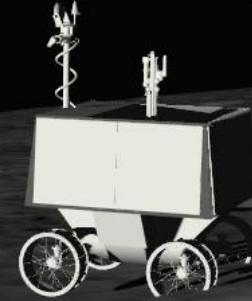




National Aeronautics and
Space Administration



An Overview of Mission Planning for the VIPER Rover

Mark Shirley & Edward Balaban

June 2, 2022

Why VIPER?



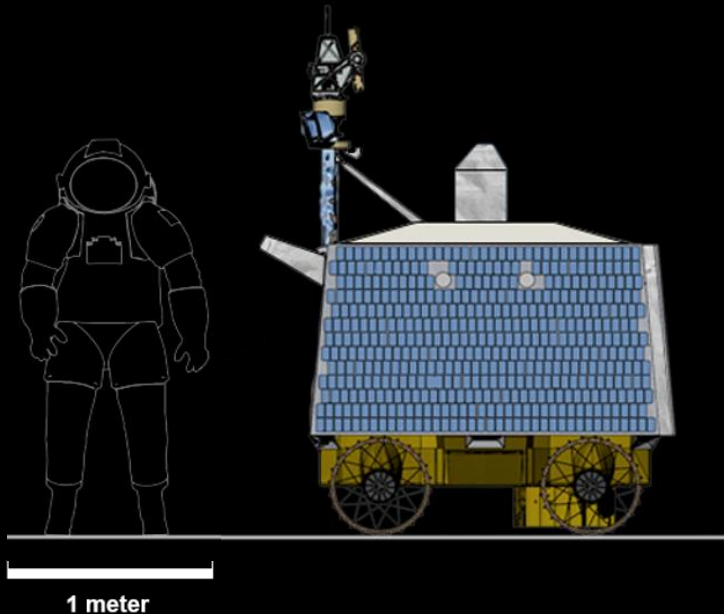
Lunar Polar Volatiles

- detected from orbit by remote sensing
- frozen water, methane ... (liquid or gas at room temp)

VIPER will ...

- make direct measurements of polar volatiles
- characterize their **physical state & composition**
- characterize horizontal & vertical **distribution** at scales relevant to potential **extraction processes**
- provide **ground truth** for orbital datasets used to create **lunar resource maps**

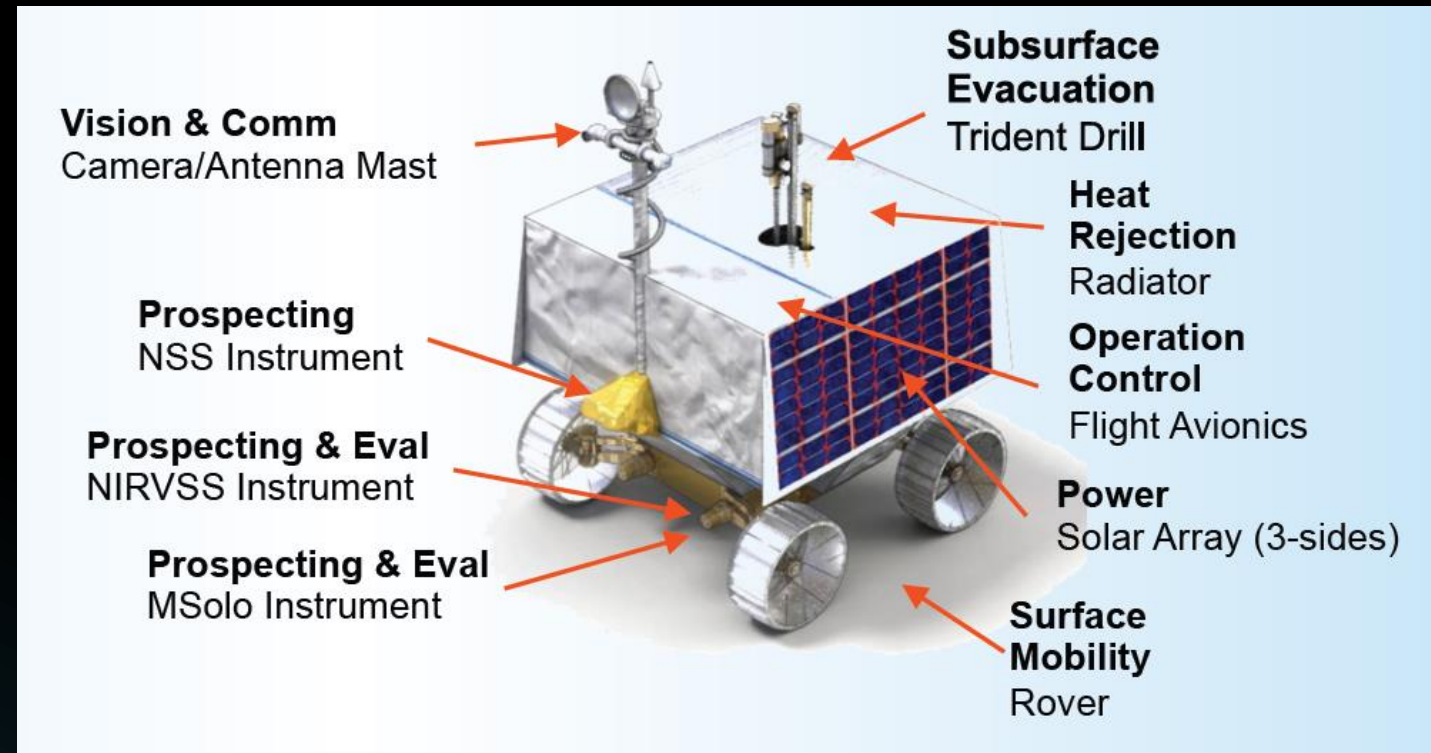
Key Engineering Specs



- Solar-powered rover
 - Dark Survivability: 50hrs in minimal power mode
 - Working Duration in shadow (w/drill): ~9 hrs
- Line-of-sight to Earth radio comms
 - Teleoperated from the ground
- Mission Duration: 100+ earth days
- Driving
 - Distance Travelled (goal): 20 km
 - 1 cm/s average speed
 - 10 cm/s when moving (waiting 90% of time)
 - 15 deg slope limit
 - Can negotiate 10 cm obstacles

