GSDART: A Global Scene-Dependent Atmospheric Retrieval Testbed for Passive Microwave Sounding Instruments

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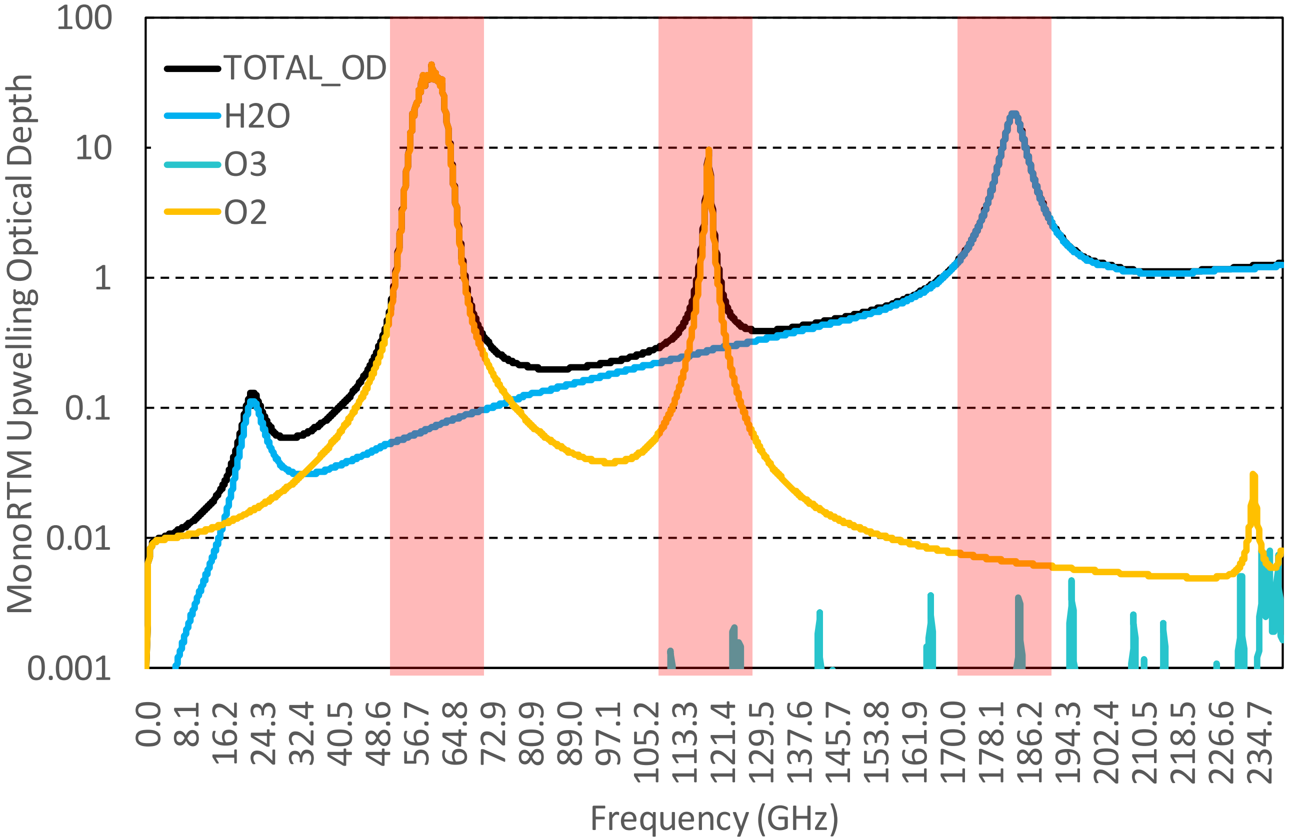
Motivation

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:

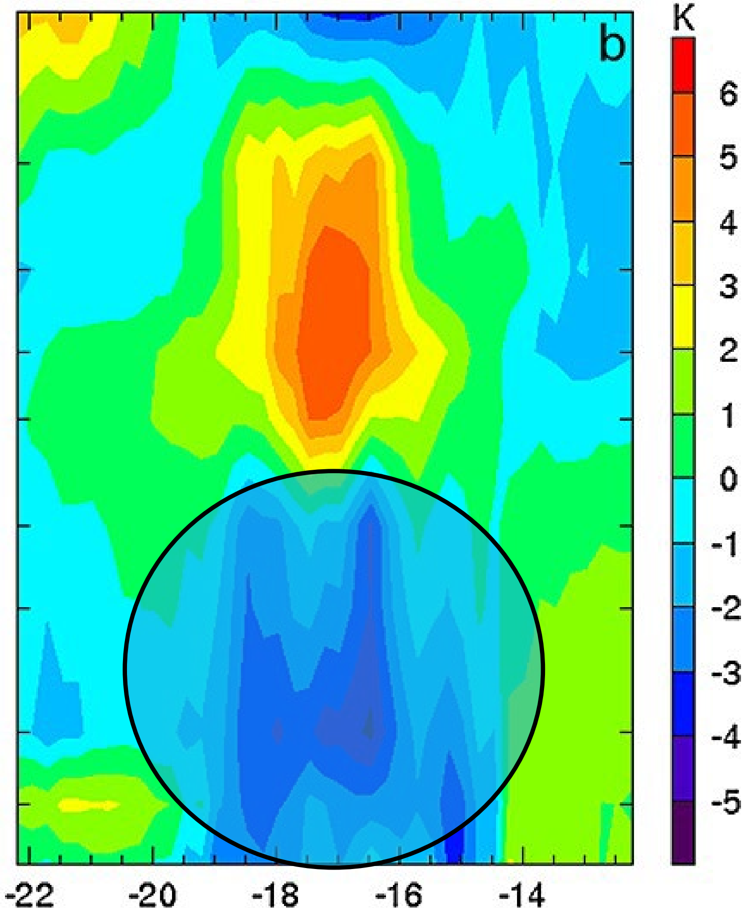
LowO2: Low frequency oxygen absorption band (50-60 GHz)
HighO2: High frequency oxygen absorption band (118 GHz)
WV: Water vapor absorption band (183 GHz)

AMSU-A: LowO2
MHS: WV
SSMIS: LowO2+WV
ATMS: LowO2+WV
FY-3D MW sounding instruments: LowO2+HighO2+WV

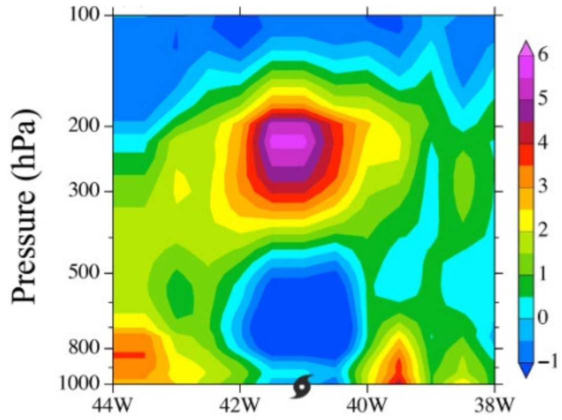
Motivation

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

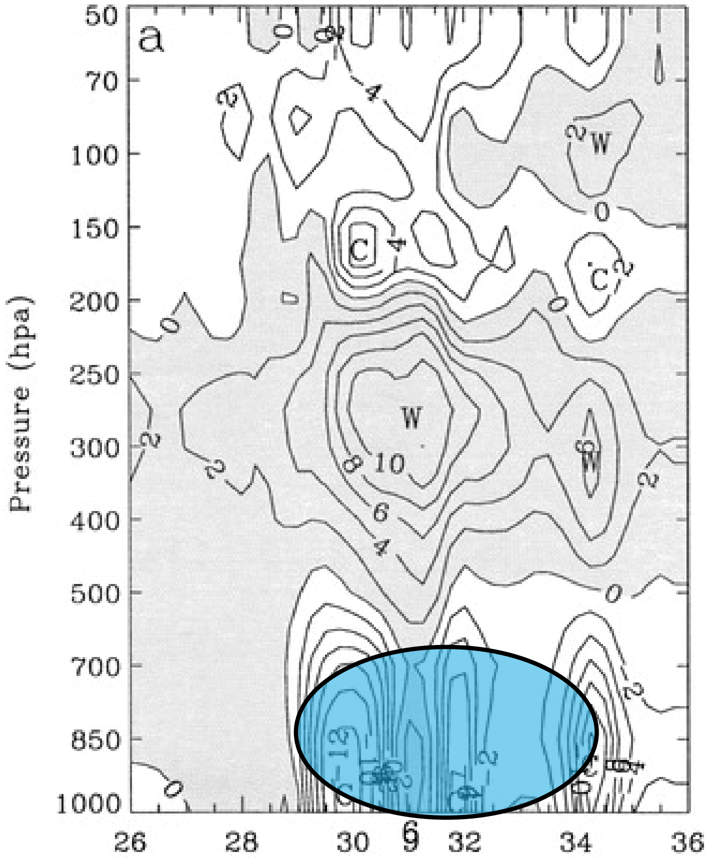
Unexpected cold anomalies exist in the lower layers of hurricanes, which could be attributed to the scattering effects.



