

# Prospects on GNSS-Reflectometry for Wind Speed Estimation and Numerical Weather Prediction

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2: Surrey Satellite Technology Limited (SSTL), UK

3: National Oceanography Centre (NOC), UK

4: IEEC, Spain

5: Spire Global

6: ECMWF

7: MetOffice, UK

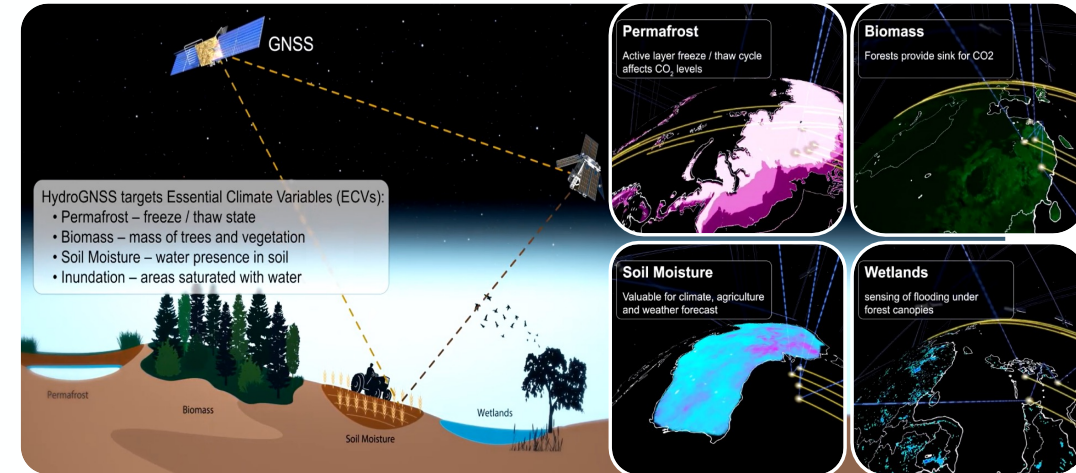
8: University of Michigan, USA

- The ESA Scout HydroGNSS Mission
- Impact of GNSS-R Observations over the Ocean in a Numerical Weather Prediction System
- Summary

# GNSS-R on HydroGNSS Mission



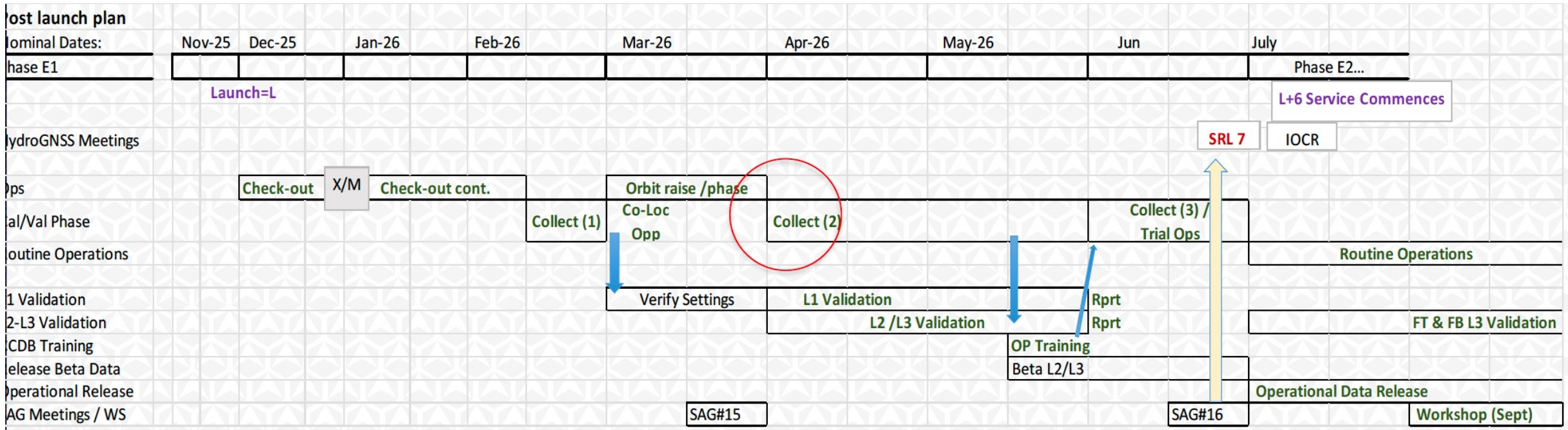
- First ESA Scout small satellite mission
- Two Sats, launched Nov 2025, undergoing commissioning
- Primary Objectives: Soil Moisture, Freeze/Thaw, Inundation, Biomass
- **Secondary products: ocean winds, sea ice extent**
- Wind Speed Product: L2 trackwise, uncertainty of  $\sim 2$  m/s for winds up to 20 m/s, resolution 25 km
- SSTL leading the Consortium and in charge of the development of the whole system
- National Oceanography Centre (NOC) in charge of the L2 wind speed product
- Fastest delivery of L2/L3 products is within 1 week of measurement, but potential to reduce to 3/6 hours (TBD with SSTL)



