A Review of the GNSS-R Wind Product from the Chinese Fengyun-3 Constellation

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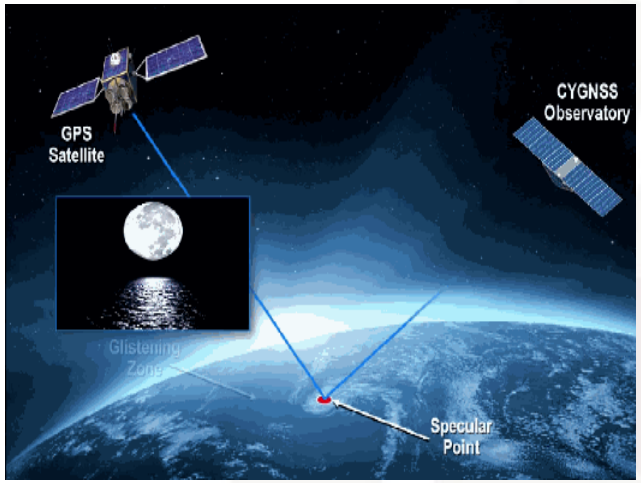
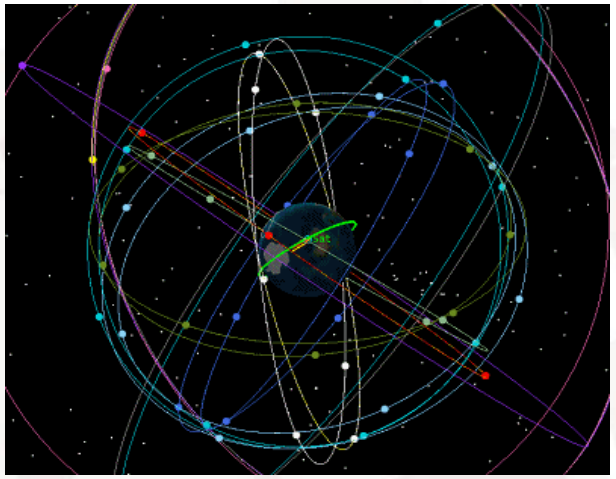
Outline

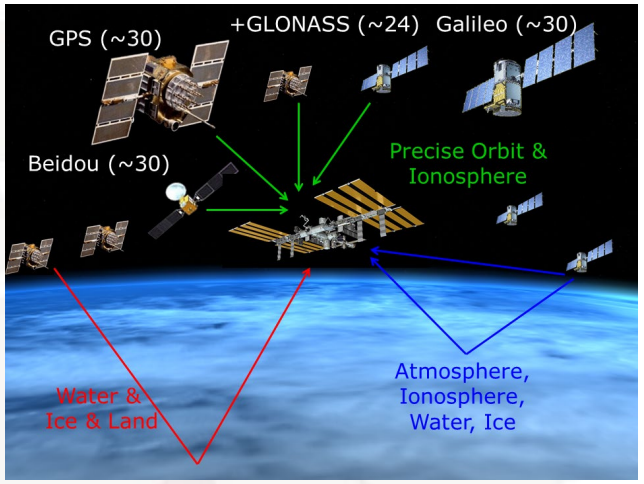
1. Mission overview
2. Calibration and wind speed retrieval
3. Cyclone wind product
4. Conclusions and Future Perspective

Mission Overview

GNSS-Reflectometry (GNSS-R): Use the reflected signals from global navigation satellites to measure the Earth surface in a bistatic configuration







Features:

- L-band forward quasi-specular reflection – sensitive to mean square slope (both wind and swell)
- Abundant signal sources
- Passive sensor, low cost/size/weight
- High spatial/temporal samplings from a constellation
- L-band signal, not affected by rains
- Provide precise positioning and timing information for the whole platform like a conventional GPS receiver

Limitations:

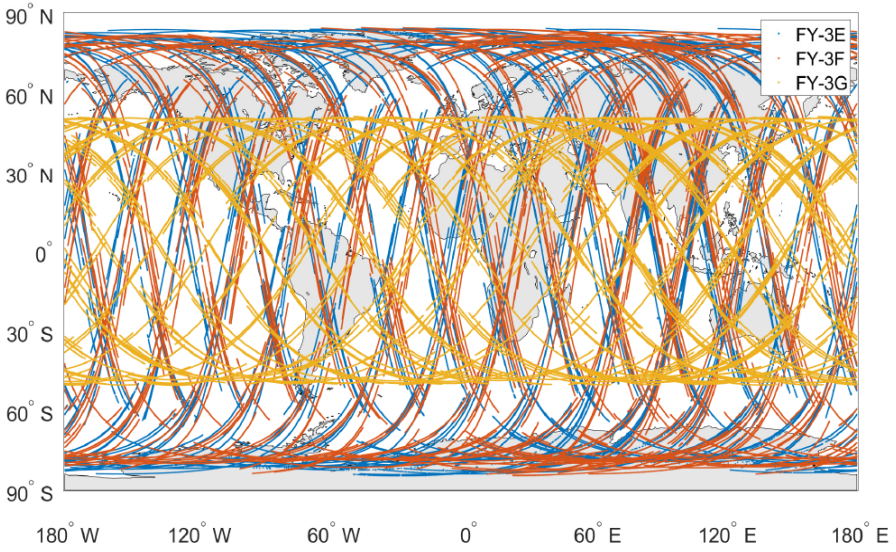
- Difficult to calibrate – the transmitter varies and we know little information about them
- SNR decreases at high wind speeds
- Gaps between observation tracks - not good to resolve TC structures

Mission overview

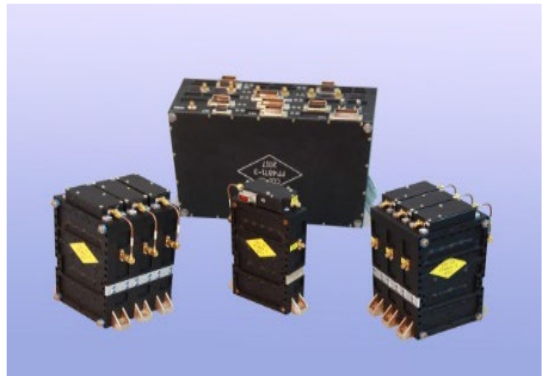
- **FengYun-3 GNSS-R Constellation**

	FY-3E	FY-3F	FY-3G
Launch date	2021-07-05	2023-08-03	2023-04-16
Altitude (km)	836	836	407
Inclination angle (°)	98.5	98.5	50
Descending Time	5:40	10:00	Drifting

Coverage of FY-3E/F/G in one day



The GNOS-II GNSS remote sensing payload



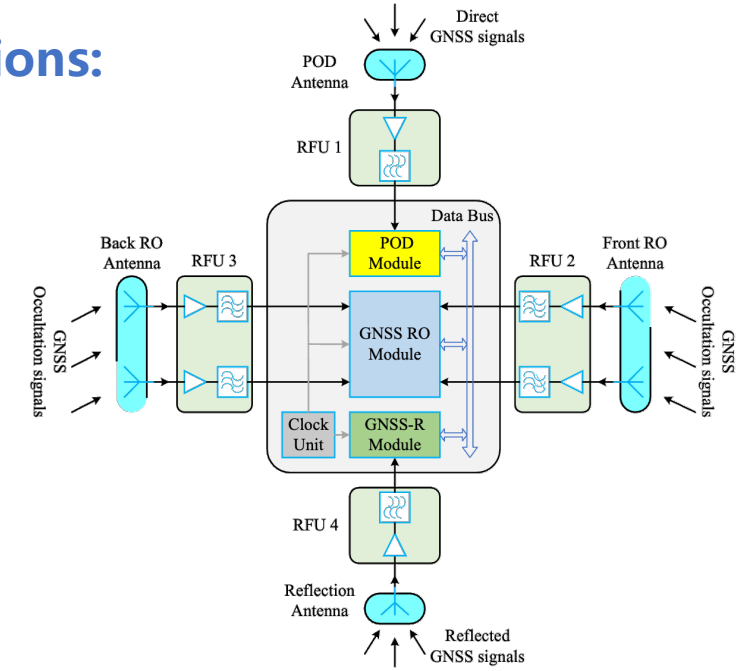
Mission overview

Major advancements of FY-3 compared to previous GNSS-R missions:

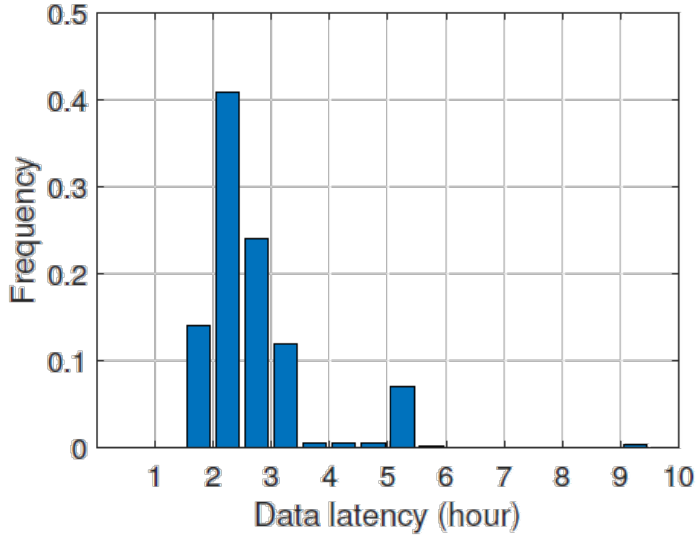
- Combination of GNSS-R and GNSS RO
- Receive signals from multiple GNSS systems (GPS, BeiDou and Galileo)
- Combination of polar orbit and low inclination orbit
- Big satellites with better attitude and temperature control

(compared to small satellites)

- Operational missions with average data latency less than 3 hours
- Work together with a scatterometer on FY-3E



