National Oceanography Centre
NATURAL ENVIRONMENT RESEARCH COUNCIL

SURREY
CHANGING THE ECONOMICS OF SPACE

esa

Towards a GNSS Reflectometry Service from the UK TDS-1 Satellite

Martin Unwin, Jonathan Rawlinson, Lucinda King, SSTL,
Christine Gommenginger, Giuseppe Foti, Matthew Hammond, NOC
Josep Rosello, ESA

GNSS+R, 20-22nd May 2019, Milan

ESA Contract: 4000123436
Ack: SSTL, NOC, ESA, Surrey, CEOI, UKSA, InnovateUK, CYGNSS

#0338680

GNSS-Reflectometry as an Operational Service

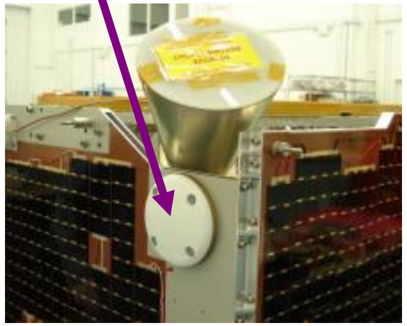
- Weather knowledge more important, globally, than ever before
  - Storm & flood risks, climate change observation, blue economy
- Small satellites can offer great complement to flagship missions
  - Constellations offer improved spatial and temporal coverage at low cost
- Experience with GNSS Reflectometry growing
  - Measurements could contribute towards NWP over ocean, land, ice, etc.
  - Fast data delivery required

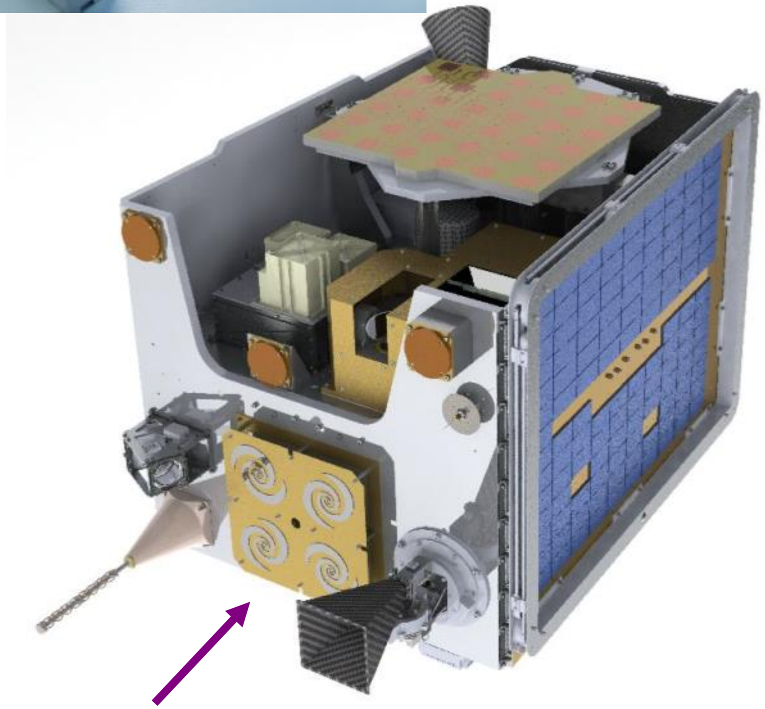
UK TDS-1 and SGR-ReSI

- SSTL UK TechDemoSat-1 Mission (TDS-1)
  - 160 kg UK Satellite Demonstration
  - 8 different payloads from UK
  - Includes SSTL's GNSS-R SGR-ReSI payload
  - Launched **July 2014**
  - Operated by SSTL & Sat App Catapult
- **SGR-ReSI**
  - COTS Based GNSS Receiver, CEOI project
  - Co-processor for real-time reflectometry
  - Zenith antenna: hemispherical dual freq patch
  - Nadir antenna – **13 dBi gain**, LHCP 30° beamwidth flared spiral
  - 5-10 watts, 1.5 kg
- Sponsorship from ESA to exploit experiment
- Same payload used for *NASA CYGNSS*

SGR-ReSI Unit

Zenith Antenna

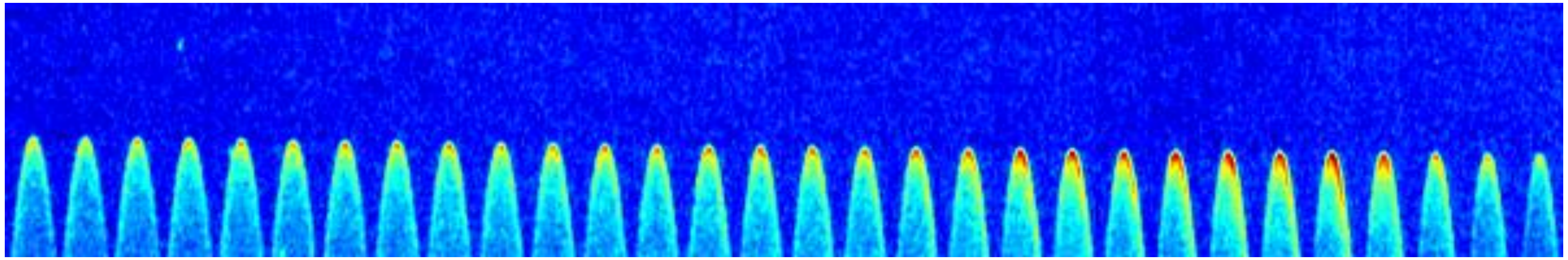




Nadir Antenna

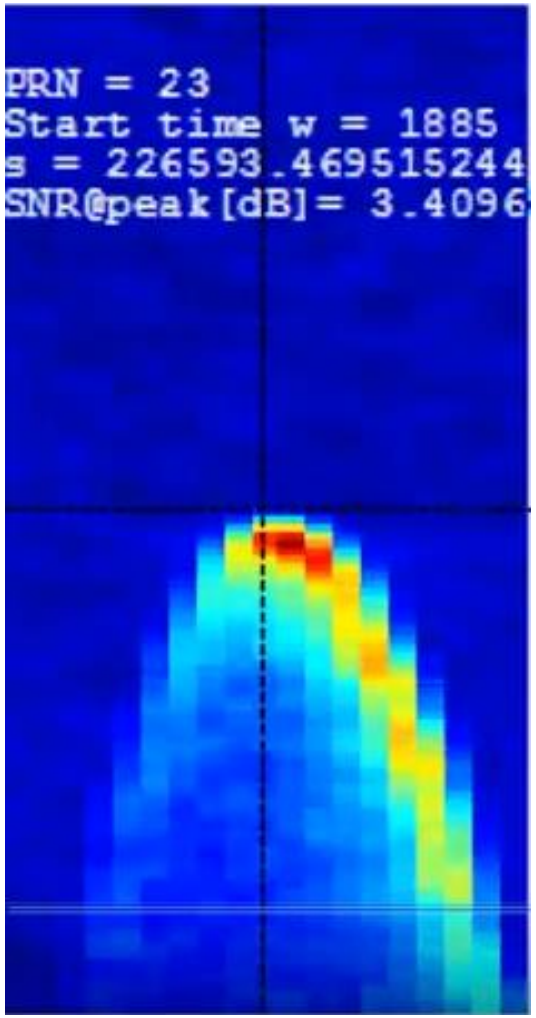
On-board DDM collection

- Occasional 2-minute raw data capture: Level 0
- On-board processed Delay Doppler Maps - Level 1A
  - Shows spread of reflected GNSS signal, related to surface roughness
- Processed on ground into Level 1B
  - Reformat, add meta-data, add calibration information
- 1 Measurement per second per track x 4 channels