## Innovations

- **DDMs from Galileo Signals**
- **Second frequency, L5/E5a**
- Dual Polarisation - Left and Right Hand Circular DDMs
- Coherent complex channel



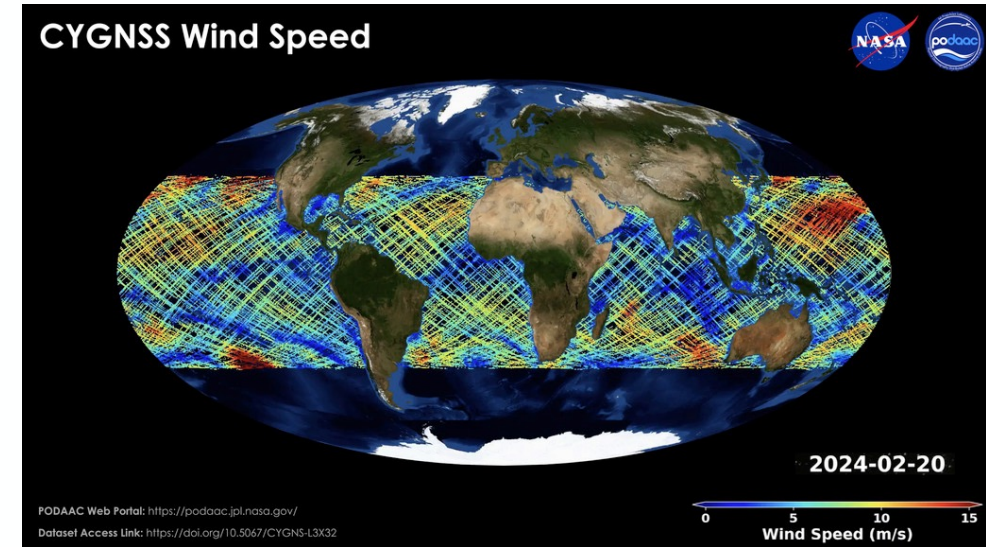


- IOCR is final review of Phase E1 - mid-July, workshop likely to be in late September
- Routine data (Delay-Doppler Map) collection using nominal settings has started on 9<sup>th</sup> April
- Products are provided as NetCDF files, via SFTP setup by SSTL, responsible for distributing the data to users
- Data publicly available after IOCR

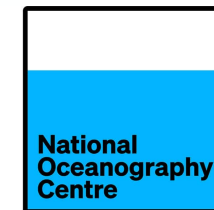
# Impact of GNSS-R over the Ocean in NWP Systems

• **What is the impact of GNSS-R ocean data when added to the operational observing system?** → *Potentially inform GNSS-R data buy*