Zhu and Weng (2013)



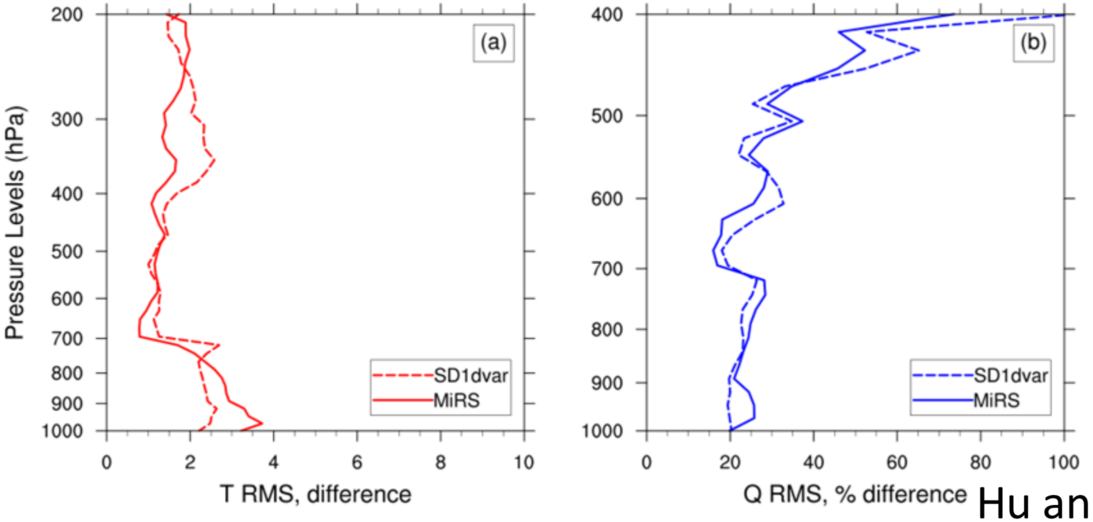
Tian and Zou (2016)



Zhu et al. (2002)

Motivation

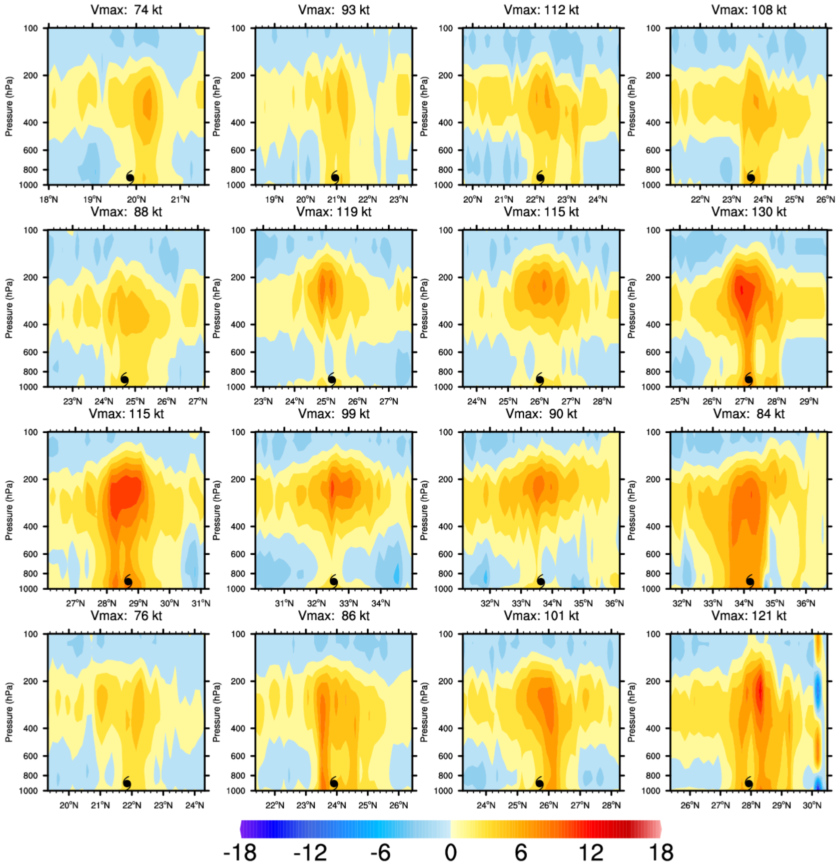
Bases on a cloud-dependent 1DVAR algorithm, a more reasonable TCs' thermal structure could be retrieved.



Hu and Han (2020)

The low-level temperature and humidity retrieval error reduced under hurricane condition, compared with MiRS products.

The purpose of this study is to expand the cloud-dependent algorithm to global usage.



Hu and Han (2020)

Hao Hu and Yang Han, Comparing the Thermal Structures of Tropical Cyclones Derived From Suomi NPP ATMS and FY-3D Microwave Sounders[J]. IEEE Transactions on Geoscience and Remote Sensing, 2020, PP(99):1-11.

Methodology

GSDART: Global Scene-Dependent Atmosphere Retrieval Testbed.

BASIC 1DVAR COST FUNCTION

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

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

$\mathbf{x}$ – 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

$$\Delta X_{n+1}=[BK_n^T(K_nBK_n^T+E)^{-1}][Y_m-Y(X_n)+K_n\Delta X_n]$$

- In GSDART, ARMS is used as forward model.
- The scene-dependent background, background covariance and error matrix are generated.
- Physical constraint vectors are introduced in 1DVAR.

PHYSICALLY CONSTRAINT 1DVAR COST FUNCTION

$$J(X)=J_B+J_O$$
$$=\frac{1}{2}[\Phi(X)-X_0]^T\times B^{-1}\times[\Phi(X)-X_0]+\frac{1}{2}\{Y_m-H[\Phi(X)]\}^T\times E^{-1}\times\{Y_m-H[\Phi(X)]\}$$

X: analysis variable

X_0: background/first guess

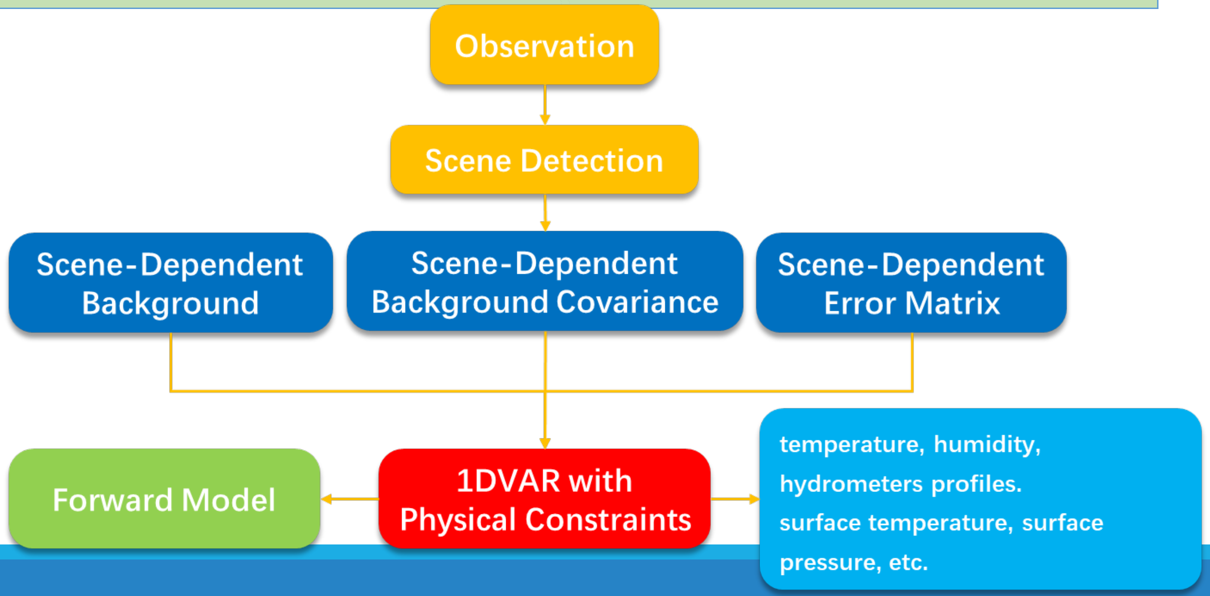
B: background covariance

Y_m: observations

H: forward model

E: forward model error covariance

$\Phi(X)$: Physical constraint vector between the ocean surface and atmospheric variables (e.g. Hydrostatic balance; Gradient wind balance; Ocean emissivity model)



