Title:

Relationships between mesoscale organisation of precipitation and the large-scale atmospheric state in the tropics

Research Question:

How is the spatial structure of precipitation on mesoscales related to the large-scale atmospheric state (both dynamic and thermodynamic)?

Hypotheses:

1) Larger precipitation objects are associated with lower effective entrainment rates

   ⇒ Larger precipitation objects will occur at lower humidity (for a given mean precipitation rate

   ⇒ Larger precipitation objects will have a shallower instability - humidity relationship

2) Larger precipitation objects ~~correspond~~ have larger stratiform components

   ⇒ Larger precipitation objects are associated with more top-heavy vertical motion

   ⇒ Larger precipitation objects are more common in the East Pacific than the West

3) Local precipitation intensity is more sensitive to instability/CAPE than area-mean precipitation

   ⇒ At fixed mean precipitation, local precipitation intensity increases with instability and is insensitive to humidity

   ⇒ Maximum precipitation intensity is a stronger function of instability/CAPE than humidity

Additional questions:

- Does the mean area of objects have the same environmental dependencies as "organisation" metrics such as I_{org}?
- Does the mesoscale structure of precipitation depend on shear?
- What weather systems are associated with more or less organised mesoscale structures?
- Is there a relationship between organisation and clouds/radiation

Approach:

Overall idea is to relate different measures of the spatial distribution of precipitation on mesoscales to the large-scale atmospheric state.

Key aspect is to control for the mean precipitation rate over mesoscale domains; we are interested in the effect of different amounts of organisation for a given value of mean precipitation

Previous relevant work:

Tobin et. al. (2012), JClim
Takes a similar approach using brightness temperature at 0.5° to quantify organisation. Focuses on radiation impacts
We will use higher resolution data (0.1°), consider stability & environment, as somewhat different questions

Louf et al. (2019), GRL
Similar approach from radar data. Does not stratify by mean rainfall
Can make similar figures for entire tropics

Retsch et. al (2022), JGR
Also from radar, does not stratify by mean rainfall

Hsiao et. al (2024), JClim
Quantifies organisation using clustering on TRMM data.
Focusses on SST relationships

Semie & Bony (2020), GRL

Interesting study of precipitation, extremes in both area-averaged precipitation and local precipitation, and organisation

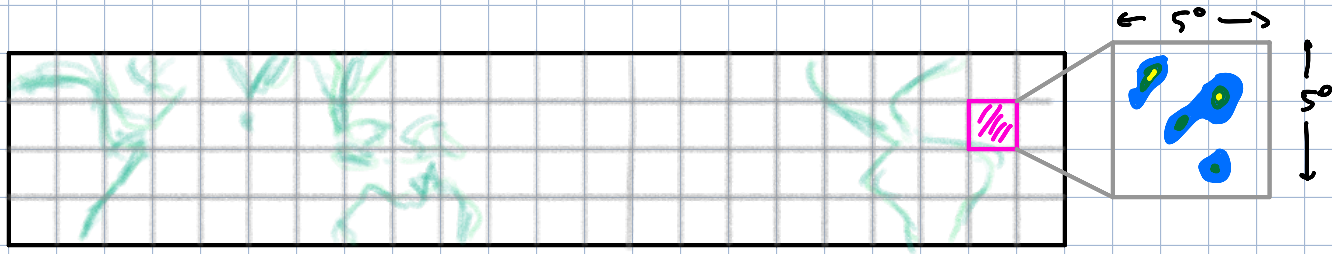
Relevant to Hypothesis 3.

