Supplement of Geosci. Model Dev., 17, 6137–6151, 2024
https://doi.org/10.5194/gmd-17-6137-2024-supplement

Geoscientific Model Development Open Access EGU

Supplement of

Objective identification of meteorological fronts and climatologies from ERA-Interim and ERA5

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S1 Smoothing and threshold selection

Figure S1 compares the number of smoothing passes to the mean length of contours of TFL $= \nabla^2 |\nabla\theta_W| = 0$ (Equation 1 in the main text) in terms of number of points located by the contouring algorithm. The mean length of contours increases rapidly at first before slowing to an approximately linear rate of increase above around eight smoothing passes. Eight smoothing passes does a good job of removing short circular contours and noise in longer contours. More than 10–12 smoothing passes and short or weak fronts that may be identified by a synoptic meteorologist may not be correctly identified.

Figure S2 compares thresholds of TFP for criterion K_1 in the main text. Thresholds are defined in terms of percentiles of TFP in the Northern Hemisphere extra-tropics (23.4°N–66.6°N). In Figure S2, criterion K_1 provides a very well defined filter for potential front locations. As the threshold is relaxed to higher quantiles, more objects are identified that would not be classified as fronts by an operational meteorologist. When the threshold is reduced below the 15th percentile, the front extending from the Mediterranean to the east and north of the Alps is almost eliminated, and the front across southern Sweden is also shortened. Both fronts appeared on Met Office charts of the time, thus thresholds below the 15th percentile would be too harsh, eliminating too many potential fronts. Meanwhile above the 25th percentile quantile the number of spurious potential fronts increases rapidly.

Figure S3 compares thresholds of $|\nabla\theta_W|_{ABZ}$ for criterion K_2 in the main text. Thresholds are defined in terms of quantiles $|\nabla\theta_W|_{ABZ}$ in the Northern Hemisphere extra-tropics (23.4°N–66.6°N). As the threshold is increased to higher quantiles, fewer fronts are identified until at the 60th percentile the front extending from the Mediterranean to the east and north of the Alps is split in two. Therefore, thresholds above the 55th percentile would be too harsh, eliminating too many potential fronts. Meanwhile, below the 50th percentile, the number of spurious potential fronts starts to increase.

Figure S4 compares thresholds of both TFP and $|\nabla\theta_W|_{ABZ}$ for criteria K_1 and K_2 combined. The 50th percentile of $|\nabla\theta_W|_{ABZ}$ clearly helps to eliminate a number of spurious potential fronts compared to the 40th percentile. Therefore the 50th quantile was chosen as the threshold for criterion K_2 In contrast, the fronts identified are relatively insensitive to the choice of criterion K_1 within the range of the 15th to 25th quantiles of TFP. However, in other examples, the 15th and 20th percentiles were found to break, shorten or eliminate some fronts identified on charts. The 25th percentile was found to be more suitable overall and chosen as the threshold for criterion K_2.

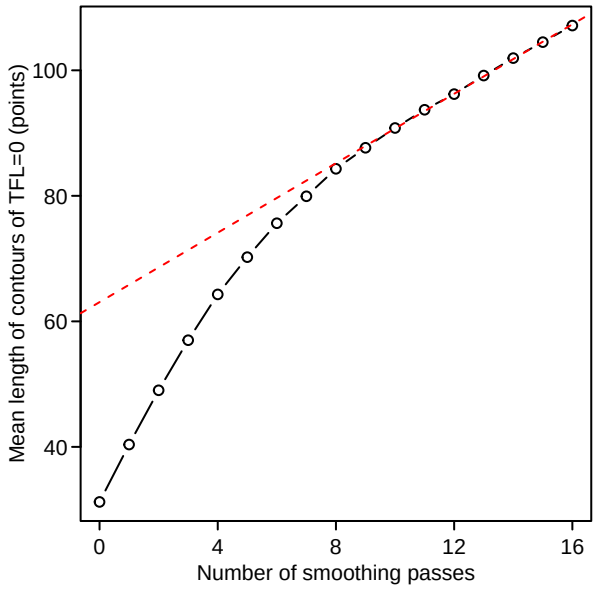

Figure S1: Comparison number of smoothing passes versus mean length of contours of TFL $= \nabla^2 |\nabla \theta_W| = 0$ in terms of number of points located by the contouring algorithm during January 2000. Dashed red line shows the linear least squares fit to the mean number of points for $n > 8$ smoothing passes.

