Abstract

The weather of the subtropical Indian region is strongly influenced by dynamical changes in the upper troposphere and lower stratosphere triggered by the Rossby wave break (RWB). These breaking events can substantially modulate regional weather and climate, often leading to sudden and severe extremes. Despite their significance, a comprehensive understanding of the characteristics and impacts of RWB in the Indian subcontinent remains limited. This thesis presents an in-depth investigation into the climatology, variability, and associated influences of the RWB in the Indian region, using long-term reanalysis and satellite datasets complemented by numerical model simulations.

To address the changes associated with RWB in India, we implemented a contour based potential vorticity detection algorithm (PV) with region specific constraints to objectively identify RWB events in the Indian subcontinent. A total of 513 RWB events were detected during the period from 1979 to 2021 uncovering a prominent ∼20% increase in frequency and intensity during 1999–2018. RWB events peak in winter, dominated by zonal wavenumbers 5–7, with deep intrusions to ∼650 hPa and 7.5°N. RWB promotes extreme rainfall by inducing instability and downstream moisture influx from upper-level PV anomalies. Pacific SST anomalies further drive interannual-decadal variability through upper-level wave modulation.

Since these breaking events can induce tropopause folding, allowing the mixing of stratospheric ozone into the troposphere, it is essential to understand their role in enhancing tropospheric ozone, particularly at lower atmospheric levels. A total of 232 events have been analysed from 2004 to 2021 using AIRS satellite data and CAMS chemical reanalysis data. Enhanced ozone was noticed on RWB days, with 46% of events enabling ozone transport to lower levels; increases of 150–250 ppbv were observed at 100–250 hPa and 10–20 ppbv at 850 hPa.

During the pre-monsoon season (March–May), a total of 139 RWB events were iden-

tified during 1979–2021, revealing significant surface temperature amplification on both the western and eastern sides of the breaking PV streamers. These anomalies persist for 3–4 days around the peak breaking day and are linked to upper-level negative PV anomalies, anticyclonic circulations at 250 hPa, and subsidence at 500 hPa, inducing hot, dry conditions over these regions. Further, the coupling between RWB and heatwaves (HWs) is examined using both observational datasets and reanalysis products over the northwestern Indian region, which has been previously identified as a hotspot for upper-level dynamical influences. In northwest India, ∼33% of heatwaves (RWB:HWs) align with RWB, featuring 14% stronger temperature anomalies, longer durations, and broader spatial extents than non-RWB events (nor:HWs), due to persistent mid-tropospheric ridges and subsidence that foster hot, dry conditions.

Further, the WRF simulations of the March 2022 RWB associated heatwave (control vs. perturbed upper-level winds/geopotential heights) confirmed dynamical contributions: perturbations suppressed RWB, weakened circulations, and cut surface temperatures by ∼1 K.

Overall, this thesis advances the scientific understanding of RWB events and its multi–faceted influence on regional weather extremes and tropospheric composition over the Indian subcontinent. The findings emphasize the importance of upper-level dynamical processes in modulating rainfall, ozone, and heatwaves, offering critical insights to improve the representation of large-scale wave flow interactions and extreme event prediction in a warming climate.