ITSC-24

中国气象局地球系统数值预报中心
CMA EARTH SYSTEM MODELING AND PREDICTION CENTRE

# The Cloud-dependent 1DVAR Algorithm for Retrieving Precipitation from FengYun-3D/E Microwave Sounders


Hao HU[1], Jintao XU[2], Ziqiang MA[2] , Xueyan HOU[1] , Fuzhong WENG[1]

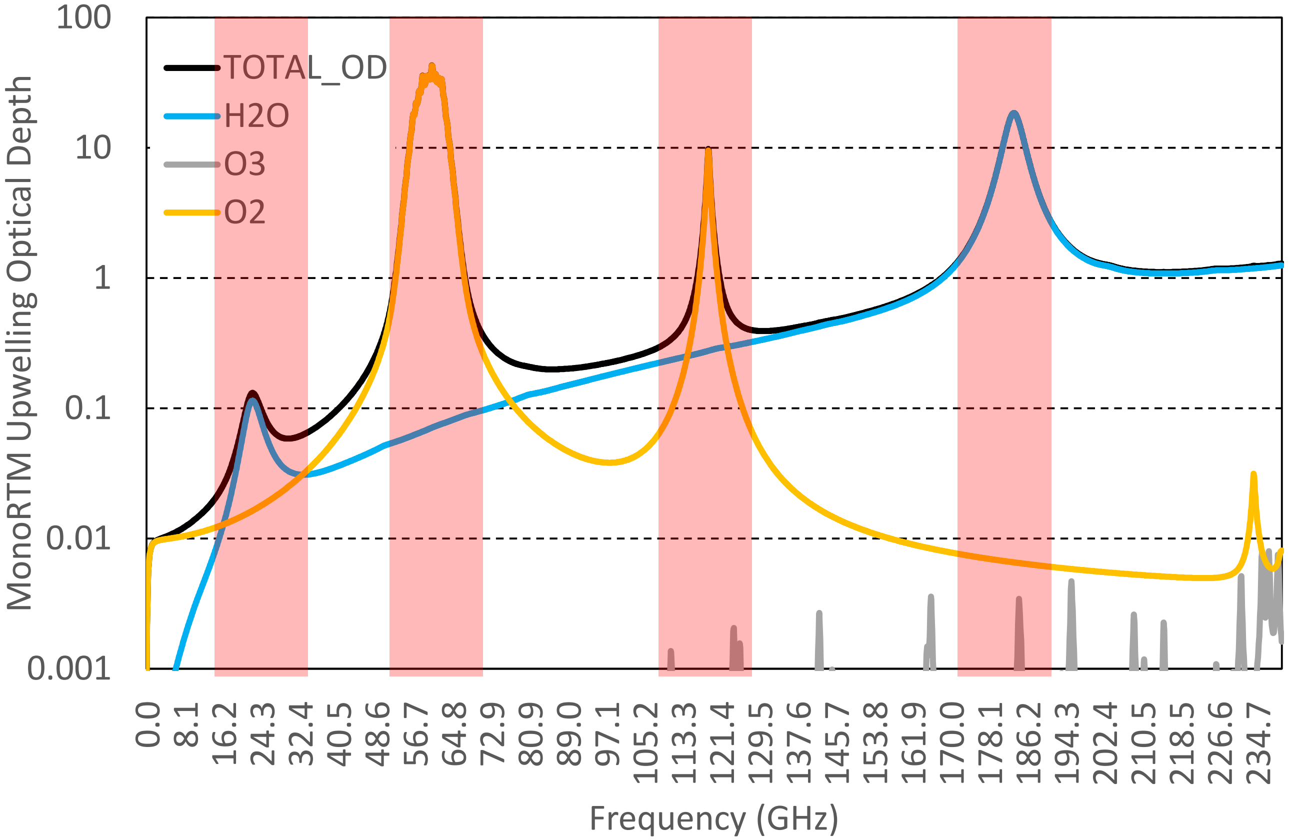
1. CMA Earth System Modeling and Prediction Centre (CEMC)
2. Peking University (PKU)

Email: huhao@cma.gov.cn

CONTENT

# 01 | Motivation

Microwave radiometers onboard satellites can receive the scattering and emitting radiation from clouds and precipitation and provide the data for detecting all-sky vertical thermal structures of global atmosphere.



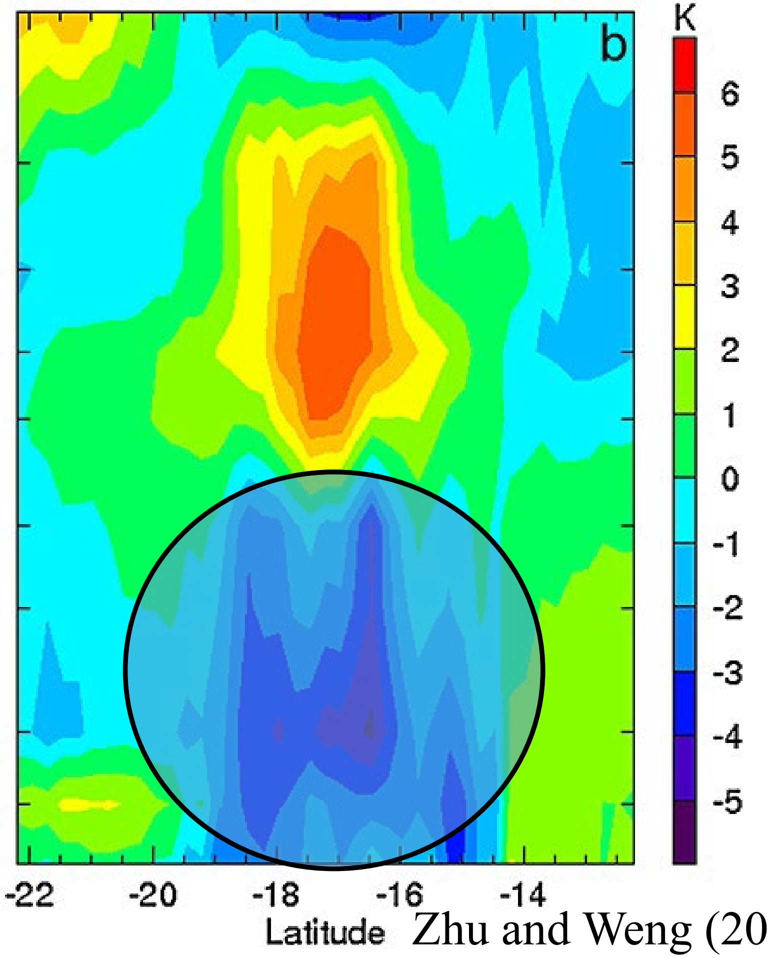

Three major absorption bands of MW sounding instruments:

LowO2: Low frequency oxygen absorption band (50-60 GHz)
HighO2: High frequency oxygen absorption band (118 GHz)
WV: Water vapor absorption band (183 GHz)

AMSU-A: LowO2
MHS: WV
SSMIS: LowO2+WV
ATMS: LowO2+WV
FY-3D/E MWTS+MWHS: LowO2+HighO2+WV

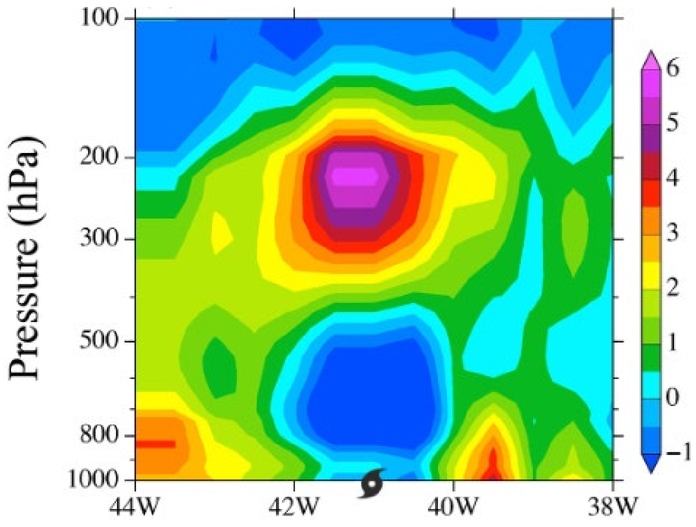
# 01 | Motivation

Previous studies found that the MW retrieved thermal structure is unreasonable in the inner region of hurricanes.

