Preparing for assimilation of the combined microwave sounding observations aboard on the early morning satellite FY-3E in GRAPES-4Dvar

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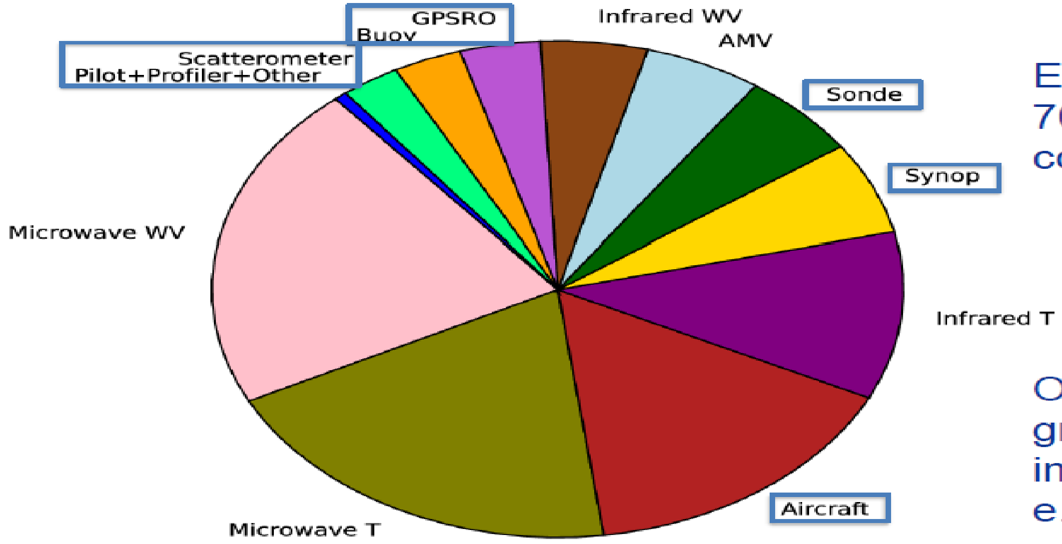
Outlines

1. Background
2. FY-3E Combined microwave sounding data (CMWS)
3. Satellite observation operator ARMS in GRAPES-4Dvar
4. Bias characteristics and bias correction
5. Physical retrieval of CLW and TPW for cloud detection
6. Conclusion and discussion

Satellite microwave observation has great contribution to NWP

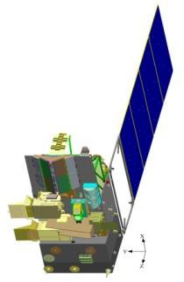


ECMWF FSOI February 2018: 70% of 24h forecast impact comes from satellite data

Overall temperature obs give greatest impact, but note how important humidity obs are now e.g. MWHS-2

ECMWF: Within 24 hours, 70% of the impact on the accuracy of numerical prediction comes from satellite data and nearly 50% from satellite microwave data.

Chinese FY-3E early morning Meteorological Satellite



Payload	Full name
MERSI-LL	Medium Resolution Spectral Imager-LL
HIRAS-2	Hyperspectral Infrared Atmospheric Sounder-2
MWTS-3	Micro-Wave Temperature Sounder-3
MWHS-2	Micro-Wave Humidity Sounder-2
GNOS-2	GNSS Radio Occultation Sounder-2
WindRad	Wind Radar
SSIM	Solar Spectral Irradiance Monitor
SIM-2	Solar Irradiance Monitor-2
X-EUVI	Solar X-ray and Extreme Ultraviolet Imager
Tri-IPM	Triple-angle Ionospheric PhotoMeter
SEM	Space Environment Monitor

Focus on preparing for assimilation of FY-3E microwave observation

Table 1. Channel setting and centre frequency for microwave sounders

FY-3D MWTS/MWHS Channel No.	FY-3E MWTS/MWHS Channel No.	ATMS Channel No.	Centre frequency (GHz)
	1	1	23.8
	2	2	31.4
1	3	3	50.3
2	4	4	51.76
3	5	5	52.8
	6		53.246±0.08
4	7	6	53.596±0.115
	8		53.948±0.081
5	9	7	54.40
6	10	8	54.94
7	11	9	55.50
8	12	10	f0=57.290344
9	13	11	f0±0.217
10	14	12	f0±0.322±0.048
11	15	13	f0±0.322±0.022
12	16	14	f0±0.322±0.010
13	17	15	f0±0.322±0.0045
		16	88.2
1	1		89.0
2	2		118.75±0.08
3	3		118.75±0.2
4	4		118.75±0.3
5	5		118.75±0.8
6	6		118.75±1.1
7	7		118.75±2.5
8	8		118.75±3.0
9	9		118.75±5.0
10			150.0
	10	17	165.5(166.0/FY-3E)
11	11	22	183.31±1
12	12	21	183.31±1.8
13	13	20	183.31±3
14	14	19	183.31±4.5
15	15	18	183.31±7

1 Temperature and humidity observation are two separate units.

✓ Combined microwave sounding data (CMWS).

2 Satellite observation operator in GRAPES-4Dvar.

✓ Transfer from RTTOV to ARMS with support of FY-3E CMWS.

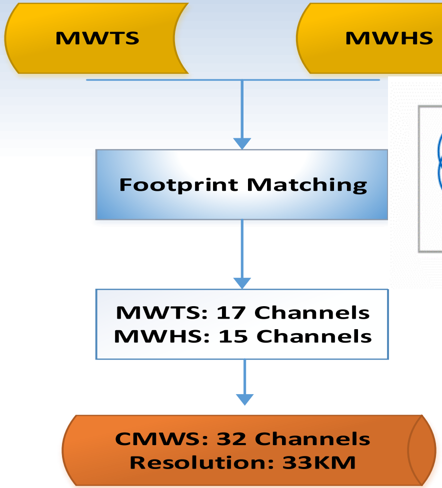
3 FY-3E data characteristics.

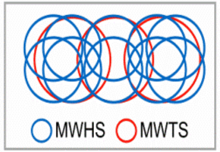
✓ Data characteristics is preliminary analyzed and bias correction gets ready.