- **Project spans 3 years – ends December 2026 (on track)**
- **Partners:**
  1. National Oceanography Centre (NOC): provision of a calibrated level 1 dataset (GNSS-R expertise)
  2. Spire: provision of a level 2 dataset (GNSS-R expertise)
  3. ECMWF (PI): forward model development & assimilation of level1 “sigma0”
  4. Met Office: assimilation of level 2 windspeed product

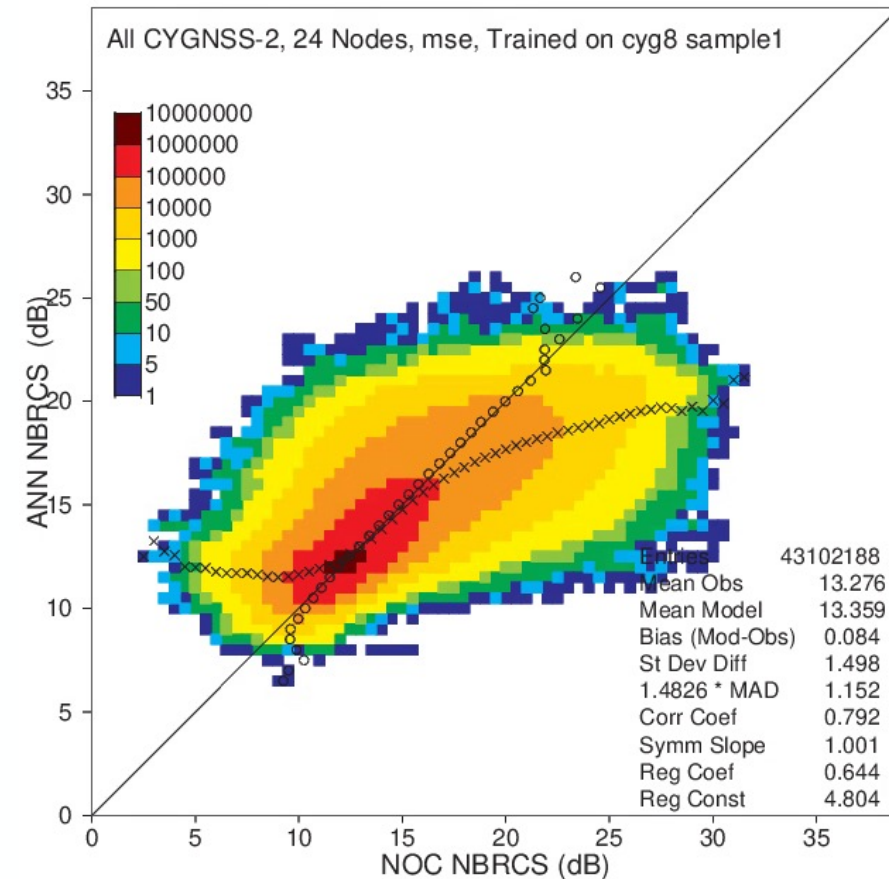


- **Assimilation experiments with CyGNSS data to ensure sufficient data volume**
- **Compare impact in Met Office and ECMWF systems**
- **ECMWF and Met Office also assessing the quality of Spire data**