Instruments

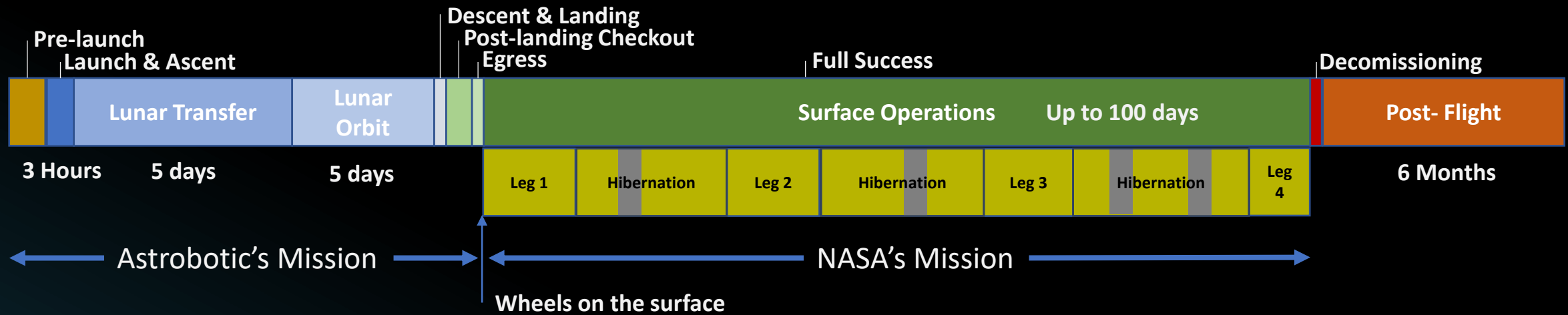
- Drill (1m)
- Spectrometers
 - Neutron (detects subsurface hydrogen-bearing compounds)
 - Near-IR (surface composition, incl. drill tailings)
 - Mass Spec (composition of volatiles)
- Cameras
 - Downward (sees surface and drill)
 - Stereo pair on mast (geological context, navigation)



Instruments were selected to operate as an integrated whole

- No resource or scheduling 'competition' between instrument teams
- Instruments are continuously active (not the drill)

Mission Plan Structure



- VIPER is a Commercial Lunar Payload Services (CLPS) mission
- Astrobotic is building the lander
- Astrobotic contracted with SpaceX for a Falcon Heavy launch

- VIPER is cargo until it's on the surface
- Our mission planning does involve scheduling activities during the transfer and lunar orbit phases
- This talk focuses on the [surface mission](#)

The heart of the planning problem

Why are solar power and DTE comms strong planning constraints?

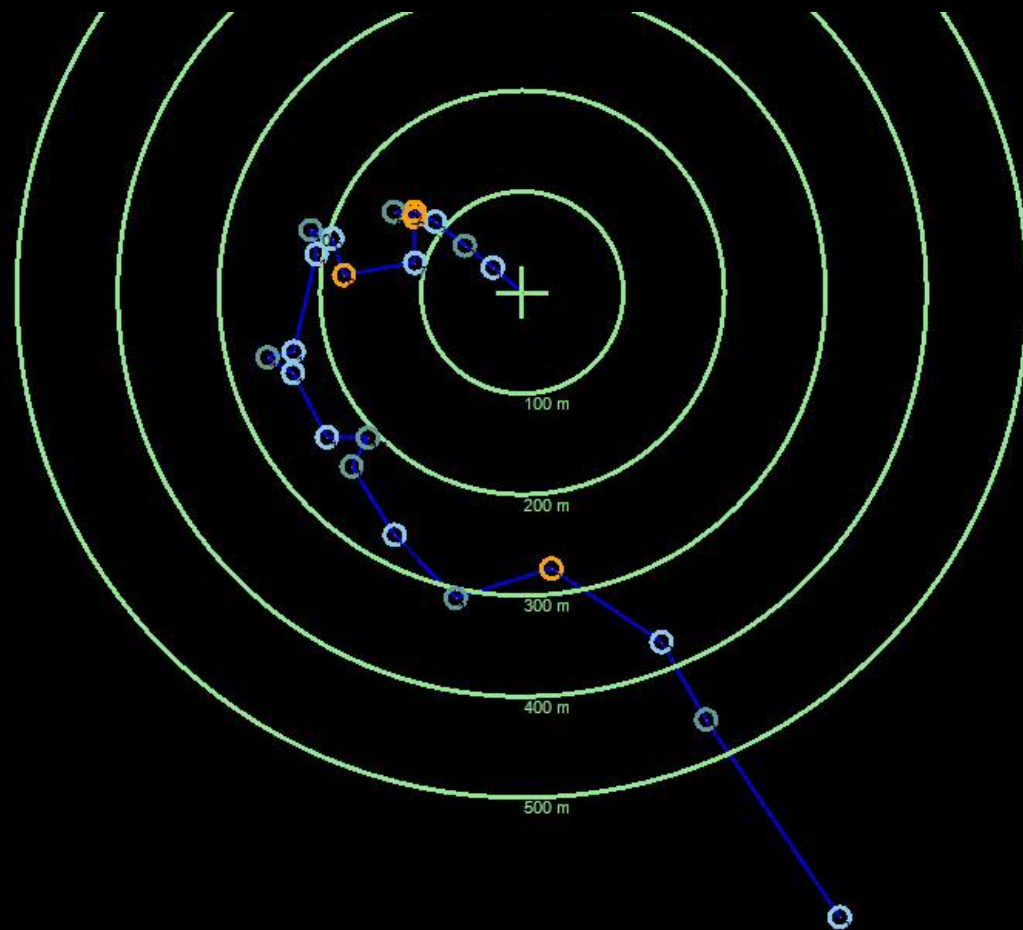
- At the poles, the sun casts long shadows



- Similar radio shadows are cast when using a line-of-site radio link to ground stations
- Sun and radio shadows move at speeds similar to VIPER's average speed
- Therefore ...

