Title: The Emerging Monsoon Rainfall Dipole After the Late 1990s

Abstract

Significant shifts in Indian Summer (South Asian) Monsoon rainfall patterns have been observed since the late 1990s, with particular emphasis on the changing regional climate forcings that govern this variability. Through a comprehensive analysis of synoptic-scale systems such as Monsoon depressions, tropical and mid-latitude dynamical interactions, and teleconnections, this research documents and explains the recent shifts in rainfall patterns: Northwest India has seen an increase, while the Indo-Gangetic Plain has a decreasing rainfall trend. This dipole pattern is not reproduced in historical climate model simulations, and its physical drivers remain poorly understood. Synthesising observational and assimilated data, along with climate model simulations, we show that this dipole is driven by North Atlantic sea surface temperature (SST) changes, which are transmitted through a barotropic governor mechanism and thereby control Asian jet stream dynamics. Enhanced barotropic energy conversion after 1999 created momentum, focusing on the jet core while weakening the east-west flanking regions, thereby fundamentally altering the monsoon circulation by modulating the local Hadley cell and shifting the low-level monsoon jet. These circulation changes subsequently induced warming in the northern Arabian Sea by altering regional ocean dynamics. Hence, there has been an increase in the formation of monsoon depressions over the northern Arabian Sea in the recent decade. This barotropic governor activation coincides with the North Atlantic cold blob attributed to a slowdown in the Atlantic Meridional Overturning Circulation (AMOC). Coupled climate models driven over the historical era systematically fail to reproduce North Atlantic SST changes, and so this atmospheric dynamical mechanism instead shows reversed barotropic energy conversion patterns and misses this key teleconnection mechanism. Prescribed SST experiments using observed North Atlantic SST changes validate the proposed mechanism, thereby successfully reproducing both observed jet dynamics and rainfall trends. The identification here of a North Atlantic-Asian teleconnection pathway modulated by the barotropic governor effect directly links the behavior of the AMOC and monsoon tipping elements to each other.

Speaker Bio:

Dr Mahendra Nimmkanti is an atmospheric and climate scientist with an academic foundation in **meteorology, oceanography, and climate dynamics**. He holds an **M.Sc. in Meteorology** and an **MTech. in Atmospheric Sciences** from **Andhra University**. He completed his **PhD from NIT Rourkela**, where his doctoral research investigated the role of regional climate forcings in governing **Indian Summer Monsoon variability after the late 1990s**. During his PhD, he was selected for the prestigious **OVDF Fellowship**,

enabling a one-year research stint at **Purdue University, USA**, underscoring his international exposure in climate science. Following his doctorate, he joined **IIT Hyderabad as a Research Associate**, contributing to **subseasonal-to-seasonal (S2S) prediction** research. He is currently a **Project Scientist at CAOS, IISc Bangalore**, working under **Prof. Govindasamy Bala**.