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A climatology of potential vorticity towers associated with extratropical cyclones

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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-40 data set, a climatology is compiled of the vertical PV structure associated with extratropical cyclones in their developing and mature stage. It is shown that PV values in the cyclone center increase during the development 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.