South-West Indian Orography influence on Large-Scale Monsoon Circulation and Synoptic Variability: A Modelling Study

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1.Introduction

This work focuses on understanding the impact of South-West Indian orography, specifically the Western Ghats (WG) and Deccan Plateau (DP), on the large-scale monsoon circulation over the Indian subcontinent and the Western North Pacific (WNP). The Indian Summer Monsoon (ISM) and the WNP Summer Monsoon (WNPSM) are crucial systems, affecting the lives of millions of people. Though previous studies have examined the role of the Western Ghats in modulating monsoon rainfall over India, the influence of the combined south-west orography (WG and DP) on larger monsoon circulations remains unexplored. This study aims to investigate how the orography impacts the monsoon circulation pattern, focusing on factors such as wind flow, relative vorticity, and mid-tropospheric heating. This study uses a global model simulation with and without orography to highlight its influence on the monsoon system.

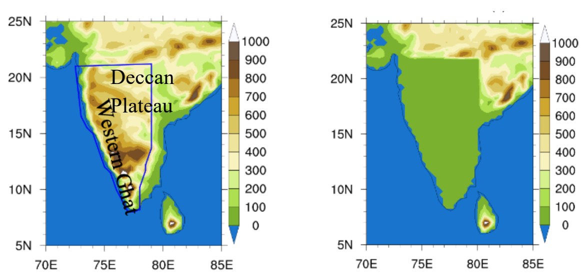
2. Model details and Results

Global Forecast System (GFS) model, version 12, developed by the National Centers for Environmental Prediction is used in this study. Two different simulations were performed: a control simulation (CTL) with orography, and an experimental simulation (EXP) where the orography between 8°N and 22°N (the region covering WG and DP) was removed. The model resolution was T574 (~27 km).

The removal of the orography led to significant changes in wind patterns and relative vorticity over the Indian subcontinent and the WNP. The south-westerly winds over the Arabian Sea (AS) and the Bay of Bengal (BoB) were altered, weakening the low-level jet (LLJ) in some regions and strengthening it in others, particularly over the WNP and the Philippines. The changes in the fluid depth due to orography removal resulted in altered vorticity patterns, which impacted monsoon circulation. The removal of orography generated stationary Rossby waves (Figure 2c), which influenced the wind flow and moisture convergence over the region. These waves, resulting from the interaction between westerlies and the western coastal orography, impacted the trough position over BoB and WNP. The study observed that changes in the orography affected mid-tropospheric heating, particularly over the WNP and the Philippines. The convergence of westerly winds from the Indian Ocean and easterly trade winds from the Pacific led to increased convective heating in the mid-troposphere, further affecting the monsoon flow. The moisture convergence patterns were altered, leading to decreased rainfall over India and increased rainfall over the WNP and the Philippines. The interaction between the westerlies from the Indian Ocean and easterlies from the Pacific anticyclone contributed to this increase in rainfall. The removal of orography reduced orographic uplift and rainfall over the Western Ghats, while enhancing moisture transport toward the WNP. The changes in trough position and vorticity due to orography removal also influenced the genesis of Low-Pressure Systems (LPS) and Tropical Cyclones (TC). The study showed an increase in LPS and TC formation over southern India, the Philippines, and East China, highlighting the critical role of orography in controlling synoptic-scale events.

3. Conclusions

This study highlights the importance of South-West Indian orography in modulating large-scale monsoon circulation. The removal of orography resulted in significant changes in wind patterns, vorticity, moisture convergence, and rainfall, particularly over the WNP and India. Stationary Rossby waves, generated due to the orography, played a key role in altering the monsoon flow and synoptic variability. The study highlights that accurate representation of orography in models is essential for better monsoon simulation and prediction. Further research is needed to examine the effects of orographic parameterization on catastrophic weather events, such as floods and droughts, and their socio-economic impacts across the Indian subcontinent and WNP region.



(a) CTL (b) EXP

Figure 1: Orography used for the two model simulations (a) Control run (CTL) and (b) Experimental simulation (EXP) with removed orography. The blue box represents the area where orography is eliminated.

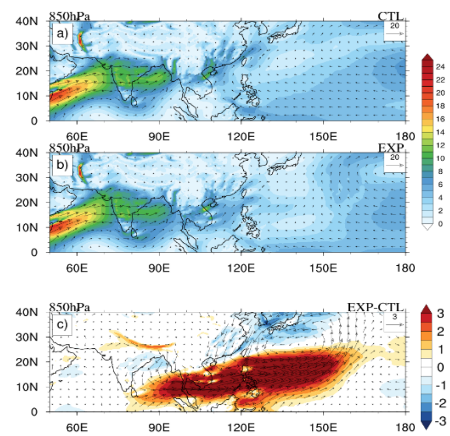


Figure 2: Seasonal (JJAS) mean wind (m/s) at 850 hPa for the (a) CTL and (b) EXP simulation. Shading in (a) and (b) represents the magnitude of wind. (c) Difference between EXP-CTL of zonal wind (m/s) at 850 hPa.

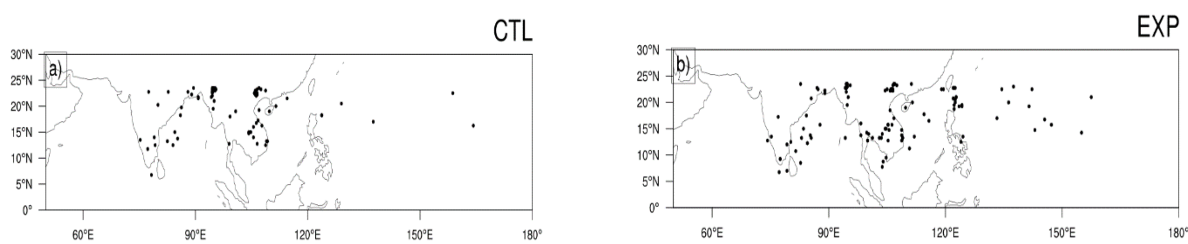


Figure 3**:** Low Pressure System (LPS) and Tropical Cyclone (TC) genesis location for the India and West North Pacific in (a) CTL and (b) EXP simulation.

References

Das, R.S., Rao, S.A., Pillai, P.A. *et al.* Role of south-west Indian orography in modulating large-scale monsoon circulation. *Theor Appl Climatol* **154**, 1277–1290 (2023). https://doi.org/10.1007/s00704-023-04597-9