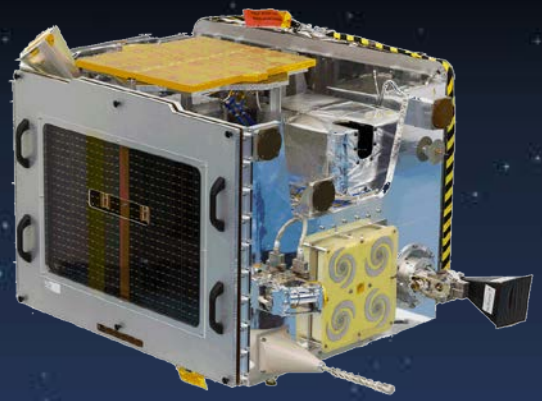
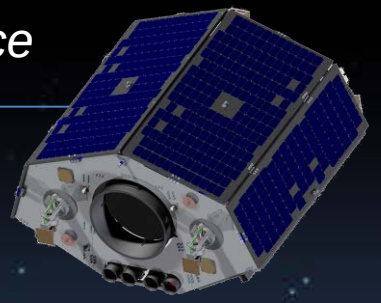
SURREY SATELLITE TECHNOLOGY LTD

Changing the economics of space





The SGR-ReSI Experiment on the TechDemoSat-1 Mission

Dr Martin Unwin

CEOI Technology Conference, 21/04/15

#0249070

Acknowledgements

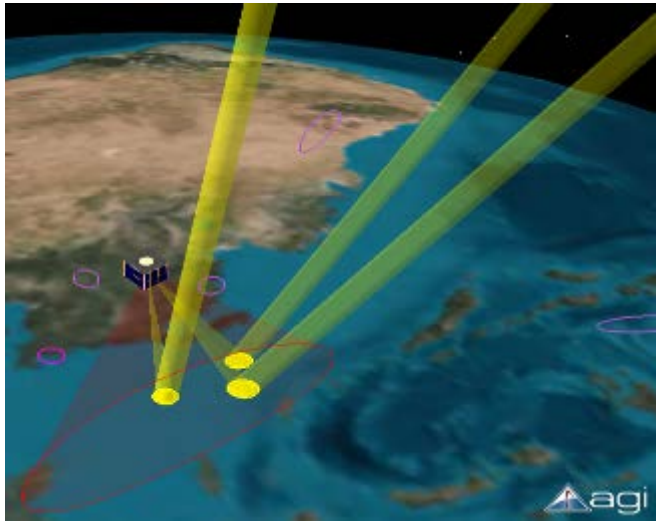
- National Oceanographic Centre
- University of Surrey
- CEOI, NERC, EPSRC
- InnovateUK, UKSA & SEEDA
- University of Bath and PIL
- Satellite Applications Catapult
- European Space Agency
- CYGNSS Project (Michigan, SWRI, etc.)
- SSTL
  - R&D funding, & TDS-1 project team
  - GNSS team, Ops team

Overview

- Background to Experiment
- SGR-ReSI
- TechDemoSat-1
- Launch & First Operations
- Overview of first results
- Website
  - Sample Data
  - Access to Catalogue of Data
  - Docs: Mission description & Product Manual
- Current Status & Future

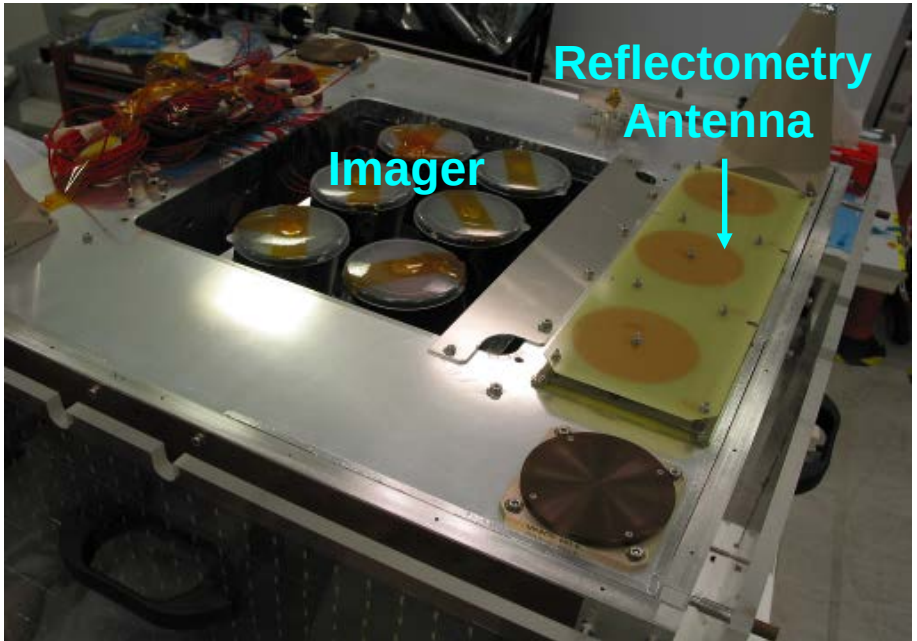
GNSS Reflectometry

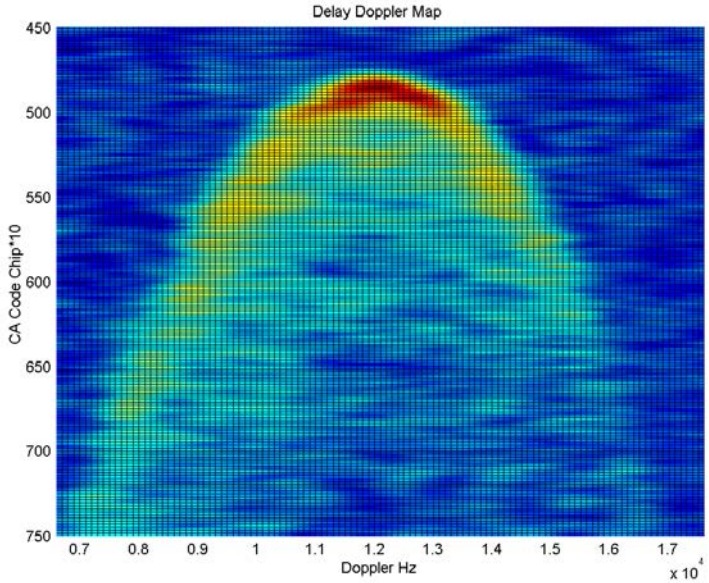
- GNSS Reflectometry
  - Detecting GPS / GNSS signals reflected off the Earth's surfaces
  - "Multipath" signals should contain geophysical imprint
- Using Earth-reflected GPS signals for ocean sensing first discussed in 1988
  - 1993 ESA proposed reflectometry for ocean **Altimetry** – PARIS
  - CCAR, & ESA studies on **Scatterometry** in late 90s – 00s
  - First reflected signal detected 1998 (JPL using SIR-C data)
  - First dedicated in-orbit experiment: UK-DMC (2003)



UK-DMC Experiment 2003

- GPS Reflectometry experiment flown as opportunity on 100kg UK-DMC satellite, Sept 2003 - 2011
- Modified GPS Receiver connected to data recorder
- Downward pointing antenna, LHCP, 12 dBi gain
- ~60 collections gathered over sea, land and ice
  - Signals collected from all surface types!
- Spread of ocean reflections shown to be related to sea state => surface winds

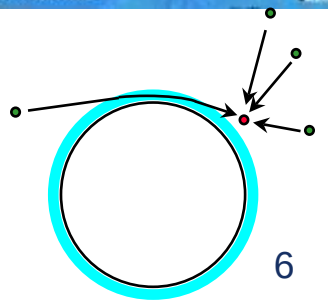




Delay Doppler Map (DDM)

Science / Operational Needs

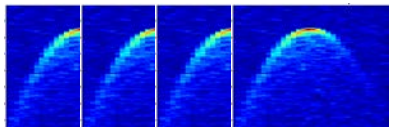
- Follow-on instrument to address needs:
- Ocean Sensing - driver
  - (GANDER – global altimeter network concept)
  - Wind and Waves – More GNSS-R data required to verify inversion models
  - Applications both near real-time, and long term
  - Meteo, navigation, off-shore operations, science
- Ice sensing
  - Ice edge detection, ice concentration
  - Dual Frequency may allow free-board measurement
- Soil Moisure potential
  - Soil mapping and crop management
  - Potential for biomass measurements?
- Atmosphere (GNSS-RO)
  - Tropospheric for weather, and research
  - Ionospheric monitoring, mapping, scintillation



