Description, Evaluation and Validation of Downscaled Daily Climate Data Version 2

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For version 2 of the downscaled climate data, the downscaling algorithm as implemented by Adam Moreno (Moreno and Hasenauer, 2015) in Python for version 1 was transferred to R/C++ by Werner Rammer.

Advantages of Version 2 compared to Version 1

- Larger spatial and temporal coverage (see Table 1)
- Better coverage of European coastline by extrapolation of E-Obs data
- Updated WorldClim input data with improved data for areas with low station density or unusual or sharp gradients
- Updated E-Eobs input data with new station data and new (time?) series
- Added periodic (1951 to 1980 and 1981 to 2010) climate data

Disadvantages of Version 2 compared to Version 1

- Reduced coverage of data for some regions in version 2 compared to version 1 due to missing data in the new version of the E-Obs input data set. Poorer coverage for some regions (North Africa, Turkey, Middle East) compared to other regions (e.g. Central Europe) applies to both versions

Data	Ver.	Spatial Extent	Spatial Resolution	Temporal Extent	Temporal Resolution
E-Obs	8.0	Lat: 25.25, 75.5 Lon: -40.5, 75.5	0.25° x 0.25° ~ 30 km at Equator	1950-01-01 to 2012-12-31	Daily with missing data
	17.0	Lat: 25.25, 75.5 Lon: -40.5, 75.5	0.25° x 0.25° ~ 30 km at Equator	1950-01-01 to 2017-12-31	Daily with missing data
WorldClim	1.4	Global (excluding Antarctica)	0.0083° x 0.0083° ~ 1 km at Equator	1960 to 1990	Monthly averages for time period
	2.0	Global (excluding Antarctica)	0.0083° x 0.0083° ~ 1 km at Equator	1970 to 2000	Monthly averages for time period
Downscaled	1.0	Lat: 34.58, 71.33 Lon: -10.83, 34. 25	0.0083° x 0.0083° ~ 1 km at Equator	1950-01-01 to 2012-12-31	Daily with missing data
	2.0	Lat: 25.25, 75.5 Lon: -40.5, 75.5	0.0083° x 0.0083° ~ 1 km at Equator	1950-01-01 to 2017-12-31	Daily with missing data

Table 1: Comparison between different input data sets (E-Obs and WorldClim) and corresponding Downscaled Climate data sets.

Changes in WorldClim and E-Obs input data

Both input datasets, WorldClim (WC) and E-Obs, were updated to newer versions (Table 1). For WC version 2.0 (http://worldclim.org/version2) was used instead of version 1.4.
For E-Obs version 17.0 (https://www.ecad.eu/download/ensembles/download.php#datafiles) was used instead of version 8.0.

E-Obs

The newer E-Obs v17 data covers the years 1951 to 2017 compared to 1951 to 2012 for the older v8 data (Table 1). In addition to added data for the years 2013 to 2017, data for years already covered in the older version have also been updated, due to new stations and series being included. In general this should lead to better data in the newer version.
Coverage of E-Obs data shows differences between v17 and v8. For temperature data (Figure 1) coverage in general is better in v17 compared to v8 for the early years. For later years v8 often covered a greater area compared to the new v17 data. The differences are not the same for minimum (Tmin) and maximum (Tmax) temperature but they do show the same general trend. For precipitation (Prcp) data (Figure 2) the earlier years are better covered in v17 compared to v8. For later years v17 does show gaps in Poland and Italy for example, that were not present in v8. An explanation for having data for a certain area for a previous version of E-Obs in a certain year, but no longer in a newer version can be found here:
http://cib.knmi.nl/mediawiki/index.php/Compare_E-OBS_v17.0_and_v16.0

From 2014 onwards v17 does only cover the western part of Russia, while the eastern part is missing. This applies to both, temperature and precipitation data.

WorldClim

Changes in WorldClim data in v2 compared to v1 can be explained by the following reasons: 1) A different time extent, 1970 to 2000 for v2 compared to 1960 to 1990 for v1 used for calculating the monthly means 2) An increase of data from climate stations, including stations at high latitudes and elevations (Fick and Hijmans, 2017) 3) General improvement of the algorithm and especially for areas with low station density or unusual or sharp gradients (e.g inversion, rain-shadows, ocean-land transition), including the use of satellite-derived and other covariables (Fick and Hijmans, 2017).

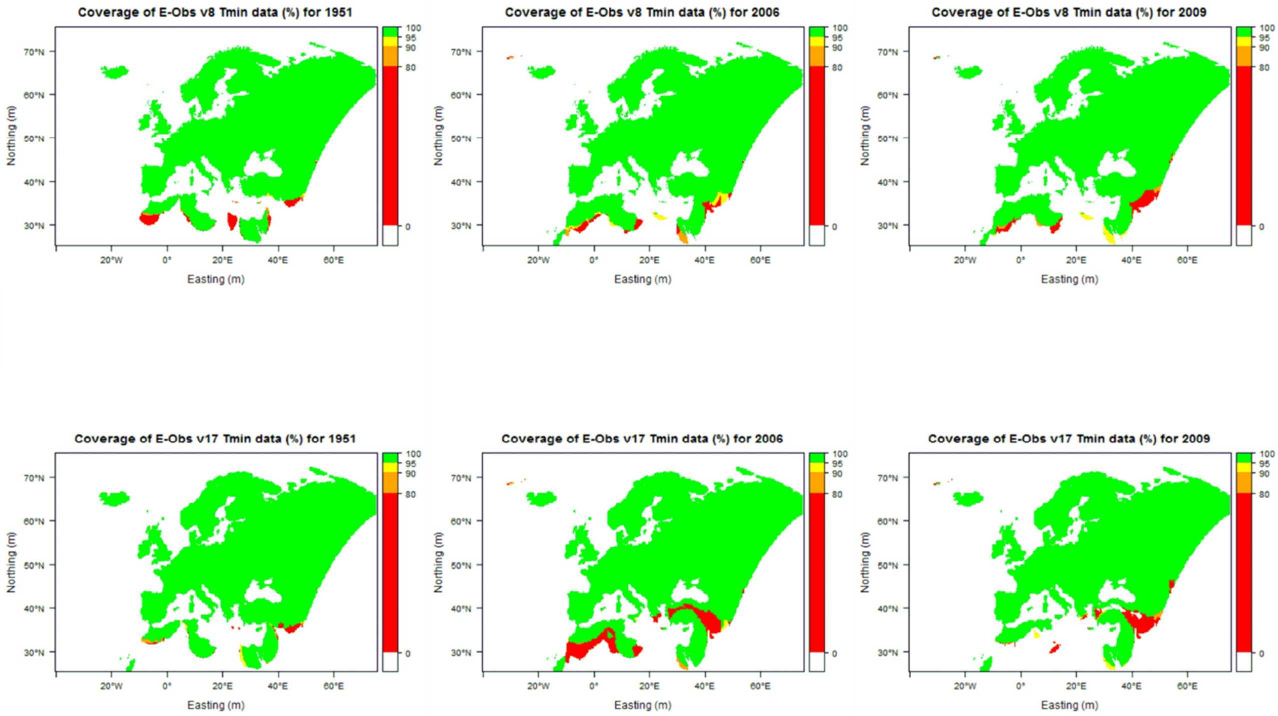

Figure 1: Coverage (days with non-NA data) of E-Obs minimum temperature (Tmin) data for version 8 (upper row) and version 17 (lower row) for the years 1951, 2006 and 2009.

