AOMSUC-15 FYSUC-2025
FIFTEENTH ASIA-OCEANIA METEOROLOGICAL SATELLITE USERS' CONFERENCE
THE JOINT 2025 FENGYUN SATELLITE USER CONFERENCE

Hybrid Observing System Simulation Experiment (Hybrid-OSSEs) for the Fengyun-4 Geostationary Orbit Microwave Satellite based on CMA-GFS

Ke Chen, Wei Han, Yingying Chen, Zihao Suo

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Ke Chen[1], Wei Han[2], Yingying Chen[1], Zihao Suo[1]

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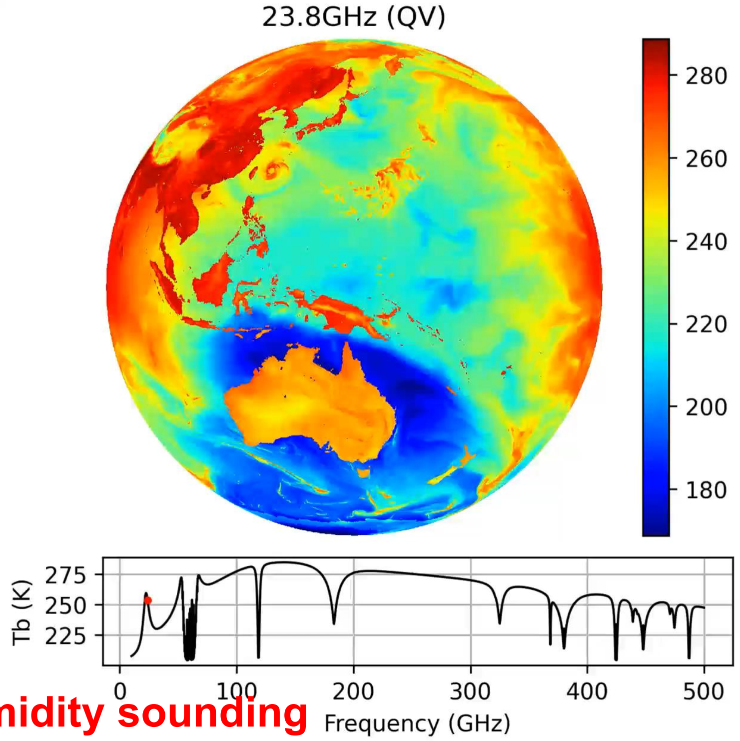
3. What is Hybrid-OSSE?

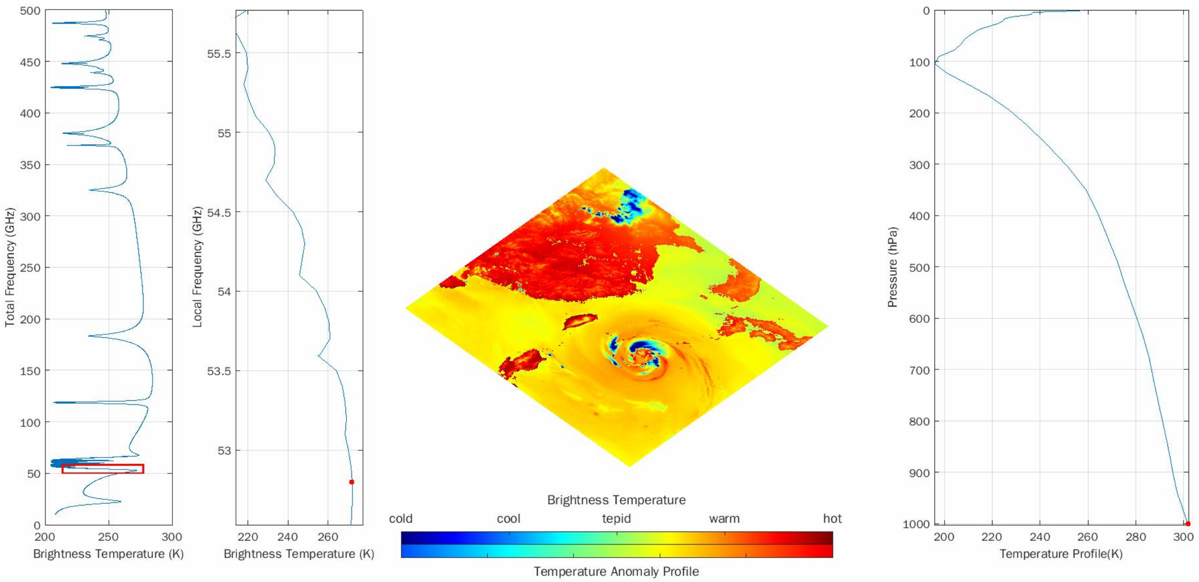
Geostationary Orbit Microwave Observation

Full Disk

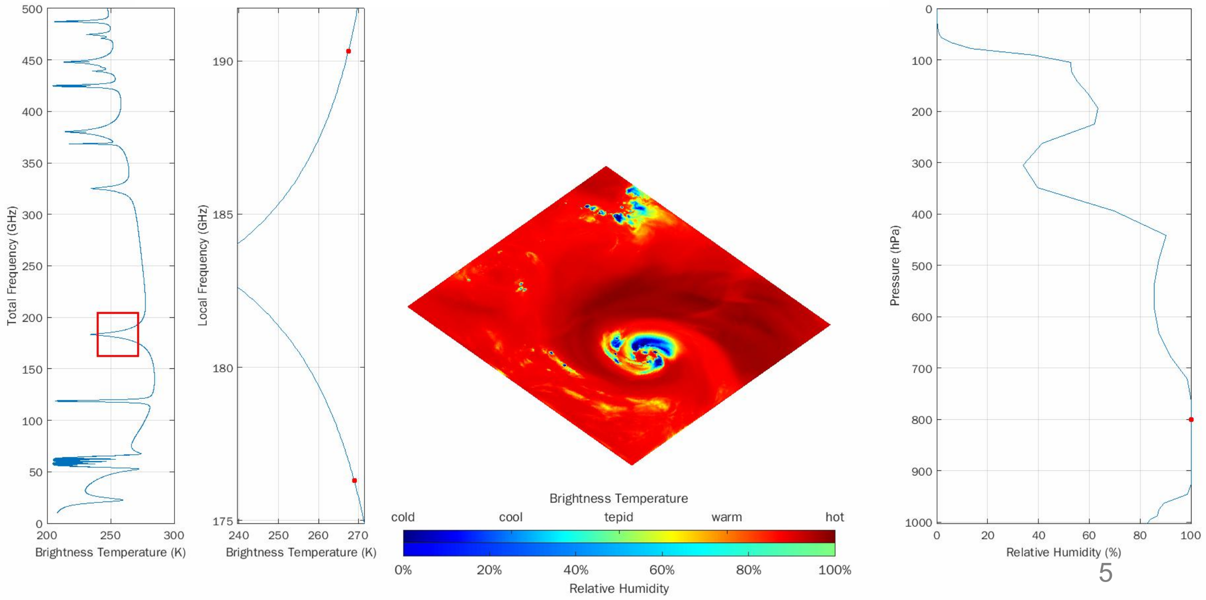


High temporal resolution

All-sky atmospheric temperature and humidity sounding



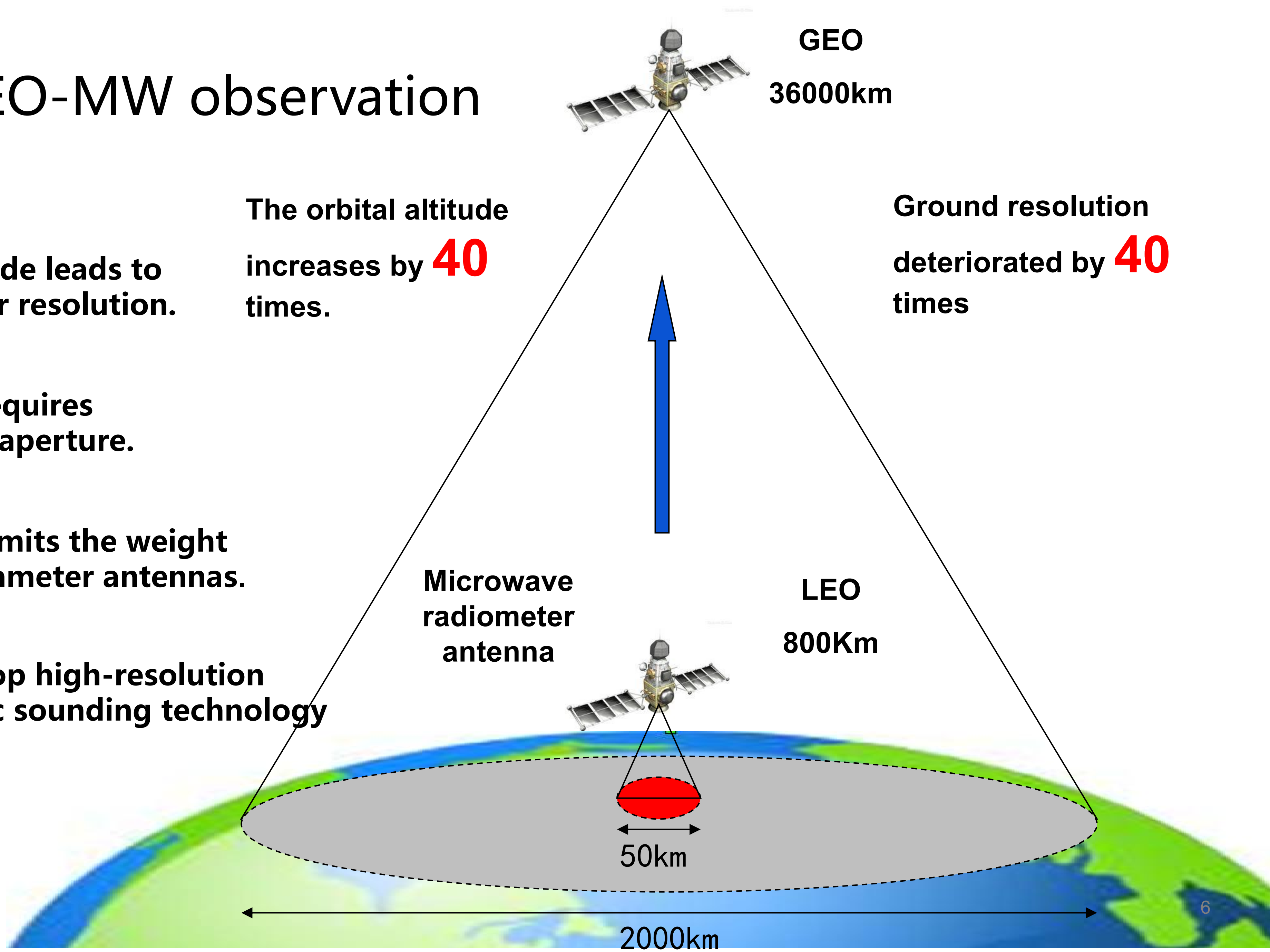
50-60GHz atmospheric temperature sounding



183GHz atmospheric humidity sounding

Difficulties in GEO-MW observation

1. **Increasing orbital altitude leads to higher requirements for resolution.**
2. **Increasing resolution requires increasing the antenna aperture.**
3. **The satellite platform limits the weight and volume of large-diameter antennas.**
4. **It is necessary to develop high-resolution microwave atmospheric sounding technology**



Technical route of GEO-MW

Real aperture

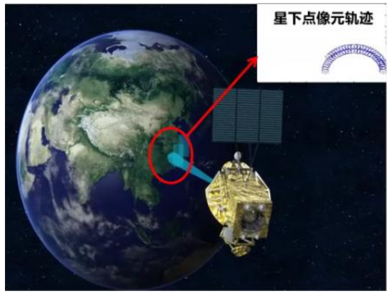
Shanghai Aerospace Electronic Technology Institute

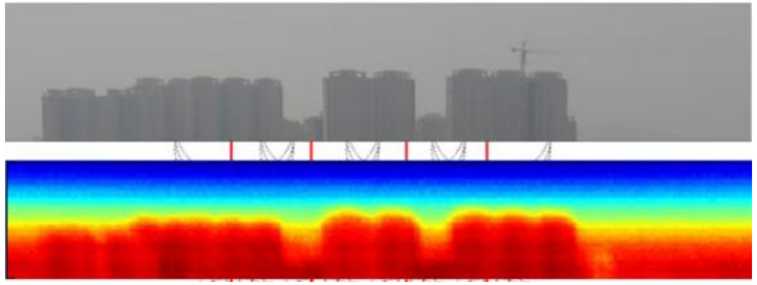
Synthetic aperture：GeoSTAR

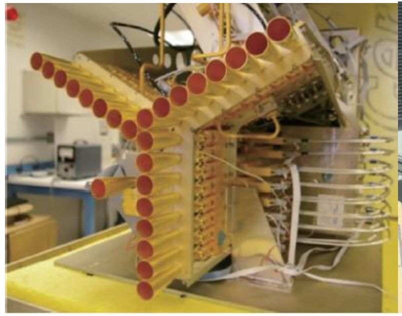
NASA JPL

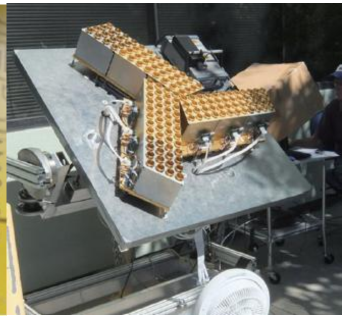
Dual-mode: Rotating Synthetic Aperture + Real Aperture GIMS

