

Challenges in Assimilating Satellite Cloudy Radiance into CMA-MESO System

卫星云辐射资料在 CMA-MESO 系统中同化的挑战

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CMA Earth System Modeling and Prediction Centre

October 29, 2025

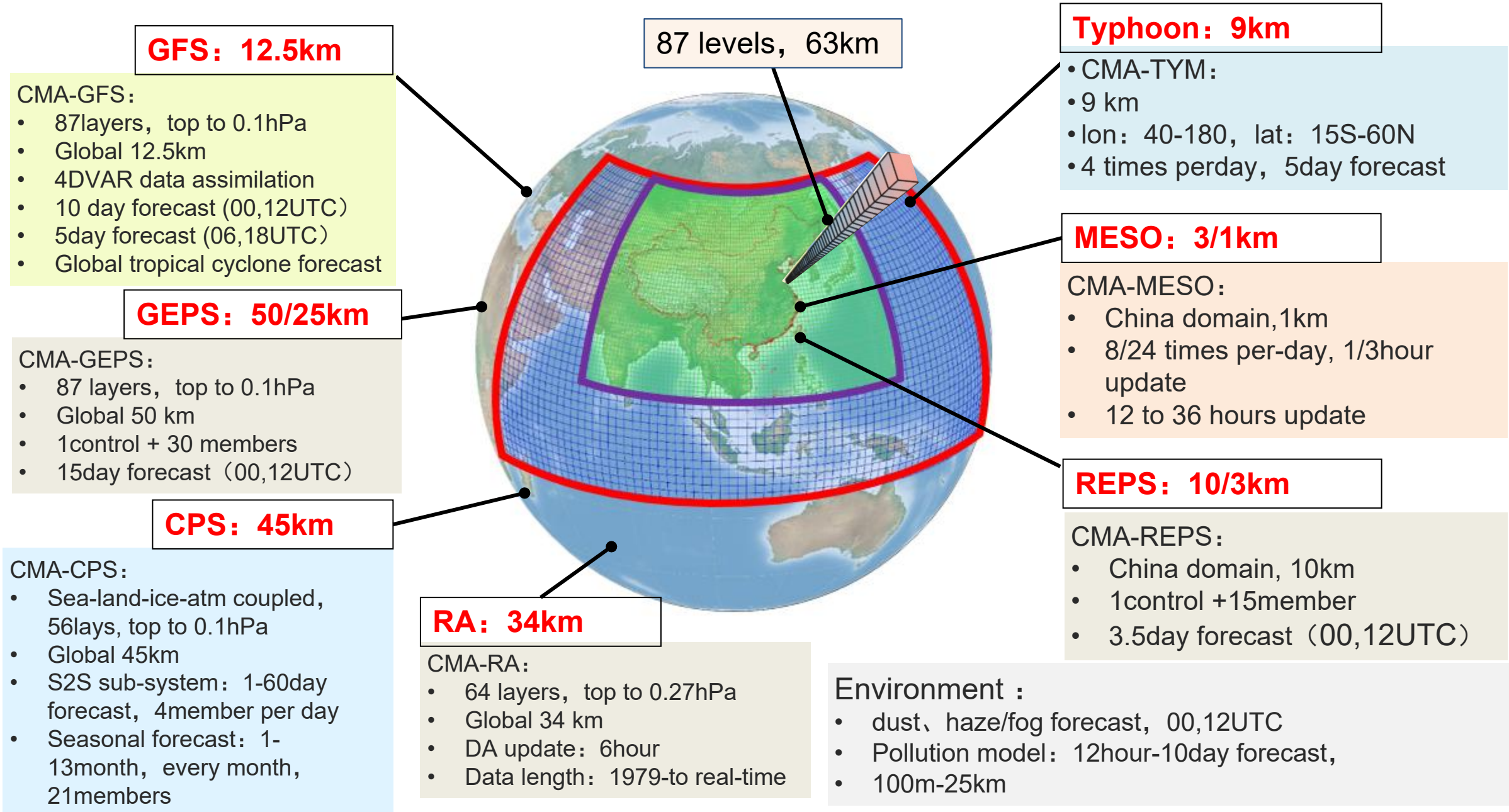
Outline

- **Major Challenges in Regional NWP Satellite Radiance Assimilation**
- **Assimilation of Microwave Cloudy Radiances from Polar-Orbiting Satellites**
- **Assimilation of Visible Radiances from Geostationary Imagers**
- **Summary and Conclusions**

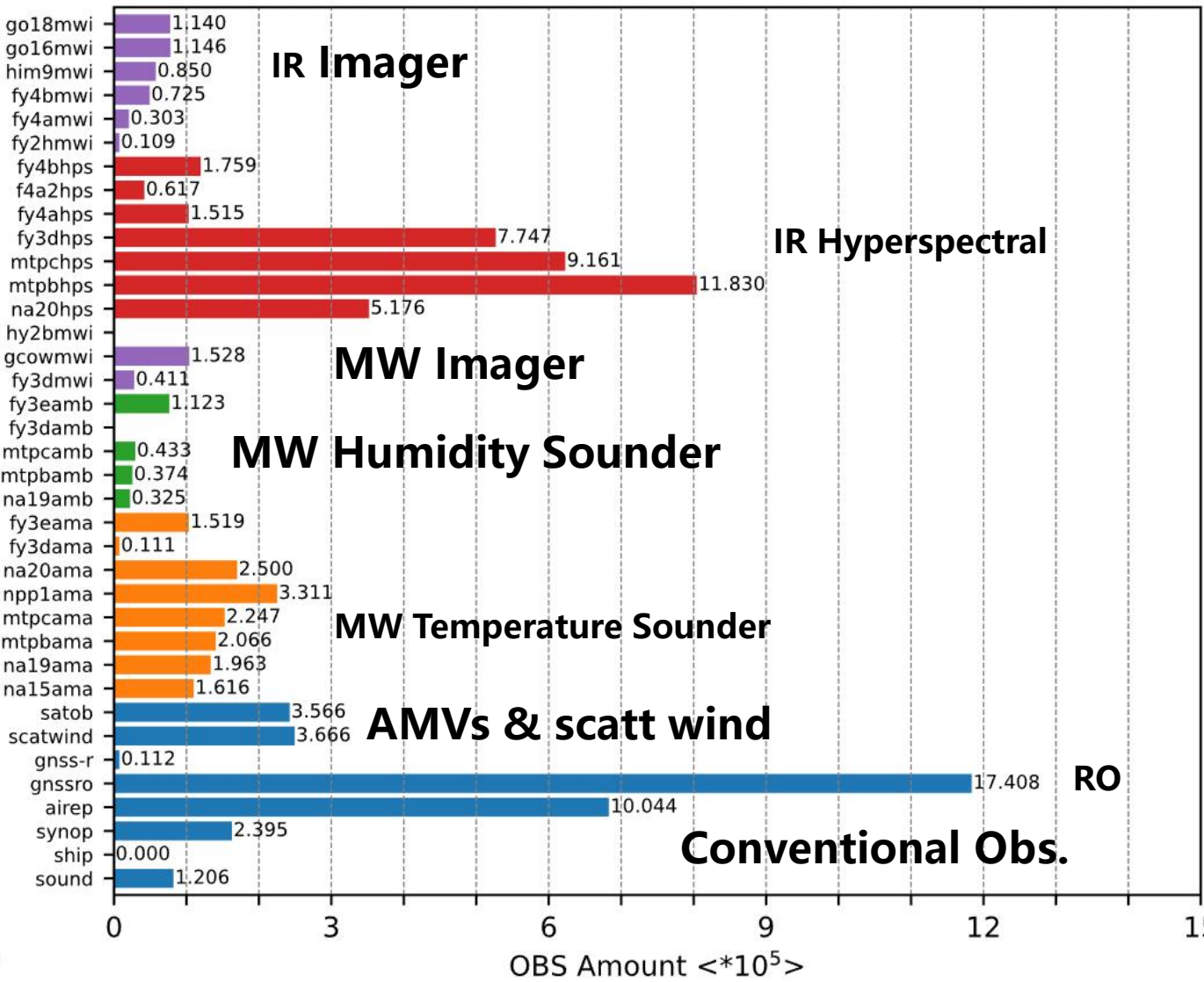
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CMA NWP Systems

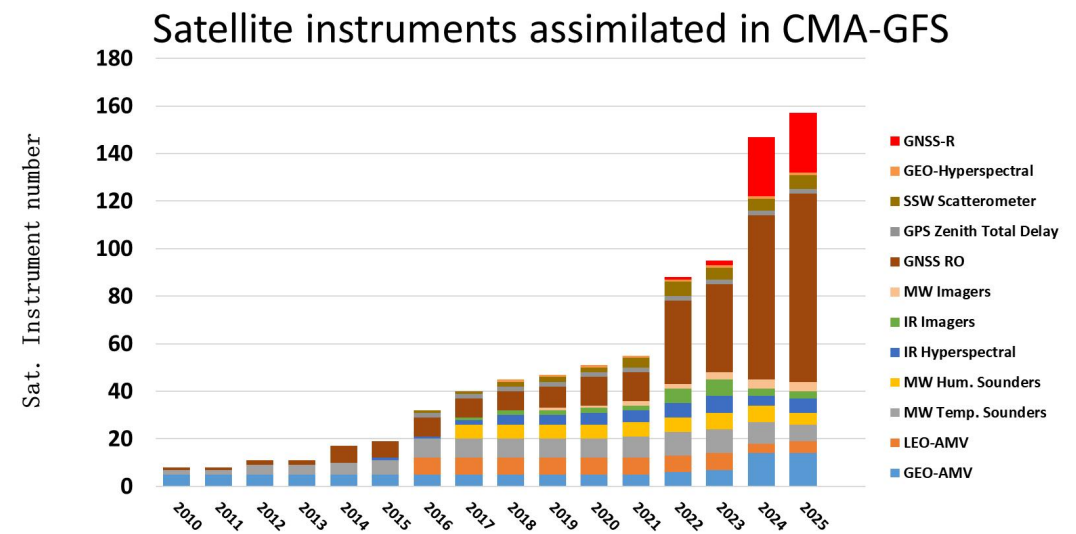


Satellite Data Used in CMA-GFS



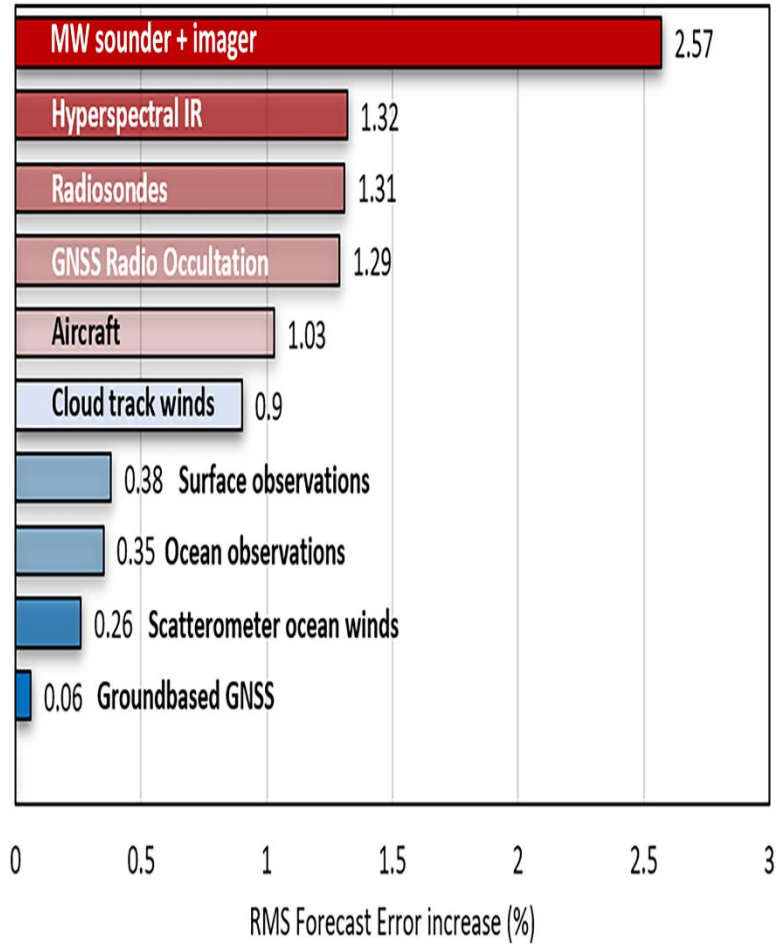
Total Satellite: 91.40% FY Satellite: 25.14%
Over 150 instruments assimilated every 6 hours.

- FY2H:** VISSR/AMV
- FY3D :** MWTS/MWHS/MWRI/HIRAS/RO
- FY3E :** MWTS/MWHS/ScattWind/RO
- FY4B:** AGRI/GIIRS
- HY2B:** SMR/ScattWind
- HY2C/2D:** ScattWind
- NPP:** ATMS/AMV
- NA20:** ATMS/CRIS
- MTPB:** AMSU/MHS
- MTPC:** AMSU/MHS/IASI
- AMVs:** MT11/INSAT
- ROs:** COSMIC2/GRACE/GEOP/Tianmu/Yun Yao

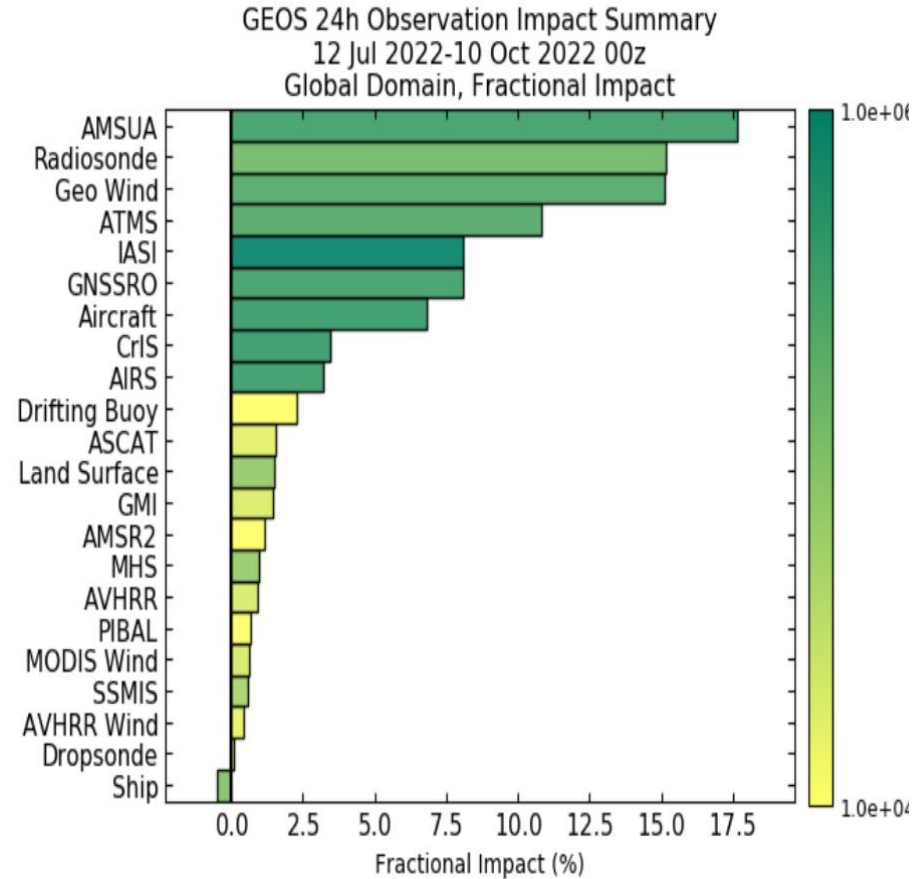


Impacts of Various Satellite Data through FSOI

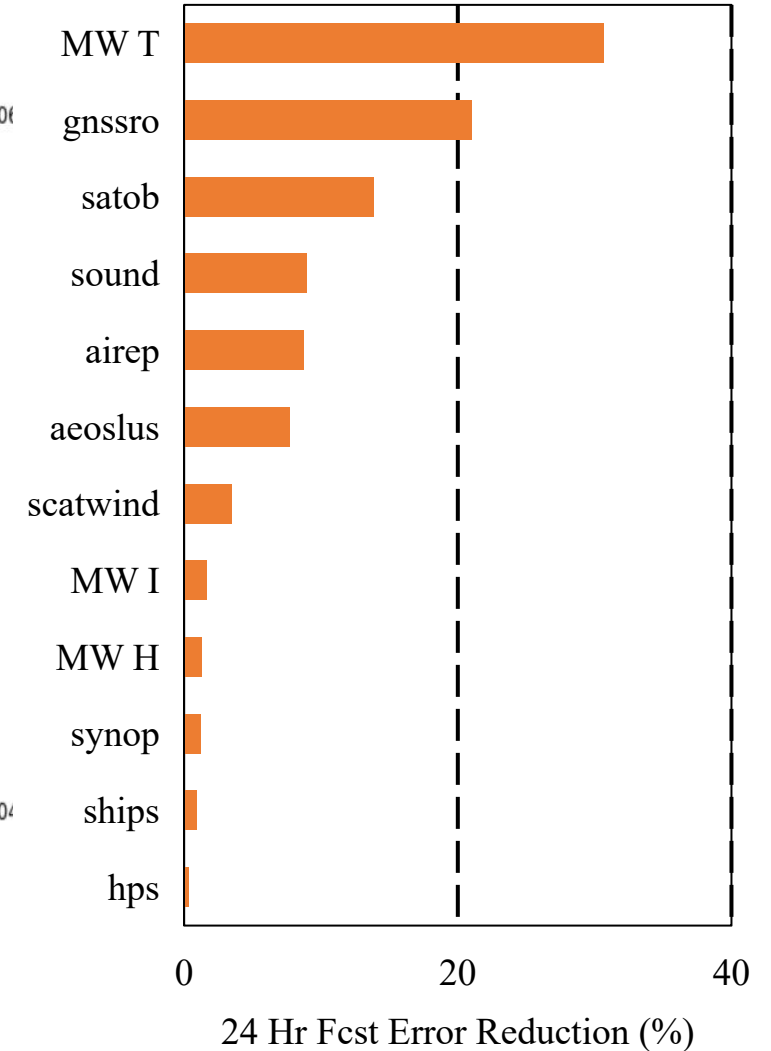
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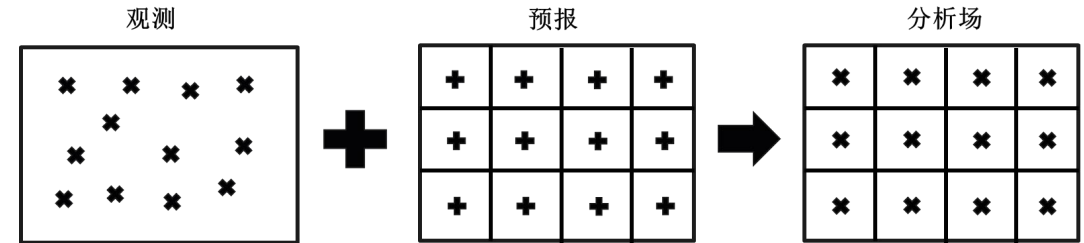
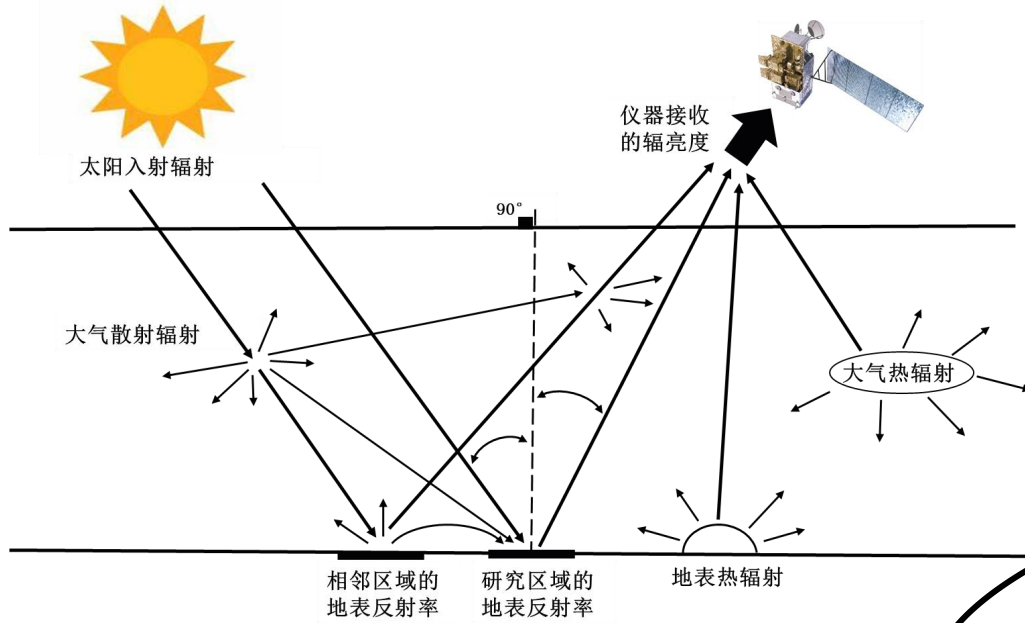
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CMA



How is Satellite Observation Operator Used in Data Assimilation?



$$\mu \frac{d\mathbf{I}(\tau, \mu, \phi)}{d\tau} = -\mathbf{I}(\tau, \mu, \phi) + \frac{\omega(\tau)}{4\pi} \int_0^{2\pi} \int_{-1}^1 \mathbf{M}(\tau, \mu, \phi; \mu', \phi') \mathbf{I}(\tau, \mu', \phi') d\mu' d\phi' + (1-\omega)B \begin{pmatrix} 1 \\ 0 \\ 0 \\ 0 \end{pmatrix} + \frac{\omega F_0}{4\pi} \exp(-\tau / \mu_0) \begin{pmatrix} M_{11}(\phi, \mu_0, \phi_0) \\ M_{12}(\phi, \mu_0, \phi_0) \\ M_{13}(\phi, \mu_0, \phi_0) \\ M_{14}(\phi, \mu_0, \phi_0) \end{pmatrix}$$

Fredholm Integral Equations of the Second Kind

Satellite observation operator is based on the solution of radiative transfer equation that describes the photons travelling through emitting and scattering earth atmosphere

$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{x} - \mathbf{x}_b)^T \mathbf{B}^{-1}(\mathbf{x} - \mathbf{x}_b) + \frac{1}{2}(\mathbf{H}(\mathbf{x}) - \mathbf{y}^{obs})^T (\mathbf{O} + \mathbf{F})^{-1}(\mathbf{H}(\mathbf{x}) - \mathbf{y}^{obs})$$

$$J(\mathbf{x}_a) = \min_{\mathbf{x}} J(\mathbf{x}) \quad \forall \mathbf{x} \text{ near } \mathbf{x}_b$$

$\mathbf{x}$ – analysis variable

$\mathbf{x}_a$ – final analysis

$\mathbf{x}_b$ – background

$\mathbf{B}$ – background error covariance

$\mathbf{y}^{obs}$ – observations

$\mathbf{O}$ – observation error covariance

$\mathbf{H}$ – observation operator

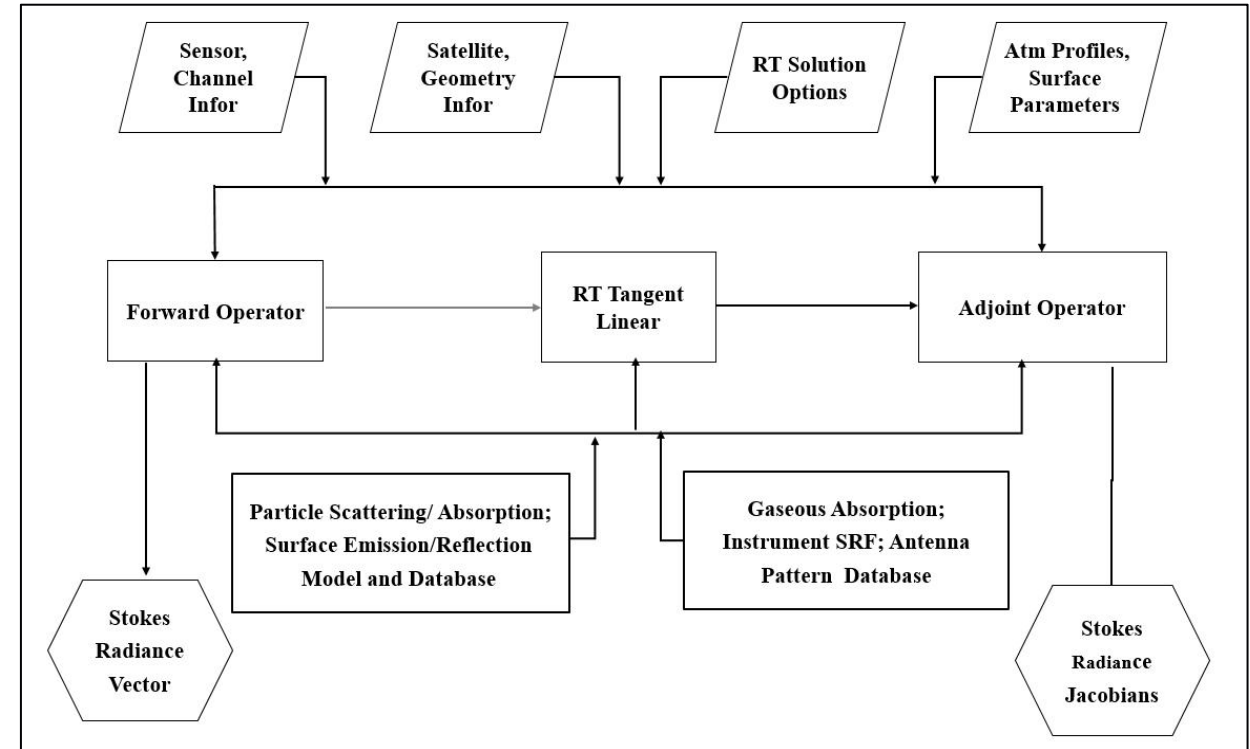
$\mathbf{F}$ – forward model error covariance