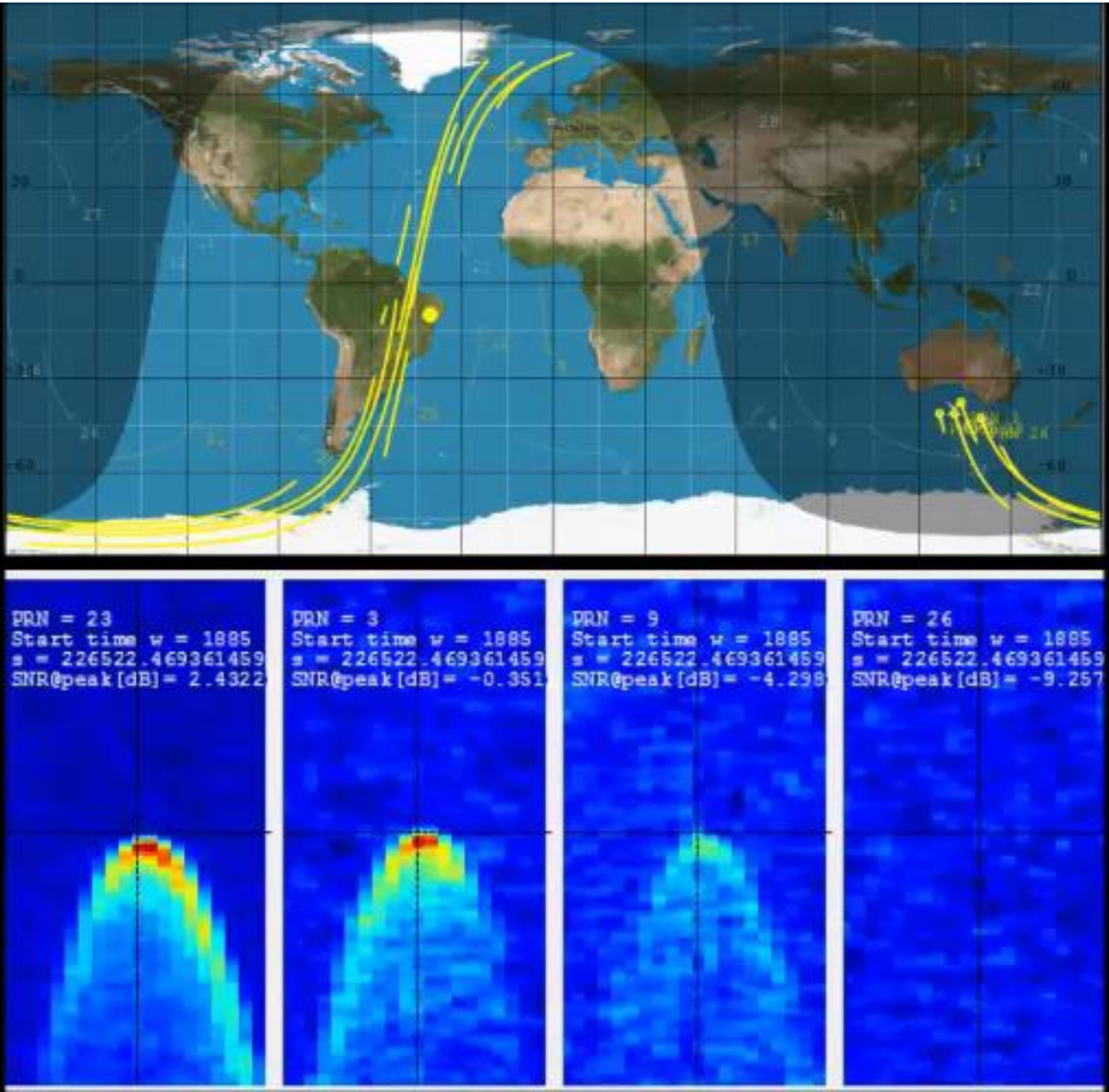


- Over ocean DDMs L1B processed into Level 2
  - ***Wind Speed*** and mean square slope
  - Products of operational use
- Low winds, flat surface => strong reflection

Delay Doppler Map

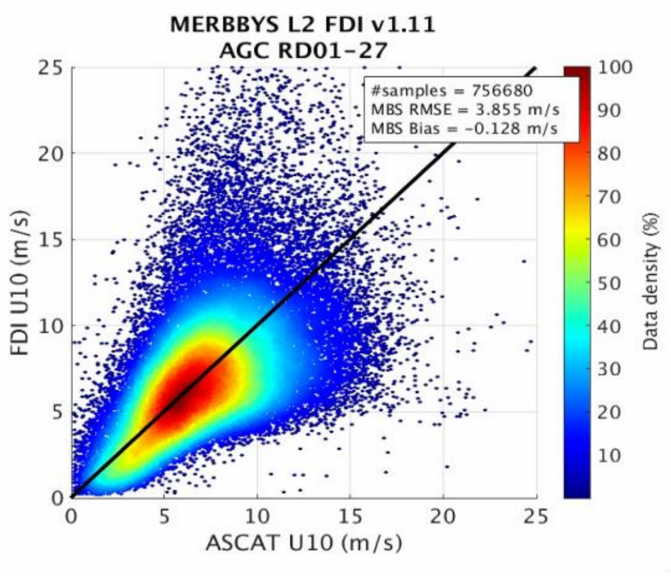


TDS-1 GNSS-R Measurements

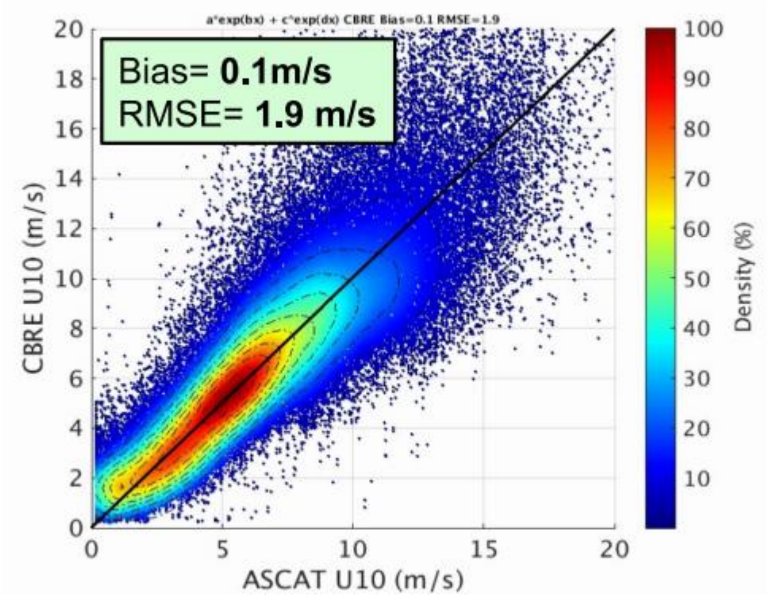


Finding Ocean Wind Speed from DDMs

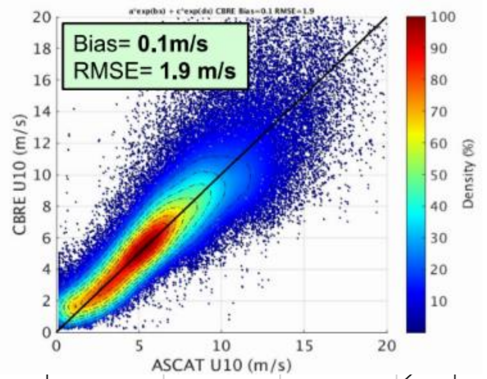
- SSTL partnered with NOC – National Oceanography Centre (NOC)
- NOC developed inversion algorithm using measurement of wind speed from ASCAT scatterometer
  - Find best model fit, then apply to whole data
- Inversion to Level 2:
  - Initially agreement with ASCAT of 3.8 m/s
  - With corrections, refinements, & filtering, indications are **2 m/s** can be achieved
  - Some limitations due to TDS-1 platform (attitude and antenna pattern knowledge)
  - Promising performance for a new global wind sensor
  - Furthermore DDMs may have closer match with *mean square slope* – a missing observable

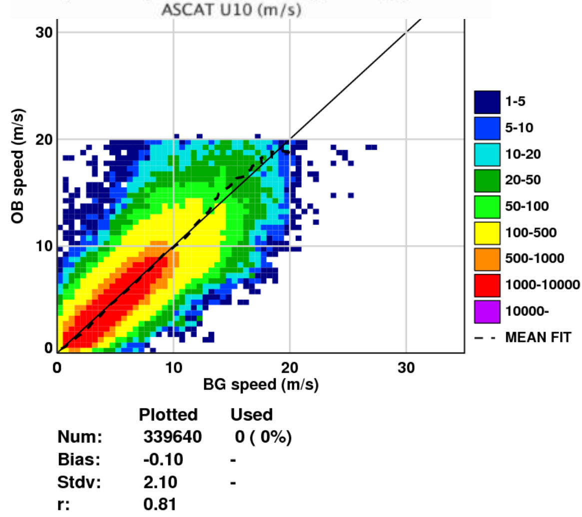


Corrections for receiver & transmitters



- ESA-funded **TGSCATT** study (May’16-May’18):
  - End-to-end scientific assessment of GNSS reflectometry scatterometric measurements from TDS-1 and data products
  - Seeks to establish the physical relation between GNSS-R signals and ocean wind and roughness properties
- Objectives/tasks
  - Revise and adapt simulation framework for TDS-1 (Wavpy)
  - Define GNSS-R observables using simulation framework
  - Develop/consolidate physical/empirical GMFs
  - Consolidation of Level1 & Level2 products (MERRByS)
  - Impact analysis on global NWP (O-B, preliminary OSEs & OSSEs)
- Successful workshop **24th May 2018**, Southampton, UK
  - http://merrbys.co.uk/events/gnss-r-workshop-may-2018