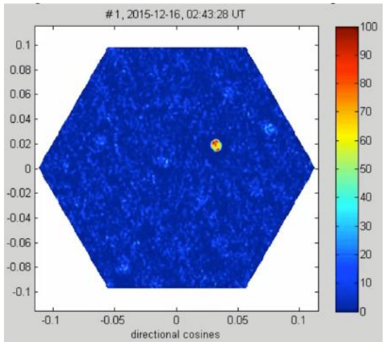
CAS NSSC

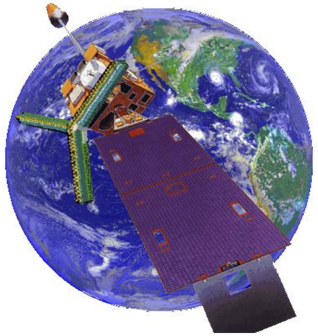


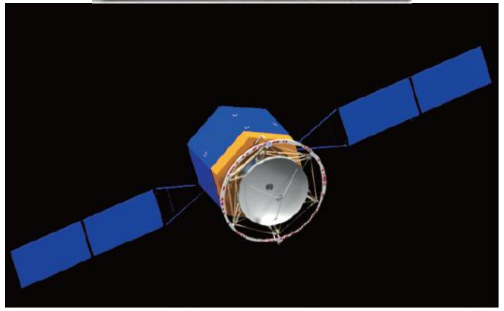








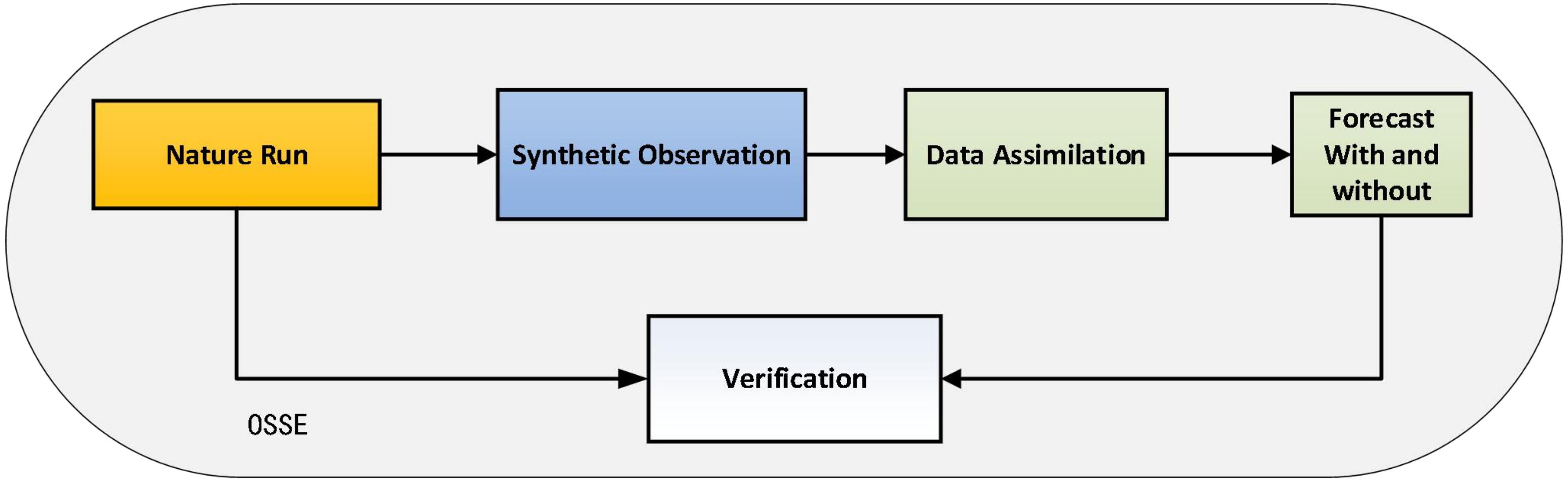




	frequency	Antenna/Array	size	number	Observation period	Resolution
Real aperture	23.8-425GHz(135 channels)	Cassegrain	5m	/	15min@1500km	50-17km
GeoSTAR	53/183GHz	Y-shaped array	3.6m	312/700	0.1-1min@fulldisk	50-25km
GIMS	50-425GHz	rotating circle array + Cassegrain	3.6m	70	1-10min@fulldisk	50-17km

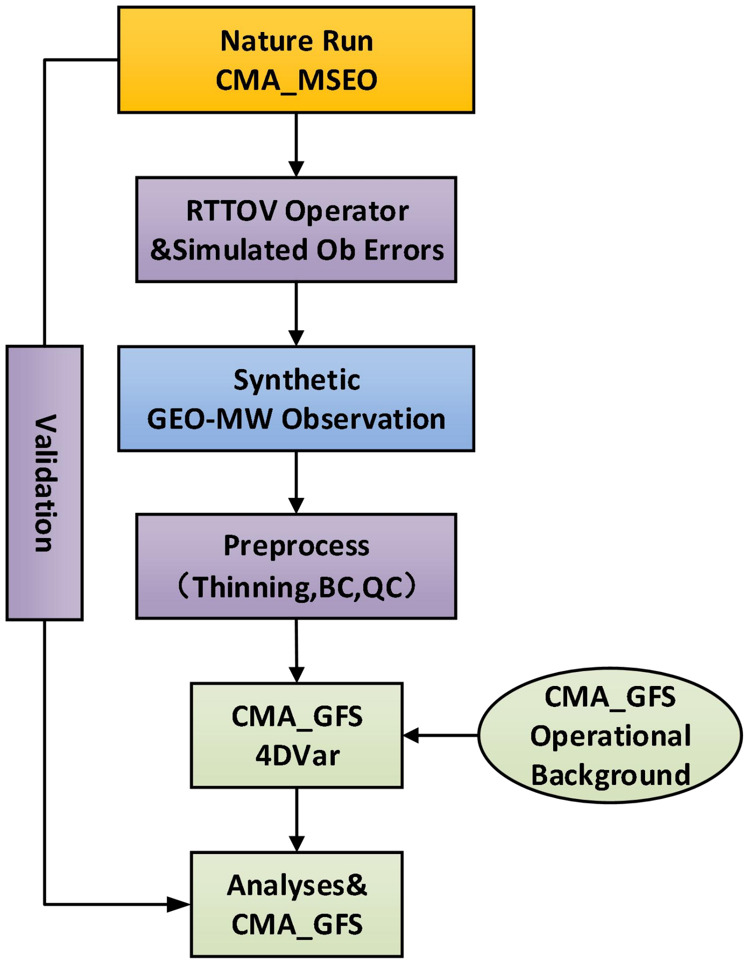
Motivation of GEO-MW OSSE

- An observing system simulation experiment (OSSE) is a modeling experiment used to evaluate the value of a new observing system when actual observational data are not available.
- The numerical weather prediction community (NWP) has developed and utilized OSSEs to understand the impact of instrument designs and new observations on numerical forecasts over the last 40 years.

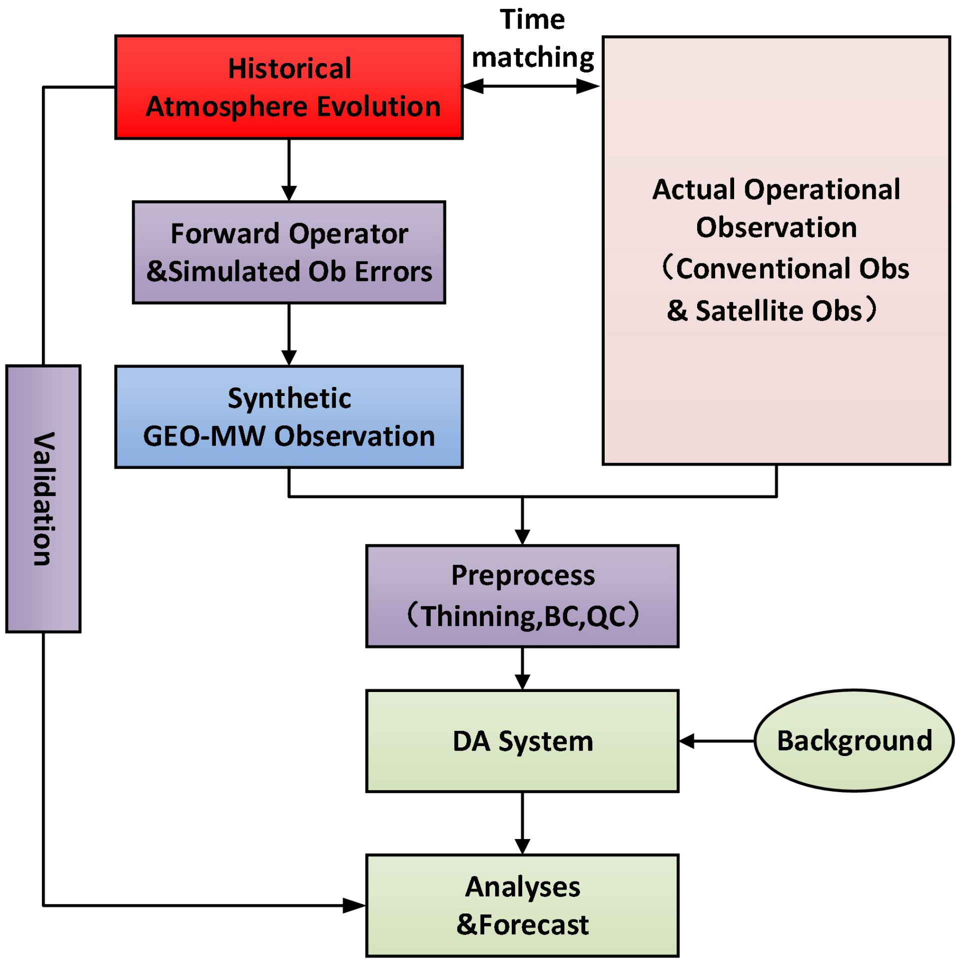


- To determine whether a new observing system will add value to NWP and analysis
- To make design decisions for a new observing system or network
- To investigate the behavior of data assimilation systems and thereby optimally tune these systems in an environment where the "truth" and hence the system's behavior is known

Quick-OSSE



Hybrid-OSSE



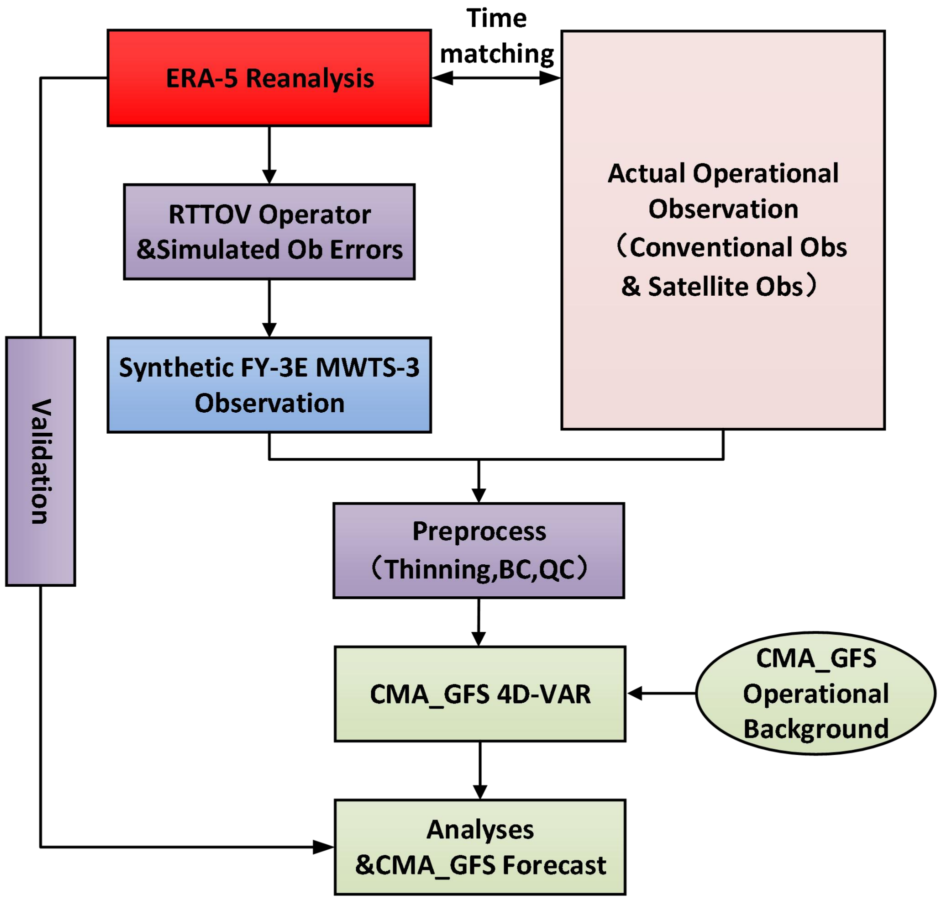
1. Ke Chen, .et al Geostationary microwave observation system simulation experiments using the GRAPES 4D-Var. Acta Meteorologica Sinica，2021，79（5）
2. Ke Chen, Zihao Suo, Wei Han. OSSEs on the FY-4M Geostationary Microwave Satellite Based on CMA-GFS and CMA-MESO, IEEE TGRS, 2024,Vol 62.
3. Ke Chen, Zihao Suo. Assessing the Potential Impact of Microwave Sounders on Typhoon Prediction using OSSEs A Comparative Study between LEO Constellation and GEO Satellites, IEEE GRSL, 2025,Vol 22.