The purpose of data assimilation is to define the current states of atmosphere and surface at the NWP model grids from satellite and conventional observations as well as the NWP forecasts. The cost function of J requires the radiative transfer model during the optimization process

Advanced Radiative Transfer Modeling System (ARMS)

Version 1.2

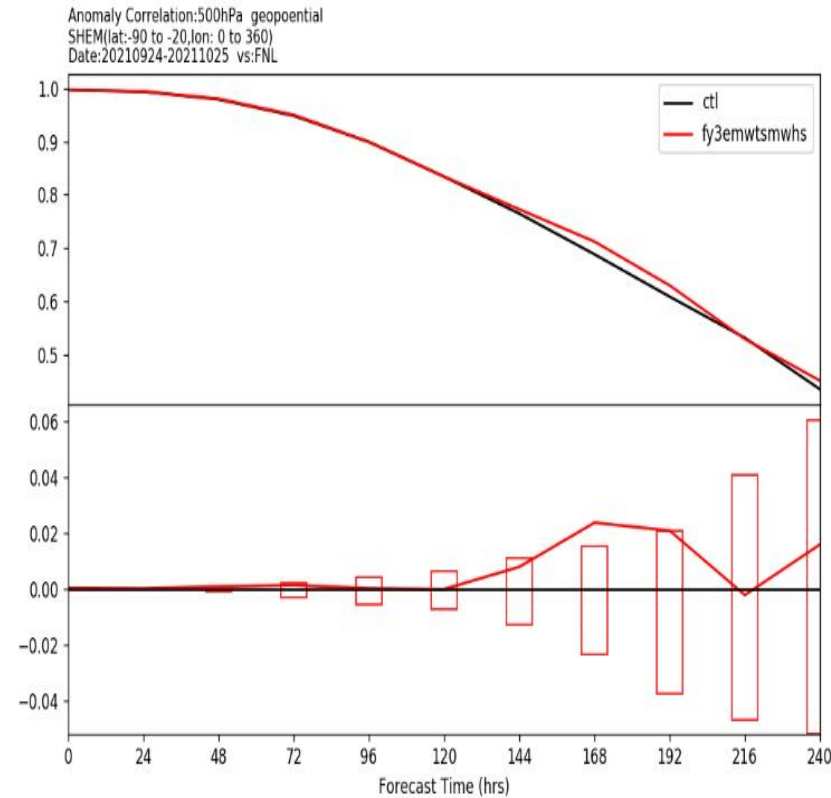
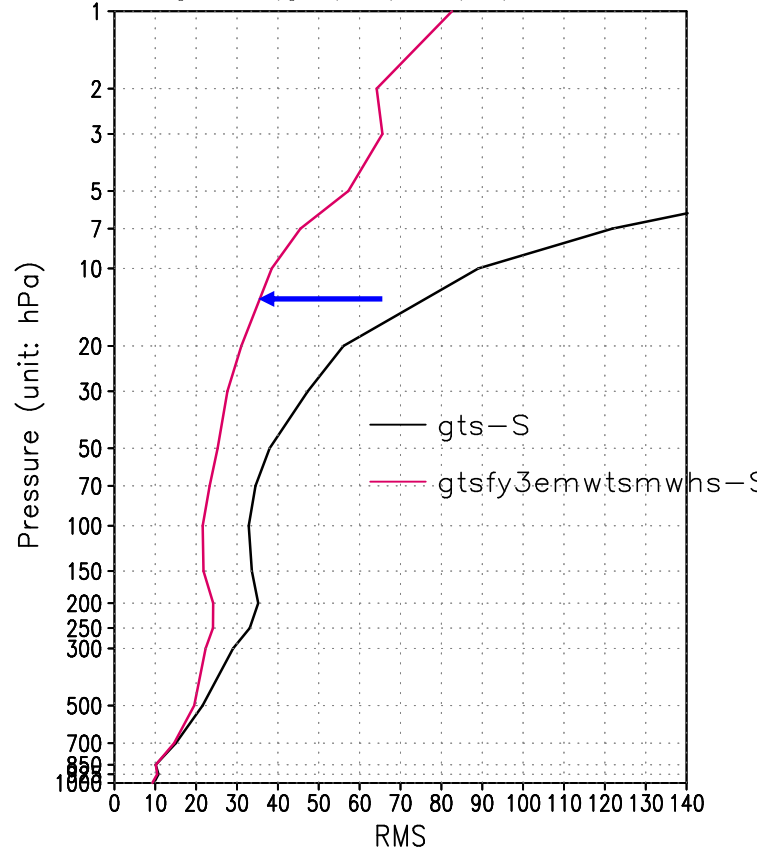
- **Atmospheric gaseous absorption**
 - Band absorption coeff trained by LBL spectroscopy data with sensor response functions
 - Variable gases (e.g. H₂O, CO₂, O₃) .
 - Zeeman splitting effects near 60 GHz
- **Cloud/precipitation scattering and emission**
 - Fast LUT optical models at all phases including non-spherical ice particles
 - Gamma size distributions
- **Aerosol scattering and emission**
 - Types: dust, sea salt, organic/black carbon
 - Lognormal distributions
- **Surface emissivity/reflectivity**
 - Two-scale ocean emissivity model (FASTEM)
 - Geometrical optics for infrared ocean emissivity
 - Land microwave emissivity model
 - Land infrared emissivity data bases
- **Radiative transfer schemes**
 - Polarization Two-Stream Approximation (P2S)
 - Advanced Doubling and Adding (ADA)
 - Tangent linear and adjoint modules of all solvers



Weng, F., X. Yu, Y. Duan, J. Yang, and J. Wang, 2020: Advanced Radiative Transfer Modeling System (ARMS): A new-generation satellite observation operator developed for numerical weather prediction and remote sensing applications. Adv. Atmos. Sci., 37(2), <https://doi.org/10.1007/s00376-019-9170-2>

Impacts of FY-3E Microwave Sounder (MWTS-3) on CMA-GFS Forecast

time-averaged $H(\text{grapes}) - H(\text{ec})$ RMS of S. He



Domain	Parameter	Level	Anomaly Correlation				RMS Error			
NH	HGT	850	▲	▲	▲	▲	▲	▲	▲	▲
		500	▲	▲	▲	▲	▲	▲	▲	▲
		250	▲	▲	▲	▲	▲	▲	▲	▲
	TEMP	850	▲	▲	▲	▲	▲	▲	▲	▲
		500	▲	▲	▲	▲	▲	▲	▲	▲
		250	▲	▲	▲	▲	▲	▲	▲	▲
	UWND	850	▲	▲	▲	▲	▲	▲	▲	▲
		500	▲	▲	▲	▲	▲	▲	▲	▲
		250	▲	▲	▲	▲	▲	▲	▲	▲
	VWND	850	▲	▲	▲	▲	▲	▲	▲	▲
		500	▲	▲	▲	▲	▲	▲	▲	▲
		250	▲	▲	▲	▲	▲	▲	▲	▲
SH	HGT	850	▲	▲	▲	▲	▲	▲	▲	▲
		500	▲	▲	▲	▲	▲	▲	▲	▲
		250	▲	▲	▲	▲	▲	▲	▲	▲
	TEMP	850	▲	▲	▲	▲	▲	▲	▲	▲
		500	▲	▲	▲	▲	▲	▲	▲	▲
		250	▲	▲	▲	▲	▲	▲	▲	▲
	UWND	850	▲	▲	▲	▲	▲	▲	▲	▲
		500	▲	▲	▲	▲	▲	▲	▲	▲
		250	▲	▲	▲	▲	▲	▲	▲	▲
	VWND	850	▲	▲	▲	▲	▲	▲	▲	▲
		500	▲	▲	▲	▲	▲	▲	▲	▲
		250	▲	▲	▲	▲	▲	▲	▲	▲
EASI	HGT	850	▲	▲	▲	▲	▲	▲	▲	▲
		500	▲	▲	▲	▲	▲	▲	▲	▲
		250	▲	▲	▲	▲	▲	▲	▲	▲
	TEMP	850	▲	▲	▲	▲	▲	▲	▲	▲
		500	▲	▲	▲	▲	▲	▲	▲	▲
		250	▲	▲	▲	▲	▲	▲	▲	▲
	UWND	850	▲	▲	▲	▲	▲	▲	▲	▲
		500	▲	▲	▲	▲	▲	▲	▲	▲
		250	▲	▲	▲	▲	▲	▲	▲	▲
	VWND	850	▲	▲	▲	▲	▲	▲	▲	▲
		500	▲	▲	▲	▲	▲	▲	▲	▲
		250	▲	▲	▲	▲	▲	▲	▲	▲
TRO	HGT	850	▼	▼	▼	▼	▼	▼	▼	▼
		500	▼	▼	▼	▼	▼	▼	▼	▼
		250	▼	▼	▼	▼	▼	▼	▼	▼
	TEMP	850	▼	▼	▼	▼	▼	▼	▼	▼
		500	▼	▼	▼	▼	▼	▼	▼	▼
		250	▼	▼	▼	▼	▼	▼	▼	▼
	UWND	850	▼	▼	▼	▼	▼	▼	▼	▼
		500	▼	▼	▼	▼	▼	▼	▼	▼
		250	▼	▼	▼	▼	▼	▼	▼	▼
	VWND	850	▼	▼	▼	▼	▼	▼	▼	▼
		500	▼	▼	▼	▼	▼	▼	▼	▼
		250	▼	▼	▼	▼	▼	▼	▼	▼

▲ : Far better
▼ : Far worse
▲ : Better
▼ : Worse
▲ : Better but not significant
▼ : Worse but not significant
■ : Equality

MWTS-3 was assimilated into CMA-GFS within 6 months after satellite launch. Impacts on global medium range forecast are mostly positive.

Major Challenges Related to Satellite Cloudy Radiance Assimilation in CMA-MESO System

- Very little satellite data are assimilated in CMA mesoscale model
- Systematic biases are found for upper-air sounding channels
- An interface of satellite observation operator is generally lacking
- Data assimilation cycle sometime is out of sync with satellite observations
- Cloud increments from cloudy radiance assimilation do not agree with its cloud analysis
- Observation error covariance matrix is fixed
- Background error covariance matrix has a space correlation length but is not well tested

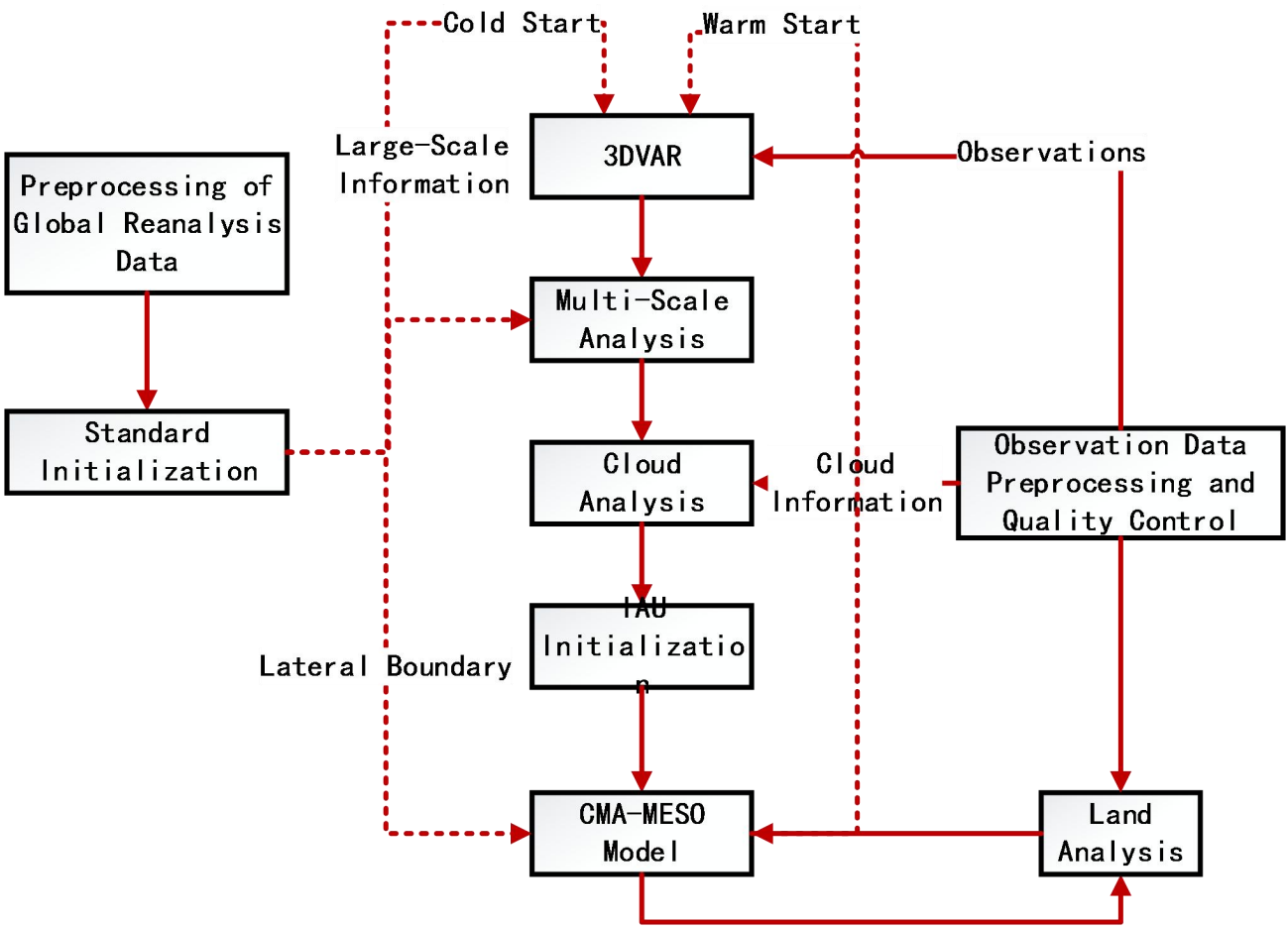
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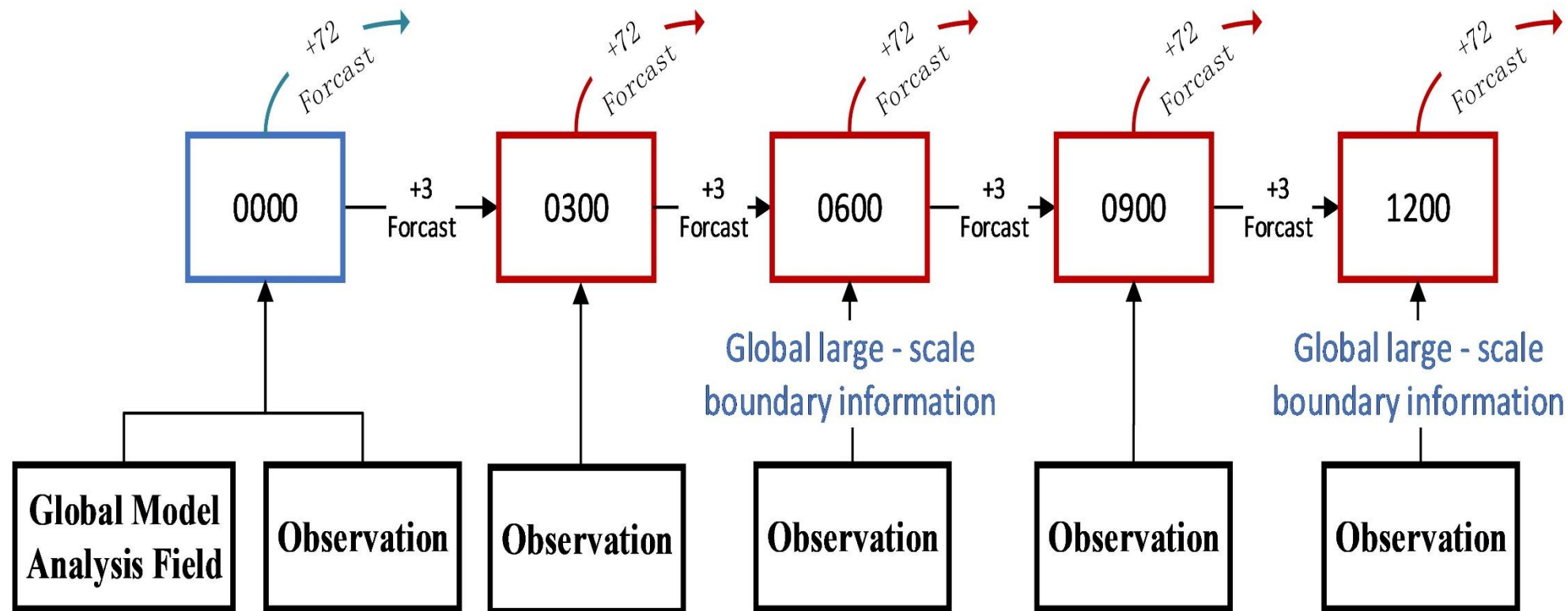
CMA-MESO Prediction and DA System

	Setting
Model Version	CMA-MESO 6.1
Horizontal Resolution	1KM
Vertical Layers	72
Model Top	10 hPa
Satellite Obs Operator	ARMS v1.2
Background	NCEP-GFS
Microphysical Scheme	Liu & Ma (QV, QC, QI, QR, QS, QG, Nr, Ni, Ns, Ng)
Satellite Data	FY-3/4, NOAA, METOP
Assimilation Scheme	3DVAR
Control Variables	T, QV, QC, QI, QR, QS, QG

Visible/IR Microwave



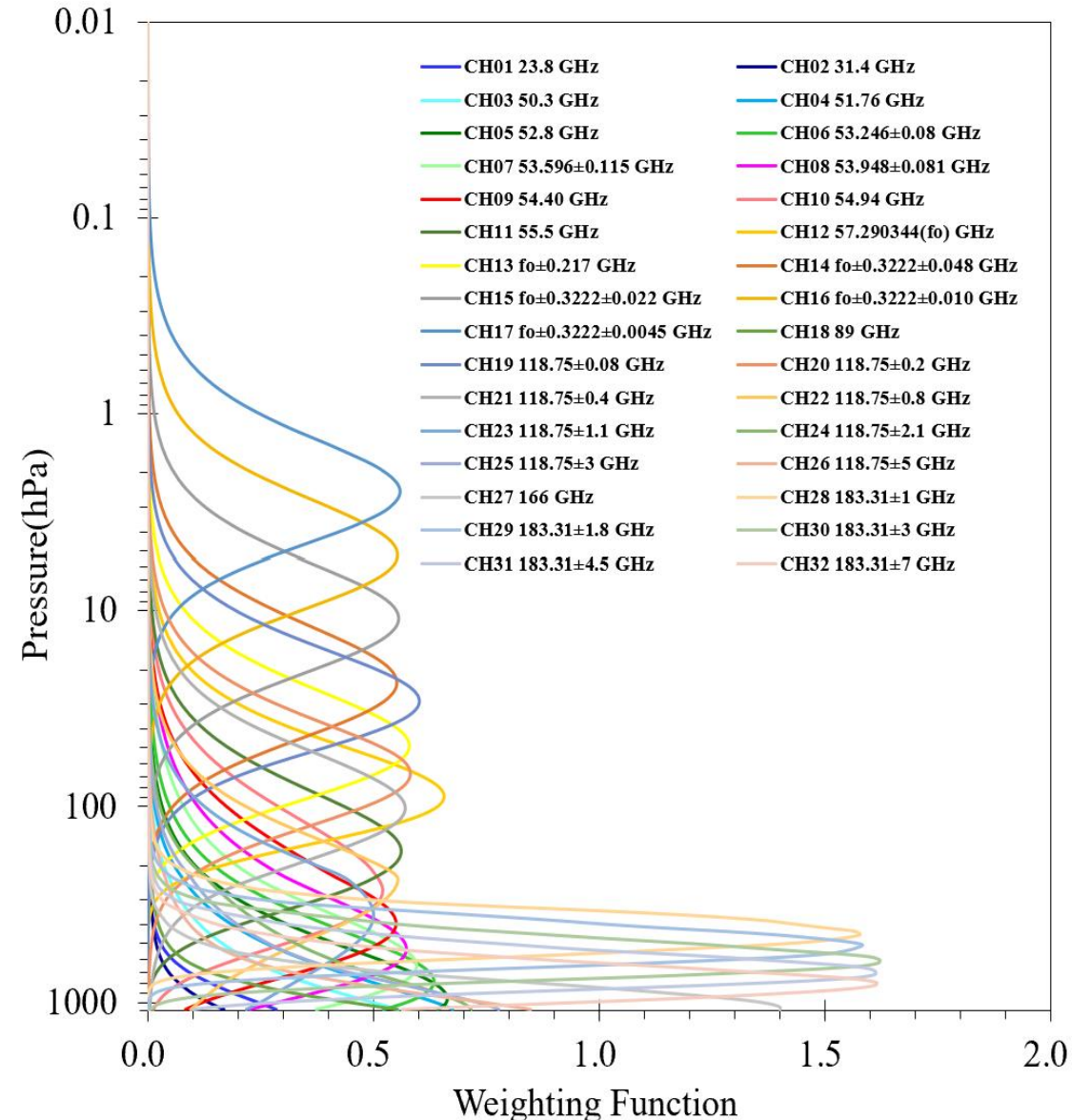
CMA-MESO Data Assimilation Cycle



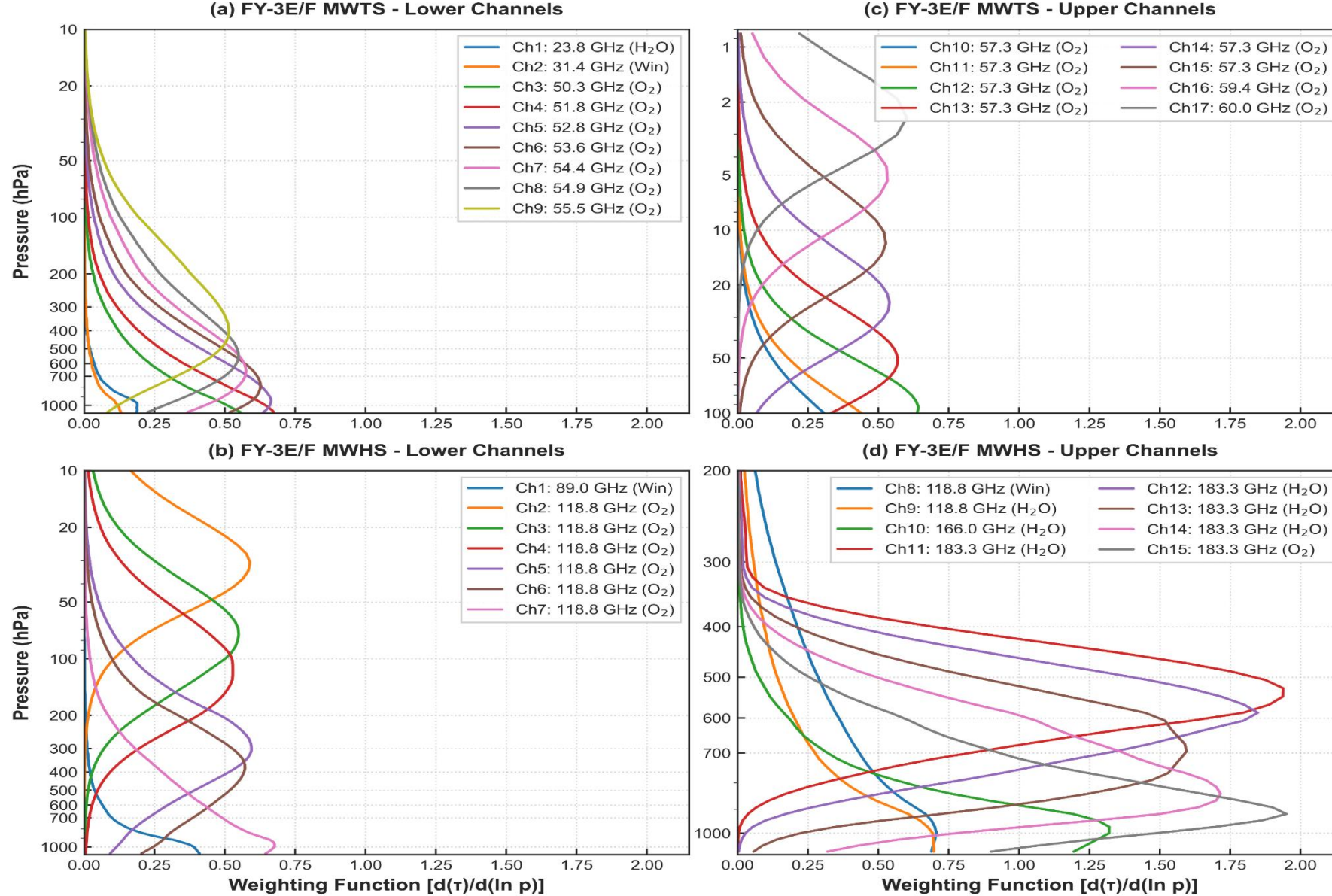
FY-3E/3F MWTS/MWHS Sounding Capabilities

