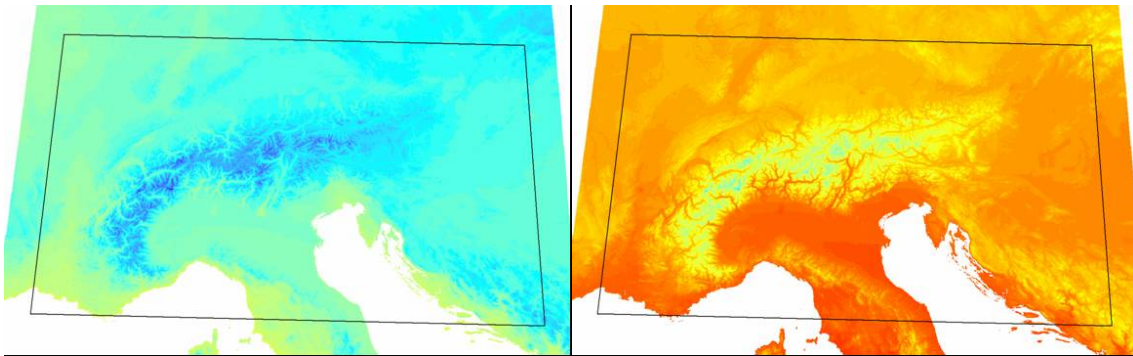


ECSN – HRT/GAR**High Resolution Temperature Climatology in Complex Terrain –
demonstrated in the test area Greater Alpine Region GAR****Final Report**

by

Ingeborg Auer, Reinhard Böhm, Johann Hiebl, Wolfgang Schöner
Central Institute for Meteorology and Geodynamics, Vienna, Austria

Jonathan Spinoni, Gianluca Lentini, Maurizio Maugeri
University of Milan, Institute of General Applied Physics. Milan, Italy

Michele Brunetti, Teresa Nanni
Institute of Atmospheric Sciences and Climate, Italian National Research Council
(ISAC-CNR), Bologna, Italy

Melita Perčec Tadić
DHMZ - Meteorological and Hydrographical Service of Croatia, Zagreb, Croatia

Zita Bihari
OMSZ – Hungarian Meteorological Service, Budapest, Hungary

Vienna, June 2008

Contents

1. Motivation	3
2. Project history	4
3. Preparation of the dataset	5
4. Construction of the Alpine Temperature	6
5. The final monthly climatologies	18
6. Outlook	20
7. Project workshops	21
8. Project presentations	21
9. Papers	21
10. References	22
Annex 1: Data Processing for a high resolution Alpine temperature climatology (ECSN/HRT-GAR)	
Annex 2: Geographical specifics of air temperature and the concept of ECSN/HRT-GAR	
Annex 3: Construction of 1961-90 high-resolution monthly temperature climatologies for Northern Italy - technical report	
Annex 4: 12 mean monthly temperature maps of the Alpine core part of GAR	

1. Motivation

High resolution climatologies offer a broad spectrum of opportunities for further applications in climate and climate change research. Although this is a well-known fact, up to now temperature climatology has not existed for the Alpine Region. Except for precipitation, Frei and Schär, 1998 provided highly resolved Alpine precipitation climatology based on measurements of some 6000 stations.

The Greater Alpine Region (GAR) has been defined as a region lying between 4-19°E and 43-49°N. At continental scale, it constitutes a sharp “climates divide” in the transitional zone between Atlantic, continental and Mediterranean influences. Its complex terrain ranges between sea level and 4,810 m (Mont Blanc) including mountain peaks, small scale valleys, plains and plateaus, cities with urban heat islands, littorals, glaciated and forested areas, and other landscape features.

The Alpine station network is one of the densest in the world; its area covers about 700000 km² encompassing 13 different national and even sub-national special features, which are often inhomogeneous in their observing practices. Some National Weather Services (NMSs) and research institutes already elaborated national as well as regional climatologies (see list of references). When trying to merge them together however, significant discontinuities appear at the borders, due to the mentioned inhomogeneous observation practices. Also spatial analysis methods and underlying geographical information, and temperature features of neighbouring countries usually are not considered by national analyses projects. At the other tail of the spectrum, Meteo France published the ECSN Climate Atlas of Europe on CD in 2004. Based on only 700 stations for the study region, this coarse Atlas provides a more general overview but cannot reproduce any small scale features. Note for example the not existing Alps in Fig.1

Moyenne annuelle des températures moyennes

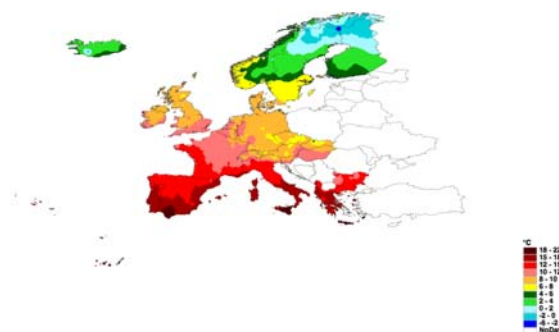


Figure 1: Annual mean temperature in the period 1971-2000; Map produced within the ECSN Climate Atlas of Europe, Meteo France, 2004

Therefore, the project team of ECSN – HRT/GAR aimed to prepare a **High Resolution Climatology for the Greater Alpine Region** (4-19°E and 43-49°N) for a 30yrs period with a temporal resolution of 1 month and a spatial resolution of 1 km x 1 km.

2. Project History

In the late 1990s an informal collaboration of a number of countries was established in order to create and maintain the HISTALP data set (Auer et al., 2007). It was more or less this group who agreed to extend that collaboration by calculating common mean monthly temperature fields for the GAR.

In October 2005, at the 26th EUMENET Council, the ECSN HRT/GAR project was approved, the informal collaboration has turned into a formal ECSN partnership including eight ECSN members and non-ECSN members, EU members and countries in transition, Alpine and non-Alpine countries, weather services and research institutes. Project duration was decided for two years starting in January 2006 and ZAMG has been appointed being the responsible project manager.

Table 2: The formal ECSN Partnership

- Austria – Central Institute for Meteorology and Geodynamics
- France – Météo France
- Germany – Deutscher Wetterdienst
- Hungary – Meteorological Service of Hungary
- Italy – Aeronautica Militare
- Luxembourg – Service météorologique Administration de l'aéroport de Luxembourg
- Norway – Det Norske Meteorologiske Institut
- Switzerland – Météo Swiss
- United Kingdom – Met Office

Besides the former ECSN community several partners informally supported the project with man power, data and their national and regional experience. In particular, three Italian tree-ring researchers (Marco Carrer, UNi-Padova, Paola Nola, Uni-Pavia, Renzo Motta, Uni-Torino) stand out by providing a great number of Italian tx-tn-datasets.

Two nationally funded parallel activities supported our project to a great extent, namely:

“The Croatian Climate Atlas”

“HRT NI - High Resolution Temperature Climatology Northern Italy” with a special report in Annex 3

3. Preparation of the data set

Data collection was characterised by an intensive search for existing temperature data for the period 1961-1990 with the leading principle to achieve the highest possible spatial density. High data density is fundamental due to the strong vertical structure of the Alps. The period 1961-1990 was chosen because many weather services had already invested intensive work on data of this official recent WMO – CLINO period.

A more recent period 1971-2000 would have caused major problems, especially in Italy, where a fundamental re-organisation of the existing networks took place during the 1990s. The original number of collected single station datasets was approximately 1800, but not all of them eventually met the requirements in terms of completeness and data-quality. Most of the data were provided in digital form, but data of 187 stations were digitised by ZAMG staff in order to elaborate a station network as dense as possible.

Before the gathered data were ready for analysis, a special quality control was applied. This concerned not only the data themselves, but also the metadata (e.g. coordinates). Fig.2 shows one example of the time consuming but necessary work on exact station location.



Figure 2: Reconstruction of coordinates of the Meteo Trentino station Passo Tonale, (lat: 46.2633, long: 10.5977, 1880 m asl.), photo source: Meteo Trentino

All activities concerning data collection, correction and adjustments are described in Annex 1 to this report.

4. Construction of the Alpine Temperature Climatology

The climate normals that could actually be used to construct the Alpine Temperature Climatology were 1726, 1448 of them located within GAR. In the first stage 98 station locations had to be excluded from the regression calculation due to several reasons: city centre location (37), direct coast location (35) and extreme inversion location (12) and some due to unknown reasons (14). All in all 1628 stations have been used for the first and overall regression calculation.

