Ocean wind retrieval using GNSS Reflectometry data from the UK TechDemoSat-1 mission

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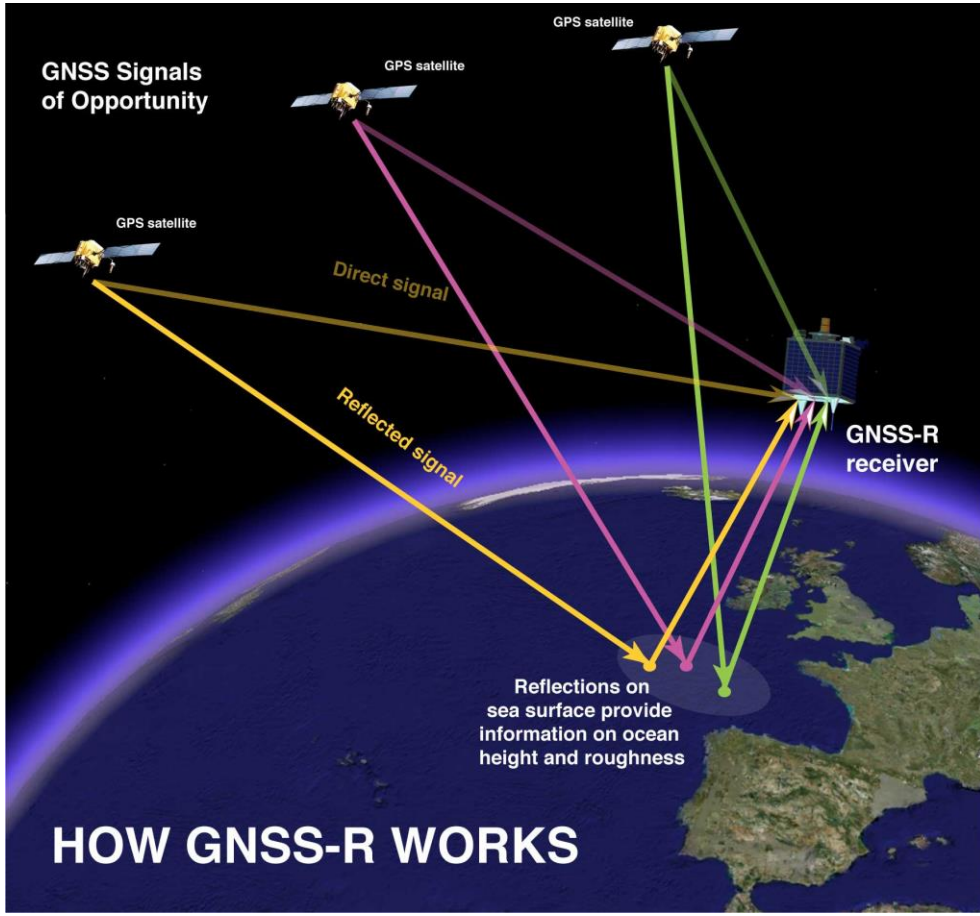
GNSS-Reflectometry

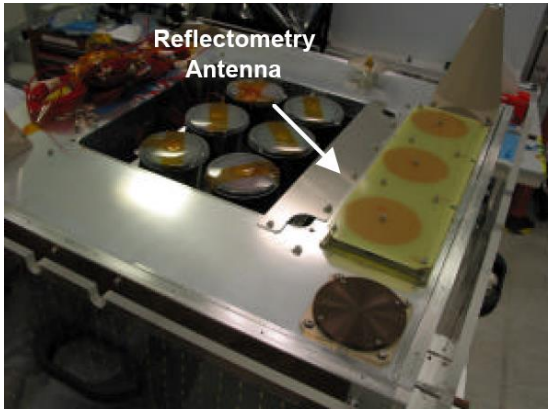
- Signals of opportunity from Global Navigation Satellite Systems e.g GPS, Galileo…
- Global, ubiquitous signals
- Small low-cost receivers
  - Can be accommodated on constellation of small satellites or piggy-backing on satellites of opportunity
    - Potential for huge improvement in space-time sampling
  - L-band (weakly affected by precipitation)

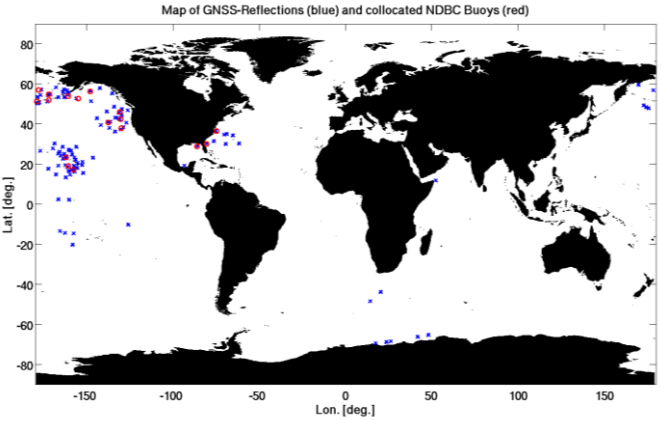


Measurements of sea surface height and ocean surface roughness (wind)

Spaceborne GNSS-R for scatterometry

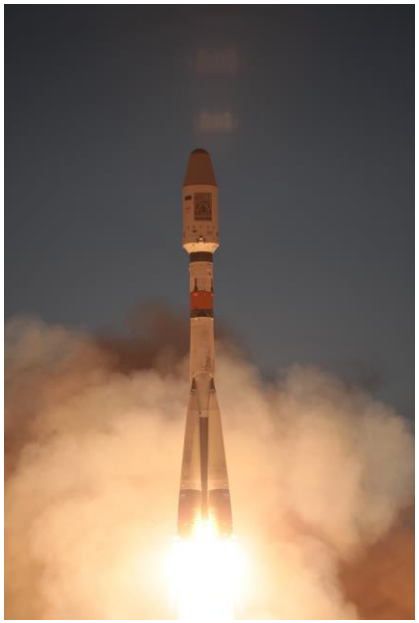
2003
Proof-of-concept on
SSTL's UK-DMC





Collected ~ 50 data points
over ocean

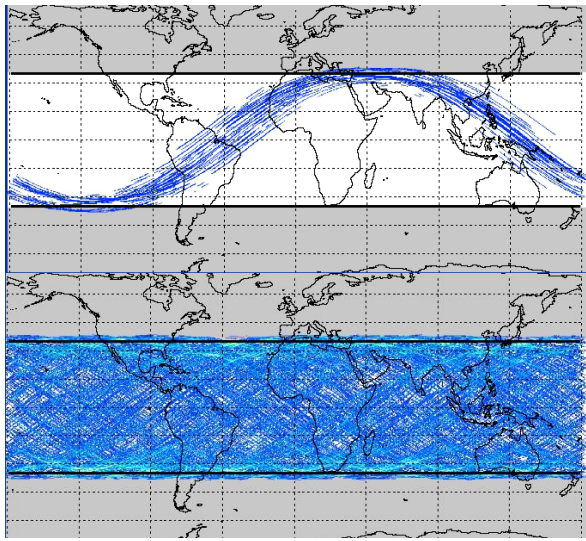
8 July 2014
UK TechDemoSat-1
launch with SGR-ReSI
GPS-R payload



