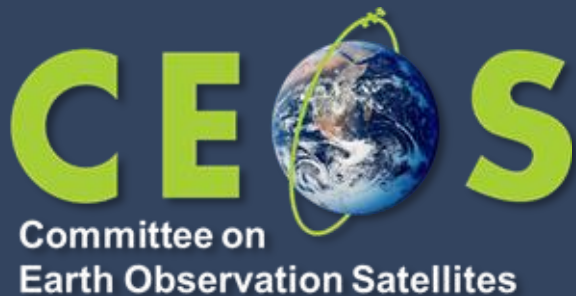


WGCV-56

Microwave Sensors Subgroup Update Report



Xiaolong DONG, NSSC/CAS

Agenda Item W2.1

WGCV-56, South Dakota, USA

April 20th - 24th, 2026

Contents:



1. Progresses of existing tasks
2. Proposal of new tasks: Cal/Val of GNSS-R
3. Coordination with GSICS MW-subgroup

MSSG covers EO sensors operated in microwave spectrum, except SAR
MWR, SCAT, ALT, GNSS-RO/R

- Microwave Radiometers (sounders, imagers) (MWR)
- Radar Scatterometers (surface and volume) (SCAT)
- Radar Altimeters (ALT)
- GNSS-Radio occultation and reflectometry (GNSS-RO/GNSS-R)

With current focuses on

- Radar Scatterometers (Active Microwave)
- Microwave Radiometers (Passive Microwave)
- *GNSS-Radio occultation and reflectometry*

Completed tasks:

- Radar Scatterometers (Active Microwave)
CEOS task CV-20-05: Standards and Metrics for Scatterometers and Wind Retrievals
- Microwave Radiometers (Passive Microwave)
ISO/TS 19159-4:2022 (published in November 2022)
Geographic information — Calibration and validation of remote sensing imagery sensors and data — Part 4: Space-borne passive microwave radiometers (ISO TC-211 19159-series)

Recent tasks:

- CV-23-05 Retrieval and validation with high winds with combined active-passive microwave measurements (**Completed**. Deliverables to be released in **June 2026**)
- CV-23-06 Retrieval and validation of sea surface atmospheric pressure with microwave remote sensing (**Completed**. Deliverables to be released in **June 2026**)

CV-23-05: Retrieval and validation with high winds with combined active-passive microwave measurements

Task lead:

Prof. Wenming Lin

Nanjing University of Information Science and Technology (NUIST)

Task Title	Retrieval and validation with high winds with combined active-passive microwave measurements
Status	Completed
Deliverables release	June 2026

❑ Deliverables :

- **Software:** Sea Surface Wind Speed Adjustment Software for Multi-Satellite Sensors
- **Data:** Extreme Wind Products from Multi-Satellite Sensors (2020–2025)
- **Technical Report:** Retrieval and Validation of High Winds with Combined Active-Passive Microwave Measurements

❑ Key results :

- Adjusted scatterometer/radiometer extreme winds;
- Combined active-passive retrieval improves accuracy;
- Merged product captures typhoon winds up to 50 m/s.

Supports typhoon disaster warning, shipping safety, and offshore wind energy with improved extreme wind products (up to 50 m/s)

Motivation

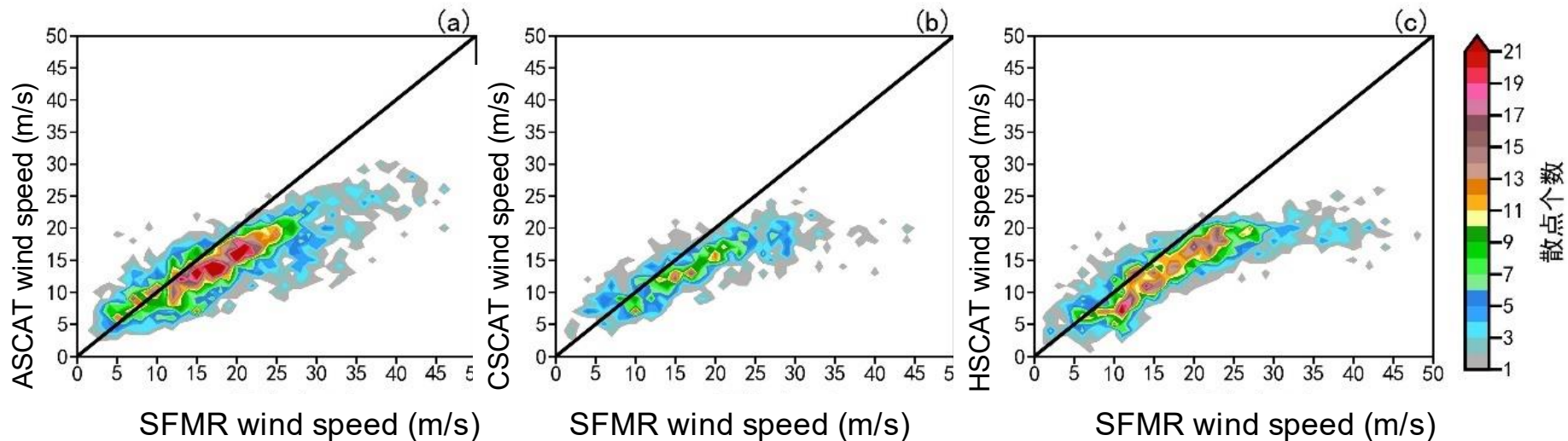
- ❑ Extreme sea surface winds (speed ≥ 32.7 m/s) may lead to storm surge, transportation disruptions, injury or death, damage to ships and coastal buildings, and etc.

- ❑ Monitoring of sea surface extreme winds using satellite-based microwave sensors is of great significance not only to the Risk Management authorities, but also the oceanic and atmospheric communities.

- ❑ The current satellite scatterometer or radiometer-derived extreme winds are far from the “truth”, due to:
 - **Rain contamination** for both active and passive sensors;
 - **Extreme wind signal saturation** for the co-polarized observations of active sensors;
 - **Limited understanding the physical fundamentals** of wave breaking, whitecaps, ...

Motivation

- It requires a **re-calibration or re-process task** in order to improve the quality of extreme winds retrieved from either satellite scatterometers or radiometers, and to achieve a consistent multi-mission extreme winds. Several approaches have been developed recently:
 - High wind calibration for satellite radar scatterometer measurements (active microwave sensors);
 - Extreme winds from low-frequency microwave radiometer measurements (passive microwave sensors);
 - Retrieval from combined active and passive microwave measurements.



Objectives:

consistent retrieval and validation of high winds from satellite microwave observations

- To re-calibrate microwave radiometer brightness temperature (BT), radar scatterometer and synthetic aperture radar (SAR) normalized radar cross section (NRCS, σ^0);
- To derive well inter-calibrated high and extreme sea surface wind products;
- To validate the high and extreme winds using collocated NOAA hurricane hunter Stepped Frequency Microwave Radiometer (SFMR) winds as reference;
- To better understand the intrinsic characteristics (e.g., the true spatial scale of each wind source) of the satellite-derived high and extreme winds.

Task team

- Nanjing University of Information Science and Technology (NUIST); (Task lead & SAR extreme winds);
- National Space Science Center (NSSC); (Rain effect for extreme winds)
- Royal Netherlands Meteorological Institute (KNMI); (SCAT extreme winds)
- National Ocean Satellite Application Center (NSOAS); (SCAT and RAD extreme winds);
- National Satellite Meteorological Center (NSMC/CMA); (C- and Ku- combined wind)
- National Oceanic and Atmospheric Administration (NOAA); (SFMR reference winds)
- Other potential contributors

For validation reference:

- Collocations in storm-centric coordinates: improve storm center location.
- Spatial representativeness: Look for suitable SFMR upscaling for each SAR, scatterometer & radiometer.

For satellite data:

- Analyze the sensitivity of each sensor measurement under high and extreme wind conditions, improve the radiation and scattering models.
- Re-calibration of radiometer brightness temperature, and radar NRCS.
- Re-calibration and/or re-process the extreme winds from the mentioned sensors.
- High and extreme wind validation using the reference data.

Data: Extreme Wind Products from Multi-Satellite Sensors (2020–2025)

1. Adjusted scatterometer extreme wind product;
 - ✓ Adjusted Advanced Scatterometer (ASCAT) high wind data; <https://www.maxss.org/>
 - ✓ Adjusted Haiyang-2 satellite scatterometer (HSCAT) high wind data; <https://www.maxss.org/>
2. Improved Haiyang-2 radiometer extreme wind data; <https://osdds.nsoas.org.cn/home>
3. Combined active and passive wind data. *(limited cases, upon request)*

Software: Sea Surface Wind Speed Adjustment Software for Multi-Satellite Sensors

- Scatterometer wind adjustment tool;
- Wind data illustration tool;

Technical report: Retrieval and Validation of High Winds with Combined Active-Passive Microwave Measurements

- Introduction of data and methods;
- Result validation;
- Discussion and perspectives.

Deliverables-1: Adjusted scatterometer extreme wind product



Improved SCAT wind product: ASCAT (C-band) wind data vs SMFR wind data

Airborne SFMR winds calibrated by Dropsondes;



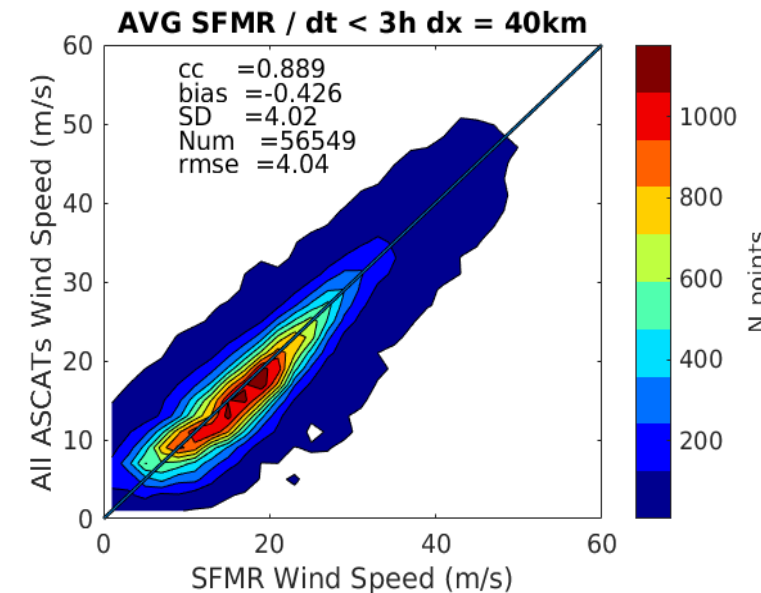
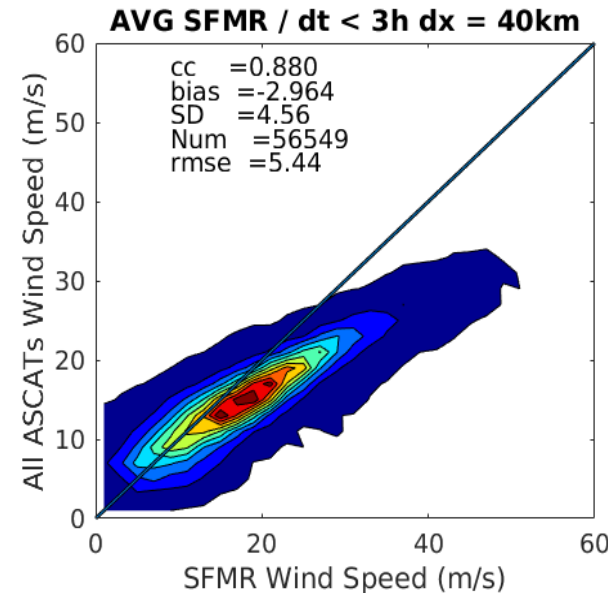
ASCAT winds collocated with the airborne SFMR winds;



ASCAT winds calibrated using a polynomial fitting function;



Other scatterometer or radiometer winds calibrated by the re-calibrated ASCAT wind speed.



(Portabella et al., 2023)

$$V_c = 0.0095 \times V^2 + 1.52 \times V - 7.6 \quad V_c = 0.01847 \times V^2 + 1.035 \times V - 2.9 \quad \checkmark$$

(Polverari et al., 2022)

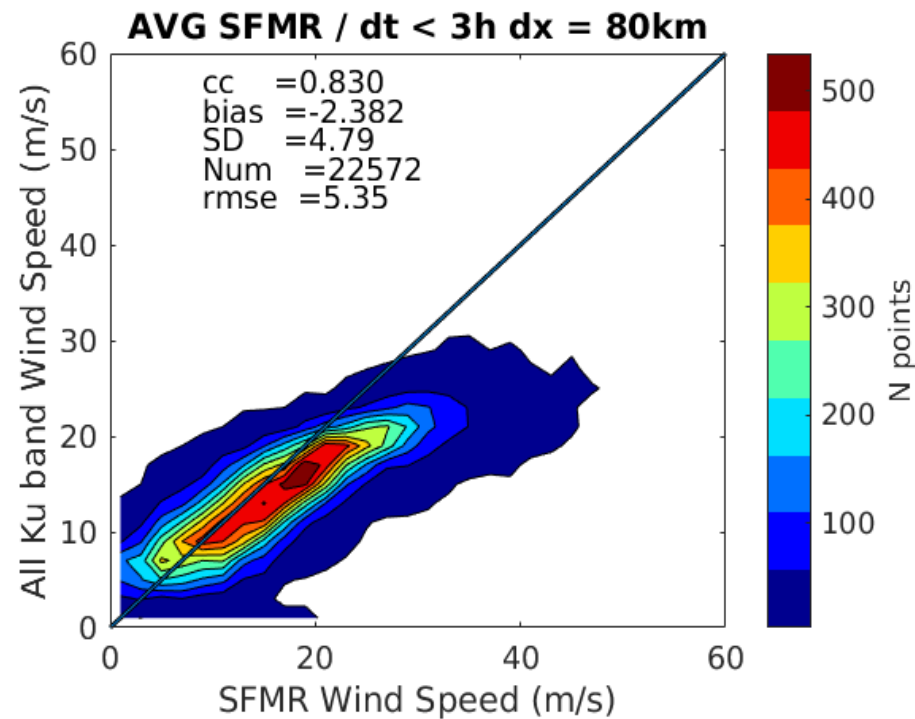
(Portabella et al., 2023)

