Department of Meteorology &
National Centre for Atmospheric Science

University of Reading

Orographic rainfall processes in India – results from the IMPROVE project

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University of Reading, University of Leeds, IITM, IMD Pune

IMPROVE PROJECT

- Met Office Newton Fund project/MoES
- September 2019-March 2021 & July 2021-March 2022
  - Main postdoctoral work undertaken by Kieran Hunt & Jayesh Phadtare
- Named collaborators in India
  - Rajib Chattopadhyay & Mahesh Kalshetti @ IITM / IMD-Pune
  - Sachin Deshpande/Subrata Kumar Das/Utsav Bhowmik @ IITM

Indian **M**onsoon **PR**ecipitation over **O**rography: **V**erification and **E**nhancement of **U**nderstanding

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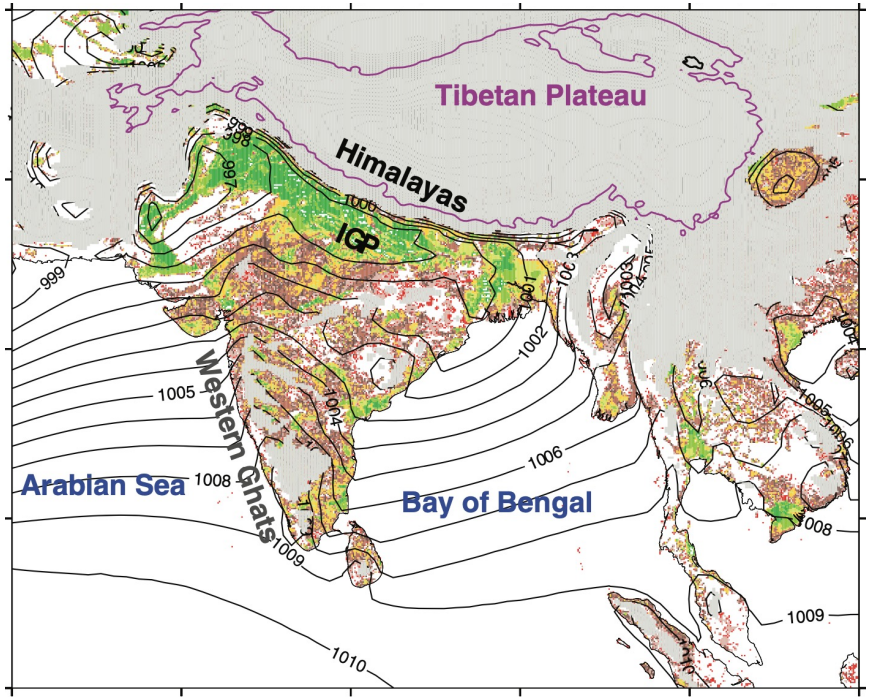
Ministry of Earth Sciences

Newton Fund

Met Office

IMPROVE scientific objectives

1. Determine the drivers of typical and extreme orographic precipitation in the Western Ghats and Himalaya
2. Determine how mechanisms of orographic precipitation and precipitation extremes are represented in models (ranging from convection-permitting km scale to global parameterized models)
3. Determine what mechanisms controlling orographic rainfall and its extremes are missing from models at a range of scales and inform model development



Jayesh Phadtare

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Western Ghats rainfall from a Froude number perspective

- Froude-number analysis (based on sounding data) reveals different rainfall regimes