4 FY-3E has 23.8 and 31.4 GHz channels.

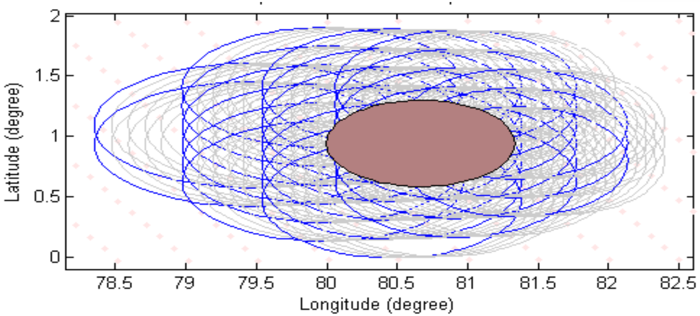
✓ Physical retrieval scheme is designed and will be used in cloud detection.

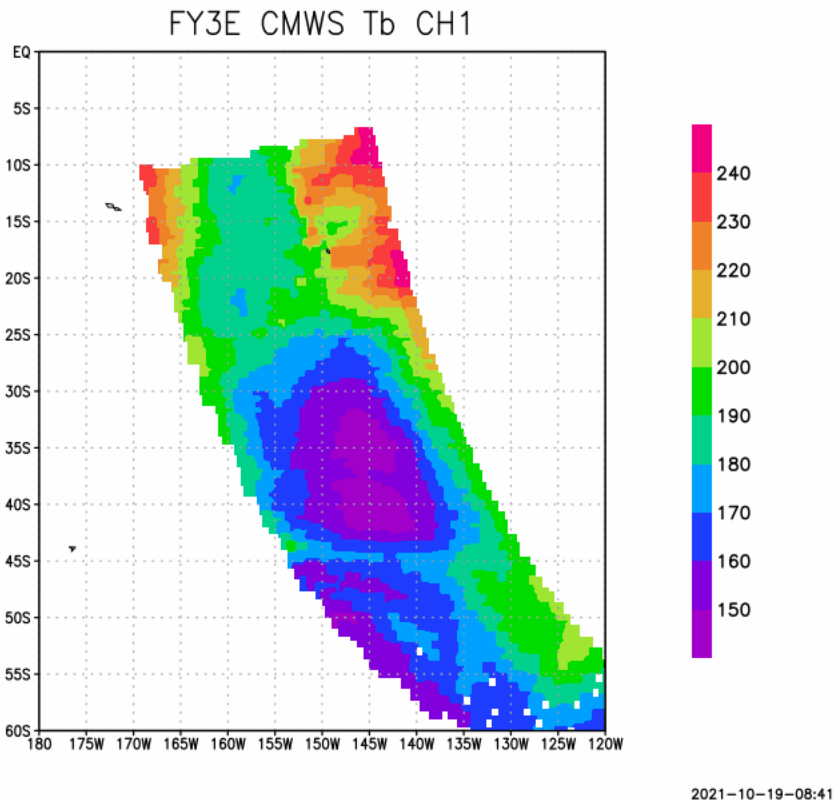
FY-3E Combined microwave sounding data (CMWS)





Backus-Gilbert re-sampling:



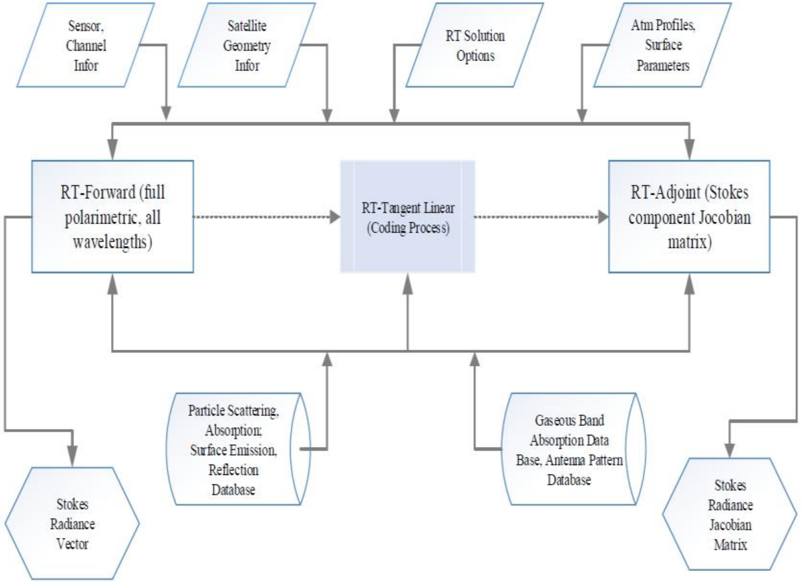


Satellite observation operator ARMS@Forward

ARMS: Advanced Radiative Transfer Modeling System. It is a new fast RTM developed by the CMA.

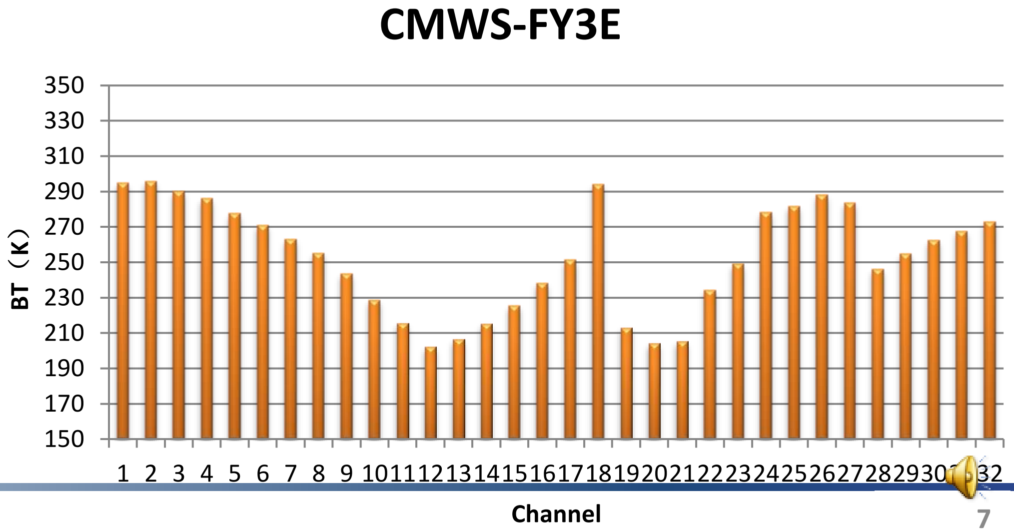
ARMS is merged into GRAPES to be the observation operator for satellite data assimilation. RTTOV was used before.

Fast tranmittance model for FY-3E CMWS data is built to make ARMS support its application.



ARMS system composition and function diagram

ARMS forward model gets the simulated FY-3E CMWS 32 channels satellite observation form GRAPES background atmospheric and surface condition.