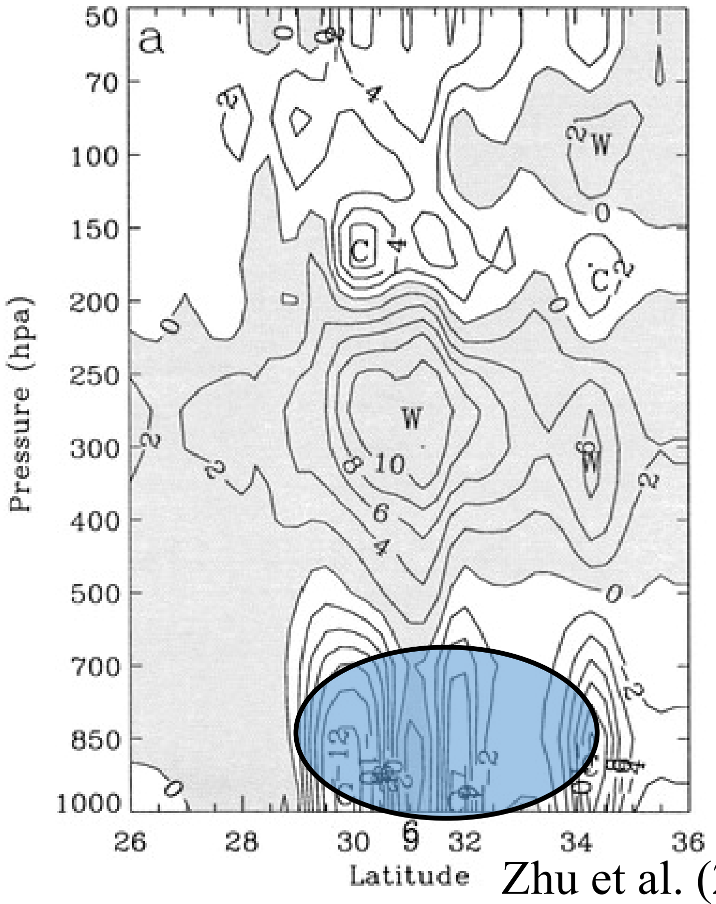



Zhu and Weng (2013)

Unexpected cold anomalies exist in the lower layers of hurricanes, which could be attributed to the scattering effects.




Tian and Zou (2016)




Zhu et al. (2002)

# 01 | Motivation

Bases on the cloud-dependent background 1DVAR method, a more reasonable TCs' thermal structure could be retrieved.

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

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

$\mathbf{x}$ – analysis variable

$\mathbf{x}_a$ – final analysis

$\mathbf{x}_b$ – background

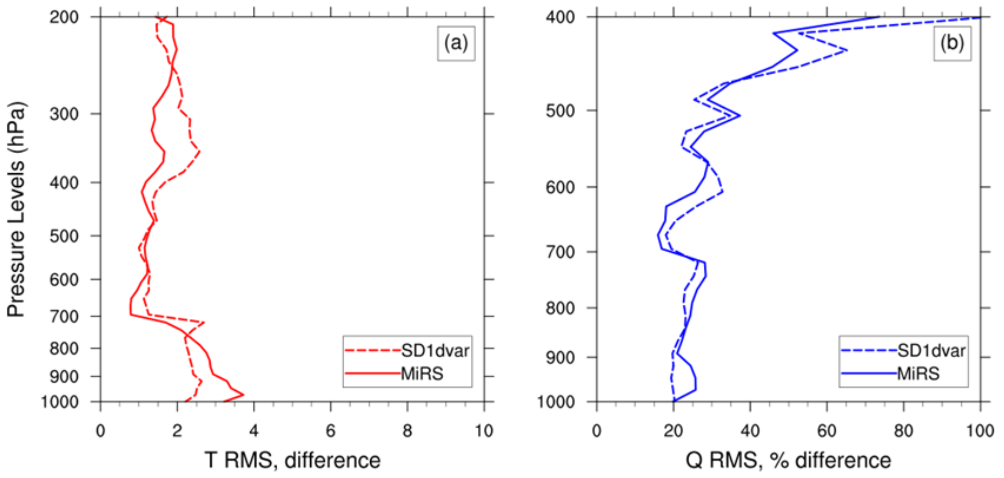
$\mathbf{B}$ – background error covariance

$\mathbf{y}^{obs}$ – observations

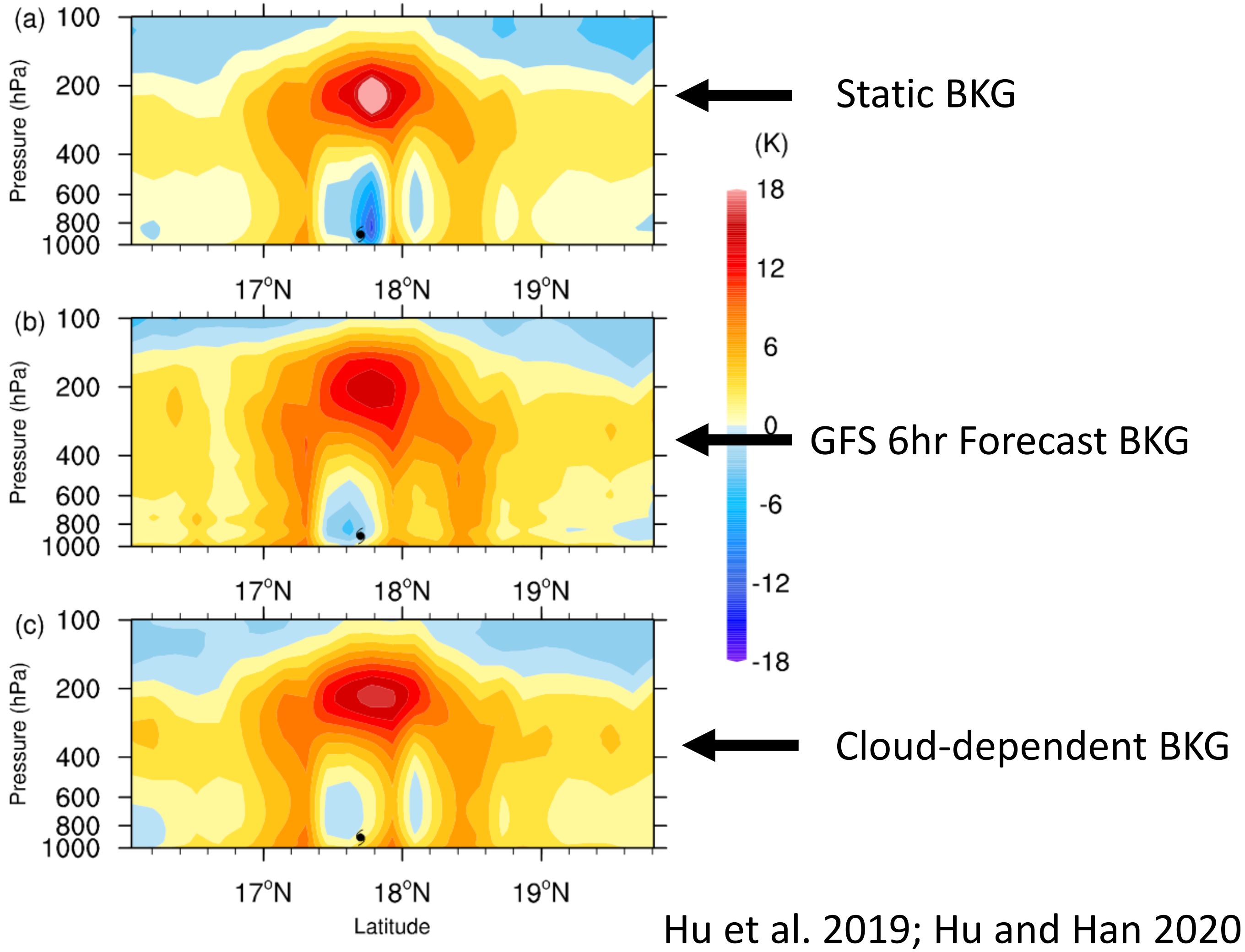
$\mathbf{O}$ – observation error covariance

