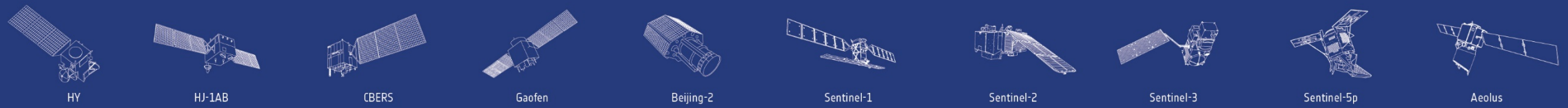



2023 DRAGON 5 SYMPOSIUM

3rd YEAR RESULTS REPORTING

11-15 SEPTEMBER 2023

# PROJECT ID. 58070

# CALIBRATION AND VALIDATION OF THE FIRST CHINESE GNSS-R MISSION— BUFENG-1 A/B

**DATE: WEDNESDAY, 13/SEP/2023**

**ID. 58070**

**PROJECT TITLE: CALIBRATION AND VALIDATION OF THE FIRST CHINESE GNSS-R MISSION—BUFENG-1 A/B**

**PRINCIPAL INVESTIGATORS: CHENG JING, LI WEIQIANG**

**CO-AUTHORS: WEI WAN, FENG LU, XINLIANG NIU, XIUWAN CHEN, ANTONIO RIUS, ESTEL CARDELLACH, SERNI RIBÓ, BAOJIAN LIU, ZHIZHOU GUO, YANG NAN**

**PRESENTED BY: CHENG JING**

*Objectives*

- Collocation of integrated ESA-CHINA EO data products and BuFeng-1 data preprocessing
- Calibration of the BuFeng-1 A/B main observables, including NBRCS, power DDM, and SNR
- Validation of the calibrated results from BuFeng-1 A/B;
- Optimization and improvements of future spaceborne GNSS-R instruments

*Details of data utilization*

- ESA EO data: SMOS (MIRAS), Sentinel-3 (SIRAL)
- CHINA EO data: FY Series (MWRI), CFOSAT (SCAT), HY-1&2 (COCTS), BF-1 A/B (GNSS-R)
- Meteorological reanalysis data: ECMWF ERA-5, CMA CRA
- In-situ data: ISMN sites
- Others: SMAP, DTU MSS

# EO Data Delivery

Data access (list all missions and issues if any). NB. in the tables please insert cumulative figures (since July 2020) for no. of scenes of high bit rate data (e.g. S1 100 scenes). If data delivery is low bit rate by ftp, insert “ftp”

| ESA /Copernicus Missions | No. Scenes |
|---|---|
| 1. SMOS (MIRAS) | |
| 2. Sentinel-3 (SRAL) | |
| 3. | |
| 4. | |
| 5. | |
| Total: | |
| Issues: | |

| ESA Third Party Missions | No. Scenes |
|---|---|
| 1. ECMWF ERA-5 | |
| 2. CMA CRA | |
| 3. ISMN sites | |
| 4. SMAP | |
| 5. DTU MSS | |
| Total: | |
| Issues: | |

| Chinese EO data | No. Scenes |
|---|---|
| 1. FY Series (MWRI) | |
| 2. CFOSAT (SCAT) | |
| 3. HY-1&2 (COCTS) | |
| 4.BF-1 A/B(GNSS-R) | |
| 5. | |
| Total: | |
| Issues: | |

# Chinese BF-1 Mission

Launch date: June 5th, 2019
Frequency: GPS L1 & BeiDou B1
Antenna gain: 14 dBi
Mass: 10 kg
Power consumption: 30 W
Specular Points: 4/s

| GNSS-R receiver | |
|---|---|
| Frequency | GPS L1 and BDS B1 |
| Antenna Gain | ≥14 dBi |
| Mass | ≤10 kg |
| Power Consumption | ≤30 W |
| **DDM Mode** | |
| Delay Chip Resolution | 1/4 chip |
| Doppler Frequency Resolution | 500 Hz |
| Specular Points | 4 from both sides of the twin SVs |
| **Raw Data Mode** | |
| L1CA Sampling Rate | 4.092 MHz |
| B1I Sampling Rate | 8.184 MHz |
| Duration | 12 sec per pass |

**Sea platform launch**

**GNSS-R Instruments**

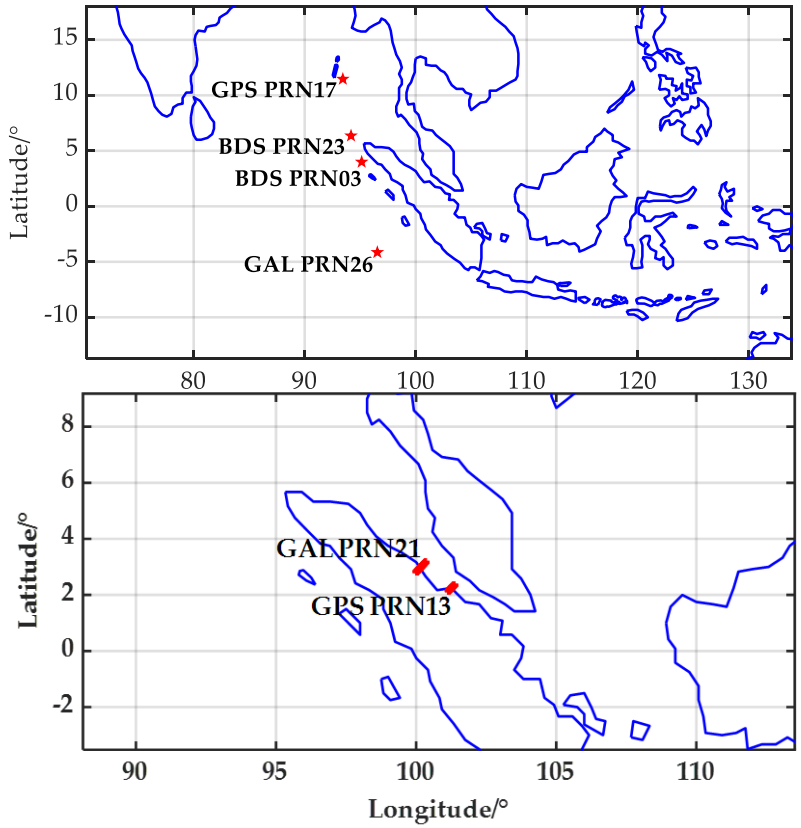
X. Niu, F. Lu, Y. Liu, et al. Application and Technology of Bufeng-1 GNSS-R Demonstration Satellites on Sea Surface Wind Speed Detection. China Satellite Navigation Conference (CSNC) 2020 Proceedings: Volume I

## BF-1 Data availability statement

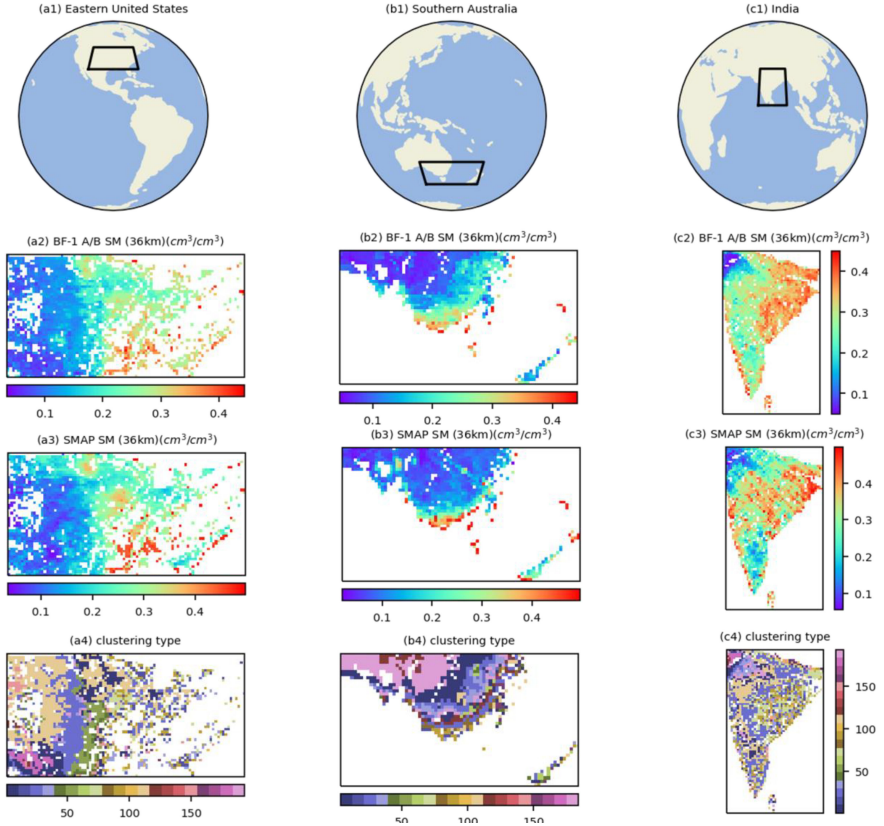
As the first Chinese spaceborne GNSS-R mission, BF-1 is a technical demonstration satellite mission. Under the Dragon 5 project framework, BF-1 data have been distributed among the participating members. In July of 2023, The 4th anniversary meeting of BF-1 mission has been taken place in Beijing and made a data sharing plan arranged by CMA and CASC. The information is scheduled to be public to the GNSS-R community. BF-1 products now are available to the GNSS-R science community from the corresponding author, Feng Lu, upon reasonable request.