Deliverables-1: Adjusted scatterometer extreme wind product

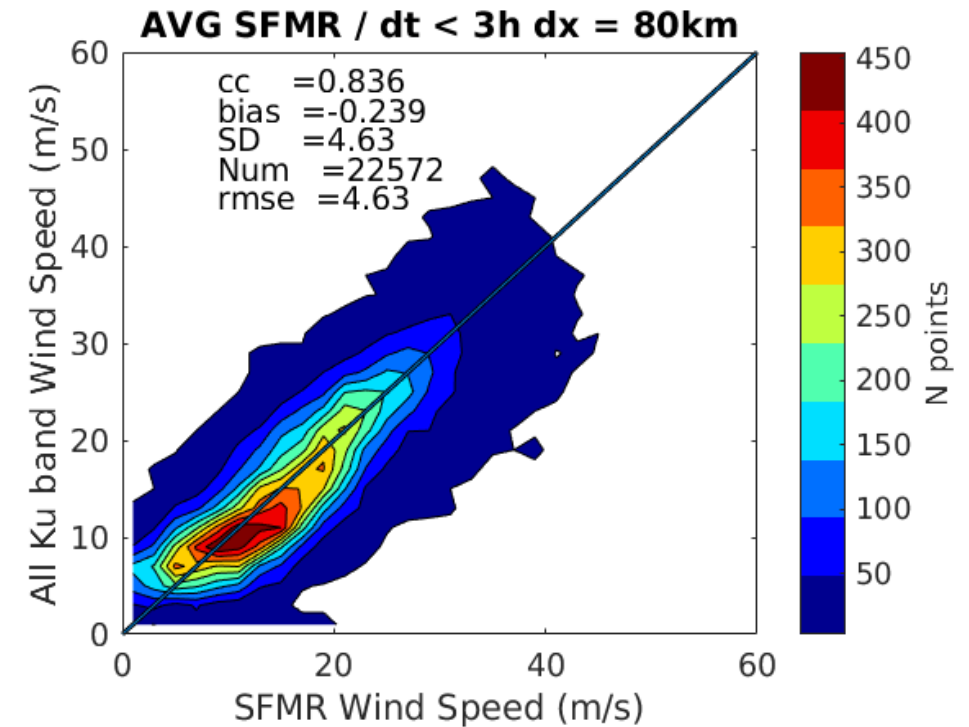


Improved SCAT wind product: Ku-band SCAT wind data vs SFMR wind data

Original Ku-band winds



Recalibrated Ku-band winds



Adjusted Ku-band winds consistent with SFMR winds (as expected)

Deliverables-2: Improved Haiyang-2 radiometer extreme wind data



Improved radiometer wind product:

<https://osdds.nsoas.org.cn/>

- H2B_OPER_SMR_L2B_SF_20200301T100745_20200301T110
- data_fields
 - Res0_Retrieve_Swath_Fast_Product
 - Abnormal_Flag
 - Ice_Flag
 - Land_Ocean_Flag
 - Lat_Of_Product
 - Long_Of_Product
 - Rain_Flag
 - Res0_AP
 - Res0_AP_Retrieve_Quality
 - Res0_CL
 - Res0_CL_Retrieve_Quality
 - Res0_IC
 - Res0_IC_Retrieve_Quality
 - Res0_SM
 - Res0_SST
 - Res0_SST_Retrieve_Quality
 - Res0_SSW
 - Res0_SSW_Retrieve_Quality
 - Res0_WW
 - Res0_WW_Retrieve_Quality
 - Res0_hSSW**
 - Scan_Time
 - Scan_Time_Trans

海洋卫星数据共享服务平台

序号	订购用户	订购单位
1	zhejiang	浙江预报中心
2	xuyuzhu	国家卫星海洋中心
3	zhejiang	浙江预报中心
4	huanglei	国家卫星海洋中心
5	ice	国家海洋环境预报中心
6	zhejiang	浙江预报中心
7	zhejiang	浙江预报中心
8	nanfang	南方数据中心
9	huanglei	国家卫星海洋应用中心
10	nanfang	南方数据中心

2020年第19号强热带风暴“天鹅”
(20201030T20:56:17 UTC -- 20201030T21:09:28 UTC)

台风时间: 20201030T21:03:52 UTC
台风位置: 129.51 15.2364
十级风半径: 153 NaN
七级风半径: 462 200 NaN 154
最大风速: 38.0 (m/s) 228

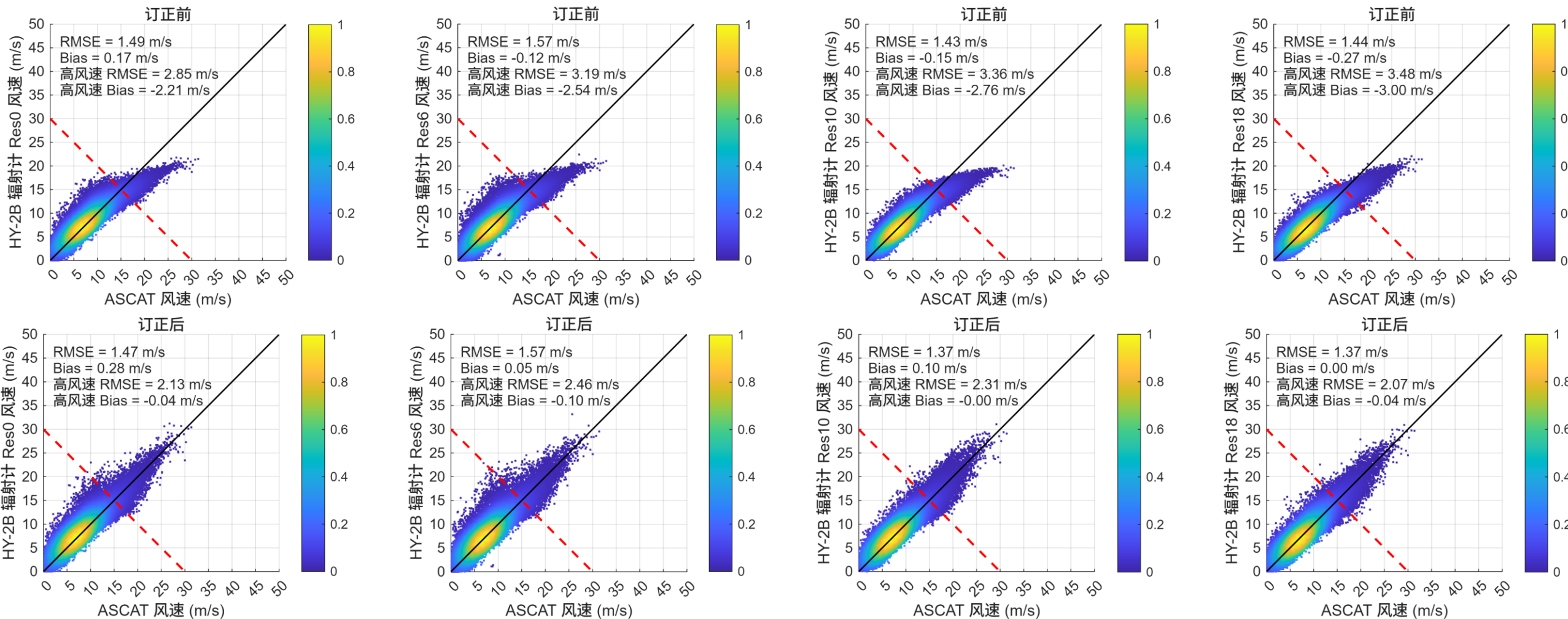
制图单位: 国家卫星海洋应用中心
制图时间: 2020年10月30日

Improved HY-2B radiometer winds disseminated by NSOAS

Deliverables-2: Improved Haiyang-2 radiometer extreme wind data



Comparison with corrected ASCAT data(2024)



Dilverables-3: Combined active and passive wind data

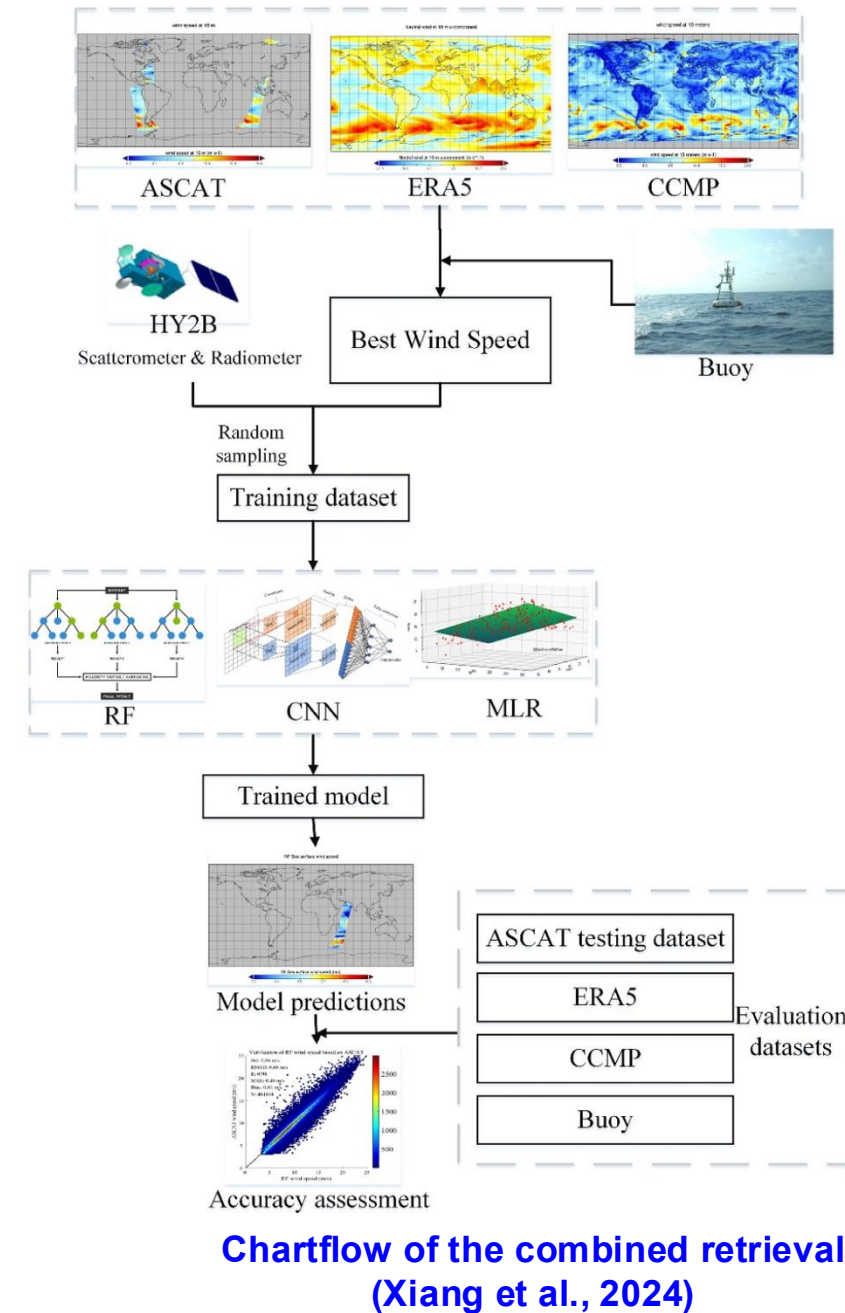
Method 1 – Random Forest & Convolutional Neural Networks (CNN) for general wind retrieval

Table 1

The Fundamental Information for the HY-2B Microwave Scatterometer and Radiometer

Sensor	Frequency (GHz)	Polarization	Swath (km)	Spatial resolution (km)
Scatterometer	13.256	HH	1,350	25
		VV	1,700	
Radiometer	6.925	V&H	1,600	90 × 150
	10.7	V&H		70 × 110
	18.7	V&H		36 × 60
	23.8	V		30 × 52
	37.0	V&H		20 × 35

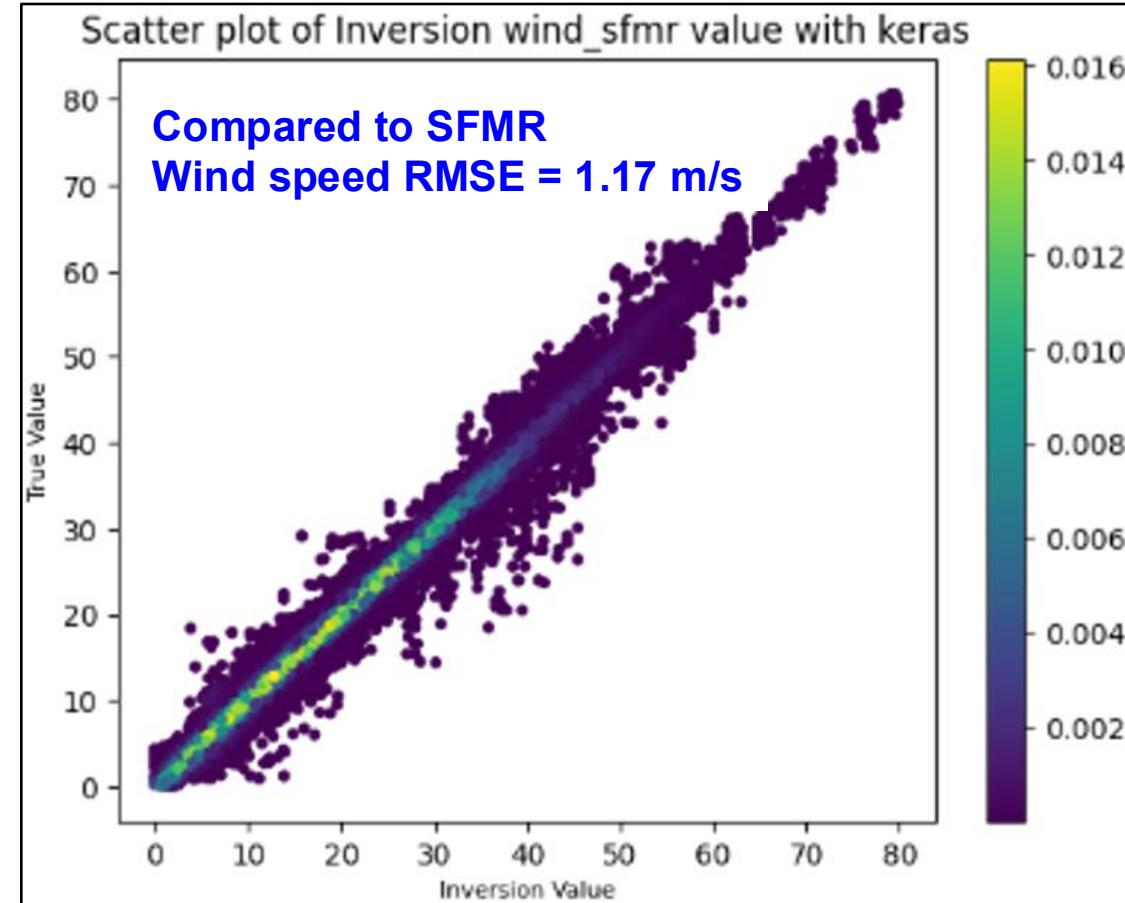
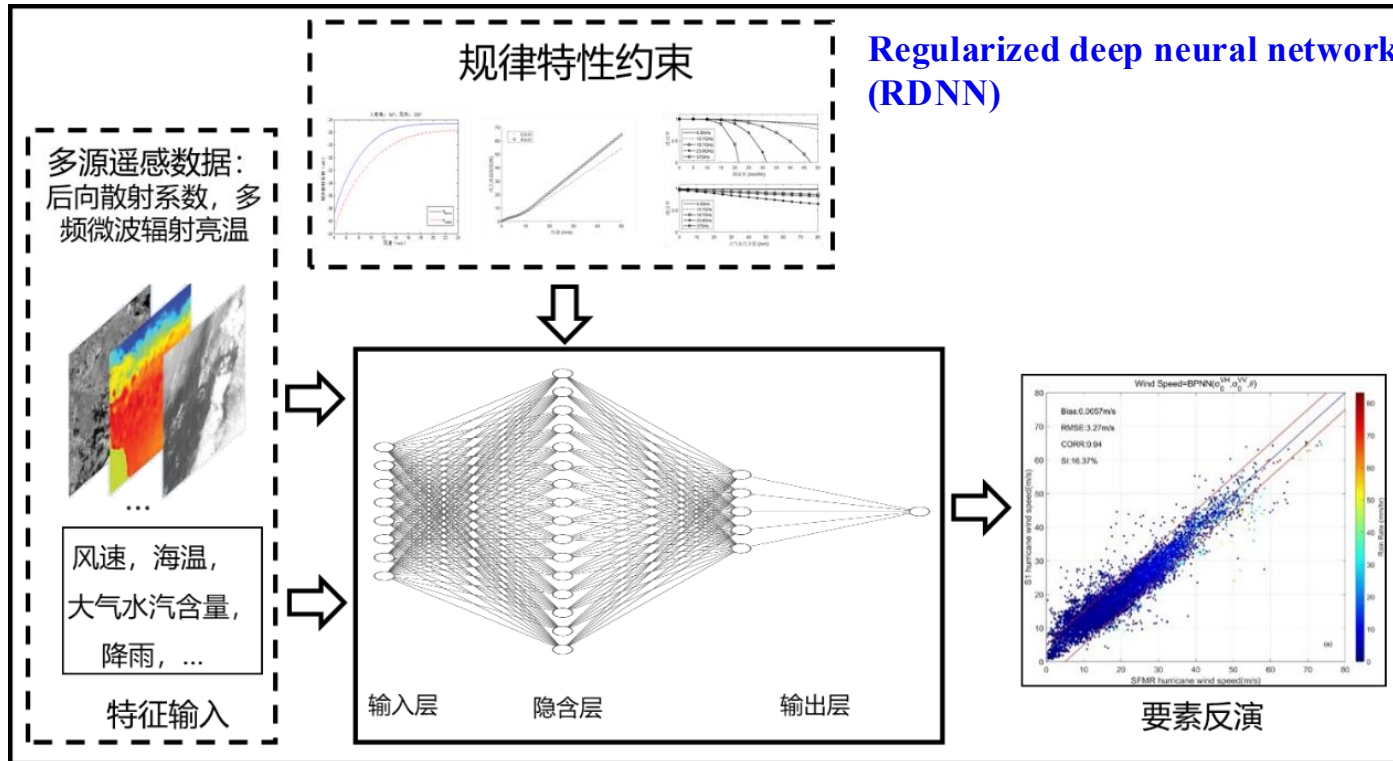
- The joint active-passive approach (**RMSE 1.16m/s**), e.g., RF and CNN models, consistently outperformed both the individual active (1.27 m/s) and passive (1.80 m/s) models.
- The accuracy assessment, conducted with buoy, ERA5, and CCMP data, confirmed the effectiveness of the integrated methodology.