Traverses must be timed to avoid moving shadows

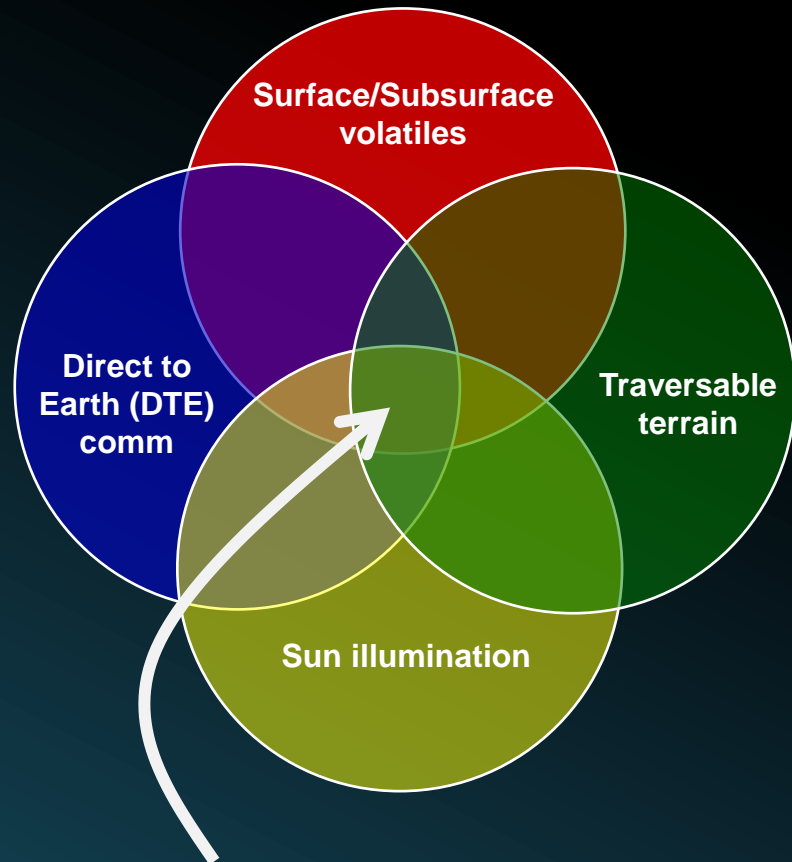
- Limiting periods of sun shadow based on battery capacity
- Avoiding comm shadow completely except for periods of sleep between earth view periods (~ half of each month)



grayscale=amount of sunlight
green=candidate landing sites; red=potential landing site

Site Selection: Where to land the rover?

Requirements



Mission sites must meet all four criteria

Preferences:

Support a multi-lunar-day mission

Support access to permanent shadow
in craters of a variety of ages

Neutron spectroscopy from Orbit

Water Equivalent Hydrogen (Lunar Prospector, '98)

Scott M

Scott

Malapert

Wapowski



LCROSS '09

Cabeus

Found 4-6% water by weight

Nobile

Haworth

Shoemaker

Ibn Bajja

Amundsen

Faustini

de Gerlache

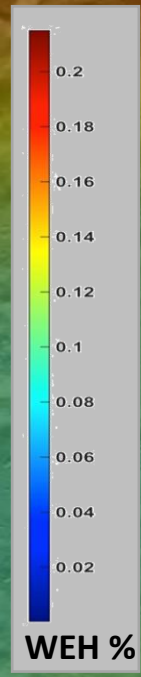
South Pole

Shackleton

To Earth

10 km

8



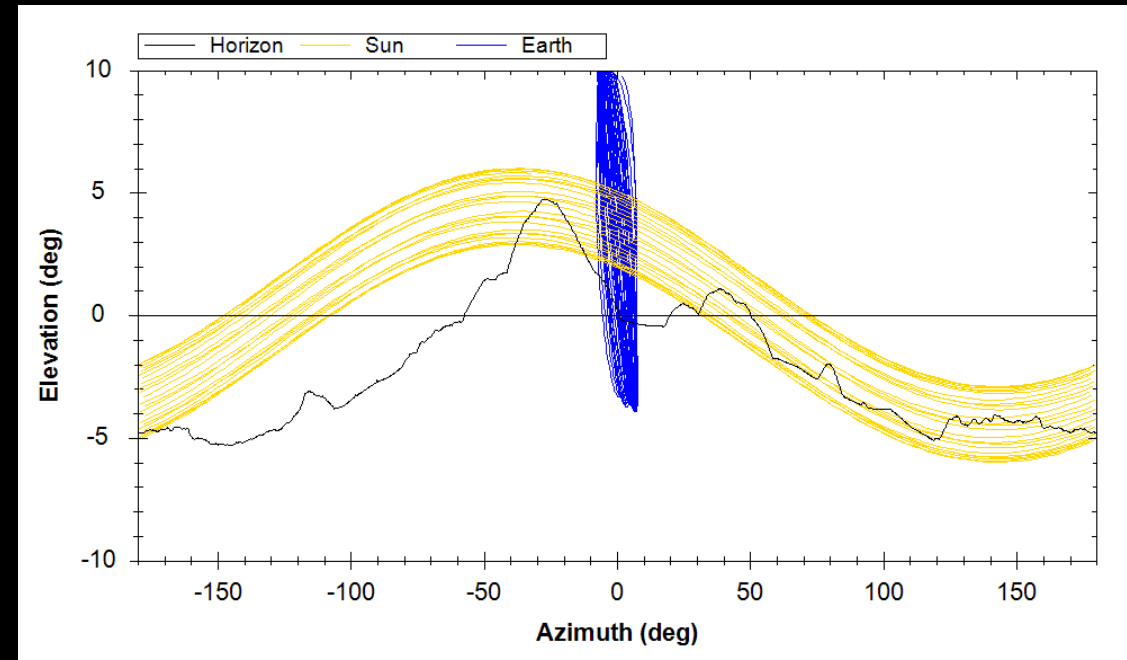
Lighting when Earth below horizon is Tightest Constraint