Hybrid-OSSE Validation——FY-3E MWTS3 /02

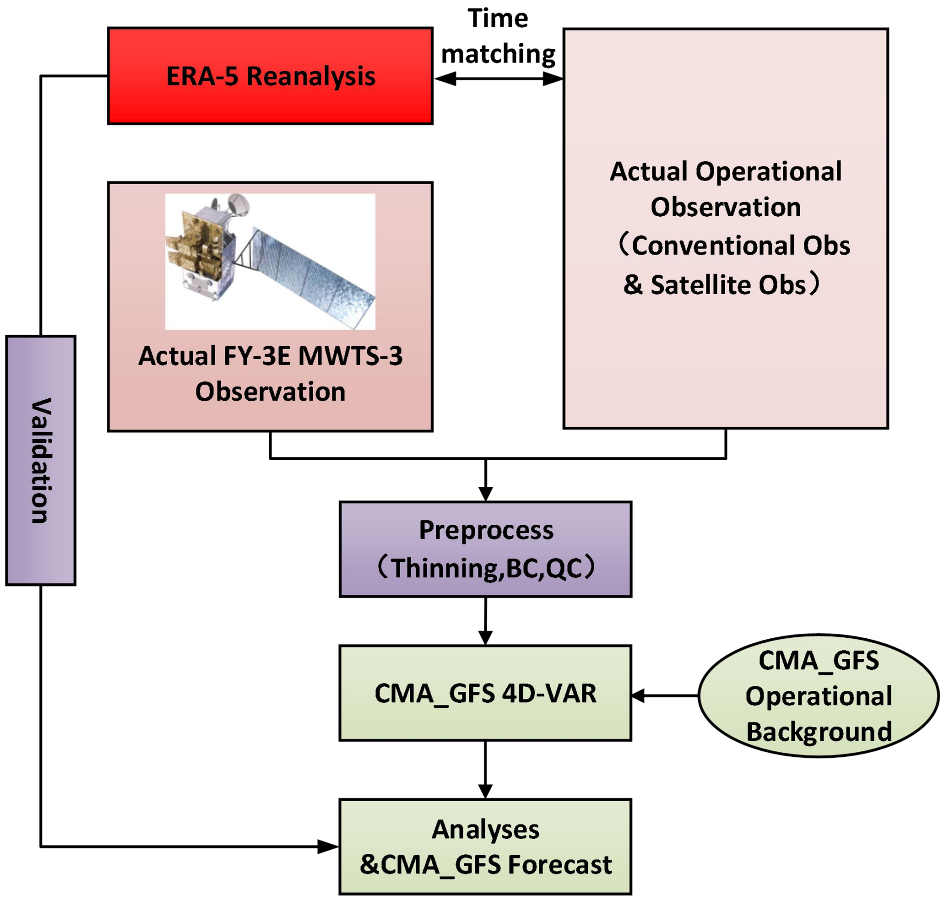
1. Analysis data verification
2. Observation space verification
3. Forecast Sensitivity to Observation (FSO) verification
4. Verification of Typhoon Track Forecast

Verification Experiment of Hybrid-OSSE Scheme Based on CMA_GFS and ERA5——FY-3E MWTS3

- Since an OSSE is fundamentally a simulation of the application of a DA system to real observations, adequate validation is required.



FY-3E MWTS3 Hybrid-OSSE Based on CMA_GFS



Actual FY-3E MWTS3 DA based on CMA_GFS

Observation type	Instrument Code	Instrument Name	Platform	Assimilated variable
CONV	TEMP	Radiosonde/Upper-air sounding		Wind, temperature, relative humidity
	SYNOP	Surface Synoptic Observation		Air pressure
	BUOY	Buoy		Wind
	SHIP	Ship-based Observation		Air pressure
	AIREP	Aircraft Report		Wind, temperature
SAT	GNSS RO	GNSS Radio Occultation	COSMIC-2, KOMPSAT, TanDEM-X, GRACE-A, TerraSAR-X , PAZ1, METOP-A/B/C, FY-3C/D	Refractivity
	GPS PW	GPS Precipitable Water		Total column water vapor
	AMV(SATOB)	Atmospheric Motion Vectors	FY-2G/H, GOES-16/17, Himawari-8, SNPP, METEOSAT-10/11, INSAT-3DR, TERRA, AQUA, HY-2B, NOAA-15/18/19/20	Wind
	SCATWIND	Scatterometer Wind	METOP-A/B/C	Wind

Platform	Instrument	Organization	Sounding purpose
FY3D	MWHS2	CMA	humidity
FY3D	MWRI	CMA	imaging
FY3D	MWTS2	CMA	temperature
FY3E	MWHS2	CMA	humidity
METOP-B	AMSUA	EUMETSAT	temperature
METOP-B	MHS	EUMETSAT	humidity
METOP-C	AMSUA	EUMETSAT	temperature
METOP-C	MHS	EUMETSAT	humidity
NOAA-15	AMSUA	NOAA	temperature
NOAA-18	AMSUA	NOAA	temperature
NOAA-19	MHS	NOAA	humidity
NOAA-20	ATMS	NOAA	Temperature, humidity
SUOMI NPP	ATMS	NOAA	Temperature, humidity

FY-3E MWTS3 Hybrid-OSSE Validation Experiment

Experimental code	Observation data composition
CONV	Conventional observations, as CTRL-1
CONV+MWTS3	Conventional observations, MWTS3
CONV+MWTS3-S	Conventional observations, MWTS3-S
CONV+SAT	Conventional observations, satellite observations (including microwave), as CTRL-2
CONV+SAT+MWTS3	Conventional observations, satellite observations, MWTS3
CONV+SAT+MWTS3-S	Conventional observations, satellite observations, MWTS3-S

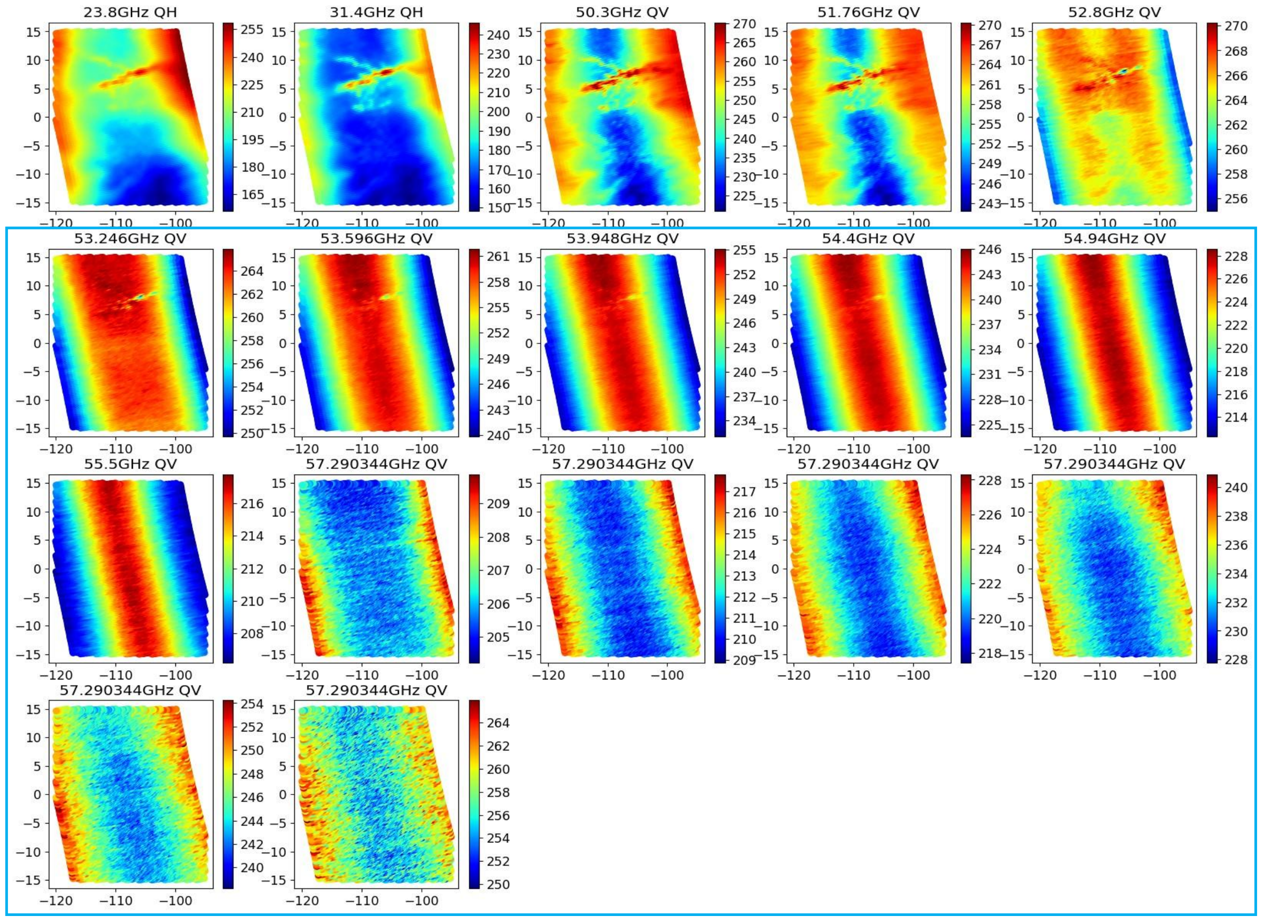
① Analysis data verification

② Observation space verification

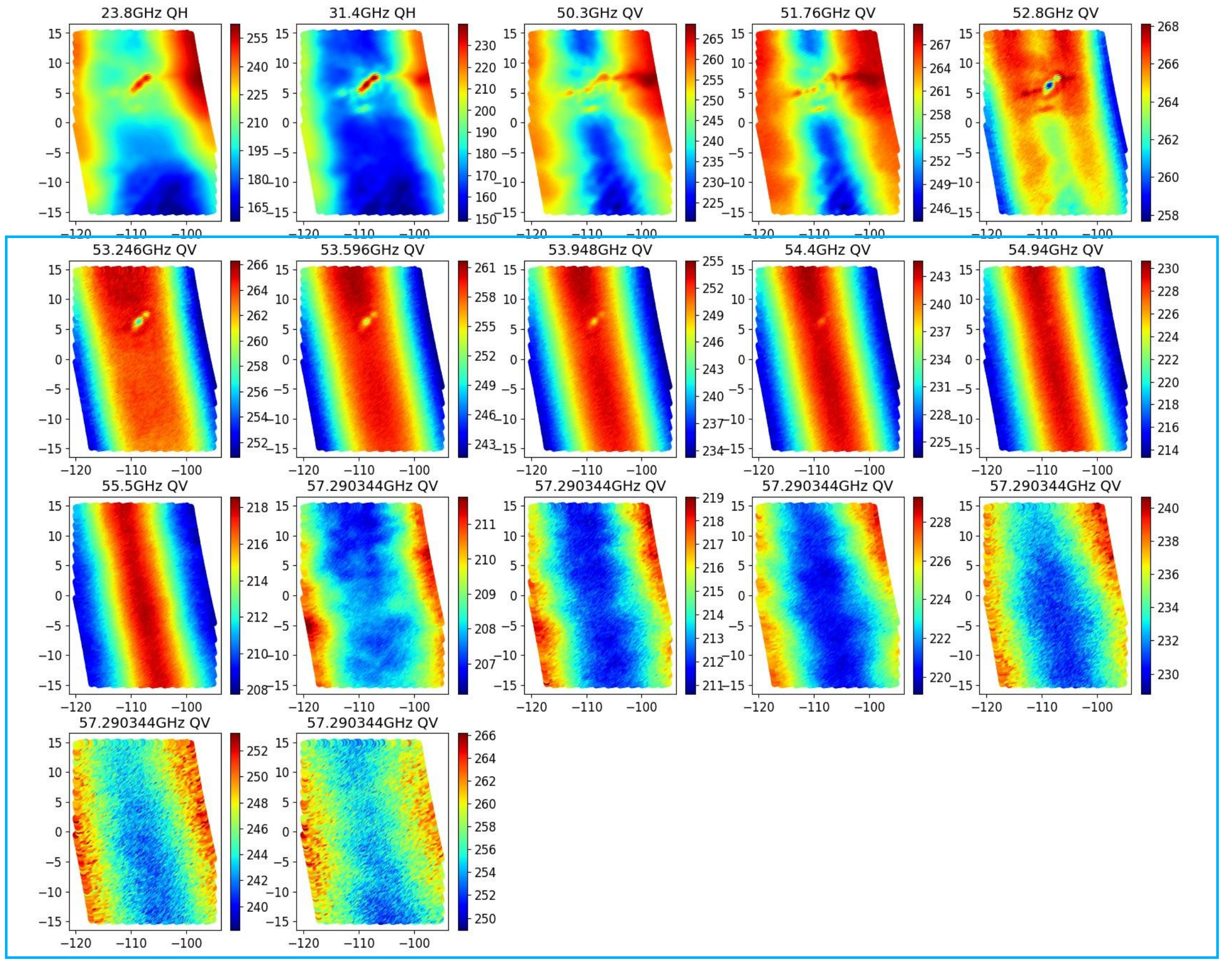
③ Forecast Sensitivity to Observation (FSO) verification

