What controls the increasing frequency of large precipitation accumulations in a warming climate?

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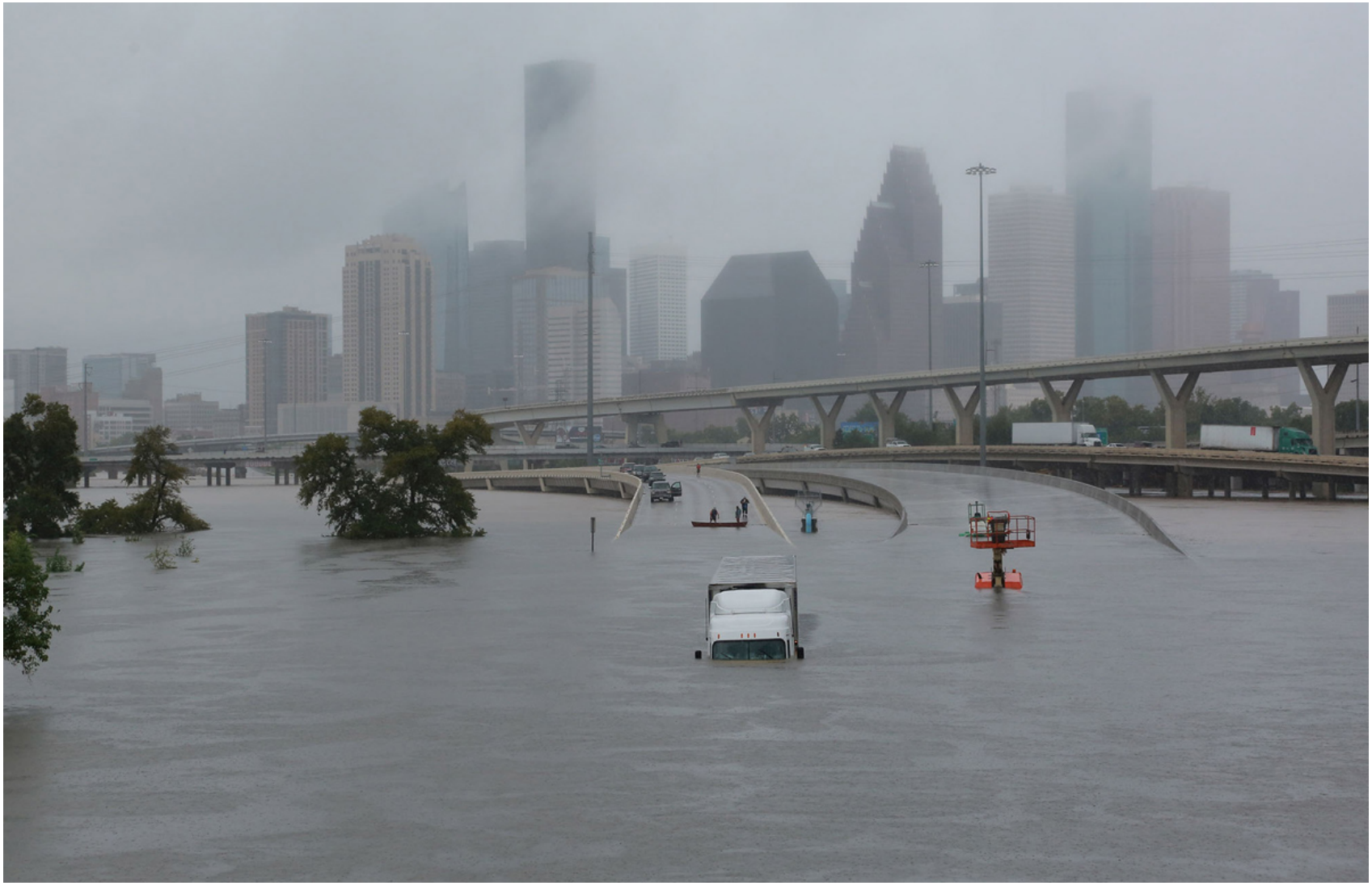
California floods 2017: accumulations ∼200 mm

