

# Chapter 11

## Spatial and Temporal Interpolation of the Meteorological Data: Precipitation, Temperature and Radiation

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**Abstract** Simulations of the impacts of climate change on the water resources need accurate meteorological drivers. In GLOWA-Danube, hourly fields of air temperature, air humidity, wind, short- and longwave radiation and precipitation were determined from weather station data for the past period from 1970 to 2006 as well as for future climates (using the statistical climate generator (Chap. 49)) with a spatial resolution of 1 km. Interpolation is based on hourly regressions of elevation gradients and a DEM and inverse square distance weighting of the regression residuals. For precipitation, additional bias correction from high-spatial-resolution monthly rainfall data was applied. The maps of average precipitation, temperature and radiation in the Upper Danube watershed are displayed. They show the overall distribution of major meteorological inputs and demonstrate that small-scale effects like dry valleys in the Alps and albedo effects of cities on radiation are documented.

**Keywords** GLOWA-Danube • Meteorological drivers • Spatial interpolation • Bias correction

### 11.1 Introduction

Meteorological parameters are key factors in modelling hydrological processes. The data used for the study area were delivered by the German DWD and the Austrian ZAMG (see Chap. 10). They were measured three times daily at the “Mannheimer

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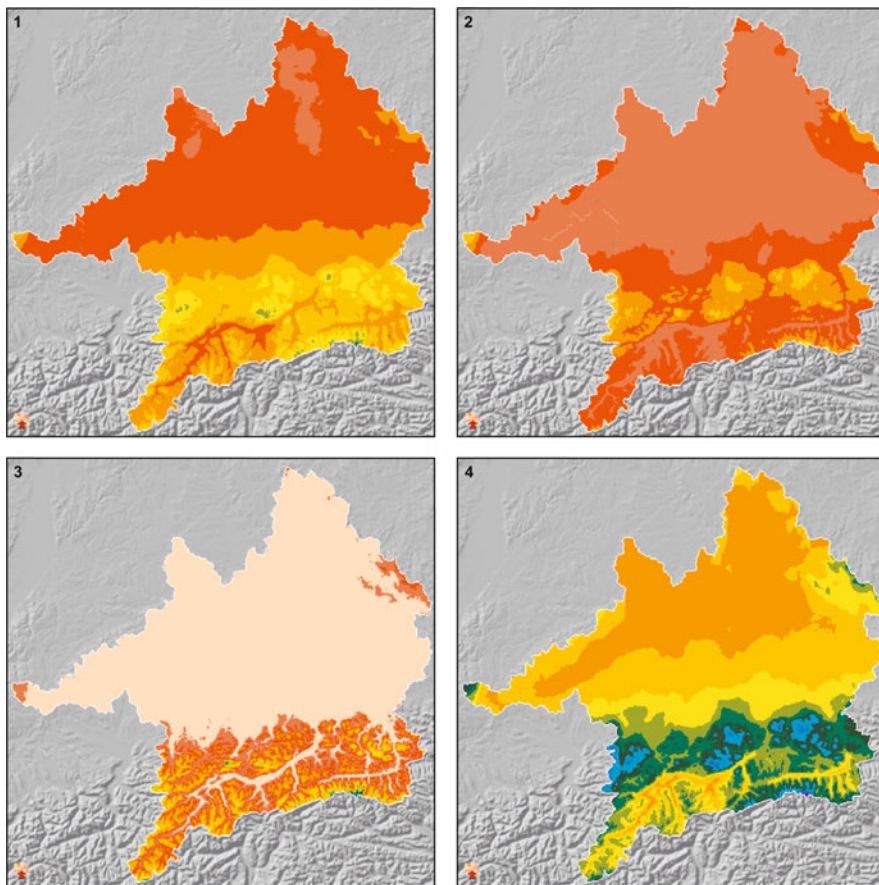
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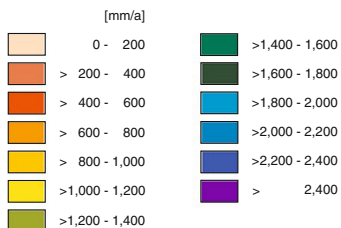
Map 1:  
Mean summer precipitation  
(May - October) 1971 - 2000