Channel		Center Frequency (GHz)	Max Bandpass Width (MHz)	Polarization (Nadir)	NEΔT (K)	Beamwidth (deg)
1		23.8	270	H	0.40	5.2
2		31.4	180	H	0.45	5.2
3		50.3	180	V	0.45	2.2
4		51.76	400	V	0.30	2.2
5		52.8	400	V	0.30	2.2
7		53.246±0.08	170	V	0.35	2.2
6		53.596±0.115	170	V	0.30	2.2
8		53.948±0.081	420	V	0.35	2.2
9		54.4	400	V	0.30	2.2
10		54.94	400	V	0.30	2.2
11		55.5	330	V	0.30	2.2
12		57.29	330	V	0.70	2.2
13		57.29±0.217	78	V	0.90	2.2
14		57.29±0.322±0.048	36	V	0.90	2.2
15		57.29±0.322±0.022	16	V	1.30	2.2
16		57.29±0.322±0.010	8	V	1.60	2.2
17		57.29±0.322±0.0045	3	V	2.80	2.2
18	1	89.0	1500	H	0.40	2.0
19	2	118.75±0.08	20	V	2.20	2.0
20	3	118.75±0.2	100	V	1.00	2.0
21	4	118.75±0.4	165	V	0.80	2.0
22	5	118.75±0.8	200	V	0.80	2.0
23	6	118.75±1.1	200	V	0.80	2.0
24	7	118.75±2.1	200	V	0.80	2.0
25	8	118.75±3.0	1000	V	0.50	2.0
26	9	118.75±5.0	2000	V	0.50	2.0
26	10	166	1500	H	0.40	1.1
27	11	183.31±1.0	500	V	0.60	1.1
29	12	183.31±1.8	700	V	0.60	1.1
29	13	183.31±3.0	1000	V	0.50	1.1
30	14	183.31±4.5	2000	V	0.50	1.1
32	15	183.31±7.0	2000	V	0.50	1.1

*CMWS ch1-17 corresponds to MWTS ch1 to 17; ch18-32 on FY-3E corresponds to MWHS 1-15;
Notice starting from FY-3F MWHS all polarization is changed for a consistency with ATMS



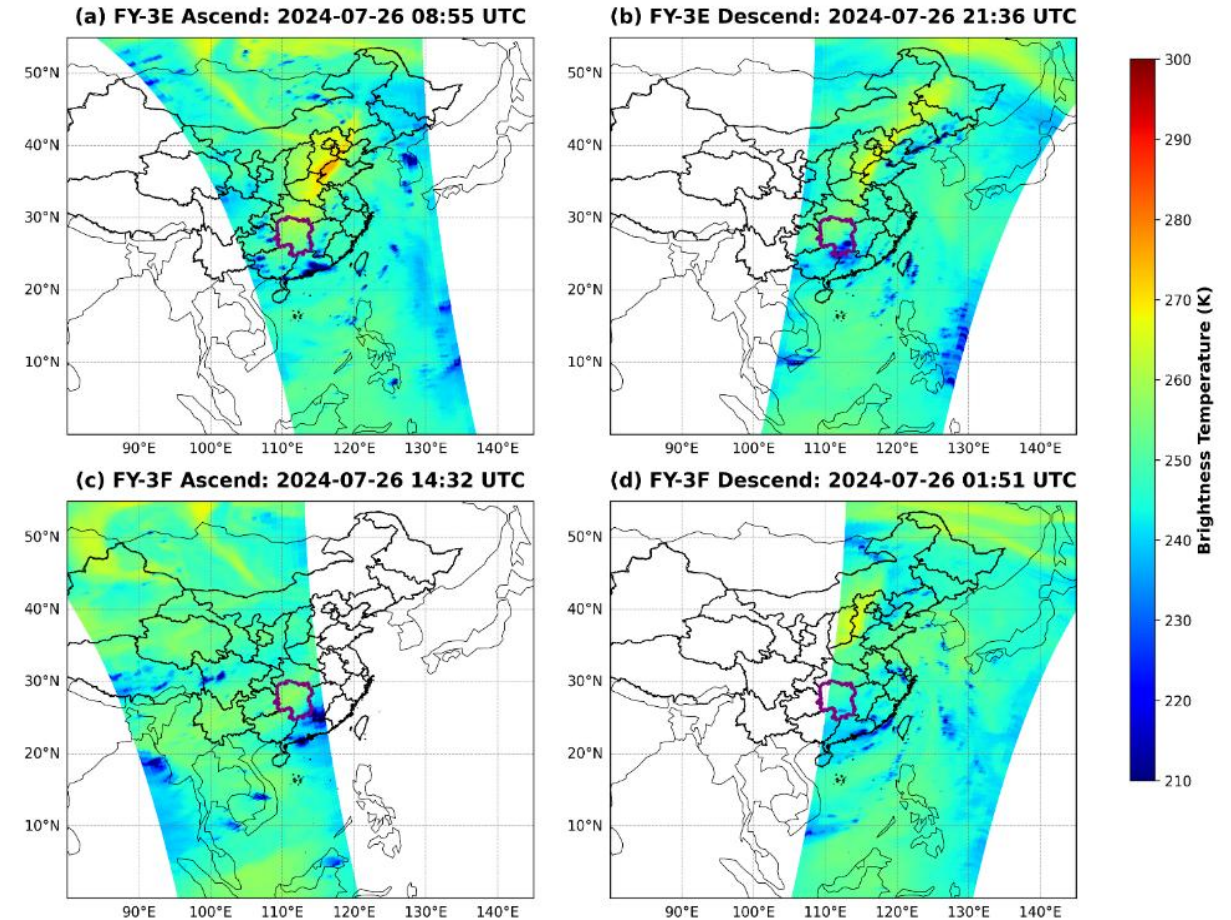
Weighting Functions of FY-3E/F MWTS/MWHS



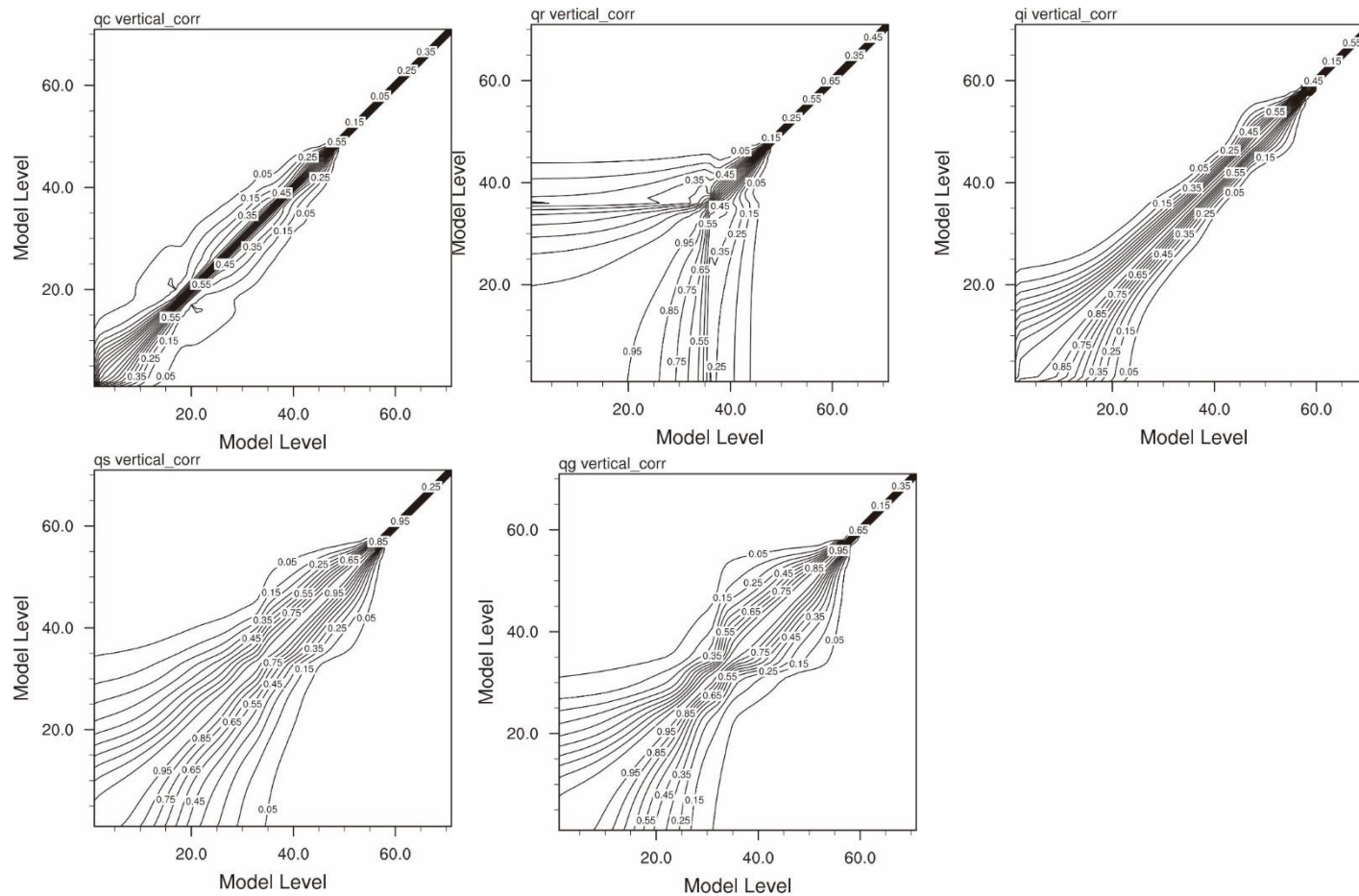
FY-3E and FY-3F Passing Times

- Meso system typically cold -starts at 00:00 and 12:00 UTC.
- At these times, the background field lacks cloud parameters, so only clear-sky assimilation is feasible
- All-sky observation data will be under-utilized

FY-3E and FY-3F Satellite Brightness Temperature (L1 Data)

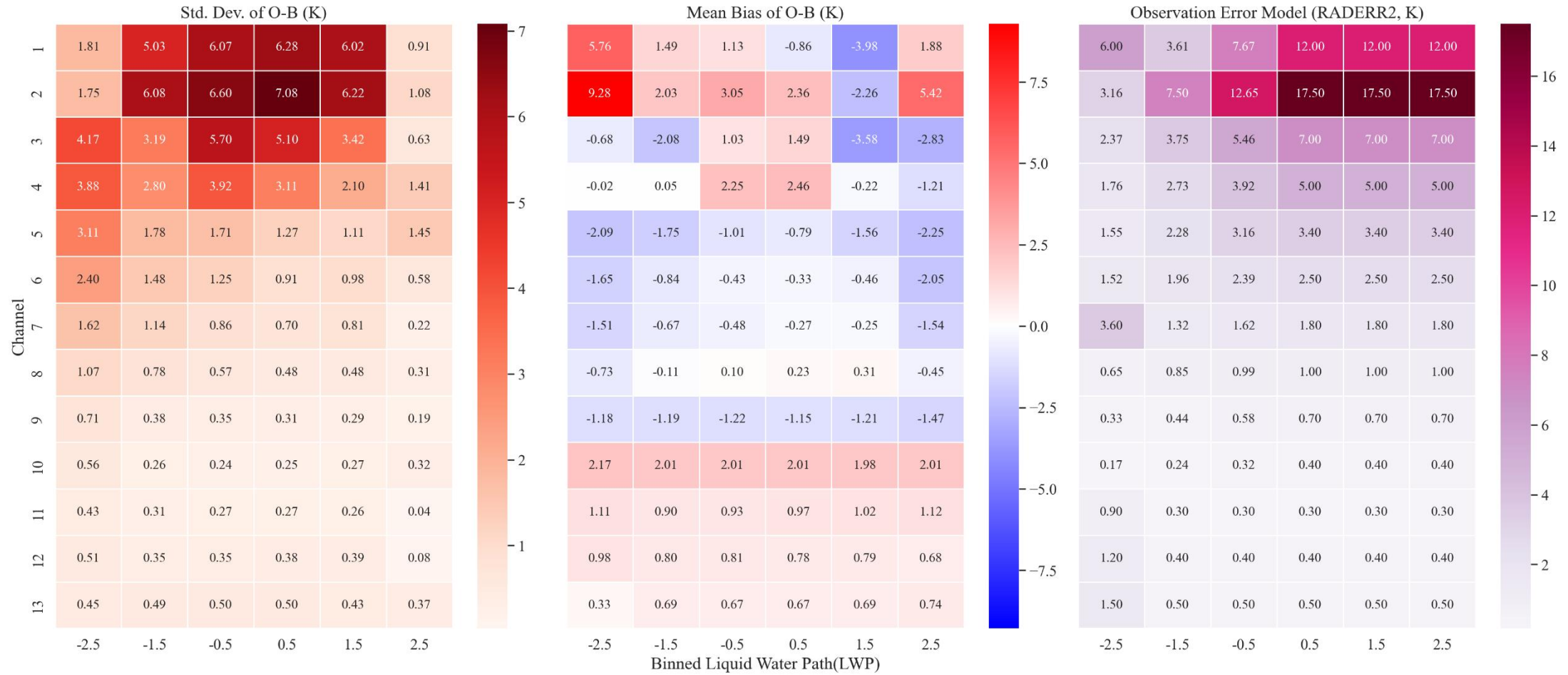


Background Error Covariance in CMA-MESO

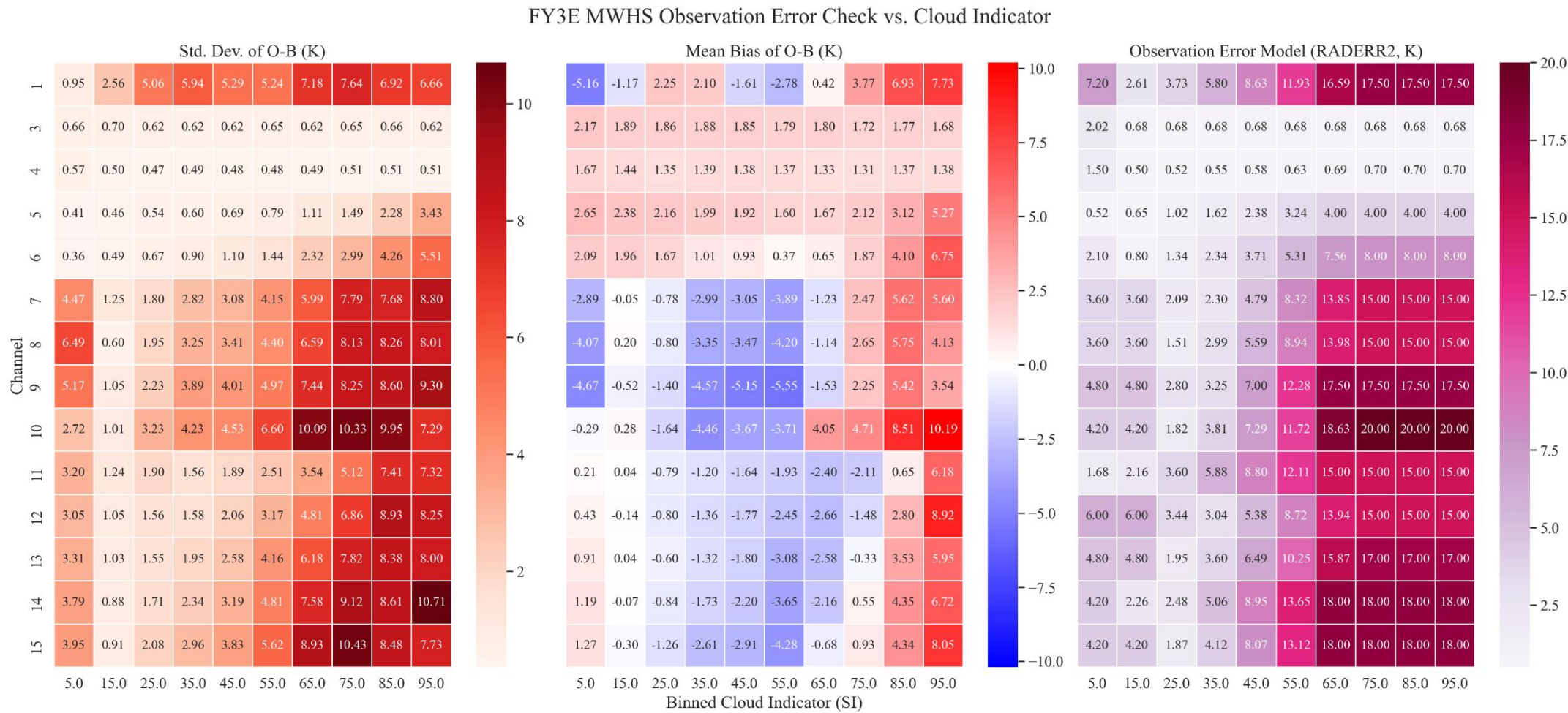


FY-3E MWTS Observation Error Model

FY3E MWTS Observation Error Check vs. Cloud Indicator

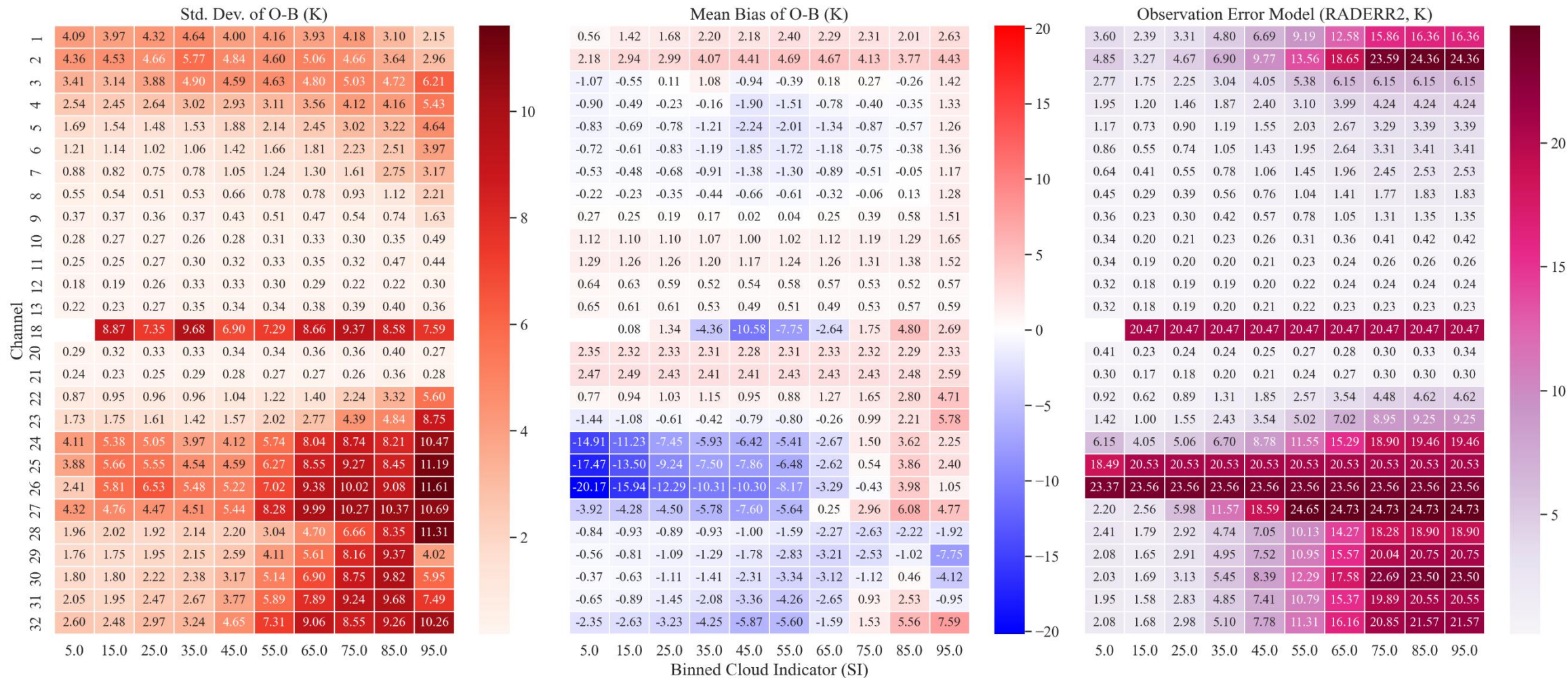


FY-3E MWHS Observation Error Model



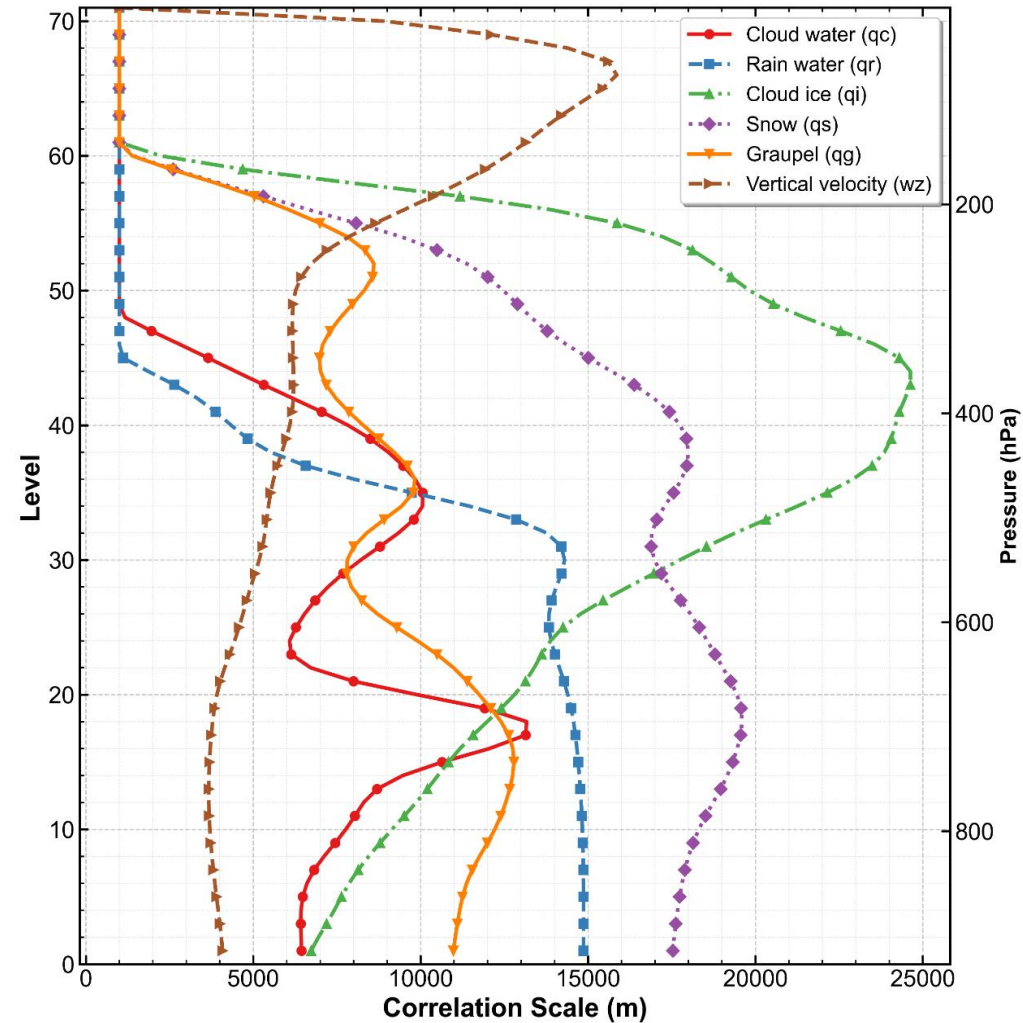
FY-3F MWTS/MWHS Observation Error Model

FY3F MWTS/MWHS Observation Error Check vs. Cloud Indicator



Correlation Length of Hydrometeor Background Error Covariance Matrix

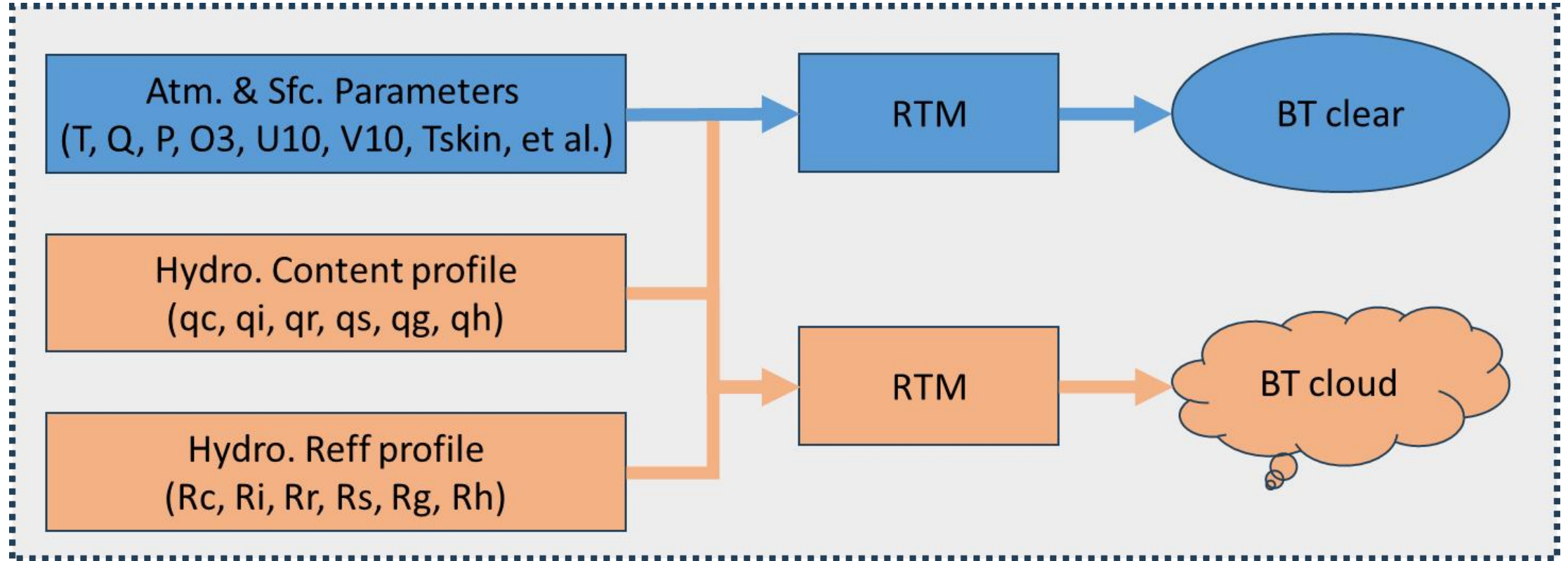
- From CMA-MESO system, all the background error covariance matrices are statistically derived using NMC methods for all the hydrometeors
- The correlation length varies with hydrometer type. It is about 25 km for cloud ice near 400 hPa. Snow also has a relatively larger correlation length
- It is a very sensitive parameter affecting the areas of precipitation.