TDS-1 Towards Operational Service: Study

- Two studies covered commissioning & exploitation of TDS-1 SGR-ReSI
  - Development of instrument, and MERRByS data distribution via MERRByS
- TDS-1 mission provisionally finished in July 2017
  - But **life extension** approved for 12+ months, de-orbit sail postponed
- New ESA-supported study for TDS-1
  - TDS-1 operated GNSS Reflectometry **February – December 2018**
  - Careful data compression permitted transition to *continuous operation, 24/7*
  - Pilot demonstration of low latency wind speed products via MERRByS
- TDS-1 end of life - early 2019

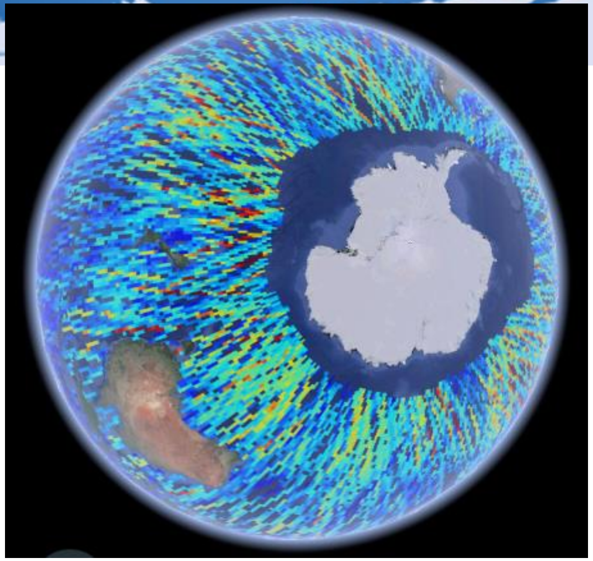
On-board Data Compression Implemented

- Upgraded ReSI firmware & software on TDS-1
- Increasing operation from 2 days out of 8 to continuous 24/7
  - Reduction in data rate
- Simple compression approach without losing data
  - Reduction from ~ 360 kbps to 60 kbps
- Further lossy compression possible, e.g. DDM size cut

Approach	Effects
Stop taking raw collections – DDMs only	Saves 1 GByte per collection
Delete DDMs with AGSP < 0dB	Reduce data rate by 2
DDM stored in 32 bits - remove top empty bits 22-32	Reduce by 1.6
Round DDMs by lowest 5 bits	Reduce by 1.3
Delta encoding – code as difference from next pixel	Reduce by 1.1 (1 bit)
Variable rate coding – store as 8, 16 or 24 bits	Reduce by ~1.3
Reduction compared to DDMs	**Approx factor of 6**

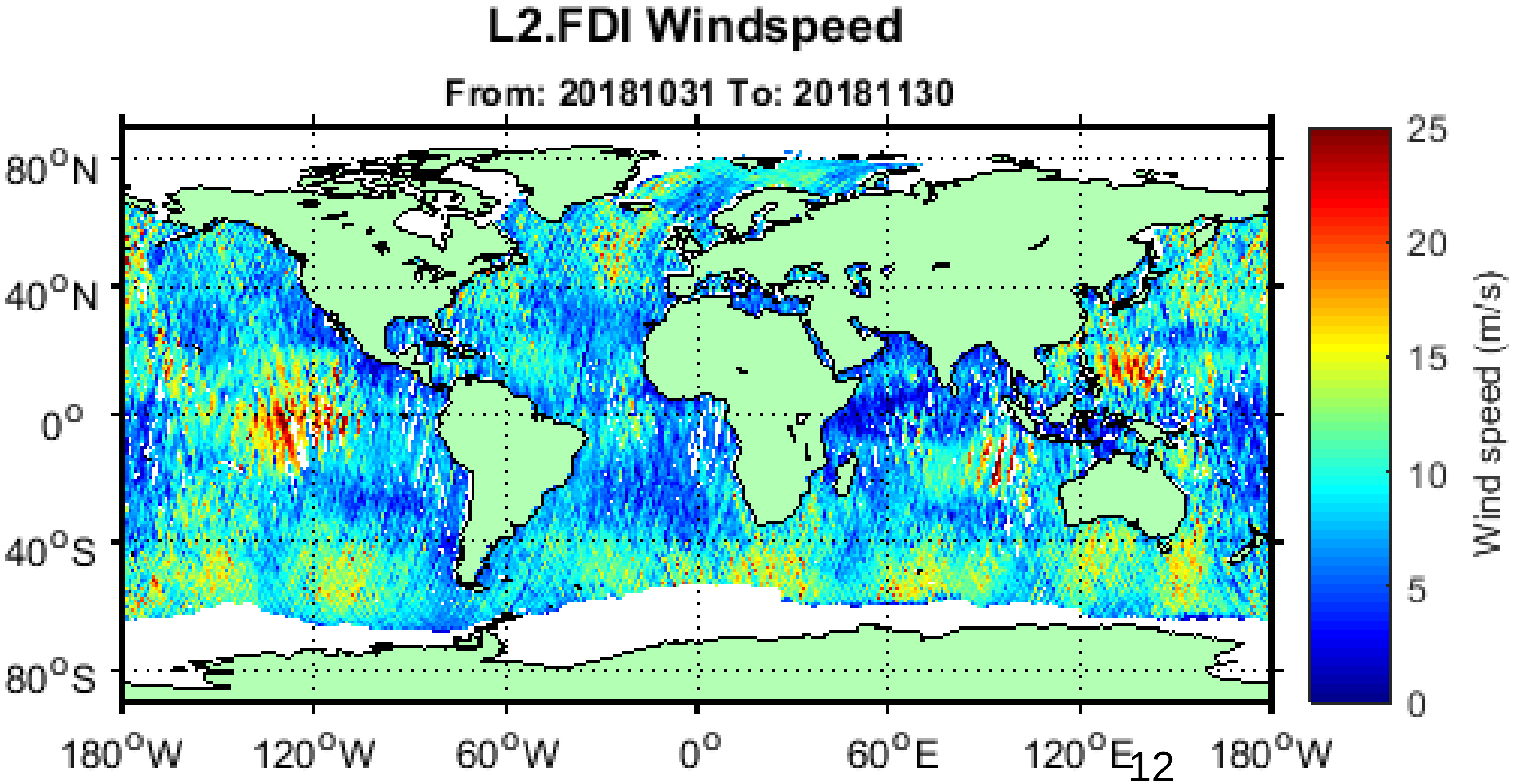
Data Access via MERRByS

- www.merrbys.org website for dissemination of GNSS-R data
  - Web site front-page,
    FTP server to access all data
  - "Standard" and "Fast" data access
- Also user forum on Google Groups
- Data freely issued - most users have been researchers, scientists, institutions
  Limited interest from commercial operators



