ABSTRACT

The Earth's atmosphere plays a pivotal role in shaping our planet's climate system. Among the many processes that occur within the atmosphere, convection stands out as a fundamental mechanism responsible for redistributing thermal energy and moisture, intriguing climate scientists for decades. Solar radiation heats the Earth's surface, and this heat is transferred to the atmospheric air primarily by conduction and convection. Convection, the vertical movement of air masses driven by the temperature and density differences, transports this heat to larger scales, leading to cloud formation and precipitation. Convection also results in the vertical redistribution of horizontal momentum through updrafts and downdrafts. This transport process causes frictional deceleration, which in turn facilitates the conversion of kinetic energy from large-scale atmospheric flows to convection and turbulence. Thus, atmospheric convection combines fluid mechanics and heat transfer in Earth's atmosphere. However, unlike classical fluid mechanics problems, for which numerical solutions are straightforward, geophysical fluid dynamics presents a challenge due to the complex three-dimensional and time-dependent nature of the flow and the phase change of water. Convection can manifest as dry or moist, shallow or deep, each exhibiting distinct characteristics.

This study focuses on deep convection, which involves the ascent of moist air to higher altitudes and the formation of towering cumulonimbus clouds. Deep convective clouds serve as a pivotal component in the regulation of the Earth's water and energy cycles. Deep convection frequently occurs over tropical oceans and varies across a range of spatio-temporal scales across the tropics, influencing weather and climate. In the Indian context, deep convection that typically occurs during the summer monsoon season of June-through-September is a fundamental process

responsible for distributing rainfall across the Indian subcontinent. In the months of summer monsoon, the Bay of Bengal area commonly witnesses the occurrence of deep convective clouds. Although these clouds also occur during other months, in the present study our focus is on the case study during the monsoon months. Understanding the deep convection during the convection with the large-scale environment in this region is crucial for improving convection simulation. Obtaining observational data over regions of interest is the ideal approach to understand these phenomena accurately. However, it is not possible to have observational data for every point. Therefore, computational studies play a crucial role in filling this gap. In addition to the ability to simulate these deep clouds, given the backdrop of global warming which is causing changes in the dynamics and thermodynamics of the atmospheric processes, understanding the impact of warming on deep clouds is a critical research question, and addressing it will enhance our comprehension of the complex convective systems of the future. The overarching objective of this thesis is to understand the atmospheric convection over the Bay of Bengal during active monsoon phase using a high-resolution model. By employing this model, the study aims to address some of the challenges mentioned above by examining each aspect in isolation and translating the knowledge gained to evaluate the impact of warming in the plausible future.

In the first part of the thesis, we use a large eddy simulation model to set up a study over the Bay of Bengal region to successfully simulate the deep convective clouds during an active convection phase and to understand the dynamical features of these clouds. Due to the lack of observational data, these simulations are based on ERA5 (Fifth generation European Centre for Medium-Range Weather Forecast atmospheric reanalysis) data. The results demonstrate that the clouds formed over the region during the active phase are deep and precipitating in nature. Given that the simulations are forced with ERA5 data, the results indicate that simulations accurately *reproduced the vertical structure of cloud hydrometeors, exhibiting similarities to that observed in ERA5 data. These clouds reach heights of around 18 km and are typically observed over the region during the monsoon season. The turbulent fluxes of heat and moisture provide details of turbulent atmosphere during active convection event. The cloud core fields are conditionally averaged, and their properties align well with the deep convective clouds reported in the literature.*

Next, we explore the impact of boundary conditions on convection evolution. Simulations performed with large-scale forcings as boundary conditions emphasize their importance in capturing deep convection phenomena. These forcings play a crucial role in representing the influence of larger atmospheric conditions on convection evolution and organization. We observe from the large-scale forcings simulations that these forcings are necessary to simulate the convection evolution. We also examine how domain size affects convection evolution and observe that smaller domains are inadequate for capturing deep convection. We observe that in smaller domains, the clouds are formed with size as big as the domain and then break and this process continues again. Thus, not allowing the simulation to reach a steady state. Therefore, to simulate deep convective clouds a larger domain size is required. Additionally, we investigate the grid size sensitivity and determine that in comparison to 125 m horizontal grid size, 250 m grid size is suitable for simulating deep convective clouds, as the results converge for both the cases. Further 250 m grid will also reduce computational time by a factor 4 in comparison to 125 m grid.

Finally, we study the impact of warming on deep convective clouds over the Bay of Bengal using large eddy simulations. By increasing both atmospheric and sea surface temperatures from the base case, we observe that warming enhances deep convection intensity, leading to higher Convective Available Potential Energy (CAPE) values and more intense convective systems with increased precipitation. The warmer atmosphere results in higher liquid water path values, *indicating intensified deep convection. The intensification of cloud hydrometeors is further augmented as cloud tops rise in response to warming conditions. We observe from these simulations that due to warming in future there will be more intense convective events over the BoB region, and this can lead to more cyclonic activity across the region. These results provide valuable insights into the complex dynamics of deep convection and its response to various factors that can be implemented in development of India centric climate model.*