Remote Sensing Receiver: SGR-ReSI

- Space GNSS Receiver – Remote Sensing Instrument
- COTS Based GNSS Receiver
  - Primarily designed for GNSS Reflectometry
  - Doubles up as platform GNSS receiver
  - With Co-processor for remote sensing
- Processes reflected GPS signals on-board into
  - Delay Doppler Maps (DDMs)
  - Alternatively can collect raw data for processing on ground
- From DDMs, invert into
  - Waves (mss)
  - & Wind (m/s)
  - Other geophysical params

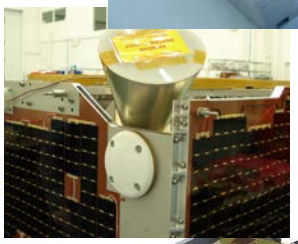
CEOI Sponsored Project



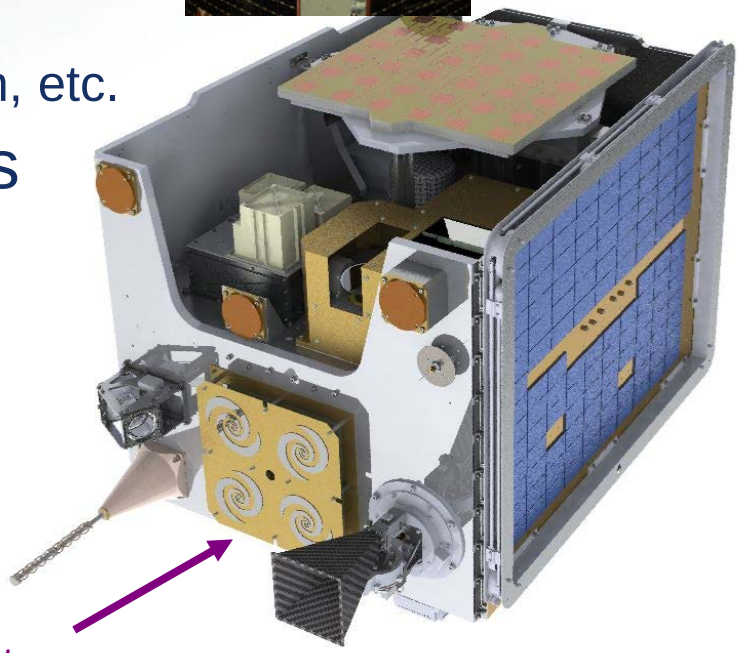
SGR-ReSI on TechDemoSat-1

- TechDemoSat-1
  - 160 kg UK Satellite,
  - Launched **July 2014**
  - Demonstration for 8 UK Payloads
    - Incl. Radiation environment sensors
    - CMS Sounder, Cubesat equip
    - Altimeter, de-orbit sail
  - Also SSTL's new technologies
    - OBC, comms, ADCS, propulsion, etc.
- **SGR-ReSI** is one of payloads
  - Two dual frequency antennas (L1 & L2C)
    - Zenith – hemispherical dual patch
    - Nadir – 13 dBi gain, 30° 3dB BW flared spiral
      Two single freq zenith patch
  - 5-10 watts, 1.5 kg

SGR-ReSI Unit



Zenith Antenna

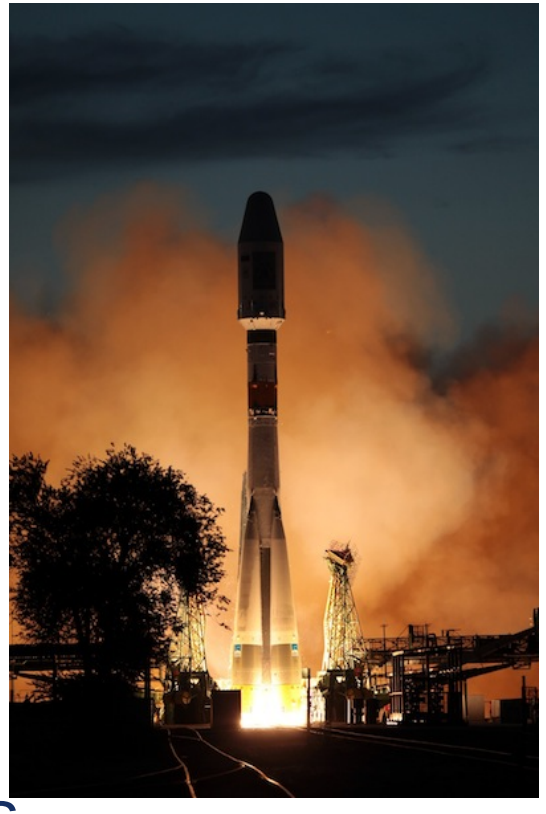


Nadir Antenna


REMOVE BEFORE FLIGHT
REMOVE BEFORE TESTING

Orbit Success – Launch 8th July 2014

Parameters	Nominal	Actual
Semi-major axis (km)	**7009.44**	**7006**
Period (mins)		97.3
Inclination	**98.399°**	**98.391°**
Eccentricity	**0.00059**	**0.00075**
Perigee (km)		630.1
Apogee (km)		640.5



- Fregat successfully deployed Meteor-2-1b plus 8 piggyback sats
- TDS-1 NORAD tracking ID: 40076

Two-Line Element Set (19th April 15):

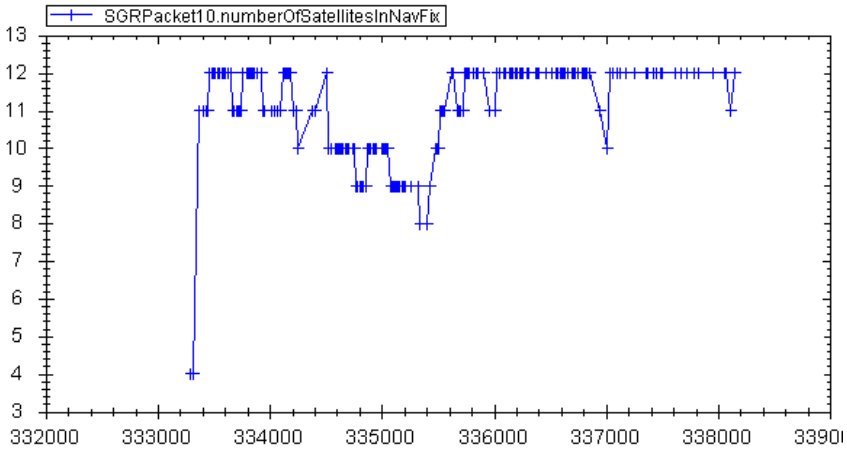
40076U 14037H 15110.46425912 .00000922 00000-0 12681-3 0 9997 2
40076 98.3550 179.6062 0007206 86.3135 273.8903 14.80859732 42275