Satellite observation operator ARMS@Tangent Linear

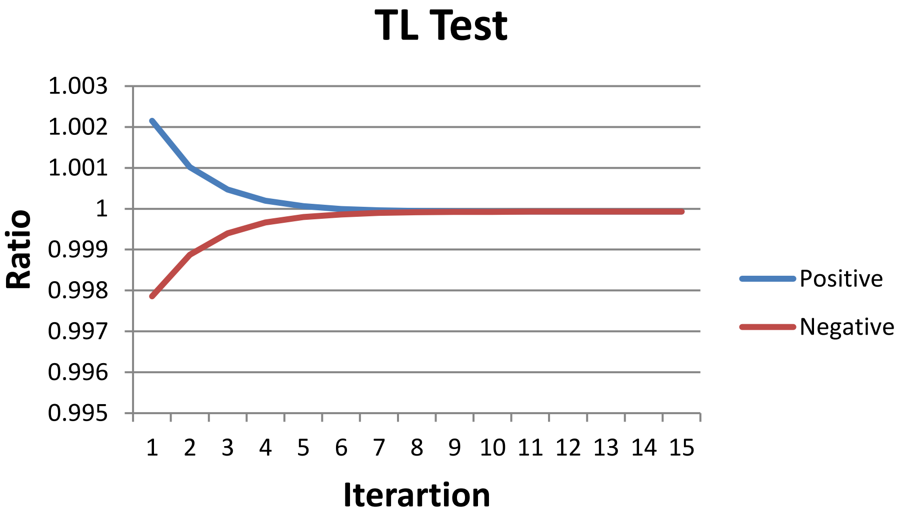
ARMS Tangent Linear gets the increment of FY-3E CMWS satellite brightness temperature for the increment of GRAPES analysis variables.

Testing TL Model consistency with Forward Model

$$\lim_{\Delta \mathbf{x}^{\pm} \to 0} \frac{\mathrm{FM}(\mathbf{x} + \Delta \mathbf{x}) - \mathrm{FM}(\mathbf{x})}{\mathrm{TLM}(\mathrm{x}, \Delta \mathbf{x})} = 1$$

This looks a lot like the definition of the derivative.

FM(x) = Forward model acting on x
FM(x+Δx)=perturbed Forward model acting on x+Δx
TL(x,Δx)= Tangent Linear model acting on Δx (at x)



Satellite observation operator ARMS@Adjoint

ARMS Adjoint gets the gradient of FY-3E CMWS satellite brightness temperature to the GRAPES analysis variables.

Adjoint testing

- **Objective: Assure that the adjoint is the transpose of the tangent linear**
- **Method: Construct Jacobians from TL and AD and compare**

N inputs -> TL -> M outputs
M inputs -> AD -> N outputs

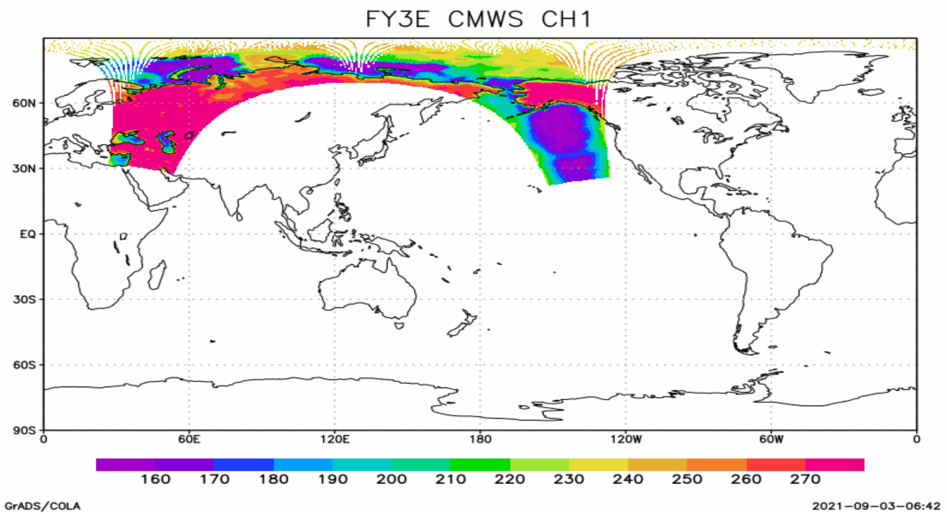
Call TL N times with the ith element=1, all other elements =0
Put output into ith row of an NxM array

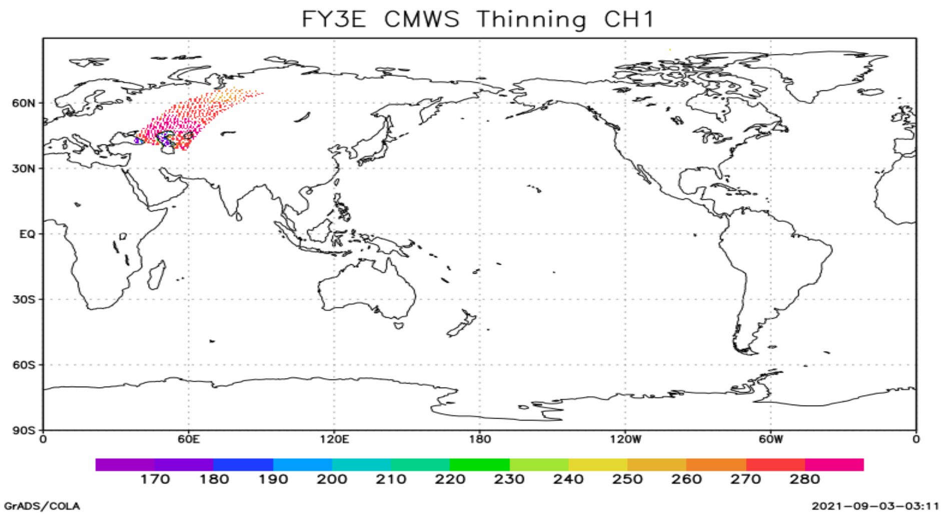
Call AD M times with the jth element=1, all other elements=0
Put output into a jth row of an MxN array