Observation

Scene Detection

Scene-Dependent Background

Scene-Dependent Background Covariance

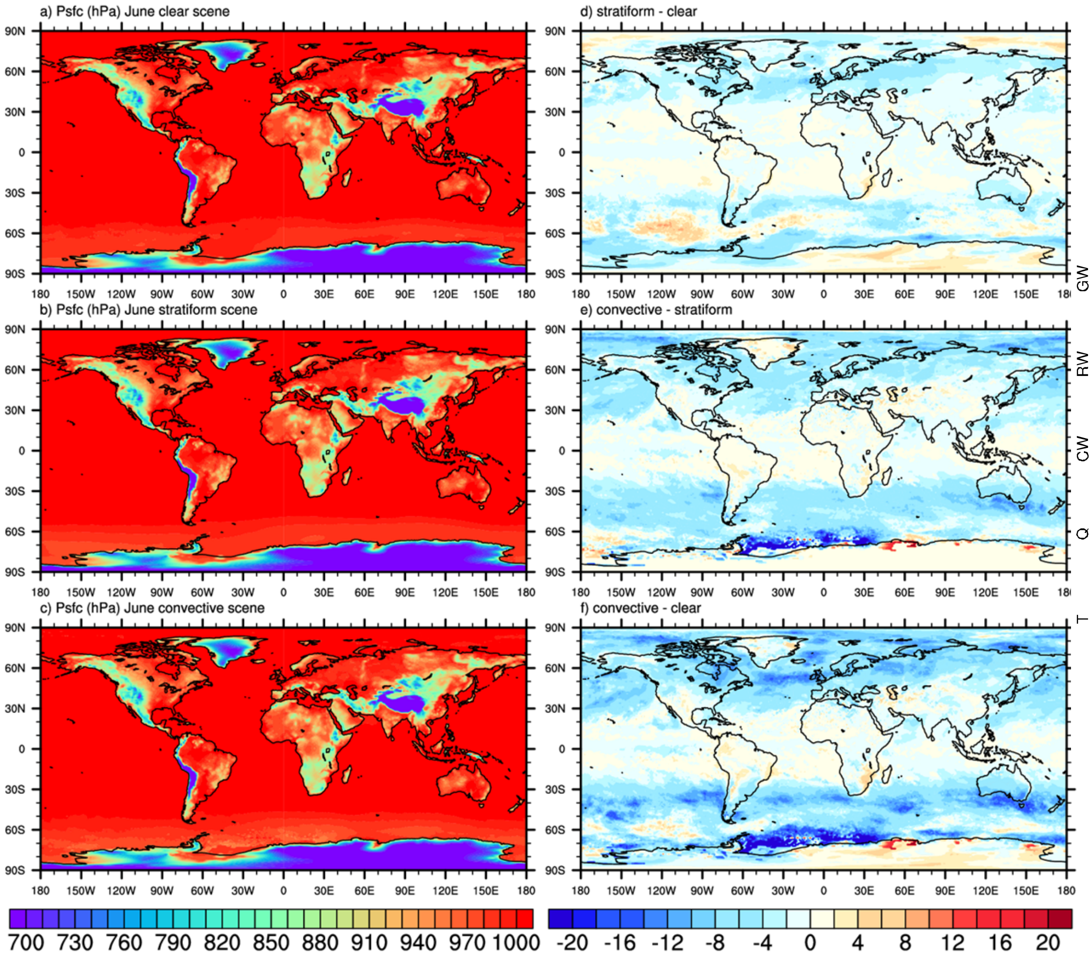
Scene-Dependent Error Matrix

Forward Model

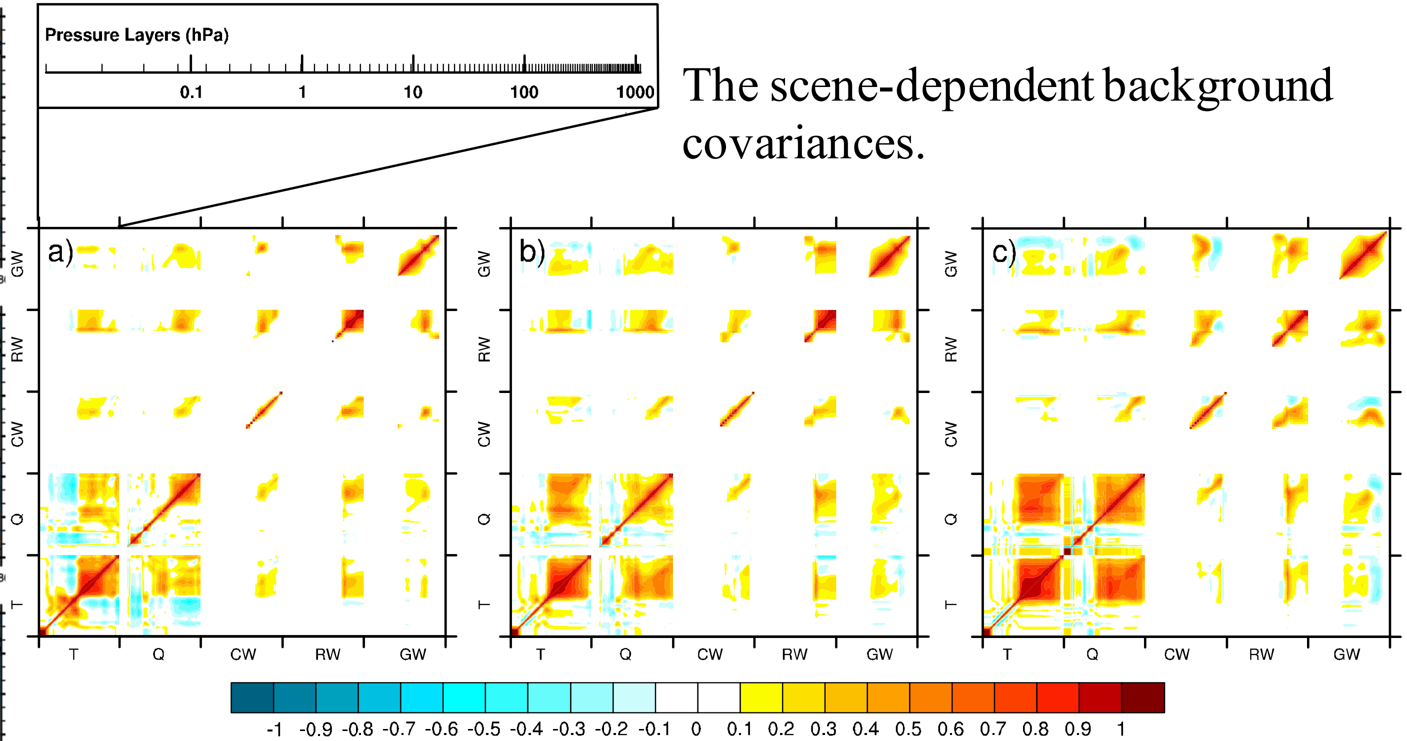
1DVAR with Physical Constraints

temperature, humidity, hydrometers profiles. surface temperature, surface pressure, etc.