Method & Data:

Mesoscale organisation of precipitation:

Use IMERG 30 minute 0.1 degree precipitation estimate over tropics

Define a grid of mesoscale domains (e.g., 2° or 5°)



At each grid calculate precipitation objects based on a precipitation threshold

For each day (48 snapshots) calculate the following statistics:

P_m	mean precipitation
P_I	precipitation intensity
P_{max}	maximum precipitation or 99.5^{th} percentile
a_s	area fraction of precipitation
A_m	mean area of objects
I_{ORG}	organisation metrics

Large-scale atmospheric state

Average the following ERA5 variables to the 5×5° mesoscale grid for each day:

2D:

- column water vapor
- column saturation fraction

3D:
- temperature
- humidity
- vertical pressure velocity
- horizontal velocity

Figures:

Fig 1:

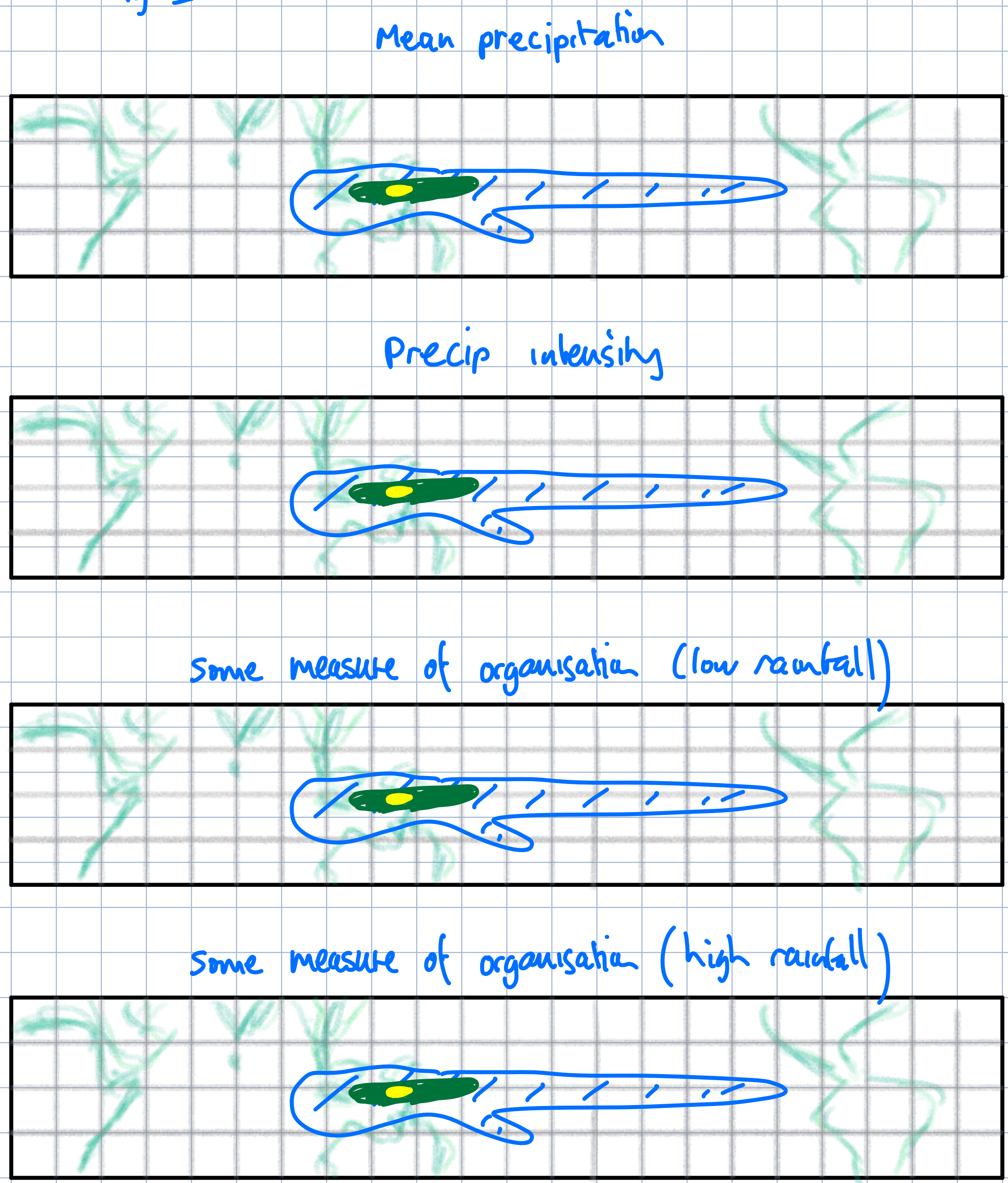


Fig 2: Panel (a) very similar to a figure in Tobin et. al (2012)
Does organisation make rainfall possible in a drier atmosphere?
Is organisation associated with higher or lower stability/CAPE

