GNSS Reflectometry for Global Ocean Wind Services: the TechDemoSat-1 Success Story

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Content of this talk

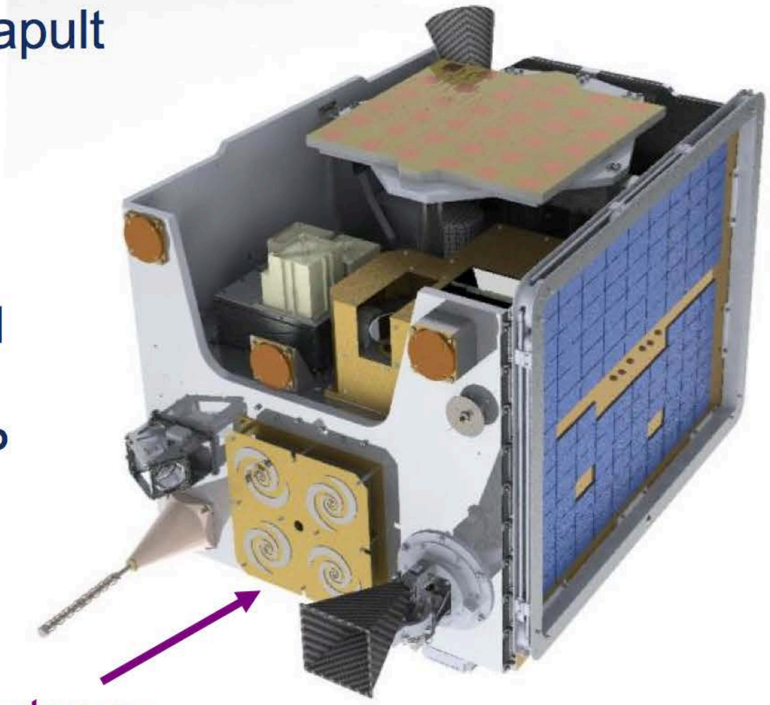
- GNSS-Reflectometry on TechDemoSat-1
- (Some) World Firsts with TechDemoSat-1
- GNSS-Reflectometry: Way forward ?

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

SGR-ReSI Unit

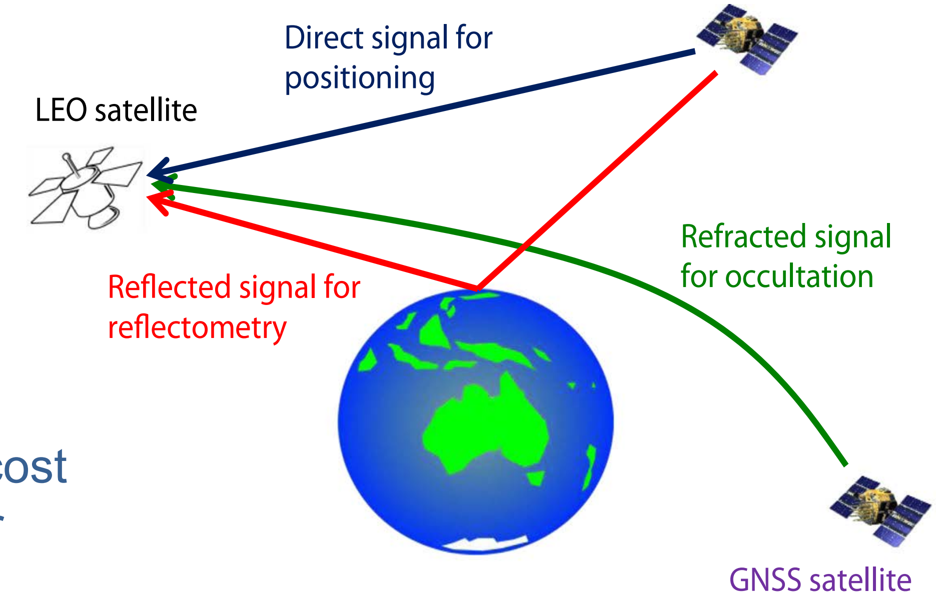
Zenith Antenna



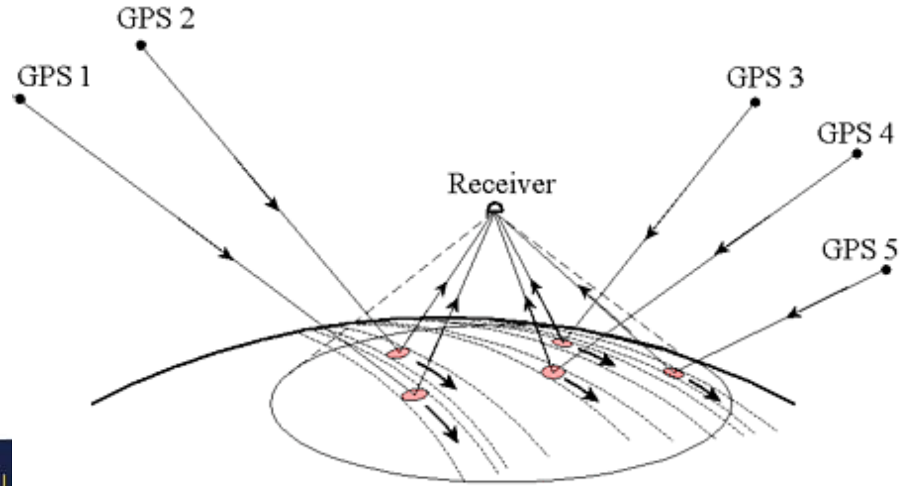
Nadir Antenna

GNSS-Reflectometry

- Global Navigation Satellite Systems
  - e.g. GPS, Galileo…
- Global, ubiquitous, dependable, free signals of opportunity
- GNSS-R need no transmitted power
  - potential for low-mass low-power low-cost receivers suitable for small satellites or piggybacking
- Scientific applications to ocean surface wind and sea level monitoring
  - Also sea ice, soil moisture, …
- Could yield significant improvement in space-time sampling
  - Wide swath and/or constellations

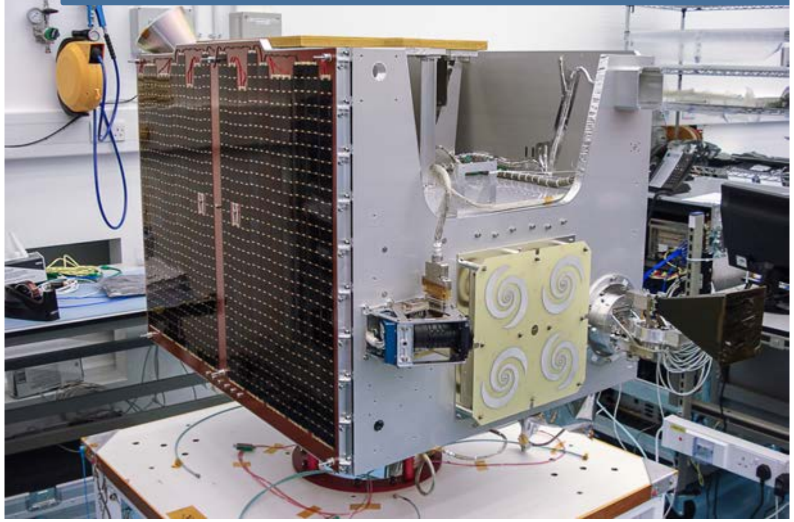


From Yu et al., 2014

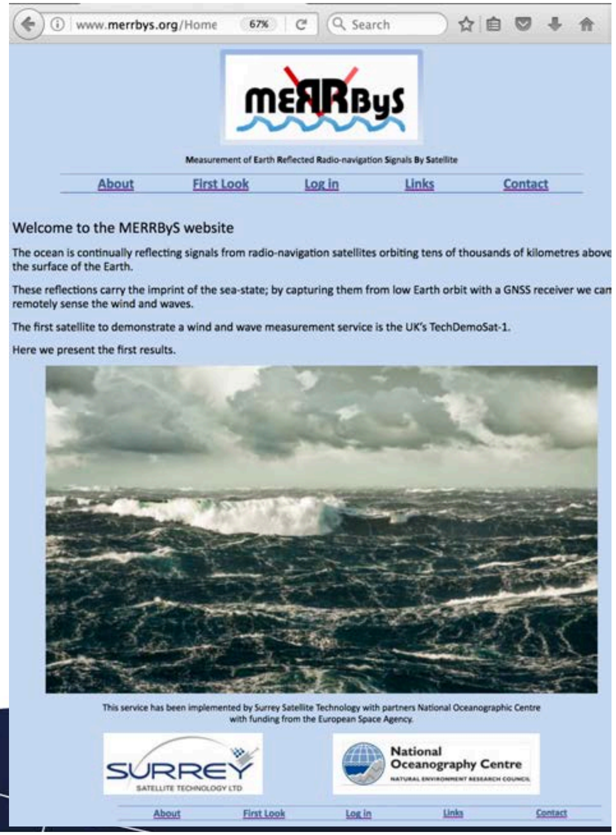


After Martin-Neira, 1993

GNSS-R on TDS-1


TechDemoSat-1 in SSTL labs

- TDS-1 launched 8 July 2014
- UK technology demonstrator mission
  - Duty cycle shared between 7 payloads
  - GNSS-R operates 2 in every 8 days
  - No UK support for data exploitation
- ESA funding to SSTL/NOC for GNSS-R data processing/dissemination (SSTL) and wind speed inversion/validation (NOC)
  - MerrBys data portal:
    http://www.merrbys.co.uk/
  - Distribution of global L1 Delay Doppler Maps & L2 wind speed products to registered users