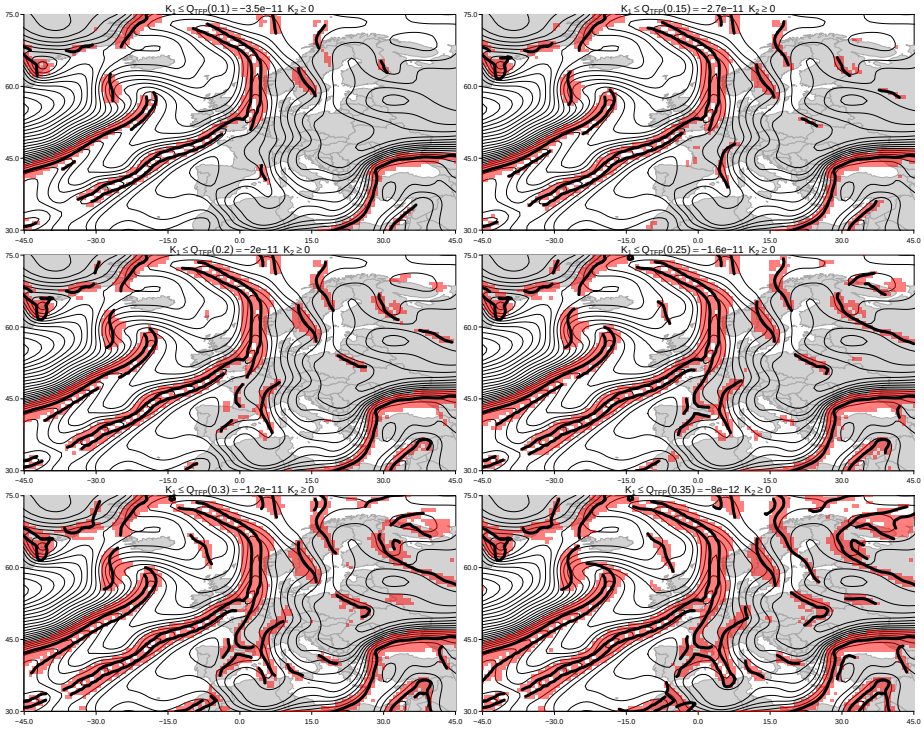

Figure S2: Comparison of thresholds of TFP for criterion K_1 in ERA-Interim at 00:00 on 2001-01-01 with $n = 8$ smoothing cycles. Threshold K_2 is fixed at $|\nabla\theta_W|_{ABZ} > 0\,\mathrm{K\,m^{-1}}$ and thus provides no constraint on fronts identified. $Q_{TFP}(p)$ indicate the pth percentile of TFP in the Northern Hemisphere extratropics (23.4°N–66.6°N). Red shading indicates the areas identified by criterion K_1. Thin black lines indicate contours of wet-bulb potential temperature θ_W. Thick black lines indicates fronts identified according to the stated thresholds. The middle right panel shows the selcted threshold.