Houston, Texas, August 2017: accumulations$\sim$1000 mm



Agartala, India, August 2017: accumulations$\sim$1000 mm

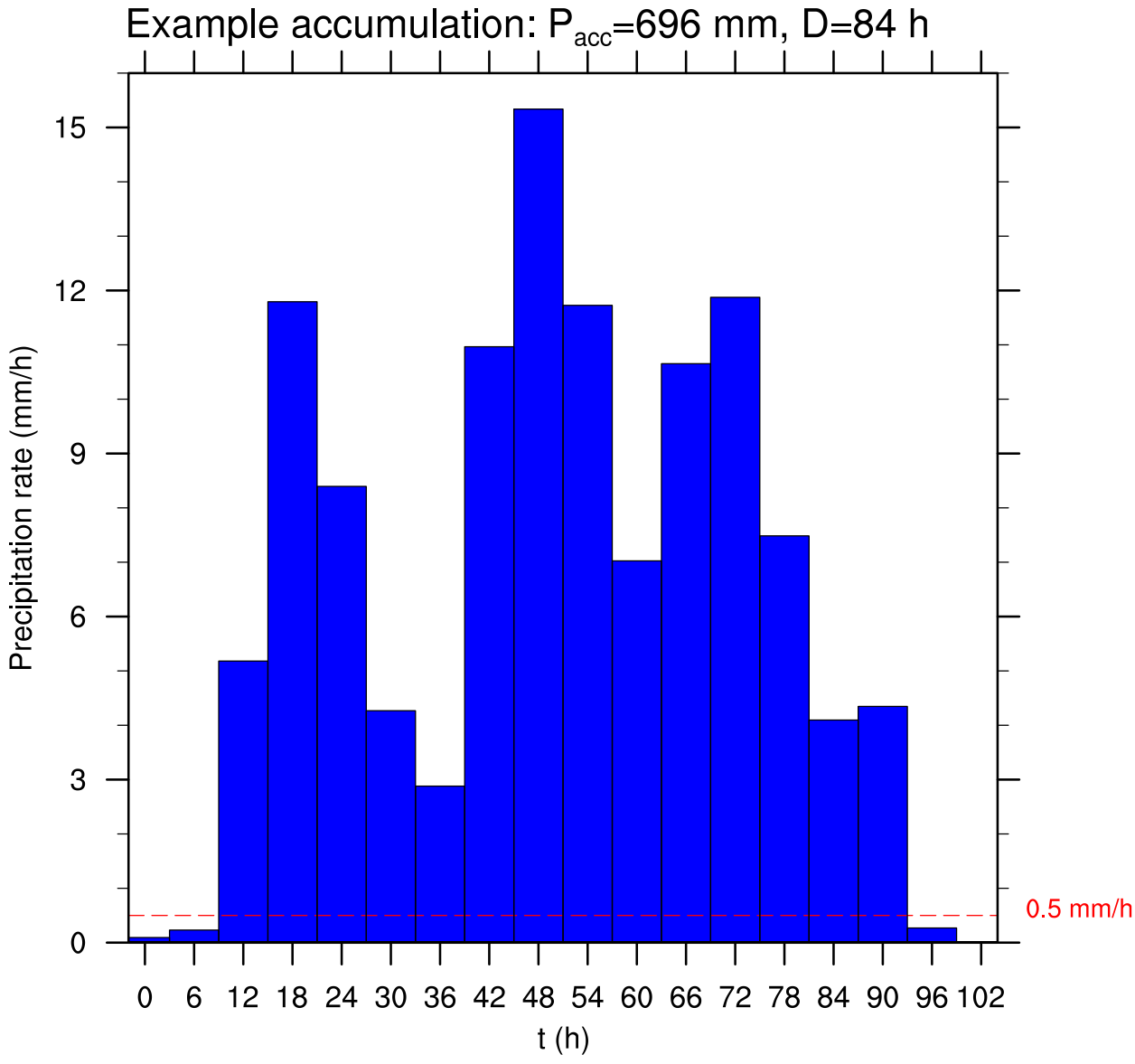
Motivation

1. How much more frequent will major accumulations, e.g., the 10-year or 100-year events, become globally?
2. How much more frequent would major accumulations become if only moisture were to change (much of a difference)?
3. What other factors affect the changing frequency?