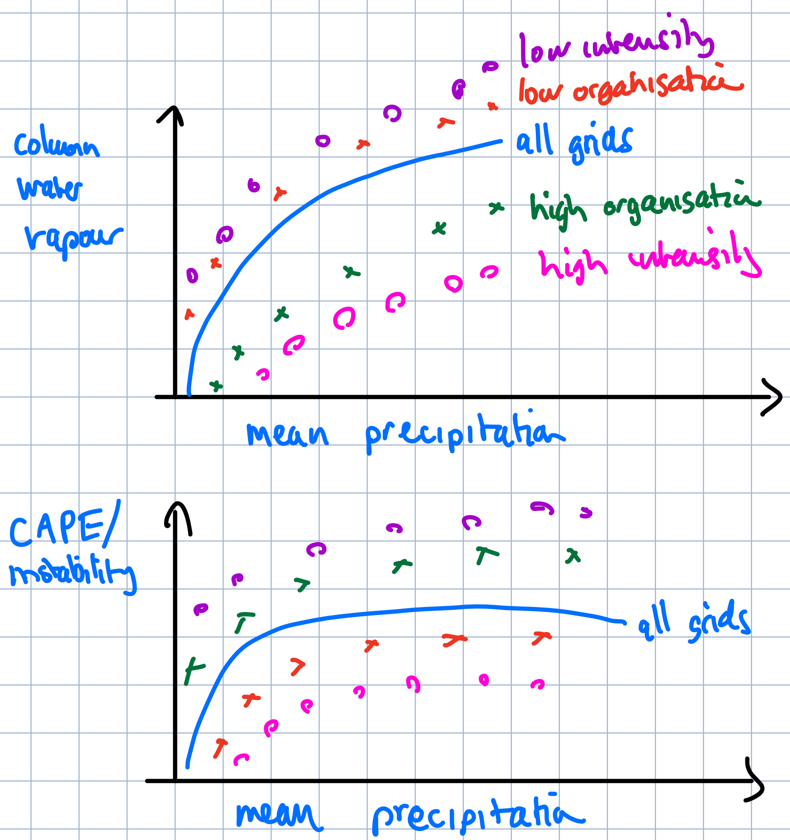


Fig 3: Does organisation change the vertical structure of upward motion?