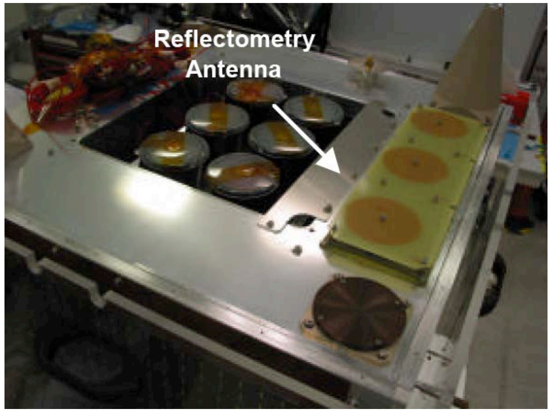
A long-term development

2003
Proof-of-concept on
SSTL's UK-DMC

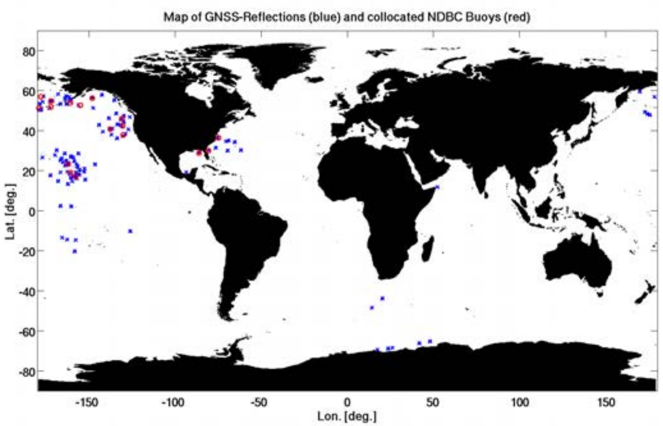
CEOI

8 July 2014
UK TechDemoSat-1
launch with SGR-ReSI
GPS-R payload

Dec 2016
NASA Cyclone Global
Navigation Satellite
System (CYGNSS) mission



Constellation of
8 SGR-ReSI



Collected ~ 50 data points
over ocean

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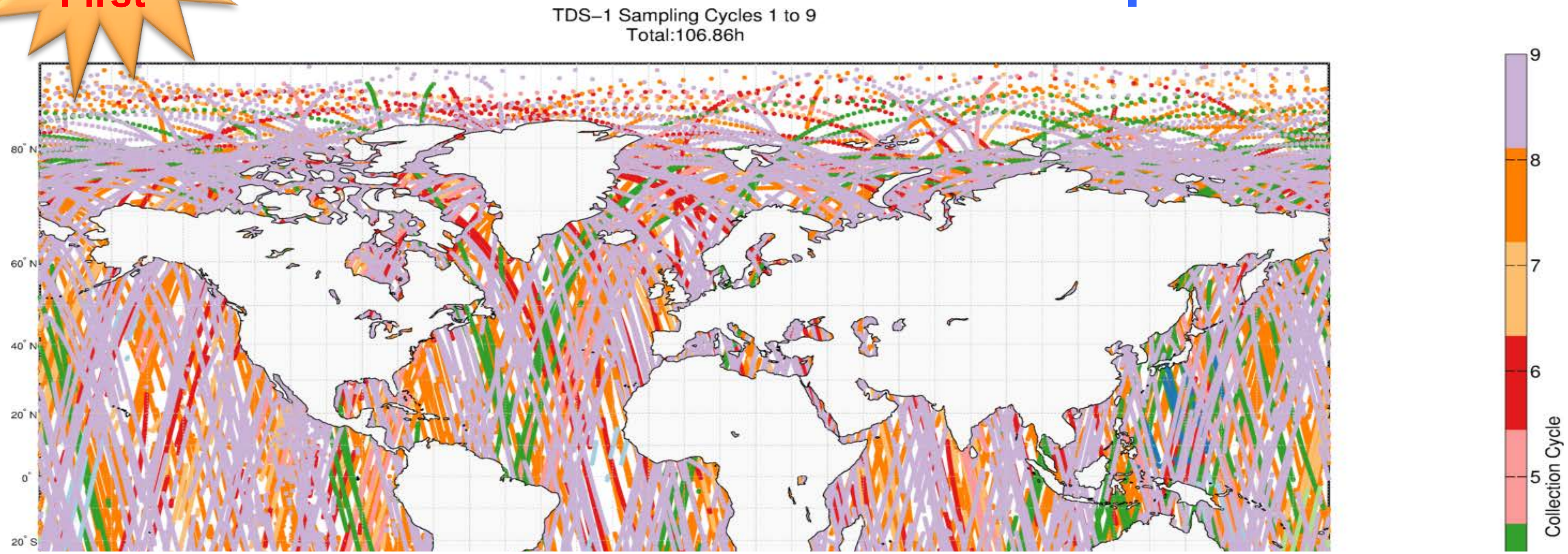
(Some) World Firsts with TDS-1

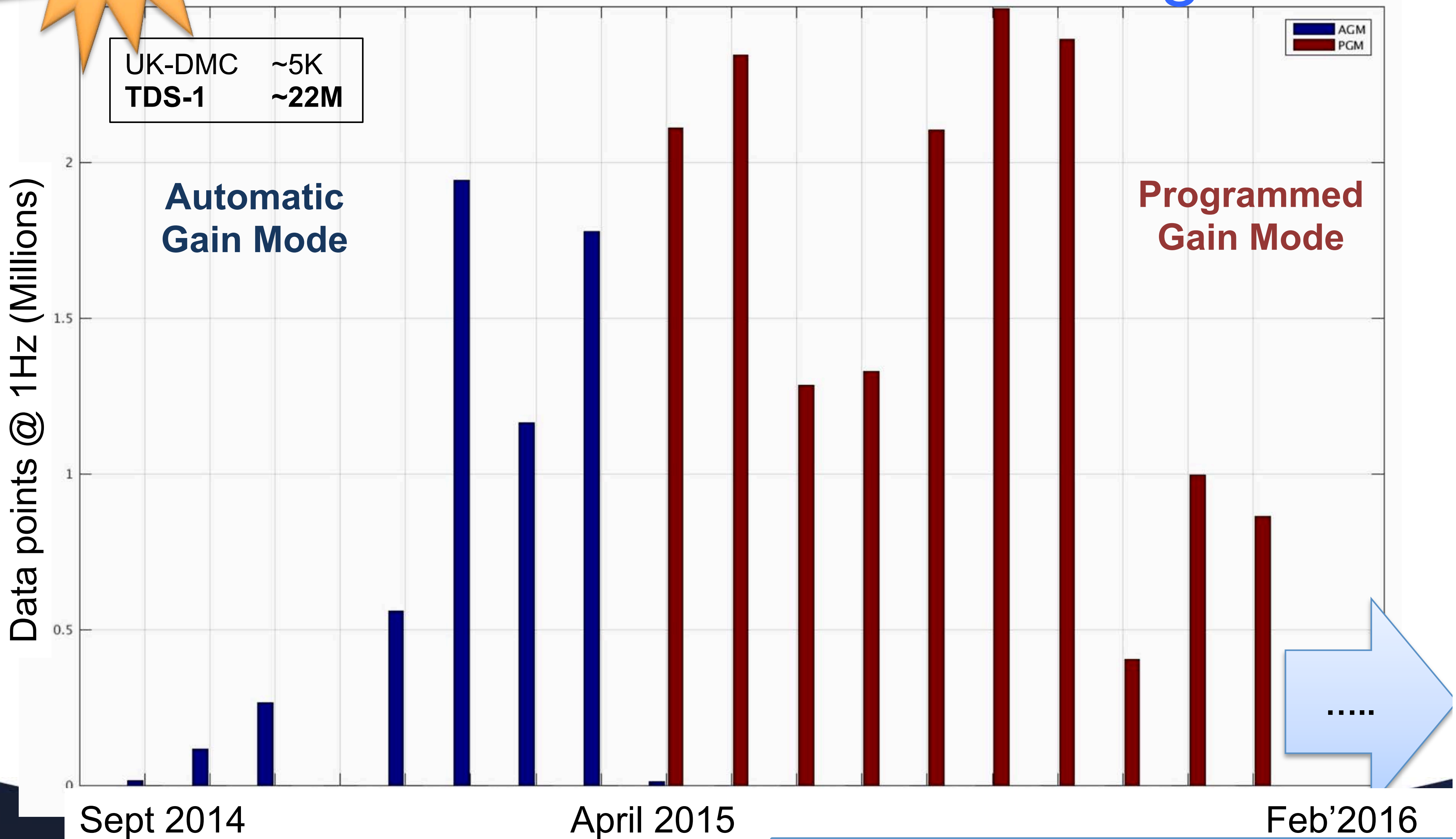
TDS-1 delivers first-ever global GNSS-R data from space



