Evaluating convection-permitting models with operational weather radars

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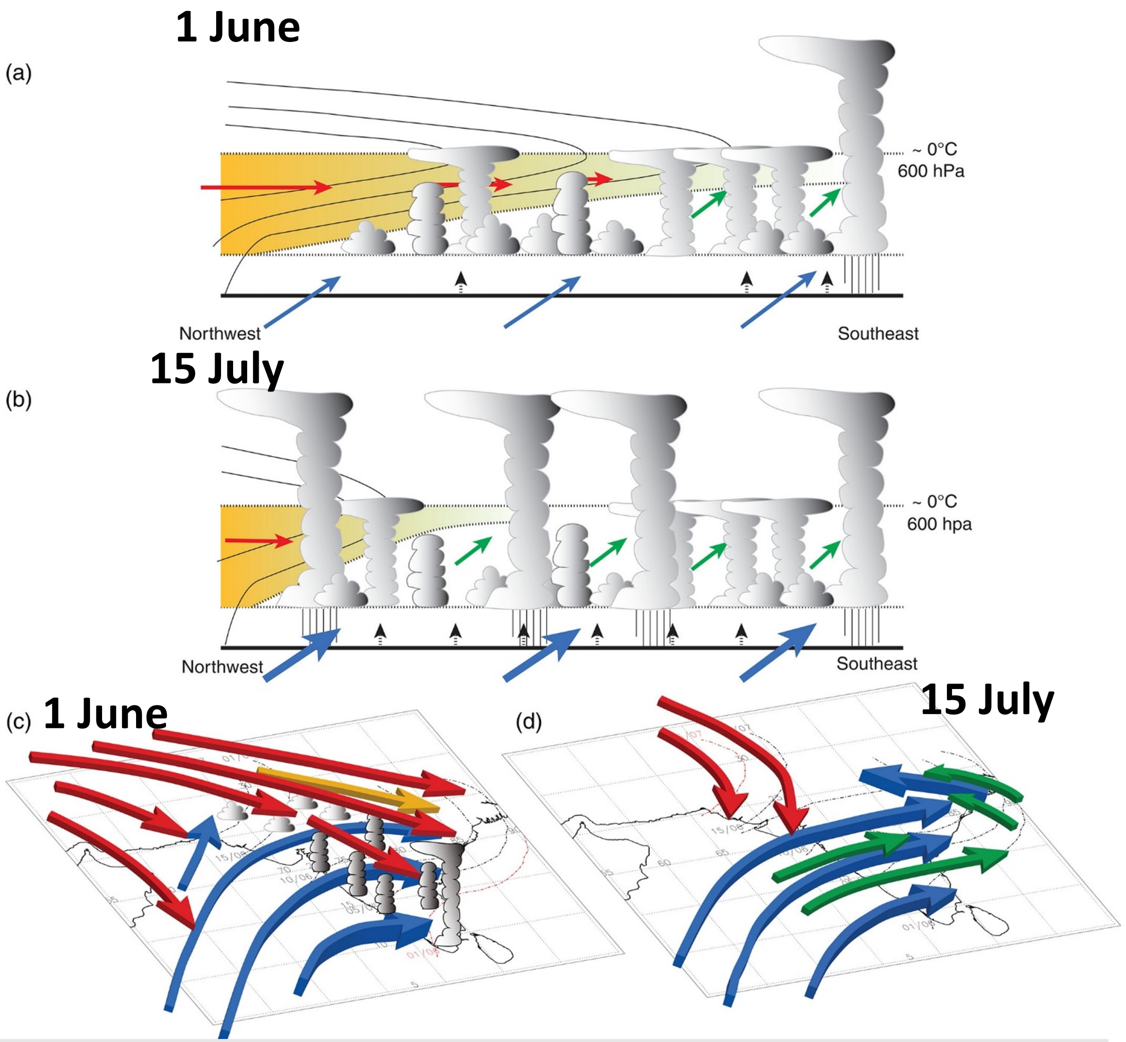
Motivation

