SigNals Of Opportunity P-band Investigation (SNOOPI): In-Space Validation of Reflectometry from 240-380 MHz

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Specialist Meeting on Reflectometry using GNSS and other Signals of Opportunity (IEEE GNSS+R 2019) 
Benevento, Italy, 20-22 May, 2019

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Outline

• Motivation: P-band Signals of Opportunity (SoOp)
• SNOOPI Mission description
• Instrument Heritage
• Mission Design
• Project Organization
• Conclusion
Motivation: Root-Zone Soil Moisture

- Water content in 0-1 m of soil
- Depth of absorption by plants
- L-band penetration ~5 cm
- L4 RZSM data products from assimilation

![Diagram showing penetration depth and frequency bands for ORBCOMM, MUOS, and GNSS.](image)

Penetration Depth (cm) vs Frequency (MHz)

- ORBCOMM: $m_v = 0.05$
- MUOS: $m_v = 0.3$
- GNSS: $m_v = 0.3$

ORBCOMM (1), MUOS (2), GNSS (3), ORBCOMM (4), MUOS (5), GNSS (6)
Motivation: Root-Zone Soil Moisture

SMAP L4

SMOS

MODIS

Motivation: Snow Water Equivalent

- SWE estimates from multi-frequency microwave

- Model spreads of -50% to 250%, - common in mid-latitude regions

Mudryk et al., 2015
Motivation: Snow Water Equivalent

• SWE retrieval from SoOp phase

$$\phi_s \approx a \cdot f \cdot SWE$$

• Long (~1m) P-band wavelength – increase phase wrapping interval
Problems in Sensing <500 MHz

12-m Large Deployable Reflector (LDR)

435 MHz Operations prohibited over N. America and Europe due to Space Objects Tracking Radar (SOTR) [ESA SP-132, 2010]

Concept: 30-m deployable antenna (435/137 MHz).

**P-band SoOp Demonstrations**

- Signals of Opportunity Airborne Demonstrator (IIP-13)

Strong Response over water

Resolution approximately First Fresnel zone

Possible RFI?
Snow observations (JPL RTD)

Retrieved SWE vs. In-situ SWE

Retrieval RMSD = 7.44 mm

[Shah, et al., 10.1109/LGRS.2016.2636664]

Presentation 12:30 Weds
SNOOPI Mission Description

• 2018 InVEST Selection
• Objective – In Space Validation of the SoOp technique in P-band
• Necessity of Space validation:
  1. Demonstrate sufficient signal coherence at orbital altitudes and speeds to make phase measurement
  2. Quantify RFI from space (broad field of view, global distribution of measurements)
  3. Model prediction and instrument tracking validated for orbital delay and Doppler.
SNOOPI Instrument Heritage

- Low Noise Front End (LNFR): NASA GSFC
  - Cubesat form factor (90 x 96 mm) derived from IIP13 experience
  - 4 channels, 80 dB available gain, internal calibration paths

RFE CAD model → Prototype during population
SNOOPI Instrument Heritage

• Digital Back End (DBE): NASA JPL
  • Based on Cion GNSS receiver for Tyvak / CICERO (TRL-8)
  • Changes:
    • Off-the-Shelf Rad-tolerant high-rel CSP computer (TRL 8)
    • P-band capability
  • Leverag existing projects (SunRISE and GNSSPro)
SNOOPI Mission Design

Notional rendition of SNOOPI in orbit.
SNOOPI Mission Design

SMAP Cal-Val Sites

Cumulative Observations

Days

GNSS+R, Benevento, Italy, 20-22 May 2019
SNOOPI Mission Design

• Link budget Assumptions:
  • 10 ms integration, 1 sec incoherent avg.
  • Receiver in 410 km orbit.
  • Soil moisture requirement: 0.03 m³/m³
  • Receiver noise figure based on SoOp-AD

<table>
<thead>
<tr>
<th>Center Freq.</th>
<th>240-270 MHz</th>
<th>360-380 MHz</th>
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<tbody>
<tr>
<td>Channel BW</td>
<td>25 kHz</td>
<td>5 MHz</td>
</tr>
<tr>
<td>EIRP</td>
<td>27 dBW</td>
<td>37 dBW</td>
</tr>
<tr>
<td>Orbit</td>
<td>GEO</td>
<td>GEO</td>
</tr>
<tr>
<td># Channels Available</td>
<td>~10</td>
<td>4</td>
</tr>
</tbody>
</table>
SNOOPI Mission Design

• Post-correlation SNR

[4 soil types from Peplinski, 1995 model]
SNOOPI Mission Design

- SMC Error in Single Observation

[4 soil types from Peplinski, 1995 model]
SNOOPI Mission Design

• SMC Error: 1 sec avg. over all Channels

255 MHz10 Chan.

370 MHz4 Chan.

Error (1σ) in \( m_v \) (average over channels)

\[ m_v (m^3/m^3) \]

[4 soil types from Peplinski, 1995 mo]
SNOOPI Mission Design

- SMC Error: Avg. over all Channel – 0.25 Chip specular offset

0 deg
50 deg
70 deg.