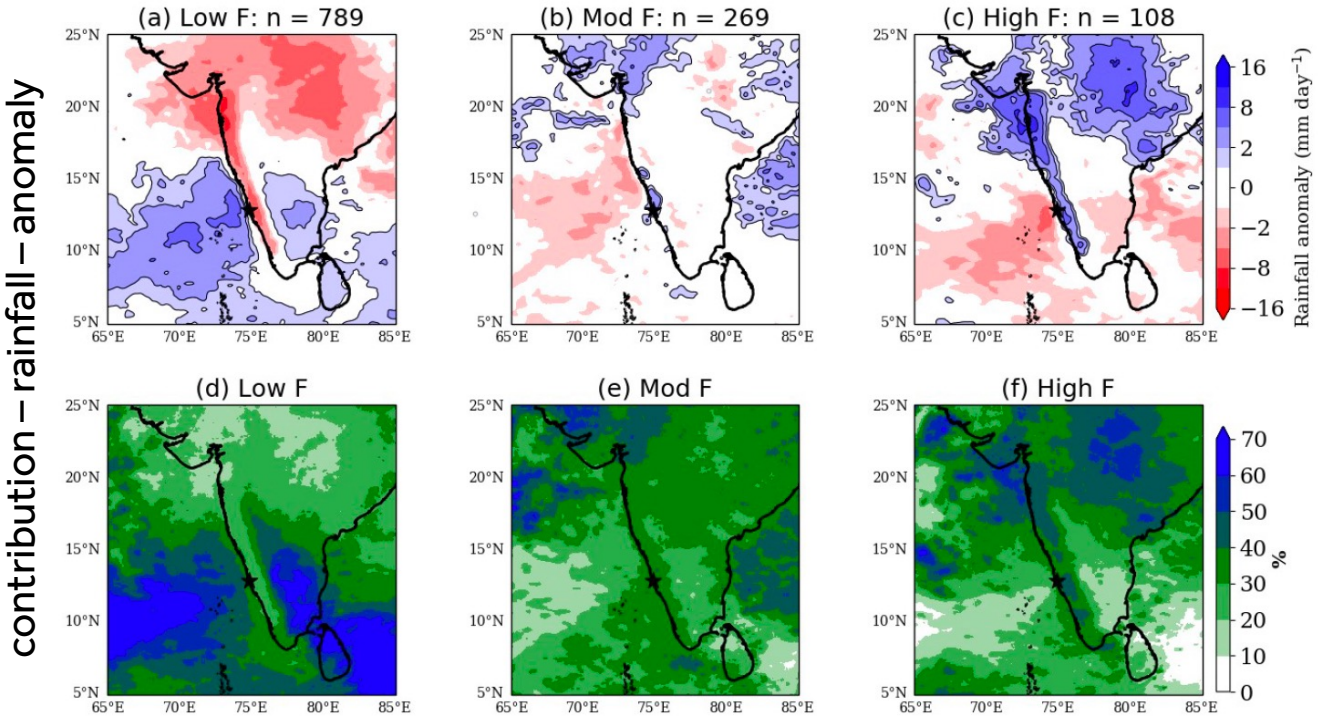
Froude Number,

$Fr_m = U/N_mH$

U – Cross barrier wind speed

N_m – Unsaturated moist Brunt-Väisälä frequency

H – Mountain height



- Example based on Mangaluru soundings & IMERG data
- Demonstrates large contribution of low-Fr days to rainfall over southeast India

Jayesh Phadtare *et al.* (2022). Froude number-based rainfall regimes over the Western Ghats mountains of India. *QJRMS*, in revision.

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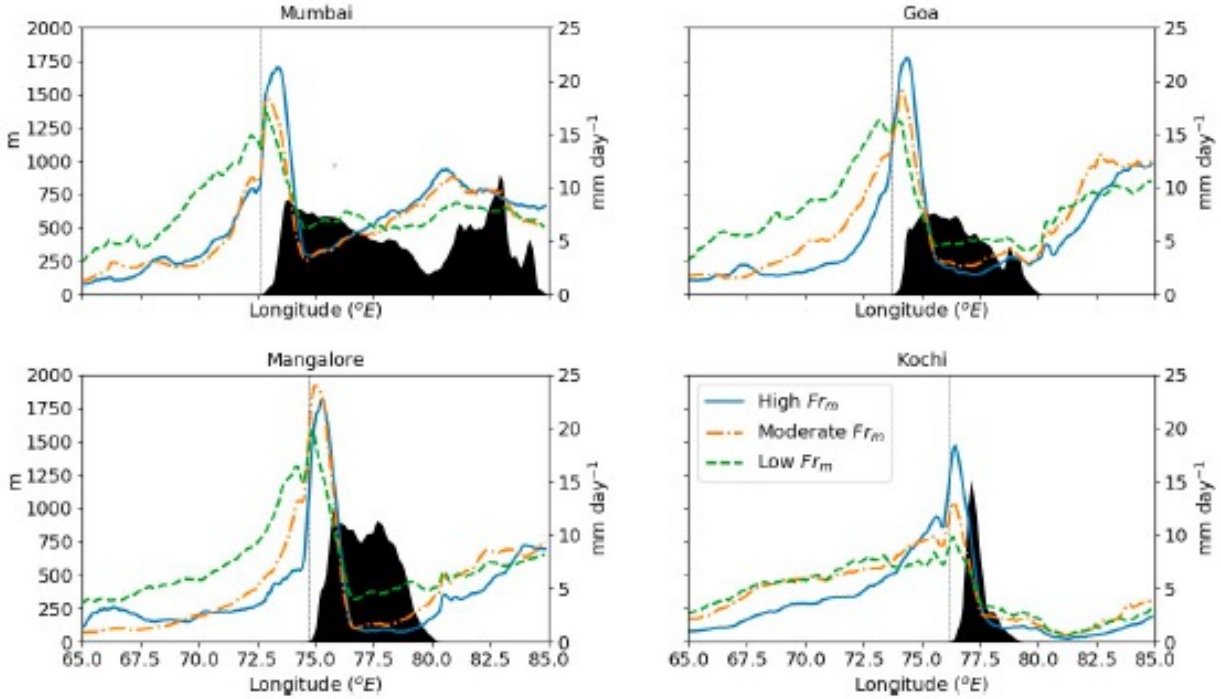
Western Ghats rainfall from a Froude number perspective

- Similar analysis for other Western Ghats sites
- BSISO phase (as expected) exerts some control over Fr
- Flow regime influences diurnal cycle