Dilverables-3: Combined active and passive wind data



Method 2 – Regularized deep neural network (RDNN) for extreme wind retrieval



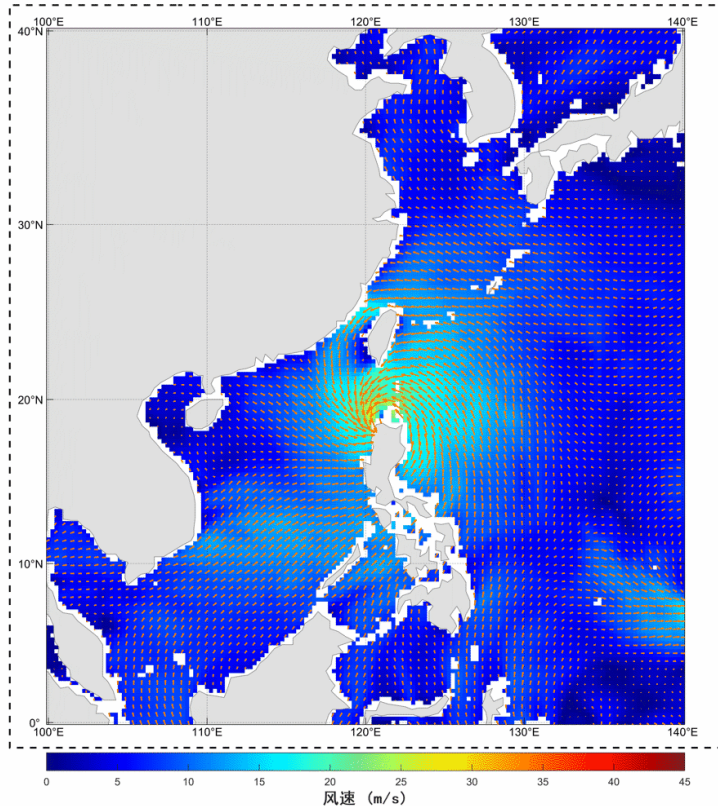
Summary:

- Although the scatterometer signals saturate at extreme winds, and the high-frequency radiometer signals are affected by rain, both active and passive sensors show great potential for the retrieval of extreme sea surface winds by applying:
 - [High wind calibration for radar scatterometers](#);
 - [Improved emissivity model for low-frequency \(C-band\) brightness temperature](#).
 - [Nonlinear Fitting Using Standard Wind Field Products](#)
- Developing Standardized Wind Field Output Software with Bias Correction Applied
- Combining active and passive measurements in the ANN model not only improves the general wind retrieval ([RF&CNN](#)), but also improves the extremes ([RDNN](#)).
- Relevant data and processing tools have been developed.
- Deliverables will be released in June 2026.
- Better understanding on the microwave backscattering/emission characteristics is needed, in order to optimize the configuration of active/passive channels for the remote sensing of extreme winds.

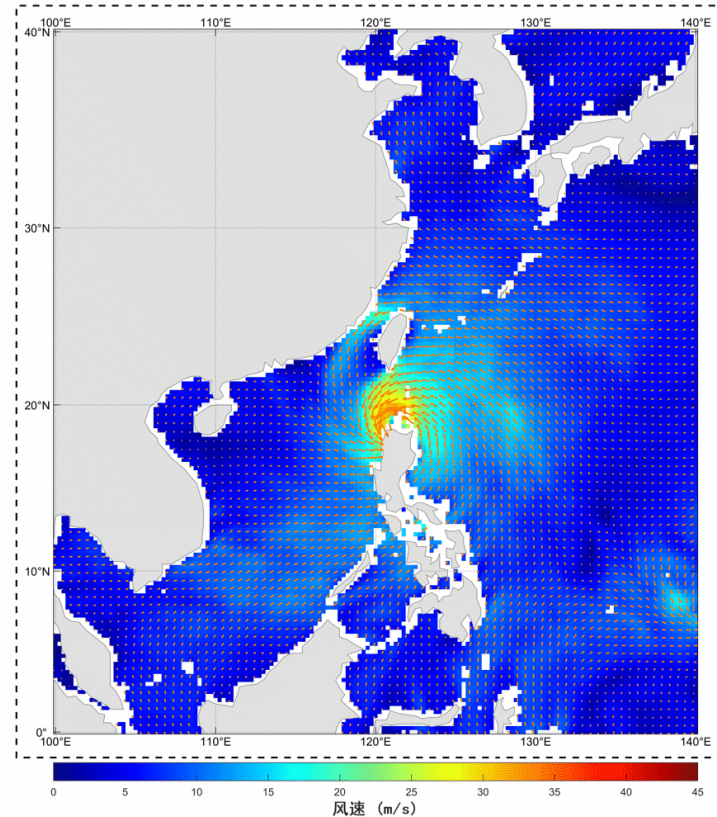
Summary:



中国近海海面风速专题图
2023年7月26日3时



中国近海海面风速专题图
2023年7月26日0时



制图单位: 南京信息工程大学 网格分辨率: $0.25^\circ \times 0.25^\circ$ 数据类型: 多源融合
制图时间: 2025年10月21日 时间分辨率: 3h 要素名称: 海面风场



制图单位: 南京信息工程大学 网格分辨率: $0.25^\circ \times 0.25^\circ$ 数据类型: 多源融合
制图时间: 2025年10月21日 时间分辨率: 3h 要素名称: 海面风场

Merged conventional remote sensing winds, $w_{\max}=29$ m/s

Merged new remote sensing winds, $w_{\max}=42$ m/s

Typhoon Doksuri and Typhoon Khanun, the 5th and 6th typhoons in 2023.

CV-23-06: Retrieval and validation of sea surface atmospheric pressure with microwave remote sensing

Task lead:
Dr. Zijin ZHANG
National Space Science Center, CAS

CV-23-06: Deliverables Summary



Task Title	Retrieval and validation of sea surface atmospheric pressure with microwave remote sensing
Status	Completed
Deliverables release	June 2026

□ Deliverables :

- **Data:** All-Weather Ocean Surface Pressure Retrievals from Joint Observations of FY-3D/MWTS-II and FY-3D/MWHTS
- **Technical Report:** Retrieval and Validation of Sea Surface Atmospheric Pressure with Microwave Remote Sensing

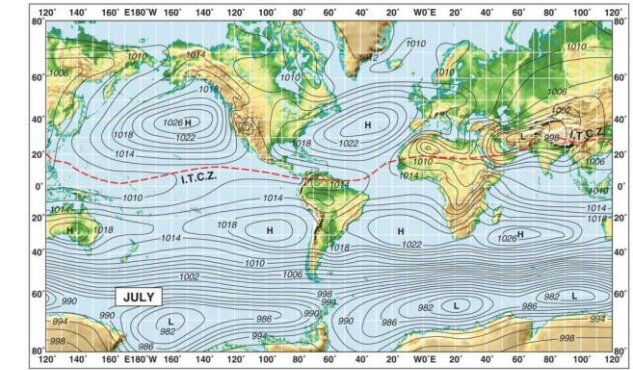
□ Key results :

- Developed joint retrieval algorithm combining 60 GHz and 118 GHz observations.
- Joint 60+118 GHz outperforms single band, warm TB anomaly improves high-wind retrieval;
- Validated against reanalysis and in situ data: RMSE 1.86–3.20 hPa (low-moderate winds) and 2.78–6.15 hPa (high winds).

Significance: Fills the gap of all-weather ocean surface pressure from space, supporting disaster and extreme weather forecasting and global climate change studies.

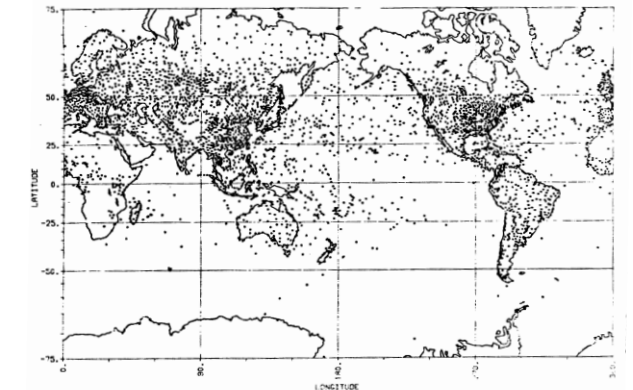
- Surface pressure data have important applications in **numerical weather prediction (NWP)**, **tropical cyclone forecasting and analysis**, **global climate change studies**.
- Currently, ocean surface atmospheric pressure data are mainly provided by buoys and ship measurements. **The spatial coverage of in situ data for use by weather forecasters is very poor.**
- Only remote sensing techniques can obtain surface pressure data with large spatial coverage and high density sampling over oceans. **However, there are no operational surface pressure retrieval products.**

Global Barometric Pressure



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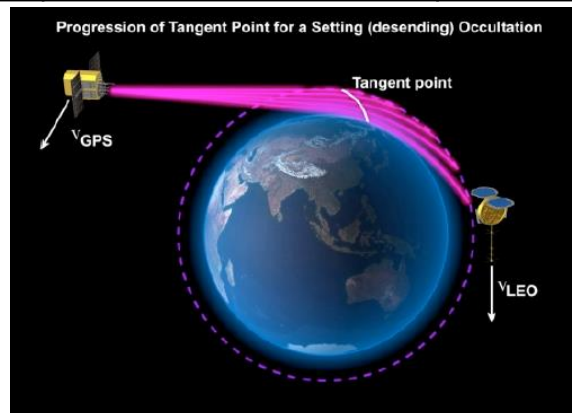
Figure 6.10



Stations reporting surface pressure

Overview of Existing Techniques

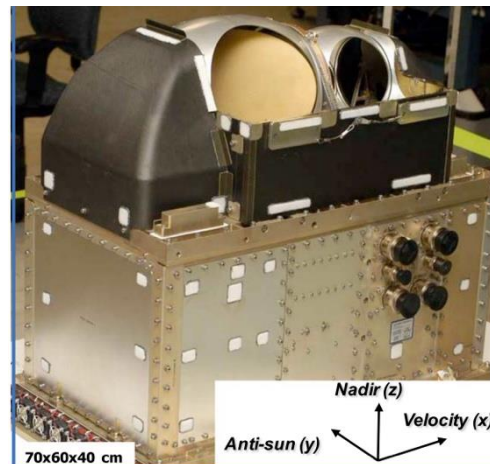
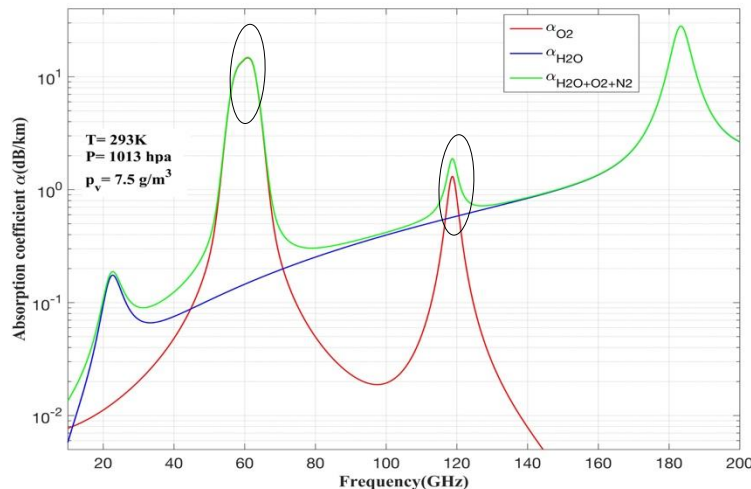
Instrument	Frequency Band	Accuracy	Disadvantages
Grating spectrometer (Mitchell and O'Brien, 1987)	O ₂ A band (759-771 nm)	1~2 hPa (Clear Sky)	Only available in daytime and clear-sky
Global Positioning System radio occultation (Healy, 2013)	L-band L1: 1.57542 GHz L2: 1.227 GHz	1~2 hPa	Horizontal resolution is several hundred kilometers
Airborne differential absorption radar (L. Millan 2014; Lin and Hu 2005)	50-56 GHz O ₂ bands	4~7 hPa	Continuous, large-scale and wide swath observations are not available
Microwave Scatterometer (Patoux et al., 2008; Zhang et al., 2011)	14.6 GHz (SASS) 13.4 GHz (QuikSCAT)	1~3 hPa (clear-sky, cloudy and rainy conditions) ~ 20 hPa (hurricanes and typhoons)	<ul style="list-style-type: none"> Performance during extremely high wind conditions (wind speed >28 m/s) are not satisfactory Data cannot be obtained in real-time



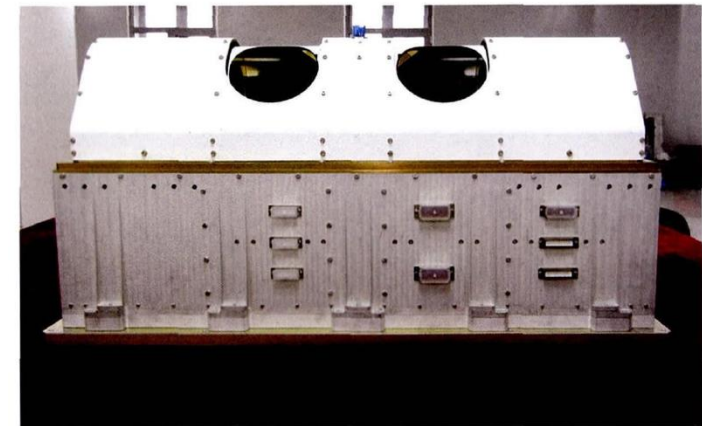
Retrieving surface atmospheric pressure from **spaceborne passive microwave observations**

Surface pressure sounding is achieved by microwave radiometers based on **measurement of the total columnar oxygen absorption**.