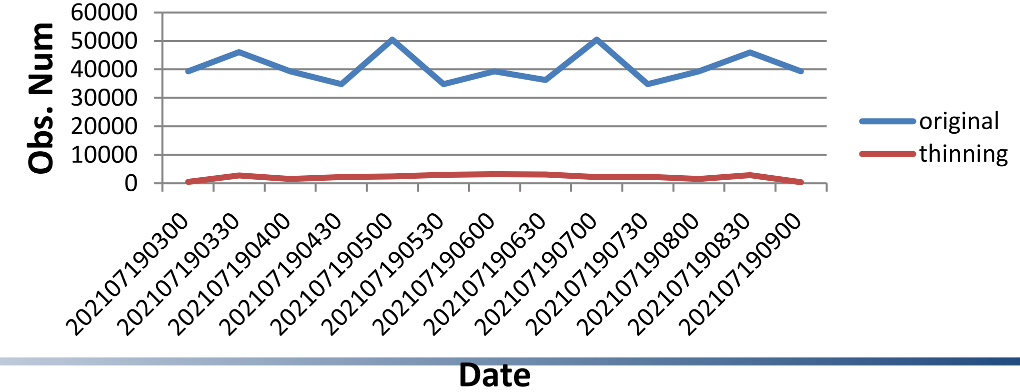
Verify that AD = TL^T to within machine precision

To make sure the channel:	1	9		
9	1	-1.012263959986517E-006	-1.012263959986517E-006	close
9	2	-2.277677536352056E-006	-2.277677536352056E-006	close
9	3	-2.490493073186355E-006	-2.490493073186354E-006	close
9	4	-2.456054947419634E-006	-2.456054947419633E-006	close
9	5	-2.212194142299011E-006	-2.212194142299011E-006	close
9	6	-8.647711369180328E-007	-8.647711369180334E-007	close
9	7	2.784668804558908E-006	2.784668804558907E-006	close
9	8	1.149210553621641E-005	1.149210553621641E-005	close
9	9	2.746170915125834E-005	2.746170915125833E-005	close
9	10	5.598702485048977E-005	5.598702485048975E-005	close
9	11	1.069624025155993E-004	1.069624025155992E-004	close
9	12	1.882807012277515E-004	1.882807012277514E-004	close
9	13	3.092873686107324E-004	3.092873686107322E-004	close
9	14	4.908281165946368E-004	4.908281165946367E-004	close
9	15	7.600352428674176E-004	7.600352428674176E-004	close
9	16	1.149142773981913E-003	1.149142773981913E-003	close
9	17	1.709637433721817E-003	1.709637433721816E-003	close
9	18	2.519578039191831E-003	2.519578039191831E-003	close
9	19	3.726149317752808E-003	3.726149317752810E-003	close
9	20	5.471091512068828E-003	5.471091512068827E-003	close
9	21	7.775318984451017E-003	7.775318984451012E-003	close
9	22	1.083408280801396E-002	1.083408280801396E-002	close
9	23	1.473644945697138E-002	1.473644945697138E-002	close
9	24	1.932342716847752E-002	1.932342716847752E-002	close
9	25	2.452943747121644E-002	2.452943747121643E-002	close
9	26	2.997916615265691E-002	2.997916615265690E-002	close

FY-3E CMWS data used in GRAPES-4Dvar 30min time window slot







FY-3E CMWS O-B

Statistic

Date: 2021-07-12 to 2021-08-09

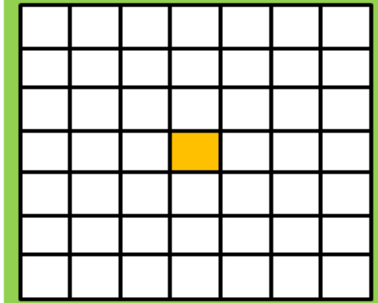
Collocation:

FY4A L2 CLM (4 km) + MWTS/MWHS

Cloud detection:

0:cloud,1:probably cloud

2:probably clear,3:clear



$(i \pm 3) \times (j \pm 3)$ grid box

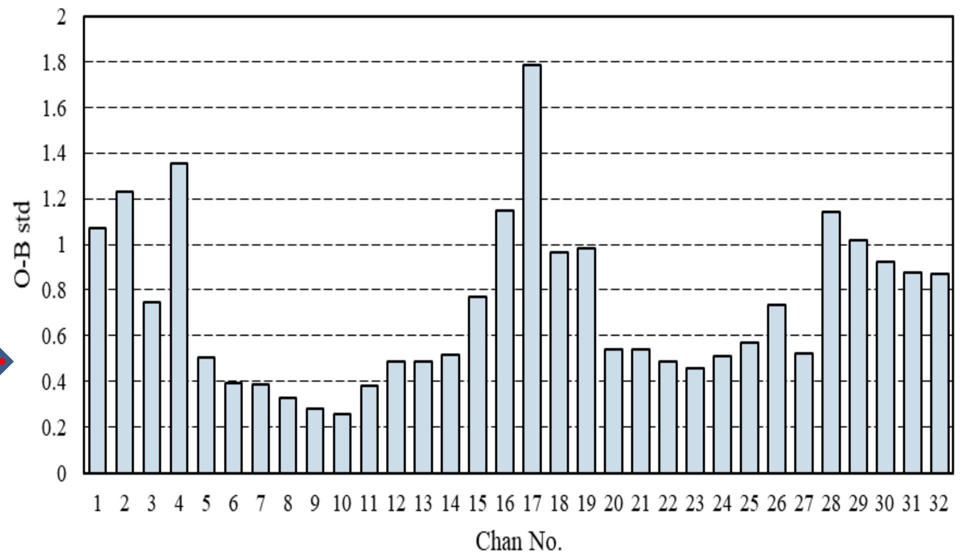
$28 * 28\ km^2$

$$nALL = 7 \times 7 = 49$$

$$ClearRatio = \frac{nClear}{nALL} \times 100\%$$

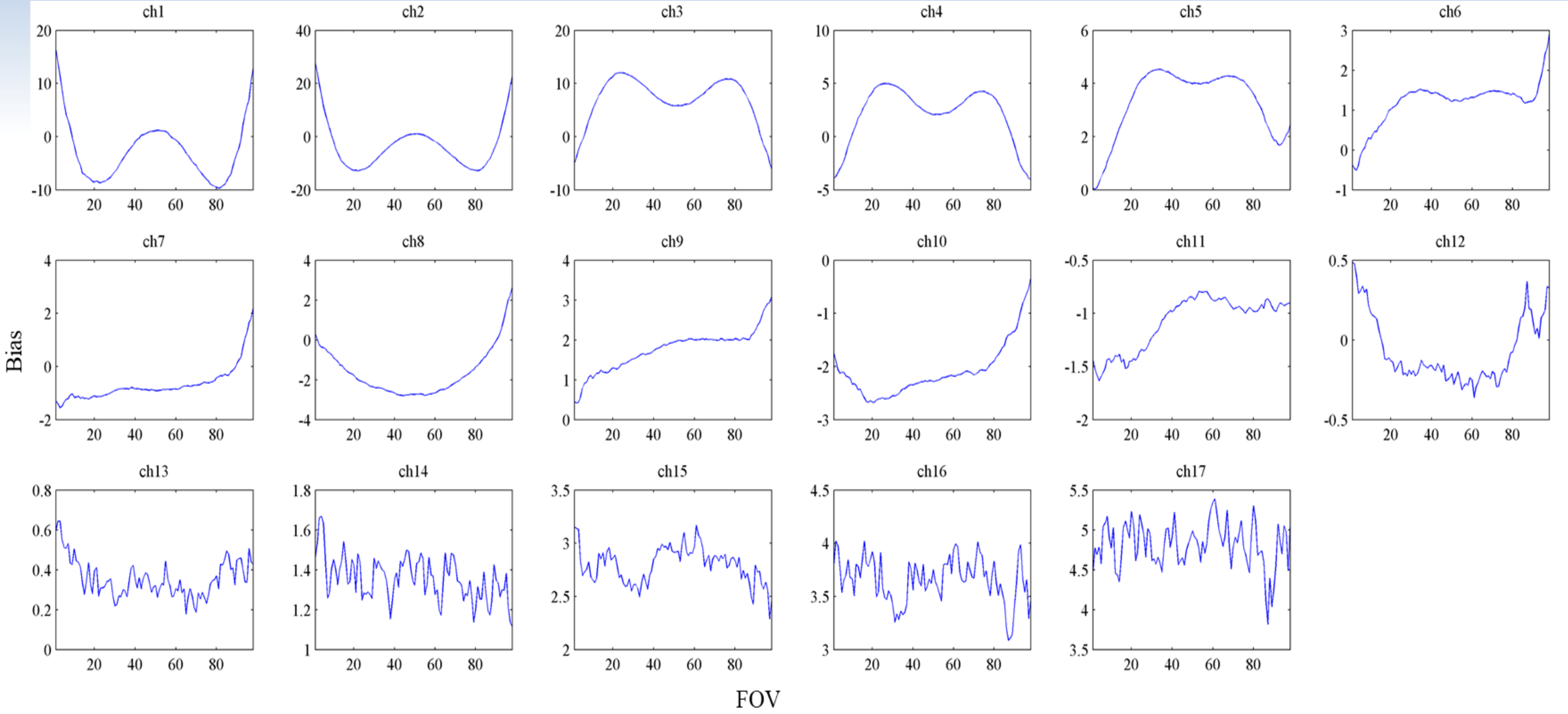
$$CloudRatio = \frac{nCloud}{nALL} \times 100\%$$

Only FOVs with 100% Clear Ratio are selected.



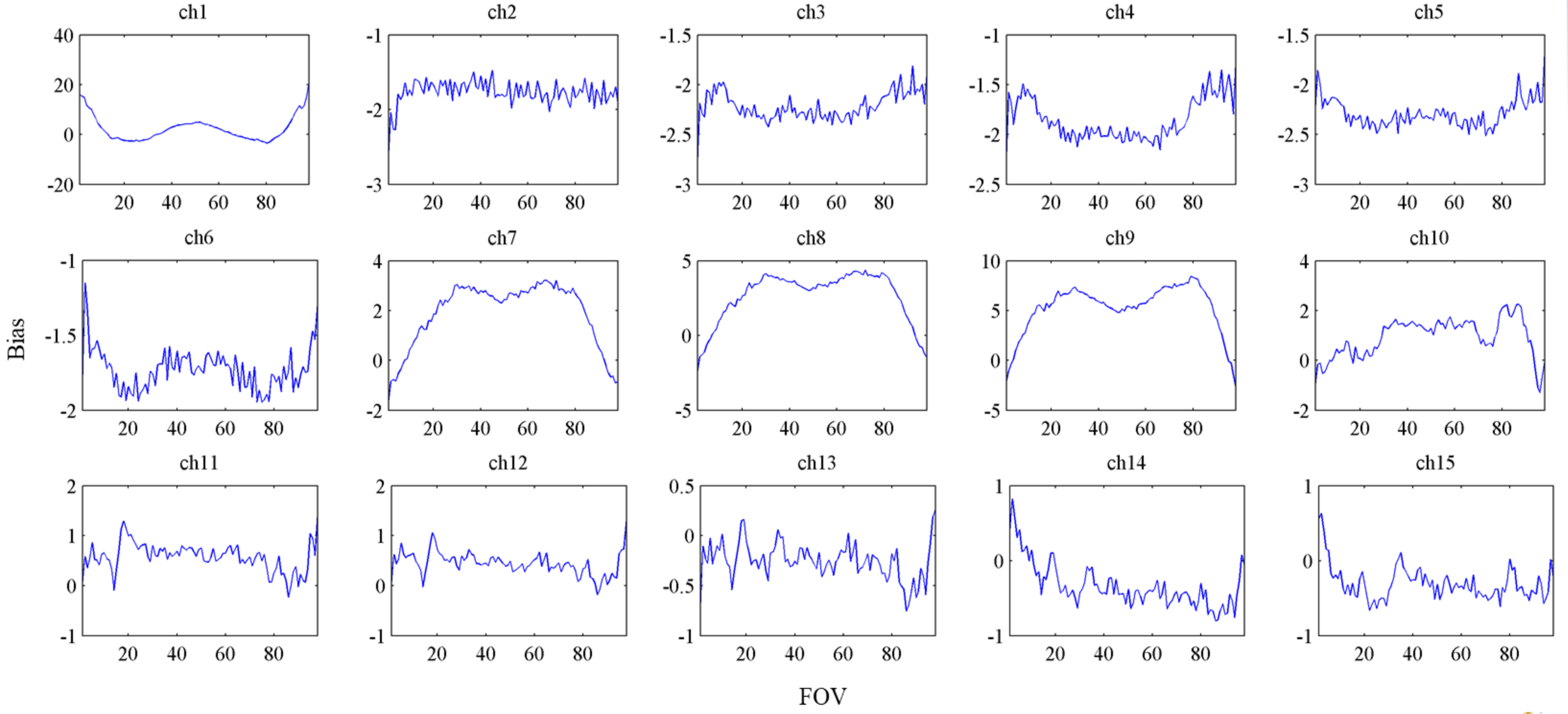
- The standard deviation of O-B is relatively stable.
- The largest standard deviation in the window region is about 1-2 K.