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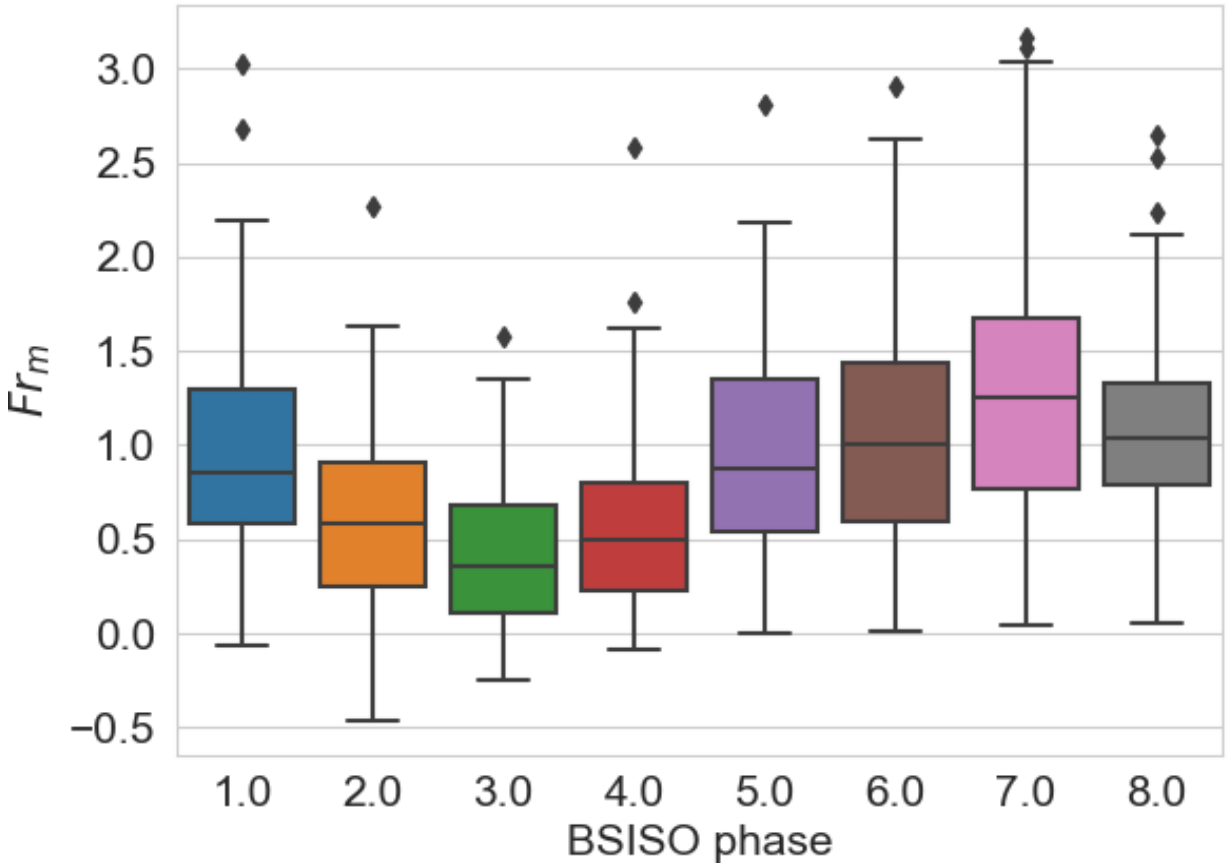