[4 soil types from Peplinski, 1995 model]
<table>
<thead>
<tr>
<th>Event</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Initiation</td>
<td>01/19</td>
</tr>
<tr>
<td>SRR</td>
<td>06/19</td>
</tr>
<tr>
<td>Bus development work start</td>
<td>06/19</td>
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<tr>
<td>PDR</td>
<td>09/19</td>
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<tr>
<td>CDR</td>
<td>03/20</td>
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<tr>
<td>SIR</td>
<td>11/20</td>
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<tr>
<td>FRR</td>
<td>03/21</td>
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<tr>
<td>Deliver to Launch site</td>
<td>06/21</td>
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<tr>
<td>Launch</td>
<td>09/21</td>
</tr>
<tr>
<td>Commissioning (2 Mo.)</td>
<td>12/21</td>
</tr>
<tr>
<td>Data Collection &amp; Processing</td>
<td>09/22</td>
</tr>
</tbody>
</table>
Summary

- All hardware is high-TRL components
  - Digital Back End (DBE) – Cion heritage
  - Low Noise Front End (LNFE) – Miniaturized SoOp-AD. (IIP-13) instrument
  - Antennas – COTS
- System (or “technique”) will be validated in this mission.
- Success criteria are achievable – technology validation based, not science measurements.
Acknowledgement

This work was supported by NASA Grant 80NSSC18K1524, “Signals of Opportunity P-band Investigation (SNOOPI)”
BACKUP
**Objective**

SNoOPI will demonstrate measurement of the reflection coefficient and phase of land surface reflections from P-band (240-380 MHz) communication satellite Signals of Opportunity. P-band Signals of Opportunity measurements will enable the spaceborne remote sensing of Root Zone Soil Moisture (RZSM) and Snow Water Equivalent (SWE) - priority variables in 2017 ESAS:

- Reflection coefficient precision: 0.07 (1-sigma)
- Reflection phase error: 10 deg. (1-sigma)

**Approach:**

Pairs of antennas receive signals along two ray paths: direct from the transmitter and reflected from the Earth's surface. Cross-correlating the signals from a pair of antennas can produce the reflection coefficient and reflected signal phase.

Reflection coefficient retrieval will be validated using a forward electromagnetic model and in-situ data at SMAP Cal/Val sites.

Phase retrieval will be validated by comparing variance to a known error model, and measuring differential phase delay due to the ionosphere.

**CoIs:** Jeffrey Piepmeier, Manuel Vega, GSFC, Rashmi Shah, JPL, David Spencer, Purdue University

**Key Milestones**

- Project Initiation: 10/18
- SRR/PDR: System requirements: 02/19
- Spacecraft Bus Contract Award: 04/19
- Spacecraft Bus CDR: 08/19
- Instrument CDR/EM Fabrication: 10/19
- Spacecraft Bus Fabrication: 03/20
- Instrument FM: 03/20
- Delivery to Observatory: 06/20
- FRR: 09/20
- Launch (Earliest Opportunity): 10/20
- On-orbit commissioning: 12/20
- Data collection and Processing: 06/21
- Data reduction: 09/21

**SNoOPI conceptual design:**

1X6U CubeSat bus provides separation between pairs of zenith and nadir antennas, at 255 and 370 MHz.

A digital back end (DBE) cross-correlates direct and reflected signals from geostationary communication satellites.

A calibrated Low-Noise Front End (LNFE) uses noise loads for estimation of reflection coefficient magnitude.
SNOOPI Mission
SNOOPI Mission

SMAP Cal-Val Sites

Cumulative Observations

Days

GNSS+R, Benevento, Italy, 20-22 May 2019
SNOOPI Mission Description
SNOOPI Mission

Antennas 257 and 370 MHz CP Dipoles

S/C Avionics Package

Digital Back-end (DBE)

Reflectometer Front-end (RFE)

RFE Filters