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Global climate modeling with improved precipitation characteristics by learning physics (GRIST-MPS v1.0) from global storm-resolving modeling

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Supplement

Numerical Weather Prediction (NWP) type experiments

We conducted a one-month rolling forecast experiment for summer 2021, spanning June–July. Forecasts were initialized daily at 00:00 UTC from 1 June to 30 June 2021, and each case was integrated continuously for 240 h (10 days). Accordingly, each experimental group produced 30 forecasts, each with a 240-h lead time. The horizontal and vertical resolutions were identical to those of the GRIST-CPS configuration used in this paper (120 km, 30 vertical levels).

First, we evaluated the precipitation intensity–frequency distribution over the tropical region. As shown in Figure S1, GRIST-MPS produces less frequency of total precipitation and light-rain events than GRIST-CPS, consistent with the free-running climate simulation results.

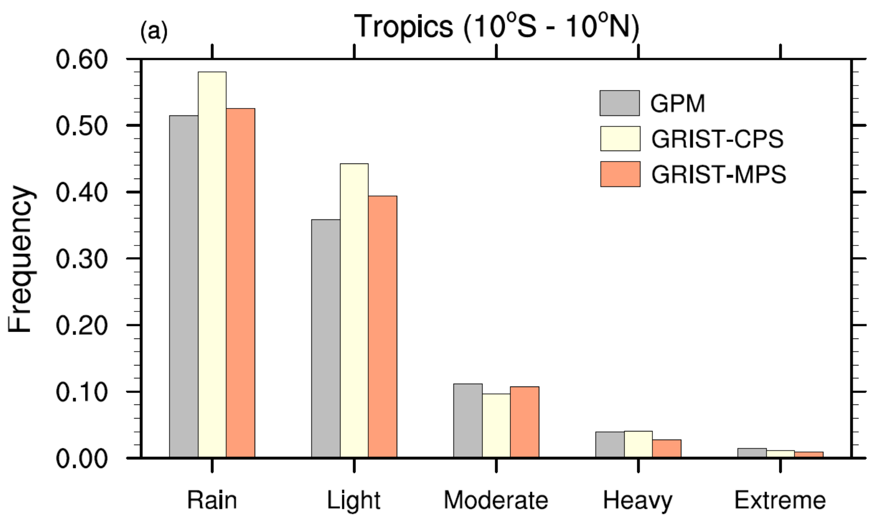

Figure S1. The frequency probability distributions of tropical 3-hourly precipitation obtained from GPM (gray boxes), GRIST-CPS (yellow boxes) and GRIST-MPS (orange boxes).

The deterministic short-term prediction skill of GRIST-CPS and GRIST-MPS was then evaluated based on the ensemble mean of these 30 samples. The Anomaly Correlation Coefficient (ACC; Eq. S1) was used as the metric to assess the model's short-term simulation capability. Its calculation formula is as follows:

$$\mathrm{ACC} = \frac{\sum_{i,j}(f_{i,j}-c_{i,j})(a_{i,j}-c_{i,j})}{\sqrt{\sum_{i,j}(f_{i,j}-c_{i,j})^2}\sqrt{\sum_{i,j}(a_{i,j}-c_{i,j})^2}} \quad \text{(S1)}$$

where f denotes the GRIST-CPS/MPS simulation field, a the ERA5 reanalysis field, and c the climatology of the ERA5 reanalysis field (for medium-range forecasts, the June climatological field during 2012–2021 is selected as the (re)analysis climatology); i and j represent the grid points in the zonal and meridional directions, respectively.

The ACC measures the spatial similarity between deterministic forecast results and reference data. We evaluated the models using three ERA5 reanalysis variables: Z500, T850, and Q700. Z500 reflects the model's ability to depict large-scale circulation patterns, while T850 and Q700 are variables directly influenced by the AI-based physical parameterization scheme (Figure S2).

GRIST-MPS yields slightly lower ACC for Z500 and Q700 than GRIST-CPS. For T850, GRIST-MPS outperforms GRIST-CPS for lead times up to 90 h, after which its skill gradually declines. Overall, these results suggest that GRIST-MPS has medium-range deterministic forecasting capability that is slightly inferior to GRIST-CPS. A possible reason is that the training data of model physics were drawn from only four 20-day simulations—which already develop substantial climate-state errors that can affect deterministic forecasts. The present results clearly indicate room for future improvement: ACC could likely be increased by training on shorter-period simulations (i.e., before climate-state errors fully develop) and/or by using datasets with more realistic large-scale circulations.

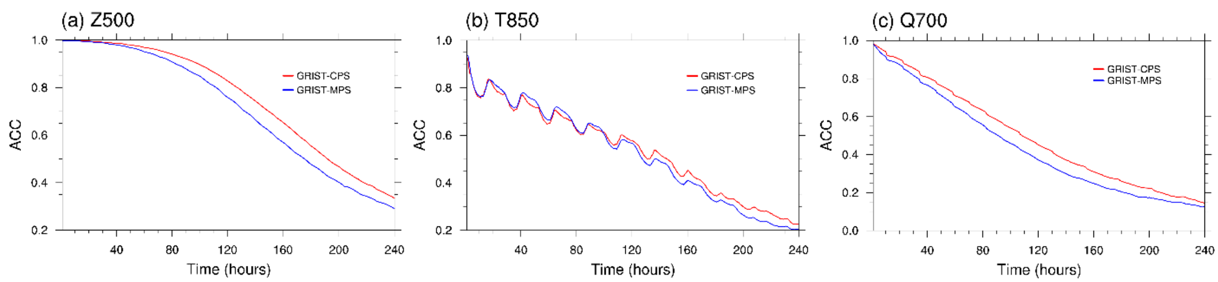

Figure S2. (a) Temporal variations in the Anomaly Correlation Coefficient (ACC) of the 500 hPa geopotential height simulated by GRIST-CPS(red line) and GRIST-MPS(blue line) against the ERA5 reanalysis data during June 2021 with the forecast integration time. (b), (c) as in (a) but for T850 and Q700.