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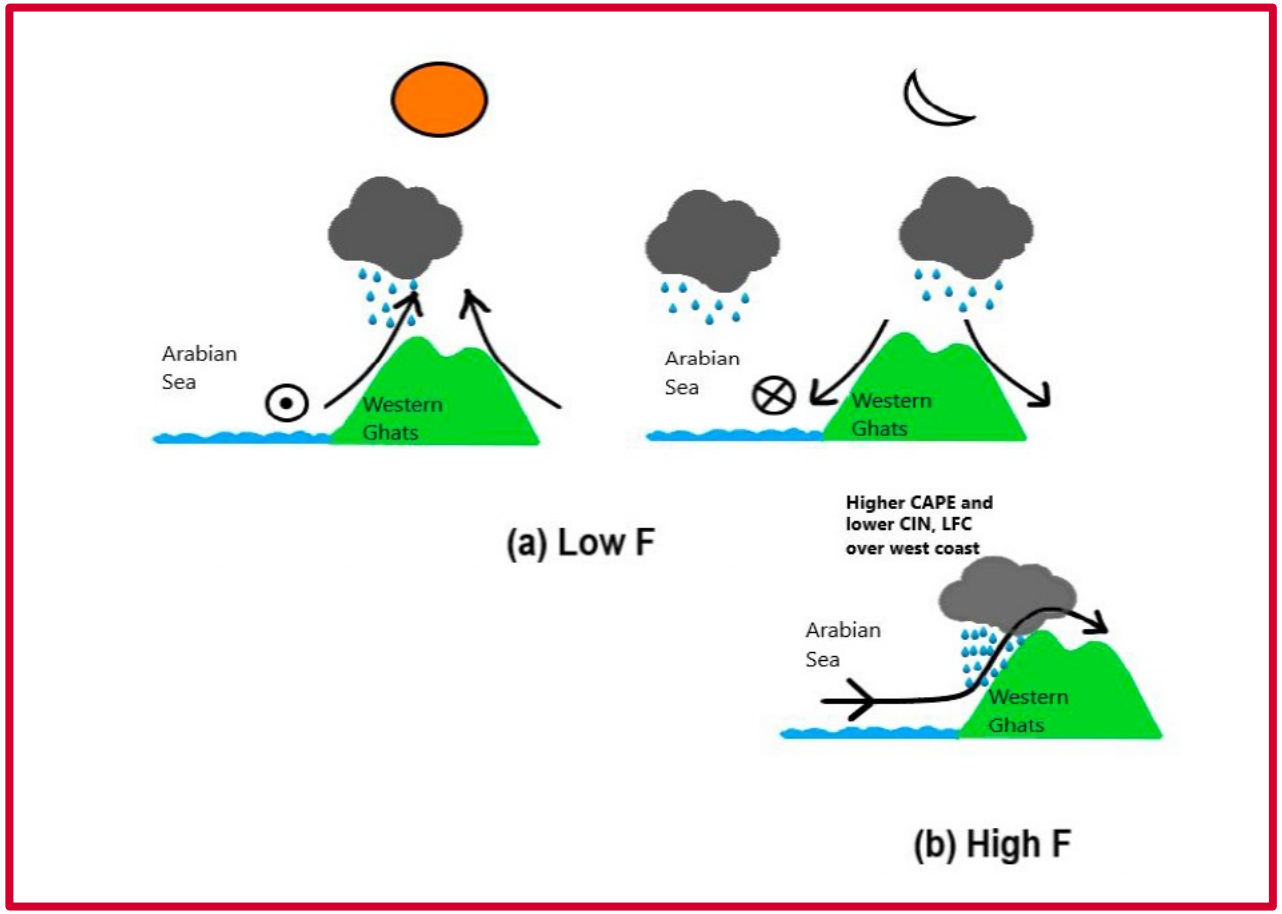
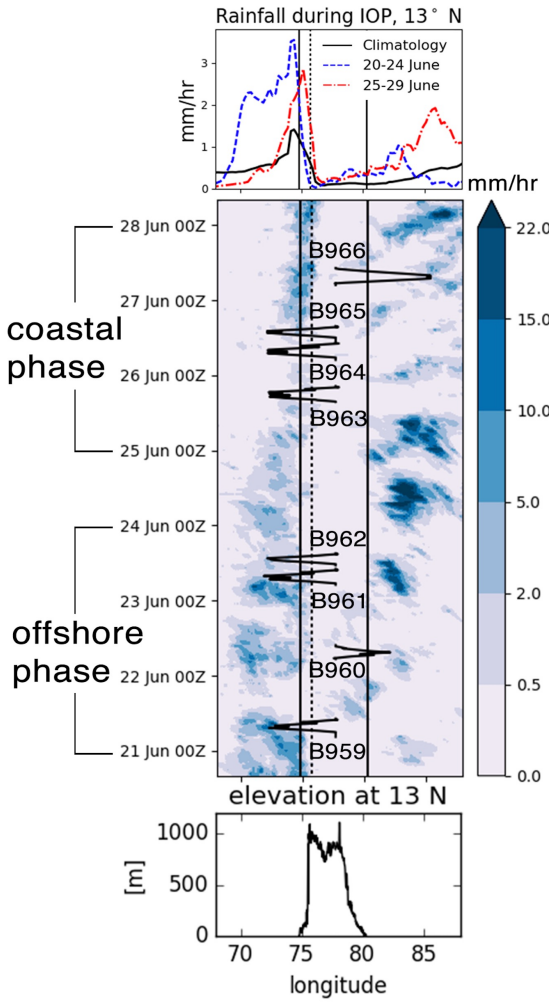
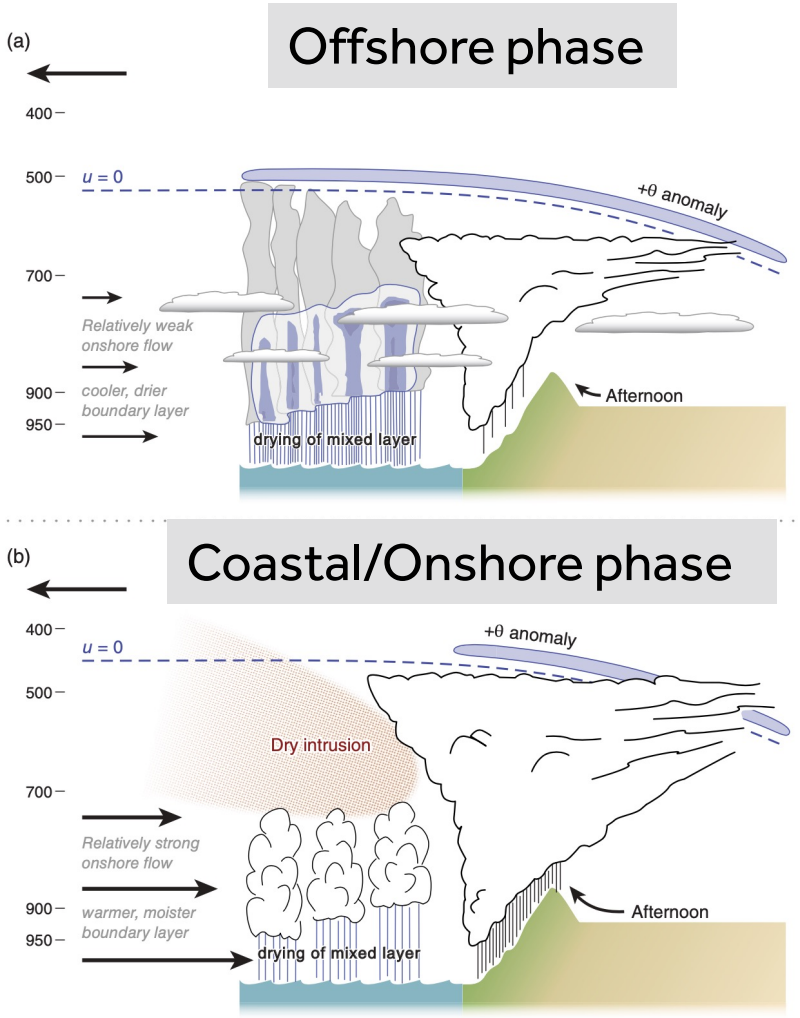


Jayesh Phadtare *et al.* (2022). Froude number-based rainfall regimes over the Western Ghats mountains of India. *QJRMS*, in revision.

Modes of coastal precipitation over SW India

Jennifer Fletcher *et al.*





- Earlier work from our INCOMPASS field campaign of aircraft & surface observations found evidence for modes of onshore & offshore convection near Western Ghats
- We hypothesized these were controlled locally by a dry intrusion and at larger scales by the BSISO

Fletcher *et al.* (2019). The dynamic and thermodynamic structure of the monsoon over southern India: New observations from the INCOMPASS IOP. *QJRMS* **146**, 2867-2890, doi:10.1002/qj.3439.

