Climate Dynamics
https://doi.org/10.1007/s00382-022-06257-6

Effects of grid spacing on high-frequency precipitation variance in coupled high-resolution global ocean–atmosphere models

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Received: 8 June 2021 / Accepted: 10 March 2022

Abstract

High-frequency precipitation variance is calculated in 12 different free-running (non-data-assimilative) coupled high resolution atmosphere–ocean model simulations, an assimilative coupled atmosphere–ocean weather forecast model, and an assimilative reanalysis. The results are compared with results from satellite estimates of precipitation and rain gauge observations. An analysis of irregular sub-daily fluctuations, which was applied by Covey et al. (Geophys Res Lett 45:12514–12522, 2018. https://doi.org/10.1029/2018GL078926) to satellite products and low-resolution climate models, is applied here to rain gauges and higher-resolution models. In contrast to lower-resolution climate simulations, which Covey et al. (2018) found to be lacking with respect to variance in irregular sub-daily fluctuations, the highest-resolution simulations examined here display an irregular sub-daily fluctuation variance that lies closer to that found in satellite products. Most of the simulations used here cannot be analyzed via the Covey et al. (2018) technique, because they do not output precipitation at sub-daily intervals. Thus the remainder of the paper focuses on frequency power spectral density of precipitation and on cumulative distribution functions over time scales (2–100 days) that are still relatively "high-frequency" in the context of climate modeling. Refined atmospheric or oceanic model grid spacing is generally found to increase high-frequency precipitation variance in simulations, approaching the values derived from observations. Mesoscale-eddy-rich ocean simulations significantly increase precipitation variance only when the atmosphere grid spacing is sufficiently fine (<0.5°). Despite the improvements noted above, all of the simulations examined here suffer from the "drizzle effect", in which precipitation is not temporally intermittent to the extent found in observations.

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Motivation

Precipitation often takes place in brief but intense events

As far as we know, an analysis of high-frequency precipitation variance has not been undertaken in the new class of high-resolution coupled ocean/atmosphere models

In these new models, the eddies in the ocean can affect atmosphere on weather time scales