- The Indian summer monsoon provides 80% of India's annual rainfall, with profound socio-economic impacts
- Interactions between the large-scale monsoon circulation and local convection are two-way & non-linear
  - Also important for monsoon onset
- Lack of historical observations of convection over India
- These factors complicate modelling and forecasting – still large biases

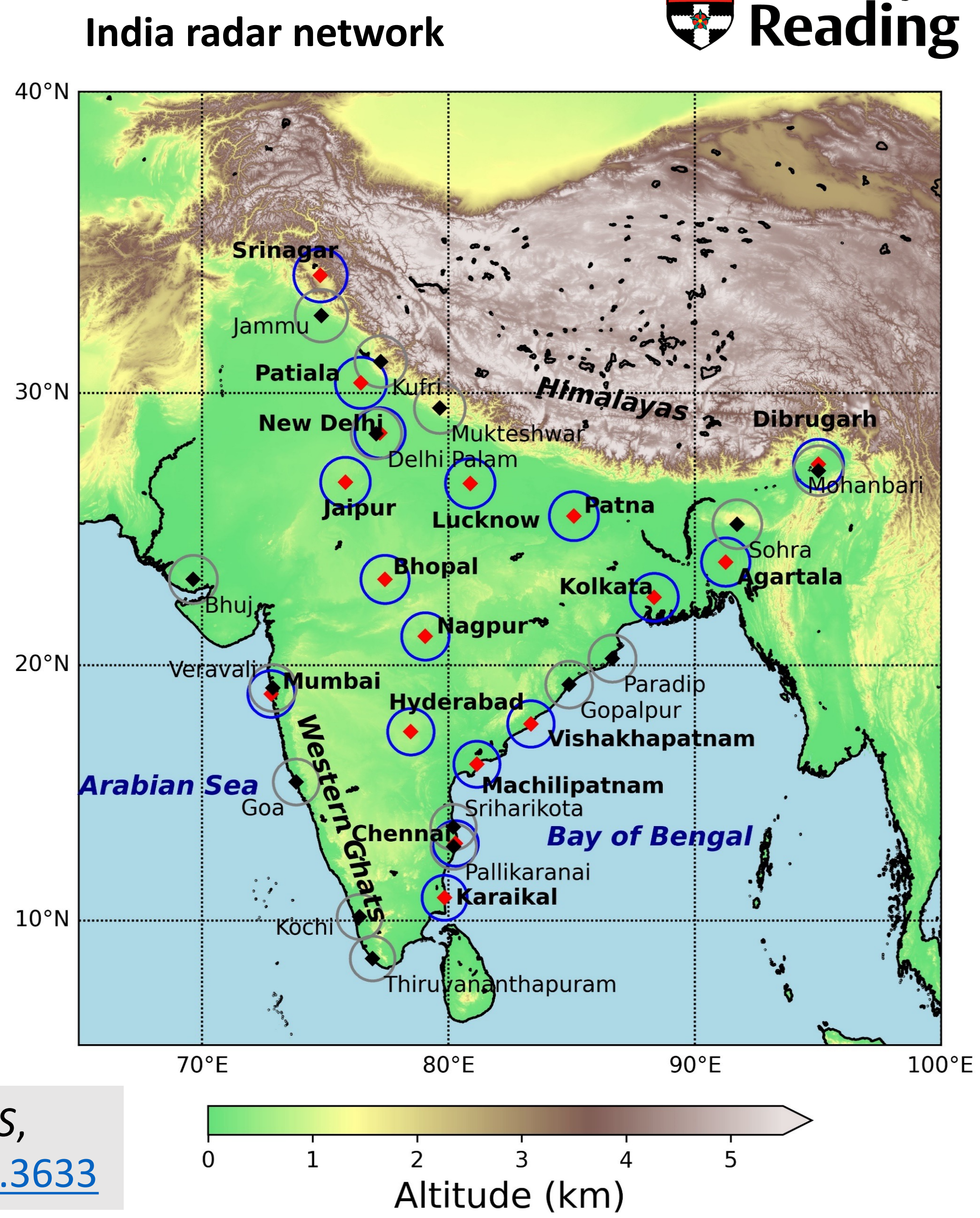
Cross-sectional climatological view of monsoon progression



