Orographic influence on rainfall distribution over the Western Ghats: Insights from radar data and WRF Simulations

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1. Introduction

One of the heaviest rainfall receiving regions during the Indian summer monsoon (ISM) is anchored around the orographic barriers of the Western Ghats (WG) in peninsular India (Romatschke and Houze 2011).

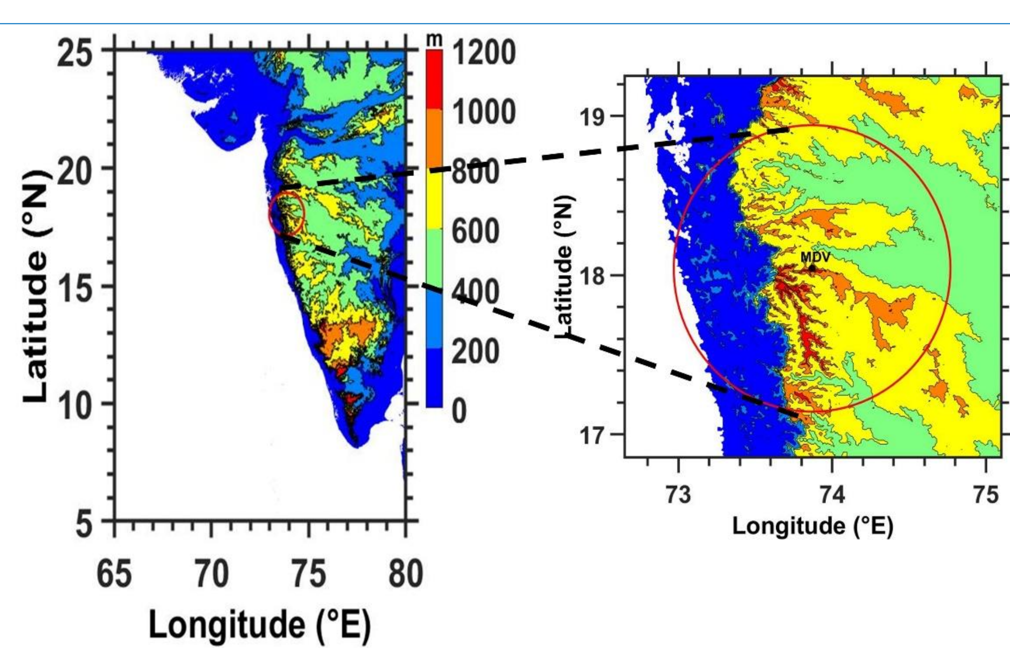
Rainfall increases from the Arabian Sea towards the Indian west coast, reaches a peak, and then decreases drastically in the leeward side of the WG. However, the exact location of rainfall maxima and associated factors are still not clear.

We address following key questions using high-resolution ground-weather radar data and Advanced Weather Research and Forecasting (WRF-ARW) simulations

- Where is the rainfall maximum wrt WG orography?
- What is the impact of orography on the rainfall distribution over the WG?

2. Study site, Data and Methodology

Radar Data



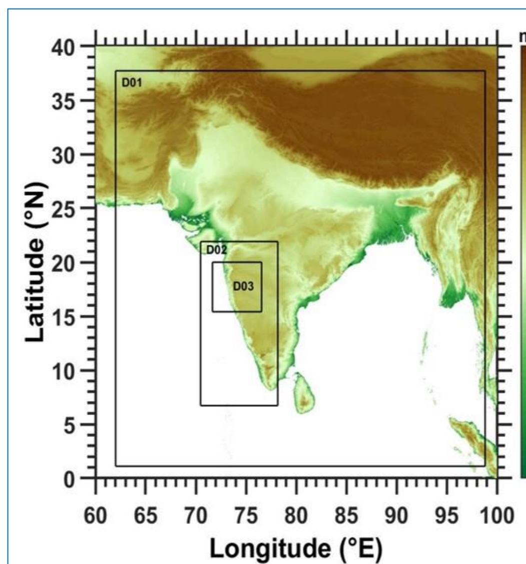
Topography map of the Western Ghats with a zoomed-in view around the radar site, MDV. The red circle indicates the100 km radar range.