In the oxygen absorption band (**50-70 GHz, 118 GHz**), the total columnar atmospheric absorption is strongly related to column oxygen mass. Oxygen is uniformly mixed in the atmosphere; therefore, the column oxygen mass is directly proportional to the surface pressure.



SNPP/ATMS (50-60 GHz)



FY-3C/MWHTS(118 GHz)

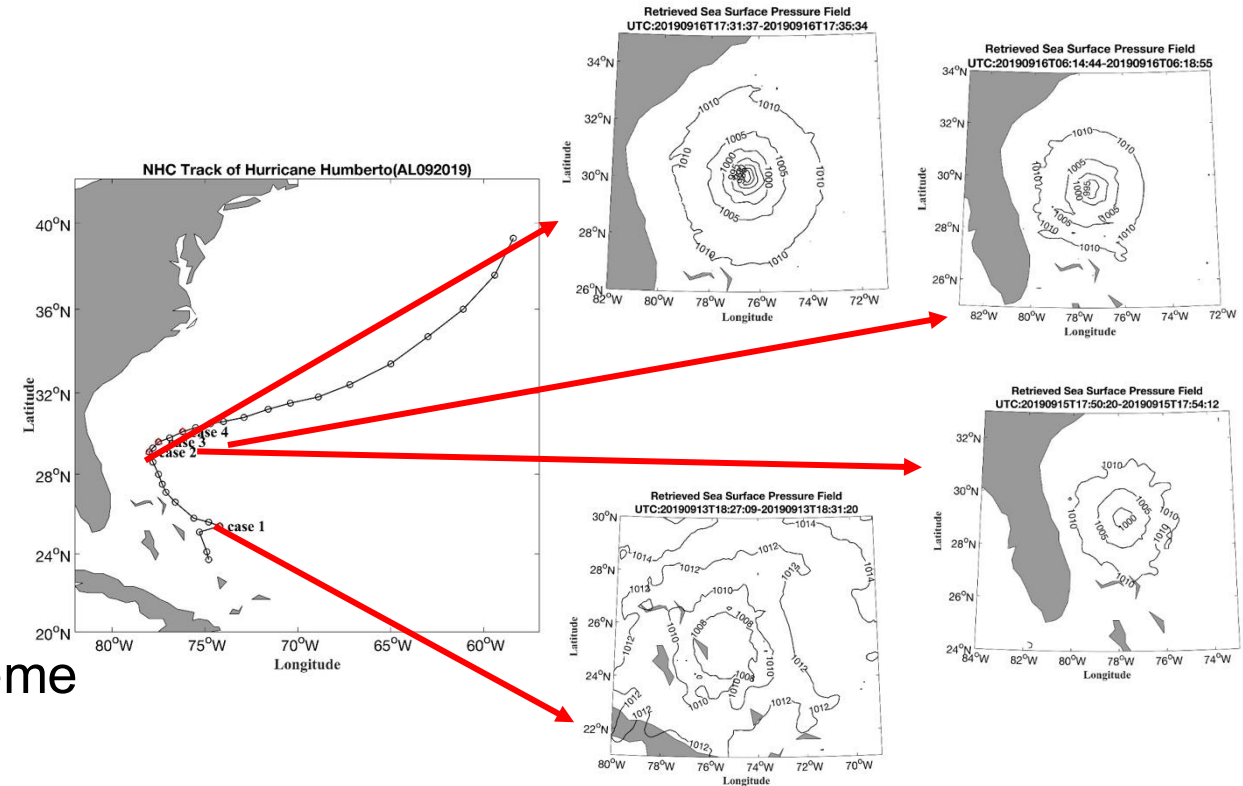
Advantages of the new technique

Advantages:

- All weather capability
- Day and night capability
- High spatiotemporal resolution (<3h, ~16km by multi-satellite joint observation)
- Wide swath observations (several thousand km): fast, continuous and stable global observations capability

Applications:

- Prediction and forecasting for disasters and extreme weather;
- Numerical weather prediction (NWP);
- Global climate change studies.



Objective

- To develop and optimize the retrieval models and algorithms for sea surface pressure by passive microwave observations.
- To validate and assess the sea surface pressure data products using collocated in situ measurement data.
- To deliver the all-weather sea surface pressure data product from passive microwave observations.

Towards all-weather quality ocean surface atmospheric pressure product

Task team

- National Space Science Center (NSSC); (Task lead & retrieval algorithm)
- Shanghai Typhoon Institute, CMA (TC data analysis);
- National Satellite Meteorological Center (NSMC/CMA); (MWTS/MWHTS data)
- National Ocean Satellite Application Center (NSOAS); (SCAT wind data);
- Hong Kong Observatory (in situ data)

For retrieval algorithms:

- Develop the retrieval algorithms for sea surface pressure by passive microwave observations.
- Optimize the algorithm under high wind conditions using warm TB anomaly (TB minus environmental TB) observations of tropical cyclones.
- Analyze the surface pressure information content obtained by 60 GHz and 118 GHz radiometers, improve the algorithm using joint 60- and 118- GHz observations.

For validation:

- Validation of the respective and joint retrieval results from 60 GHz and 118 GHz radiometers using **collocated reanalysis and analysis data** (ERA-interim, ERA5, and GDAS/FNL analysis).
- validations using the **collocated *in situ* data** by buoy, ship and dropsonde.

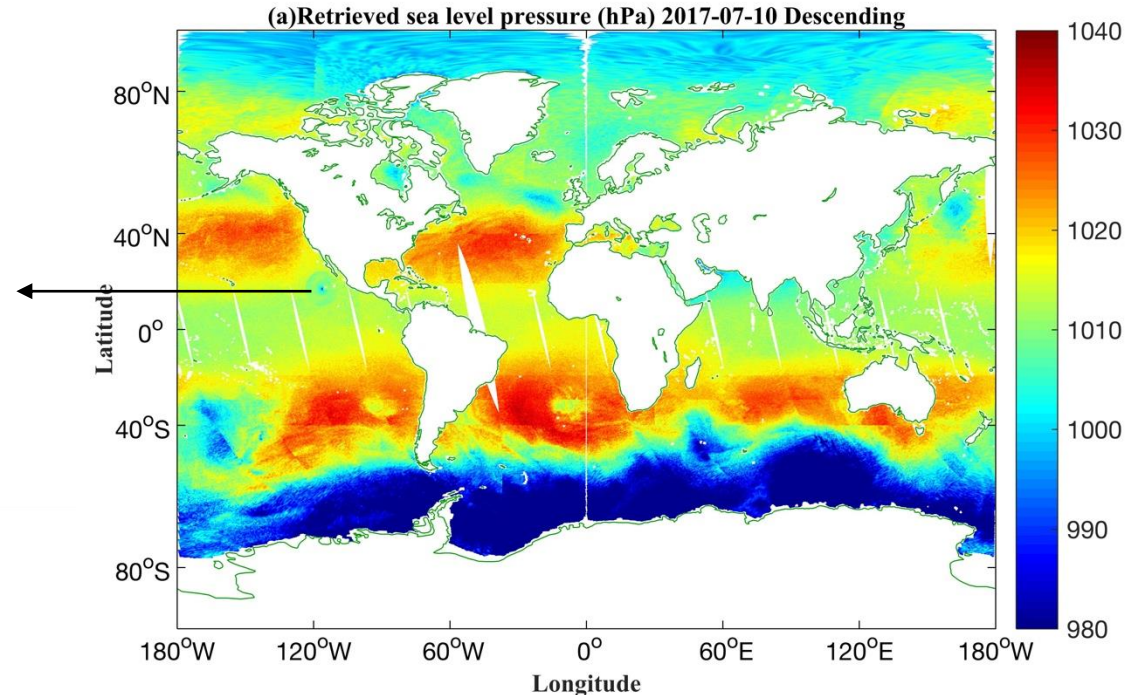
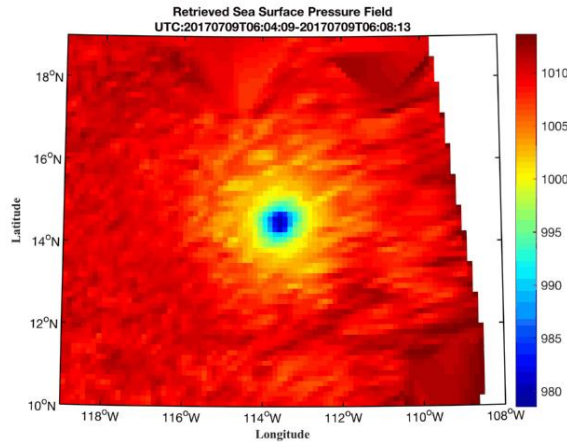
Data: All-Weather Ocean Surface Pressure Retrievals from Joint Observations of FY-3D/MWTS-II and FY-3D/MWHTS

- Weather conditions: clear-sky, cloudy, rainy, and high wind
- Temporal coverage: 2023
- Sensors: FY-3D/MWTS-II and FY-3D/MWHTS radiometers
- Spatial resolution: ~32 km (nadir)
- Format: HDF5

Technical report: Retrieval and Validation of Sea Surface Atmospheric Pressure with Microwave Remote Sensing

- Introduction to the data and retrieval algorithm
- Validation report based on collocated reanalysis and in situ data
- Discussion and perspectives

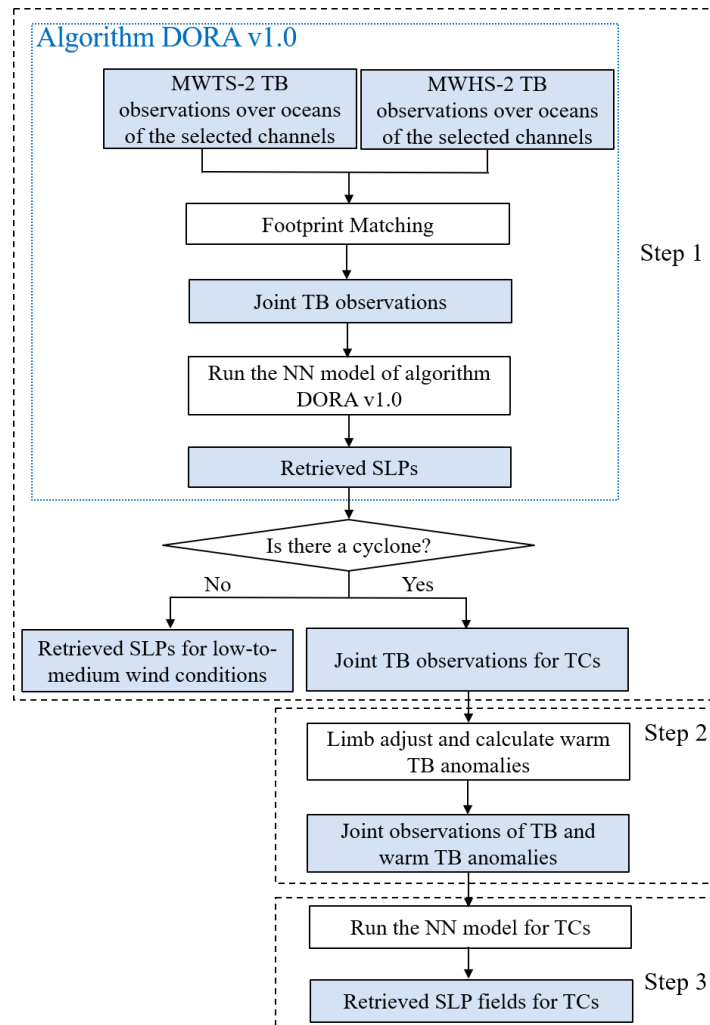
Data



All-weather (clear-sky, cloudy, rainy and high wind conditions) ocean surface pressure retrievals from joint observations of FY-3D/MWTS-II and FY-3D/MWHTS

- Spatial resolution (nadir): 32 km
- Parameters: Latitude, Longitude, Time, Retrieved surface pressure value, uncertainty
- Data: FY-3D/MWTS-II and FY-3D/MWHTS data provide by NSMC/CMA (<https://satellite.nsmc.org.cn>)

Retrieval algorithm



- Inputs: TB data by MWTS-II and MWHTS.
 - Outputs: All-weather ocean surface pressure retrievals
 - Algorithm: Based on backpropagation neural network (BPNN) algorithm
- ✓ Warm TB anomaly (TB minus environmental TB) observations are used to improve the performance under high wind conditions
 - ✓ Joint retrieval with 60- and 118- GHz TB data to improve the performance under both low-to-medium wind conditions and high wind conditions

Z. Zhang *et al.*, "Retrieval of Tropical Cyclone Sea-Level Pressure Fields From the MWTS-2 and MWHS-2 Onboard the FengYun-3D Satellite," in *IEEE Transactions on Geoscience and Remote Sensing*, vol. 63, pp. 1-14, 2025, Art no. 5301814, doi: 10.1109/TGRS.2025.3574455.