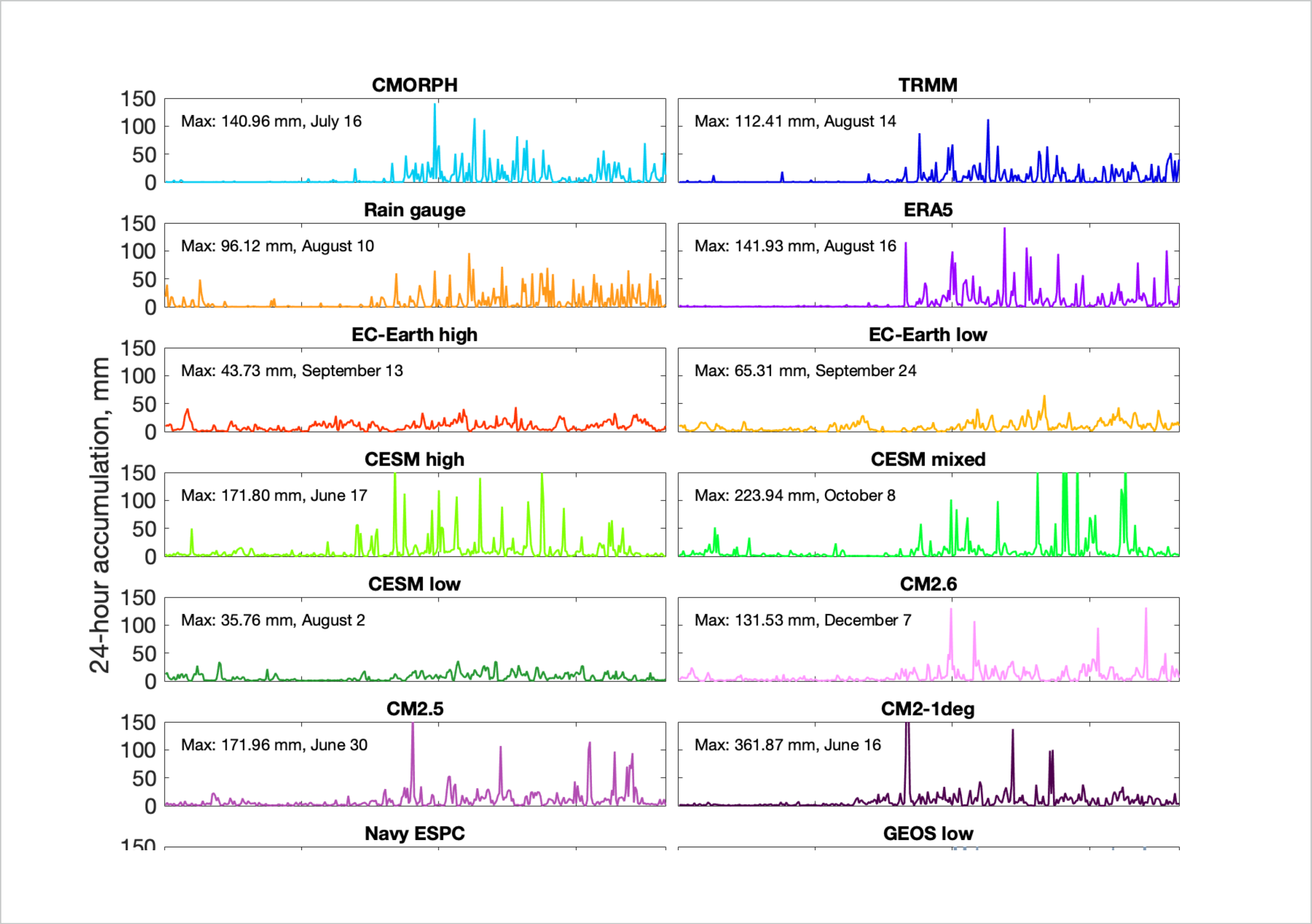
Datasets and models used

- Satellite products: TRMM and CMORPH
- Rain gauges
  - SPURS-II rain gauge over ocean
  - Cluster of seven NOAA rain gauges in US Atlantic sector
- Reanalysis
  - ECMWF ERA5
- Weather model
  - US Navy ESPC
    - NAVGEM atmosphere with 19 km grid spacing
    - HYCOM ocean with 1/25° grid spacing
- Non-operational models
  - EC-Earth: 1/12° ocean, 15 and 60 km atmospheric model grid spacings
  - NOAA GFDL: 1/2° atmosphere, ocean model spacings of 1, 1/4th, 1/10th degree
  - CESM: 1/4° atmosphere with ocean model spacings of 1, 1/10th degree; there is also a 1° / 1° combination
  - CCSM: 1/2° atmosphere, ocean model spacings of 1, 1/10th degree
  - llc2160/GEOS: 1/8° atmosphere + 1/12° ocean, 1/16° atmosphere + 1/24° ocean

Example precipitation time series

At SPURS-II site (10° N, 125° W)

Drizzle effect clearly seen in some models: No days with zero precipitation



Variance analysis of Covey et al. 2018

Their conclusions:

1) Most variance in CMORPH is irregular subdaily

2) Low-resolution climate models do not capture this ISD variance

3. Analysis Methods

Starting from hourly or 3-hourly precipitation data, we resolve the time series into components isolating variations associated with monthly, daily, and subdaily time scales. For each month, let $X_{i,\,n}$ be a time-point value for hour i of day n with $n = 1, 2, \ldots, N$ days and $i = 1, 2, \ldots, D$. ($D = 24$ for hourly data, $D = 8$ for 3-hourly data, etc.) The relevant means are

1. the mean diurnal cycle $\overline{X_i^{\mathrm{dc}}} \equiv N^{-1}\Sigma_{n=1}^{N} X_{i,n},\quad i = 1, 2, \ldots, D$
2. the daily mean $\overline{X_n^{\mathrm{dm}}} \equiv D^{-1}\Sigma_{i=1}^{D} X_{i,n},\quad n = 1, 2, \ldots, N$
3. the overall monthly mean $\overline{X^{\mathrm{all}}} \equiv N^{-1}\Sigma_{n=1}^{N}\overline{X_n^{\mathrm{dm}}} = D^{-1}\Sigma_{i=1}^{D}\overline{X_i^{\mathrm{dc}}}$

Note that $\overline{X_i^{\mathrm{dc}}}$ includes all Fourier harmonics in the daily cycle (once a day "diurnal" term, twice a day "semidiurnal" term, thrice a day "terdiurnal" term, . . .), but it does not include subdaily periods that are not simple harmonics of 24 hr, for example, the principal lunar semidiurnal period of 12.4 hr.

