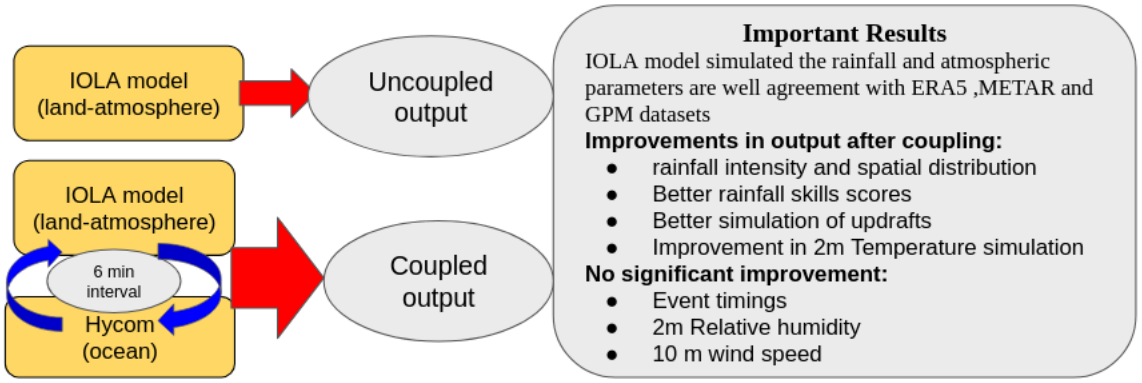
Simulation of extreme rainfall events using the Indian Ocean-Land- Atmospheric (IOLA) coupled modeling framework

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In the context of global warming, the extreme rainfall frequency and intensity have significantly increased. Such events often trigger floods and landslides, causing severe damage to human life, infrastructure, and socio-economic assets. As defined by the India Meteorological Department (IMD), a cloudburst is high-intensity rainfall exceeding 100 mm/hr at a station or over a 20-30 sq km area. This study analyzes heavy rainfall events, including the cloudburst event, using the latest Indian Ocean Land Atmosphere (IOLA) coupled model. The IOLA model experiments are performed in two modes, with and without ocean coupling. The results show that the IOLA model well simulates cloudburst events with minimal spatial and temporal errors. The ocean-coupled simulation of the IOLA model yields better results than the uncoupled simulation: rainfall intensity prediction improves, and the thermodynamic parameters, especially omega and the 2 m surface temperature, are improved. The skill score tests also indicate that the IOLA model consistently simulates well, with better scores (>0.4 for lower thresholds <10 mm and >0.2 for higher thresholds >10 mm). The Skill score tests also show that, after coupling the IOLA model, rainfall prediction skills improve by ~10-15%. Overall, the coupled IOLA model simulation can help to improve predictions of heavy rainfall events and cloudbursts. Overall, this study provides valuable insights for the modeling community, enhancing understanding of cloudburst dynamics through an advanced coupled Ocean–Land–Atmosphere modeling framework.



Graphical abstract showing the model setup and important results

Theme: Toward High Resolution Representation of the Climate System

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Abstract

In the context of global warming, the extreme rainfall frequency and intensity have significantly increasedSuch events often trigger floods and landslides, causing severe damage to human life, infrastructue, and socio-economic assets. As defined by the India Meteorological Department (IMD), a cloudburst ishigh-intensity rainfall exceeding 100 mm/hr at a station or over a 20-30 sq km area. This study analyzes heavy rainfall events, including the cloudburst event, using the latest Indian Ocean Land Atmosphere (IOLA) coupled model. The IOLA model experiments are performed in two modes, with and without ocean coupling. The results show that the IOLA model well simulates cloudburst events with minimal spatial and temporal errors. The ocean-coupled simulation of the IOLA model yields better results than the uncoupled simulation: rainfall intensity prediction improves, and the thermodynamic parameters, especially omega and the 2 m surface temperature, are improved. The skill score tests also indicate that the IOLA model consistently simulates well, with better scores (>0.4 for lower thresholds <10 mm and >0.2 for higher thresholds >10 mm). The Skill score tests also show that, after coupling the IOLA model, rainfall prediction skills improve by ~10-15%. Overall, the coupled IOLA model simulation can help to improve predictions of heavy rainfall events and cloudbursts. Overall, this study provides valuable insights for the modeling community,enhancing understandingof cloudburst dynamics through an advanced coupled Ocean–Land–Atmosphere modeling framework.