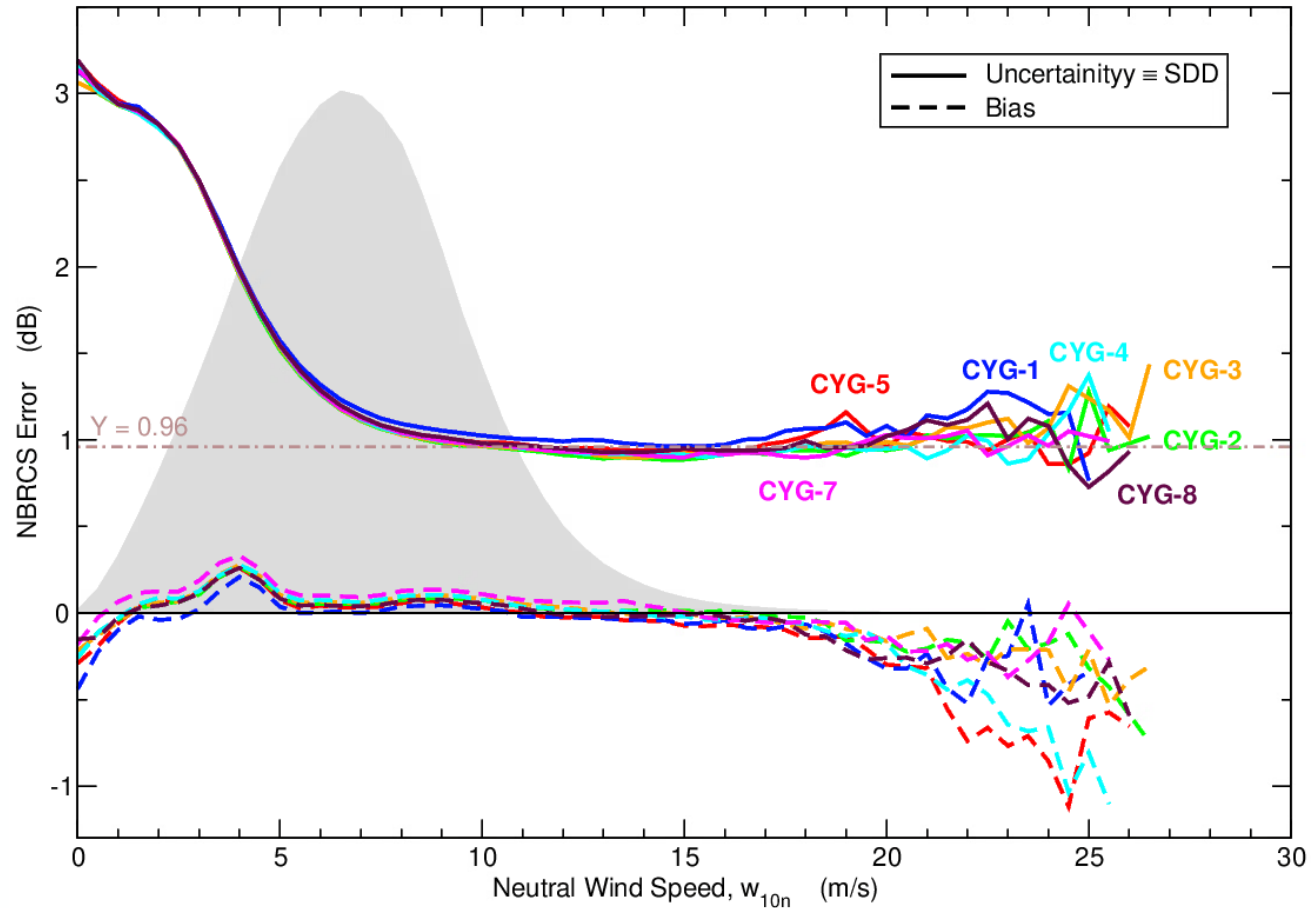
- ECMWF developed an ML-based GNSS-R Normalised Radar Cross Section (NRCS) forward model
- Model trained on CyGNSS-8 but applicable to all satellites. Standard deviation of the CYGNSS-2 departures is 1.498 dB

Model Elements	Description
Model type	Sequential
Number of layers	1 input, 1 output and 2 hidden
Type of hidden layers	Dense
Number of nodes	24 for each hidden layer (other number of nodes were tested)
Activation function	Rectified linear (ReLU) for training; and Hyperbolic tangent ( <i>tanh</i> ) for implementation
Input layer	Input nodes are: <ul style="list-style-type: none"> <li>- 10-m neutral equivalent windspeed</li> <li>- Charnock Parameter</li> <li>- Latitude and longitude</li> <li>- Specular incidence angle</li> <li>- Antenna (port or starboard)</li> </ul>
Output layer	1 node for $\sigma^0$
Loss function	Optimisation of mean square error (mse)
Optimiser	Stochastic gradient descent (SGD)