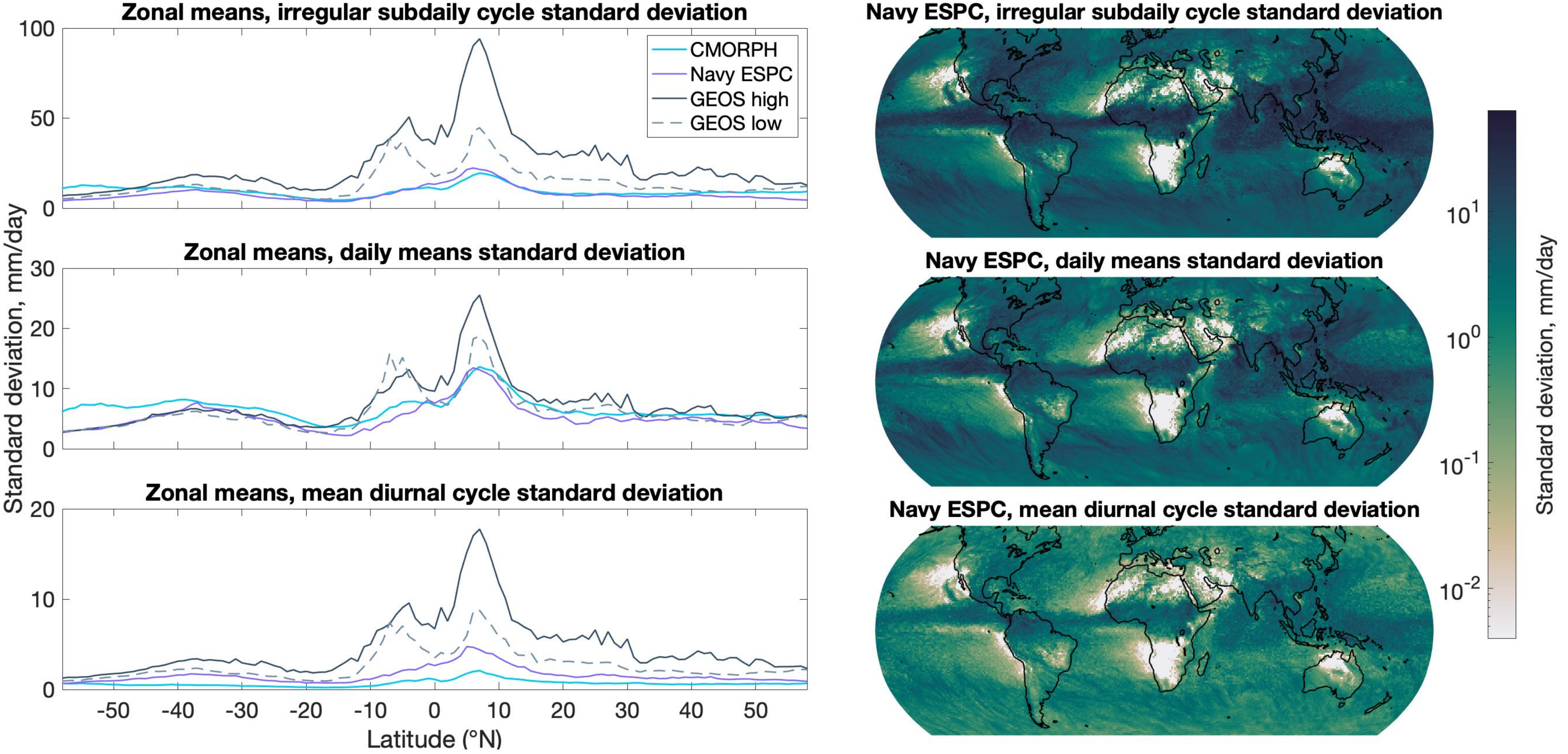
The corresponding variances are

1. $\sigma_{\mathrm{mdc}}^2 \equiv D^{-1}\Sigma_{i=1}^{D}\left(\overline{X_i^{\mathrm{dc}}} - \overline{X^{\mathrm{all}}}\right)^2$
2. $\sigma_{\mathrm{dm}}^2 \equiv N^{-1}\Sigma_{n=1}^{N}\left(\overline{X_n^{\mathrm{dm}}} - \overline{X^{\mathrm{all}}}\right)^2$
3. $\sigma_{\mathrm{all}}^2 \equiv (D\,N)^{-1}\Sigma_{i,n}\left(X_{i,n} - \overline{X^{\mathrm{all}}}\right)^2$

We resolve the overall variance σ_{all}^2 into three orthogonal components: variance of the mean diurnal cycle σ_{mdc}^2, variance of daily means σ_{dm}^2, and a final term that arises from irregular subdaily variations, $\sigma_{\mathrm{isd}}^2 \equiv \sigma_{\mathrm{all}}^2 - \sigma_{\mathrm{mdc}}^2 - \sigma_{\mathrm{dm}}^2$. Thus,

$$\sigma_{\mathrm{all}}^2 = \sigma_{\mathrm{dm}}^2 + \sigma_{\mathrm{mdc}}^2 + \sigma_{\mathrm{isd}}^2 \tag{1}$$

