FY-3D 1DVAR sounding system with scene-dependent error covariances and its applications for typhoon monitoring

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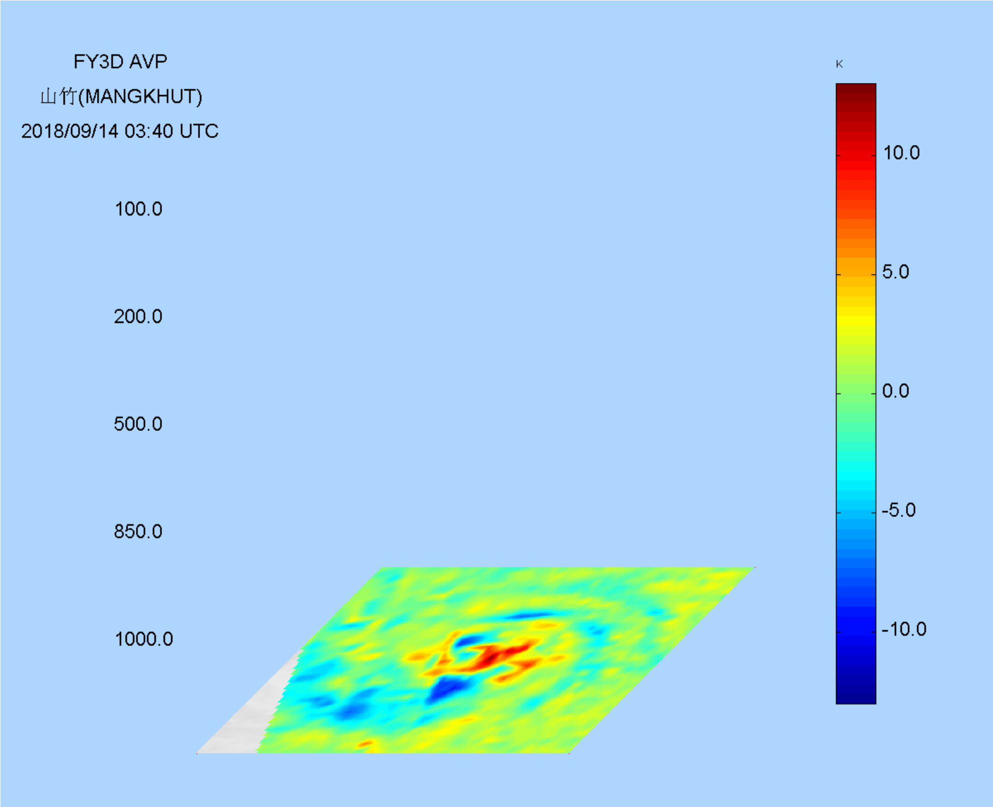
- Retrieved products from microwave sounding instruments
- Retrieved products from hyperspectral instruments
- Conclusion

Motivation

With the ability of penetrating clouds and precipitations, the satellite microwave sounding instruments could be an important way to identify atmosphere profiles of sever weather systems, such as tropical cyclones.

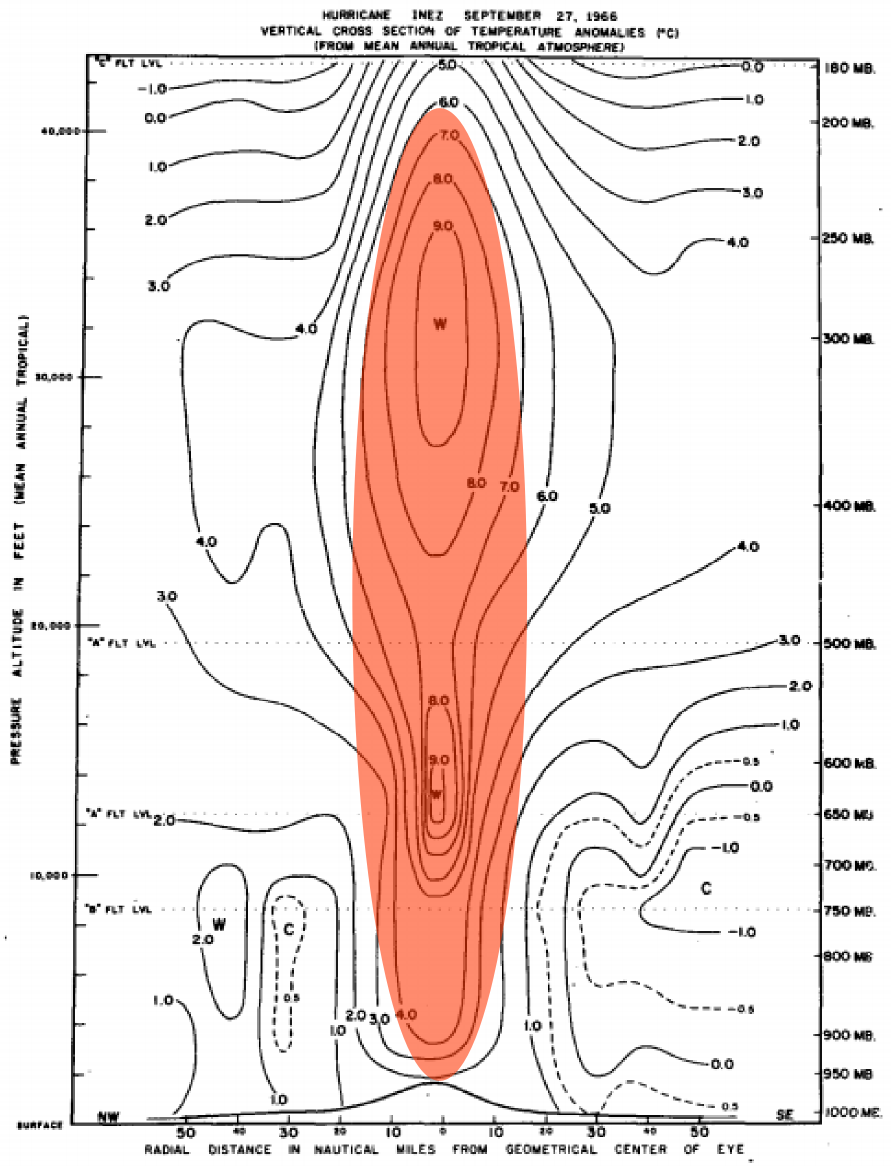
However, the microwave observations, as well as their products, could still be affected by large scattering processes, such as the heavy precipitation in the inner region of strong tropical cyclones.



Motivation

The warm core structure is one of the most distinctive characteristics of tropical cyclones, with the temperature within the eye region warmer than that of the environment.

This structure has been proved by early studies using aircraft measurements.



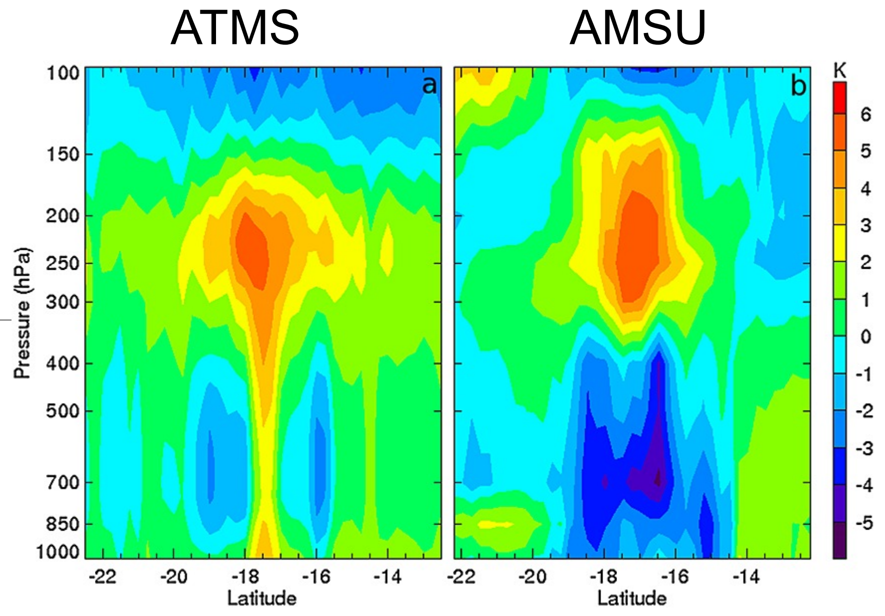
Hawkins and Imbembo (1975)

Motivation

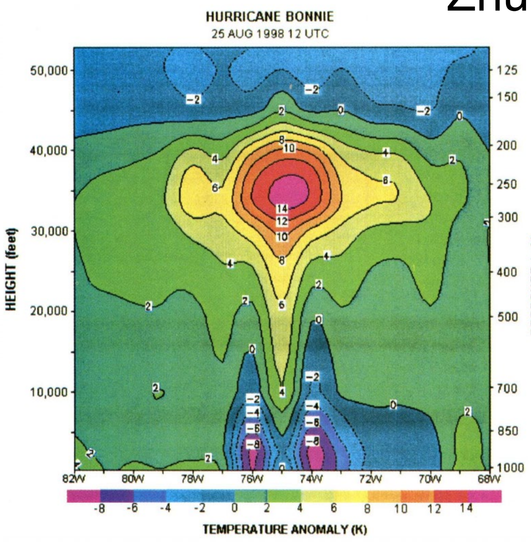
Since 2000s, researchers have tried to use statistical regression algorithms to derive the warm core structure based on microwave sounding instruments.

Though a reasonable warm core structure could be retrieved, an unexpected cold anomaly in low-level thermal structure could be spotted in their results, especially for those cases with strong intensity.

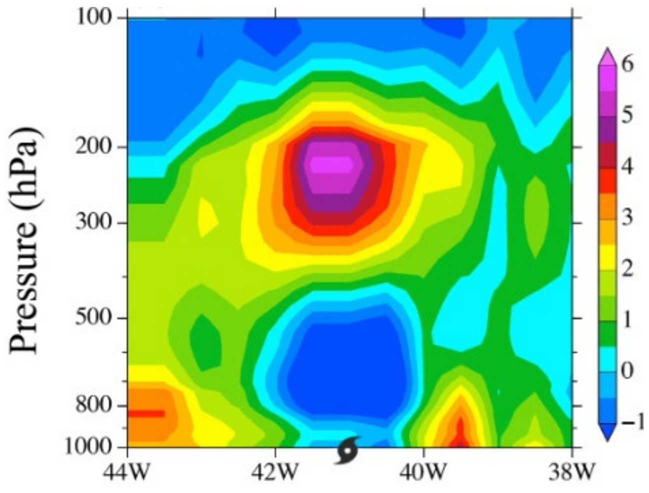
This could be attributed to the large scattering effect of clouds and precipitation in low-level of tropical cyclones.