Introduction

The term “cloudburst” signifies the sudden discharge of a cloud’s entire water content, producing rainfall rates above the normal threshold of heavy precipitation (Woolley, 1946). In India, cloudbursts are frequent during the monsoon season due to strong convection associated with orographic forcing over the Himalaya, Western Ghats, and northeastern hills. The previous studies describe cloudburst as highly localised, high-intensity rainfall events, which are hard to monitor due to sparse observations. The development in the field of computation, satellite and radar observation capabilities enabled scientists to analyse the cloudburst events by means of remote sensing and numerical modelling.

Data and Model Configuration

Data	Description
NCEP GFS	spatial resolution 0.25°×0.25° and temporal resolution of 3-h, for initial and boundary conditions for IOLA model
RTOFS	a spatial resolution of 1/12° × 1/12° (~8 km), 36 vertical layer and a temporal resolution of 3 hours.
Global Precipitation Measurement (GPM)	~10 km spatial resolution and 0.5 h temporal resolution
ERA reanalysis	~25 km spatial resolution and 1 h temporal resolution

Configuration	Description
Grid distance	4.5 km,1.5 km, and 0.5 km
Time step	10s, 3.3s, and 1.11s
Vertical levels	75 with 10 hPa increment
Long-wave radiation	RRTM Longwave Scheme
Short-wave radiation	RRTM Shortwave Scheme
Cumulus	Kain-fritsch
Microphysics	Thompson
PBL	Yonsei University (YSU)
Surface Layer	Revised MM5 similarity
Land Surface	Noah LSM

- Coupling interval of 6 minutes

Result and Discussion

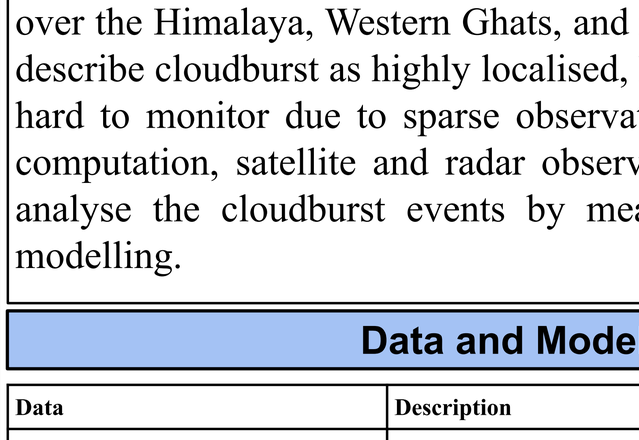


Fig 1. 24-h accumulated rainfall from GPM, IOLA-uncoupled and coupled simulations

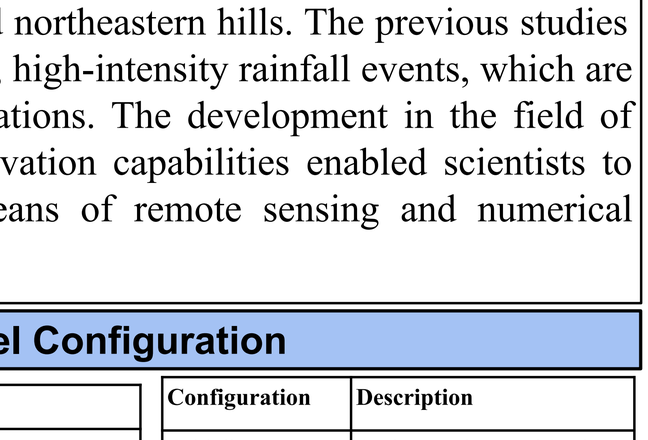


Fig 2. Rainfall from GPM, IOLA-uncoupled and coupled simulations during the cloudburst hour.