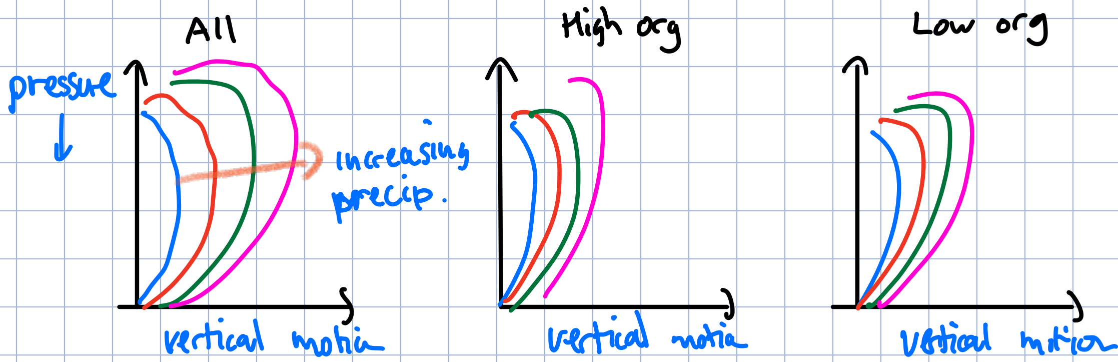
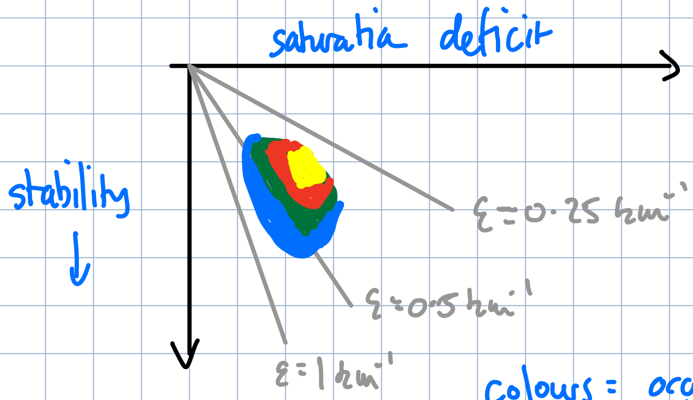
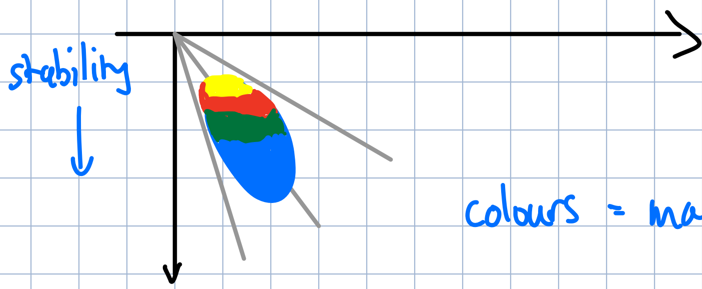


Fig 4: Is organisation associated with lower entrainment
Following Palmer & Singh 2024.



colours = organisation (I_{org} or A_m)



colours = max precipitation

Fig 5.

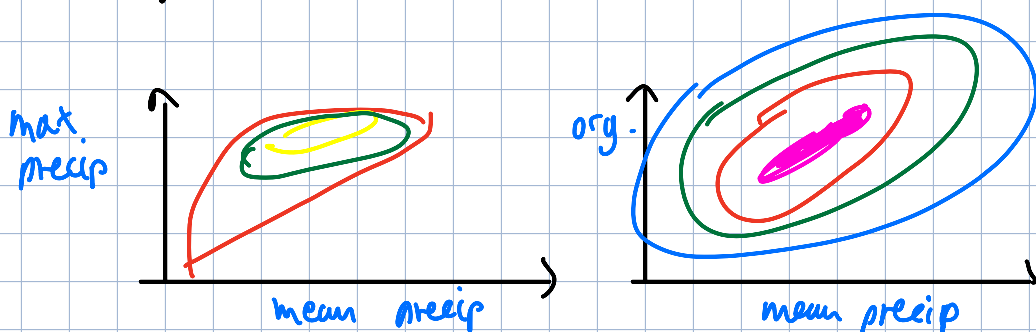


Fig 6.

