Analysing Scales of Precipitation (ASoP) in GCMs and observations

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1. Tropical rainfall biases in GCMs

General circulation models (GCMs) have been criticised for failing to represent observed scales of precipitation, particularly in the tropics where simulated rainfall is often said to be too light, too frequent and too persistent (e.g., [1]). However, previous assessments have used temporal or spatially averaged precipitation, which offers little actionable information for model developers, since the physics-dynamics interactions that produce precipitation occur at the native gridscale and timestep. Temporal and/or spatial averaging can change markedly the distribution of precipitation intensities, particularly for models whose convection schemes produce temporally or spatially intermittent precipitation (Fig. 1).

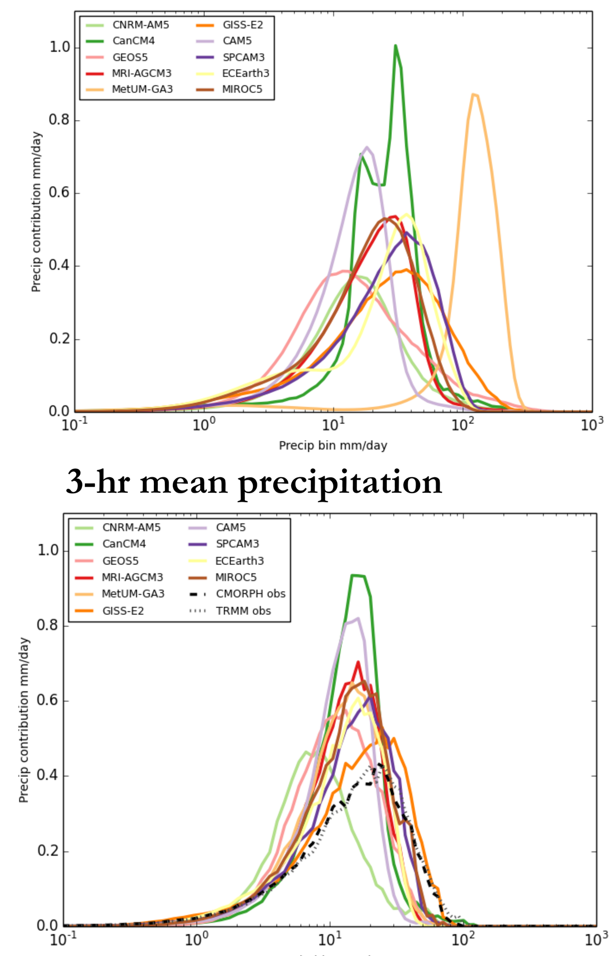

Figure 1: Histograms of precipitation intensities for (top) timestep and (bottom) 3-hr mean precipitation, using data from the "Vertical Structure and Physical Processes of the MJO" inter-comparison project, in a domain over the tropical Warm Pool. CMORPH and TRMM 3-hr data for the same domain and period are shown in the dashed and dotted black lines, respectively.

2. Analysing Scales of Precipitation (ASoP)

We introduce a set of diagnostics (ASoP) to compare the spatial and temporal scales of precipitation across GCMs and observations, which can be applied to data ranging from the gridscale and timestep to regional and sub-monthly averages [2]. These diagnostics include:

- Histograms of precipitation intensities (Fig. 1)
- Two-dimensional histograms of precipitation at consecutive timesteps (Fig. 2)
- Correlations of precipitation with distance and temporal lag (Fig. 3)
- Contributions to total precipitation from events within certain intensity ranges (Fig. 4)
- Summary metrics of spatial and temporal coherence (Fig. 5)

