the Lunar South Pole

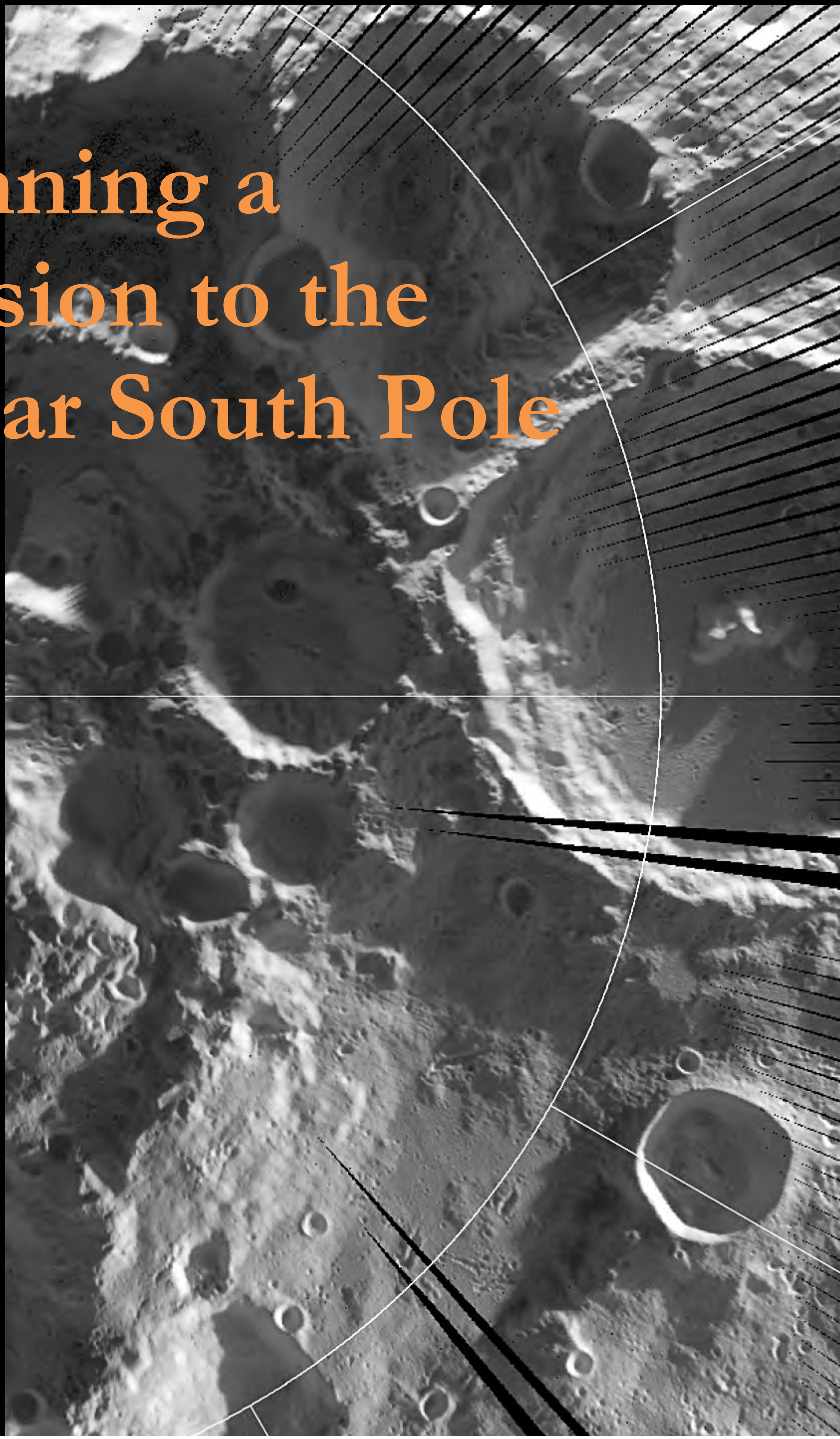

Table of Contents

Teacher Guide

Grade Level:

Gr. 9-10

Time Required:

90 minutes

Overview

In this activity, students learn about permanently-shadowed regions on the Moon and are introduced to two instruments aboard NASA's Lunar Reconnaissance Orbiter that are vital to our understanding of these regions. After evaluating an assortment of data, students decide which of seven locations situated in the lunar south polar region is the most suitable for a future settlement, taking into account four environmental factors – temperature, water supply, illumination, and communication.

Learning Objectives

Students will:

- learn about recent discoveries in lunar science.
- deduce information from various sources of scientific data.
- use their judgment to assess the suitability of locations.
- participate in team-based decision-making.
- use logical arguments and supporting information to justify their decisions.

National Standards

National Science Education Standards Grades 9-12

- Science as Inquiry (Std A)
  - Abilities necessary to do scientific inquiry
    - Student Guide
- Science and Technology (Std E)
  - Understanding about science and technology
    - Background

National Geography Standards

- The World in Spatial Terms
  - How to use maps and other geographic representations, tools and technologies to acquire, process, and report information from a spatial perspective
    - Student Guide
- Environment and Society
  - How physical systems affect human systems
    - Tips for Lunar Explorers

Principles and Standards for School Mathematics

- Standard 5: Data analysis, statistics, and probability
  - Develop and evaluate inferences, predictions, and arguments that are based on data
    - Student Guide
- Standard 9: Connections
  - Recognize, use, and learn about mathematics in contexts outside of mathematics
    - Weighting data

Student Prerequisites

Students must already be familiar with:

- the electromagnetic spectrum.
- basic molecular chemistry.

