# Systematic evaluation of performance and bias of a mesoscale chemistry transport model (WRF-Chem) over high-altitude locations in the Himalaya

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## Highlights

- The seasonality of black carbon (BC) trend is captured well across South Asia except in Himalayan cities.
- Central Himalayan cities show higher BC concentration during pre-monsoon compared with other seasons.
- The mesoscale chemistry transport model shows transport of BC from the Indo-Gangetic Plain (IGP) during pre-monsoon for such inversion, which is not visible in observations.
- While eastern Himalayan cities do not exhibit such differences, they do indicate an inversion in the seasonal trend over the central Himalaya due to upper boundary and deposition parameterization in the model.

## Literature review

- Previous studies on South Asia such as Kumar et al. (2015) and Adhikary et al. (2007) reported similar issues in capturing seasonality over central Himalayan cities like Kathmandu and Nainital.
- Mues et al. (2017) increased the anthropogenic BC in the model by five times, but the results were still not realistic.
- Most studies have pointed to errors in the emission inventory for the contradiction between the observations and the results.

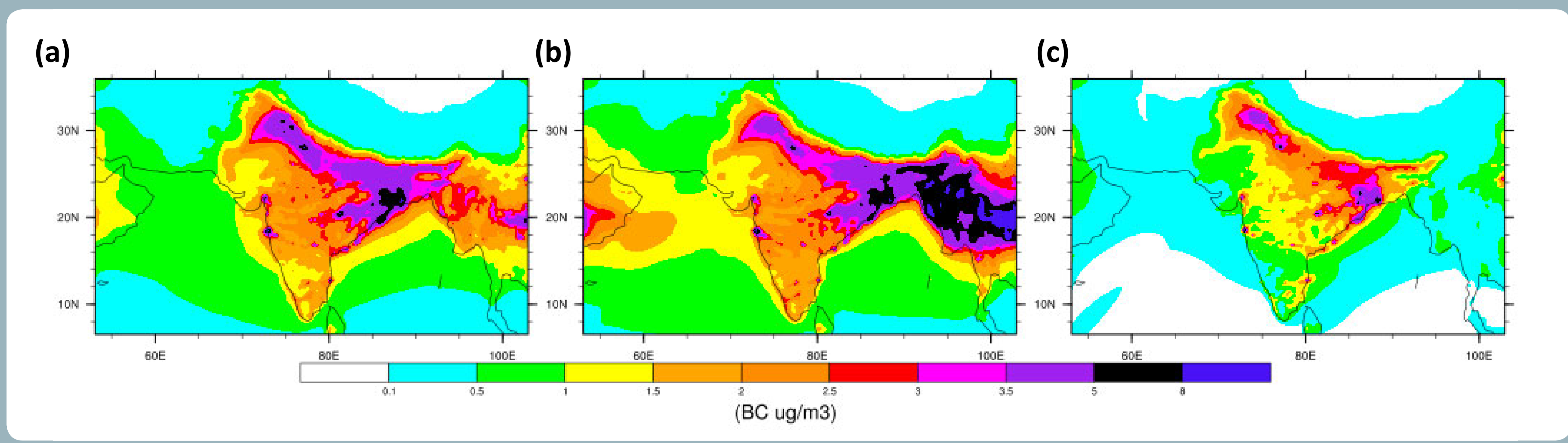


Fig. 1: BC surface concentration: (a) annual, (b) pre-monsoon, and (c) monsoon

## Climatology

- Asian monsoon is an intercontinental climate circulation system impacting about 60% of the world's population.
- El Niño–Southern Oscillation (ENSO) effects are very pronounced during the South Asian monsoon cycle.
- Thunder and lightning are considered as a signature of deep convection events.