Correspondence: lufeng@cma.gov.cn

# Data and Study Area




**Raw IF data Study Areas**




**In-land Soil Moisture Areas**

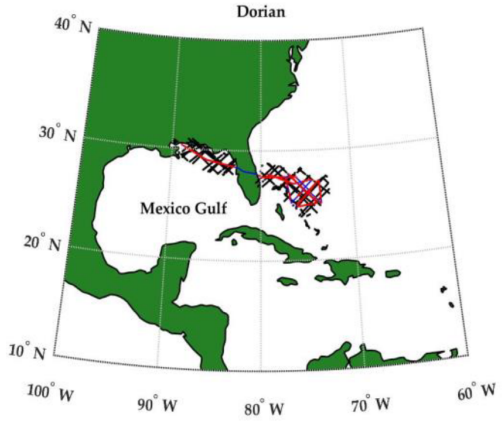



**Table 1.** NOAA Hurricane Season Data 2019

| Name | Date | Volume |
|---|---|---|
| Barry | 7/11-7/23 | 9 |
| Dorian | 8/26-9/6 | 35 |
| Humberto | 9/13-9/19 | 10 |
| Ivo | 8/17-8/24 | 5 |
| Jerry | 9/19-9/24 | 12 |
| Karen | 9/22-9/26 | 7 |
| Lorena | 9/19-9/21 | 3 |
| Lorenzo | 9/28-9/29 | 2 |

**Hurricane Observation Area**

**the results after 3 years of activity**

**BF-1 Sea Surface Height Measurement**

## Sea Surface Height Measurements

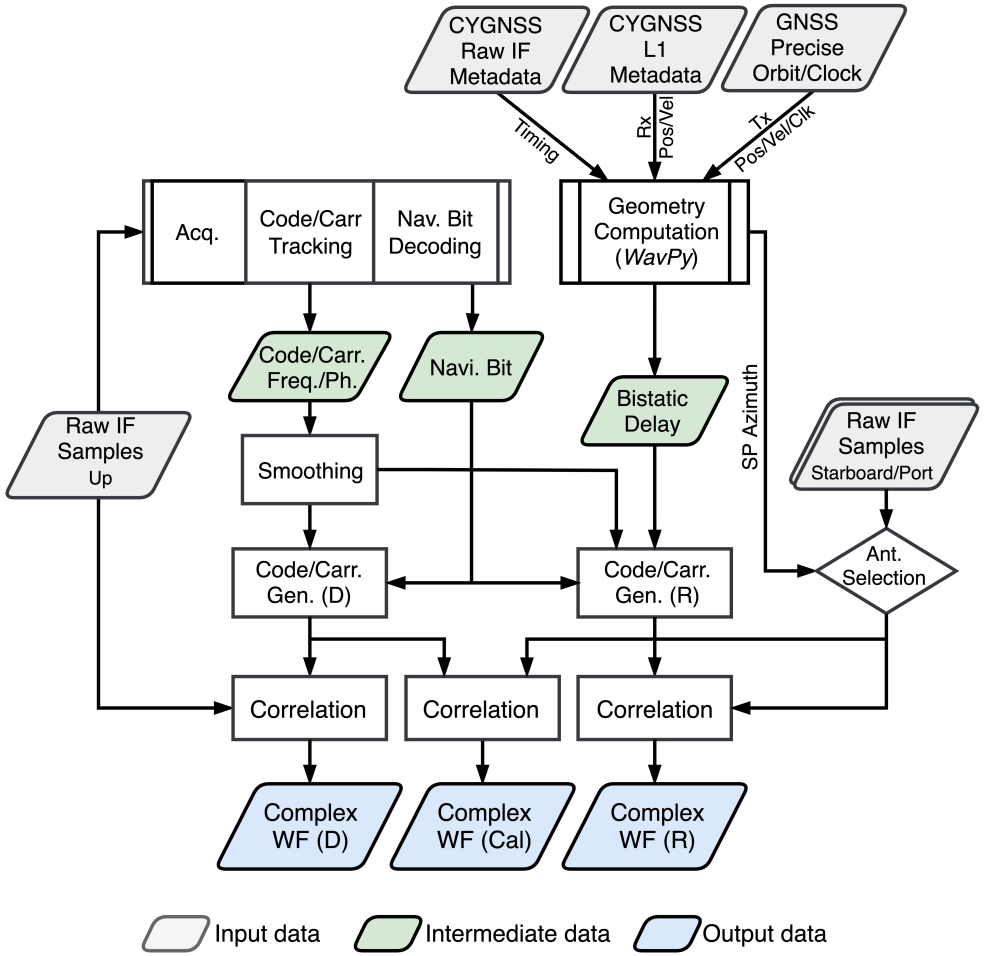
- Data Latency: diagnostic mode will start the raw IF data collecting about 12 seconds within every pass
- Data Time: the year of 2020
- Frequency: GPS L1, BDS B1, GAL E1
- Channels: 1 direct, 2 reflections
- Auxiliary data: IGS, ECMWF reanalysis, DTU MSS

**BF-1 Spaceborne GNSS-R Raw IF data of 2020**

| Date | Start Time | Resource | Code | Mode |
|---|---|---|---|---|
| 2020/2/12 | 17:42:17 | GPS PRN17 | L1 C/A | Group Delay |
| 2020/2/13 | 16:02:22 | BDS PRN23 | B1C | Group Delay |
| 2020/2/16 | 16:04:26 | BDS PRN03 | B1I | Group Delay |
| 2020/2/23 | 12:47:58 | GAL PRN26 | E1 | Group Delay |
| 2020/2/13 | 16:02:22 | GAL PRN21 | / | Carrier Phase |
| 2020/8/23 | 21:07:00 | GPS PRN13 | / | Carrier Phase |

# Sea Surface Height Measurements

- Close-loop processing of the direct signal
- Open-loop (OP) processing of the reflected delay-waveforms
- Ancillary information: the positions, velocities, and timing information of the GNSS transmitters and BF-1 satellites
- Corrections: ionospheric delay, tropospheric delay, and the tidal corrections.

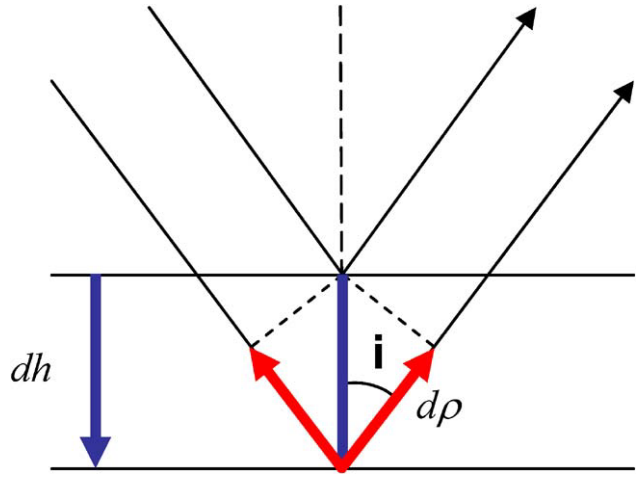



Li, W., et al. (2018). "Revisiting the GNSS-R waveform statistics and its impact on altimetric retrievals." IEEE Transactions on Geoscience and Remote Sensing **56(5): 2854-2871.**
Li, W., et al. (2019). "Assessment of spaceborne GNSS-R ocean altimetry performance using CYGNSS mission raw data." IEEE Transactions on Geoscience and Remote Sensing **58(1): 238-250.**

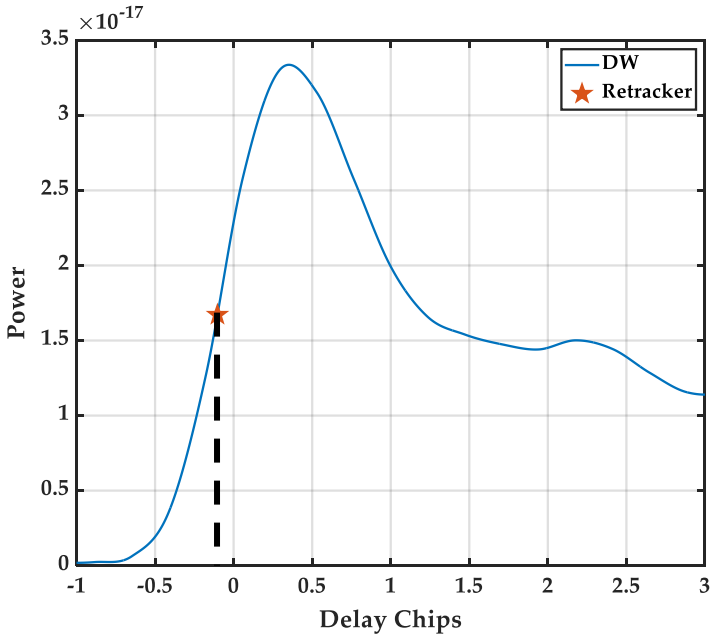
# Sea Surface Height Measurements

## Group Delay

- Signal path: delay between paths
- Specular point positions recalculation
- Retracker: DER, HALF, and FIT
- Corrections: ionospheric and tropospheric delays, tides, dynamic bar, etc.