ARMS Supports All-sky Radiance Assimilation

- ARMS supports assimilation of satellite data from global observing systems
 - ARMS in the Next-Generation Assimilation System
 - Complete the integration of ARMS into the next-generation assimilation system and carry out accuracy tests for modules such as forward modeling, tangent linear, and adjoint.
 - All-sky and All-surface Assimilation
 - Develop an observation error model for cloud and rain areas
 - Establish an assimilation scheme for surface-sensitive channels of microwave sounding instruments;
- FY-3A MWTS
 - FY-3A MWHS
 - FY-3B MWTS
 - FY-3B MWHS
 - FY-3C MWTS-2
 - FY-3C-MWHS-2
 - FY-3D MWTS-2
 - FY-3D MWHS-2
 - FY-3 B/C/D MWRI
 - FY-3 B/C VIRR
 - FY-3C MERSI
 - FY-3C IRAS
 - FY-3D MERSI-2
 - FY-3D HIRAS
 - FY-4A GIIRS
 - FY-4A AGRI
 - FY-4M GMIS
 - FY-3E MWTS
 - FY-3E MWHS
 - FY-3E-HIRAS
 - FY-3F MWTS
 - FY-3F MWHS
 - FY-3F-HIRAS
 - FY-4B AGRI
 - FY-4B GIIRS
 - NOAA 15 to 19 AMSU-A
 - NOAA 18-19 MHS
 - NOAA 18-19 HIRS
 - NOAA 15-19 AVHRR
 - SNPP/NOAA-20/21 ATMS
 - SNPP/NOAA-20/21 CrIS
 - SNPP/NOAA-20/21 VIIRS
 - METOP-A to C IASI
 - METOP-A to C IASI
 - METOP-A to C AMSU-A
 - METOP-A to C AVHRR
 - JAXA AMSR2
 - NASA GMI
 - EOS Aqua AIRS
 - EOS Terra/Aqua MODIS
 - EPS-Stenna AWS

Radiative Transfer Scheme for Cloudy Radiance Simulations

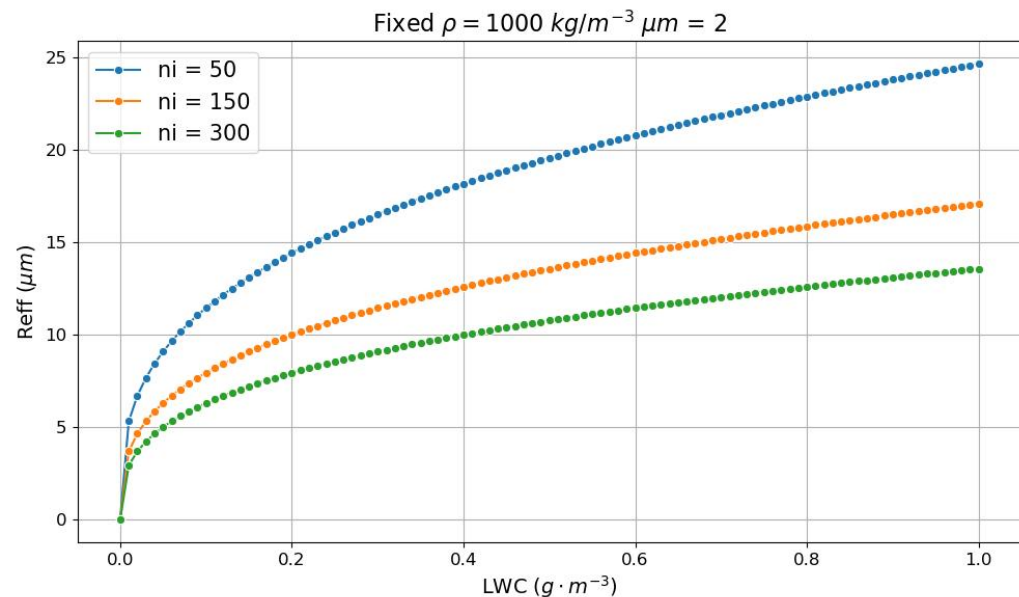
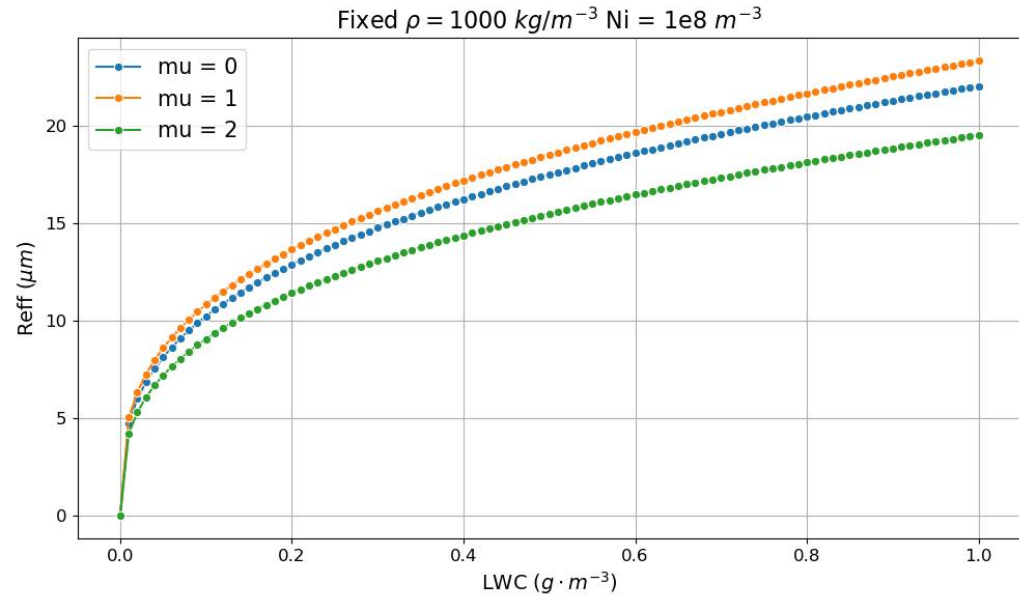


Hydrometeor Effective Radius Determined from CMA-MESO

$$r_e = \frac{1}{2} \frac{\int D^3 N(D) dD}{\int D^2 N(D) dD} = \left[\frac{3(\mu+3)^3 \rho_a Q_x}{4\pi \rho_x N_x} \frac{\Gamma(\mu+1)}{\Gamma(\mu+4)} \right]^{\frac{1}{3}}$$

	Cloud	Rain	Ice	Snow	Graupel
Q_x (kg/kg)	✓	✓	✓	✓	✓
N_x (/cm ³)	100	✓	✓	✓	✓
μ	2	0	1	1	1
ρ_x kg/m ³	1000	1000	920	100	400

**From "Fixed Radius" to "Dynamic Spectral Distribution":
Refined Calculation of Hydrometeor Effective Radius to
Optimize the Radiative Transfer Simulations**



Symmetric Cloud Index for Microwave Sounder Data

MWTS	$Z_{D0} = C1 - (C_2 + C_3 * \cos(\text{zazim})^2)$ $Z_{D1} = 0.754$ $Z_{D2} = -2.265$
	$LWP = \cos(\text{zazim}) * (Z_{D0} + Z_{D1} * \log(285 - TB_1) + Z_{D2} * \log(285 - TB_2))$
	$LWP_{sys} = \frac{LWP_{obs} + LWP_{bkg}}{2}$

MWHS	$SI = TB_1 - TB_{10} - (-45.94 + 0.248 * SATZEN)$
	$SI_{sys} = \frac{SI_{obs} + SI_{bkg}}{2}$

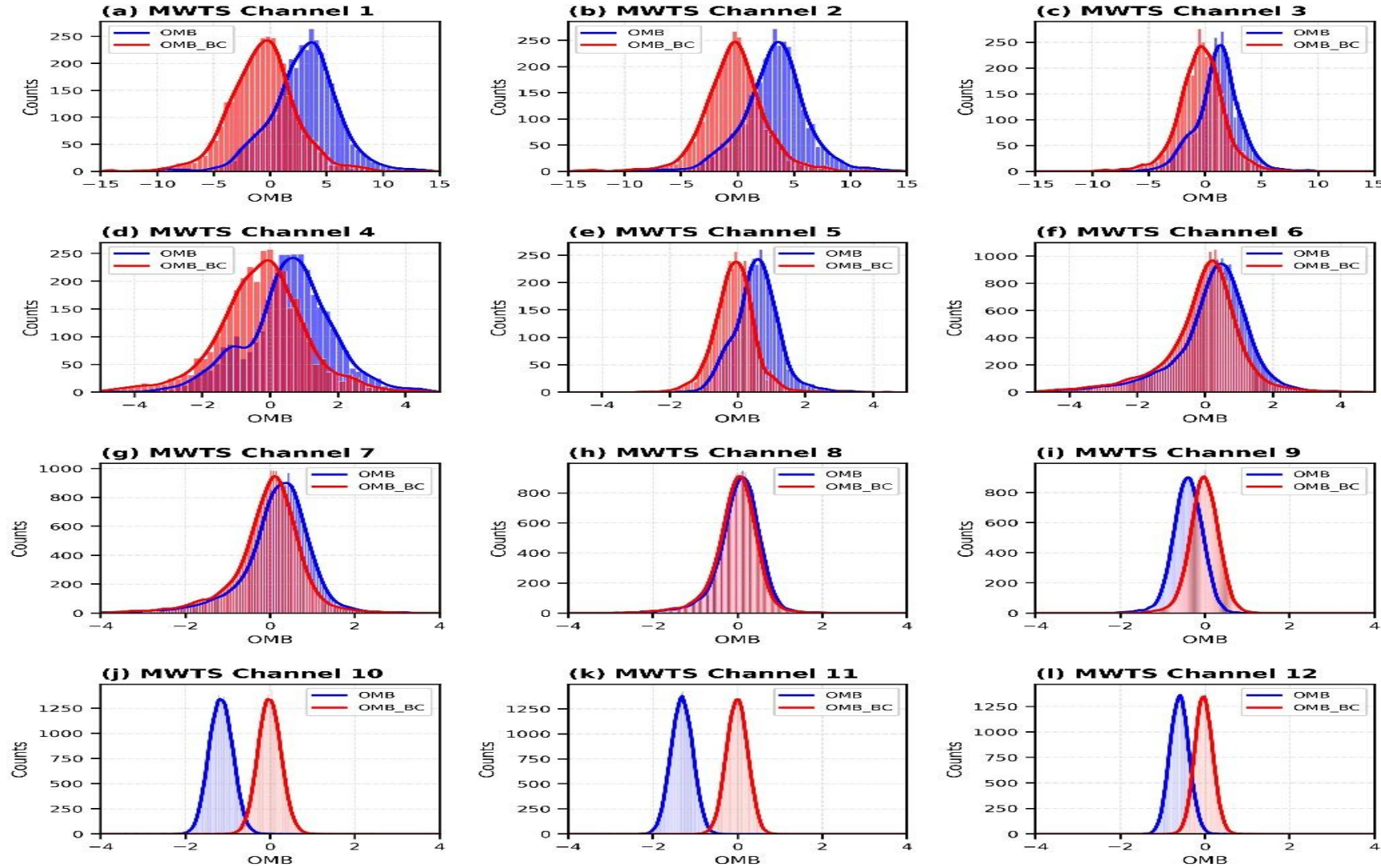
$$g(C_{SYM}) = \begin{cases} g_{clr} & \in C_{SYM} \leq C_{clr} \\ g_{clr} + (g_{cld} - g_{clr}) \left(\frac{C_{SYM} - C_{clr}}{C_{cld} - C_{clr}} \right)^2 & \in C_{clr} < C_{SYM} < C_{cld} \\ g_{cld} & \in C_{SYM} \geq C_{cld} \end{cases}$$

MWTS				
Channel	g_{clr}	g_{cld}	$Index_{clr}$	$Index_{cld}$
1	2.0	12	-2	0
2	2.0	17.5	-3	0
3	2.0	7	-3	0
4	1.5	5	-3	0
5	1.5	3.4	-2.5	-0.5
6	1.4	2.5	-3	-0.5
7	1.2	1.8	-2	-0.25
8	0.6	1	-3	-0.75
9	0.3	0.7	-3	0
10	0.15	0.4	-3	0
11	0.3	0.3	/	/
12	0.4	0.4	/	/
13	0.5	0.5	/	/
14	0.6	0.6	/	/
15	0.6	1.2	-4	3
16	1.4	2.2	-4	3
17	1.4	3.5	-4	0

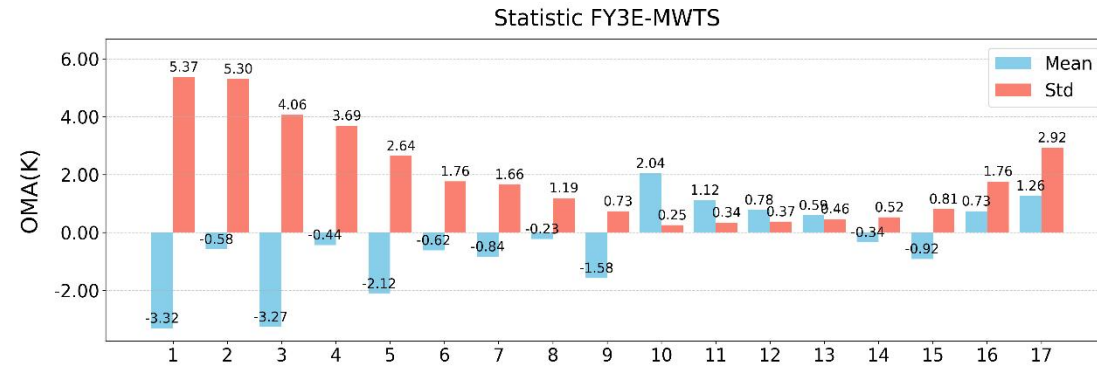
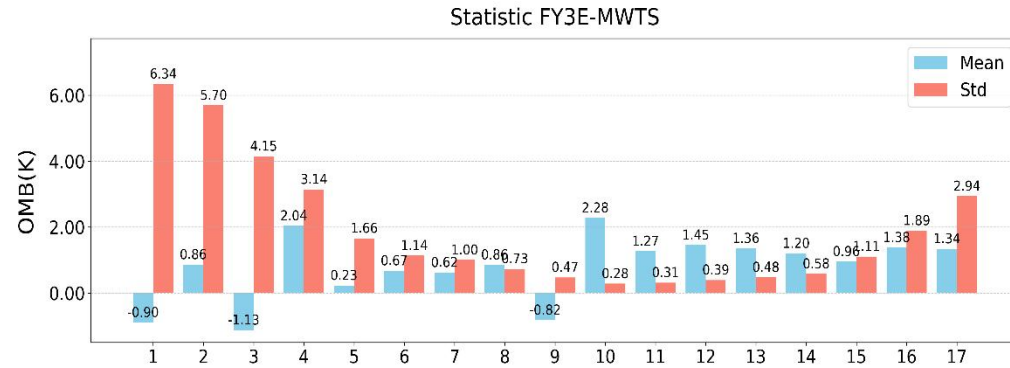
MWHS				
Channel	g_{clr}	g_{cld}	$Index_{clr}$	$Index_{cld}$
1	2.4	17.5	10	75
3	0.675	0.675	/	/
4	0.5	0.7	10	75
5	0.5	4	5	70
6	0.7	8	10	75
7	1.2	15	25	75
8	1.2	15	20	75
9	1.6	17.5	25	70
10	1.4	20	20	75
11	1.6	15	5	70
12	2.0	15	25	75
13	1.6	17	20	75
14	1.4	18	15	70
15	1.4	18	20	70

Calculate the symmetric cloud index using CLW and scattering index and fit the STD of OMB with above formulas.

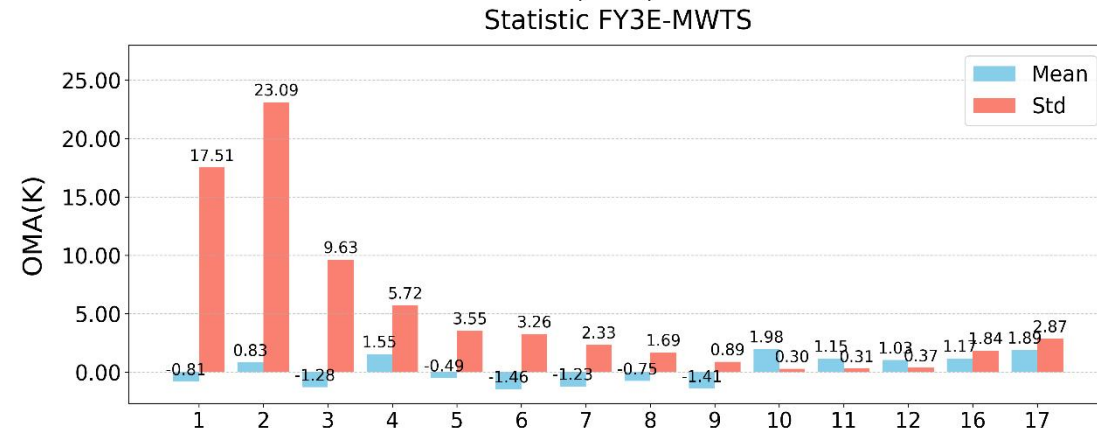
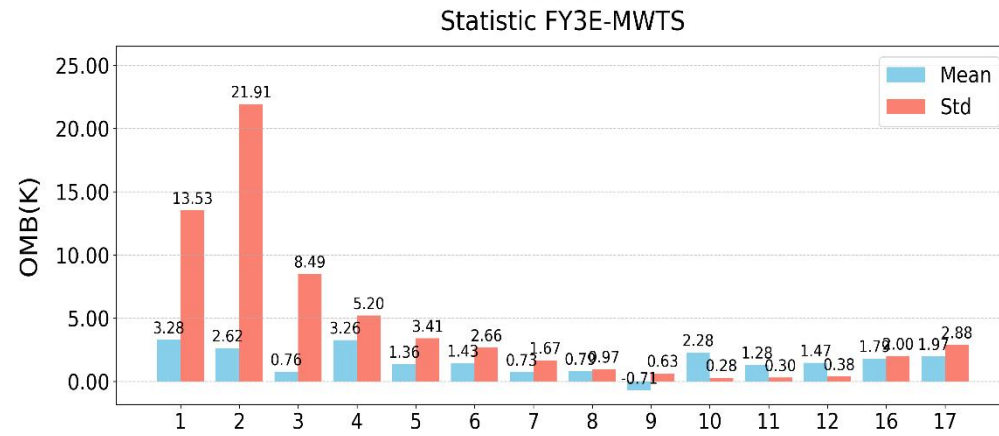
MWTS Biases from Channel 9 to 12



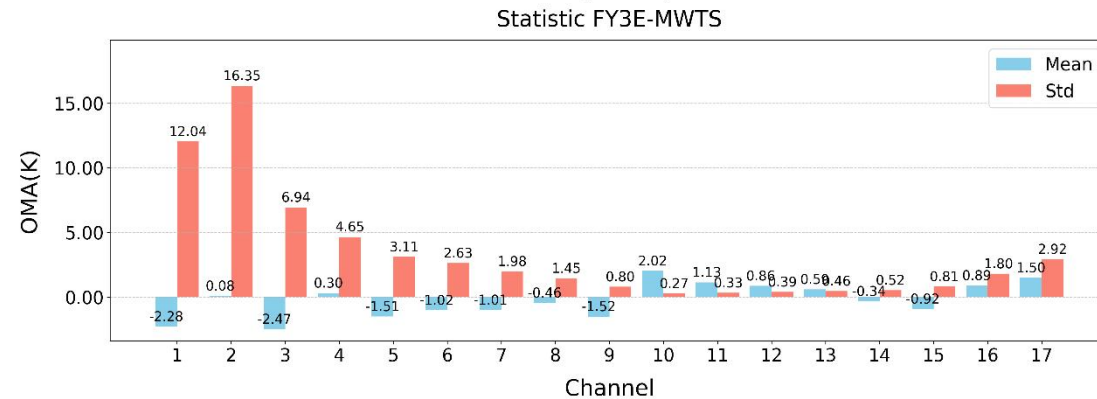
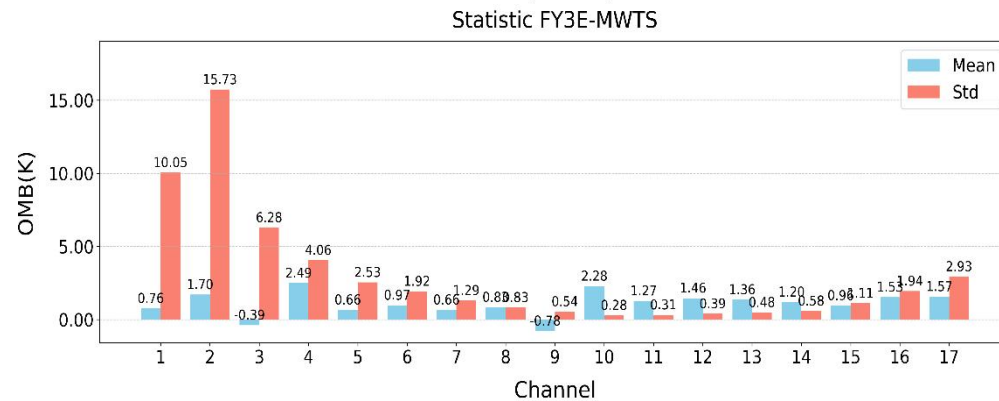
All-Weather Satellite Observation Simulation (FY-3E/MWTS)