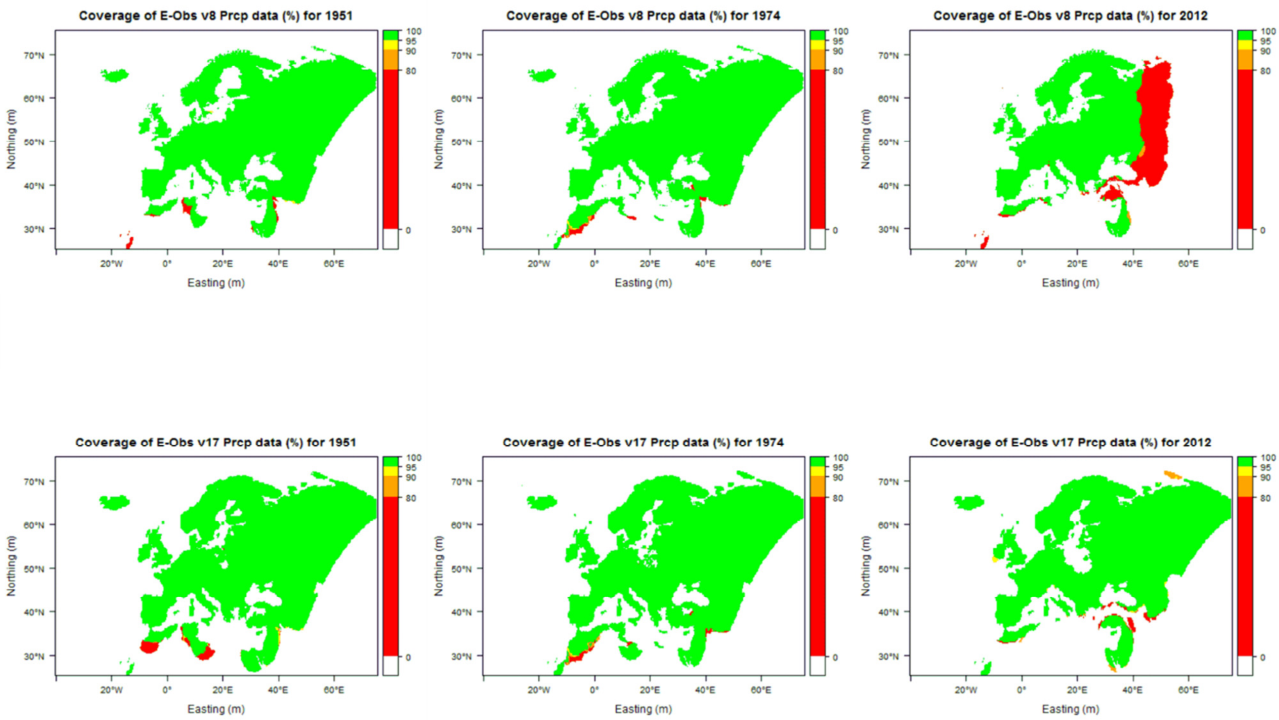

Figure 2: Coverage (days with non-NA data) of E-Obs precipitation (Prcp) data for version 8 (upper row) and version 17 (lower row) for the years 1951, 1974 and 2012.

Extended coverage of Downscaled Climate Data Version 2

Version 1 of the Downscaling was strictly limited to the area covered by the E-Obs data set which led to poor coverage along the coasts (Figure 3, left). In version 2 the coverage was extended by extrapolating the E-Obs data. We first selected potential target cells for extrapolation by choosing cells which are adjacent to E-Obs cells and have high coverage (>95% of the days between 1950 and 2012, Figure 4). This excludes areas with low data availability (e.g., North Africa) from extrapolation. For the selected cells extrapolated values for temperature and precipitation were calculated as a focal mean of available E-Obs cells (3x3 window). The thus extended E-Obs data set was then used for the downscaling. The grid “extrapolate_mask.tif” provides the cells for which we used extrapolated E-Obs data for downscaling.

Figure 3: Change in coverage due to the extrapolation of E-Obs data for Italy. Black: Coverage of the WorldClim 2 (1km) data set, blue: Coverage of the Downscaled Climate Data. Left: version 1, right: version 2. Since the extrapolation is limited to one adjacent E-Obs pixel, some areas remain uncovered (e.g., Elba and some islands along the coast of Croatia).

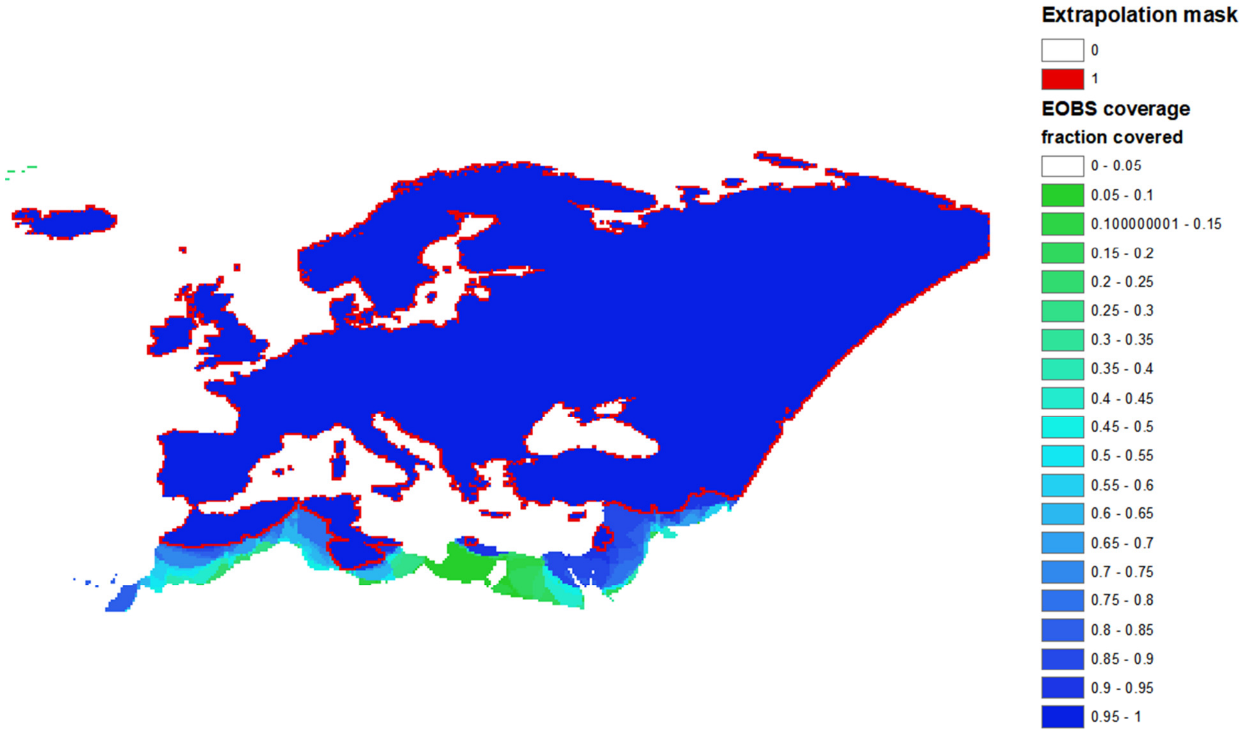

Figure 4: Coverage of E-Obs data (fraction of days between 1950 and 2012) and the cells eligible for extrapolation (red).

Annual and Periodic Data Version 2

Annual Data

Annual average temperature (Tavg) and total precipitation data are also available in the downscaled data version 2. Average temperature Tavg is taken as the mean of minimum temperature (Tmin) and maximum temperature (Tmax).

Annual mean Tavg and annual total precipitation (Prcp) were calculated for points with coverage greater than >95%, coverage being the number of days with non-NA data for the respective year. Annual mean Tavg was then calculated by dividing the sum of daily Tavg by the number of days with valid data (non-NA). Annual total Prcp was calculated by adding up the daily precipitation data for the respective year.

Periodic Data

Periodic mean Tavg and mean Prcp for two periods (1951 to 1980 and 1981 to 2010) are also available in the downscaled data version 2.

Perdiodic Tavg and Prcp were calculated for points with coverage of greater than 95%, coverage being the number of years with non-NA data within the respective period. Periodic mean for both variables (Tavg and Prcp) was calculated by dividing the sum of the annual data by the number of years with non-NA data.

Differences between Downscaled Climate Data Version 2 and Version 1

As previously stated, both input data sets (E-Obs and WorldClim) show differences compared to their respective older versions. These differences also transfer into the downscaled (DS) climate data (Table 2). In general the changes in WorldClim (WC) data show a higher influence on the resulting DS data, compared to the changes in E-Obs data.

	Tmin (°C)				Tmax (°C)				Prcp (mm)			
Year	**v1**	**v2**	**RMSE**	**BIAS**	**v1**	**v2**	**RMSE**	**BIAS**	**v1**	**v2**	**RMSE**	**BIAS**
1951	3.646	3.498	0.652	-0.148	12.194	12.211	0.554	0.017	1.955	2.373	2.636	0.418
1961	3.361	3.337	0.535	-0.023	12.669	12.675	0.492	0.006	2.404	2.415	0.796	0.011
1971	2.721	2.659	0.563	-0.062	12.066	12.052	0.487	-0.014	1.899	1.909	0.633	0.009
1981	2.963	2.896	0.546	-0.067	11.590	11.604	0.478	0.013	1.549	2.672	4.057	1.123
1991	2.877	2.823	0.542	-0.054	11.595	11.620	0.498	0.025	2.249	2.273	0.668	0.024
2001	3.676	3.678	0.474	0.002	12.210	12.251	0.497	0.041	2.598	2.621	0.675	0.024
2011	4.108	3.830	1.002	-0.279	13.443	13.447	0.751	0.004	1.452	2.251	4.065	0.799
∑*	3.217	3.135	0.597	-0.082	11.91	11.92	0.516	0.011	2.192	2.507	1.923	0.318

*Table 2: Yearly difference in mean minimum temperature (Tmin), maximum temperature (Tmax) and Precipitation values for downscaled climate data v2 compared to v1, as well as the root mean square error (RMSE) and bias. Means were taken for a square area covering Austria (Lat: 46.00-50.00, Lon: 9.00 – 18.00; see Figure 6). * The summary shows the mean values of the annual mean values for all years covered by v1 and v2 (1951 to 2012) and not only the years shown in the table.*

Temperature

Where E-Obs data changed markedly these changes are also represented in the DS data (e.g. Figure 5, Scandinavia). Most changes in the DS data can be accounted for by changes in the WorldClim (WC) data though (Figure 6, Figure 7 - Scandinavia, Figure 8, Figure 9, Figure 10).

