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A daily time-step observed and scenario climate dataset on a European grid for crop modelling applications

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Abstract: This paper describes a daily time-step observed and scenario climate dataset on a European grid with 25 km x 25 km spatial resolution. The dataset was developed for crop modelling applications in the MACSUR project. The dataset covers the period 1980-2010 for observations; this is, for a baseline period of 1981-2010 and the year 1980 for crop model simulations with sowing dates in the autumn. It also covers the periods 2040-2069 and 2070-2099 for 5 Global Climate Models (GCMs) x 2 forcing scenarios (RCP4.5 and RCP8.5) and 2 GCMs with RCP2.6 from the Coupled Model Intercomparison Project Phase 5 (CMIP5). The Joint Research Centre's (JRC) Agri4Cast gridded dataset was used for the baseline. The scenarios have been calculated using an enhanced delta change method that applies changes in aspects of temperature and precipitation variability in addition to changes in mean climate.

Keywords: Climate change, crop modelling, agricultural systems, database, European Union.

1 ORIGINAL PURPOSE: A consistent daily weather dataset with historic data for 1981-2010 and a set of scenarios for the periods 2040-2069 and 2070-2099 has been constructed for agricultural applications on a regular grid for Europe covering the EU-27 countries plus Norway, Liechtenstein, Switzerland, the Balkan region and Kaliningrad. The primary purpose for this dataset was to serve as input data for gridded crop model simulation experiments, in which the effect of processes on drought and heat stress were evaluated (Webber et al. 2018), and future prospects for soybean cultivation were assessed (Nendel et al. 2023). The dataset is suitable for crop modelling and other applications requiring agroclimatic data under different climate change scenarios.

Three versions of the dataset have been prepared: version 1 (https://www.doi.org/10.4228/ZALF.DK.59 consisting of 8709 grid cells) that was used by Webber et al. (2018), an updated version 2 (https://www.doi.org/10.4228/ZALF.DK.94 consisting of 8748 grid cells) that corrects an error that occurred when a correction for differences in altitude was applied to agricultural cultivation areas, and version 3 (https://doi.org/10.4228/zalf.vjcp-vep3) consisting of 9220 grid cells that corrects an error in the scenario values for vapour pressure and dew point temperature and expands the study region to include Switzerland, Lichtenstein, the Balkan region and Kaliningrad.. It is recommended to use the latest version, unless the data are intended to be used for direct comparison with the crop model results of Webber et al. (2018, 2020).

2 DATA AND METHODS

2.1 Baseline climate data

Weather data source

Daily weather data was downloaded from the JRC Agri4Cast database (available at http://agri4cast.jrc.ec.europa.eu/DataPortal/) (version 1.0) for grid cells covering the EU-27 countries (Austria, Belgium, Bulgaria, Cyprus, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Malta, Netherlands, Portugal, Romania, Spain, Sweden, United Kingdom, Czech

Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Slovenia, Slovak Republic) and Norway, Liechtenstein, Switzerland, the Balkan region and Kaliningrad. The data were interpolated from approximately 4000 weather stations in Europe to a regular grid of 25 km x 25 km resolution with the Lambert Azimuthal Equal Area projection (Toreti et al. 2019; Van der Goot et al. 2004). In version 1.0 of the AgriCast dataset used here, interpolated temperature variables are corrected by altitude by using the median of all arable land points within a grid cell if arable land covers more than 5%, and the lower quartile of all points (arable and not arable) within grid cell is if arable land covers less than 5% (A. Toreti, pers. comm.).

The downloaded variables were daily minimum, average and maximum surface air temperature, precipitation, 10-meter wind speed, global radiation and actual vapour pressure. Data were downloaded for the period 1980 to 2010.

Filling of gaps in baseline data

The Agri4Cast dataset (version 1.0) has data gaps of one year over large parts of northern Europe and smaller regions elsewhere and of up to 15 years in parts of Finland (Figure 1). These gaps were filled with the daily long-term average of each grid cell for the remaining years. Long-term averages have a smoother time-evolution lacking daily extreme values (Figure 2). Precipitation is also always greater than 0 mm/day in the long-term average, i.e. there are no days without any precipitation. Note that a new version of the JRC AgriCast dataset (version as of January 2025: 2024.02) with fewer data gaps has been published in 2019 after our analysis has been conducted. For applications not requiring future scenarios, it is recommended to use baseline data from the most recent version available at JRC AgriCast.