- Large amounts of GNSS-R data over the full globe
- Massive data uptake worldwide to develop many new applications
  - Hurricane forecasting/ocean winds, cryosphere, atmosphere, soil moisture/wetland monitoring
- Dedicated GNSS-R workshops and sessions at international conferences
- Special issue on TDS-1 in IEEE JSTARS journal
- Unwin et al (2016) wins JSTARS 2017 Best Paper Award for TDS-1 paper

Increasing data volumes & changing instrument modes in-flight

World First



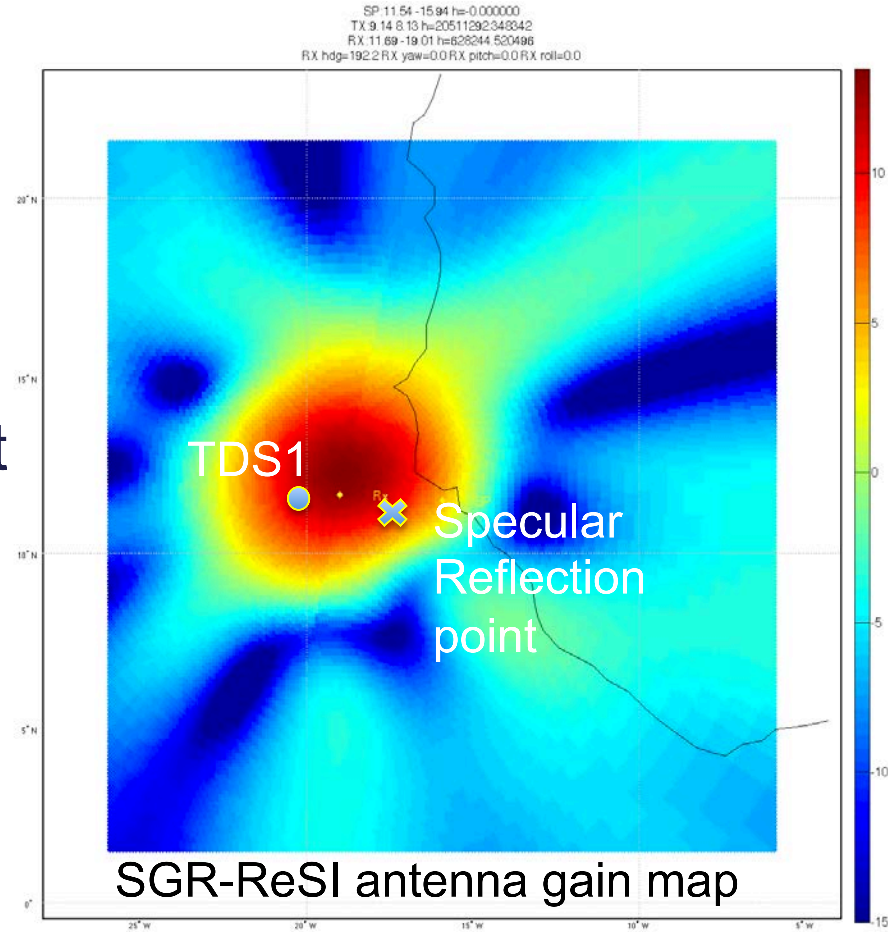
Since July'16, Experimental mode (including blackbody load calibration)

World First

GNSS-R wind inversion

$$\left\langle \left| Y(\hat{\tau},\hat{f}) \right|^2 \right\rangle = \frac{T_i^2 P_T G_T \lambda^2}{(4\pi)^3} \iint_A \frac{G_R \Lambda^2(\hat{\tau}-\tau) S^2(\hat{f}-f)}{R_R^2 R_T^2} \sigma^0 dA$$

- Zavorotny & Voronovich (2000)
- Bistatic Normalized Radar Cross Section (σ°)
  - Based on SNR measurement corrected for antenna gain, path losses and geometry
- First-order effect: antenna gain at the Specular Point
  - Lessons learned: GNSS-R needs:
    - Pre-launch antenna characterisation
    - Good knowledge of satellite attitude