- Radar reflectivity (Z) data collected during June-September (JJAS) 2018; 2500 h of 2928 h of radar data used
- Prior to analysis, Z data corrected for bias and attenuation (Ambuj et al. 2024)
- Volume data converted to 3 D Cartesian coordinates with a resolution of 1 km × 1 km in the horizontal and 0.25 km in the vertical
- Columns having Z<5 dBZ at 2 km height (AGL) are discarded
- For spatial rainfall estimation, Z at 1.5 km AGL (~2.8 km AMSL) was used with cloud-type-specific Z-R relationships (Das et al., 2017):

  $Z=144R^{1.31}$ (Shallow-convective),
  $Z=96R^{1.61}$ (convective)
  $Z=272R^{1.26}$ (stratiform)
  $Z=218R^{1.36}$ (mixed stratiform-convective)

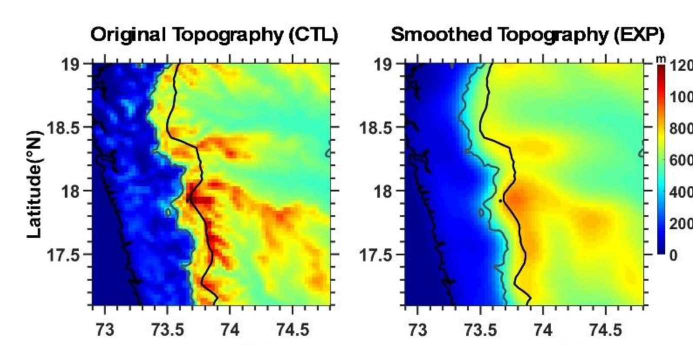
- Topography data was obtained from Shuttle Radar Topography Mission (SRTM, ~1 km), and rainfall climatology was taken from 16 years (1998-2013) of TRMM PR 2A25 data (0.05° resolution).

WRF-ARW



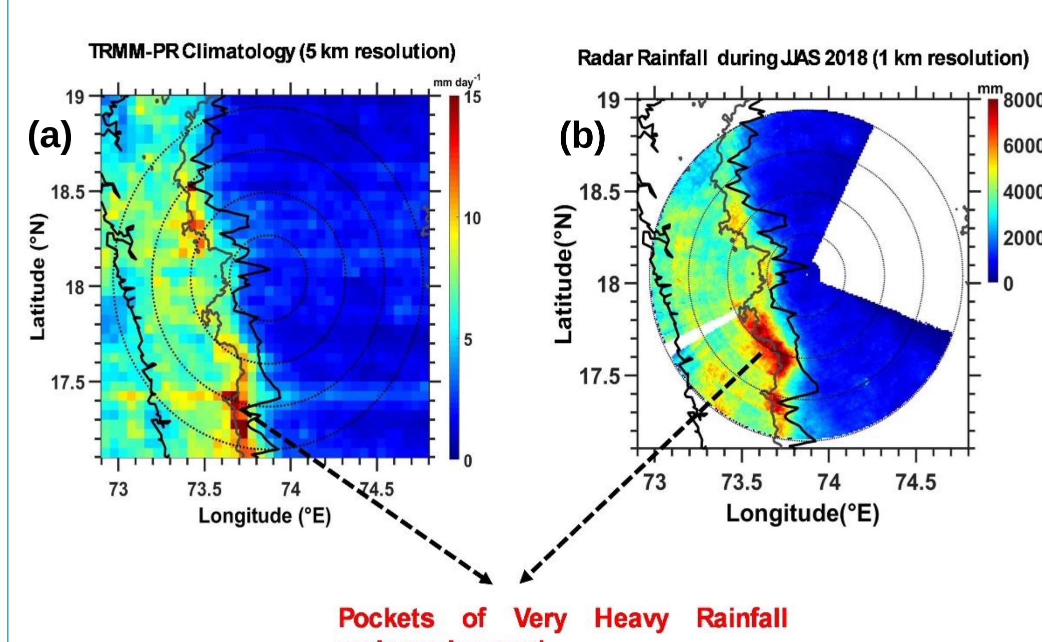
Parameter	D01	D02	D03
Horizontal resolution	27 km	9 km	3 km
Terrain elevation	USGS topography data	Same	Same
Initialization data	ERA5 0.25 deg (3- hourly)	Same with Boundary conditions updated every 3 -hourly	Same with Boundary conditions updated every 3 -hourly
Vertical levels	Eta (45 levels)	same	same
Microphysics	Thompson scheme	same	same
Cumulus scheme	Kain-Fritsch scheme	Kain-Fritsch scheme	No scheme
PBL	YSU Scheme	same	same

