Precipitation Buoyancy Diagnostics

The precipitation-buoyancy diagnostics POD evaluates the thermodynamic sensitivity of model precipitation. The observational baseline for the comparison is constructed using ERA5 thermodynamic profiles and TRMM 3B42 precipitation. The evaluation identifies if the model shows a precipitation-buoyancy relationship, and then assesses how sensitive the model precipitation is to relative measures of conditional instability and lower-tropospheric sub-saturation. This evaluation also places the candidate model being evaluated among a collection of CMIP6 models with respect to measures of thermodynamic sensitivity.

Version & Contact info

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Functionality

The currently package consists of following functionalities:
(1) The POD driver script (precip_buoy_diag.py)
(2) The POD utility script containing all fucntions (precip_buoy_diag_util.py)
(3) A cython setup script (precip_buoy_diag_setup_cython.py)

The driver script first compiles the cython script. The driver script then preprocesses model files (if preprocessed output is unavailable), then bins the precipitation by the various buoyancy components (if binned output is unavailable), and finally plots the relevant diagnostics.

As a module of the MDTF code package, all scripts of this package can be found under <CODE_ROOT>/diagnostics/ precip_buoy_diag/

and pre-digested observational data under <OBS_DATA_ROOT>/ precip_buoy_diag/

Required Programming language and libraries

The package was written using python 3.7.9. The required packages are nco, netCDF, cython, xarray, numpy, scipy, matplotlib, network, numba, pandas, seaborn, dask. These packages are listed under <CODE_ROOT>/src/conda/ env_precip_buoy_diag.yml

Required model output variables

The following 3-D (lat-lon-time) high-frequency model field is required:

Precipitation rate (units: kg m^{-2} s^{-1}; **6-hrly avg. or shorter**).

The following two 4-D (time-height-lat-lon) high frequency model fields are required:

1. Temperature (units: K, **6-hrly avg. or shorter**). Time stamps should preferably match that of precipitation.
2. Specific humidity (units: kg/kg, **6-hrly avg. or shorter**). Time stamps should preferably match that of precipitation.

The following 3-D (lat-lon-time) high-frequency model field is optional:

Surface pressure (units: Pa; **6-hrly avg. or shorter**). Time stamps should exactly match that of temperature and specific humidity.

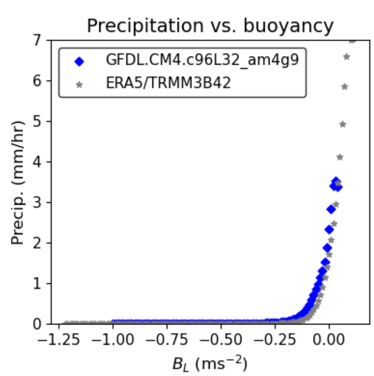
References

1. Ahmed, F., & Neelin, J. D. (2018). Reverse engineering the tropical precipitation–buoyancy relationship. *Journal of the Atmospheric Sciences*, *75*(5), 1587-1608.
2. Ahmed, F., Adames, Á. F., & Neelin, J. D. (2020). Deep convective adjustment of temperature and moisture. *Journal of the Atmospheric Sciences*, *77*(6), 2163-2186.
3. Ahmed, F., & Neelin, J. D. (2021). A process-oriented diagnostic to assess precipitation-thermodynamic relations and application to CMIP6 models. *Geophysical Research Letters (Submitted).*

Interpreting the POD output

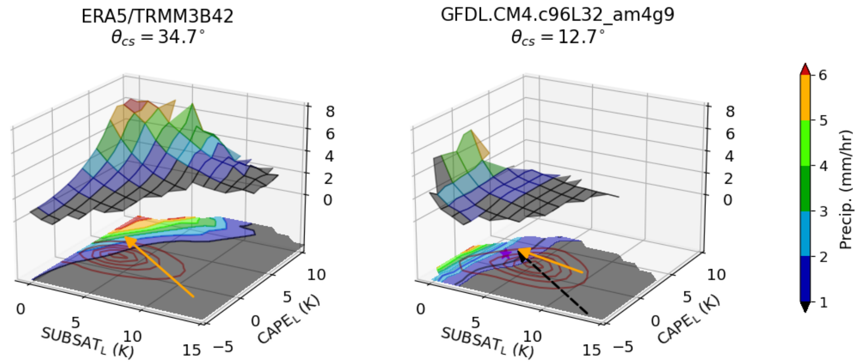
The model evaluation is done with three figures.

1) Precipitation conditionally averaged by B_L.



The first figure shows how precipitation relates to a measure of lower tropospheric buoyancy (B_L) by comparison with an observational (ERA5/TRMM 3B42) baseline. In this example to the left, the candidate model shows a strong precipitation pickup as a function of B_L. *This compares favorably with the observational baseline set by the ERA5/TRMM 3B42 data.*

2) Precipitation conditionally averaged by CAPE$_L$ and SUBSAT$_L$.