Distribution of data latency



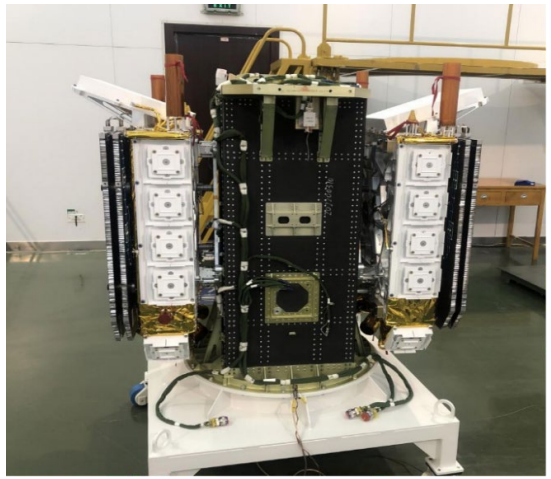
Number of nadir antenna	1
Number of reflection channels	8
GNSS frequency	GPS L1C/A, BeiDou B1I and Galileo E1B
Reflection antenna peak gain	15 dBi
Sampling frequency	1 Hz
DDM dimensions	122 delays 20 Dopplers

Mission overview

- “Tianmu”(天目) Constellation（2023）

Now 10 small satellites on-orbit（520km, SSO）

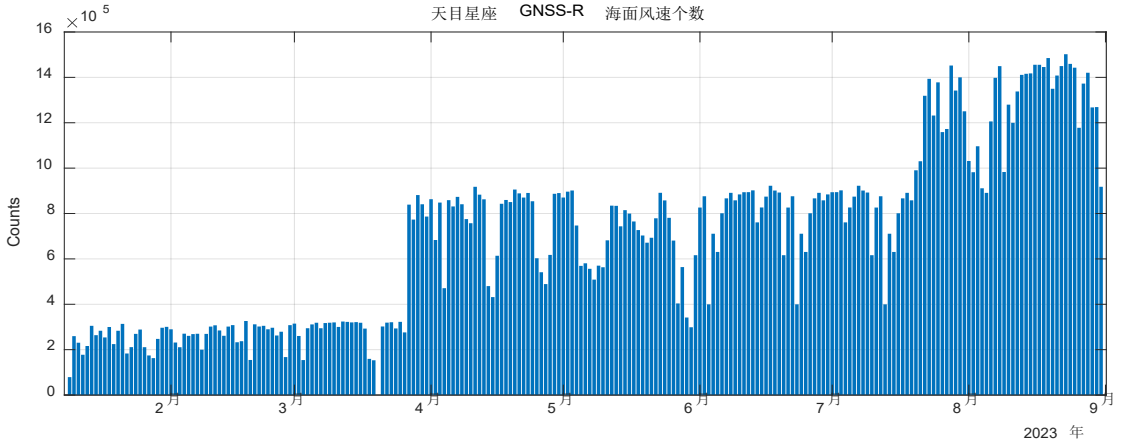
2023/01/09	TM01-02
2023/03/22	TM03-06
2023/07/20	TM07-10
2023/12	TM11-22

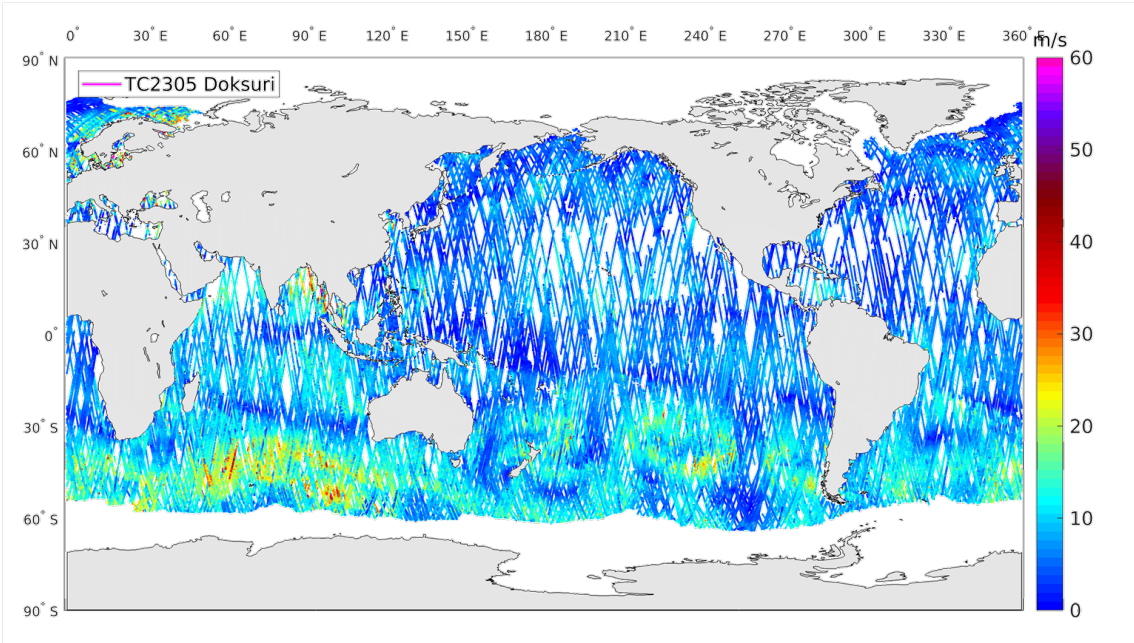


50 kg,70 W, 820×420×1065 (In-folder)

The instrument and technology are almost the same as FY-3

Number of wind speeds per day

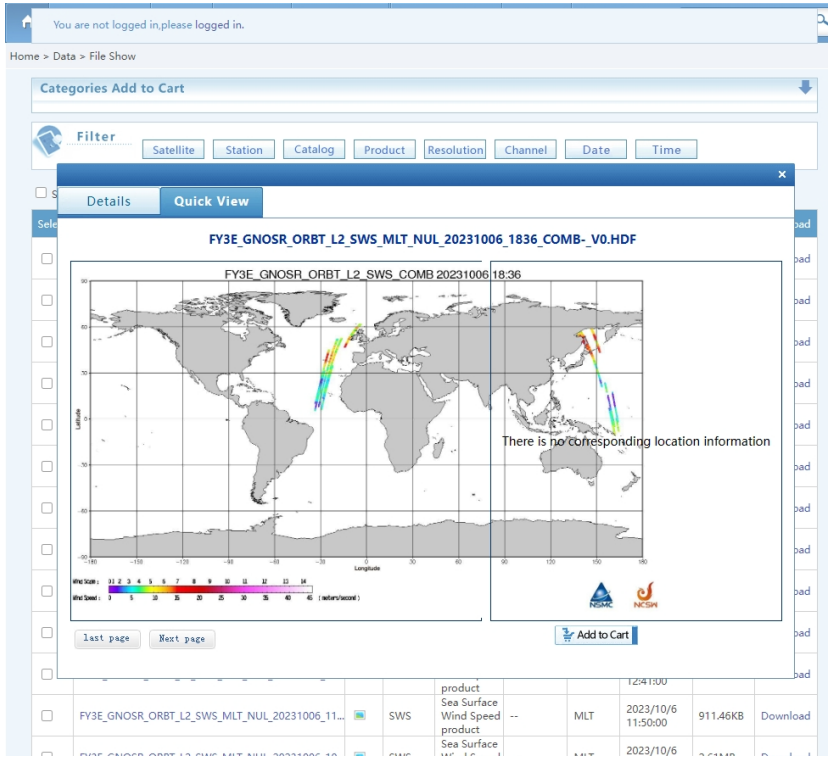




Mission overview

GNSS-R product and key variables:

Product	Description
L1 product	Delay-doppler maps (DDMs) geometry parameters, observables, antenna gain and SNR
L2 wind product	Ocean surface winds, mean square slope, smoothed observables and spatial resolution
L2 soil moisture product	Land reflectivity, soil moisture, spatial resolution and ancillary data
Raw IF product	Raw IF sampling data, GNSS PRN code, and collection time



Raw IF product: 12 geographical illumination targets deployed for each satellite to trigger raw sampling mode for scientific research including:

Coast winds, RFI, phase altimetry, river detection, .etc.

FY-3E GNSS-R L1 and L2 wind data can be download at FengYun Satellite Data Center: http://data.nsmc.org.cn/portalsite/default.aspx?currentculture=en-US

Outline

Calibration and Wind Speed Retrieval

Calibration and wind speed retrieval

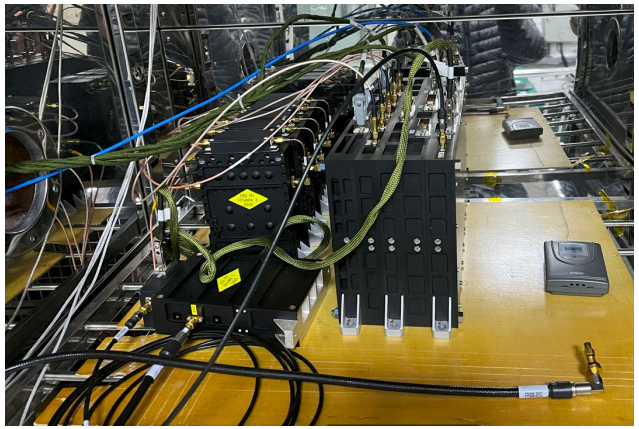
- **Calibration of the instrument gain**