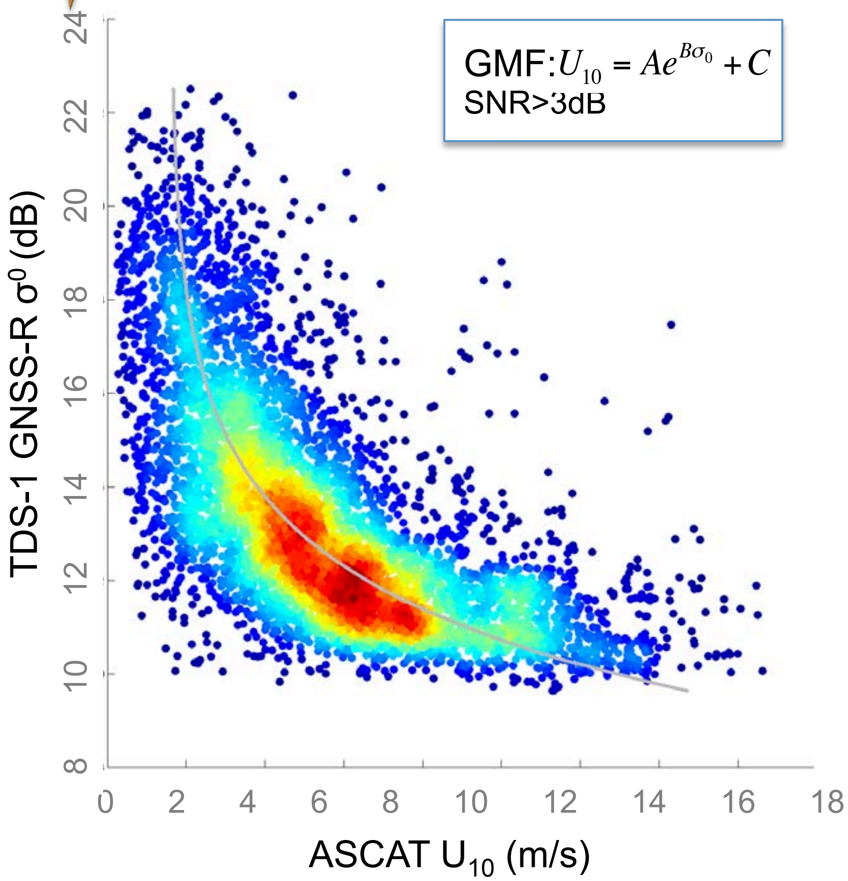


World First

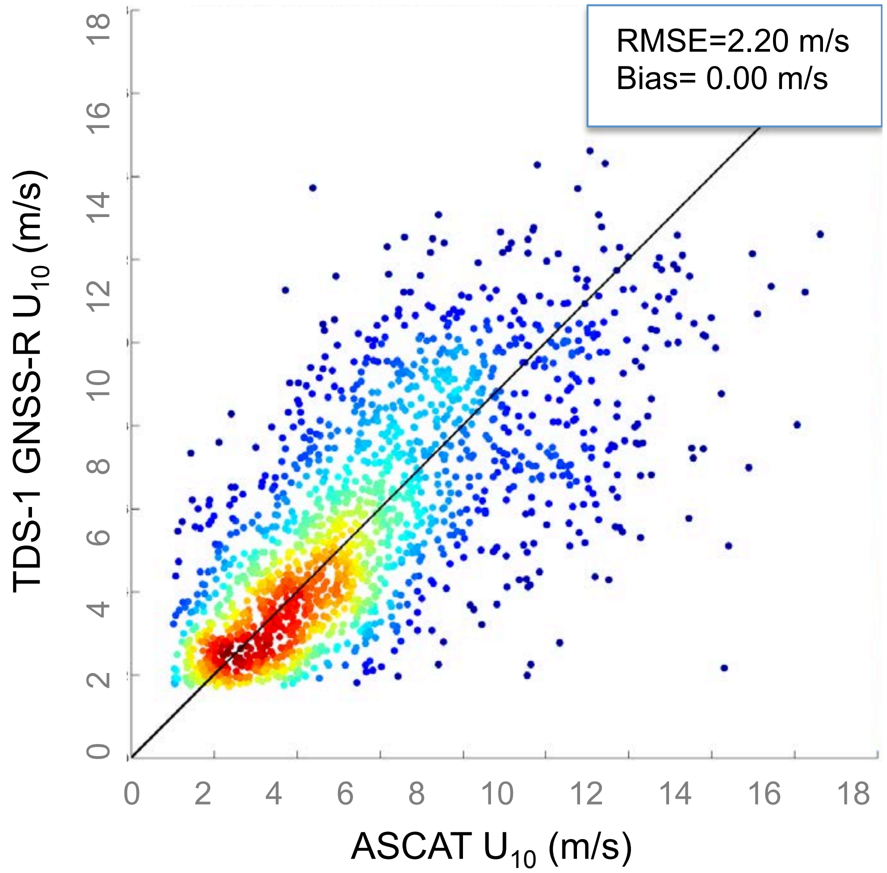
GNSS-R winds

(main antenna lobe)

75% training dataset



25% validation dataset

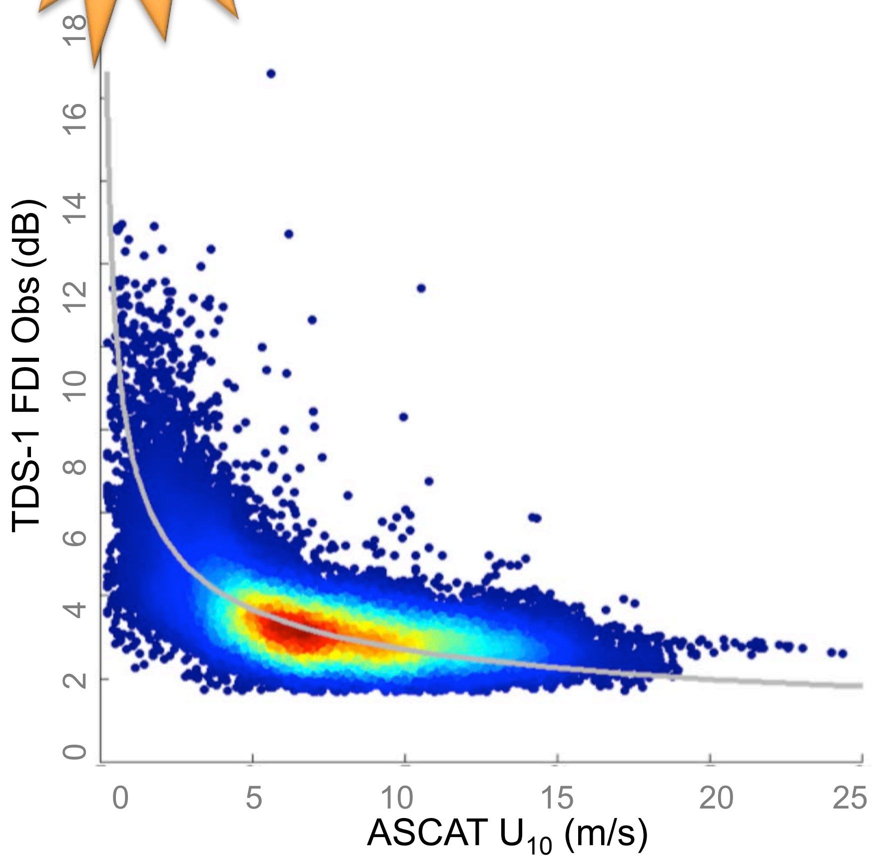


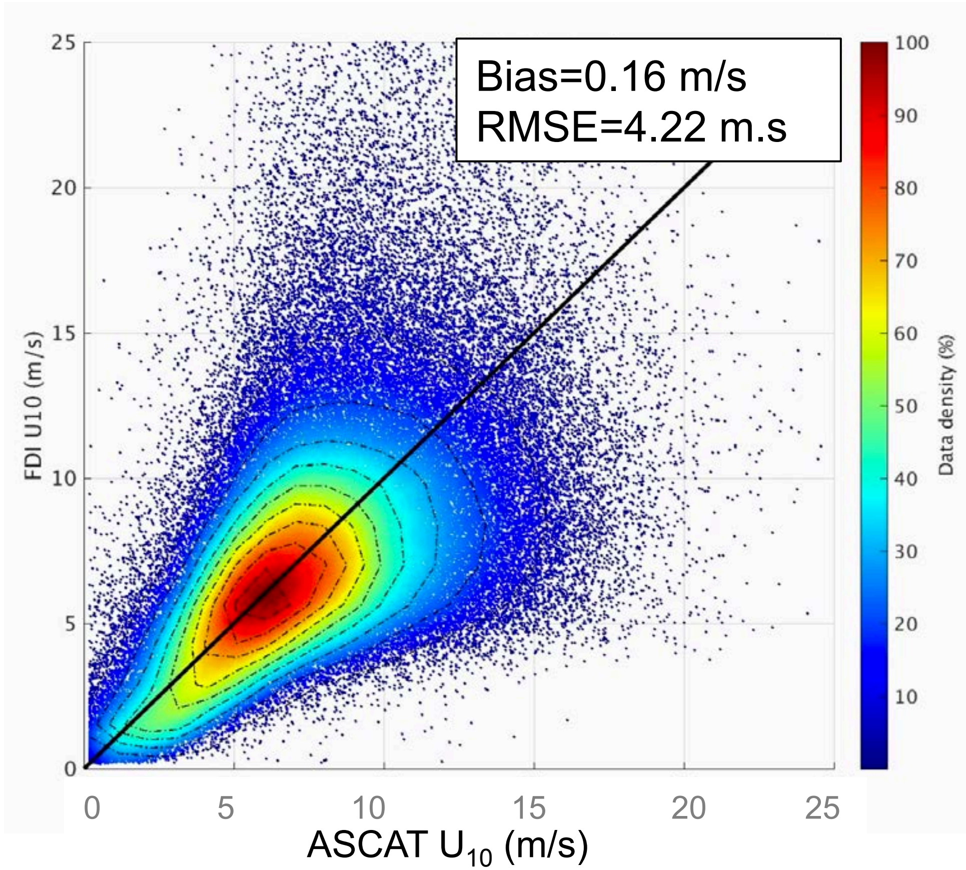
Foti et al, GRL, 2015

World First

GNSS-R winds

(full antenna footprint)