TechDemoSat-1

First SGR-ReSI operation - navigation

- SGR-ReSI first switched on 16th July 2014

From 20:16 – 22:00 UTC

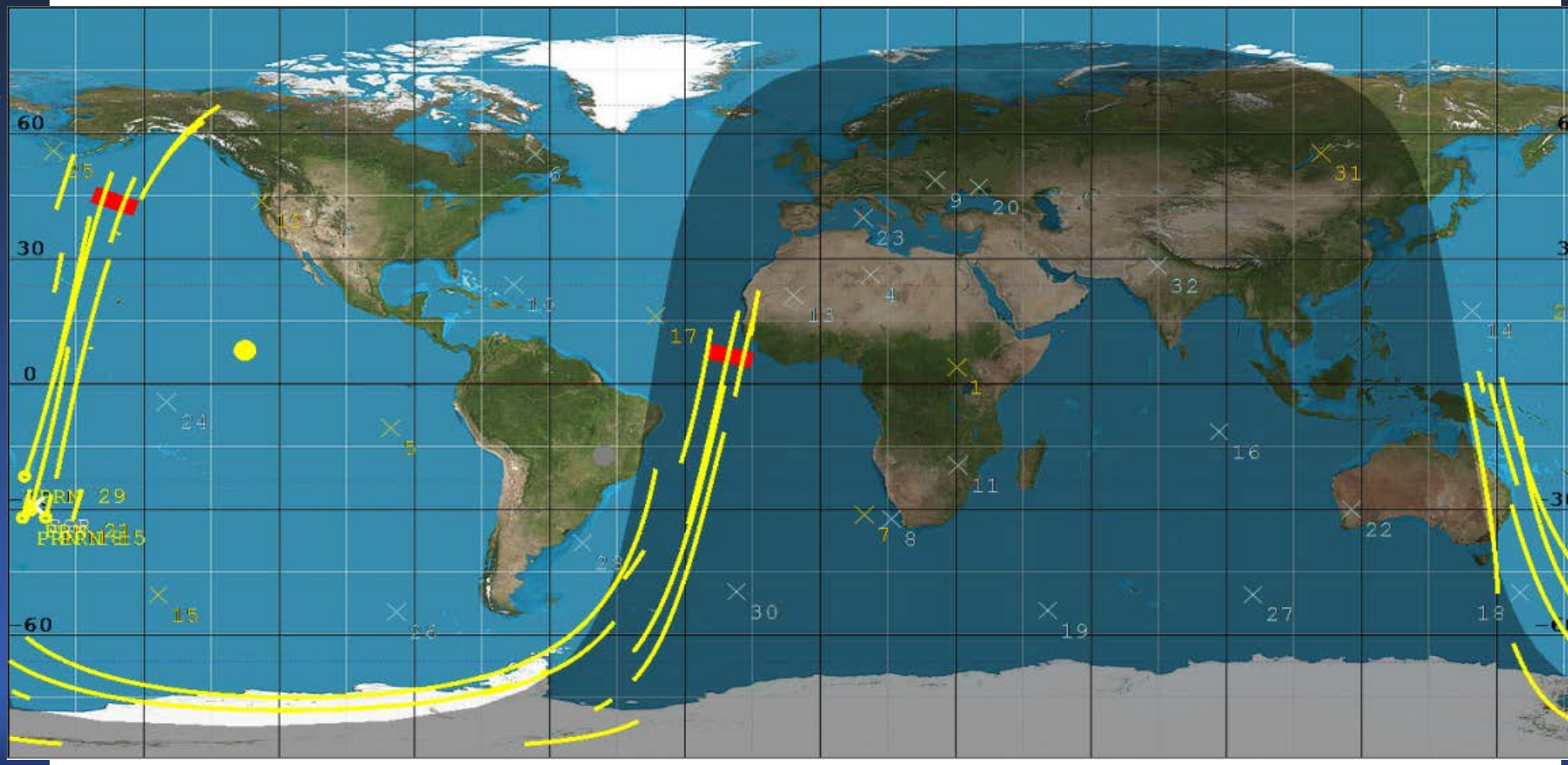


SV	Pseudorange Residuals (m)	Range Rate Residua
1	-3.258267	2.749481
28	-1.562889	2.956008
32	0.1926875	-0.1328386
17	-2.318973	6.790369
12	-2.33883	3.330171
18	-3.126989	-0.3578756
22	0.8753037	1.036655
24	-0.3724754	7.361742
4	-0.5150235	2.20552
14	-2.119796	1.645988
11	-2.420414	0.4344346
15	-1.344057	3.334653

- Positioning, tracking 12 GPS satellites!
  - Self-consistency residuals approx 1.5m
  - Initially, 12 of 24 channels were enabled
    - Up to 15 GPS satellites tracked when all 24 channels enabled

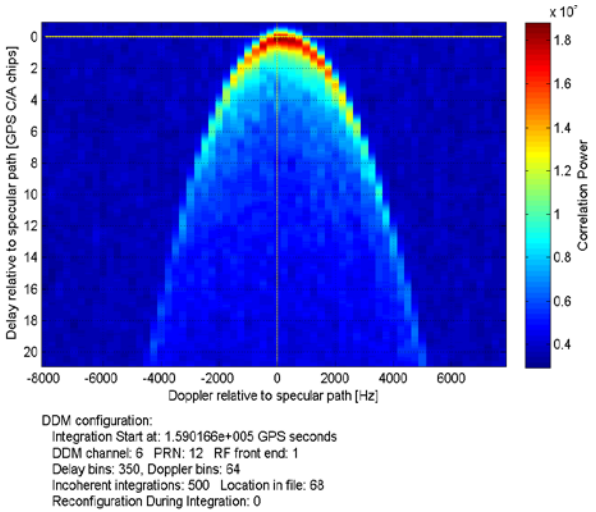
First Reflectometry Operation in Orbit

- DDMs and raw data gathered 1st Sept 2014
  - 10:33 UTC
  - 20:08 UTC
- Red indicates raw data, yellow indicates DDM tracks
  - Four times the DDMs gathered in whole UK-DMC lifetime

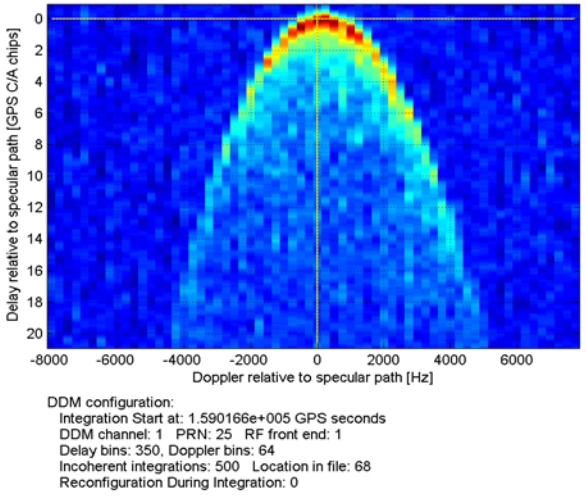


Raw Data through Software receiver

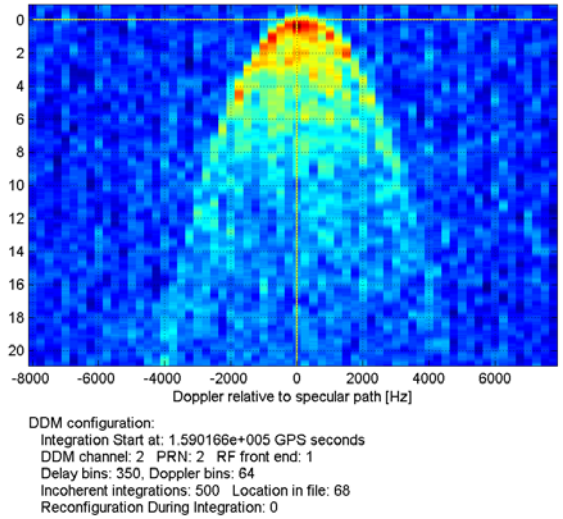
- MATLAB-based software receiver modified to produce DDMs
  - Processing algorithms reconfigurable
  - Allows testing of new algorithms/different parameters
- Generation of 1 minute of Delay Doppler Maps
  - Taken off the coast of Alaska
  - Good signals from 3 of 5 PRN channels processed
    - 4 ms coherent integration, 2 seconds incoherent



