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Generating isoline maps from spatially-exhaustive climate reanalysis data

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Abstract:

Printed isoline maps make it possible to quickly assess the variety of patterns a climatic variable like temperature is spatially bound to: from a more zonal structure in large-scale to more complex patterns in small-scale maps. They are often paired with climate diagrams, whose interpretation is a traditional approach in geography education (Reuschenbach, 2018). In the past, isoline maps in the Swiss World Atlas have been manually derived from spatially scarce point data using a mix of linear interpolation and geographic knowledge of the cartographer. These maps often showcase strong cartographic exaggeration, for instance a concentric fried egg-like structure of temperature around elevated terrain. As the isolines in climatological maps have remained unchanged over many versions of the atlas, we aim now at updating all climatological maps using normals of the most recent reference period (1991-2020). Changing the values of the displayed stations requires, aside from the data collection, little effort. Changing the underlying isolines is more complicated. While the spatial pattern of a quantity like temperature is not expected to change fundamentally over time, as its spatial expression is tied to topography and proximity to water bodies, the location of isolines for specific values will shift with time and climate change, as well as with the primary data the isolines are derived from.

Meteorological data is increasingly available in spatially and, to a certain extent, temporally comprehensive formats. By integrating historical in-situ point data and remote sensing observations into weather models, reanalysis provides spatially extensive historical data on a grid, circumventing the problem of measurement scarcity and offering a valuable base for algorithmic isoline extraction. It also represents a viable alternative to the manual interpolation process, providing a more detailed foundation. The grid's spatial support (Pebesma & Bivand, 2023) is larger than that of point data, providing an incidental yet convenient pre-generalization. For continental and global maps without relief this can be entirely sufficient to define the baseline geometry of the isolines. However, in the presence of relief, isolines derived from such a grid surface may lack the spatial detail needed to reflect the complexity of the terrain, resulting in a lower-quality draft.

The isoline generation from a raster surface faces challenges common to contours derived from digital terrain models as well as specific problems stemming from the spatial variability of the variable. Temperature, for instance, varies smoothly over space (Dodson & Marks, 1997), whereas precipitation can change in some regions in a log-linear or exponential way (Daly et al., 1994). These differences in the nature of spatial change directly influence the spacing of isolines, with smoother temperature changes resulting in more evenly spaced and predictable contours, while the abrupt or non-linear changes in precipitation can lead to irregularly spaced or tightly clustered isolines. Resulting isolines based on a raster exhibit an angular appearance and upon smoothing, proximity conflicts can occur when metric constraints of a minimum distance allowing for legibility are not met. Consequently, the smoothed features must undergo cartographic displacement as part of the generalization process. Given that isolines are conceptually closed loops and can be considered as a mosaic of polygons, the topology of neighbouring isopolygons (e.g. avoiding gaps and overlaps) must be maintained during conflict resolution. Previously, a polygon generalization algorithm that ensures a minimum distance between edges while preserving topology has been proposed (Galanda & Weibel, 2003). But, apart from parameter setup, this automated generalization method is not expert-guided i.e. a relief layer or the local situation is not being considered when vertices are edited.

We propose a workflow (Figure 1) for isopolygon extraction from raster data (based on ERA5 reanalysis data from the European Centre for Medium-Range Weather Forecasts ECMWF) and subsequent semi-automated generalization that accounts for the underlying relief when resolving proximity conflicts and enables the production of maps that adhere to cartographic principles for the printed Swiss World Atlas. We use a tool to flag narrow polygon sections based on map scale relevant and line width dependent minimal width and length constraints and subsequently manually edit the bottlenecks, accounting for the relief. Prior to the conflict resolution, small crumb polygons are eliminated, the remaining ones simplified (while retaining critical bends (Wang & Müller, 1998)) and smoothed. To accommodate varying levels of smoothing intensity over land and water, we derive line features from the polygons, clip them at the land-ocean transition, and apply stronger smoothing to the oceanic portion once imported into the vector graphics

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software. An additional factor that needs to be considered are potential artefacts introduced by the simplification enforcement based on a points per path limit of Adobe Illustrator.

Overall, the introduced procedure results in satisfying isoline maps showcasing overlaps with the old atlas but also limitations in maps where a relief is present (Figure 2). Some topographic effects are not captured, and the maps need therefore further manual refinement and cartographic exaggeration to be in tune with the underlying relief.

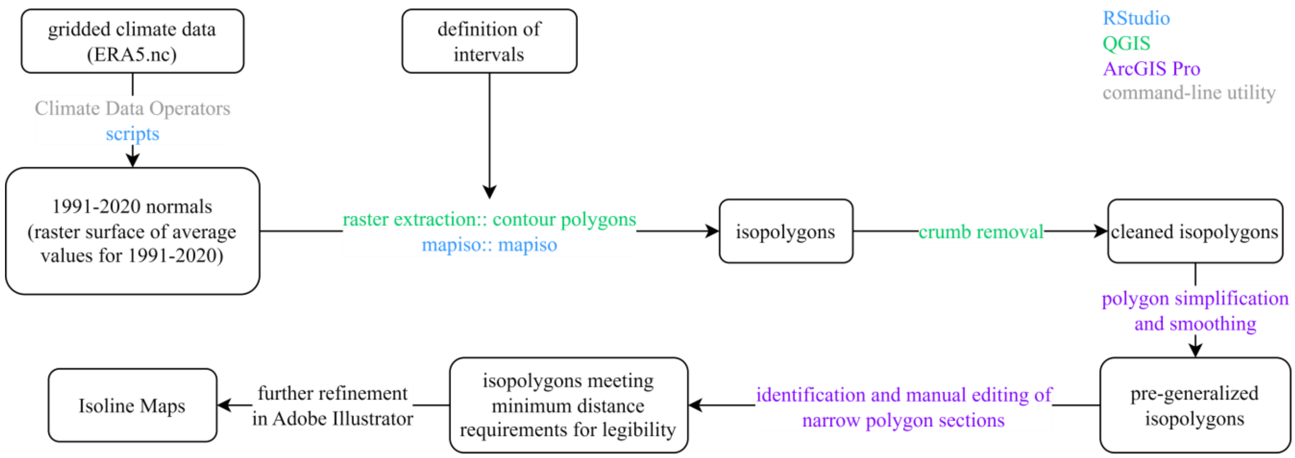

Figure 1. Workflow of isopolygon extraction and refinement from gridded climate data.

Figure 2. January temperature isoline maps (left: old manual version; right: based on new approach)

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