SURREY
SATELLITE TECHNOLOGY LTD

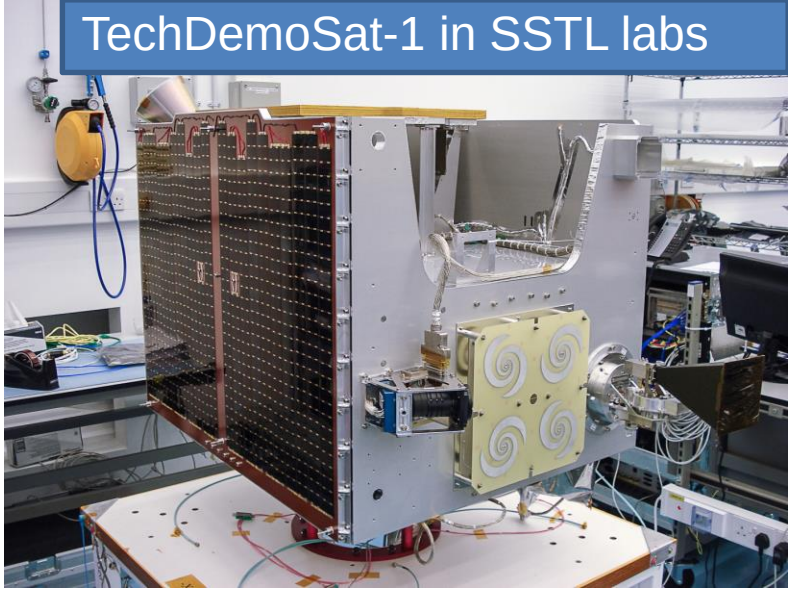
Dec 2016
NASA Cyclone Global
Navigation Satellite
System (CYGNSS) mission

Constellation of
8 SGR-ReSI

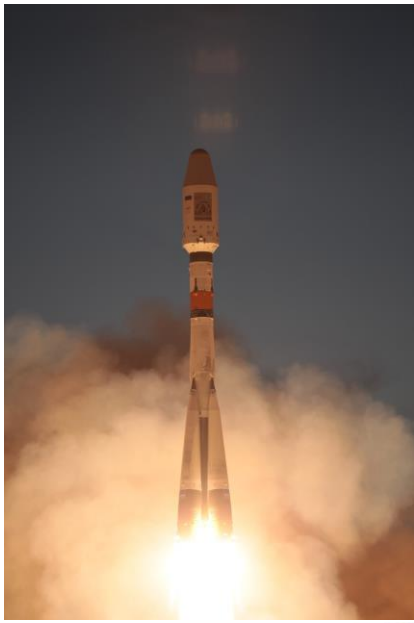


Aims for mean revisit
time ~ 4 hours

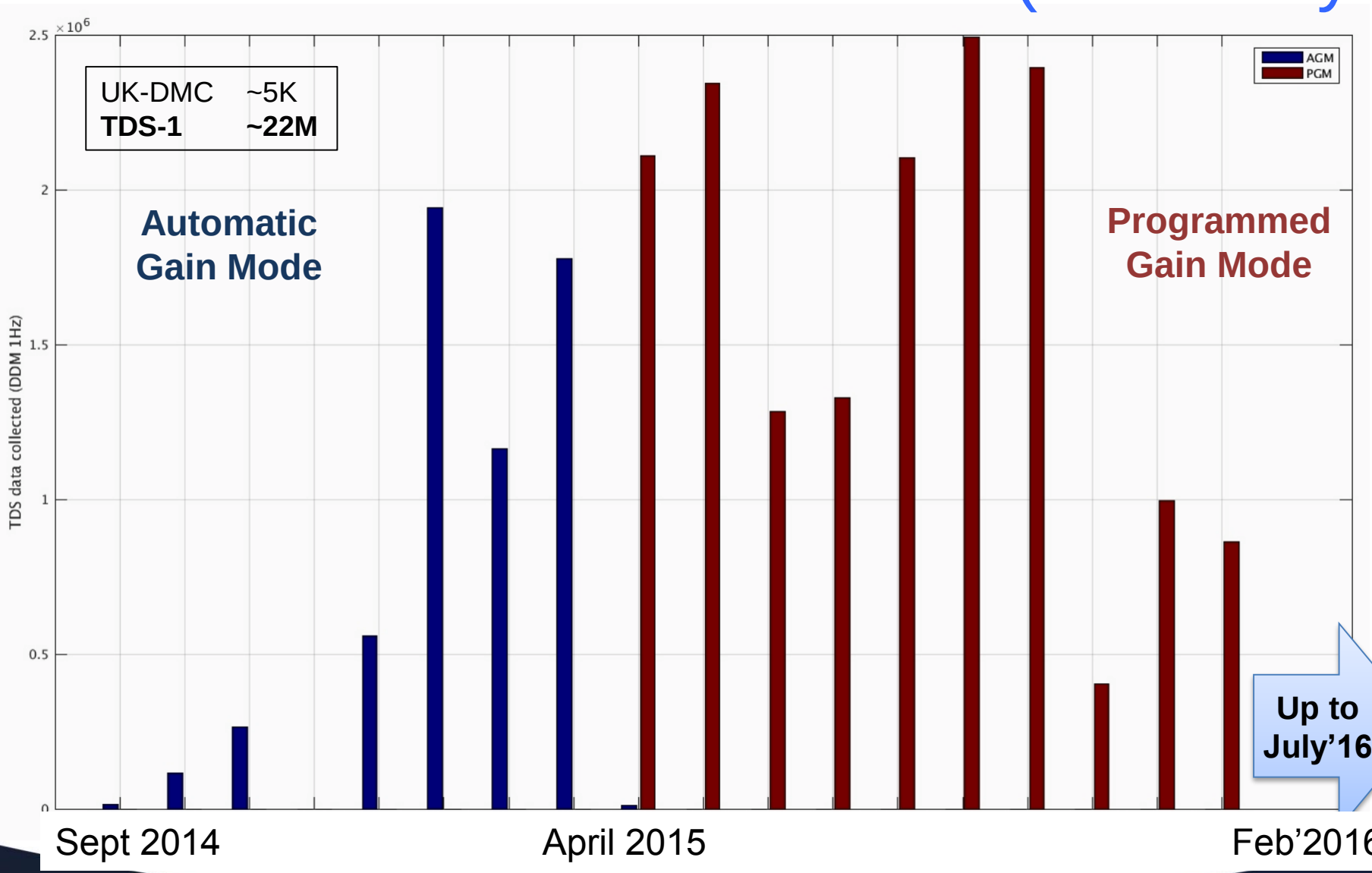
TechDemoSat-1 (TDS-1)


TechDemoSat-1 in SSTL labs

- Built & launched by Surrey Satellite Technology Ltd (SSTL)
  - Launched 8 July 2014
- UK-funded **technology demonstrator** mission
  - Duty cycle shared between 7 payloads
  - GNSS-R payload operates only for 2 in every 8 days
- Quasi sun-synchronous orbit with a local time ascending node (LTAN) drift of 1.42 h/yr
- Tracks up to four reflections simultaneously
- Ground processing, data dissemination and Level 2 inversion & validation funded by ESA
  - http://www.merrbys.co.uk/
  - L1 Delay Doppler Maps & L2 wind speed @ 1Hz



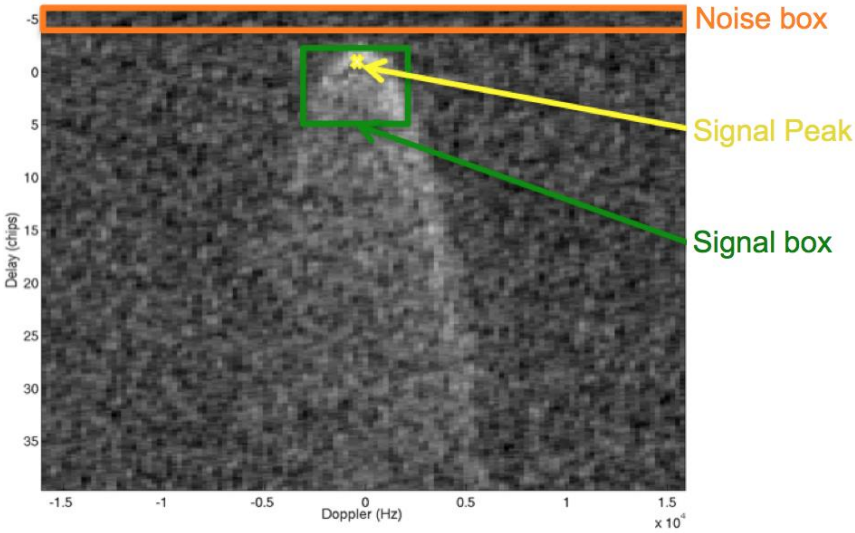
TDS-1 GNSS-R data volumes (2 in 8 days)



