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Analysis of Tropical Clouds with GMI and CloudSat Data

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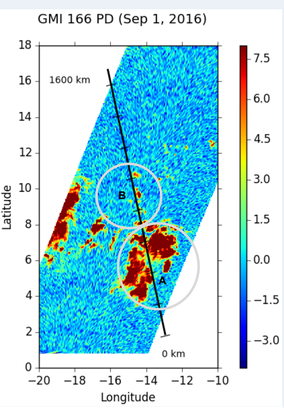
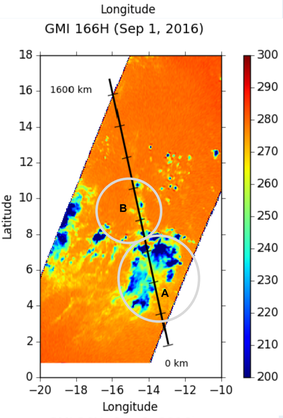
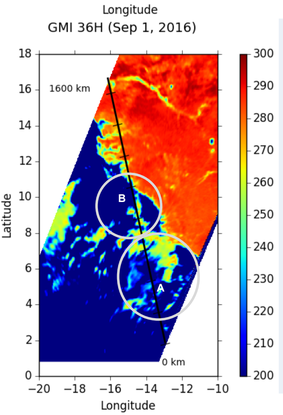
1. Motivation

Tropical clouds are usually classified into two types: shallow (or cumulus) and deep (or cumulonimbus) convection, which are associated with large-scale vertical circulations. Johnson et al. (1999), based on field campaign observations, found a third cloud type of cumulus congestus with abundant populations, providing a new clue to understand the interaction between tropical convection and large-scale circulations.

In this study, the three cloud types are analyzed using the data of GMI (Global Precipitation Measurement(GPM) Microwave Imaginer) and CloudSat. Special attention is given on cumulus congestus and its anvil.







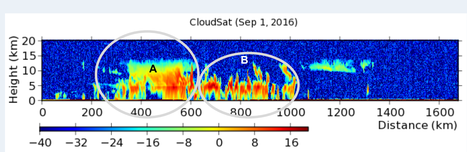
3. Case 1 near Western Africa

Case 1 in Figs 1 and 2 occurred at the intersection of GPM and CloudSat over the Atlantic Ocean near western Africa on Spet. 1, 2016. The case provides two cloud systems

- A: Deep convection with large anvil
- B: Cumulus congestus with little anvil.

Fig. 1 shows the positive PD (polarization difference) at 166 GHz over cloud system A, suggesting the prevalence of horizontally oriented ice crystals there.

Fig. 2 shows the tops of cumulus congestus in B are usually ~ 5 km, with a few above 5 km.



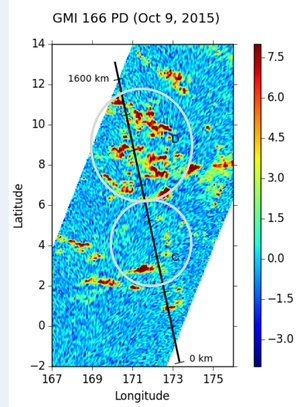
↑ *Fig. 2 Vertical cross section of the CloudSat radar reflectivity along the CloudSat track (see Fig. 1) over the Atlantic Ocean and western Africa. Dataset starts over 1.89° N and 12.94° W at 14:36:40 and ends over 16.64° N and 16.14° W at 14:40:45 UTC, 1 September 2016*

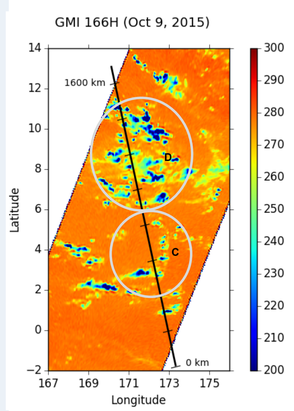
← *Fig. 1 GMI image of the polarization difference at 166 GHz (top), and the GMI images of brightness temperature from the channels with horizontal polarization at 166 (middle) and 36.5 GHz (bottom) at 14:36 UTC on Sept. 1, 2016. Thick lines denotes the CloudSat track that heads north.*

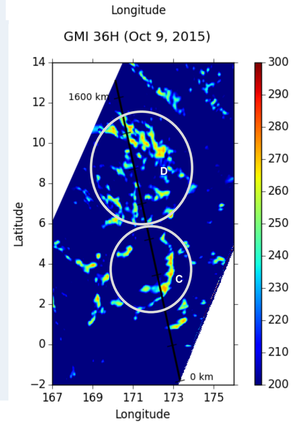
2. Coincidence Data of GMI and CloudSat

GPM and CloudSat fly in sun-asynchronous and synchronous orbits and thus cross each other frequently. Their intersections (or coincidences) thus provide unique data to analyze tropical clouds. In this study, the coincidence dataset of Turk (2017) is used from March 2014 to October 2017.