Materials and Preparation

- Student Guide (1 per group of four), which includes the following:
  - Student Worksheets (4 individual + 1 group)
  - Color prints of:
    - Diviner temperature map
    - LEND neutron map
    - Earth visibility map
    - Sun visibility map
- Calculators
- Pens
- Whiteboard/flip chart for recording student responses

Activity Steps

1. Divide students into groups of four.
2. Pose the question: "If humans were to colonize another planet, what are the essentials that we would need?" Students should discuss within their groups and each group should volunteer an answer. Record student answers on whiteboard or flipchart.
3. Ask students which answers they think are the most important, and circle, highlight, or otherwise indicate these answers in the list.
4. Review the background topics.
5. Distribute Student Guides (1 per group).
6. Explain that each group will be analyzing scientific data from the lunar south polar region. There are seven sites that have been pre-selected based on the fact that they represent a range of environments. Students are to determine which sites are most ideal for a lunar colony based on four environmental factors: temperature, illumination, water supply, and communications.

7. Ask students to look at the Earth visibility map. Explain that the map shows the number of Earth days each year that the Earth is visible above the local horizon, which is a requirement for direct line of sight communication. Ask students what they notice about the pattern of earth visibility? Why is that? *[Top half of map represents the nearside of the Moon, which is the side always facing Earth. Conversely, locations on the farside always face away from Earth and are obstructed from view by the curvature of the Moon's surface].*
8. Ask students to look at the Sun visibility map. Explain that the map shows the number of Earth days each year that the sun is visible in it's entirety above the local horizon (bear in mind that the Sun is only up for half of the day). Ask students to describe what color the permanently-shadowed regions are on this map? *[Gray – 0 days sun visibility.]*
9. Ask them to compare this map to the temperature map, which shows model-calculated yearly average surface temperatures derived from Diviner measurements. Explain that actual day-to-day surface temperatures may be higher or lower than the yearly average but the map is a good approximation of daily temperatures at depths of greater than one meter below the lunar surface. Ask students why they think this is? How do temperatures correlate with illumination? Is this the same on Earth? Why or why not? *[Temperature is strongly correlated with illumination on the Moon; permanently-shadowed regions can get extremely cold because unlike on Earth, there is no atmosphere to redistribute heat.]*
10. Lastly, ask students to look at the LEND neutron map. Explain that the map shows measurements of neutrons from the uppermost half meter of lunar soil, correlating with hydrogen concentrations. The hydrogen is inferred to exist in the form of hydroxyl (and OH ion) or water (H2O).
11. If necessary, review the method for weighting data.
12. Read "Tips for Lunar Explorers"
13. Divide students into groups. Instruct them to decide who should take on the following roles:
    a. **Thermal analyst:**
       Analyzes the **Diviner Temperature Map** and ranks the sites in order of suitability based on their temperature.
    b. **Hydrologist:**
       Analyzes the **LEND Neutron Map** and ranks sites in order of suitability based on their potential for water.
    c. **Communications technician:**
       Analyzes the **Earth Visibility Map** and ranks sites in order of suitability based on their potential for communications.
    d. **Energy technician:**
       Analyzes the **Sun Visibility Map** and ranks sites in order of suitability based on their illumination levels.

14. Distribute worksheets and datasets accordingly.
15. Instruct students that at the end of the 30 minute exercise, each group will give a presentation to the rest of the class so that everyone can compare results.

Student Assessment

Use the chart on the next page and the answer sheet to record student levels of achievement for each of the tasks. The chart uses a scale of 5-1, with 5 representing the highest level of achievement and 1 representing the lowest.

For each task, put a check in the appropriate column. Total the number of checks, then multiply the total number in each column times the achievement level it represents.

Example: If student X scored:
4 in the Level 5 column
9 in the Level 4 column
8 in the Level 3 column
2 in the Level 2 column
0 in the Level 1 column
Then…
4 x 5 = 20 points
9 x 4 = 36 points
8 x 3 = 24 points
2 x 2 = 4 points
Total Score = 84 points

Student Product	Indicator of Achievement	5	4	3	2	1
Individual Worksheets						
Table	I. Table is complete					
	II. Readings are accurate					
	III. Student has ranked locations in a logical order					
Questions	I. All questions have been answered					
	II. Student uses complete sentences					
	III. Student provides detailed explanations to back up their decisions					
	IV. Student uses information provided in this activity to justify their decisions					
	V. Student draws on outside information to justify their decisions					
Group Worksheets	I. Table is complete.					
	II. Group has weighted data correctly - weighting reflects relative importance as described in presentation, calculations are free of errors					
Group Presentations	I. Student participates in presentation					
	II. Group provides detailed explanations for its decisions					
	III. Group uses information provided in the background to justify its decisions					
	IV. Group draws on outside information to justify its decisions					
	V. Group uses logical arguments					

Answer Sheet[1]

	Thermal Analyst	Hydrologist	Communications Technician	Energy Technician
	Temperature (+/-10K)	Neutron Count (+/-0.05)	Earth Visibility (+/-20 days)	Sun Visibility (+/-10 days)
AM	100K	5.1	140	100
LC	35K	4.95	70	0
MM	175K	5.02	320	150
M5	180K	5.03	0	170
SC	125K	5.1	210	100
SH	40K	5.02	0	0
SM	40K	4.95	70	0
Question 1	• Scores locations from high to low temperature. • Recognizes warmest locations in the region are colder than the coldest temperatures measured on Earth. • Acknowledges limitations of spacesuits and equipment.	• Scores locations from low to high neutron count. • Recognizes water content (hydrogen) is inversely correlated with neutron count. • Acknowledges limitations of transporting water from Earth.	• Scores locations from high to low earth visibility. • Recognizes potential for communication in locations with more days of earth visibility per year.	• Scores locations from high to low sun visibility. • Recognizes increased potential for solar power in locations with more days of sun visibility per year.
Question 2	• Eliminates sites with temperatures lower than 113K (spacesuit temperature).	• Takes into account surrounding regions of sites with high neutron count.	• Takes into account surrounding regions of sites with low earth visibility.	• Takes into account surrounding regions of sites with low sun visibility.
Question 3	• Acknowledges that warmer sites pose less risk to humans and machines. • Considers potential to regulate thermal environments.	• Acknowledges the advantages of a local water supply. • Recognizes water supply doesn't have to be onsite. • Considers potential to recycle water.	• Acknowledges benefits of constant line of communication with Earth. • Recognizes communications facility doesn't have to be onsite. • Suggests alternative methods of communication (satellites, relays).	• Acknowledges importance of exploitable energy resource. • Recognizes power supply doesn't have to be onsite. • Suggests alternatives (nuclear, geothermal, biomass).