CESM Large Ensemble

Moisture budget analyzed with Community Earth System Model (CESM) Large Ensemble (LENS)

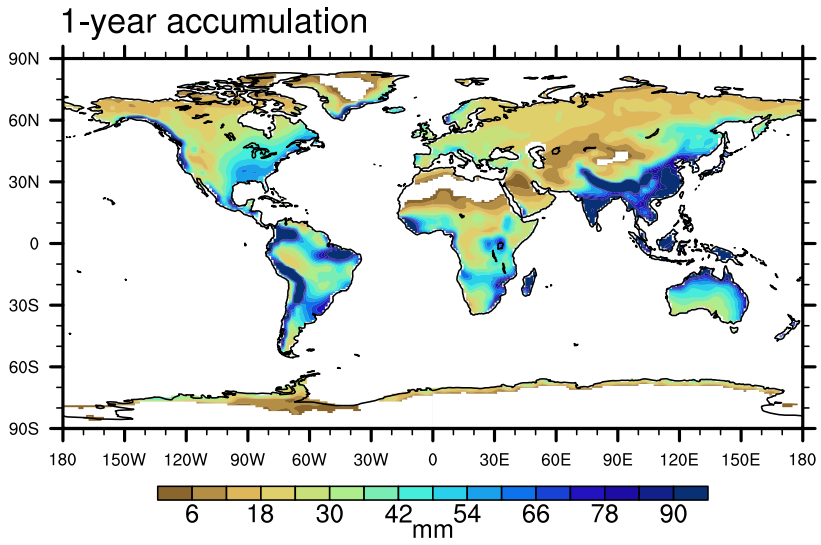
- coupled atmosphere–ocean model
- 40 ensemble members for current climate (1990–2005) and late 21st Century (2071–2080)
- Approx 1° grid spacing, 30 vertical levels
- RCP8.5 forcing from 2006 onward (approx. 3 K warming by late 21st Century)
- Accumulations calculated based on 6-hourly output

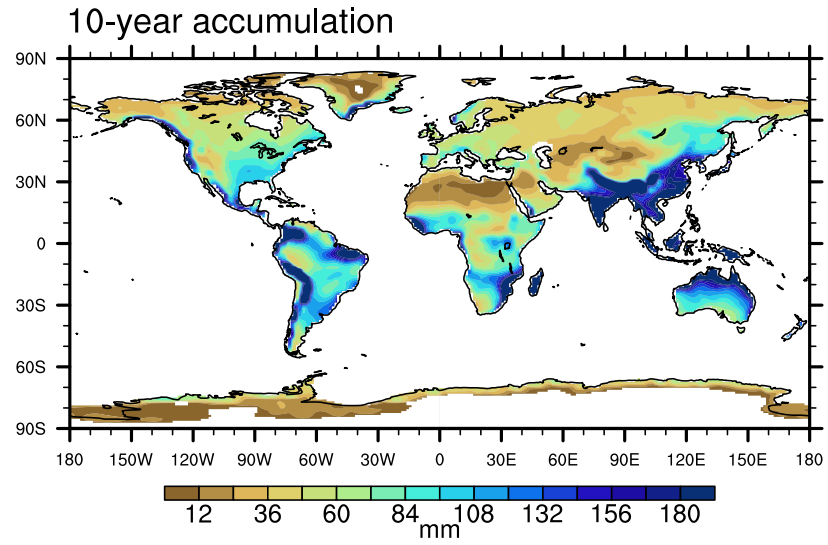

Example accumulation: P_acc=696 mm, D=84 h
Precipitation rate (mm/h)
0
3
6
9
12
15
0.5 mm/h
0 6 12 18 24 30 36 42 48 54 60 66 72 78 84 90 96 102
t (h)

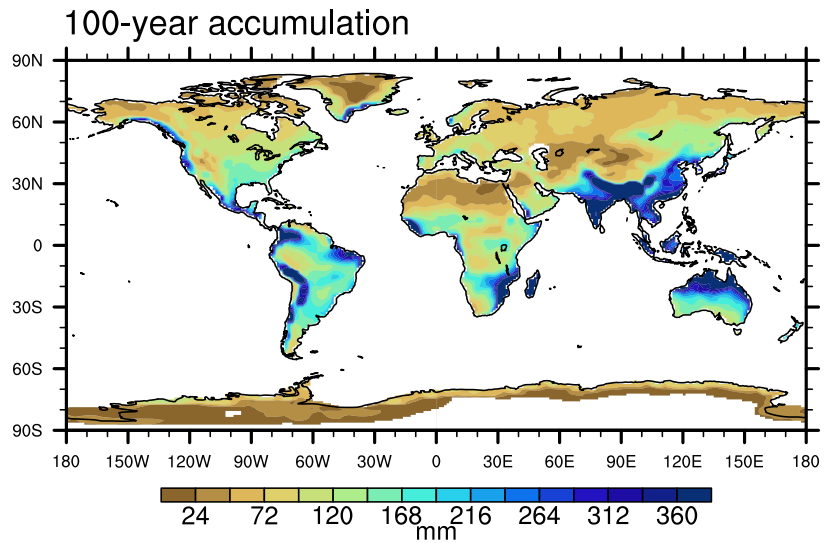
Conditional-mean accumulation as function of recurrence interval