$H$ – observation operator **ARMS**

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

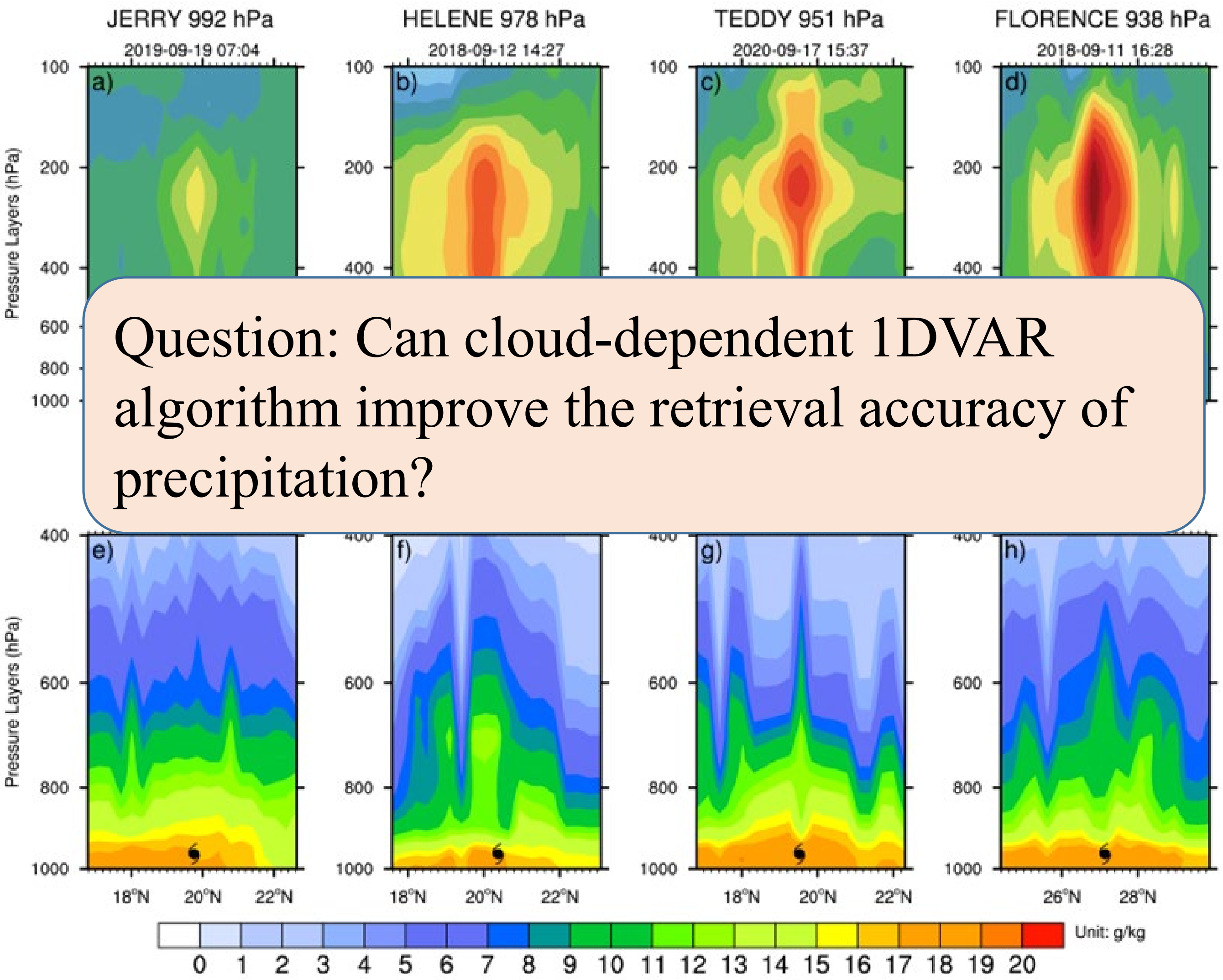



The low-level temperature and humidity retrieval error is reduced under hurricane conditions.




Hu et al. 2019; Hu and Han 2020

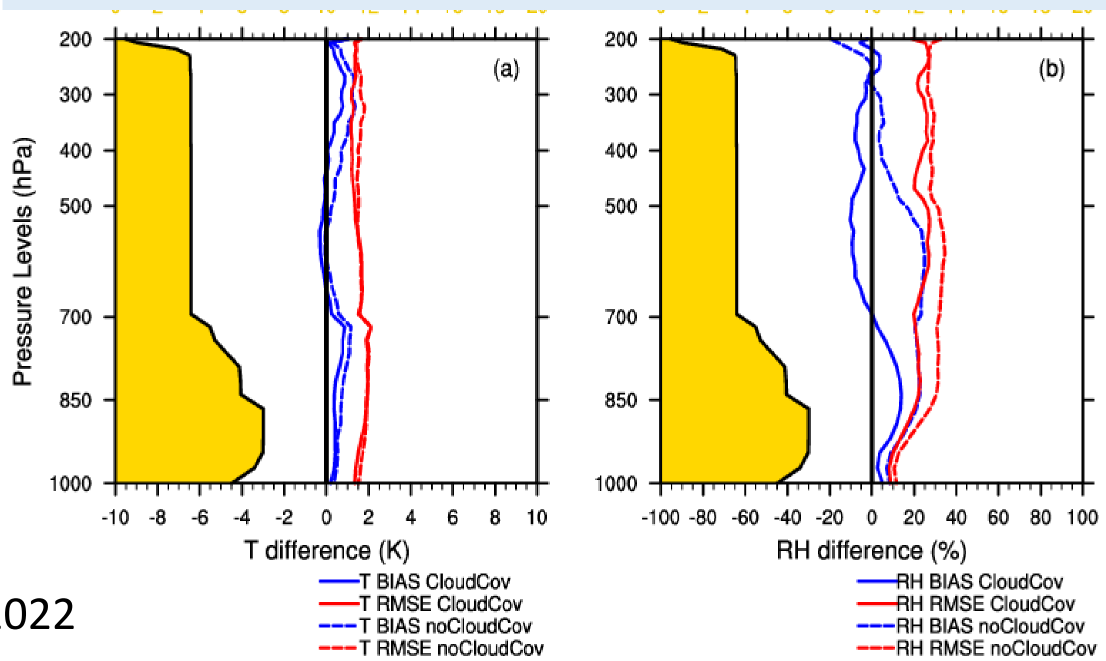
# 01 | Motivation




Question: Can cloud-dependent 1DVAR algorithm improve the retrieval accuracy of precipitation?

Based on the cloud-dependent covariance 1DVAR method, the warm core structure could be retrieved for any stage of TCs.

Compared with flight dropsonde observations under TC conditions, the temperature and humidity errors could be reduced to around 1.5 K and 10-20%, respectively, throughout the troposphere.