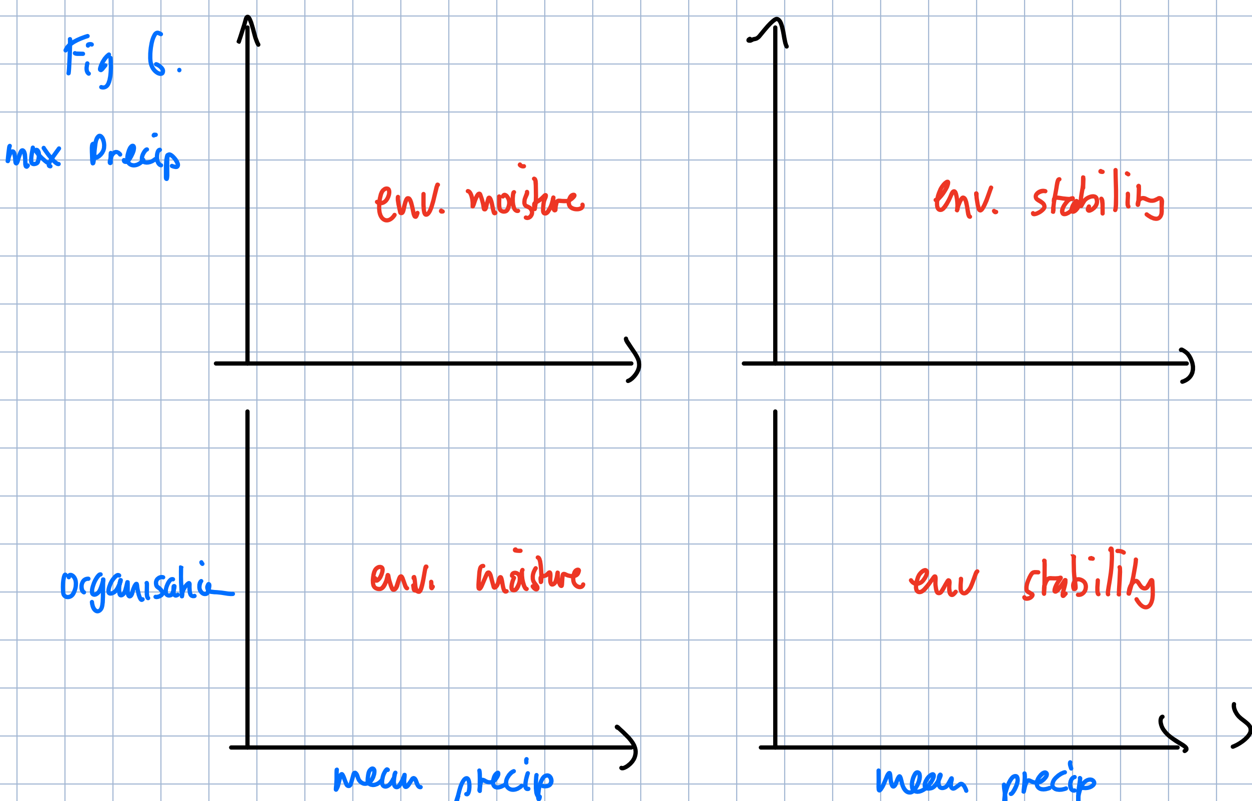


Fig 7.