Parker *et al.* (2016) *QJRMS*, https://doi.org/10.1002/qj.2815

Radar data and processing

- Data collected during the 2016 INCOMPASS field campaign allows us to objectively analyse monsoon storms
- 17 available radars with data for 2016 monsoon season
- Quality control: Radar reflectivity is calibrated, and re-gridded onto discrete vertical levels out to a range of 100 km
- Reflectivity echoes used to identify storm statistics, i.e., **storm height, size, intensity**



Turner *et al.* (2020) *QJRMS*, http://doi.org/10.1002/qj.3633

INCOMPASS project

part of the NERC/MoES Monsoons Programme 2015-2018

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RESEARCH ARTICLE

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Key Points:

- Indian Doppler Weather radars are used to analyze cell-top height (CTH) during the 2016 monsoon season
- CTH exhibits clear diurnal and intraseasonal variation
- CTH varies by region and is affected by local features and the wider monsoon circulation

Supporting Information:

Supporting Information may be found in the online version of this article.

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2016 Monsoon Convection and Its Place in the Large-Scale Circulation Using Doppler Radars

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Abstract Convective cloud development during the Indian monsoon helps moisten the atmospheric environment and drive the monsoon trough northwards each year, bringing a large amount of India's annual rainfall. Therefore, an increased understanding of how monsoon convection develops from observations will help inform model development. In this study, 139 days of India Meteorological Department Doppler weather radar data is analyzed for seven sites across India during the 2016 monsoon season. Convective cell-top heights (CTHs) are objectively identified through the season, and compared with near-surface (at 2 km height) reflectivity. These variables are analyzed over three time scales of variability during the monsoon: monsoon progression on a month-by-month basis, active-break periods and the diurnal cycle. We find a modal maximum in CTH around 6–8 km for all sites. Cell-averaged reflectivity increases with CTH, at first sharply, then less sharply above the freezing level. Bhopal and Mumbai exhibit lower CTH for monsoon break periods compared to active periods. A clear diurnal cycle in CTH is seen at all sites except Mumbai. For south-eastern India, the phase of the diurnal cycle depends on whether the surface is land or ocean, with the frequency of oceanic cells typically exhibiting an earlier morning peak compared to land, consistent with the diurnal cycle of precipitation. Our findings confirm that Indian monsoon convective regimes are partly regulated by the large-scale synoptic environment within which they are embedded. This demonstrates the excellent potential for weather radars to improve understanding of convection in tropical regions.