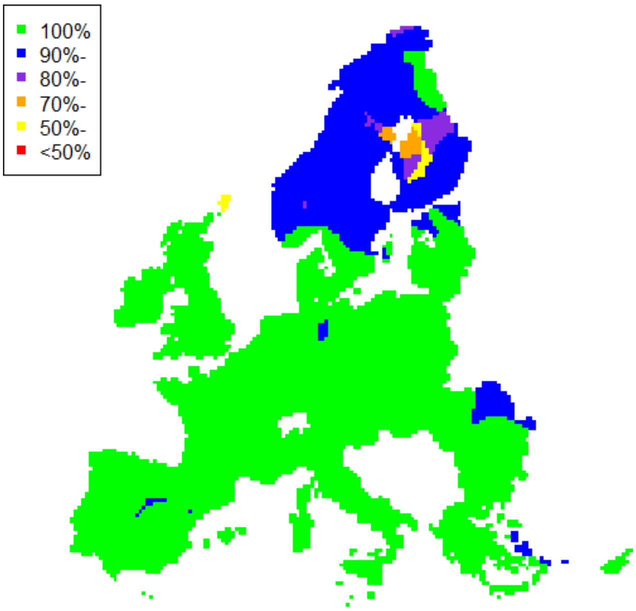

Figure 1. Data coverage of Agri4Cast weather data (version 1.0) for the period 1980-2010.

Correction of errors and known issues in the baseline data

The JRC Agri4Cast dataset has vapour pressure values of 0 kPa in four grid cells in France (two days in each) and one grid cell in Denmark (one day). These values were regarded as implausible and replaced by the average of the days before and after. The grid cells in France also had consistently lower values for vapour pressure in these grid cells in the year 1991 compared to other years which had annual averages ~80% larger than the 1991 value.

In a few days of the 31-year time-series in most grid cells, the maximum daily temperature was smaller than the minimum. This could be an artefact of the interpolation or simply an error. Most grid cells only had a single day where this happened, many grid cells had a few (2-5) days, but there were also grid cells with ~100 days in the 31-year period (i.e. 11323 days). The maximum number was from a grid cell in Austria with 143 days. Values for minimum and maximum temperature were exchanged in these cases to ensure physical consistency.

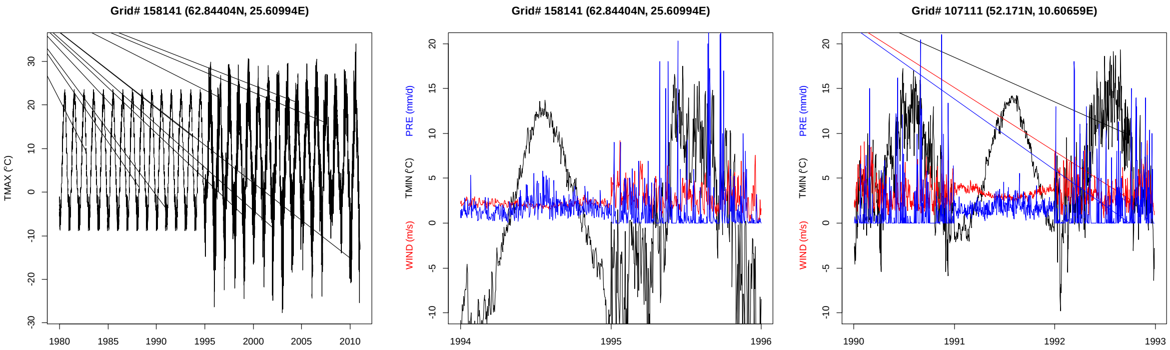

Figure 2. Time-series of weather variables for a grid cell in Finland (left and centre panels) and Germany (right panel) with missing years filled with the daily long-term average of the remaining years. The gap for the grid cell in Finland was for 1980-1994; the grid cell in Germany had missing data for 1991.

Version 1 of our dataset contains an error when accounting for altitude differences to agricultural cultivation areas which was corrected in version 2. Webber et al. (2018) have used version 1 before it could be corrected and have subsequently excluded grid cells with an error of greater than 1°C in their analysis.

Derivation of weather variables

Wind speed at 2 metre height was estimated from the Agri4Cast value at 10 metre height using a logarithmic conversion (equation 47 in Allen et al. 1998). Values for relative humidity at the time of the minimum and maximum daily temperatures and dew point temperature were estimated from daily average vapour pressure and minimum and maximum temperature (equation 14 and 18 in Allen et al. 1998). Note that while two daily values for relative humidity are provided, actual vapour pressure and dew point temperature are assumed to be constant during a day.

2.2 Future projections

Climate scenario selection

Five Global Climate Models (GCMs) were selected out of a larger ensemble of simulations that took part in the Coupled Model Intercomparison Project Phase 5 (CMIP5; Taylor, Stouffer, and Meehl 2012) (Table 1). The selected GCM/RCP combinations span a good proportion of the uncertainty range of future temperature and precipitation projections in Europe (*cf*. Fig. 3). The selected simulations are also within the range spanned by SSP-based simulations from the Coupled Model Intercomparison Project Phase 6 (CMIP6; Eyring et al. 2016), that have become available after the work on the dataset presented here had started.