Hu and Weng 2022

# 02 | The Cloud-dependent 1DVAR Algorithm

$$PR = 2.339 * CLW^{1.156} + 3.879 * (RWP + GWP)^{1.103}$$

**Grassotti et al., 2020**

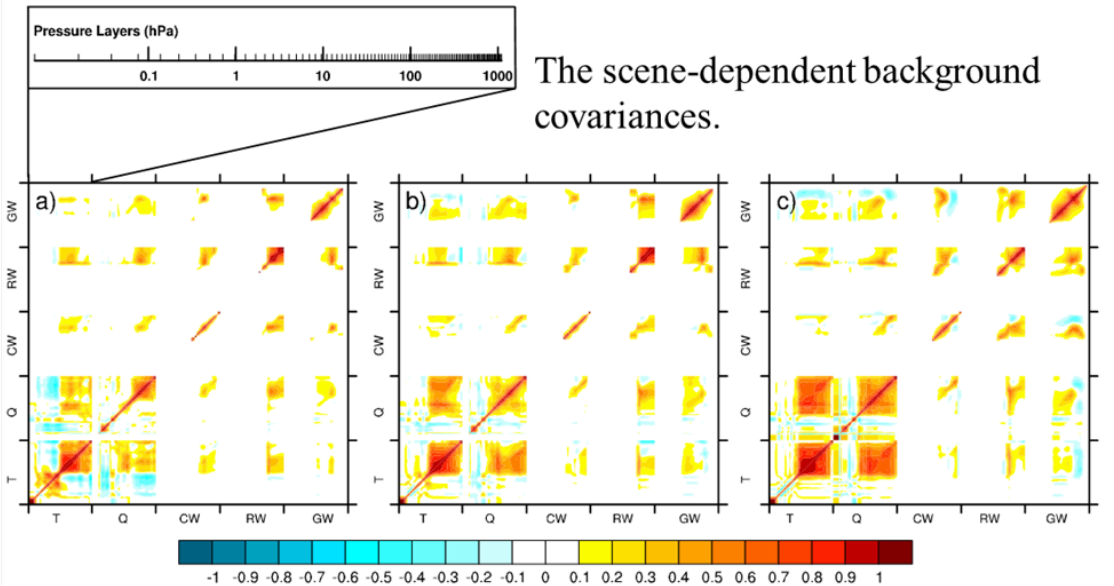
**1DVAR Precipitation Retrieval Algorithm (from MiRS)**

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

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

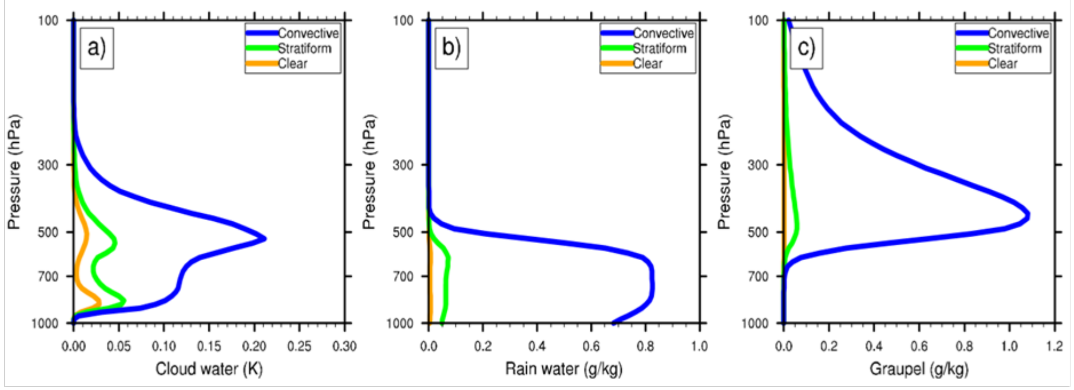
- $\mathbf{x}$ – analysis variable
- $\mathbf{x}_a$ – final analysis
- $\mathbf{x}_b$ – background
- $\mathbf{B}$ – background error covariance
- $\mathbf{y}^{obs}$ – observations
- $\mathbf{O}$ – observation error covariance
- $H$ – observation operator
- $\mathbf{F}$ – forward model error covariance

ARMS is used as a forward model. The scene-dependent **Xb** and **B** are generated.

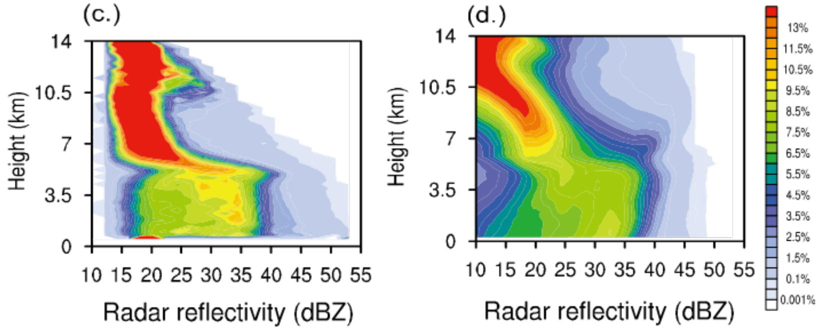



The scene-dependent background covariances.

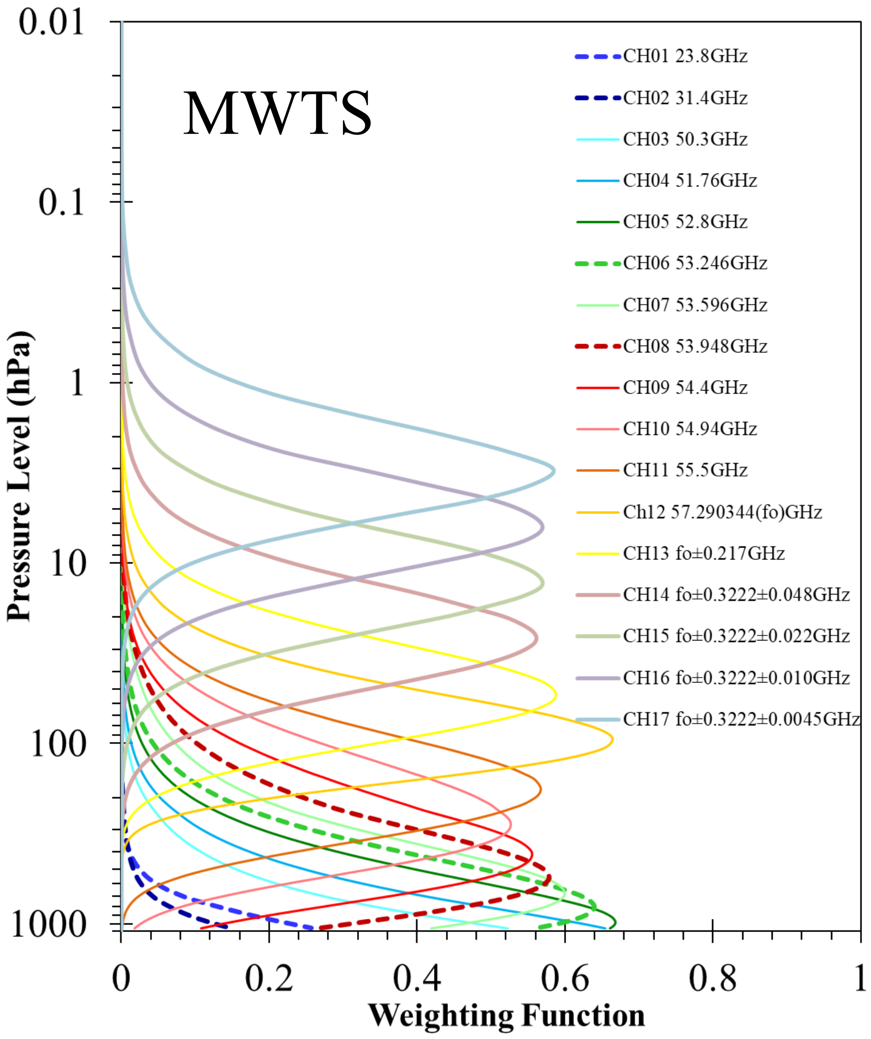
Hydrometer **B** and **Xb** are generated based on WRF simulation.