**Path delays**



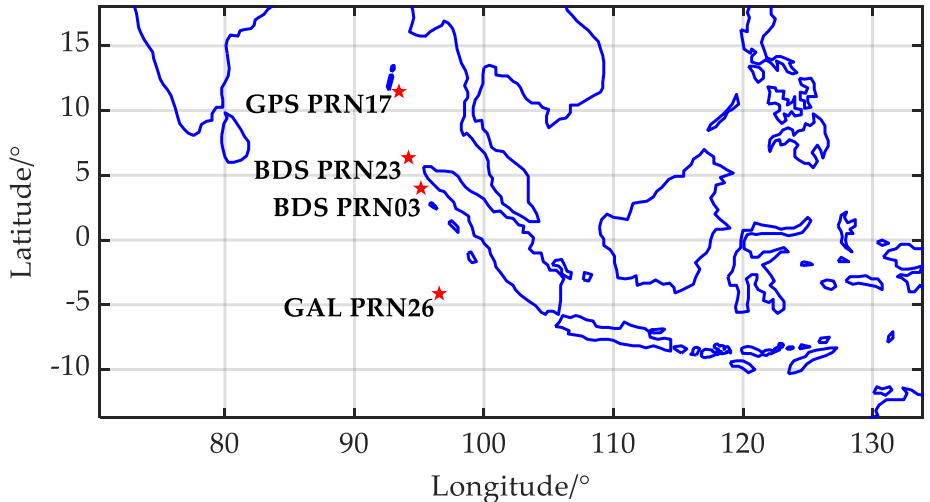

**Wave retracker**

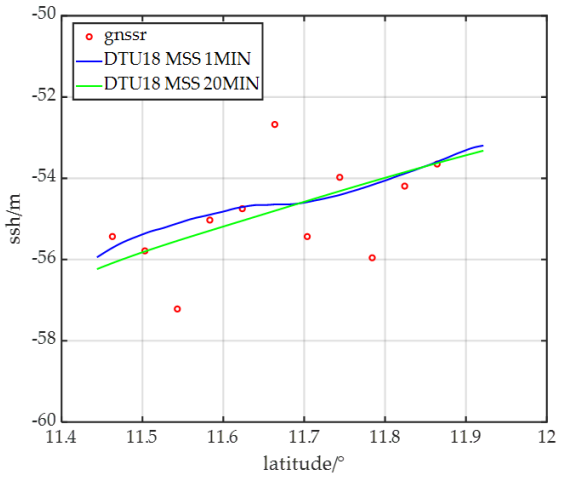
Li, W., et al. (2018). "Revisiting the GNSS-R waveform statistics and its impact on altimetric retrievals." IEEE Transactions on Geoscience and Remote Sensing **56(5): 2854-2871.**
Li, W., et al. (2019). "Assessment of spaceborne GNSS-R ocean altimetry performance using CYGNSS mission raw data." IEEE Transactions on Geoscience and Remote Sensing **58(1): 238-250.**

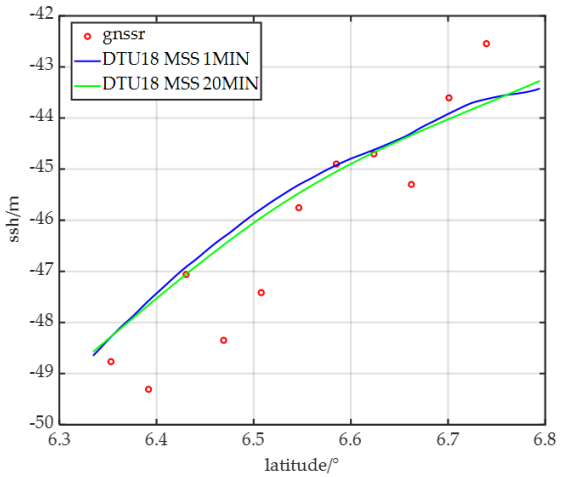
# Results after 3 Years of Activity

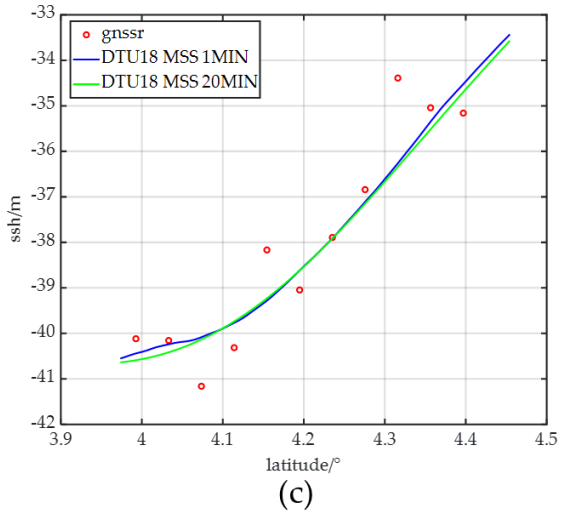
## Sea Surface Height Measurements - Group Delay Results

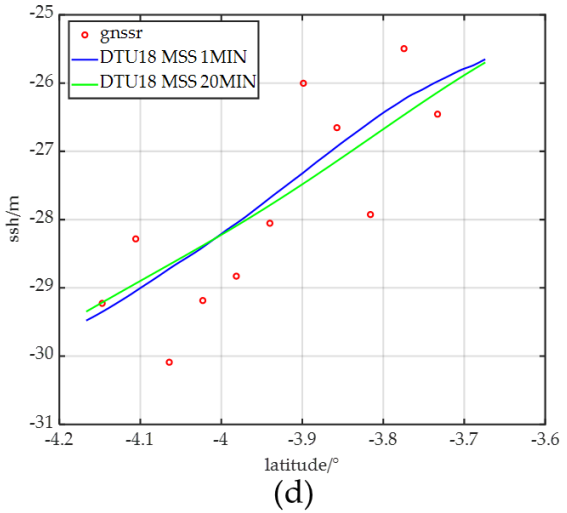
- Four specular points with 11-sec latency
- Resolution: ~3.3-MIN (1 Hz)
- Validation: DTU MSS 1-MIN & 20-MIN
  - (a) GPS PRN17: RMSD of 1.06 m
  - (b) BDS PRN23: RMSD of 1.01 m
  - (c) BDS PRN03: RMSD of 0.81 m
  - (d) Galileo PRN26: RMSD of 0.86 m.