Zhu and Weng (2013)

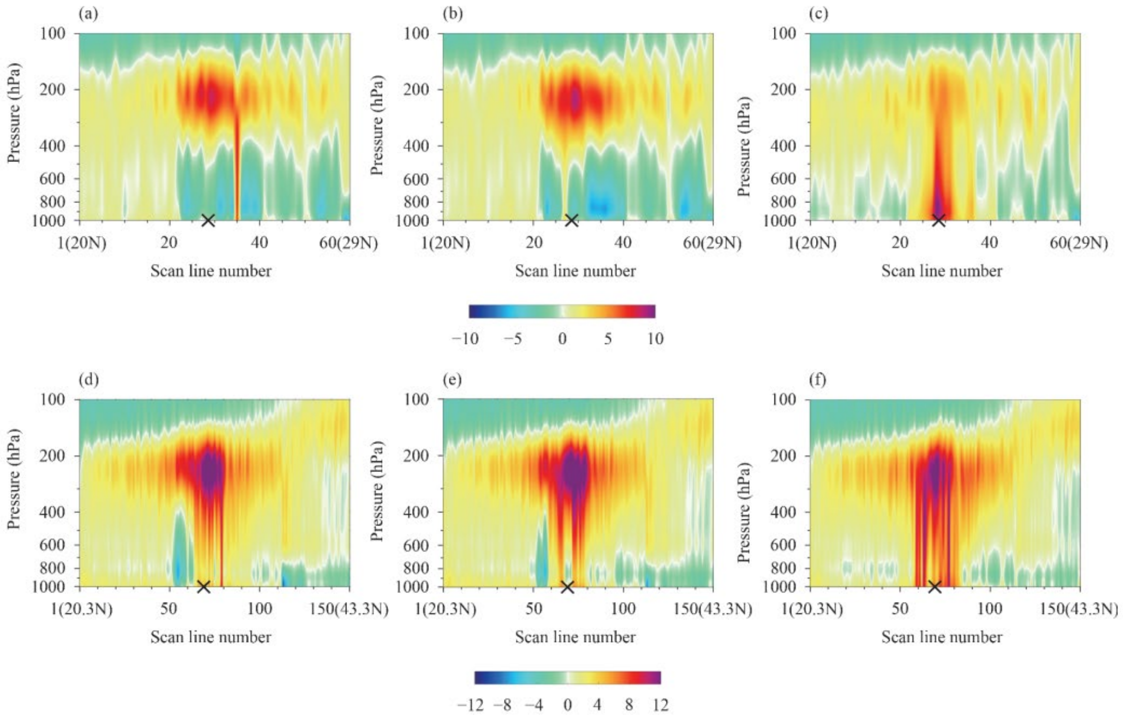


Kidder et al. (2000)



Tian and Zou (2016)

Motivation



Han and Weng (2018)

Besides the statistical regression algorithms, some studies tried to use the one-dimensional variation algorithm (1DVAR) to retrieve tropical cyclones' thermal structures.

The unexpected cold anomaly in low-level thermal structure still exists.

Thus, the key issue of retrieving TC's thermal structure is how to deal with the scattering effects in the algorithm.

Scene-depended 1dvar (SD1dvar) retrieval algorithm

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

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

$\mathbf{x}$ – analysis variable

$\mathbf{x}_a$ – final analysis

$\mathbf{x}_b$ – background

$\mathbf{B}$ – background error covariance

$\mathbf{y}^{obs}$ – observations

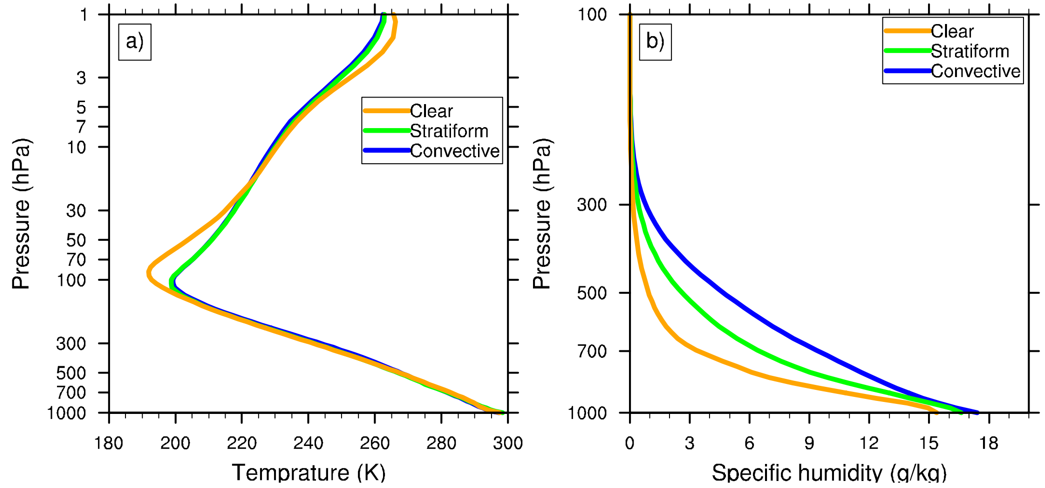
$\mathbf{O}$ – observation error covariance

H – observation operator

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

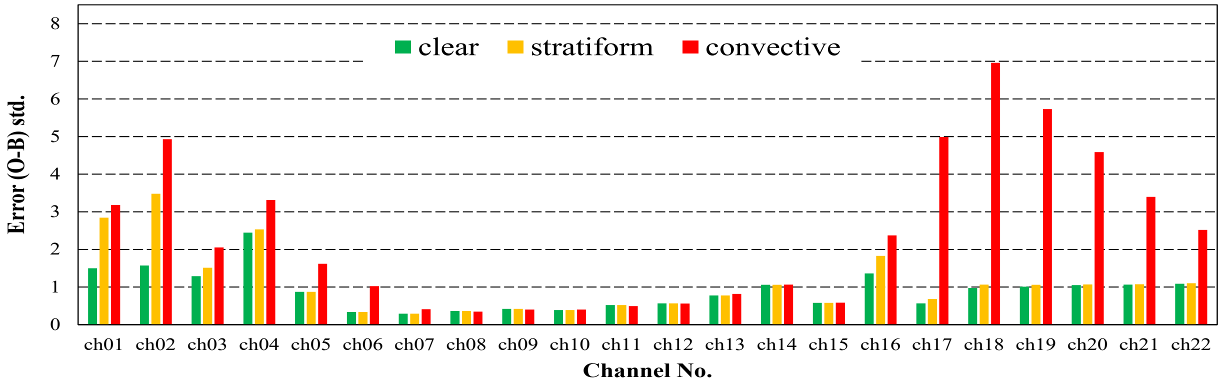
Different from traditional 1DVAR algorithm, we used dynamic background and error covariance based on the scattering conditions.

Scene-depended 1dvar (SD1dvar) retrieval algorithm



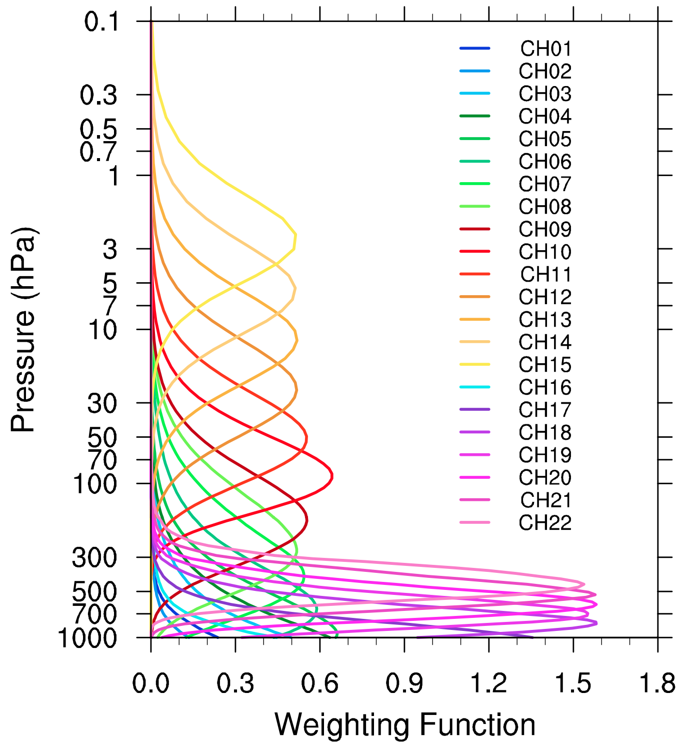
Using the ERA-Interim reanalysis dataset, we calculated the temperature and specific humidity profiles under three scattering conditions: clear sky, stratiform cloud and convective could.

The error covariance was also calculated based on different scattering conditions for every channel.

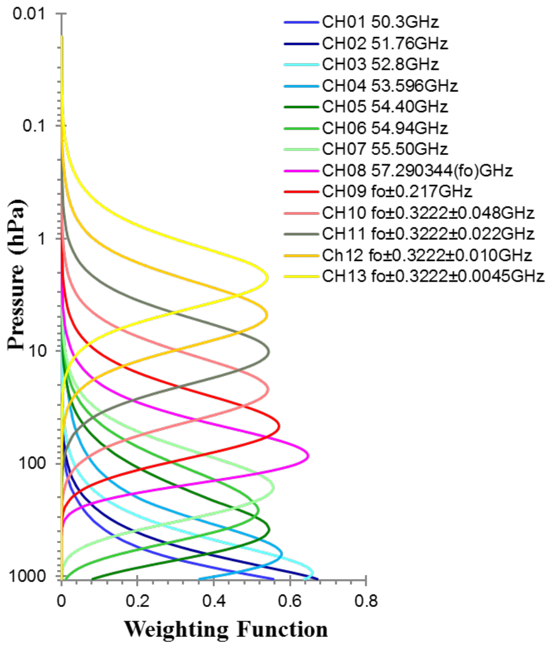


Error covariance for SNPP ATMS

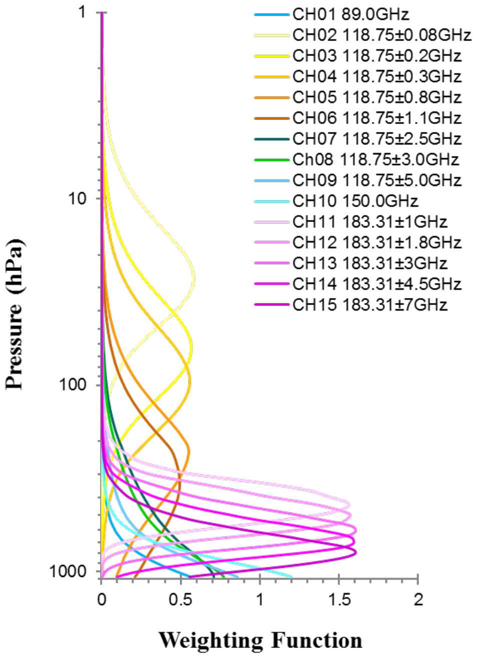
Retrieved products from microwave sounding instruments