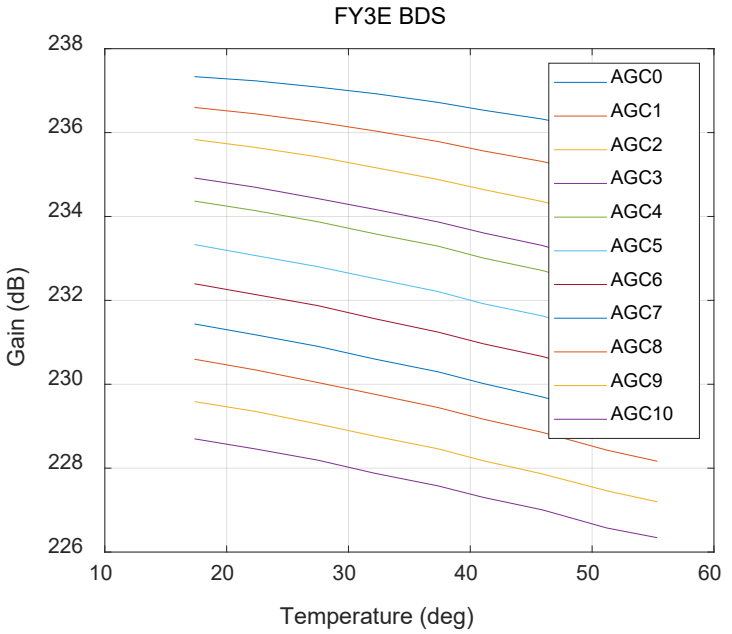
$$P(\tau, f) = GC_r(\tau, f)$$

Power

Receiver raw digital count

Prelaunch thermal cycling experiment





Calibration and wind speed retrieval

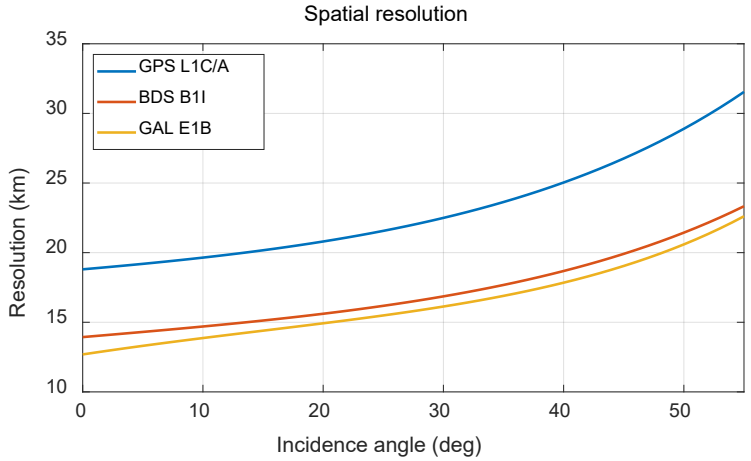
Calibration of normalized bistatic radar cross section (NBRCS)

NBRCS power GNSS EIRP Antenna pattern Scattering area

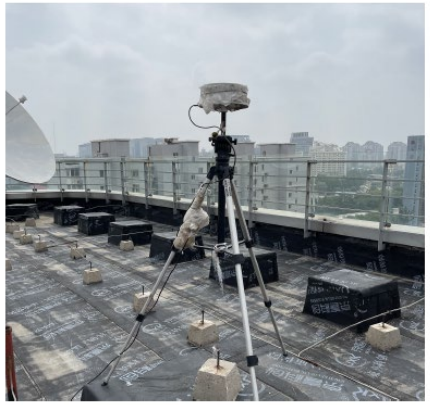
$$\sigma^0 = \bar{P}_{sp}\left(\frac{\lambda^2 P_t G_t G_r}{(4\pi)^3 R_t^2 R_r^2}\right)^{-1} \bar{A}^{+1}$$

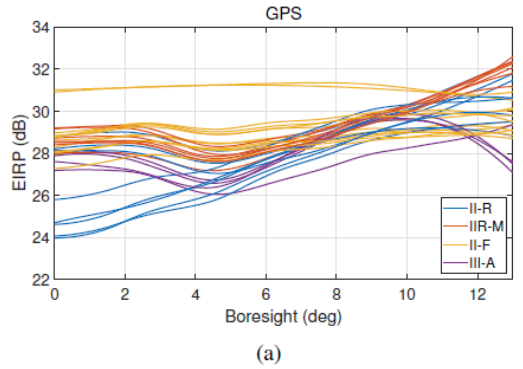
$$A_{\tau,f} = \iint_A \Lambda^2_{\tau,x,y} S^2_{f,x,y} dxdy$$

Spatial resolution/Scattering area: GPS>BDS>GAL



EIRP profiles of all GNSS satellites are measured by a static power monitor





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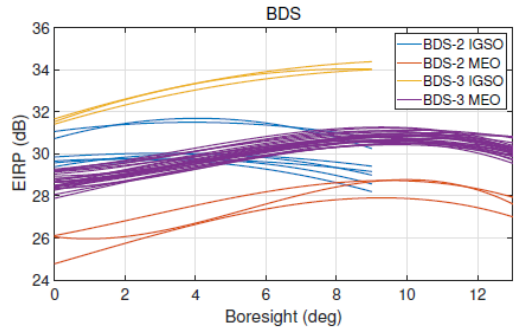

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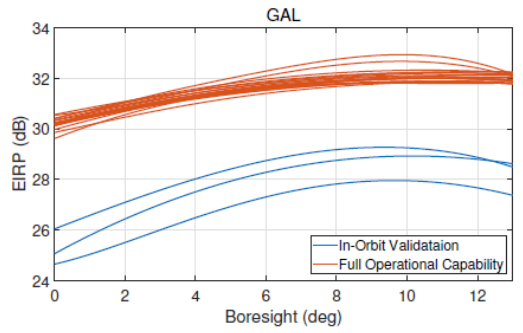


(c)

Calibration and wind speed retrieval

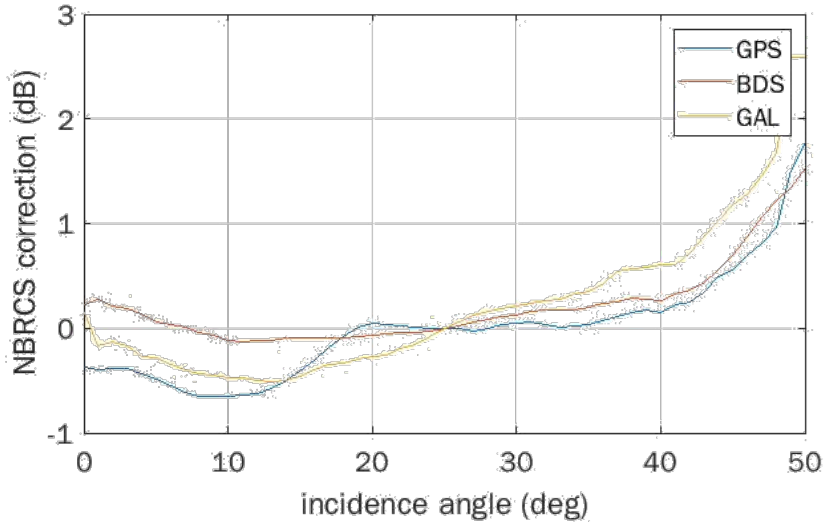
In-orbit ocean calibration by incidence and azimuth angle:

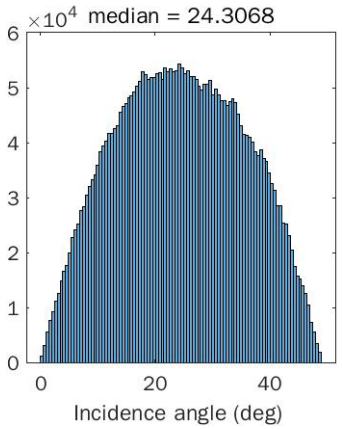
Reference inc angle: 25°

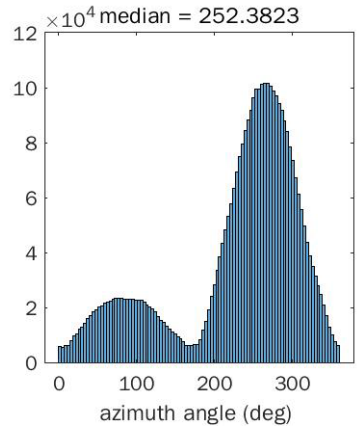
Reference azimuth angle: 90/180/270 °

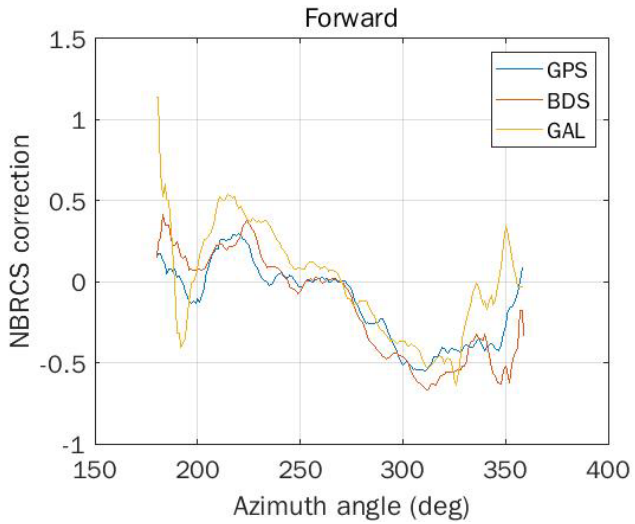
(depending on the antenna pointing direction)

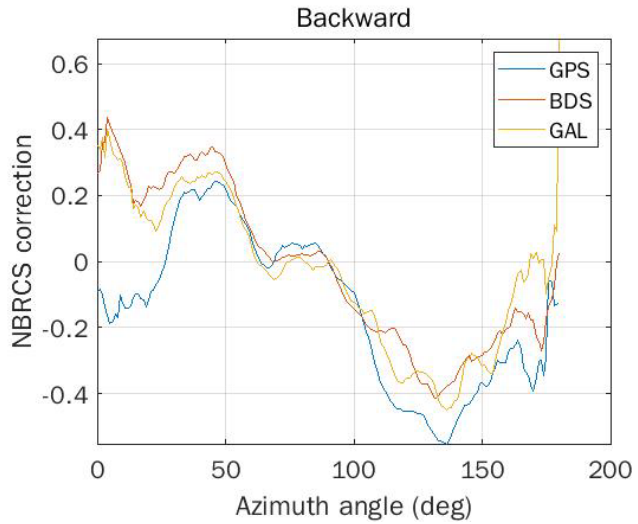
To remove calibration errors such as EIRP, antenna patterns…