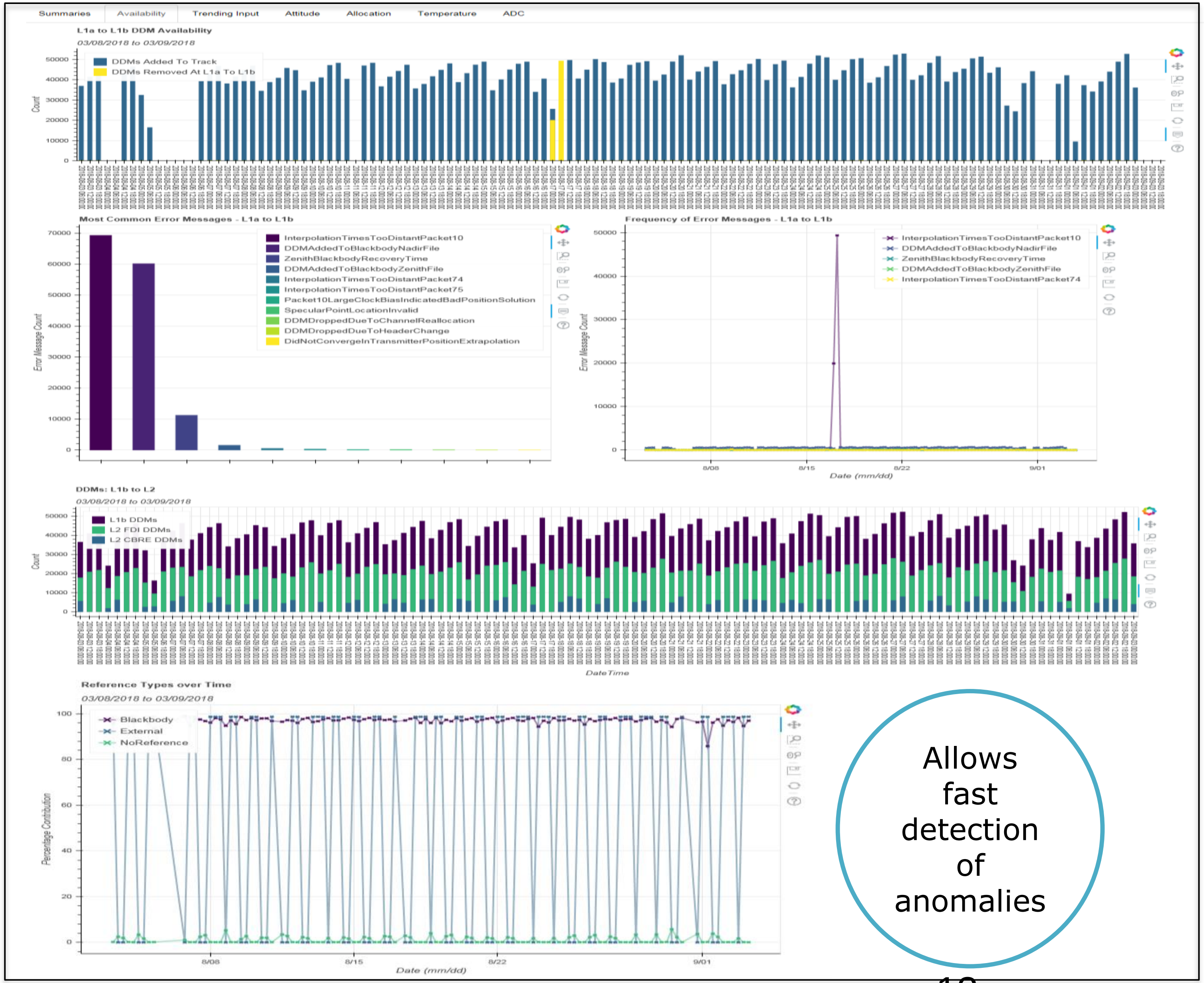
Wind Speed Data Availability

- Monthly maps were made available on website
- Track data on ftp server automatically for password holders - Format NetCDF – structured in 6 hourly data sets
- Standard users - Data available with delay of *30 days*
- Fast users
  - Shorter delay, but subject to TDS-1 Ground Station limitations, 24-48 hrs
  - In future with near-polar stations, could aim for 3 hour delay
  - Potential for institutional & commercial operational users



MERRByS Dashboard (Internal)

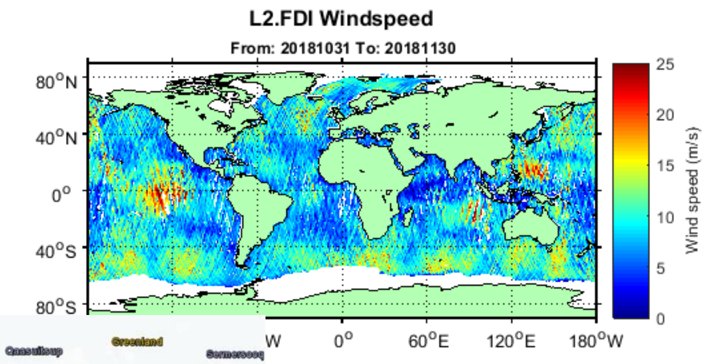
- Python-based dashboard developed
- Updated every 6 hours
- Monthly dashboard saved
- Info includes
  - No. of DDMs
  - Variance in L2-CBRE
- Aids managing of service



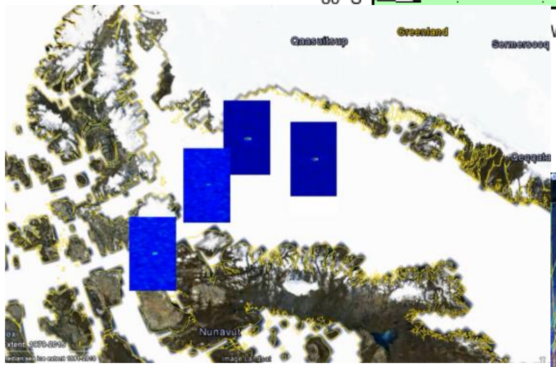
Allows fast detection of anomalies

Reflectometry Service Could Support Many Applications

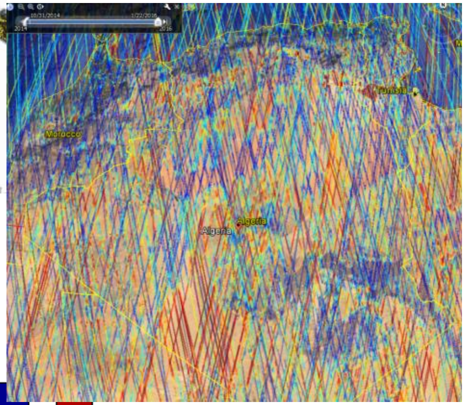
- TDS-1 data enabled a number of applications
- Ocean wind speed and *mss* measurement
  - Feed into Numerical Weather Predictions



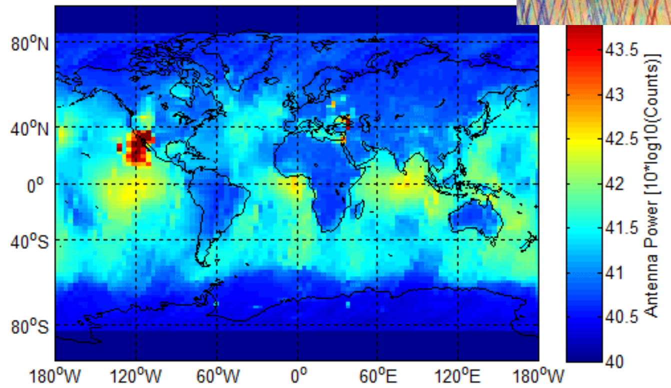
- Ice extent and sea surface sensing
  - Polar navigation, energy
  - Potential for altimetry over thick & thin ice



- Sensing of land reflections
  - Soil moisture & biomass influence signals
  - High resolution of river edges under canopy