PRN 12



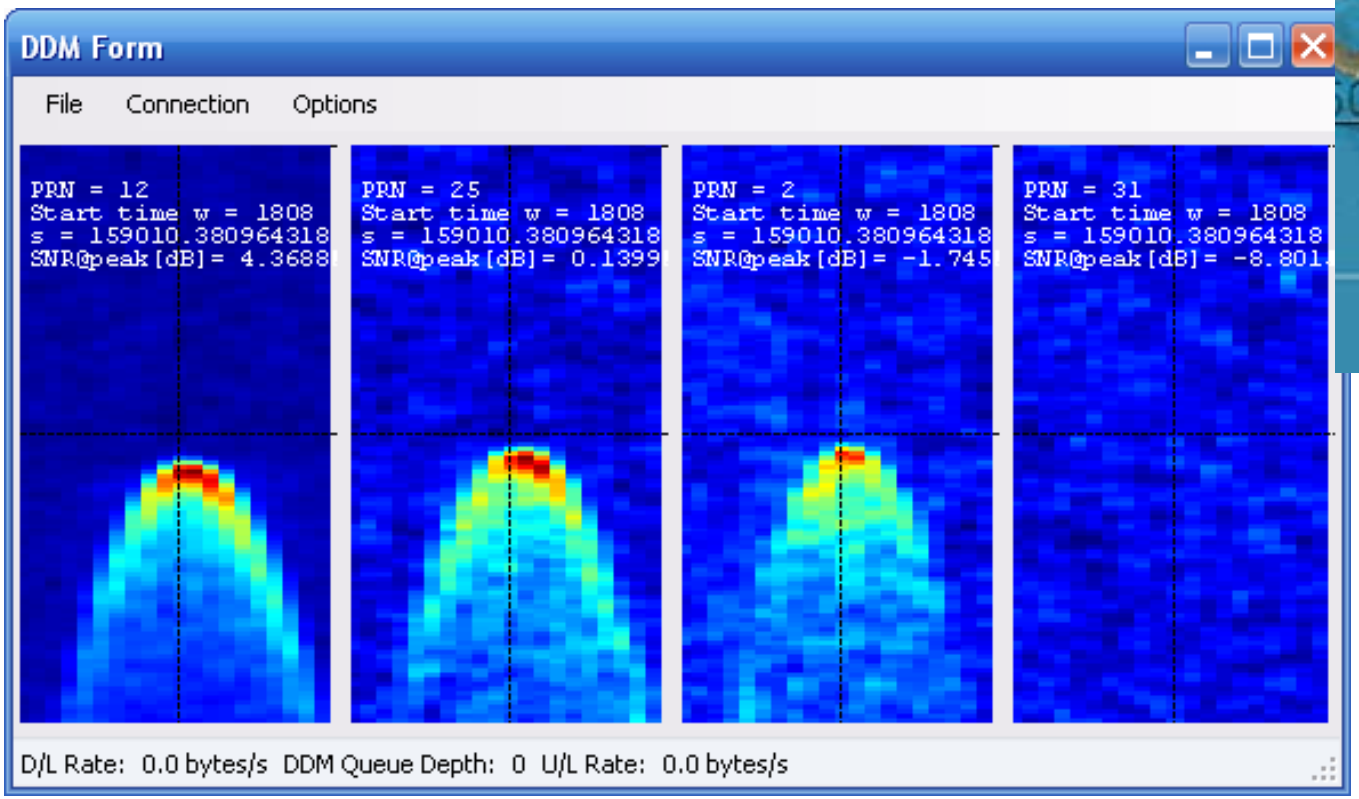
PRN 25

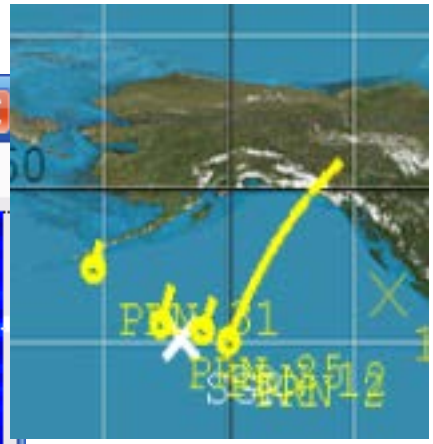


PRN 2

On-board Delay Doppler Maps

- First Delay Doppler Maps from on-board processing
  - Gathered ~80 minutes of DDMs over sea, ice & land
  - Generally 1 strong signal, sometimes up to 4
  - Stable DDM generation (though a known Doppler-related offset observed)