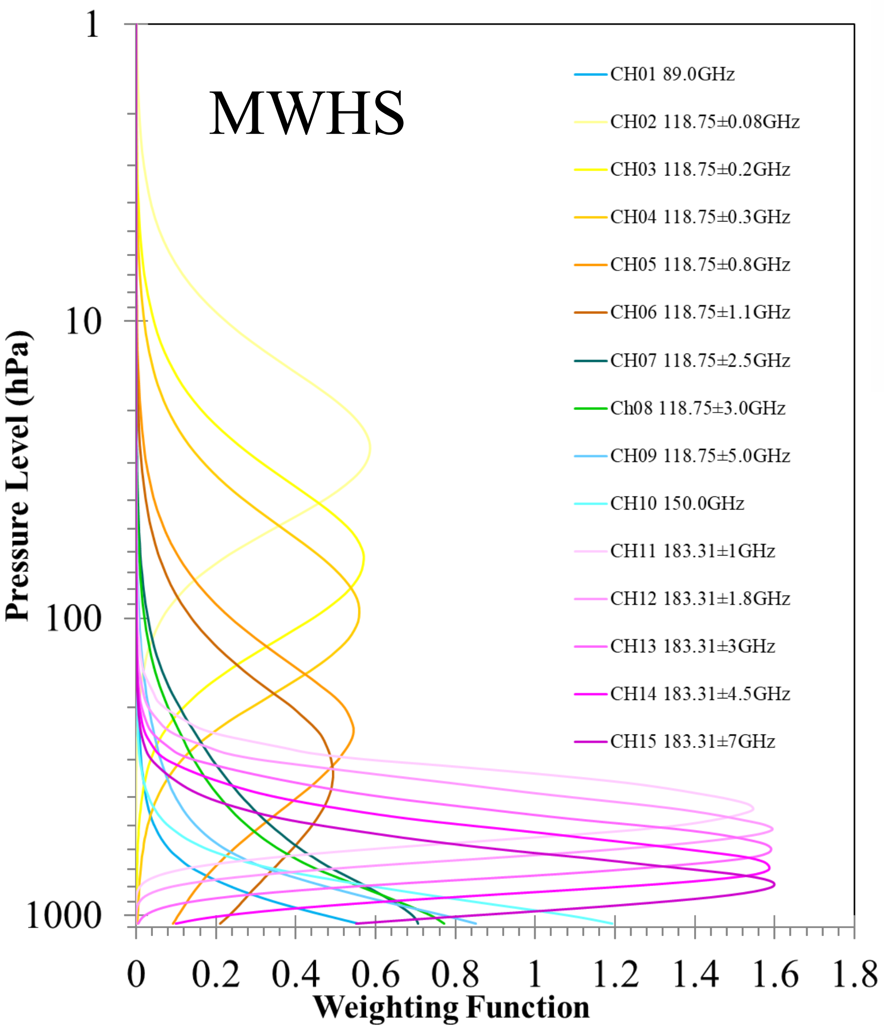


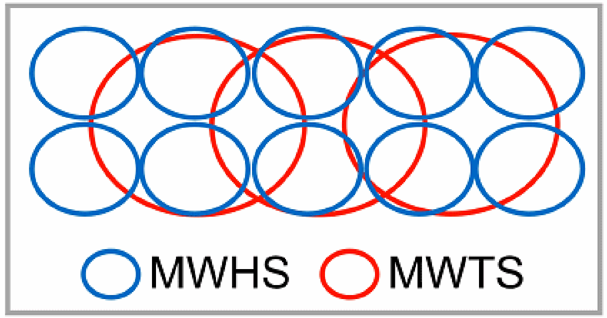

$$\begin{cases} mdbz > 39\ dBZ & convective \\ RainRate < 0.1\ mm/hr & clear \\ Others & stratiform \end{cases}$$



# 03 | Retrieved Products from FY-3D/E Microwave Sounders



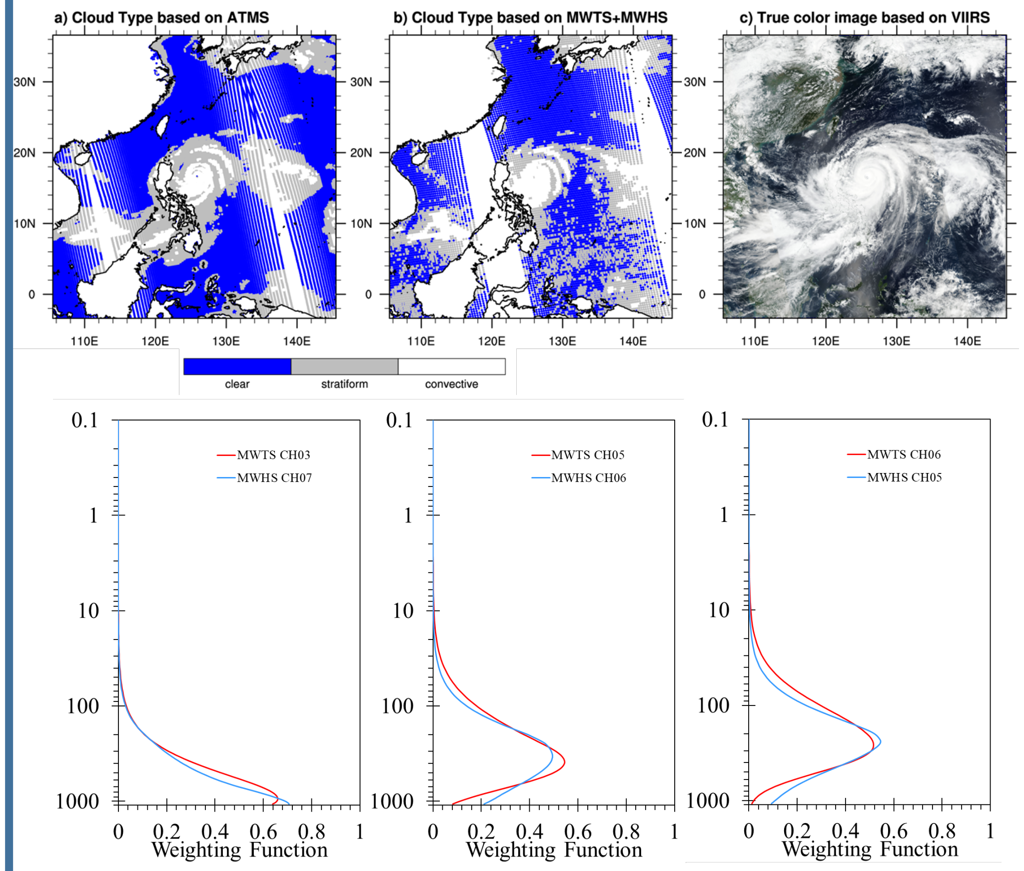




MWHS onboard FY-3D and FY-3E are similar.

FY-3E MWTS adds four new channels.

