CFODD Warm Rain Microphysics Diagnostic Package

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The CFODD (Contoured Frequency by Optical Depth Diagram) warm rain microphysics diagnostic package computes the PDF of radar reflectivity on in-cloud optical depth bins for warm-topped clouds which are classified based on cloud-top droplet effective radius. By comparing with pre-digested A-Train Satellite results, the package reveals biases in modeled warm rain formation process — the transition from non-precipitating regime to precipitating regime. The statistics are built over oceans. Cold-topped clouds (cloud top temperature <273.15 K) are excluded. The package requires satellite simulators (e.g. COSP[1]) to be implemented in the host model.

Version & Contact info

Version 1.2 (8-Mar-2019, Xianwen Jing, AORI, U-Tokyo)
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Functionality

The currently package consists of following functionalities:

(1) Contoured Frequency by Optical Depth Diagram (CFODD) for warm clouds over global ocean (CFODD_warm_rain_microphysics.py)

As a module of the MDTF code package, all scripts of this package can be found under
mdtf/MDTF_$ver/var_code/CFODD_warm_rain_microphysics[2]
and pre-digested observational data under
mdtf/inputdata/obs_data/ CFODD_warm_rain_microphysics

Required programming language and libraries

The driver of the package is written in Python 2, and requires the following Python packages:
os, glob, json, Dataset, numpy, scipy, matplotlib, networkx, warnings, numba, & netcdf4
These Python packages are already included in the standard Anaconda installation.

The computing and plotting functions are written in NCL. The NCL version 6.4 or later is recommended.

Required model output variables

The following 4-D (time-pressure-lat-lon) high-frequency (6-hrly snapshot or shorter) model fields are required:

(1) Cloud water mixing ratio (units: kg/kg)
(2) Cloud ice mixing ratio (units: kg/kg)
(3) Air temperature (units: K)
(4) Cloud optical depth at each model layer

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[1] COSP refers to the CFMIP Observation Simulation Package (https://www.earthsystemcog.org/projects/cfmip/).

[2] $ver represents the actual version appears in the folder name.

The following 4-D (time-pressure-lat-lon) high-frequency fields (6-hrly snapshot or shorter) from sub-column outputs of satellite simulators (e.g. COSP) are required:

(5) CloudSat CPR Radar reflectivity (units: dBZ; each sub-column written to a single file)
(6) Cloud type (=1: stratiform cloud; =2: convective cloud; each sub-column written to a single file)

Either of the following high-frequency fields (6-hrly snapshot or shorter) is required:

(7) 3-D (time-lat-lon) Cloud top droplet effective radius (units: m) .or.
(8) 4-D (time-pressure-lat-lon) Cloud droplet effective radius profile (units: m)

References

Suzuki, K., Stephens, G.L., Bodas-Salcedo, A., Wang, M., Golaz, J.-C., Yokohata, T., and Tsuyoshi, K., 2015. Evaluation of the warm rain formation process in global models with satellite observations. *J. Atmos. Sci.*, *72*(10), 3996–4014. https://doi.org/10.1175/JAS-D-14-0265.1.

Jing, X., Suzuki, K., Guo, H., Goto, D., Ogura, T., Koshiro, T., and Mülmenstädt, J., 2017. A multimodel study on warm precipitation biases in global models compared to satellite observations. *J. Geophys. Res.: Atmospheres*, *122*, 11806-11824. http://doi.org/10.1002/2017JD027310.

More about this diagnostic

The CFODD methodology composites the radar reflectivity profiles in the form of the probability density function normalized at each in cloud optical depth, which is determined by vertically slicing the cloud optical thickness. The statistics are further classified according to ranges of cloud-top droplet size to reveal how the vertical microphysical structure of warm-topped clouds tends to transition from non-precipitating regime to precipitating regime as a fairly monotonic function of the particle size. Fig.1 shows an example evaluation of the GFDL AM4 model (Zhao et al., 2018a, b) using this package.