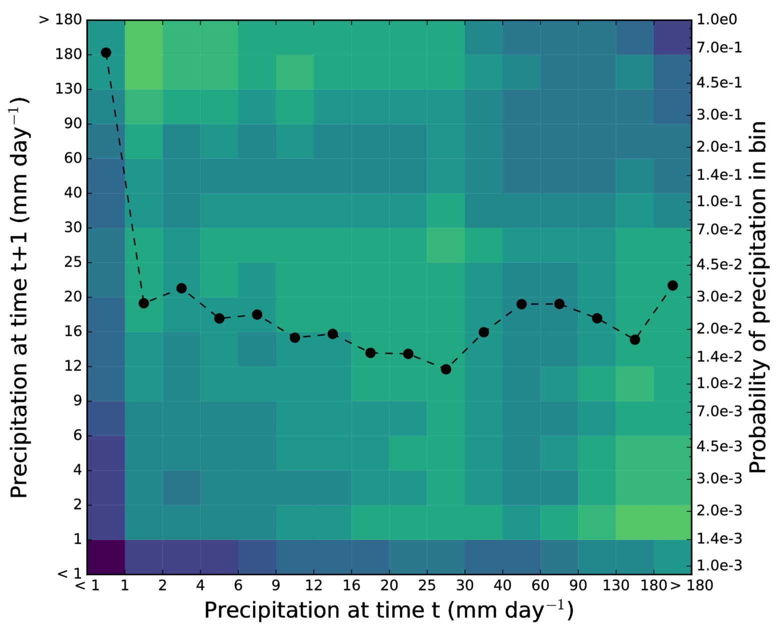

Figure 2: An example 2D histogram of precipitation on consecutive 3-hr intervals, using CMORPH data.

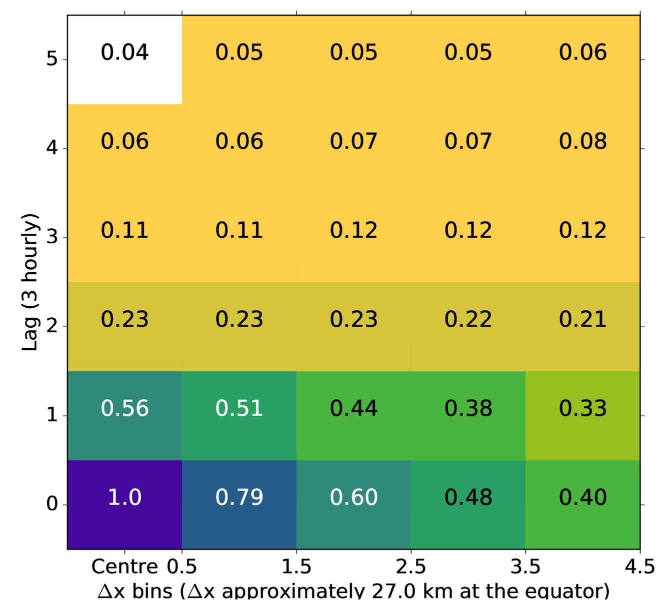

Figure 3: An example matrix of precipitation correlations with distance (x-axis) and time (y-axis), using CMORPH data. Correlations are against the central gridpoint at lag-0 (bottom left corner).

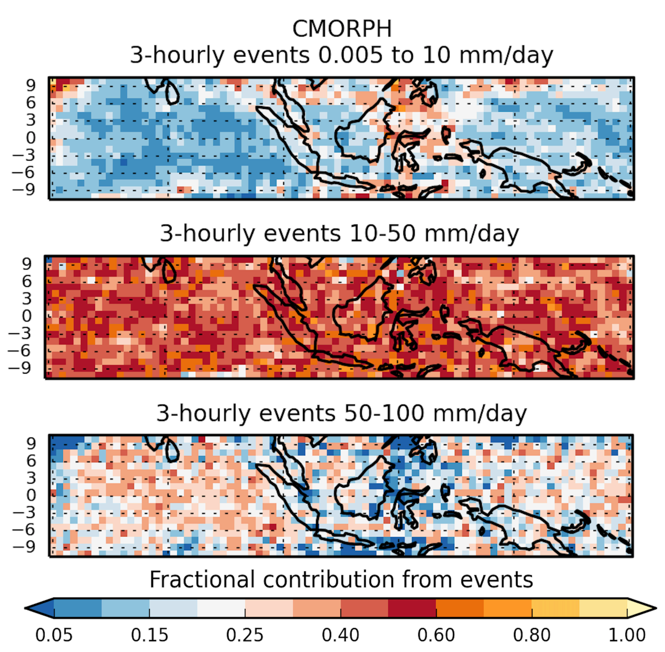

Figure 4: The contributions of precipitation from each intensity range to the total precipitation at that gridpoint, using CMORPH data.