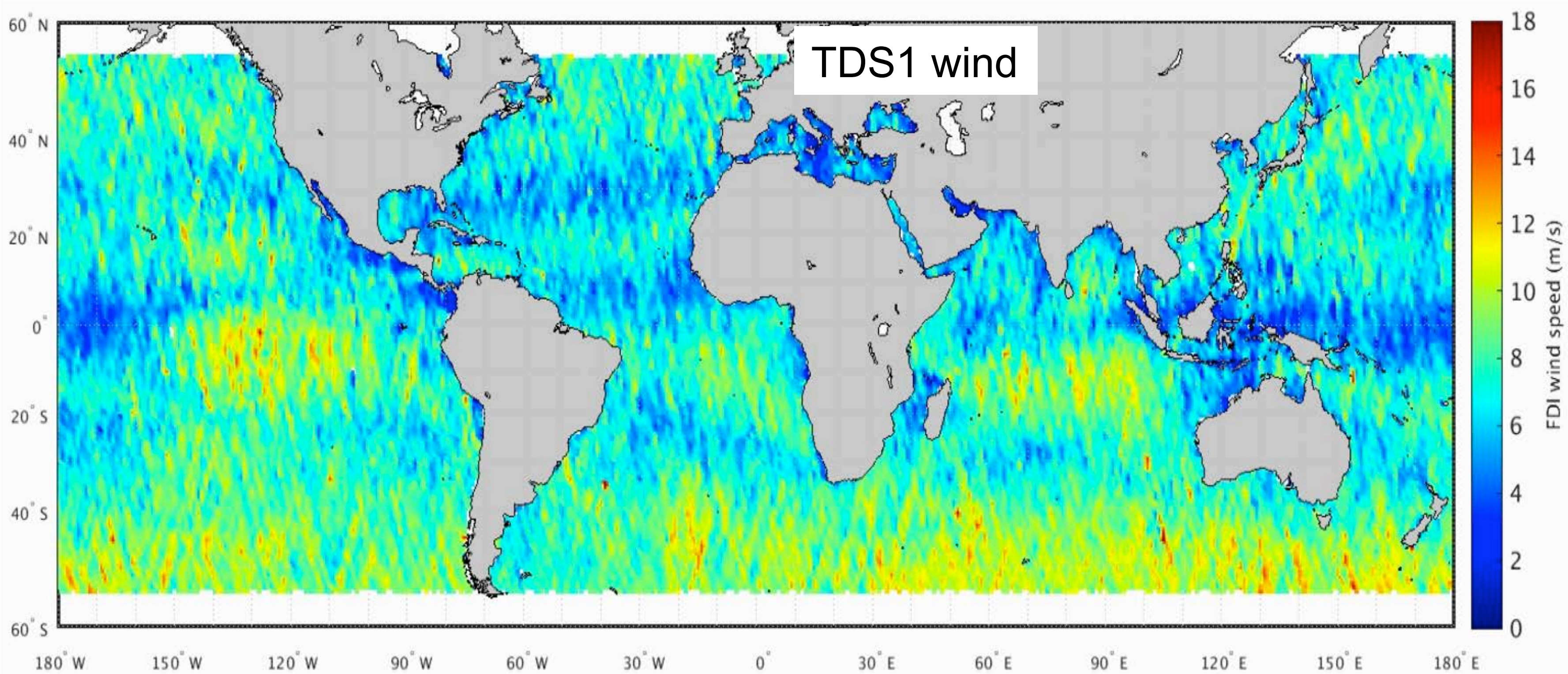


- Level 2 winds available on http://www.merrbys.co.uk/

Unwin et al, JSTARS, 2016

Global GNSS-R winds

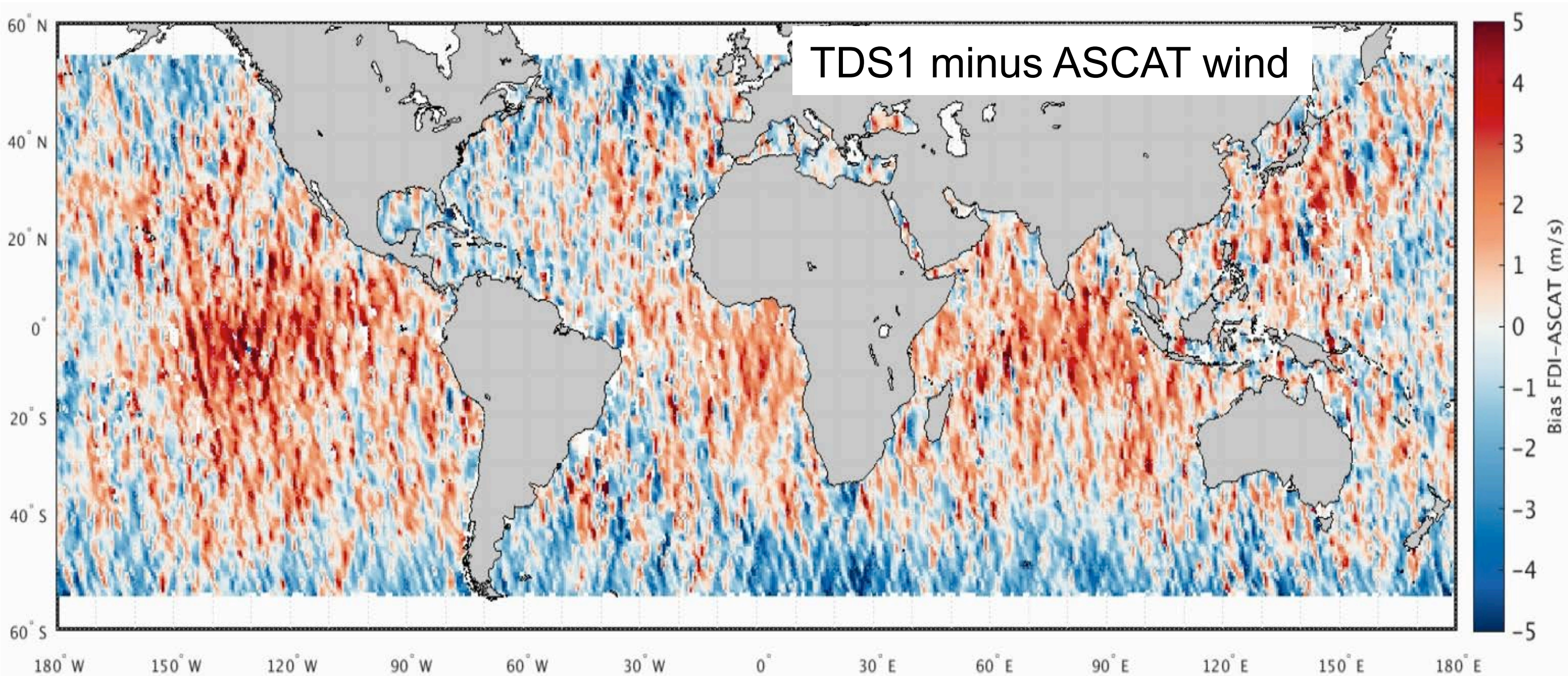
NOC FDI v1.11 May15 – Feb16; 1deg



- Level 2 winds available on http://www.merrbys.co.uk/
- Spatial distribution similar to ASCAT winds…