Deliverables-2: Algorithm

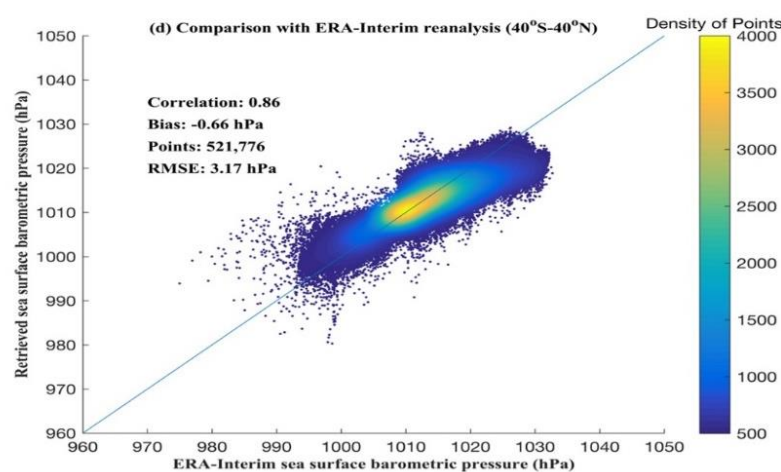
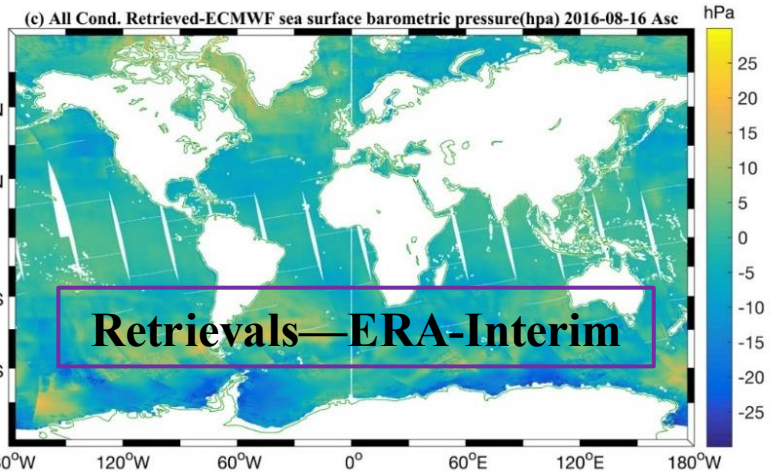
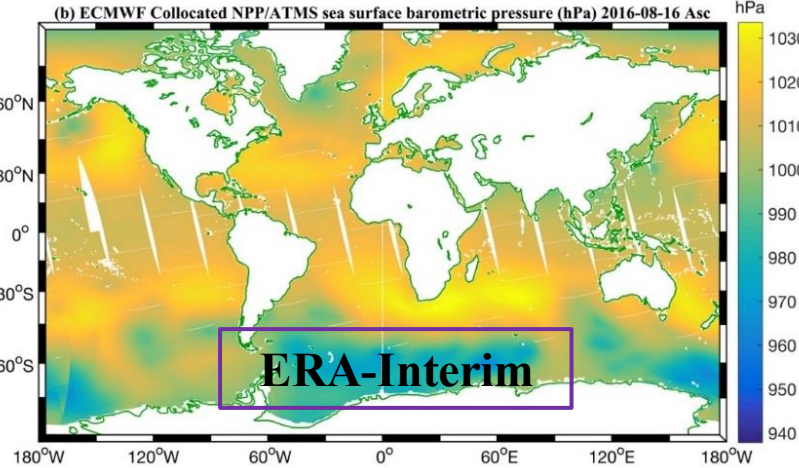
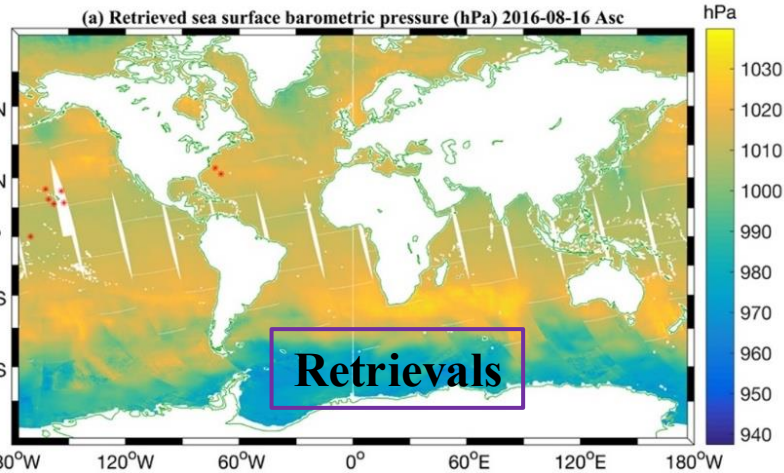


Validation:

1) Validation using reanalysis/analysis data

Validate the retrievals from SNPP/ATMS using **ERA-Interim reanalysis**

Retrievals from SNPP/ATMS correlate well with the ERA-Interim surface pressure reanalysis data.

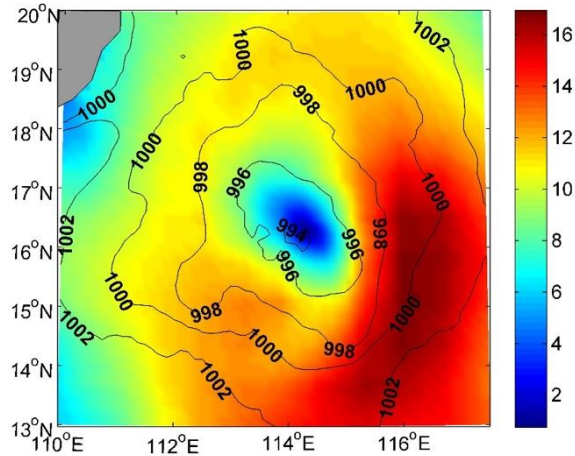


Retrieval results using the SNPP/ATMS ascending data in August 16, 2016 (Zhang et al., 2018).

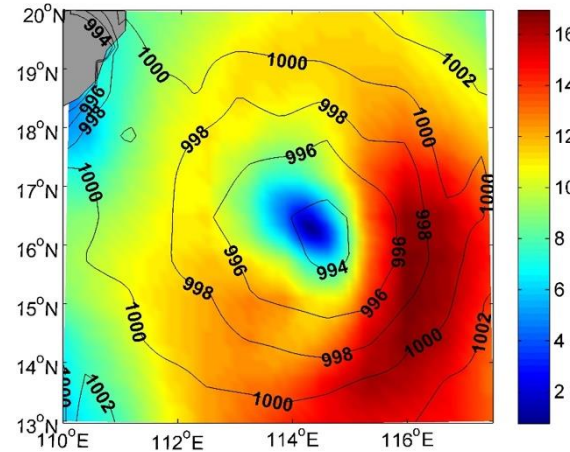
Deliverables-2: Algorithm



Retrievals

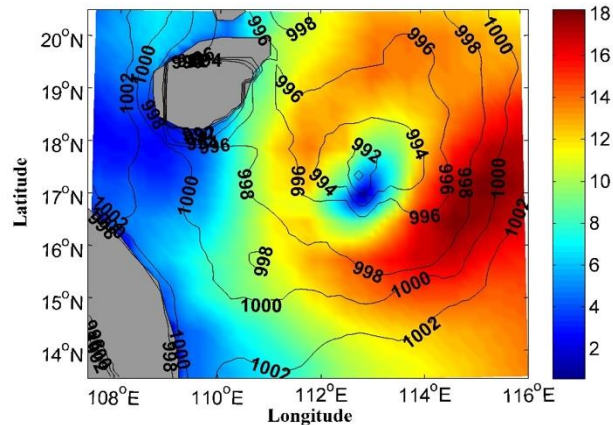


NCEP analysis

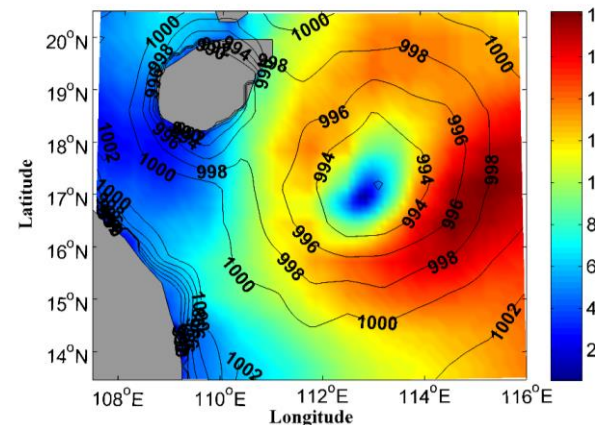


Validate the retrievals from **SNPP/ATMS** using **NCEP GDAS/FNL** analysis

Retrievals



NCEP analysis



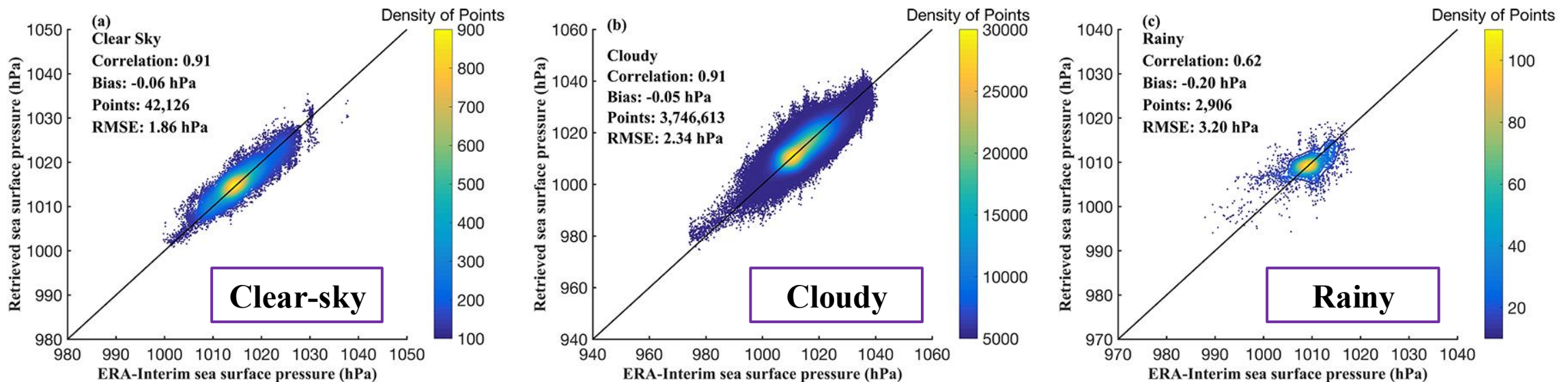
- Retrievals correlate well with the NCEP GDAS/FNL surface pressure analysis data.
- The TC structure described by the retrievals agree well with that described by the NCEP GDAS/FNL 10m wind speeds.

Retrieved surface pressure shown using contour, and NCEP GDAS/FNL 10m wind speeds shown using shade for tropical storm Jebi at 0604 UTC (top) and 1835 UTC (bottom) 1 August 2013.

Deliverables-2: Algorithm



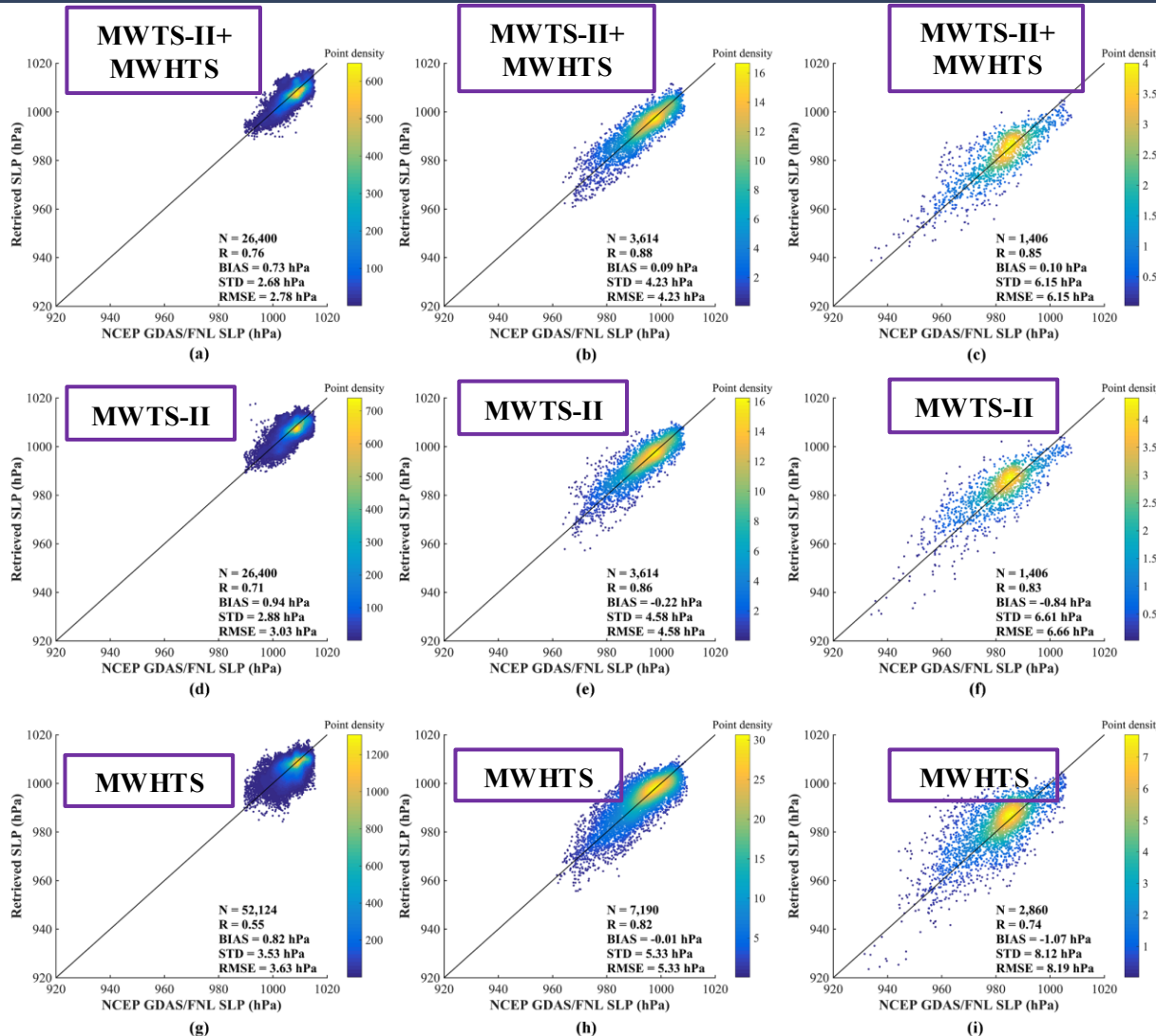
Validate the retrievals from MWTS-II, MWHTS and joint observations using **ERA-Interim reanalysis** under **low-to-medium wind conditions**



Data source	RMSE (hPa)		
	Clear sky	Cloudy	Rainy
MWTS-II	1.95	2.77	3.47
MWHTS	1.98	2.91	3.53
MWTS-II+MWHTS	1.86	2.34	3.20

- The joint approach outperformed both the 60 and 118 GHz models under low-to-medium wind speed conditions.

Deliverables-2: Algorithm



Validate the retrievals from MWTS-II, MWHTS and joint observations using **NCEP GDAS/FNL analysis** under **high wind speed conditions**

Data source	RMSE (hPa)		
	Tropical depressions and tropical storms	Typhoons or hurricanes	Severe typhoons or major hurricanes
MWTS-II	3.03	4.58	6.66
MWHTS	3.63	5.33	8.19
MWTS-II+MWHTS	2.78	4.23	6.15

Validated with 185 TC cases in 2023, the joint approach outperformed both the 60 and 118 GHz models under high wind speed conditions.