- All 40 members aggregated to give dataset of several 100 years.
- Accumulations binned according to recurrence interval: what is the, e.g., 100-year accumulation?.
- Analysis performed at each grid point for end-of-20th (E20) and end-of-21st (E21) Centuries separately.
- Focus on land.

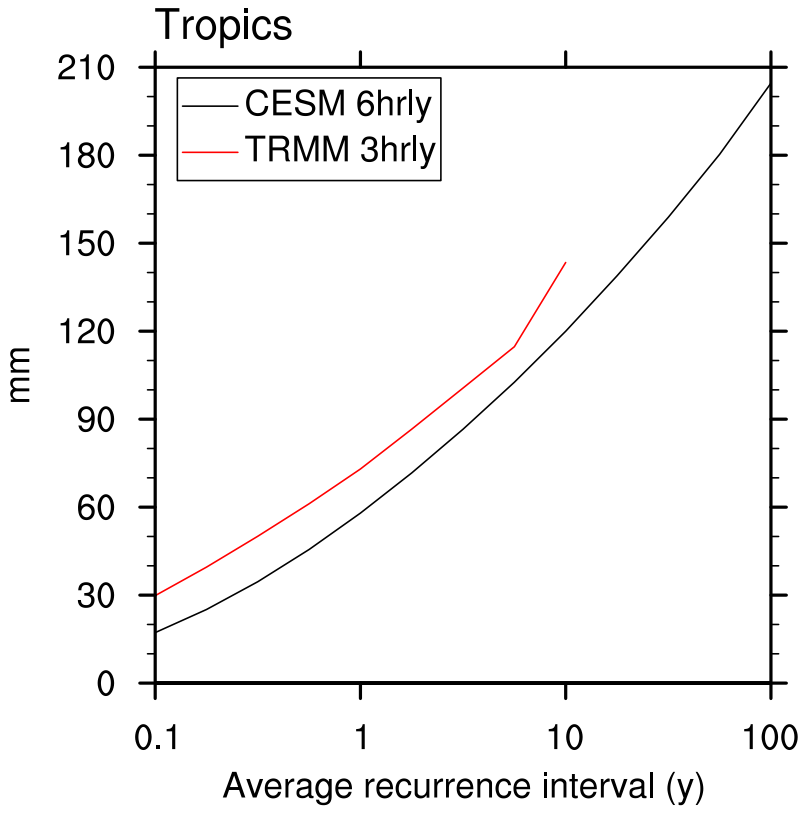
What is the 1, 10, and 100-year accumulation?