Global GNSS-R winds

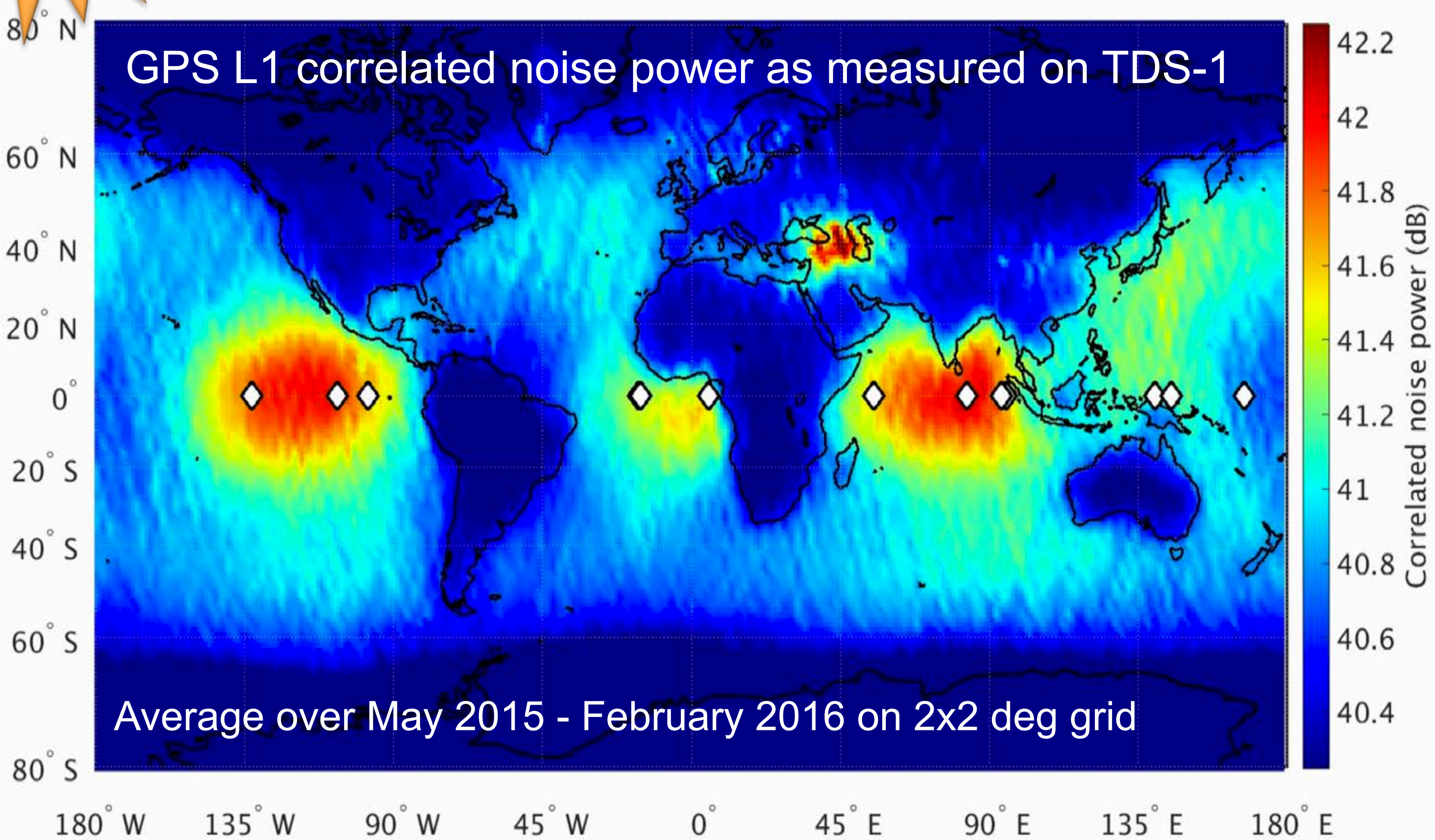
NOC FDI v1.11 May15 – Feb16; 1deg



- …but some strong biases in equatorial regions

World First

Persistent GNSS noise hotspots



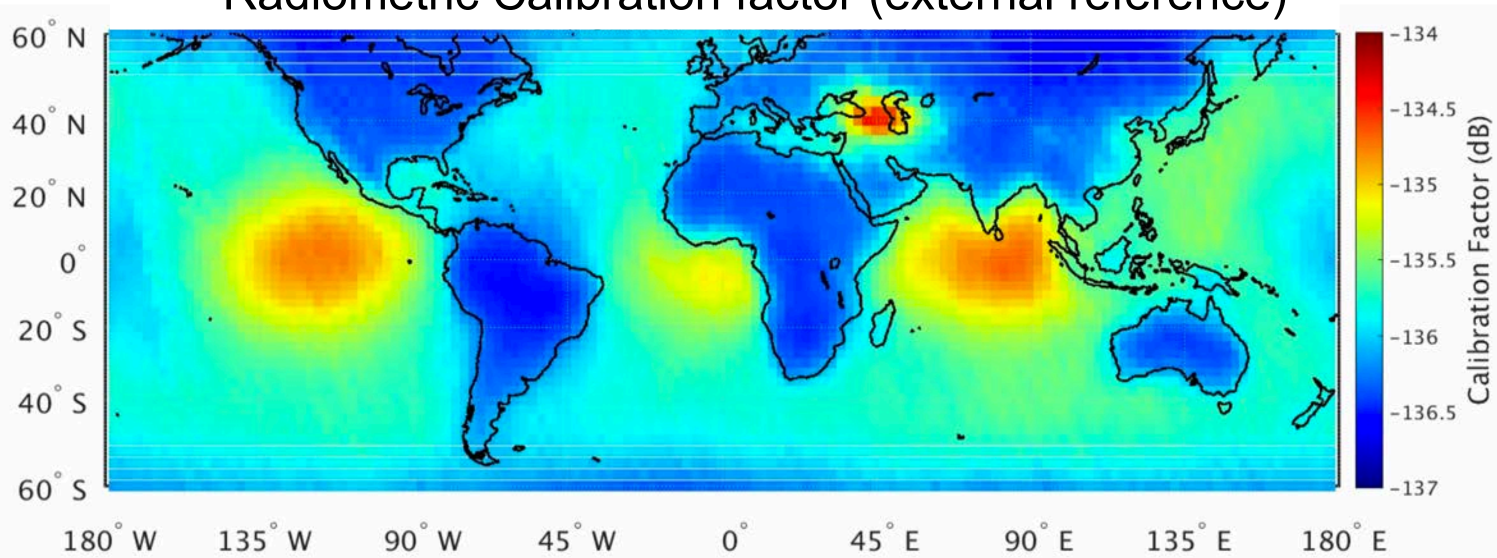
Foti et al, JSTARS, 2017

In-flight GNSS-R radiometric calibration

World First

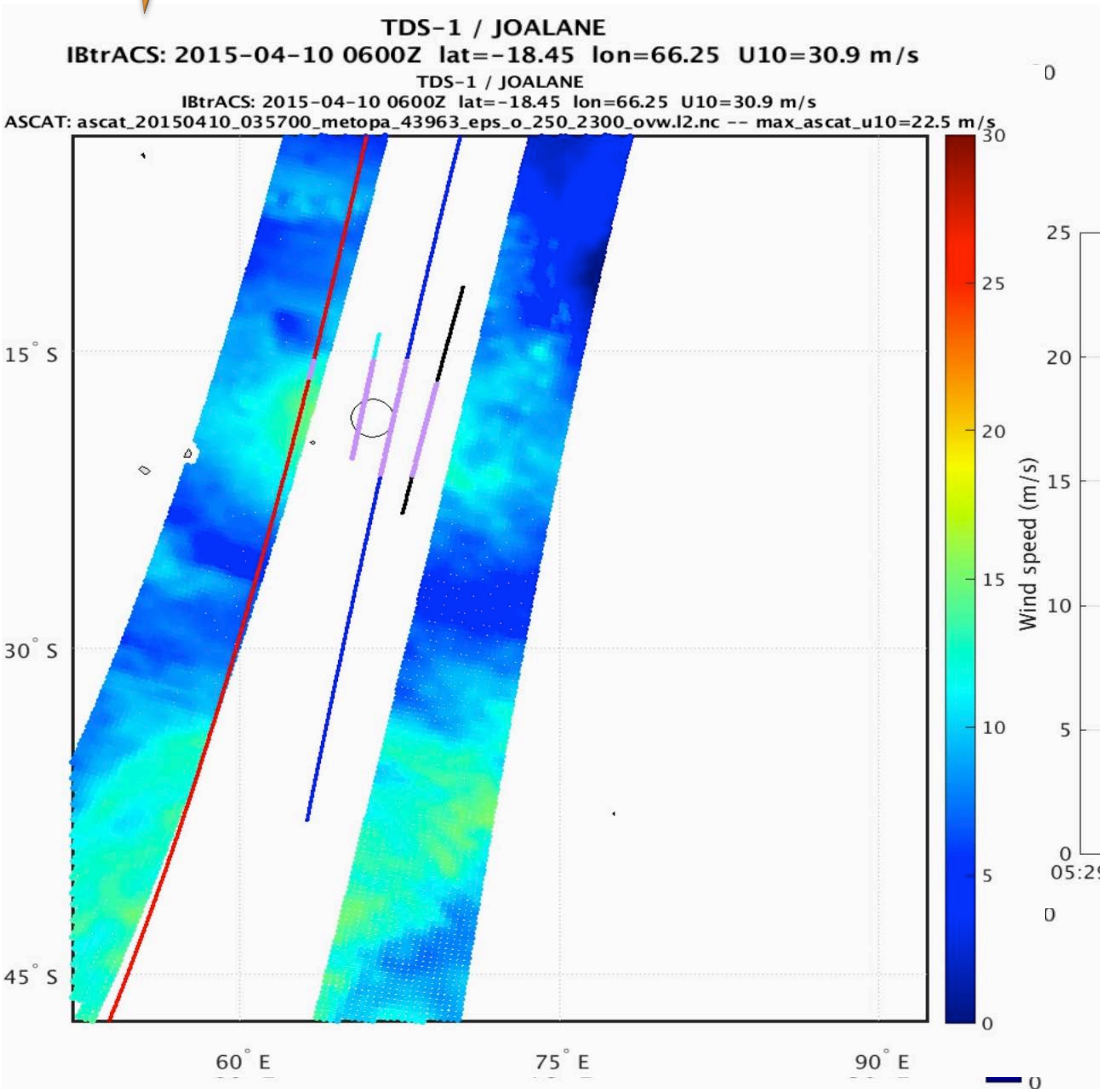
- Two radiometric calibration methods demonstrated in-flight by SSTL
  - Calibration with onboard black-body load switching (like CYGNSS)
  - Vicarious calibration using external reference (Dome-C, Antarctica)
- Vicarious calibration now implemented by NOC to mitigate equatorial biases linked to GNSS hotspots