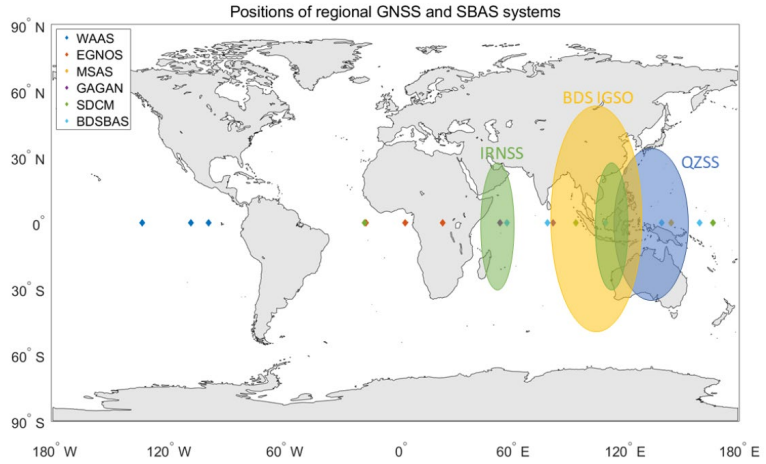


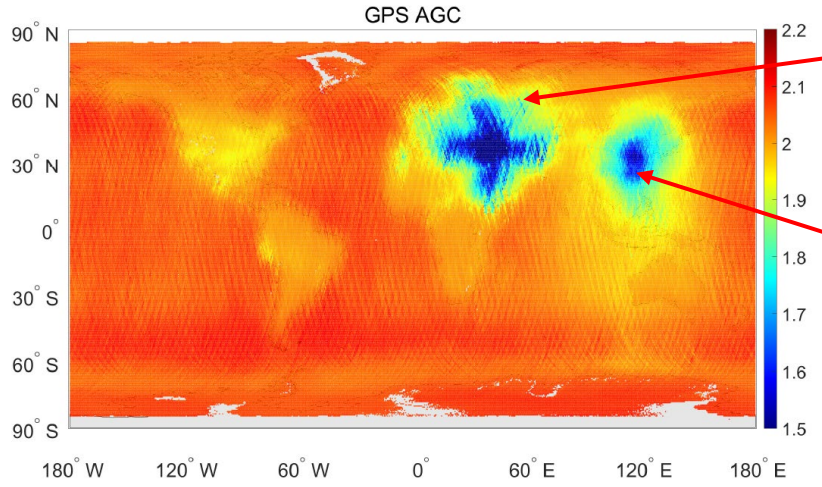


Calibration and wind speed retrieval

Correction for radio frequency interference based onboard automatic gain control (AGC):

GNSS SBAS systems





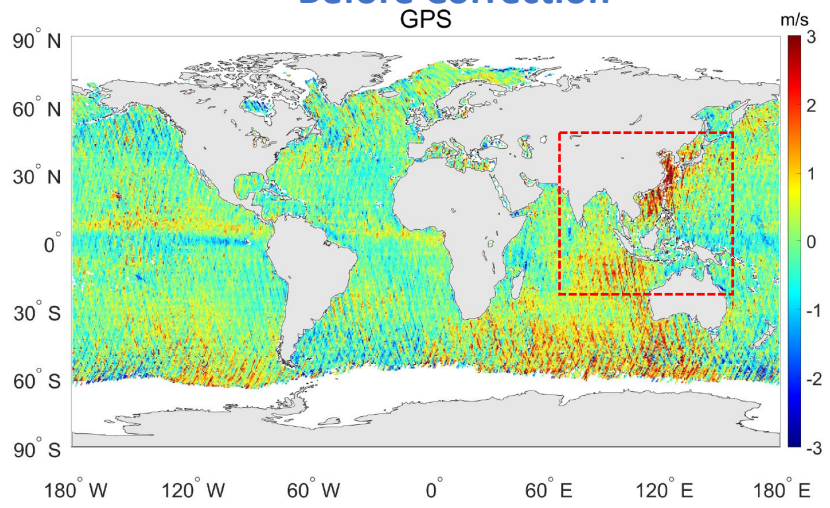
Ground GNSS jamming

L-band communication signals

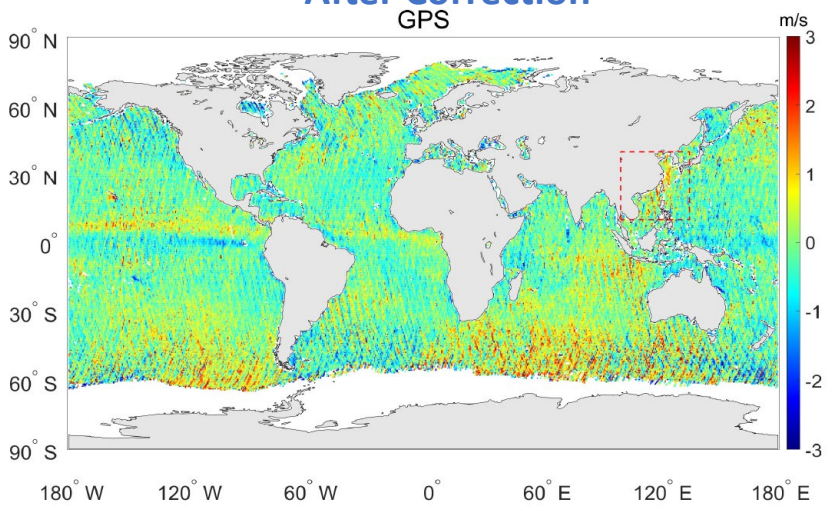
Huang, Feixiong, Cong Yin, Junming Xia, et al. "Analysis and Mitigation of Radio Frequency Interference in Spaceborne GNSS Ocean Reflectometry Data." ***IEEE Transactions on Geoscience and Remote Sensing*** (2023).

Global Wind speed bias

Before Correction



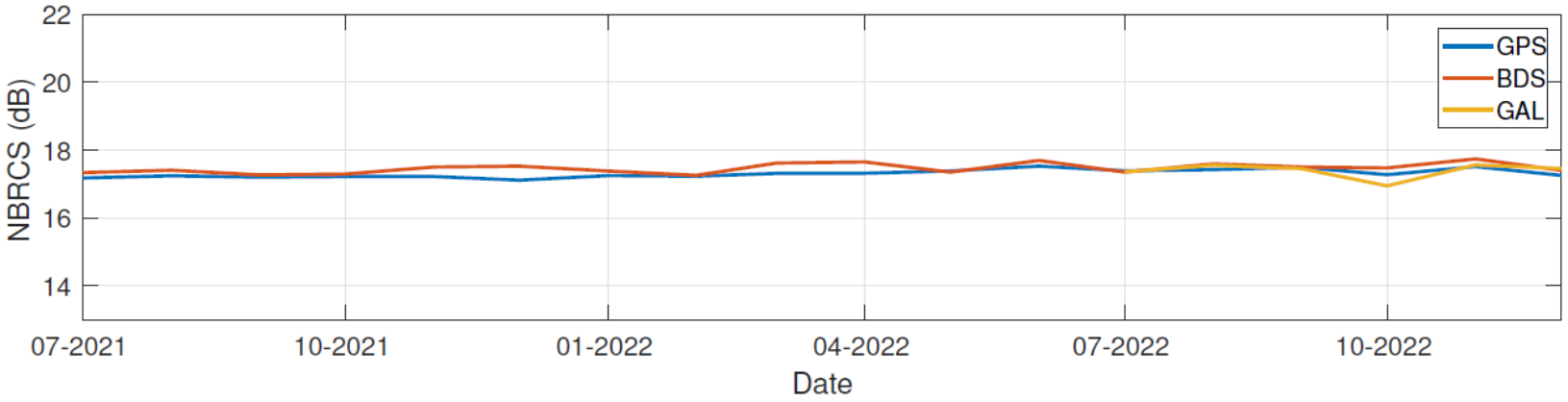
After Correction

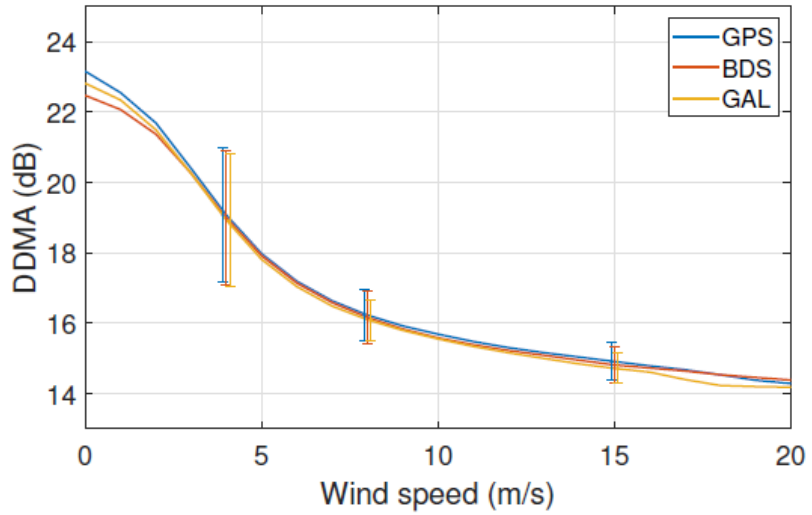


GNSS-R is a good tool to monitor L-band RFI!

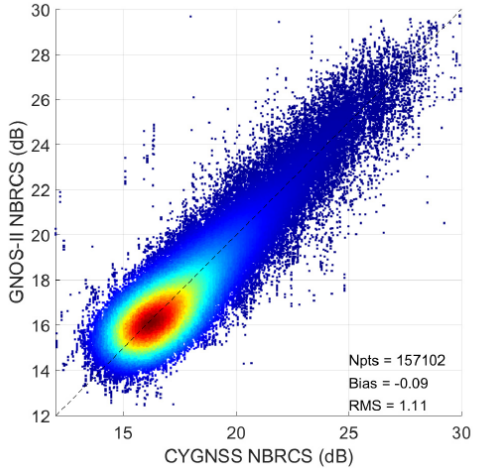
Calibration and wind speed retrieval

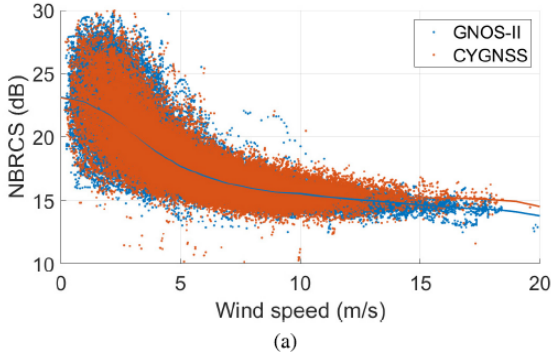
Intercalibration between GPS/BDS/GAL:





Consistent with US CYGNSS NBRCS





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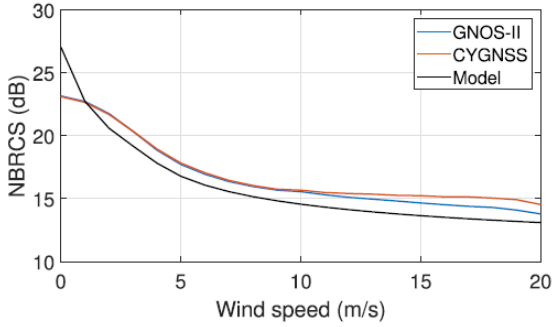