④ Verification of Typhoon Track Forecast

FY-3E MWTS3 Observation



FY-3E MWTS3 Simulation

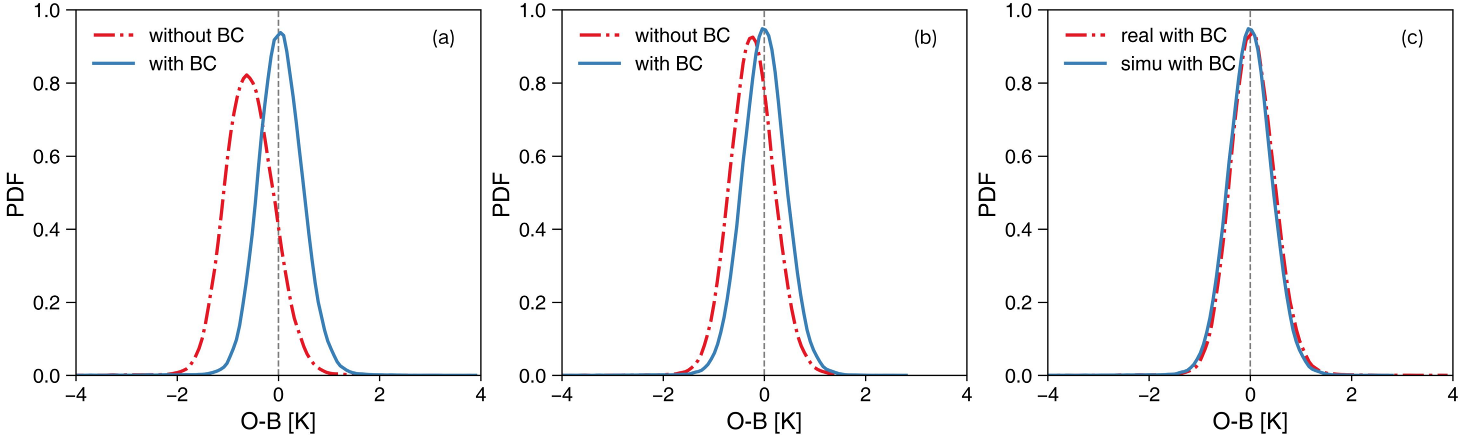


The noise matching of simulated and observed MWTS3 TB

- OSSE faces the challenge of inconsistent noise between simulated and actual observations, resulting in discrepancies in OMB statistics compared to those in the real DA system

No.	Frequency	STD (obs.) - σ_1	STD (noise-free simu.) - σ_2	NEDT	n
6	53.246±0.08GHz	0.49	0.35	0.35	0.33
7	53.596±0.115GHz	0.45	0.26	0.3	0.36
8	53.948±0.081GHz	0.48	0.24	0.35	0.41
9	54.4GHz	0.44	0.18	0.3	0.40
10	54.94GHz	0.38	0.21	0.3	0.32
11	55.5GHz	0.34	0.28	0.3	0.20
12	57.290344GHz(f0)	0.46	0.52	0.7	0.15
13	f0±0.217GHz	0.59	0.48	0.9	0.33
14	f0±0.3222±0.048GHz	0.78	0.72	0.9	0.32
15	f0±0.3222±0.022GHz	1.33	1.16	1.3	0.64
16	f0±0.3222±0.01GHz	2.12	1.73	1.6	1.13
17	f0±0.3222±0.0045GH	2.70	2.05	2.8	1.50

$$n = \sqrt{\sigma_2^2 - \sigma_1^2}$$

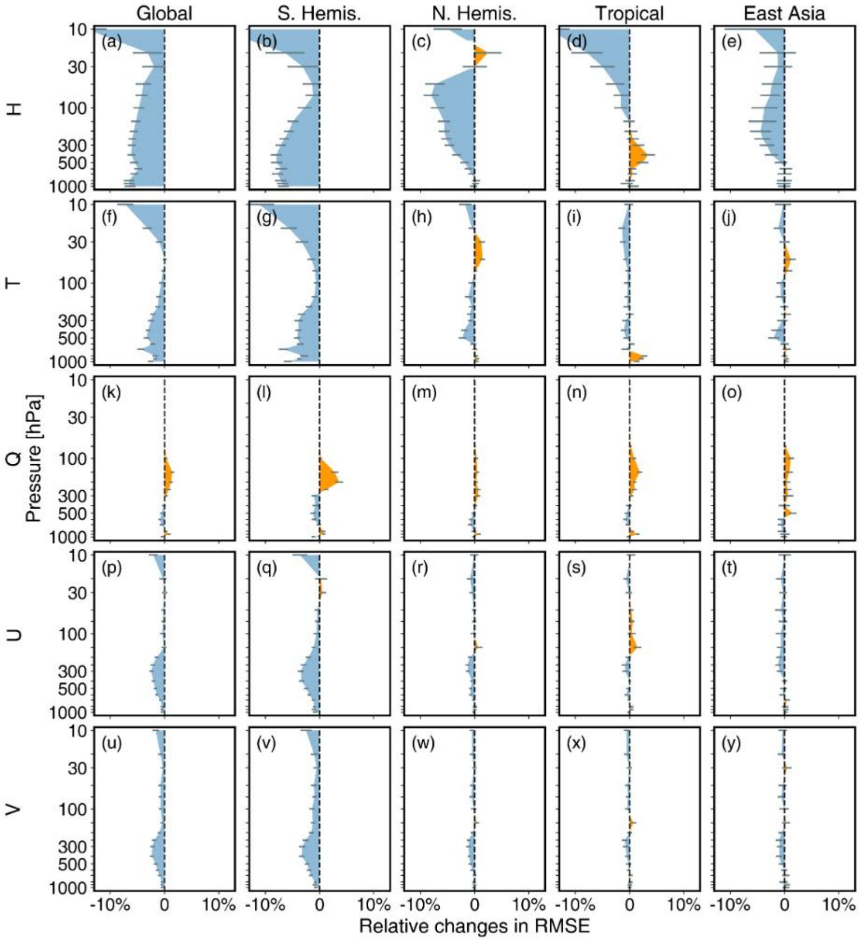


real brightness temperature   simulated brightness temperature   real and simulated brightness temperature

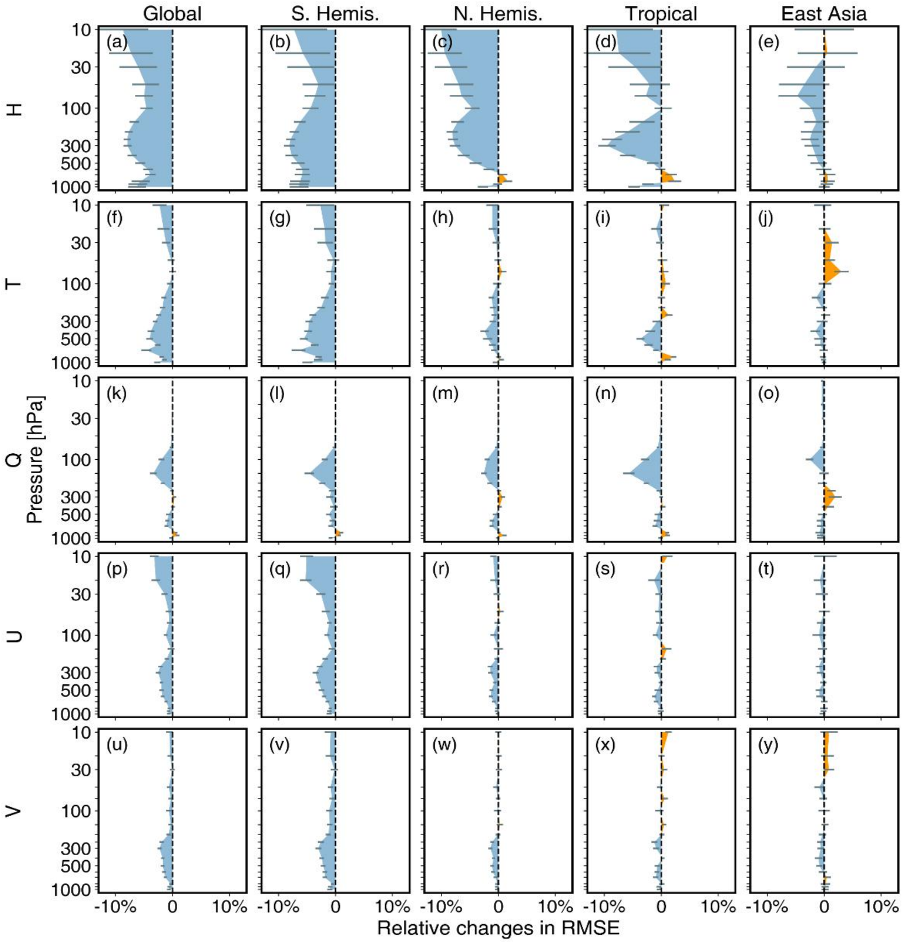
53.596 ± 0.115GHz
PDF distribution of OMB

FY-3E MWTS3 Hybrid-OSSE Validation——Analysis field

- Compare the analysis field assimilating CONV + MWTS3 data with that of the CTRL-1 (CONV).
- Blue — positive effect, orange — negative effect



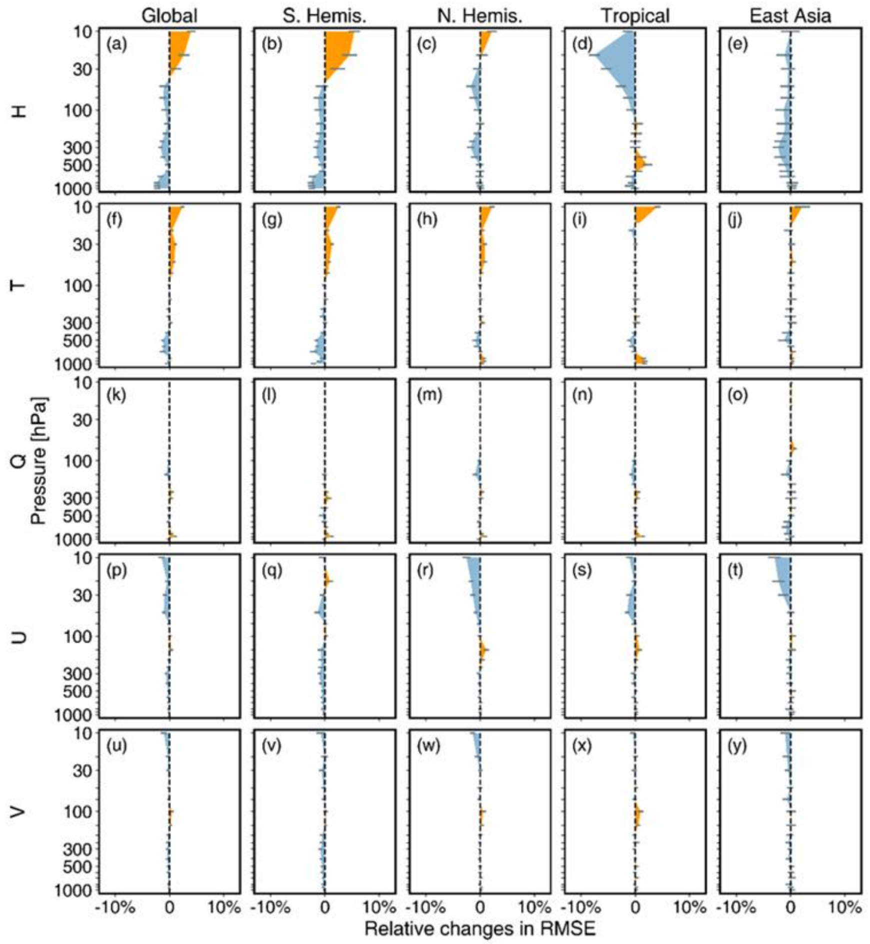
CONV+MWTS3 (real)



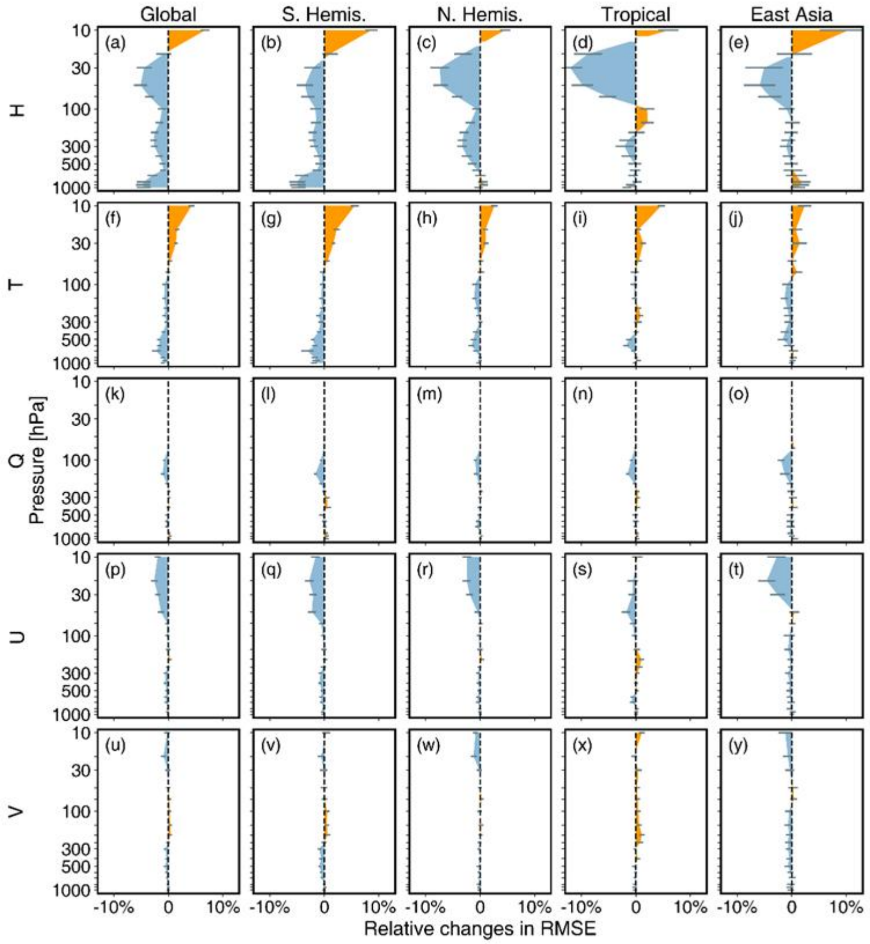
CONV+MWTS3-S (simulated)