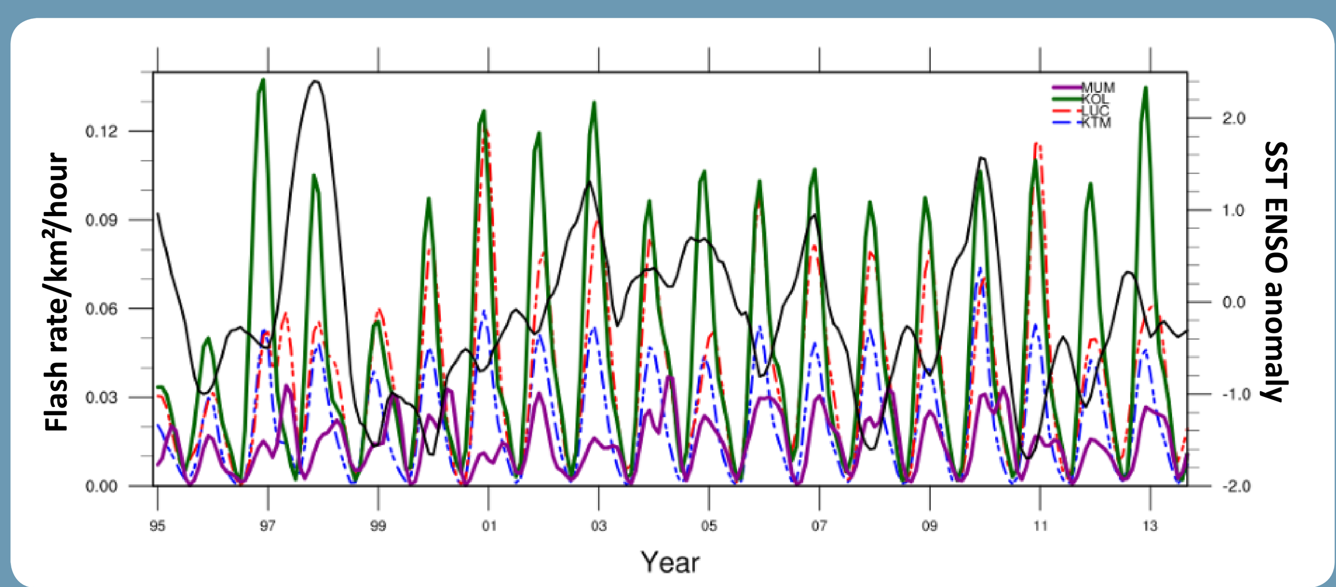


Fig. 2: Time series of the lightning flash rate over Mumbai (solid dark pink), Kolkata (solid dark green), Lucknow (dashed red), and Kathmandu (dashed blue), with sea surface temperature (SST) anomaly (solid black).