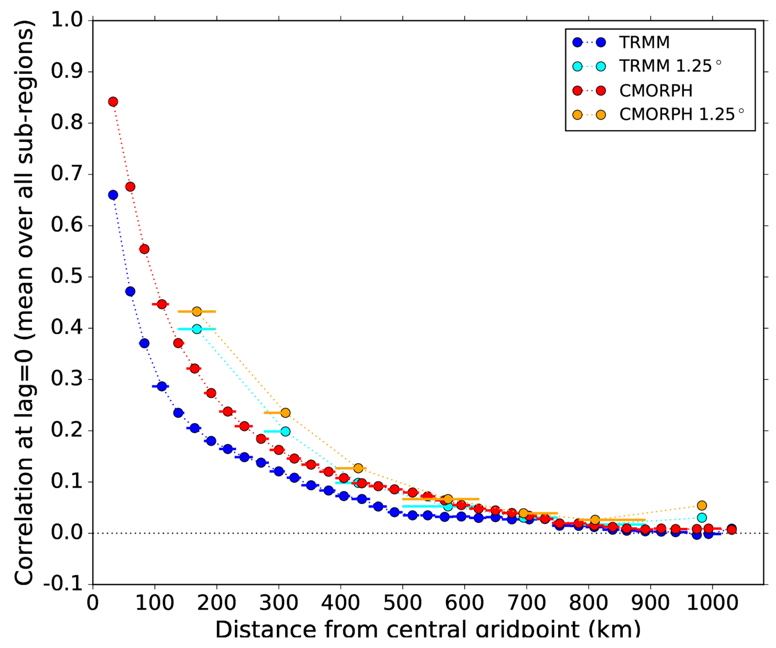

Figure 5: Correlations of precipitation with distance, using TRMM and CMORPH data, showing the effects of spatial averaging from 0.25° to 1.25°.

3. MetUM timestep intermittency

Application of the ASoP diagnostics to timestep precipitation from MetUM climate and NWP data has found that the convection scheme produces highly intermittent precipitation in space and time, regardless of horizontal resolution [2,3] (Fig. 6). Ongoing research seeks to understand and limit the causes of this intermittency.

