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How representative are turbulence diagnostic statistics on seasonal time scales?

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The current state of knowledge about the occurrence of turbulence in the upper troposphere and lower stratosphere (UTLS) is linked to our understanding of the underlying atmospheric instabilities, the reliability of diagnostics for identifying them in gridded numerical model data, and the availability of measurements to validate the theoretical approach. Although advances in observational coverage and model resolution have led to ongoing reevaluation of the predictive accuracy of turbulence diagnostics, their climatological characteristics, and the alignment with measurement-based climatologies, these aspects are seldom examined together within individual studies using the same datasets. This separation has left room for the interpretation of model-based turbulence maps as a key source for turbulence statistics in the free atmosphere.

We present a climatology of upper tropospheric relativ turbulence frequency maps from several hundred million automated EDR turbulence reports from commercial aircraft between January 2017 and September 2024, made available by the NOAA MADIS ACARS (National Oceanic and Atmospheric Administration – Meteorological Assimilation Data Ingest System – Aircraft Communications Addressing and Reporting System) archive. Sampling biasses in the archived data are taken into account by analyzing only consistently reported turbulence intensities along regularly sampled flight tracks.

The relative frequency maps of observed turbulence indicate distinct large-scale maxima over the northern hemisphere winter storm tracks, whereas North America exhibits minimum turbulence frequencies across broad areas. Additional maxima are evident along tropical flight routes over the Atlantic and Pacific. The 99th percentile of the Richardson number derived from ERA5 reanalysis data as one key diagnostic shows good agreement with the measurements on seasonal scales, whereas the Ti1 index indicates a distinct northward shift of the storm track maxima as the predominant feature. Linking the seasonal signals with the local forecast precision and probability of detection shows high variability across all longitudes and latitudes, which resolves the apparent contradiction between highest-ranking overall classification skill of the Ti1 index and low agreement with observations on seasonal timescales.