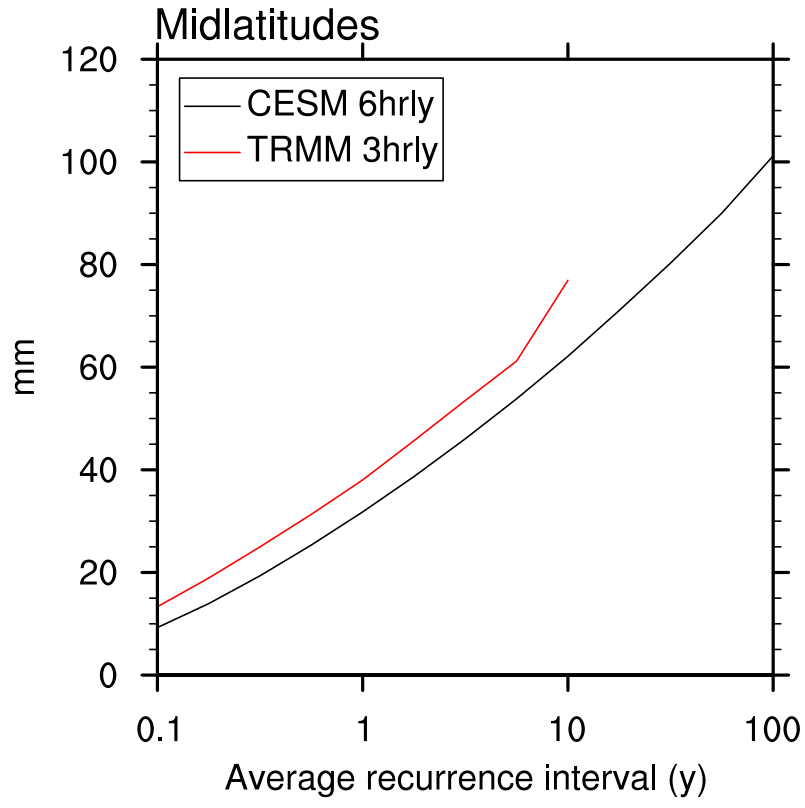




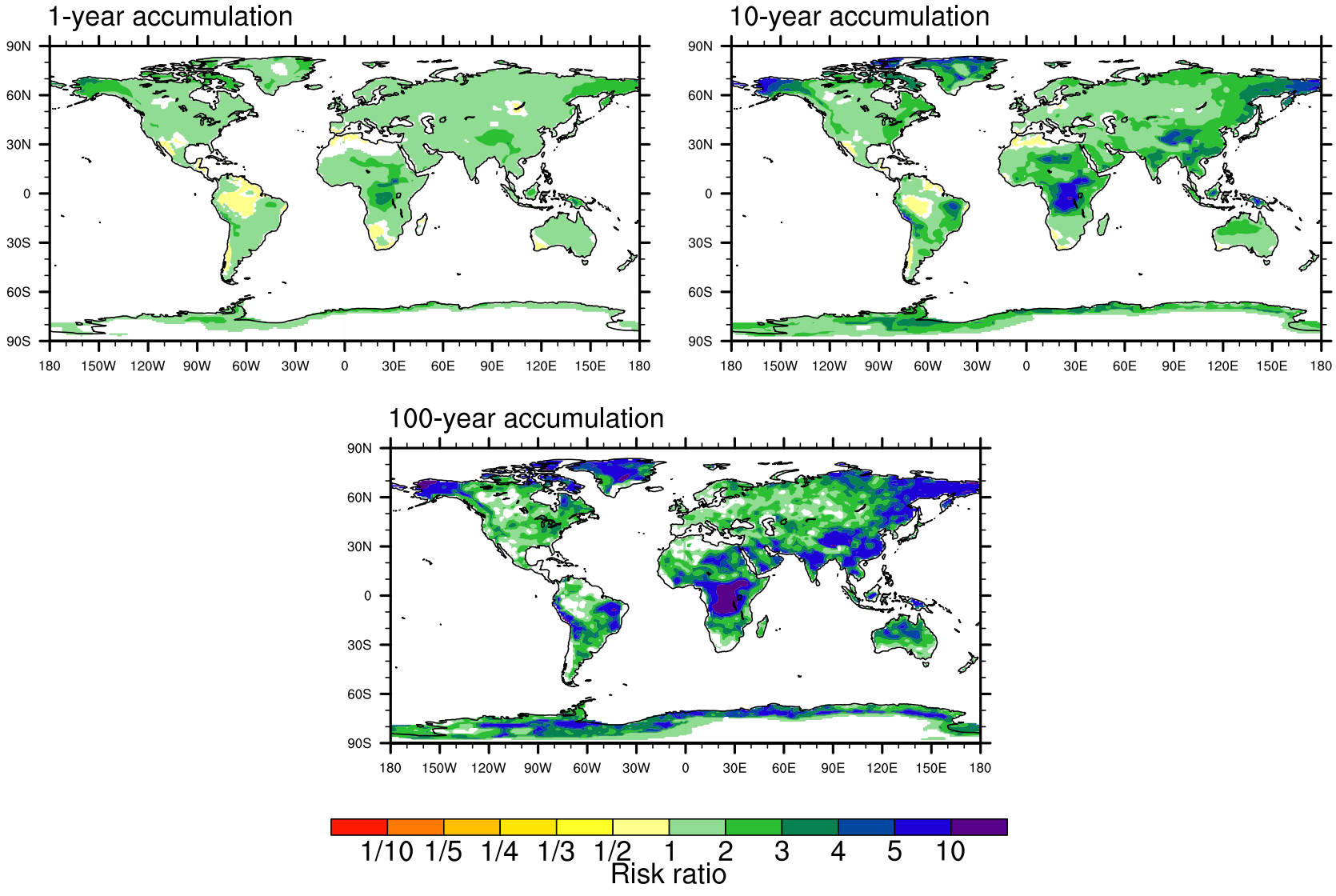


Accumulations well represented compared to TRMM 3B42





Greater increase in frequency for larger accumulations



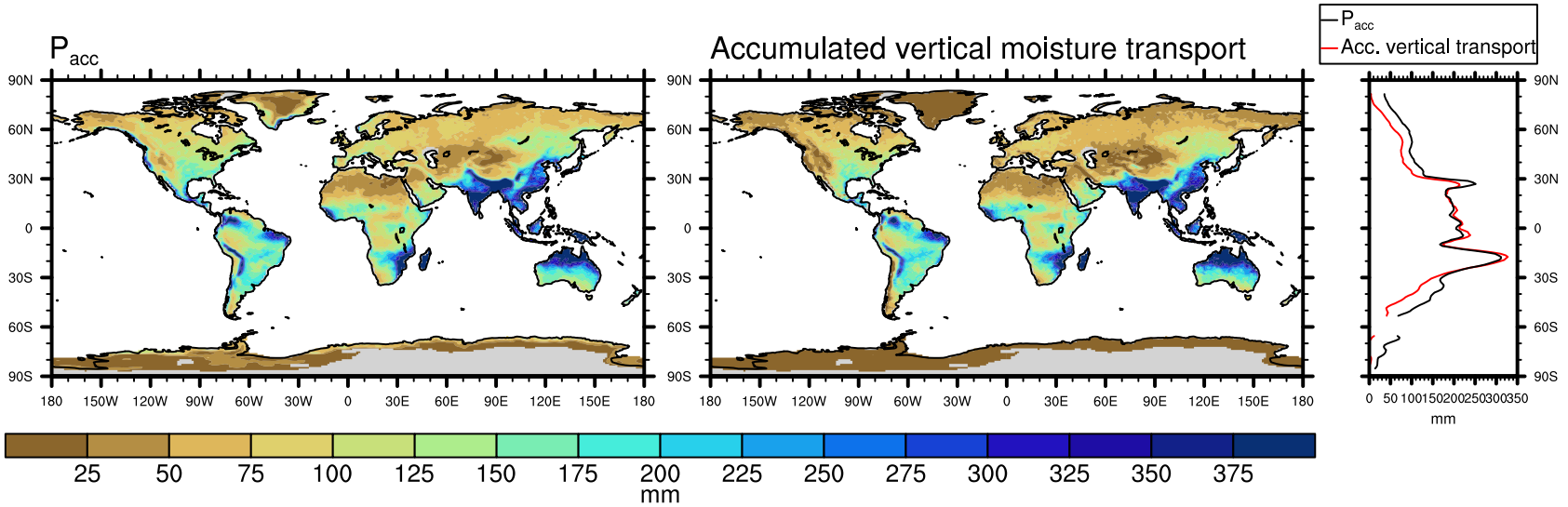
Moisture budget approximation: accumulated precipitation approx. equal to accumulated vertical moisture transport

$$P_{\text{acc}} \approx \underbrace{D \sum_{k} \overline{q_k}\,\overline{C_k}}_{\textit{accumulated vertical moisture transport}}$$