ATMS 22 channels



MWTS 15 channels



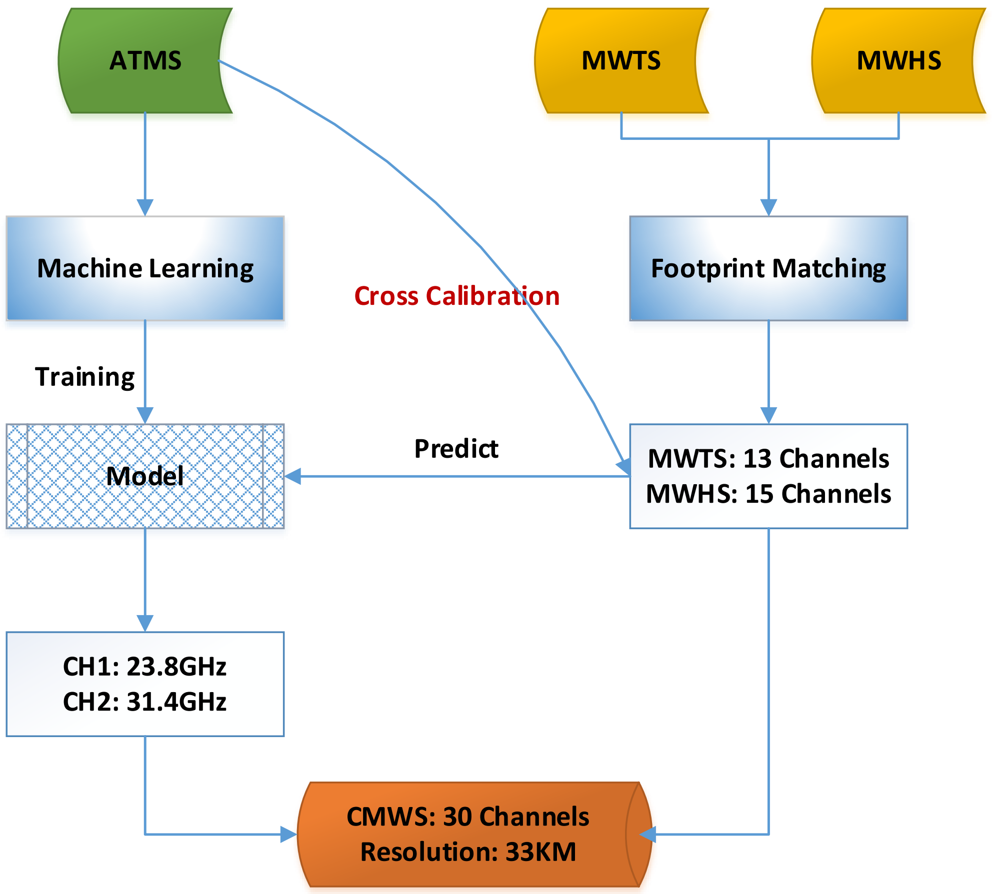
MWHS 13 channels

Different from ATMS, the microwave sounding instruments onboard FY-3D do not have window channels with frequency at 23.8 and 31.4 GHz. Besides, MWHS contains 8 sounding channels with the center frequency near 118.75 GHz, which ATMS doesn't have.

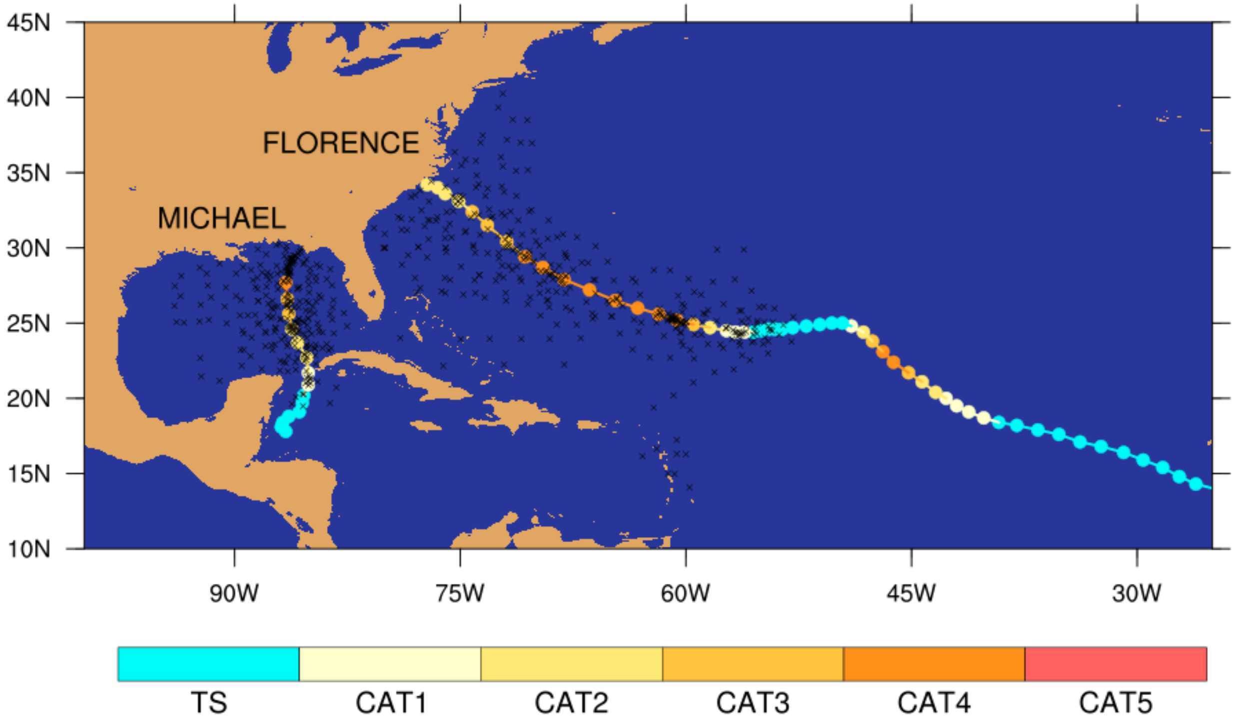
Retrieved products from microwave sounding instruments

Before retrieving FY-3D microwave instruments, we combined the MWTS and MWHS FOVs and generated 23.8 and 31.4 GHz channels similar with ATMS using random forest algorithm.

The combined product, named as CMWS, has 30 channels containing all 28 FY-3D microwave sounding channels and 2 simulated window channels.



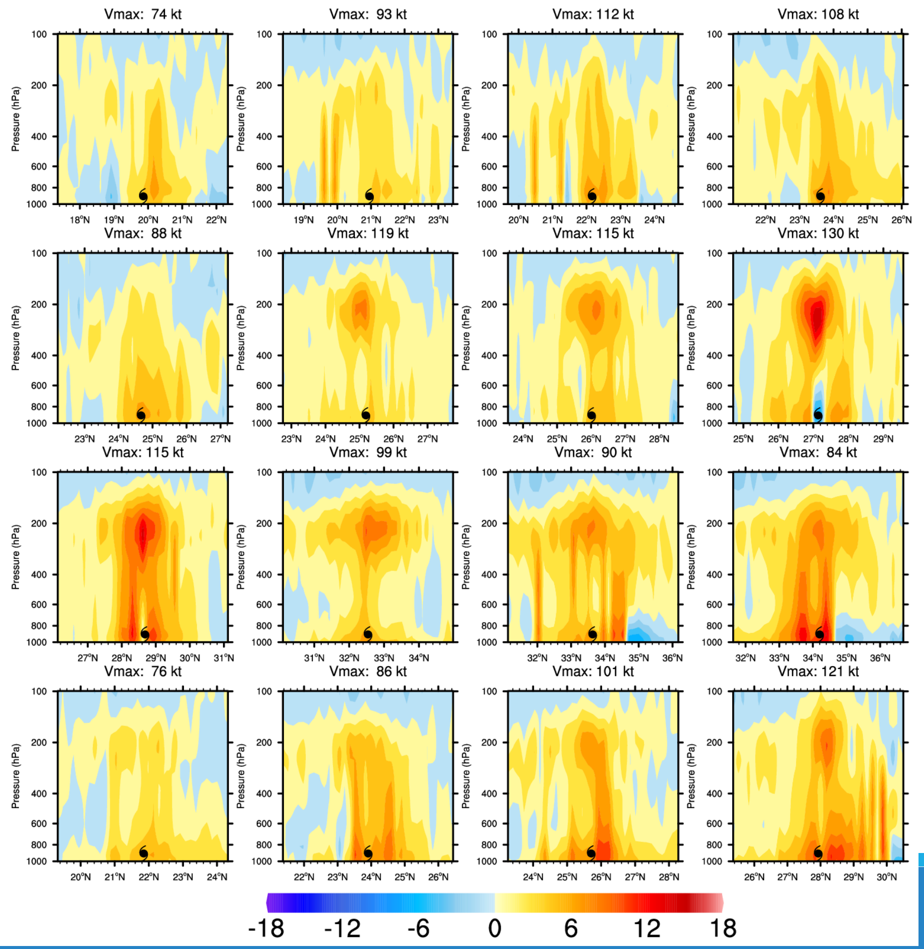
Retrieved products from microwave sounding instruments



We choose hurricane Florence and Michael in 2018 to do assessment of our retrieval algorithm. Microwave sounding instruments onboard SNPP and FY-3D are used as observations. And the MiRS sounding products are used as comparison.

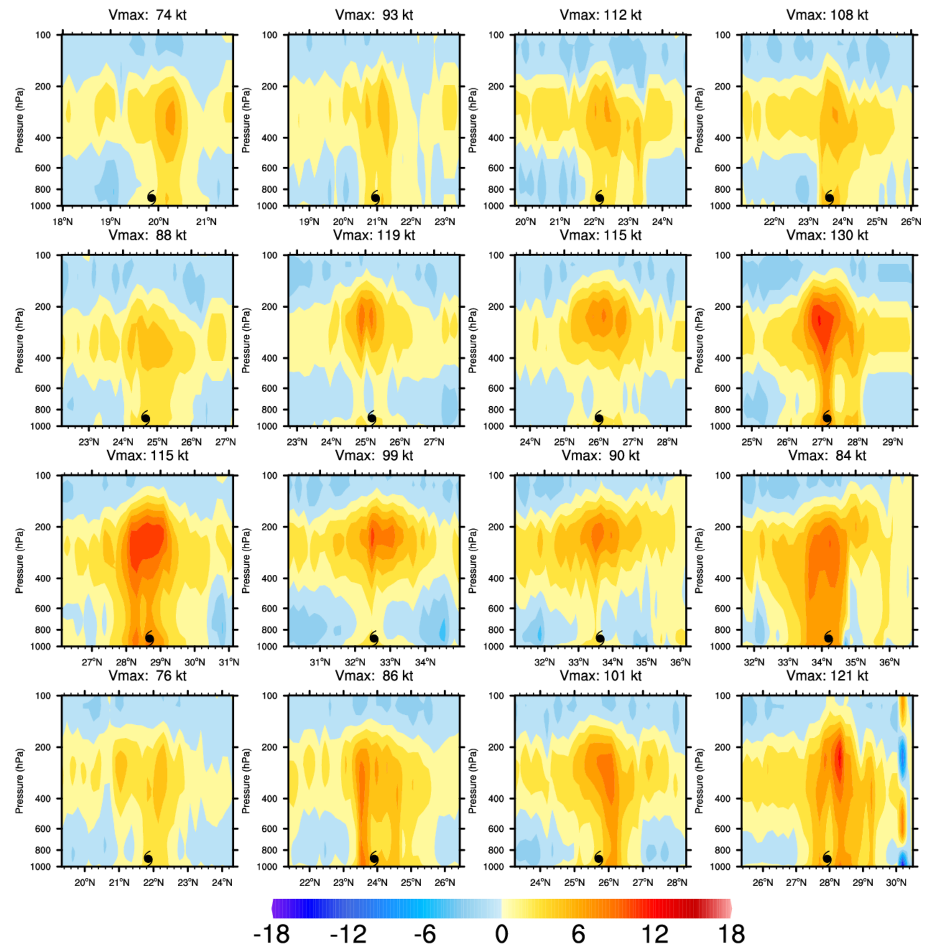
Retrieved products from microwave sounding instruments