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

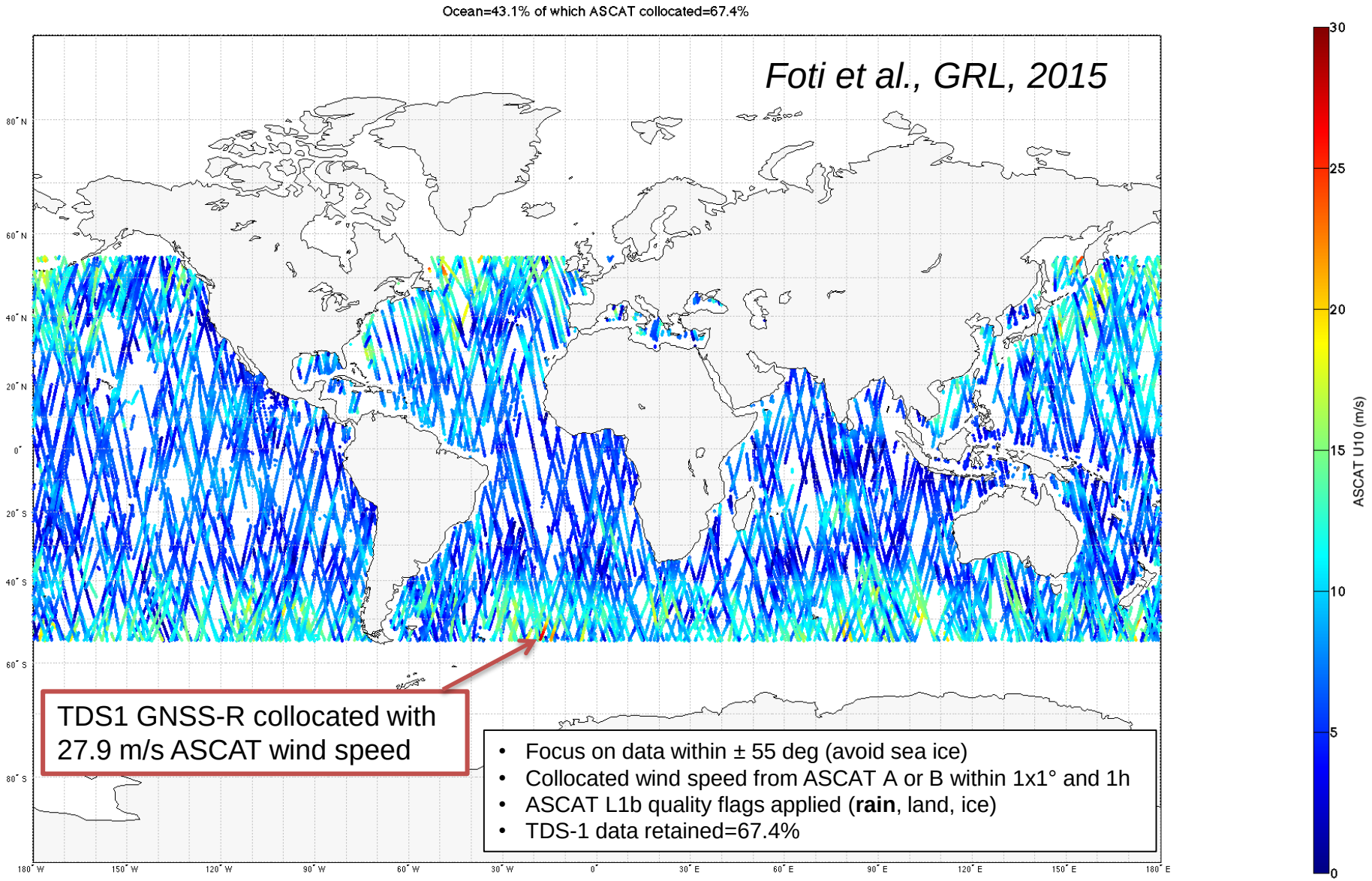
TDS-1 Level 2 wind speed inversion

- So far, TDS-1 inversions based on un-calibrated SNR
  - to exploit full dataset (unknown system gain in AGM)
- Peak signal in delay Doppler maps around the Specular Point (SP)
  - Automated robust peak location detection



- TDS-1 L2 algorithms
  - Fast-Delivery Inversion (FDI): purely empirical
  - Bistatic Radar Equation (BRE): corrects for antenna gain, path losses, geometry
- All algorithms developments based on collocation of TDS-1 with ASCAT-A/B

Collocation with ASCAT



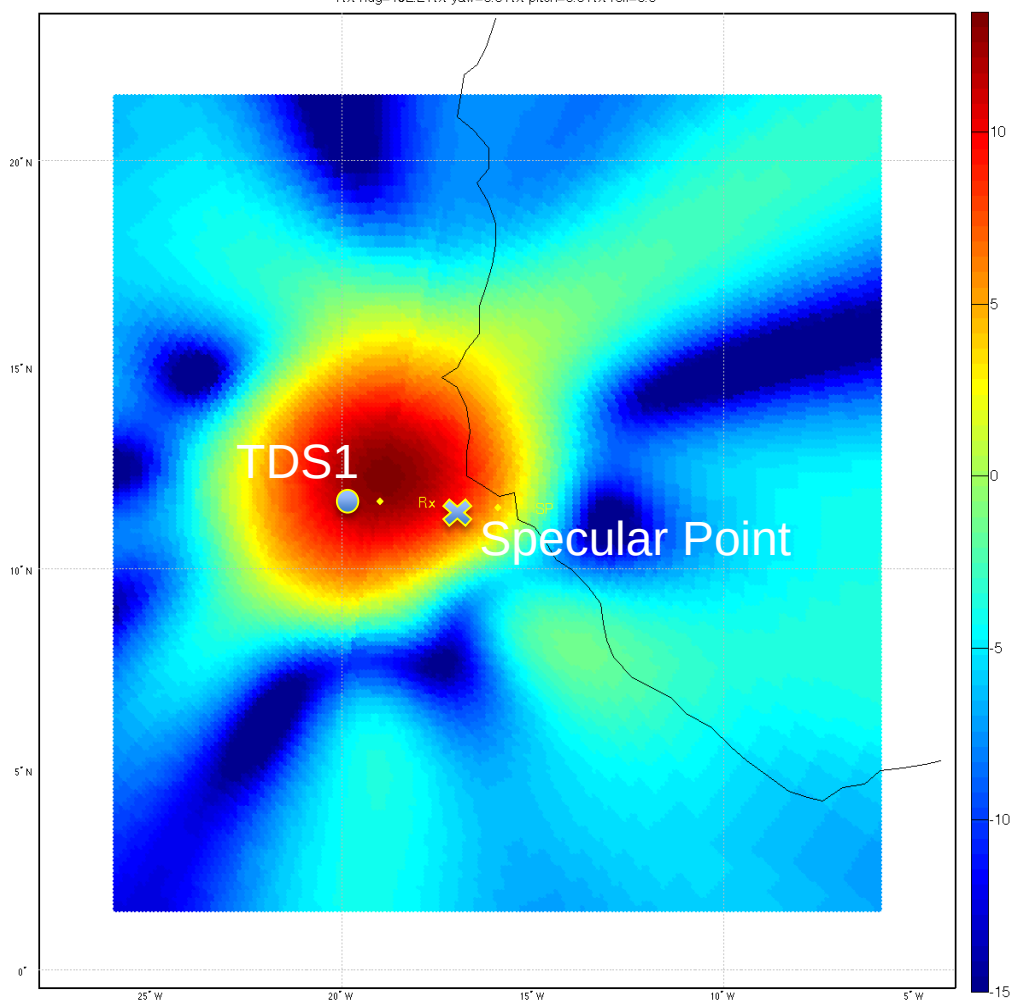
TDS1 GNSS-R collocated with 27.9 m/s ASCAT wind speed

- Focus on data within ± 55 deg (avoid sea ice)
- Collocated wind speed from ASCAT A or B within 1x1° and 1h
- ASCAT L1b quality flags applied (**rain**, land, ice)
- TDS-1 data retained=67.4%