Where changes in both input data sets are small, the differences between the downscaled data versions 2 and 1 are also small (Figure 10).

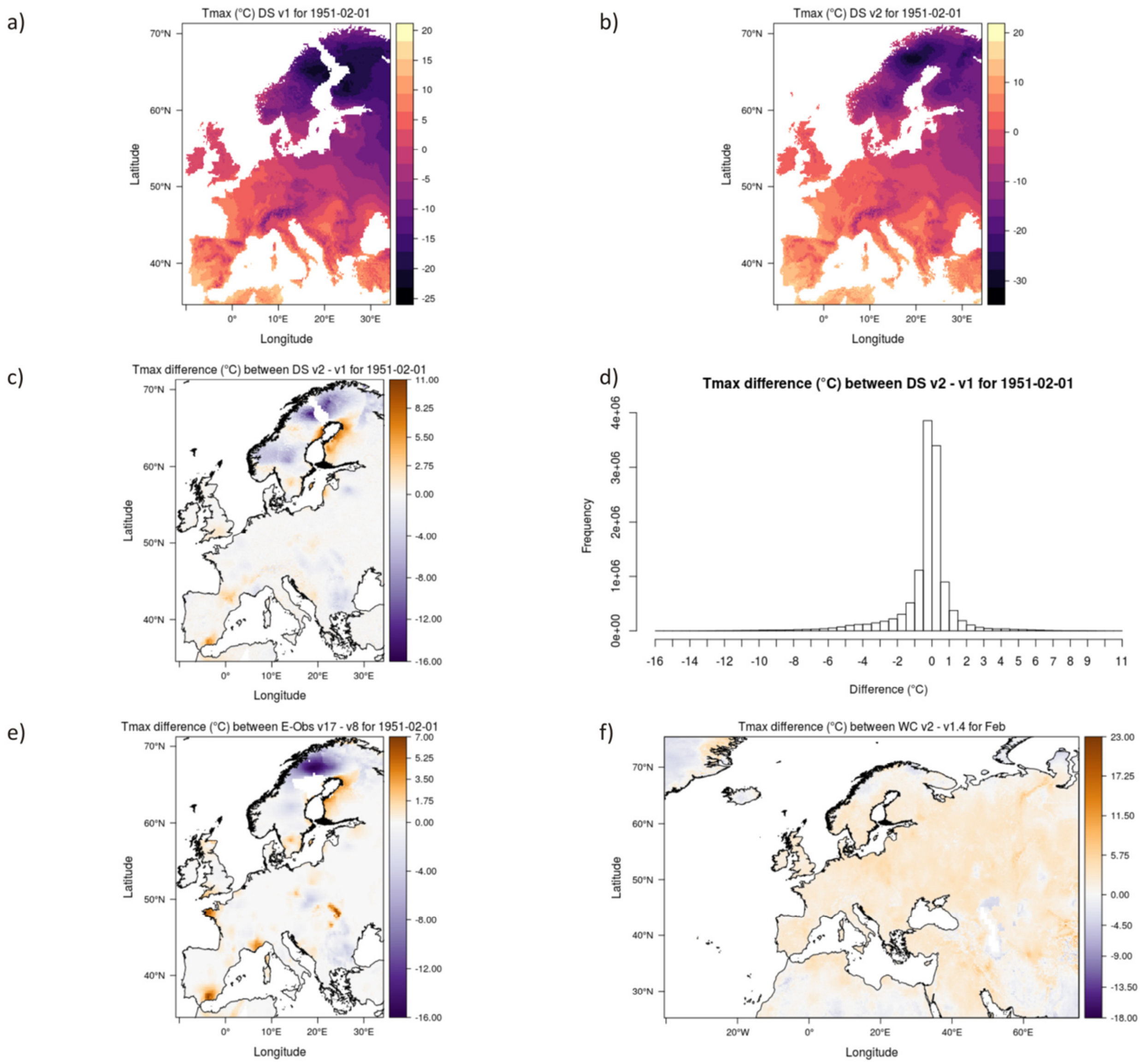

Figure 5: Maximum temperature (Tmax) data for 1951-02-01 a-d) Difference of downscaled (DS) data between v2 and v1 e) Difference in E-Obs input data. Note differences in Scandinavia or Iberia which are also reflected in the DS data f) Difference in WorldClim (WC) input data.

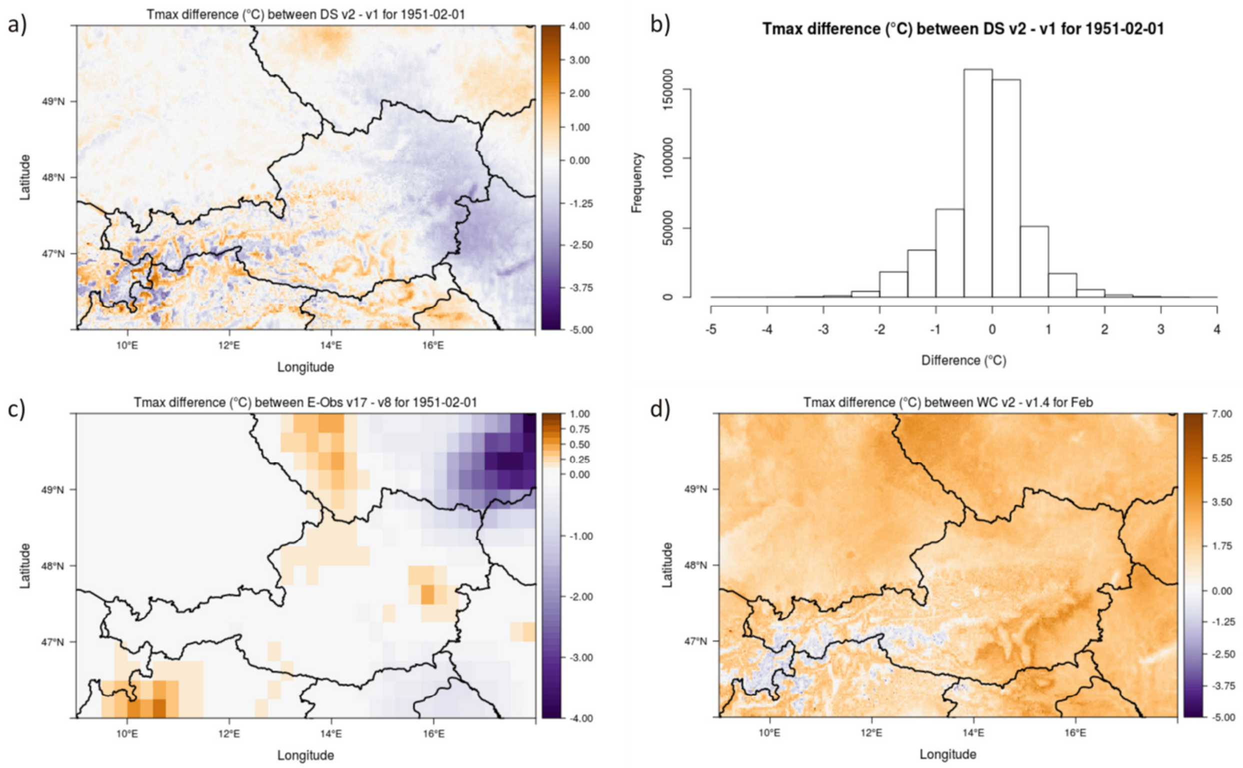

Figure 6: Maximum Temperature (Tmax) data in Austria for 1951-02-01. a-b) Difference of downscaled (DS) data between v2 and v1 c) Difference in E-Obs input data d) Difference in WorldClim (WC) input data. Changes of DS data in the Eastern Alps and south-eastern Germany can mainly be related to changes in WC data.