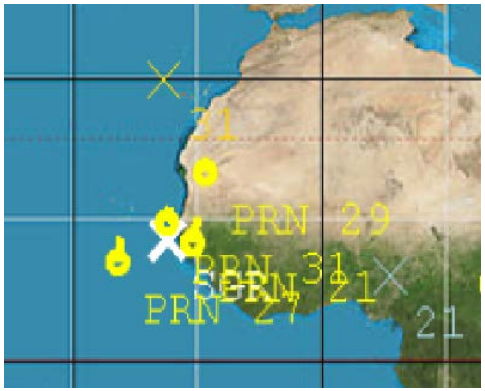


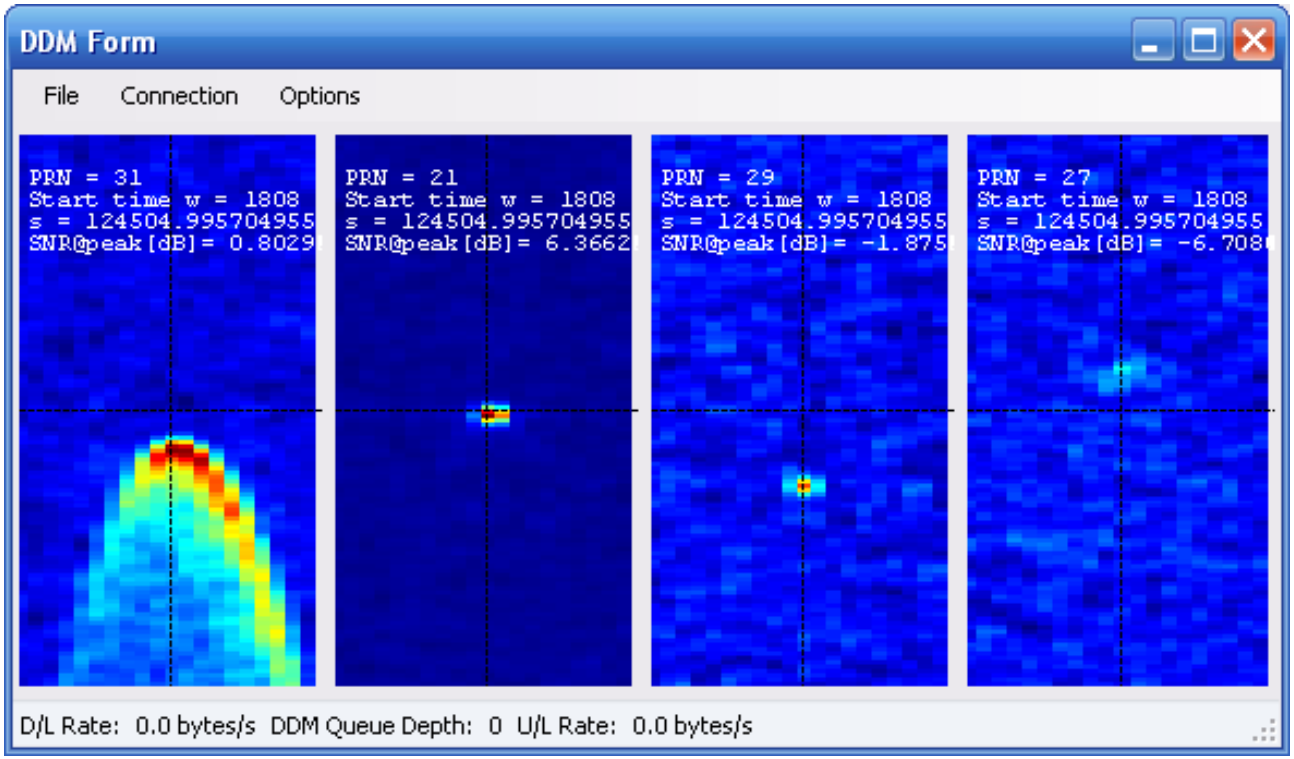


Example of ocean reflections near Alaska

Collections over Land & Ocean

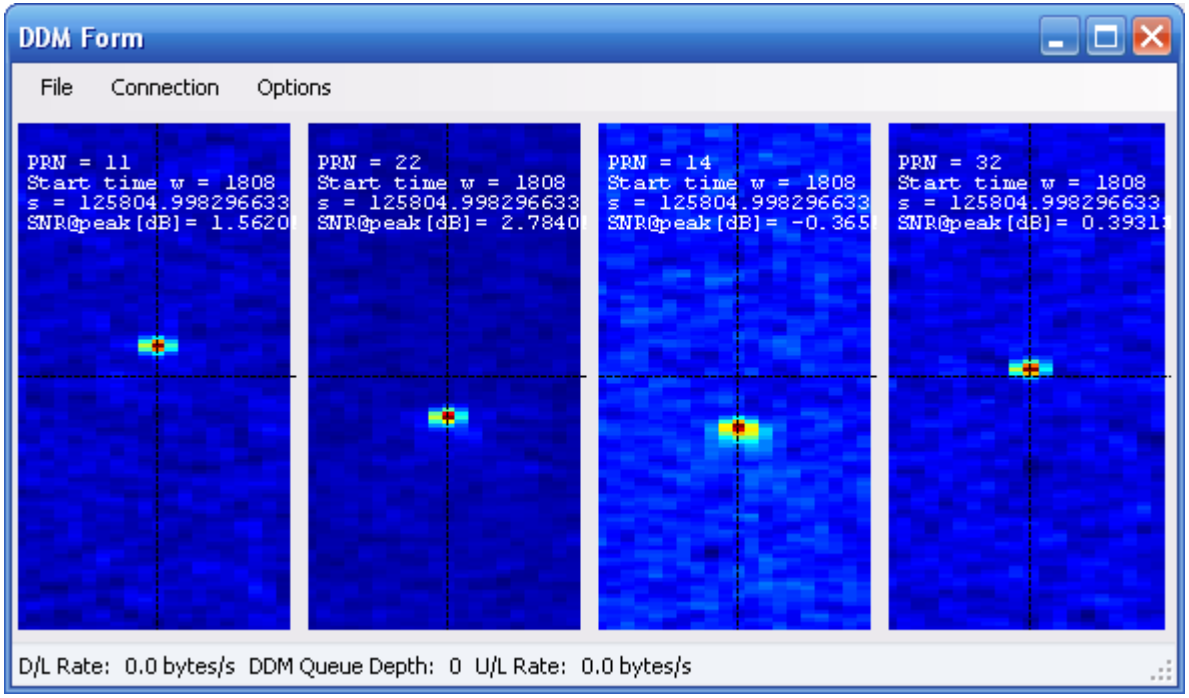
- Reflections on and off West Coast of Africa
  - Strong signals off land and sea
  - Captured transitions over coast

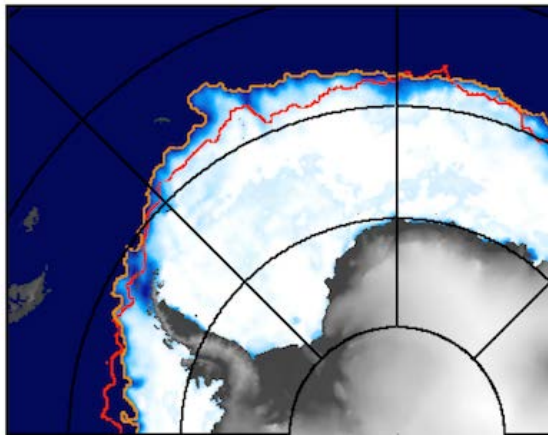




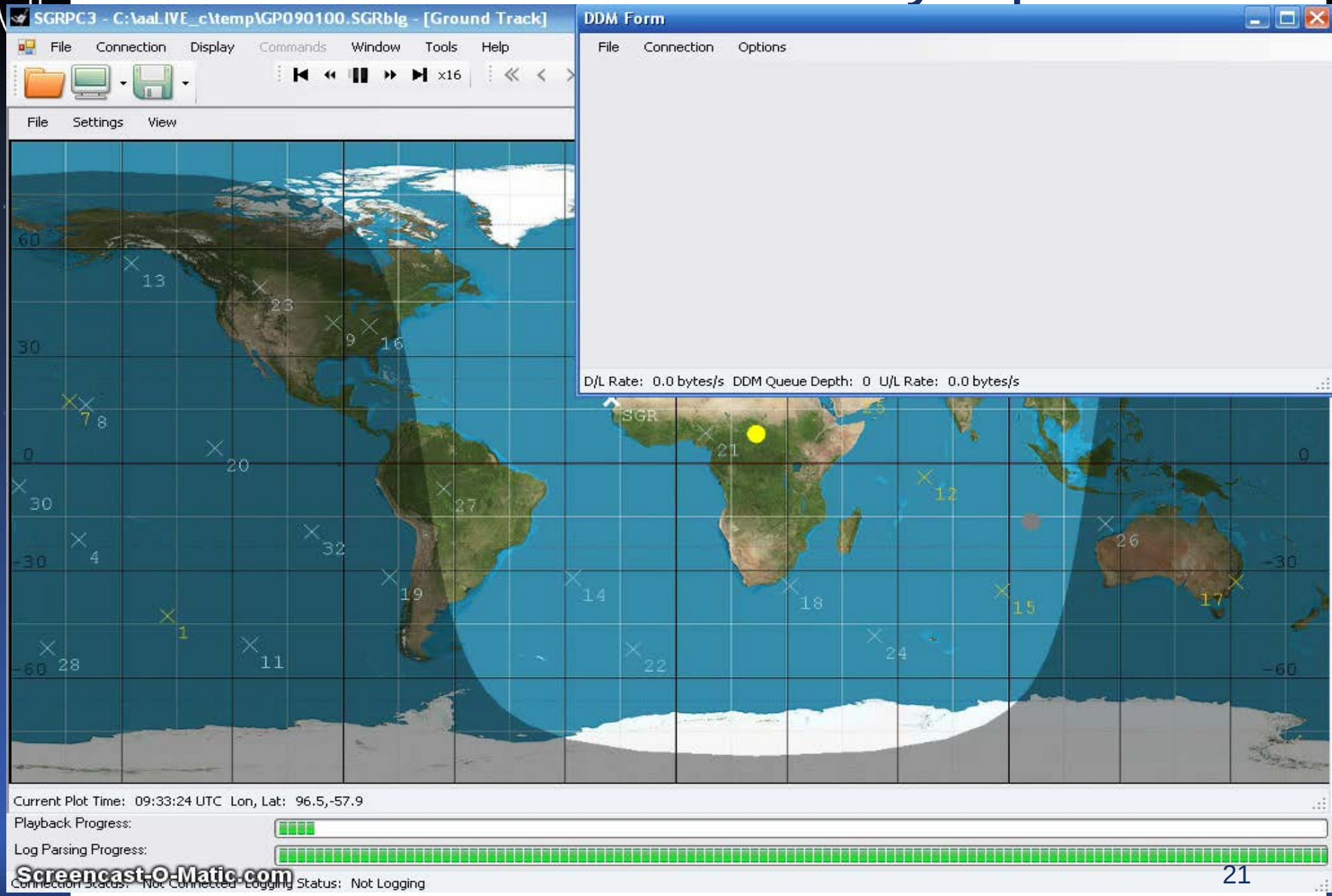
Reflections off Ice

- Captured DDMs over Weddell Sea
  - Web data confirms sea ice present
  - Very strong reflections