Pass QC

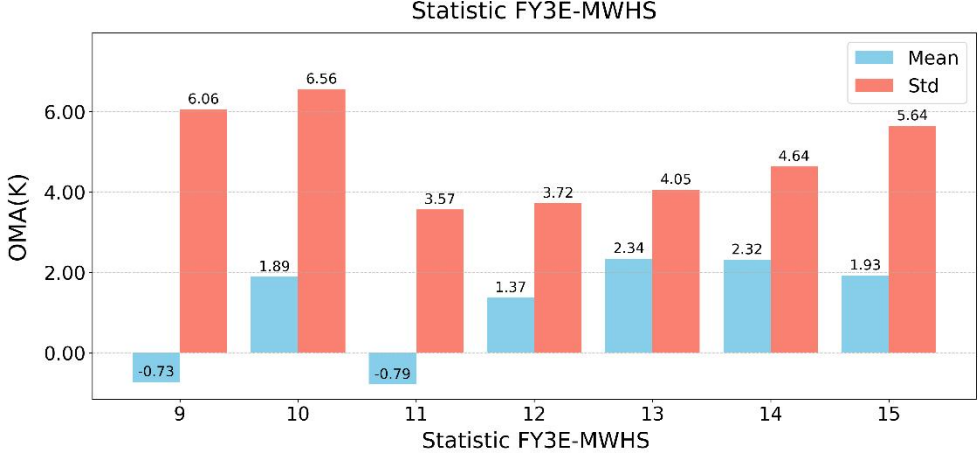
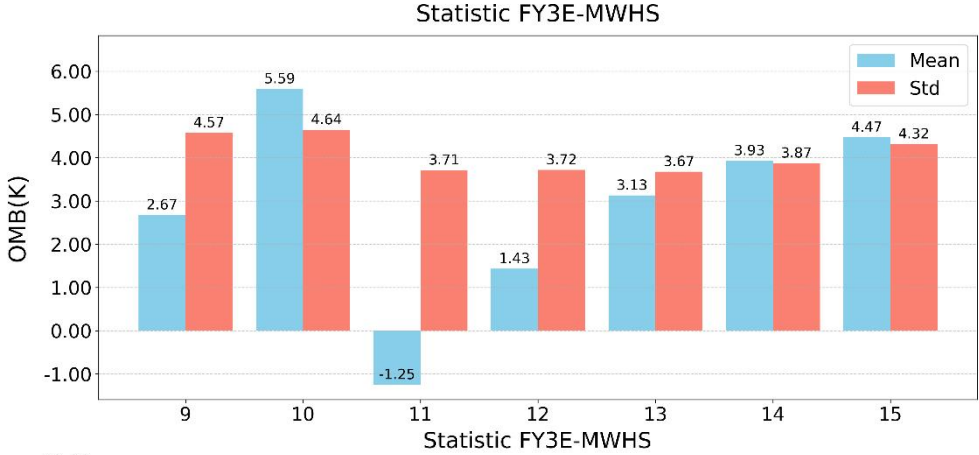


Failed QC

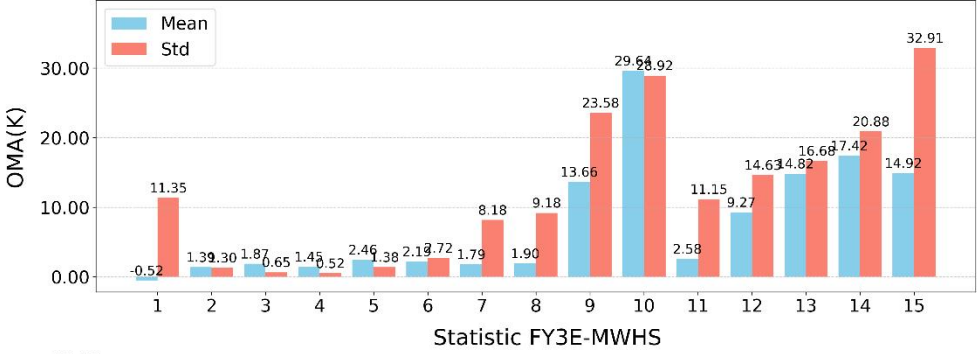
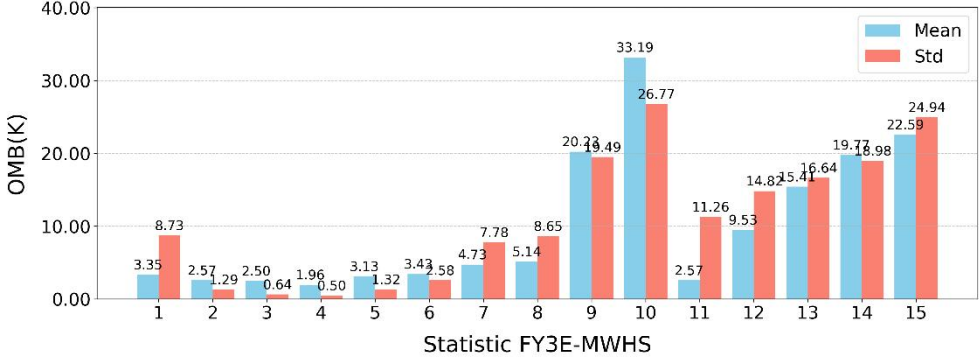


ALL

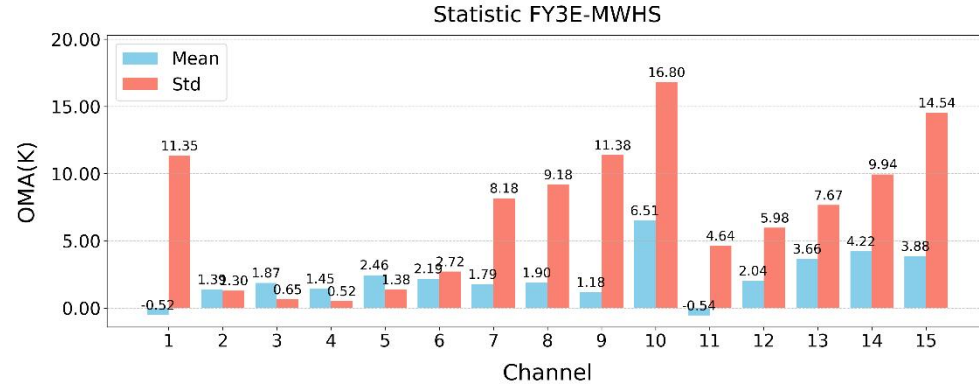
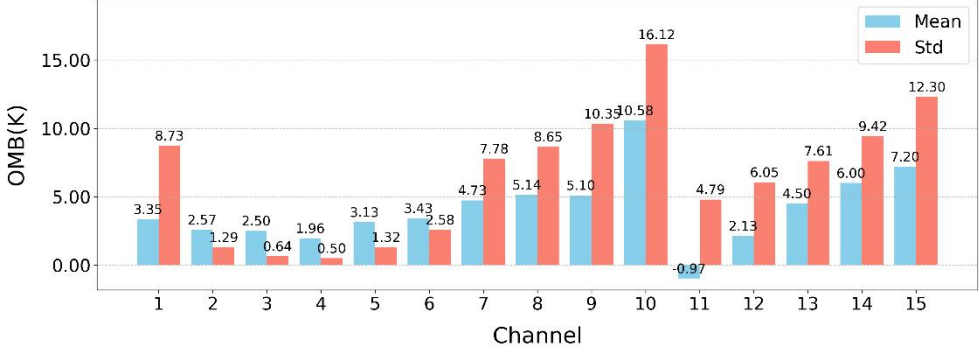
All-Weather Satellite Observation Simulation (FY-3E/MWHS)



Pass QC



Failed QC



ALL

Data Assimilation Experiments

Experiment	Data Assimilated	ARMS Version
CTRL	None	Not Applicable
EXPR1	FY-3E/F Radiances (All-Sky)	Fixed effective radius, standard Delta-Eddington scattering
EXPR2	FY-3E/F Radiances (All-Sky)	Adaptive effective radius, corrected delta-M scattering

Evaluation of 24-Hour Accumulated Precipitation in CMA-MESO

Satellite Data Assimilation

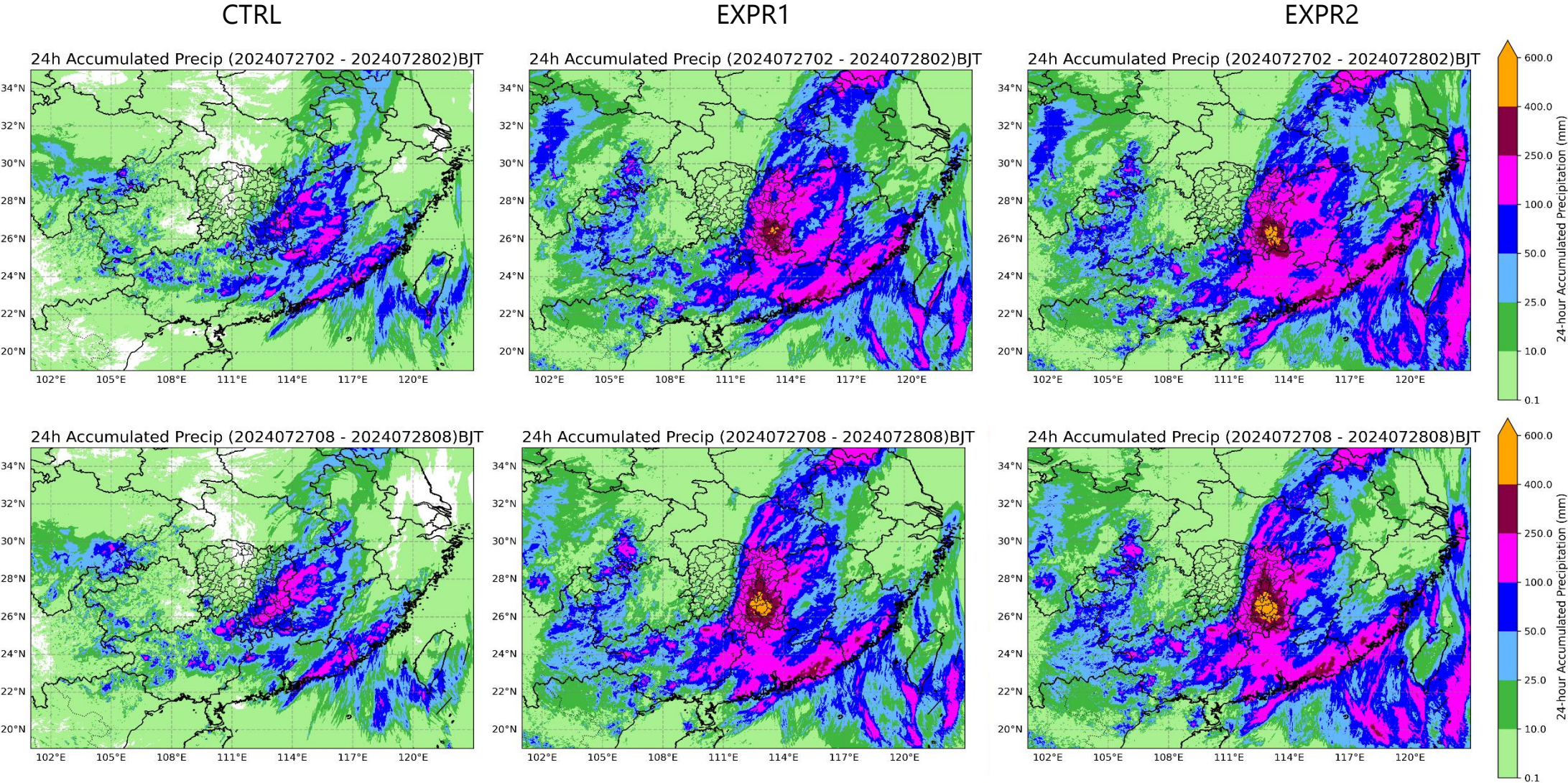
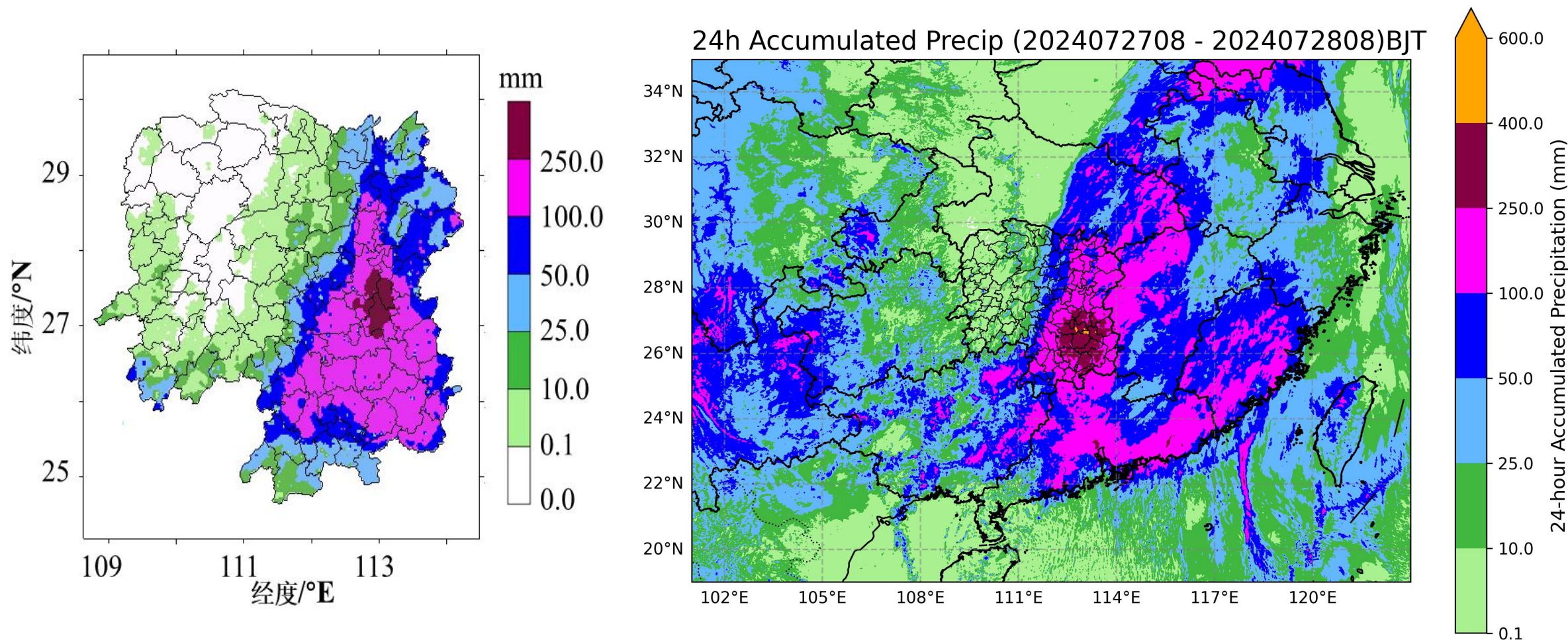


Figure 19. Comparison of 24-hour accumulated precipitation (mm).
The panels show: (a) CTRL, (b) EXPR1, and (c) EXPR2 experiments.

Evaluation of 24-Hour Accumulated Precipitation in CMA-MESO

Satellite Data Assimilation



The forecast for Typhoon Mawar (2024) showed good performance in both precipitation distribution and intensity. However, due to the relatively low level of numerical prediction at that time, Zixing suffered significant economic losses and casualties.

Evaluation of 24-Hour Accumulated Precipitation in CMA-MESO

Satellite Data Assimilation

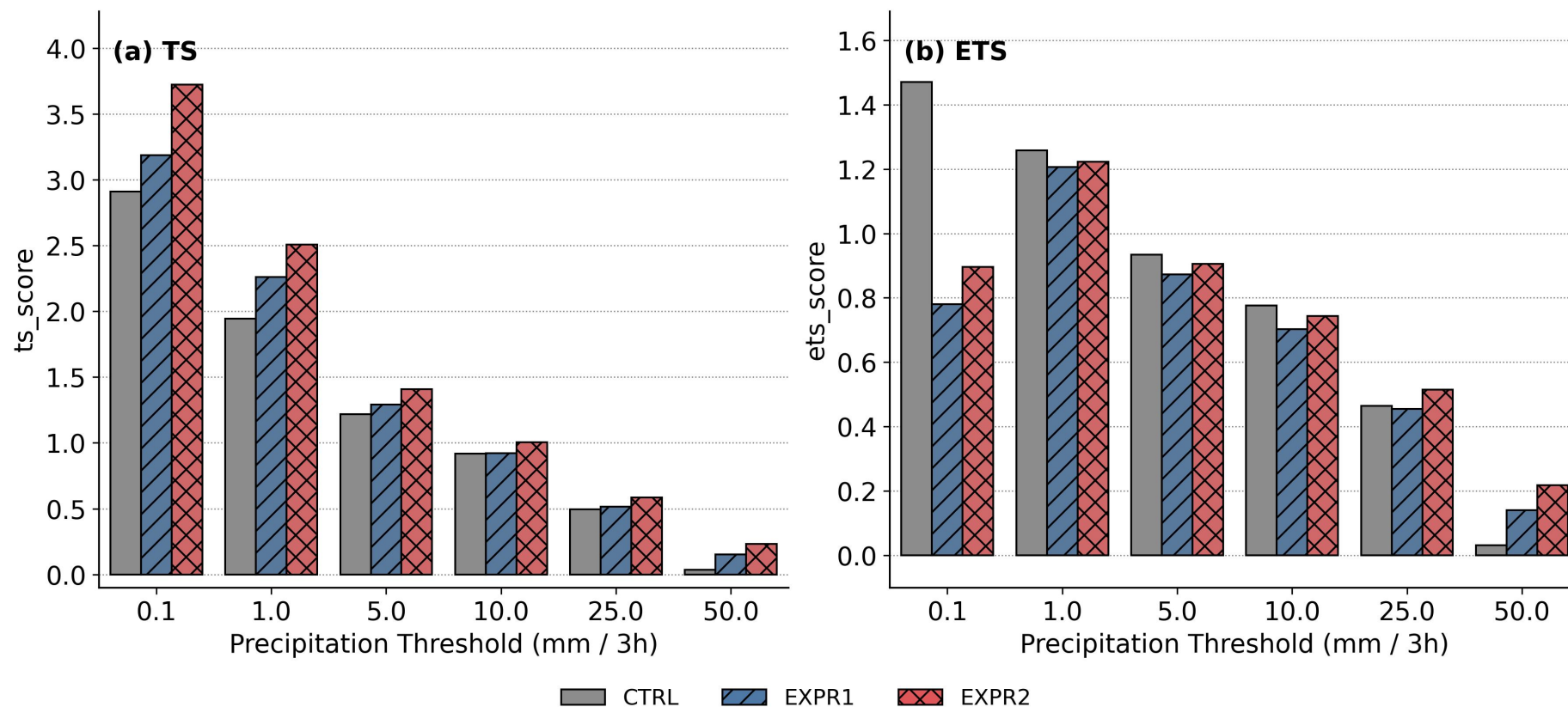


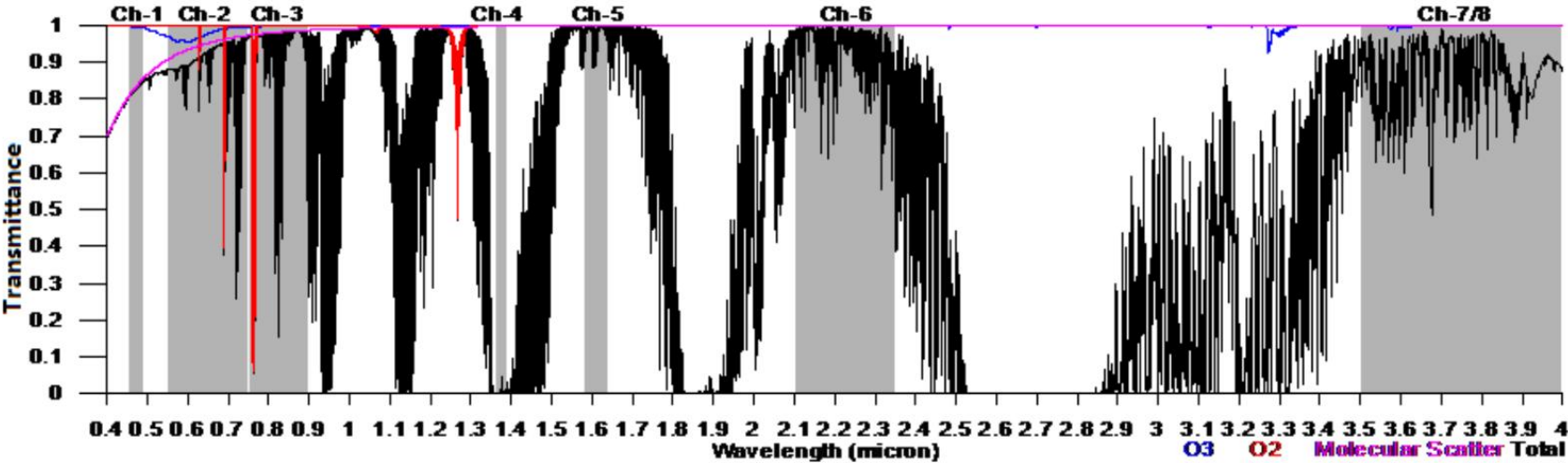
Figure 20. Quantitative verification of the 3-hour precipitation forecasts from the three experiments, computed against station observations over the entire 48-hour simulation period. The panels show the (a) Threat Score (TS) and (b) Equitable Threat Score (ETS) for various precipitation thresholds. Higher scores indicate better forecast skill.