# GNSS-R Forward Model: Departure Statistics

- Statistics computed for all satellites for 2024 data
- Use a  $\sigma_0$  uncertainty model as a function of windspeed/Charnock parameter in assimilation



- **Status of HydroGNSS:**
  - IOCR in Mid-July and dedicated workshop in September
  - data publicly available to users after IOCR, via SFTP, in NetCDF format
  - Ocean Surface Wind Speed secondary product from L1(GPS)/E1(Galileo) reflections, plus possibility to exploit the new L5/E5a signals
  - Nominal timeliness is 1 week, but possibility to bring it down to a few hours
- **Status of GNSS-R Impact Study over Ocean**
  1. Recalibration of L1 data, rederivation of L2 wind speeds and forward model development completed
  2. Analysis of Spire data has started
  3. Currently preparing the integration of NN forward operator into the NWP system
  4. Some modifications of the SCAT sigma0 code to be completed
  5. MetOffice Preparing for L2 wind speed DA Experiment

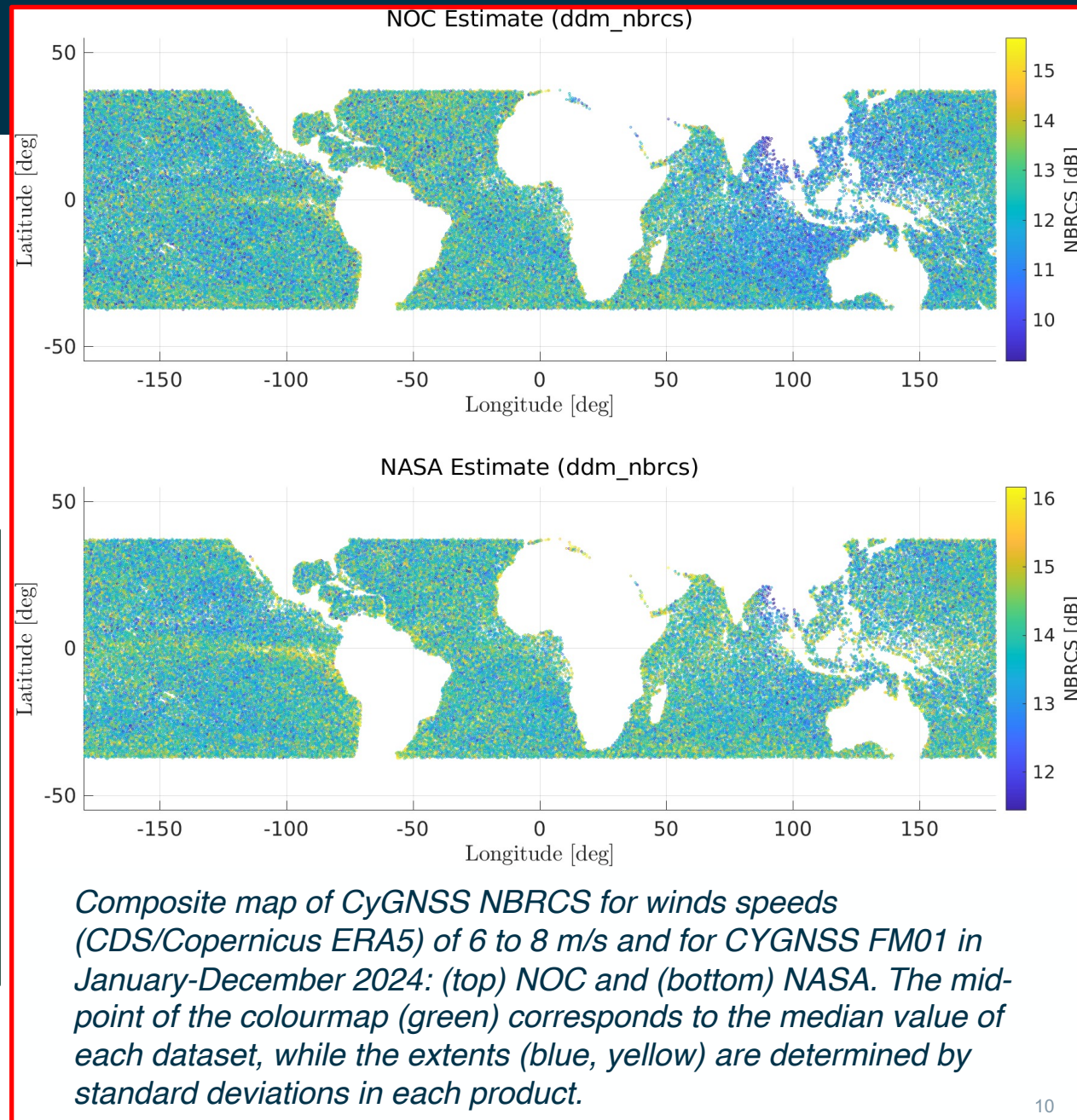
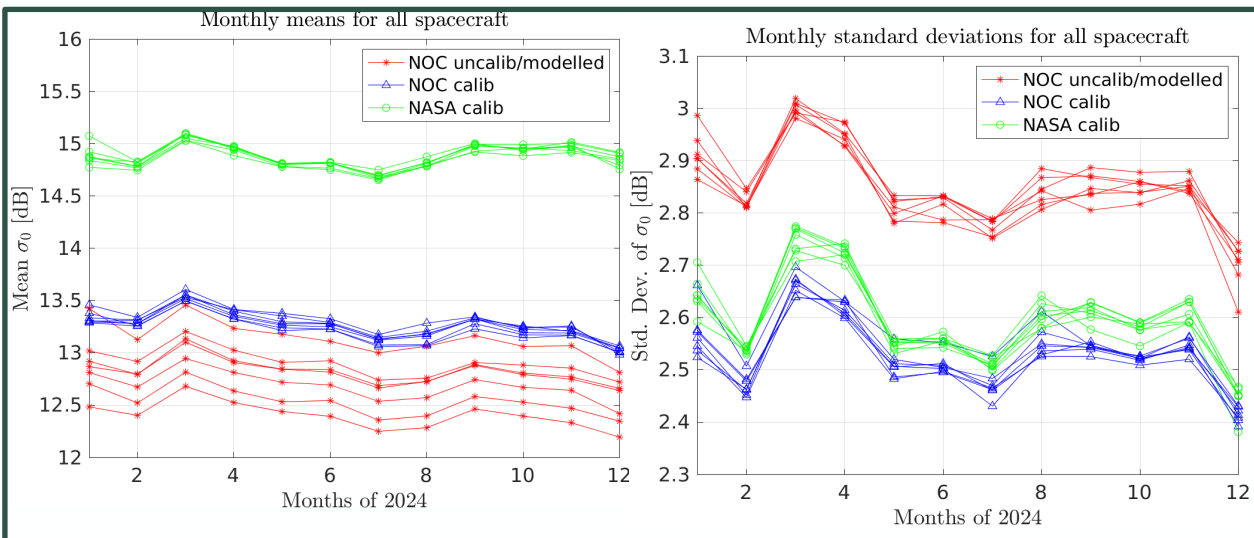
**Thank you!**