FY-3E MWTS3 Hybrid-OSSE Validation——Analysis field

- Compare the analysis field assimilating CONV+SAT+MWTS3 data with that of the CTRL-2 (CONV+SAT).
- Blue — positive effect, orange — negative effect

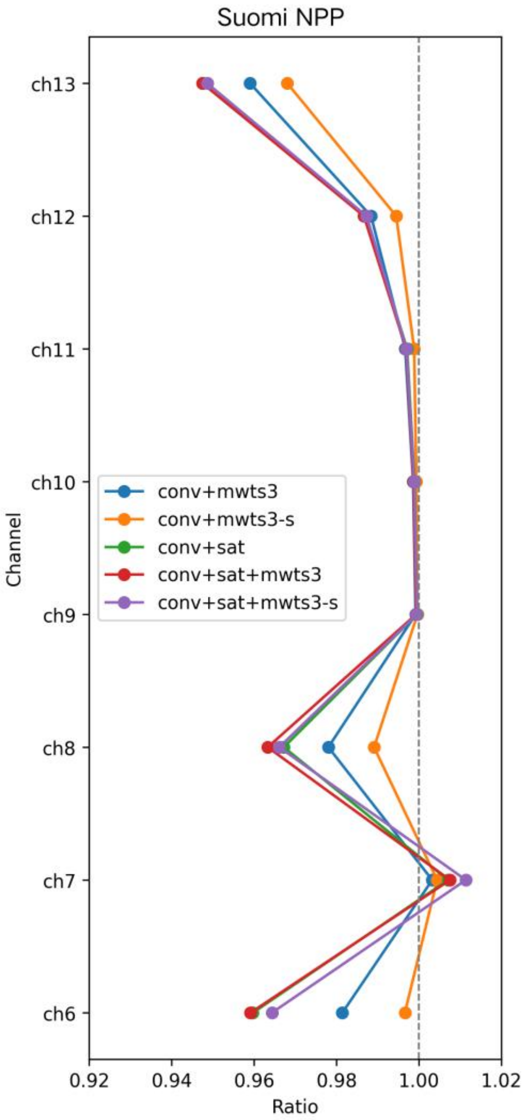


CONV+SAT+MWTS3 (real)



CONV+SAT+MWTS3-S (simulated)

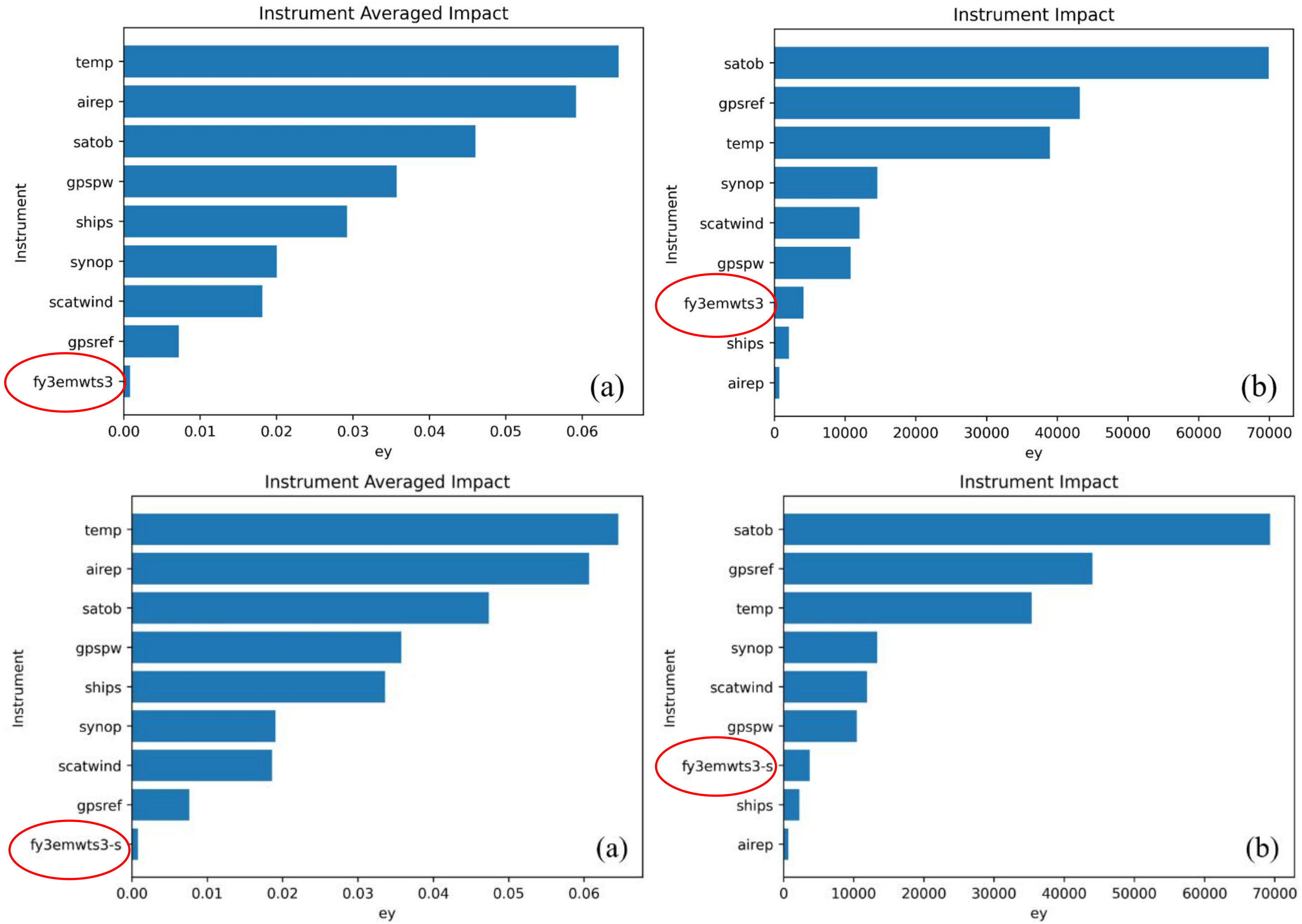
FY-3E MWTS3 Hybrid-OSSE Validation——Observation & FSO



Observation verification—ATMS

MWTS3 (real)

MWTS3-S (simulated)

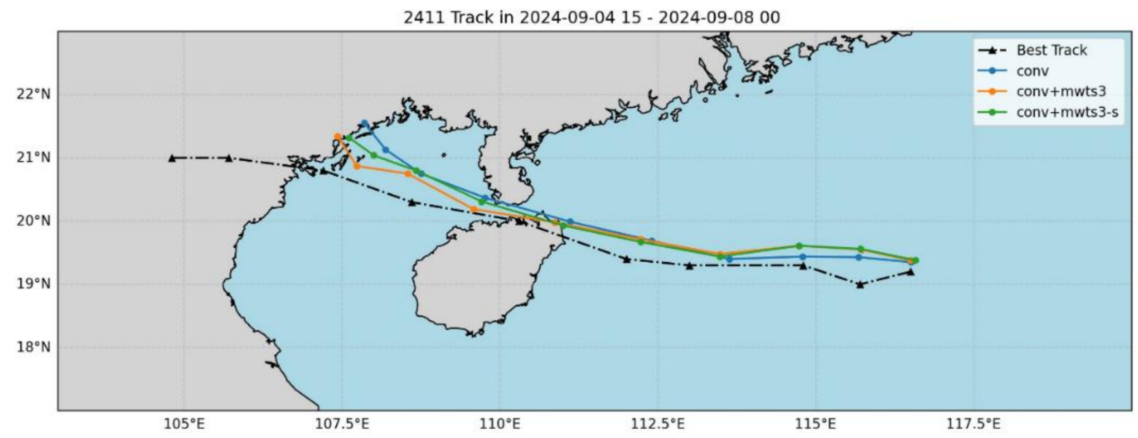


FSO:
Average contribution per observation

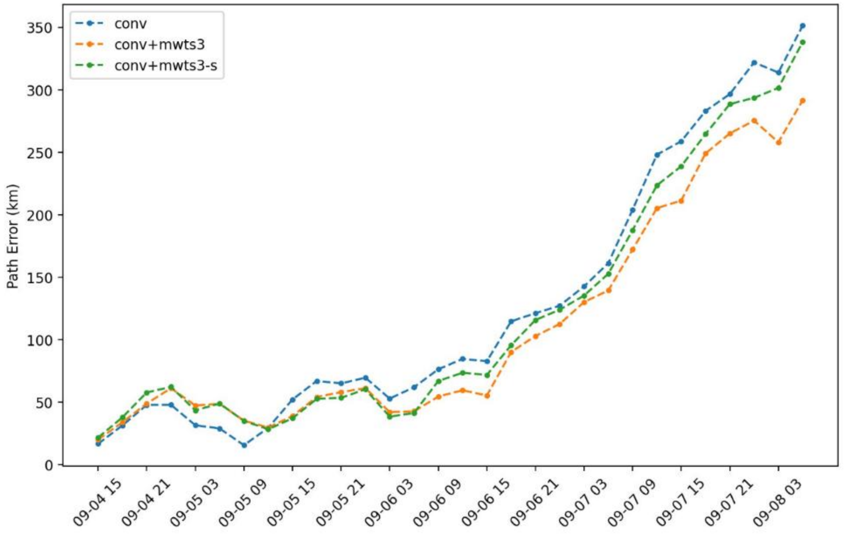
FSO:
Total contribution by instrument

FY-3E MWTS3 Hybrid-OSSE Validation——Typhoon Track Forecast

- For Typhoon Yagi, the 11th typhoon in 2024, the initial time is set as UTC15:00 on September 4, 2024, to conduct the typhoon track forecast for the next three days.
- The experimental results show that whether assimilating MWTS3 or MWTS3-S, both are superior to or inferior to the CONV experiment in most cases, which further verifies the similarity between MWTS3 and MWTS3-S in terms of typhoon track forecasting.



Comparison of typhoon Yagi track forecasts among different experiments

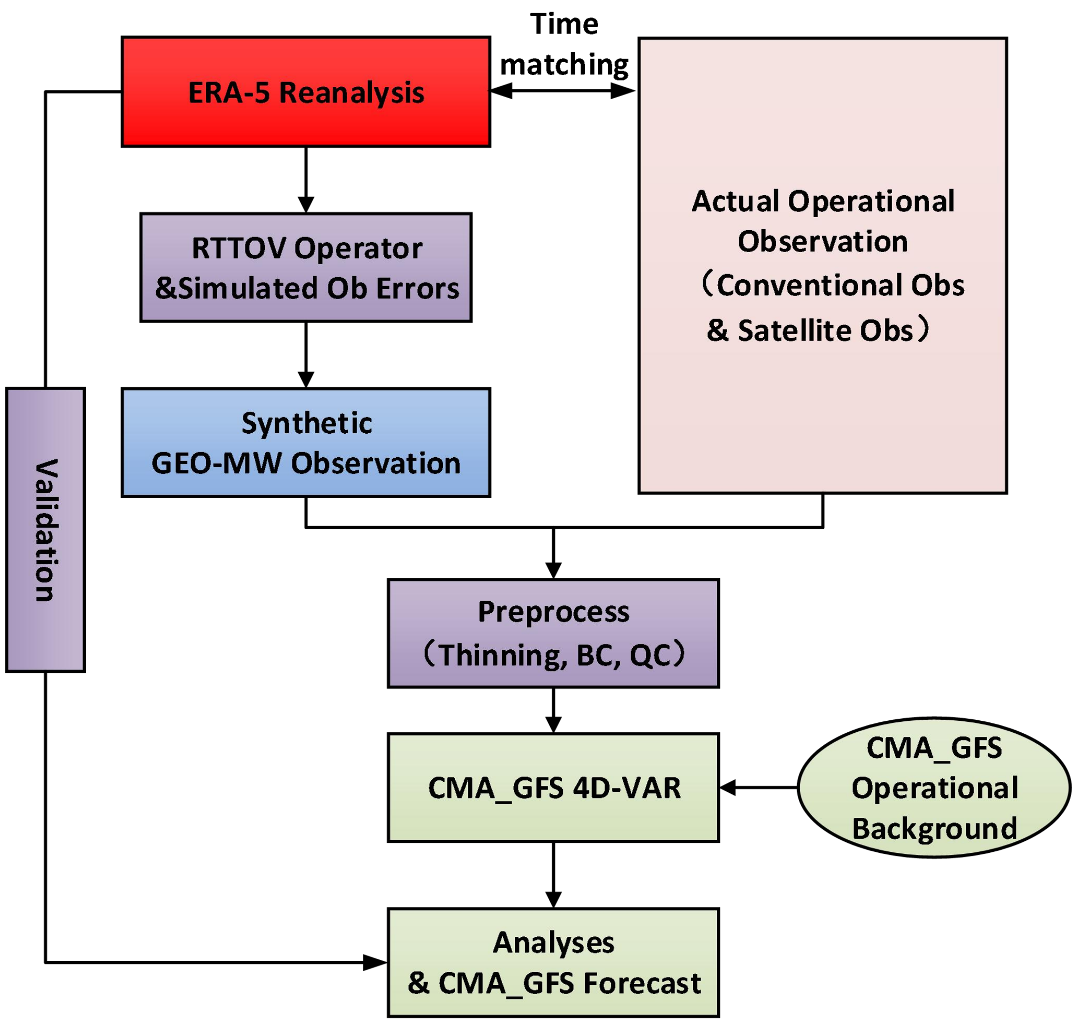


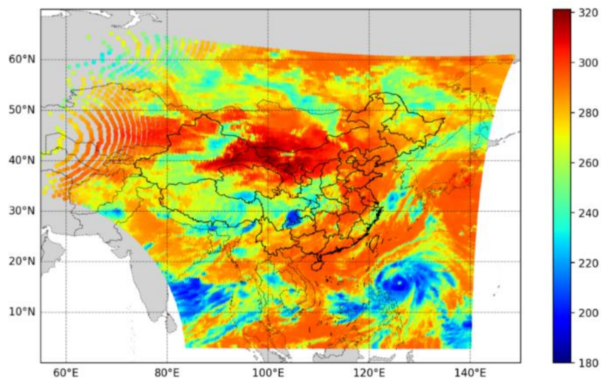
Comparison of typhoon Yagi track forecasting errors among different experiments