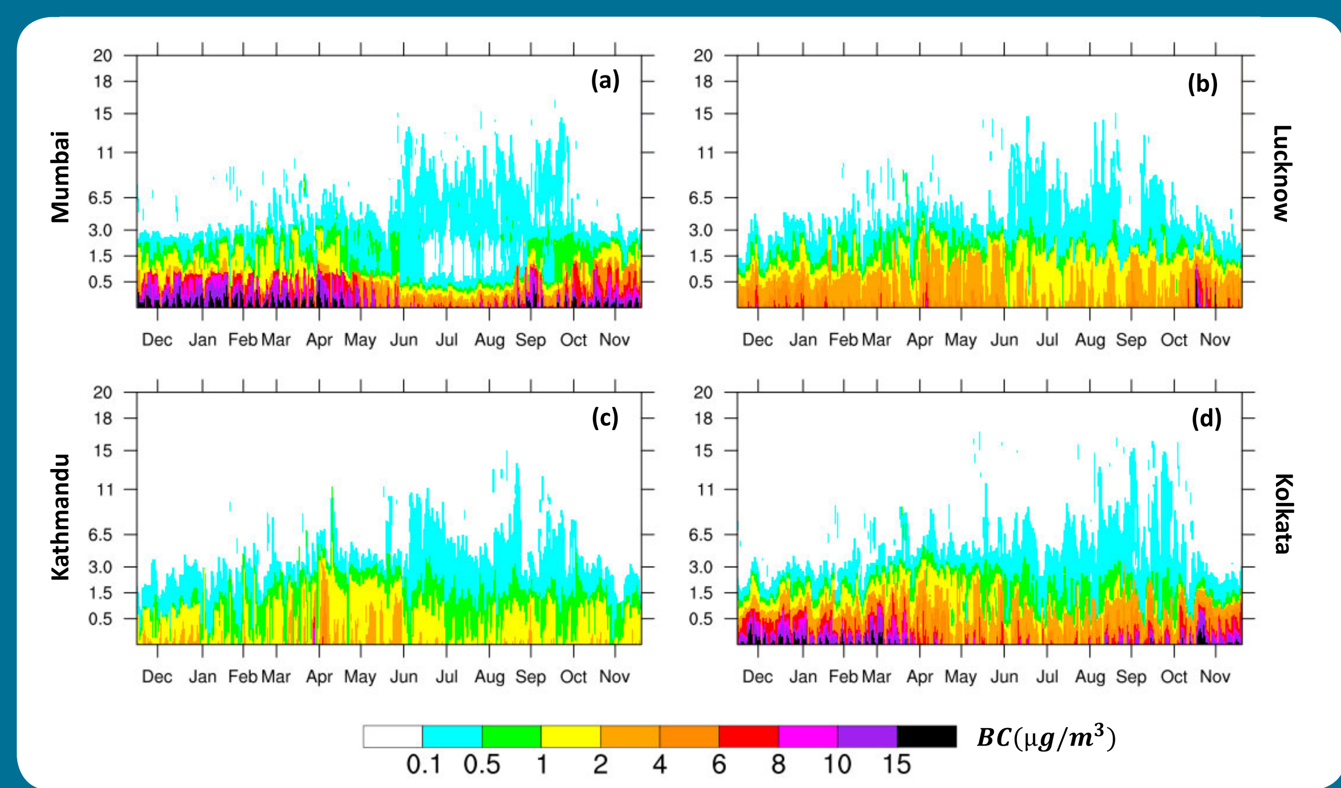


Fig. 3: Annual atmospheric profile concentration of BC (above ground level) for the selected cities: (a) Mumbai, (b) Lucknow, (c) Kathmandu, and (d) Kolkata.

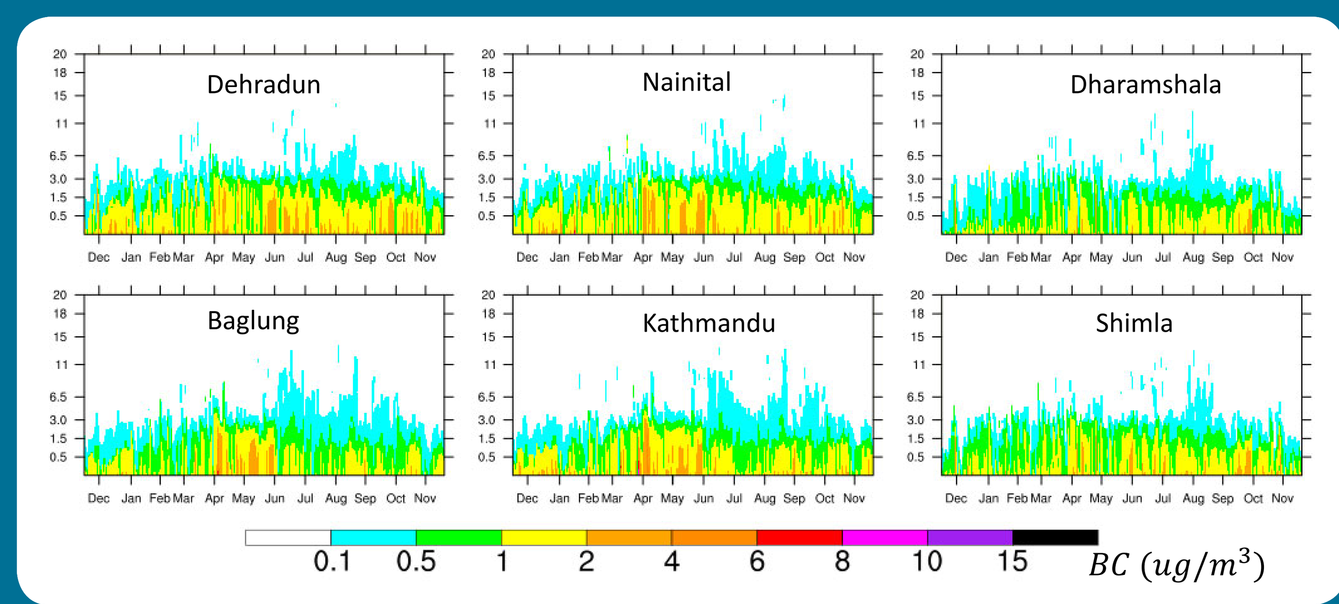


Fig. 4: Annual atmospheric profile concentration of BC (above ground level) over central Himalayan cities.