* This is not a definitive list of answers. Students should be given credit for demonstrating an understanding of the background material and for using logical reasoning to explain their decisions. For example, in Q2 on the thermal analyst worksheet, students might argue that spacesuit capability is likely to improve in the future and therefore choose to include locations colder than 113K.

Background

The Lunar Thermal Environment

The Moon's surface thermal environment is among the most extreme of any planetary body in the solar system. At the equator, noontime surface temperatures reach 127ºC, which is hotter than boiling water (which boils at 100ºC). Lunar nighttime temperatures are almost as cold as liquid oxygen (-173ºC).

In addition, there are places in the lunar polar regions where temperatures as low as -248ºC have been measured – these are the coldest places observed to date within our entire solar system!

The primary reason for these extremely low temperatures at the lunar poles is that the Moon's axial tilt is only 1.5°, compared to 23.5° on Earth. This means that at the lunar poles the Sun is constantly low on the horizon, and the insides of polar impact craters receive no direct energy from the sun. They are what have become known as '**permanently-shadowed regions**'.

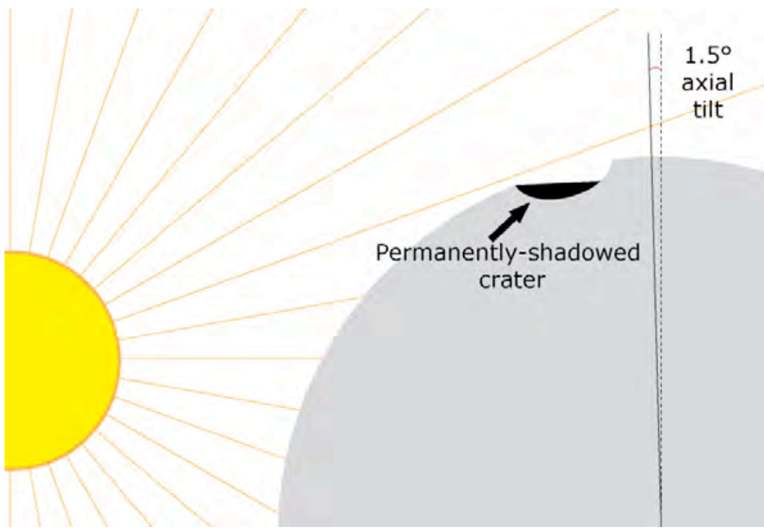

Figure 1. Permanently-shadowed crater at the lunar pole (Not to scale).

The Kelvin Temperature Scale

When describing extremely cold temperatures such as those observed on the Moon, scientists use the Kelvin (K) unit of measurement. Unlike the Celsius or Fahrenheit temperature scales, there are no negative values of Kelvin. This is because 0K corresponds to **absolute zero** - the coldest possible temperature at which point an object's molecules would cease to vibrate and therefore no longer produce any heat. The relationship between Kelvin and Celsius can be expressed as the following mathematic equation:

°C = K + 273

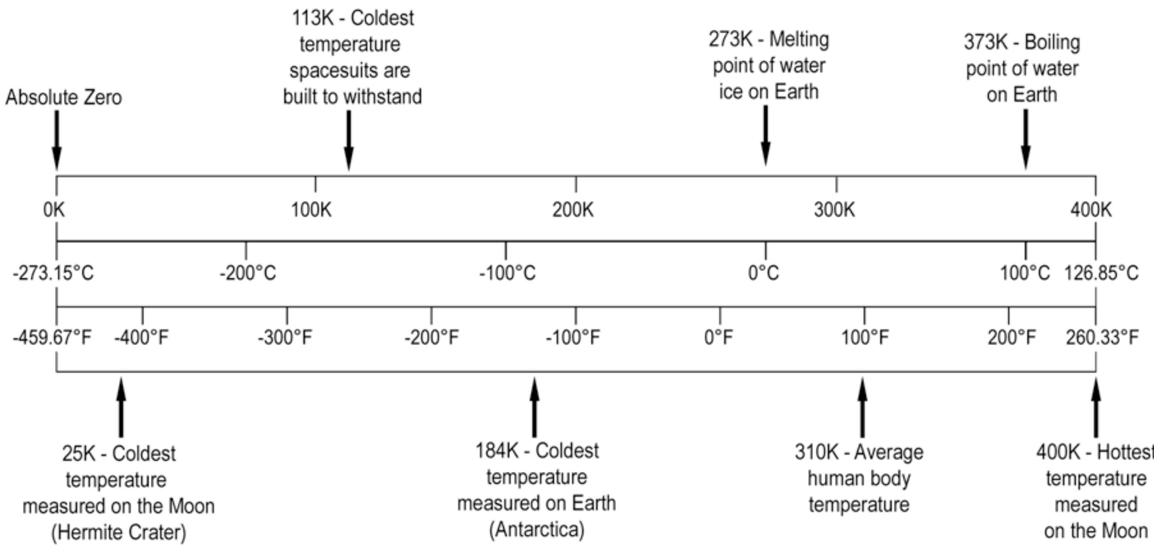

Figure 2. Temperature scales: Kelvin (top), Celsius (middle) and Fahrenheit (bottom).