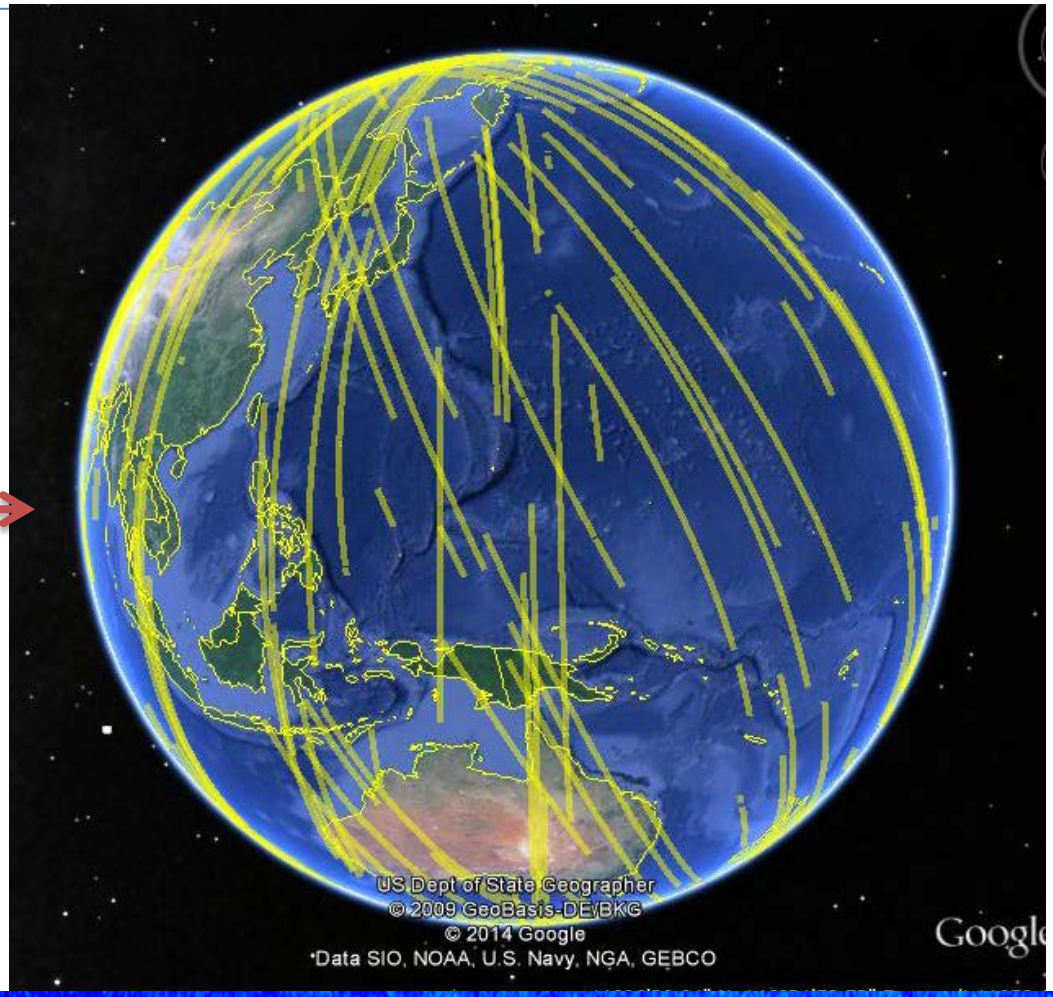


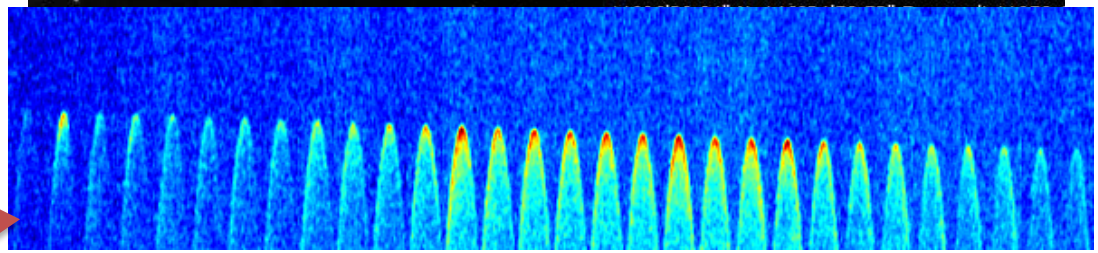
Video of First Reflectometry Operation



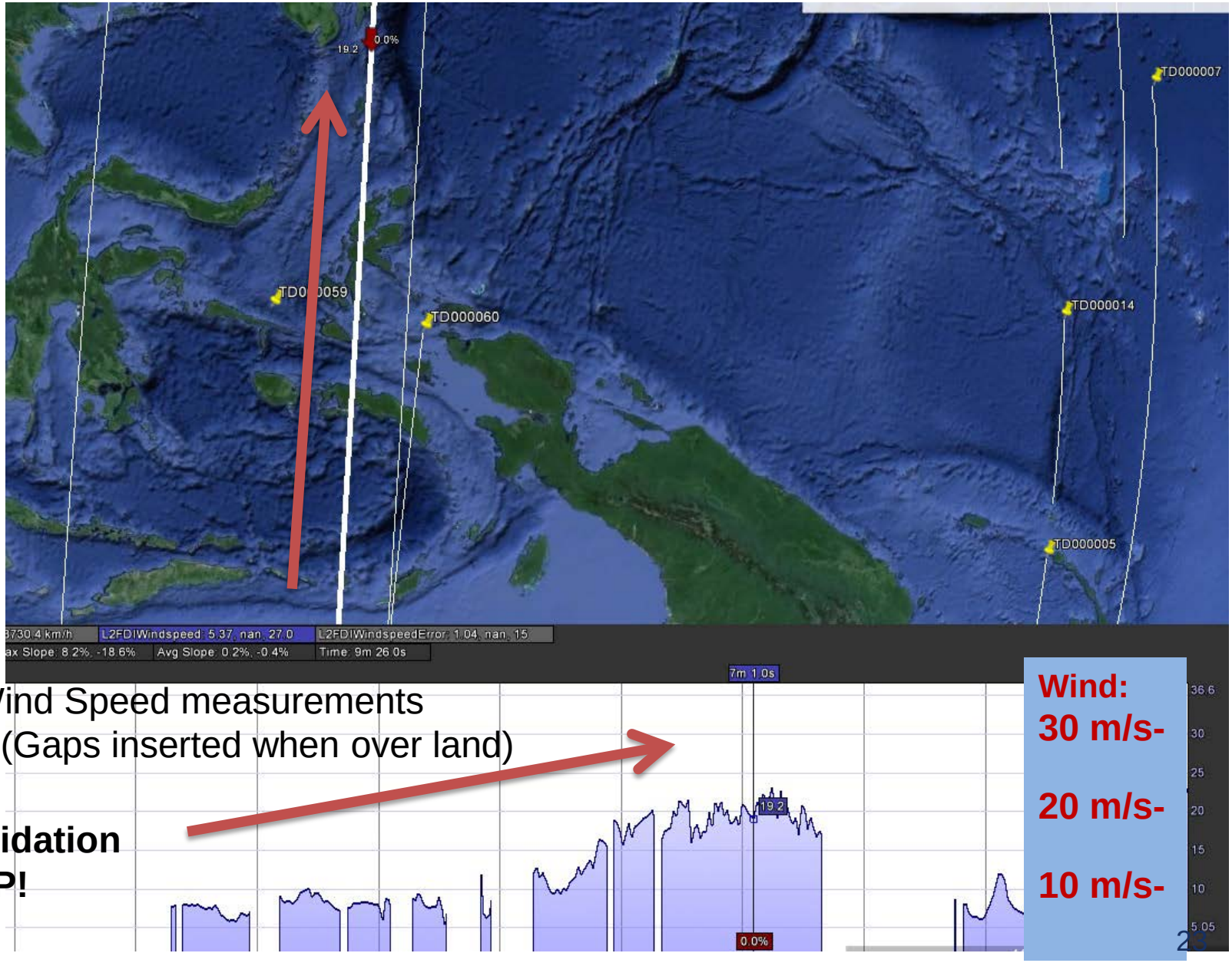
Example TDS Track Collections

- Operations of TDS-1 only 2 days out of 8
- Data collected in 2hr bursts over 24-48 hours
- Example is RD6
  - 30th Oct 2014
  - Approx 20 hours
- Each track generates sequence of DDMs
  - One per second, up to 4 simultaneous tracks
  - Signals become stronger as they pass through maximum gain of TDS antenna
  - Decimated Summary





Trial Inversion to L2: Wind Speed



Wind Speed measurements
(Gaps inserted when over land)

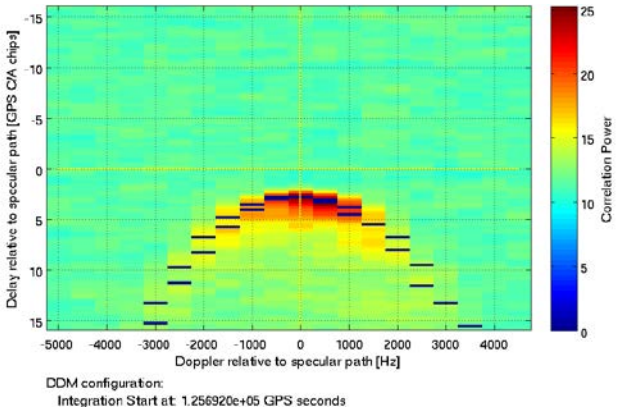
Validation WIP!