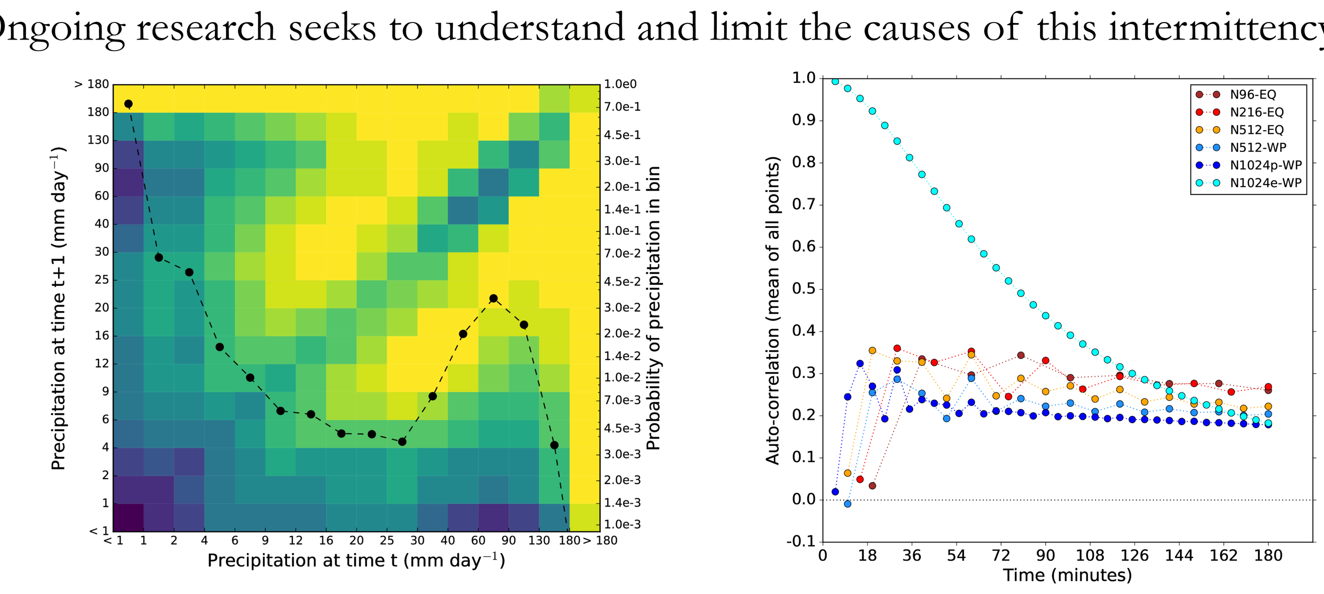

Figure 6: (left) 2D histogram of MetUM precipitation on consecutive timesteps ; (right) auto-correlations of MetUM timestep precipitation with parameterized convection, as well as a ~16km simulation with the deep convection scheme disabled (light blue).

Summary

- The ASoP diagnostics allow a detailed investigation of spatial and temporal variability in precipitation across scales, in models or observations. Python code to produce all diagnostics shown here, and others, can be downloaded from **https://github.com/nick-klingaman/ASoP**.
- Attributing climatological biases in regional precipitation to deficiencies in physical parametrizations remains a challenge for model developers. By examining the behaviour of modelled tropical rainfall at a range of spatial and temporal scales, we hope to shed light how such biases develop.

4. Effects of spatial and temporal averaging

As shown in Fig. 1, averaging timestep precipitation data to 3-hr means reduces inter-model variability in precipitation intensity spectra. The same effect applies to the spatial and temporal coherence of precipitation (Fig. 7). Models that produce highly intermittent precipitation, such as MetUM, "benefit" more from spatial and/or temporal averaging (Fig. 8).

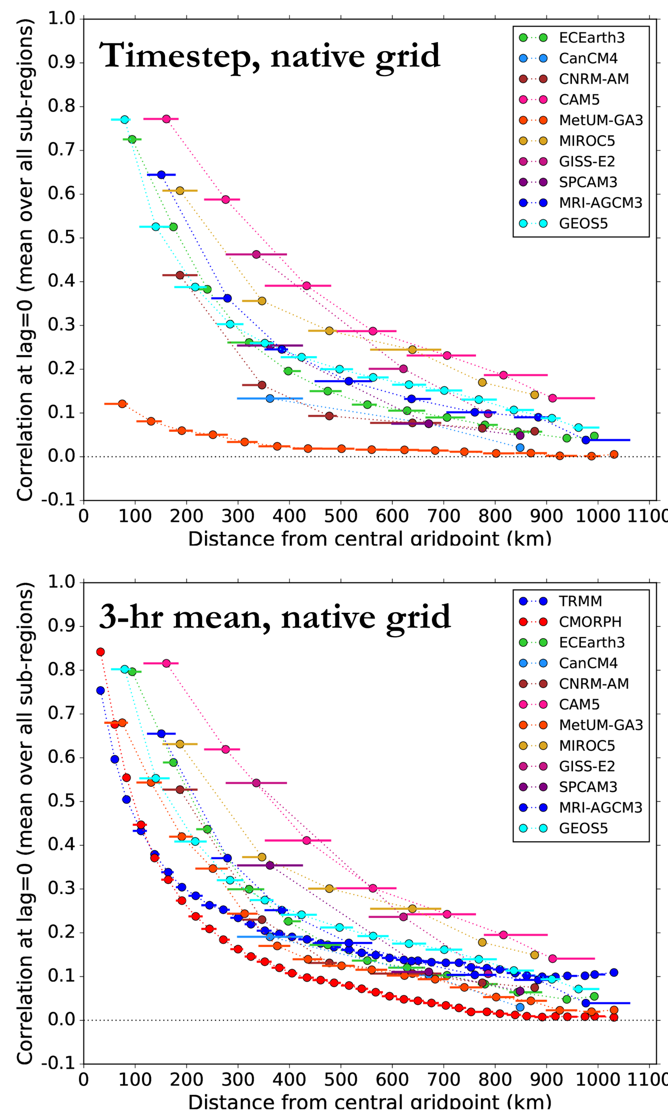

Figure 7: Correlations with distance for models from the "Vertical Structure and Physical Processes of the MJO" project