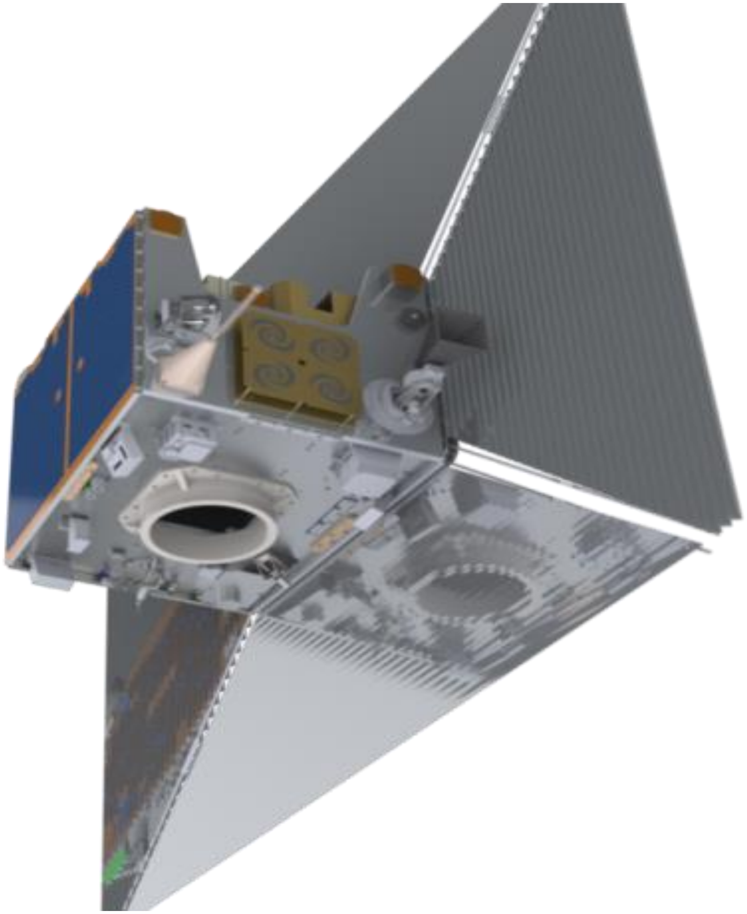


- Background noise sensing
  - Mapping of environment in L-band



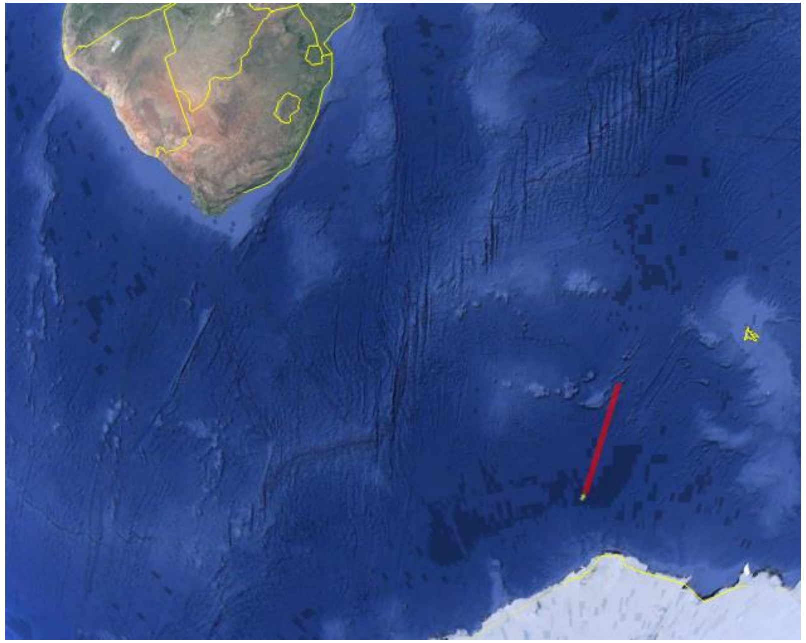
End of TDS-1, 2019!

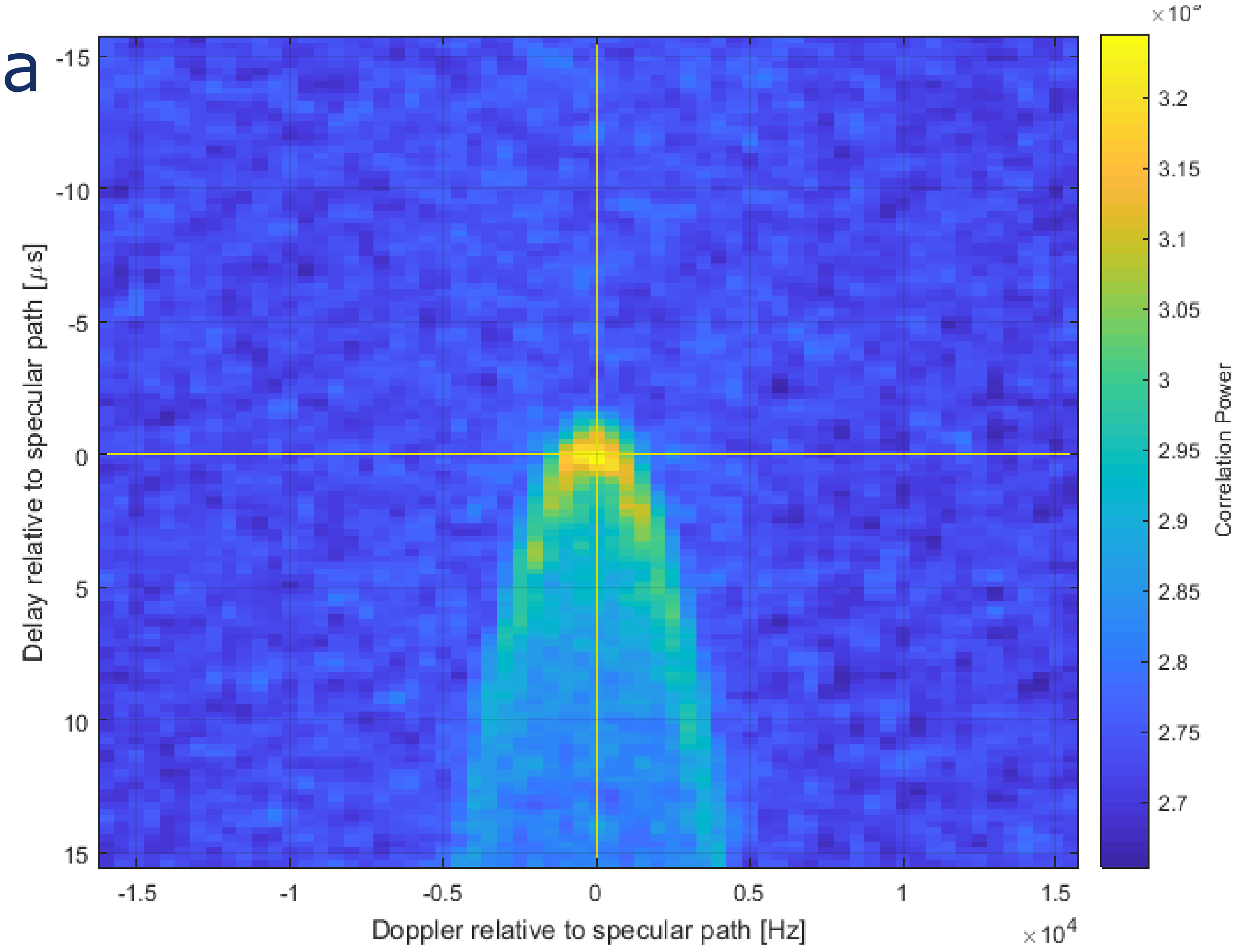
- Final experiment on TDS-1 is drag-sail
- Satellite first passivated
  - All propellant expelled
- Final ReSI data collections, March 2019
- SSTL in process of deploying de-orbit sail on TDS-1, April-May 2019
  - Increases surface area and drag of satellite
    - Thin atmosphere takes energy out of its orbit
  - Ensures lifetime <25 years before re-entry
- Sadly, no further ReSI operations are anticipated after deployment
  - Solar panels and sensors masked, downlink antenna blocked, complete change of thermal/power budget



New TDS-1 Signal Collections, Oct 2018, Mar 2019

- Recent collection TDS-1 raw data
- Contains GPS L1 and Galileo E1
  - Example Reflected Galileo DDM
    – **18th October 2018**, off Antarctica