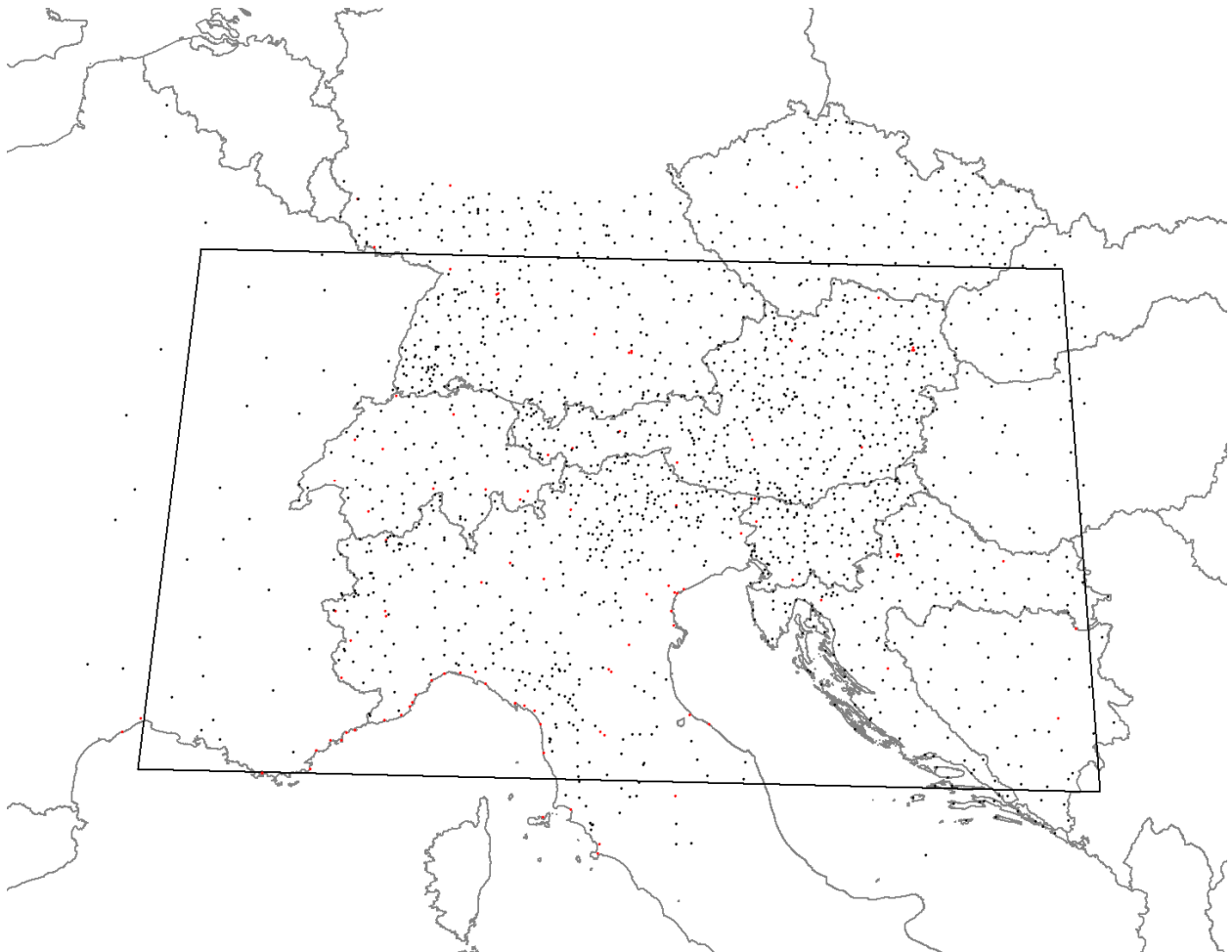


Figure 3: The final ECSN/HRT-GAR station network with climate normals of 1726 climate stations for the period 1961-1990

After calculating multiple linear regressions and residual analysis (details in Annex 2), spatial interpolation of air temperature has been performed within sub-regions. Due to the residual analysis, rough borders for the six horizontal sub-regions have been proposed, while the exact definitions of borderlines were defined according to additional regional expert knowledge of project participants. Figure 4 displays the six principal sub-regions with clear borders at the main ridges of the Alps and of the Apennines, but unclear situations in Friuli – Istria and the interior Alpine region. For the vertical dimension, an additional group H (stations between 1501 and 3580 m asl) has been defined (Figure 5).

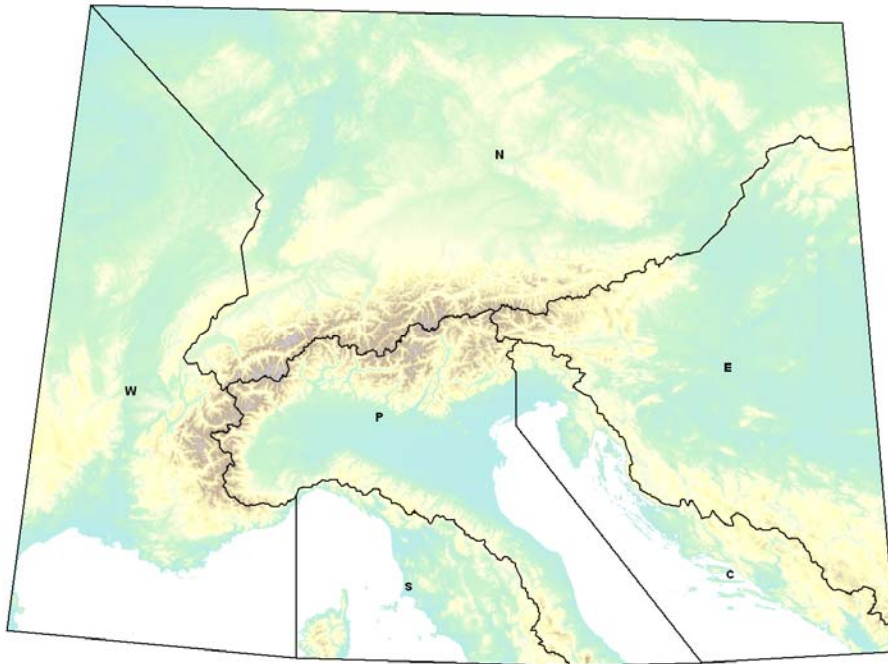


Figure 4 : Map of the six principal horizontal sub-regions within ECSN/HRT-GAR: W–West, N–North, E–East, S–South, C–Eastern Adriatic Coast, P–Po Plain



Figure 5: Vertical sub-region H above 1500 m asl.

Station density was found varying in the different regions. Highest station density was provided in sub-region N, lowest in sub-region W (compare Table 2)

Table 2: Station density in different sub-regions of GAR

Sub-region	No. of stations	Station density (1000 km ⁻²)
W	37	0.2
N	694	2.9
E	380	2.2
C	128	0.7
S	54	1.1
P	237	2.0
H	98	1.4

Considering seven sub-regions for every month, seven multiple regressions had to be calculated in the form:

$$t = a*\lambda + b*\varphi + c*z + d*cd + e$$

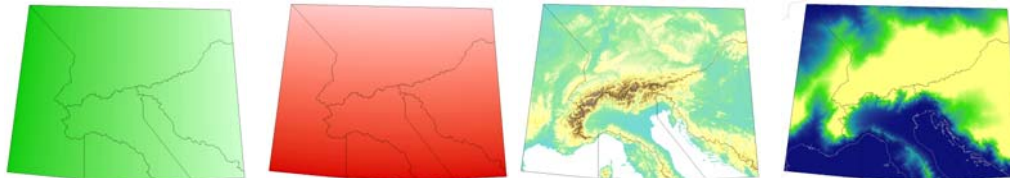
with

λ : longitude

φ : latitude

z : altitude

cd : z-weighted coast distance



However, calculating regressions within two vertical sub-regions only, an artificial break appeared at 1500 m as can be seen in Figure 6. Thus it was decided to work with three vertical layers, 1-700 m, 701-1800 m and 1801-3580 m. For the intermediate layer, an interpolation has been performed at every 1*1km raster pixel.

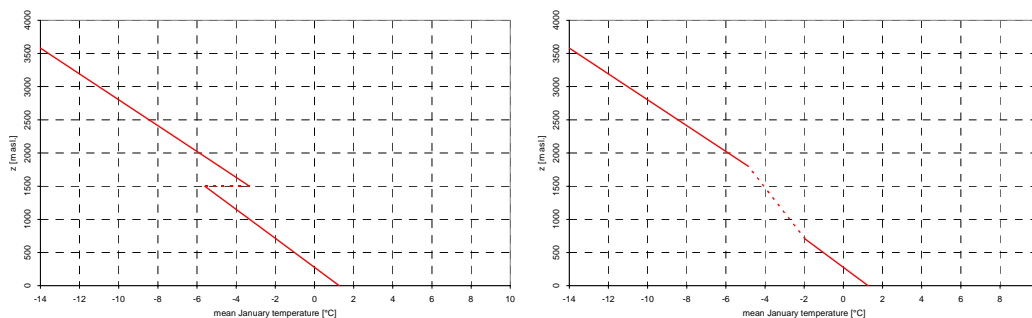


Figure 6: Comparison of calculated regressions within a two layer (left) and a three layer (right) model.

Now, on the basis of six horizontal and three vertical sub-regions the first raw maps could be drawn. The example map of January is displayed in Figure 7. The same Figure shows the respective residuals within a range of +/- 3.5°C. The regional distribution of residuals offer a number of possibilities for further improvements of the temperature estimates, such as improvements in the inversion areas, near the coasts and lakeshores, in the cities and on slopes.

A number of such effects were investigated during a special Workshop which has taken place in Vienna in February 2007. A summary of these studies is given in Annex 2.