- An active rainfall period during 11-18 August 2018 is simulated with initial 18 h spin-up data discarded from the analysis
- To analyse the role of steep slopes on the rainfall,the WRF-ARW model was run for two cases: (a) a control run with actual orography (CTL) and (b) an experiment with smoothed slopes using a Gaussian filter (EXP).

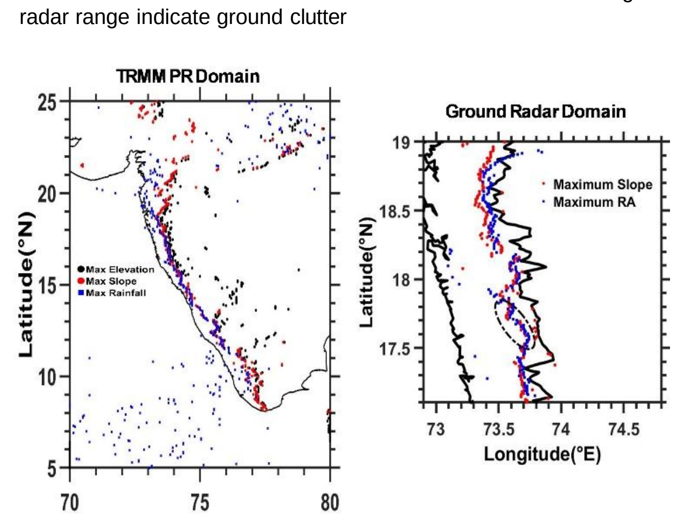


3. Results

Positioning of Rainfall Maxima



Spatial distribution of (a) TRMM-PR based June-September climatology of mean daily rainfall and (b) total accumulated rainfall derived using radar data.The thick black line over the WG shows the location of mountain summit and the thin (gray) curve represents 500 m elevation. Circles are drawn at intervals of 25-km radar range. Blank sectors/regions within 100 km radar range indicate ground clutter



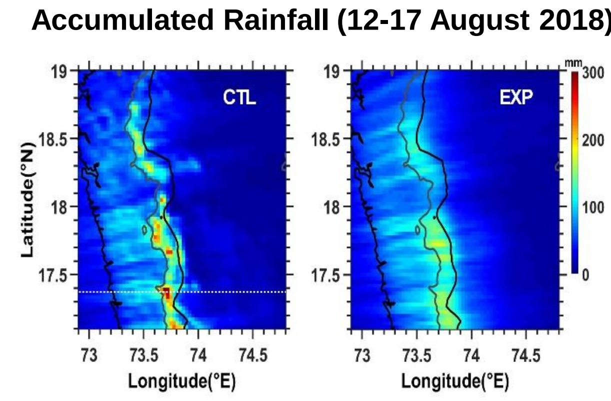
Longitudinal positions of peak elevation, peak slope and peak rainfall at different latitudes

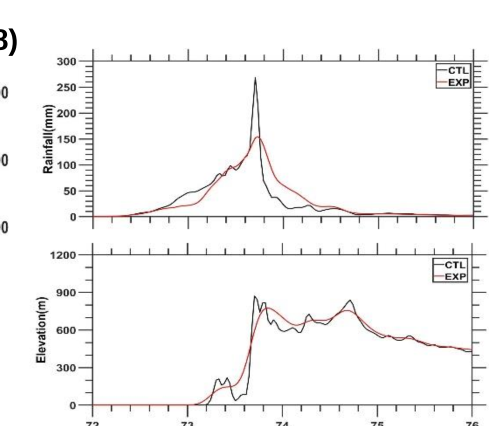
Rainfall maxima locations are closely tied to maximum slope than local mountain peak