Variance analysis of Covey et al. 2018



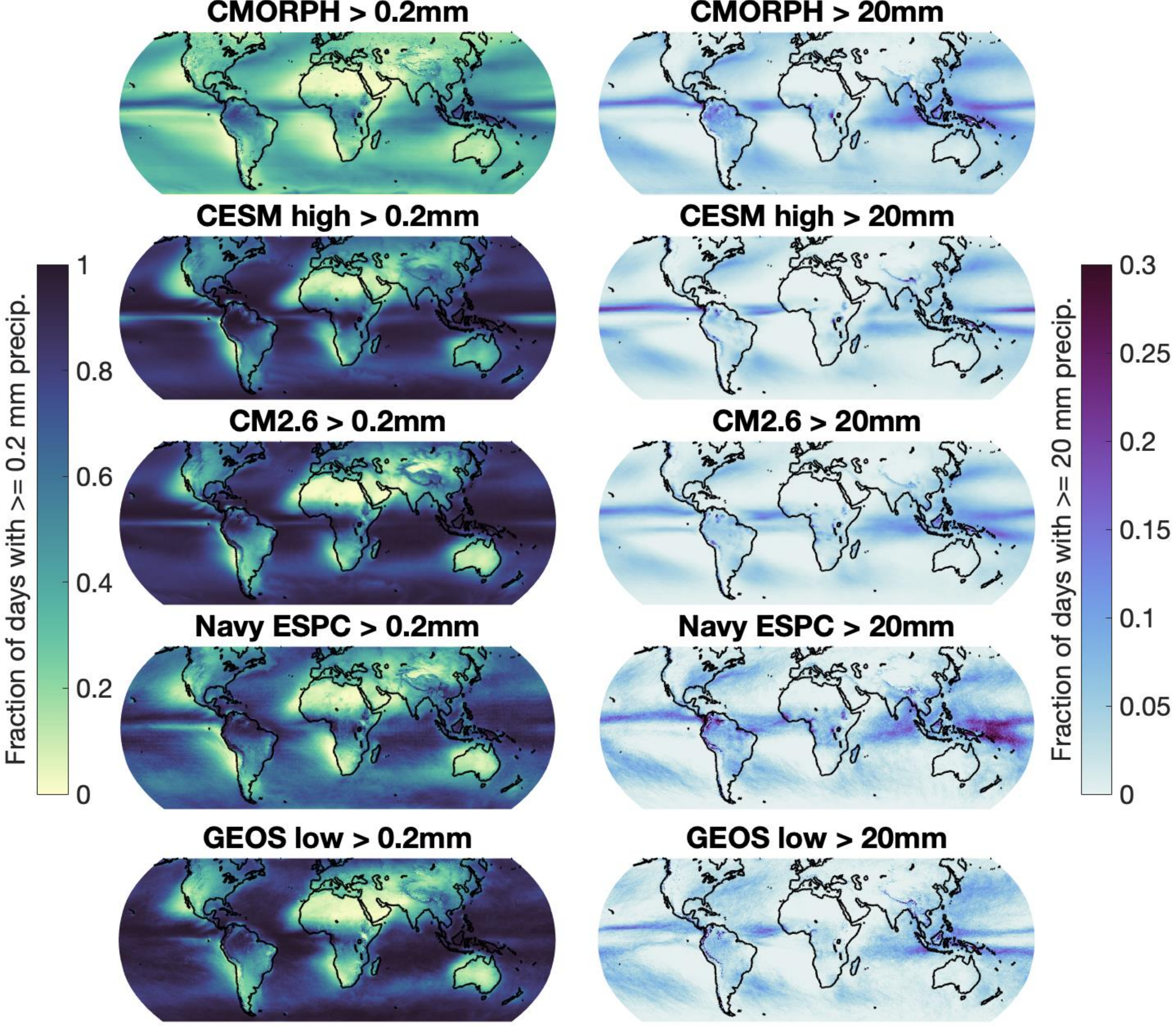
Can’t do Covey et al. 2018 analysis with most of our models…