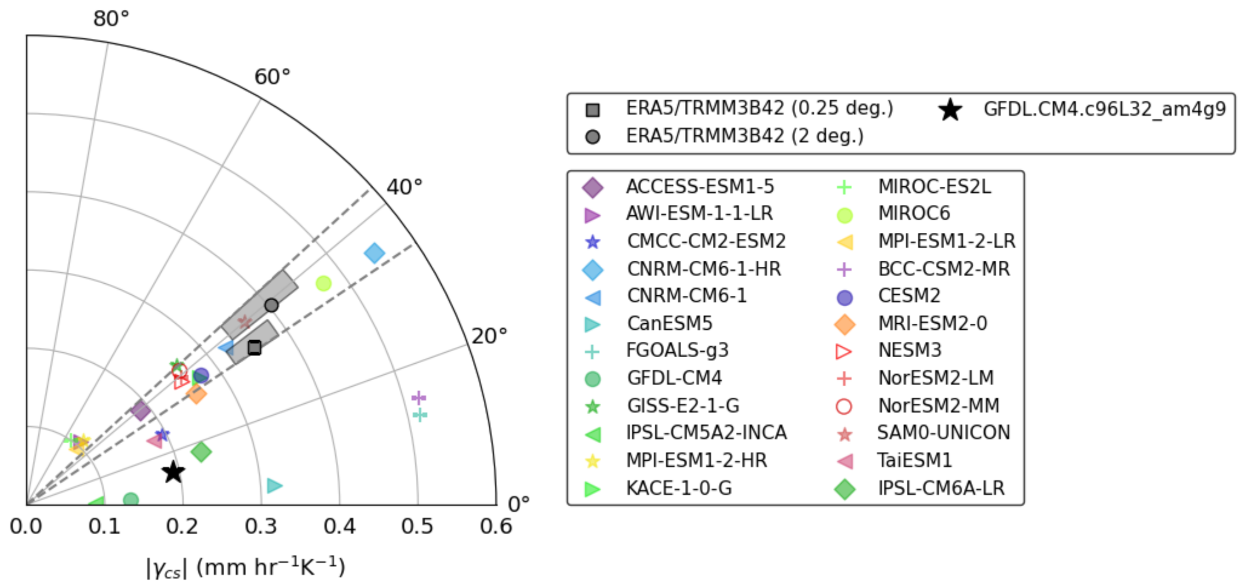
The second figure (above) compares the observational baseline (ERA5/TRMM 3B42) to the candidate model (right). This figure condenses several properties of how the model precipitation is related to the thermodynamic environment:

- The precipitation conditionally averaged by CAPE$_L$ and SUBSAT$_L$ is shown as colored contours in the CAPE$_L$-SUBSAT$_L$ plane as well as a precipitation surface using a 3D perspective. This helps visualize the strength of the precipitation pickup.
- The orange arrow is a vector (γ_{CS}) with direction approximately in the direction of the strongest precipitation pickup, and magnitude that captures the pickup strength. The angle that γ_{CS} makes with the SUBSAT$_L$ axis is termed θ_{CS}. This angle measures the relative sensitivity of the precipitation to CAPE$_L$ vs. SUBSAT$_L$. A smaller angle indicates greater SUBSAT$_L$ (~moisture) sensitivity. The value of this angle is shown in each figure title. The γ_{CS} vector for the observational baseline is reproduced in the candidate model (right) plot as a black dashed arrow for comparison.
- The maroon contours are the pdfs of the precipitating points. The mode of the ERA5/TRMM 3B42 precipitating pdf is shown in the candidate model plot as a magenta star. This allows a comparison between the model and the observational baseline precipitating mean states.

From the figure above, we can conclude that the candidate model *is more sensitive to SUBSAT$_L$ than the observational baseline*. This could indicate either an underactive convective scheme or compensating errors due to large moisture sensitivity built into the convective scheme (e.g. the trigger function). However, *the precipitating mean state of the model is close to the baseline*.

3) Comparison to CMIP6 models

The third figure (below) places the candidate model precipitation's CAPE$_L$-SUBSAT$_L$ sensitivity in context with other CMIP6 models from as well the uncertainty range within observations. This is done in a polar plot, in which each model has co-ordinates ($|\gamma_{CS}|, \theta_{CS}$), where $|\gamma_{CS}|$ measures the magnitude of the precipitation pickup and θ_{CS} measures the relative SUBSAT$_L$ sensitivity of precipitation.



In this figure above, the observational baselines for two versions of the ERA5/TRMM 3B42 data—the 0.25 deg. and 2.0 deg. horizontal resolutions—are shown as grey markers. The shaded grey regions around these markers denote the uncertainty range in the observational baseline as estimated using a bootstrapping procedure. The dashed grey lines bound the uncertainty range in θ_{CS} values for both versions of the ERA5/TRMM 3B42 data. The black star marker denotes the position of the candidate model in this plot. Compared to the baseline, *this particular candidate model has a weaker precipitation pickup as well as excessive SUBSAT$_L$ sensitivity*. This model is thus positioned among a set of CMIP6 models that are *over-sensitive to lower-tropospheric moisture*.