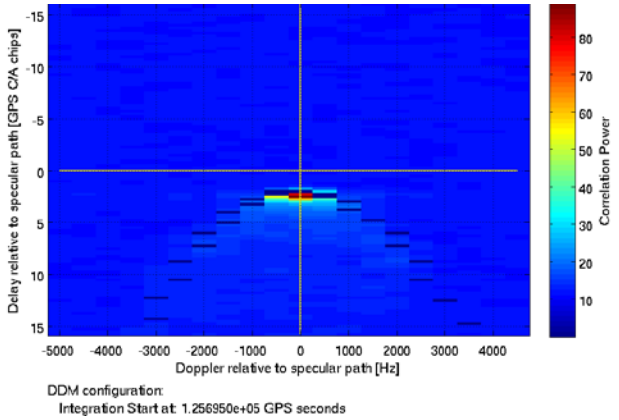
Wind:
30 m/s-

20 m/s-

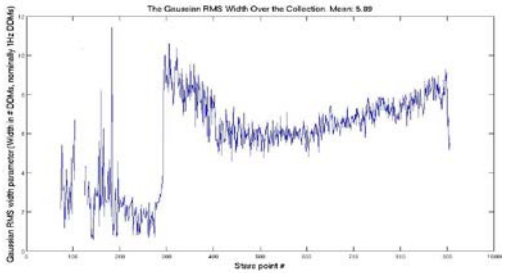
10 m/s-

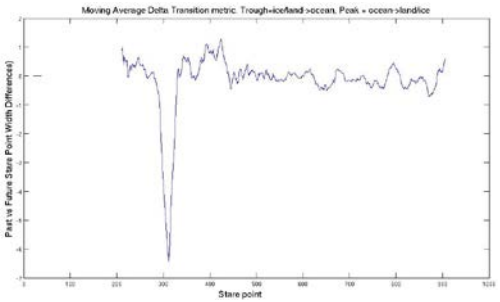
Ice Edge & Transition Sensing





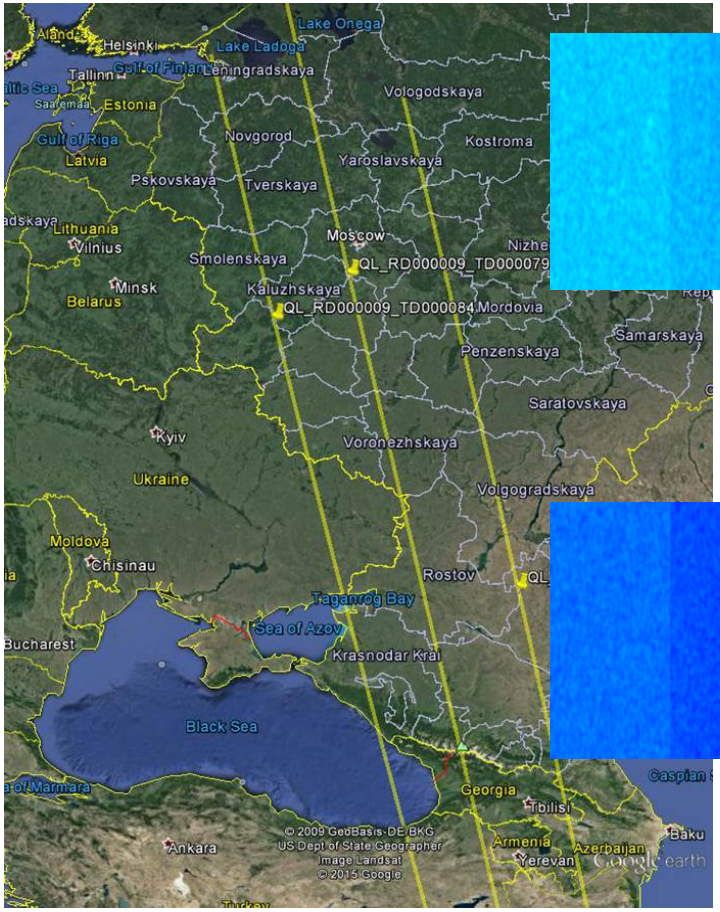
- Transitions from ocean to ice in Delay Doppler Maps
  - Transitions obvious to eye
    - Algorithms being developed to identify boundaries
  - By using “moving average stare processing” approach, a higher resolution can be achieved
  - Testing against land boundaries which can be tested
    - Geolocation accuracies of < 10 km are being achieved
    - Further work needed to make reliable, verify / remove biases, etc.

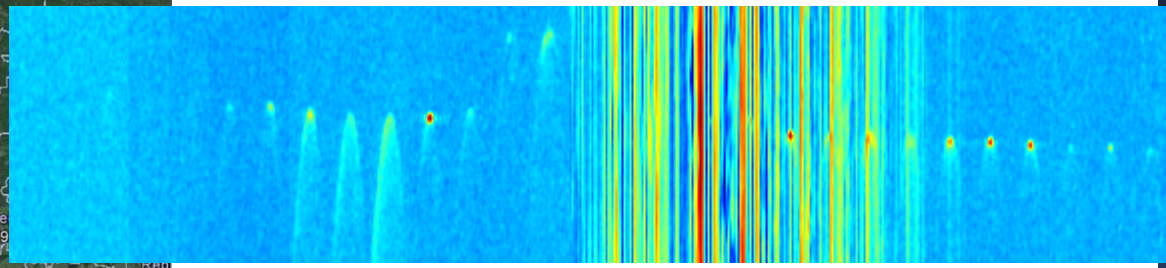




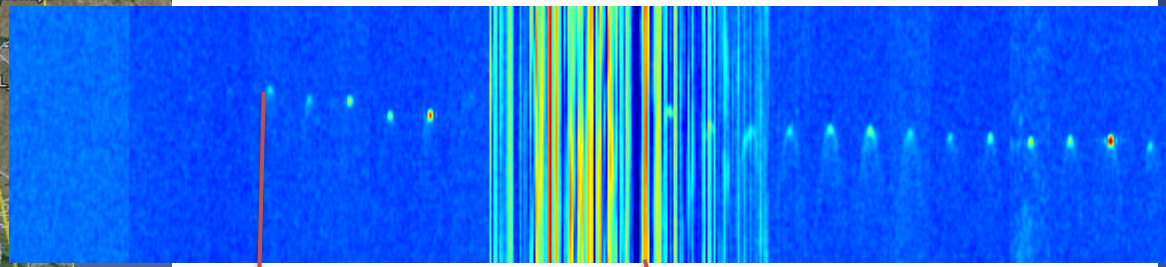
Interference / Jamming Issues

- Some interference issues to GNSS observed
  - E.g. Ukraine / Russian border (and other places around globe)
  - Suspicion of GPS jamming supported by reports from OSCE





