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3-hourly quantitative precipitation estimation over Central and Northern Europe from rain gauge and radar data

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Continental-scale 3-hourly precipitation fields have been analysed from operational CERAD (Central European Radar) and BALTRAD (Baltic Radar) networks and adjusted with daily precipitation measurements from about 10,000 synoptic and climate stations. Here we focus on the application of CERAD and BALTRAD for quantitative precipitation estimation (QPE) that is the choice of quality control methods, the impact of input radar data quality on the analysis results and the analysis algorithm. The quality of the radar derived precipitation fields has been estimated by comparison with ground truth fields at the spatio-temporal scale of the ELDAS (European Land Data Assimilation System) project grid (0.2°/daily). Additionally, statistics on the availability of CERAD and BALTRAD data for the entire ELDAS period from Oct. 1999 to Dec. 2000 have been compiled. The final ELDAS precipitation product covers the whole of Europe and is available in GRIB format from the ECMWF MARS archive.

1. Introduction

A European meso-scale precipitation product with a spatio-temporal resolution of 0.2°/3 h is introduced. It firstly combined the Central European radar network, CERAD (Köck, 1999), and the Baltic radar network, BALTRAD (Michelson et al., 2000; Raschke et al., 2001), respectively (Rubel et al., 2004). It should be noted that recently both radar networks have been included into the Europe-wide operational programme for the exchange of weather radar information, OPERA (Holleman et al., 2008), which should simplify future radar data handling. The radar observations were calibrated using daily surface observations from dense national rain gauge networks collected by Rubel (2004).

The development of this new precipitation product was carried out within the European Union's 5th framework project ELDAS, the development of a European land data assimilation system to predict floods and droughts (van den Hurk, 2002), and has its origins in the 4th framework projects NEWBALTIC I and II, the numerical studies of the energy and water cycle of the Baltic region (Bengtsson, 2001). The goal was to provide the numerical weather prediction (NWP) community a reference data set for the period from Oct. 1999 to Dec. 2000. Together with observed radiation data, this data set was used to calculate land surface soil moisture fields to be assimilated by NWP models.

To analyse continental-scale precipitation fields basically data from three observational techniques may be used. These are measurements from dense precipitation gauge networks, ground based radar networks and space-borne satellite instruments. All these measurement techniques have assets and drawbacks as discussed briefly in the following.

Generally, precipitation analyses from rain gauge networks are considered to be the most accurate precipitation estimates. Nevertheless, even these analyses from direct ground measurements contain various sources of errors (Rubel and Hantel, 2001). These comprise systematic undercatch of precipitation gauges due to wind-induced losses as well as losses from wetting and evaporation, which may be corrected operationally as demonstrated by Rubel and Hantel (1999) and Ungersböck et al. (2001). Further, the reliability of areal precipitation estimates is limited by the density of the gauge networks. While the density of daily precipitation measurements for the area of the European Union is high enough to analyse precipitation on the 0.2°, ELDAS grid

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Fig. 1. Locations of CERAD (dots) and BALTRAD (stars) weather radar sites available for the period from Oct. 1999 to Dec. 2000. Some sites (underlined) contribute to both networks.

(equidistant in geographical latitude and longitude), this is unfortunately not the case for 3-hourly measurements.

Quantitative precipitation estimates (QPEs) from weather radar networks are a second possibility to generate high-resolution precipitation fields. The advantage of operational radar networks is their availability for real-time applications, while most of the dense precipitation gauge networks (except the spares synoptic networks) are operated off-line or on-line with restricted access to national authorities. Due to the temporal resolution of weather radars, which is much higher than those needed to force NWP models, several radar pictures per hour must be accumulated to 3-hourly QPEs. However, radar specific uncertainties become visible particularly in these accumulated radar fields. Therefore it is of essential importance to eliminate or at least reduce these artefacts in radar data prior accumulation. Additionally, to derive realistic QPEs, data from operational weather radar networks must be adjusted with ground measurements from gauges.

The third possibility to derive precipitation fields is the application of remote sensing from space. At the beginning of the ELDAS project high resolution operational precipitation estimates from satellites were not available, especially not for the ELDAS model domain and the period from Oct. 1999 to Dec. 2000. In the meantime Kottek and Rubel (2007), for example, proposed global daily precipitation estimate based on co-kriging of operational GPCP-1DD satellite estimates (Huffman et al., 2001) and gauge measurements.

