Topics

Randomly:
• Earth Venture proposal experience.
• The requirement flow-down.
• The Science Traceability Metrics.
• Understanding the limitations.
• Next steps.
Introduction

• The Mission to Understand Ice Retreat proposal was developed by Andrea’s team for the Earth Venture Instrument 2 call.
• The Proposal was not submitted because we were not ready for this call.
• Next two calls in the 12-18 months time frame.
• This is a competitive call, only the best proposal (in all aspects) is going to be selected.
• We were not ready in many aspects.
Science case

- What fraction of glacier mass loss is driven by solar radiation?
- Determine how albedo drives ice loss
- MUIR simultaneously measures mass change and albedo

- The science case was initially well received
- Is it strong enough in light of the competition?
- Free telescope time can be used for additional science, how to get credit for that without making the story to confusing.
Science Requirements

• Compelling science requirements is not sufficient.
• Need to convert science case into hypothesis and model.
• Define what parameters need to be determined through the science mission.
• Quantify how well you need to measure the experimental parameters to meet your science objectives.
• The cleaner the objective->experimental measurement story, the stronger the proposal.
• A model of the science experiment or even better experimental results from a similar (flight/airborne) experiment are key to build the case.
• Ideally, we can generate key sensitivity for driving requirements: volume error vs vertical resolution,...
Developing a model to flow requirements

Conservation of Energy and Mass

<table>
<thead>
<tr>
<th>Terms</th>
</tr>
</thead>
<tbody>
<tr>
<td>• ( \Delta E_s = \text{Absorbed solar energy} )</td>
</tr>
<tr>
<td>• ( \Delta M = \text{Total mass change} )</td>
</tr>
<tr>
<td>- ( \Delta M_M = \text{Mass lost from melting} )</td>
</tr>
<tr>
<td>- ( \Delta M_O = \text{All other sources of mass (precipitation, mass wasting, etc.)} )</td>
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<tr>
<td>• ( L = \text{latent heat of melting ice} )</td>
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- \( \Delta M = \Delta M_M + \Delta M_O \) (total mass lost)
- \( \Delta M_M = \Delta E_s / L \) (amount of ice melted from absorbed solar energy)
- \( \Delta M_O = \Delta M - \Delta E_s / L \) (compute mass lost from other sources)
- \( \Delta M_M / \Delta M_O \) (Fraction of mass lost from absorbed solar energy)

MUIR measures \( \Delta E_s \) and \( \Delta M \) for *hundreds* of glaciers
## The Science Traceability Matrix

<table>
<thead>
<tr>
<th>Science Goals</th>
<th>Science Objectives</th>
<th>Science Measurement Requirements</th>
<th>Science Requirements</th>
<th>Instrument Requirements</th>
<th>Projected Performance</th>
<th>Mission Requirements (Top Level)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Observables (function of time)</td>
<td>Physical Parameters</td>
<td></td>
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<tr>
<td>Determine the fraction of glacier mass loss driven by solar radiation</td>
<td>Determine glacier mass balance variability</td>
<td>Glacier extent (M1) Georectified coregistered imagery (P1)</td>
<td>Targets ≥396 quarterly</td>
<td>727 quarterly</td>
<td>Mountain glaciers</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>Single image resolution 1 m/pixel nadir ground scale</td>
<td>80 cm diffraction limited resolution</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Combined images resolution 50 cm (post-processed)</td>
<td>30 cm (post-processed)</td>
<td>Tie points in image</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Field of view ≥ 1 km at nadir</td>
<td>1.9 x 2 km at nadir</td>
<td>Sub-seasonal sampling</td>
<td></td>
</tr>
<tr>
<td>Flow rates (M2)</td>
<td>Correlated changes between passes (P2)</td>
<td>Group motion of features</td>
<td>30 cm/pair</td>
<td>10 cm/pair</td>
<td>≥4 passes of observations /target/year</td>
<td></td>
</tr>
<tr>
<td>Glacier surface shape (M3)</td>
<td>Digital Elevation Models (DEMs) (P4)</td>
<td>Vertical resolution 50 cm (post-processed)</td>
<td>35 cm (post-processed/pixel)</td>
<td>Staring capability</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Field of regard 50° radius cone around nadir</td>
<td>60° along/50° cross track at nadir</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pointing control knowledge accuracy jitter</td>
<td>At nadir 100 m 150 m 250 m 50 cm</td>
<td>At nadir 97 m 113 m 214 m 38 cm</td>
<td>Non-sun synchronous orbit</td>
<td></td>
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<tr>
<td></td>
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<td>Bidirectional reflectance bidirectional reflectance distribution function (BRDF) (P5)</td>
<td>Views per pass ≥10 each color</td>
<td>10-95 each color</td>
<td>Variable illumination</td>
<td></td>
</tr>
<tr>
<td>Determine solar energy input to glaciers</td>
<td>Albedo (M4)</td>
<td>Reflectance (scene average) SNR ≥100</td>
<td>SNR 100–170</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Multispectral (P6)</td>
<td>Color Blue, green, red, NIR</td>
<td>487, 562, 660, 835 nm</td>
<td>Filter wheel</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Integrated BRDF over all angles (P7)</td>
<td>Accuracy 2%</td>
<td>1%</td>
<td>Monochromatic imagery</td>
<td></td>
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</tbody>
</table>
Mission/Instrument Requirements