Methodology



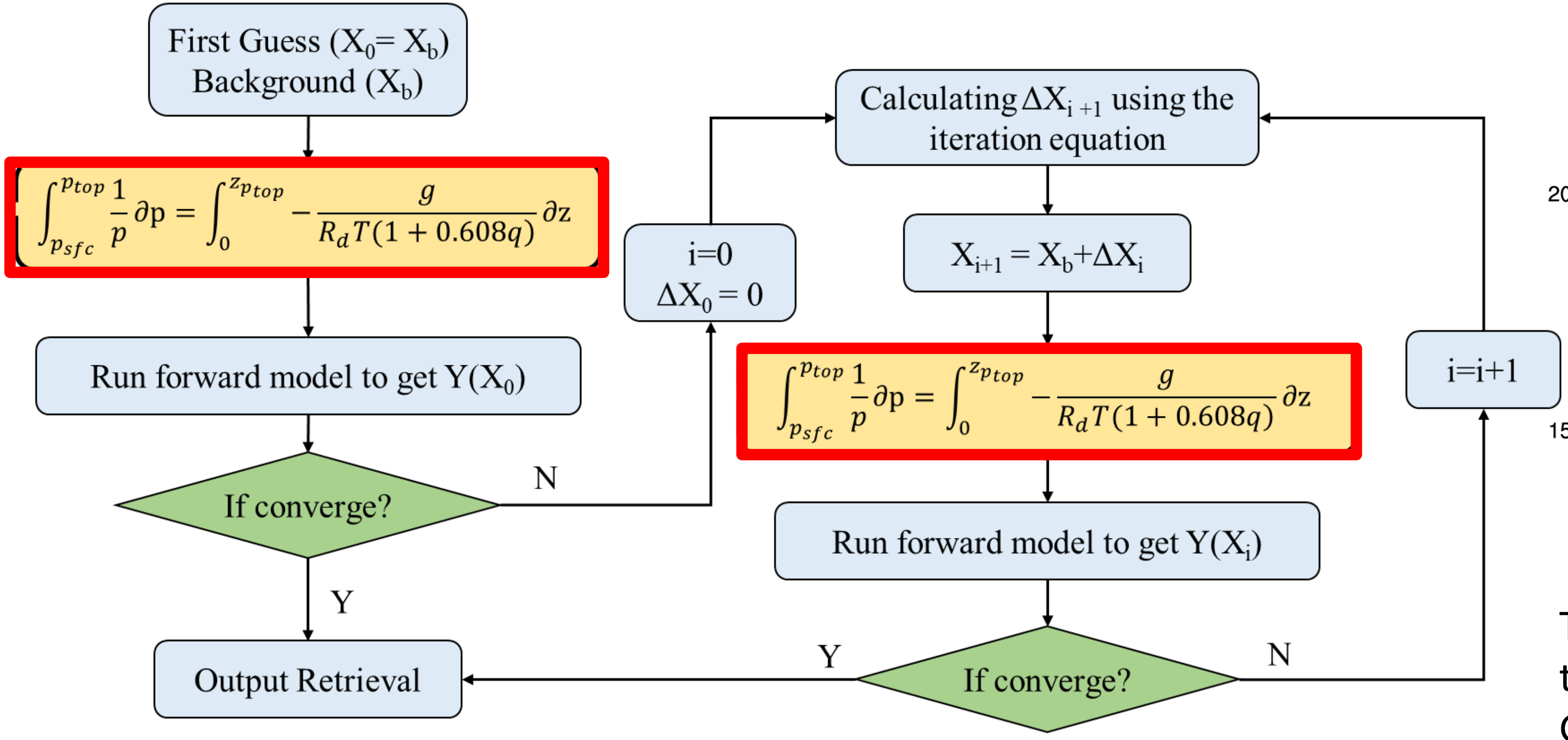
The scene-dependent backgrounds
Taking surface pressure as example.



The scene-dependent background covariances.

The scene-dependent backgrounds are generated based on ERA5 reanalysis dataset.
The scene-dependent background covariances are generated based on mesoscale numerical weather model WRF.

Methodology



First Guess ($X_0 = X_b$)
Background (X_b)

$$\int_{p_{sfc}}^{p_{top}} \frac{1}{p}\,\partial p = \int_{0}^{z_{ptop}} -\frac{g}{R_d T(1+0.608q)}\,\partial z$$

Run forward model to get $Y(X_0)$

If converge?

N

i=0
$\Delta X_0 = 0$

Calculating ΔX_{i+1} using the iteration equation

$X_{i+1} = X_b + \Delta X_i$

$$\int_{p_{sfc}}^{p_{top}} \frac{1}{p}\,\partial p = \int_{0}^{z_{ptop}} -\frac{g}{R_d T(1+0.608q)}\,\partial z$$

Run forward model to get $Y(X_i)$

If converge?

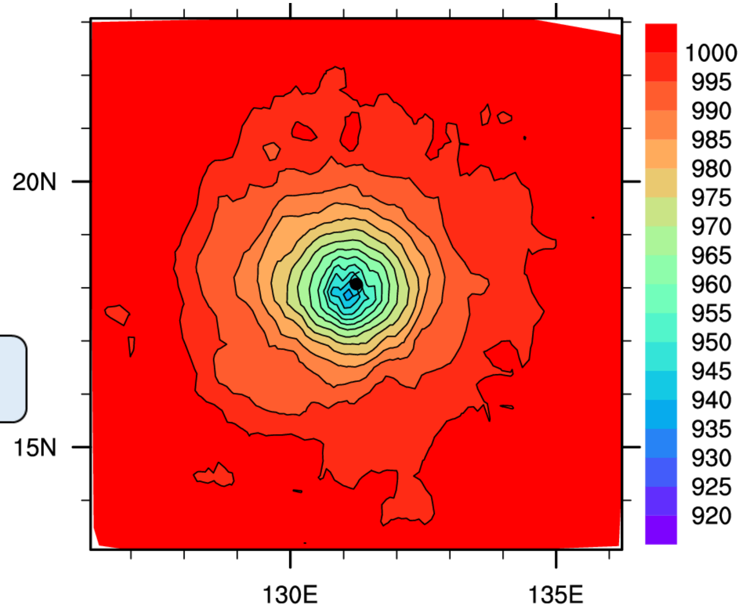
N

i=i+1

Y

Output Retrieval

Y



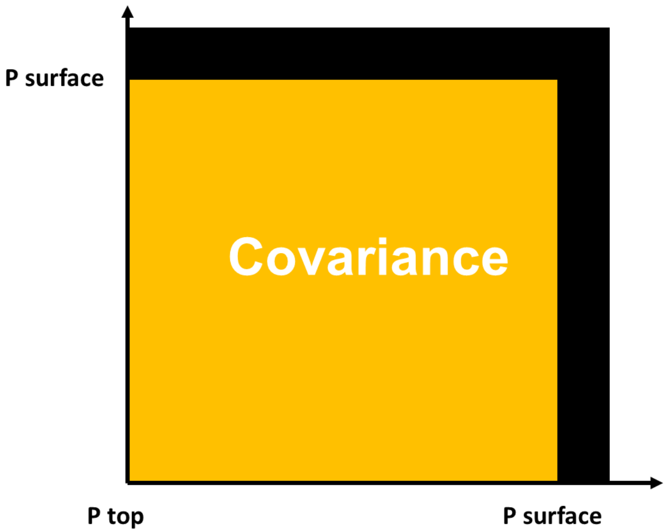
The surface pressure filed of super typhoon Yutu (1827) retrieved from GSDART.

$$J(X) = J_B + J_O = \frac{1}{2}\left[\boxed{\Phi(X)} - X_0\right]^T \times B^{-1} \times \left[\boxed{\Phi(X)} - X_0\right] + \frac{1}{2}\left\{Y_m - H\left[\boxed{\Phi(X)}\right]\right\}^T \times E^{-1} \times \left\{Y_m - H\left[\boxed{\Phi(X)}\right]\right\}$$

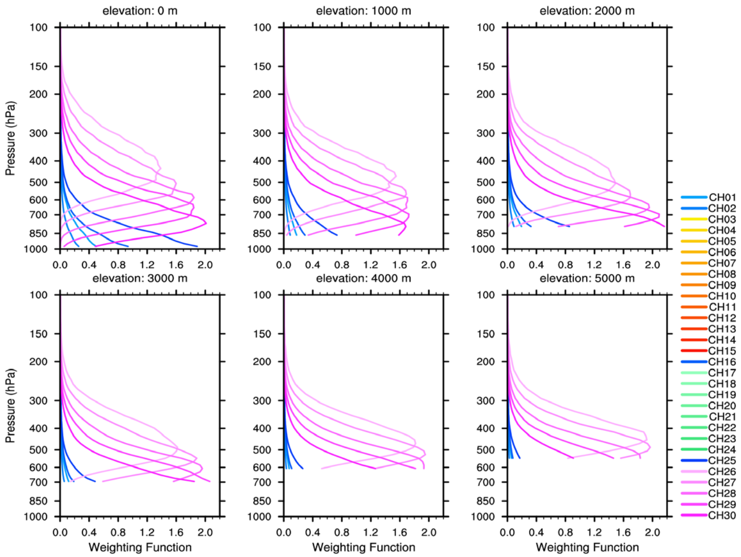
Example of physical constraint in 1DVAR: coupling hydrostatic balance equation in 1DVAR iteration.