Doyle *et al*. (2021) *JGR Atmospheres*, https://doi.org/10.1029/2021JD035496

Indian monsoon convection

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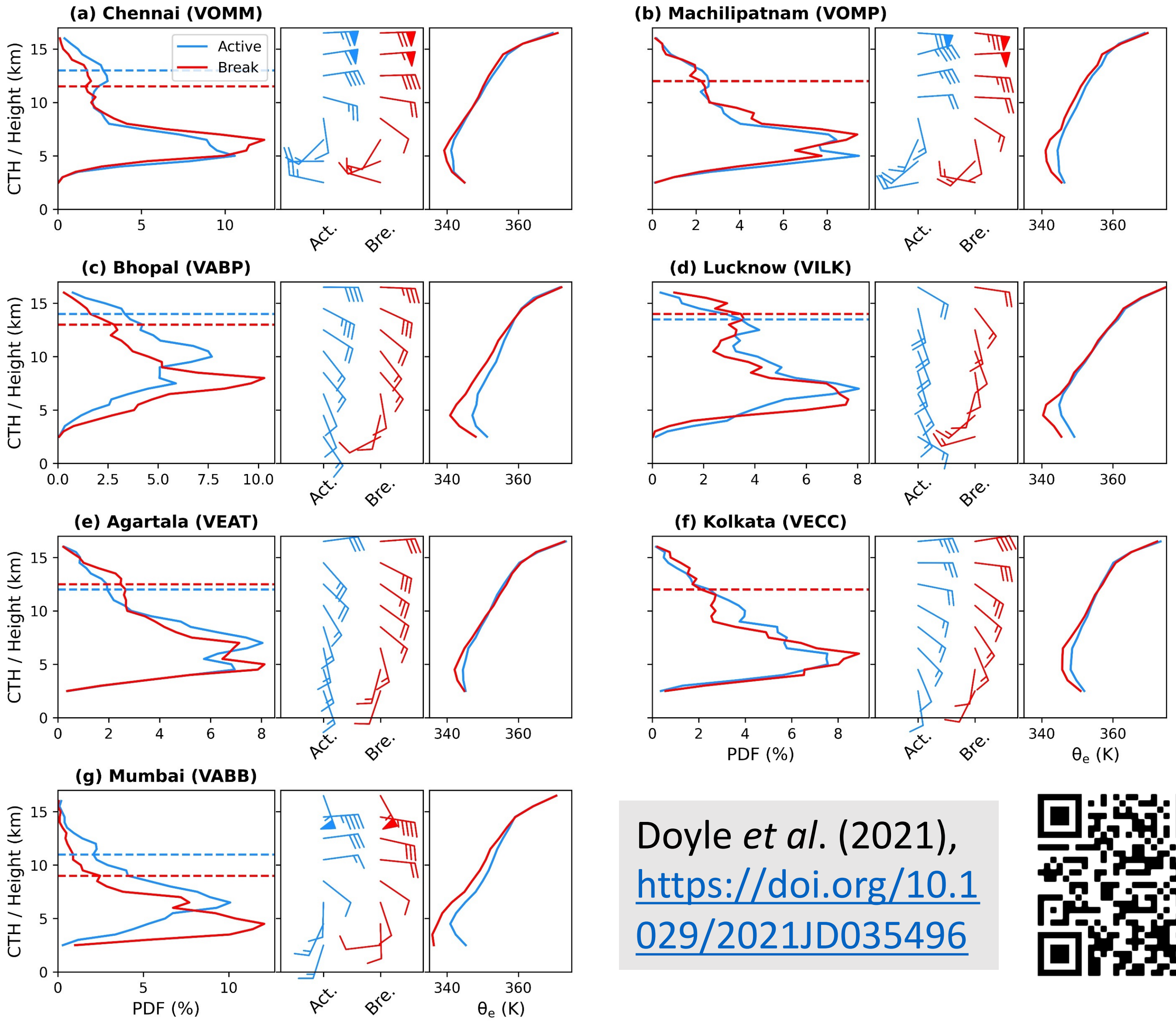
Storm heights (CTH) for active & break periods
Wind barbs and θ_e also shown

- Monsoon rainfall exhibits intraseasonal variability leading to active (blue) & break (red) periods

Active periods:

- Wetter in western and central India and vice versa for breaks
- Coincide with enhanced circulation → more background moisture in core monsoon zone (Bhopal & Mumbai)
  - Modal CTH increases here
  - Small differences elsewhere
