On the importance of high frequency gravity waves for ice nucleation in the tropical tropopause layer

Recent investigations of the influence of atmospheric waves on ice nucleation in cirrus have identified a number of key processes and sensitivities: (1) ice concentrations produced by homogeneous freezing are strongly dependent on cooling rates, with gravity waves dominating upper tropospheric cooling rates; (2) rapid cooling driven by high-frequency waves are likely responsible for the rare occurrences of very high ice concentrations in cirrus; (3) sedimentation and entrainment tend to decrease ice concentrations as cirrus age; and (4) in some situations, changes in temperature tendency driven by high-frequency waves can quench ice nucleation events and limit ice concentrations. Here we use parcel-model simulations of ice nucleation driven by long-duration, constant-pressure balloon temperature time series, along with an extensive dataset of cold cirrus microphysical properties from the recent ATTREX high-altitude aircraft campaign, to statistically examine the importance of high-frequency waves as well as the consistency between our theoretical understanding of ice nucleation and observed ice concentrations. The parcel-model simulations indicate common occurrence of peak ice concentrations exceeding several hundred per liter. Sedimentation and entrainment would reduce ice concentrations as clouds age, but 1-D simulations using a wave parameterization (which underestimates rapid cooling events) still produce ice concentrations higher than indicated by observations. We find that quenching of nucleation events by high-frequency waves occurs infrequently and does not prevent occurrences of large ice concentrations in parcel simulations of homogeneous freezing. In fact, the high-frequency variability in the balloon temperature data is entirely responsible for production of these high ice concentrations in the simulations.