Title:	Understanding the spatiotemporal variability and trends of surface ozone over India
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Abstract:	With rising anthropogenic activities, surface ozone levels have increased across different parts of the world including India. Previous studies have shown that surface ozone shows distinct characteristics across India but these results are based on isolated locations and any comprehensive and spatiotemporally consistent study about surface ozone variability lacks thus far. Keeping these facts in mind, we utilize ground-based observations and reanalysis datasets to investigate spatiotemporal variations of surface ozone and its linkages with meteorology and precursors over Indian region. A validation exercise shows that the Copernicus Atmosphere Monitoring Service Reanalysis (CAMSRA) reasonably compares against the ground-based observations showing better correlations (> 0.7) over southern regions and relatively lesser (> 0.5) correlations over northern and eastern regions. We have further quantified this agreement in terms of range, mean absolute error (MAE), and root mean square error (RMSE). A time series analysis shows that the CAMSRA captures seasonal variations irrespective of location. Spatial distribution of surface ozone shows higher (lower) concentrations of about 40–60 ppb (15–20 ppb) during pre-monsoon (monsoon) months over northern and western parts and peninsular India. A prominent increase during May is noted over the northern region, especially over the Indo-Gangetic Plains (IGP). These seasonal variations are linked to solar radiation (SR), temperature, low-level circulation, and boundary layer height (BLH). CAMSRA-based surface ozone shows increasing trends across all four regions (north, east, west, and south India) and also India as a whole (0.069 ppb year−1, p = 0.001) with highest trends over the eastern region. Furthermore, principal component analysis (PCA) reveals that the first (second) mode shows a high percentage variance explained, ranging between 30 and 50% (10–20%). The corresponding PC-1 time series exhibits a notable increase in the surface ozone over south and central India, which corroborates the trend obtained through the area averaged time series. The second mode (PC-2) indicates prominent interannual variability over the IGP (southern India) in the pre-monsoon (post-monsoon). During the monsoon season, an interesting dipole pattern is noticeable, which closely resembles the active and break spell patterns of the Indian summer monsoon. Further, we quantify the weightage of precursors and meteorological parameters on surface ozone concentrations. The analysis suggests that PC1 of surface ozone is strongly influenced by CO and NOx (the precursors) while meteorology seems to dominate the PC2 during the pre-monsoon season. Overall, the results indicate that changes in the precursors or meteorological conditions have significant influences on the surface ozone concentrations across India.
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