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The role of land surface processes on the mesoscale simulation of the July 26, 2005 heavy rain event over Mumbai, India

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ABSTRACT

A record-breaking heavy rain event occurred over Mumbai, India on July 26th, 2005 with 24-h rainfall exceeding 944 mm. Operational weather forecast models failed to predict the intensity and amount of heavy rainfall. The objective of this study was to test the impact of the three different land surface models when coupled to the Weather Research Forecasting (WRF), and also to investigate the ability of the WRF model to simulate the Mumbai heavy rain event. Numerical experiments were designed using the WRF model, with three nested domains (30, 10, and 3.3 km grid spacing). Results confirmed that the simulated rainfall is sensitive to the grid spacing (with finer grids leading to higher rainfall). Results also suggest that simulated precipitation amounts are sensitive to the choice of cumulus parameterization (with Grell–Devenyi cumulus scheme performing relatively best). To reduce the confounding impact of cumulus parameterization in studying the impacts of land surface models, we evaluated results for the 3.3 km grid spacing domain with explicit convection. Simulations were performed from 12Z, July 25th to 00Z, July 27th with identical boundary conditions and model configurations for three different land surface models (the Slab, the Noah, and a modified version with photosynthesis module—the Noah-GEM). The model results were compared with observed rainfall, surface temperature, and operational soundings over three locations: Mumbai, Bangalore and Bhopal. Model results showed that: (i) The simulated rainfall was sensitive to the chosen land surface model. The rainfall spatial distributions, as well as their temporal characteristics, were different for each of the three WRF runs with different LSMs. (ii) In contrast to the findings over mid-latitudes, the relatively simpler Slab model had a relatively better performance than the modestly complex Noah and Noah-GEM LSMs. For example, the highest observed rainfall over Mumbai was 944 mm and the simulated amounts for Slab, Noah and Noah-GEM runs were 781 mm, 733 mm and 678 mm, respectively. (iii) Overall, the Slab model simulated a relatively cooler surface and a shallower boundary layer. Most significantly, the Slab model resulted in a convergence hotspot at both the 850 mb and 500 mb levels, which lead to high moisture accumulation and higher rainfall activity over Mumbai. Noah and Noah-GEM, on the other hand, resulted in a divergence zone over Mumbai and the Western Ghats leading to more widespread runs but relatively lower rainfall amounts over Mumbai. Additional synthetic experiments were performed to test the sensitivity of land use land cover, the model start time and run duration. Results indicated that the WRF model was able to reproduce several features of the Mumbai rain event, and that the land surface representations would have substantial impact on the heavy rain simulations. Future studies with more up to date land use land cover data, and regional calibration of the land surface model parameters, show the potential for improving the performance of the Noah-WRF over the Indian monsoon region.

1. Introduction

On July 26th, 2005, the Indian Meteorology Department (IMD) observatory at Santa Cruz (19.2°N, 72.53°E) in northern Mumbai recorded 944 mm of rainfall over a 24 h period (ending 0300 UTC on July 27th, 2005), while the Colaba observatory (18.93°N, 72.85°E), (about 25 km south of Santa Cruz) recorded 74 mm for the same period. The highest rainfall recorded for the event was 1049 mm at Lake Vihar in northern Mumbai (19.14°N, 72.53°E), (Jenamani et al., 2006). The rain gauge observations for this rain event are shown in Fig. 1a. The previous record of the heaviest 24-h rainfall over Mumbai was 578 mm for Colaba in 1974, and 399 mm for Santa Cruz in 1991. The Tropical Rainfall Measuring Mission (TRMM) satellite, which

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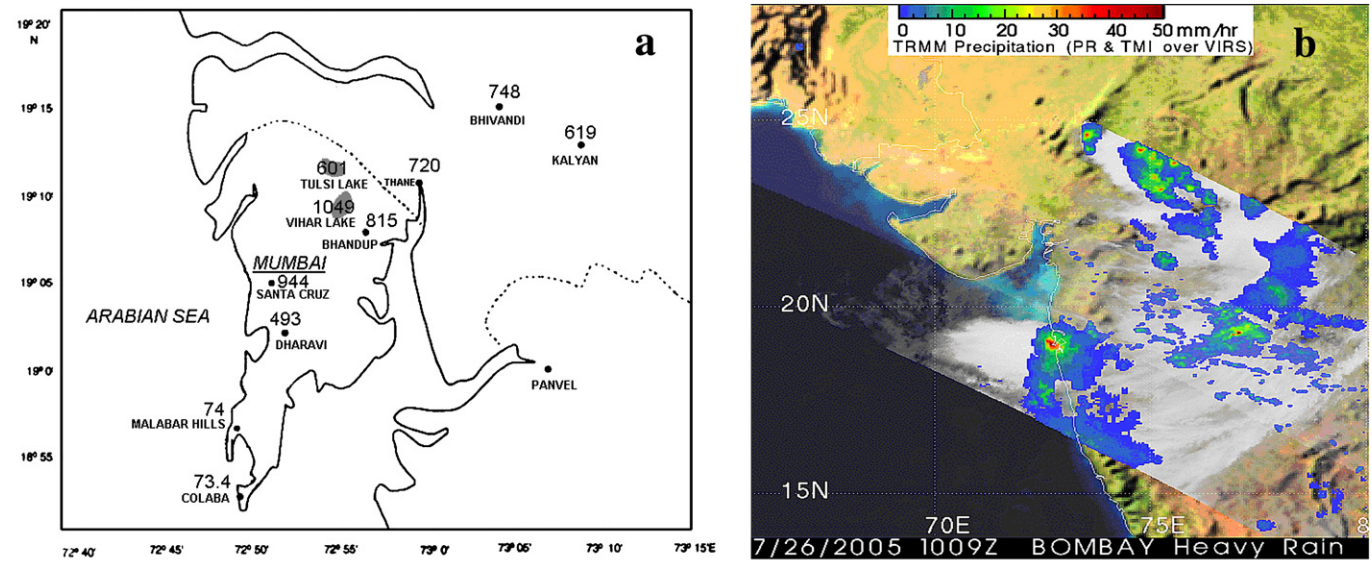