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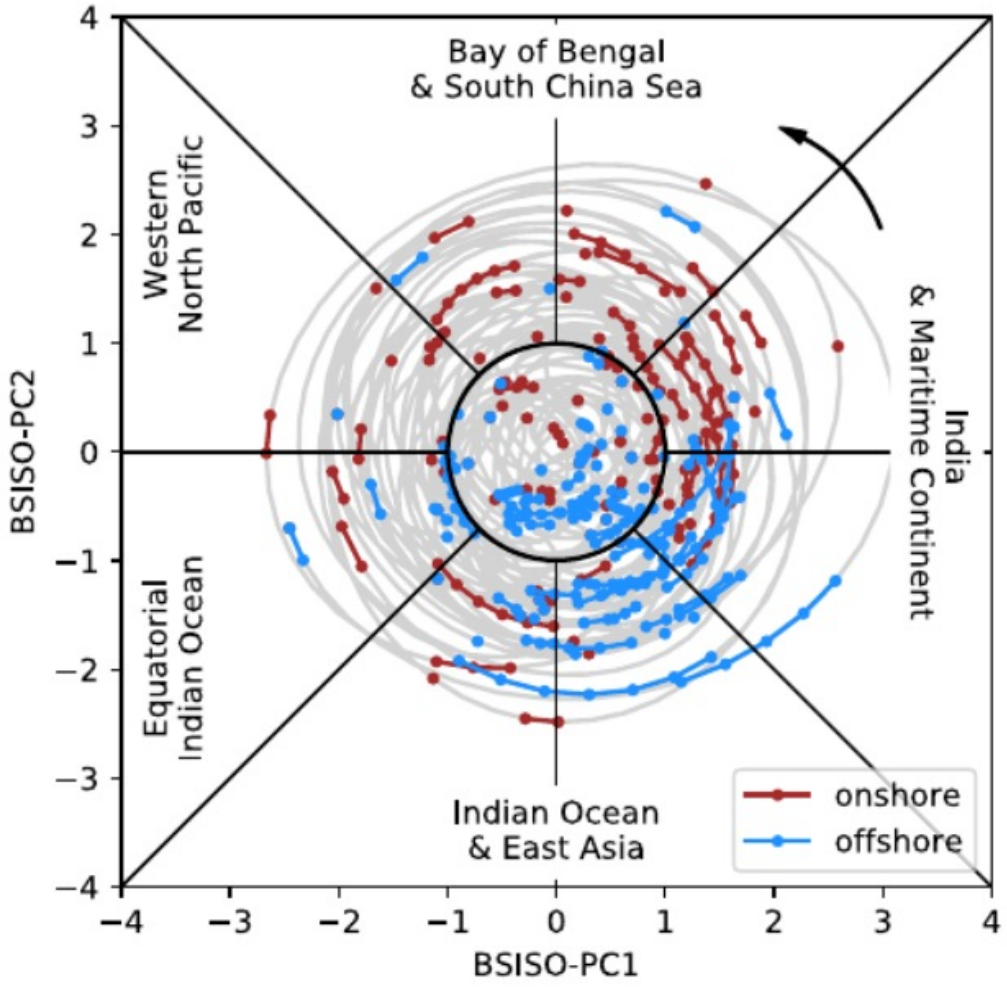
Modes of coastal precipitation over SW India …and their relationship to ISV

Kieran Hunt *et al.*



- EOF analysis identifies periods of “onshore” & “offshore” rainfall near SW Indian coast
- Radiosonde and moisture trajectory analysis shows rainfall location most sensitive to mid-tropospheric moisture
- BSISO exhibits strong control on local moisture

→ predictability (see left) on offshore (phases 3 & 4) vs onshore rainfall (phases 5 & 6)

Hunt, K. M. R., A. G. Turner, T. H. M. Stein, J. K. Fletcher and R. K. H. Schiemann (2020). Modes of coastal precipitation over southwest India and their relationship to intraseasonal variability. *QJRMS*, **147**(734): 181-201, https://doi.org/10.1002/qj.3913

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Analytical model of 2-layer flow