Methodology

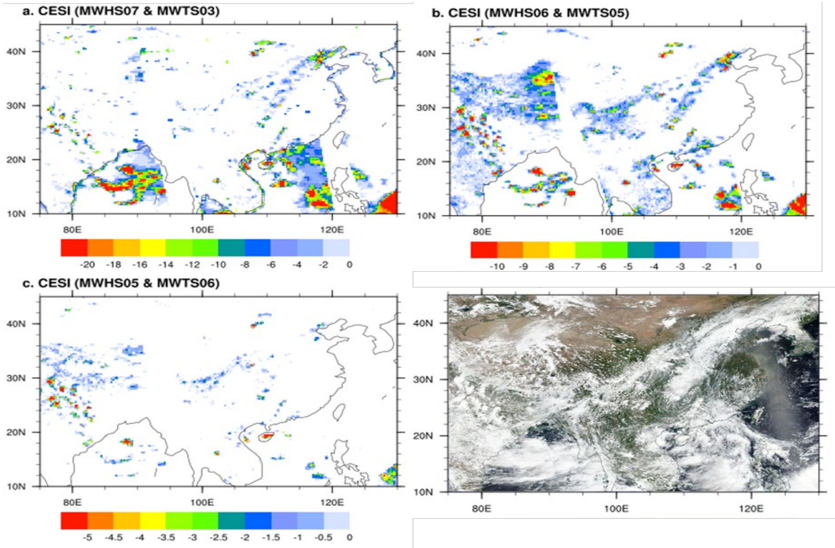
Covariance shrink scheme



Channel selection scheme

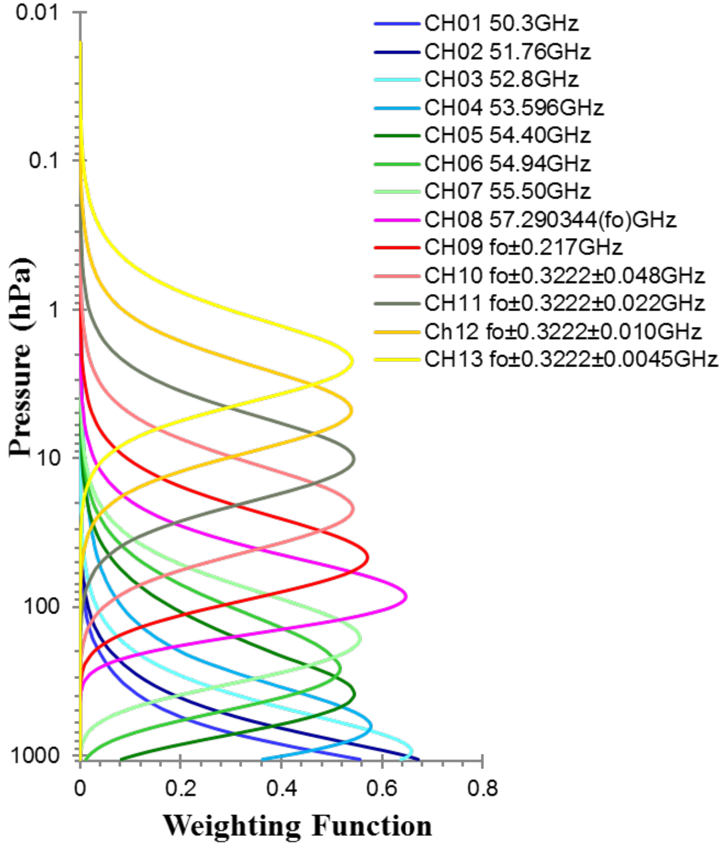


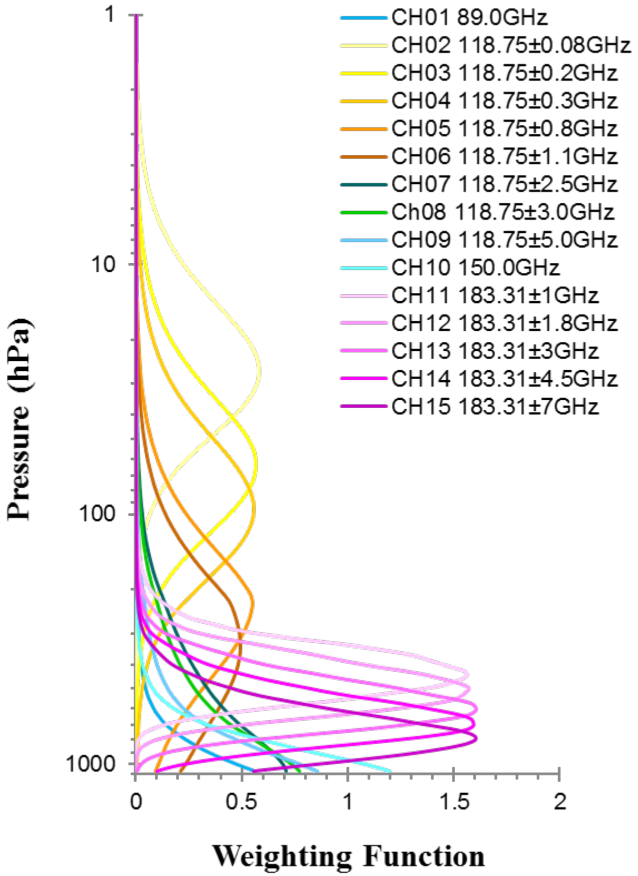
Cloud detection scheme



For land region, we developed the elevation-dependent covariance shrink scheme and channel selection scheme, and modified the cloud detection scheme based on elevation.

Results

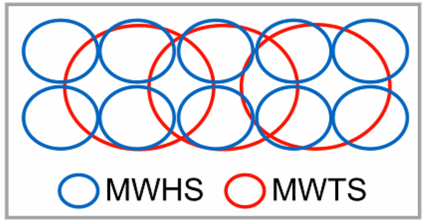

MWTS


MWHS

All MWTS channels are located at the low frequency oxygen absorption band at 50-60 GHz.

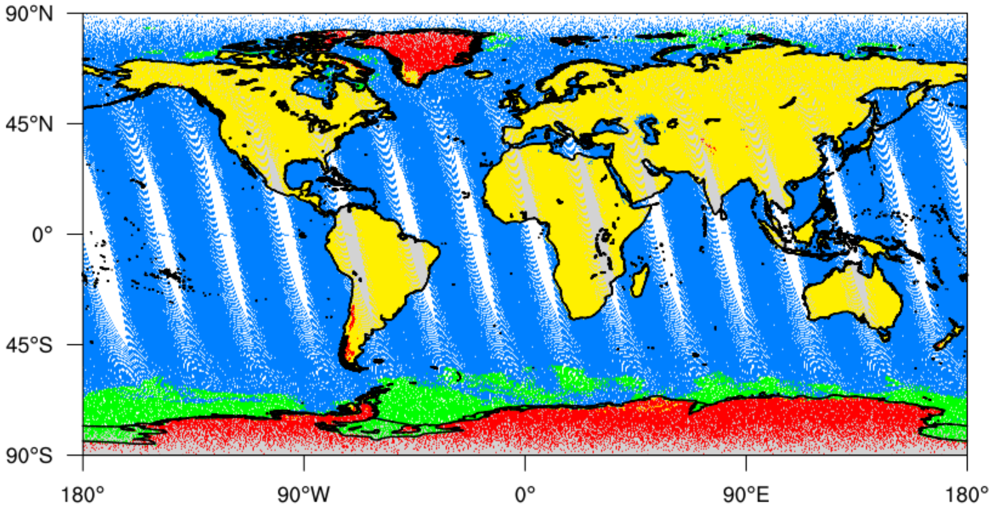
MWHS has 8 channels located at the high frequency oxygen absorption band near 118 GHz, 5 channels located at the water vapor absorption band near 183 GHz, and 2 window channels at 89 and 150 GHz.

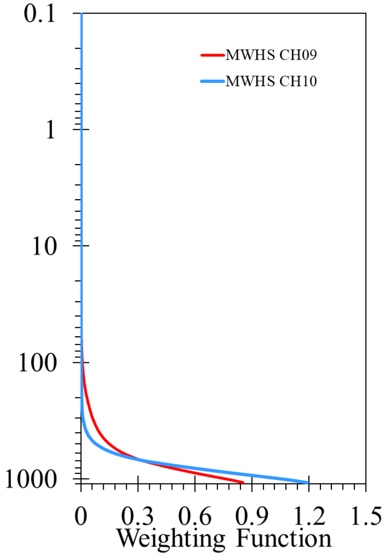
Results



Fusion of MWTS and MWHS observation data.