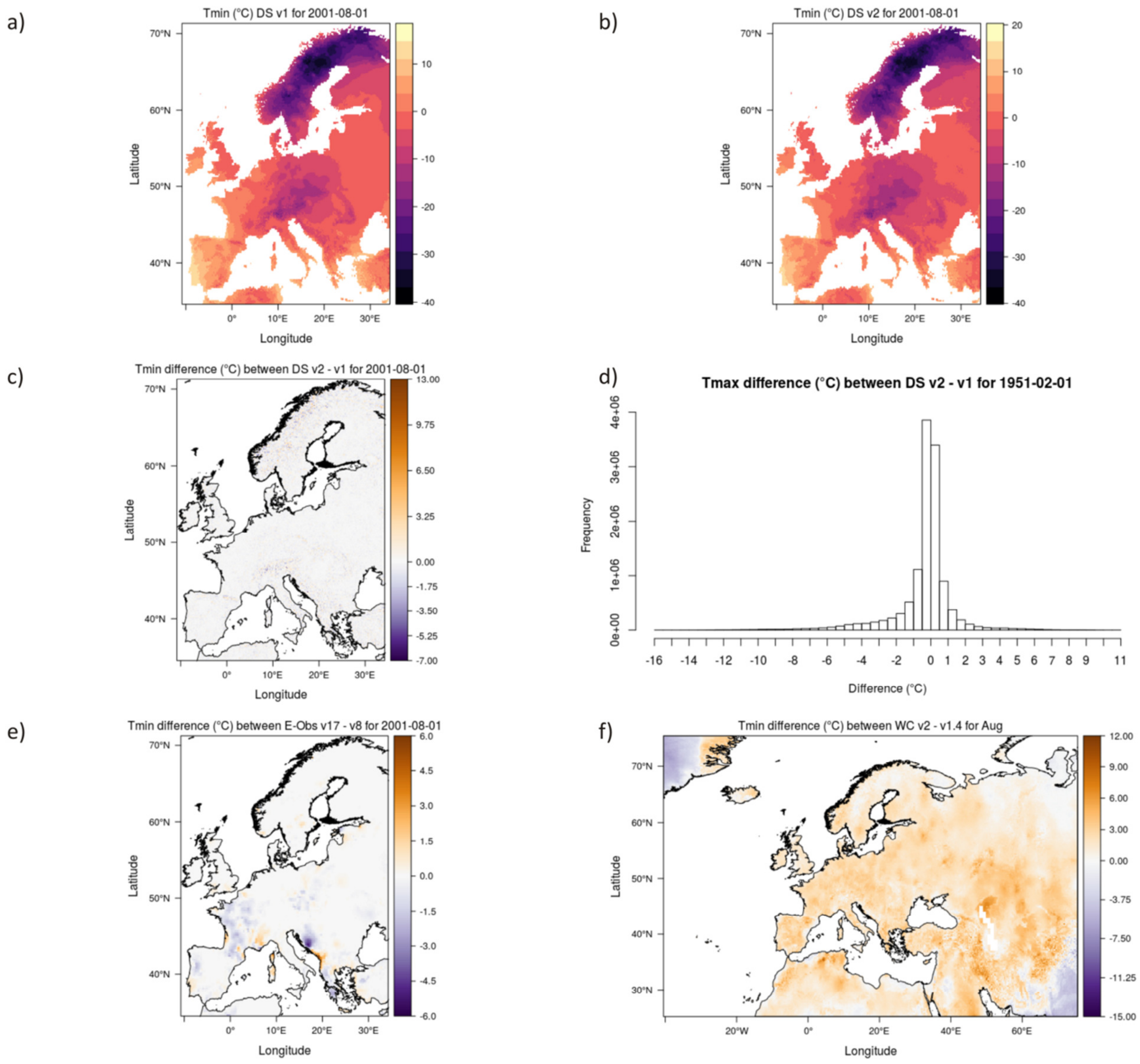

Figure 7: Minimum temperature (Tmin) data for 2001-08-01 a-d) Difference of downscaled (DS) data between v2 and v1 e) Difference in E-Obs input data f) Difference in WorldClim (WC) input data. Difference in DS data in Scandinavia and the Alps are due to changes in WC data.

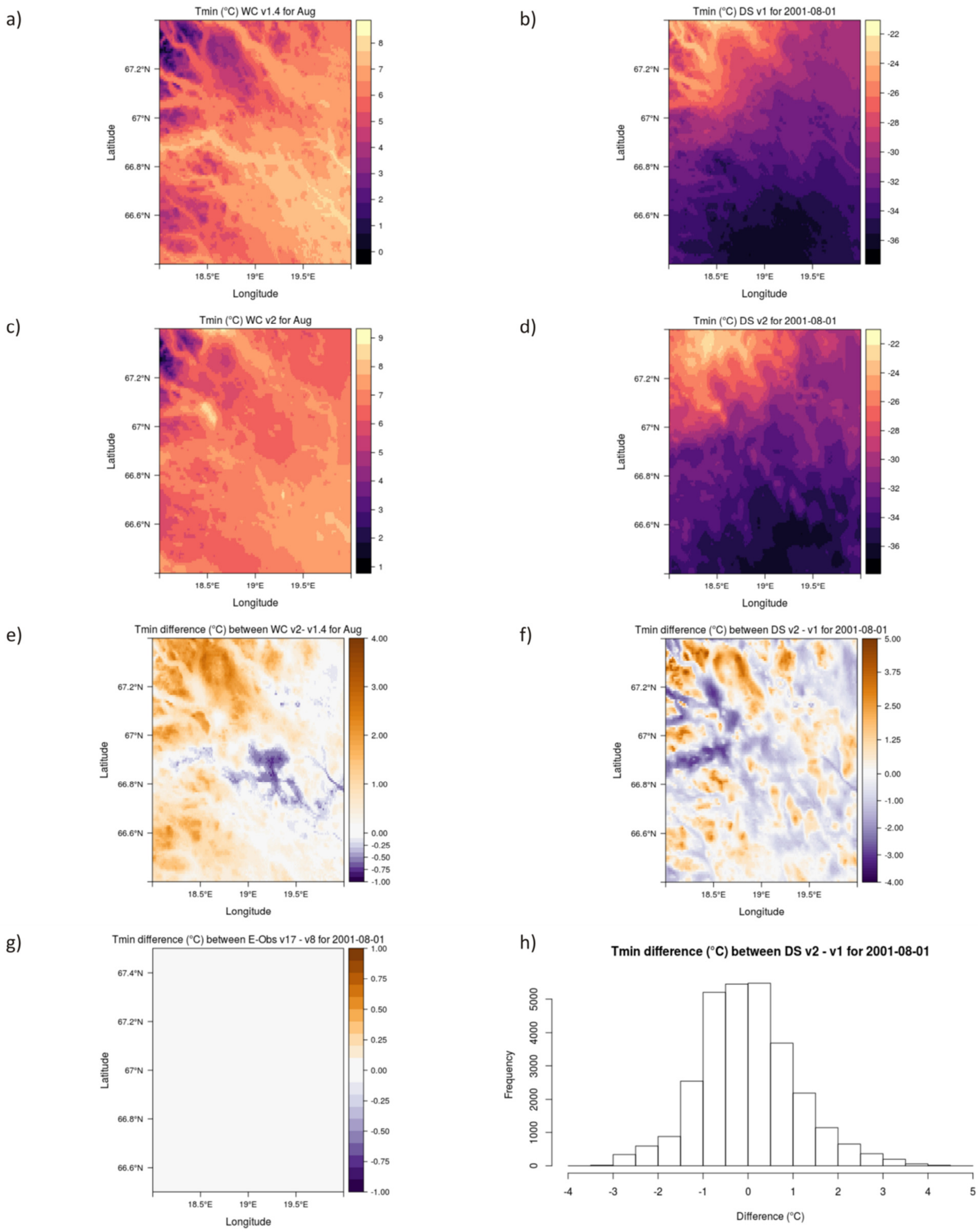

Figure 8: Minimum temperature (Tmin) data in northern Sweden for 2001-08-01 a-b) WorldClim (WC) v1.4 input data and corresponding downscaled (DS) v1 data c-d) WC v2 input data and corresponding downscale (DS) v2 data e-f) Difference in WC input data and DS data g) There are no visible changes in E-Obs input data in this area h) Histogram of changes in DS data, that can be accounted for by changes in WC data