BRE: Bistatic Radar Equation

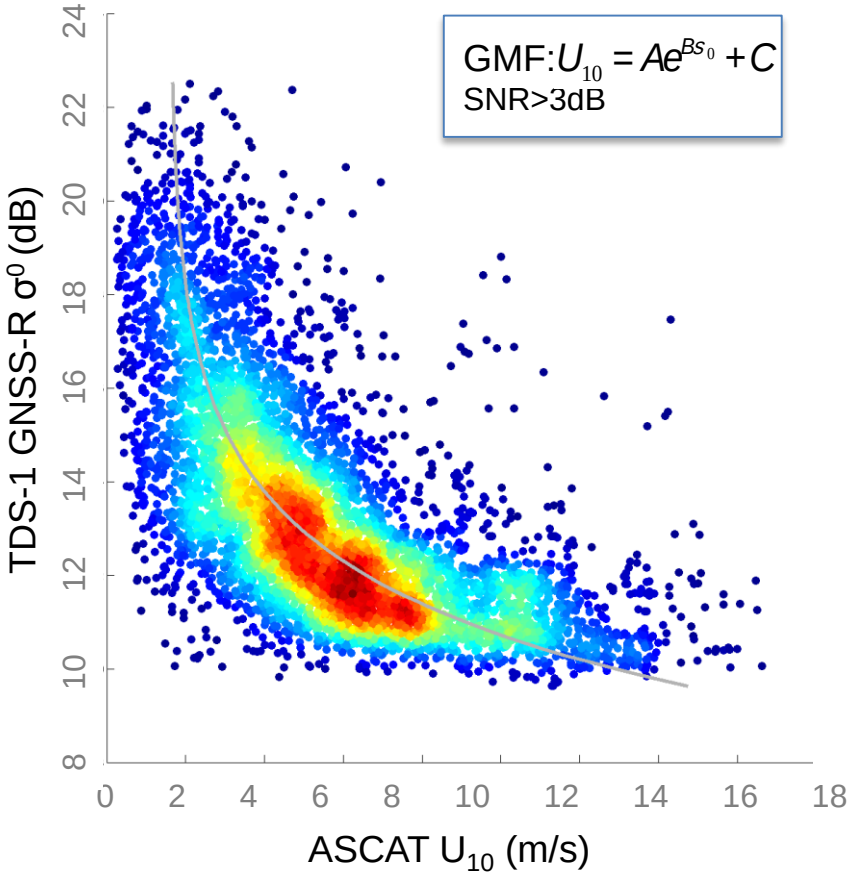
$$\left\langle \left| Y(\hat{t}, \hat{f}) \right|^2 \right\rangle = \frac{T_i^2 P_T G_T \lambda^2}{(4\pi)^3} \iint_A \frac{G_R \Lambda^2(\hat{t} - t) S^2(\hat{f} - f) \sigma^0 dA}{R_R^2 R_T^2}$$

- Zavorotny & Voronovich (2000)
- Bistatic Normalized Radar Cross Section (σ°)
  - Corrects for antenna gain, path losses and geometry
- First-order effect is antenna gain at SP
  - Restricting analyses to reflections in main antenna lobe minimises impact of satellite mispointing uncertainty

