Real-time science operations to support a lunar polar volatiles rover mission

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RESOLVE is a lunar rover mission to

(1) locate near subsurface volatiles,
(2) excavate & analyze samples of volatile-bearing regolith,
(3) demonstrate the form, extractability and usefulness of the materials.

RESOLVE = Regolith and Environment Science and Oxygen & Lunar Volatile Extraction
Site selection

Depth to Stable Ice (m)

LCROSS

South pole
Site selection

Maximum Days of Sunlight Using LOLA DEM

LCROSS
South pole
Site selection

**Combined Site Analysis**

<table>
<thead>
<tr>
<th>Site</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ice Depth</td>
<td>&lt;0.1 m</td>
<td>&lt;0.2 m</td>
<td>&lt;0.1 m</td>
</tr>
<tr>
<td>Shallow “Frost Line”</td>
<td>&lt;10°</td>
<td>&lt;15°</td>
<td>&lt;10°</td>
</tr>
<tr>
<td>Neuron Depletion</td>
<td>4.5 cps</td>
<td>4.7 cps</td>
<td>4.9 cps</td>
</tr>
<tr>
<td>Temporary Sun*</td>
<td>4 days</td>
<td>2-4 days</td>
<td>5-7 d</td>
</tr>
<tr>
<td>Comm Line of Sight*</td>
<td>8 days</td>
<td>17 days</td>
<td>17 days</td>
</tr>
</tbody>
</table>

* may not coincide
Site selection

**Combined Site Analysis**

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<td>&lt;0.1 m</td>
<td>&lt;0.2 m</td>
<td>&lt;0.1 m</td>
</tr>
<tr>
<td>Slopes</td>
<td>&lt;10°</td>
<td>&lt;15°</td>
<td>&lt;10°</td>
</tr>
<tr>
<td>Neutron Depletion</td>
<td>4.5 cps</td>
<td>4.7 cps</td>
<td>4.9 cps</td>
</tr>
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Mission duration → **2-7 days of expected sunlight**.

Due to the limited operational time, **science operations must be near real time**.

→ Requires immediate situational awareness, data analysis and decision support tools.

**Site selection affects concept of operations.**
July 2012 field campaign

Rover field site = Hawaii
Operations centers = distributed.
**Science**: Direct comm with Flight Director. Relay science information between Flight and Science Team.

**RT (Real Time) Science**: Relay consensus science recommendations to Science, consult with Science Team to answer Flight Director questions re. science ops. Monitor real-time data.

**Spec (Spectrometer) Science**: Recommend traverse plan modifications based on science. Monitor real-time data.

**Science BR (Backroom)**: Assist RT & Spec Sci, conduct more detailed data analysis, create traverse plan updates, monitor real-time data.
Science communications

- Flight Director
- Science
- Real-Time Science
- Spec Science
- Science Backroom
Real-time science operations

Flight control center in Hawaii

Science Backroom at NASA Ames
# Prospecting payload

- **NIR spectrometer (NIR):** surface volatiles
- **Neutron spectrometer (NS):** volumetric volatiles

## RESOLVE Truth Table

<table>
<thead>
<tr>
<th>Subsystem Alert Status</th>
<th>NIR Signal: YES</th>
<th>NIR Signal: NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>NS Signal: YES</td>
<td>Indication: Both volumetric and surficial volatiles present.</td>
<td>Indication: Subsurface volatiles only.</td>
</tr>
<tr>
<td></td>
<td>Recommendation: Auger and/or core</td>
<td>Recommendation: Auger</td>
</tr>
<tr>
<td>NS Signal: NO</td>
<td>Surficial material only, or volumetrically minor constituent (&lt; 1 wt% equivalent)</td>
<td>No volatiles of significance.</td>
</tr>
<tr>
<td></td>
<td>Recommendation: Drill/auger if time/energy permits</td>
<td>Recommendation: Only auger if the 12-hr flight rule is in play.</td>
</tr>
</tbody>
</table>
Real-time science operations activities require novel software capabilities to enable:

1) real-time monitoring of the prospecting data to support science decision-making and
2) real-time traverse plan updates.

xGDS: Exploration Ground Data Systems

Intelligent Robotics Group (IRG), NASA Ames Research Center (Terry Fong & Matt Deans)
xGDS: Traverse planning

- Shadow in PM
- Dark Area (run-off)
- Dark Area (low spot)
- Rocks on slope
- Single dark streak
- Multiple dark streaks
- White spot
- Base of cinder cone
- Bushes 1
- Bushes 2
- Bushes 3
- Rocks at base of cinder cone
- Shadow in AM
- Rocks at base of cinder cone 2
xGDS: Traverse planning
xGDS: Real-time data monitoring

NS: bulk water

NIR: surface-bound water
xGDS: Real-time data monitoring

NS: bulk water

NIR: surface-bound water

Bulk water only
Surface-bound water only
Surface-bound and bulk water
xGDS: Real-time data monitoring
xGDS: Real-time data monitoring

Drill Thrust

Drillhead Position

NIR Waterband 1
Contact with ground

Soft material

Harder material

Extraction

No appreciable water signal

xGDS: Real-time data monitoring
Conclusions

• This lunar polar volatiles mission requires highly efficient, real time, remotely operated rover operations.

• The mission requires real-time communication between science operations personnel and flight mission operators to ensure results of key science observations are available for mission operations and planning decisions.

• A science backroom is required to enable real-time science support for the science operations personnel.

• Ground support software is required to enable real-time data monitoring and decision making.

• The RESOLVE July 2012 field campaign demonstrated that this novel methodology of real-time science operations is possible and can yield important new insights regarding lunar polar volatiles for both science and exploration.