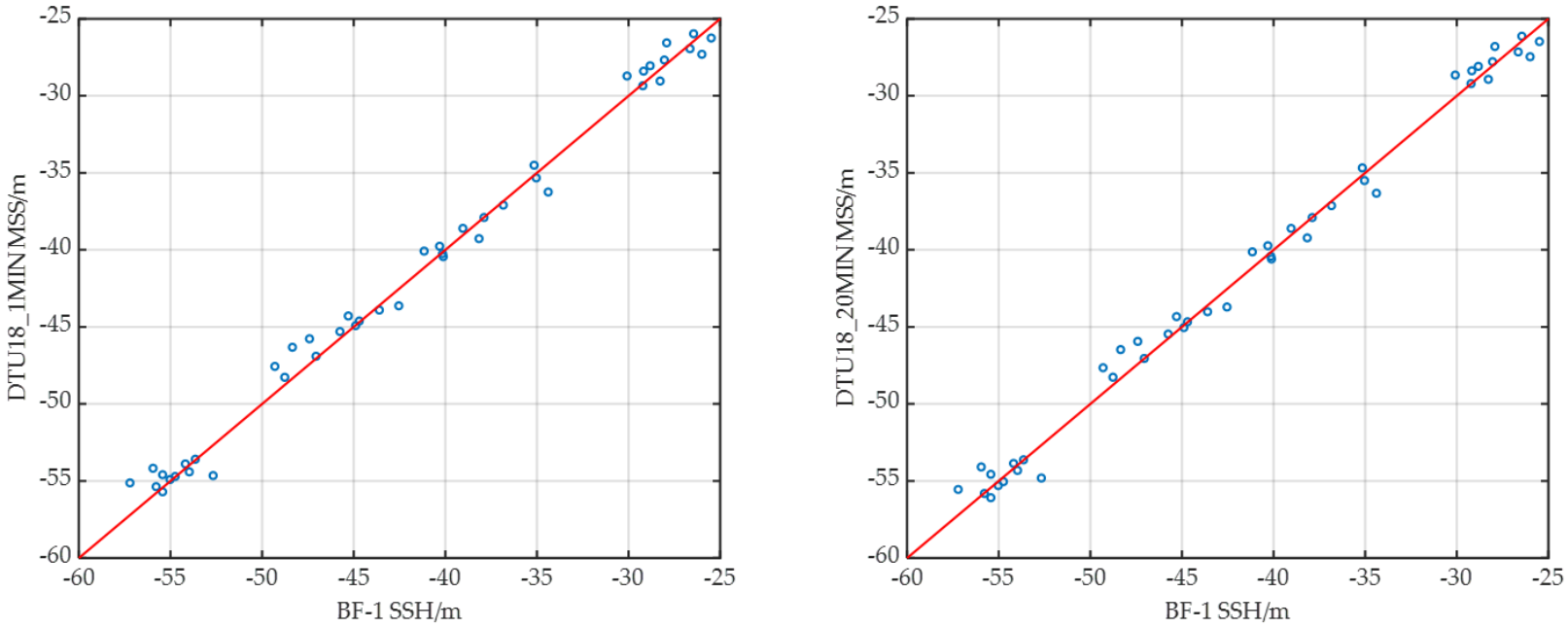



# Sea Surface Height Measurements - Group Delay Results

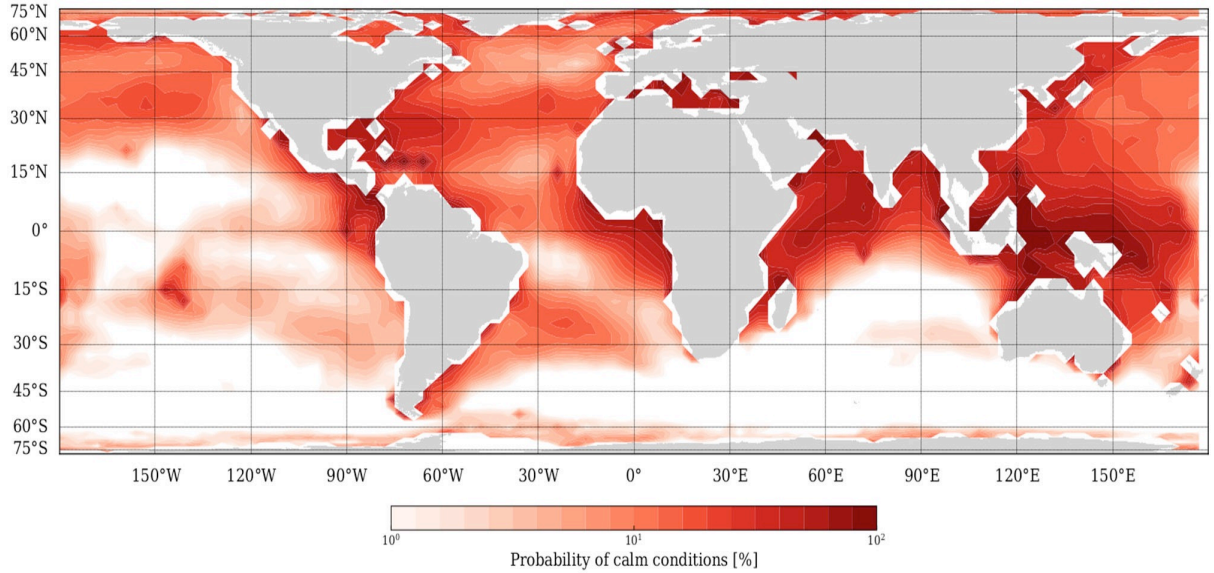



(a) results compared with DTU18 1-min mean sea surface measurements. The total RMSD is 0.93 m with the $R^2$ of 99.17%. (b) results compared with DTU18 20-min products. The parameters of RMSD and $R^2$ are 0.94 m and 99.15%, respectively.

# Sea Surface Height Measurements

## Carrier Phase

- BF-1 raw IF data with the GA feature are abstracted to track and measure the sea level
- Global map of calm condition of high probability
- High spatial resolution of 20 Hz but low coverage
- No high gain antenna needed




**Global Map of Sea Calm Condition**

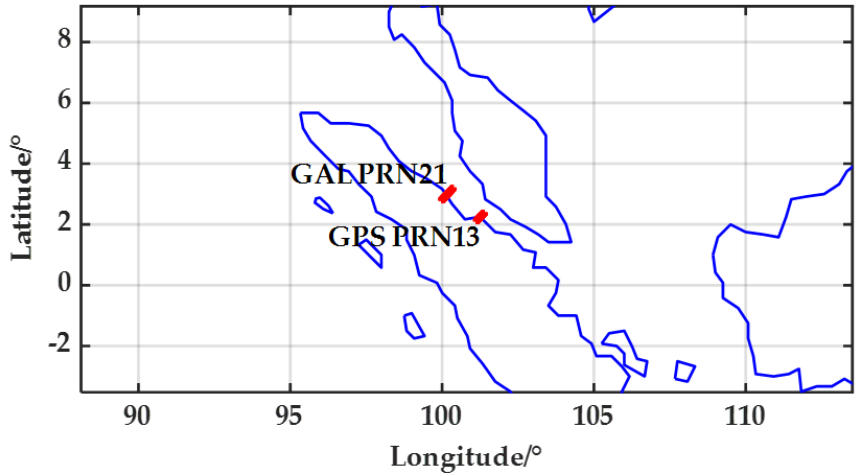
Li, W., et al. (2017). "First spaceborne phase altimetry over sea ice using TechDemoSat-1 GNSS-R signals." Geophysical Research Letters **44(16): 8369-8376.**

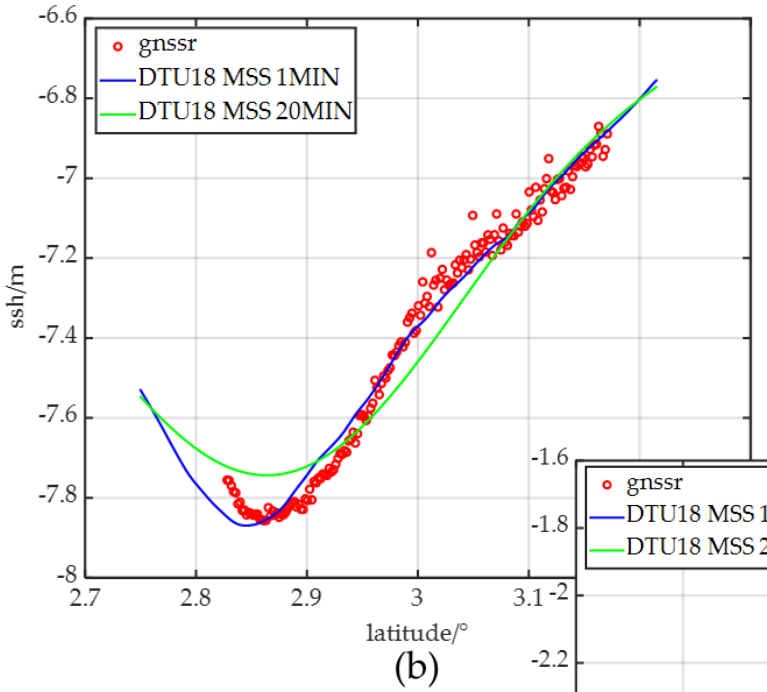
Cardellach, E., et al. (2019). "First precise spaceborne sea surface altimetry with GNSS reflected signals." IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing **13: 102-112.**

# Results after 3 Years of Activity

## Sea Surface Height Measurements - Carrier Phase Results

- BF-1 raw IF data with the GA feature
- Signal: Galileo PRN21, GPS PRN13
- Validation: DTU MSS 1-MIN & 20-MIN
- Area: calm sea surface roughness
- Resolution: ~0.16-MIN (20 Hz)
- Accuracy: 6.65 cm vs DTU MSS 1-MIN
  4.04 cm vs DTU MSS 20-MIN

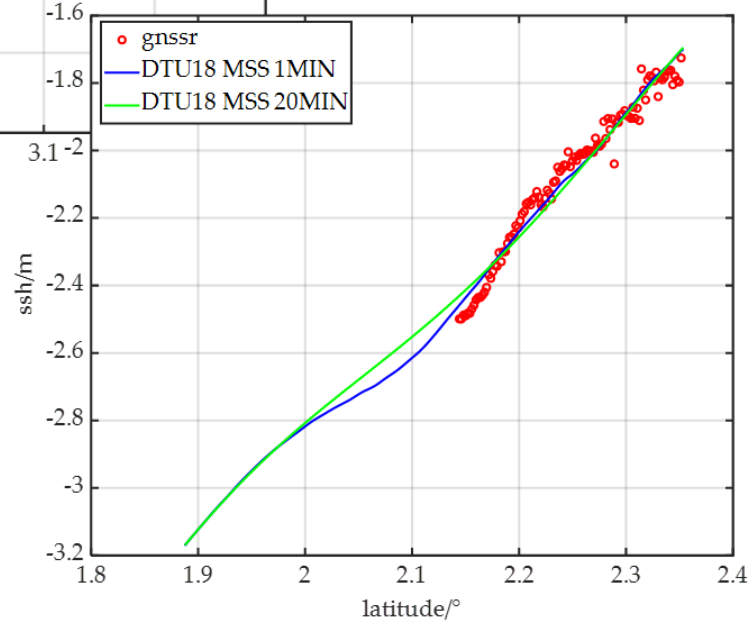



(b)