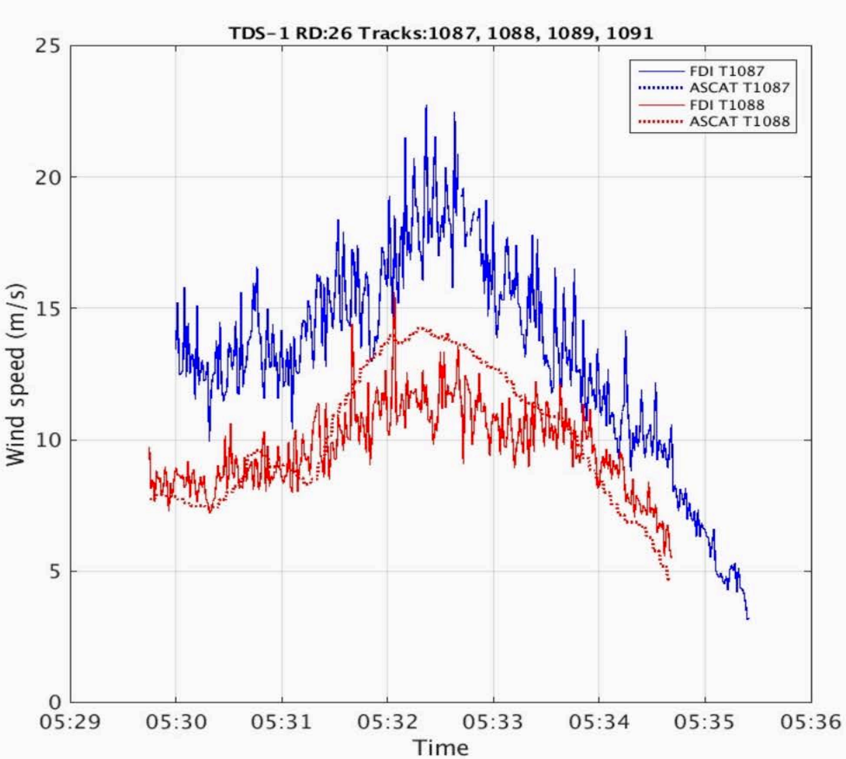
Radiometric Calibration factor (external reference)