Outline

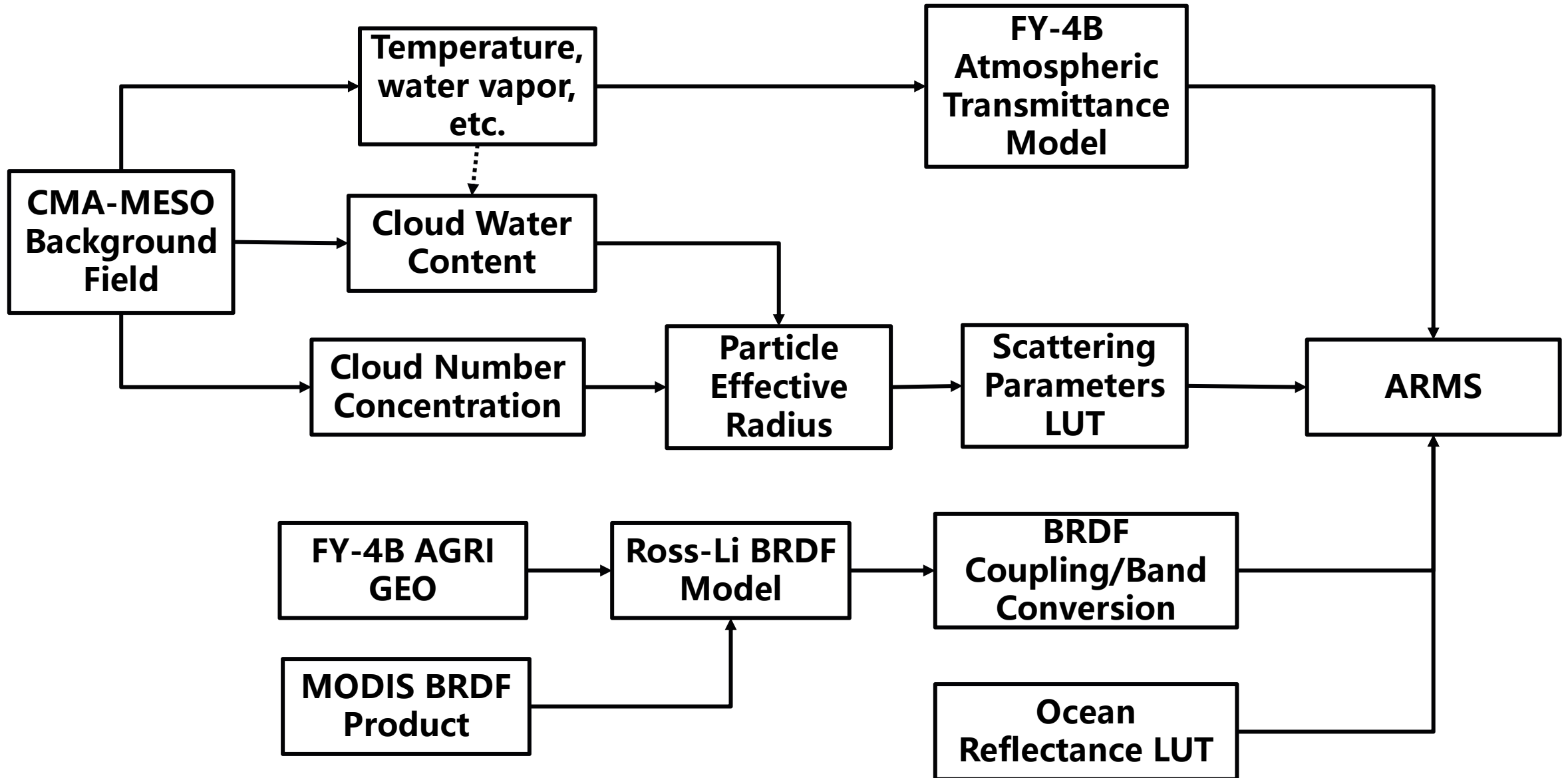
- **Major Challenges in Regional NWP Satellite Radiance Assimilation**
- **Assimilation of Microwave Cloudy Radiances from Polar-Orbiting Satellites**
- **Assimilation of Visible Radiances from Geostationary Imagers**
- **Summary and Conclusions**

FY-4B AGRI Visible Bands

Band	Central Wavelength (μm)	Bandwidth (μm)	Spatial Resolution (km)	Temporal Resolution (min)
1	0.47	0.45 ~ 0.49	1	15
2	0.65	0.55 ~ 0.75	0.5	15
3	0.825	0.75 ~ 0.90	1	15
4	1.379	1.371 ~ 1.386	2	15
5	1.61	1.58 ~ 1.64	2	15
6	2.25	2.10 ~ 2.35	2	15
7-15	...	...	4	15



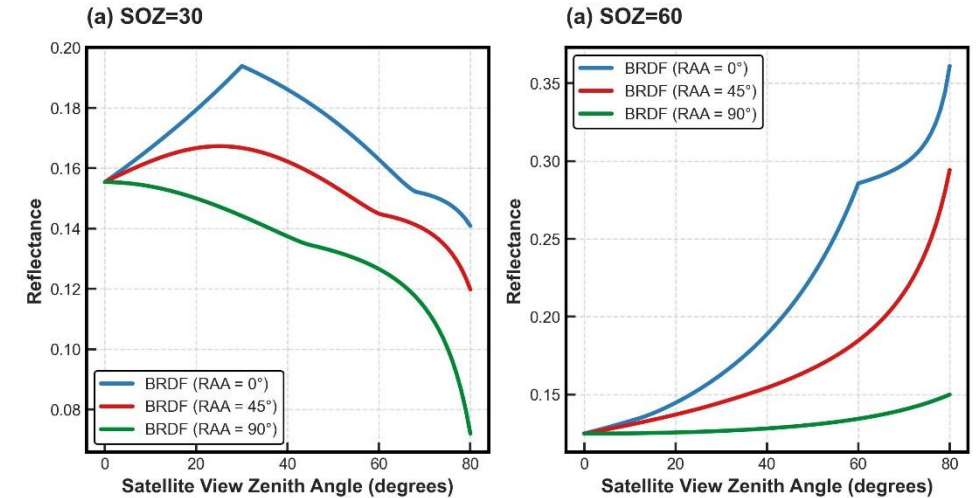
All-sky Assimilation s of VIS-NIR Radiances



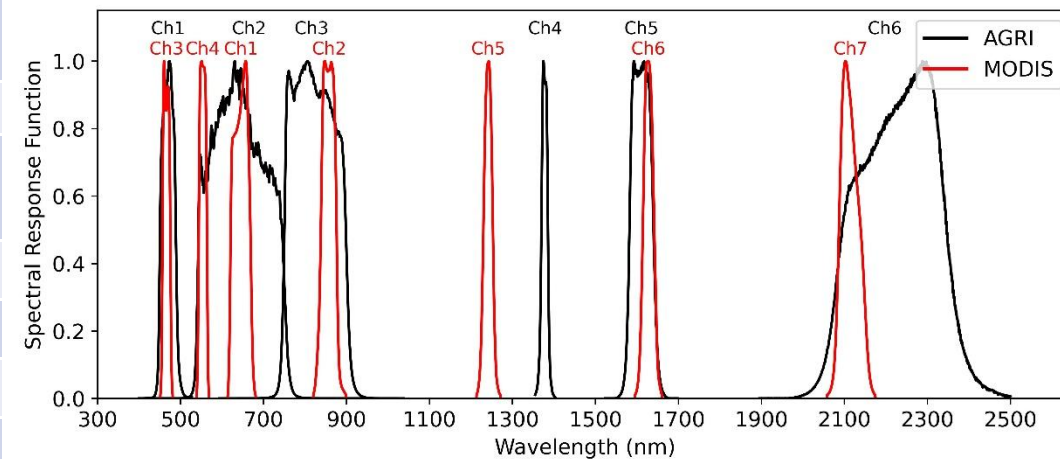
MODIS BRDF Dataset

- The surface BRDF describes the reflection characteristics of natural surfaces under different incident and observation geometric conditions;
- Using MODIS BRDF products and the **Ross-Li BRDF model**, the reflectance of ground objects at any observation angle can be calculated:

$$R(\theta_s, \theta_v, \Delta\varphi) = f_{iso} + f_{vol} K_{vol}(\theta_s, \theta_v, \Delta\varphi) + f_{geo} K_{geo}(\theta_s, \theta_v, \Delta\varphi)$$

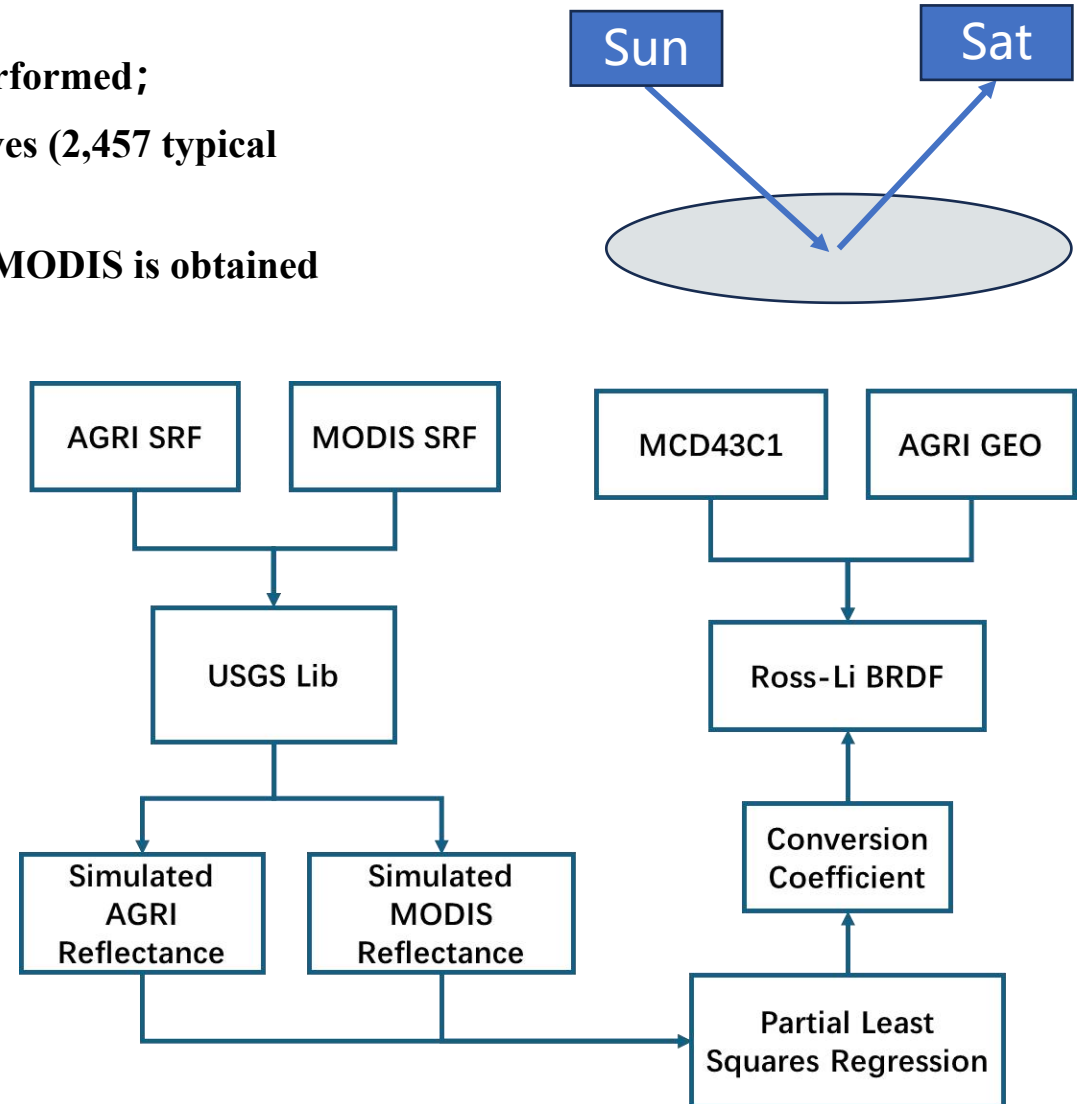
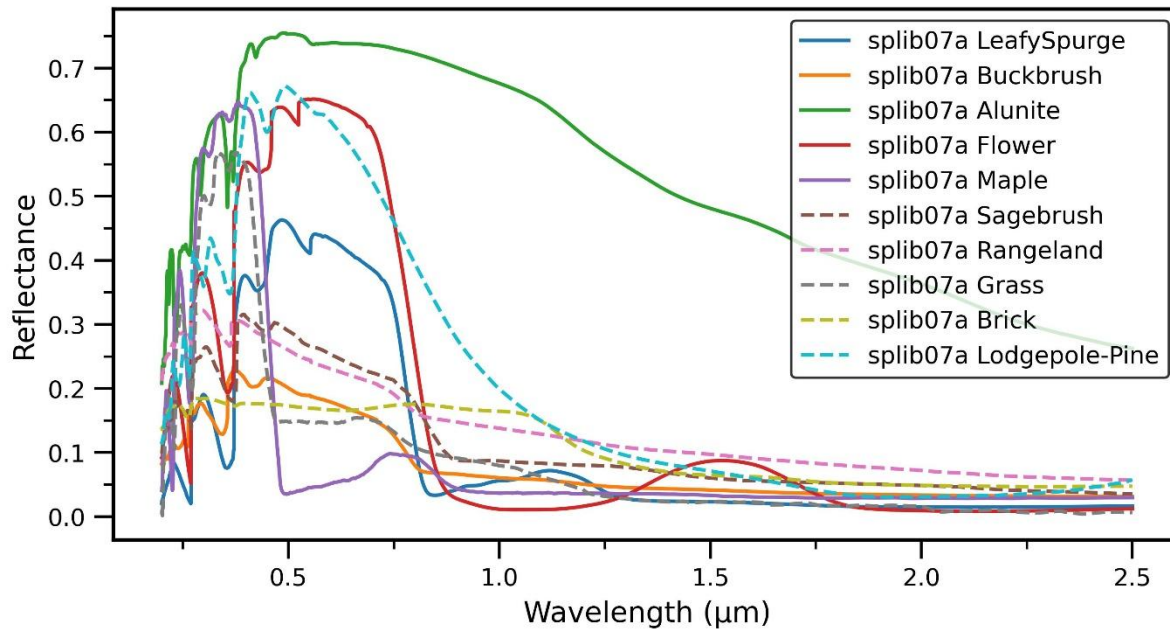


Band	Bandwidth(μm)	Spatial Resolution(m)	Main Applications	Signal-to-Noise Ratio
1	0.620-0.670	250	Land/Cloud/Aerosol Boundary	128
2	0.841-0.876	250	Same as above	201
3	0.459-0.479	500	Land/Cloud/Aerosol Properties	243
4	0.545-0.565	500	Same as above	228
5	1.230-0-1.250	500	Same as above	74
6	1.628-1.652	500	Same as above	275
7	2.105-2.155	500	Same as above	110



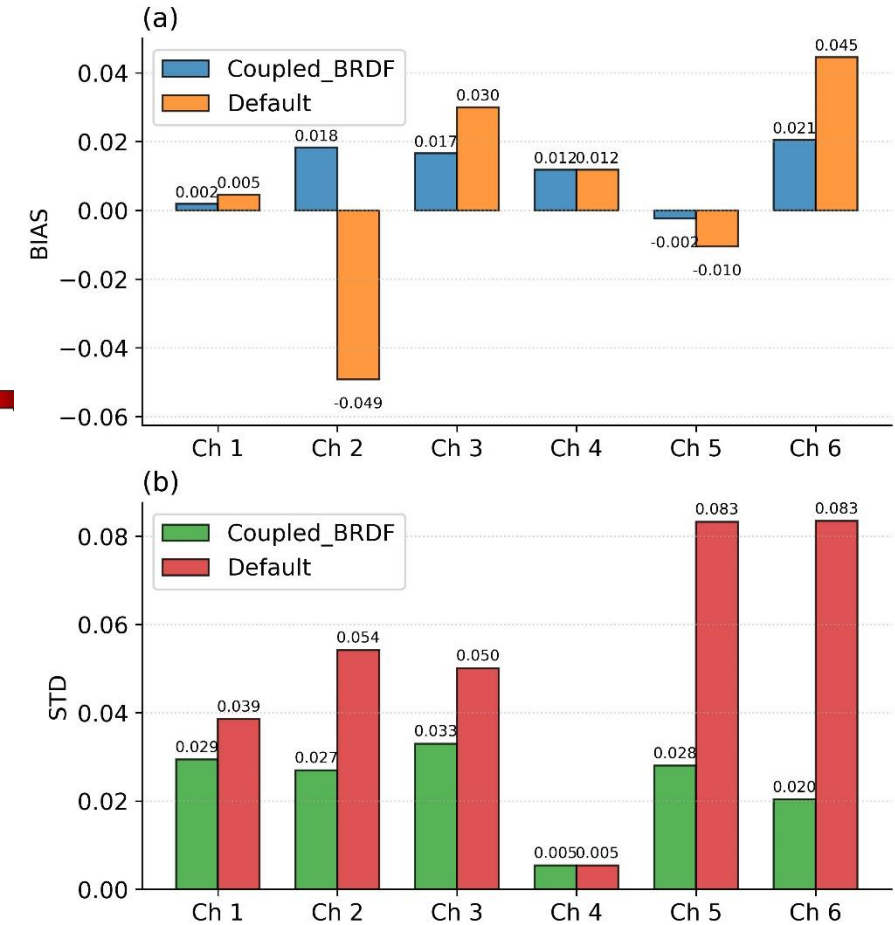
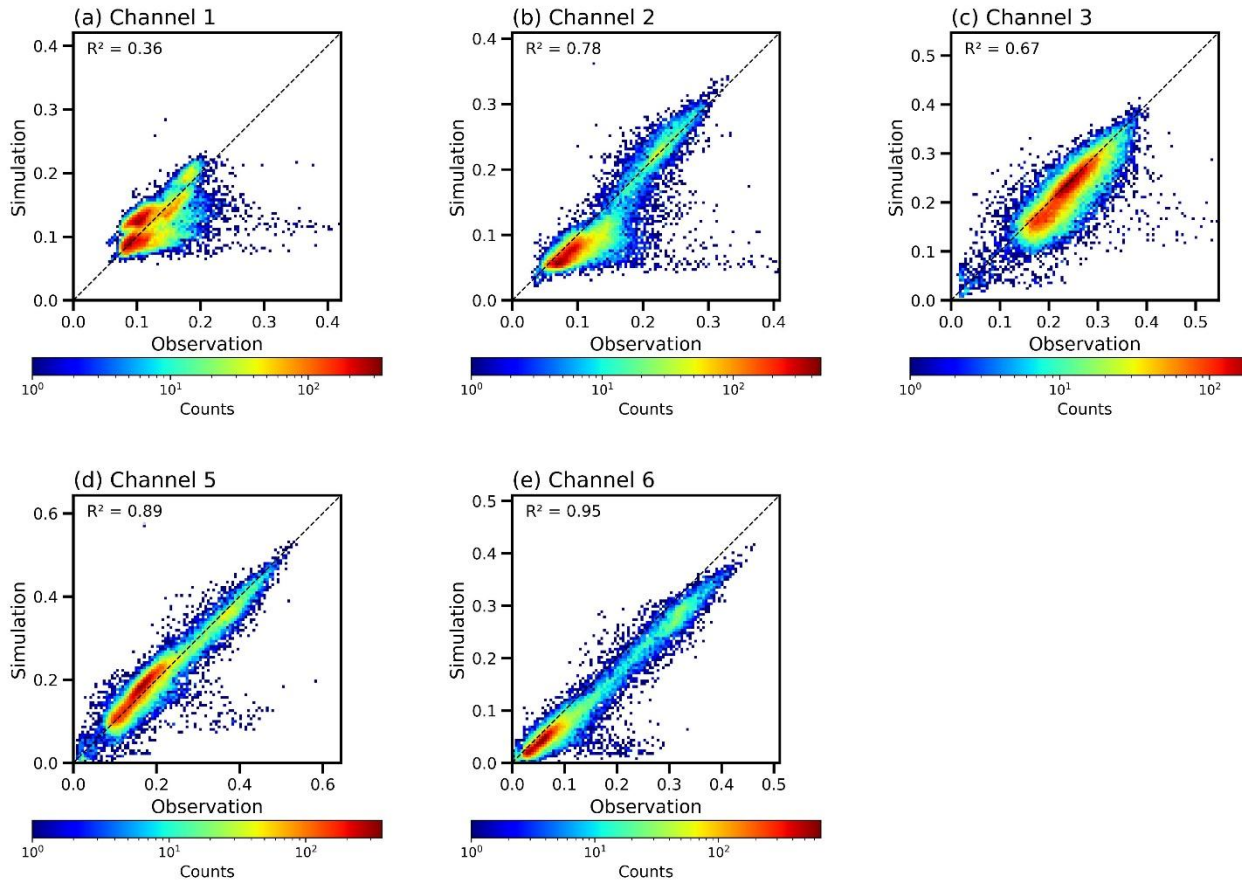
Conversion of MODIS BRDF to AGRI

- Band conversion of the BRDF describing direct solar radiation is performed;
- The SRF is convolved with the USGS Version 7 surface spectral curves (2,457 typical land cover types);
- The surface reflectance conversion relationship between AGRI and MODIS is obtained based on partial least squares regression;



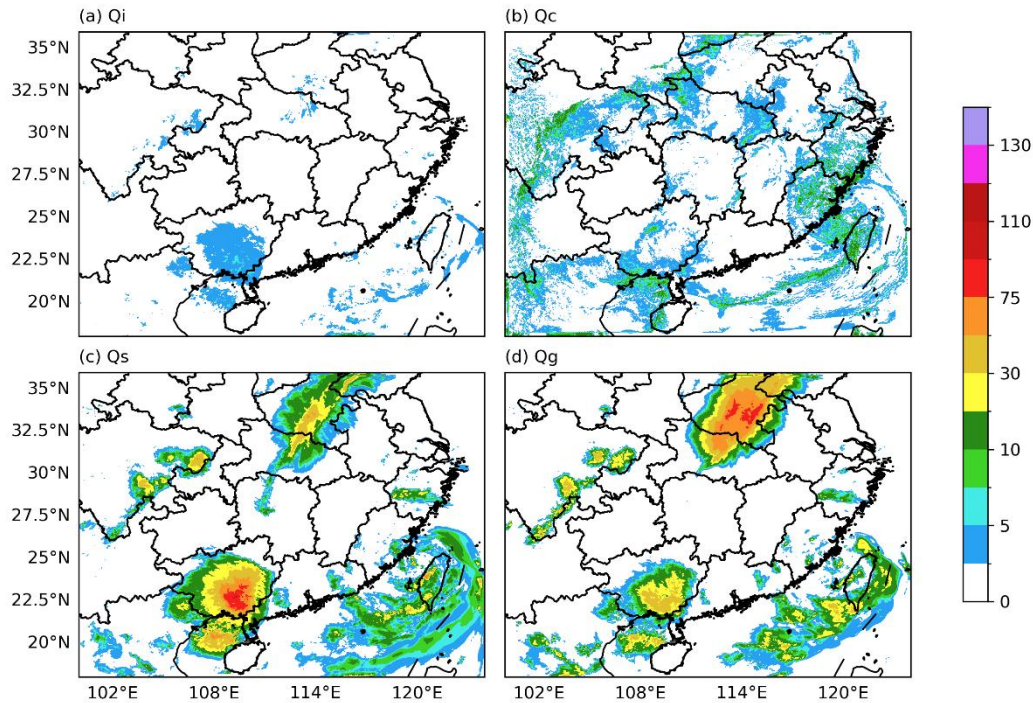
Evaluation of AGRI Simulations from CMA-MESO Outputs

- The left figure is a scatter density plot: the simulation results of the five surface-sensitive channels all have a good dynamic range.;
- The right figure is an accuracy evaluation plot: the simulation accuracy with coupled BRDF is much higher than that of the default settings.

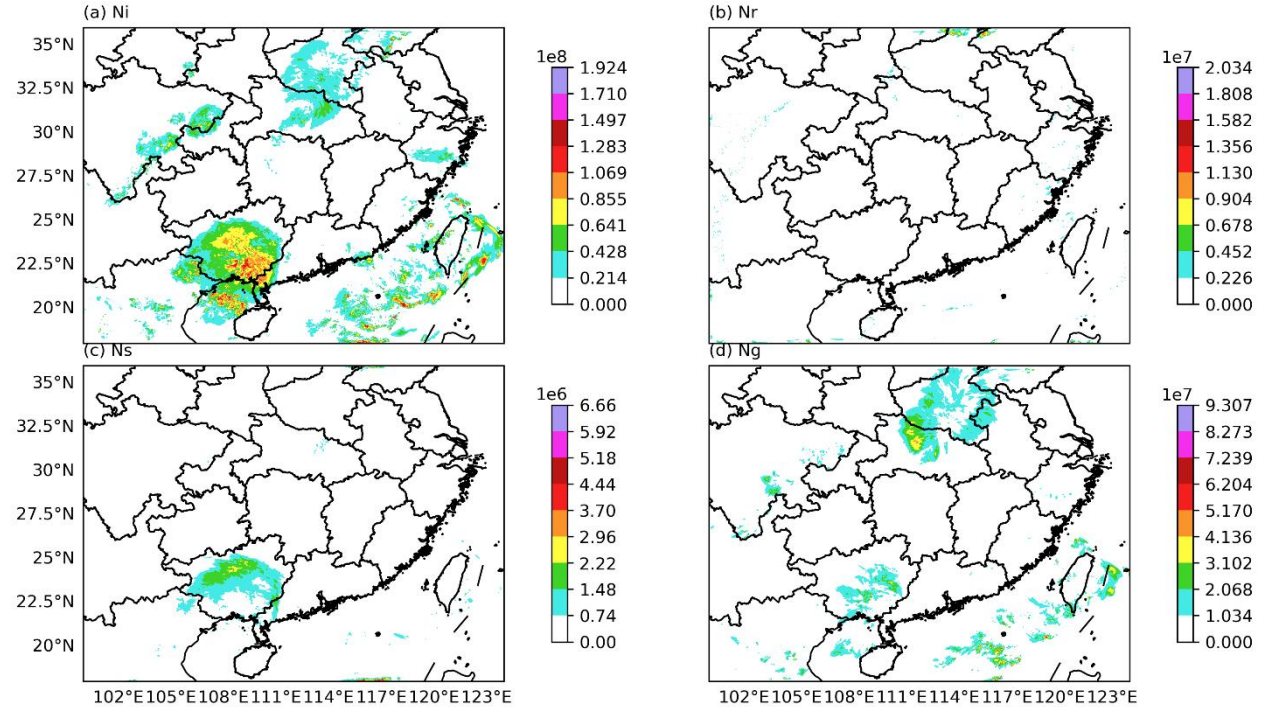


Number Concentration of Cloud Hydrometeors from CMA-MESO

CMA-MESO6.0 RTM-ARMS Valid:2025-05-25 03Z(UTC)
Total Column Hydrometeors(Unit: g/m^{-3})



CMA-MESO6.0 RTM-ARMS Valid:2025-05-25 03Z(UTC)
Total Column Number concentration(Unit: m^{-3})