Map 2:  
Mean winter precipitation  
(November - April) 1971 - 2000

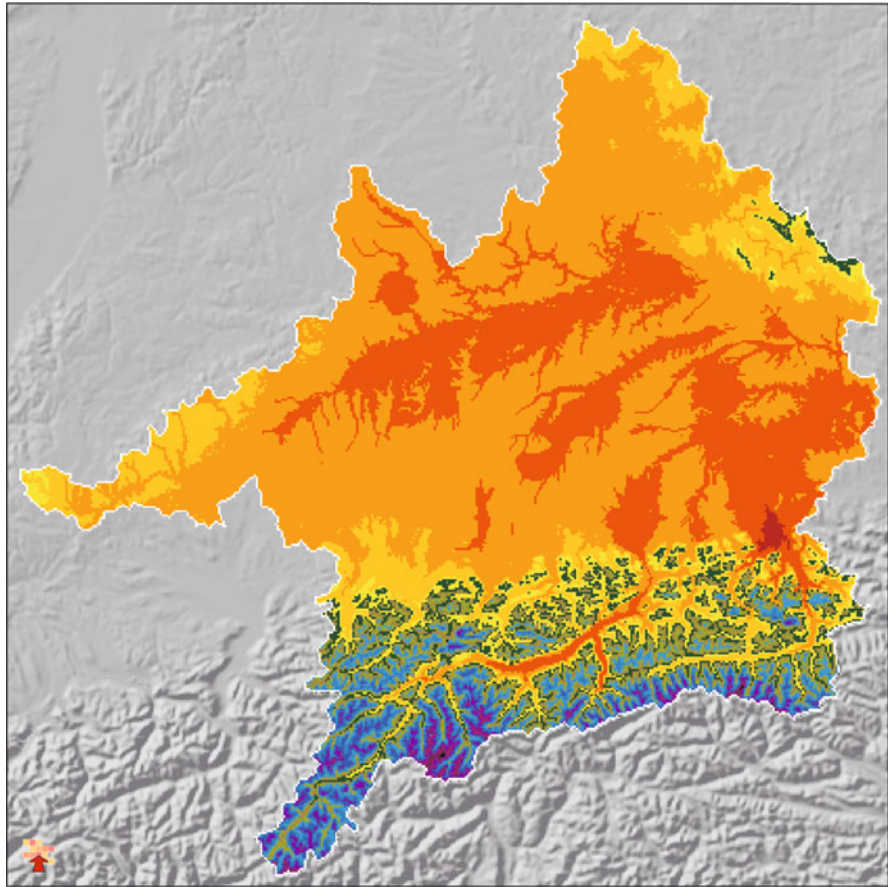
0 30 60 90 120 km

Map 3:  
Mean snow precipitation  
1971 - 2000

Map 4:  
Mean annual precipitation  
1971 - 2000



**Map 11.1** Calculated precipitation (Data sources: DWD Deutscher Wetterdienst; ZAMG, Zentralanstalt für Meteorologie und Geodynamik)