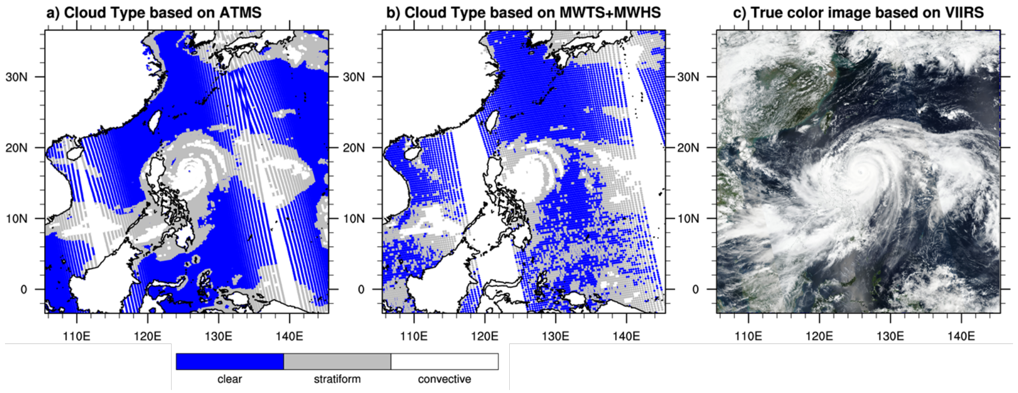
Surface type detection based on MWTS and MWHS

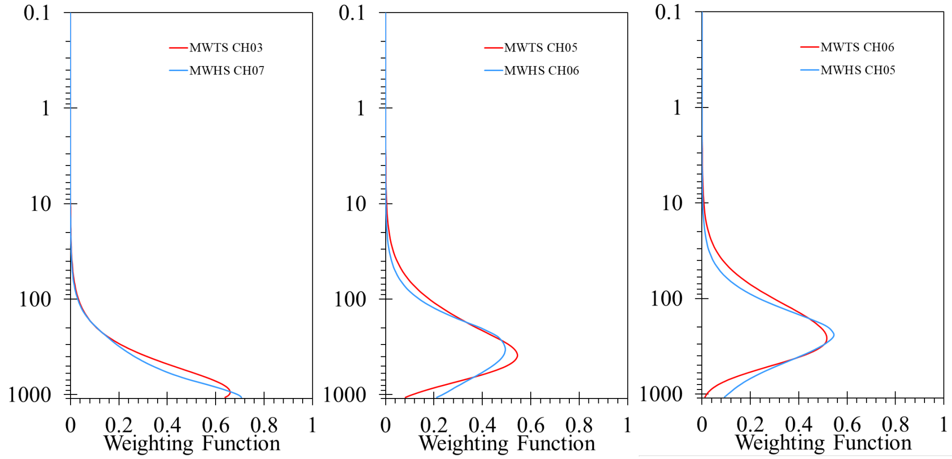




MWHS CH09 (118.75±5 GHz QH)　MWHS CH10 (150 GHz QV)

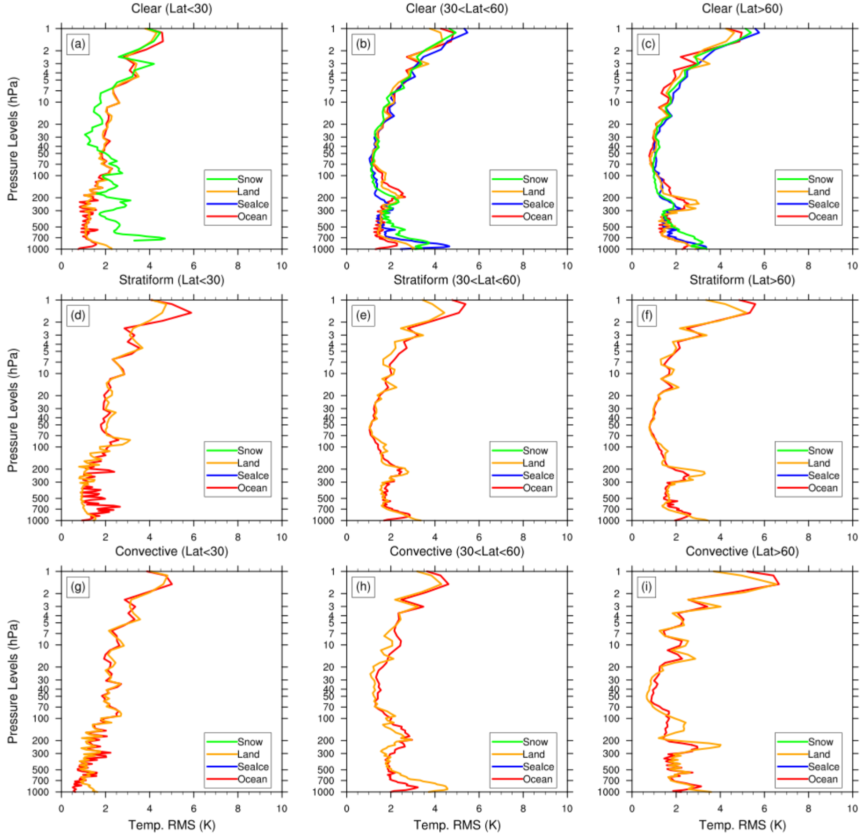
Cloud detection based on MWTS and MWHS (dual oxygen bands method)