**Galileo PRN21**

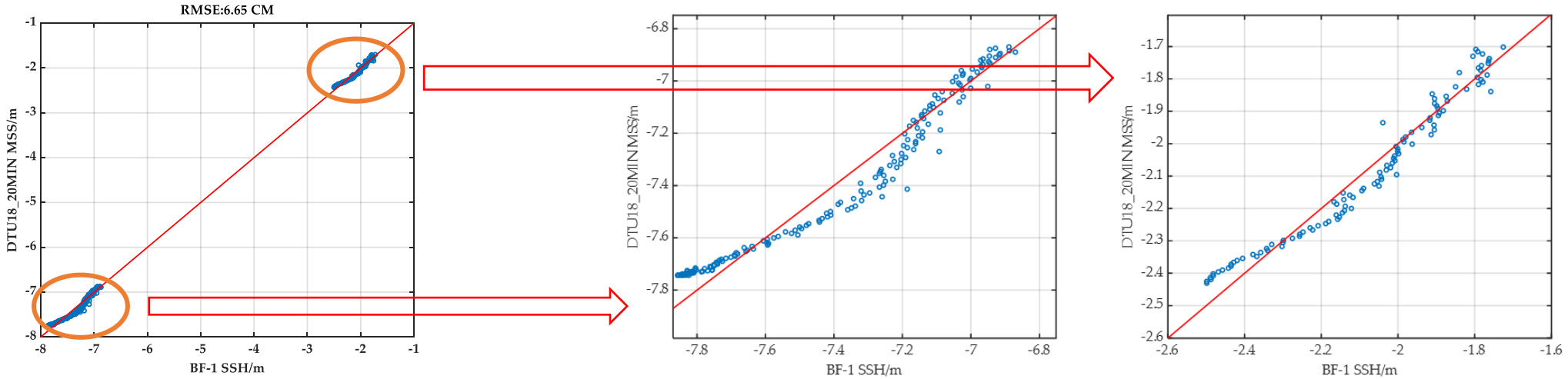
**GPS PRN13**



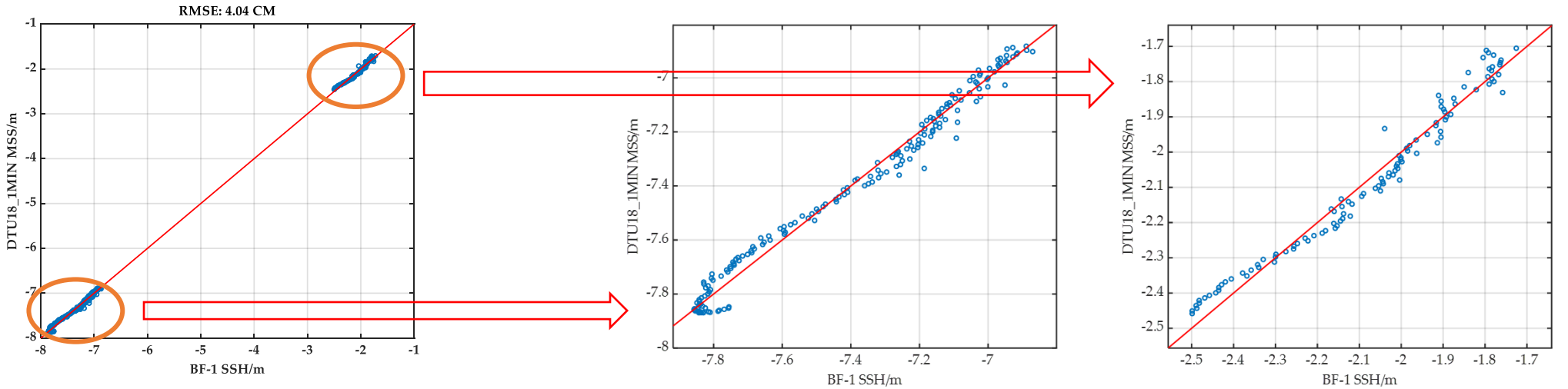

(c)

# Sea Surface Height Measurements - Carrier Phase Results

**20-MIN RES.**
**RMSE=6.65 CM**




**1-MIN RES.**
**RMSE=4.04 CM**




**Galileo PRN21**

**GPS PRN13**

## Sea Surface Height Measurements - Corrections

- GNSS-R SSH corrections
- Similar with the radar altimeter

GNSS-R related biases (above the water):

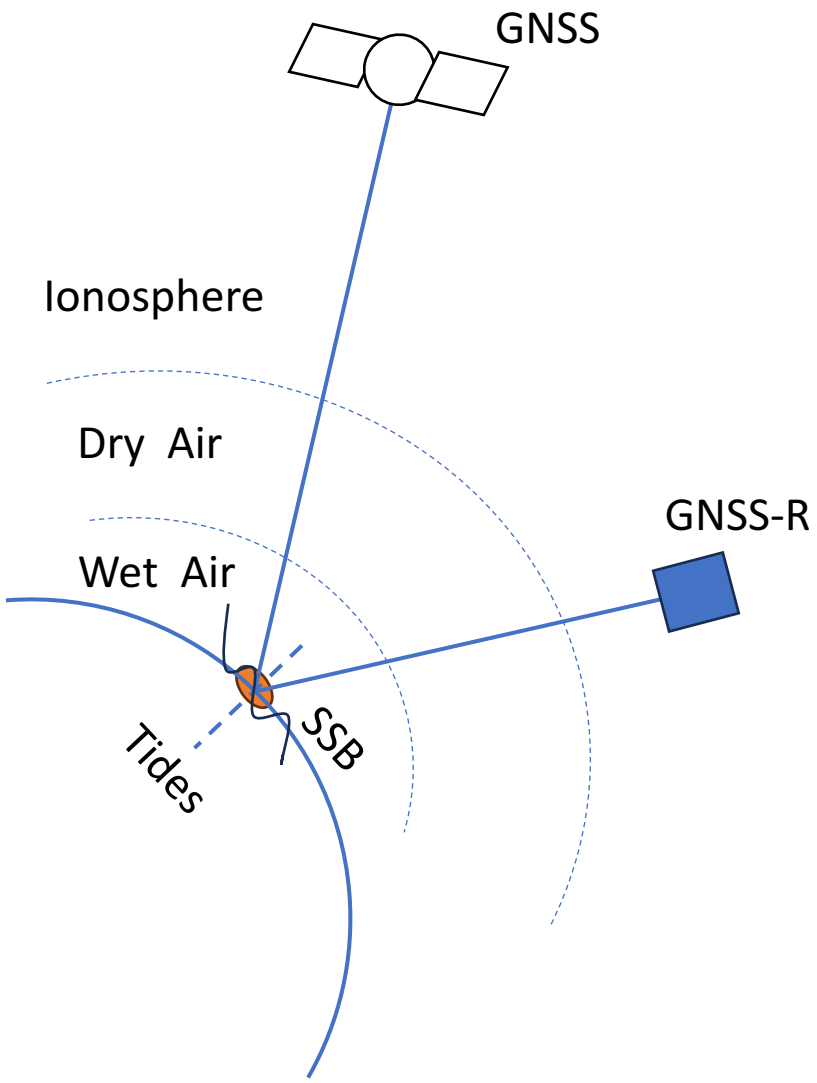
Ionosphere: L-band dual-frequency

Sea state bias: waveform derived sea surface roughness

Slant delays of Dry atmosphere and wet atmosphere.

Sea surface corrections:

Dynamic Inversive Bar (DIB), Pole tide, sea tide, and solid tide.



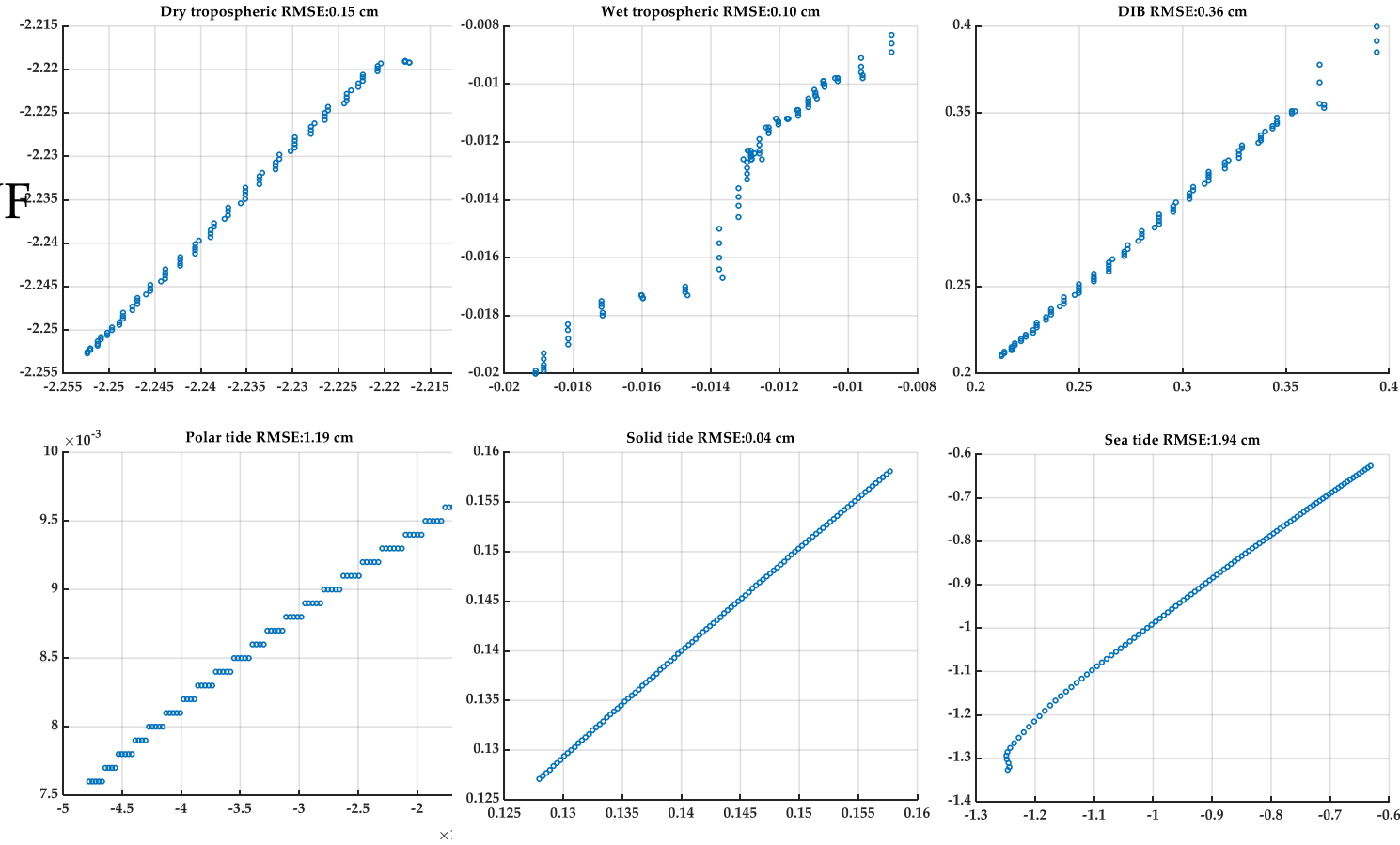
# Sea Surface Height Measurements - Corrections