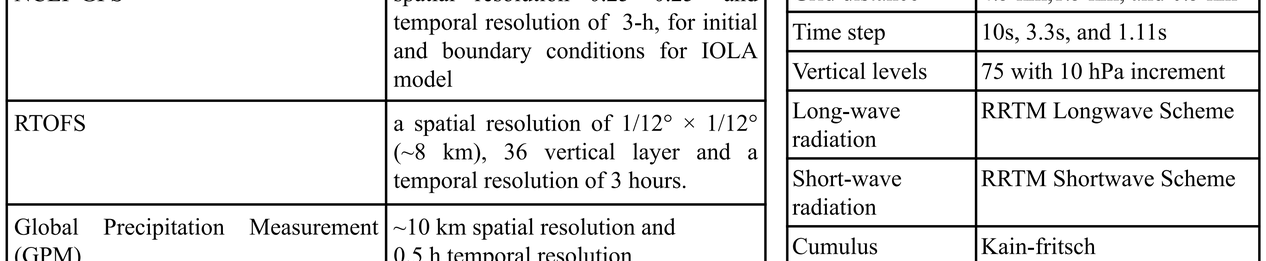


Fig 3. Mean skill scores (a) Probability of Detection (POD), (b) Critical Success Index (CSI), and (c) Fraction Skill Score (FSS) from IOLA-uncoupled and IOLA-coupled simulations compared against GPM IMERG Similar to (a), (b), (c), but for a 3 mm threshold at different forecast hours.

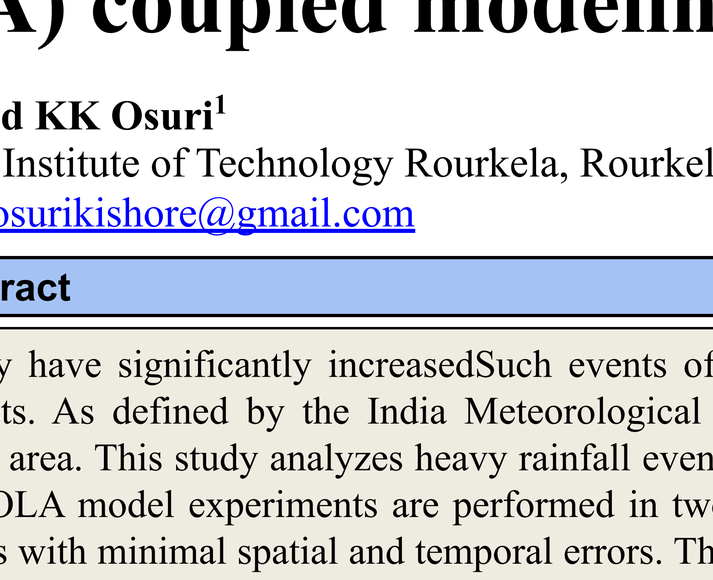


Fig. 4 Pressure-latitude plot of Specific Humidity (contour; g/kg) and omega (shaded; Pa/s) averaged over longitude. The rainfall (mm/day) is averaged and presented along the latitude in the (purple) line plot, and values are presented in the Secondary Y-axis. The black dashed line represents the latitude of Mumbai .The right-hand side figure is a similar Pressure-longitude plot, but for Specific Humidity (contour; g/kg) and omega (shaded; Pa/s) are averaged over latitudes, while the dashed line represents the longitude of Mumbai. The plot is shown from ERA-reanalysis-GPM (1st row), IOLA uncoupled model simulated (2nd row) and 3rd IOLA coupled model simulated.

