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The climatology of potential vorticity towers associated with extratropical cyclones, their development and related processes

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The dynamics of strong extratropical cyclones typically involves the interplay of intense baroclinicity (and upper-level jet streams), pronounced upper-level positive potential vorticity (PV) disturbances (sometimes associated with tropopause folds), and low-level positive PV anomalies produced mainly by latent heat release due to condensation. As shown in several case studies, in the mature stage of the cyclone development the three involved anomalies (warm air at the surface, high PV in the lower and upper troposphere) become vertically aligned and form a so-called "PV tower", representing a troposphere-spanning column of air with high PV-values (typically 1-4 pvu). In this framework, cyclone formation and intensification can be regarded as the interplay of distinct PV anomalies that form through adiabatic (upper-level PV) or diabatic (low-level PV) processes.

In this study, based upon the ERA-Interim data set, a climatology is compiled of the vertical PV structure associated with extratropical cyclones in their developing and mature stage. In the mature stage, lower tropospheric PV values are typically very high (>1.5 pvu) for intense cyclones and much lower in weak cyclones. This corroborates findings from case studies that diabatic processes (which are responsible for the elevated PV values in the bottom part of the tower) play an essential role for most intense cyclones, and a less important role for weak cyclones. In addition, for different regions of cyclogenesis, the climatological PV towers show an interesting variability. For instance, intense cyclones in the North Pacific have higher PV values in the upper part of the tower and lower PV values in the bottom part of the tower compared to their counterparts in the North Atlantic. Differences between stronger and weaker cyclones are much more pronounced in the Atlantic than in the Pacific. In addition to this detailed investigation of the mature stage, the vertical PV structure of the cyclones is also analyzed during their development stage. A quasigeostrophic omega equation diagnostic is used to identify the center of the upper-level trough associated with each surface cyclone, which allows to diagnose temporal evolution of the PV structure along the tilted axis connecting the upper-level trough with the surface low. It is shown that PV values in the cyclone centre increase during the development stage. This analysis will shed additonal light on the relevance of adiabatic upper-level PV vs. diabatically produced low-level PV for the formation and intensification of extratropical cyclones.