FY-4 GEO-MW Hybrid-OSSE Experiment /03

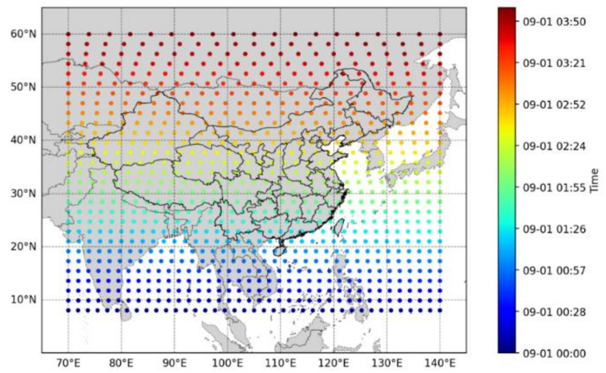
1. Analysis field evaluation
2. Forecast Sensitivity to Observation (FSO)
3. Typhoon Track Forecast

FY-4 GEO-MW Hybrid-OSSE Experiment Configuration





Brightness temperature from the FY-4B GIIRS 11.119 μm channel over a two-hour period



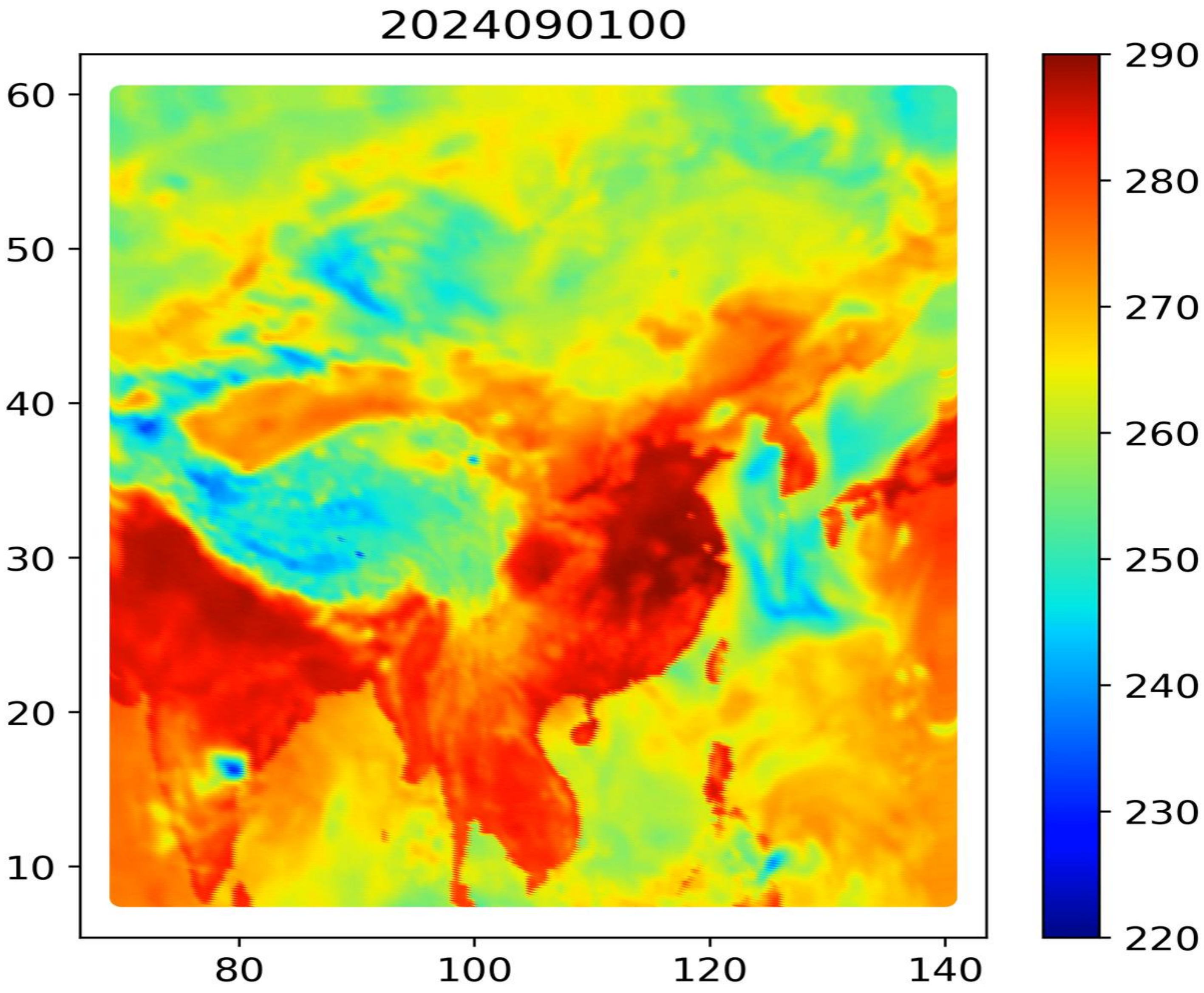
FY-4 GEO-MW Hybrid-OSSE, covering an area of 6000 km × 6000 km, was conducted over a four-hour period from 2024.9.1 to 2024.9.8.

Experimental code	Observation data composition
CONV	Conventional observations, as CTRL-1
CONV+FY-4M(MWTS3)	Conventional, FY-4M（only 50GHz band channels used）
CONV+FY-4M(MWTS3+MWHS2)	Conventional, FY-4M（only 50,118,183GHz band channels used）
CONV+FY-4M (ALL)	Conventional, FY-4M（all 46 channels）
CONV+SAT	Conventional, satellite observation, as CTRL-2
CONV+SAT+FY-4M (MWTS3)	Conventional, satellite, FY-4M（only 50GHz channels）
CONV+SAT+FY-4M (MWTS3+MWHS2)	Conventional, satellite, FY-4M（only 50,118,183GHz band channels used）
CONV+SAT+FY-4M (ALL)	Conventional, satellite, FY-4M（all 46 channels）

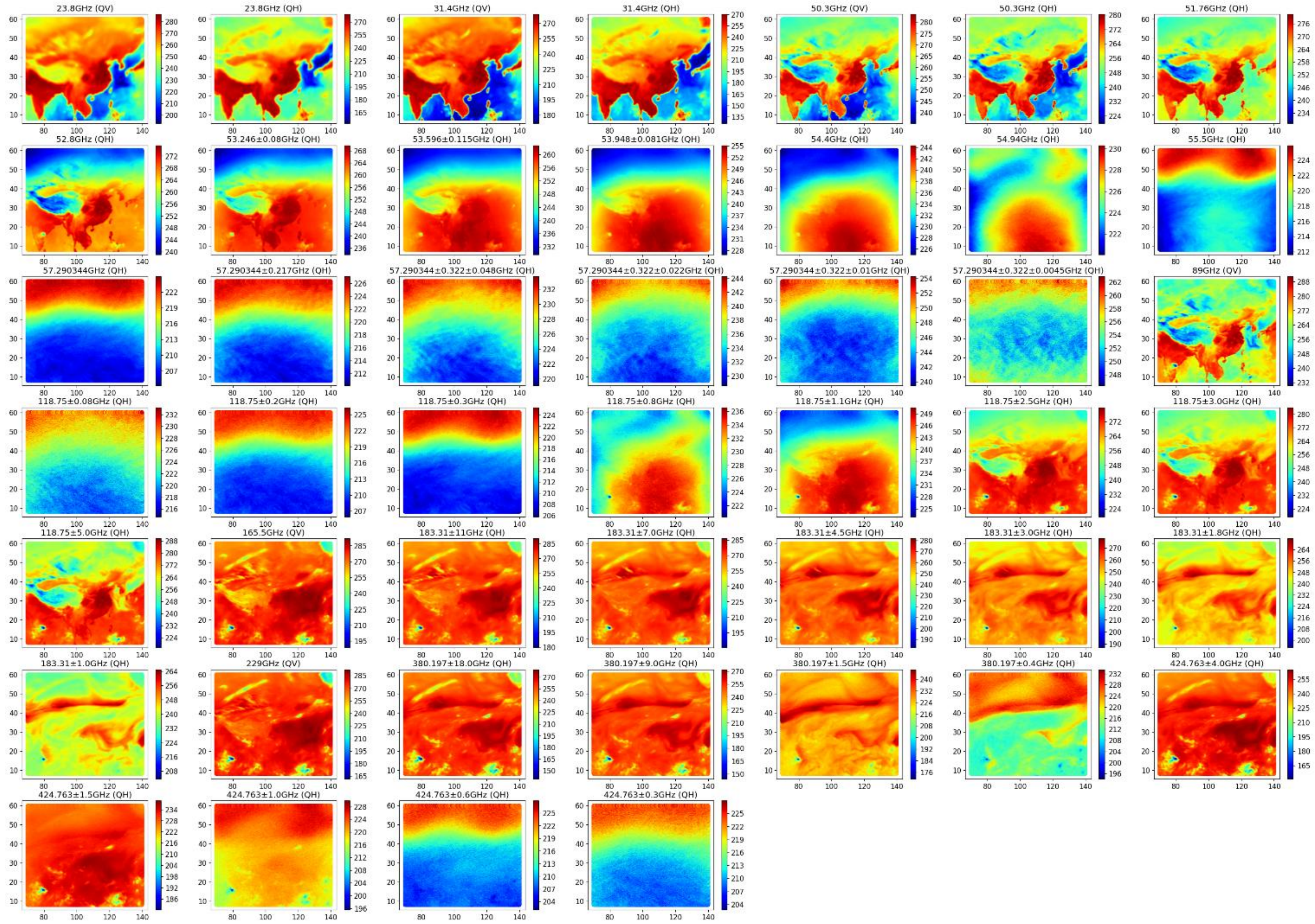
FY-4 GEO-MW frequency channels

No.	Frequency (GHz)	No.	Frequency (GHz)
1	23.8	112	118.75±0.2
2	23.8	113	118.75±0.3
3	31.4	114	118.75±0.8
4	31.4	115	118.75±1.1
5	50.3	116	118.75±2.5
6	50.3	117	118.75±3.0
7	51.76	118	118.75±5.0
8	52.8	119	165.5
9	53.246±0.080	120	183.31±11
10	53.596±0.115	121	183.31±7.0
11	53.948±0.081	122	183.31±4.5
12	54.4	123	183.31±3.0
13	54.94	124	183.31±1.8
14	55.5	125	183.31±1.0
15	57.290344(f0)	126	229
16	f0±0.217	127	380.197±18.0
17	fg±0.322±0.048	128	380.197±9.0
18	f0±0.322±0.022	129	380.197±1.5
19	f0±0.322±0.010	130	380.197±0.4
20	f0±0.322±0.0045	131	424.763±4.0
21-67	52.6-55	132	424.763±1.5
68-109	55-57.3	133	424.763±1.0
110	89	134	424.763±0.6
111	118.75±0.08	135	424.763±0.3

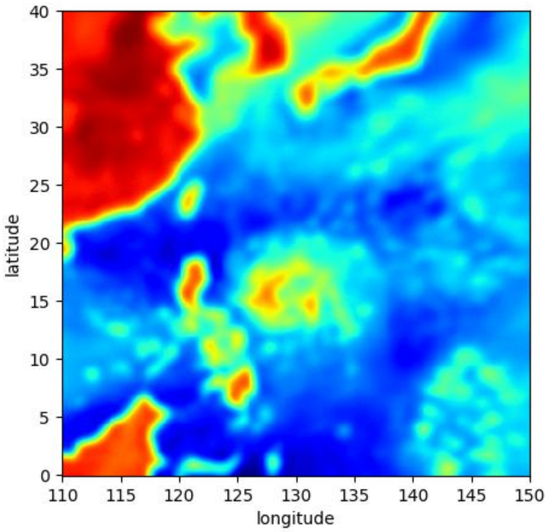
FY-4 GEO-MW simulated brightness temperature—89GHz QV



