A GNSS-Reflectometry Instrument for Wetland Extent and Dynamics

Jeff Dickson (PI), Stephan Esterhuizen*, Casey Handmer, Stephen Lowe (presenting), Son Nghiem, David Robison, Larry Young

(*) Now at Spire
Outline

• Measurement concept
• Science motivation and requirements
• Instrument design
  • Front end: Low-power RF ASIC
  • Real-time navigation/timing: Real-Time Gipsy X (RTGx)
  • Processing surface-reflected signals: Delay Doppler Map
  • Noise calibration system
• Current status & near-term work
• Summary
GeNeSiS
GNSS-Reflections Multistatic Radar for Wetland Dynamics

Concept:
GeNeSiS collects Earth-reflected GNSS signals for remote sensing

Primary Science: Wetland inundation/extent

Primary Measurement: Delay-Doppler Map

Small size/cost/power: Deploy 6-8 in single launch for dense surface coverage

Instrument collects reflected GNSS signals (green) for remote sensing the Earth’s surface, direct signals (upper white) for POD, and rising/setting signals (orange) for radio occultations

ESTF2018 Silver Spring, MD
GeNeSiS

Concept Advantages:
• Multiple, simultaneous bistatic measurements
• No transmitter - lower cost
• Low power (RF ASIC developed under ACT)
• Constellations feasible (e.g. CyGNSS) - High spatial/temporal coverage
• Forward scattering, L-Band - Improved penetration through vegetation
• Increasing number of GNSS/SBAS transmitters - Currently ~100 transmitters
• Long-term GNSS stability

Decadal Survey Priorities Addressed:
• “Understanding the sources and sinks of carbon dioxide and methane, and how they may change in the future.”
• “Quantifying trends in water storage…”

Decadal Survey Goals Addressed:
• Cost Effectiveness
• Science Continuity
Spatial Coverage – Concept Mission

24 hour coverage simulation:

- 8 satellites
- 60° inclination orbit
- GNSS + SBAS
Primary Science: Wetland Inundation and Dynamics

- Wetlands largest contributor to atmospheric methane
  - Largest contribution uncertainty
- Connections to carbon and water cycles
- Dynamics studies possible with high sampling rates

Secondary Science:

- Soil Moisture
- Freeze/Thaw Cycle
- Sea-ice extent (polar orbit)
- Ocean surface winds (CyGNSS)

Other Capabilities:

- Simultaneous Radio Occultation measurements (GNSS-RO)
  - Atmospheric temperature and humidity
- Precise Orbit Determination (POD)

Wetlands: 177-284 Tg/yr
Fossil Fuels: 85-105 Tg/yr
Livestock: 87-94 Tg/yr

Atmospheric Methane
From IPCC AR5 Report
Science Requirements

Wetland/Hydrology Science Requirements

Hydrologic cycle:

• Dynamics: runoff operates on ~4 week time scales

• Catchment area / Wetland inundation extent: 1-2 km spatial resolution

⟹ Require global (+/- 60° latitude) inundation maps every 10 days
  • Process all GNSS + SBAS signals
  • 5 Hz observations: 0.5 km spot travels 1.5 km
  • 2 km cell size: ⟹ ~2 receivers
## Instrument Specifications

<table>
<thead>
<tr>
<th></th>
<th>GENESIS</th>
<th>Current State-of-the Art</th>
<th>Motivation</th>
</tr>
</thead>
</table>
| **Surface Spatial Res.** | 1 km (wetlands)  
7 km (oceans) | 25 km (ocean)            | Required for wetlands          |
| **Polarization**        | H+V (Dual Pol)              | LCP                      | May help remove vegetation effects |
| **Simultaneous Reflections** | 32                          | 4                        | Improved coverage               |
| **GNSS Signals**        | >=1 signal from all GNSS    | GPS L1CA                 | Improved coverage               |
| **Power**               | 15 W                        | 12 W                     | Small sat                       |
| **Radiation**           | 100 kRad                    | 5 kRad                   | Good for all LEO orbits         |
| **Channel Bandwidth**   | 43 MHz                      | 4 MHz                    | Better delay precision          |
| **Radio Occultation Support** | Yes                        | No                       | Additional science              |
| **Beamforming Support** | Yes                         | No                       | Improved Coverage               |
| **Antenna Inputs**      | 12                          | 2                        | Improved coverage               |
| **Science Data Rate**   | 10 Hz                       | 1 Hz                     | Wetland cell size               |
RF-ASIC