One Kelvin is equivalent in magnitude to one degree Celsius (°C). This means that intervals in the two scales are equally spaced; for example, the melting and boiling points of water, which are 273K (0°C) and 373K (100°C) respectively. This is not the case with the Fahrenheit scale (32°F and 212°F).

Permanently-Shadowed Regions and Ice

Scientists have long theorized that in the extremely cold, permanently-shadowed regions of the lunar poles, water and other volatile molecules could become '**cold-trapped**' or frozen within the soil, leading to the accumulation of reservoirs of ice over billions of years.

For a long time, scientists weren't sure whether this ice actually existed; but in 2009, the Lunar CRater Observation and Sensing Satellite (LCROSS) impacted a permanently-shadowed region inside Cabeus crater, which is situated near the Moon's south pole, and a significant amount of ice was observed. It's still unclear where the ice came from or how it got there, or how much ice exists outside of Cabeus, but data suggest that the polar ice deposits are extensive enough to be a potentially viable resource.

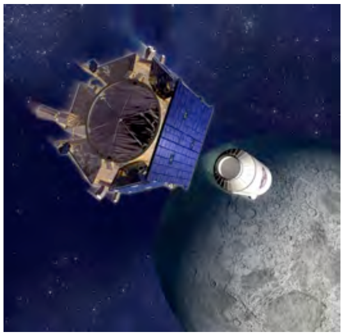

Figure 3. LCROSS

There are currently two instruments involved in characterizing the lunar cold-traps:

The Diviner Lunar Radiometer

Figure 4. Diviner

The Diviner Lunar Radiometer is one of seven instruments aboard NASA's Lunar Reconnaissance Orbiter (LRO), which has been orbiting the Moon since June 2009. It is the first instrument to measure the entire range of temperatures on the Moon's surface.

How it works

When solar radiation hits the Moon, some of it is reflected back out to space, while some is absorbed and re-emitted as infrared radiation. Diviner measures the amount of emitted infrared and reflected solar radiation, and from these measurements scientists are able to determine the temperature of the Moon's surface, along with other information such as the amount of illumination the surface receives.

The Lunar Exploration Neutron Detector

The Lunar Exploration Neutron Detector (LEND) is also aboard LRO. It measures the flux of neutrons from the Moon's surface, which can be used to infer the presence of water.

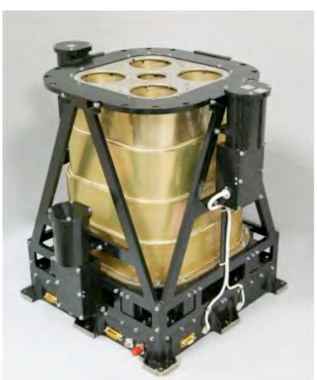

Figure 5. LEND

How it works

When cosmic rays bombard the Moon, they break down atoms in the lunar soil, sending high-energy neutrons flying out into space. These high-energy neutrons are slowed down and absorbed by the atoms of other elements within the soil, particularly hydrogen, which is similar in size. LEND measures the amount of neutrons from the lunar surface; the fewer high-energy neutrons that are observed, the higher the concentration of hydrogen.

Why Colonize the Moon?

For years, humans have envisioned one day building an outpost on the Moon. With the recent discovery of ice at the lunar poles, the prospect of colonizing the Moon has become more of a reality.

We know what to expect

The Moon is our closest neighbor. Back in the 60s, it only took three days for the Apollo astronauts to make the trip there, and there's a good chance we can improve on this time with future technology. In addition, the communication delay between Earth and the Moon is less than three seconds, allowing for almost instantaneous audio and visual contact.

Learning about the Moon will help us understand the evolution of Earth…

Early in its history, the Earth was impacted by a Mars-sized object, which resulted in a huge amount of debris being blown into space. The debris that remained in orbit around Earth eventually gathered together and formed our Moon. The Moon is the only planetary body in our solar system that shares the same origins as Earth, and therefore an ideal place to look for answers to questions such as "Where do our oceans come from?"

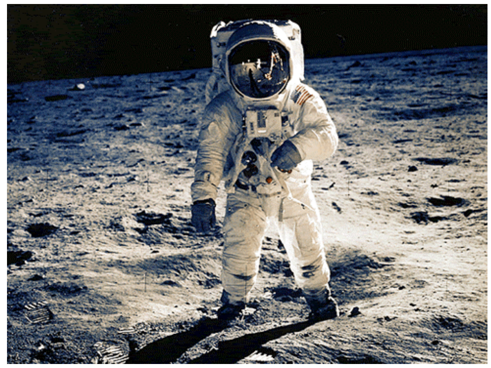

Figure 6. Astronaut Buzz Aldrin on the lunar surface during the Apollo 11 mission, 1969.

…and the Solar System

The Moon doesn't have an atmosphere or oceans, and it's not subject to any of the geologic processes that continuously shape Earth's surface. As a result, the Moon's surface is a near perfect record of what was going on in the early solar system, including the mysterious '**Late Heavy Bombardment**' – a period of heightened meteorite activity that is known to have occurred around 3.9 billion years ago.

It will give us good practice

Our Moon will be the first 'off planet' destination where Mankind will learn to live and work on other planets and it will be the dress rehearsal for manned missions to Mars. Building a lunar colony will not only provide us with most of the skills and knowledge required to colonize another planet, but also the means to do it - with a gravitational field only 1/6th of Earth's, the Moon is an ideal base for launching rockets out into the solar system and beyond.