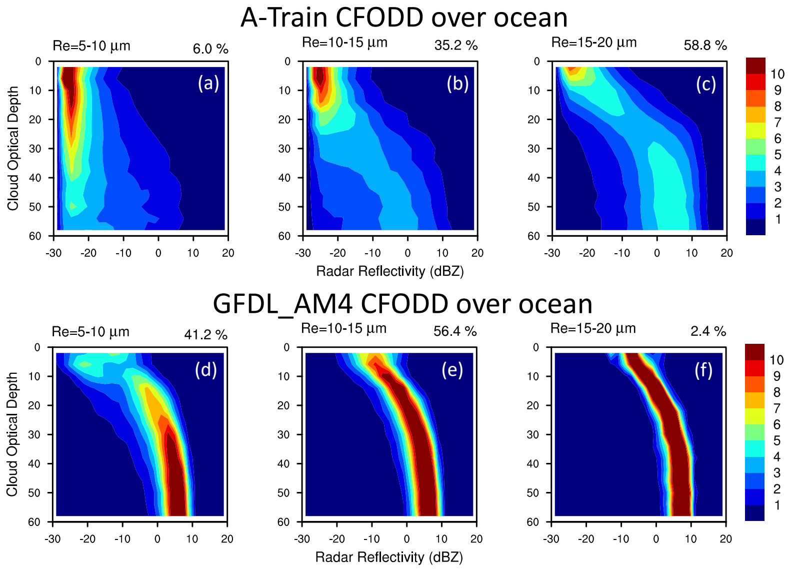

Figure 1. The probability density function (color shading in the unit of %/dBZ) of radar reflectivity (abscissa) normalized as a function of cloud optical depth increasing downward (ordinate), which is further classified according to different ranges of cloud-top droplet effective radius (R_e) for (left to right) 5-10mm, 10-15mm and 15-20mm obtained from (top) A-Train satellite observations and (bottom) GFDL-AM4 simulation.

The A-Train satellite-based statistics (Fig.s 1a–c) show that the observed radar reflectivity (RR) shifts monotonically from small (RR< −15 dBZ) to larger values (RR> 0 dBZ) with increasing droplet effective radius (R_e) at the lower parts (optical depth > 40) of the diagrams. Note that clouds with RR< −15 dBZ, –15 dBZ< RR< 0 dBZ, and RR>0 dBZ are conventionally regarded as containing non-precipitating, drizzling (i.e. light rain), and raining (i.e. heavy rain) hydrometeors (e.g., Haynes et al. 2009), respectively. Fig. 1a shows that when cloud particle sizes are sufficiently small (R_e< 10 µm, Fig. 1a), RR is mostly <–15 dBZ, implying that precipitation is rarely observed even though the cloud optical depth can reach a considerable magnitude. Clouds with R_e =10–15 feature intermediate RR (–15 dBZ< RR< 0 dBZ) (Fig. 1b), suggesting that precipitation onset is triggered in this R_e range, which is supported by *in situ* observations (Boers et al. 1998; Pawlowska and Brenguier 2003). The satellite-based results thus illustrate how the vertical microphysical structure of warm clouds tends to transition from non-precipitating to precipitating profiles as a fairly monotonic function of the cloud-top particle size.

In contrast, the model results (Figs. 1d–f) show virtually no non-precipitation profiles, even for the smallest R_e range. This suggests that the rain formation process in the model is already quite efficient even when cloud top droplet sizes are too small to sustain such an efficient collision and coalescence growth of droplets.

The CFODD methodology provides a direct insight into the coalescence process, parameterized with autoconversion (collision and coalescence of cloud droplets to form rain drops) and accretion (collection of cloud droplets by rain drops) formulations.

Additional references:

Haynes, J. M., T. L'Ecuyer, G. L. Stephens, S. D. Miller, C. Mitrescu, N. B. Wood, and S. Tanelli, 2009: Rainfall retrievals over the ocean with spaceborne high-frequency cloud radar. *J. Geophys. Res*., 114, D00A22, https://doi.org/10.1029/2008JD009973.

Boers, R., J. B. Jensen, and P. B. Krummel, 1998: Microphysical and short-wave radiative structure of stratocumulus clouds over the Southern Ocean: Summer results and seasonal differences. *Quart. J. Roy. Meteor. Soc.,* 124, 151–168, https://doi.org/10.1002/qj.49712454507.

Pawlowska, H., and J.-L. Brenguier, 2003: An observational study of drizzle formation in stratocumulus clouds for general circulation model (GCM) parameterizations. *J. Geophys. Res*., 108, 8630. https://doi.org/10.1029/2002JD002679.

Zhao., M., and Coauthors, 2018a: The GFDL Global Atmosphere and Land Model AM4.0/LM4.0 - Part I: Simulation Characteristics with Prescribed SSTs. *J. Adv. Model. Earth Sy*., 10(3), DOI:10.1002/2017MS001208.

Zhao., M., and Coauthors, 2018a: The GFDL Global Atmosphere and Land Model AM4.0/LM4.0 - Part II: Model Description, Sensitivity Studies, and Tuning Strategies. *J. Adv. Model. Earth Sy.*, 10(3), DOI:10.1002/2017MS001209.