- Higher θ_e through large part of troposphere important for deeper convection



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Convection embedded within the large-scale circulation

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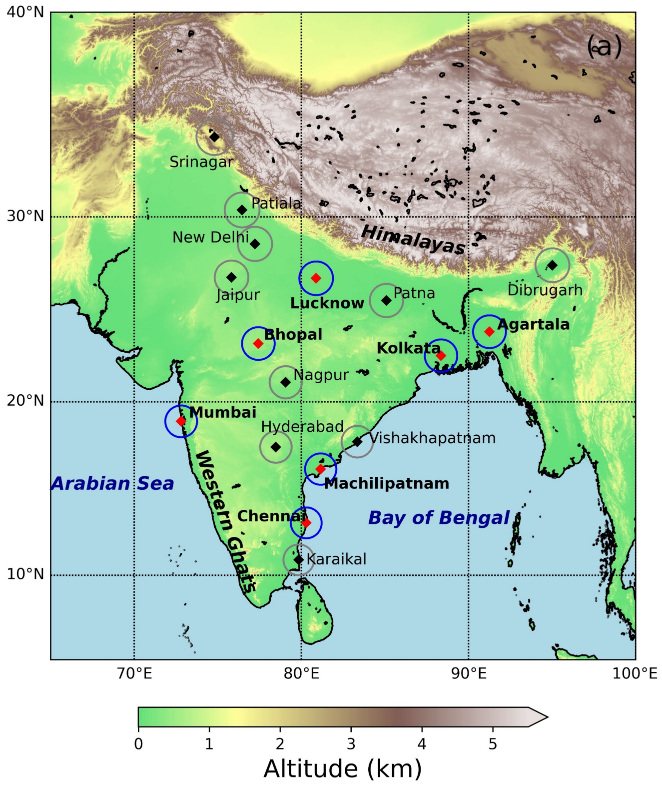
- Diurnal cycle of convection observed by radars shows a clear relationship with GPM-IMERG observed rainfall
- Inland sites (Bhopal & Lucknow) display a gradual deepening of convection in the afternoon
- Agartala has more convection in the early afternoon overall, but more deep convection at night, which seems to contribute the most rainfall