References

For more information about NASA's Lunar Reconnaissance Orbiter mission:
http://lunar.gsfc.nasa.gov/
For more information about the Diviner Lunar Radiometer:
http://diviner.ucla.edu/
For more information about the Lunar Exploration Neutron Detector:
http://ps.iki.rssi.ru/lend_en.htm
For more information about the Lunar CRater Observation and Sensing Satellite:
http://lcross.arc.nasa.gov/
For more information about NASA's plans to colonize the Moon:

http://www.nasa.gov/centers/goddard/news/series/moon/why_go_back.html
For more information about permanently-shadowed regions and ice:
http://www.messenger-education.org/library/pdf/ice_shadows.pdf

Student Guide

Within your teams of four you will analyze various datasets from the Moon's south polar region to determine which location is the most suitable for a lunar base. There are seven potential sites to choose from, each of which has advantages and disadvantages. You will need to use the available information to evaluate which factors are the most important, and come to a decision based on your assessment.

Plan of Action

Individual Worksheets

1. Review "Tips for Lunar Explorers".
2. Using information from "Tips for Lunar Explorers", and what you learned at the beginning of the lesson, decide:
   a. how you are going to order the sites in terms of suitability, and
   b. if there are any conditions that the sites have to meet in order to be considered.

   Write your criteria on your worksheet.
3. Analyze the relevant dataset(s) and record your measurements on the worksheet.
4. Eliminate sites that do not meet the conditions that you deem essential.
5. Score the remaining sites in order from most to least favorable, with seven points given to the most favorable, six to the next most favorable and so on until each of the sites has a score. If two or more sites are tied, give them each the same score.
6. Answer the questions.

Group Presentation

1. Transfer your individual scores onto the group worksheet.
2. Discuss your observations as a group and come to a decision about the relative importance of the four environmental factors.
3. Weight them accordingly and calculate final scores using the method described in "Weighting Data".
4. Rank the sites based on their scores.
5. Prepare a 5 minute presentation for rest of the class. You will need to cover the following points:
   a. The location that you deem most suitable for a lunar base
   b. The weighting that you gave each of the datasets and why
   c. If you ruled out any sites and why
   d. The drawbacks of your chosen location, and how these might be overcome.

e. What additional data/information would have been helpful in coming to a decision.

Key Points

- There are no right or wrong answers.
- All decisions should be justified with supporting evidence from the background.

Weighting Data

If there are three equally-important factors – A, B and C, that determine variable D, the equation to determine D would be:
A + B + C = D

However, if the factors were not equally important, this equation would no longer be valid. Instead, each factor would need to be weighted according to its importance by multiplying by a percentage. For example, if A is deemed to be just as important as B + C put together, and C is the least important factor, the following weighting might be applied:

Factor	Weight
A	0.5
B	0.3
C	0.2
Total	1

The correct formula would read:
(0.5)A + (0.3)B + (0.2)C = D

Since you are calculating the percent weight for each factor, make sure that each of your weights, when added, equal one.

TIPS FOR LUNAR EXPLORERS

A lunar colony has to be completely self-sustaining. It would be prohibitively expensive to transport all the materials required by a colony from Earth so it is vital that the colony can produce resources to meet its own needs. This includes food, water, air, power and eventually, as the colony expands, construction materials, efficient systems for air and water recycling, and waste management.

WATER SUPPLY

The human body needs water to stay alive; without it, we would only survive for a few days. We also need it for growing food, cooking and bathing. It is imperative that a future lunar base has access to a clean water supply.

POWER SUPPLY

Solar energy is the most viable power source for lunar colonies. Everything that runs on electricity requires a power supply, including lighting, vehicles, communications equipment, air pressurization units (machinery used to create a breathable atmosphere inside a structure) and hydroponic equipment (equipment used for growing crops under artificial conditions).

TEMPERATURE

With modern technology, we are able to substantially regulate our thermal environment. Spacesuits have been designed that withstand temperatures as low as 113K and a well-insulated, underground shelter could make even the harshest climates livable. However, extremely low temperatures are a risk to mechanical equipment. Also, see Figure 2.

COMMUNICATION

Even though a lunar colony would be self-sufficient, it would still need to maintain communications with Earth in order to coordinate back and forth transportation of goods and people, and to request help or supplies in the case of an emergency.

Thermal Analyst Worksheet

Name ________________________________

Write your evaluation criteria:

Site	Temperature (K)	Eliminated?	Score
Amundsen Crater (AM)			
LCROSS Impact Site (LC)			
Malapert Mountain (MM)			
M5			
Scott Crater (SC)			
Shackleton Crater (SH)			
Shoemaker Crater (SM)			

Q1. Explain your reasoning behind scoring the sites in the way that you have.

Q2. Based on your criteria, are any of the locations unsuitable? Why?

Q3. Explain how you think the Diviner data should be weighted in relation to the three other datasets and why.

Hydrologist Worksheet

Name ___________________________________

Site	Neutron Count (K)	Eliminated?	Score
Amundsen Crater (AM)			
LCROSS Impact Site (LC)			
Malapert Mountain (MM)			
M5			
Scott Crater (SC)			
Shackleton Crater (SH)			
Shoemaker Crater (SM)			

Q1. Explain your reasoning behind scoring the sites in the way that you have.

Q2. Based on your criteria, are any of the locations unsuitable? Why?

Q3. Explain how you think the LEND data should be weighted in relation to the three other datasets and why.

Communications Technician Worksheet

Name ________________________________

Site	Earth Visibility (days/yr)	Eliminated?	Score
Amundsen Crater (AM)			
LCROSS Impact Site (LC)			
Malapert Mountain (MM)			
M5			
Scott Crater (SC)			
Shackleton Crater (SH)			
Shoemaker Crater (SM)			

Q1. Explain your reasoning behind scoring the sites in the way that you have.