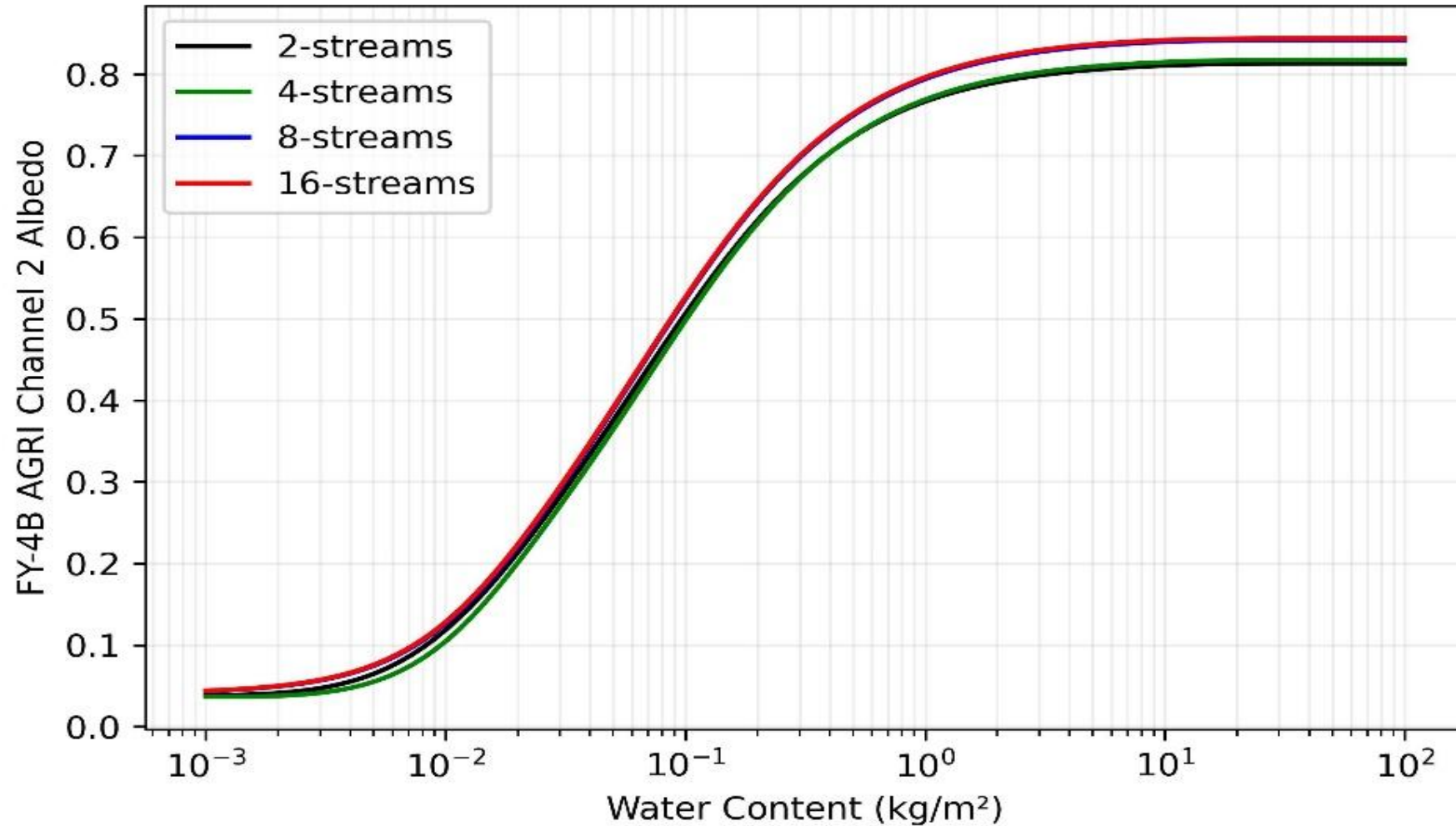
Small particle number concentration but large hydrometeor content:

- **Mature precipitation process:** This is the most typical case
- **Efficient Growth Mechanisms:** This indicates the presence of efficient particle growth mechanisms in the cloud (Coalescence/Accretion/Freeze-on/Aggregation)

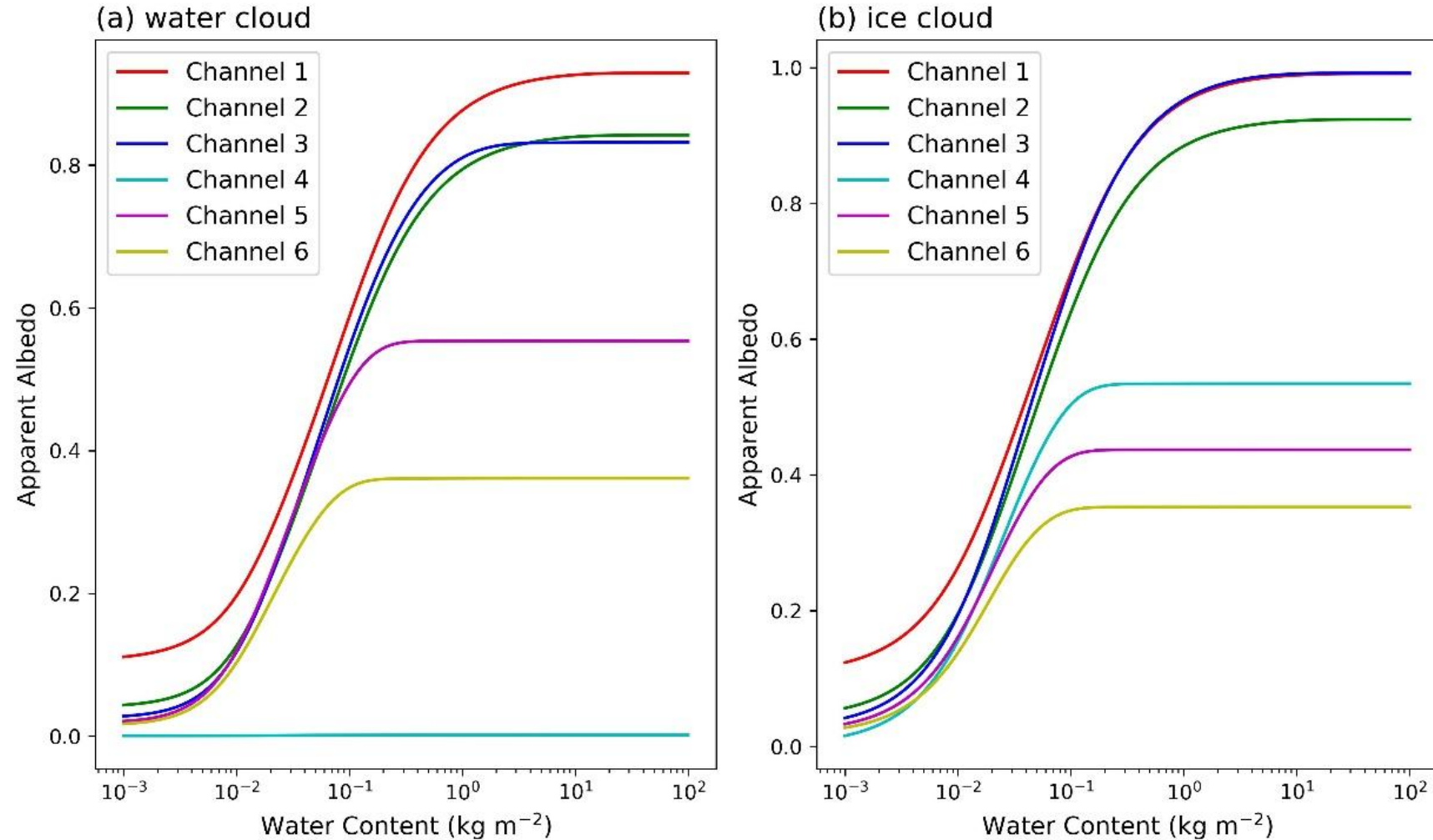
High particle number concentration but low hydrometeor content:

- **Initial Formation Stage of Clouds:** When water vapor begins to condense or sublimate, a large number of small cloud droplets or ice crystals form. At this point, the number of particles is very high.
- **Weak Growth Mechanisms:** Particles do not have sufficient time or favorable conditions to grow significantly.
- **Environment with High Aerosol Concentration (for Liquid Clouds), Newly Formed Ice Crystals**

Sensitivity of AGRI Albedo Simulation vs. Number of Streams in ARMS Solver

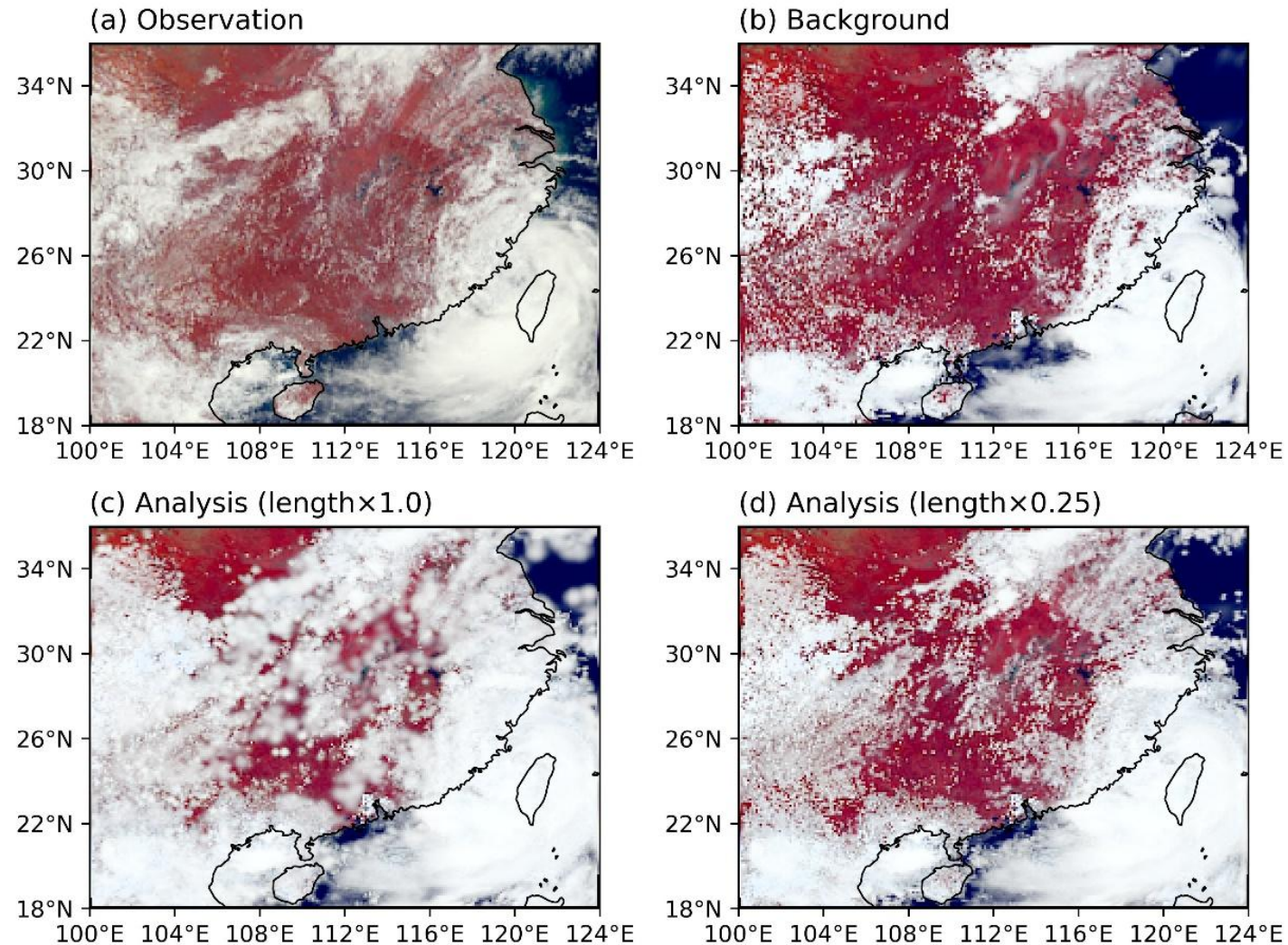


FY-4B AGRI Albedo of Water and Ice Clouds vs. Cloud Water Contents



Channel 4 (1.38 μm) is only affected by ice clouds

Influence of Horizontal Correlation Length of CMA-MESO Background Error Covariances on Cloud Increment



Correlation length should be multiplied by a factor of 0.25 to produce better cloud coverage

Satellite Visible Reflectance Simulation vs. Observations

01

The assimilation of FY-4B AGRI reflectance can be regarded as the assimilation of "cloud images"

02

Satellite cloud images can be simulated using model background fields (or forecast fields) combined with observation operators.

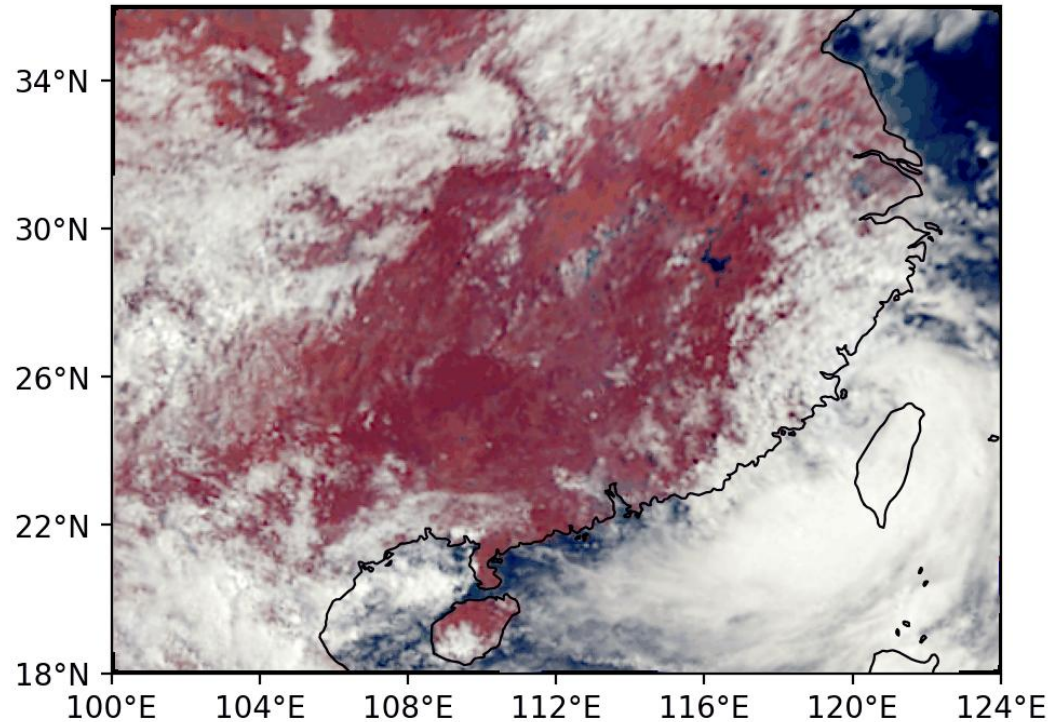
03

Satellite observations can be used to evaluate model background fields and observation operators.

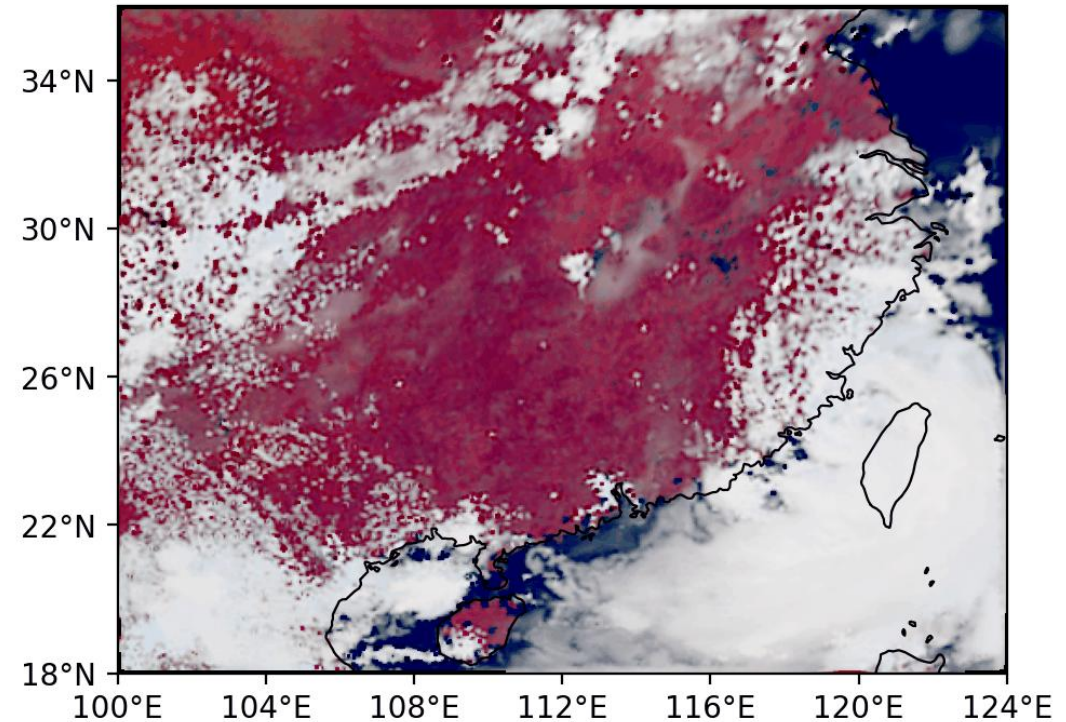
04

After assimilating FY-4B AGRI cloud images, the simulated cloud images gradually approach the observations, leading to more accurate forecasts.