- They do not save precipitation at sub-daily intervals

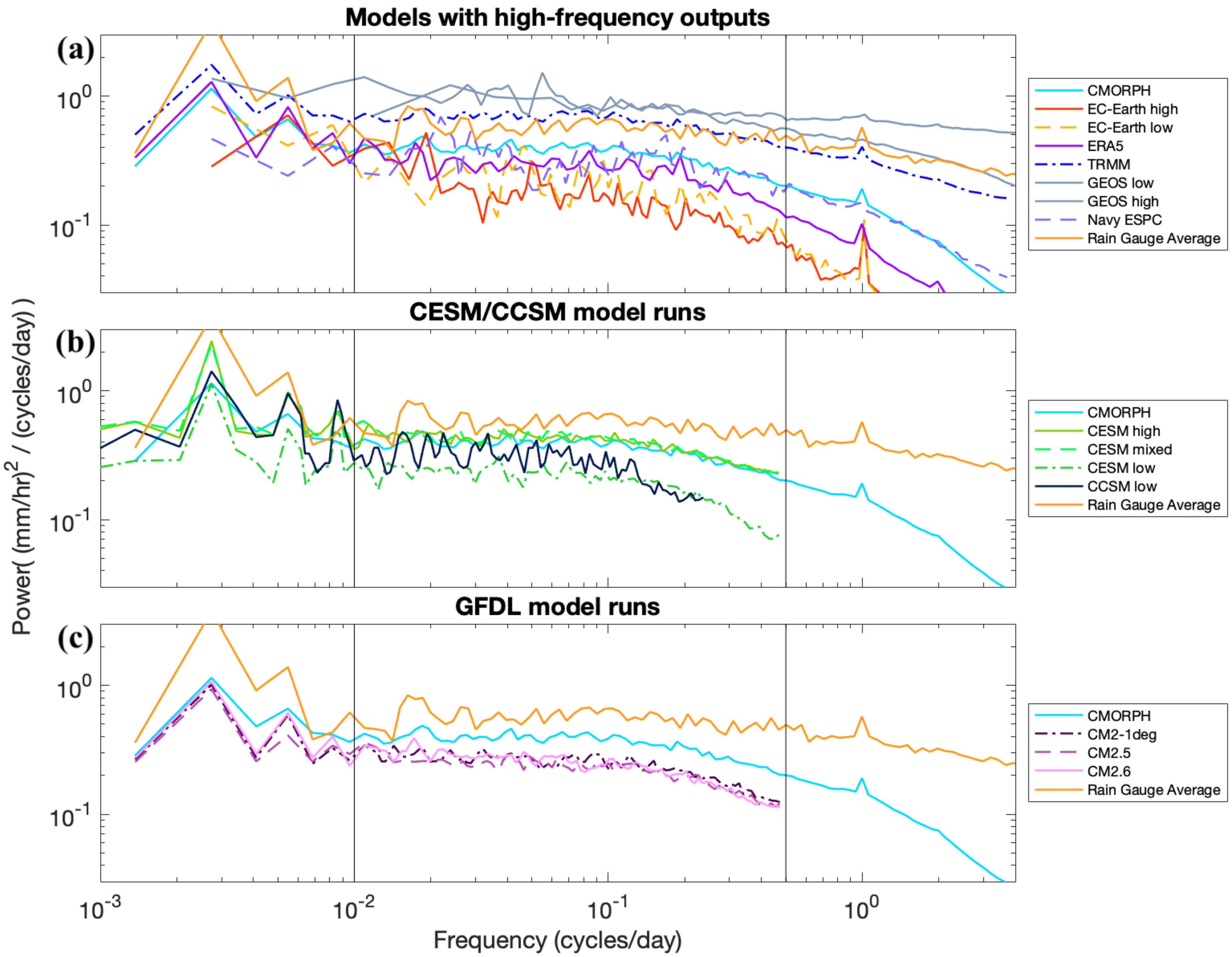
- Instead we turn to frequency spectra and CDFs
  - Frequency spectra analysis focuses on 0.01-0.5 cpd
  - Still relatively high-frequency, in context of climate models

CDFs demonstrate "drizzle effect"

Assimilation in Navy model lessens drizzle effect, strengthens extreme events



Frequency spectra for Atlantic coast region



Impact of atmospheric and ocean model resolution on mid-frequency precipitation variance

Model/Dataset	Spectral Density Integral $(mm/hr)^2$	95% Confidence Interval Width	Region
CMORPH	0.3170	±3.6%	Kuroshio
EC-Earth low	0.1729	±14.8%	Kuroshio
EC-Earth high	0.1986	±14.8%	Kuroshio
ERA5	0.2526	±6.6%	Kuroshio
Navy ESPC	0.2233	±14.8%	Kuroshio
CMORPH	0.2092	±3.5%	Gulf Stream
CESM high	0.2003	±3.3%	Gulf Stream
CESM mixed	0.1745	±3.3%	Gulf Stream
CESM low	0.0904	±3.3%	Gulf Stream
CMORPH	0.1669	±3.6%	Northwest Pacific
CM2-1deg	0.0841	±3.3%	Northwest Pacific
CM2.5	0.0847	±3.2%	Northwest Pacific
CM2.6	0.0921	±3.2%	Northwest Pacific

Table 3. Integral of precipitation variance / spectral density between 0.01-0.5 cycles/day for certain spectra displayed in Figure 9 a-c.

Conclusions of precipitation paper

- Generally, a decrease in atmosphere or ocean model grid spacing leads to greater precipitation variance at high frequencies.
- Ocean model grid spacing matters more when the atmospheric model has relatively fine grid spacing.
- The new llc2160/GEOS simulations have too much high-frequency precipitation variance, relative to observations.
- All models examined here still exhibit the “drizzle effect”.