• Once the science requirements are established and justified, we need to develop the Mission and Instrument requirements.

• Again a mission/instrument model showing how the science requirements can be met for a set of instrument parameters.
Pointing accuracy and field of view

Minimum Required Pointing Accuracy: 250m RMS (500m 2σ)

Pointing Accuracy:
- Design: 213m RMS
- Performance: 149m RMS

Pointing Knowledge:
- Design: 161m RMS
- Performance: 113m RMS (284μrad RMS)

Pointing Control:
- Design: 139m RMS
- Performance: 97m RMS (244μrad RMS)

Camera FOV

Scene

GSD resolution: 0.8m per pixel

95% probability to fall entirely in detector

Dimensions:
- 2.70km x 1.7km
- 2.92km x 1.7km

2.50m RMS
Imaging resolution error budget

Stereo-Imaging (30 views over 100°)
Vertical Height Resolution
0.70m Design
0.55m Performance

Horizontal Resolution at nadir
1.45m Design (1.82pix)
1.14m Performance (1.42pix)

Diffraction FWHM (λ/D)
1.06m Design (1.33pix)
0.9m Performance* (1.13pix)
*for 562nm Green channel

Pointing Jitter one sigma
0.50m Design (0.63pix)
0.35m Performance (0.44pix)

RMS height error vs. # views, 0.8m pix, 0.91pix RMS noise

Diffraction (25cm aperture)

Pointing jitter (20ms)
EVI-2 Lessons-learned

- Started by an instrument of similar size as SkySat1.
- Develop science/mission/instrument requirements.
- Concluded that the instrument had to be significantly increased to meet the requirements.
- However: “Who believe we cannot do game changing science with a dedicated SkySat1-like satellite?”
- We need to start the requirement definition/validation process very early to get a chance to iterate.
The limitation for glaciers

• Super-resolution:
  – Can beat down optical aberration, under-sampling.
  – Works well with high contrast scene, high SNR data.
  – Cannot compensate for diffraction limitations.
  – Does not work well with low contrast scene, low SNR data.

• 3D reconstruction:
  – Accuracy increase with angle diversity.
  – Need features and texture to build the DEM.
  – Features and texture need to be well contrasted.
  – Features and texture vary with viewing angles.
  – Features and texture can vary significantly from visit to re-visit.
The limitation for short events in process

- Staring imaging is time expensive: ~5 minutes repointing for 5 minutes staring.
- For an optimized schedule the number of observations is likely no more than 4 observations per orbit.
- Taking into account land surface, S/C downtime, cloud coverage, the mission efficiency is likely less than 20 observations per day.
- Establishing a science case around observing short, rare, unpredictable event (landslide, avalanches) is not credible.
Conclusion

• We learned a lot from the EV2 proposal experience.
• There is a clear interest/need for this type of Space instrument.
• We are a lot better off than one year ago.
• The collaboration with SkyBox1 can go a long way to help us.
• Glacier data and algorithms exist to build the foundation for a strong proposal.
• We need to start the requirement process and the mission definition as early as possible.