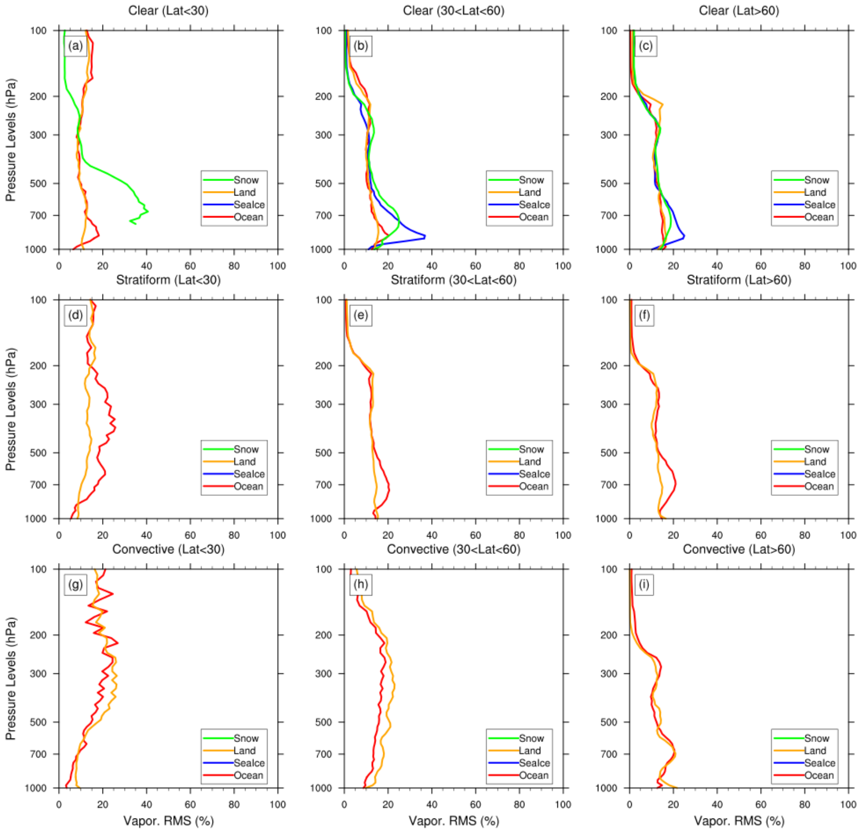


Results

Temperature error



Humidity error

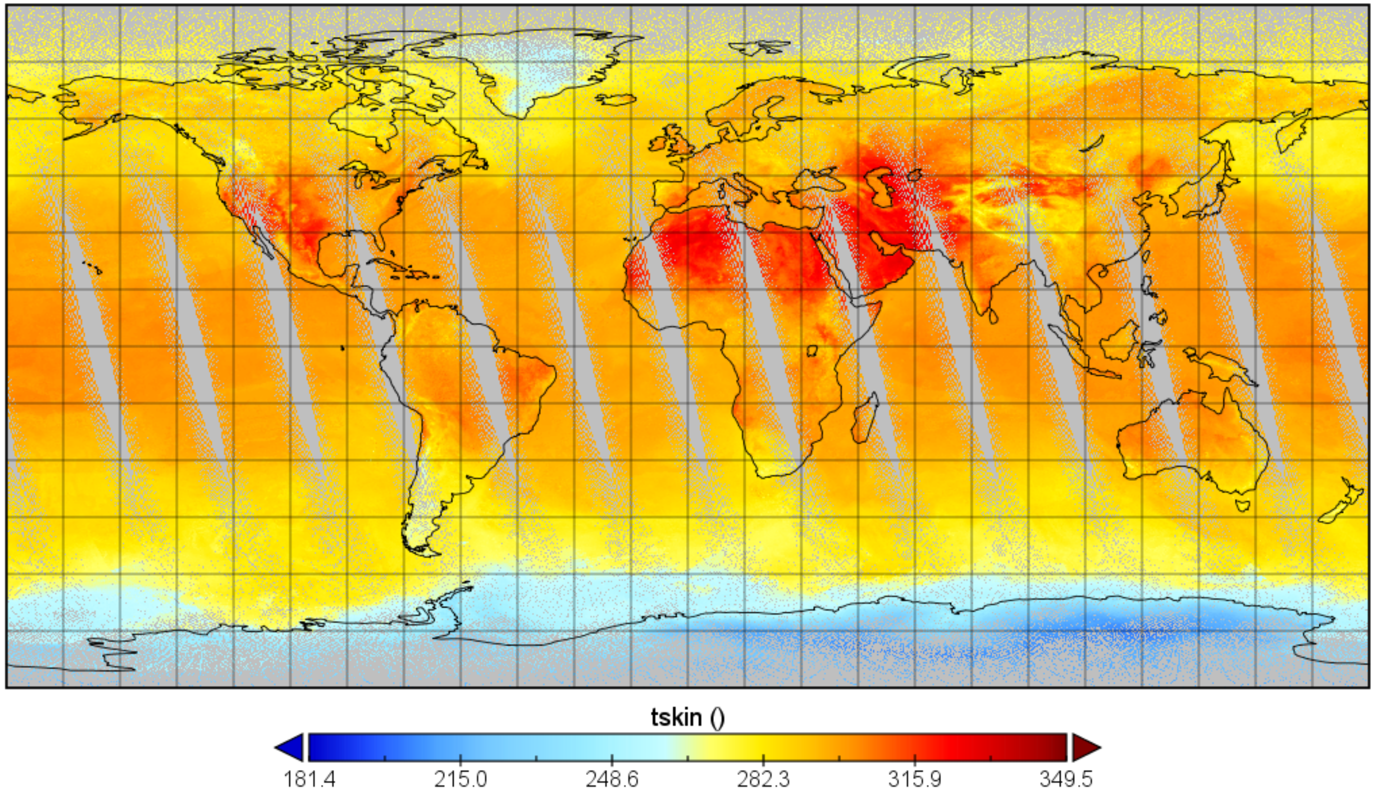


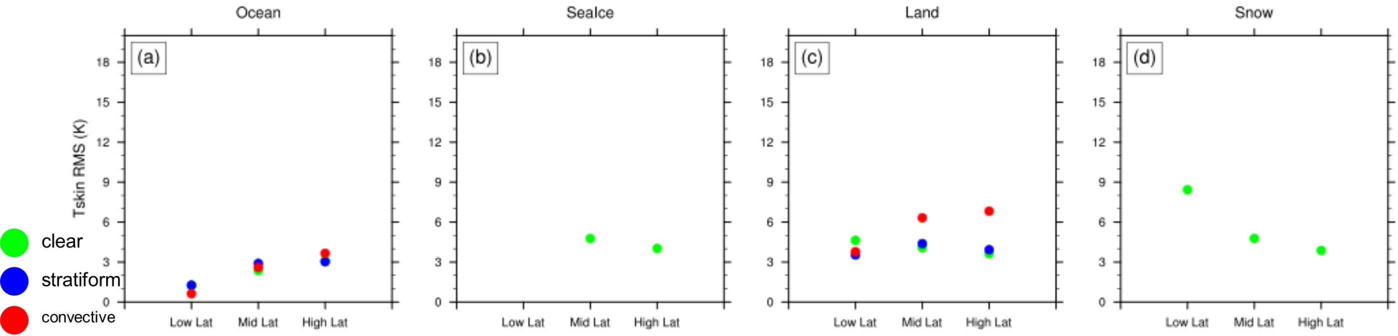
The RMSE of the retrieved temperature profile is maintained within 2 K in low latitude areas (latitude less than 30°) for all weather conditions over land and ocean surface.

The RMSE of water vapor profile is under 20% for all latitudes and weather conditions over land and ocean surface.

We retrieve MWTS+MWHS one day per month in 2018 using GSDART, and validated the results with ERA5 reanalysis dataset.

Results



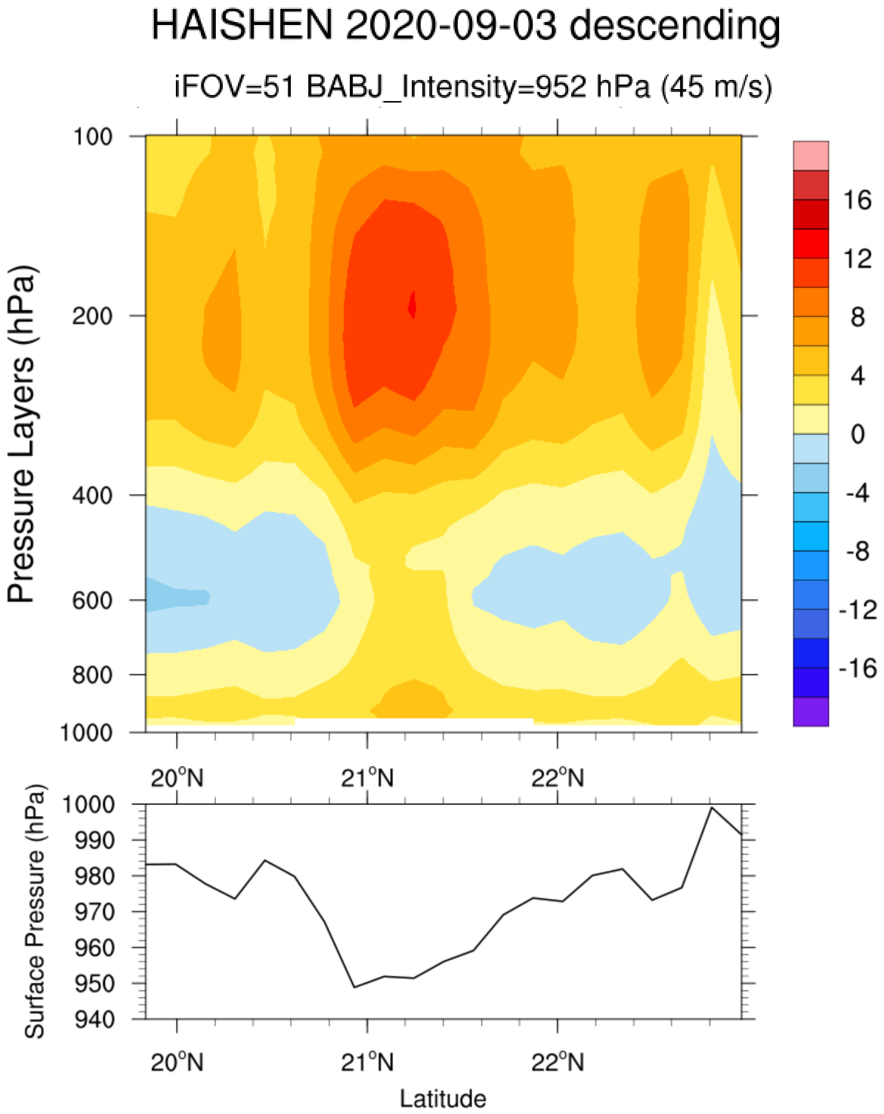


Comparing with ERA5 dataset, the RMSE of GSDART retrieved skin temperature is lower than 1.5 K for all weather conditions over tropical ocean, and increasing to around 3 K over high latitude ocean.

Compared with the ocean type, other underlying surface conditions have larger skin temperature retrieve errors.

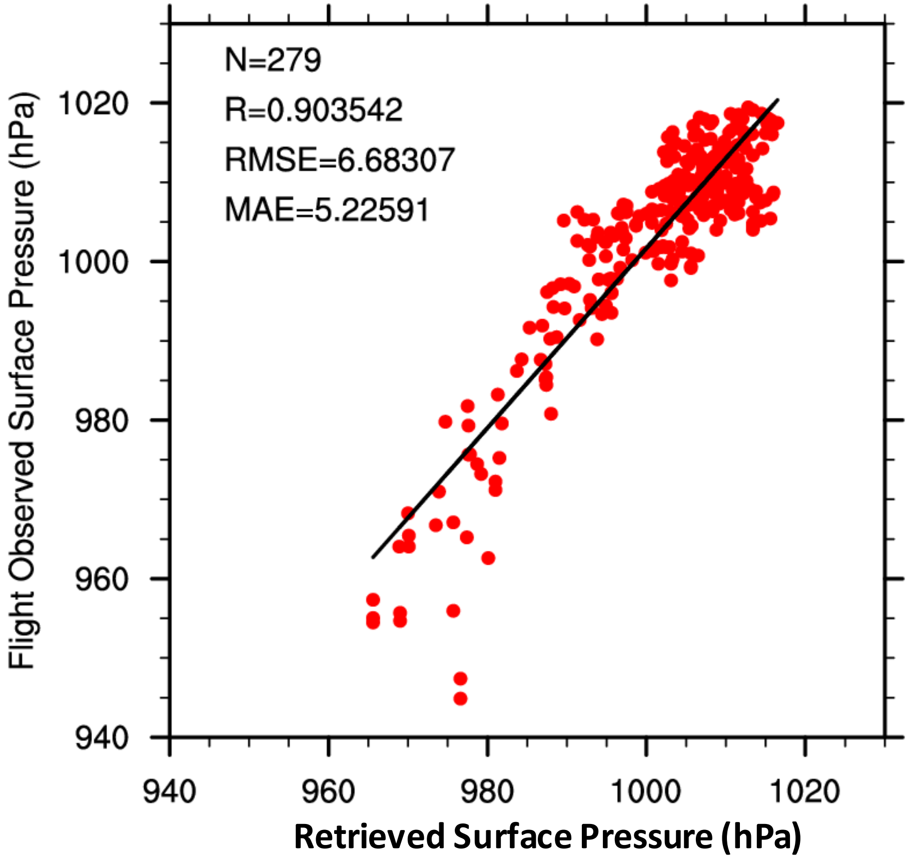
We retrieve MWTS+MWHS one day per month in 2018 using GSDART, and validated the results with ERA5 reanalysis dataset.