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Q2. Based on your criteria, are any of the locations unsuitable? Why?

____

____

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Q3. Explain how you think the earth visibility model should be weighted in relation to the three other datasets and why.

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Energy Technician Worksheet

Name ______________________________

Site	Sun Visibility (days/yr)	Eliminated?	Score
Amundsen Crater (AM)			
LCROSS Impact Site (LC)			
Malapert Mountain (MM)			
M5			
Scott Crater (SC)			
Shackleton Crater (SH)			
Shoemaker Crater (SM)			

Q1. Explain your reasoning behind scoring the sites in the way that you have.

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Q2. Based on your criteria, are any of the locations unsuitable? Why?

____

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Q3. Explain how you think the sun visibility model should be weighted in relation to the three other datasets and why.

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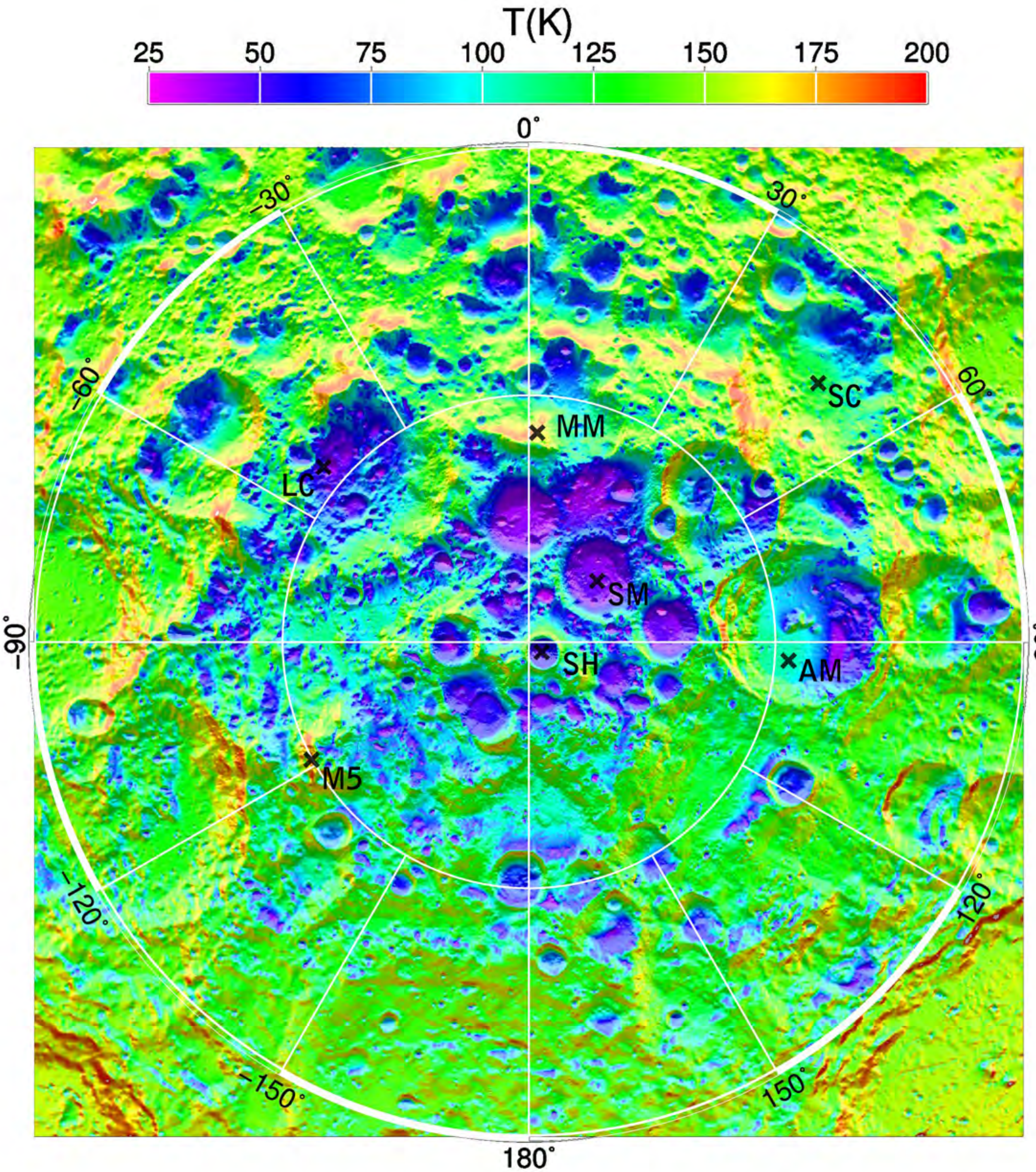
Group Worksheet