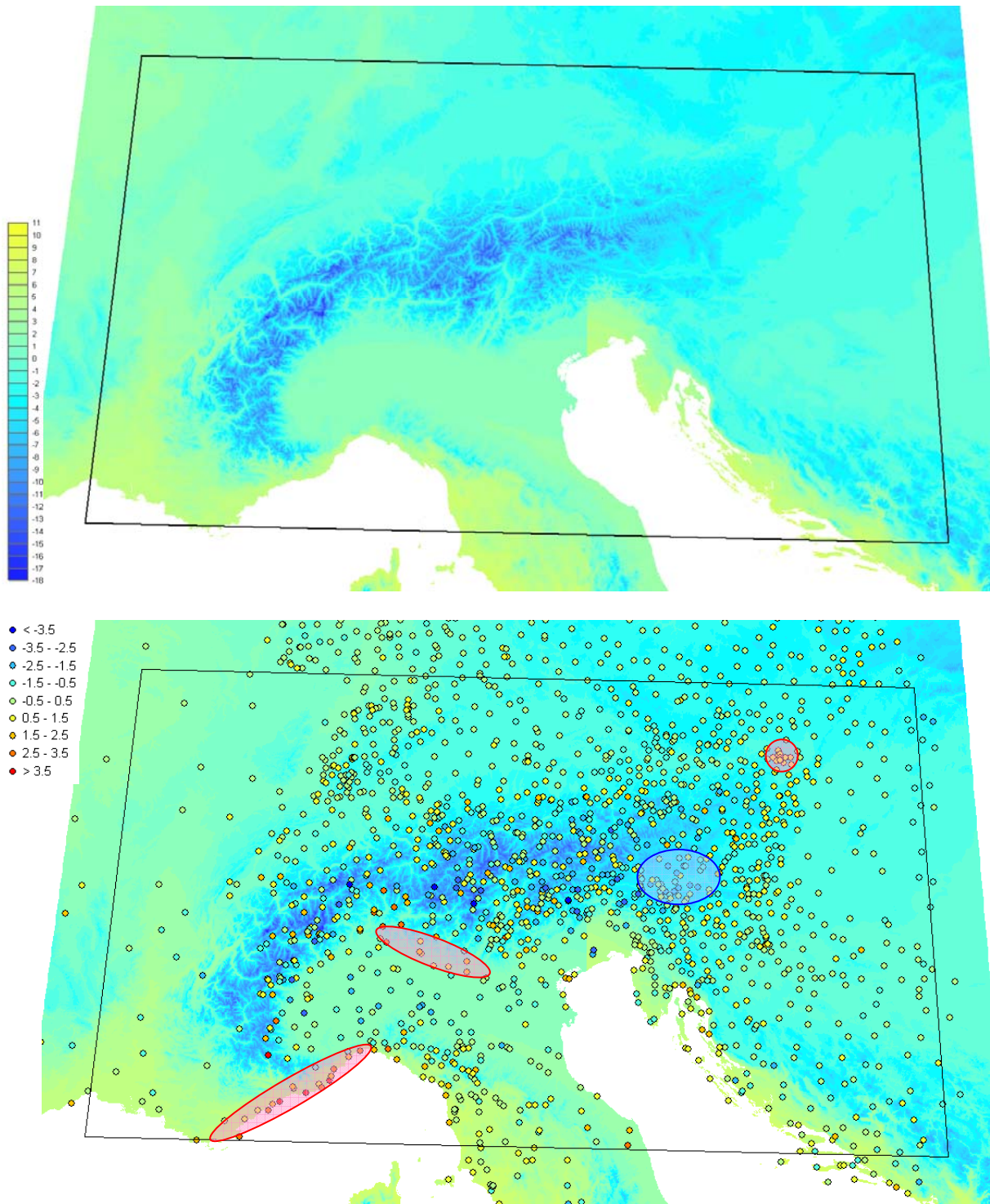


Figure 7: Raw map (after stage 1 multiple regression of January temperature (top) and respective residuals (bottom)).

4.1. Further improvements by working on inversions

13 inversion areas have been identified: Po Plain, Swiss high valleys, Giudicarie, Trentino, Inn Valley, Cadore, Puster Valley, Val Canale, Klagenfurter Basin, Salzach Valley, Mura Valley, Enns Valley, and Graz Basin. Examples for the vertical January residual distributions representing inversions are given in

Figure 8. In every inversion area, a mean correction factor was calculated for every month and correction has been applied in previously defined vertical layers (Table 3). Some layers had their base at the surface and others were restricted between two vertical levels. Inversions show a prominent annual course with largest negative values up to -3°C in December and January. Some of the inversions disappear during summer, but not all of them. Especially Cadore, Swiss high valleys and the Graz Basin are cooler the whole year round (Figure 9). Details are presented in Annex 2.

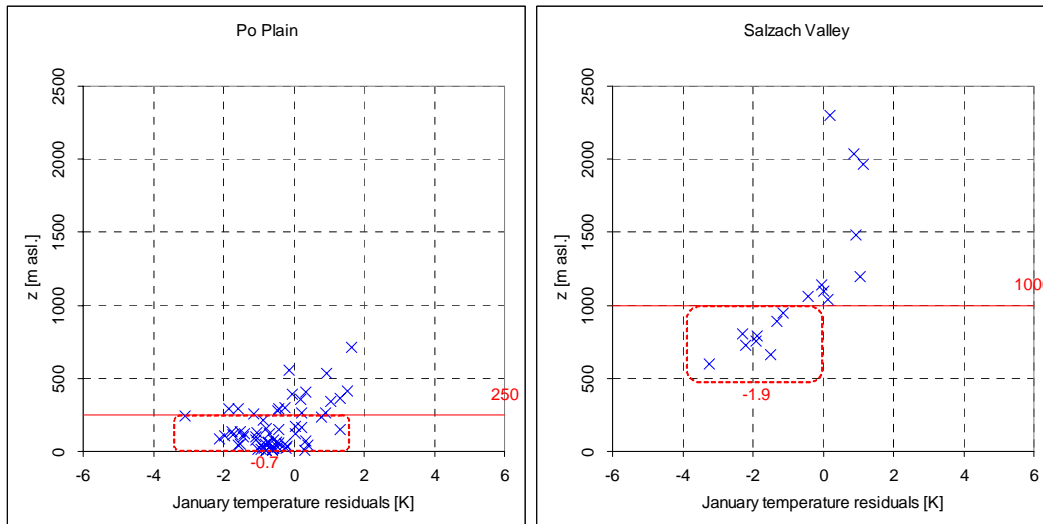


Figure 8: Examples for inversions: Height dependence of January temperature residuals for Po Plain and the Salzach Valley. The adjustment factors have been calculated with -0.7°C for Po Plain (left) and -1.9°C for Salzach Valley (right). The elevation range for correction has been determined with $< 250\text{ m}$ in the Po Plain and $500\text{--}1000\text{ m}$ in the Salzach Valley. Note the positive residuals in both cases at higher altitudes – they were subject of slope-corrections later (section 4.5)

Table 3: Altitude range for adjustment in 13 inversion regions in the GAR with corresponding temperature adjustment altitude ranges.

area	adjustment range [m asl.]
Swiss high valleys	1500–2100
Inn Valley	<1500
Giudicarie	<800
Trentino	<600
Puster Valley	1000–1600
Cadore	<1100
Salzach Valley	<1000
Klagenfurt Basin	<700
Val Canale	300–1000
Mura Valley	<1300
Enns Valley	<900
Graz Basin	<400
Po Plain	<250

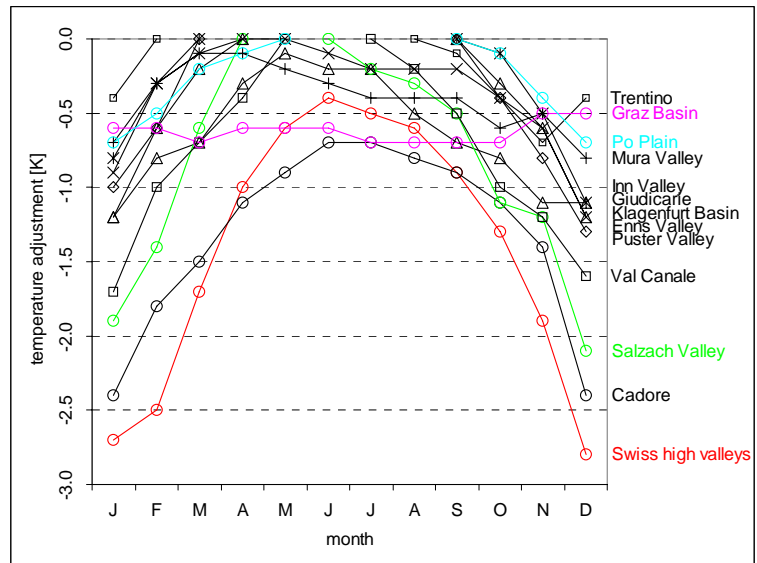


Figure 9: Annual course of temperature adjustments in 13 inversion regions.

