TechDemoSat-1 Status

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Ack: SSTL, NOC, ESA, CEOI/InnovateUK, CYGNSS

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Spaceborne GNSS Reflectometry

- **GNSS Reflectometry**
  - Detecting GPS / GNSS signals reflected off the Earth’s surfaces
  - “Multipath” signals should contain geophysical imprint
  - Bistatic radar – but no need for radar transmitter
- **Using Earth-reflected GPS signals for ocean sensing** first discussed in 1988
  - 1993 ESA proposed reflectometry for ocean **Altimetry** – PARIS
  - US & European 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) – feasibility*

  **First on-board processing instrument: UK TDS-1 (2014)**

  *First GNSS-R Constellation: NASA CYGNSS (Dec 2016)*
UK TDS-1 and SGR-ReSI

- **TechDemoSat-1 Mission**
  - 160 kg UK Satellite Demonstration
  - 8 UK payloads
  - Includes SSTL’s GNSS-R payload the SGR-ReSI
  - Launched **July 2014**
  - Operated by SSTL & Sat App Catapult

- **SGR-ReSI**
  - COTS Based GNSS Receiver
  - Co-processor for Reflectometry
  - Zenith antenna: hemispherical dual patch
  - Nadir antenna – **13 dBi gain**, LHCP 30° beamwidth flared spiral
    - Also two single freq. zenith patch antennas
  - 5-10 watts, 1.5 kg
On-board DDM collection

• On-board processing of data generates 4 x Delay Doppler Maps - Level 1A
  – Shows spread of reflected GNSS signal
  – Spread related to surface roughness
• Processed on ground into Level 1B
  – Reformat, add meta-data,
  – calibration information
• 1 Measurement per second per track

• Over ocean DDMs L1B processed into Level 2
  – Wind Speed and mean square slope
  – Products of operational use
• Strong reflection => low winds
Data Shared to Promote Applications

- Metadata helps processing & visualisation
  - E.g. playback in Google Earth
- Data not now real-time
  - But could be NRT
- Current activities - vital
  - Radiometric refinement
  - Bias removal in L2
    - See Presentations by P. Jales & G. Foti
  - Product refinement & Impact - TGScatt
  - Improve TDS-1 attitude
  - Streamlining data flow to reduce data delay
    - Prepare pilot service
MERRByS Database

- [www.merrbys.org](http://www.merrbys.org) website for dissemination of GNSS-R data
  - Web site front-page, Catalogue (Atlas), FTP server to access all data
- User forum on Google Groups
- **Data release v0.7 coming…**
- User Workshop in Sept/Oct, TBC

Over 100 users
TDS-1 was Precursor to CYGNSS

• NASA CYGNSS mission
  – 8 small satellites sensing hurricanes using GNSS Reflectometry
• SGR-ReSI payload DDMI
  – Designed in SSTL UK
  – Manufactured in SST-US
• Orbits: 35º incl. to target tropics
  – Potential for follow-on polar constellation
• Launched 15th Dec 2016
  – Entered Operational Phase 23rd March 2017
TDS-1 GNSS-R Measurements
Land Applications: North Africa

- **Land Collections** show geophysical patterns
  - Water, soil moisture, soil roughness, salinity, biomass,

- **Strong reflections**
  - Salt lakes in Tunisia and Algeria
  - Some desert areas

- **Weak reflections**
  - Vegetation
  - Mountain ranges
  - Other deserts

- **Some temporal variations visible, but TDS data is sparse**

Many applications – hydrology, flooding, climate, etc.
Ice Sensing

- Reflections off ice very strong
  - Can detect edges, resolution few kms
  - Also potential for altimetry over ice
- E.g. Northwest Passage – iced over in March 2016
TGSCATT

- ESA-funded TGSCATT study (May’16-Feb’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 L1 & L2 products (MERRByS)
  - Impact analysis on global NWP (O-B, preliminary OSEs & OSSEs)

- Partners: NOC, SSTL, MetOffice, SatOC (UK), ICM, IEEC (ES)

- Final workshop aims to present results Feb 2018
Dual Frequency Experimentation on TDS-1

- Demonstrate Precise Orbit Determination on TDS-1
  - UKSA-funded study – 2016/17
  - Partnership- SSTL and Newcastle Uni (Prof P Moore)
- Using new GPS L2C signals (direct signals)
  - Preparing for future GPS/Galileo L1/L5 instrument
- Implemented GPS L2C tracking
  - First ever orbit recovery using GPS L2C signals
- Also demonstrated
  - First tracking of Galileo E1 in orbit
- Orbit fit of TDS-1 down to \(~30\) cm consistency
  - On going work – we know better performance possible
- TDS-1 still has potential for first ever reflectometry using dual frequency L1, L2C GNSS signals…
ORORO Study

- ESA funded SSTL study
  - “ORORO” constellation - combines GNSS Radio Occultation with GNSS-Reflectometry
  - Low cost concept for satellite constellation
- High spatial / temporal measurements for weather
  - Complementary ocean wind speeds, temperature, pressure
- New instrument based on SGR-Axio
  - L1 and L5 GPS / Galileo signals
  - Challenges: Bending angles, OL processing
  - Processing, zenith signals common to both
- Aim is breadboard bench demo in 2018
  - Then instrument prototype for in-orbit demo
Visualisation of ORORO

1. Launch Phase
2. Separation
3. Autonomous Detumble and Orbit Phasing
4. Nominal Operations

GNSS Constellations

Radio Occultation Measurements

Ground Segment

User Segment Network

GNSS Reflectometry Specular Point

GNSS-RO
TechDemoSat-1 Prospects

• TDS-1 still operating 2 days out of 8
  – Data gathering and scientific review
• Experimentation on-going
  – New signals L2c, Galileo E1, etc., new processing
  – Potential for ocean altimetry with TDS-1
• TDS-1 Contract Ends July 8th 2017
  – Originally de-orbit sail deployment, game over…
• Mission extension proposal submitted
  – TDS-1 remains healthy
  – New data format will support low delay data delivery
  – Even with CYGNSS, TDS-1 remains valuable mission
    • Continuity with CYGNSS, & experimental flexibility
    • Only GNSS-R polar coverage, dual frequency, Galileo
    • Stepping stone towards future missions
TDS-1 Extended Service Concept

• After July 2017, SGR-ReSI could go full time
  – 24/7 collection of GNSS-Reflectometry
• Aim is to provide
  1) Fast data pilot service for subscribers
     Allows experimentation with fast ingestion
  2) Delayed data still available for researchers
• Technical challenges
  – Data-flow is being streamlined
    • Reduced files, slimmed products, eliminate empty DDMs
    • Lower latency data – S-band, X-band,
  – Data availability, quality & assurance
    • Improved attitude, direct signals, L2 quality checking
  – TDS-1 life issues
• On going funding challenges
  – Value of products still being established
• Paving the way for new satellites & future reflectometry service
• SSTL launches 2-4 sats into LEO per year
Future of GNSS Remote Sensing

- Quality vs Quantity of satellites?
  - Studies suggest best solution is combined:
  - Core of high quality measurements (few)
  - Augmented by many observatories, medium quality

- Only small satellites (<30 kg) needed for GNSS
  - Cost need not be high for many sats, fast to deploy
  - Strength is in spatial and temporal coverage

- But after science missions, no more constellations unless funding framework

- Institutional or commercial?
  - Precedents for commercial approach to GNSS-RO
  - But how to combine with institutional missions?
    - Or Private Public Partnership?

Where there’s a will there’s a way!