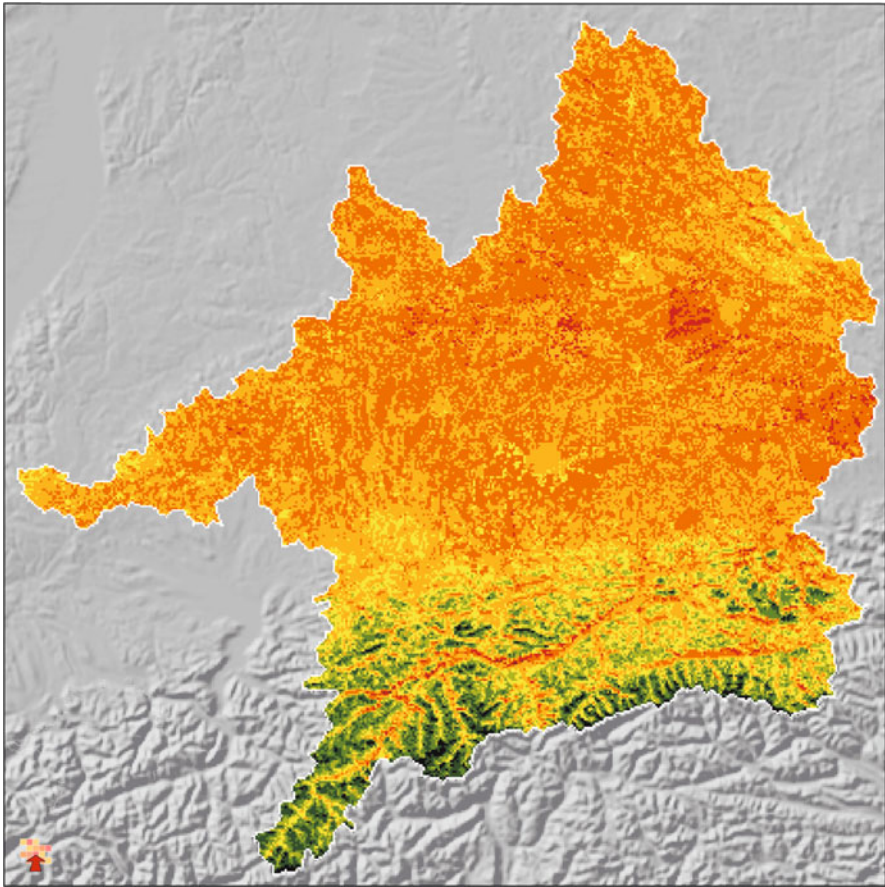


Mean air temperature 1971-2000 [°C]



0 15 30 45 60 km

**Map 11.2** Calculated air temperature (Data sources: DWD Deutscher Wetterdienst; ZAMG, Zentralanstalt für Meteorologie und Geodynamik)



Annual radiation balance 1971-2000 [kWh/a/m<sup>2</sup>]

0 15 30 45 60 km

- 0 - 100
- >100 - 200
- >200 - 300
- >300 - 400
- >400 - 500
- >500 - 600
- >600 - 700
- >700 - 800
- >800 - 900

**Map 11.3** Calculated radiation balance (Data sources: DWD Deutscher Wetterdienst; ZAMG, Zentralanstalt für Meteorologie und Geodynamik)

Stunde” at 7:30, 14:30 and 21:30 local time. They exist only as station point data and moreover have the advantage of being available at a large number of stations at the expense of too low a temporal resolution for a detailed process modelling. Therefore, temporal and spatial interpolation must be applied in order to obtain discrete values for each time step and every proxel (process pixel: a geo-located pixel, in which processes take place, see Chap. 2); the interpolated values can then serve as input data for the model.

The land surface processes that exhibit the greatest temporal variability and spatial heterogeneity determine the requirements for temporal and spatial resolution of the meteorological drivers of DANUBIA. Evapotranspiration, sensible heat flux, infiltration, snow accumulation and ablation as well as the fast components of the interflows from the run-off formation process are of particular temporal variability. These parameters have pronounced diurnal variation that is significantly affected by the daily energy availability pattern (net radiation), air temperature and precipitation.