MiRS_ATMS



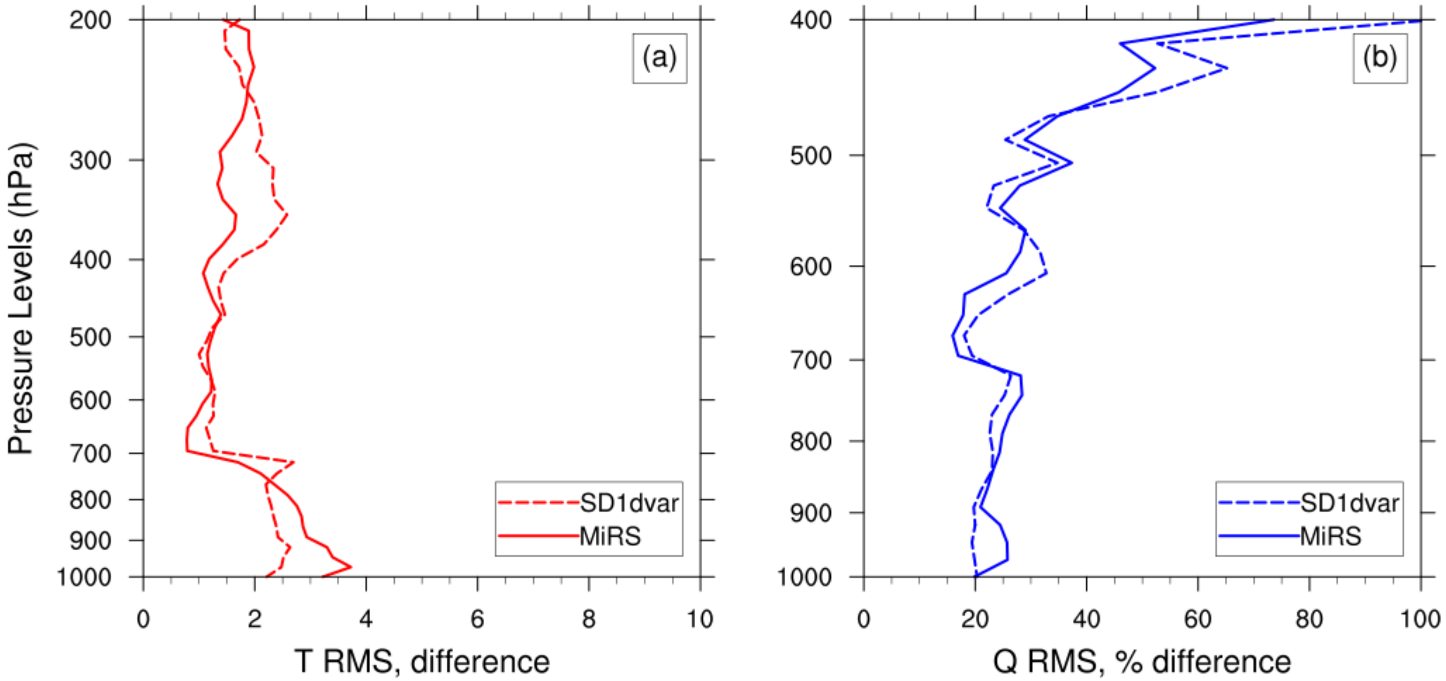
Compared with MiRS products, the warm core structure from our retrieval algorithm is more reasonable, with the weak storm to have clear warm core structure and the strong storm to be less effected by scattering processes.

SD1dvar_ATMS



Retrieved products from microwave sounding instruments

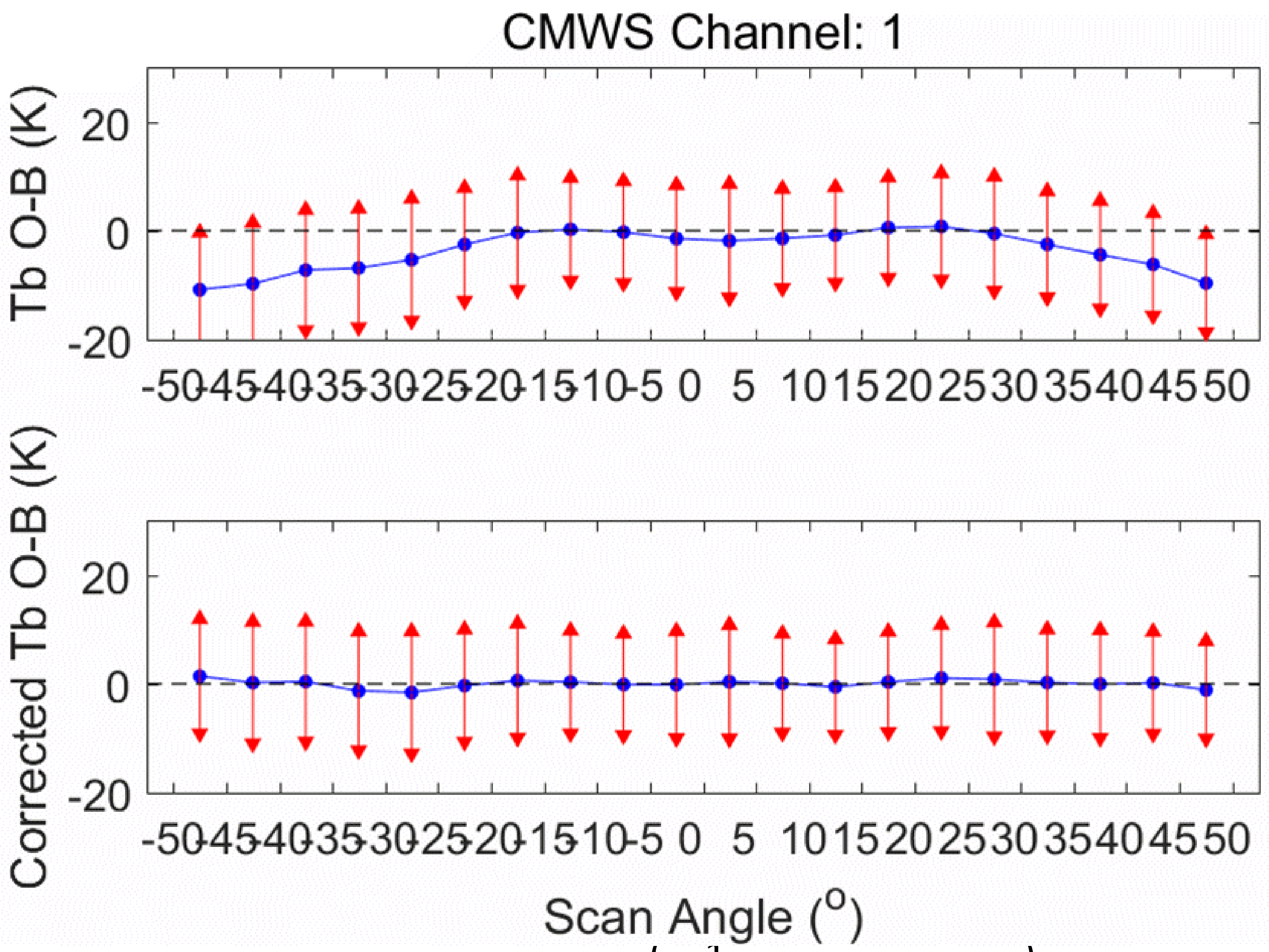
Dropsonde 0-400 km from TC center



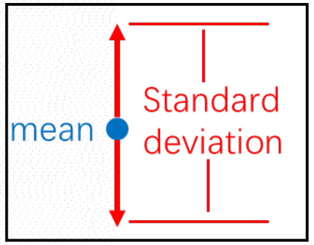
Collocation threshold: within 33 km & within 30 minutes
Number of collocated dropsondes: 190

The humidity error profile is similar between these two products, except in the low-level where SD1dvar have less humidity error. Meanwhile, the SD1dvar has less temperature error in low-level but larger error in the upper-level compared with MiRS products.

All in all, SD1dvar could retrieve better temperature and humidity structure in the low-level region.



Before retrieving CMWS, a scan angle bias correction of all channels is done to erase the asymmetric bias of brightness temperature.

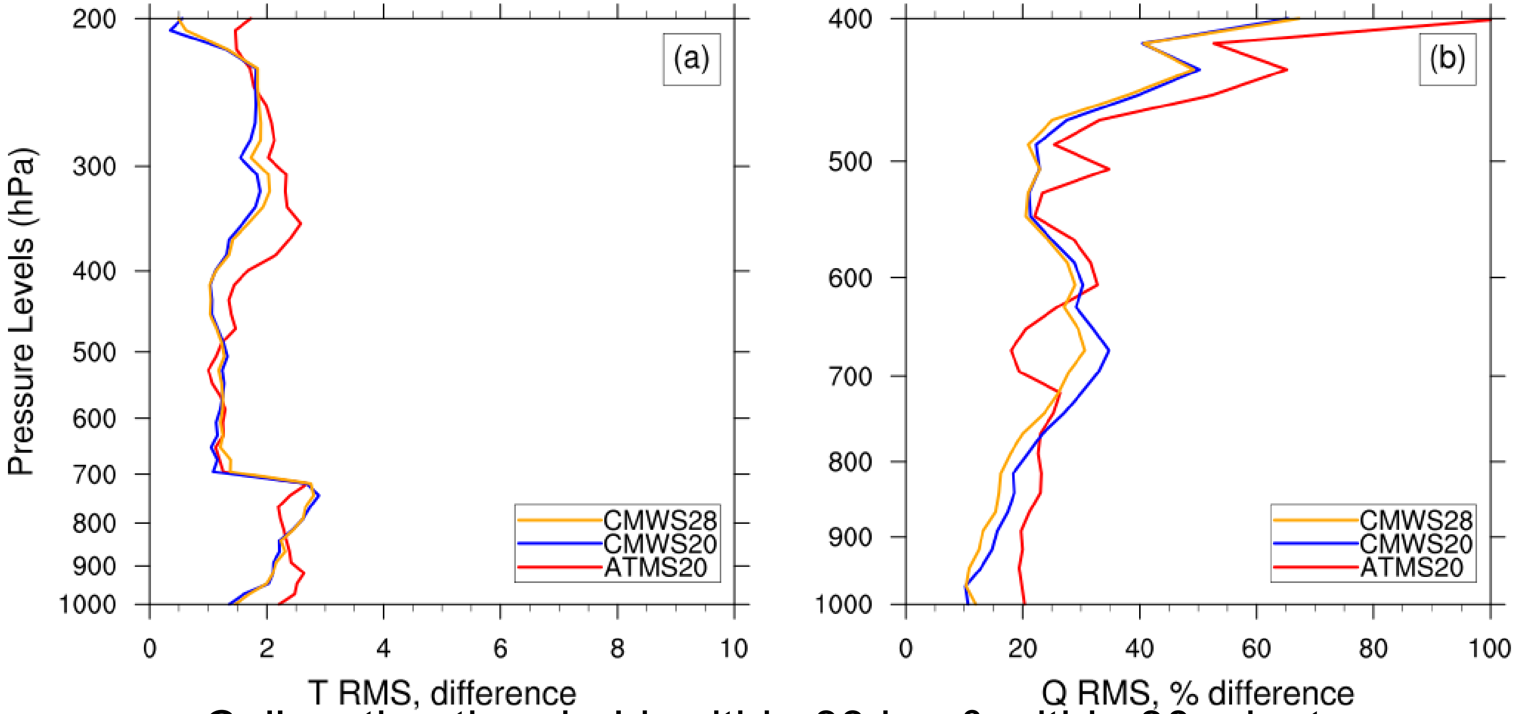


$$\Delta T_b = A_0 exp\left\{-\frac{1}{2}[(\theta_s - A_1)/A_2]^2\right\} + A_3 + A_4\theta_s + A_5\theta_s^2$$