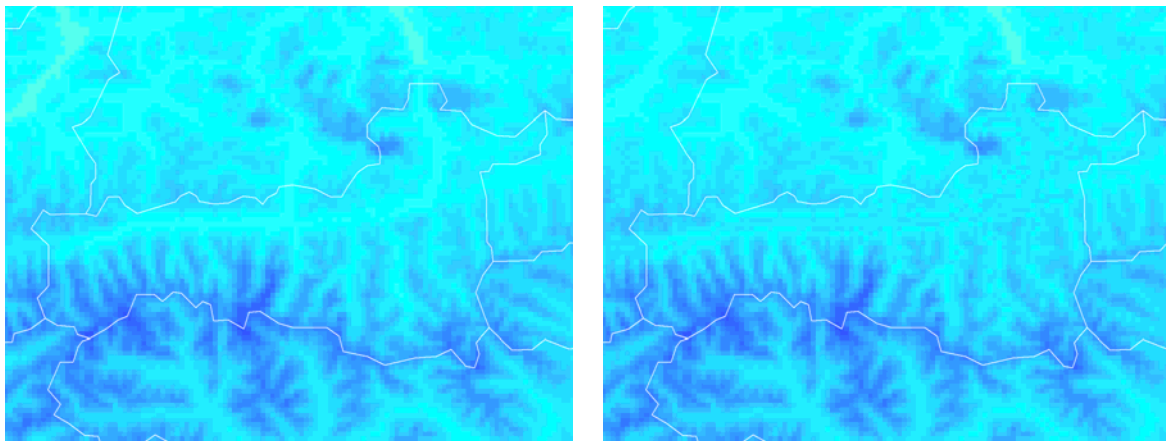


Figure 10: January temperature maps for the Salzach Valley: raw map (left) and improved map by inversion temperature adjustment of -1.9K for areas below 1000 m asl (right).

4.2. Improvement by working on coast lines

Three areas have been defined (Figure 11) in order to improve the temperature fields near the coastline of Golfe du Lion, Ligurian and Adriatic Sea. Within the 6 km wide coast-belt, the temperature has been adjusted linearly from maximum adjustment value at the coast to 0 value at 6 km from the coast. At Golfe du Lion, maximum adjustments were up to $+3^\circ\text{C}$ in January and December. In summer, smaller negative adjustments had to be added. The annual course of maximum adjustments at 0 km distance to coast is displayed in Figure 12.

Note that the coastline correction is not the only consideration of oceanic influence in the analysis. The "altitude weighted coast distance" is one of the predictors in initial multiple regression models of the coarse resolution principal subregions (Figs. 4 and 5).

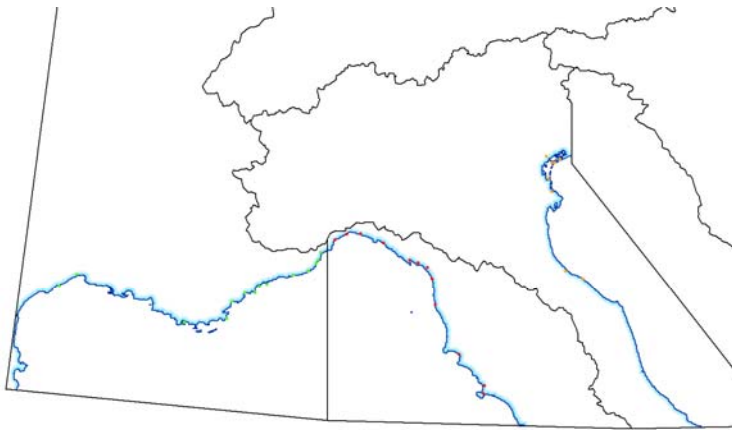


Figure 11: Regionalisation of coast lines for the sub-regions W, P and S.

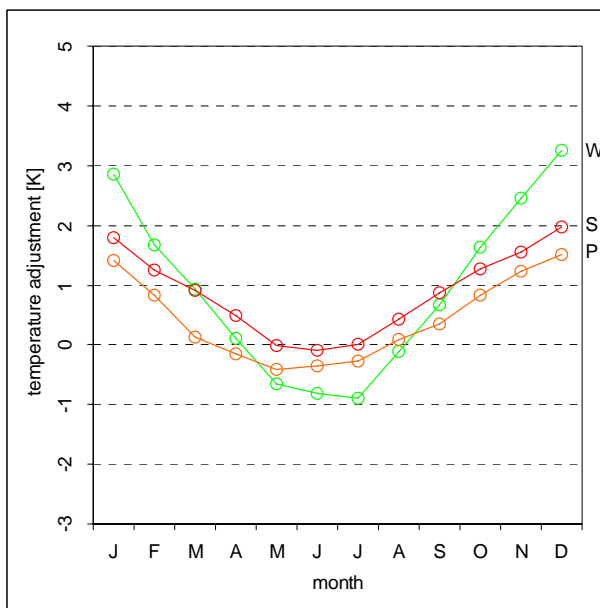


Figure 12: Annual course of temperature adjustments at 0 km distance from the coast (W- Golfe du Lion, S- Ligurian coast, P- western Adriatic coast).

Working on coastal areas led to a further improvement of the ECSN/HRT-GAR climatology, as can be seen in Figure 13.

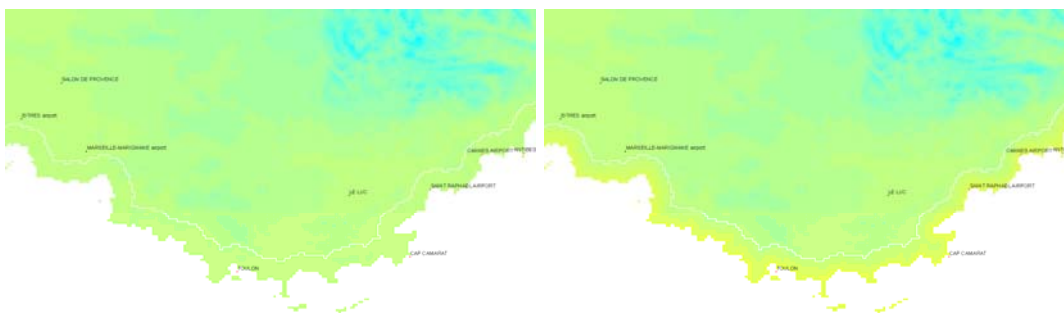


Figure 13: Improvement of the ECSN/HRT-GAR climatology by working on coastlines: raw January map of Golfe du Lion (left) and improved January map with a maximum adjustment of +2.9K (right).

4.3. Improvement by working on lake shores

The surroundings of ten lakes or groups of lakes covering more than 10 km², - except shallow lakes like Lake Balaton or Lake Neusiedl have been used to apply further improvements on the maps (Figure 14)

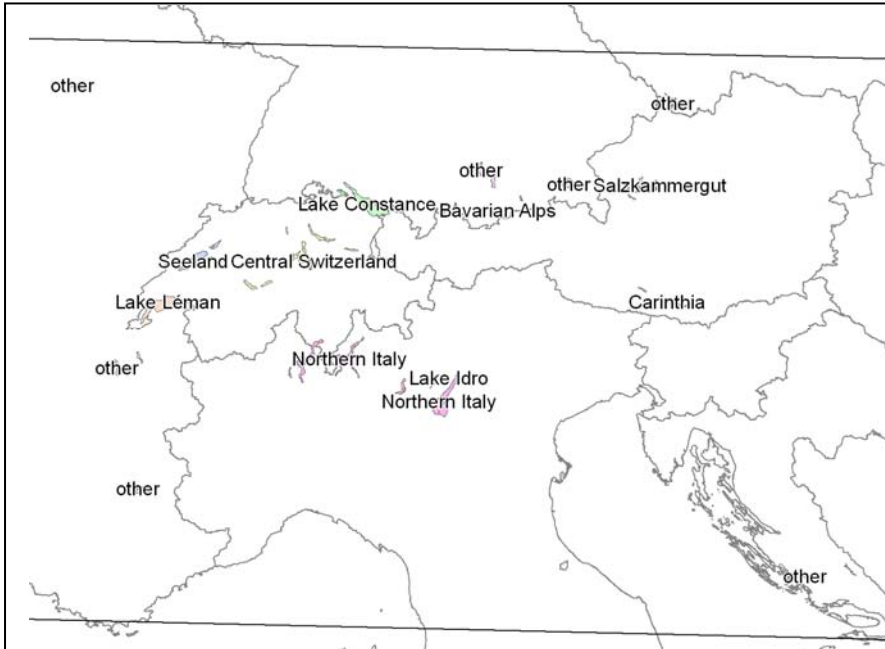


Figure 14: Map of GAR displaying 10 lakes regions for ECSN/HRT-GAR climatology improvement.

Temperatures of waterside stations at lakes have been compared to altitude adjusted lake surrounding stations. Calculated differences were used as adjustment factors (Fig. 15). The correction has been applied in two belts, each 1 km width. From 0-1 km from the lake shore, the average adjustment factors have been applied, while in the second belt, from 1-2 km from the shore, only 1/2 of the adjustment factors have been used to smooth the correction. The annual course of temperature adjustments is given in Figure 15 and details in Annex 2.