DDM sequences
- Each 1 minute apart

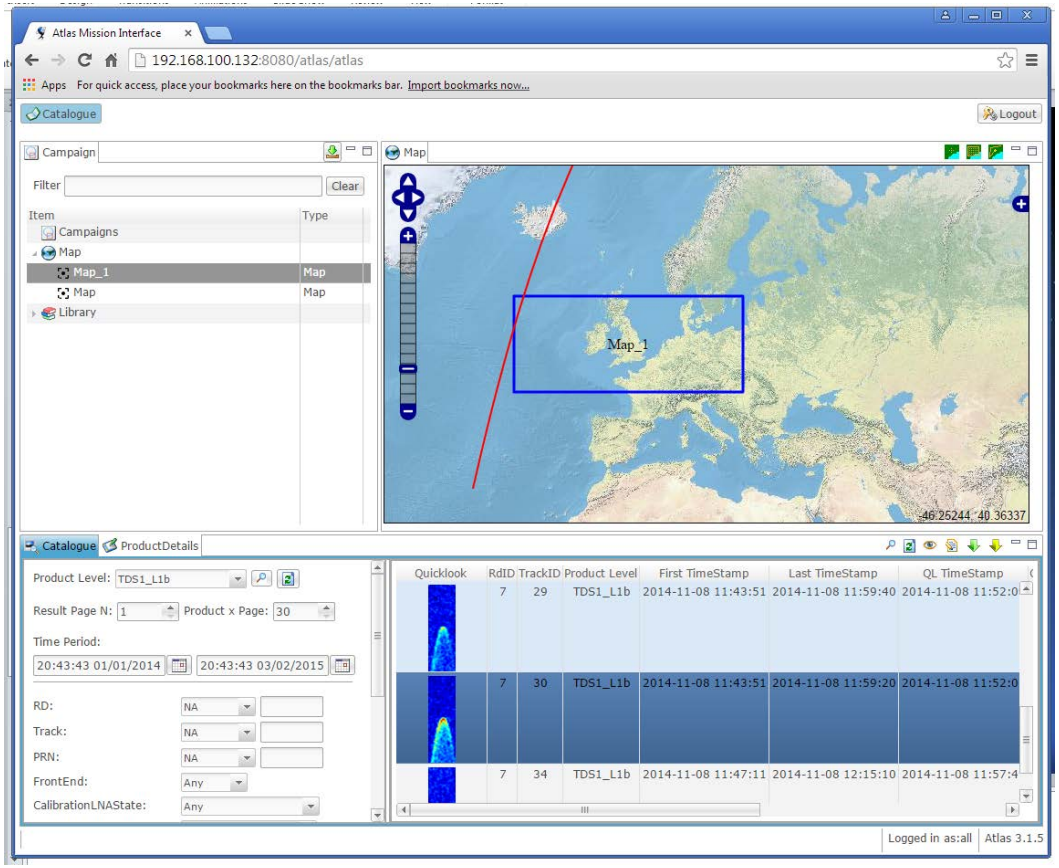


Good DDMs

Interference

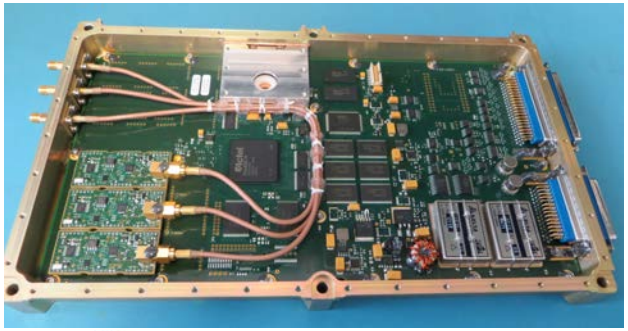
GNSS-R Data Service

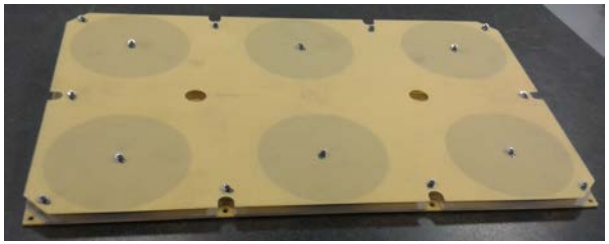
- MERRByS
  - **M**easurement of **E**arth **R**eflected **R**adio-navigation signals **By** **S**atellite
- SSTL, NOC supported by ESA
  - Development of ground processing to produce timely data for customers
- L1b Products
  - DDMs
- L2 Products:
  - Ocean Wind Speed
  - Mean Square Slope
  - Aimed at
    - Meteorologists
    - Offshore energy
    - Shipping, Insurance
    - Scientific users: Climate research
- First demo from TDS
  - Future missions can supply data for service



Next Mission with ReSI: CYGNSS

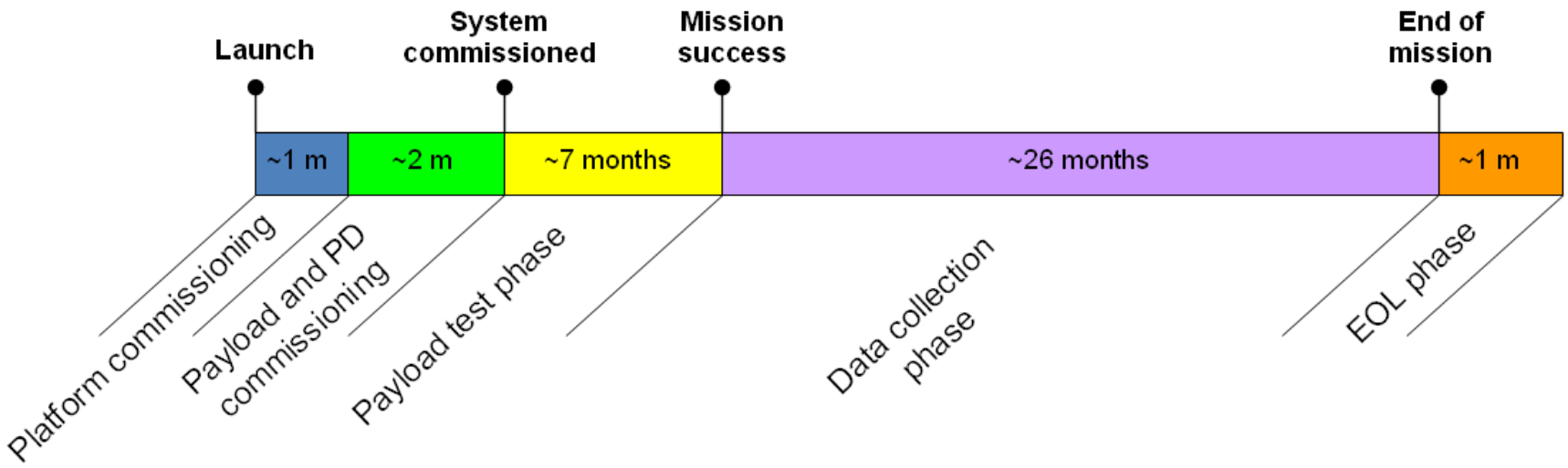
- SGR-ReSI selected for NASA CYGNSS project
- Measure hurricanes using GPS
- 8 satellite constellation ~ 22 kg each
- Working with SST-US (US office)
- Uni Michigan, SWRI
  - SGR-ReSI Modules (“DMR”)
    - Including 3 x RF receivers, processor, coprocessor, SSDR
  - Low Noise Amplifiers
    - Including cavity filter and switched black body load
  - Nadir antennas
    - 6 element fixed gain arrays ~ 14 dBiC LHCP gain
  - Zenith antennas
    - Passive patch antenna
- 8 x FM DMR unit manufacture
  - Handled by SST-US in Colorado





TechDemoSat-1 Status & Schedule

- TDS-1 launched 8th July 2014
  - Operated by Sat Apps Catapult Centre and SSTL
- Payload test phase commenced 22nd Oct 2014
- "Mission Success" in approx May 2015
  - Transitioning to Data Collection Phase
  - 2 Years more life – may be extendable



User Accessibility

- Users will determine if GNSS-R continues…

www.merrbys.co.uk

- We are giving users access to
  - **Sample data sets** – Level 0, Level 1b and Level 2
    - Taster of data types, quality, data format
    - Gaining orientation with data
  - **Full catalogue** of L1b and L2 DDMs

- Significant effort to prepare data products & service
  - Please excuse bugs, omissions!
  - Feedback welcome

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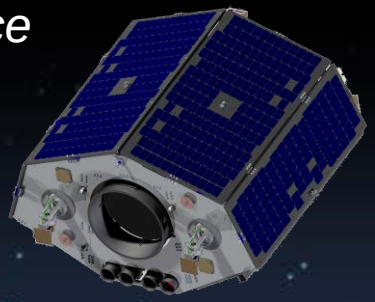
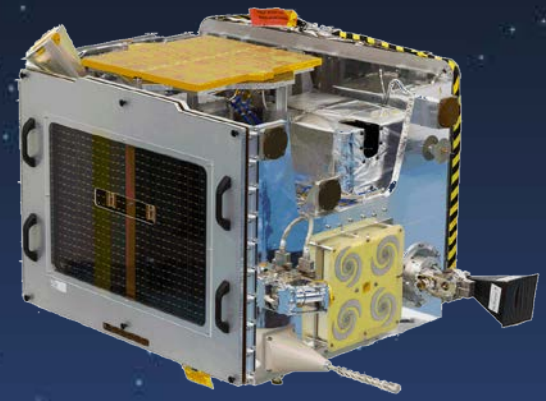
Changing the economics of space





Thank You

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