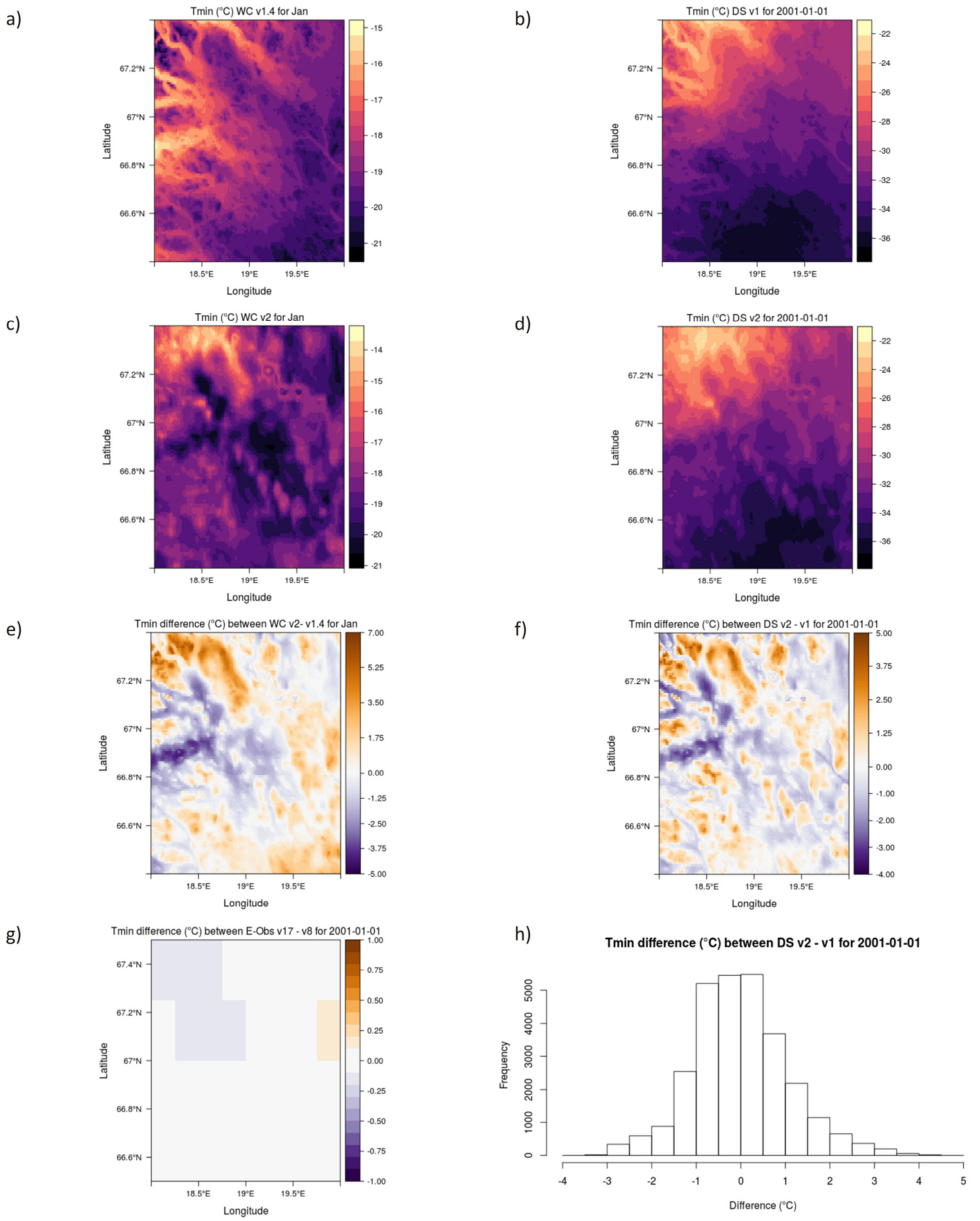

Figure 9: Minimum temperature (Tmin) data in northern Sweden for 2001-01-01 a-b) WorldClim (WC) v1.4 input data and corresponding downscaled (DS) v1 data. c-d) WC v2 input data and corresponding DS v2 data e-f) Difference in WC input data and DS data g) Difference in in E-Obs input data h) Histogram of changes in DS data, that can be accounted for by changes in WC data

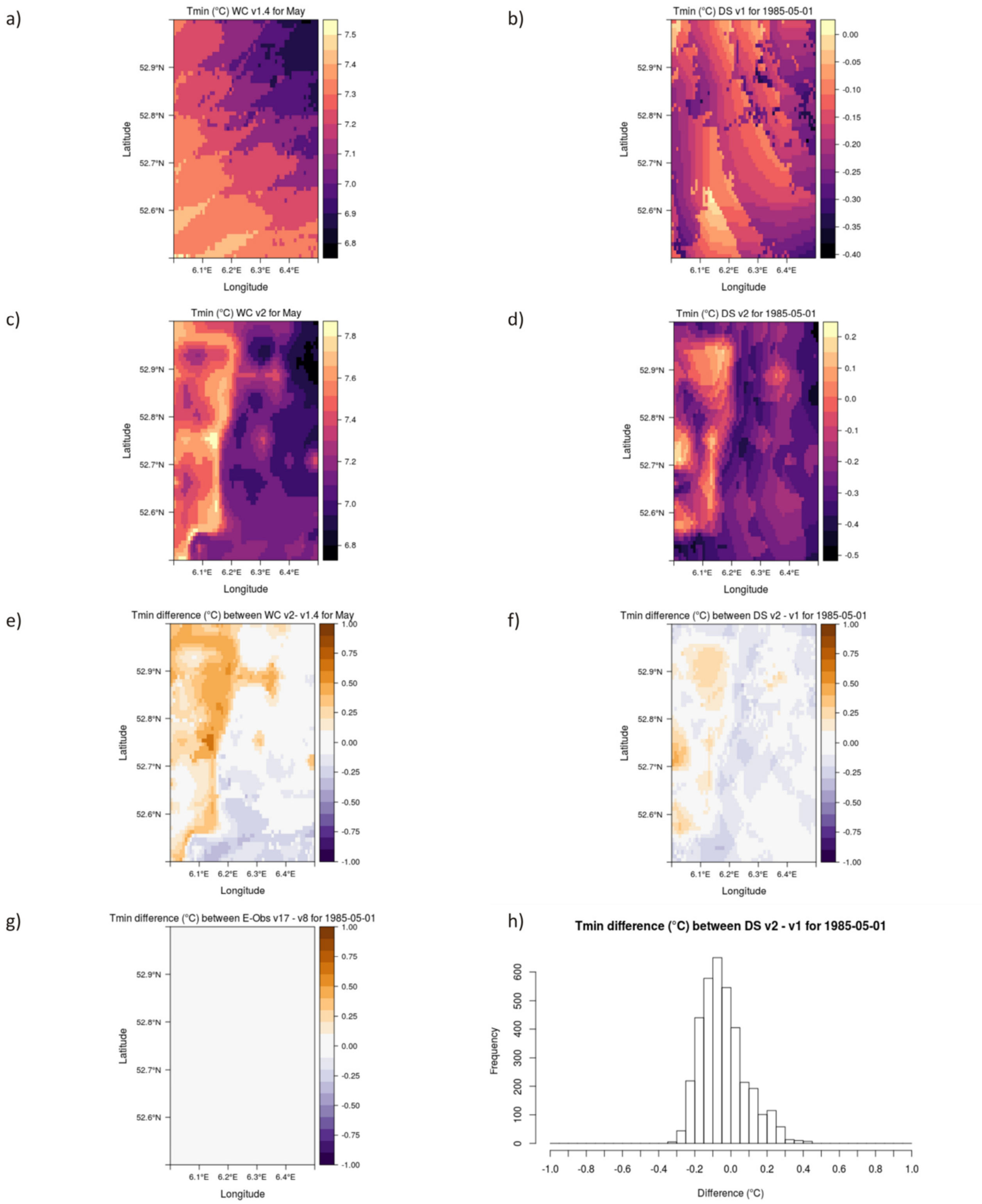

Figure 10: Minimum temperature (Tmin) data in northern Netherlands for 1985-05-01 a-b) WorldClim (WC) v1.4 input data and corresponding downscaled (DS) v1 data c-d) WC v2 input data and corresponding DS v2 data e-f) Difference in WC input data and DS data g) There are no visible changes in E-Obs input data h) Histogram of changes in DS data, that can be accounted for by changes in WC data.

Precipitation

Where E-Obs data changed markedly these changes are also represented in the DS data (Figure 11, Figure 13, Figure 14, Figure 15, Figure 16), while where changes are small the effect on the DS data is low, or may be compensated by changes in WC data (Figure 12). Changes in WC data in general do not have much influence on the DS data (Figure 12, Figure 14, Figure 16).