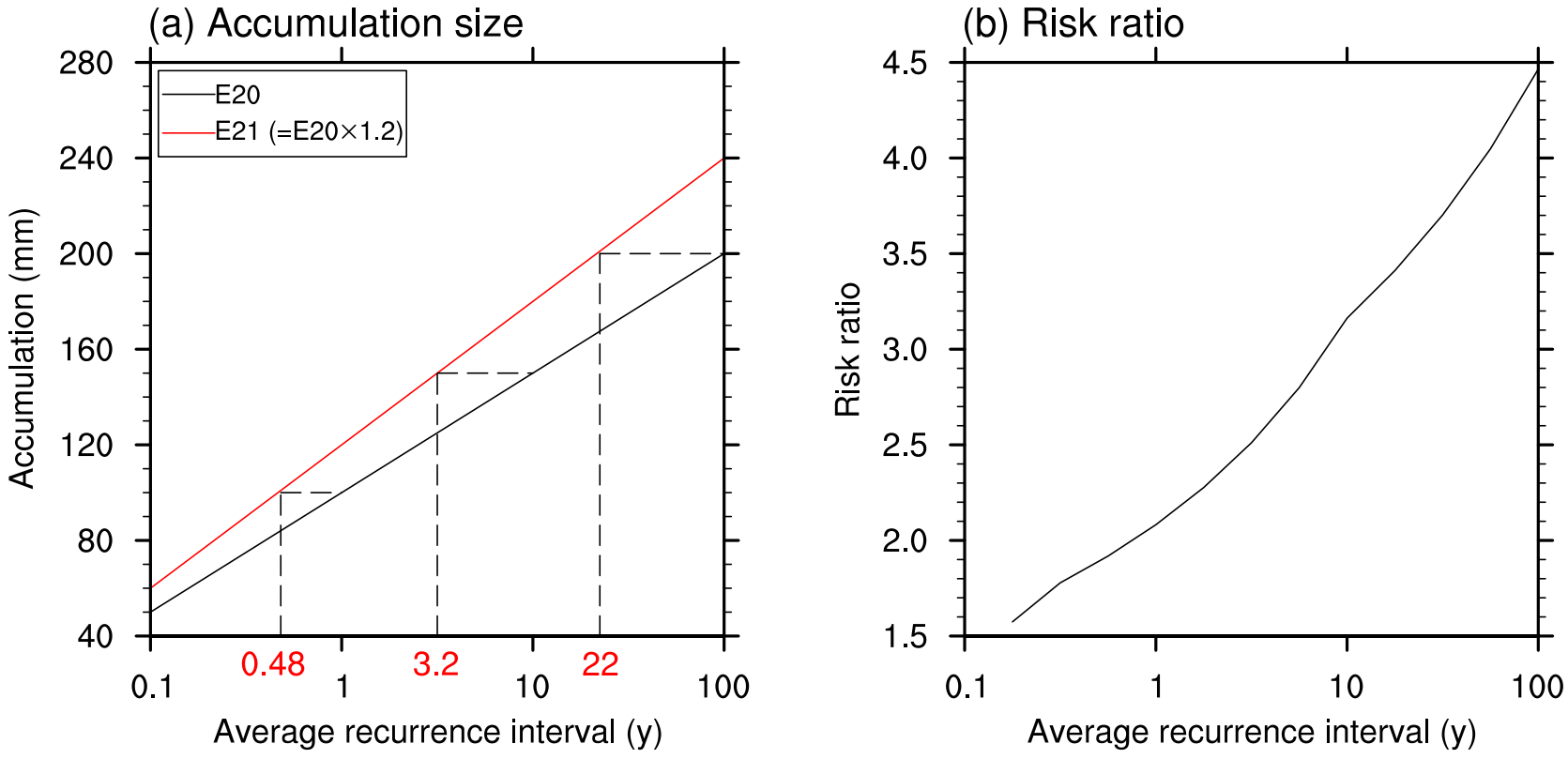
where D is duration, $\overline{q_k}$ is event-mean moisture at the kth model level, and $\overline{C_k}$ is event-mean mass convergence at the kth model level

- Neglects evaporation, moisture advection, and moisture storage terms

Accumulated precip approx. equal to vertical transport for 100-year accumulation (similarly for other recurrence intervals)