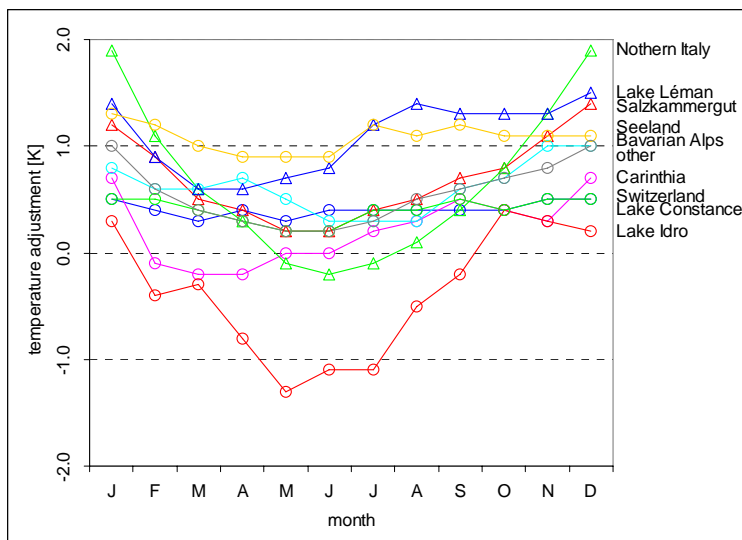


Figure 15: Annual course of lake shore adjustments for the improvement of the ECSN/HRT-GAR climatology.

Working on lake surroundings led to a further improvement of the ECSN/HRT-GAR climatology, as can be seen in Figure 16.

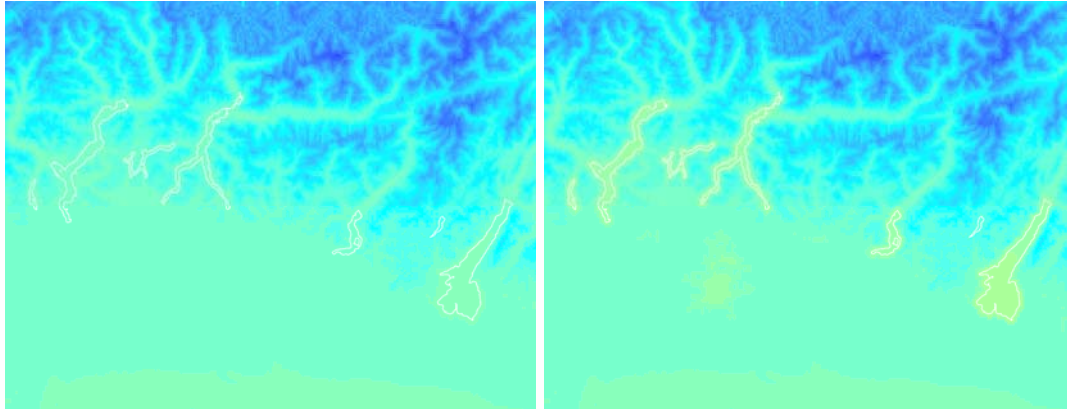


Figure 16: Improvement of the ECSN/HRT-GAR climatology by working on lake areas: raw January map of Northern Italy (left) and improved map by adjusting for +1.9 K within 0-1 km belt and for 0.9 K within 1-2 km from lakefront (right)

4.4. Further improvement by working on cities

Cities have been identified using the 1-km pan-European land cover database PELCOM (Pan-European Land Use and Land Cover Monitoring, <http://www.geo-informatie.nl/projects/pelcom/public/index.htm>). Cities have been grouped into mega-cities (>200 km²) and large cities (20-200 km²) separately for the North/East and cities in the South. Temperature of city-centre stations has been compared to altitude adjusted surrounding rural stations. For city centres the total difference, and for suburbs within a 0–1 or 0–2 km buffer half the difference has been used for correction. The ECSN HRT-GAR network offered twelve usable urban–rural station ensembles. Details are in Annex 2.

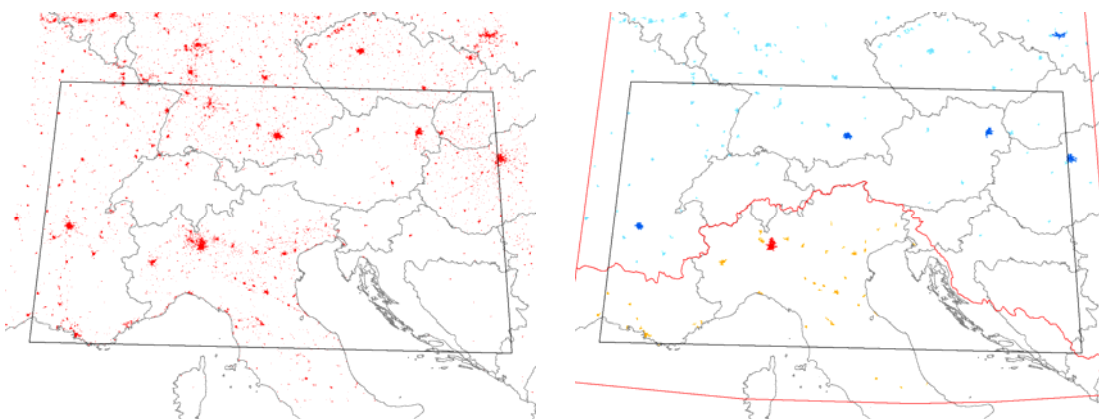


Figure 17: Land-use data of PELCOM. Left: Identifying cities, right: division of cities into mega-cities (>200 km²) -northern in dark-blue, southern in red- and large cities (20–200 km²) - northern in light-blue, southern in orange.

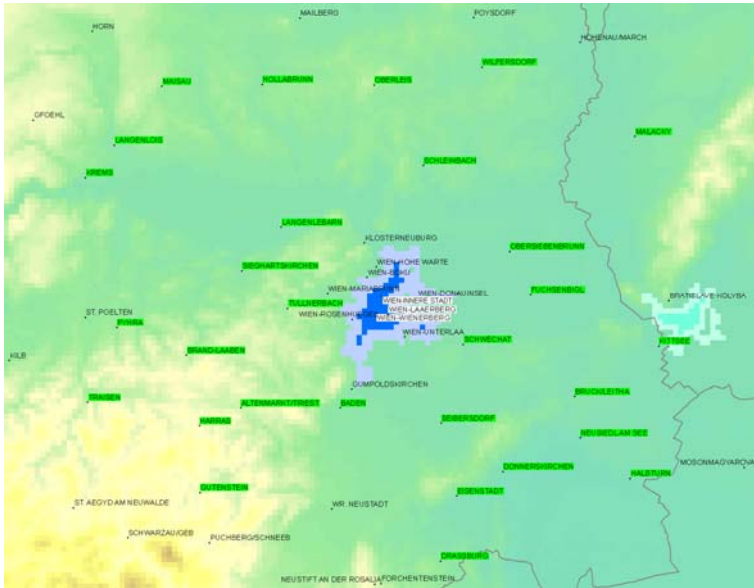


Figure 18: The city of Vienna and surroundings stations.

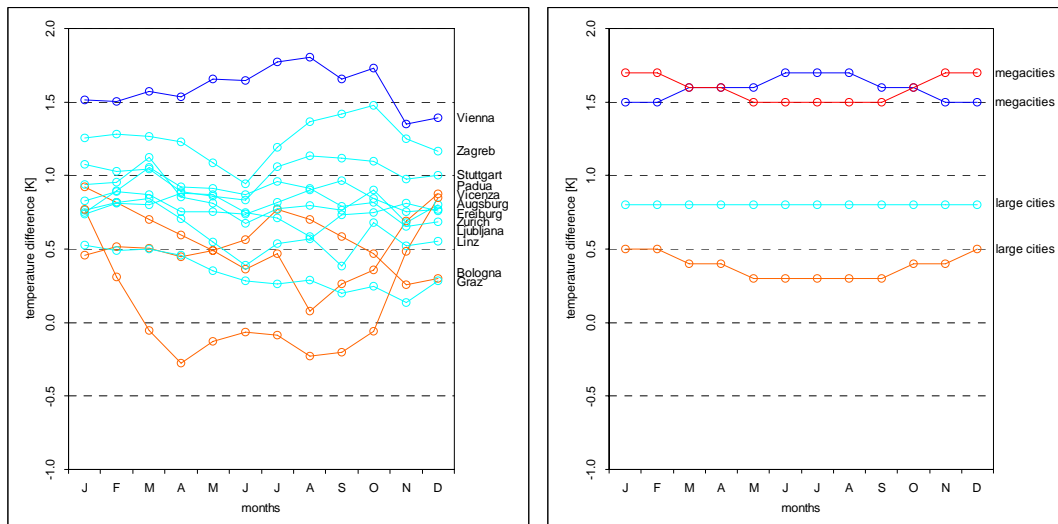


Figure 19: Annual course of urban heat island temperature difference: left: single stations, right: averaged and filtered course of urban heat island temperature difference for four groups of cities.