Tropical depression and storm

Hurricane or typhoon

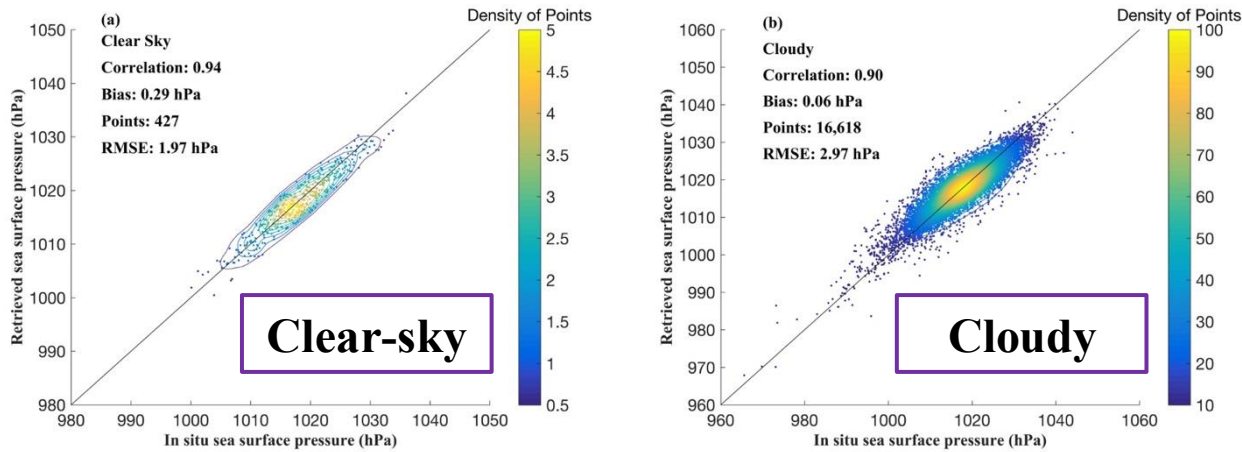
Major hurricane or severe typhoon

Deliverables-2: Algorithm

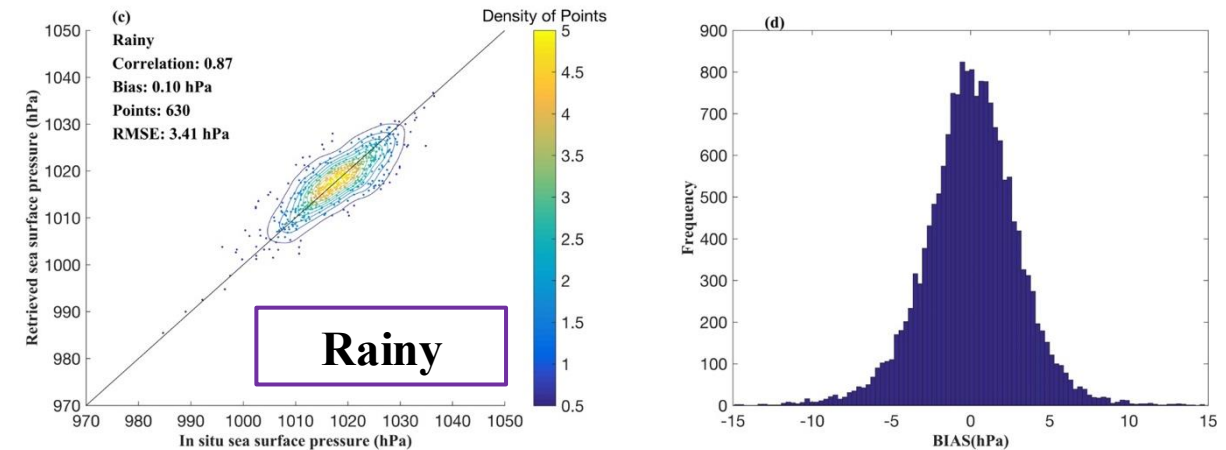
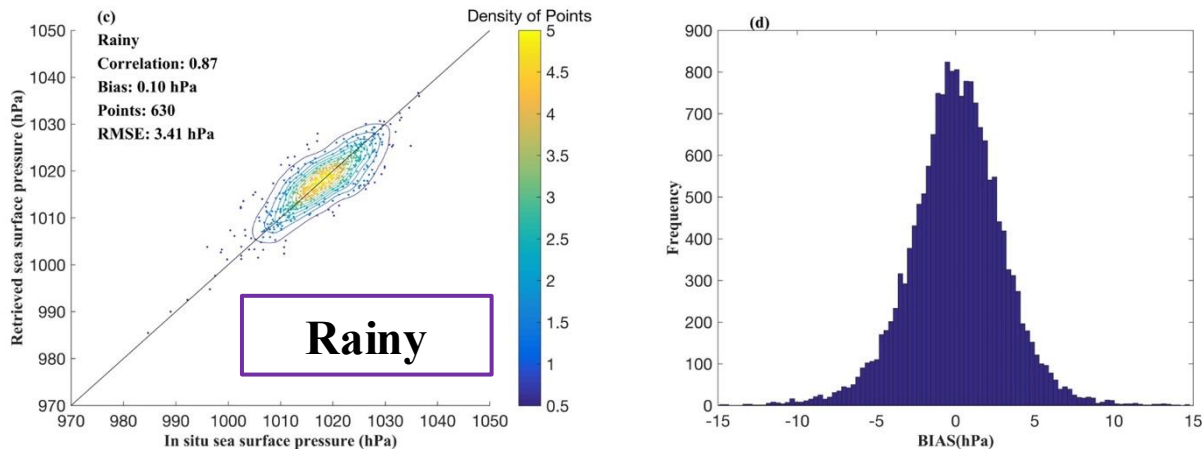
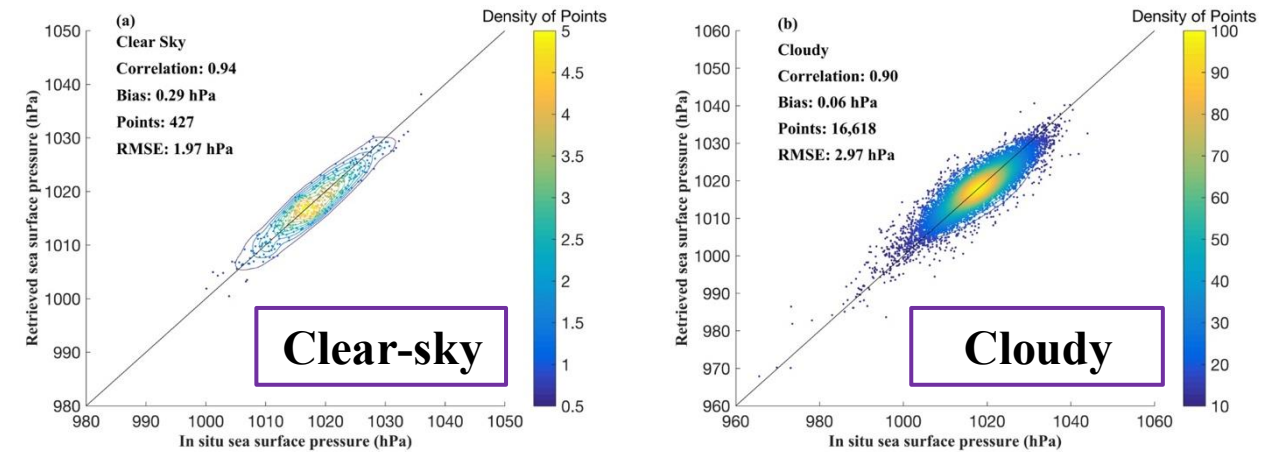


Validation: 2) Validation using in situ data

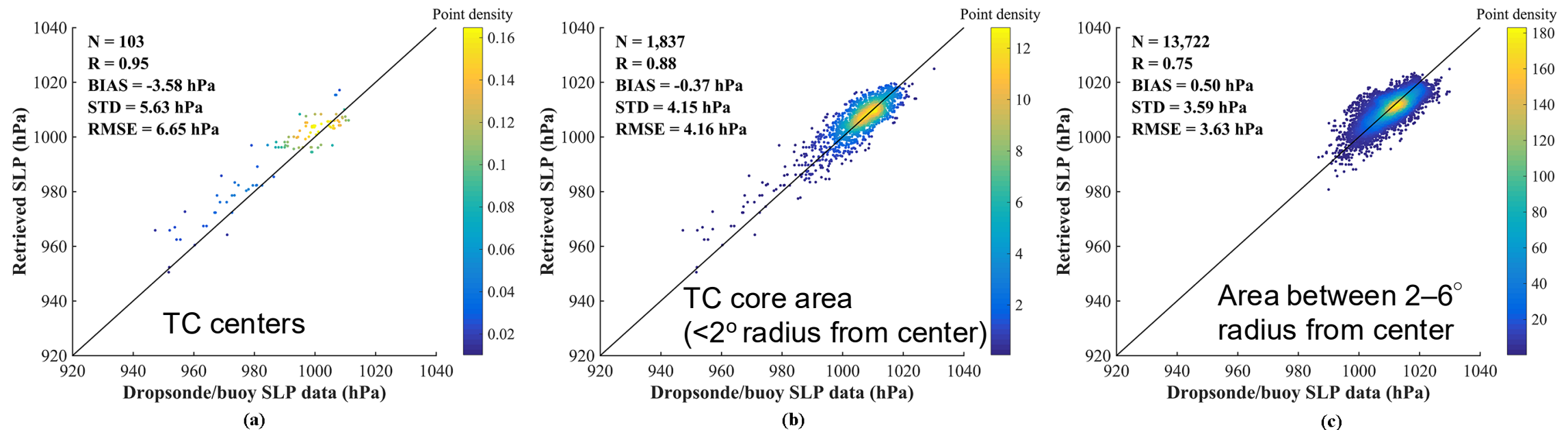
Validate the retrievals from SNPP/ATMS



Validate the retrievals from FY-3C/MWHTS

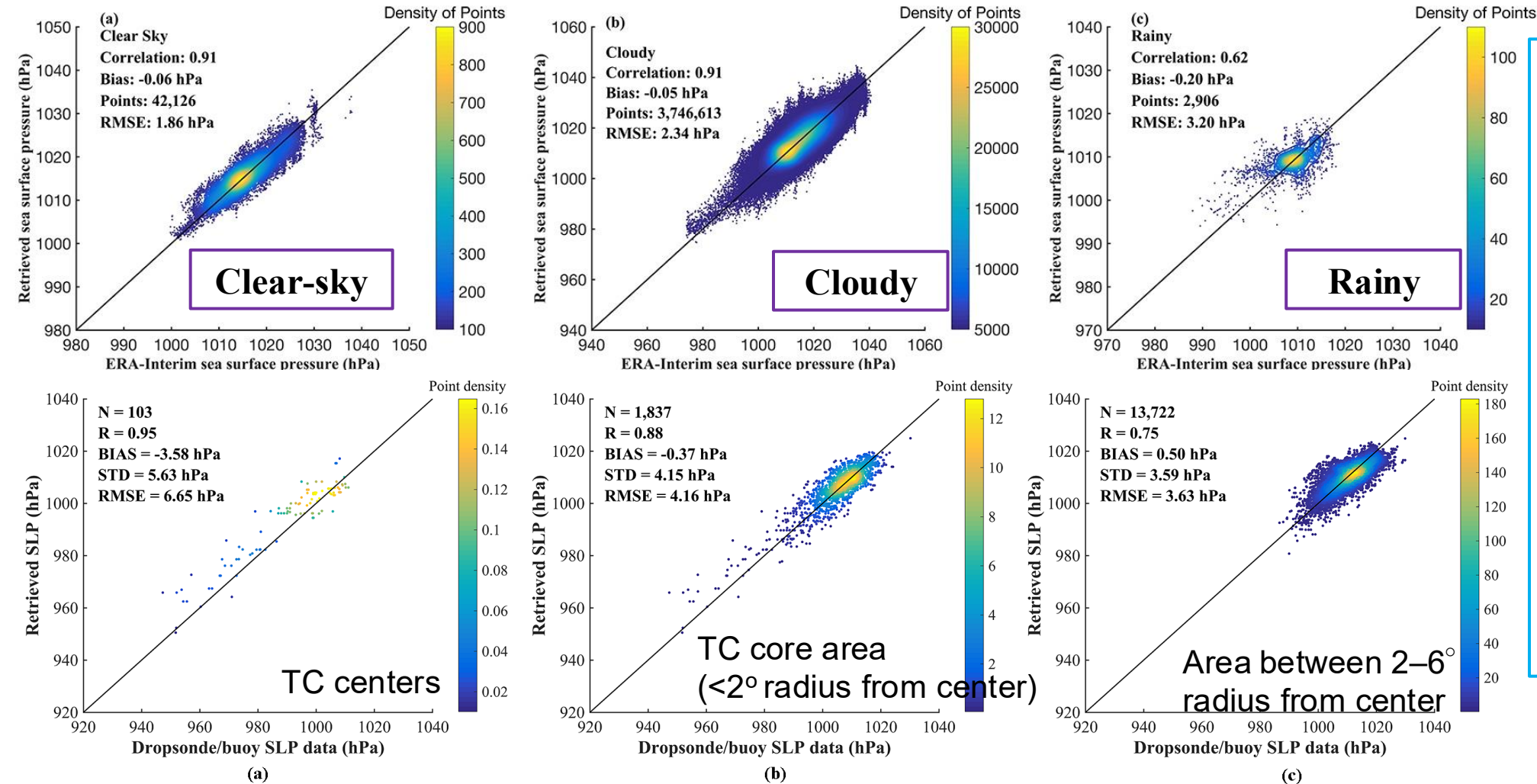


Validate the retrievals from joint observations of FY-3D/MWTS-II and FY-3D/MWHTS using in situ data



- Validations using reanalysis data and in situ data demonstrate that the retrieval accuracy of the optimized retrieval algorithm is 1.86 hPa for clear-sky, 2.34 hPa for cloudy, and 3.20 hPa for rainy, 2.78 hPa for the core area of tropical depressions and tropical storms, 4.23 hPa for the core area of typhoons or hurricanes, and 6.15 hPa for the core area of severe typhoons or major hurricanes.

Summary of Validation results



- RMSE:**
- Clear-sky: 1.86 hPa
 - Cloudy: 2.34 hPa
 - Rainy: 3.20 hPa
 - Core area of tropical depressions and tropical storms: 2.78 hPa
 - Core area of typhoons or hurricanes: 4.23 hPa
 - Core area of severe typhoons or major hurricanes: 6.15 hPa

Summary:



- Sea surface atmospheric pressure data can be retrieved from observations of spaceborne microwave radiometers operating in the O₂-band, which relies on the radiometers' capability to measure total columnar O₂ absorption.
- A backpropagation neural network (BPNN)-based retrieval algorithm is developed and optimized to retrieve sea surface pressure from passive microwave observations.
- Validations using reanalysis data and in situ data demonstrate that the retrieval accuracy of the optimized retrieval algorithm are:
 - ✓ 1.86 hPa for clear-sky; 2.34 hPa for cloudy; 3.20 hPa for rainy;
 - ✓ 2.78 hPa for the core area of tropical depressions and tropical storms;
 - ✓ 4.23 hPa for the core area of typhoons or hurricanes;
 - ✓ 6.15 hPa for the core area of severe typhoons or major hurricanes.
- Relevant methodology and data have been developed.
- Deliverables will be released in June 2026.