World First

GNSS-R in hurricanes

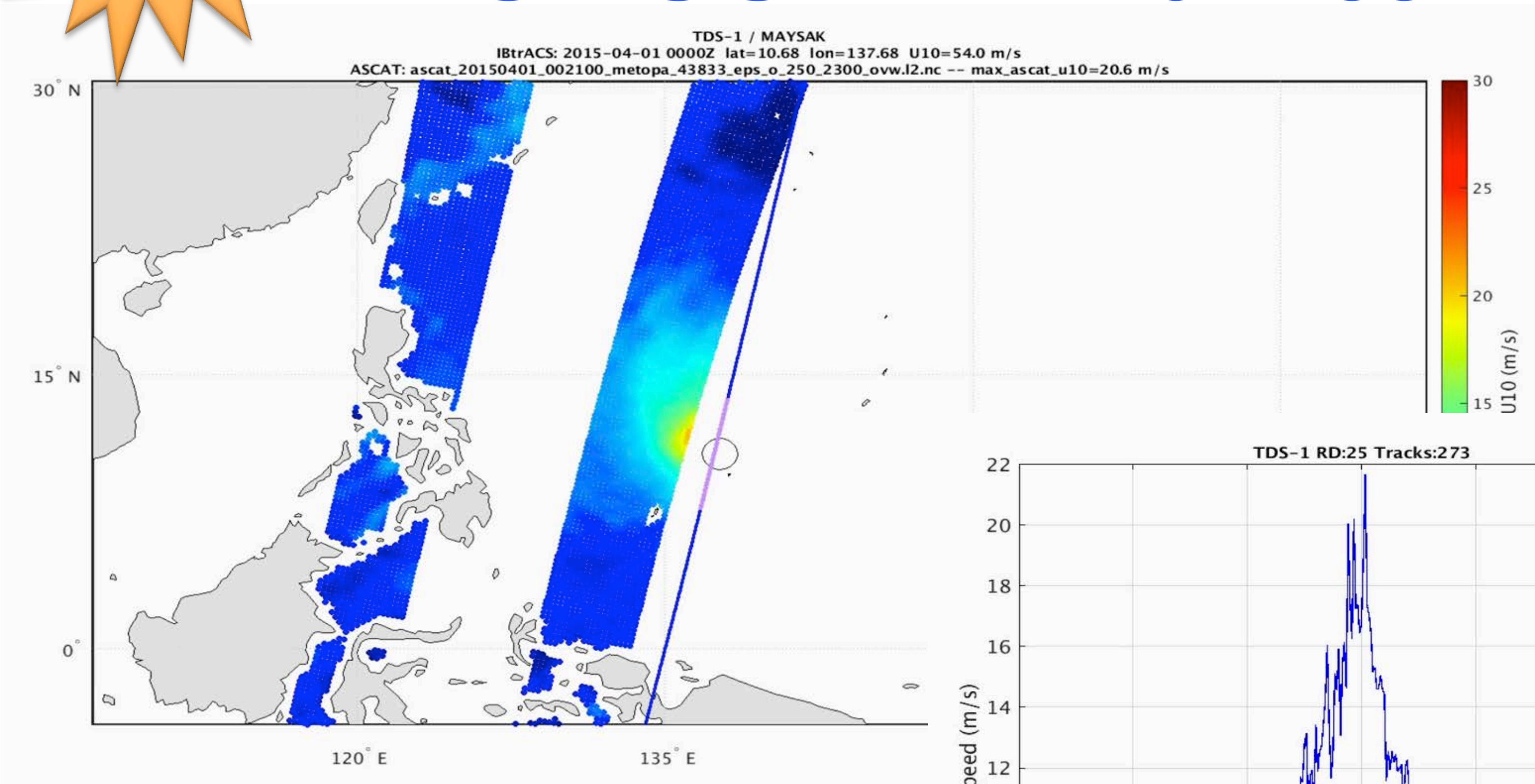


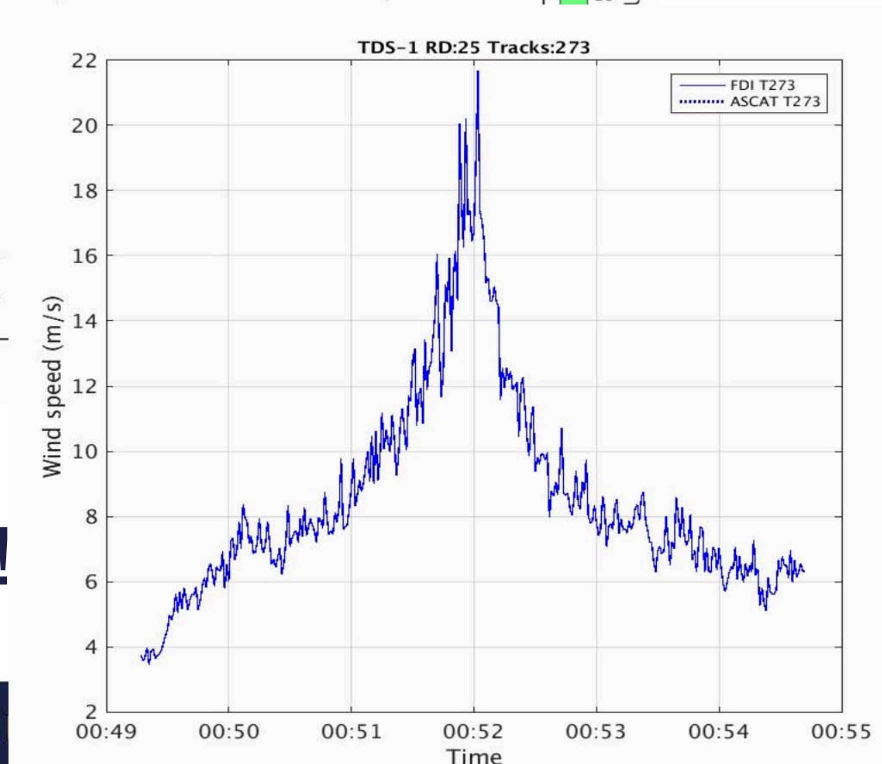


NERC SCIENCE OF THE ENVIRONMENT

World First

GNSS-R in hurricanes





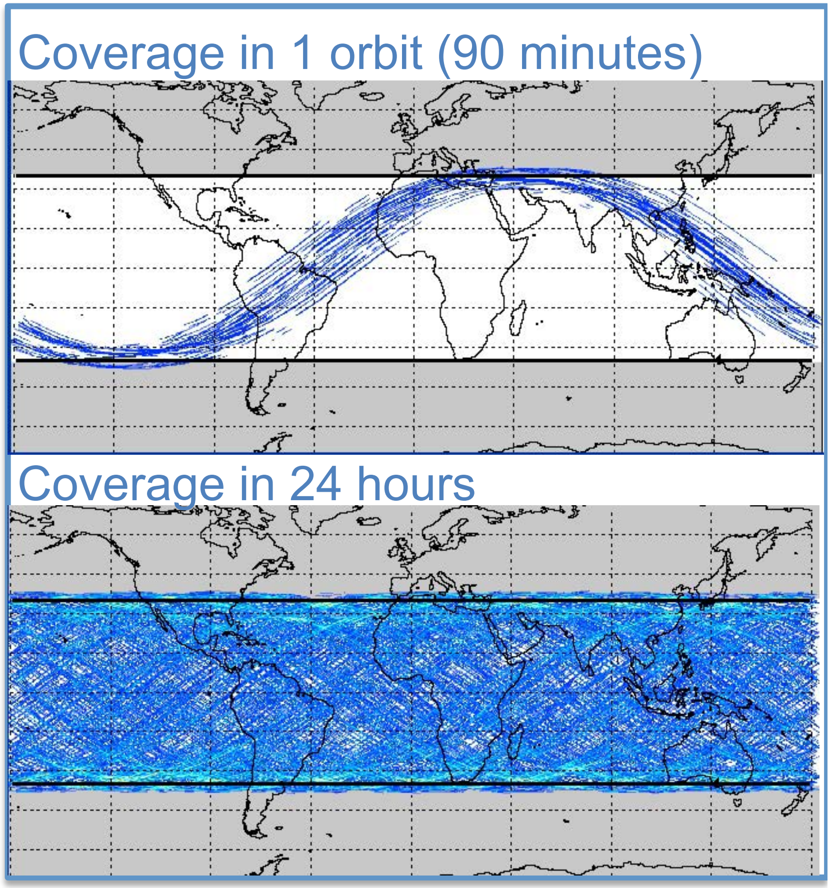
- Directly relevant to the NASA CYGNSS mission !

National Oceanography Centre
NATURAL ENVIRONMENT RESEARCH COUNCIL

noc.ac.

GNSS-R: The way forward

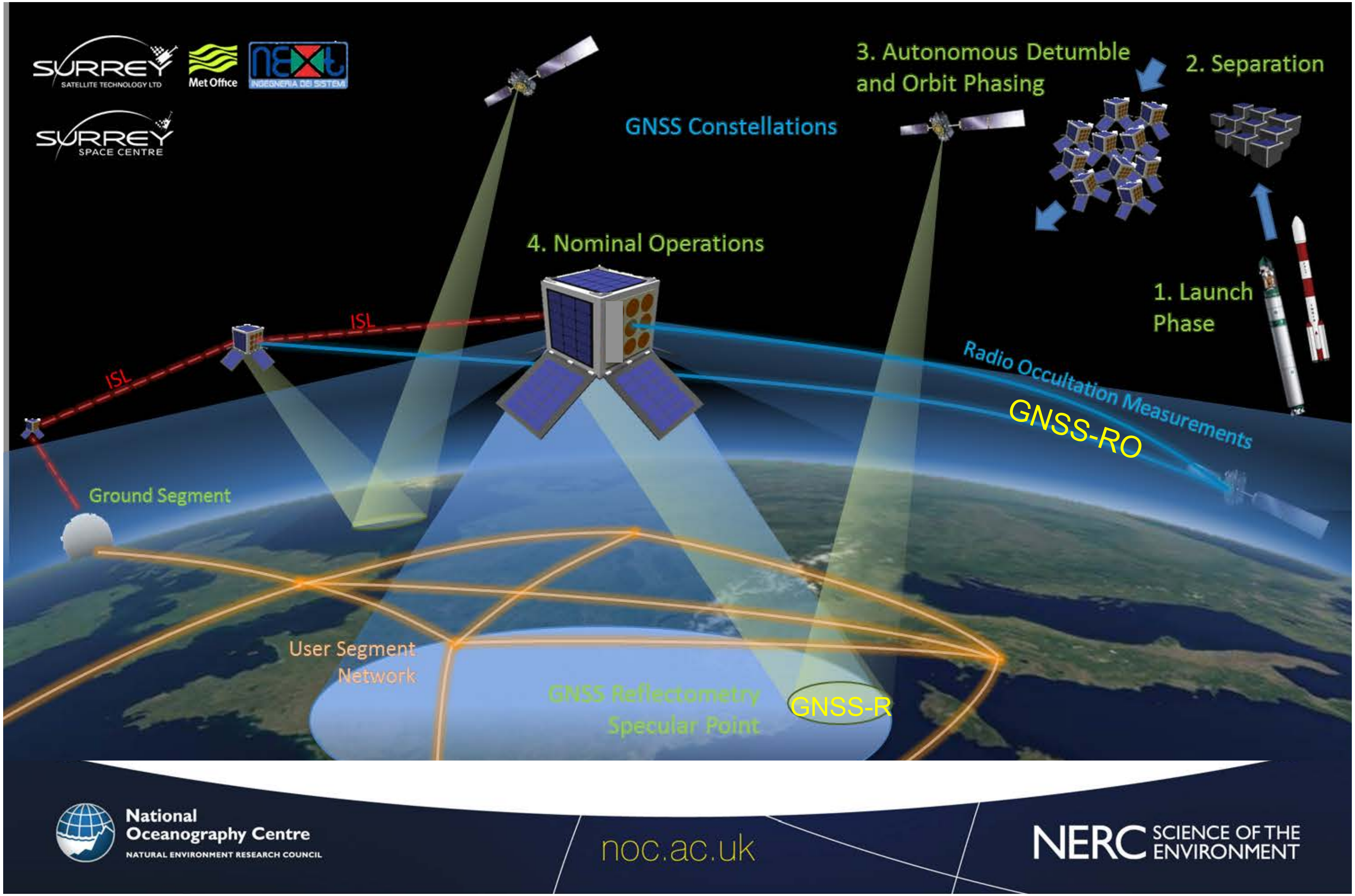
- NASA Earth Venture 2 CYGNSS
  - Cyclone Global Navigation Satellite System
  - PI: Chris Ruf, University of Michigan
- Ocean surface winds through the life cycle of tropical storms
  - Constellation of 8 microsatellites in one orbital plane
  - GNSS-R receiver by SSTL similar to TDS-1 SGR-ReSI
  - Low inclination orbit (35 deg) to achieve
  - 4 hour mean revisit time
- Launched: 15 December 2016
  - CYGNSS science operations phase started March'17



GNSS-R: The way forward

- Beyond TDS-1 and CYGNSS ?
  - NASA study for “CYGNSS-2” mission
  - ESA study for ORORO (30 satellite constellation; GNSS-RO & GNSS-R)
    - 10-20kg sats = low-cost but miniaturisation challenges
    - Also, **no current funding framework for constellations in Europe**

ORORO Initial Concept



GNSS-R: The way forward

- In the meantime…TDS-1 still operating 2 days out of 8
  - Experimentation ongoing (L2c, Galileo E1, new processing)
  - Potential of TDS-1 for altimetry still to be explored
- TDS-1 mission ends Summer 2017
  - Possible mission extension ?
  - 24/7 pilot GNSS-R wind data service ?
    - Interest from weather and marine forecasting users
  - Continuity with CYGNSS, experimental flexibility, GNSS-R data at high latitudes & polar regions, stepping stone to ORORO

Summary

- TechDemoSat-1 is an unequivocal success for GNSS-R
  - Numerous world-first advances, both technical and scientific
  - High international visibility and impact
    - Relatively low UK investment but long-term industry/academia partnership
    - ESA support for data processing & scientific exploitation was critical
- Lessons learned from TDS-1 will directly benefit the NASA CYGNSS mission
  - Transfer of technological and scientific IP from Europe to US
- Future of GNSS-R beyond TDS-1 and CYGNSS ?
  - Studies at NASA and ESA for future GNSS-R payload/mission
    - Constellations of low-cost satellites for improved time/space sampling
    - Technical challenges linked to miniaturisation
  - No clear funding framework to take GNSS-R forward in Europe at present

Thank You!