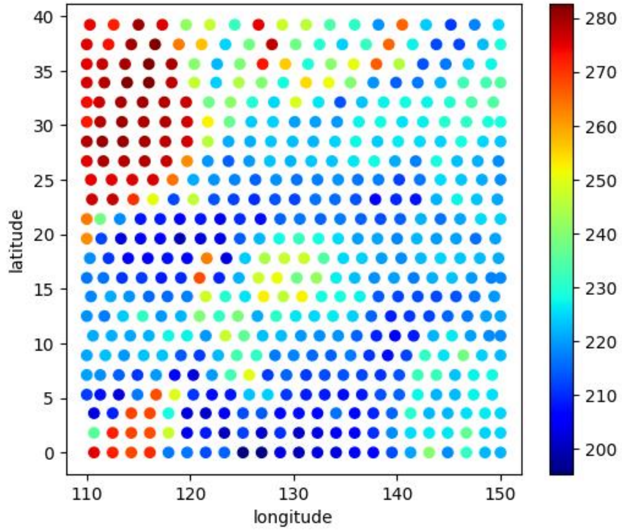
FY-4 GEO-MW simulated brightness temperature——46 channels



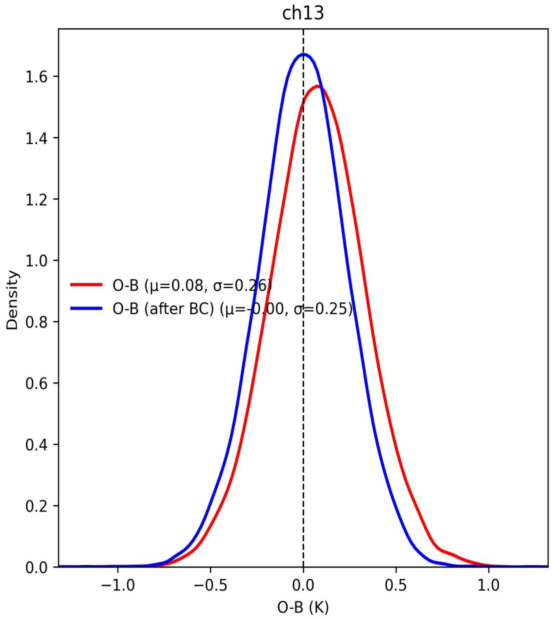
FY-4 GEO-MW preprocess——Thinning, BC, QC

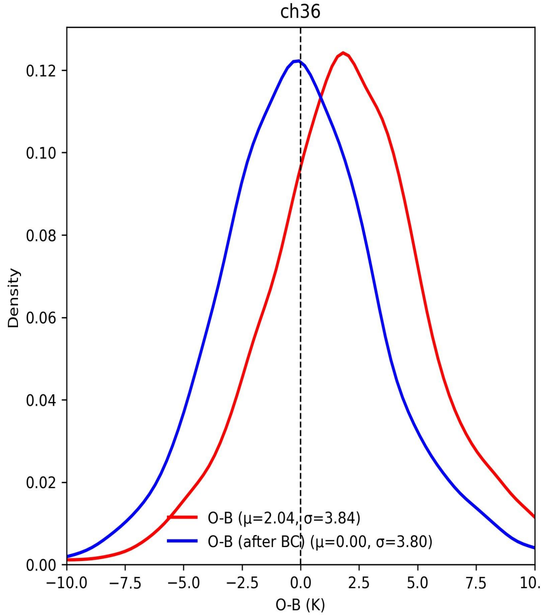


Thinning



Bias Correction Factors
1000-300 hPa altitude difference
200-50 hPa altitude difference
50-10 hPa altitude difference
10-2 hPa altitude difference
Zenith angle^1
zenith angle^2
zenith angle^3
zenith angle^4



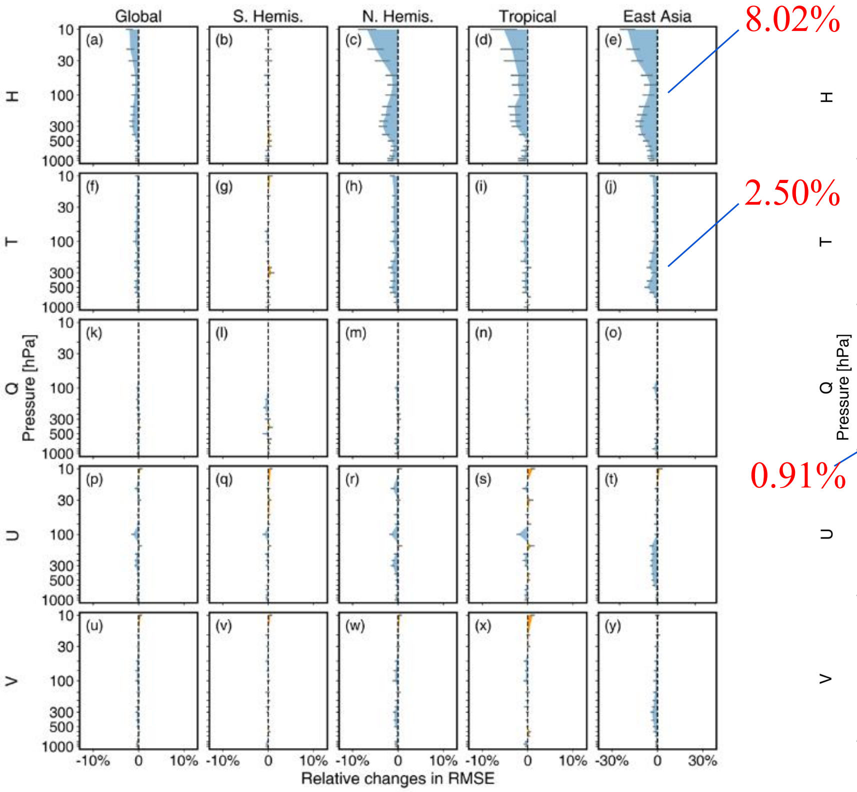


QC scheme is as follows:

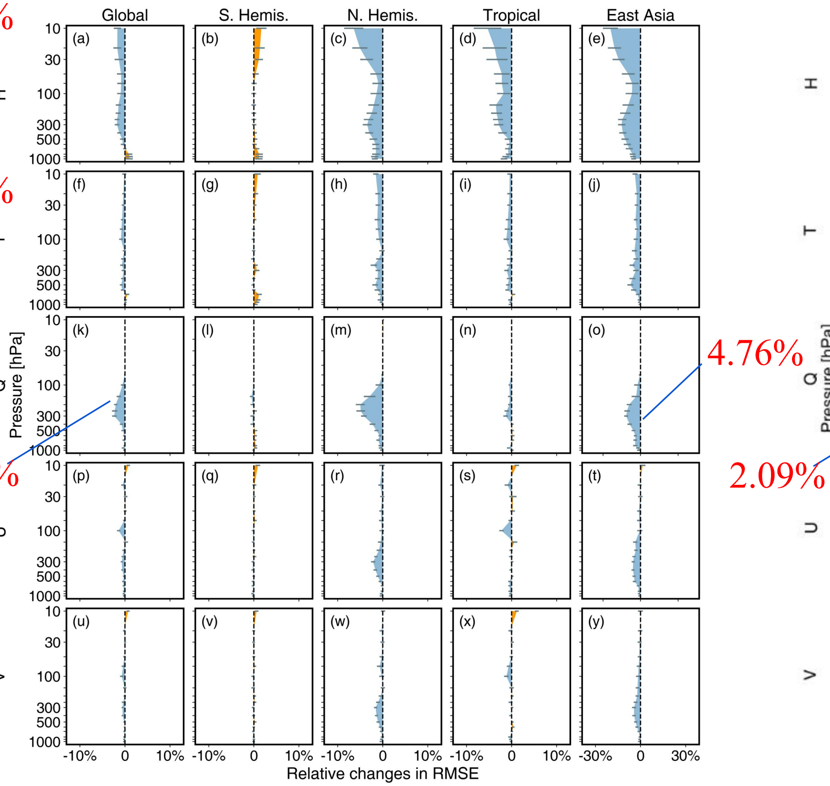
1. For coastlines, all channels are removed.
2. For all window channels and low-layer channels which in 50GHz, 118GHz bands, all land observations are removed.
3. For observations with OMB greater than 5K at 50.3 GHz, all window channels and scattering channels are removed.
4. Observations from each channel will be excluded if the absolute value of the OMB exceeds 10 K for that specific channel.
5. For observations with OMB greater than 3 times the observation error, all channels are removed.
6. For observations with brightness temperature (165 GHz) - brightness temperature (229 GHz) greater than 5K, all window channels and scattering channels are removed.

FY-4 GEO-MW Hybrid-OSSE Experiment——Analysis field

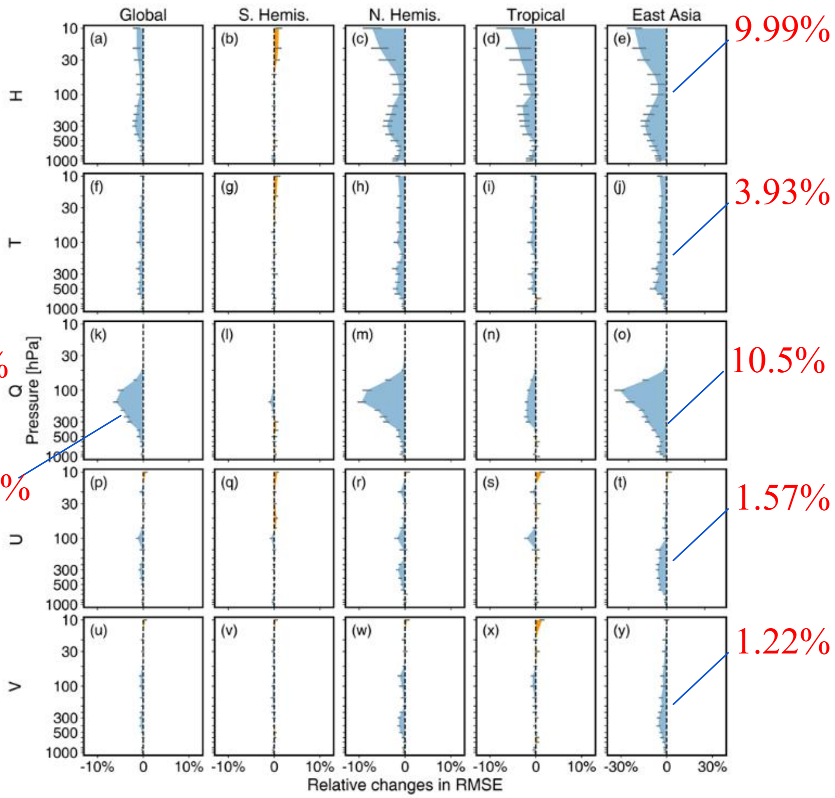
- Compare the analysis field assimilating CONV + FY-4M data with that of the CTRL-1 (CONV)
- Blue — positive effect, orange — negative effect