Bias characteristics for FY-3E CMWS@MWTS



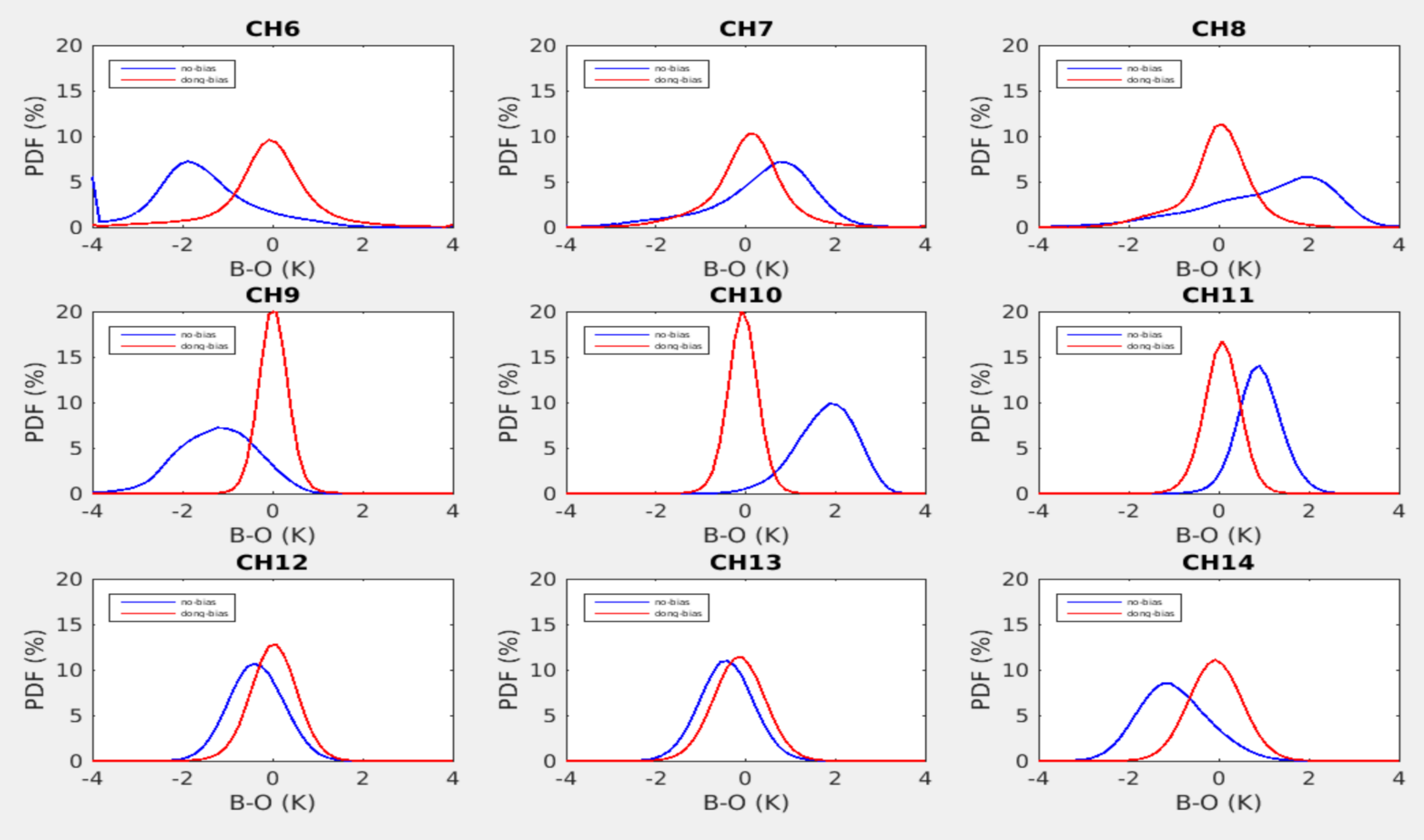
The angular dependence of channels 1-10 is obvious, especially for channel 1-4.

Bias characteristics for FY-3E CMWS@MWHS

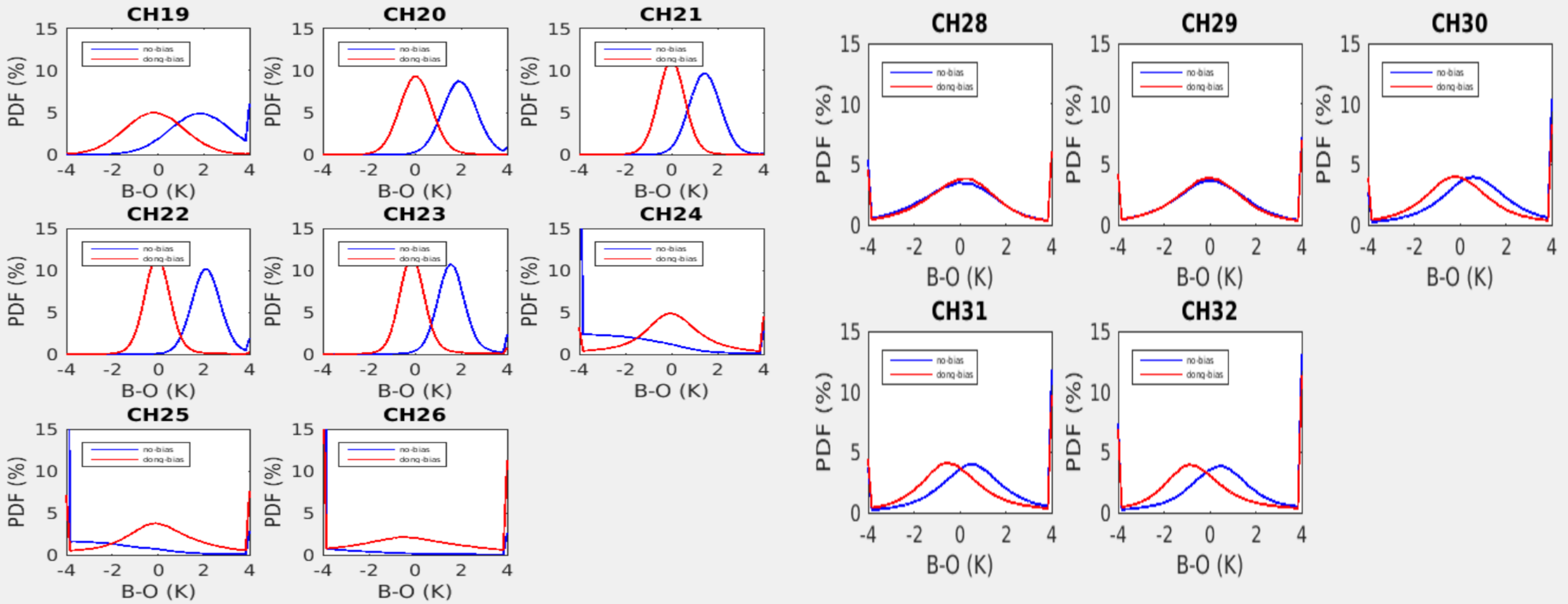


The angular dependence of channels 1 and 6–10 is obvious, especially for channel 1 and 7-9.