In contrast to many other hydrological model approaches that describe the land surface processes using daily time steps (e.g. The Soil and Water Assessment Tool SWAT 2000, Neitsch et al. 2002) and therefore must use highly parameterized approaches with low deterministic process representation, DANUBIA uses nonlinear modelling that is based on detailed physical descriptions of processes. In order to consider the high temporal variability in the meteorological data and the nonlinearity of the processes under consideration, a 1-h time interval was selected in DANUBIA. With a total of 288 available precipitation stations in the study area and a spatial resolution of  $1 \times 1 \text{ km}^2$ , one precipitation station covers an average area of  $16 \times 16 \text{ km}^2$ . At a mean precipitation intensity of 2.6 mm/h for individual events, the mean maximum spatial precipitation gradient is thus 0.16 mm/km between a station with precipitation and a neighbouring station without precipitation. The actual spatial precipitation gradients are significantly higher during convective precipitation events in the Alpine foothills. However, at present, this fact cannot be sufficiently accounted for as a result of the low density of stations.

The challenge in developing the interpolation described below is thus to devise a computationally efficient, stable and precise method that is capable of processing the list of meteorological data listed below and that can take into account the prevalent and sizeable topographical and climatic gradients of the Upper Danube basin.

## 11.2 Data Processing

The following meteorological parameters were spatially modelled on an hourly basis and in fields of  $1 \times 1 \text{ km}^2$  resolution as input data for the various simulation model components in DANUBIA:

- Atmospheric temperature [ $^{\circ}\text{C}$ ], relative humidity [%] and wind velocity [m/s], in each case 2 m above the ground surface
- Precipitation intensity [mm/h]

- Direct and diffuse shortwave radiation (0.3–3  $\mu\text{m}$ ) and longwave radiation (3–100  $\mu\text{m}$ ) [ $\text{W}/\text{m}^2$ ]
- Standard air pressure and daily  $\text{CO}_2$  partial pressure based on selectable IPCC SRES scenarios [hPa]

### ***11.2.1 Temporal Interpolation***

Interpolation values were generated from the three available measurements per day of the meteorological parameter's atmospheric temperature, relative humidity, wind velocity, cloud cover and precipitation for every desired 1-h time step for all stations. Temporal interpolation between the measured values was performed using a cubic spline interpolation function (third-order polynomial) for all parameters except precipitation; the polynomial function was uniquely determined through four consecutive measurements. The hourly values between measurements could then be determined from the course of the polynomial function.

However, precipitation is always tied to a precipitation event and is, therefore, contrary to the above-mentioned meteorological parameters, not representing a spatially continuous field. In addition, precipitation values are aggregated values, in that they refer to a value that includes the total precipitation falling within a specific time period. For this reason, the precipitation totals measured at 7:00, 14:00 and 21:00 need to be temporally disaggregated. This is accomplished in two ways: whenever there was no precipitation before and after a measured precipitation, a convective event is assumed. The intensity of the measured precipitation is then distributed using a Gaussian distribution across the 7 h prior to the time of measurement. Similarly, whenever there was a precipitation before and after a measured precipitation, an advective event is assumed. The measured total precipitation at the time of measurement is distributed evenly to the hours before the measurement. If two precipitation measurements follow a measurement point with no precipitation, the precipitation intensity increases linearly. The same likewise applies to the opposite situation, when a measurement with no precipitation followed two precipitation measurements.

### ***11.2.2 Spatial Interpolation***

For each hour, the temporally interpolated values at the measurement stations are transferred to the area of the Upper Danube basin. The method used is based on the interpolation of residuals based on the spatial support parameter topography and is applied to all temporally interpolated parameters.

It is generally assumed that all parameters are related to terrain elevation and that this relationship allows a regression line to be determined between the temporally

interpolated values for each meteorological parameter at the meteo-station and the altitude of the stations. This regression line then allows the calculation of an altitude-dependent parameter value for all locations of meteo-stations. It cannot be expected that with this regression, the parameter values at the location of the station will exactly reproduce the measured value. Instead, the residuals of the regression analysis will yield the differences between the measured values and the regression values determined using the digital elevation model. The residual field of the regression is thus corrected for the topographical trend of the considered parameter and represents the local specificity of each measurement at the location of the considered station and at the considered time. These site-specific deviations from the mean topographical property of a considered parameter are then spatially interpolated. The residual values at the six neighbouring stations of the considered proxel are used to spatially interpolate the residuals. To do this, first, the closest station is determined in each quadrant. Then, the two next closest of the remaining stations are determined. The relative weight for these stations for calculation of the relevant residual value at the position of the proxel in question is determined using the inverse of the square of its distance to the selected station. The final step then involves the summation, for each proxel, of the mean topographical field determined from regression and the interpolated residual of the considered meteorological parameter.