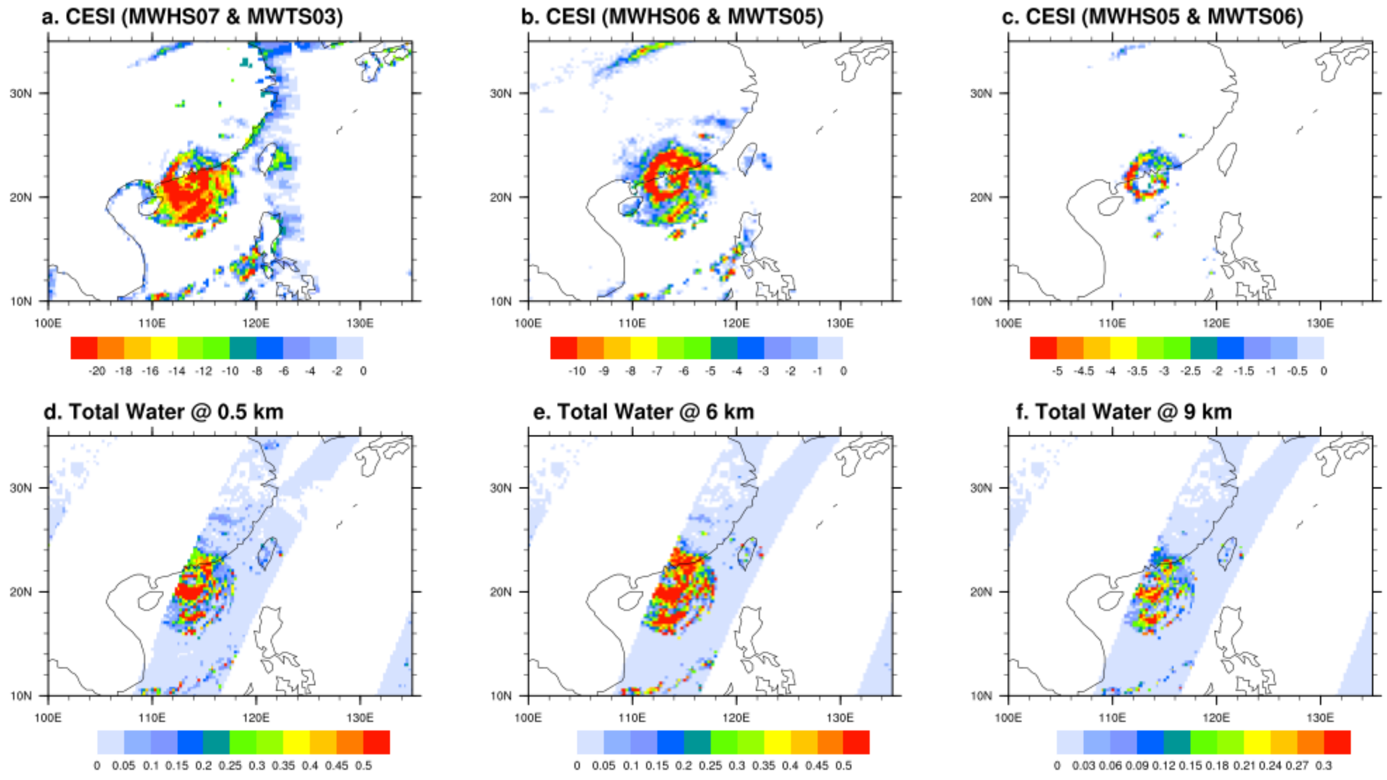
MWHS FOVs are remapped onto MWTS FOV to use all MW sounding channels in 1DVAR.

Cloud detection based on MWTS and MWHS (dual oxygen bands method)



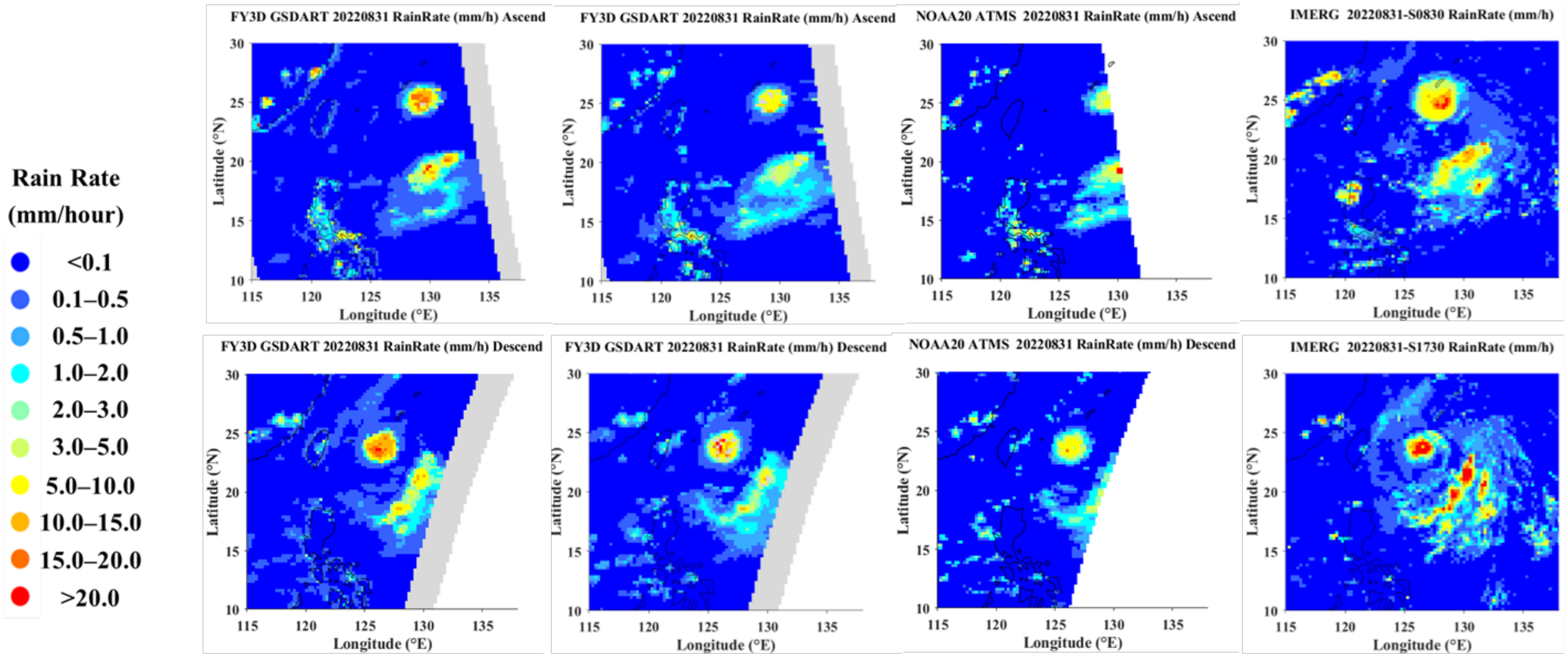

Kan, Hu* and Weng 2022

$$CESI = TB^{O}_{MWHTS1} - A * TB^{O}_{MWHTS2} + B$$




Compared with GPM hydrometer products, CESI can identify the distribution of hydrometeors at different heights on both land and ocean underlying surfaces.

# 03 | Retrieved Products from FY-3D/E Microwave Sounders




(a) FY3D MWTS/MWHS (Cloud-Dependent 1DVAR)

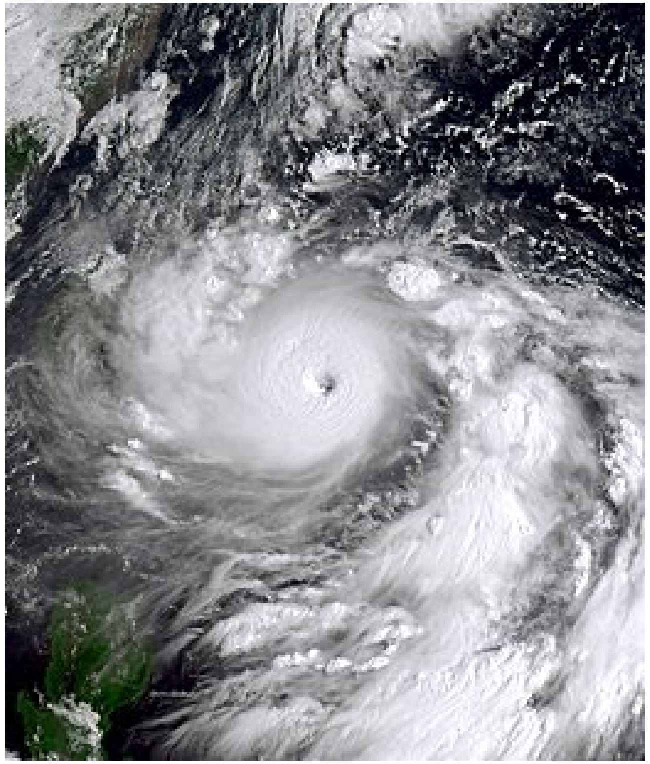
(b) FY3D MWTS/MWHS (1DVAR)

