Mechanistic understanding of the amplification of forecast errors and forecast uncertainty in a quantitative potential-vorticity framework

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This presentation introduces a quantitative potential-vorticity (PV) framework to investigate the mechanisms that lead to the amplification of forecast errors and forecast uncertainty. The framework is based on the well-established PV perspective of midlatitude dynamics. A tendency equation is derived for PV error-enstrophy and is applied to a series of numerical upscale-error-growth experiments. Our analysis identifies, from the mechanistic perspective, distinct stages of error growth: The first stage is dominated by diabatic PV tendencies associated predominantly with moist processes, the second stage with upper-tropospheric divergence displacing the strong midlatitude PV gradient, and the third stage with nonlinear tropopause/Rossby-wave dynamics. The analysis confirms an existing hypothesis of multi-stage error growth but provides a novel, quantitative interpretation of the governing error-growth mechanisms.

Furthermore, a PV-tendency equation for the evolution of ensemble variance is derived in order to quantify the contributions of individual processes to the evolution of forecast uncertainty. This newly developed framework is applied to operational ECMWF ensemble forecasts covering the NAWDEX Golden Case “Karl”. Consistent with our previous error-growth analyses, ensemble spread increases, on average, predominantly due to the divergence of the nonlinear tropopause dynamics in the individual ensemble members. The analysis points to individual regions in which spread increases particularly rapidly. In these regions, i.e., locally, the relative contribution of individual processes to spread amplification vary distinctly. The extratropical transition of Karl is such a region and, in contrast to the mean picture, increase in tropopause-near ensemble spread is mostly due to uncertainties in ridge building by upper-tropospheric outflow and baroclinic amplification. Karl is further contrasted to another “hotspot” of spread amplification: Large uncertainties in the absorption of a cut-off in the North Pacific are due to nonlinear tropopause dynamics and arguably lead to the largest forecast errors in all ensemble members.