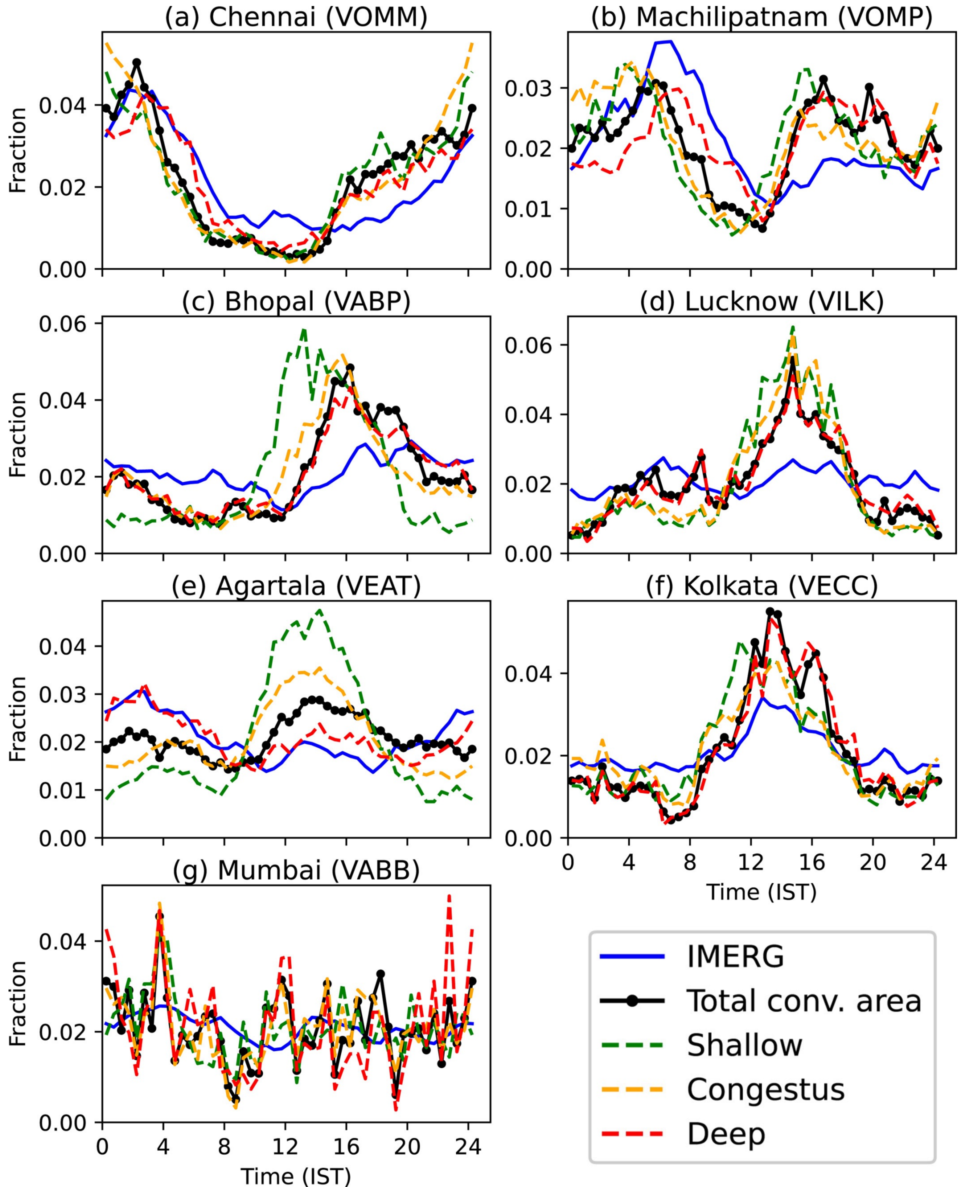
CTH = Cell-top height

Shallow: CTH < 5 km

Congestus: 5 ≤ CTH < 8 km

Deep: CTH ≥ 8 km

Diurnal cycles of convection & rainfall