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# Backup Slides

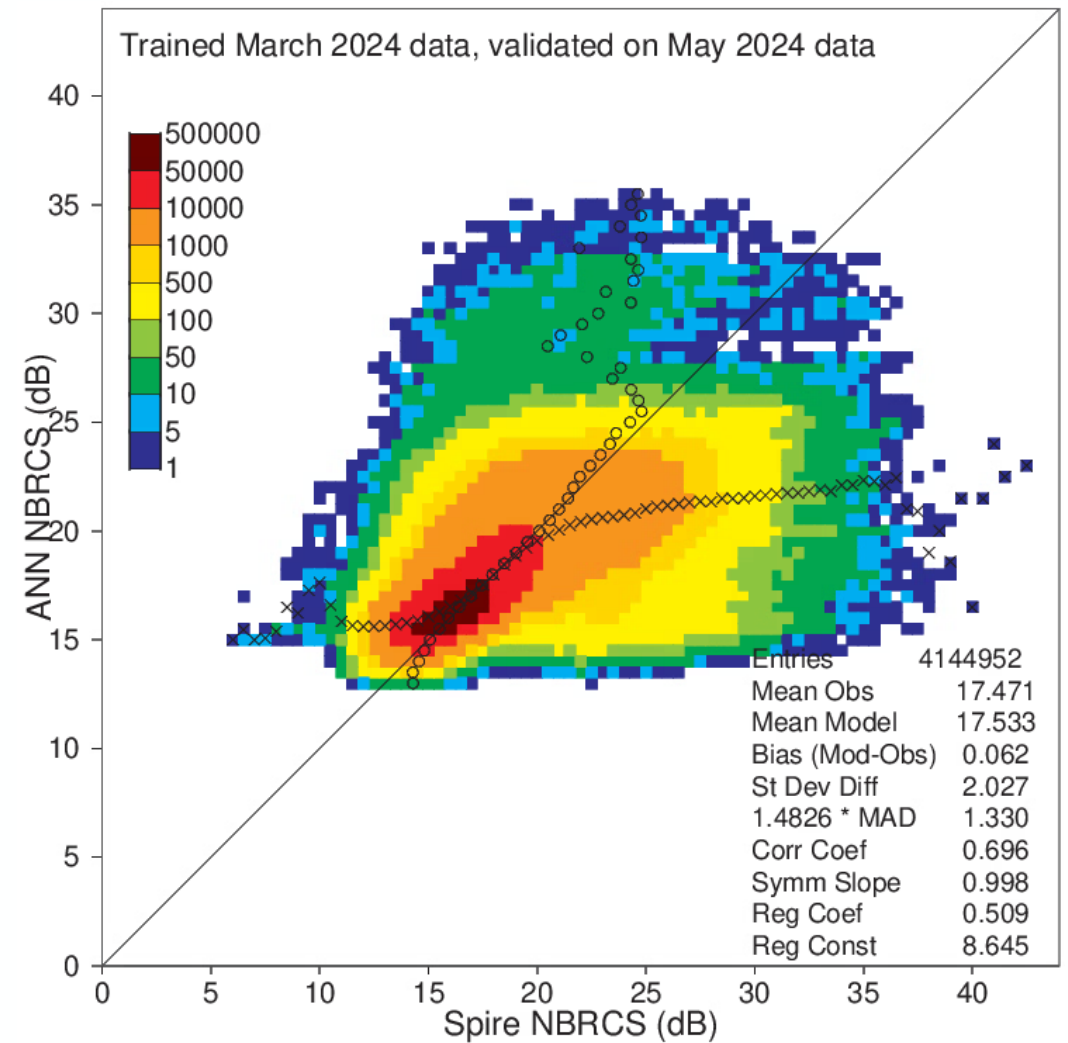
# NOC Calibration

- NOC Approach to calibration of CYGNSS data based on building LUTs of bias corrections, functions of transmitter/receiver geometry and GPS satellite
- Results are compared to CYGNSS SDR v3.2 data



# Adapting the Forward Model to Spire Data: First Look

- Spire GNSS-R L1 and L2 data will be ingested in the ECMWF and Met Office NWP systems and monitored passively (no weight given in the assimilation system)
- The “observed minus background” (o-b) departure statistics will be produced in both NWP systems
- They will be compared with the corresponding statistics produced for CYGNSS data



# Sigma0 vs Wind Speed