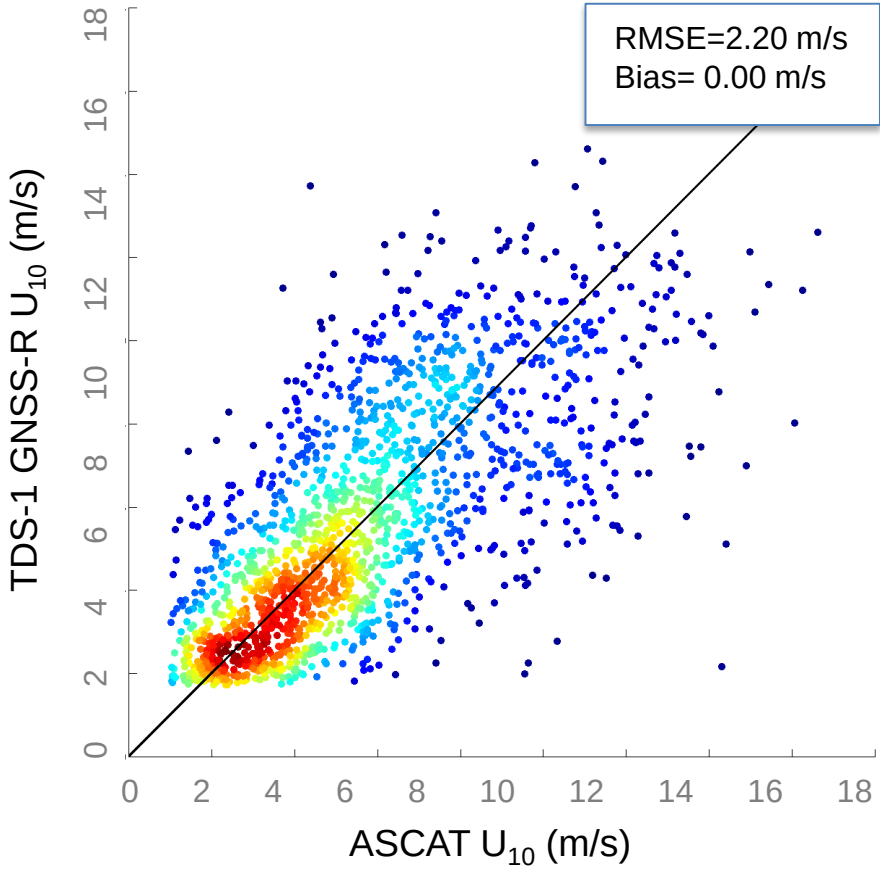


BRE performance for wind speed

75% training dataset

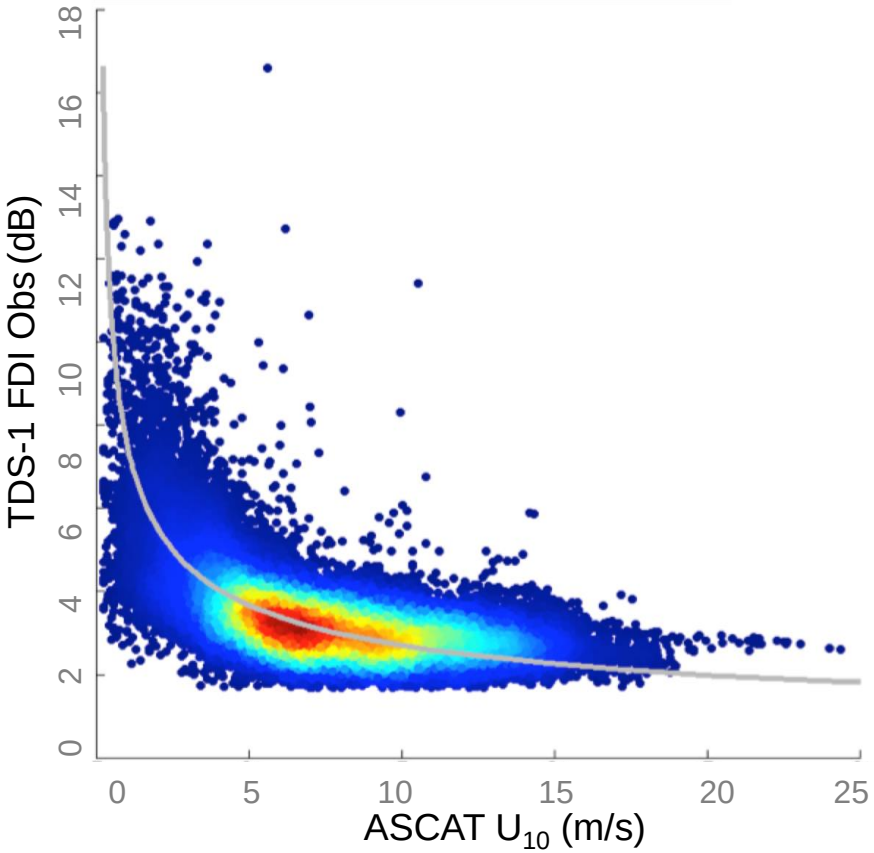


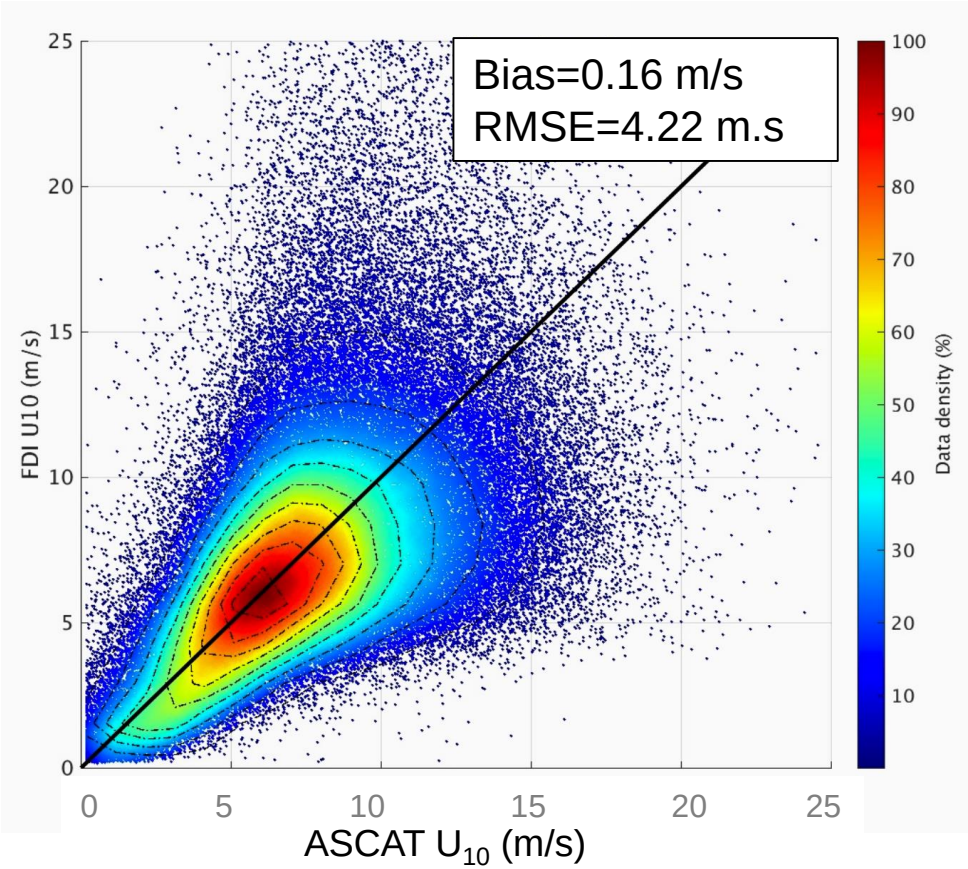
25% validation dataset



Foti et al, GRL, 2015

Fast-Delivery Inversion (FDI)

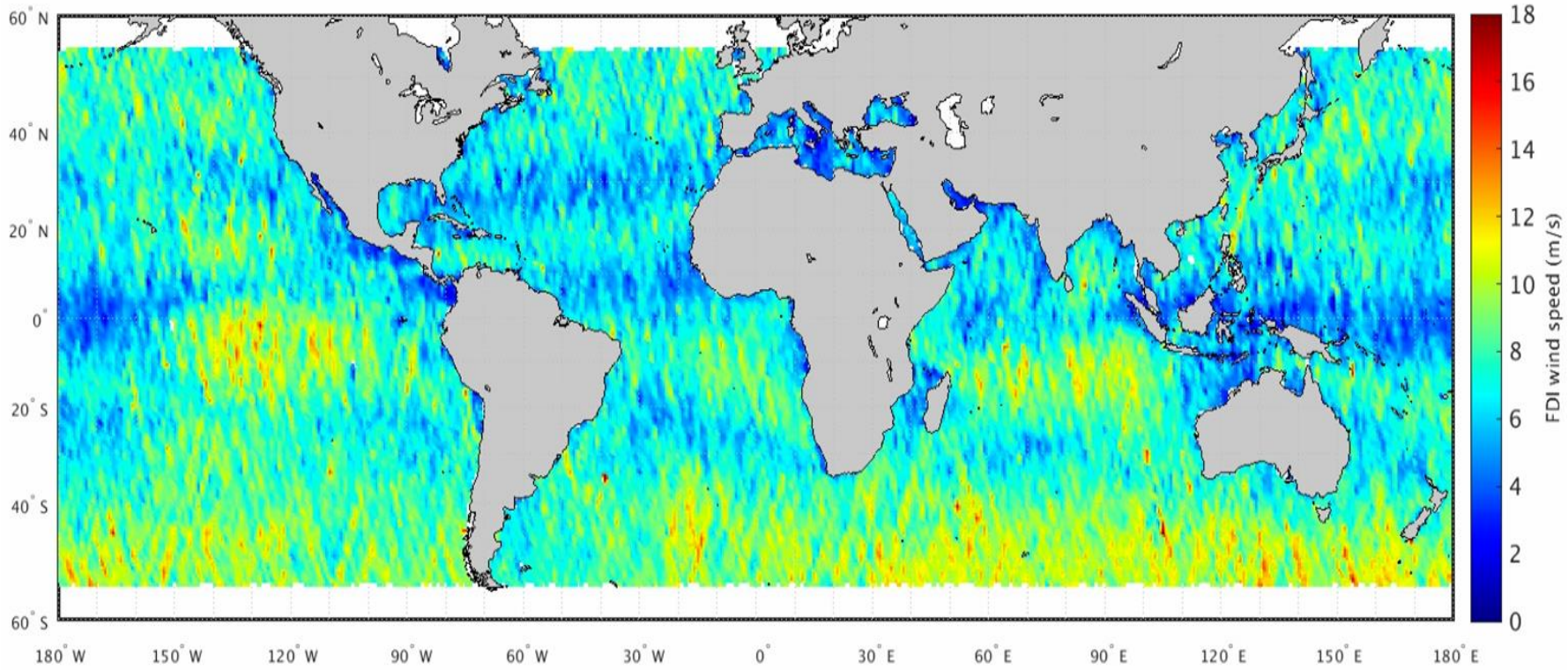




- Level 2 winds available on http://www.merrbys.co.uk/
- AGM + PGM36; 4.6M L2 samples; FDI U10 capped at 40m/s