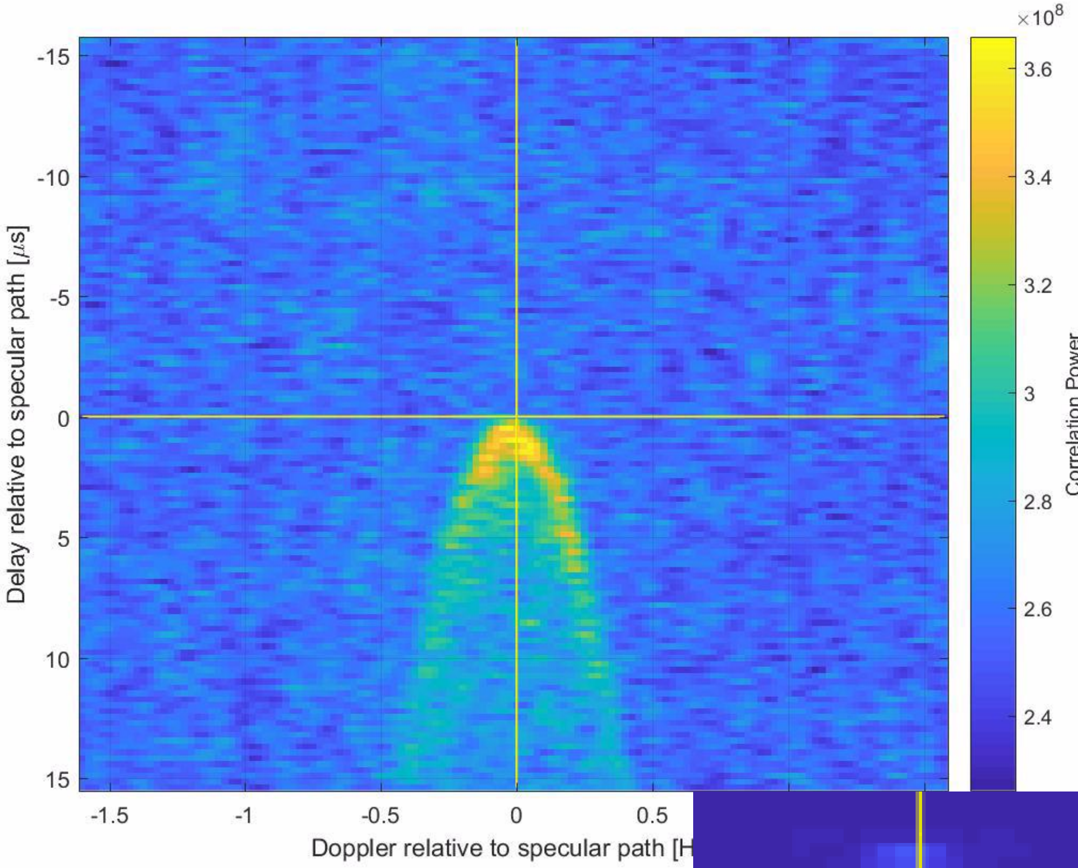


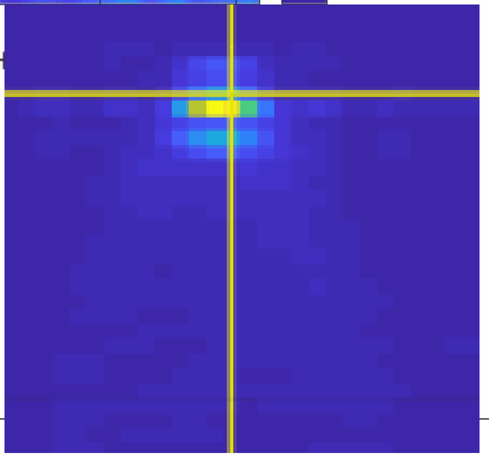


- Assessing Galileo reflections,
  Aim to implement Galileo DDMs on next mission

More on TDS-1 Galileo Collections – March 2019

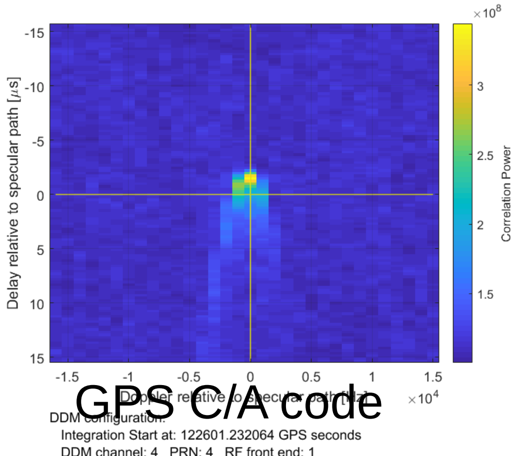
- Now 23 Galileo satellites transmitting in orbit
  - 12 new Galileo satellites being built by SSTL & OHB at present
- Galileo E1 more complex than GPS C/A Code
  - Wider Bandwidth, (4 MHz), BOC(1,1) subcarrier, longer code - 4 ms
  - Wider BW gives higher resolution, but smaller area reflects less power off ocean?
  - Reflected E1 signal approx 3 dB less than C/A
  - Multiple correlation peaks – visible over ice
- Alternative approaches trialled to recover reflections
  - 1 millisecond – can use zero padding method with 4 x 1 ms
  - 4 millisecond – integrate coherently for 4 ms
  - To date – 4 ms approach is showing more gain, more promising approach



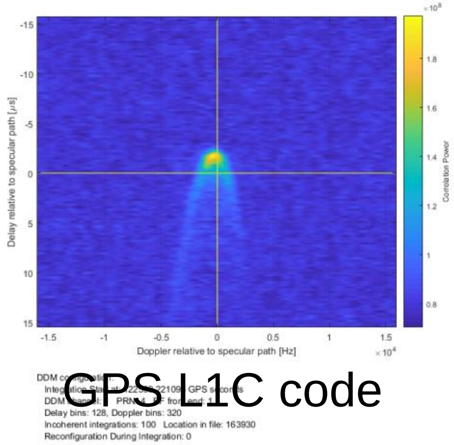


GPS Block III Broadcasting L1C signals

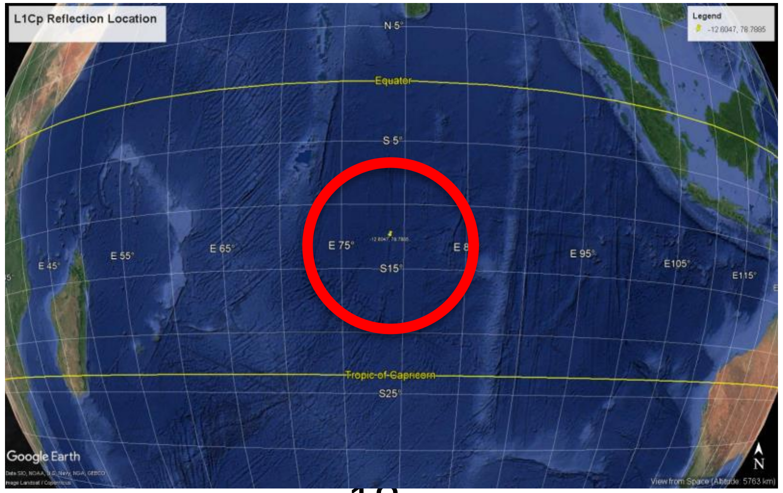
- First GPS Block III satellite launched (PRN 4)
  - Transmitting signals - though marked “unhealthy”
- New signal: GPS L1C available
  - Essentially same BOC(1,1) 4 MHz spectrum as Galileo, different codes, 10 ms long Weil codes
  - Also transmits GPS C/A code at same time from satellite
  - Gives opportunity for collocated test of BOC(1,1) vs C/A code BPSK
  - Useful information for understanding Galileo signals
- Signal collected: 25/03/19