- Validation data: Sentinel-3 (SRAL)

Troposphere: Saastamoinen & ECMWF
Sea Tide Correction: EXPO9
Polar Tide Correction: IERS
DIB Correction:

$$\rho_{bar} = -\frac{1}{\rho_w g}\left(p_a - \bar{p}_a\right) = -0.9948\left(p_a - \bar{p}_a\right)$$

Solod Tide Correction:
Munk&Cartwright (1966)



# the results after 3 years of activity
# BF-1 Sea Surface Wind Retrieval by ML

# Results after 3 Years of Activity

## Sea Surface Winds by Machine Learning (ML)

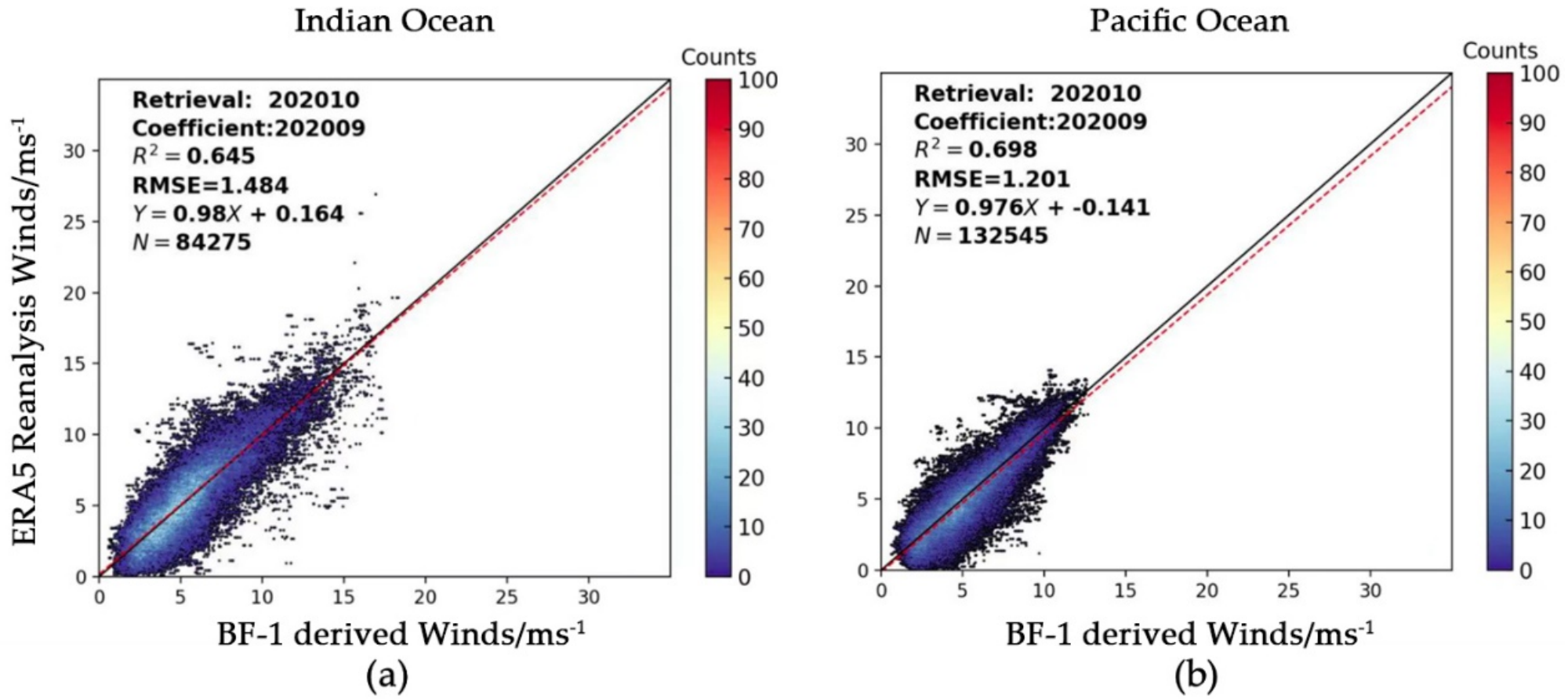
High-performance computing cluster by CMA NSMC (BF-1 Client)

- open-source autoML framework named AutoGluon
- DDM observable is the NBRCS
- Data time: September and October, 2020
- Validation set: ECMWF ERA5 reanalysis

| Input for Training | Wind speed retrieval | Result |
|---|---|---|
| NWP forecast windspeed | NWP forecast windspeed | Derived sea surface wind speed |
| Specular point latitude | Specular point latitude | |
| Specular point longitude | Specular point longitude | |
| Incident angle | Incident angle | |
| Receiver latitude | Receiver latitude | |
| Receiver longitude | Receiver longitude | |
| DDM SNR | DDM SNR | |
| NBRCS | NBRCS | |
| ERA5 reanalysis windspeed | | |

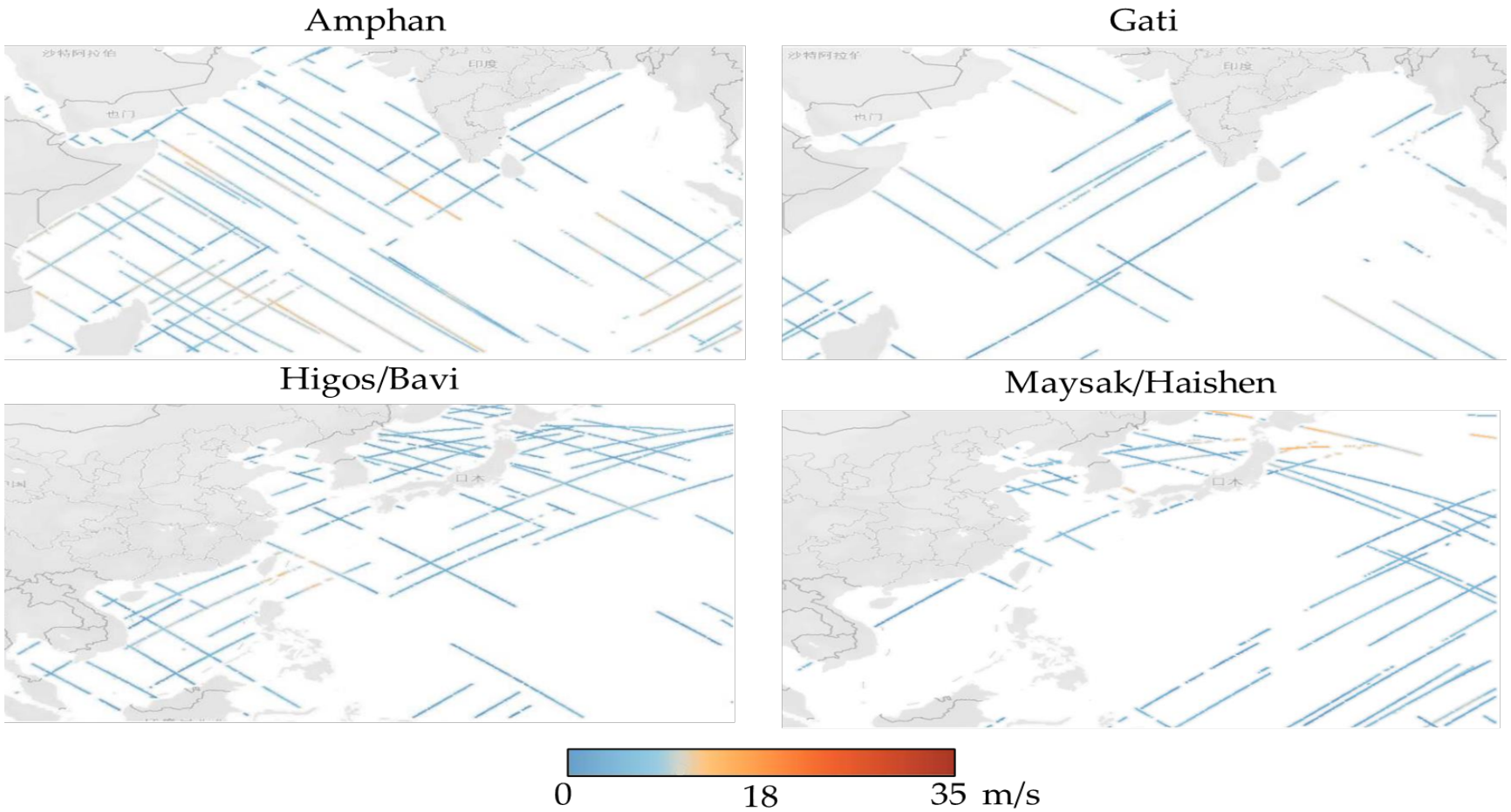
Lu, F., et al. (2023). BF-1 GNSS-R Sea Surface Wind Speed Retrieval and Observing Experiments. the proceeding of 16th international wind workshop, Montreal, Canada.

# Sea Surface Winds by Machine Learning （ML） Results




Lu, F., et al. (2023). BF-1 GNSS-R Sea Surface Wind Speed Retrieval and Observing Experiments. the proceeding of 16th international wind workshop, Montreal, Canada.