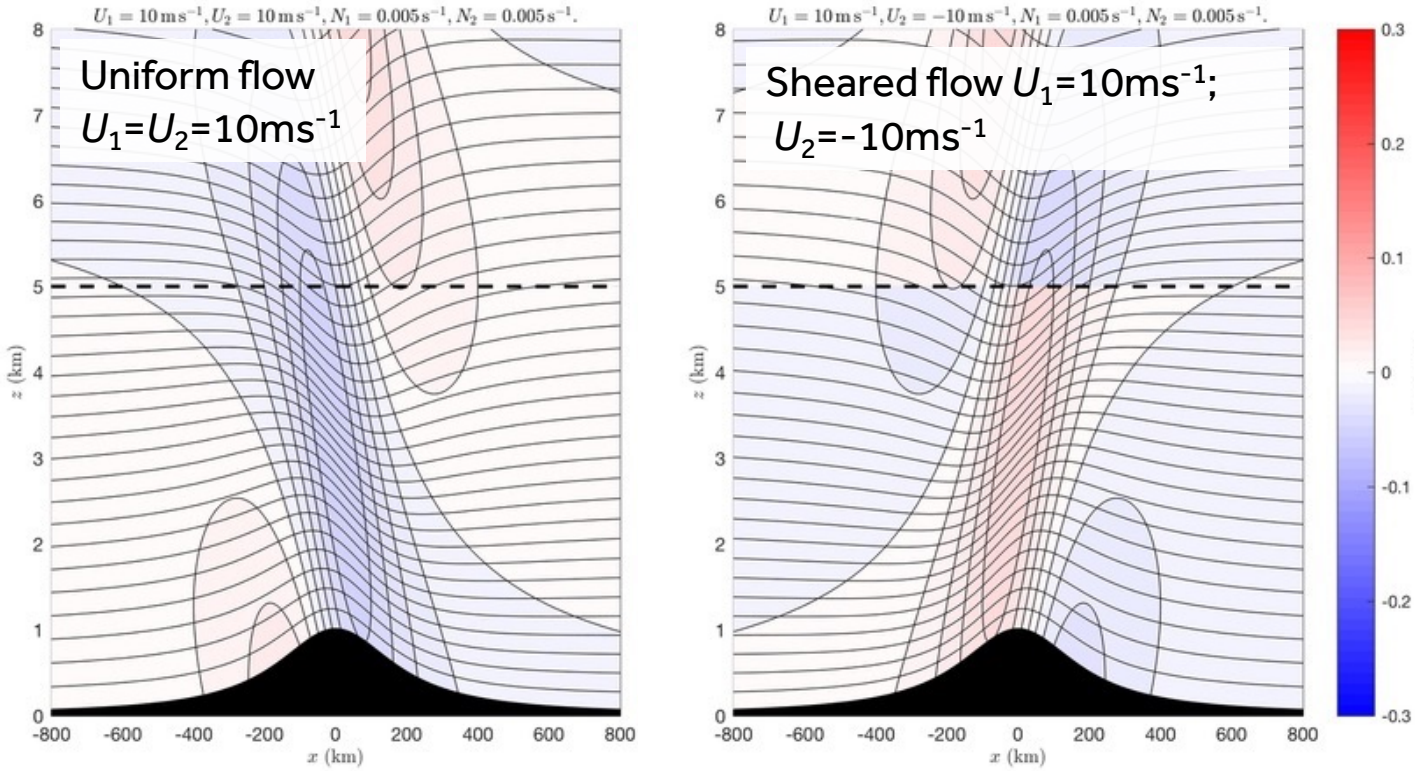
Stephen Griffiths & Andrew Ross

UNIVERSITY OF LEEDS

- A 2-layer model has been designed to test the tole of horizontal flow and stratification in each layer, for perpendicular flow incident on a mountain ridge
- Can different phases of convection near the coast can be driven by different flow structures $U(z)$ [& buoyancy frequency $N(z)$] interacting with Western Ghats orography?
- Calculate 2D steady linear response over topography $z=h(x)$.
- Use analytical solution for special case [hydrostatic, non-rotating, step profiles in $U(z)$ & $N(z)$]

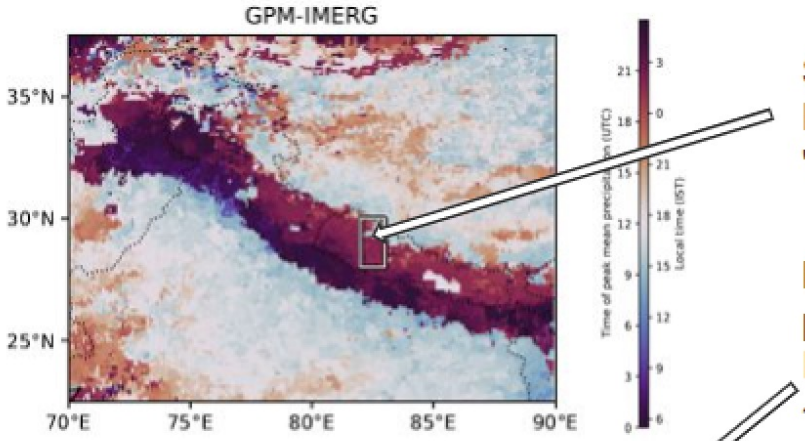
Future work:

- Adapt model to more realistic setup
- Supported by detailed process studies in WRF