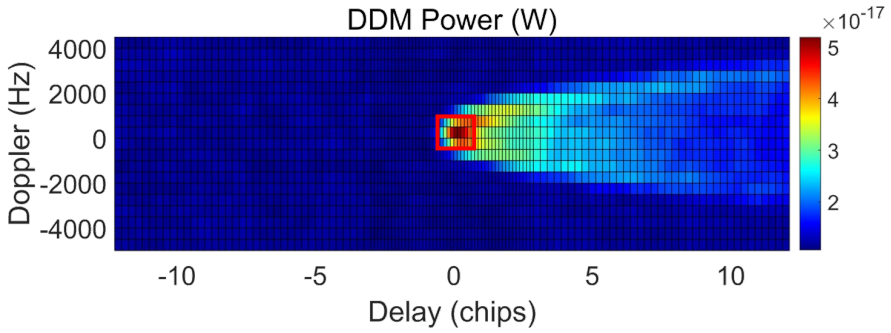
(b)

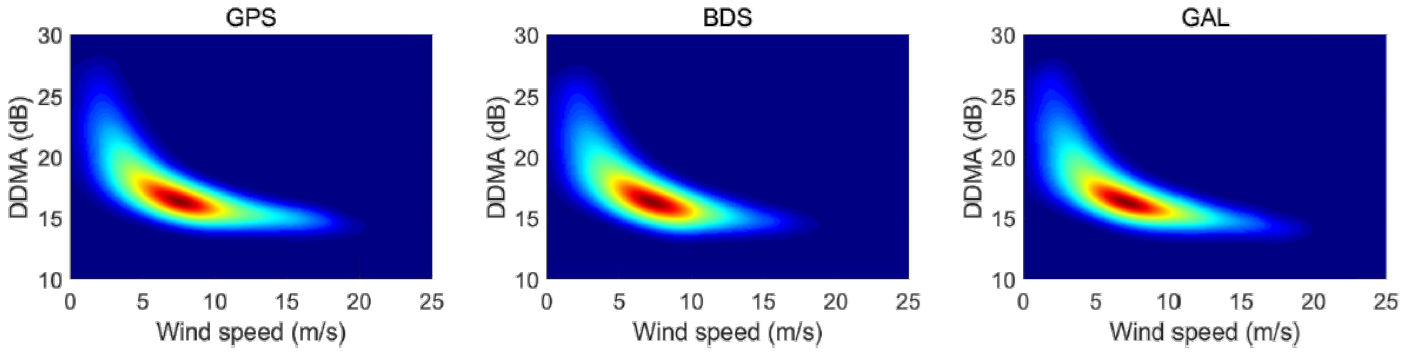
Huang, F., Xia, J., Yin, C., Bai, W., Sun, Y., Du, Q., ... & Duan, L. (2022). Characterization and Calibration of Spaceborne GNSS-R Observations Over the Ocean From Different BeiDou Satellite Types. *IEEE Transactions on Geoscience and Remote Sensing*, 60, 1-11.

Calibration and wind speed retrieval

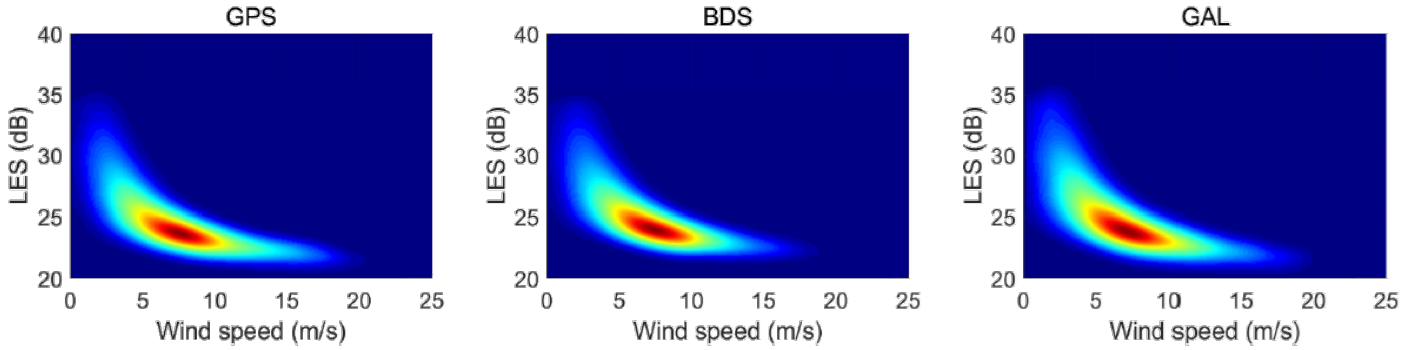
Two observables, DDMA and LES, are used to train GMF for wind speed retrieval

- Trained by collocated ECMWF ERA5 winds
- Wind speed retrieved by a minimum variance estimation
- Different GMF (actually almost same) for each GNSS system (GPS/BDS/GAL)





(a)

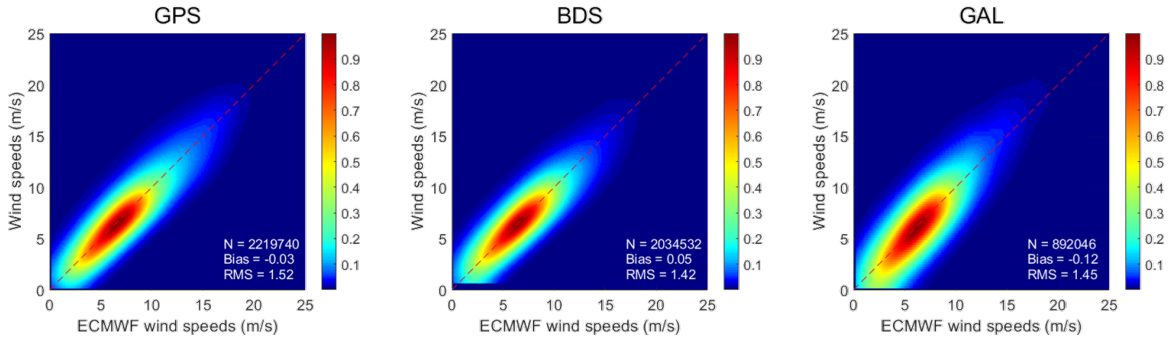


(b)

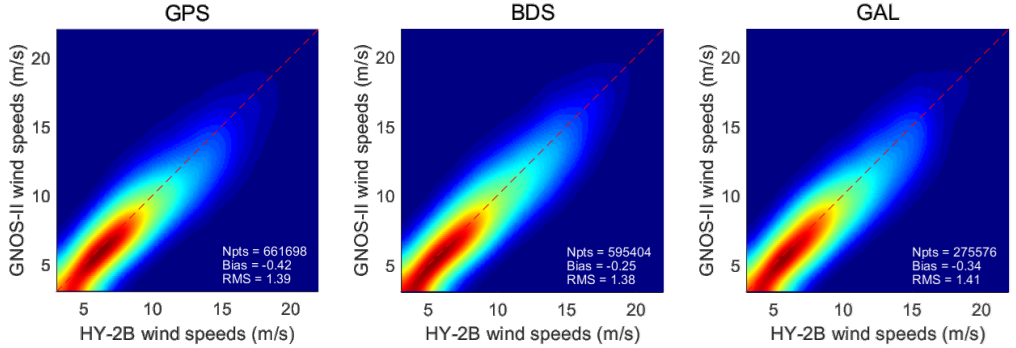
Calibration and wind speed retrieval

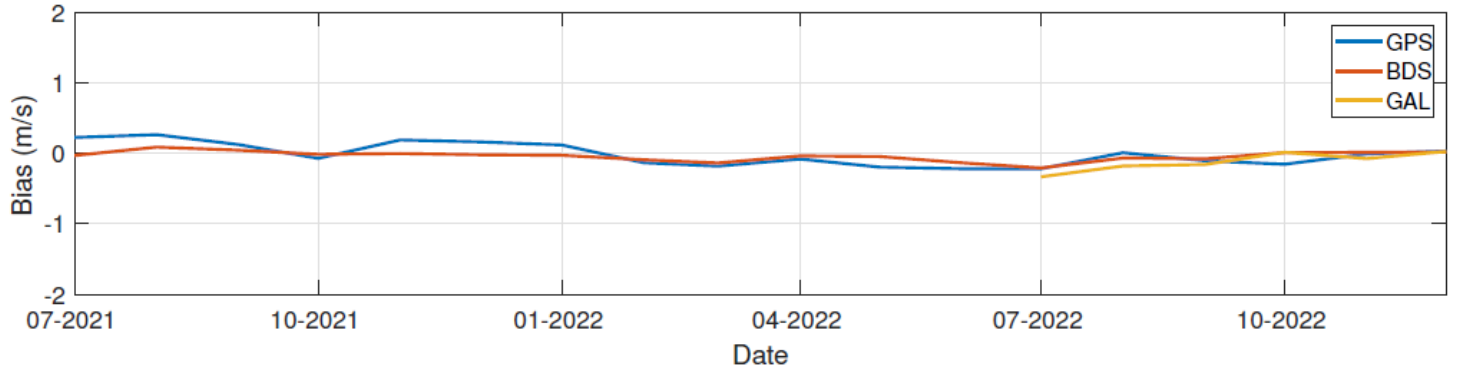
Wind speed retrieval statistics: (FY-3E during July 1 to August 31, 2022)
Overall RMSE ~1.4-1.5 m/s

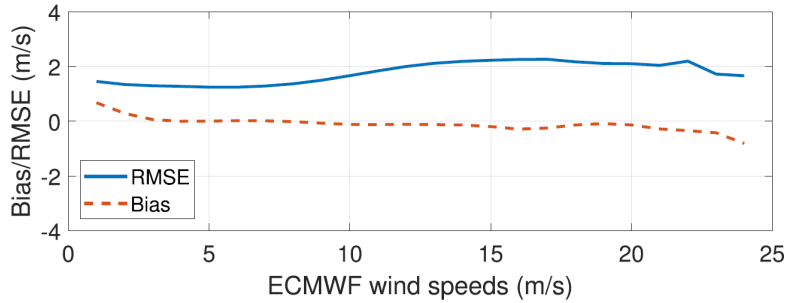
Compared to ECMWF ERA5:



Compared to HY-2B scatterometer:





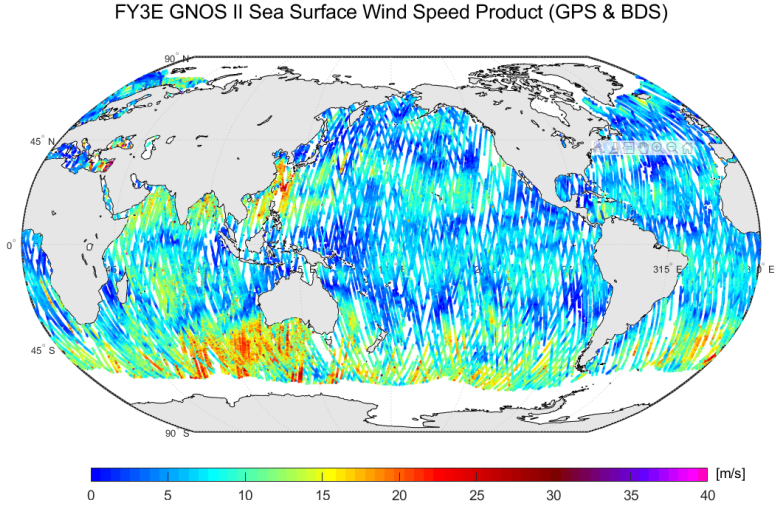


The GNSS-R wind speeds of FY-3E has been operationally assimilated into the CMA-GFS NWP system!

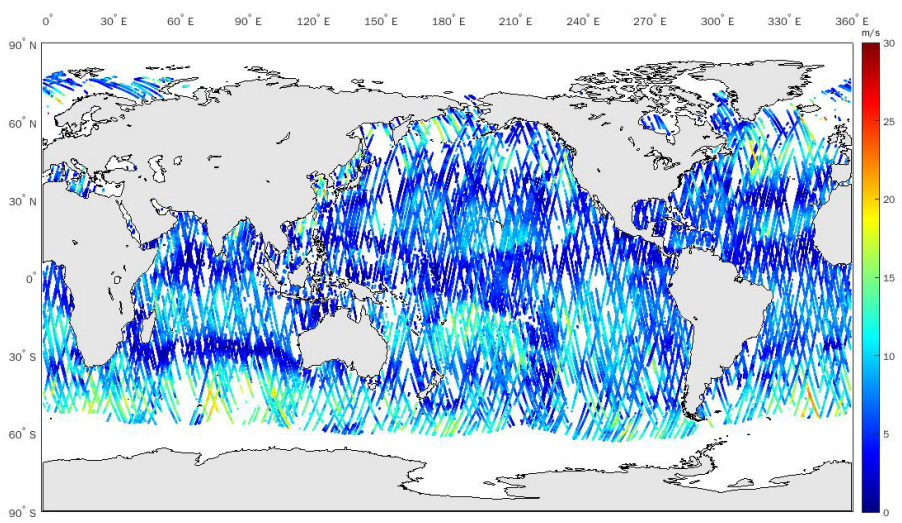
Calibration and wind speed retrieval

FY-3E/F/G wind speeds in 5 days:

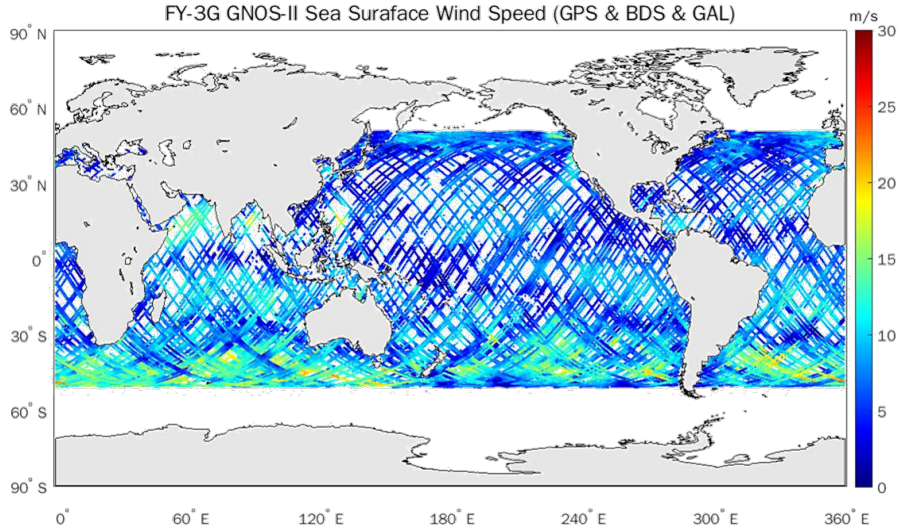
FY-3E



FY-3F

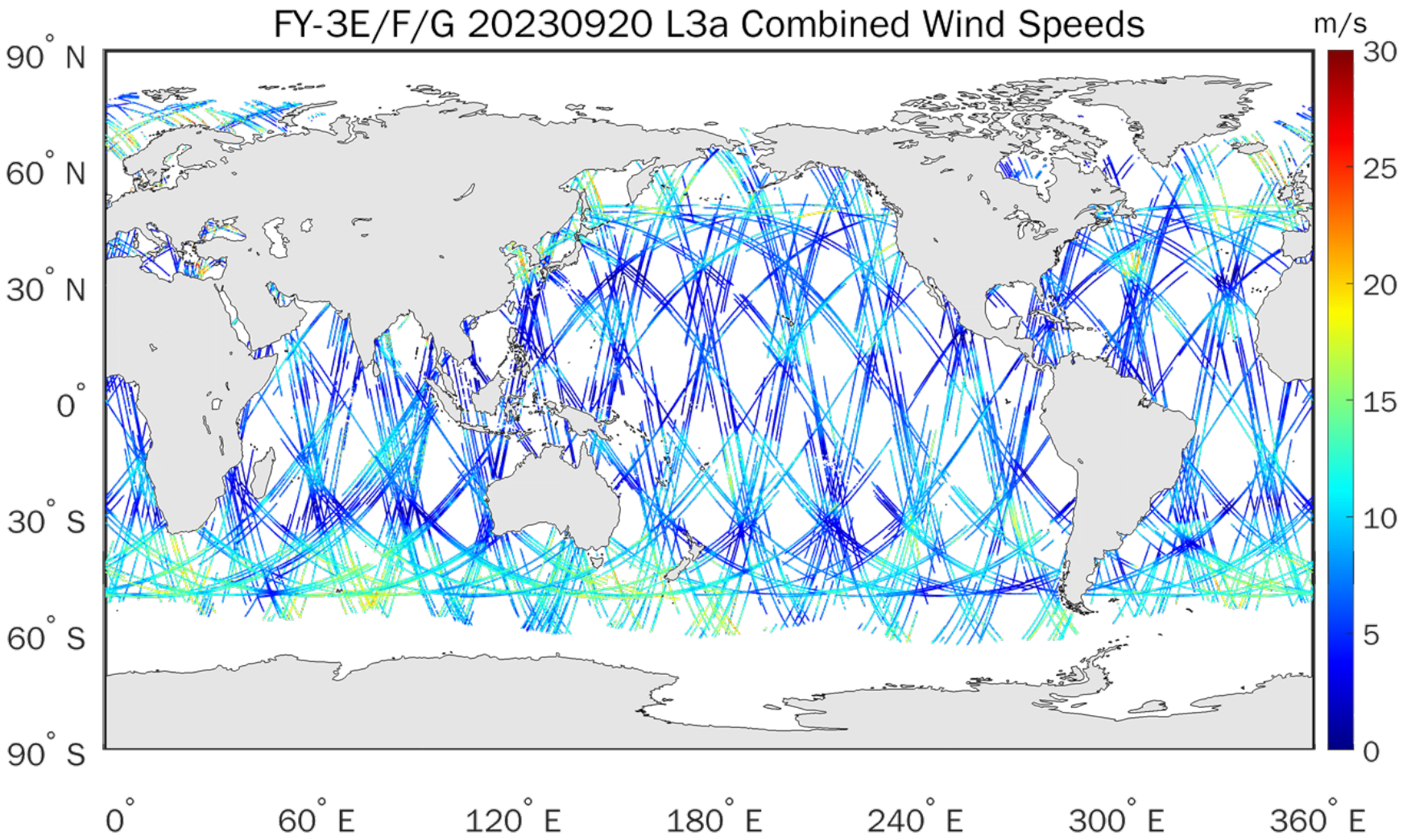


FY-3G



Calibration and wind speed retrieval

Combined FY-3E/F/G wind speeds in one day:



Outline

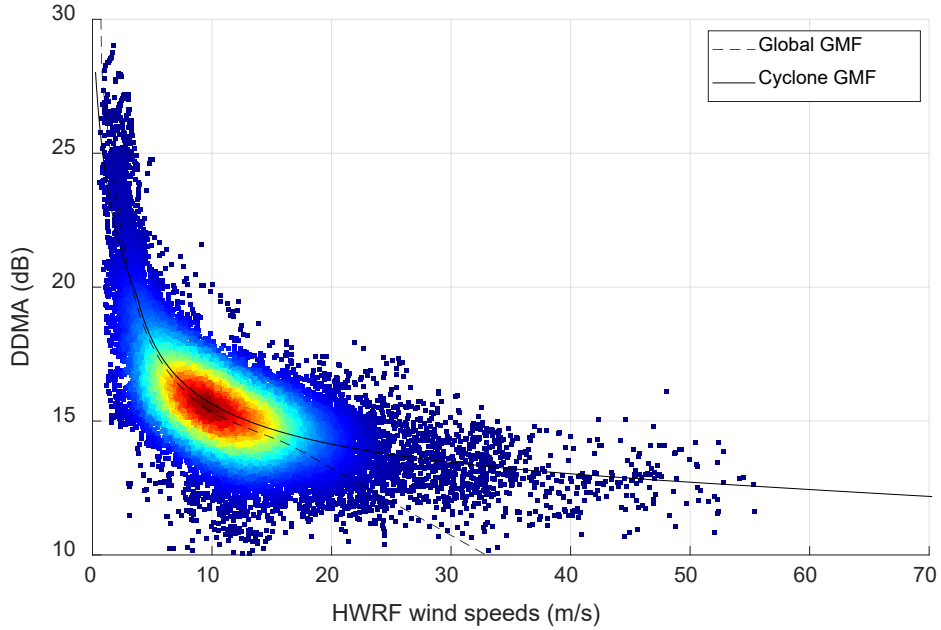
Cyclone Wind Product

Cyclone Wind Product

In the condition of tropical/extratropical cyclones, the sea state is different from normal cases (fully-developed sea vs. young sea with limited fetch)