Digitized Frequencies: 690 MHz

Developed under ACT

Digitizes all L-band GNSS signals
- GPS L1/L2/L5
- GLONASS L1/L2
- GALILEO E1/E5a/E5b/E6
- Beidou B1/B2/B3
- IRNSS L5
- QZSS L1/L2/L5 LEX
- WAAS, EGNOS, MSAS, GAGAN, SDCM

RF-ASIC 3 antenna input
1 W total
Reflections Processing: Delay Doppler Map

- Delay doppler map (DDM): matrix of received signal power vs. doppler and delay
- Primary observable for GNSS scatterometry
- Accumulation of incoming signal with signal model for various values of doppler and PN code delay

\[
DDM = \int s(t) e^{j2\pi(f_c + f_D) c(t + \tau)} dt, \quad \forall f_D, \tau
\]

\( s(t) \): incoming signal
\( c(t) \): PRN code sequence
\( f_c \): signal carrier frequency
\( f_D \): doppler frequency (local signal model)
\( \tau \): code delay (local signal model)
DDM Algorithm

**Signal Model**

- **Delay Generation** (shift register)
- **Delay Correlation** (& sub-accumulation)
- **Doppler Correlation**
- **Signal Accumulation**

**Incoming Signal** (from channelizer)

Time-multiplexed FFT module
(logic resource shared by all delay channels)

**DDM Output**

ESTF2018 Silver Spring, MD
Hardware Demonstration (Feb 2018)

RFASIC Dev Board

ASIC-to-FMC PCB

FPGA Board

Sig Gen PRN1

PC For Display

Generate Real-Time DDM
Real-Time Gipsy X (RTGx) Navigation Software

- A state-of-the-art GNSS navigation software package from JPL
- Real-time precise orbit determination (POD)
- For GNSS-R: Provides real-time estimates of current (and future) receiver/transmitter locations.
- Decimeter-level real-time on-board positioning
  - Limited by ephemeris
  - SW good to cm-level
- Predicts for science scheduling
Noise Calibration Technique

Receiver measures Signal-to-Noise ratio

Need to calibrate
- Antenna gain vs angle
  - Measured on satellite to include multipath
- System noise
  - Monitored while tracking

JPL precise noise calibration technique sponsored by the USAF GPS OCX system
- Continuous data collection: no deadtime during calibration
- Rapidly switch between signal (S) and signal + calibrated noise (S+N)
- Separately process S and S+N
- US Patent 20140065994

US Patent 20140065994
# Year 1 (Feb 2017 – Feb 2018) Milestone Status

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instrument requirements definition</td>
<td>Complete</td>
</tr>
<tr>
<td>Processor and Operating System (OS) trade study</td>
<td>Complete</td>
</tr>
<tr>
<td>Integration of RF ASIC (ACT2013) into existing GNSS testbed</td>
<td>Complete</td>
</tr>
<tr>
<td>GNSS software development to support reflections (GPS)</td>
<td>DDM complete</td>
</tr>
<tr>
<td>3rd RF ASIC Fabrication run</td>
<td>Deferred to Year 2</td>
</tr>
<tr>
<td>Prototype unit using COTS development boards, RF ASIC</td>
<td>Complete</td>
</tr>
</tbody>
</table>
Year 2 (Feb 2018 - Feb 2019) Milestones

- Schematic Design of RF and Digital Processing Board
- Chassis Design and Fabrication (or leverage COTS boards)
- Implementation of Reflection Schedule Software
  - Functionality completed in year 1 – need to integrate into operations
- GNSS software to support reflections (Glonass, Beidou, etc.)
- Port RTGx to selected operating system
  - This work has started in year 1. Evaluating scope to port to RTEMs
- Layout and Fabrication of EM boards
- Evaluate ASIC update plans
Summary

• **We’re building highly capable GNSS reflectometry instrument for space applications**
  - Improved number of simultaneous DDMs
  - Improved number/type of GNSS signals processed
  - Improved number of antenna inputs

• **Unique features:**
  - Low-power RF ASIC: enables antenna arraying
  - Antenna arraying
  - RTGx for Position Navigation and Timing (PNT)
  - Continuous noise calibration system (no deadtime)
  - Radio-occultation support

• **On schedule:**
  - 3 months into 2nd year of 3-year program