Understanding twin diurnal rainfall peaks in the central Himalaya

Kieran Hunt *et al.*

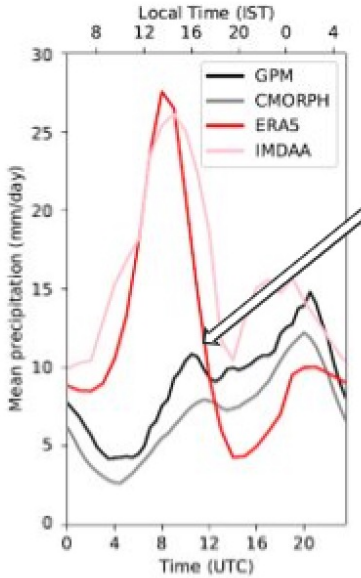


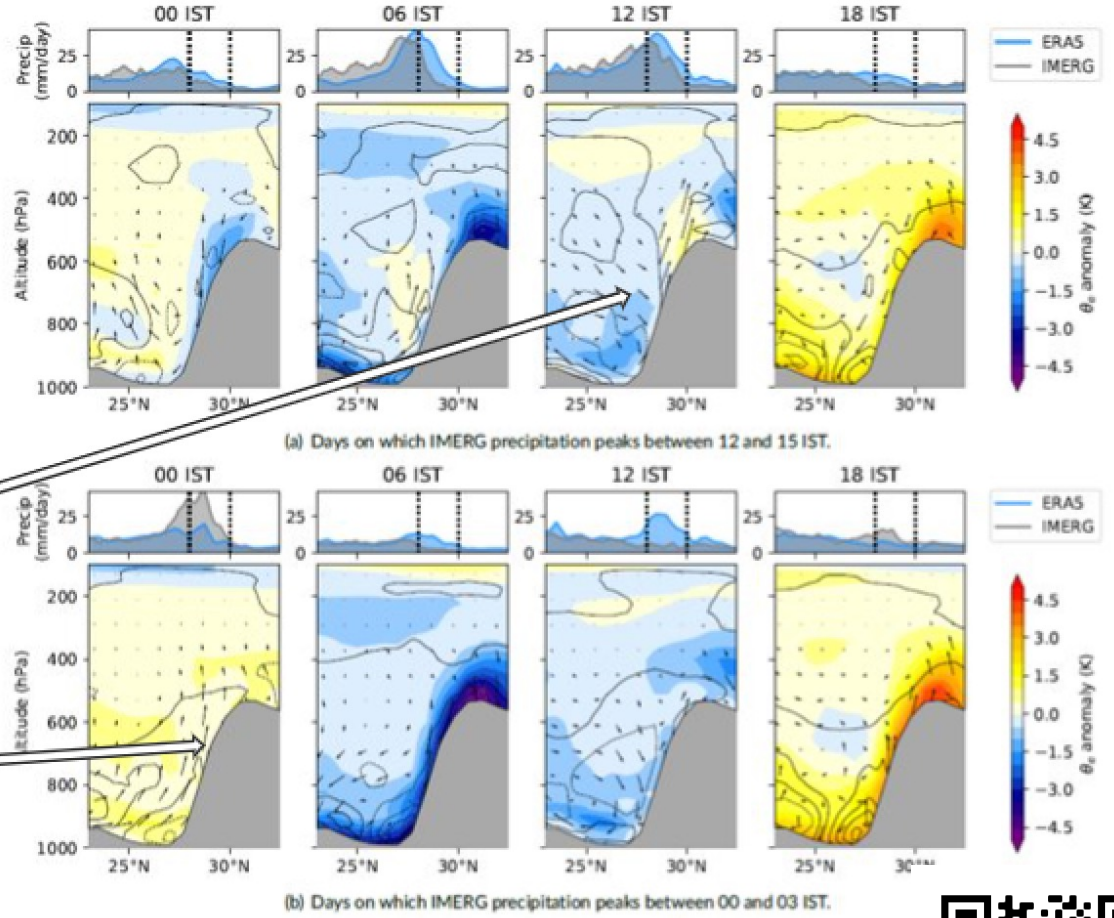
Study region in Central Himalaya sits in region of "nocturnal" precipitation.

But there are actually two peaks: a "daytime" peak at ~15 IST and a "nocturnal" peak at ~03 IST. Models weight the two peaks incorrectly.

Daytime peak caused by mesoscale convective systems enhanced by anabatic flow.

Nocturnal peak (more common) caused by convergence of katabatic flow and monsoon southeasterlies.

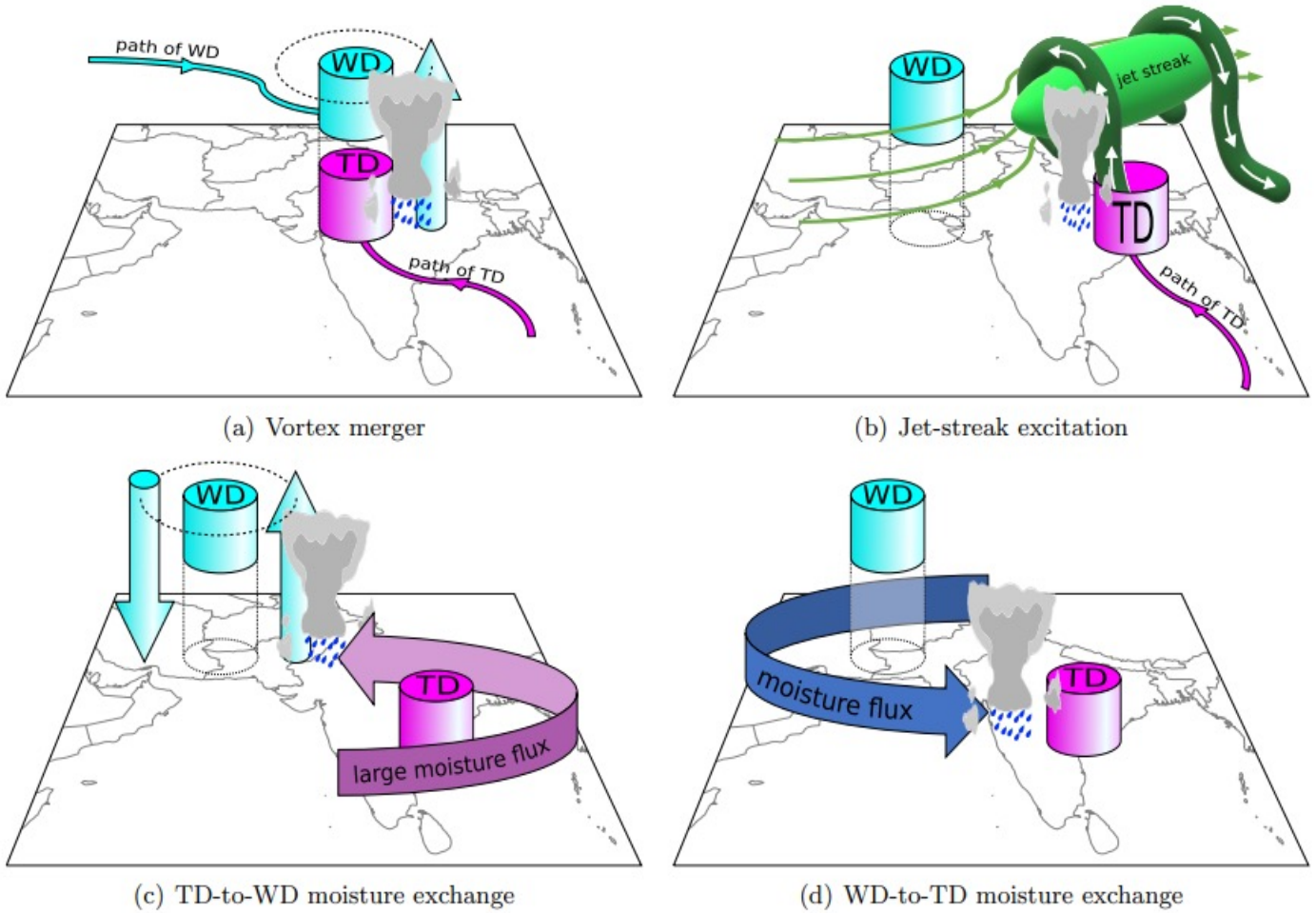




Hunt, K. M. R., A. G. Turner and R. K. H. Schiemann (2022). Katabatic and convective processes drive two preferred peaks in the precipitation diurnal cycle of the Central Himalaya. *QJRMS*, https://doi.org/10.1002/qj.4275