- VIPER uses sunlight for power
- NASA prefers a mission lasting more than one lunar day
- From near the south pole, the Earth is below the horizon for $\frac{1}{2}$ of each lunar day, preventing DTE comms
- During these times, VIPER will be in a low power 'hibernation' mode, waiting for commands

- Key question:

How much is the Sun up while the Earth is down?

- Suppose the rover can survive 50 hours in shadow in a low-power mode
- Where could that be?
- We call those locations **Safe Havens**

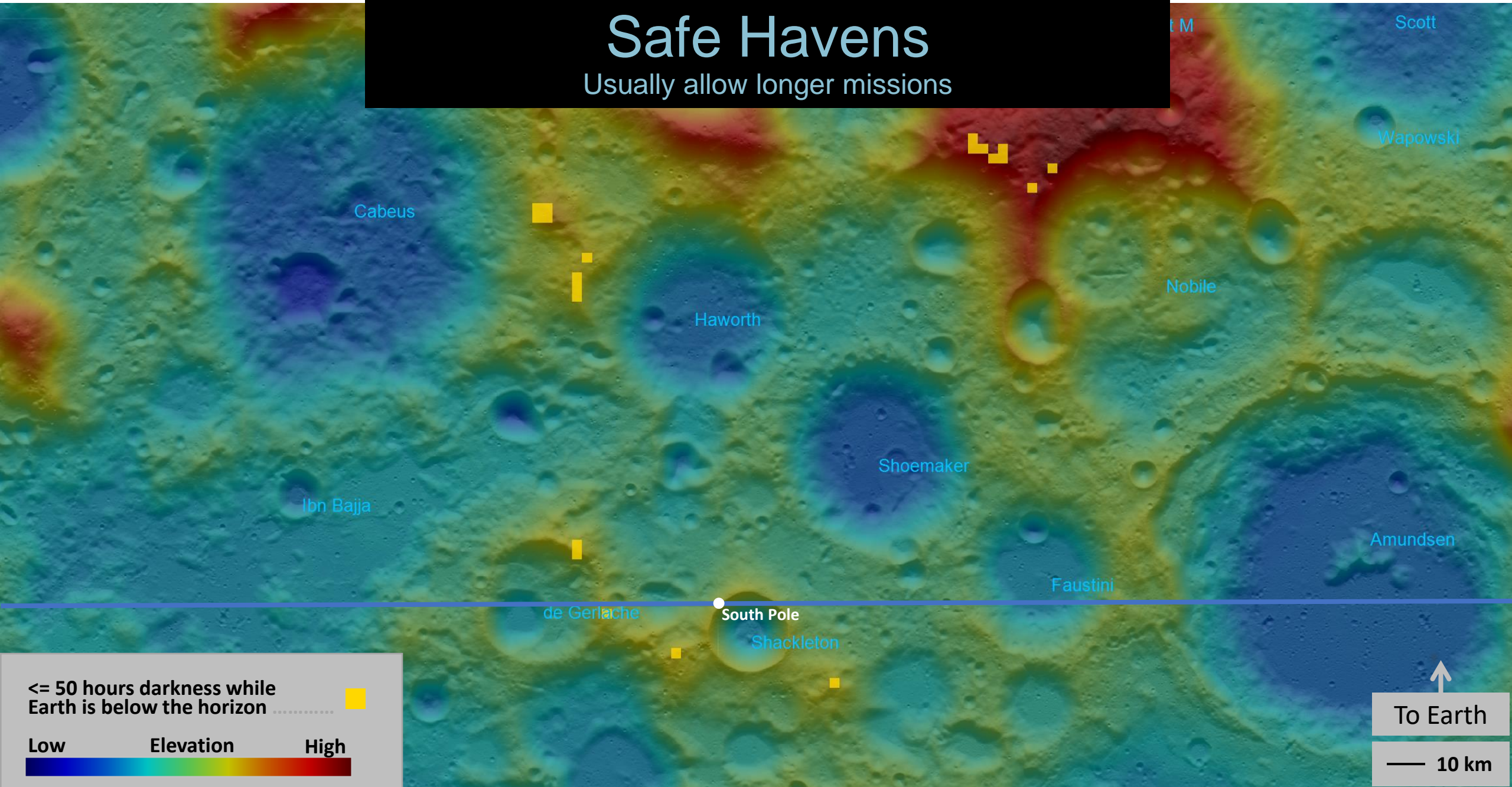


How we found them

- Calculate horizons for all pixels in a ~3000 square mile DEM (20m spacing)
- Calculate lighting and Earth visibility for each pixel over a 6 month period in '23-'24
- Search for appropriate intervals of earth and sun visibility