Unwin et al, JSTARS, 2016

Global GNSS-R winds
NOC FDI v1.11 May15 – Feb16; 1deg



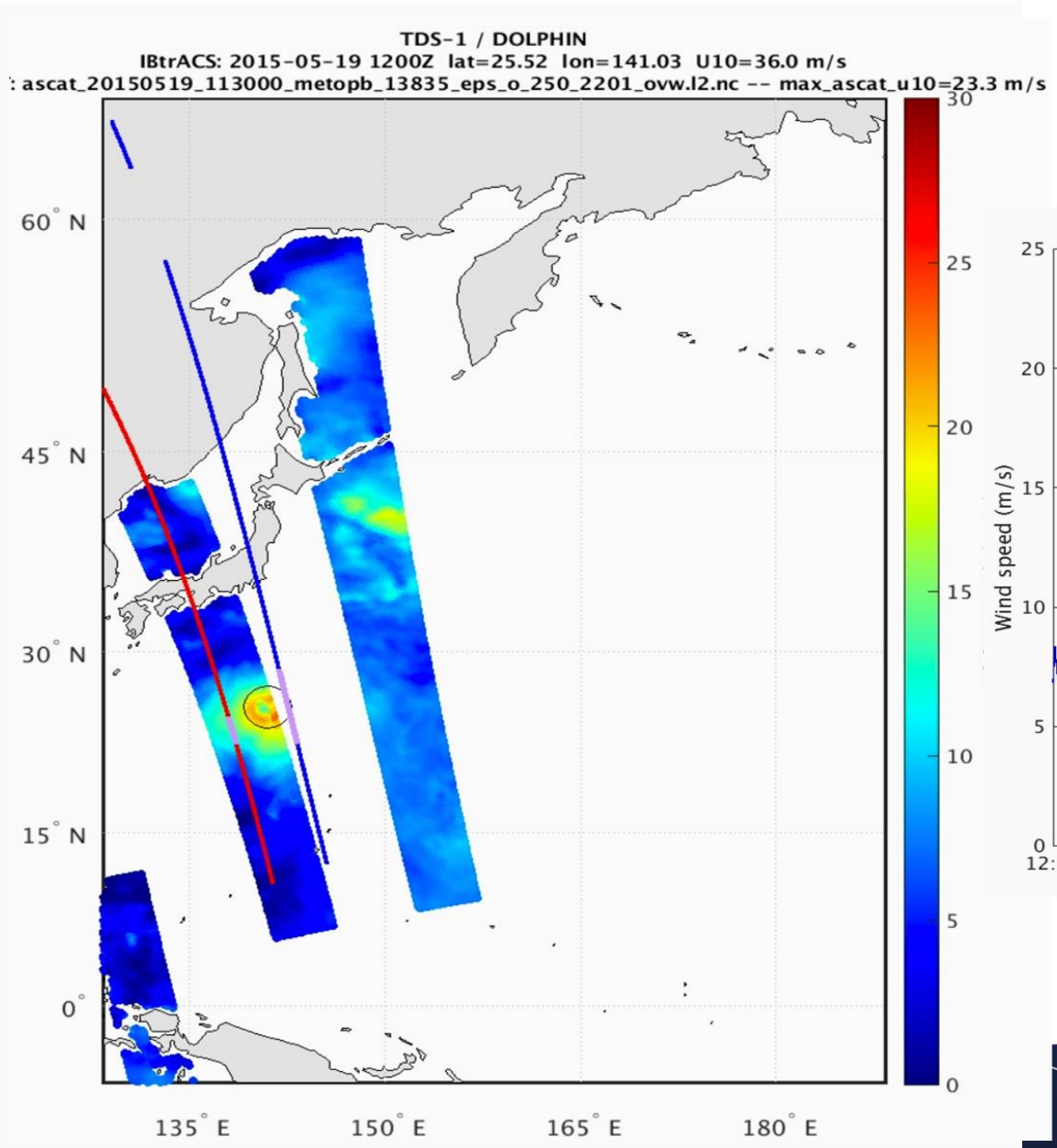
- Spatial distribution similar to ASCAT winds
- Some biases in equatorial regions (L-band noise hotspots)
  - Need for calibrated GNSS-R signals

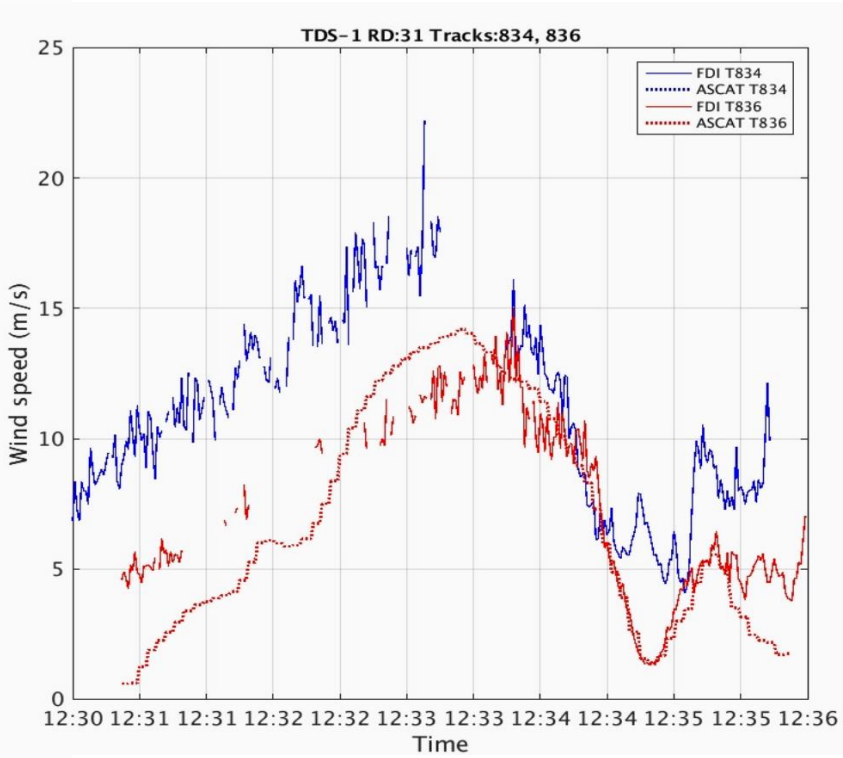
Spaceborne GNSS-R in high winds?