(c) NOAA20 ATMS (MiRS)

(d) GPM-IMERG Late Run

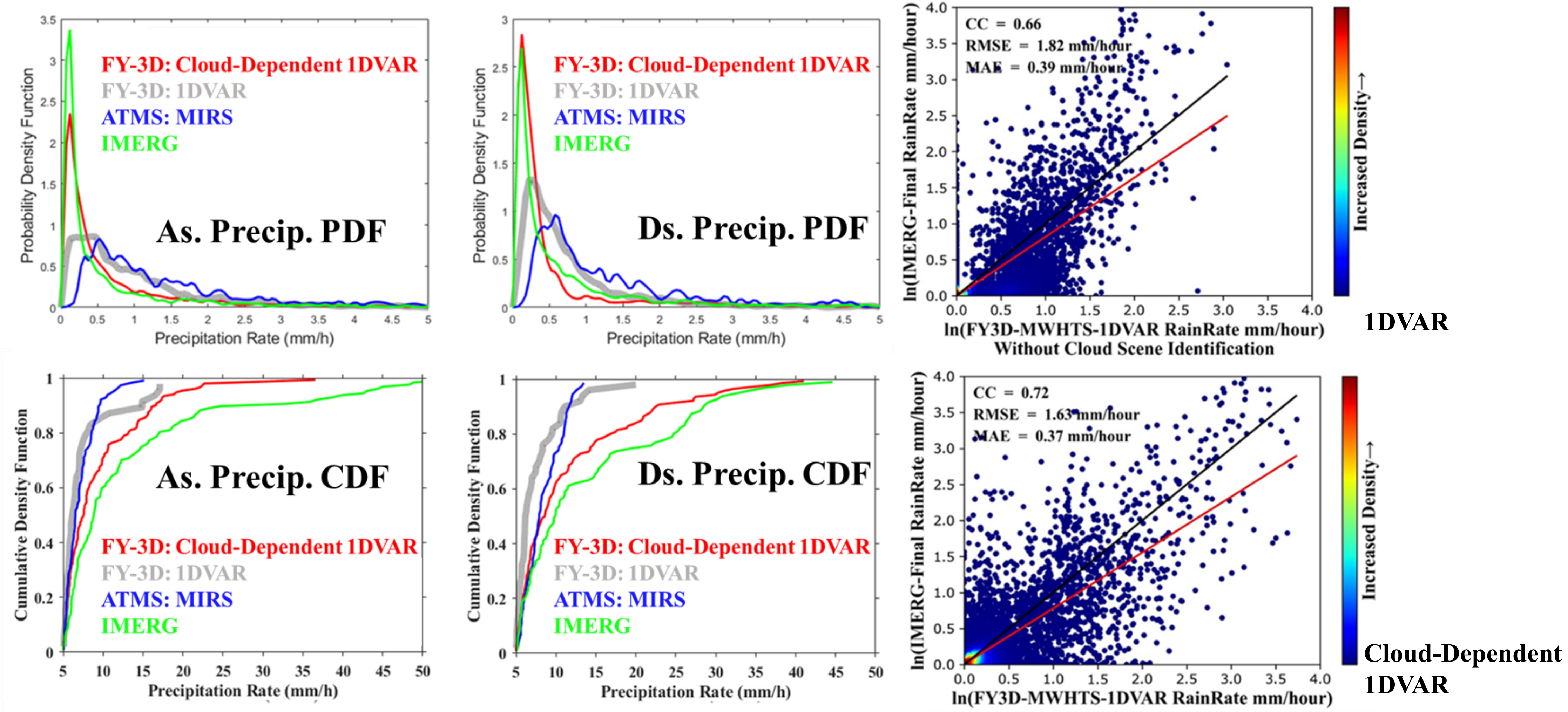
Spatial distributions of precipitation rates for (a) FY3D MWTS/MWHS (Cloud-Dependent 1DVAR), (b) FY3D MWTS/MWHS (1DVAR), (c) NOAA20 ATMS (MiRS), and (d) GPM-IMERG LateRun on August 31, 2022. The first row is for ascending passes (~05:00 UTC), and the second row is for descending passes (~17:30 UTC).

Precipitation product from cloud-dependent 1DVAR performs better in capturing the light and heavy precipitation.



*Typhoon Hinnamnor (2022)*

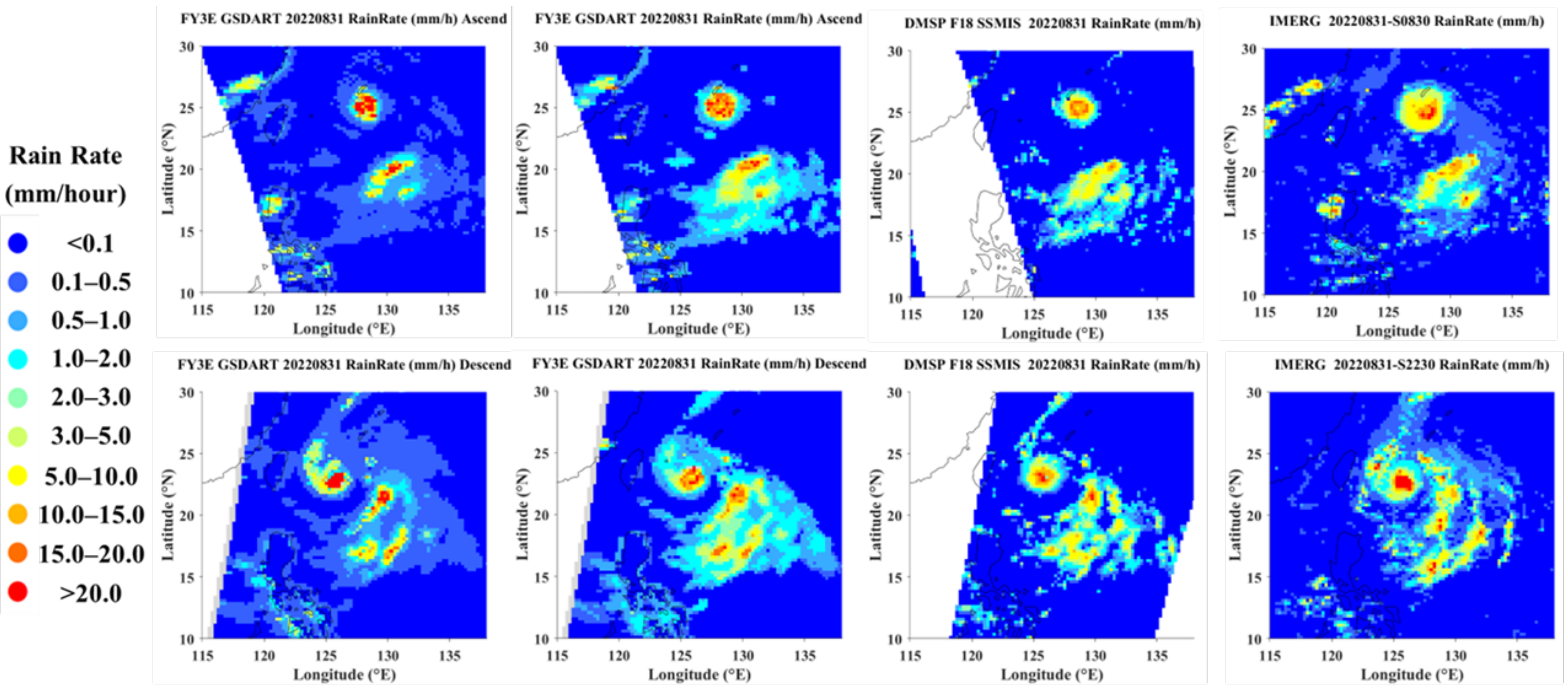
# 03 | Retrieved Products from FY-3D/E Microwave Sounders




The cloud-dependent 1DVAR algorithm can greatly improve the retrieval accuracy of both light rain and heavy rain, and the PDF and CDF are closer to IMERGE products. CC increased from 0.66 to 0.72, RMSE reduced from 1.82 to 1.63 mm/hr.