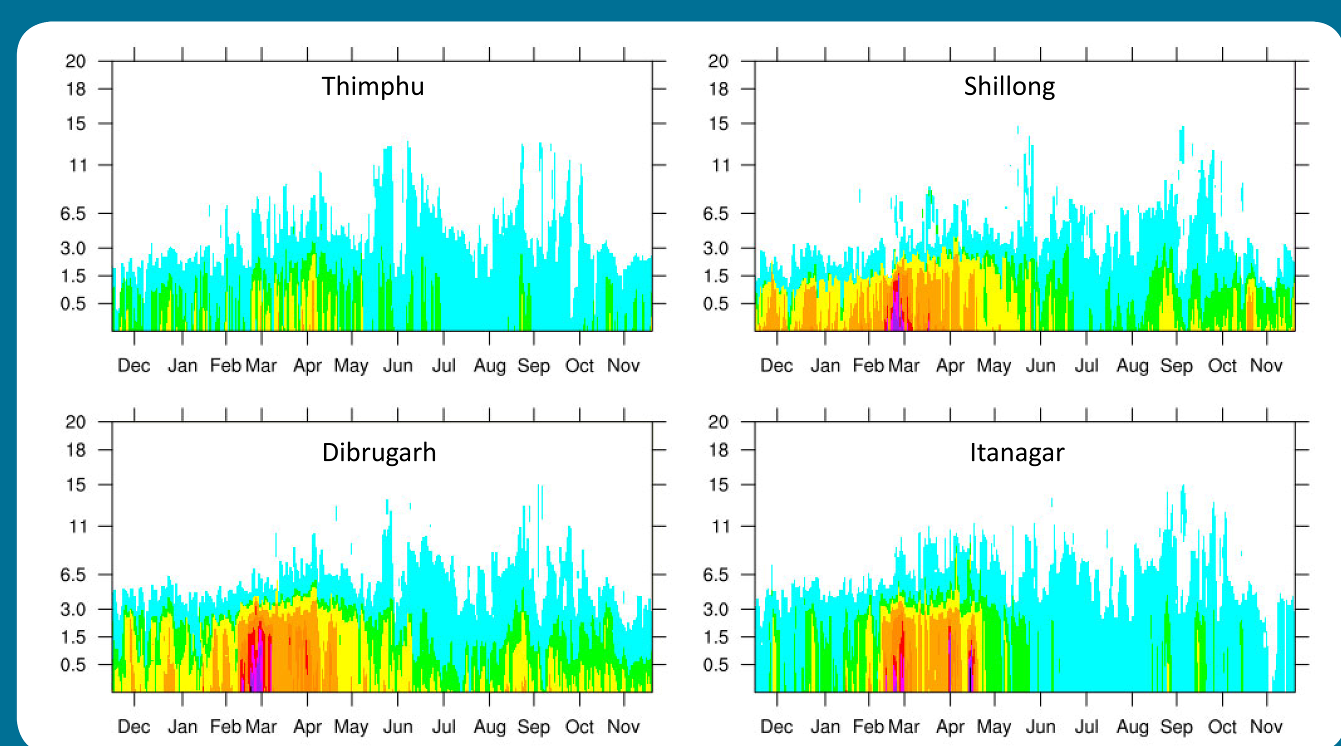


Fig. 5: Annual atmospheric profile concentration of BC (above ground level) over eastern Himalayan cities.