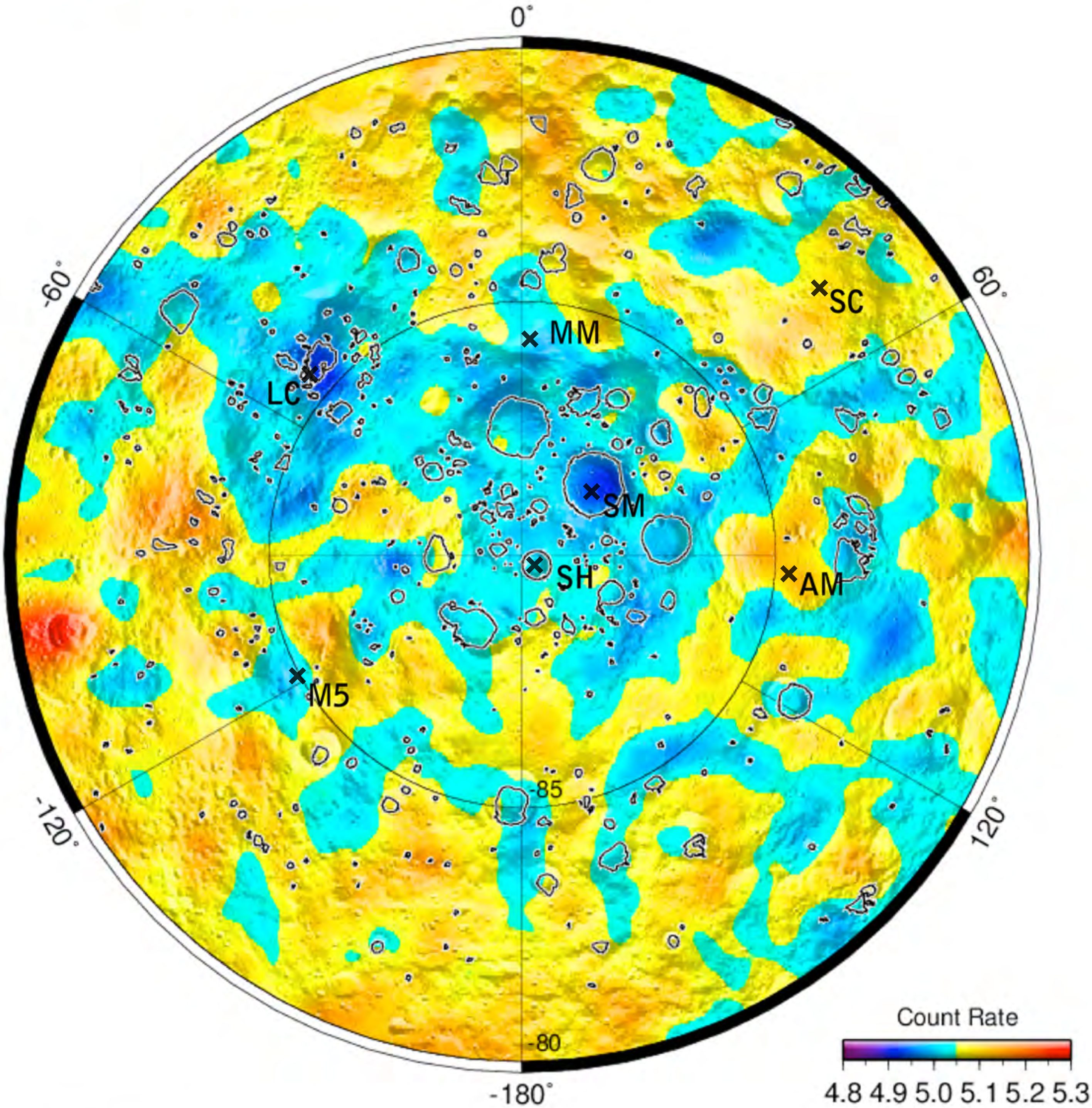
Site	Temperature			Water			Illumination			Communication			Total Score	Rank
	Score	Weight	Weighted Score	Score	Weight	Weighted Score	Score	Weight	Weighted Score	Score	Weight	Weighted Score		
Amundsen Crater														
LCROSS Impact Site														
Malapert Mountain														
M5														
Scott Crater														
Shackleton Crater														
Shoemaker Crater														

Diviner Temperature Map



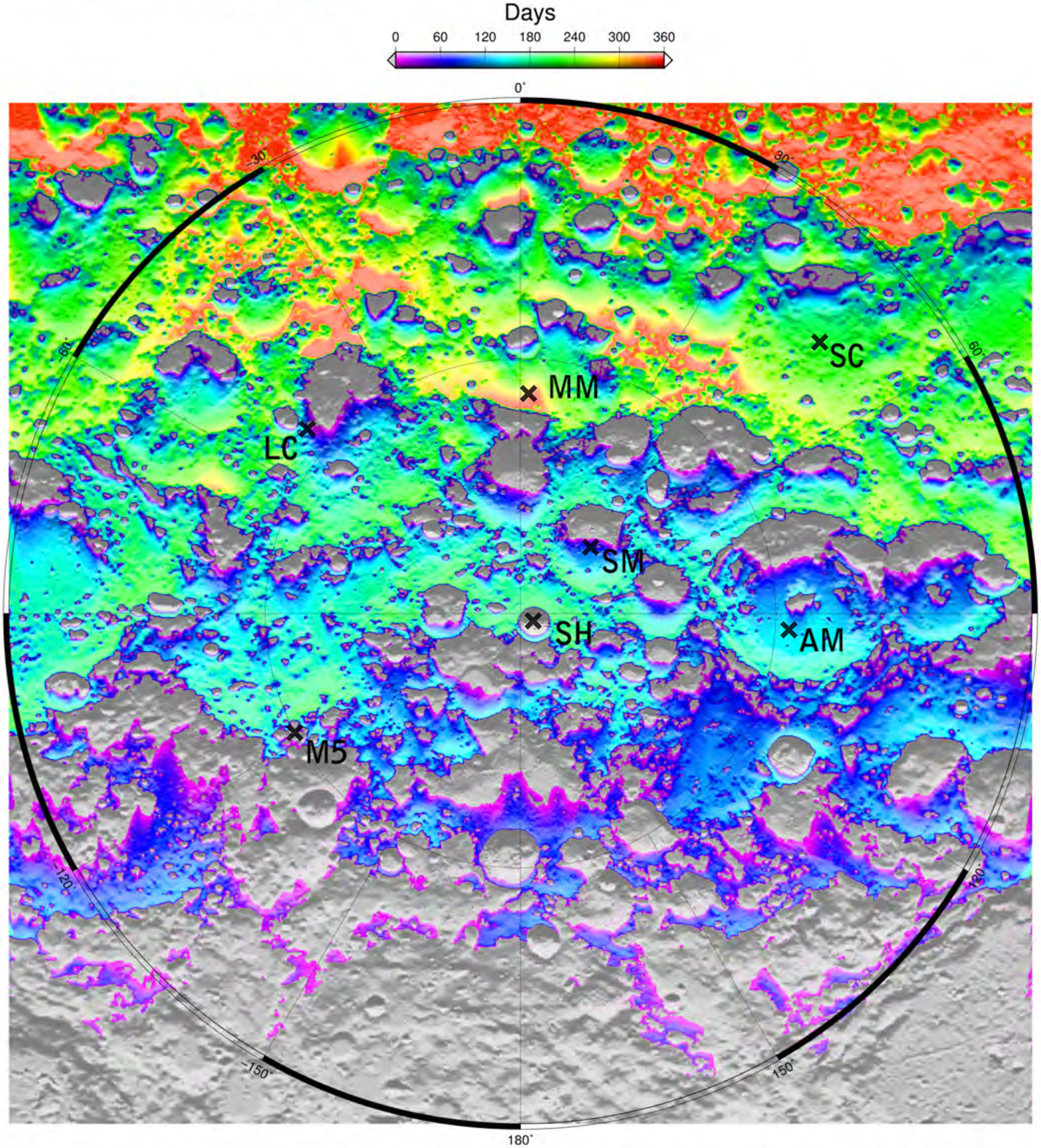
Map showing model-calculated yearly average surface temperatures in the lunar south polar region.