Bias Correction for FY-3E CMWS@MWTS



Bias Correction for FY-3E CMWS@MWHS



Statistical and physical approach for retrieval of CLW and TPW

$$T_b = T_s[1-(1-\varepsilon)\Upsilon^2] - \Delta T(1-\Upsilon)[1+(1-\varepsilon)\Upsilon]$$

$$V = \cos\theta[a_0 + a_1\ln(T_s - T_{b23}) + a_2\ln(T_s - T_{b31})]$$

$$L = \cos\theta[b_0 + b_1\ln(T_s - T_{b23}) + b_2\ln(T_s - T_{b31})]$$

Statistical Approach

$$a_0 = 247.92 - (69.235 - 44.177\cos\theta)\cos\theta$$

$$a_1 = -116.27 \qquad a_2 = 73.409$$

$$b_0 = 8.240 - (2.622 - 1.846\cos\theta)\cos\theta$$

$$b_1 = 0.754 \qquad b_2 = -2.265$$

(Grody et al.,2001)

Physical Approach

$$L = a_0\mu\,[\ln(T_s - TB_{31}) - a_1\ln(T_s - TB_{23}) - a_2]$$

$$V = b_0\mu\,[\ln(T_s - TB_{31}) - b_1\ln(T_s - TB_{23}) - b_2]$$

$$a_0 = -0.5\kappa_{v23} / (\kappa_{v23}\kappa_{l31} - \kappa_{v31}\kappa_{l23})$$

$$b_0 = 0.5\kappa_{l23} / (\kappa_{v23}\kappa_{l31} - \kappa_{v31}\kappa_{l23})$$

$$a_1 = \kappa_{v31} / \kappa_{v23}$$

$$b_1 = \kappa_{l31} / \kappa_{l23}$$

$$a_2 = -2.0(\tau_{o31} - a_1\tau_{o23}) / \mu + (1.0 - a_1)\ln(T_s) + \ln(1.0 - \varepsilon_{31}) - a_1\ln(1.0 - \varepsilon_{23})$$

$$b_2 = -2.0(\tau_{o31} - b_1\tau_{o23}) / \mu + (1.0 - b_1)\ln(T_s) + \ln(1.0 - \varepsilon_{31}) - b_1\ln(1.0 - \varepsilon_{23})$$

$$\kappa_l = a_l + b_l T_l + c_l T_l^2$$

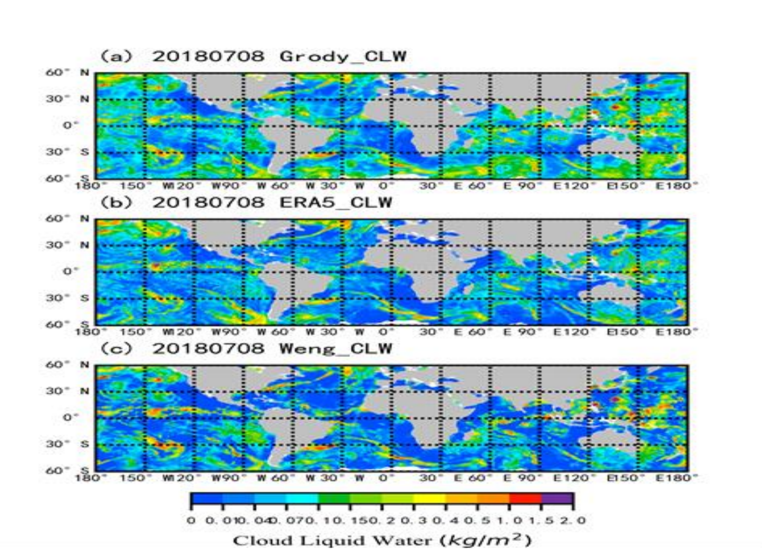
$$\tau_o = a_o + b_o T_s$$

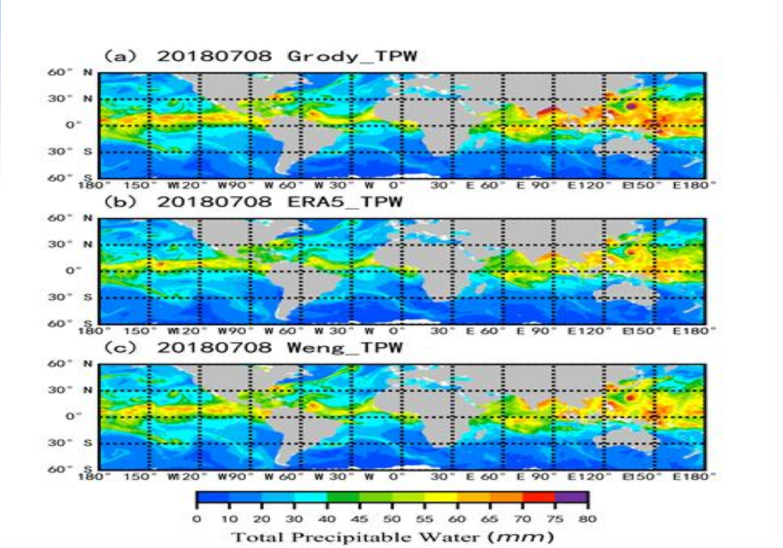
Sea Surface Temperature

Cloud Temperature

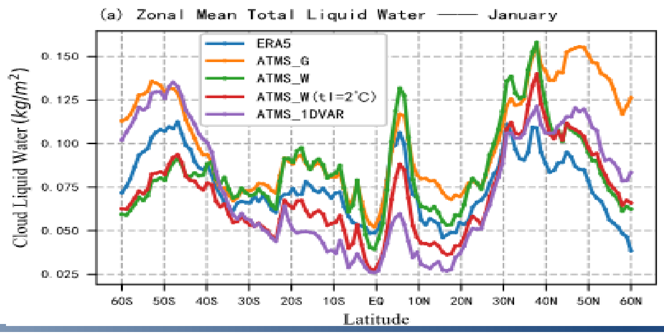
(Weng et al.,2003)