Safe Havens

Usually allow longer missions



≤ 50 hours darkness while Earth is below the horizon



Low Elevation High

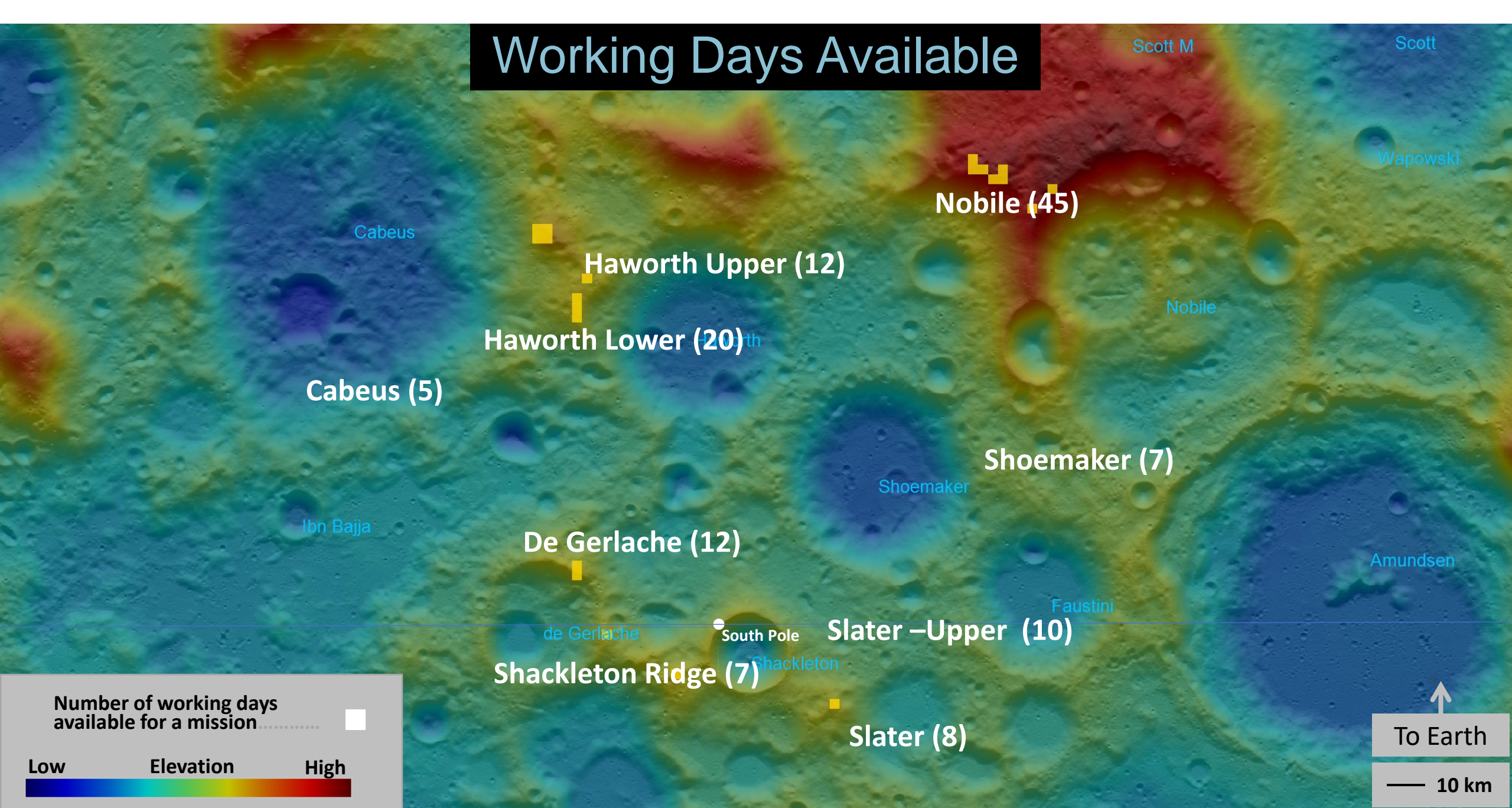


To Earth

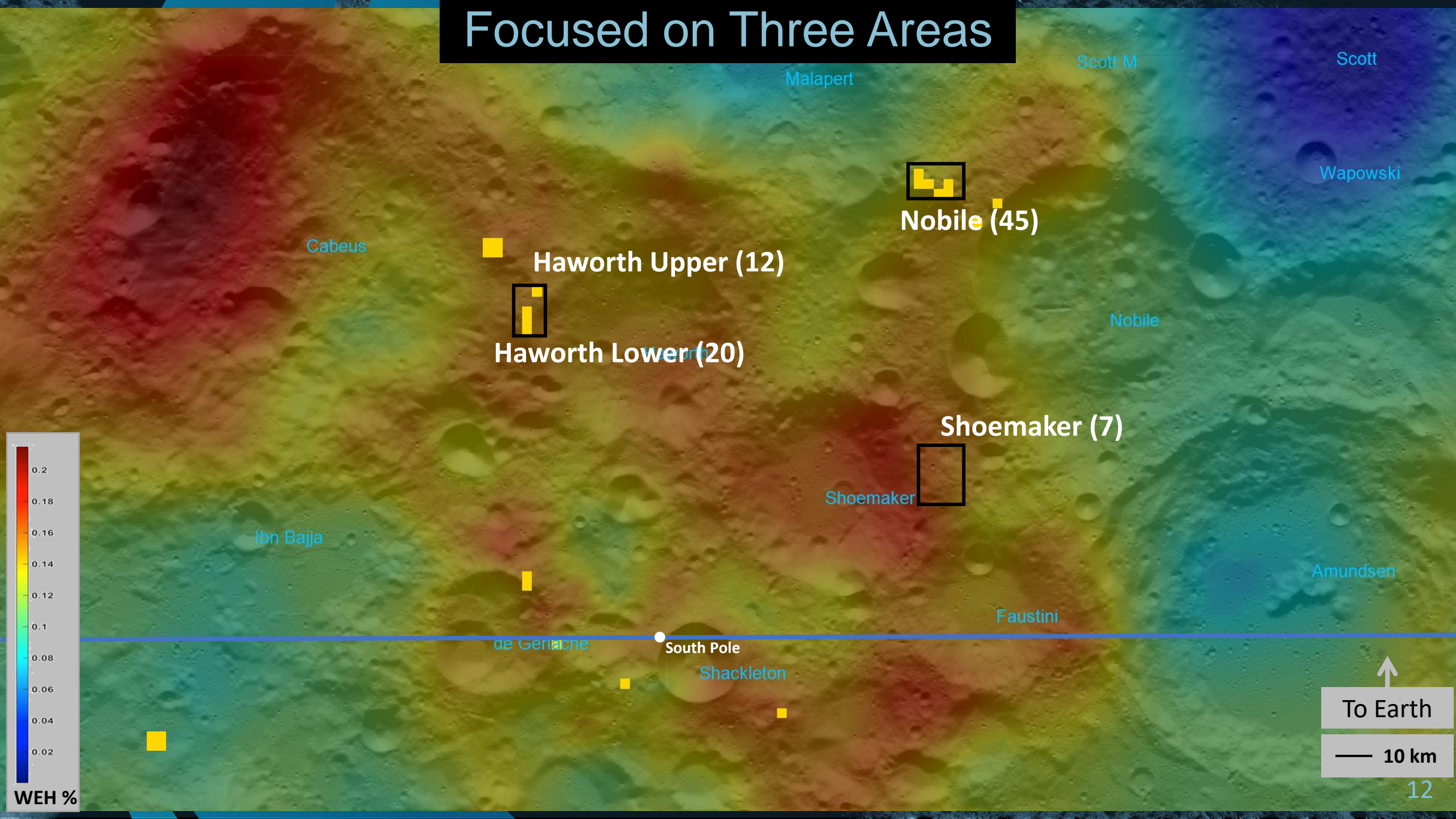
10 km

10

Working Days Available



Focused on Three Areas



Malapert

Scott M

Scott

Wapowski

Cabeus

Haworth Upper (12)

Nobile (45)

Haworth Lower (20)

Nobile

Shoemaker (7)

Shoemaker

Ibn Bajja

Amundsen

Faustini

de Germaine

South Pole

Shackleton

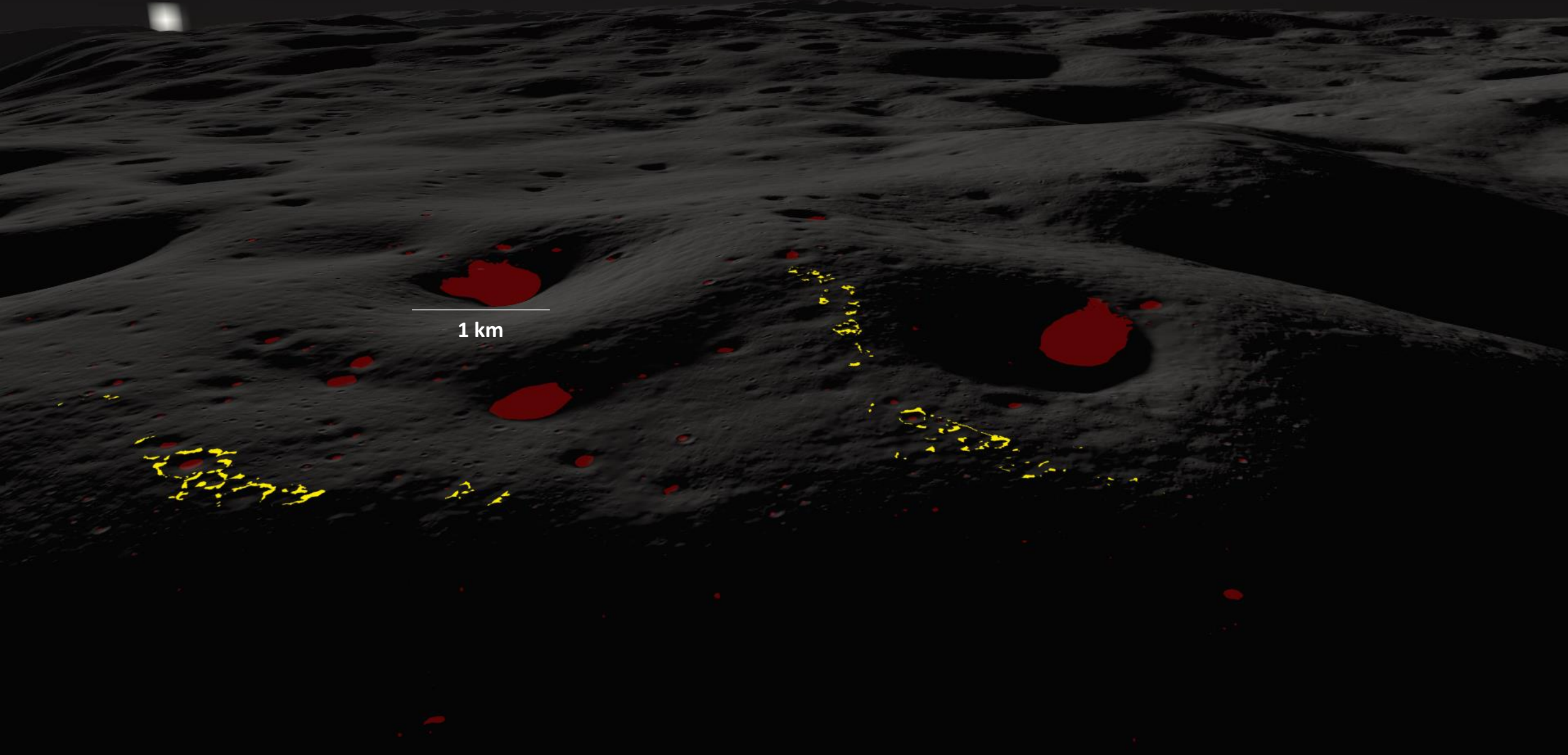
To Earth

10 km

12

WEH %

Nobile Site Overview



1 km

Surface Mission Design Drivers

Science Station

- A virtual measurement using all instruments
- Goal: Estimate the amount of volatiles in top meter of a 3800 m² area
- Resource need case: 5% water => O₂ for crew of 4 for 1 year
- Instrument coverage: 10-15% of the area produces adequate statistics for estimate
- Linear coverage: 224-335 m of driving
- Drill 3 times to 1m depth to ground truth the measurements made while driving