Results



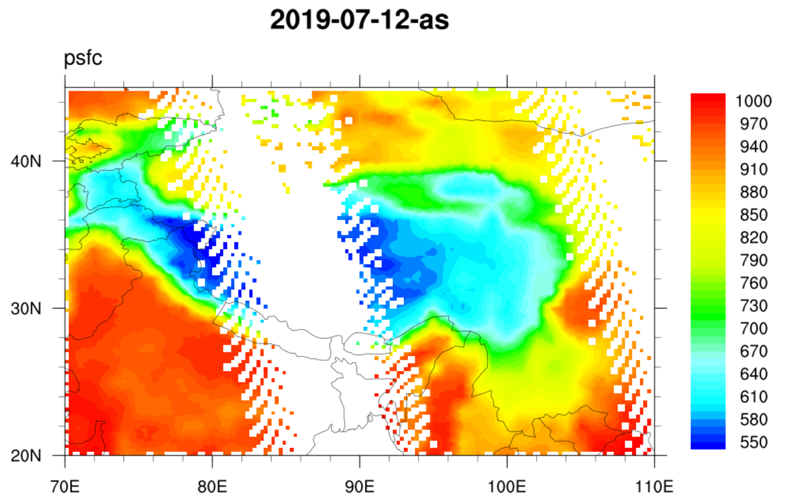
HAISHEN 2020-09-03 descending

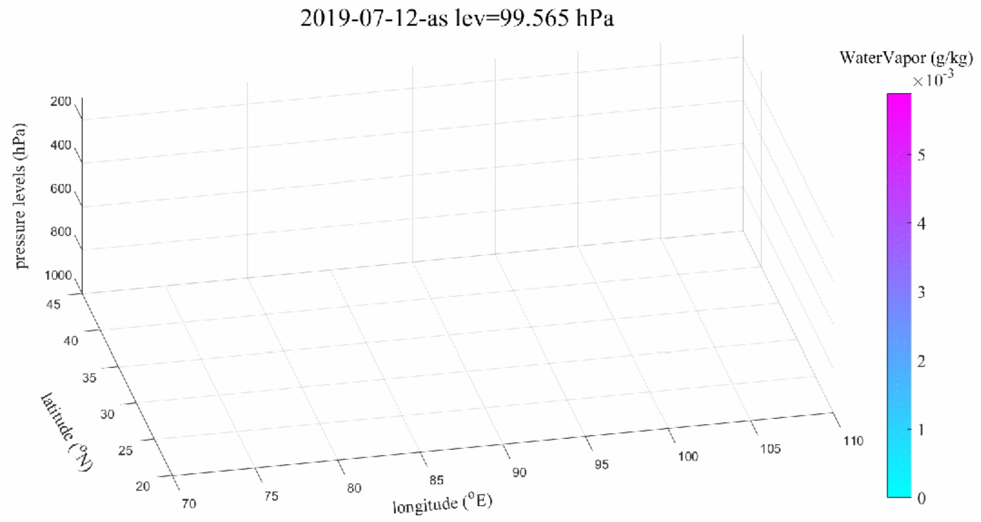
iFOV=51 BABJ_Intensity=952 hPa (45 m/s)

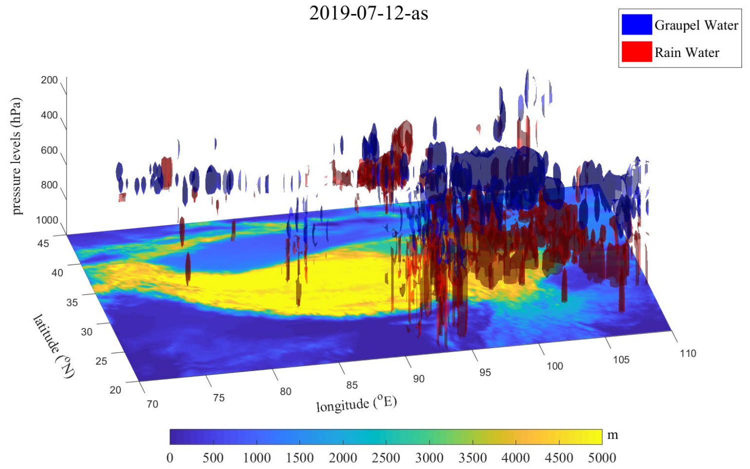


Comparing with flight observed Psfc under hurricane condition between 2018 and 2019, the MAE and RMSE of GSDART retrieved Psfc is 5.23 and 6.68 hPa, respectively. The correlation coefficient could reach 0.90.

Results


2019-07-12-as


2019-07-12-as lev=99.565 hPa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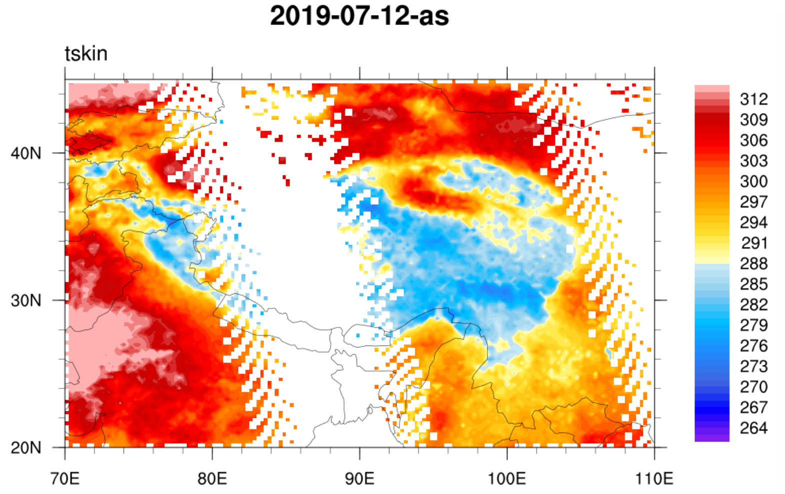
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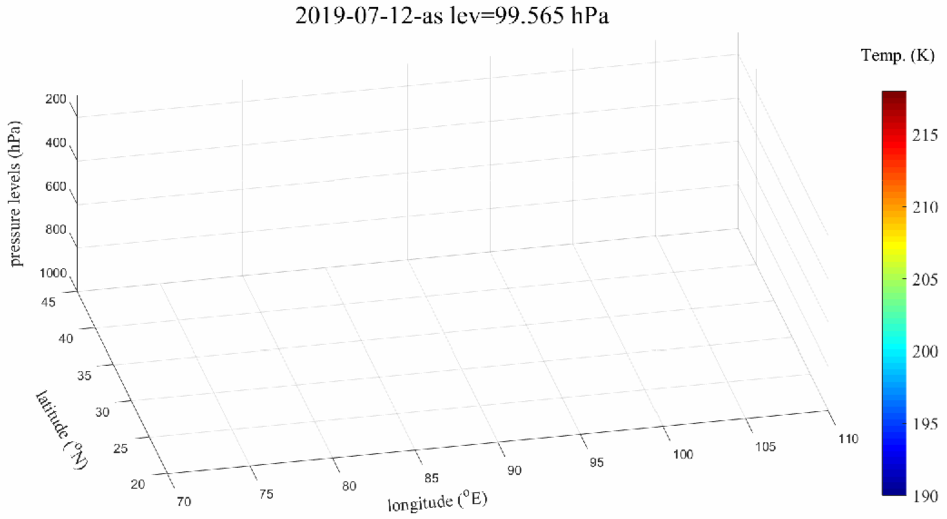
2019-07-12-as lev=99.565 hPa

GSDART is capable of retrieving 3D thermal structures, as well as some surface parameters, over plateau region. The assessment work is still undergoing for these results.

Conclusion

In this study, we introduced a Global Scene-Dependent Atmospheric Retrieval Testbed (GSDART), which could retrieve the FY-3D microwave sounding instruments to obtain the all-sky three-dimensional thermal structure of the global atmosphere.

Results indicate that GSDART could retrieve temperature and humidity profiles with RMSE lower than 2 K and 20%, respectively. For surface parameters, the retrieved skin temperature and surface pressure could be lower than 1.5 K and 6.68 hPa, respectively, for all weather conditions over ocean.

Future works will focus on validating the retrieved products over plateau regions, and retrieving more parameters from instruments onboard different platforms to increase the global coverage and shorten the revisit time.

Thank you!

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