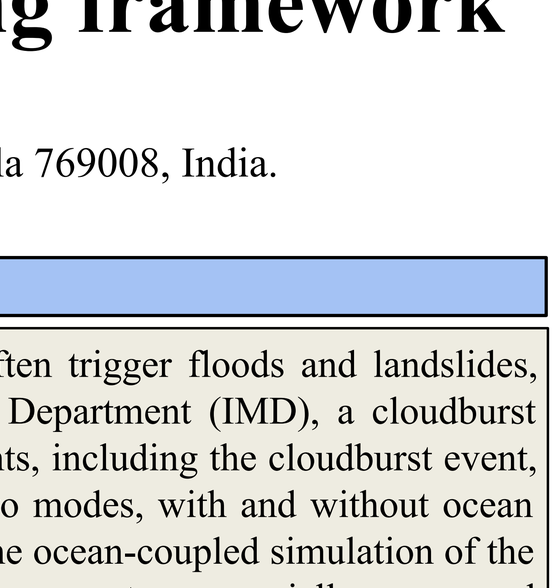


Fig 5. Intercomparison of IOLA uncoupled and coupled model simulated surface parameters; (a) 2m Relative humidity (RH2, %), (b) 2m Temperature (T2M, °C), (c) 10m Wind Speed (WS10; ms-1) for the Mumbai case of 2025 May 26.

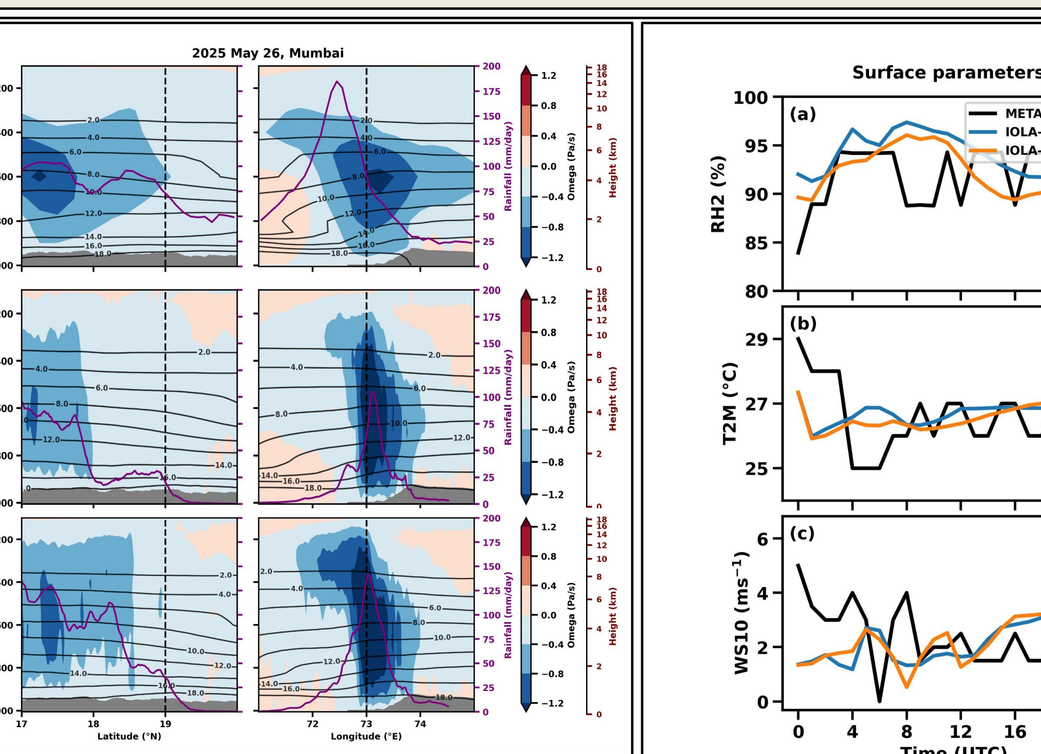


Fig 6. ERA re-analysis and IOLA simulated 850 hPa winds during time period (±2 hrs) of cloudburst events in both cases.Green Shade represents wind speed and arrow represents wind direction.

Conclusion

- The IOLA model effectively simulatesd extreme rainfall and cloudburst rainfall over Mumbai. Enhanced moisture availability and strong orographic lifting are clearly evident in both the IOLA simulations and the ERA datasets.
- The influence of ocean–land-atmosphere coupling on cloudburst events is verified and the coupled simulation shows better performance compared to uncoupled simulation.

References

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