Table 1. Climate models and forcing scenarios selected from the CMIP5 ensemble; for details of the models, see Flato et al. (2013).

GCM	RCP 2.6	RCP 4.5	RCP 8.5
GFDL-CM3		x	x
GISS-E2-R		x	x
HadGEM2-ES	x	x	x
MIROC5		x	x
MPI-ESM-MR	x	x	x

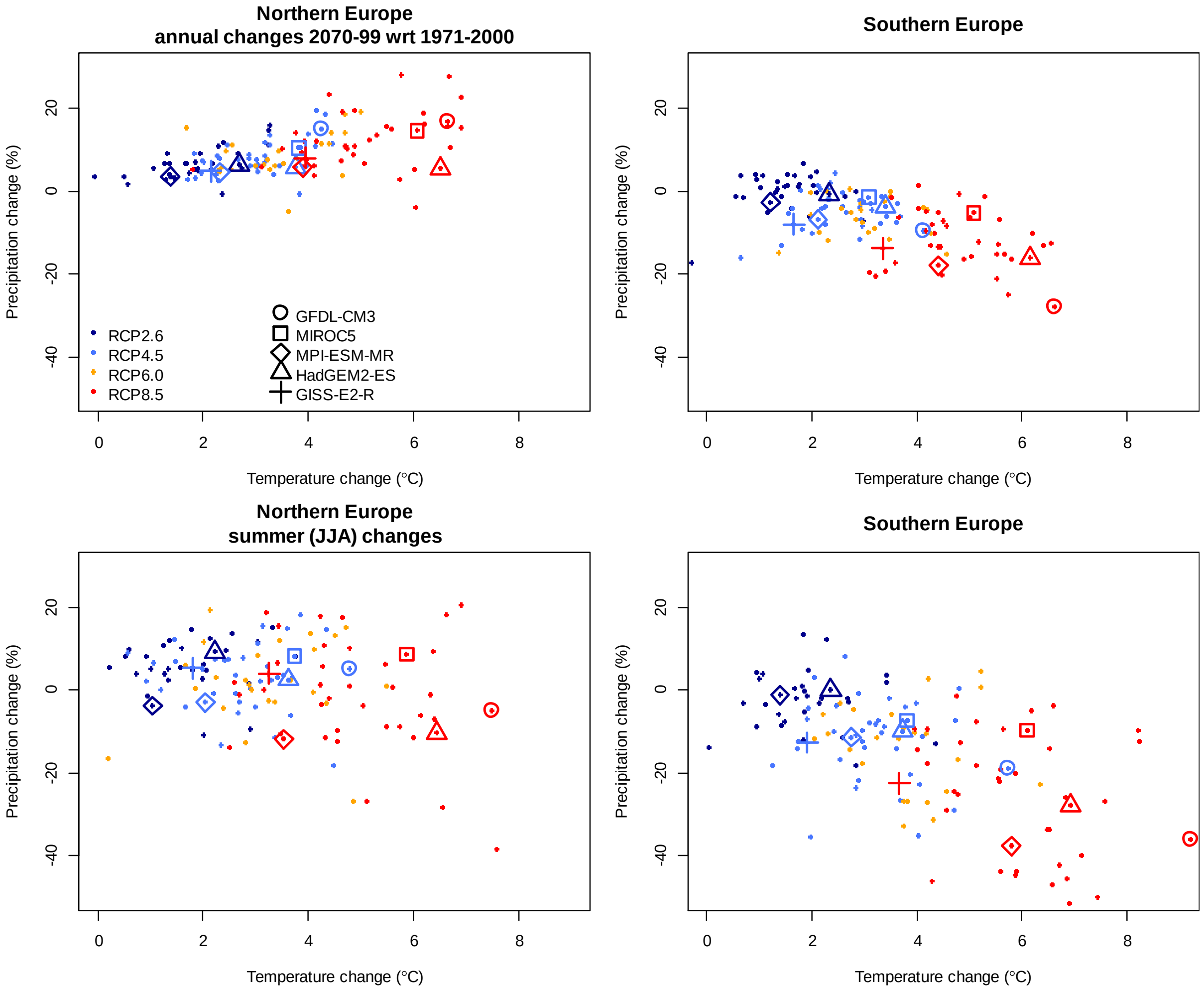

Figure 3. Changes in annual (top panels) and summer (June-August; bottom) temperature and precipitation averaged for Northern (left) and Southern Europe (right) in degrees per century and % per century for the CMIP5 ensemble and the 12 simulations selected.