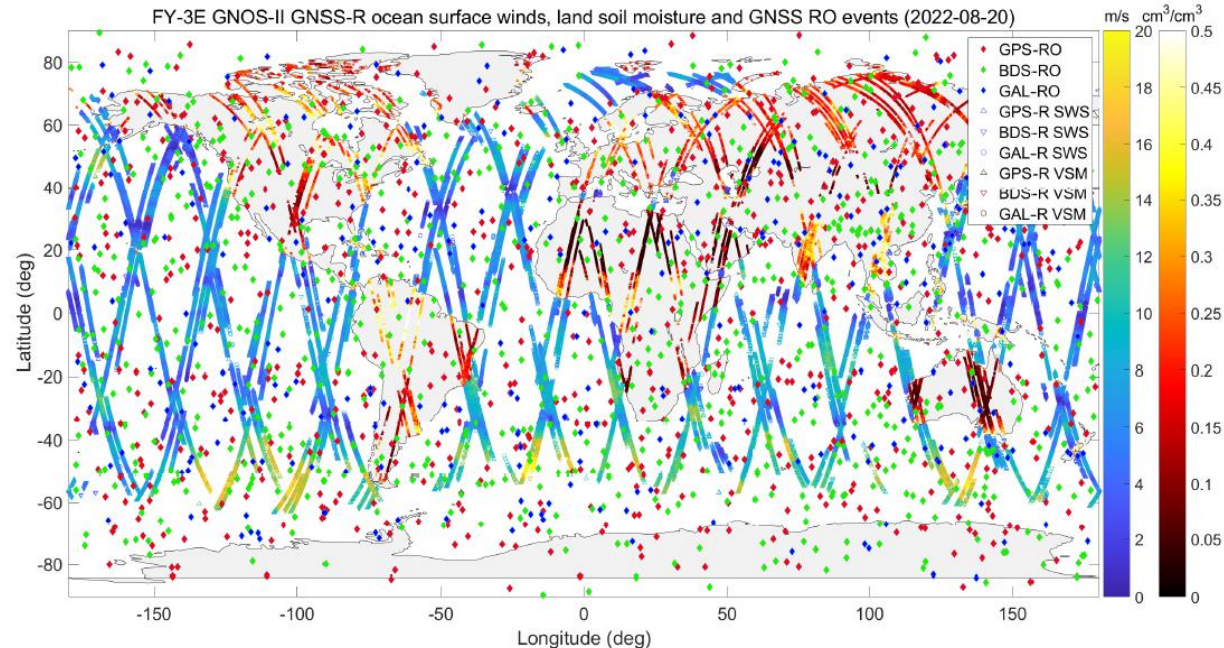
2. Proposal for new tasks



Calibration and Validation of GNSS-R Data for
microsats/cubesats

Introduction

- GNSS-RO and GNSS-R provide important data for atmospheric and ocean/land surface;
- GNSS-RO constellations and GNSS-R constellations, as well as constellations, such as Chinese FengYun-3 missions (FY-3E/F/G/H), with GNSS RO and GNSS-R together, have been operational for several years, which provide observations of atmospheric profiles, ionospheric profiles, ocean surface winds, land soil moisture and sea ice parameters



Introduction of GNSS (L-band) radio occultation (RO)

Measurements & atmospheric products:

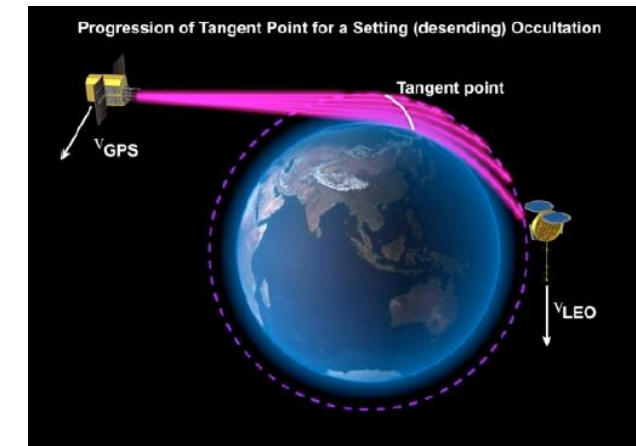
- Time (Carrier-wave phase)
- Excess phase
- **Bending angle**
- **Refractivity**
- Temperature
- Humidity
- Pressure

Features:

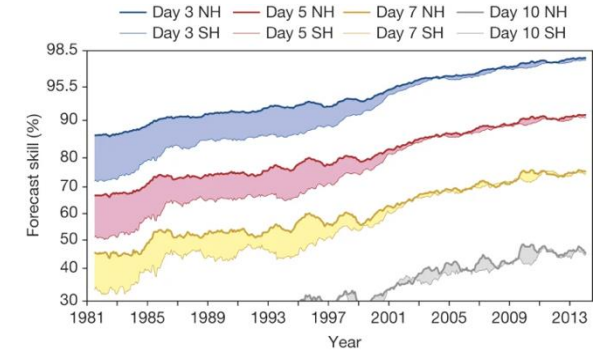
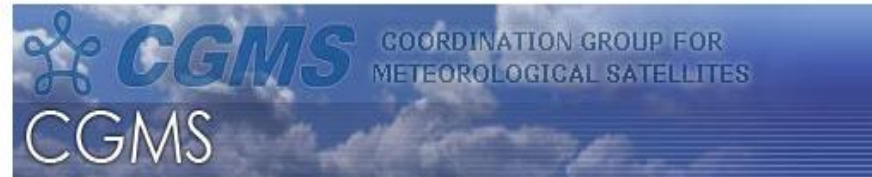
- **Measurements traceable to SI time standard**
- High vertical resolution
- High accuracy
- All-weather capability
- Global coverage
- Long-term stability

Applications:

- Climate monitoring
- Numerical weather prediction (NWP)
- Meteorological disaster monitoring



Cal/Val tasks of GNSS-RO under CGMS/IROWG



Coordination Group for Meteorological Satellites (CGMS):

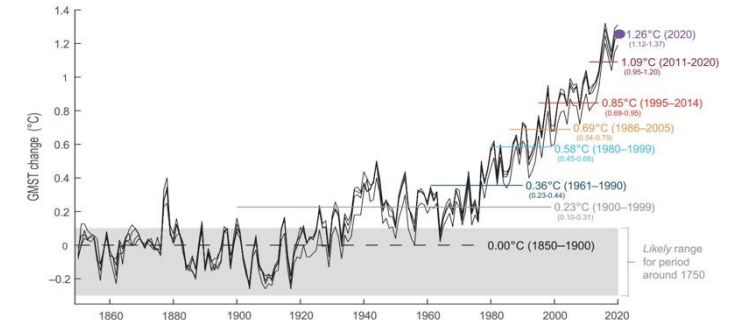
- Protection of in-orbit assets
- Contingency planning
- Data quality improvement
- Shared data access facilitation
- Satellite product application development

International Radio Occultation Working Group (IROWG):

- Established as a permanent CGMS working group at its 37th meeting (2009, South Korea)
- Co-sponsored by CGMS and WMO
- Serves as a forum for operational & research users of radio occultation data

Cal/Val tasks:

- **rOPS** for Climate monitoring application
- **ROMEX** for Numerical weather prediction (NWP) application



Cal/Val tasks of GNSS-RO under CGMS/IROWG

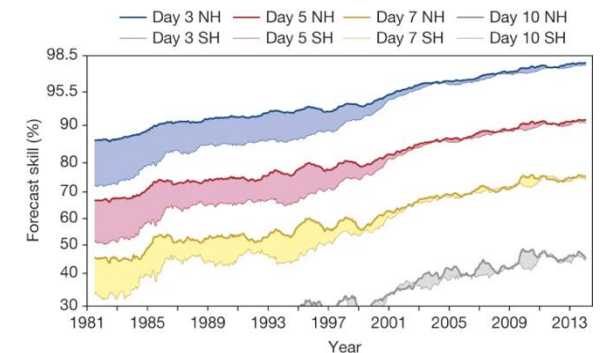
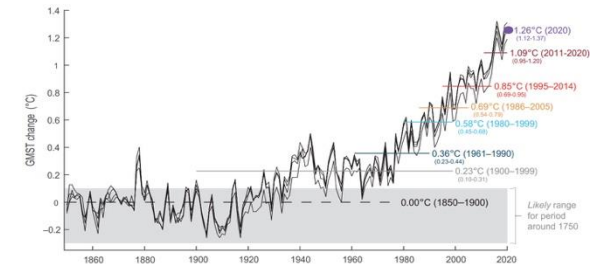
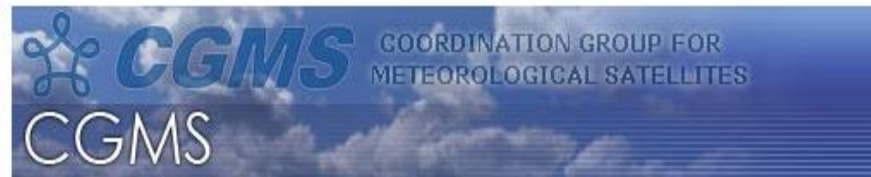
Coordination Group for Meteorological Satellites (CGMS):

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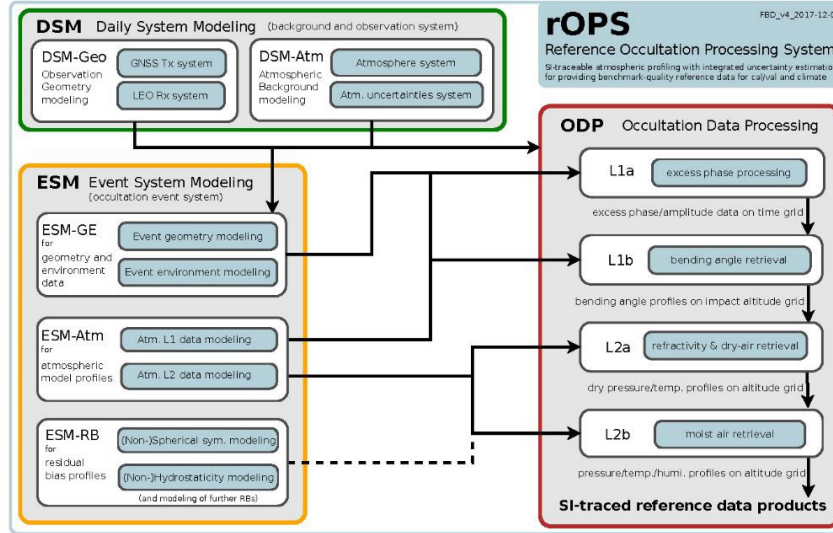
Reference occultation processing system (rOPS)

RO processing with fully traceable uncertainties:
rOPS approach allows highly reversible analysis up and down the chain of all RO variables, enables SI-traceable profiling & uncertainty estimation.

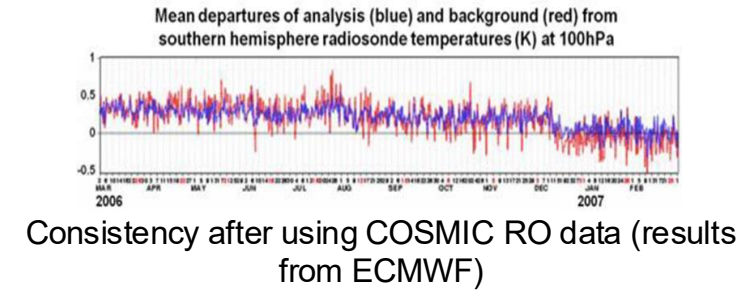
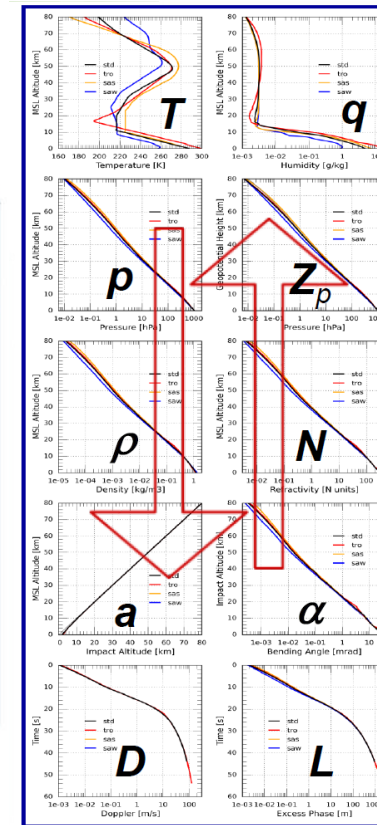
...rOPS international advisers and cooperation partners

- EUMETSAT: Christian Marquardt, Yago Andres, Axel von Engeln, Riccardo Notarpietro
 - EUM/ROM SAF (DMI, ECMWF): Stig Syndergaard, Joe Nielsen, Kent Lauritsen, Sean Healy
 - UCAR, JPL: Bill Schreiner, Doug Hunt, Tony Mannucci, Chi Ao
 - IAP, TUG: Michael Gorbunov, Torsten Mayer-Gürr
 - AIUB, DLR: Adrian Jäggi, Oliver Montenbruck
 - NSSC/CAS, IGG/CAS, RMIT: Congliang Liu, Ying Li, Kefei Zhang
 - ...and more may join as the work proceeds...thanks all!
- Two main lines of cooperation:**
- joint papers (on specific rOPS-related key issues to be solved)
 - advice & expert meetings (~1-day review/advice meetings at WEGC)

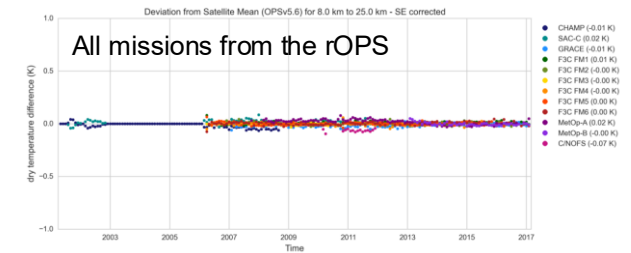
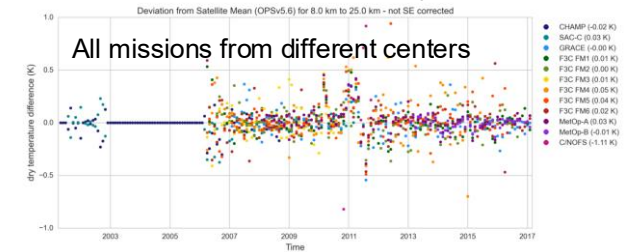
The rOPS team led by Prof. Gottfried Kirchengast from WEGC, including: EUMETSAT, DMI, ECMWF, UCAR, JPL, IAP, TUG, DLR, **NSSC**, RMIT, et al.



Logic of the rOPS system modeling and data analysis approach



Consistency after using COSMIC RO data (results from ECMWF)

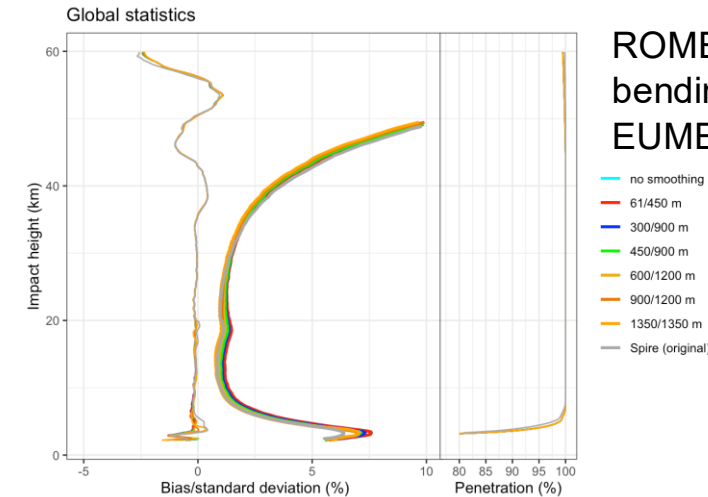


Cal/Val Conclusions for IPCC: RO data quality validated by rOPS team and accepted by AR6 co-author, then published as benchmark dataset in IPCC AR6.