A few examples

Collocated TDS-1/ASCAT with Storm Best Tracks

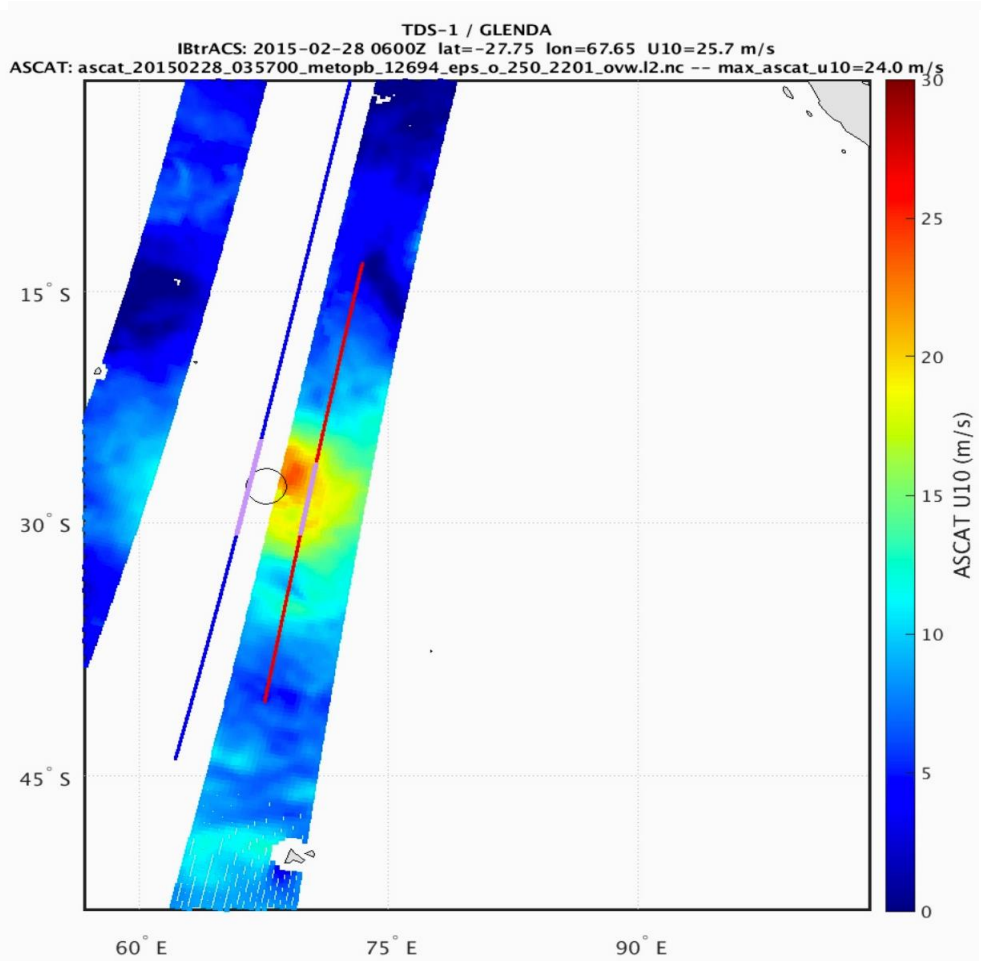
DOLPHIN

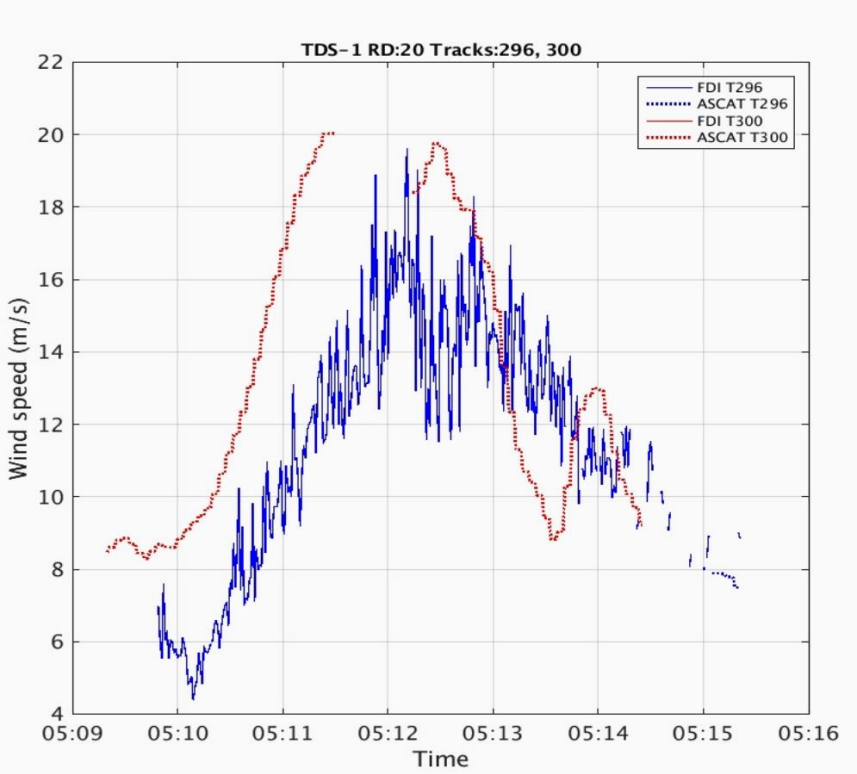




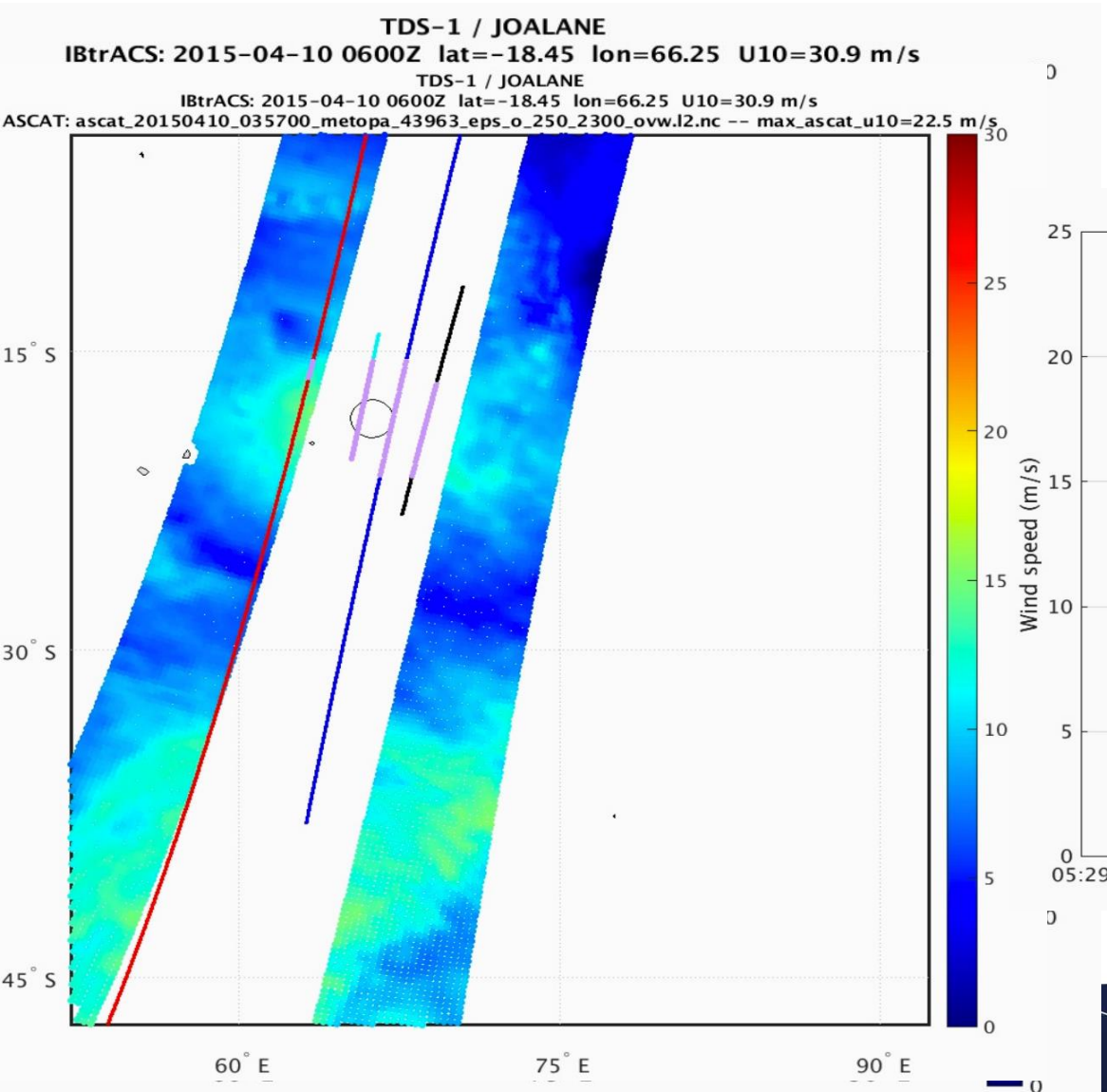
NERC SCIENCE OF THE ENVIRONMENT

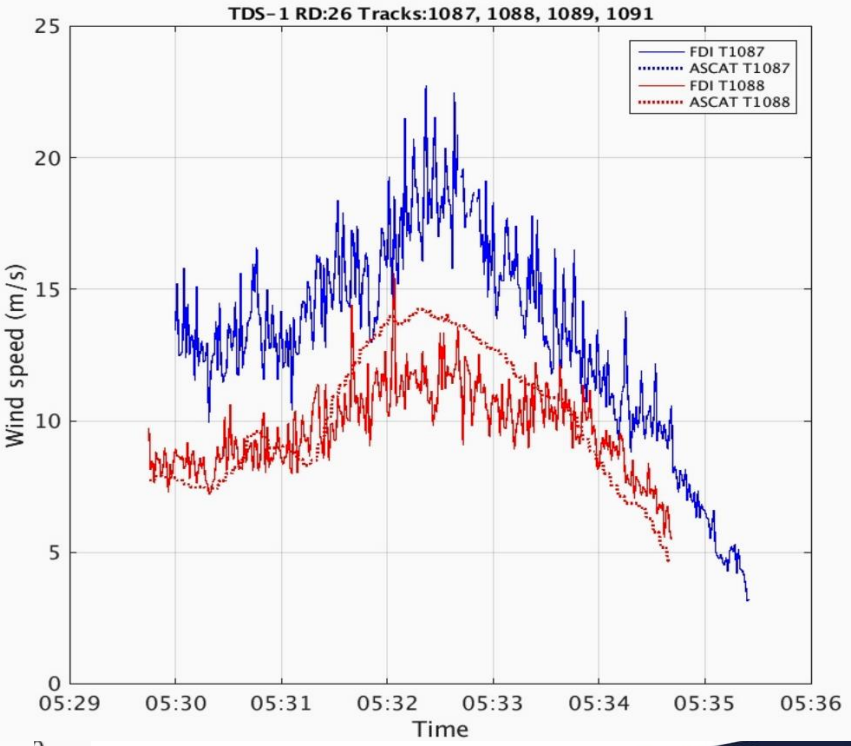
GLENDA


TDS-1 / GLENDA
IBtrACS: 2015-02-28 0600Z lat=-27.75 lon=67.65 U10=25.7 m/s
ASCAT: ascat_20150228_035700_metopb_12694_eps_o_250_2201_ovw.l2.nc -- max_ascat_u10=24.0 m/s
15° S
30° S
45° S
60° E
75° E
90° E
ASCAT U10 (m/s)
0
5
10
15
20
25
30