Full mission success involves executing 6 science stations

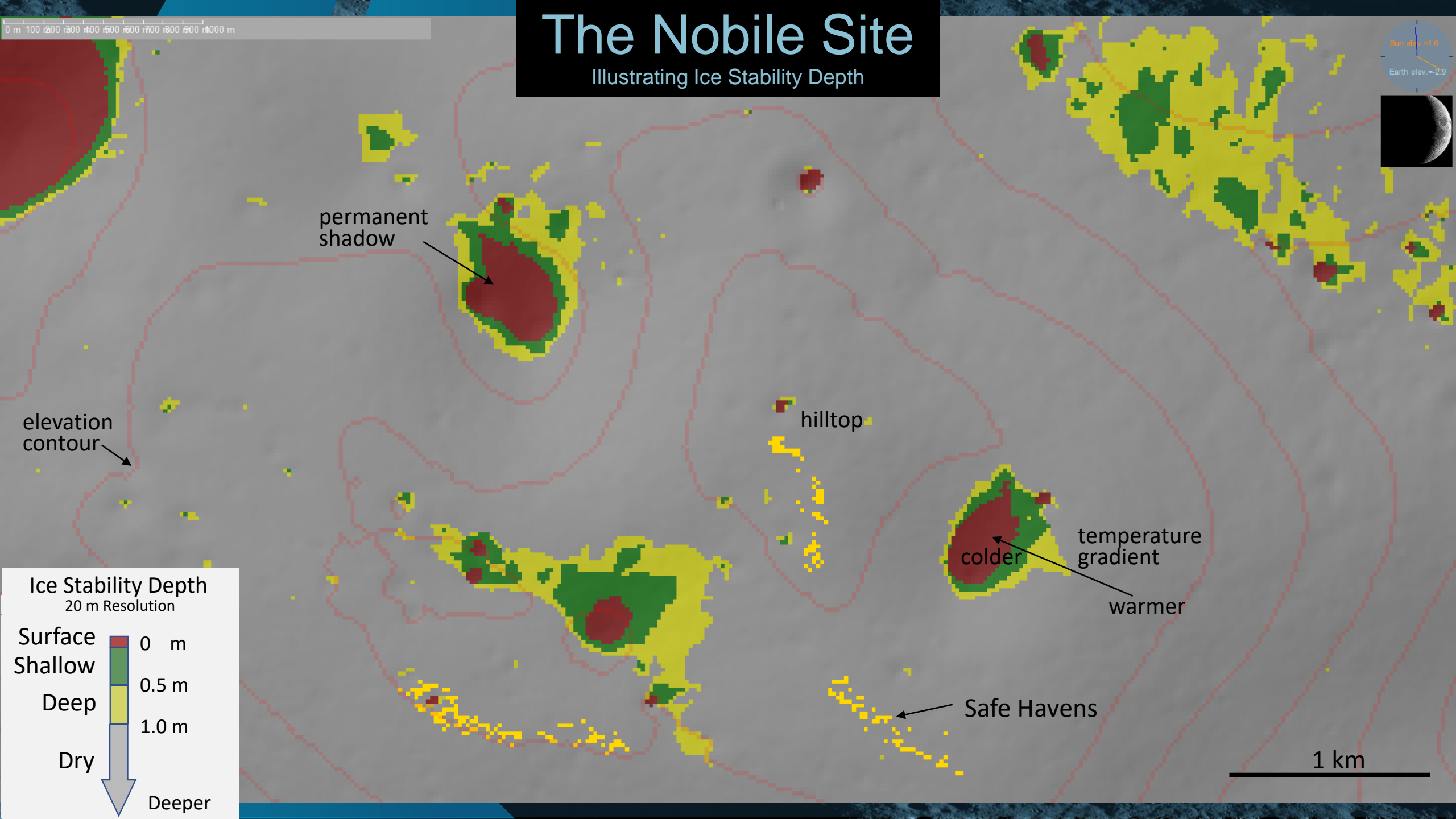
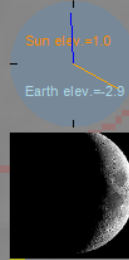
Science stations must be placed across a variety of **thermal environments**