With this method of interpolation, computationally efficient spatial fields of the meteorological parameters can be determined. For atmospheric temperature, relative humidity, percentage clear sky and wind velocity, this approach has proven suitable. For the presentation of the spatial distribution of precipitation, however, it was shown that the use of the terrain model alone did not sufficiently reproduce the spatial pattern of precipitation with satisfactory precision. Many spatial precipitation processes related to topography cannot be accounted for by the altitude gradients and the sparse measurement network. Therefore, the climatological analysis of B. Früh (see Chap. 32) was used. In her study, the measurements from over 2,000 precipitation collectors in the drainage basin over 10 years were analysed and interpolated for each month. These monthly precipitation values with high spatial resolution served to determine local correction factors for the hourly interpolated precipitation. A monthly correction factor was determined for every proxel using the quotient of the total monthly precipitation determined there and the mean total precipitation for the entire area. As an example, the outcome from this correction led to a significant reduction in precipitation in the dry valleys of the Alpine region, as can be clearly seen in Map 11.1. This small-scale specific feature that is not dependent on local topography but rather on the Alpine ensemble of mountains protecting the inner valleys from inflowing precipitation cannot be accounted for by conventional interpolation methods.

A radiation model was developed for the determination of direct and diffuse shortwave radiation and longwave radiation, which uses the topography of the proxel in question (geographic coordinates, terrain elevation, inclination, exposure) as well as the actual percentage of visible clear sky derived from the surrounding

mountain topography. The astronomical parameters solar zenith and azimuth angle that were calculated from the geographical location of the proxel, together with the solar constant, yielded the top-of-atmosphere shortwave radiation input (Brutsaert 1982). The attenuation of direct shortwave radiation from absorption and dispersion and the diffuse shortwave radiation were calculated according to McClatchey et al. (1972), and the shortwave radiative flux directed towards the earth's surface was calculated taking into account the cloud cover according to Möser and Raschke (1983). Longwave radiation was estimated from atmospheric temperature and percentage cloud cover using the approaches of Czeplak and Kasten (1987) and Swinbank (1964). Radiation balance resulted from the determination of reflection and emission at the land surface, taking into account short- and longwave albedo and atmospheric temperature.

### 11.3 Results

Maps 11.1, 11.2 and 11.3 present the average annual precipitation [mm/a], atmospheric temperature [°C] and radiation balance [kWh/a/m<sup>2</sup>] as important meteorological variables for hydrological modelling for the Upper Danube basin from 1971 to 2000.

Map 11.1 shows that precipitation in the Alpine region can reach peak values of up to 1,400 mm during the summer season, whereas the northern part of the basin receives up to a maximum of 800 mm summer precipitation. Precipitation during the winter season is significantly lower and even in the Alpine region only infrequently amounts to more than 800 mm. Snowfall above 200 mm only takes place in the Alpine mountain regions, the low mountain ranges and in the western part of the basin (the Swabian Jura).

Easily discernible in Map 11.2 is the dependency of atmospheric temperature on terrain elevation. Thus, the mean temperature in the higher sites of the Central Alps, the Alpine foothills and the low mountain ranges are noticeably lower than in the lower lying regions. Even the extremely small-scale temperature differences caused by the strong relief between valley and mountain sites stand out.

Larger built-up areas in which the net radiation is between 400 and 500 kWh/a/m<sup>2</sup> can be clearly seen in Map 11.3 of radiation balance due to their difference in albedo. The heterogeneity of net radiation in the drainage basin can be explained as the result of the diverse land use and the varying terrain elevation.

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