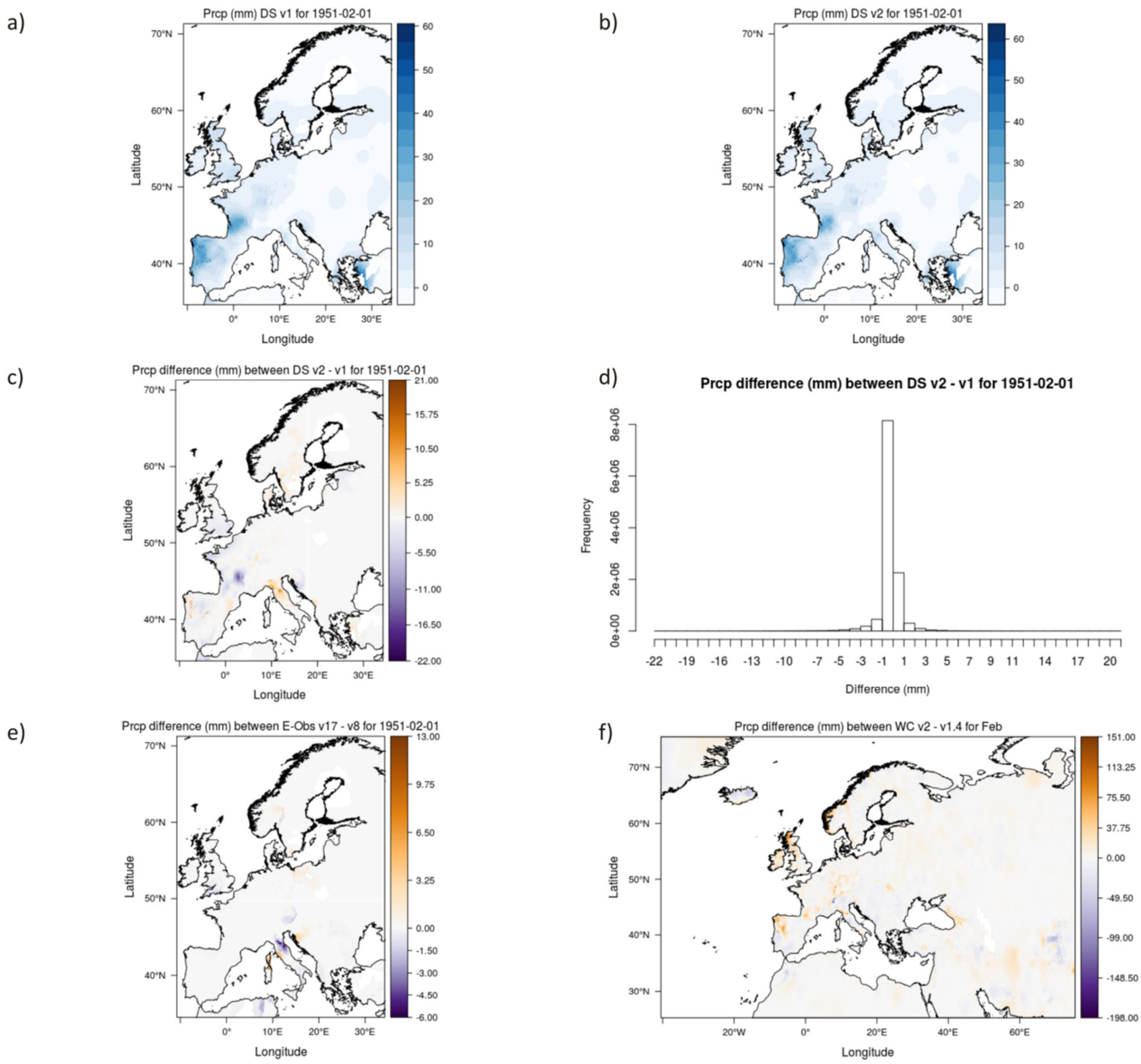

Figure 11: Precipitation (Prcp) data for 1951-02-01 a-d) Difference of downscaled (DS) data between v2 and v1 e) Difference in E-Obs input data f) Difference in WorldClim (WC) input data.

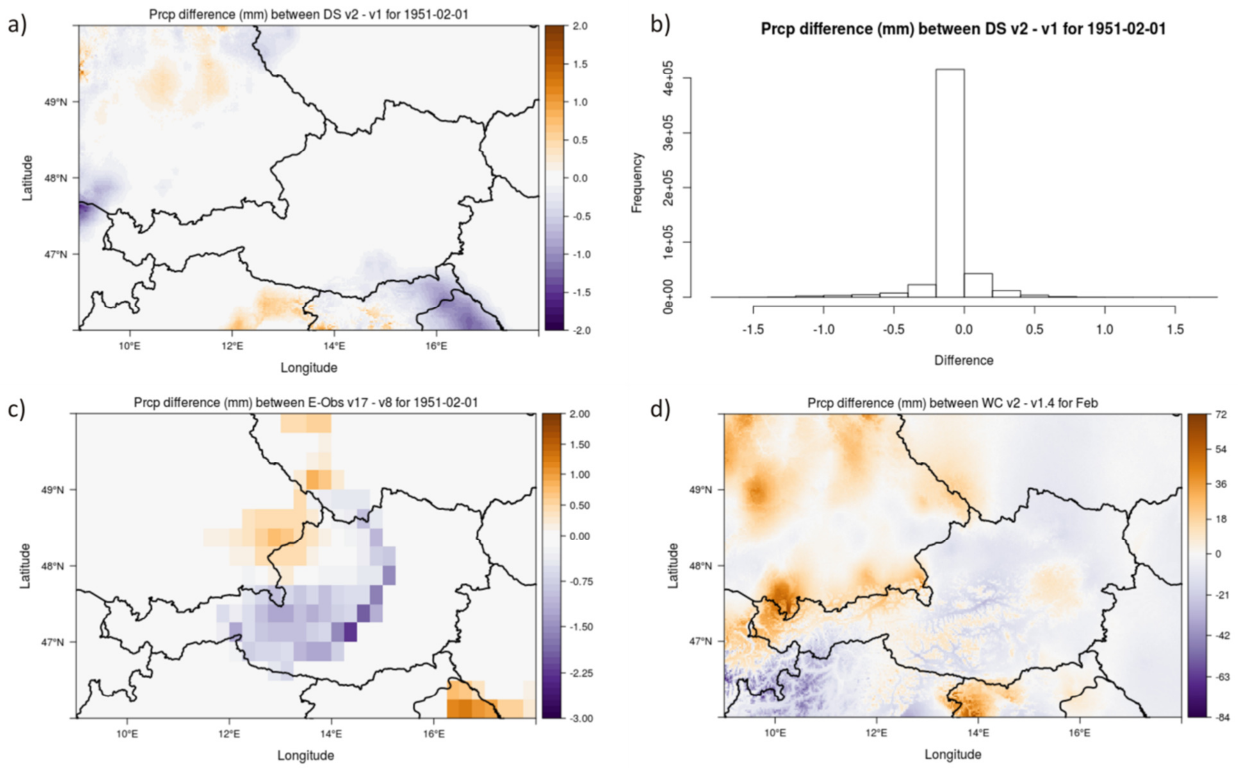

Figure 12: Precipitation (Prcp) data in Austria for 1951-02-01. a-b) Difference of downscaled (DS) data between v2 and v1 c) Difference in E-Obs input data d) Difference in WorldClim (WC) input data.