（Weng et al. 2003）

EXP. NAME	DESCRIPTION
SD1dvar_ATMS20	Use all ATMS channels except chan. 1 & 2
SD1dvar_CMWS20	Use CMWS channels with frequency similar to SD1dvar_ATMS20
SD1dvar_CMWS28	Use all CMWS channels except chan. 1 & 2

Dropsonde 0-400 km from TC center

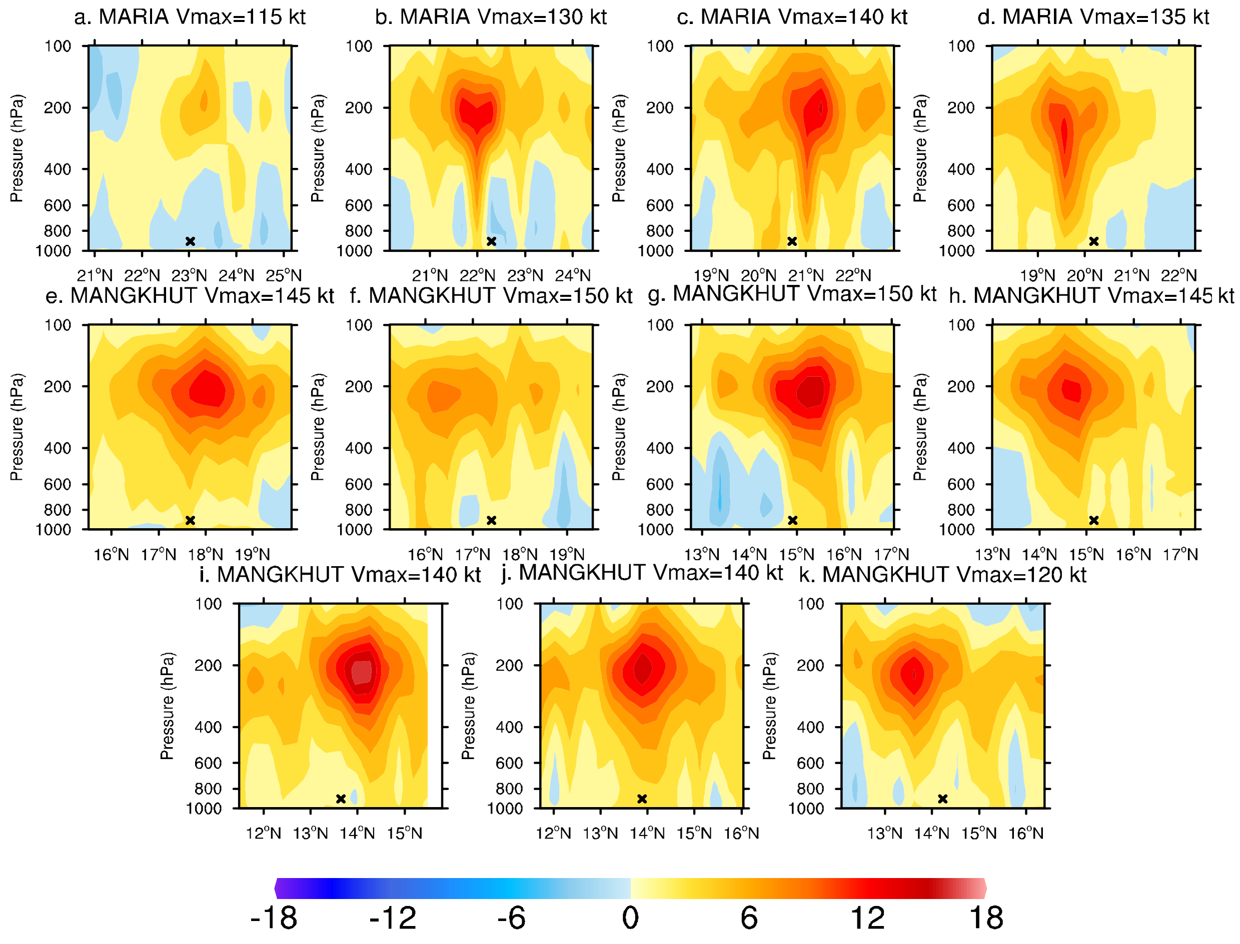


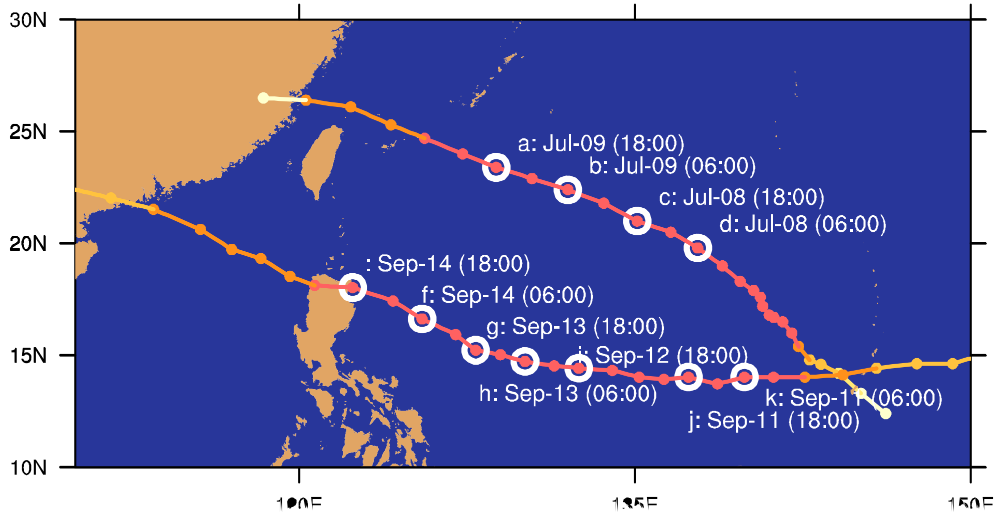
Collocation threshold: within 33 km & within 30 minutes
Number of collocated dropsondes for ATMS: 190
Number of collocated dropsondes for CMWS: 96

The retrieved temperature error is similar among three experiments, indicating that SD1dvar has relatively stable performance between different instruments.

The retrieved humidity profile seems to have better quality when using CMWS observations, especially for CMWS28, indicating that involving the 118 GHz channels could improve the humidity retrievals.

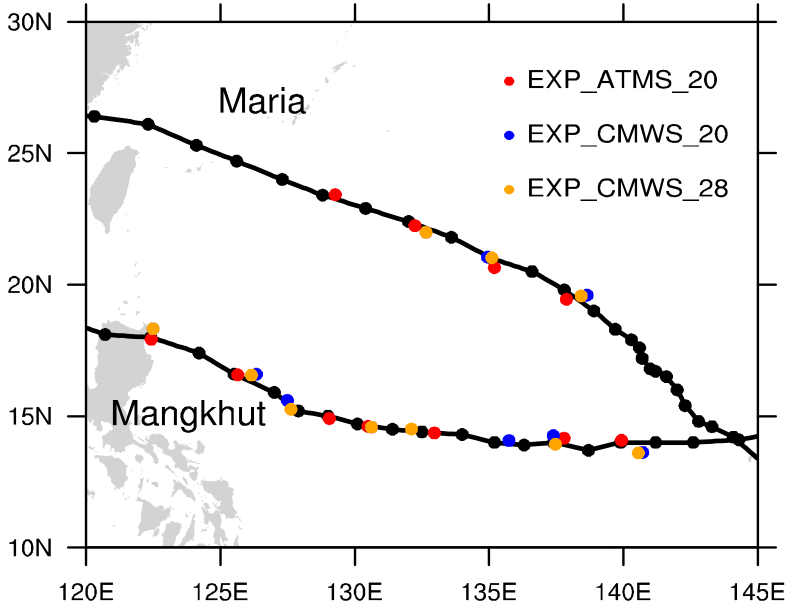
Retrieved products from microwave sounding instruments

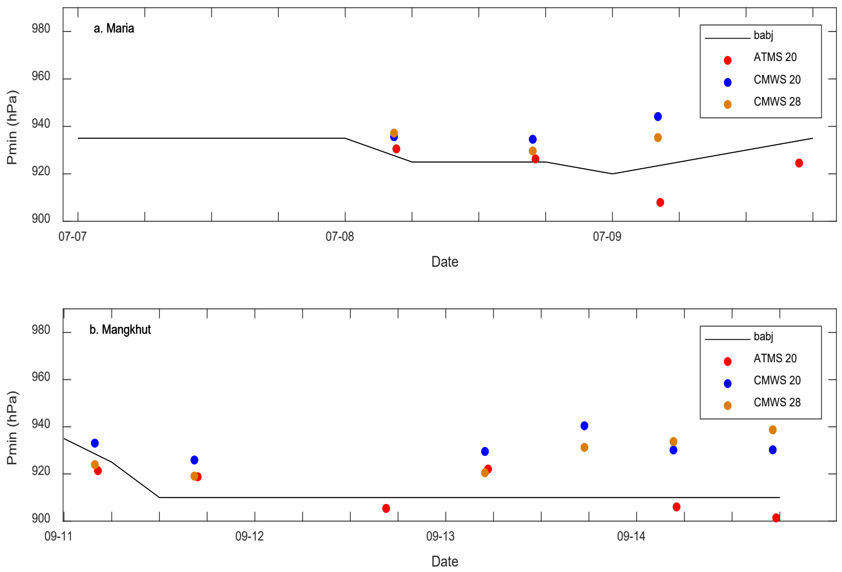




We also test our algorithm for typhoons in the Western Pacific. Results show that the retrieved warm core structures from CMWS28 are reasonable. Due to the lack of dropsonde observations, no quantitative error assessment for typhoon retrievals has been done yet.