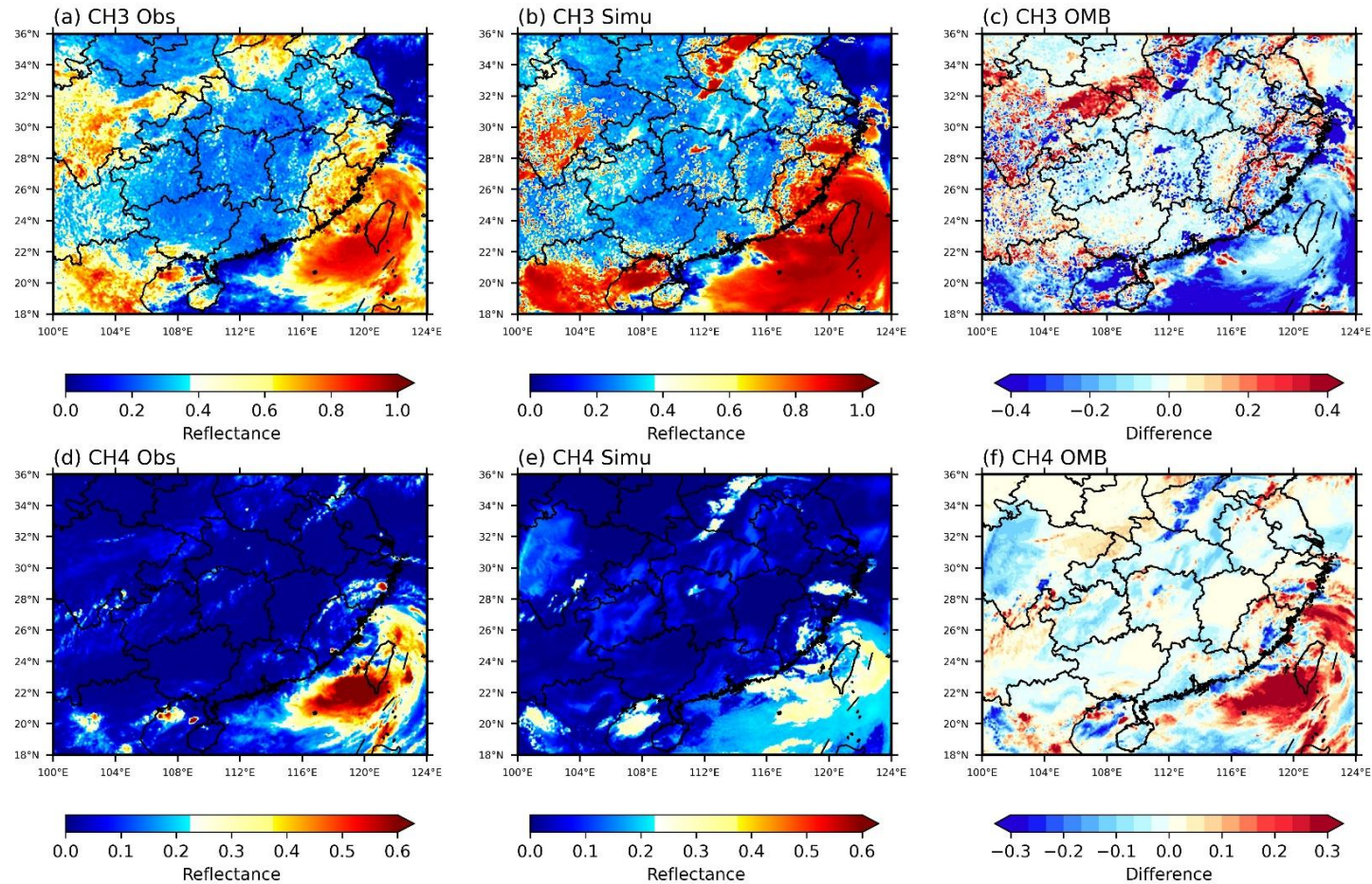
(a) Observation 20240725 BTC 9:00



(b) Simulation 20240725 BTC 9:00

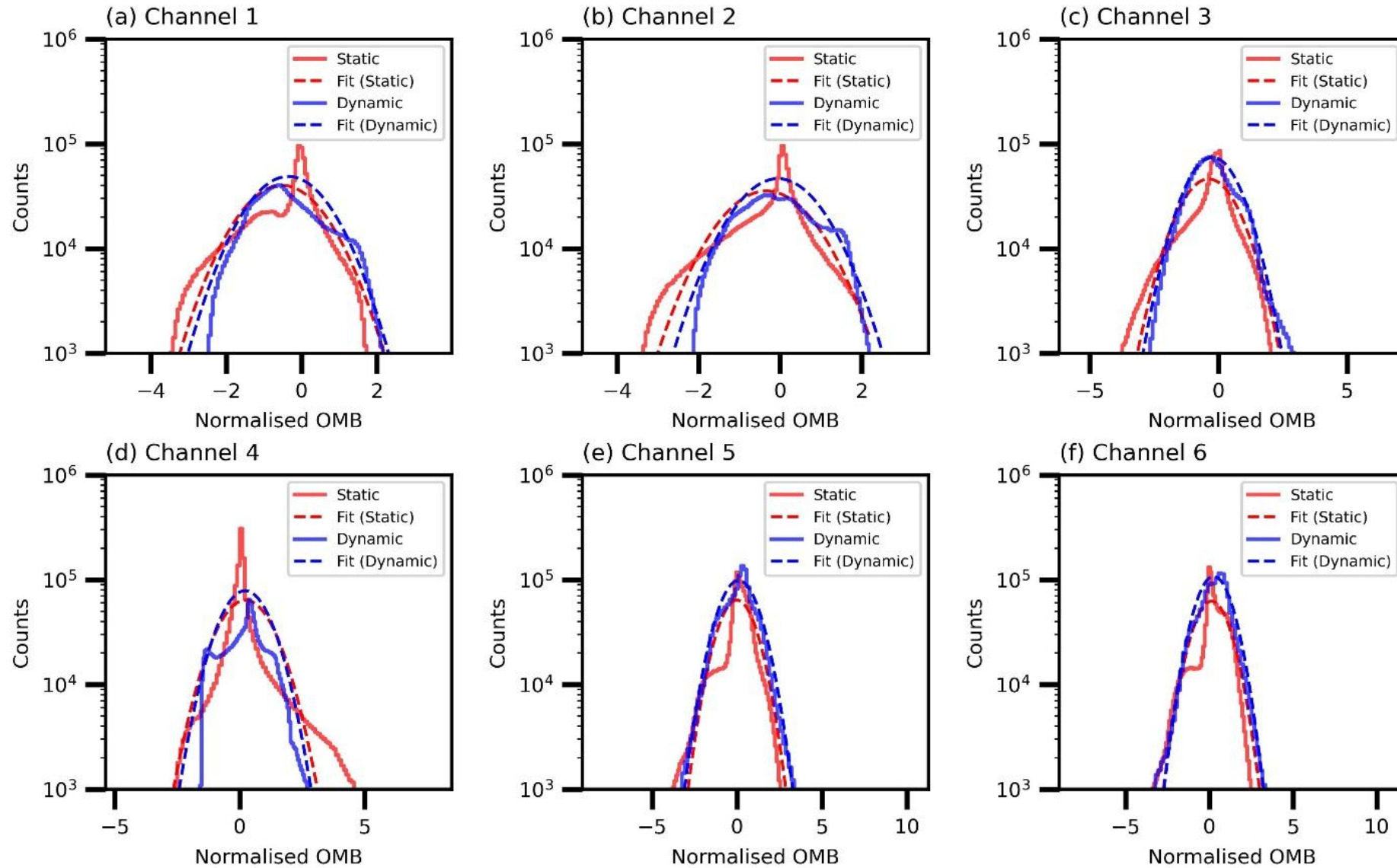


Comparison of Cloudy Areas from Model Prediction and Observations

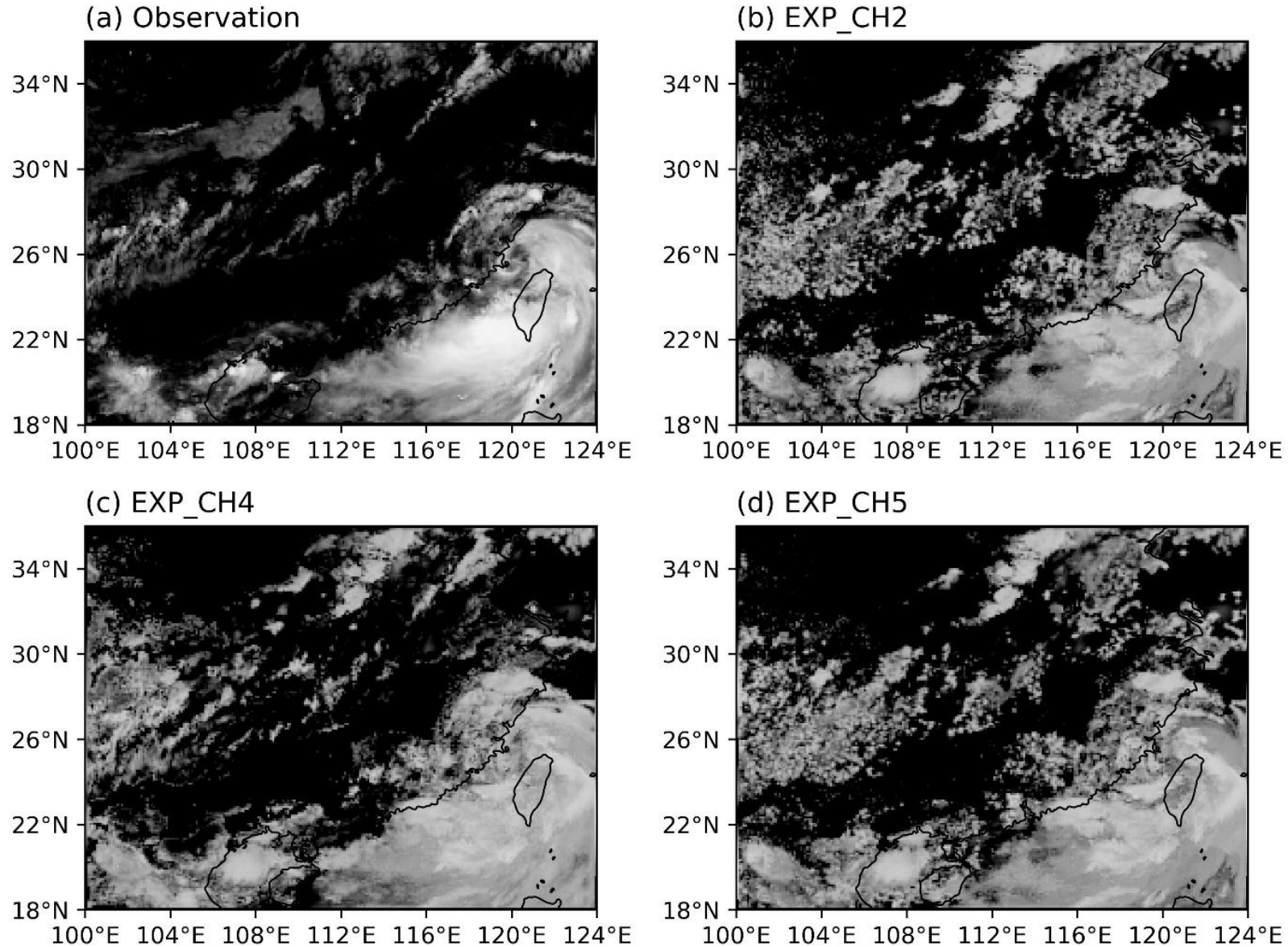


- In CMA-MESO, cloud background fields exhibit misalignment with observations, manifesting as "model-predicted clouds absent in observations" or "observational clouds missing in models".
- FY-4B AGRI's high spatio-temporal resolution data shows great potential in resolving cloud misalignment and optimizing cloud coverage.

FY-4B AGRI O-B Distributions



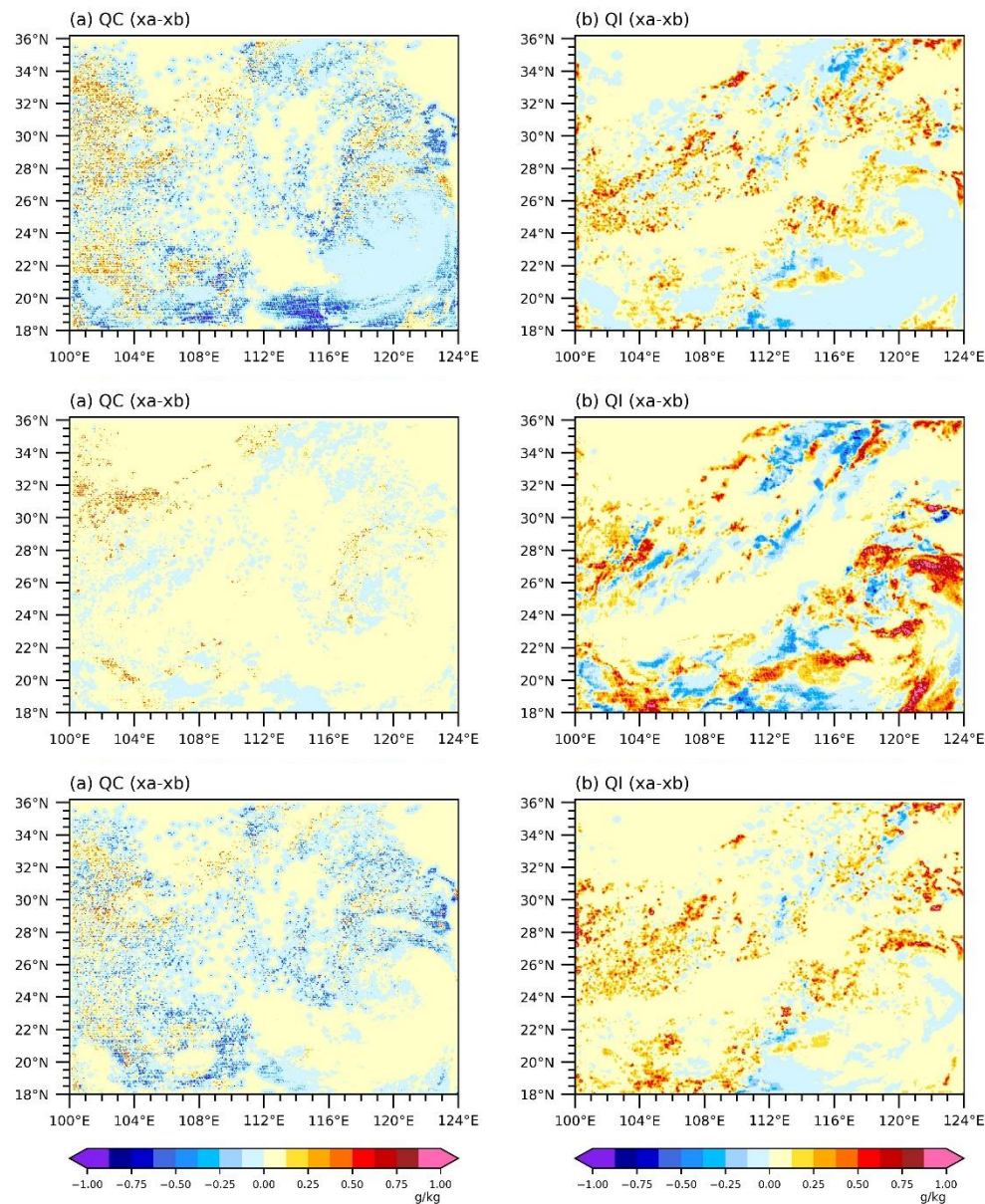
Influence of Channel Selection on Cloud Increments



Channel 4 results in better cloud analysis field.

Influence of Channel Selection on Cloud Increments

- ❑ Different channels exhibit varying sensitivities to clouds.:
 - CH2 (0.65 μm): Sensitive to water clouds and ice clouds.
 - CH4 (1.38 μm): Sensitive to ice clouds
 - CH5 (1.61 μm): Sensitive to water clouds and ice clouds, but the penetration ability is weaker than that of CH2.
 - -----
- ❑ Single-channel assimilation experiments: assimilating Channel 2/4/5 respectively
- ❑ Purpose: To analyze the impact of different channels on cloud increments.
- ❑ Conclusion:
 - The increment of ice clouds varies significantly among channels.
 - The increment of Channel 4 is concentrated in ice clouds; the increments of Channel 2 and 5 are "allocated" to both water clouds and ice clouds.
 - The increments of Channel 2 and 5 result in cloud type confusion: for example, the increment of water clouds may be mistakenly identified as that of ice clouds.

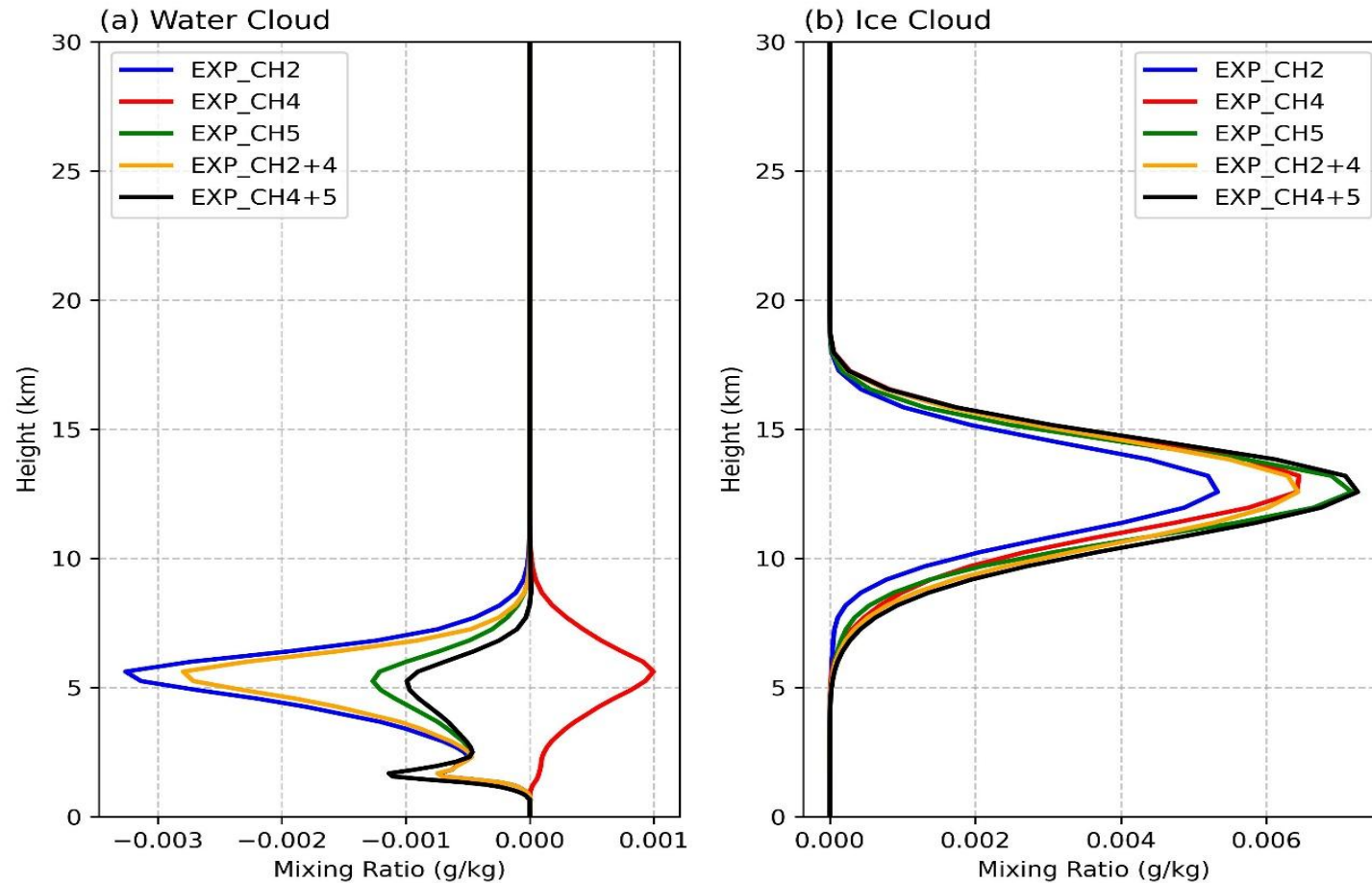


EXP_CH2

EXP_CH4

EXP_CH5

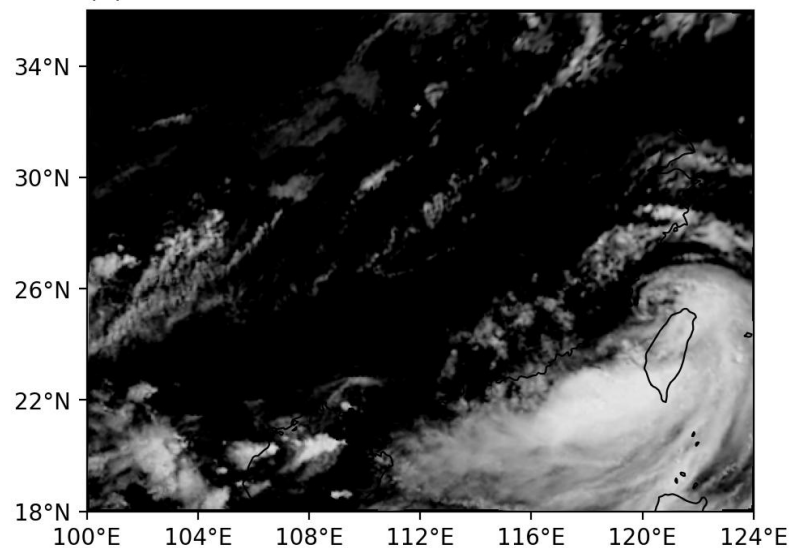
Influence of AGRI Channel Selection on Cloud Increments



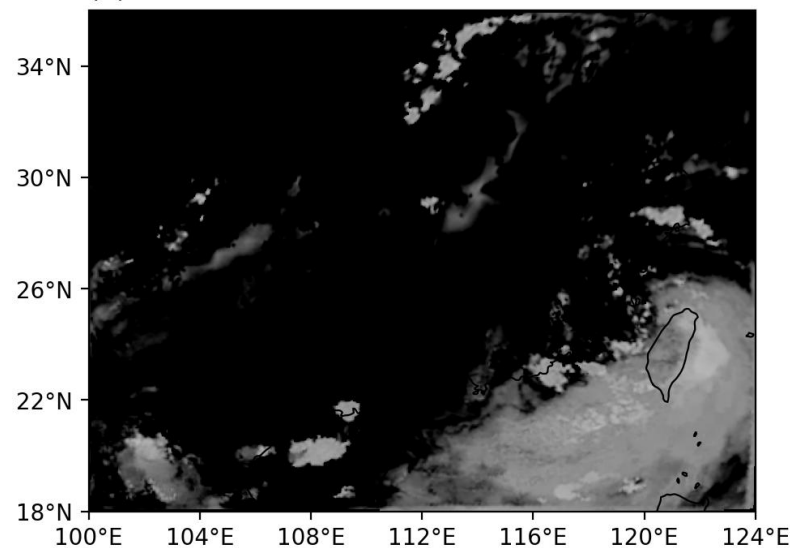
- Five groups of assimilation experiments: three single-channel assimilation experiments; two combined assimilation experiments: EXP_CH2+4 and EXP_CH4+5.
- The increment of water clouds is below 10 km; The increment of ice clouds is concentrated at 10-15 km.
- Assimilation of Channel 2 or 5 is not feasible, and combined assimilation with water vapor absorption channels is required.

Hourly Assimilation of Water Vapor Absorption Bands to Optimize Ice Cloud Coverage

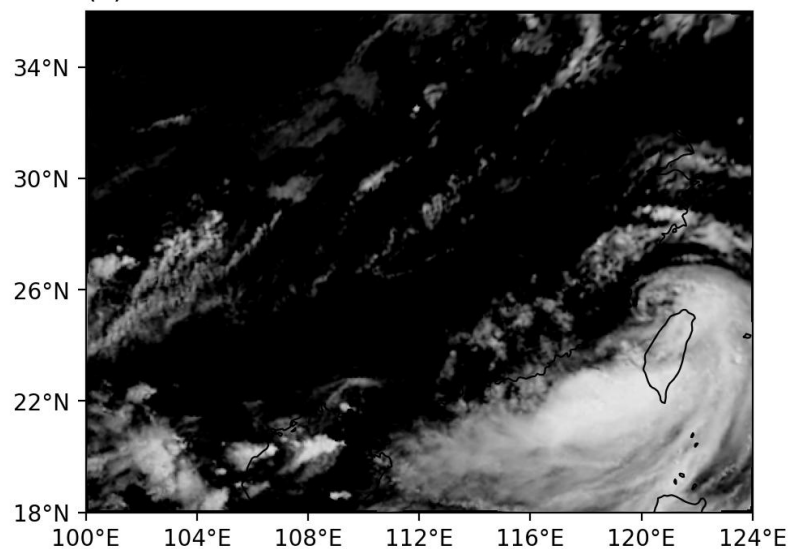
(a) Observation 20240725 BTC 9:00



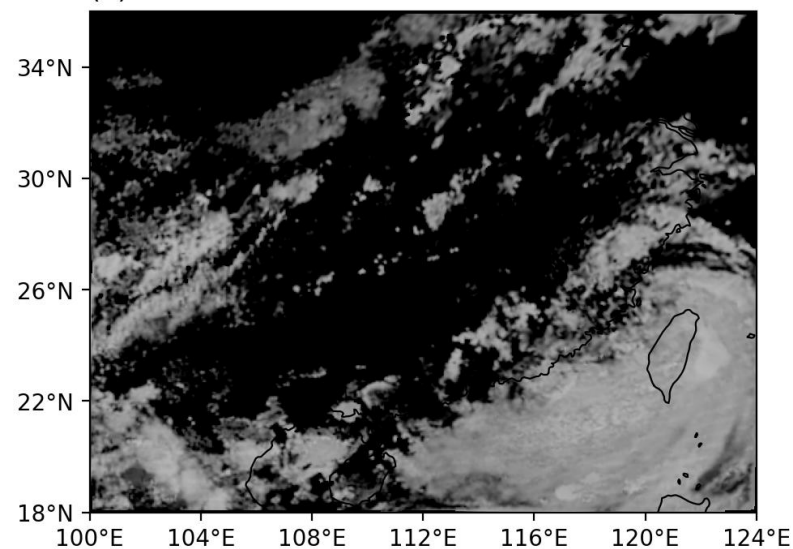
(b) Simulation 20240725 BTC 9:00



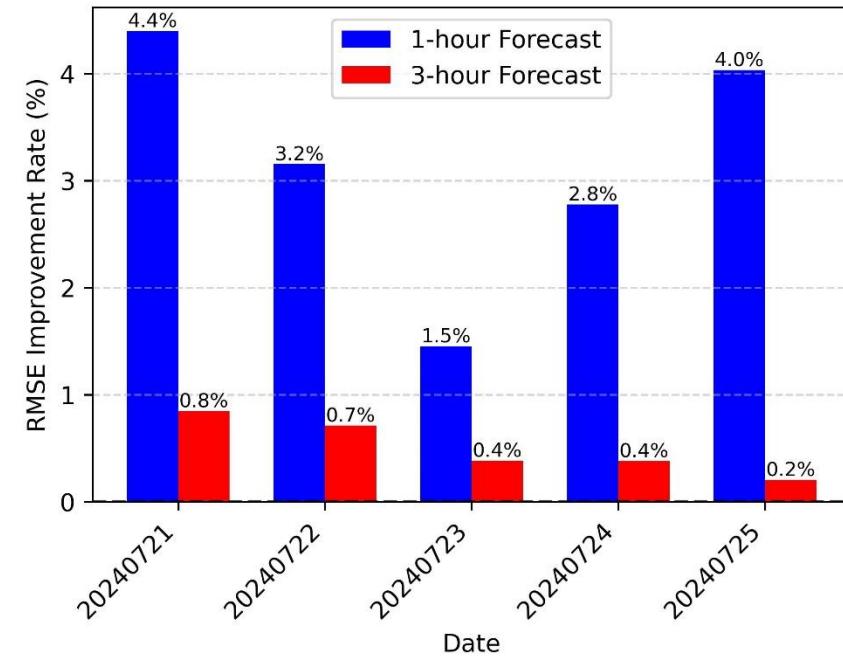
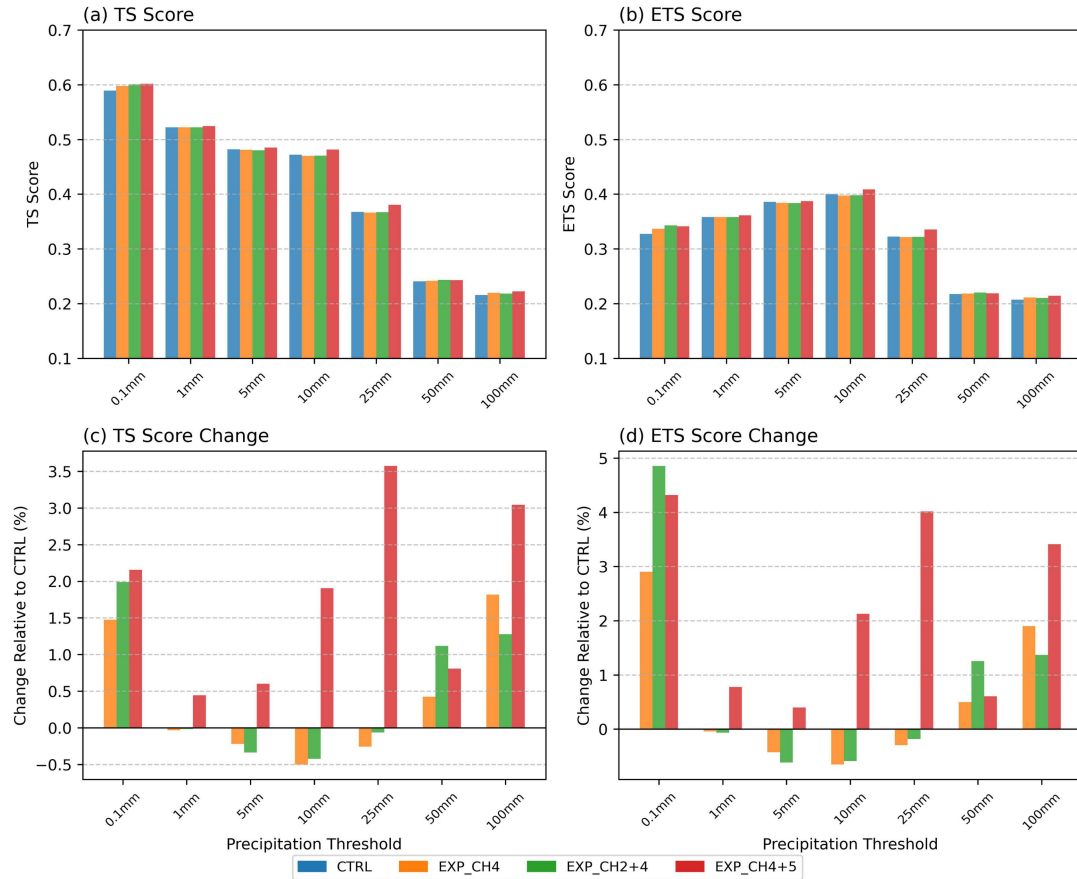
(a) Observation 20240725 BTC 9:00



(b) Simulation 20240725 BTC 9:00



Impacts of Assimilating Visible Reflectance on Precipitation Forecasting



- Assimilating VIS data can improve the accuracy of 12-hour accumulated precipitation forecasting.
- It can also enhance the forecasting accuracy of surface short-wave radiation flux: the RMSE of 1-hour forecast has decreased by up to 4.4%.

Summary and Conclusions

1. A robust interface of Fengyun satellite data with CMA-MESO cloud microphysics is established for cloudy radiance assimilation.
2. A variety of symmetric cloud index is developed for characterizing the observation errors as well as for correcting the biases.
3. Surface BRDF model are also implemented for visible data assimilation.
4. Impacts from FY-3 microwave data on 3 hour accumulated precipitation is largely positive.
5. Impacts from FY-4 visible data also result in positive impacts on 12 hour precipitation forecasts.