Abstract

The mesosphere and lower thermosphere (MLT) constitute a key region in the atmosphere for vertical coupling processes, where tides, planetary waves, and gravity waves exchange momentum and energy with the background circulation, thereby modulating large-scale circulation and variability. This cumulative thesis investigates planetary-scale dynamics in the low-latitude MLT using meteor radar observations, satellite measurements, whole-atmosphere simulations, and global reanalysis datasets, focusing on (i) the climatology and variability of diurnal tides over Jicamarca, Peru, and (ii) the abnormally strong March 2023 phase of the Mesospheric Semiannual Oscillation (MSAO).

The first part of the thesis presents a climatological analysis of more than three years of SIMONe meteor radar observations and SD-WACCM-X simulations. The results confirm that the diurnal tide is the dominant mode of variability in the low-latitude MLT and exhibits pronounced seasonal, interannual, and day-to-day variability. Comparisons with simulations reveal that SD-WACCM-X reproduces the main seasonal characteristics of mean winds and tides, but systematically underestimates tidal amplitudes. Beyond the analysis of climatological amplitudes, observed and simulated tidal phase profiles were analyzed as a diagnostic tool to infer seasonally significant contributions from nonmigrating tidal components. Additionally, to investigate day-to-day variability beyond the seasonal cycle, a methodology based on complex tidal amplitudes derived from least-squares tidal fits and subsequent wavelet analysis was developed. By retaining both amplitude and phase information, the method provides a robust framework for identifying tidal modulation, revealing variability on timescales of approximately 5–80 days associated with planetary waves and tropical intraseasonal oscillations.

The second part of the thesis characterized the abnormally strong westward phase of the MSAO observed during the March equinox of 2023. Observations from a network of low-latitude meteor radars showed zonal winds reaching -80 m s^{-1} at 82 km altitude, making it the strongest event observed in at least the last decade. The analysis indicated that the anomaly was associated with favorable gravity-wave filtering conditions linked to the westerly phase of the stratospheric Quasi-Biennial Oscillation and the absence of major sudden stratospheric warmings, together with enhanced breaking of the migrating diurnal tide, as revealed by satellite temperature observations. These results suggest that strong MSAO phases arise from the combined action of multiple wave-forcing mechanisms.

Additional insight was obtained from a collaborative study using the JAWARA whole-atmosphere reanalysis, which successfully reproduced both the magnitude and spatial structure of the event. Momentum-budget analyses showed that the strong westward acceleration near the mesopause resulted from comparable contributions of resolved-wave forcing and parameterized gravity-wave forcing, largely counteracted by upward advection of eastward momentum by the residual circulation. The analysis further revealed that anomalous background winds modified critical-level

filtering conditions, favoring the upward propagation and dissipation of waves that enhanced westward momentum forcing in the upper mesosphere. These results highlight the importance of wave–mean-flow interactions and dynamical coupling across multiple atmospheric regions in shaping strong MSAO events.

Overall, this thesis provides new observational constraints, methodological advances for the analysis of tidal variability, and dynamical insight into low-latitude MLT dynamics, improving our understanding of wave–mean-flow interactions and vertical coupling processes in the middle atmosphere and lower thermosphere.