EXP. NAME	DESCRIPTION
SD1dvar_ATMS20	Use all ATMS channels except chan. 1 & 2
SD1dvar_CMWS20	Use CMWS channels with frequency similar to SD1dvar_ATMS20
SD1dvar_CMWS28	Use all CMWS channels except chan. 1 & 2





Based on the hydro-static balance, we could calculate surface pressure from the retrieved thermal structures and obtain the typhoons' center location and intensity.

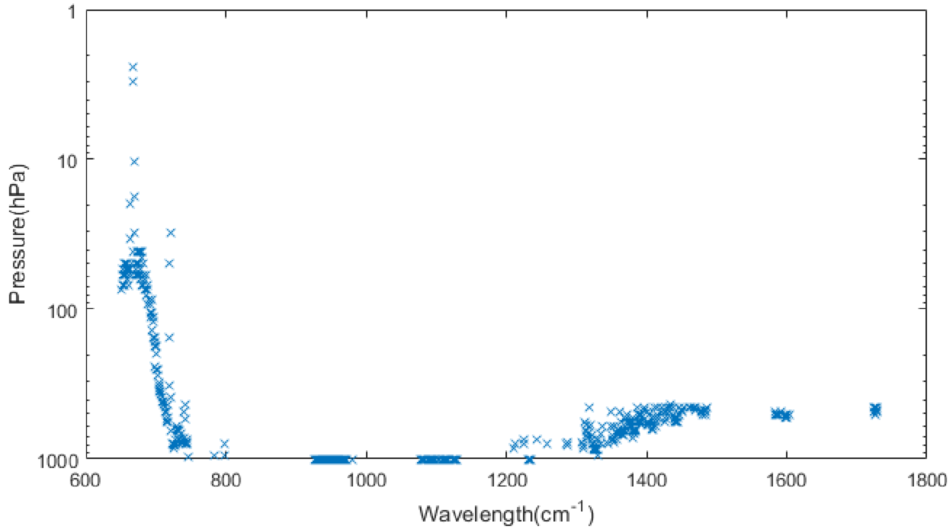
The location error is within one FOV, while the intensity error retrieved from CMWS is larger than that from ATMS.

$$\frac{\partial p}{\partial z} = -\frac{gp}{R_d T_v} = -\frac{gp}{R_d T(1+0.608q)}$$

$$\int_{p_{sfc}}^{p_{top}} \frac{1}{p}\partial \mathrm{p} = \int_0^{z_{p_{top}}} -\frac{g}{R_d T(1+0.608q)}\partial z$$

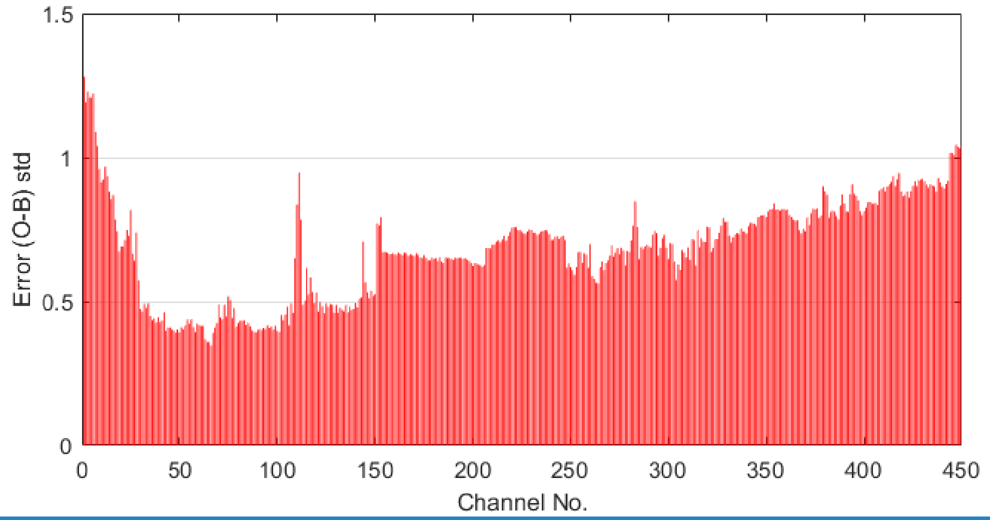
EXP. NAME	LOCATION ERROR	INTENSITY ERROR
SD1dvar_ATMS20	23.89 km	7.51 hPa
SD1dvar_CMWS20	50.59 km	16.57 hPa
SD1dvar_CMWS28	36.89 km	13.77 hPa

Retrieved products from hyperspectral instruments

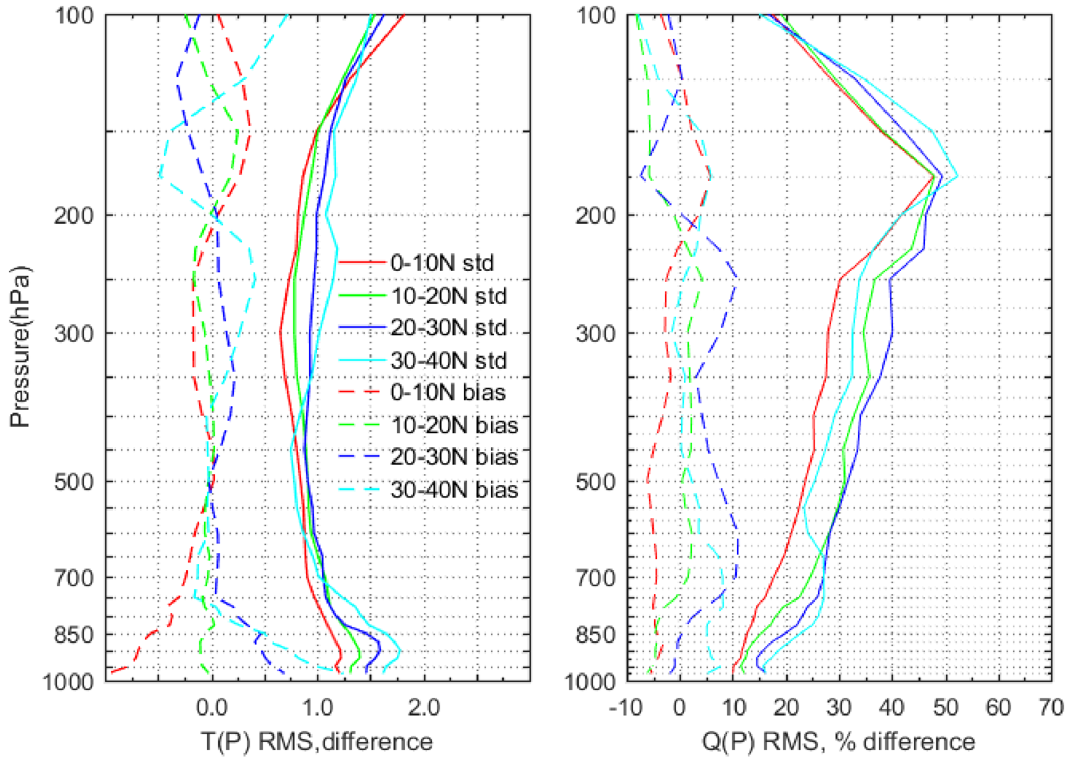


We further tested our 1dvar algorithm for hyperspectral instrument (HIRAS) onboard FY-3D under clear sky condition. We choose 450 channels among all 2275 full resolution channels for retrieval based on information content analysis.

When conducting the 1dvar retrieval based on HIRAS observations, the background profiles used is similar with clear conditions introduced before, and the error covariance is generated based on ERA5 dataset for the chosen 450 channels.



Retrieved products from microwave sounding instruments

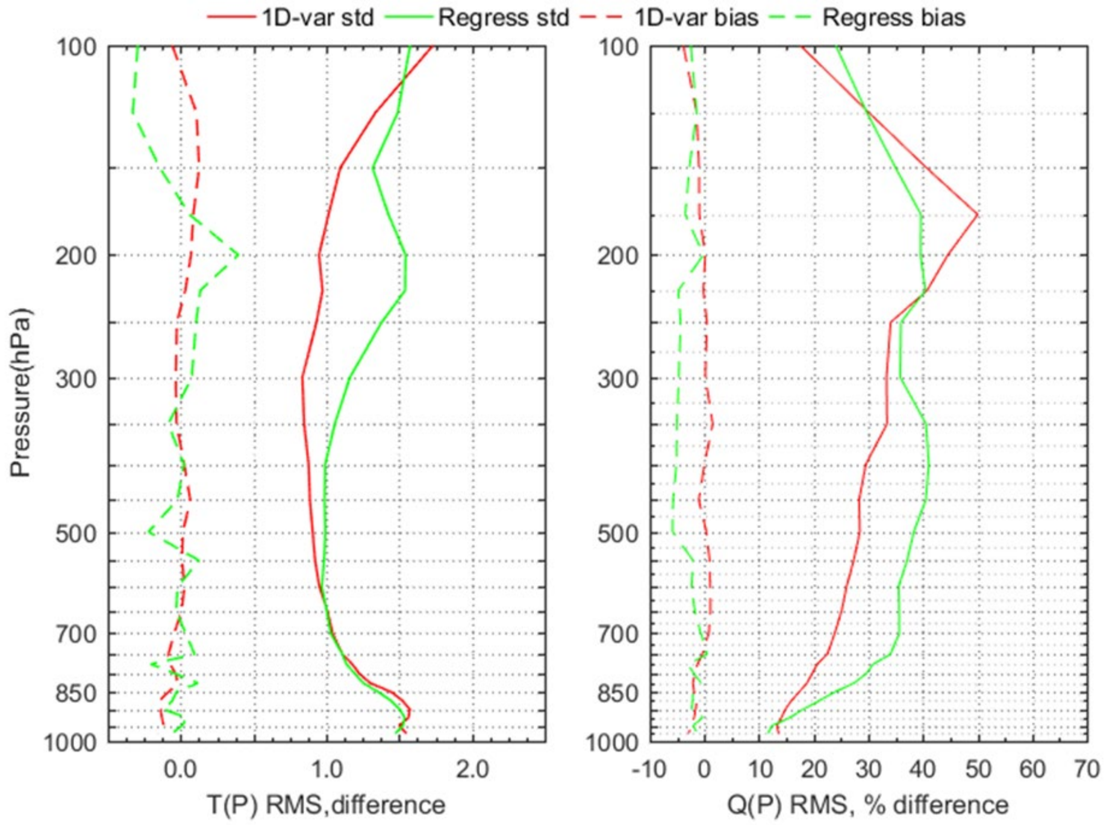


Data between June 2018 to May 2019 are used for retrieval, validation with ERA5 reanalysis.

Compared with ERA5 profiles, the retrieved temperature and humidity profiles perform better in mid-low latitude, especially for tropical regions where temperature and humidity error is under 1 K and 30 % for most vertical levels, respectively.

Collocation threshold: within 8 km & within 15 minutes

Retrieved products from hyperspectral instruments



Data between June 2018 to May 2019 are used for retrieval, validation with ERA5 reanalysis

We further compare our 1dvar results with the stepwise regression retrieval results.

Results indicate that 1dvar retrieved temperature and humidity error is less than regression results on most vertical levels.