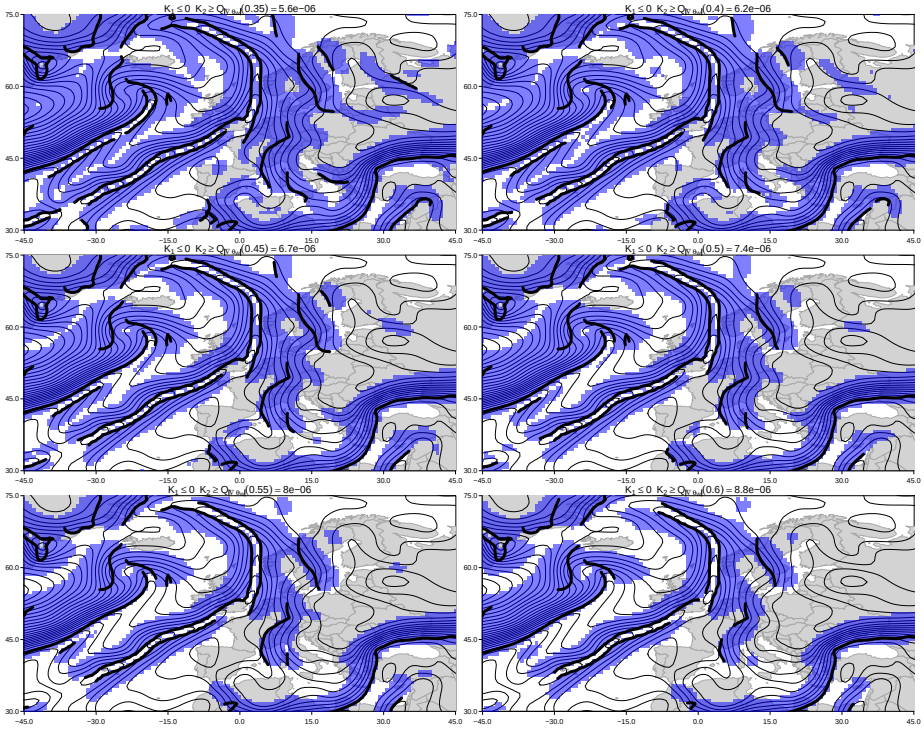

Figure S3: Comparison of thresholds of $|\nabla\theta_W|_{ABZ}$ for criterion K_2 in ERA-Interim at 00:00 on 2001-01-01 with $n = 8$ smoothing cycles. Threshold K_1 is fixed at TFP $< 0\,\mathrm{K\,m^{-2}}$ and thus provides the least possible constraint on fronts identified. $Q_{|\nabla\theta_W|}(p)$ indicate the pth percentile of $|\nabla\theta_W|_{ABZ}$ in the Northern Hemisphere extra-tropics (23.4°N–66.6°N). Blue shading indicates the areas identified by criterion K_2. Thin black lines indicate contours of wet-bulb potential temperature θ_W. Thick black lines indicates fronts identified according to the stated thresholds. The middle right panel shows the selected threshold.

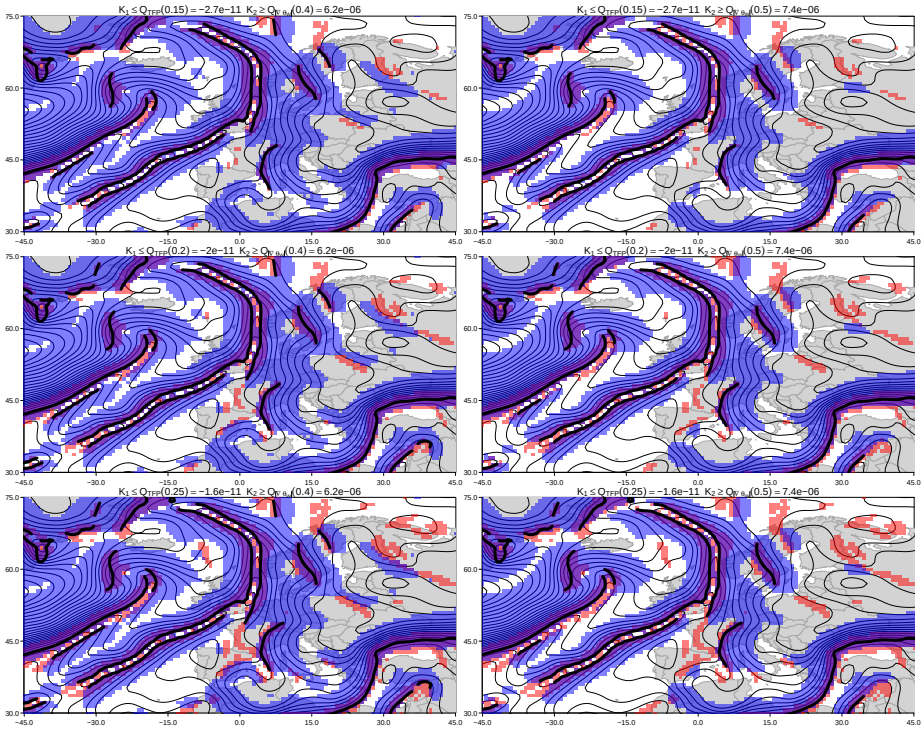

Figure S4: Comparison of thresholds of for criteria K_1 and K_2 in ERA-Interim at 00:00 on 2001-01-01 with $n = 8$ smoothing cycles. Different thresholds for criterion K_1 are compared (top) $K_1 > Q_{TFP}(0.15)$, (middle) $K_1 > Q_{TFP}(0.20)$, and (bottom) $K_2 > Q_{TFP}(0.25)$.Different thresholds for criterion K_2 are compared (left) $K_2 > Q_{|\nabla\theta_W|}(0.4)$, and (right) $K_2 > Q_{|\nabla\theta_W|}(0.5)$.Purple shading indicates the areas where criteria K_1 and K_2 overlap. Thin black lines indicate contours of wet-bulb potential temperature θ_W. Thick black lines indicates fronts identified according to the stated thresholds. The bottom right panel shows the final selected thresholds.