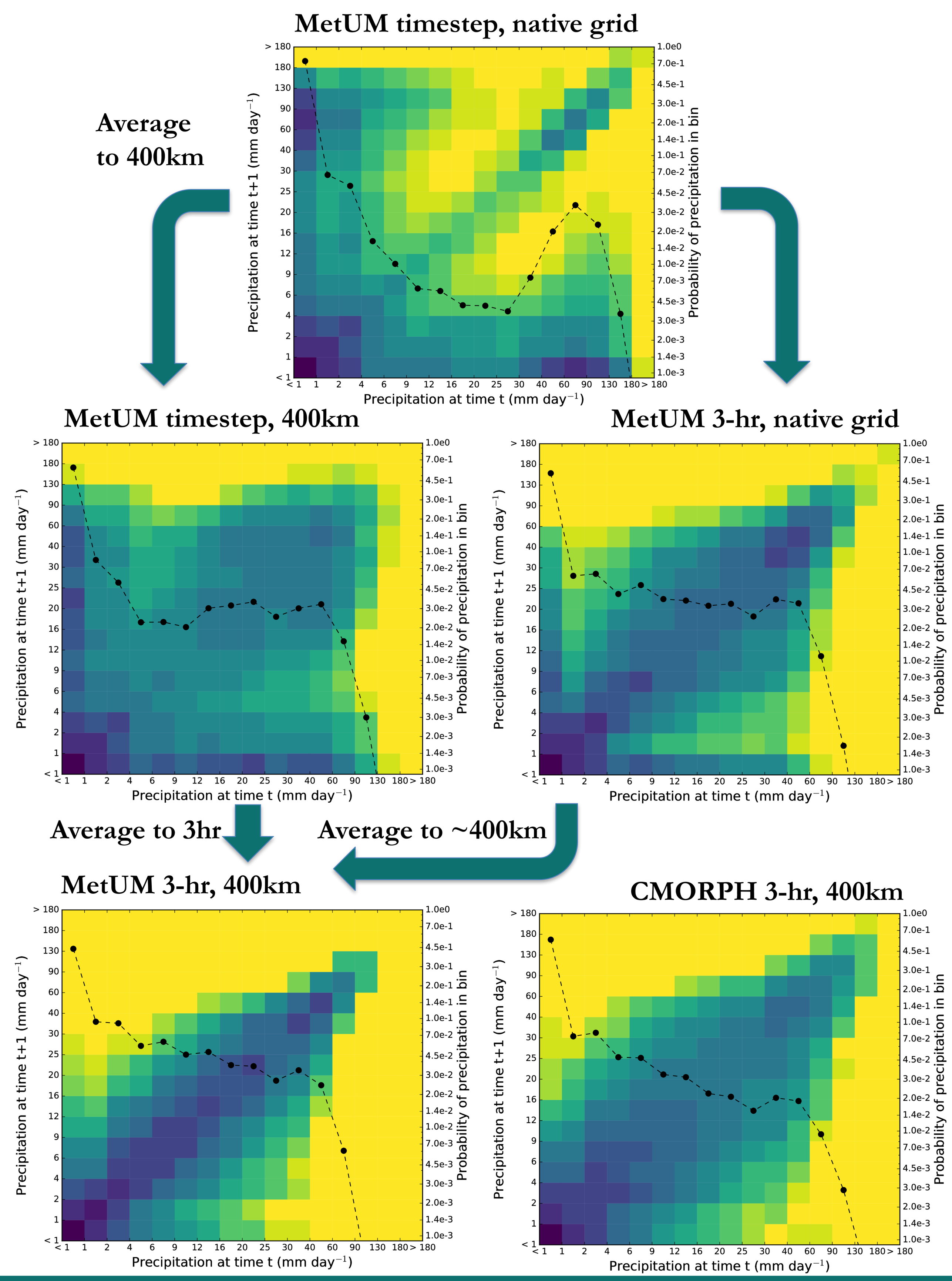

Figure 8: 2D histograms of precipitation on consecutive temporal intervals from MetUM data at ~150km.

5. Exploring model rainfall biases

We can use the ASoP diagnostics to examine how sub-daily precipitation intermittency may influence rainfall characteristics at longer timescales (up to ~ 20 days), in order to shed light on the processes driving model climatological rainfall biases in various regions (Figs. 9).