GPS C/A code

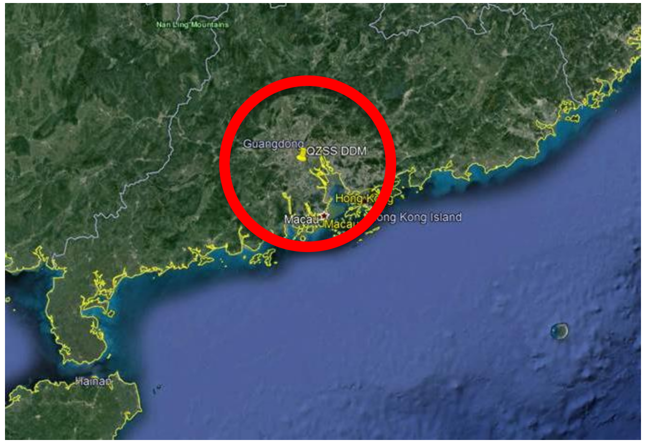


GPS L1C code

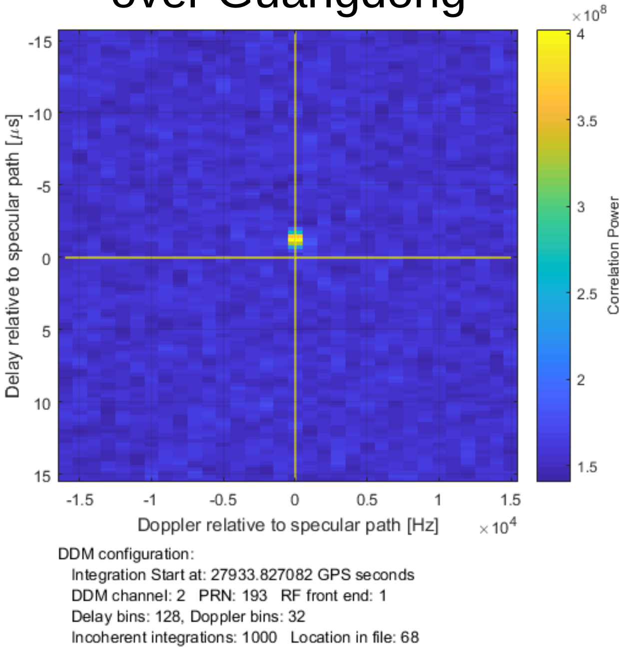


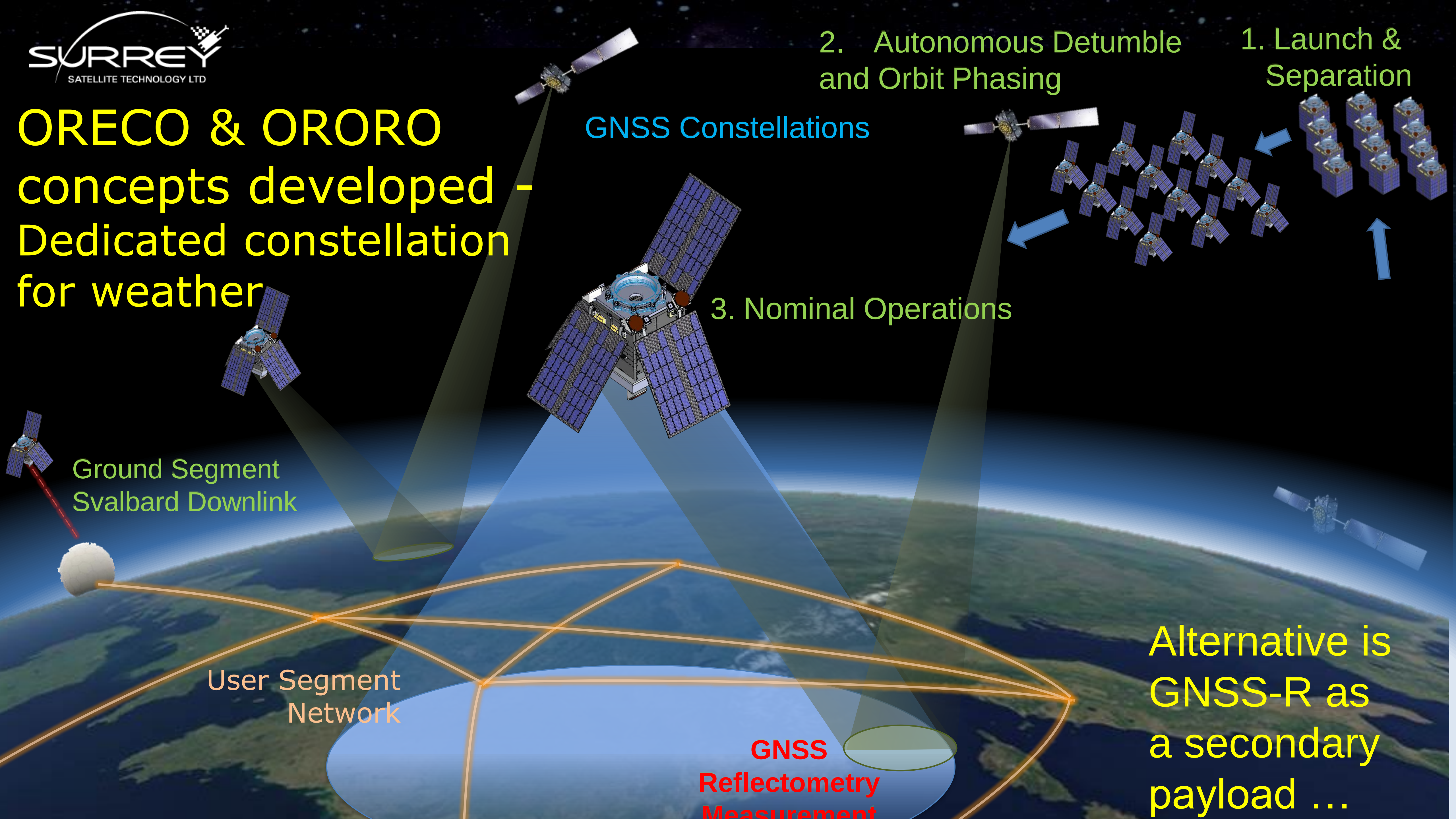
Other signals from TDS-1 Collections

- Other signals in L1 band can be found
  - SBAS, and QZSS (Japanese GNSS)
- Several collections made using dual frequency (L1 and L2C)
  - Second frequency present in SGR-ReSI hardware
  - Problem with interference spike in L2 band due to oscillator harmonic
- Success in finding direct L2C signals
  - Application of notch filtering to remove harmonic
- Work in progress in L2C direct tracking, & finding reflected signals