Radio Occultation Modeling EXperiment (ROMEX)

ROMEX IROWG-Led RO Cal/Val Task:

- Scope: Numerical weather prediction (NWP)
- Experimental datasets of ~35,000 daily RO profiles
- Data source: 13 missions (Sept–Nov 2022)
- **International campaign involving:**
 - Data providers: COSMIC/Metop/Spire/Fengyun/TianMu/YunYao, et al.
 - Processing centers: EUMETSAT/UCAR/NSSC/DMI
 - Forecasting institutions: ECMWF/CMA/Met Office
 - Global research & operational communities



ROMEX Cal/Val results of bending angle from EUMETSAT

BAMS
Article

Radio Occultation Modeling Experiment (ROMEX): Determining the Impact of Radio Occultation Observations on Numerical Weather Prediction

Richard A. Anthes,^a Christian Marquardt,^b Benjamin Ruston,^c and Hui Shao^f

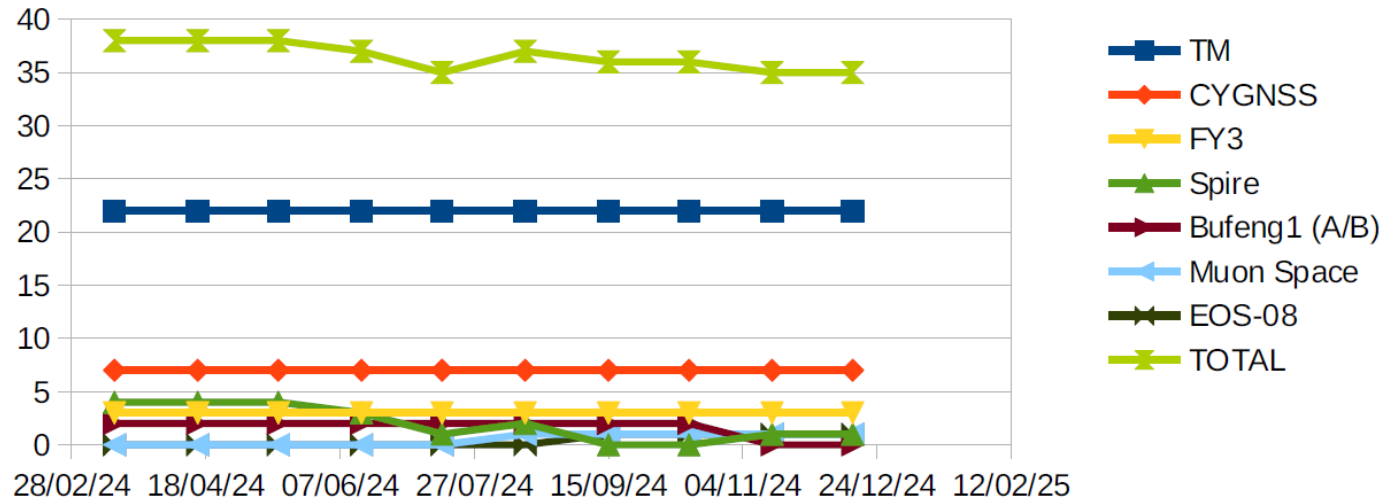
Cal/Val Conclusions for CGMS: All bending angle data sets for ROMEX exhibit similar data characteristics and are of sufficient data quality to carry out experiments required for ROMEX.

Next phase: Impact study in NWP models

Demand for GNSS-R CaI/Val

- There are currently **near 40 GNSS-R satellites** in orbit from multiple national and commercial missions including CYGNSS, Fengyun-3, Bufeng-1, Spire, Tianmu-1, Muon, DoT-1, TRITON, EOS-8 and future missions such as HydroGNSS, Amazonia-1B, FY-3 follow-ons and FY-5.

Approximate number of GNSS-R operating satellites



- FY-3 series are large core satellites
- The others are microsats/cubesats (some are commercial satellites)

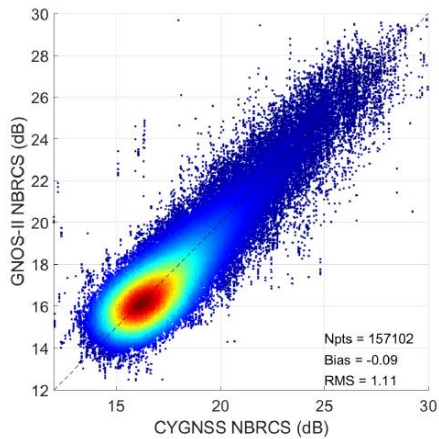
From Estel Cardellach et al. in IEEE GNSS+R25 in Leiden

Motivation of GNSS-R Cal/Val

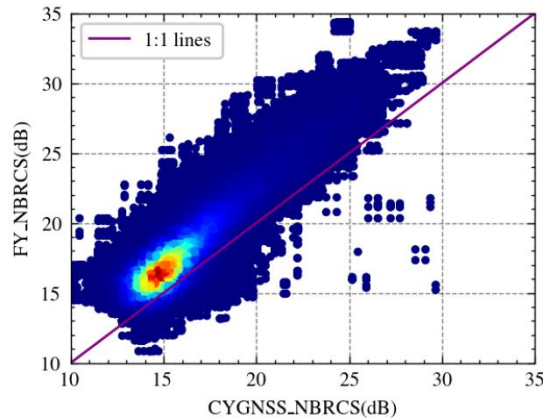
- Some GNSS-R missions are extensive calibrated (such as CYGNSS and FY-3), but some others are not (especially commercial ones).
- There are significant inconsistencies in the L1 normalized bistatic radar cross section (NBRCS/ σ_0) over the ocean from different GNSS-R missions and different GNSS constellations (GPS/BeiDou/Galileo/GLONASS..)
- It is urgent to establish a benchmark for GNSS-R NBRCS over the ocean for the intercalibration of different missions.
- It will be very helpful to build an inter-calibrated virtual GNSS-R constellation of 40+ satellites (e.g. the METACONRef Project of ICE-CSIC/IEEC)

Motivation of GNSS-R Cal/Val

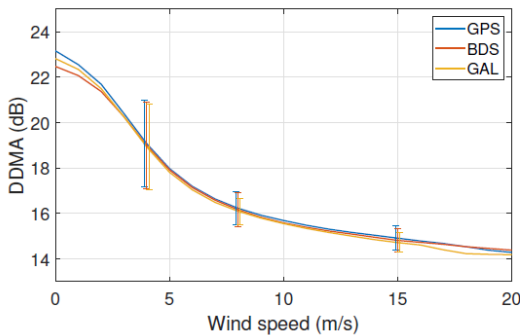
FY-3E vs. CYGNSS v3.0



FY-3E vs. CYGNSS v3.1

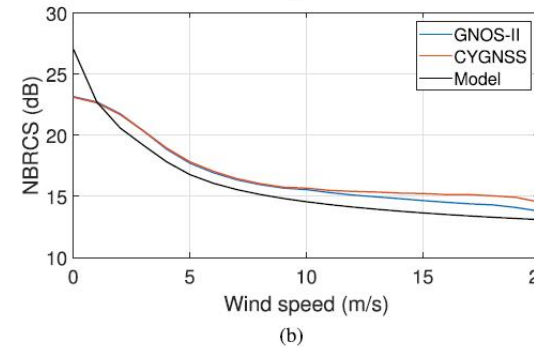
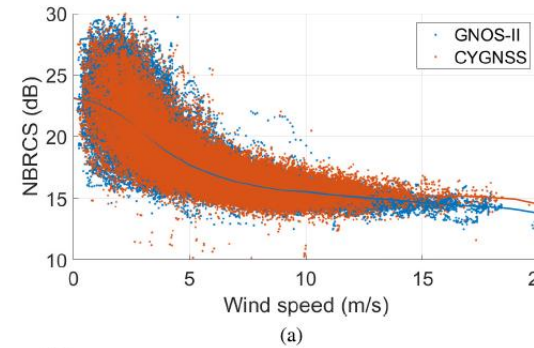


Yang et al. 2025



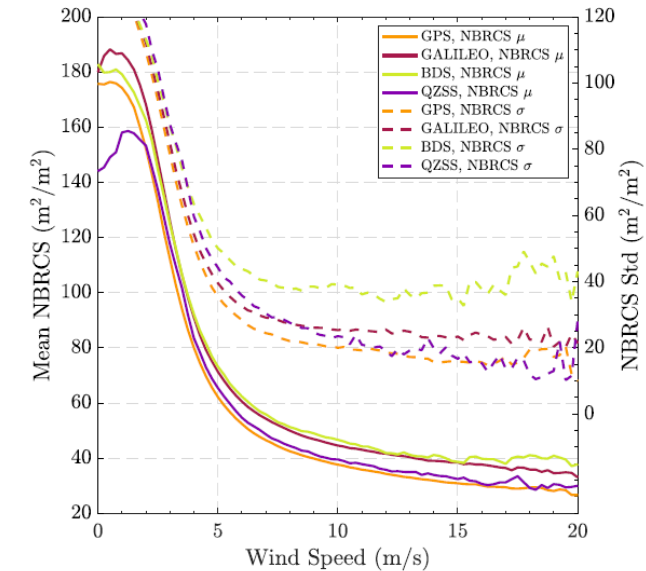
Huang et al. 2022

satellite observation vs. empirical model



Huang et al. 2022

Spire's LEMUR-2



M. Al-Khaldi et al. 2023

Significant inconsistencies in the GNSS-R radar cross section between different missions/GNSS systems/models

Proposal for GNSS-R Cal/Val



A two-stage calibration workflow:

- **Power calibration**

$$P_N = G C_N$$

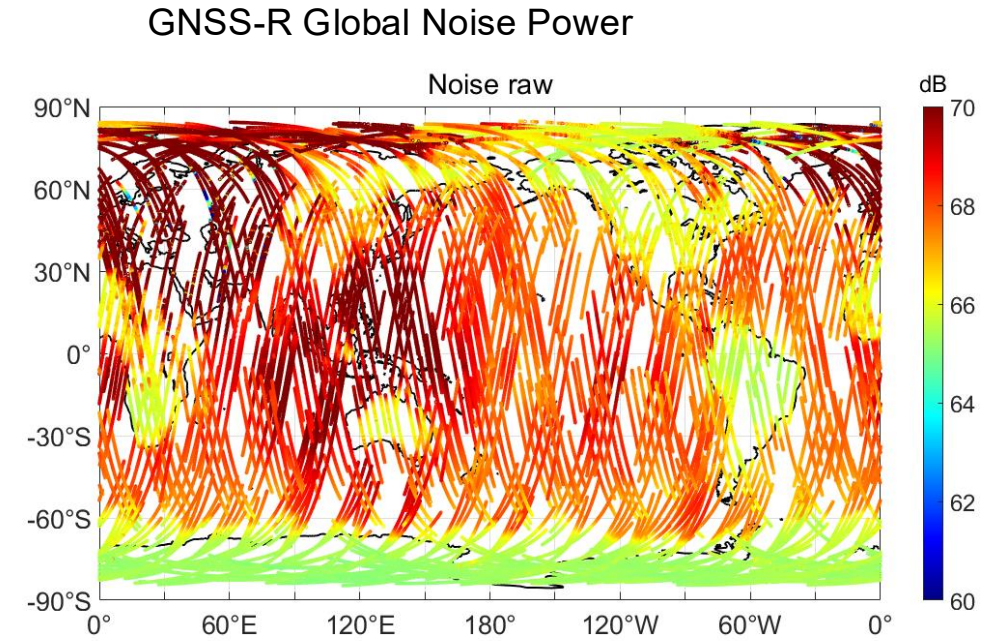
Use **noise from the Antarctic** as reference

- **NBRCS/sigma0 calibration**

$$\sigma_0 = P_r \left(\frac{\lambda^2 P_t G_t G_r}{(4\pi)^3 R_t^2 R_r^2} \right)^{-1} A_{eff}^{-1}$$

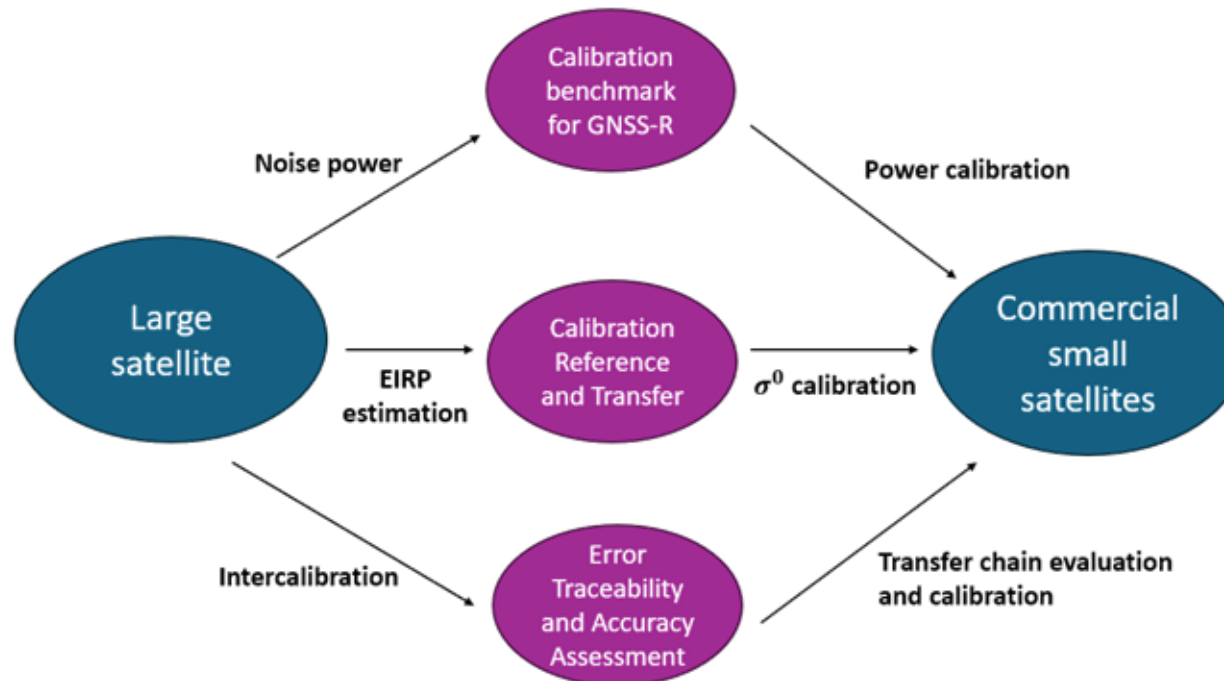
Two approaches for NBRCS/sigma0 calibration

- Use a generalized forward model (minimize O-B)
- Use a reference satellite for intercalibration



Proposal of using a core satellite (e.g. FY-3/FY-5...) to calibration commercial Microsat/Cubesats

- Large satellites (e.g., FY-3 series) feature superior thermal and attitude control and high calibration accuracy, whereas small satellites, particularly commercial platforms, are generally less well calibrated.
- It is thus suggested to employ a highly calibrated large satellite as a benchmark for the calibration of small satellites.



Task Objective and expected deliverables

1) Establish a benchmark for **GNSS-R NBRCS (sigma-0)** over the oceans

- Provide a reference model of GNSS-R ocean NBRCS in a function of wind speed and incidence angle (and potential swell height and wave age)
- A Best Practices Protocol Document for the Cal/Val of GNSS-R NBRCS

2) Provide a **well-calibrated GNSS-R datasets** for the **CAL/VAL** of **ALL** missions

3) Develop the **standard methodology** for calibration/validation of GNSS-R products, including cross calibration

Proposed Task Team

- National Space Science Center (NSSC), EUMETSAT ([Task lead or co-leads](#))
- Plan to invite members from other missions ([CYGNSS](#), [HydroGNSS](#), [.etc](#))
- NSSC also has groups of scatterometer and GNSS-RO (more standardized internationally than GNSS-R) which can provide a lot of good suggestions.
- CYGNSS and FY-3 are the only two GNSS-R missions whose data are fully open to the public and well calibrated), so they are the best for us to start with.

3. Coordination with GSICS MW-subgroup



Topic:

Characterization of onboard calibration and cross-calibration for microwave sounders of microsat constellations

- Characterization of onboard calibrator;
- Characterization of onboard calibration measurements;
- Reference transfer and cross-calibration.