# Sea Surface Winds by Machine Learning（ML）Model Rerun for Typhoon/Hurricane




Lu, F., et al. (2023). BF-1 GNSS-R Sea Surface Wind Speed Retrieval and Observing Experiments. the proceeding of 16th international wind workshop, Montreal, Canada.

# the results after 3 years of activity
# BF-1 Sea Surface Wind under Hurricane Condition

# Results after 3 Years of Activity

## Sea Surface Winds by GMF for Typhoon/Hurricane

Model function building with NOAA SFMR

- DDM observable is the NBRCS
- Wind range: 0.4 – 69.3 m/s
- Aligned pairs: 5,708
- QC: SNR>2
- R=0.78

Also follow the power function (y=Axb+c)
Using the average of different elevation bins

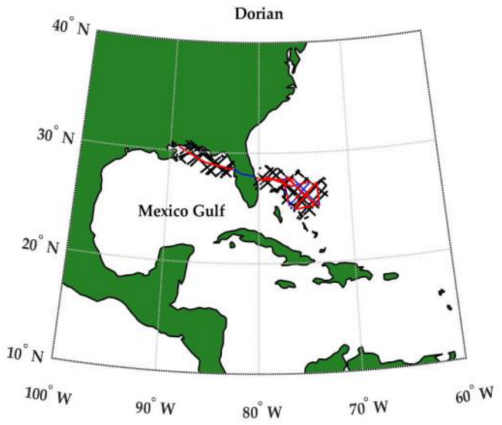



**Table 1.** NOAA Hurricane Season Data 2019

| Name | Date | Volume |
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| Dorian | 8/26-9/6 | 35 |
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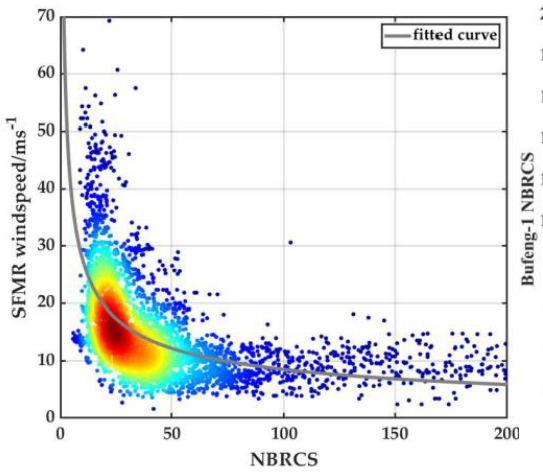
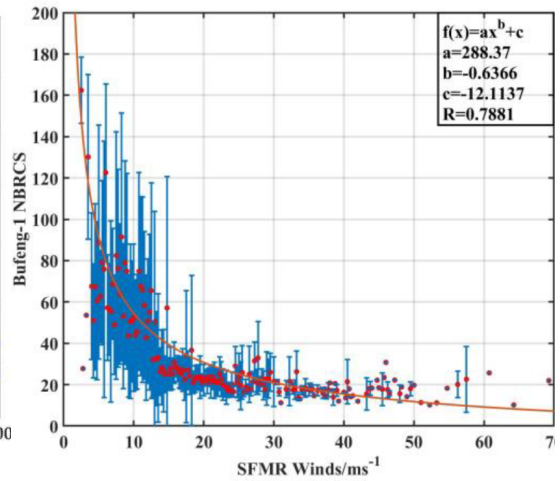
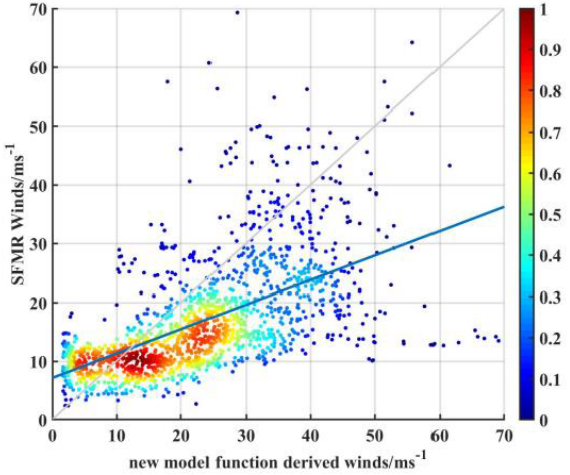



Jing, C., et al. (2021). GNSS-R from the Bufeng-1 twin satellites for sea surface winds under hurricane condition. 2021 IEEE International Geoscience and Remote Sensing Symposium IGARSS, IEEE.

**the results after 3 years of activity**
**BF-1 Land Surface Soil Moisture**

# Results after 3 Years of Activity

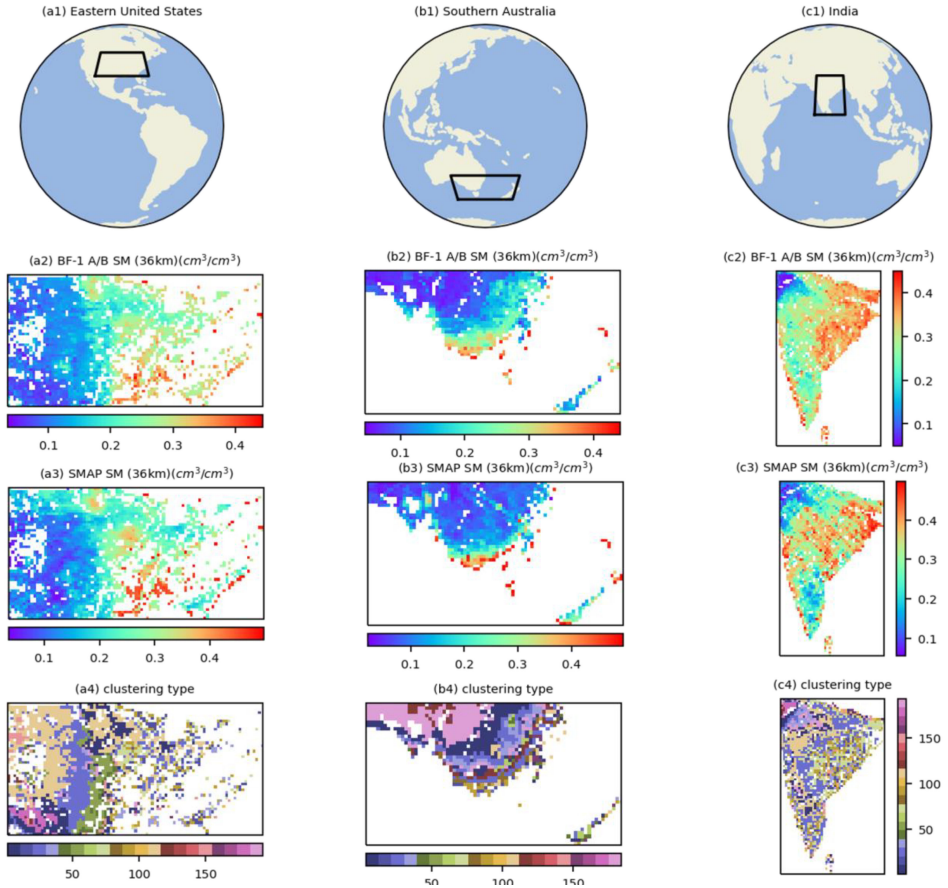
## Inland Soil Moisture
## By Land Surface Clustering Algorithm(LSC)

The LSC algorithm is developed by PKU

- DDM observable is equivalent specular reflectivity
- Study area: Eastern United States, Southern Australia, and India
- Aligned data: ISMN sites, SMAP
- Performances:

SMAP vs BF-1: ubRMSE=0.07 cm3/cm3, R=0.82

ISMN sites vs BF-1: ubRMSE=0.036 cm3/cm3



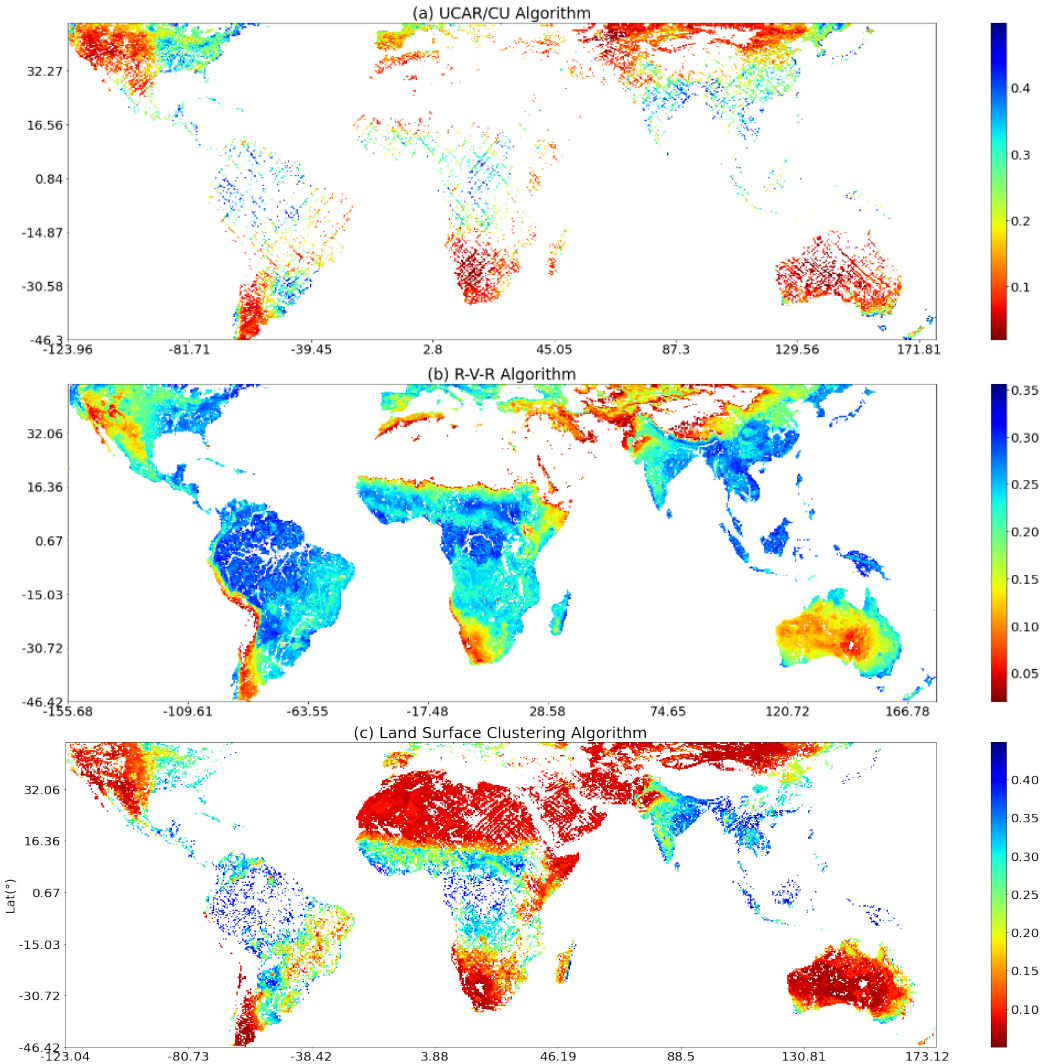


Guo, Z., et al. (2022). "Soil moisture retrieval using BuFeng-1 A/B based on land surface clustering algorithm." IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing **15: 4680-4689.**

Wan, W., et al. (2021). "Initial evaluation of the first chinese GNSS-R mission BuFeng-1 A/B for soil moisture estimation." IEEE Geoscience and Remote Sensing Letters **19: 1-5.**

# Results after 3 Years of Activity

## Comparison of the performances of SM retrieval algorithms




**UCAR/CU products**
**ubRMSE=0.057 $cm^3/cm^3$, R=0.86**
**Available SM area percentage(%) = 17.06**

**RVR( the reflectivity–vegetation–roughness)**
**ubRMSE=0.09 $cm^3/cm^3$, R=0.69**
**Available SM area percentage(%) = 47.38**

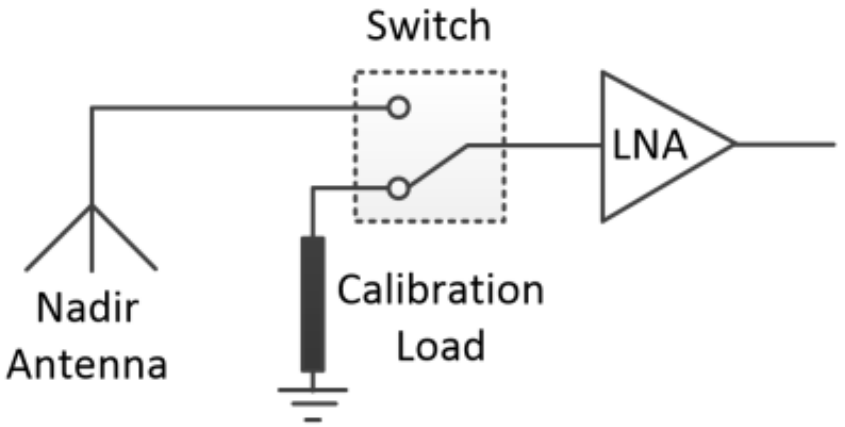
**PKU algorithm**
**ubRMSE=0.07 $cm^3/cm^3$, R=0.82**
**Available SM area percentage(%) = 35.63**

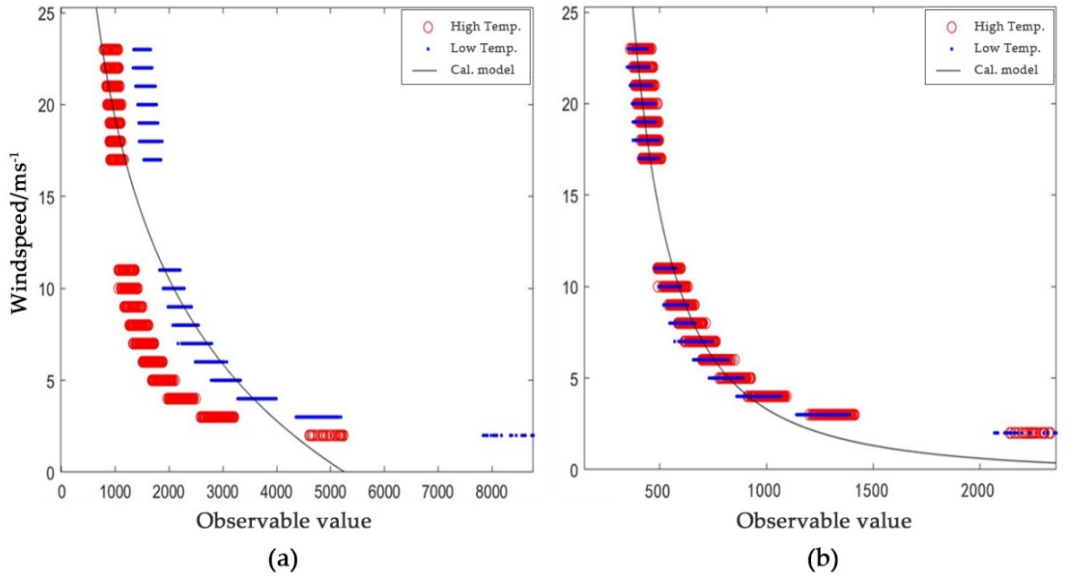

Guo, Z., et al. (2022). "Soil moisture retrieval using BuFeng-1 A/B based on land surface clustering algorithm." IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing **15: 4680-4689.**

# the results after 3 years of activity
# BF-1 Calibration and Validation

## BF-1 Power Calibration

- power DDM collected by BF-1 GNSS-R instruments
- noise DDM output by blackbody payload every minute
- Low Noise Amplifier (LNA) instrument is easily affected by ambient temperatures.
- Calibration by a Power function




Wan, B., et al. (2020). Calibration and error analysis of the BF-1 demonstration GNSS-R satellites. China Satellite Navigation Conference, Springer.

# Schedule, Planning & Contribution

## SCHEDULE & PLANNING:

- Phase 1: Preparation: Kick Off (KO) - KO+18
- Phase 2: Data Acquisition: KO - KO+42
- Phase 3: Calibration and validation: KO + 6 - KO + 48
- Midterm Theme Workshop 2022
- Phase 4: Showcases KO +32 - KO+48
- Phase 5: Integration KO +42 - KO+48
- Final Theme Workshop 2024
- Final project reporting

## FUTURE CONTRIBUTIONS & PUBLICATION

- Ground observation for BDS EIRP and auto-correlation functions
- Preparing the data sharing to the GNSS-R community
- The instruments, high gain antennas and high rate receivers, are designed and developing for future ground validation experiments.
- The simulations of spaceborne GNSS-R bistatic waveforms and DDMs has been developed for ongoing and future space missions.
- Experiments of GNSS-SAR and airborne GNSS-R are expected in the next year.
- A review paper has been submitted to GSIS: A Review of The BuFeng-1 GNSS-R Mission: Calibration and Validation Results of Sea Surface and Land Surface

# YOUNG SCIENTISTS CONTRIBUTIONS

# Results after 3 Years of Activity

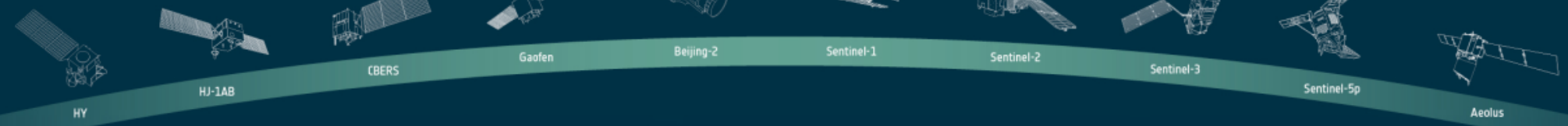
**European Young scientists :**

*Dr. Yang Nan* received the B.S. degree and M.S. degree in geomatics from Chang'an University, Xi'an, China, in 2012 and 2017 respectively. After Since 2019, He has studied at the Earth Observation Research Group, Institute of Space Sciences (ICE), Spanish National Research Council (CSIC), Institut d'Estudis Espacials de Catalunya (IEEC), Barcelona, Spain as a PhD students. He has been involved in Spaceborne GNSS-R retrieve wind field. Now he is a teacher of Tianjin Universiy.

**Chinese Young scientists :**

*Dr. Baojian Liu has* received his Ph.D. degree in photogrammetry and remote sensing at Peking University. His research activity includes using spaceborne GNSS-R data and SMOS data to retrieve ocean salinity. Now he is a teacher of Beijing Forestry University.

*Mr. Zhizhou Guo* is pursuing his Ph.D. degree in photogrammetry and remote sensing at Peking University. His research activity includes using spaceborne GNSS-R data to retrieve soil moisture content.




# Thanks for your attention