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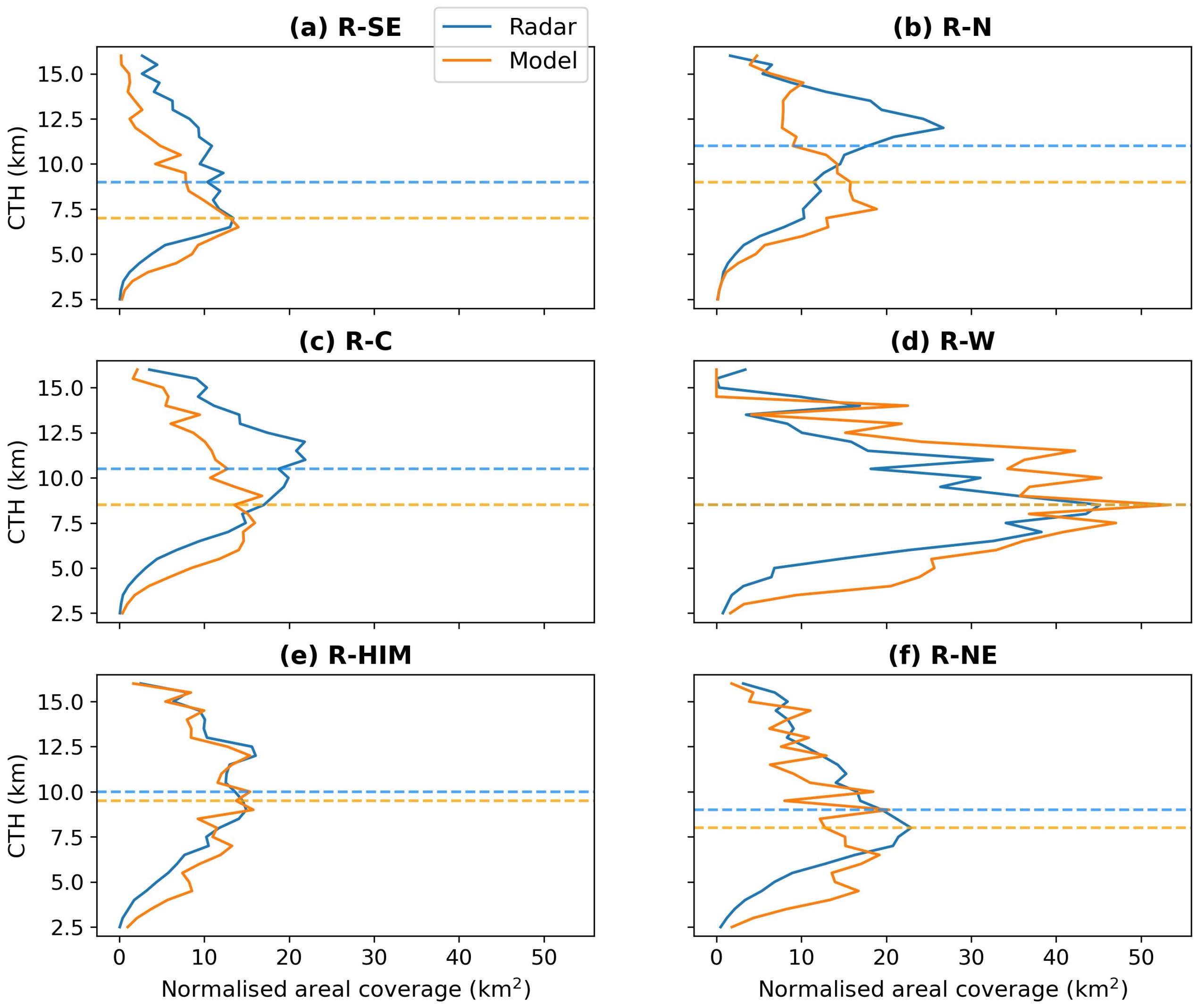
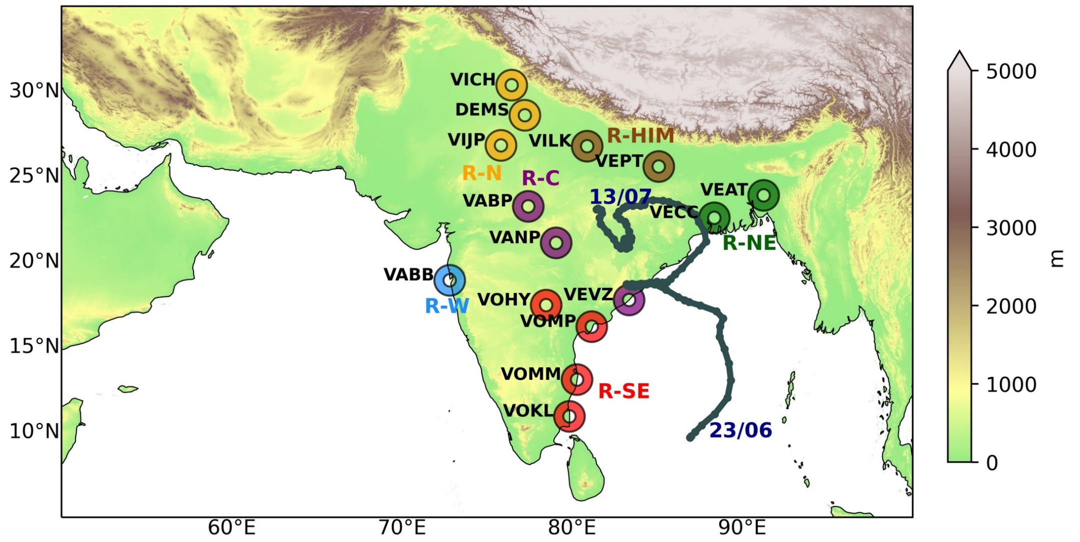
Model evaluation using DWR