- **Global wind product**
  - Highest accuracy for global low-to medium wind speeds (< 25 m/s)
  - GMF trained by ECMWF ERA5

- **Cyclone wind product**
  - Optimized for high wind speeds (up to 60 m/s) for tropical and extratropical cyclones
  - GMF trained by HWRF model winds (to obtain enough high wind speed collocations)
  - For cyclone monitoring, regional data assimilation and related studies



Release the two products at the same time, and let users to decide which one to use

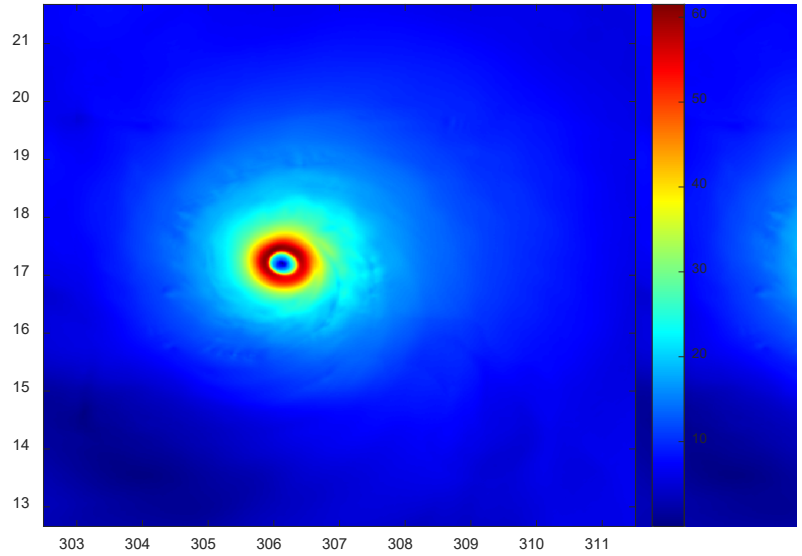
Cyclone Wind Product

HWRF (The Hurricane Weather Research and Forecasting) :

- US NOAA operational regional model specially for tropical cyclones, used by NHC and JTWC
- Assimilate SFMR winds in the Atlantic and East Pacific
- Provide reference winds for all TCs

- HWRF has products with different resolutions, we use 2km product and smooth it to 25km in the comparison

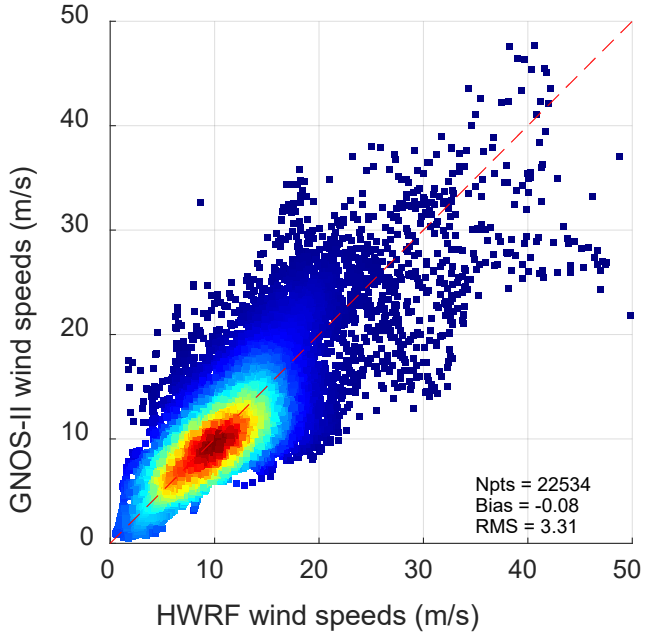
2km HWRF model winds



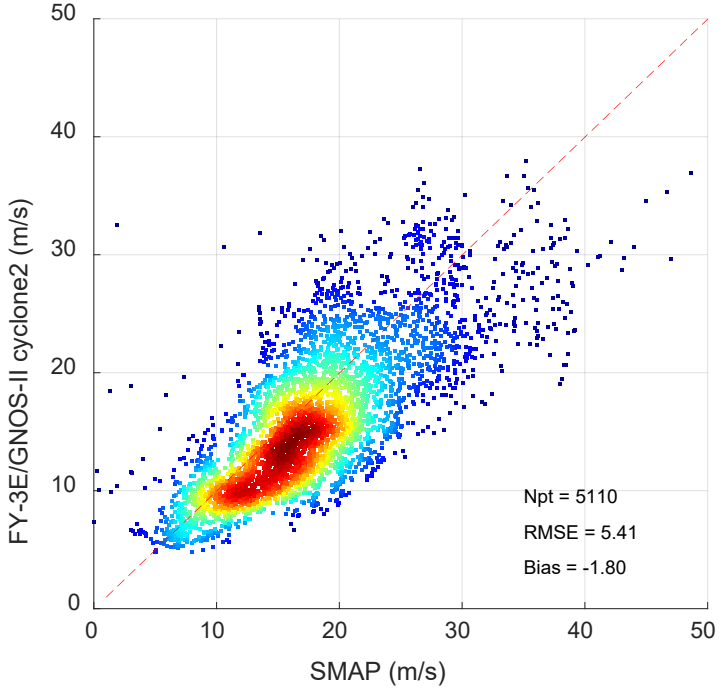
Cyclone Wind Product

- **Semi-empirical GMF was trained in a similar method**
- **Assessed by SMAP and HWRF winds**

Compared to HWRF winds for TCs in 2021-2023
(smoonthed to 0.25deg, time threshold = 1 hour)

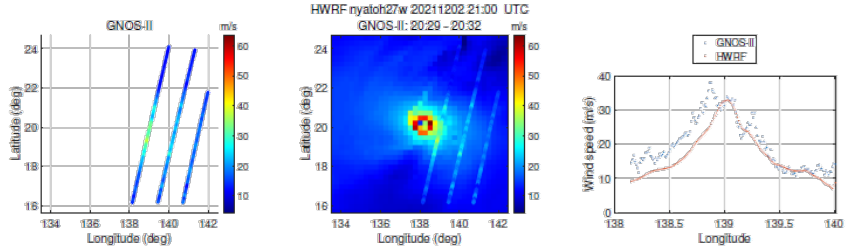


Compared to SMAP winds for observations
inside R34 for TCs in 2021-2023
(time threshold = 1 hour)

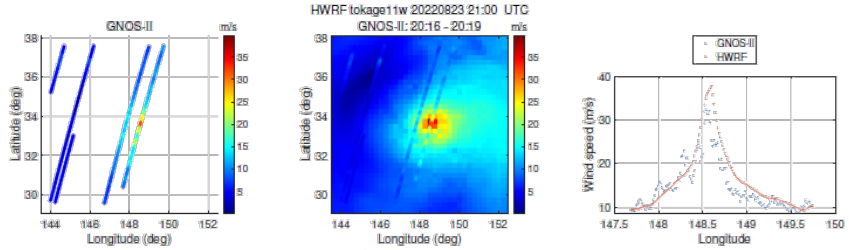


Cyclone Wind Product

Typhoon “Nyatoh” (2021)

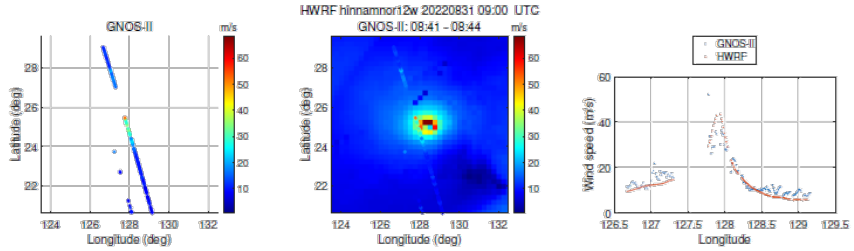


Typhoon “Tokage” (2022) (a)



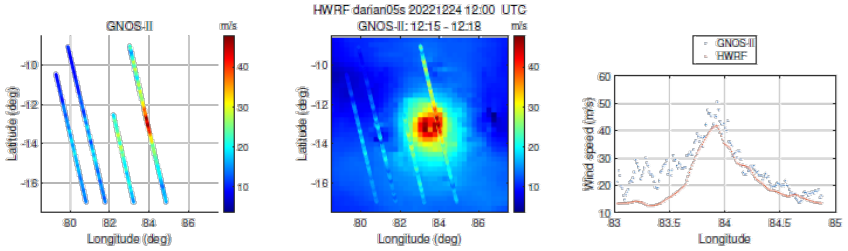
Typhoon “Hinnamnor” (2022)

(b)



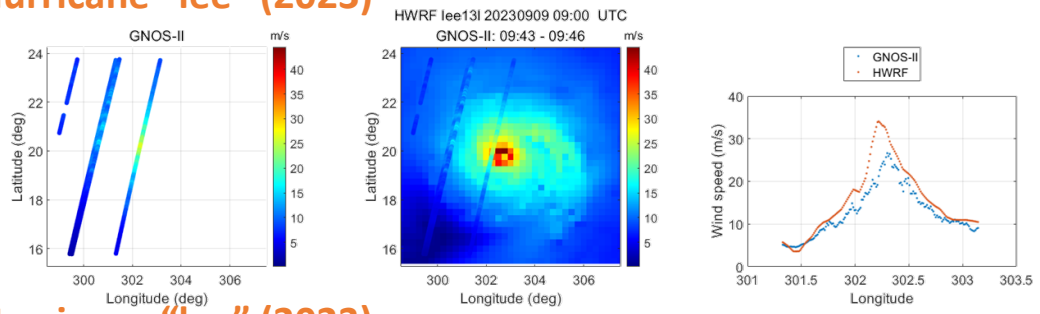
(c)