Comparison of the approach@global retrieval

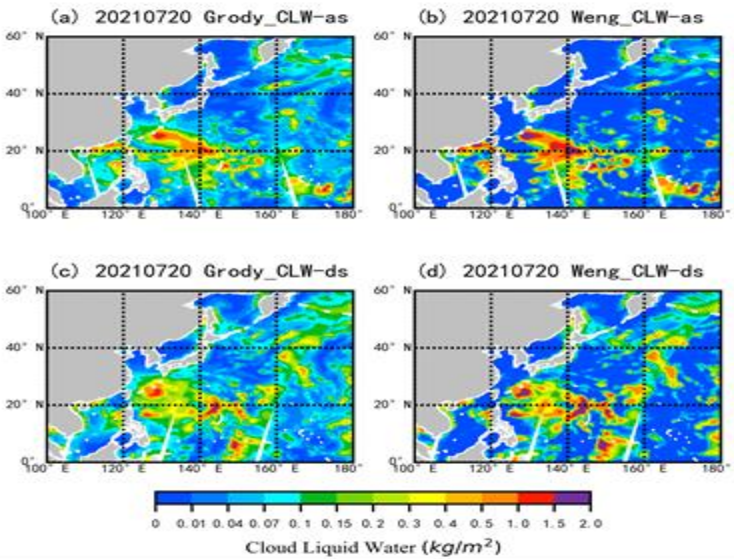


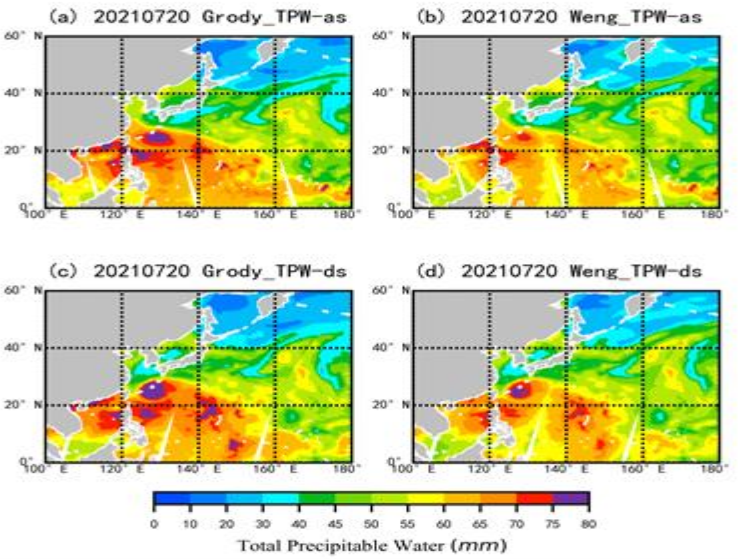


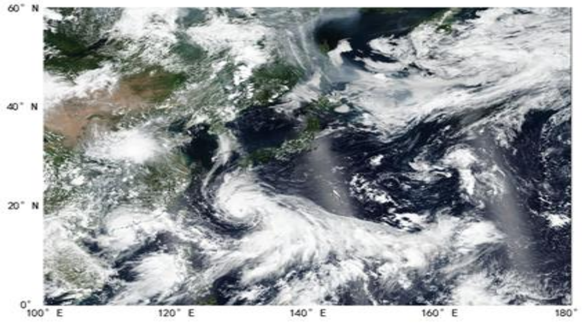
The global inversion results show that the numerical value and range of the cloud liquid water path in the middle and high latitudes of the statistical algorithm are generally higher than that of the physical algorithm and reanalysis data.



Comparison of the approach@regional retrieval







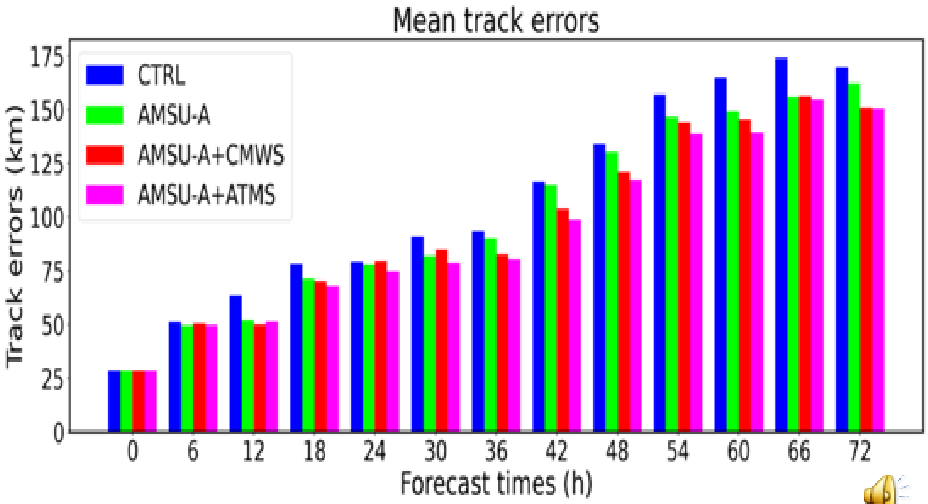
The comparison between the two algorithms and the VIIRS visible cloud image shows that the physical algorithm corresponds well to the visible light cloud image, and the statistical algorithm misjudges the non-cloud area as having clouds.

Conclusion and discussion

The homework is doing well to assimilate the microwave observation onboard the early morning satellite FY-3E into GRAPES-4Dvar. The key points are:

- MWTS and MWHS are joined into a combined microwave sounding data (CMWS), making the temperature and humidity observation are assimilated in one data stream.
- The satellite observation operator in GRAPES is transferred to ARMS. The accuracies of the ARMS forward tangent linear and adjoint models implemented for FY-3E CMWS are verified.
- The data bias, especially scan-angle dependent bias is highly concerned and bias correction is prepared.
- The retrieval of CLW and TPW with physical constraints are more reliable. It will be used in QC procedure.

Assimilation of a proxy data FY-3D CMWS has produced a positive forecast impact on typhoon numerical prediction. It is highly anticipated that FY-3E CMWS will contribute a lot to NWP.



Thanks for your attention