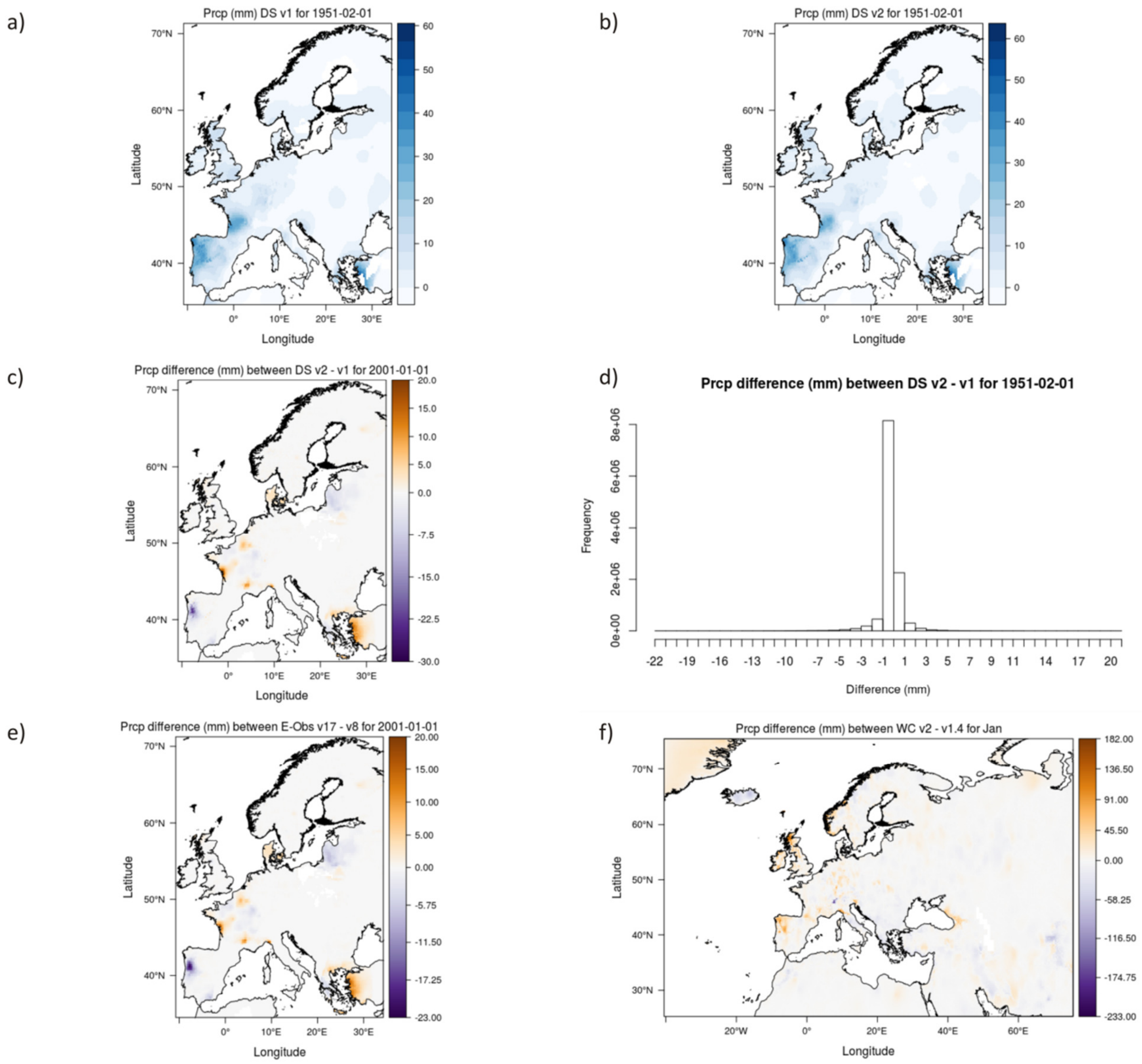

Figure 13: Precipitation (Prcp) data for 2001-01-01 a-d) Difference of downscaled (DS) data between v2 and v1 e) Difference in E-Obs input data. Differences in DS data can mostly be accounted for by differences in E-Obs data f) Difference in WorldClim (WC) input data.

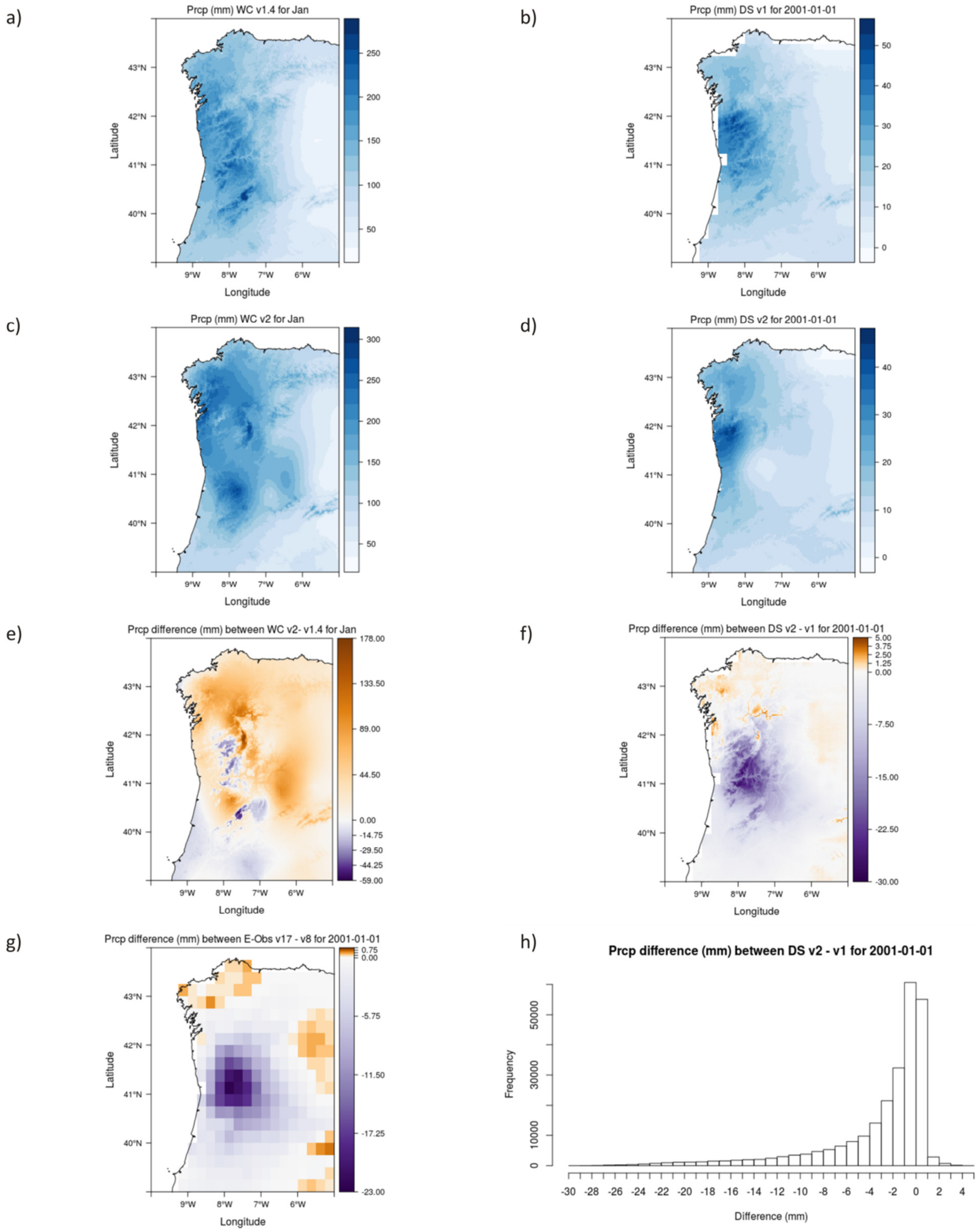

Figure 14: Precipitation (Prcp) data in north-western Iberia for 2001-01-01 a-b) WorldClim (WC) v1.4 input data and corresponding downscaled (DS) v1 data c-d) WC v2 input data and corresponding DS v2 data. Note better coverage of the coastline in DS v2 compared to v1 e-f) Difference in WC input data and DS data g) Difference in E-Obs input data h) Histogram of changes in DS data. Changes in DS data can mostly be accounted for by changes in E-Obs data.