Enhanced delta method

Scenario time-series of weather variables have been calculated using an enhanced delta change method that applies changes to the 1980-2010 baseline data in aspects of temperature and precipitation variability in addition to changes in mean climate. The method, developed in the Agricultural Model Intercomparison and Improvement Project (AgMIP), fits theoretical distributions of the baseline time-series of temperature and precipitation, modifies the parameters according to changes simulated with GCMs and then constructs scenario time-series according to the modified distributions (Rosenzweig et al. 2013; Ruane et al. 2015). Gaussian distributions are fit for temperature and gamma distributions for precipitation for each month using the daily data of the full baseline period. Global radiation is increased by 10% when a wet day in the baseline becomes a dry in the scenario and vice versa decreased by 10% when a dry day is turned into a wet day.

The algorithm failed to fit a theoretical distribution to the precipitation time-series in some individual grid cells and months (Figure 4). In these cases, only changes in mean climate, but no changes in variability of the precipitation time-series were applied.

Derivation of weather variables for scenarios

Wind speed and relative humidity are assumed to not change in the scenarios and values from the baseline period were repeated. Vapour pressure was estimated from adjusted future temperature and relative humidity in the same way as was done for the baseline; dew point temperature was then calculated from vapour pressure (equation 14 in Allen et al. 1998).

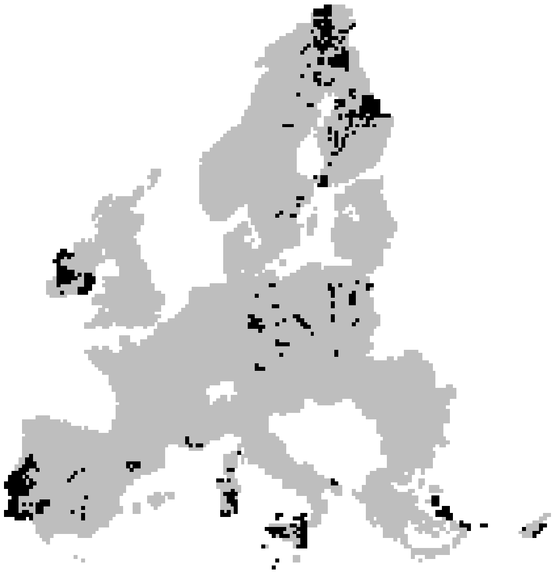

Figure 4. Grid cells for which no changes in variability for precipitation could be applied in at least one scenario and one month (black squares).

3 DATA AVAILABILITY AND FORMAT: Data files can be downloaded from:
- https://doi.org/10.4228/zalf.vjcp-vep3 (version 3),
- https://www.doi.org/10.4228/ZALF.DK.94 (version 2) and
- https://www.doi.org/10.4228/ZALF.DK.59 (version 1).

The data files provided are listed in Table 2. All data files are in comma-separated ascii format with a single header line and were compressed with gzip.

Table 2. Names and content descriptions of provided data files.

File name	Content description
DK94-DK59_gridcells_altitude.csv.gz	Grid cell numbers (format: 5 or 6 digits as <YY><XXX> or <YYY><XXX>, coordinates of grid cell centre points and mean altitudes of agricultural land
<period_id>/<GCM>/<Y>_<X>_v3.csv.gz	Weather data files, one file per grid cell, with baseline and scenario data for the grid cell with coordinate number Y and X in subfolders for three periods (period_id: 0 – 1980-2010, 2 – 2040-2069, 3 – 2070-2099) and five climate models (GCM, see Table 3)
DK_59_DK_94_missing_data.csv.gz	Grid cell numbers and years which were missing in the Agri4Cast baseline data and filled with the long-term average of the remaining year (cf. Figure 1)

Weather data are provided as single file per grid cell with the file naming convention <Y>_<X>_v3.csv.gz, each file containing data of the baseline and future periods for all 12 scenarios. The columns are listed in Table 3. Coordinates for the grid numbers are apparent from the file name. In the date column, dates of the baseline period are repeated for future periods.

Table 3. Weather variables, their units and other columns of the weather data files.

Column name	Description	Unit
period	time period: `0` – baseline (1980-2010), `2` – 2040-2069, `3` – 2070-2099	-
sce	GCM/RCP simulation denoted as `<GCM>_<RCP>`, where `GCM` is one of GFDL-CM3, GISS-E2-R, HadGEM2-ES, MIROC5, MPI-ESM-MR and `RCP` one of 26, 45 and 85 for RCP2.6, RCP4.5 and RCP8.5	-
date	date (YYYYMMDD)	-
tmax	maximum air temperature	°C
tmin	minimum air temperature	°C
vprsd	mean daily vapour pressure	kPa
wind	mean daily wind speed at 2m	km/d
rain	sum of precipitation	mm/day
srad	total global radiation	MJ/m2.d
rhumd_tn	relative humidity at TMIN	%
rhumd_tx	relative humidity at TMAX	%
dewp	dewpoint temperature (°C)	°C

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