CONV+FY-4M（MWTS3）



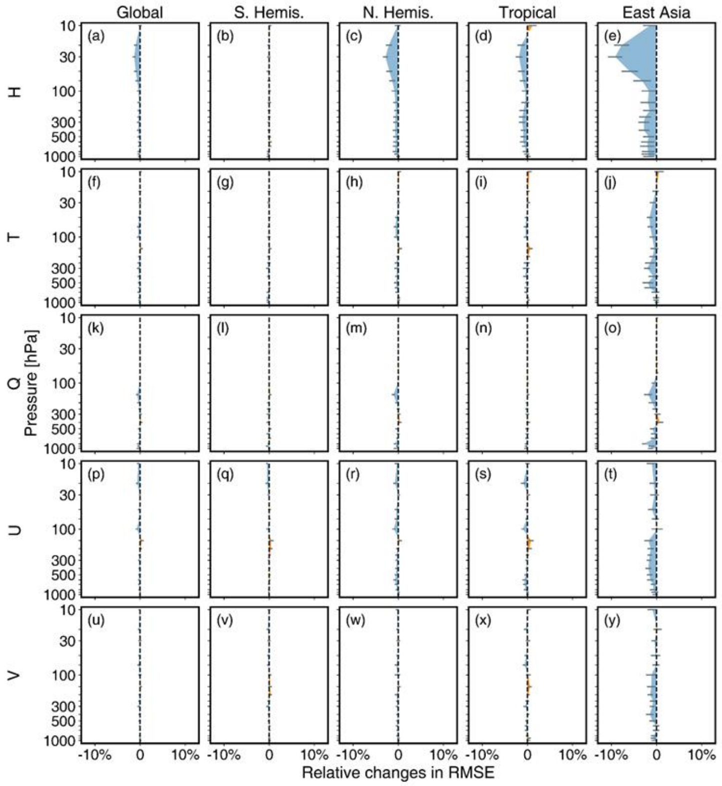
CONV+FY-4M（MWTS3+WMHS2）



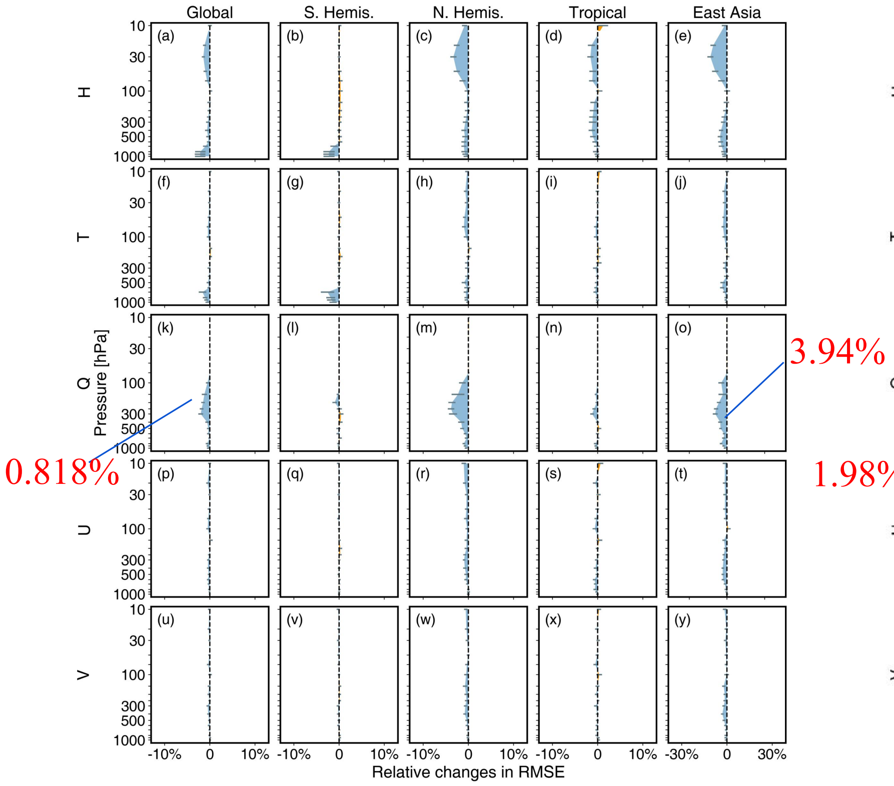
CONV+FY-4M（ALL）

FY-4 GEO-MW Hybrid-OSSE Experiment——Analysis field

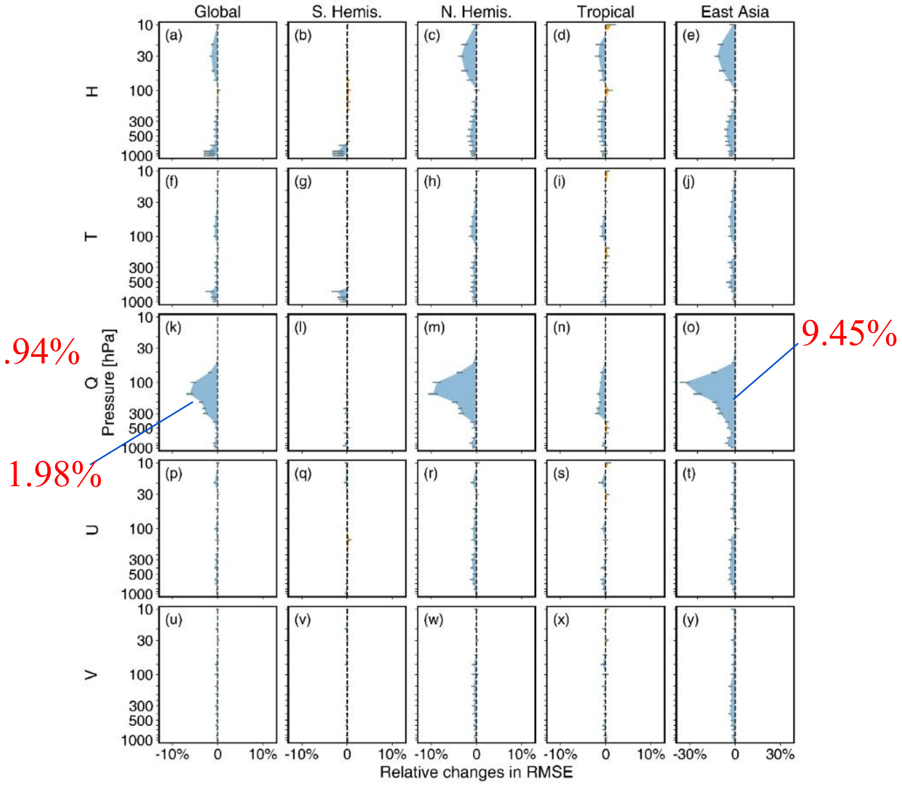
- Compare the analysis field assimilating CONV +SAT+FY-4M data with that of the CTRL-2 (CONV+SAT)
- Blue — positive effect, orange — negative effect



CONV+SAT+FY-4M（MWTS3）

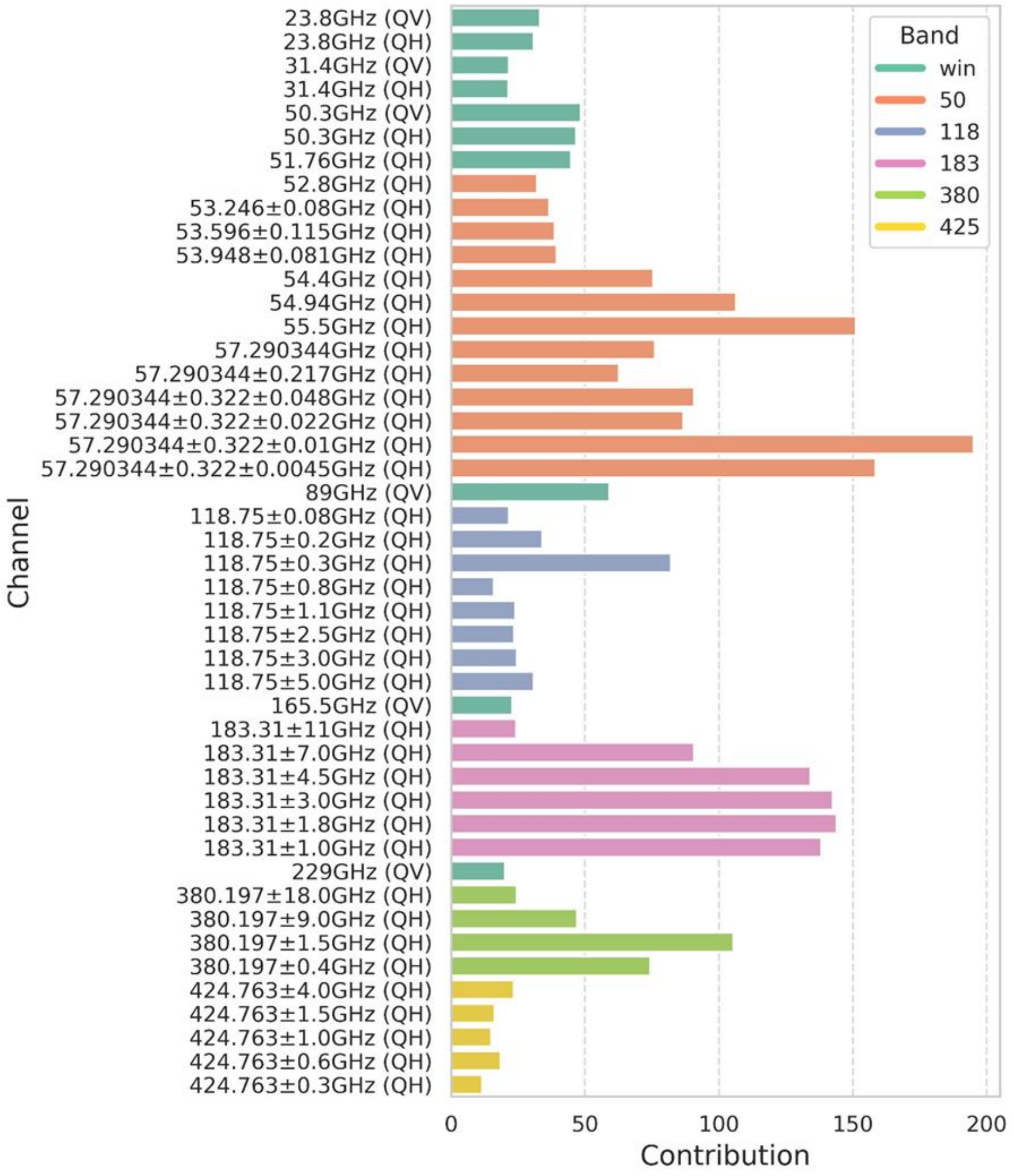


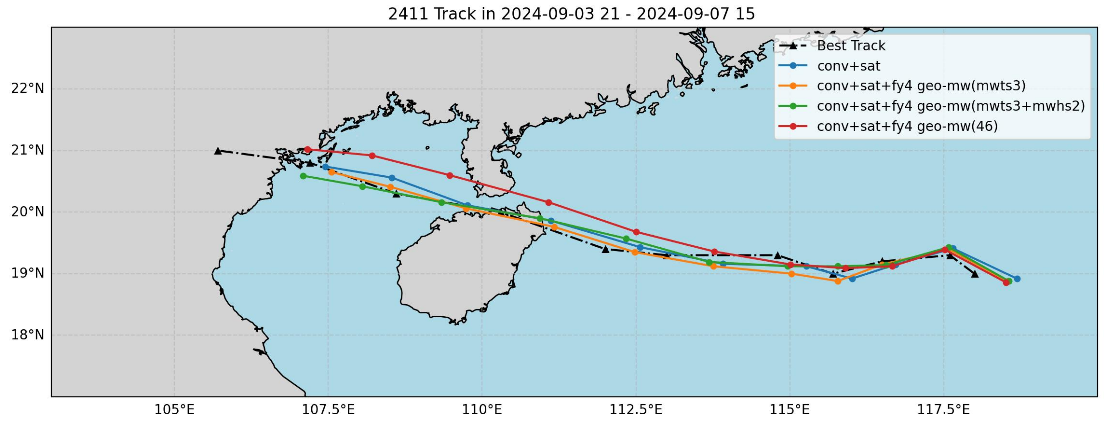
CONV+SAT+FY-4M（MWTS3+WMHS2）

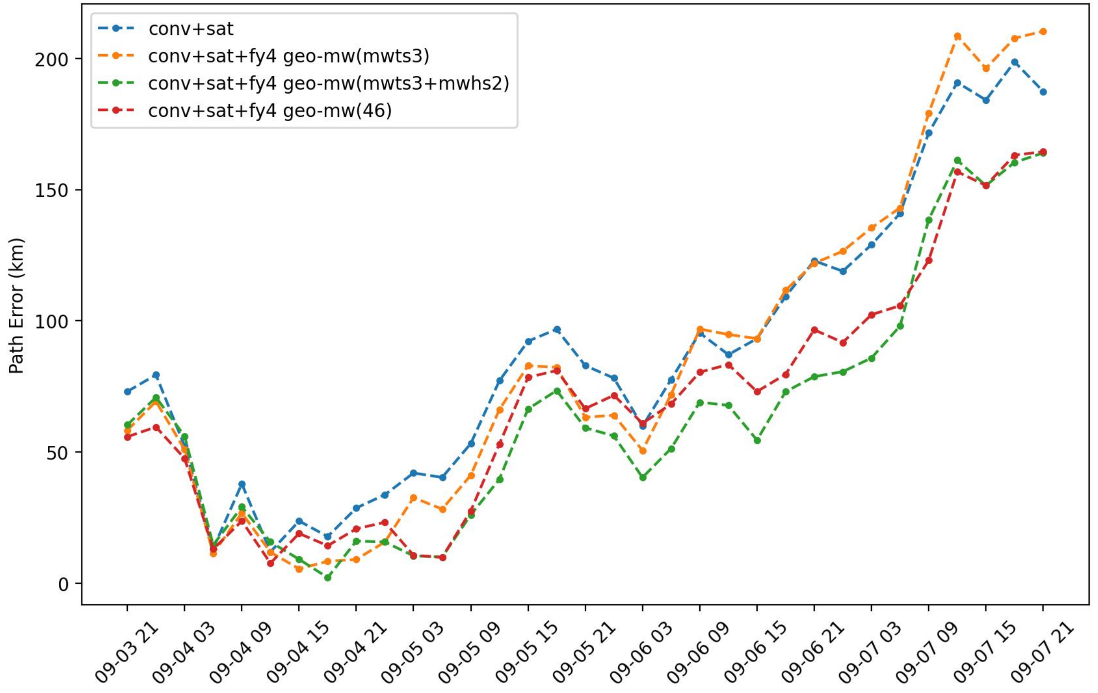


CONV+SAT+FY-4M（ALL）

FY-4 GEO-MW Hybrid-OSSE——FSO & Typhoon Track Forecast







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Summary

① Firstly, a Hybrid-OSSE scheme validation experiment was conducted using the FY-3E MWTS3 instrument. The results were evaluated from four perspectives—analysis field, observation space, FSO diagnosis, and typhoon track forecast—and demonstrated good consistency between the Hybrid-OSSE using simulated MWTS3 brightness temperatures and the assimilation results obtained from real MWTS3 observations, thereby confirming the reliability of the proposed Hybrid-OSSE framework.

② The FY-4 GEO-MW Hybrid-OSSE results show that, even with the presence of existing polar-orbiting microwave observations, assimilating GEO-MW data still yields positive impacts on the atmospheric field over the East Asian region. For example, in East Asia, the geopotential height field exhibits an average improvement of 9.99%, and the temperature field shows a 3.93% enhancement, demonstrating that increasing the temporal resolution of observations in a specific region can significantly improve data assimilation performance.

③ The addition of 380 GHz and 425 GHz frequency bands to the FY-4 GEO-MW satellite, which were absent in previous microwave atmospheric sounders, contributes positively to overall assimilation.

④ High-time-resolution observations from the FY-4 GEO-MW satellite exhibit unique advantages in improving the accuracy of water vapor analysis field, yielding average improvements of 1.98% globally and 9.45% over East Asia. Even within a multi-source satellite observation system, their contribution to enhancing humidity analysis field remains substantial.

Hybrid Observing System Simulation Experiment for the FY-4 Geostationary Orbit Microwave Satellite based on CMA-GFS, IEEE TGRS, 2nd revision.

Thanks