## Results/discussion

- The model can capture BC's seasonal trend over most South Asian cities, coasts, and plains, but the Himalayan city Kathmandu shows a higher BC concentration during pre-monsoon and early monsoon (Fig. 3).
- Further analysis suggests that all central Himalayan cities follow a similar trend (Fig. 4), whereas eastern Himalayan cities exhibit a normal trend (Fig. 5).
- In the model, cross-sectional analysis (Fig. 6) suggests that active convection during pre-monsoon and monsoon causes BC and other pollutants to lift from the southern side of the Himalaya and deposit around Himalayan cities. This results in a higher BC concentration in these cities; however, this phenomenon is not evident through observation.
- The model also shows that pollution from the IGP uplifts and deposits around central Himalayan cities. In contrast, eastern Himalayan cities have cleaner southern neighbours and are therefore unaffected by the seasonal trend.

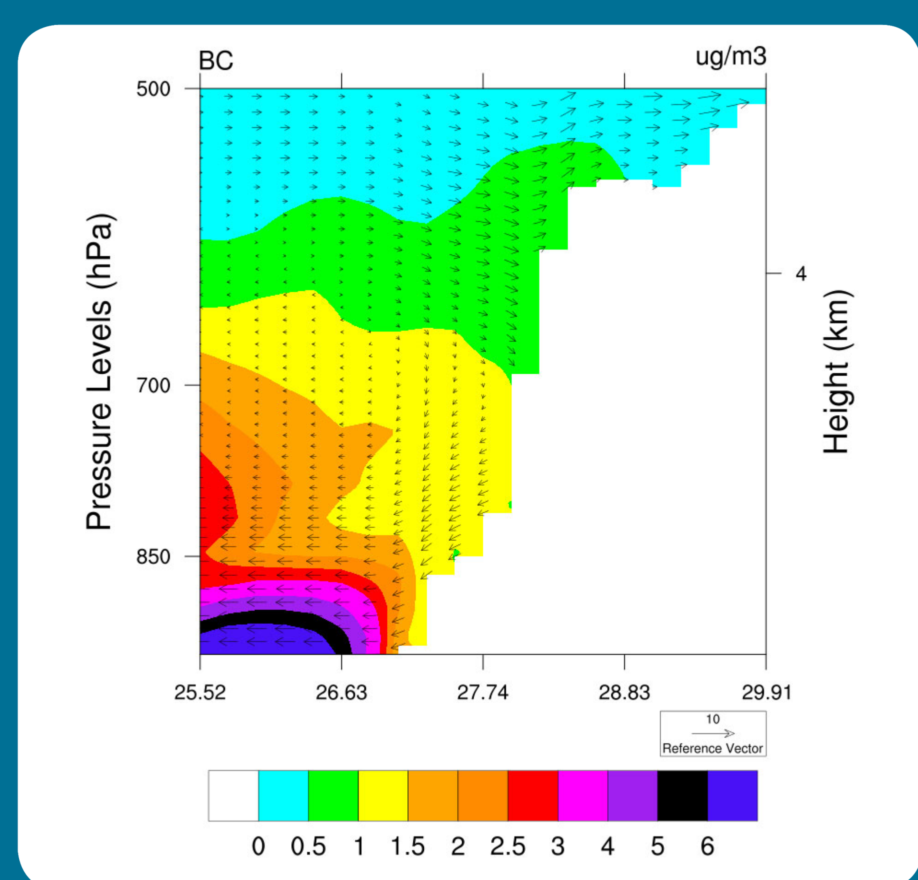


Fig. 6: Pre-monsoon cross-section profile of BC concentration passing through central Himalayan cities (cross section over Kathmandu).

## Conclusion

- The model can capture the seasonal trend over coasts and plains with the same set of parameterization and emission inventory, whereas central Himalayan cities show an inverted trend during pre-monsoon and monsoon.
- Previous studies have claimed that the emission inventory are responsible for the model disagreement with observations. This is true in terms of concentration but not the seasonal trend, since eastern Himalayan cities with the same inventory can capture the seasonality.
- Convective lifting of BC from pollution hotspots and deposition from the upper boundary in central Himalayan cities are evident in this study.
- This indicates that the model needs to explore better parameterization for the upper boundary condition and deposition scheme in central Himalayan cities.

### Bibliography

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