Area covered by different storm heights: Radar & model





3-week case study period: 19 June – 11 July 2016

- Regional convection-permitting Met Office Unified Model at 1.5 km resolution from INCOMPASS
- Hourly resolution, high-resolution in the vertical, vertical grid size increasing quadratically with height up to model lid of 38.5 km
- Use total radar reflectivity forward-modelling
- Directly compare model to 15 radar locations, split into subregions

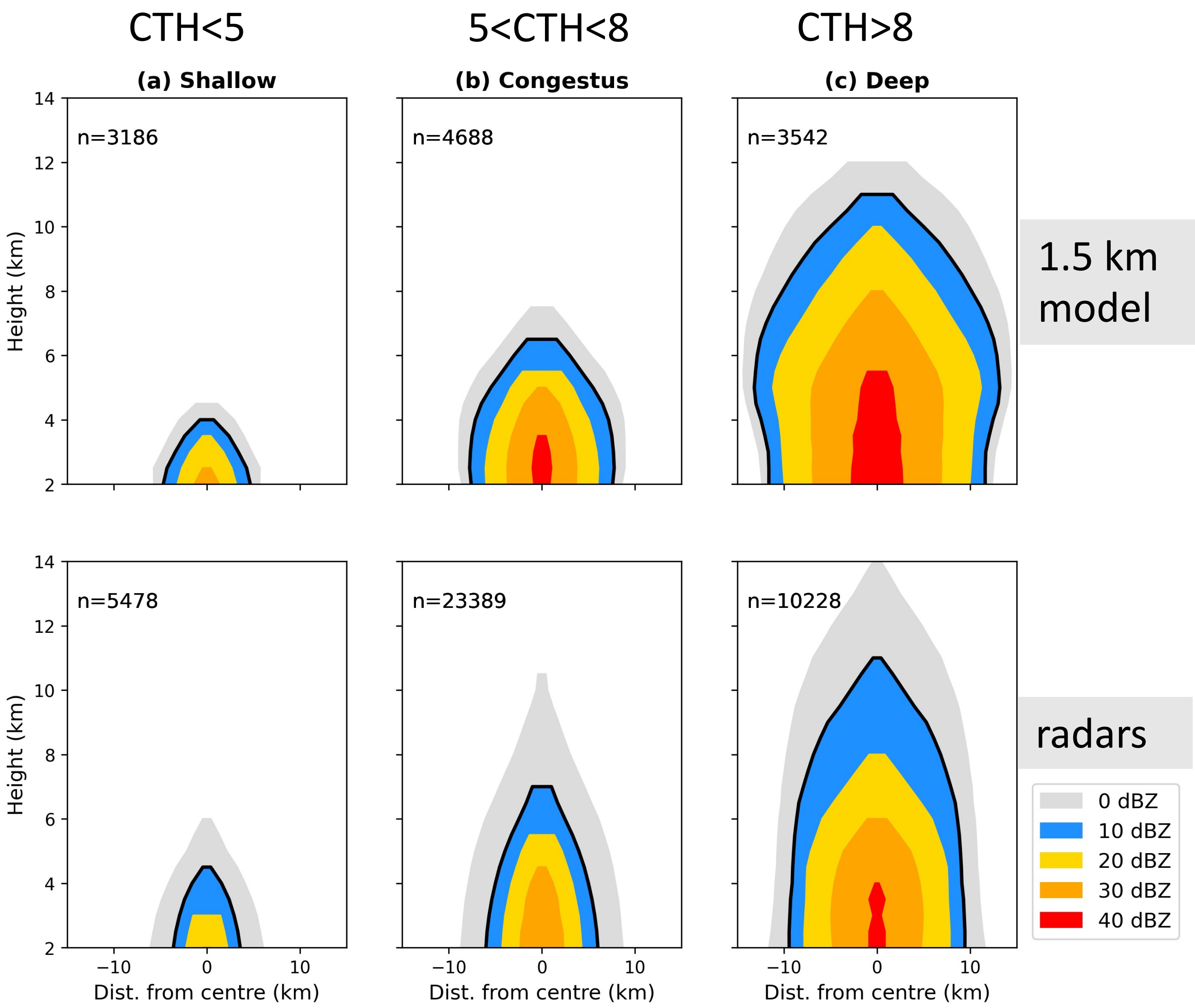
Too much area covered by shallow convection in model (blue) for all Indian regions, and not enough deep convection for northern, central, and south-eastern India

Model evaluation using DWR

We can analyse storm reflectivities at each discrete height level and compare model vs. radars:

- 40 dBZ contour (red): **Much more intense convective core in model** for all storm heights, especially deep
- 10 dBZ contour (black line): **Deep storms bulge outwards** around freezing level
  - Doesn't occur in observations
- Large area of drizzle/small crystals surrounding storms with no associated cloud ice aloft?
- 1 km models have been found to underestimate high-level cloud ice associated with anvils

Composite storm morphology (all locations)



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Outlook

- Operational radar are powerful tools for identifying convective cells
  - More radars are becoming available: especially useful in tropics where convection is frequent, yet historical observations may be lacking
- Model evaluation can also be performed with radars
  - Biases in convection-permitting models (and monsoon biases generally) remain poorly understood
  - The reasons for these biases are complex to understand, and require in-depth understanding of model microphysics, as well as large-scale dynamical biases
- More communication between model developers and researchers a useful future step
- We look to work in future with collaborators in India to study radar outputs over multiple seasons and encourage the availability of these data for the modelling community
- How do models perform at different convection permitting scales?

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