Abstract

On the causes of observed and projected changes in daily and sub-daily precipitation extremes in major urban areas in India

Urban areas are the centers of population, economic growth, and wealth. Daily and sub-daily extreme precipitation events in urban areas cause flooding, disrupt transportation, damage urban infrastructure, and often result in loss of human lives. Despite the implications of precipitation extremes for urban infrastructure and stormwater designs, our understanding of the major drivers of daily and sub-daily precipitation extremes in urban areas remains limited. In this dissertation the following major questions are addressed:

1) To what extent daily extreme precipitation events have changed during the past and if rapid urbanization in India has contributed to the observed changes in precipitation extremes?,

2) How do local surface air temperature (SAT) and dew point temperature (DPT) affect daily and sub-daily precipitation extremes in India?,

3) What is the contribution of dynamic and thermodynamic scaling in sub-daily precipitation extremes in India? And

4) How will daily and sub-daily precipitation extremes that are relevant to urban stormwater infrastructure change under the 1.5 and 2.0°C warming worlds?

To address the above questions, we used observations and model simulations from different sources including Indian Meteorological Department (IMD), Global Summary of the Day (GSOD), Climate Hazards Group Infra-Red Precipitation with Station data (CHIRPS), Tropical Rainfall Measuring Mission (TRMM), Climate Prediction Center morphing technique (CMORPH), Multi-Source Weighted-Ensemble Precipitation (MSWEP), Coordinated Regional Climate Downscaling Experiment (CORDEX) and phase five of Coupled Model Intercomparison Project (CMIP5). First, we studied the changes in extreme daily precipitation due to the climate change (pre and post-1955) and urbanization (pre and post-1983) in urban areas in India using observed IMD precipitation data (1901-2010). Our results do not indicate any significant change
(p>0.05) in mean and distribution of the daily extreme precipitation indices for the pre and post 1955 and 1983 periods revealing an insignificant role of climate change and urbanization respectively, on daily precipitation extremes in urban areas. We further used daily precipitation projections from Regional Climate Models (RCMs) to estimate precipitation maxima (1-3 day duration and 100-year return period). We find that the number of urban areas with significant increases in precipitation maxima under the projected future climate is far larger than the number of areas that experienced significant changes in the historic climate (1901-2010), which warrants a careful attention for urban stormwater infrastructure planning and management.

Since understanding the relationship of precipitation extremes with temperature is helpful in predicting future precipitation extremes, next, we studied the sensitivity of precipitation extremes in response to warming (scaling: the relationship between precipitation extremes and temperature) at the selected urban locations where long-term (1979-2015) daily station data from GSOD are available. We used 3-hourly precipitation from TRMM and found a negative relationship between (sub-daily and daily) precipitation extremes and SAT in India at the majority of urban locations. The negative relationship between precipitation extremes and SAT in India can be attributed to cooling (SAT) due to the monsoon (June to September) season precipitation events suggesting SAT alone is not a good predictor of precipitation extremes. In contrast, a strong (higher than 7%/K) positive relationship between precipitation extremes and DPT and tropospheric temperature (T850) is shown at most of the locations, which was previously unexplored. Moreover, sub-daily precipitation extremes were found to be more sensitive to DPT and T850 than daily precipitation extremes. We, subsequently, used DPT and T850 as covariates for non-stationary daily design storms and found higher magnitude design storm under the assumption of a nonstationary climate.

As daily and sub-daily precipitation extremes are influenced by both local and large-scale processes, for a better understanding of the scaling relationship of precipitation extremes under the warming climate, consideration of both dynamic (controlled by the large-scale atmospheric processes) and thermodynamic (controlled by the saturation of atmospheric moisture) scaling is important. We, therefore, evaluated the role of dynamic and thermodynamic scaling in changes in sub-daily and daily precipitation extremes at urban locations in India. We find that the contribution of dynamic scaling in the rise in the frequency and intensity of sub-daily precipitation
extremes is higher than the thermodynamic scaling indicating the controls of large-scale factors. Furthermore, half-hourly precipitation extremes show higher contributions from the both thermodynamic (~10%/K) and dynamic (~15%/K) scaling than daily (6%/K and 9%/K, respectively) extremes indicating the role of warming on the rise in the sub-daily precipitation extremes in India.

Next, we analyzed the scaling relationship of sub-daily precipitation extremes with global mean temperature (GMT). We find that the sub-daily precipitation extremes show the scaling coefficient $9-10%/K$ with GMT indicating that extreme precipitation events in India are sensitive to the rise in GMT. Since the Paris agreement aims to limit the rise in GMT below 2.0°C and with a more ambitious target of 1.5°C from the pre-industrial level, we evaluated the sensitivity of rise in GMT on sub-daily precipitation maxima relevant to urban stormwater designs. For this, we used observations and projections of the sub-daily precipitation from 15 General Circulation Models (GCMs) over urban areas in India. We find that a rise of 1.5 (2.0°C) in GMT from the pre-industrial level is projected to cause 20 (25%) increase in 3-hourly precipitation maxima at 100 year return period under the stationary condition, which can further rise by 10% under the nonstationary condition. Projected warming results in a much faster (almost twice) increase in 3-hourly precipitation maxima than 24-hourly 100 year precipitation maxima. Moreover, 3-hourly 100 year precipitation maxima is projected to increase significantly at 78 locations (out of 89) if GMT rises from 1.5 to 2.0°C from the pre-industrial level. Our findings provide a better understanding of the observed and projected changes in daily and sub-daily extreme precipitation events in India. Moreover, we identify the major drivers that contribute to the changes in precipitation extremes at urban locations. Changes in daily and sub-daily precipitation extremes driven by the local and large-scale factors under stationary and nonstationary conditions provide robust estimates of precipitation extremes that are relevant to urban stormwater designs in India.