Typhoon’s Thermal and Hydrometeor Profiles Derived from Fengyun-3D Microwave Instruments

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Outline

- Past observations on tropical cyclones
- Issues in microwave sounding of tropical cyclones
- Scene-dependent 1dvar (SD1dvar) retrieval algorithm
- Retrieved products from microwave sounding instruments
- Summary and conclusions
Tropical cyclones (TCs) cause tremendous death and damages every year on earth.

The warm core structure is the most distinctive characteristics of TCs, and has been proved to be related to its intensity and structure.

Hawkins and Imbembo (1975)
Issues in microwave sounding of tropical cyclones

With the ability of penetrating clouds and precipitations, the satellite microwave sounding instruments could be an important way to identify vertical structures of severe weather systems.
Unrealistic cold pool in low troposphere due to clouds and precipitation from statistical retrievals

Using statistical regression algorithms, previous retrieval studies could obtain reasonable warm core structures, but an unexpected cold anomaly in low-level thermal structure could be spotted in their results, especially for those cases with strong intensity.

Zhu and Weng (2013)

Kidder et al. (2000)

Tian and Zou (2016)

Lin and Weng (2018)
Unrealistic cold pool in low troposphere due to clouds and precipitation from 1dvar retrievals

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.

Han and Weng (2018)

The key issue of retrieving TC’s thermal structure is how to deal with the scattering effects in the algorithm.
Scene-dependent 1dvar (SD1dvar) retrieval algorithm

\[ J(x) = \frac{1}{2} (x - x_b) B^{-1} (x - x_b) + \frac{1}{2} (H(x) - y_{obs})^T (O + F)^{-1} (H(x) - y_{obs}) \]

\[ J(x_a) = \min_x J(x) \quad \text{x near } x_b \]

- **x**: analysis variable
- **y_{obs}**: observations
- **x_a**: final analysis
- **O**: observation error covariance
- **x_b**: background
- **H**: observation operator
- **B**: background error covariance
- **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 cloud.

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

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 was not in ATMS. The combined MWTS and MWHS have much better profiling capability, comparing to ATMS.
The combined microwave sounder (CMWS) product, has 30 channels containing all 28 FY-3D microwave sounding channels and 2 simulated window channels similar with ATMS channel 1 & 2, at frequency of 23.8 and 31.4 GHz, respectively.
Retrieved products from microwave sounding instruments

A bias correction process is conducted based on CRTM to reduce the system bias along with scan angle of CMWS.

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

(Weng et al. 2003)
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

Comparing to MiRS products, the warm core structure from our retrieval algorithm is more reasonable. Weak storms to have clear warm core structures and strong storms.
Retrieved products from microwave sounding instruments

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.

Collocation threshold: within 33 km & within 30 minutes
Number of collocated dropsondes: 190
<table>
<thead>
<tr>
<th>EXP. NAME</th>
<th>DESCRIPTION</th>
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</thead>
<tbody>
<tr>
<td>SD1dvar_ATMS20</td>
<td>Use all ATMS channels except chan. 1 &amp; 2</td>
</tr>
<tr>
<td>SD1dvar_CMWS20</td>
<td>Use CMWS channels with frequency similar to SD1dvar_ATMS20</td>
</tr>
<tr>
<td>SD1dvar_CMWS28</td>
<td>Use all CMWS channels except chan. 1 &amp; 2</td>
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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.

Collocation threshold: within 33 km & within 30 minutes
Number of collocated dropsondes for ATMS: 190
Number of collocated dropsondes for CMWS: 96
We also test our algorithm for 2018 typhoon Maria and Mangkhut in the Western Pacific.

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.
\[ \frac{\partial p}{\partial z} = -\frac{gp}{R_dT_v} = -\frac{gp}{R_dT(1 + 0.608q)} \]

\[ \int_{p_{sf c}}^{p_{top}} \frac{1}{p} \partial p = \int_{0}^{z_{p_{top}}} -\frac{g}{R_dT(1 + 0.608q)} \partial z \]

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.

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<th>EXP. NAME</th>
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<th>INTENSITY ERROR</th>
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<tr>
<td>SD1dvar_ATMS20</td>
<td>23.89 km</td>
<td>7.51 hPa</td>
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<tr>
<td>SD1dvar_CMWS20</td>
<td>50.59 km</td>
<td>16.57 hPa</td>
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<tr>
<td>SD1dvar_CMWS28</td>
<td>36.89 km</td>
<td>13.77 hPa</td>
</tr>
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Summary and Conclusions

1. A scene-depended 1dvar (SD1dvar) algorithm is tested for microwave sounding instruments onboard FY-3D and SNPP. 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.
Thank you!
cloud detection

\[ \text{CLWP} = \cos \theta \left[ \alpha_0 - (\alpha_1 - \alpha_2 \cos \theta) \cos \theta + \alpha_3 \ln (T_0 - T_{b1}) - \alpha_4 \ln (T_0 - T_{b2}) \right] \] Grody et al. (2001)

\[ \text{SI} = T_{b16} - T_{b17} - (0.248\theta - 46.94) \] Bennartz et al. (2002)

\[
\begin{cases}
\text{CLWP} \leq 0.05 & \text{Clear} \\
\text{CLWP} \geq 1.0 \text{ or } SI \geq 20 & \text{Convective} \\
0.05 < \text{CLWP} < 1.0 \text{ and } SI < 20 & \text{Stratiform}
\end{cases}
\]