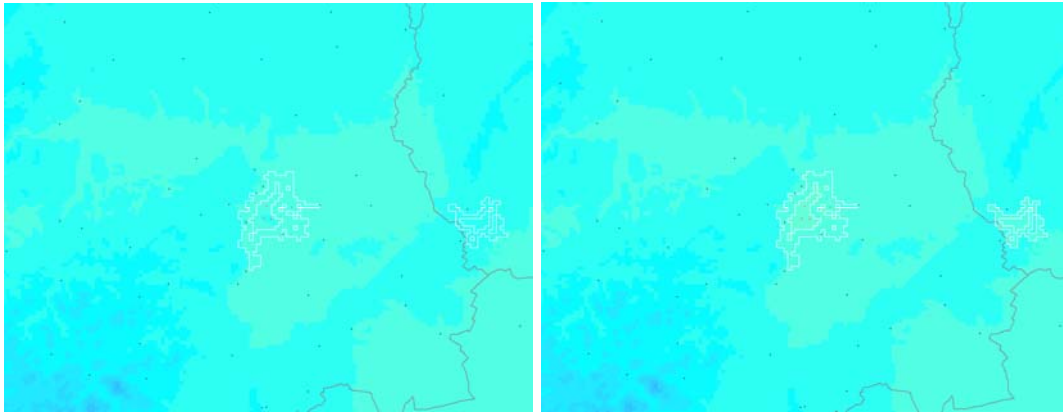


Figure 20: Improvement of the ECSN/HRT-GAR climatology by working on cities: left: example of raw January map showing Vienna and surroundings, right: example of improved January map of Northern Vienna and surroundings by adjusting +1.5 K for the city centre and 0.8 K for suburbs.

4.5. Further improvement by working on slopes

Using the DEM all slopes $> 10^\circ$ were identified and classified depending on their N, NW/NE, W/E, SW/SE, S aspects.

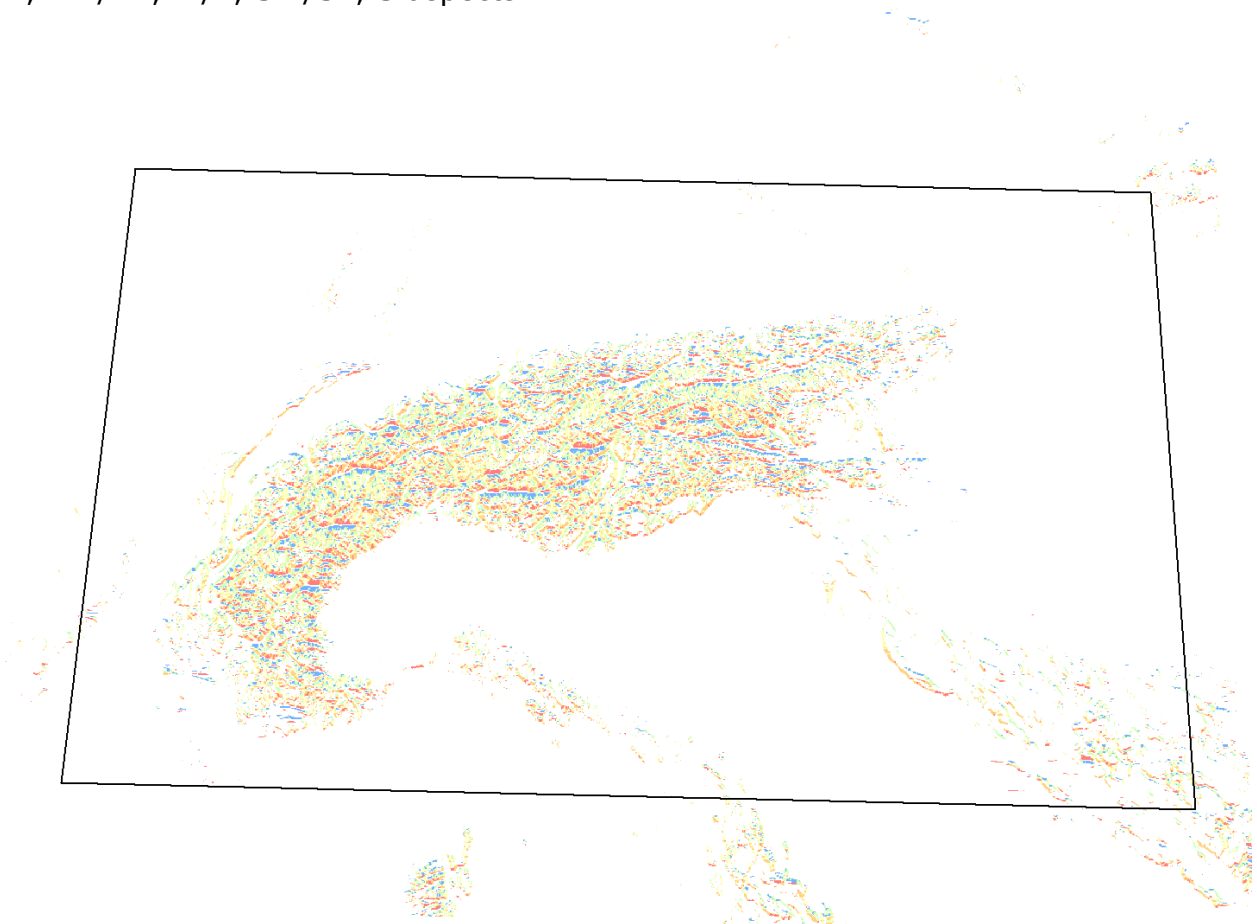


Figure 21: GAR topography classified for slopes 10° and aspects of N, NW/NE, W/E, SW/SE, S.

For a subset of 100 sites with a sufficient site description a number of different shape-effects showed systematic mean temperature deviations from topographically neutral locations. The strongest (valleys and basins) were considered already under section 4.1, ranking second were slopes for which Figure 22 shows the mean monthly corrections which were applied. Details are in Annex 2.

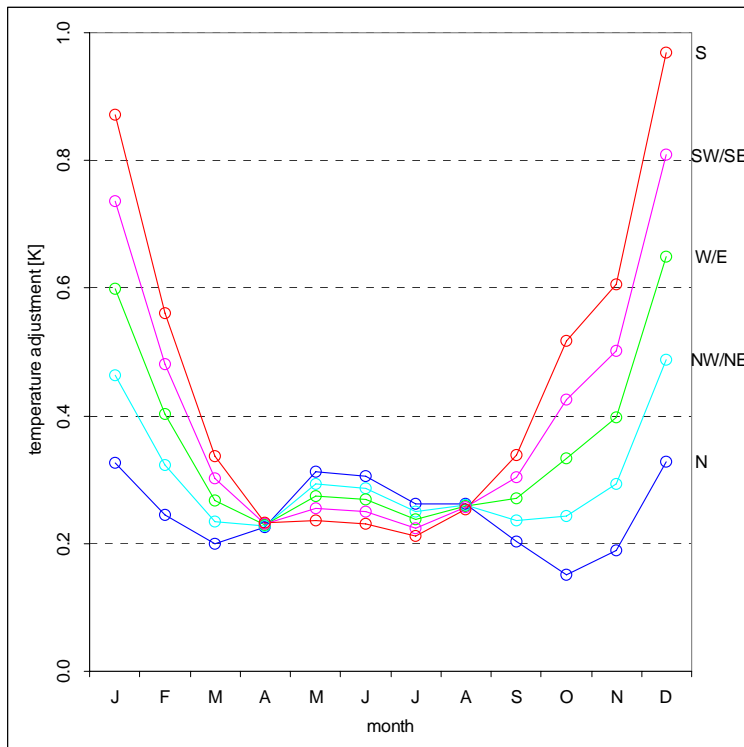


Figure 22: Annual course of adjustments to correct temperature on slopes due to the aspects based on a station sample of 85 Austrian sites with extensive topographic descriptions. For Ticino January map e.g. corrections between 0.3 and 0.9K had been applied

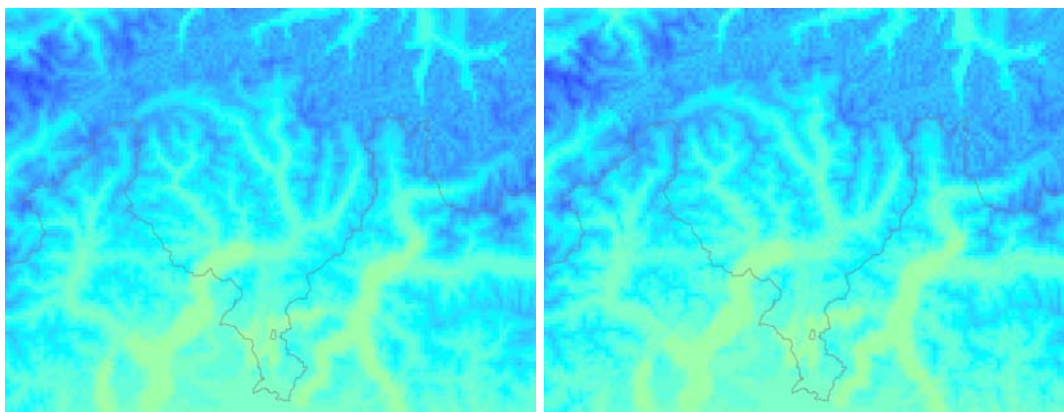


Figure 23: January temperature field, left: raw map, right improved map with slope temperature adjustment of +0.3 for N, +0.5 for NW/NE, +0.6 for W/E, +0.7 for SW/SE and + 0.9K for S orientated slopes.