Steep slopes along with cascaded mountain ranges may lead to heavy rainfall pockets

WRF Simulations

Accumulated Rainfall (12-17 August 2018)

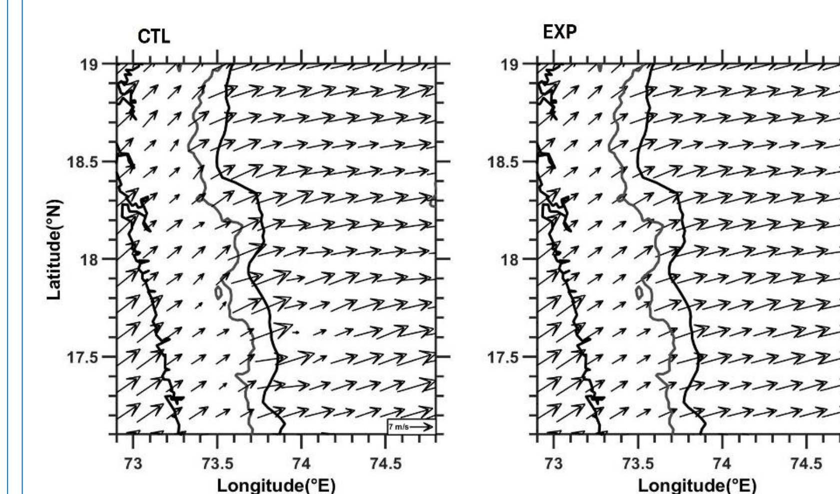




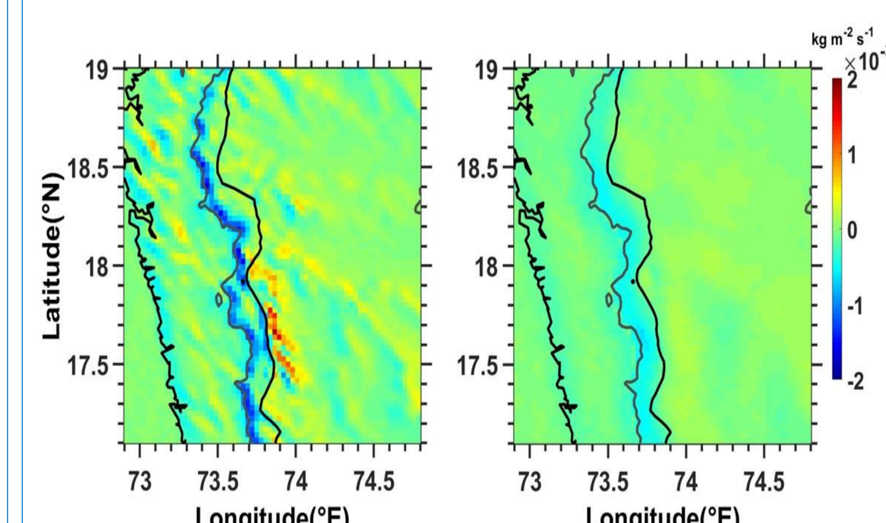
Rainfall drastically decreases (~50%) with decrease in steepness of slopes

Variation of rainfall and elevation along 17.37° N (Max Rainfall location)

Mean 10 m winds and Vertically Integrated Moisture divergence (VIMFD) simulations



EXP Winds increase in speed over the windward slopes, indicating weakening of orographic blocking



VIMFD tightly aligned with 500 m contour in CTL; decreases as slopes become gentle which leads to reduction in rainfall activity

4. Conclusions

- Accumulated rainfall decreases substantially as slopes become gentle, especially in areas of heavy rainfall
- Orographic blocking weakens with decrease in steepness of terrain which leads to enhancement in low-level winds
- Moisture convergence reduces with gradually inclined slopes
- Steeper slopes increase the blocking effect and thus, govern the rainfall distribution over the Western Ghats

Acknowledgements & References

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