LEND Neutron Map



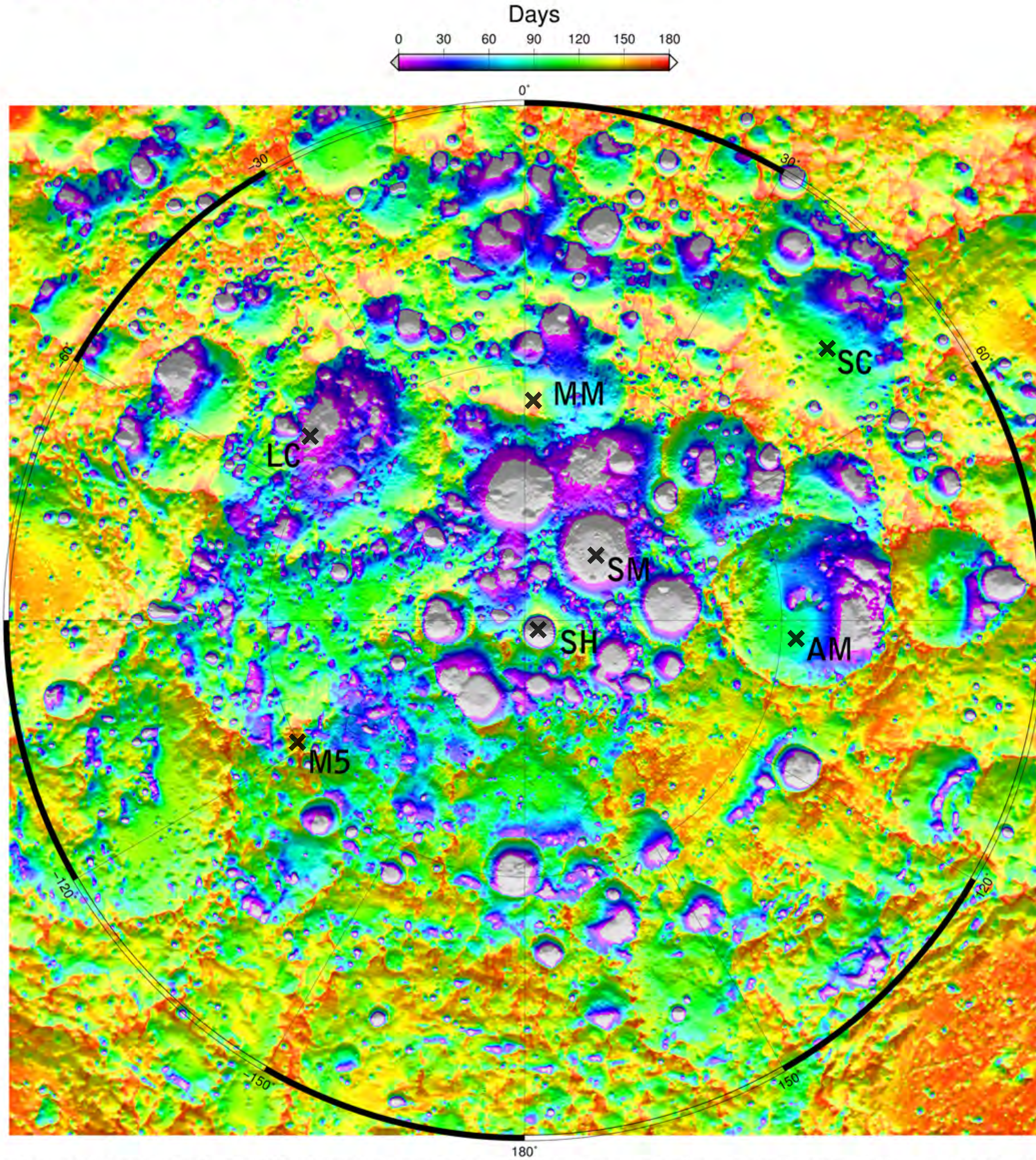
Map showing measurements of epithermal neutrons from the uppermost 0.5m of lunar soil in the lunar south polar region.

Earth Visibility Map



Map showing number of Earth days each year that the Earth is visible above the local horizon in the lunar south polar region.

Sun Visibility Map



Map showing number of Earth days each year that the sun is visible in it's entirety above the local horizon in the lunar south polar region.