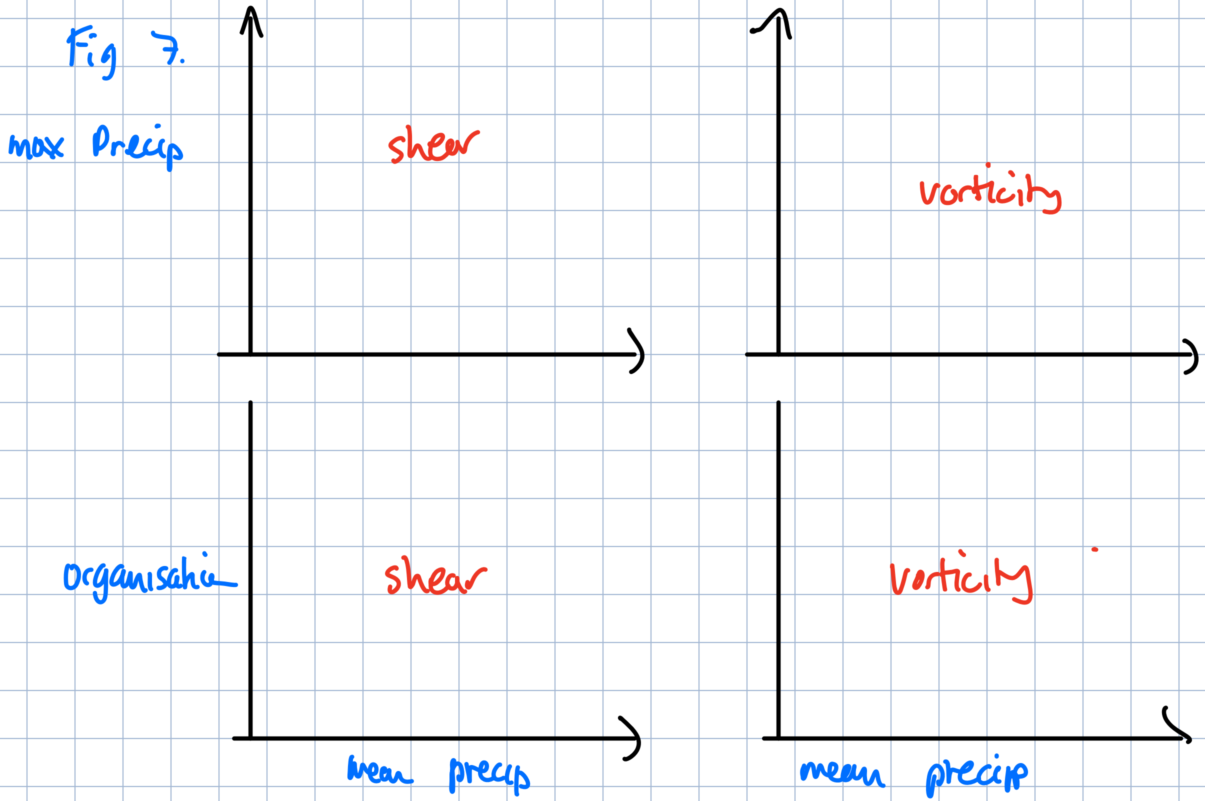
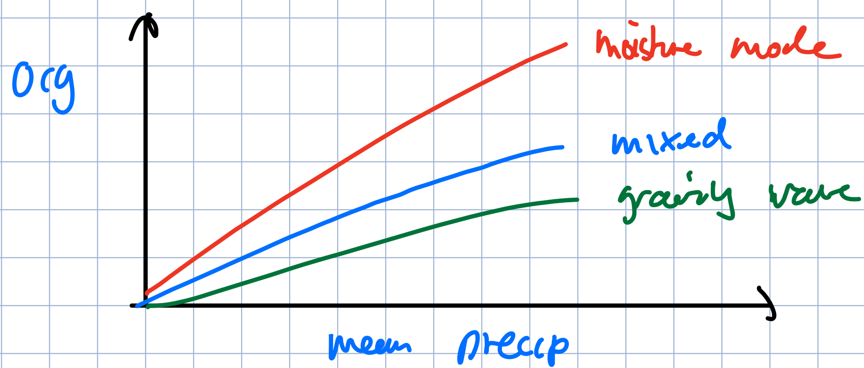

max Precip
shear
vorticity
organisation
shear
vorticity
mean precip
mean precip

Fig 8:


Org
moisture mode
mixed
gravity wave
mean precip

Tasks

1) Calculate mesoscale precipitation statistics on 5x5° daily grid (Philip)

2) Calculate ERA5 averages on 5x5° daily grid (Marty)

3) Relate precipitation statistics to large-scale thermodynamic conditions (Fig 2, 5, 6) (Dongqi)

4) Relate precipitation statistics to large-scale dynamical conditions (Fig 7)

4) Plot spatial distribution of precipitation statistics (Fig 1) (Yi-Xian)

5) Plot large-scale vertical velocity as a function of mean precipitation and organisation metrics (Fig 3) (Yi-Xian)

6) Plot stability humidity phase space (Fig. 4 (Marty)

7) Plot organisation as function of mean precipitation for different weather systems (Fig 8) (Reyhan)