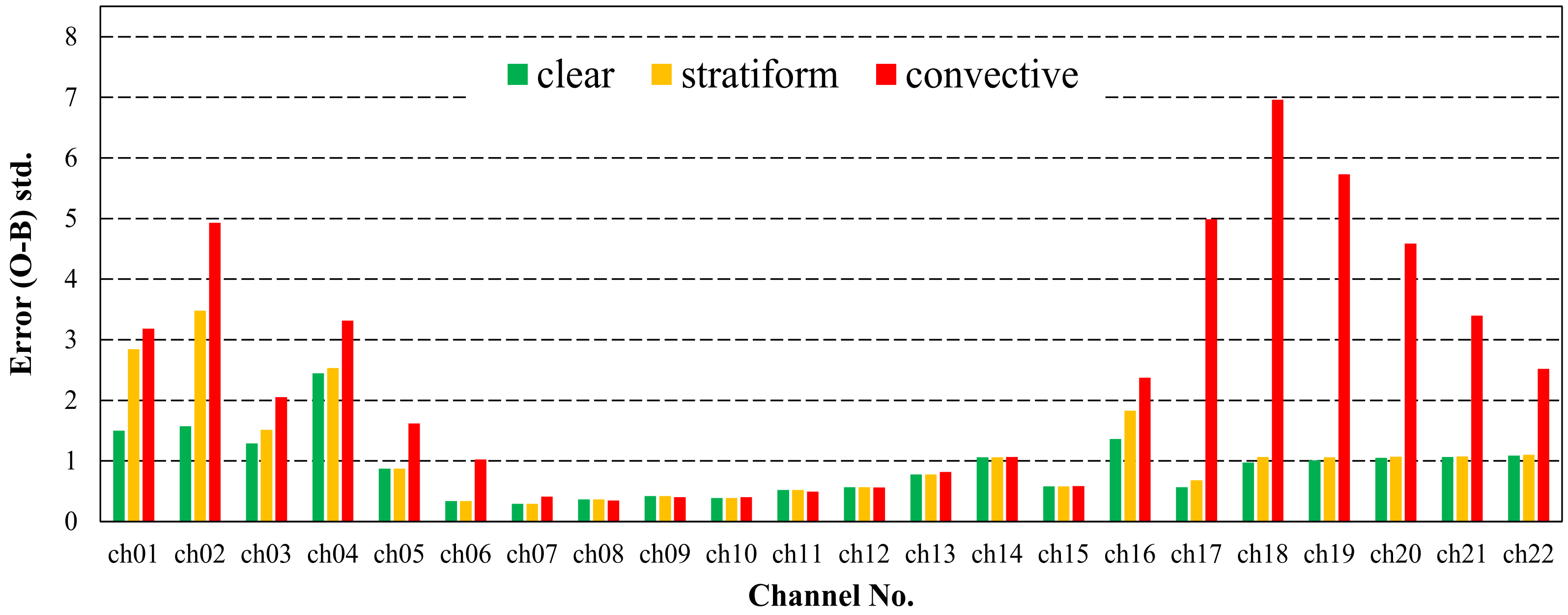
Conclusion

1. A scene-depended 1dvar (SD1dvar) algorithm is tested for microwave sounding instruments and hyperspectral instruments onboard FY-3D. Results show that the SD1dvar algorithm could significantly reduce the scattering effects and retrieve reasonable thermal structures for tropical cyclones.

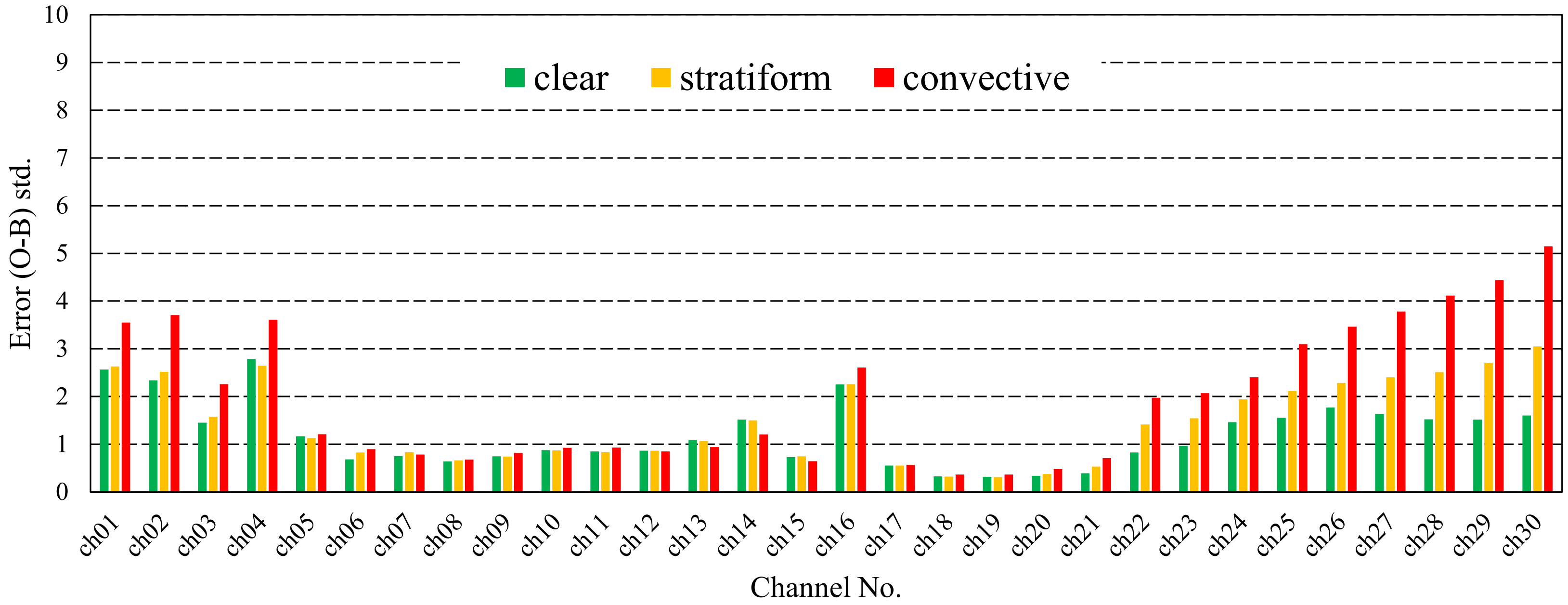
2. The retrieval error is similar between microwave sounding instruments onboard FY-3D and SNPP when using similar channels. And involving 118 GHz channels could further reduce the retrieval error, especially for humidity products.

3. The SD1dvar algorithm could be used to retrieve hyperspectral instruments onboard FY-3D. The retrieved temperature and humidity error is less than that from regression algorithm.

Thank you!



Error covariance for SNPP ATMS

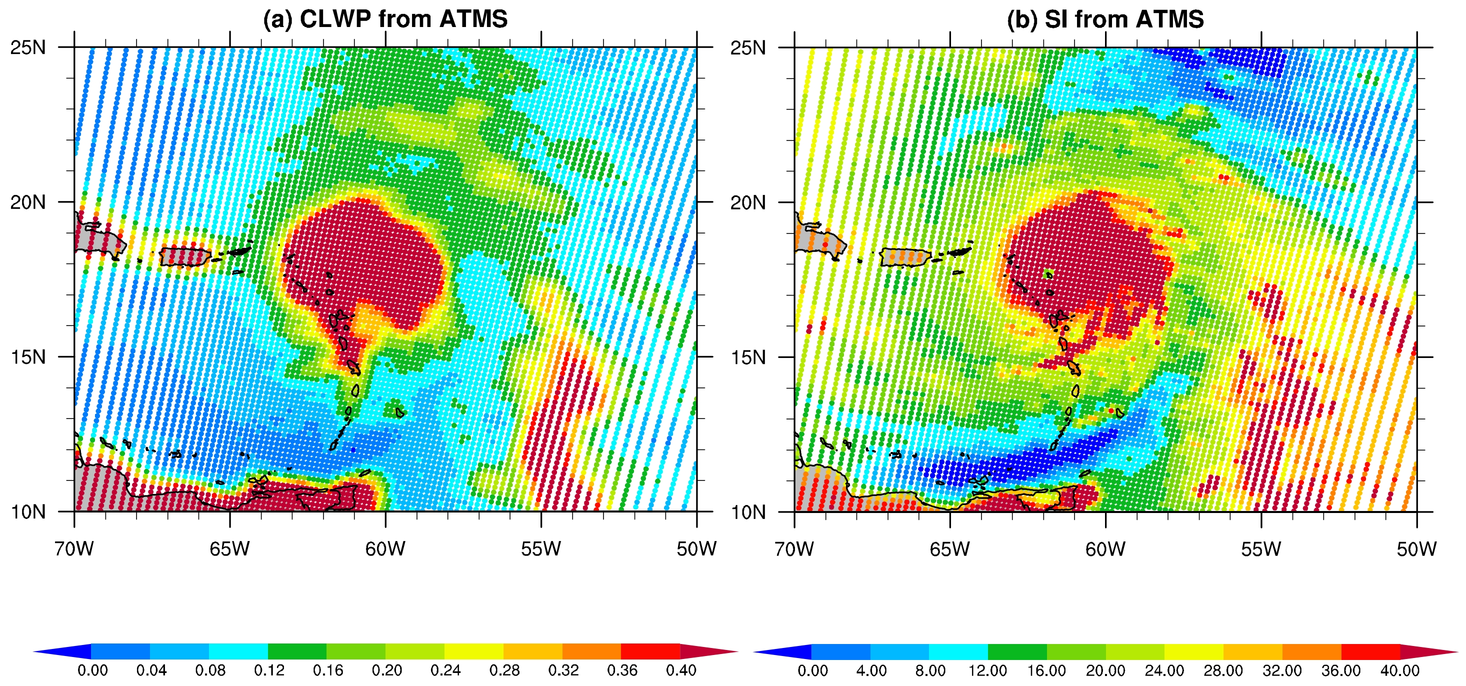


Error covariance for CMWS

ATMS cloud detection

$$CLWP = \cos\theta[\alpha_0 - (\alpha_1 - \alpha_2\cos\theta)\cos\theta + \alpha_3 ln(T_0 - Tb_1) - \alpha_4 ln(T_0 - Tb_2)]$$ Grody et al. (2001)