TDS-1 RD:20 Tracks:296, 300
FDI T296
ASCAT T296
FDI T300
ASCAT T300
Wind speed (m/s)
Time
4
6
8
10
12
14
16
18
20
22
05:09
05:10
05:11
05:12
05:13
05:14
05:15
05:16

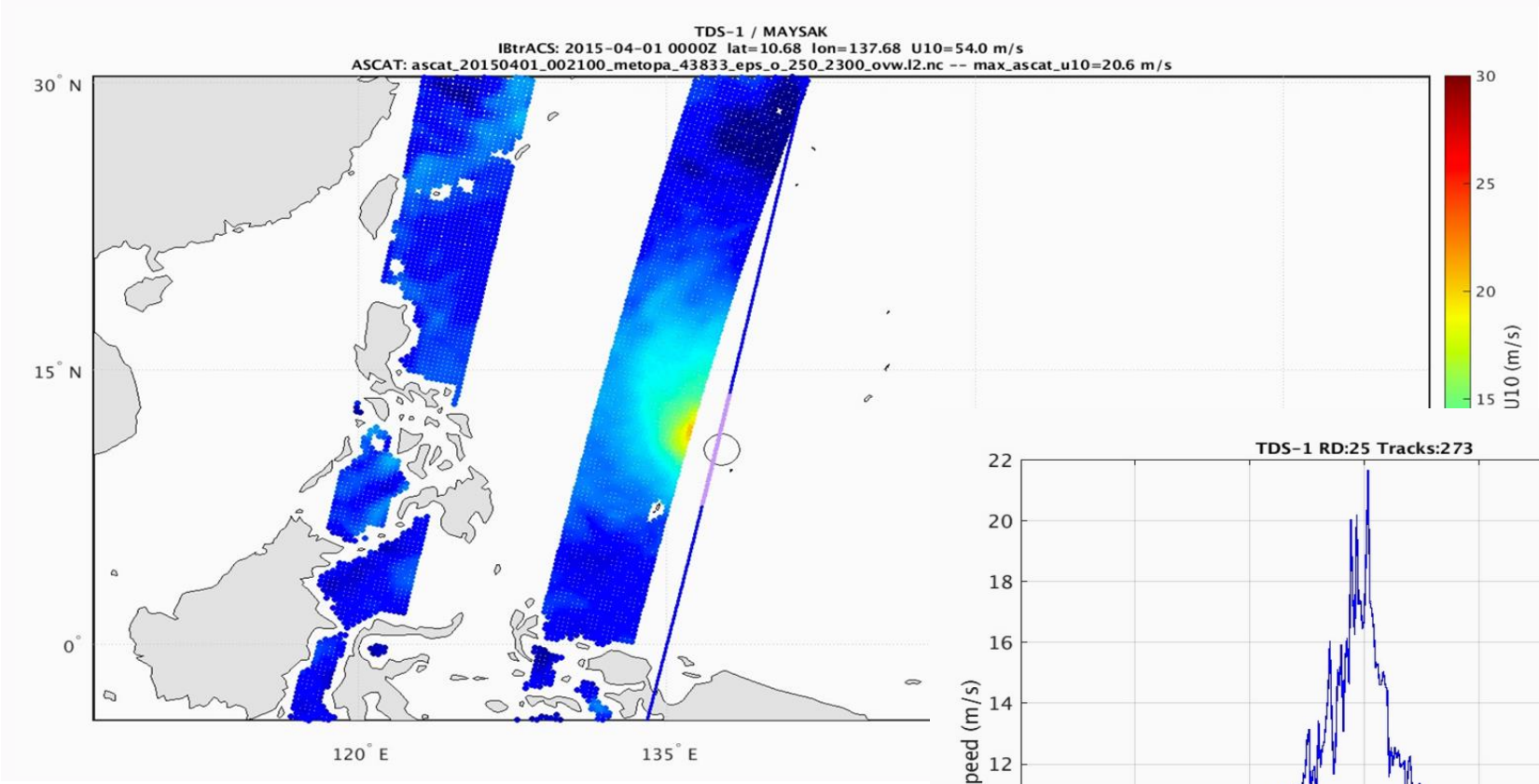
JOALANE

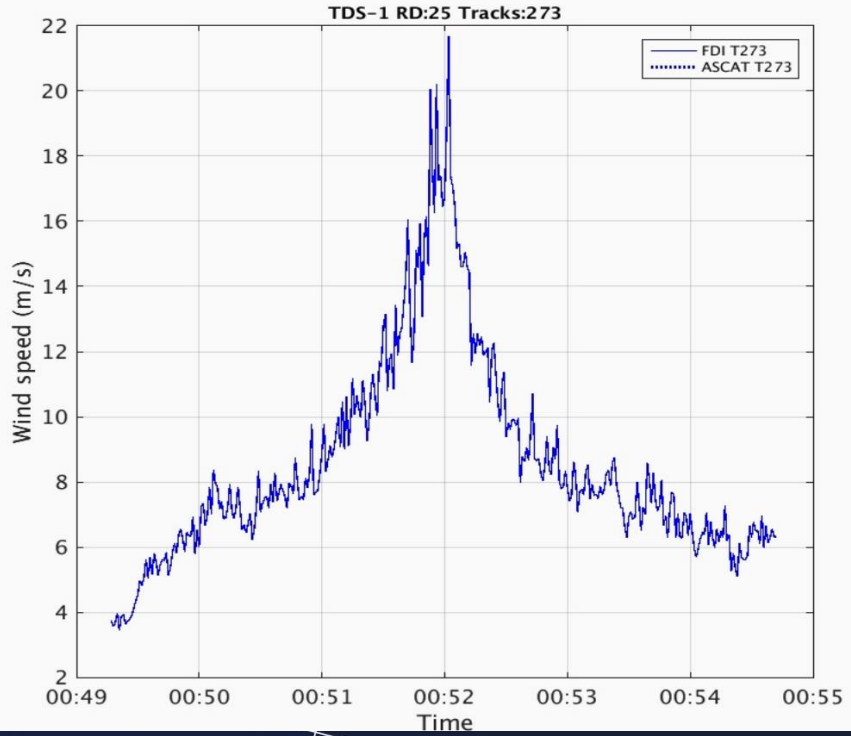




NERC SCIENCE OF THE ENVIRONMENT

MAYSAK


TDS-1 / MAYSAK
IBtrACS: 2015-04-01 0000Z lat=10.68 lon=137.68 U10=54.0 m/s
ASCAT: ascat_20150401_002100_metopa_43833_eps_o_250_2300_ovw.l2.nc -- max_ascat_u10=20.6 m/s
30° N
15° N
0°
120° E
135° E
30
25
20
15
U10 (m/s)


TDS-1 RD:25 Tracks:273
FDI T273
ASCAT T273
Wind speed (m/s)
22
20
18
16
14
12
10
8
6
4
2
00:49
00:50
00:51
00:52
00:53
00:54
00:55
Time

Summary & Outlook

- TDS-1 continues to acquire large volumes of spaceborne GNSS-R data since Sept 2014
  - Ground processing & data dissemination in place up to L2 wind speed
- Development of TDS-1 wind speed inversion is ongoing
  - Many approaches to GNSS-R inversion and calibration/validation
  - Many complex effects linked to TDS-1 mission (system gain, antenna gain, attitude uncertainty) and new discovery of environmental factors (sea state, RFI, elevated L-band noise at Equator,…)
  - Many lessons learned!

Summary & Outlook

- First look at spaceborne GNSS-R in high wind conditions
  - Examples of successful TDS-1 acquisitions in high winds
    - Very promising for CYGNSS (+ better mission parameters)
  - Illustrates how GNSS-R sampling can complement ASCAT dual-swath
  - Evidence that GNSS-R signals are sensitive to wind field structure…
  - …but FDI wind speed too low
  - …but FDI inversion never designed for high winds
  - Many interesting aspects to explore e.g. impact of rain, sensitivity to wind direction, impact of small scale variability/surface heterogeneity,..

Thank You