5. The Final monthly climatologies

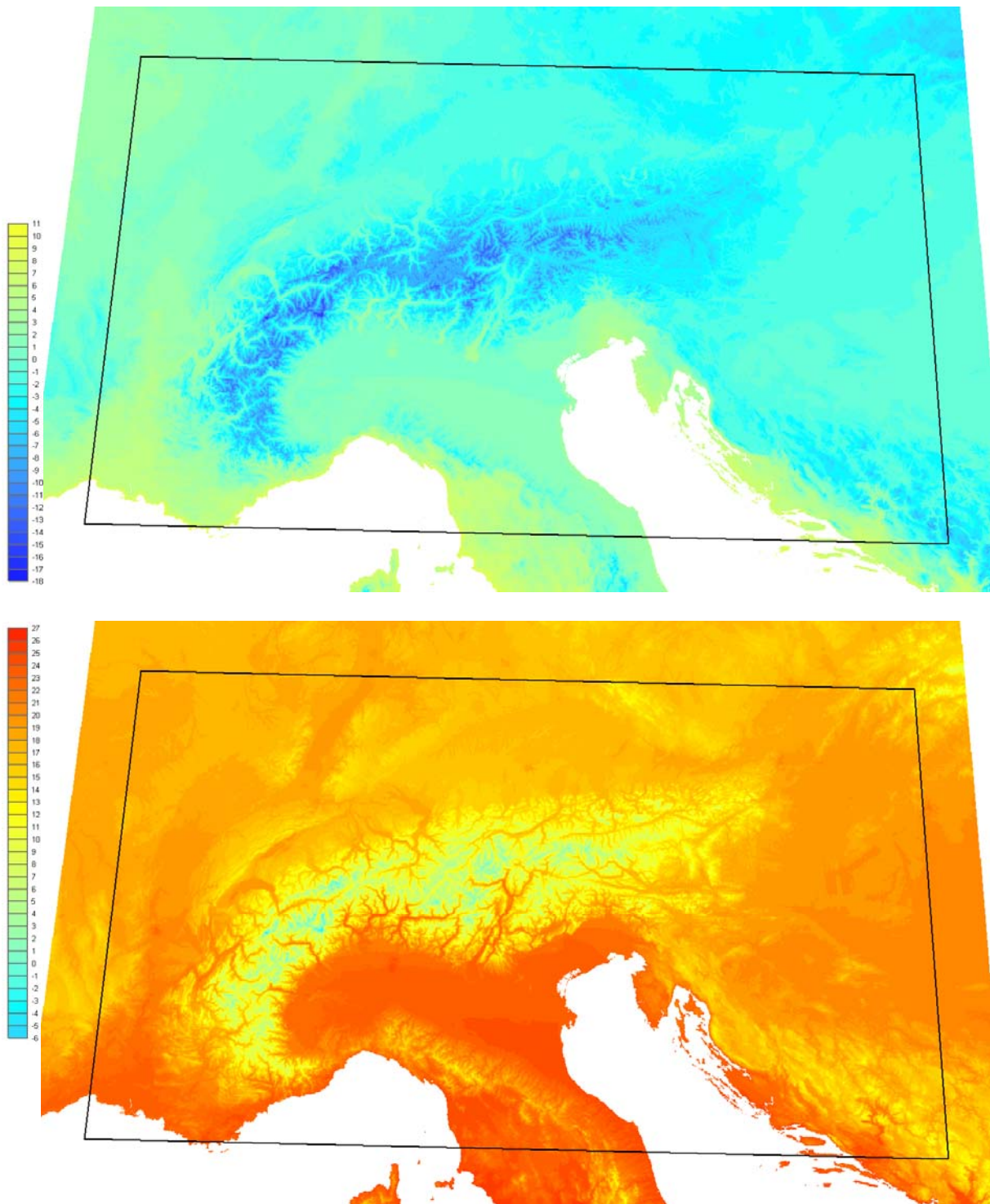


Figure 24: Finalised temperature climatologies for January (top) and July (bottom).

After the application of all the described improvements, final monthly climatologies have been calculated. It was a long way to reach the desirable goal of a standard error (SE) below 1K (varying between SE04=0.648, SE12=0.887). We would like to stress that this remaining SE is only partly an error and our ultimate goal was not to reach SE=0K. We have to consider that stations always contain also local peculiarities and do not represent data of a 100% neutral surrounding. Figure 25 displays the way of map improvements from overall simple regression, to overall multiple regression, to regionalisation until final improvements by adjustments for inversions, sea shores, lake shores, cities and slopes.

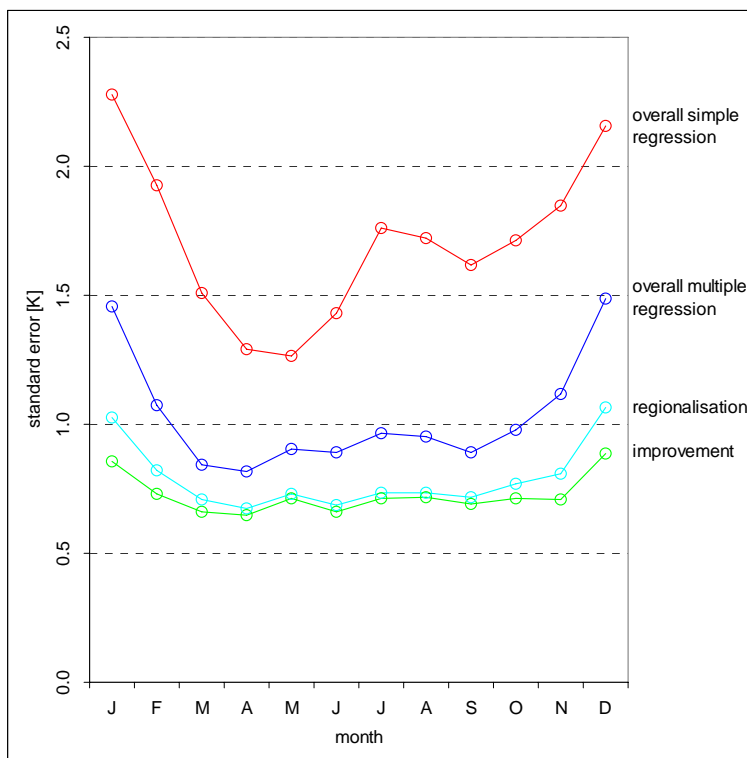


Figure 25: Remaining standard error of monthly ECSN/HRT-GAR temperature climatologies by applying step by step improvements.

6. Outlook

The created ECSN/HRT-GAR temperature climatology is a high quality data product for a European region with a complex and complicated terrain. Its results are based on the special experience and knowledge of experts of the involved countries, however methods and findings may well be generalised and transferred to other regions. The dataset is now available and ready to support further climate and climate impact research. Here we can present only some of our plans and ideas.

- Making the dataset available (website of ZAMG).
- Producing additional versions at other resolutions: for local practical applications a higher resolution (e.g.: by adding to each 1km² pixel a local vertical lapse rate) would be desirable, or a lower resolution comparative to other existing datasets (e.g. the 1/6° lat-long like the respective precipitation dataset of Efthymiadis et al., 2006 or the 1/2° lat-long for the continental scale CRU dataset).
- Blending ECSN/HRT-GAR with the long-term HISTALP series to a series of high resolution monthly temperature fields back to 1760 like it was done for precipitation by Efthymiadis et al., 2006: Producing medium resolution three-dimensional monthly anomaly-fields based on the long-term HISTALP series back to 1760 - fit the resolution of the anomaly fields to the achieved 1km resolution - add the anomaly fields to the 1961-90 mean HR-fields - test the results vs. real station data in a data rich period apart from 1961-90
- Using a close fit (tanh) of the liquid-solid precipitation ratio in order to split an already existing long-term precipitation dataset (Efthymiadis et al, 2006) into the solid and liquid components: The basic idea is based on the fact that the solid/liquid precipitation ratio is closely correlated to mean monthly temperature. This allows for splitting the existing Efthymiadis-precipitation dataset (monthly fields since 1800 at 1/6° resolution) into a solid and a liquid part. This method was already successfully applied to some locations in Austria and Switzerland.

7. Project Workshops

- 02-03 February 2006: kick-off meeting in Vienna
- 07 September 2006: ECSN/HRT-GAR Core Group Meeting in Ljubljana during EMS/ECSN 2006
- 20 February 2007: Workshop on study of geographical specifics of air temperature in the GAR
- 2008 04 20: Public Project Presentation and internal Workshop on "post"-project activities

8. Project presentations

- M. Percec Tadic, I. Auer , R. Böhm , J. Hiebl , W. Schöner , Z. Bihari, P. Bissolli , M. Brunetti , M. Dolinar , J. Spinoni. 2008. High resolution digital climatological maps for Croatia with comparison to the selected European and global climatological data sets submitted to ECAC 2008.
- 16-17 March 2006: Österreichischer Klimatag, poster
- Auer I, Böhm R, Schöner W. 2006. EUMETNET Project ECSN/HRT-GAR: High Resolution Temperature Climatology in Complex terrain – demonstrated in the test area Greater Alpine Region (GAR). Poster Presentation for EMS/ ECAC 2006 in Ljubljana.
- Final COST-719 Workshop: First steps towards a new Temperature Climatology of the Greater Alpine Region (GAR), oral presentation
- November 2006: oral presentation of ECSN/HRT-GAR activities on the occasion of the 1st MedClivar Workshop in Carmona-Seville, Spain
- Auer I, Böhm R, Potzmann R, Schöner W, Müller Westermeier G, Kveton V, Cegnar T, Dolinar M, Gajic Capka M, Zaninovic K, Maugeri M, Brunetti M, Nanni T, Carrer M, Mercalli L, Majstorovic Z, Begert M, Moisselin JM, Ceron JP, Bochnicek O, Bitari Z, Nola P. 2005 A High Resolution Temperature Climatology for the Greater Alpine Region (GAR) Poster presentation at ICAM/MAP 2005,