# 03 | Retrieved Products from FY-3D/E Microwave Sounders

Similar with FY-3D, precipitation product from cloud-dependent 1DVAR performs better in capturing the light and heavy precipitation.

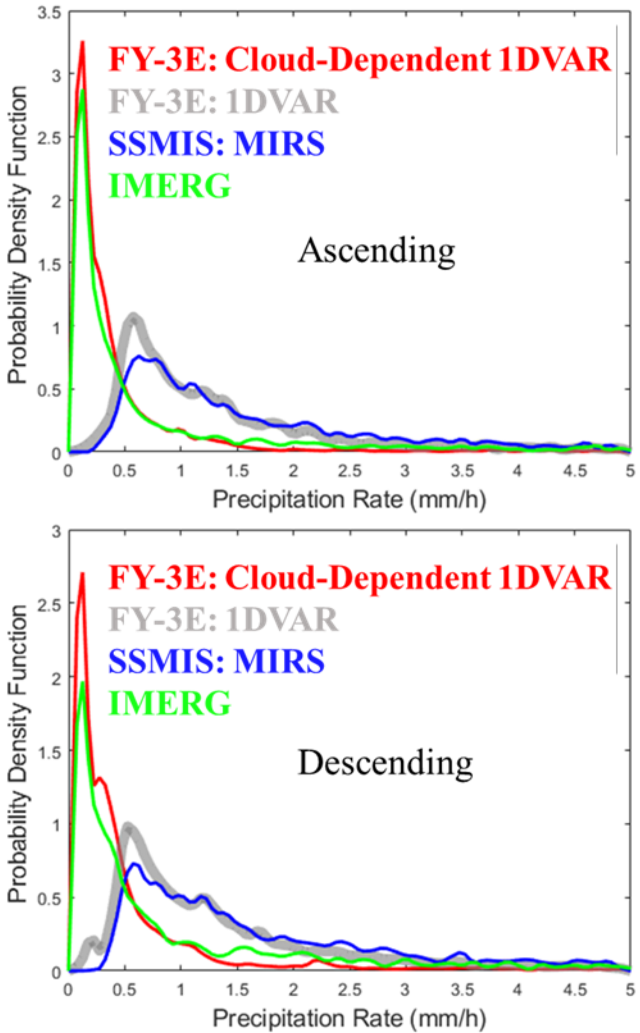



(a) FY3E MWTS/MWHS (Cloud-Dependent 1DVAR)

(b) FY3E MWTS/MWHS (1DVAR)

(c) DMSP F18 SSMIS (MiRS)

(d) GPM-IMERG Late Run

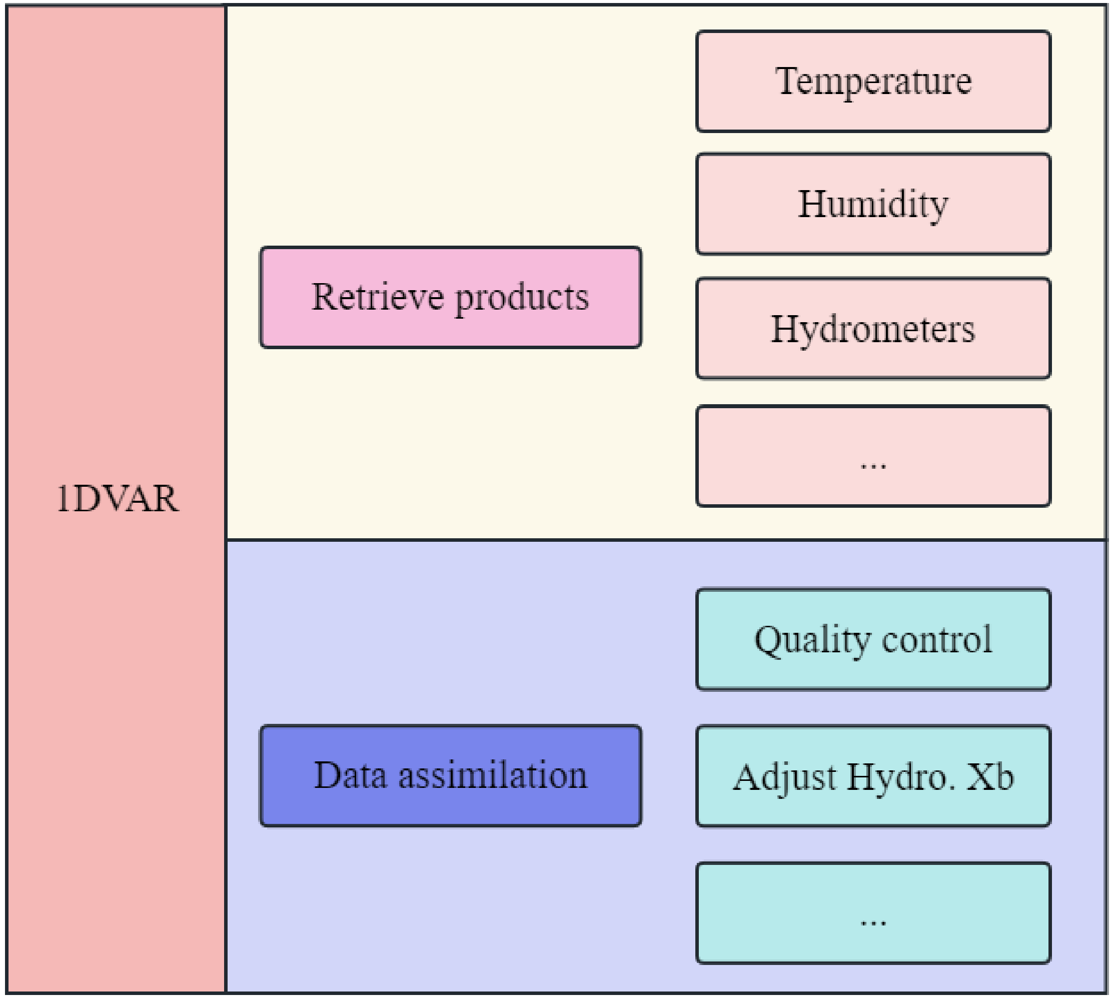



Spatial distributions of precipitation rates for (a) FY3E MWTS/MWHS (Cloud-Dependent 1DVAR), (b) FY3E MWTS/MWHS (1DVAR), (c) DMSP F18 SSMIS (MiRS), and (d) GPM-IMERG LateRun on August 31, 2022. The first row is for ascending passes (~08:30 UTC), and the second row is for descending passes (~22:30 UTC).

# 04 | Conclusions and discussion

1. The cloud-dependent 1DVAR performs better in capturing heavy & light precipitation for both FY-3D & E MW sounders.

2. The accuracy of the precipitation retrievals considering cloud scene identification (CC ~ 0.72 and RMSE ~ 1.63 mm/h) is obviously better than that of the precipitation retrievals without distinguishing cloud scenes (CC ~ 0.66 and RMSE ~ 1.82 mm/h)



# THANKS!

Email: huhao@cma.gov.cn