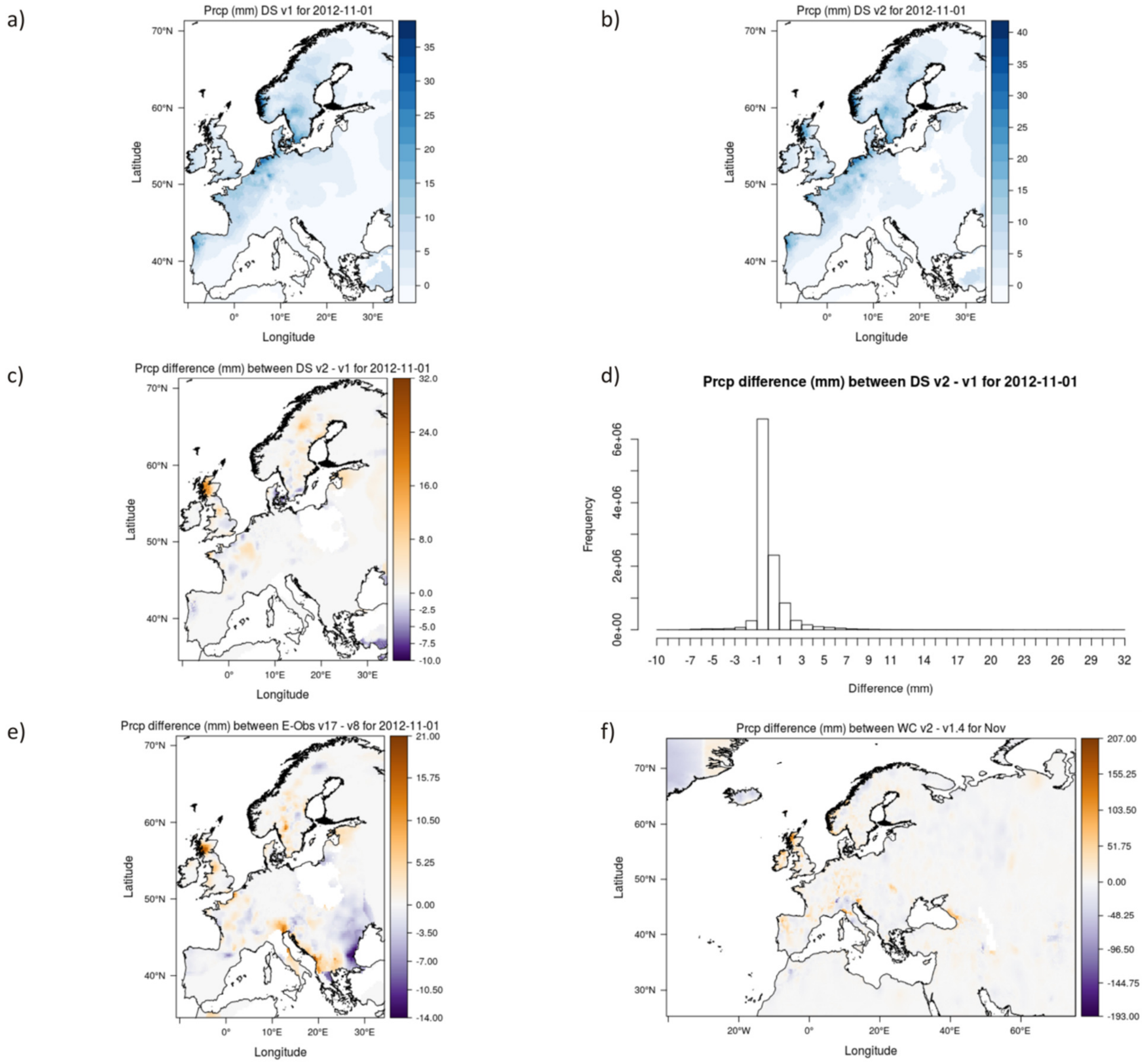

Figure 15: Precipitation (Prcp) data for 2012-11-01 a-d) Difference of downscaled (DS) data between v2 and v1 e) Difference in E-Obs input data. Differences in DS data can mostly be accounted for by differences in E-Obs data f) Difference in WorldClim (WC) input data.

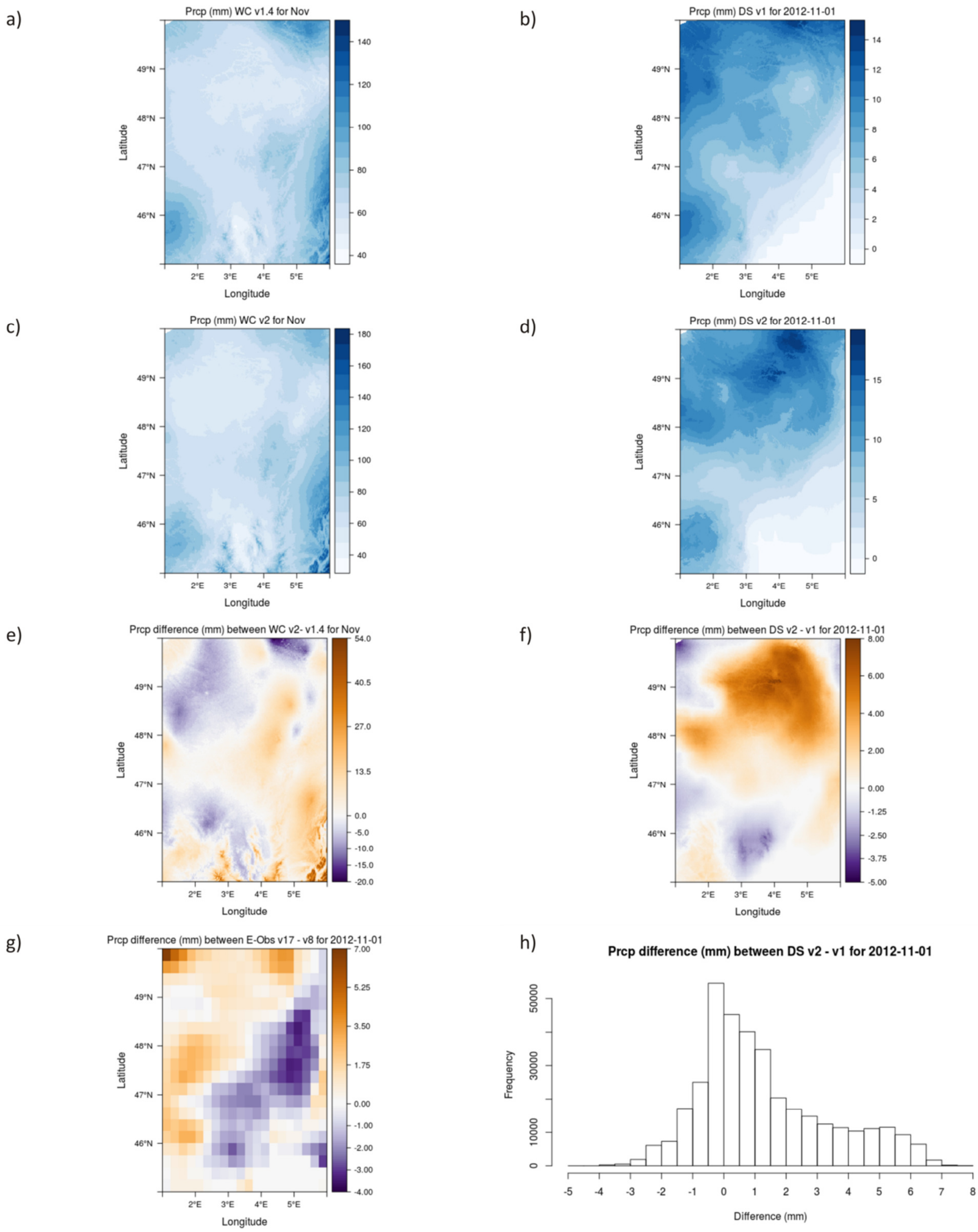

Figure 16: Precipitation (Prcp) data in northern France for 2012-11-01 a-b) WorldClim (WC) v1.4 input data and corresponding downscaled (DS) v1 data c-d) WC v2 input data and corresponding DS v2 data. e-f) Difference in WC input data and DS data. Great changes in WC data at the lower right boundary are not reflected in the DS data g) Difference in E-Obs input data h) Histogram of changes in DS data. Changes in DS data can mostly be accounted for by changes in E-Obs data.

Validation of E-Obs and Downscaled Climate Data

E-Obs and Downscaled (DS) data were validated using Austrian weather station data (2002 to 2011) from the corresponding grid cell (Table 3). Compared to the E-Obs data, the DS data better matches the weather station observations for both versions (DS v1 with E-Obs v8 and DS v2 with E-Obs v17). For precipitation (Prcp) DS v2 does a better job in matching the observations compared to DS v1. However, for temperature (Tmin, Tmax) DS v1 better matches the weather station observations compared to DS v2. This can be attributed by a worse match of the E-Obs v17 data used for DS v2 compared to E-Obs v8 used for DS v1.

			Weather station	**E-Obs**							**Downscaled**						
	# Stations	# Observ.	$\bar{x}$ (min, max)		$\bar{x}$ (min, max)	MAE	RMSE	R^2	LEPS	CSI		$\bar{x}$ (min, max)	MAE	RMSE	R^2	LEPS	CSI
T_{min} (°C)	400	939435	3.7 (-30.8, 26.0)	v8	3.1 (-25.9, 23.2)	1.94	2.57	0.90	0.73	NA	v1	3.9 (-26.8, 23.4)	1.54	2.10	0.93	0.79	NA
				v17	3.0 (-26.0, 23.5)	2.00	2.66	0.89	0.72	NA	v2	3.7 (-27.1, 24.3)	1.56	2.09	0.93	0.79	NA
T_{max} (°C)	400	939432	13.0 (-26.1, 39.5)	v8	11.5 (-20.7, 38.4)	2.76	3.76	0.87	0.68	NA	v1	12.8 (-20.9, 38.7)	1.40	1.95	0.96	0.84	NA
				v17	11.5 (-20.6, 38.4)	2.77	3.78	0.87	0.68	NA	v2	12.7 (-21.3, 38.7)	1.48	2.03	0.96	0.83	NA
Prcp (mm)	414	984652	2.8 (0.0, 1099.8)	v8	3.1 (0.0, 166.0)	1.81	5.24	0.53	NA	0.73	v1	2.6 (0.0, 159.4)	1.85	5.45	0.47	NA	0.67
				v17	3.2 (0.0, 174.7)	1.89	5.37	0.52	NA	0.73	v2	3.0 (0.0, 196.0)	1.76	5.15	0.53	NA	0.73

Table 3: # Stations and # Observ. refer to the number of weather stations and observations (days with valid data) used for the validation. Only Austrian weather stations are used. These are in general the same that were used for the validation of the Downscaled data version 1 (Moreno and Hasenauer, 2015). Weather station data for the years 2002 to 2011 was used. $\bar{x}$ (min, max) provide the mean, minimum and maximum values of the data set. Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and the squared Pearson's correlation (R^2) were calculated using the weather station data as observations and the E-Obs and Downscaled data as predictions. Linear Error in Probability Space (LEPS) and Critical Success Index (CSI) were calculated as described in Moreno and Hasenauer (2015).

Acknowledgements and References

We acknowledge the E-OBS dataset from the EU-FP6 project ENSEMBLES (http://ensembles-eu.metoffice.com) and the data providers in the ECA&D project (http://www.ecad.eu)

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