9. Papers

- Auer I, Böhm R, Schöner W. 2006 Report on Past and Ongoing Data Recovery and Rescue Activities in the Adriatic and Ligurian Realm. Proc. of the 1st MedCLIVAR Workshop: Reconstruction of past Mediterranean Climate: Unexplored sources of high resolution data in historic time. http://www.medclivar.eu/1wrkshp_extabstracts.pdf
- Schöner W, Auer I, Böhm R. 2006. First steps towards a new temperature climatology of the Greater Alpine Region (GAR). In: Dobesch H., Dumolard P., Dyras I. (Eds). Spatial Interpolation for Climate Data. The Use of GIS in Climatology and Meteorology, ISTE, ISBN: 9781905209705, 189-197
- Auer I, Böhm R, Potzmann R, Schöner W, Müller-Westermeier G, Kveton V, Cegnar T, Dolinar M, Gajić-Čapka M, Zaninović K, Maugeri M, M. Brunetti M, T. Nanni T, M. Carrer M, L. Mercalli L, Majstorovic Z, . Begert M, Moisselin JM, Ceron JP, Bochnicek O, Bihari Z, P. Nola P. 2006 A High Resolution Temperature Climatology in Complex Terrain– demonstrated in the test area Greater Alpine Region (GAR) Tagungsband des 9. Österreichischen Klimatags "Klima, Klimawandel und Auswirkungen", 16.-17. März 2006, AustroClim, P29.
- Auer I, Böhm R, Potzmann R, Schöner W, Müller Westermeier G, Kveton V, Cegnar T, Dolinar M, Gajic Capka M, Zaninovic K, Maugeri M, Brunetti M, Nanni T, Carrer M, Mercalli L, Majstorovic Z, Begert M, Moisselin JM, Ceron JP, Bochnicek O, Bitari Z, Nola P. 2005 A High Resolution Temperature Climatology for the Greater Alpine Region (GAR) ICAM/MAP 2005, Croatian Meteorological Journal, 593-596.

Based on the ECSN/HRT-GAR grids on request two tailored maps have been produced to be included in the 2nd Report of the state of the Alps (Alpenzustandsbericht). focus: water for the Alpine Convention (Alpenkonvention)

10. References

- Auer I, Böhm R, Jurkovic A, Lipa W, Orlik A, Potzmann R, Schöner W, Ungersböck M, Matulla C, Briffa K, Jones PD, Efthymiadis D, Brunetti M, Nanni T, Maugeri M, Mercalli L, Mestre O, Moisselin JM, Begert M, Müller-Westermeier G, Kveton V, Bochnicek O, Stastny P, Lapin M, Szalai S, Szentimrey T, Cegnar T, Dolinar M, Gajic-Capka M, Zaninovic K, Majstorovic Z, Nieplova E. 2007 HISTALP – Historical Instrumental Climatological Surface Time Series of the Greater Alpine Region. *Int. J. Climatol.* **27**: 17-46 (2007). Published online in Wiley InterScience (www.interscience.wiley.com) DOI: 10.1002/joc.1377,
- Auer I, Böhm R, Mohnl H, Potzmann R, Schöner W, Skomorowski P. 2001: *Öklim – Digitaler Klimaatlas Österreichs*, CD Zentralanstalt für Meteorologie und Geodynamik.
- Auer I, Böhm R, Leymüller M, Schöner W. 2002: *Das Klima des Sonnblicks. Klimaatlas und Klimatographie der GAW Station Sonnblick einschließlich der umgebenden Gebirgsregion. Österreichische Beiträge zu Meteorologie und Geophysik. Heft 28.* Bayrischer Klimaforschungsverbund (BayFORKLIM). 1996. *Klimaatlas von Bayern.*
- Böhm R, Potzmann R. 1999. Systematic Climate Mapping in Complicated Terrain – Part one: from Point Measurement to Maps of Means (a GIS-Supported Procedure including quantitative Error Analysis). *ÖGM bulletin* **99/1**, 21-30.
- Bundesamt für Meteorologie und Klimatologie Meteo Schweiz. 1982. *Klima-Atlas der Schweiz*
- Frei F, Schär C. 1998. A precipitation climatology of the Alps from high-resolution rain-gauge observations. *Int. J. Climatol.* **18**: 873 – 900.
- Gajić-Čapka M, Tadić Perčec M, Patarčić M. 2003: *Digitalna godišnja oborinska karta Hrvatske.* Hrvatski meteorološki časopis **38**, 21-33.
- Hidrometeoroloski zavod Republike Slovenije. 1995. *Klimatografija Slovenije 1961-1990.*
- Kämtz FL. 1860. Über die Anleitung mittlerer Resultate aus meteorologischen Beobachtungen (On the calculation of mean results from meteorological observations). *Repertorium für Meteorologie (Kämtz FL)*, Vol. **1**, 107-134
- Kveton V. 2001. Climatological Normals of Air Temperature of the Czech Republic in the Period 1961-1990 and Selected Air Temperature Characteristics of the Period 1961-2000. *Narodni Klimaticky Prfogram Ceske Republiky.*
- Mercalli L. (ed.). 2003. *Atlante climatico della Valle d'Aosta.* Societa Meteorologica Subalpina (SMS): Torino; 416
- MétéoFrance. 1999: *Le climat de la France (CD-rom)*
- Meteo France. 2004 : *Climate Atlas of Europe*
- Míková T, Stríž M, Radim, Tolasz R, Valeriánová A, Voženílek V. 2007. *Climate Atlas of Czechia.* Czech Hydrometeorological Institute.
- Perry M, Hollis D. 2005. The Generation of a Monthly Gridded Dataset for a Range of Climatic Variables over the UK. *Int. J. Climatol.* **25**: 1041-1054.
- Perry M, Hollis D. 2005. The Development of a Set of Long-term Climate Averages for the UK. *Int. J. Climatol.* **25**: 1023-1039.
- Schwarb M. 2001: *The Alpine Precipitation Climate. Evaluation of a high Resolution Analysis Scheme Using Comprehensive Rain gauge data.* Diss. ETHZ 13'911. Zürcher Klimaschriften, Heft **80**, Institut für Klimaforschung ETH, Verlag Institut für Klimaforschung ETH Zürich
- SMS 2003: *Atlante climatico della Valle d'Aosta.*
- Tveito OE, Foerland E, 1998: Spatial interpolation of temperatures in Norway applying a geostatistical model and GIS. DNMI, report No **26/98**

Tveito OE, Foerland E, Heino R, Hanssen-Bauer I, Alexandersson H, Dahlström B, Drebs A, Kern-Hansen C, Jonsson T, Vaarby Laursen E, Westman Y. 2000. Nordic temperature maps. DNMI, Report no. 09/00.

Zaninovic, K., Gajic-Capka, M., Percec-Tadic, M. et al. Klimatski atlas Hrvatske: Climate atlas of Croatia; maps M. Percec Tadic, edited by K. Zaninovic, Zagreb: Meteorological and Hydrological Service of Croatia, 2008, 120 p (in print).

Acknowledgements

The project has been supported by EUMETNET/ ECSN (EMN/Decisions/C26-2) by the participating members of Austria, France, Germany, Hungary, Italy, Luxembourg, Norway, Switzerland and United Kingdom. The authors want to thank Steve Noyes and Aryan van Engelen for providing valuable comments on this report.

Further thanks go to the following persons or institutions for supporting the project with their valuable expert knowledge and ideas as well as data provision

Walter Kirchhofer – former ECSN Manager and MeteoSwiss
Vit Kveton – Hydro-meteorological Institute of the Czech Republic
Jean Pierre Ceron and Jean Marc Moisselin – Meteo France
Marco Career – University of Padua
Luca Mercalli – Società Meteorologica Italiana
Paola Nola– University of Pavia
Giancarlo Rossi - Venice
Renzo Motta - University of Torino
Claude Alesch – Service meteorologique de Luxembourg
Ole Einar Tveito – Norwegian Meteorological Institute
Christoph Frei, Michael Begert – Meteo Swiss
Matthew Perry - UK Met Office
Oliver Bochnicek – Slovak Hydro-meteorological Institute
Zelko Mastorovic, MeteoBiH
Gerhard Müller-Westermeier und Peter Bissoli - Deutscher Wetterdienst
Ksenija Zaninovic, Croatian Weather Service
Tanja Cegnar, Mojca Dolinar - ARSO
Zita Bihari - OMSZ, Budapest:

ANNEX 1

DATA PROCESSING

ANNEX 2

GEOGRAPHICAL SPECIFICS OF AIR TEMPERATURE AND THE GENERAL CONCEPT OF HIGH RESOLUTION SPATIAL ANALYSIS

ANNEX 3

TECHNICAL REPORT OF A NORTHERN ITALIAN RELATED PROJECT

ANNEX 4

12 MEAN MONTHLY TEMPERATURE MAPS OF THE ALPINE CORE PART OF GAR



ECSN/HRT-GAR FINAL PROJECT REPORT