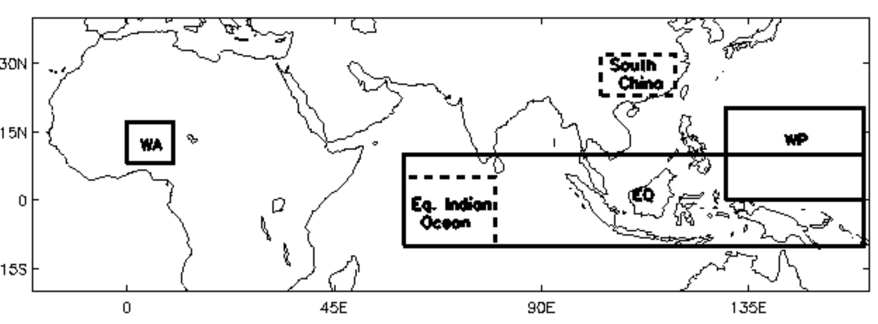

Figure 9: Map illustrating the regions used in Fig. 10. "WA": western Africa; "WP" western Pacific.

The movement of the spectra towards smaller values when averaged to successively longer timescales (Fig. 10) indicates that there is variability at the longer timescale (such that including drier periods in the average decreases the longer timescale mean).

For the WP and Eq. IO regions (wet bias), the model lacks variability on the longer timescales (also illustrated by Fig. 11). For S. China (wet bias), the day to day variability is reasonable but the daily totals are too large. For W. Africa (dry bias), rainfall totals are underestimated on all timescales analysed.