Extra slides

Covey et al. 2018 results

Most variance is "irregular sub-daily"

CESM simulations here are deficient in ISD variance.

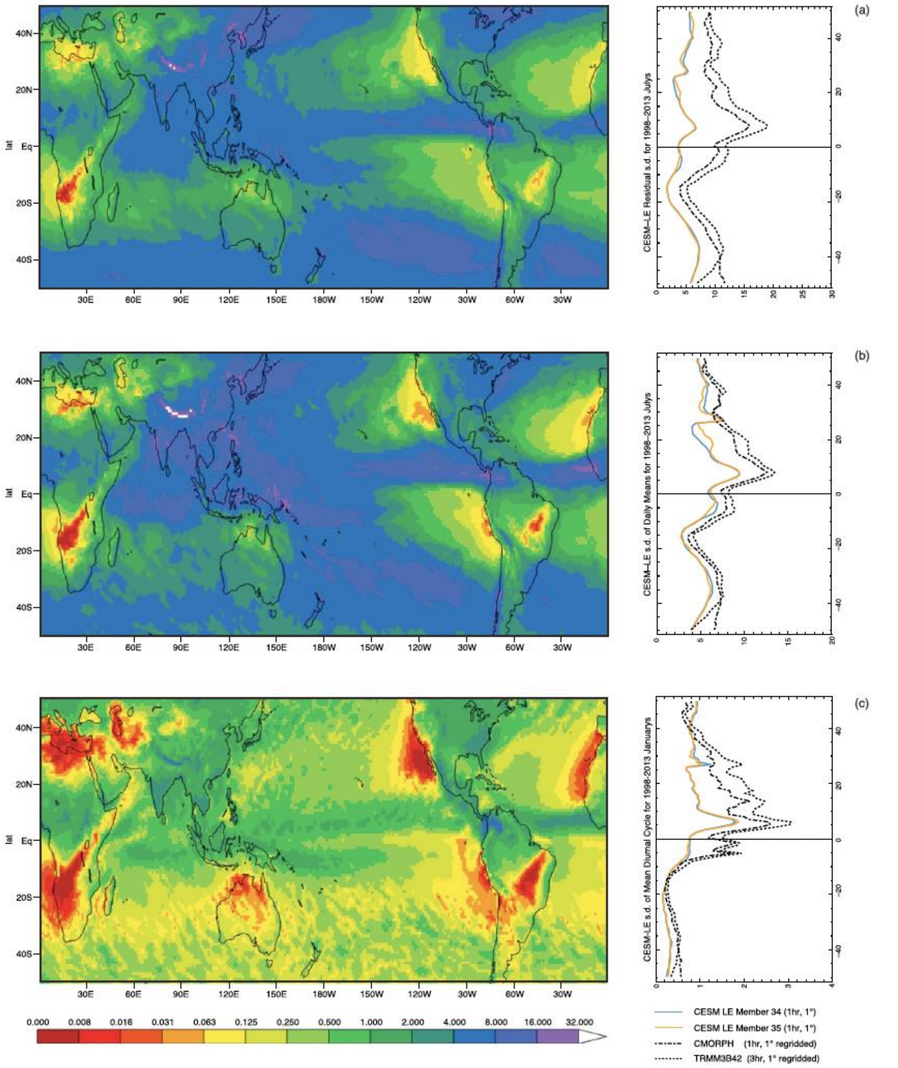
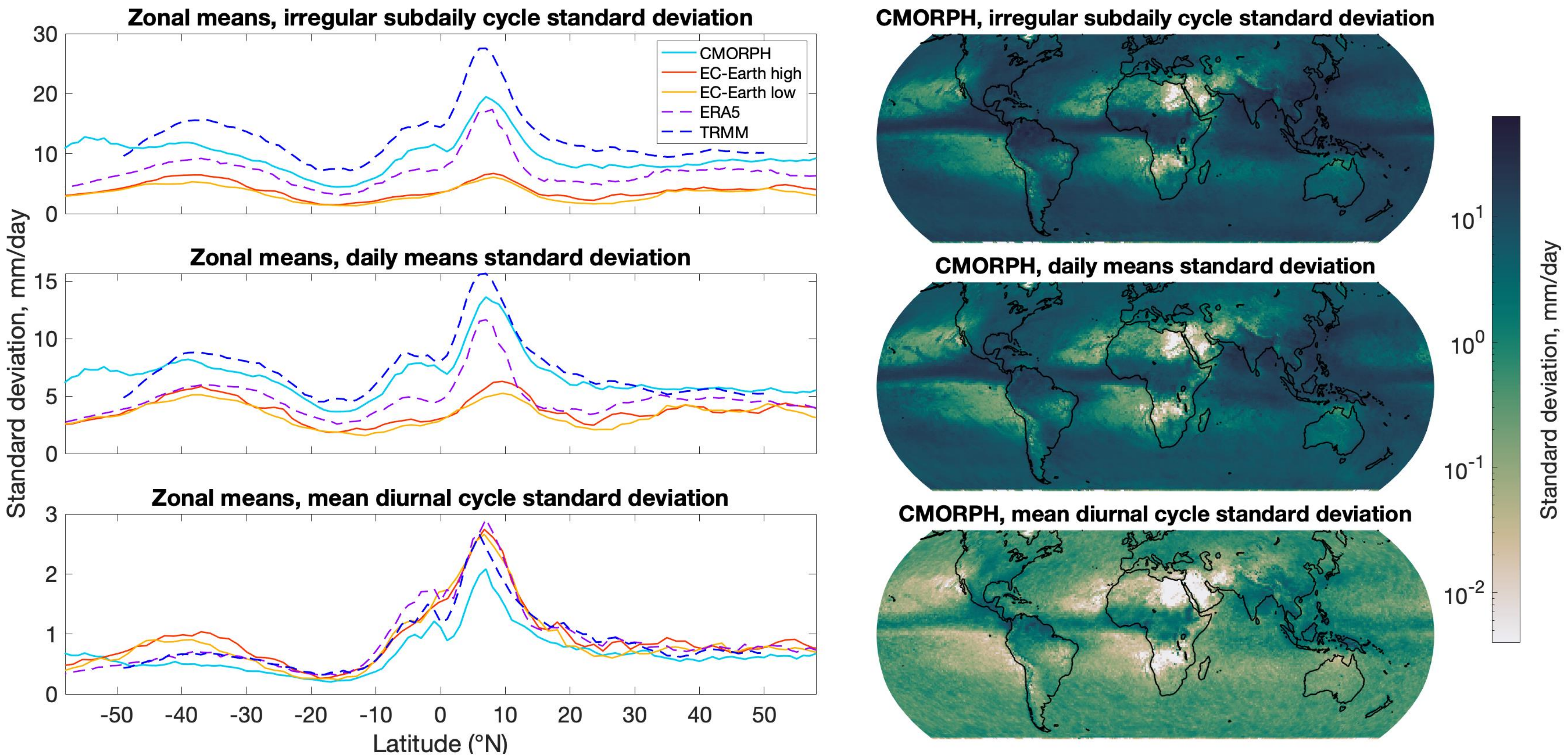
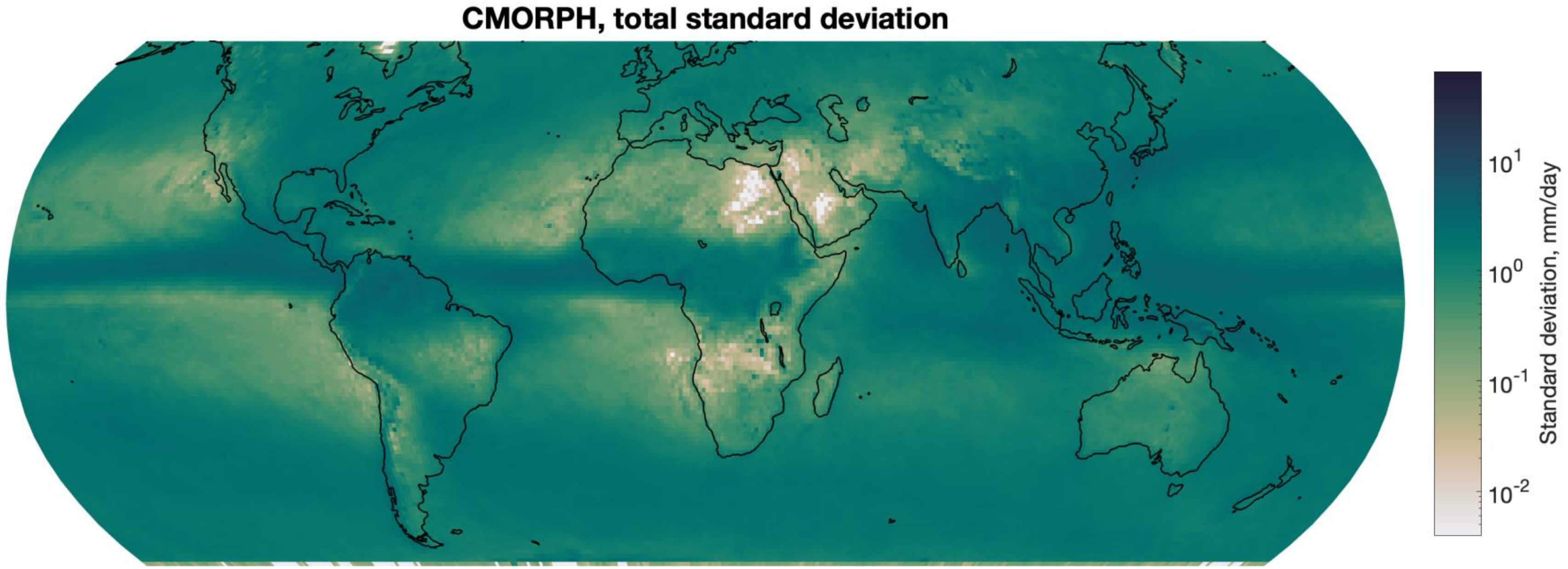
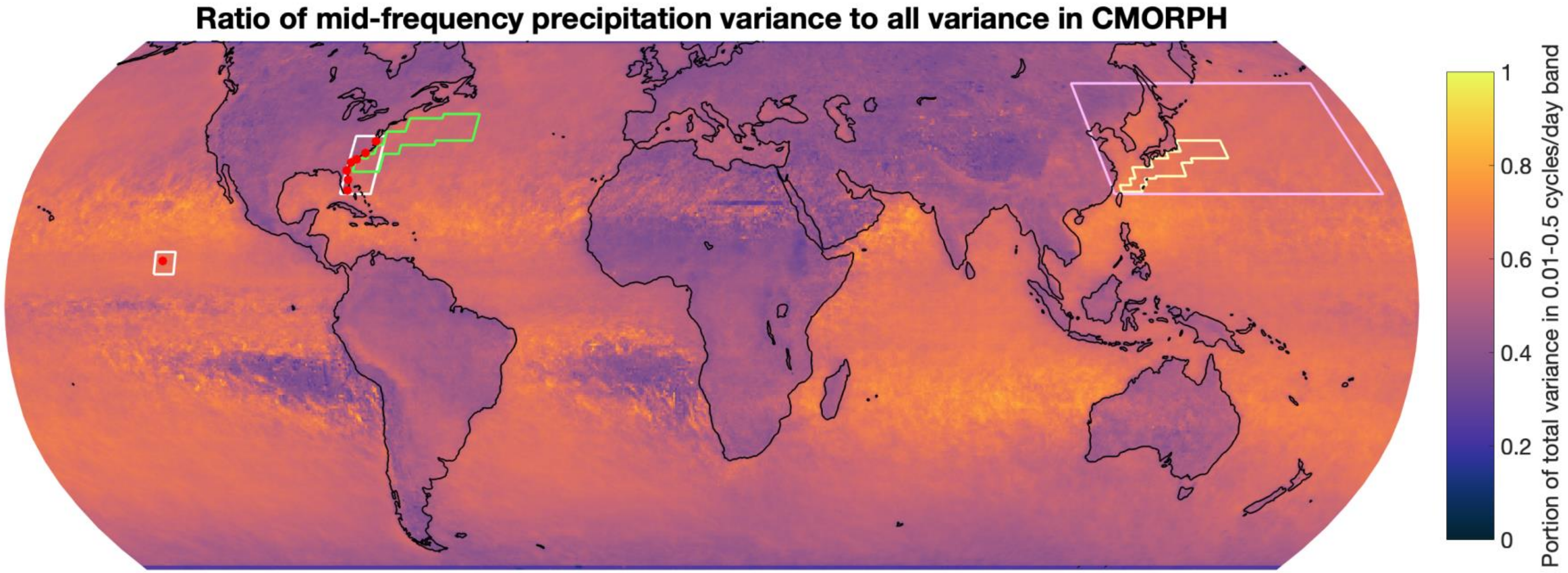


Figure 2. Same standard deviations as in Figure 1 for CESM1 large ensemble simulations (for the same time periods: Composite Julys of the years 1998–2013). Left-hand panels map output from ensemble Member #35 (the same member examined in Trenberth et al., 2017). Right-hand panels show zonal means (root-mean-square) of the Member #35 output together with corresponding zonal means from Member #34. Also shown in the zonal mean plots, for comparison with observations, are data from the subset of Figure 1 in which CMORPH and TRMM are regridded to match the coarser resolution of CESM1. TRMM = Tropical Rainfall Measuring Mission; CESM1 = Community Earth System Model version 1; CESM LE = Community Earth System Model large ensemble; s.d. = standard deviation.

Variance analysis of Covey et al. 2018




CMORPH, total standard deviation
Standard deviation, mm/day
10^{1}
10^{0}
10^{-1}
10^{-2}


Ratio of mid-frequency precipitation variance to all variance in CMORPH
Portion of total variance in 0.01-0.5 cycles/day band
1
0.8
0.6
0.4
0.2
0