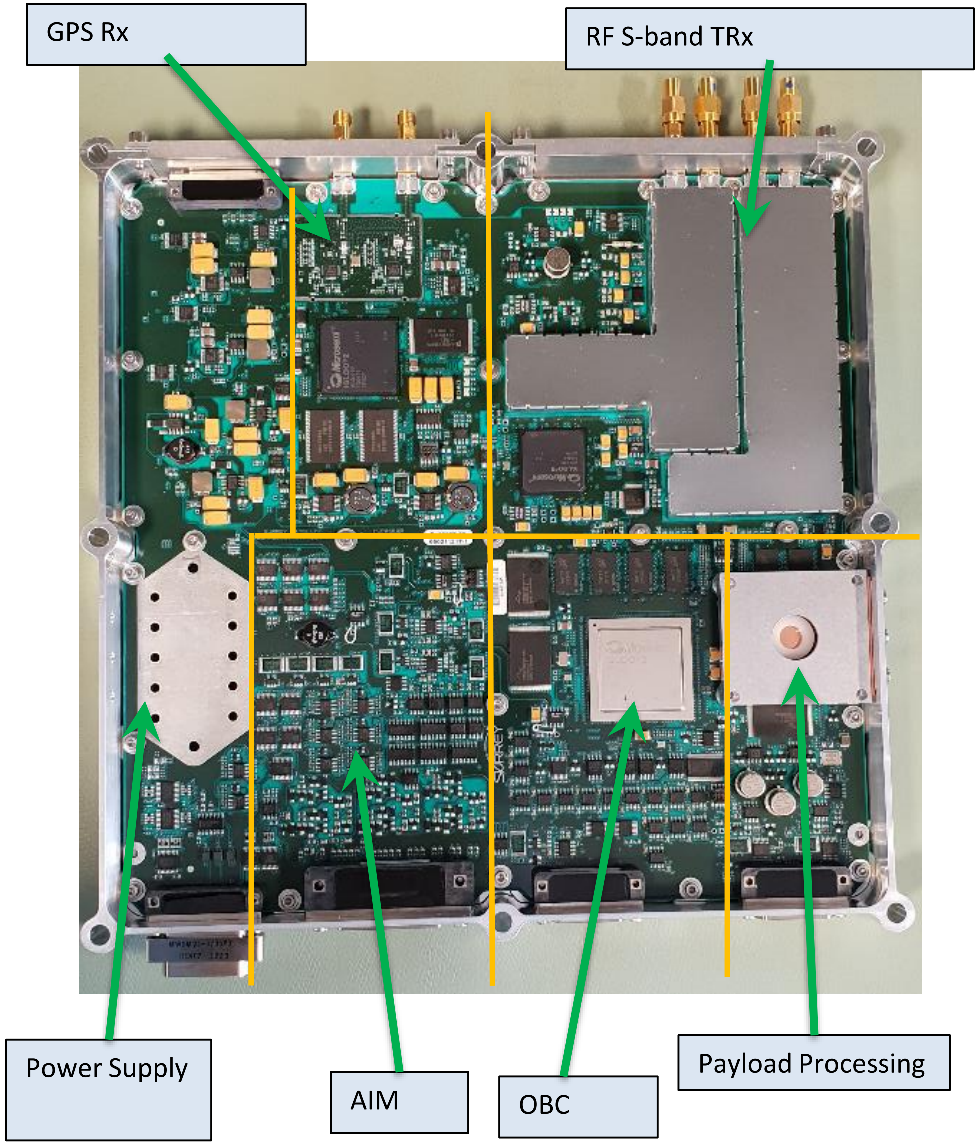


QZSS L1 C/A code reflection over Guangdong



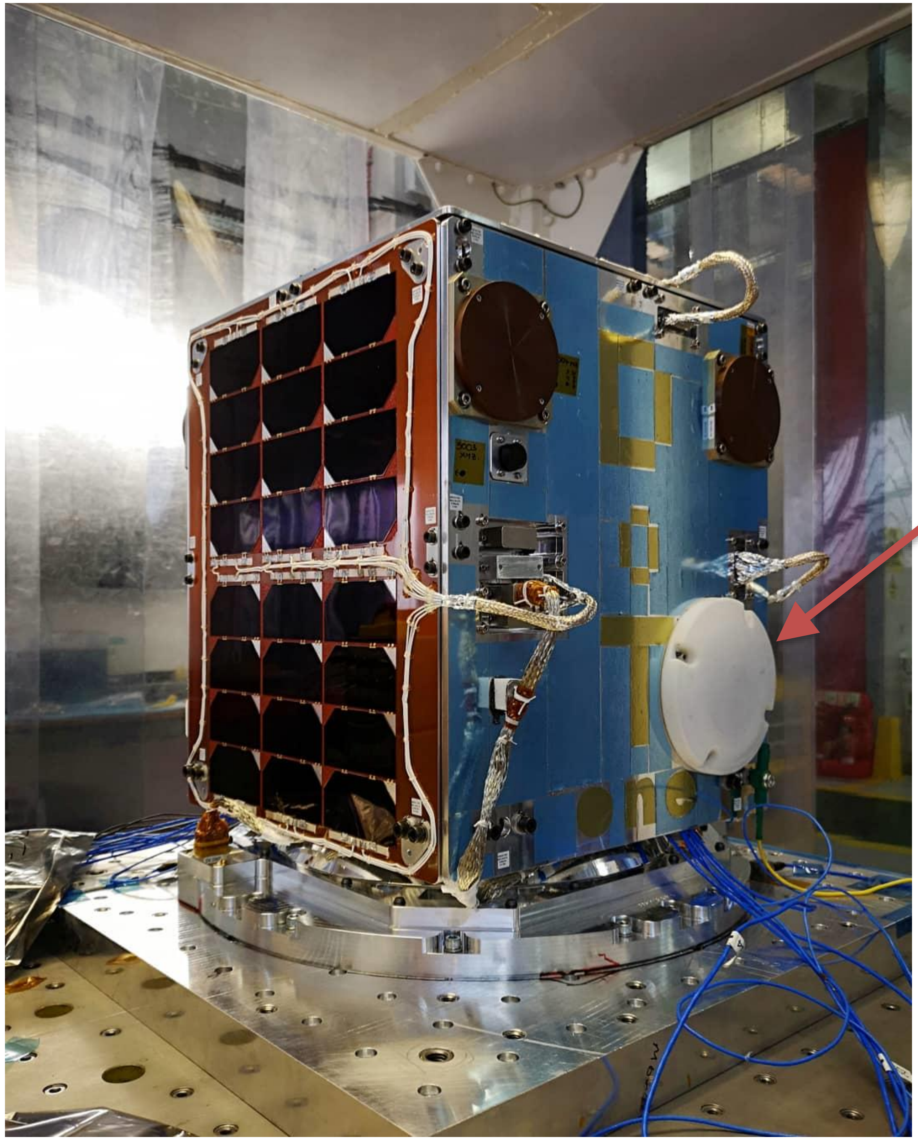

SURREY
SATELLITE TECHNOLOGY LTD
ORECO & ORORO concepts developed - Dedicated constellation for weather
GNSS Constellations
2. Autonomous Detumble and Orbit Phasing
1. Launch & Separation
3. Nominal Operations
Ground Segment
Svalbard Downlink
User Segment
Network
GNSS
Reflectometry
Measurement
Alternative is GNSS-R as a secondary payload …

New SSTL Core Avionics can support GNSS-R



- Core of SSTL's satellite carries SGR-Ligo GNSS receiver
- Dual GNSS front-ends available
- Payload processor can accommodate GNSS/ZTC algorithms
- Potential to add GNSS Reflectometry to future constellations as secondary payload - at low cost

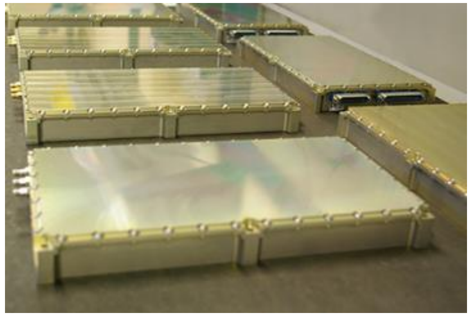
DoT-1 - Avionics Demonstration Satellite

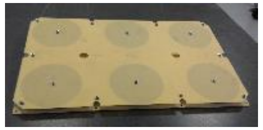


- 21kg SSTL technology satellite
  - Due for launch end-June 2019
- Main aim is to prove new avionics
- But carries new integrated GNSS- R experimental payload
  - LHCP antenna using 3D printed radome
  - Gain of **8.5 dBi**
- Comparison with TDS-1
  - Boresight gain lower (c.f. 13dBi), but… lower altitude, lower NF, less sensitive to attitude, wider coverage
- TDS-1 measurement > 7 dBi had 43° FOV
- DoT-1 equiv. gain > 7 dBi, **50° FOV**
  - i.e. more useful measurements than TDS-1
- Aims:
  - Prepare technology for future missions
  - Test if lower gain gives same/better results
  - Distribution of GNSS-R data via MERRByS
  - Expand to include on-board Galileo DDMs

GA-EMS OTB-3

- General Atomics – Electromagnetic Systems (GA-EMS) manufacturing Orbital Test Bed 3 (OTB-3)
  - 110 kg Technology Carrying Satellite
- OTB-3 will carry Argos A-DCS
  - Data collection from thousands of transmitters e.g. on buoys, wildlife monitor, maritime security
  - Payload from CNES, Sponsored by NOAA
- Satellite will also carry SGR-ReSI
  - Former SST-US (US manufacturer of SGR-ReSI) is now part of GA-EMS
- Project kicked off Q1 2019
  - SSTL anticipated to provide support





Conclusions

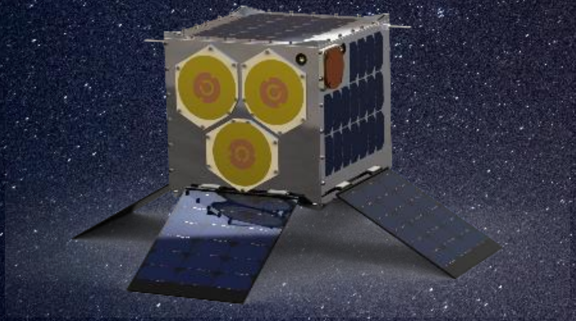
- TDS-1 reached end of life
  - But in 2018, demonstrated periods of continuous 24/7 data collection
  - Achieved by minimal loss compression of DDM data
  - Delivered Standard & Fast GNSS-R services from space
- Many users of TDS-1 data across world – 220 registered
  - New applications springing up in surprising areas, sea, land, ice
- Demonstration of other GNSS reflections from raw data
  - Reflections from Galileo E1, and also GPS BIII L1C
- New missions with GNSS-R on the way
  - DoT-1 and OTB-3
- New low resource technique of measuring ocean winds
  - Could be added as hosted payload on constellations at very low cost

National Oceanography Centre
NATURAL ENVIRONMENT RESEARCH COUNCIL

SURREY
CHANGING THE ECONOMICS OF SPACE

esa

Thank You



ESA Contract: 4000123436
Ack: SSTL, NOC, ESA, Surrey, CEOI, UKSA, InnovateUK, CYGNSS

MERRByS

www.merrbys.co.uk

© Surrey Satellite Technology Ltd.
Tycho House, 20 Stephenson Road, Surrey Research Park, Guildford, Surrey, GU27YE, United Kingdom
Tel: +44(0)1483803803 | **Fax**:+44(0)1483803804 | **Email**: info@sstl.co.uk | **Web**:www.sstl.co.uk

GNSS Receivers on SSTL-Built Satellites in 2018

- Carbonite-2
  - SGR-Axio, dual frequency
  - New smallsat wideband GNSS antenna
- LeoV-1
  - SGR-07 higher altitude
- NovaSAR
  - SGR-Axio DF
- 4th DMC3
  - SGR-10
- **RemoveDebris**
  - SGR-07 (& Cubesat's GPS)
- Vesta
  - SGR-Ligo
- Also receivers on non-SSTL missions

RemoveDebris deployed & viewed from ISS
On-board camera demonstrated capture of Cubesat "Debris"