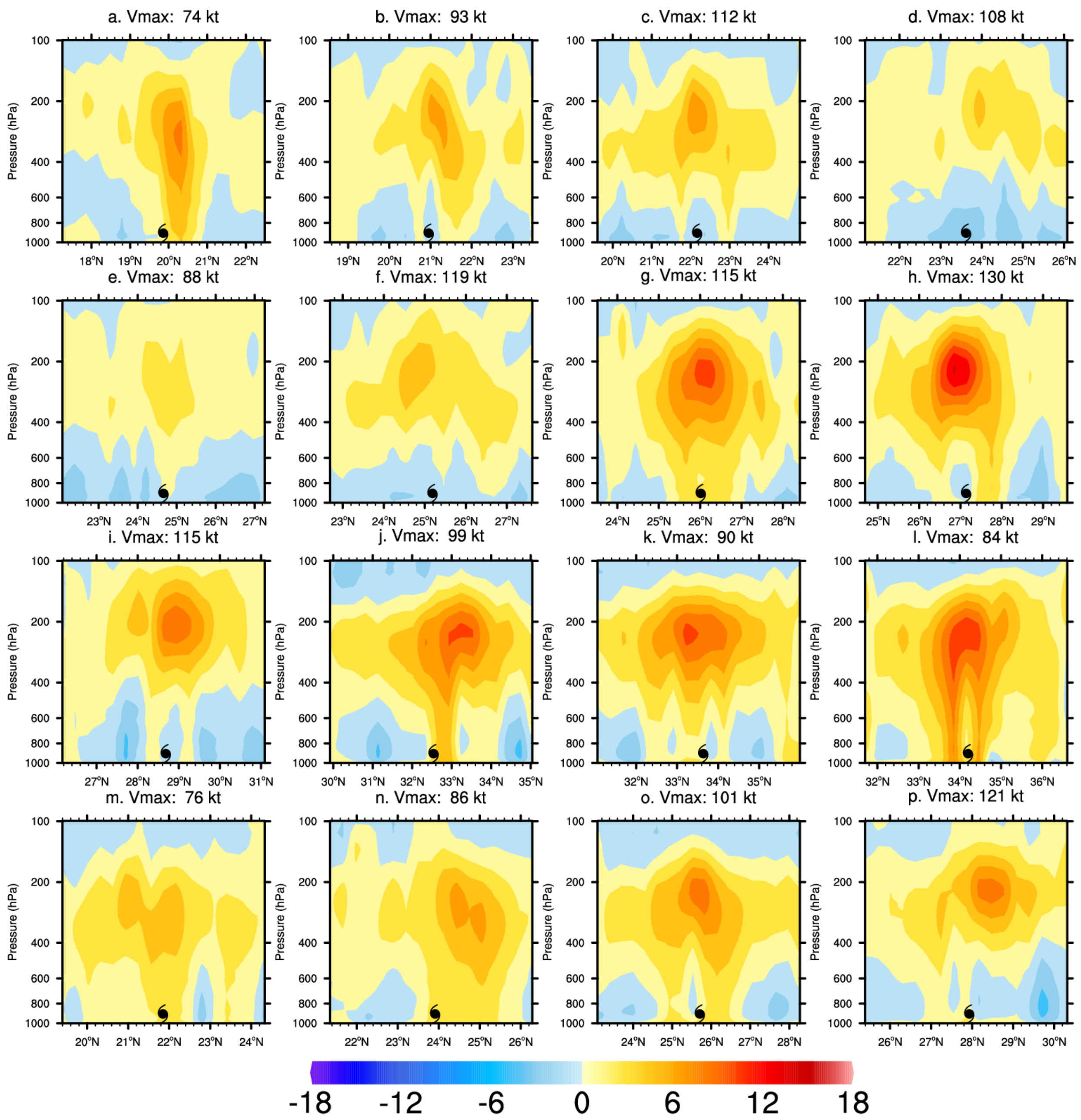
$$SI = Tb_{16} - Tb_{17} - (0.248\theta - 46.94)$$ Bennartz et al. (2002)



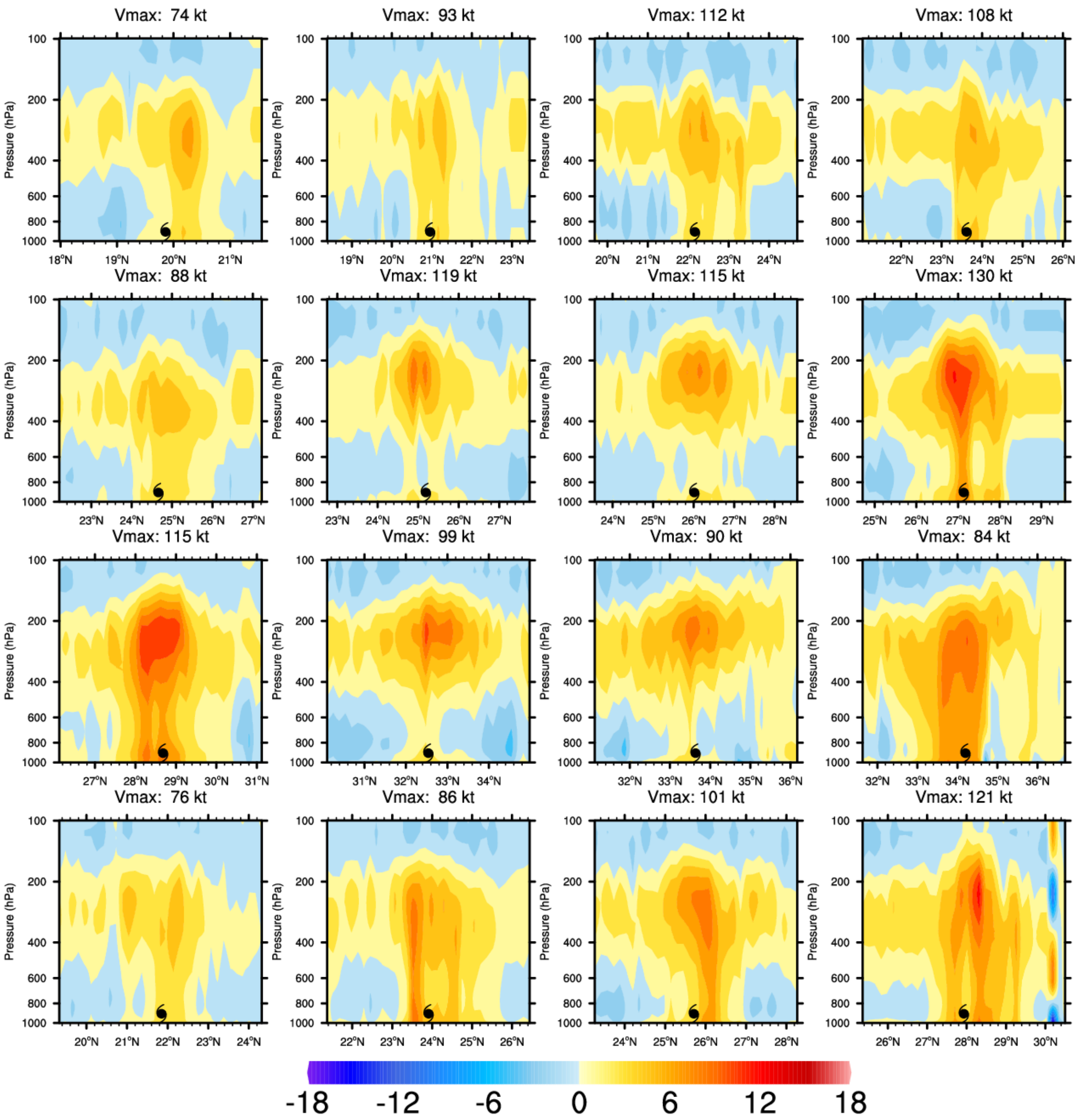
Sep. 6th 2018 05:30 UTC Hurrican Irma CLWP (a) and SI (b) from ATMS

$$\begin{cases} CLWP \le 0.05 & Clear \\ CLWP \ge 1.0 \ or \ SI \ge 20 & Convective \\ 0.05 < CLWP < 1.0 \ and \ SI < 20 & Stratiform \end{cases}$$

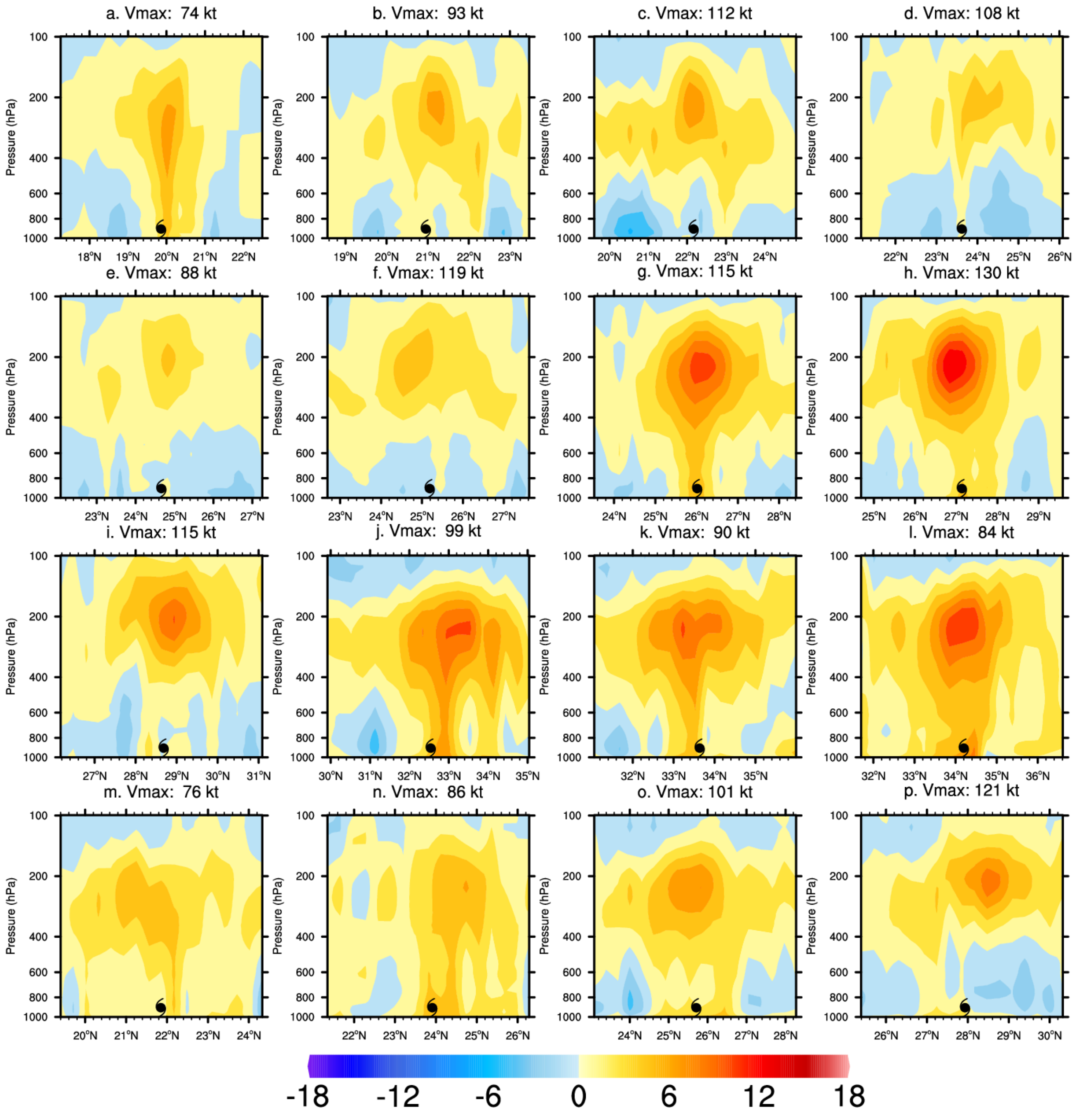
SD1dvar_CMWS20



SD1dvar_ATMS



SD1dvar_CMWS28



SD1dvar_ATMS