Increased frequency of large accumulations in a future climate



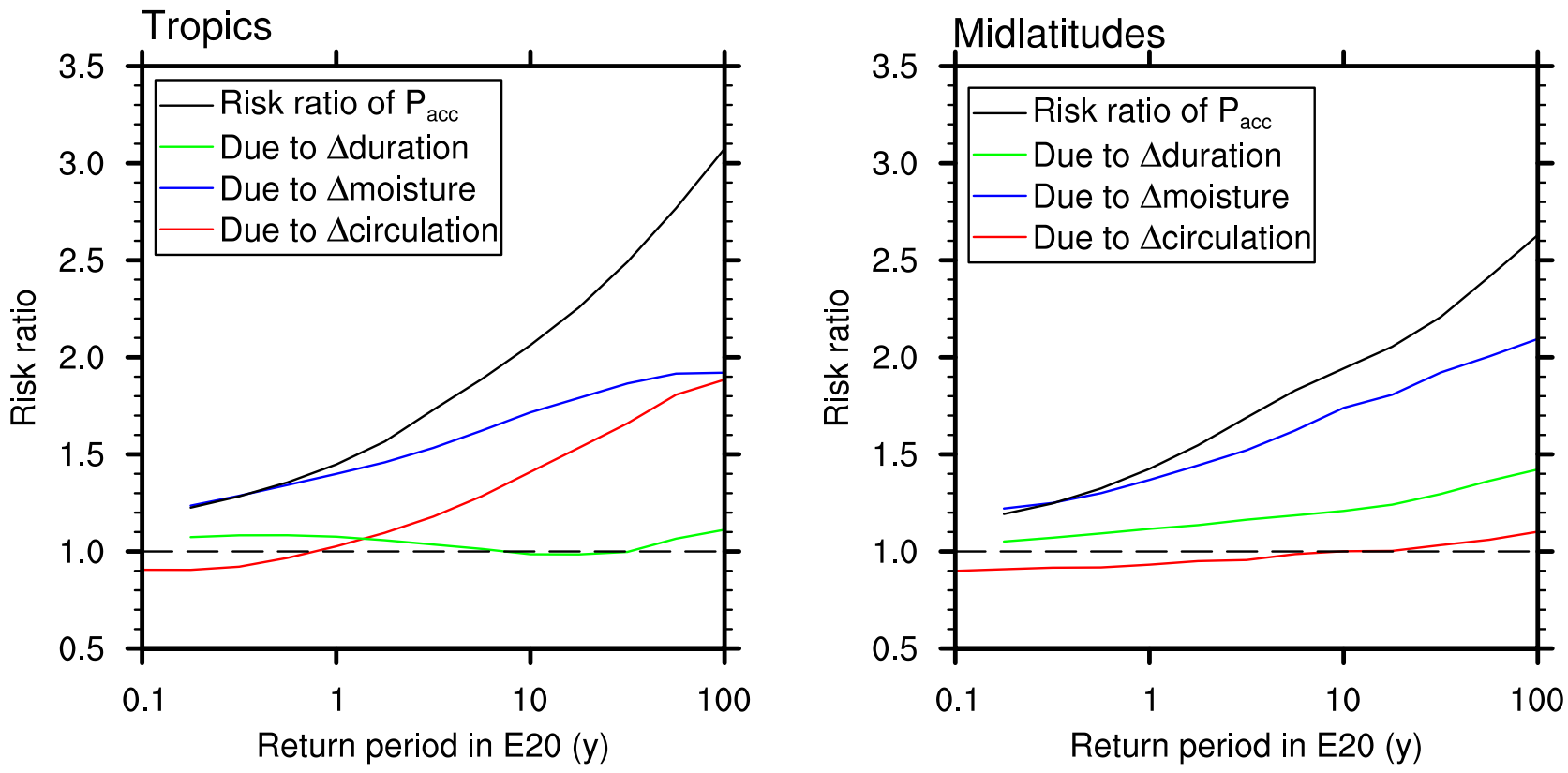
Increases for a given recurrence interval due to individual factors

$$\Delta P_{\text{acc}} \approx \underbrace{D \sum_k \overline{C_k} \Delta \overline{q_k}}_{\textit{due to moisture}}$$

$$+ \underbrace{D \sum_k \overline{q_k} \Delta \overline{C_k}}_{\textit{due to convergence}}$$

$$+ \underbrace{\Delta D \sum_k \overline{q_k}\,\overline{C_k}}_{\textit{due to duration}}$$

For large recurrence intervals, increasing moisture insufficient to explain increasing frequency



Summary

- For accumulation sizes corresponding to low recurrence intervals ($<$1 year), increasing frequency is purely due to greater moisture.
- For accumulation sizes corresponding to longer recurrence intervals ($>$10 years), frequency increases by more than moisture alone explains.
  - In tropics/monsoon regions, circulation changes just as important as moisture increase.
  - In the midlatitudes, increasing duration plays a role, but less important than moisture.

Risk ratio of 20-year accumulation