Thermal environments are characterized by a calculated **ice stability depth**

The Nobile Site

Illustrating Ice Stability Depth

0 m 100 200 300 400 500 600 700 800 900 1000 m



elevation contour

permanent shadow

hilltop

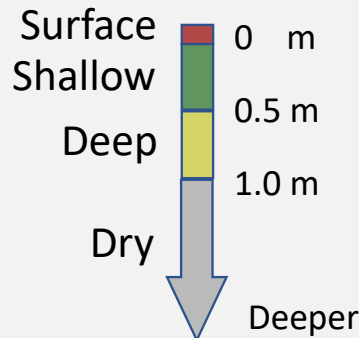
colder

temperature gradient
warmer

Safe Havens

1 km

Ice Stability Depth
20 m Resolution

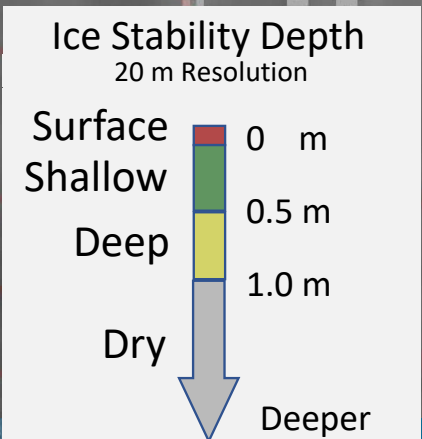


Candidate Science Stations

0 m 100 200 300 400 500 600 700 800 900 1000 m

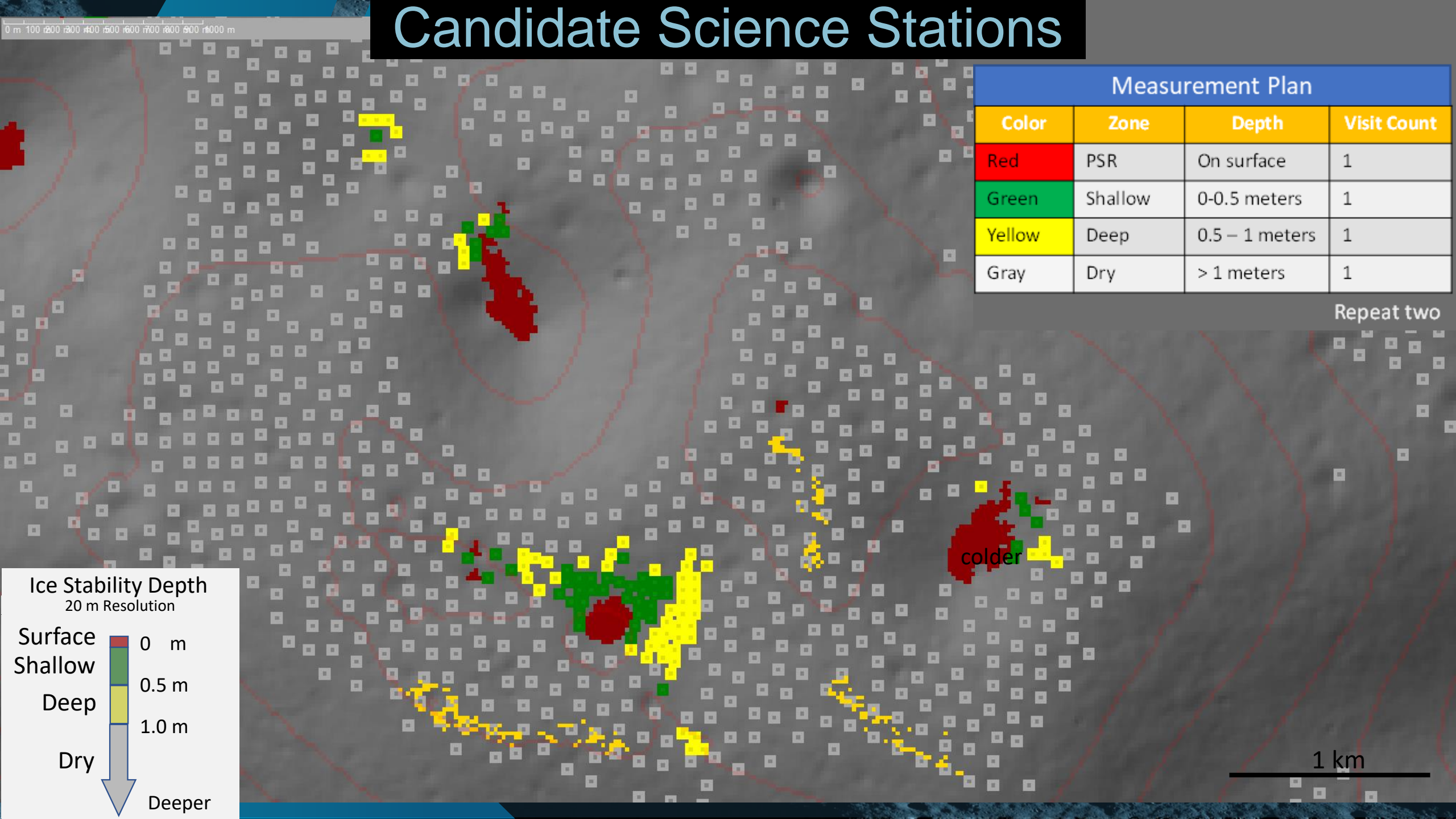
Measurement Plan			
Color	Zone	Depth	Visit Count
Red	PSR	On surface	1
Green	Shallow	0-0.5 meters	1
Yellow	Deep	0.5 – 1 meters	1
Gray	Dry	> 1 meters	1

Repeat two



colder

1 km



Traverse Planning Algorithm #1

Divide planning into

1. Select a sequence of visits to candidate science stations
2. Plan route inside each science station by hand

Step #1 is treated as

- a cost-constrained traveling salesman problem
 - Cities have a score
 - Visit a subset of them, not all
 - Maximize the sum of the city scores
 - Drives between cities have a cost (which models time)
 - Don't exceed a total cost (the time Earth is above the horizon at the site)
- with time window constraints
 - Science station visits must occur in sun (except for entry into permanent shadow)
 - Drives must occur in sun

Comparing Sites by the Traverses They Support

- My solution for this problem isn't particularly interesting (brute force worked well enough ... 3-6 hours runtime)
- This algorithm generated families of traverses for the Nobile, Haworth and Shoemaker sites
- The Nobile site had the longest and most varied traverses and was chosen
- We've moved to a more sophisticated algorithm for strategic planning
- Described next