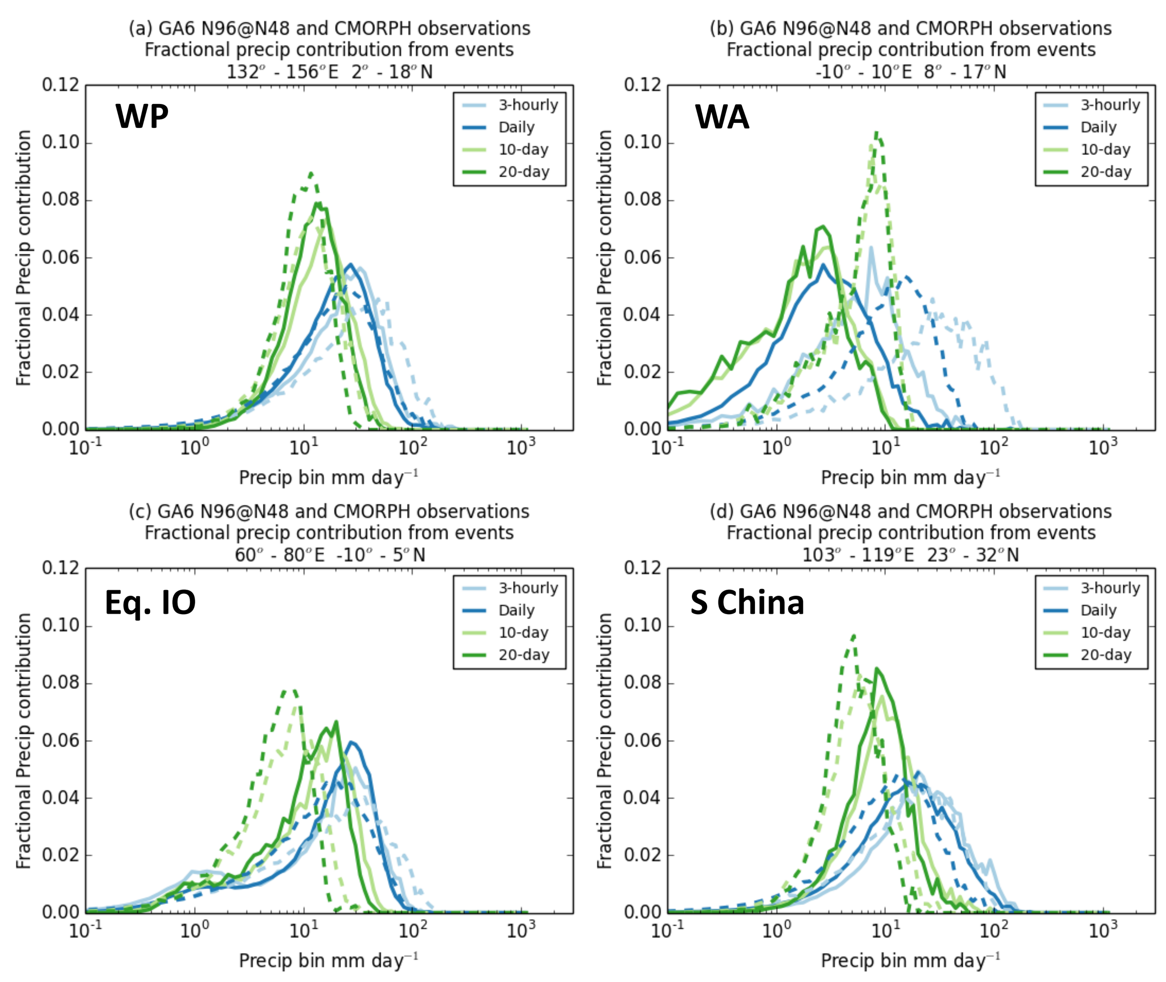

Figure 10: Spectra of 3-hourly, daily, 10-day and 20-day rainfall totals (in mm day^{-1}) from the MetUM-GA6 N96 configuration (solid lines), averaged over the regions in Fig. 9.

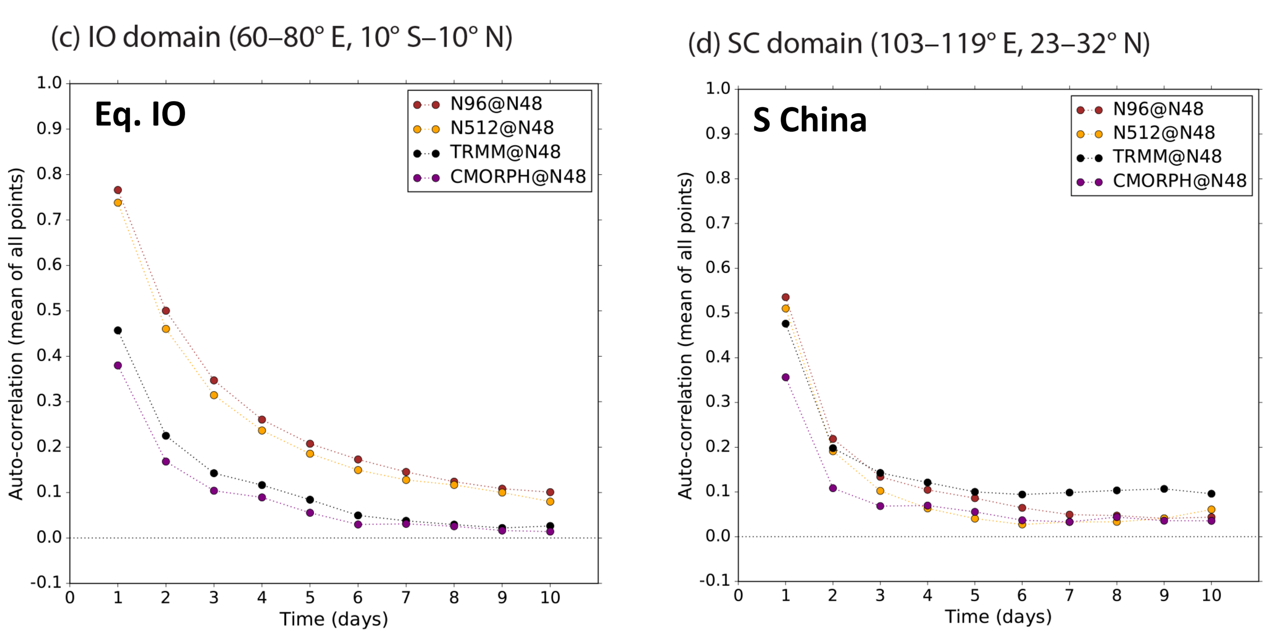

Figure 11: Auto-correlations of daily precipitation at different time lags.

References

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[3] Martin, G.M., N.P. Klingaman and A.F. Moise (2017): Connecting spatial and temporal scales of tropical precipitation in observations and the MetUM. Geosci. Model Dev., 10, 105-126, doi:10.5194/gmd-10-105-2017