Generally speaking, GMI channels at 166 GHz provide information on optically thick ice clouds, whereas the channels at 36.5 provide information on deep convection (or mixed-phase clouds) and warm clouds. In addition, CloudSat provides vertical cross sections of clouds, ranging from optically thin ice clouds to deep convective ones.







4. Case 2 over Western Pacific Ocean

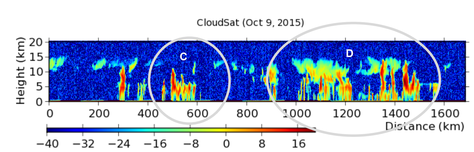
Case 2 in Figs. 3 and 4 occurred at the intersection of GPM and CloudSat over the western Pacific Ocean on Oct. 9, 2015. The case provides two cloud systems too

- C: Cumulus congestus with little anvil
- D: Mixture of deep convection and cumulus congestus.

Fig. 3 displays a bow shape of cumulus congestus cluster of C.

Fig. 4 displays a mixture of deep convection and cumulus congestus in system D.

Both Figs. 2 and 4 exhibit abundance of optically thin clouds above 10 km.



↑ *Fig. 4 Same as Fig. 2 except over the western Pacific Ocean (see Fig. 3). Dataset starts over 1.75° S and 173.33° E at 02:13:55 and ends over 13.08° N and 170.14° E at 02:18:09 UTC, 9 October 2015.*

← *Fig. 3 Same as Fig. 1 except over the western Pacific Ocean at 02:14 UTC on October 9, 2015.*

5. Statistical Analysis of CloudSat Data

The three cloud types area analyzed statistically using CloudSat data. A pixel is classified as a thick cloud if its CloudSat radar reflectivity falls between 5 and 20 dBZ, and as a thin cloud if its radar reflectivity falls between -20 and 5 dBZ. These two kinds of cloud categories exclude deep convection with radar reflectivity above 20 dBZ and extremely thin clouds such as subvisual cirrus clouds.

Fig. 5 displays the fractions of thin and thick clouds versus height over land and sea, showing

- Thick cloud fraction reaches three maxima at 7.5, 4.5 km and below 2 km, which correspond to the detrainment of the three cloud types,
- Thin cloud fraction reaches the maximum and minimum at 11 and 4.5 km, respectively.

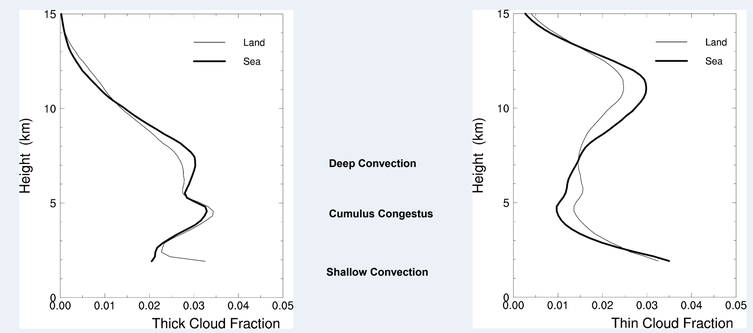


Fig. 5 Fractions of thick clouds (left; with radar reflectivity between 5 and 20 dBZ) and thin clouds (right; between -20 and 5 dBZ) observed by CloudSat over the tropics. Values are normalized by their total cloud pixel numbers above 2 km, respectively.

6. Conclusions & Future Work

- GMI and CloudSat show that cumulus congestus occurs as clusters of lines and has small anvil in comparison with deep convection.
- The observed vertical profiles of thick cloud fraction support the trimodal characteristics of tropical convection found by Johnson et al. (1999).
- The vertical distribution of thin clouds, different from that of thick ones, needs an explanation from new models (e.g., Zeng 2018).

7. References

- Johnson, R. H., T. M. Rickenbach, S. A. Rutledge, P. E. Ciesielski, and W. H. Schubert, 1999: Trimodal characteristics of tropical convection, *Journal of Climate*, **12**, 2397-2418.
- Turk, J., 2017: CloudSat-GPM Coincidence Dataset, Version 2A, https://pps.gsfc.nasa.gov/Documents/CSATGPM_COIN_ATBD.pdf
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The authors greatly appreciated Dr. Joe Turk for providing the coincidence data of GMI and CloudSat. This research was supported by the NASA Precipitation Measurement Mission (PMM) project under grant NNX16AE24G.