How interactions between depressions & western disturbances enhance heavy precip

Kieran Hunt *et al.*



- WD and TD track catalogues used to find 59 interaction case studies
- Four different interaction types
- Interactions either involve dynamical coupling of the two systems or moisture exchange between them (or both)
- Interactions involving a jet entrance result in the most intense rainfall

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Hunt *et al.* (2021). How interactions between tropical depressions and western disturbances affect heavy precipitation in South Asia. *Monthly Weather Review*, **149**(6): 1801-1825, https://doi.org/10.1175/MWR-D-20-0373.1

Kieran Hunt & A P Dimri

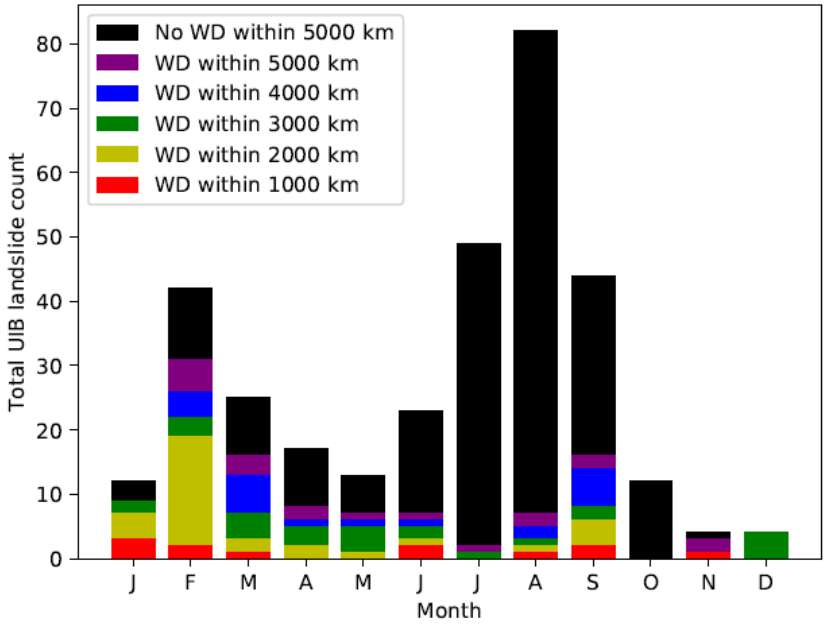
University of Reading

Addressing Himalayan impacts – landslide risk

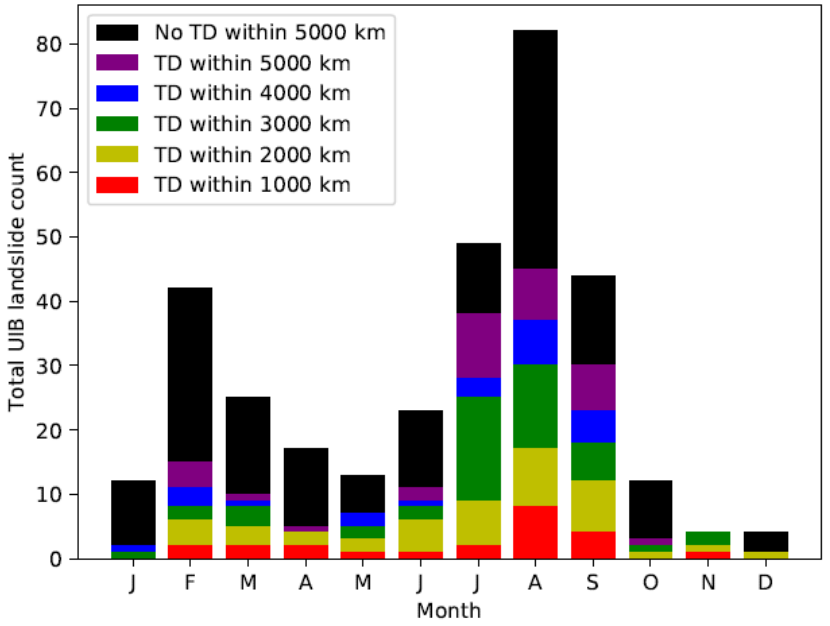
Examining synoptic precursors:

- Majority of landslides occur in presence of a TD (summer) or WD (winter)
- WDs increase likelihood by strengthening moist southwesterlies from the Arabian Sea
- TDs increase likelihood by either extending monsoon trough to NW or by enhancing south-easterly

Hunt, K. M. R. and A. P. Dimri (2021). Synoptic-scale precursors of landslides in the western Himalaya and Karakoram. *Sci. Tot. Environ.*, 776: 145895, https://doi.org/10.1016/j.scitotenv.2021.145895.



(a) western disturbances



(b) tropical depressions

Thank you for your attention!

- Phadtare, J. A., J. K. Fletcher, A. N. Ross, A. G. Turner and R. K. H. Schiemann (2022). Froude number-based rainfall regimes over the Western Ghats mountains of India. *QJRMS*, in review.
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- Hunt, K. M. R. and A. Menon (2020). The 2018 Kerala floods: a climate change perspective. *Climate Dynamics*, 54: 2433-2446, https://doi.org/10.1007/s00382-020-05123-7.