TC “Darian” (2021)

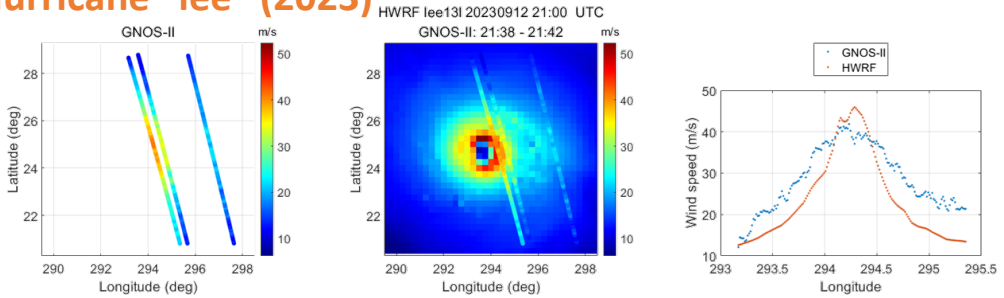


(d)

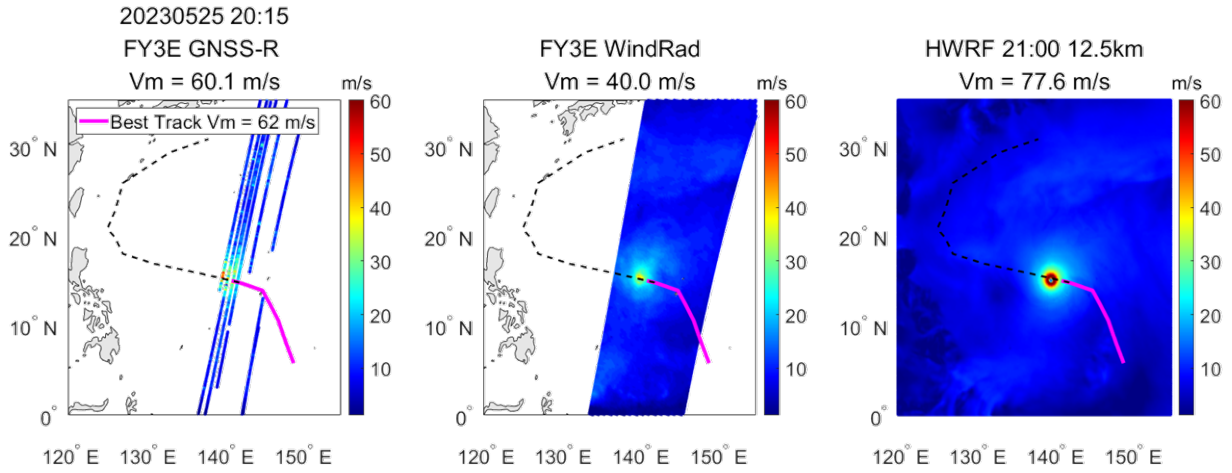
Hurricane “lee” (2023)



Hurricane “lee” (2023)

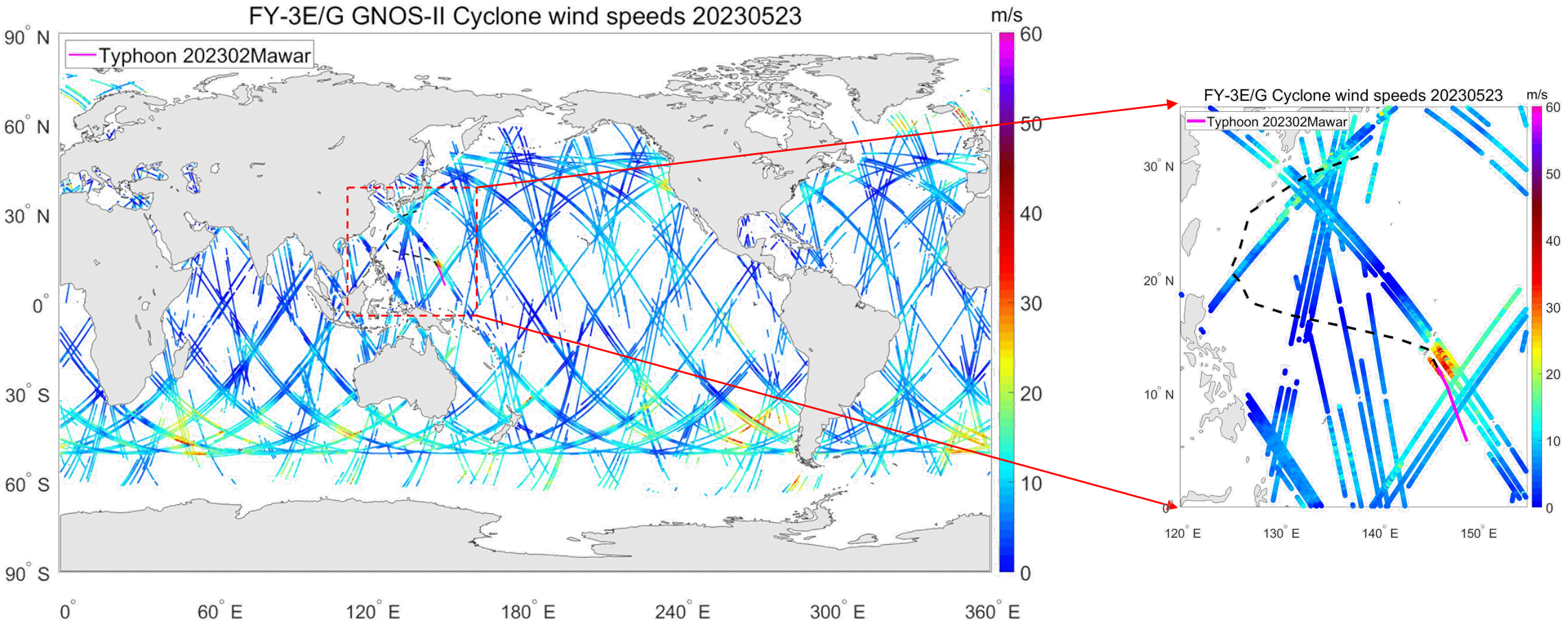


Typhoon “Mawar” (2023)



Cyclone Wind Product

- **Super Typhoon “Mawar” (2023) – monitoring the TC track**



Outline

Conclusions and Future Perspective

Conclusions and Future Perspective

Summary:

- There are three operational Fengyun-3 satellites (FY-3E/F/G) carrying GNSS-R payloads
- The data of FY-3E are open to the public and also operationally assimilated into the CMA-GFS model
- After extensive calibration, the RMSE of wind speeds is around 1.4 m/s globally compared to ECMWF and scatterometer winds
- A cyclone wind product is specially developed for TC, and validated by HWRF and SMAP winds

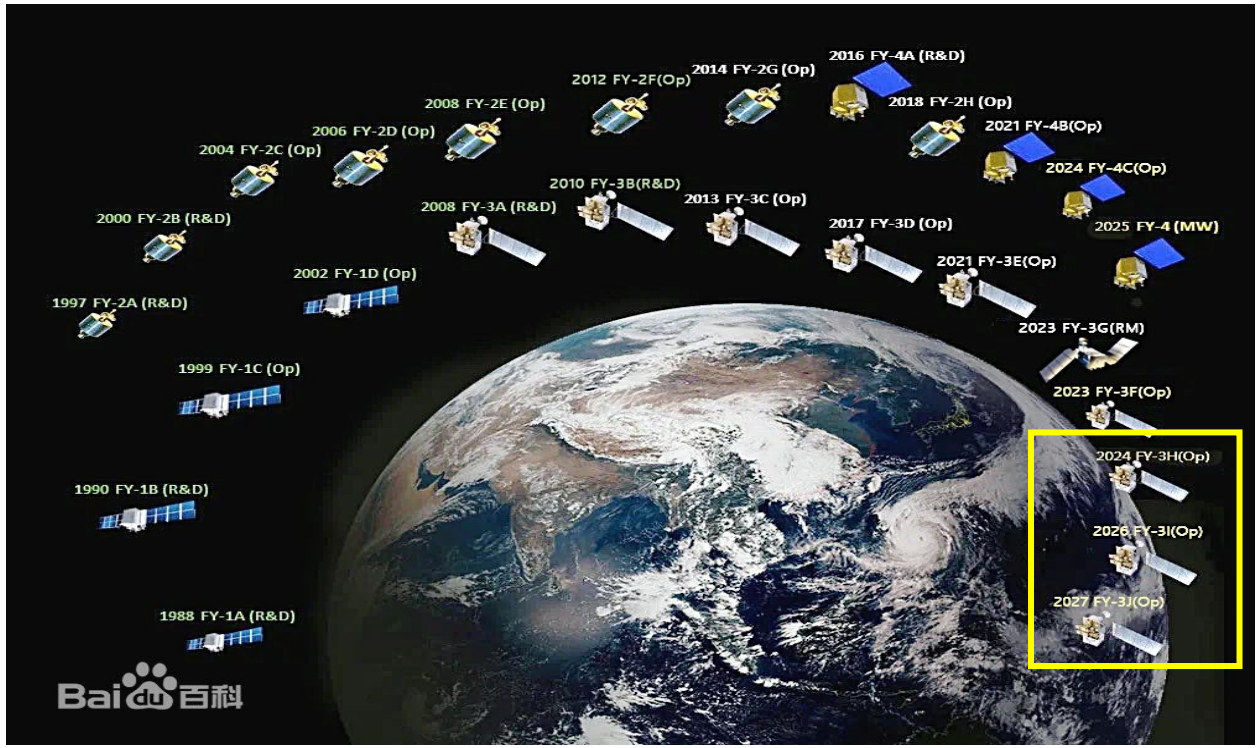
Future work:

- Fill the gaps between tracks using interpolation/ML/full DDM observations
- Improve the cal/val at high wind speeds
- Validation in extratropical cyclones

Conclusions and Future Perspective

Three more FY-3 satellites (FY-3H/I/J in 2024-2027) will also carry GNSS-R payloads

FY-5 series in mission design with enhanced instrument capabilities such as advanced antenna, polarization, etc.



Thank you!

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backup