Fig. 1. (a) Rainfall observations across Mumbai (mm); (b) TRMM rainfall rate (mm/h) for July 25–27, 2005 (Source: NASA Goddard Space Flight Center/Tropical Rainfall Measurement Mission Extreme events archive. http://trmm.gsfc.nasa.gov/publications_dir/bombay_july05_rain.html).

passed over Mumbai at 3:39 PM local time (1009 UTC), also captured a highly localized and intense rainfall locale over the Indian subcontinent (Fig. 1b).

Jenamani et al. (2006) studied the observational and forecasting aspects of the Mumbai rain with satellite and surface observations. They also compared this rain event case with other historical intense rain episodes over India. Observations indicated that a weak monsoon condition existed between July 19th and 22nd. The monsoon strengthened due to a low pressure system over the northern area of the Bay of Bengal on July 23rd. Jenamani et al. (2006) concluded that the low pressure system positioned the rain bands over the Western Ghats, and mesoscale interactions lead to the formation of the severe Mumbai rainfall. Shyamala and Bhadram (2006) extended the analysis using observational data for synoptic and thermodynamic fields and radar, and visible satellite imagery. They confirmed that a cloud band formed over the Arabian Sea on July 25th, which corresponded with strong low level winds over Mumbai with mid-tropospheric dryness, which may have contributed to the heavy rain.

Per many media reports, the event was not correctly forecasted by the operational weather forecast centers. The heavy deluge thus caught the public by surprise and led to loss of over 3.5 billion USD and over thousand human beings (NCDC, 2007). To synthesize the

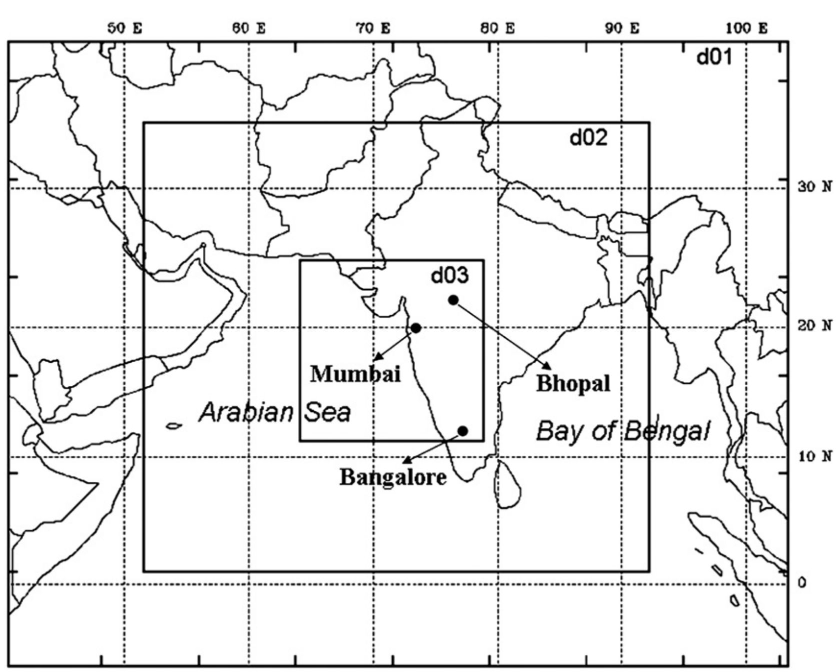

Fig. 2. Domains used for WRF simulations with 30 km (domain d01), 10 km (domain d02), and 3.3 km (domain d03) horizontal grid spacing and 31 vertical layers. Also, three selected meteorological stations for which sounding and surface data are available for comparisons within the model's third domain (d03) results are indicated. The three locations are Mumbai, Bangalore, and Bhopal.