According to the different observation techniques discussed above, it was decided to generate ELDAS QPEs from 3-hourly accumulated data of the two continental-scale weather radar networks CERAD and BALTRAD (Fig. 1) adjusted on a daily basis using about 10,000 precipitation gauges from high resolution national networks. A similar approach was recently proposed by Paulat et al. (2008), who presented a national hourly precipitation climatology for Germany. Their data set covers the period from 2001 to 2004 and was analysed on a high resolution grid. Its horizontal resolution is 7 km, corresponding to the resolution of current NWP models. Hourly QPEs were generated by disaggregating the daily gauge measurements with the information from national radar composites.

2. Observational data

2.1. CERAD — the Central European radar network

The Central European radar network, CERAD, consists of single radar stations or national radar networks from the 11 European countries Austria, Belgium, Croatia, Czech Republic, Germany, Hungary, the Netherlands, Poland, Slovakia, Slovenia, and Switzerland. Detailed specifications of radars used in CERAD (Köck et al., 2000; OPERA, 2008) are summarised in Table 1. A total number of 41 radar stations, 30 of them C-band Doppler radars, contribute to the CERAD composite. Due to the different ranges and precipitation intensity classes applied by these radars, as a compromise, CERAD provides precipitation fields defined by 7 intensity classes (in units of mm/h). The algorithm used to calculate the final CERAD composite from the single radar images is the so-called *Maximum Intensity Display* (Köck, 1999). This means, that for regions of overlapping radar images, the maximal precipitation value is taken for the composite image. The spatio-temporal resolution of CERAD is 4 km/30 min.

Table 1
CERAD specifications after OPERA (2008).

Radar location	Lat. [°N]	Lon. [°E]	Height [m]	Band	Doppler	Since
Austria						
Wien/Schwechat	48.119	16.562	183	C	Yes	1979
Salzburg/Feldkirchen	48.065	13.062	581	C	Yes	1997
Patscherkofel	47.209	11.461	2254	C	Yes	1997
Zirbitzkogel	47.072	14.560	2372	C	Yes	1997
Belgium						
Zaventem	50.900	4.467	73	C	Yes	1988
Wideumont	49.915	5.505	592	C	Yes	2001
Croatia						
Osijek	45.503	18.566	88	S	No	1995
Bilogora	45.883	17.206	231	S	No	1994
Slijeme	45.908	15.973	985	S	No	1980
Czech Republic						
Brdy–Praha	49.658	13.818	916	C	Yes	2000
Skalky	49.501	16.790	767	C	Yes	1996
Germany						
Hamburg Fuhlsbüttel	53.623	9.992	46	C	No	1990
Rostock–Warnemünde	54.172	12.056	36	C	Yes	1995
Emden	53.340	7.024	58	C	Yes	1994
Hannover	52.458	9.692	81	C	Yes	1994
Ummendorf	52.156	11.173	185	C	Yes	1996
Berlin–Tempelhof	52.474	13.386	80	C	Yes	1991
Essen	51.407	6.968	180	C	No	1991
Flechtdorf	51.334	8.852	550	C	Yes	1997
Dresden	51.122	13.768	262	C	Yes	2000
Neuhaus am Rennweg	50.500	11.137	873	C	Yes	1994
Neuheilenbach	50.106	6.500	585	C	Yes	1998
Frankfurt am Main	50.052	8.568	146	C	No	1988
Eisberg	49.541	12.402	799	C	Yes	1997
Türkheim	48.585	9.784	765	C	Yes	1998
München–Fürholzen	48.336	11.614	511	C	No	1987
Feldberg	47.871	8.003	1517	C	Yes	1997
Hungary						
Budapest	47.429	19.182	163	C	Yes	1999
Napkor	47.963	21.889	155	XS	No	1991
Farkasfa	46.194	16.317	327	XS	No	1993
The Netherlands						
Den Helder	52.954	4.791	51	C	Yes	1997
De Bilt	52.100	5.183	44	C	Yes	1997
Poland						
Legionowo	52.4	20.967	125	XS	No	1991
Katowice	50.142	18.726	357	C	Yes	1995
Bolkow	50.883	16.04	692	C	Yes	2000
Slovakia						
Maly Javornik	48.256	17.153	600	C	Yes	1998
Kojsovska hola	48.787	20.995	1262	XS	No	1991
Slovenia						
Lisca	46.068	15.290	941	C	Yes	2002
Switzerland						
Albis	47.285	8.513	928	C	Yes	1994
La Dole	46.426	6.100	1680	C	Yes	1995
Monte Lema	46.042	8.834	1625	C	Yes	1993

The Central European weather radar data used for the ELDAS study have been provided by the University of Technology Graz, Austria, where CERAD composites are generated and archived.

2.2. BALTRAD — the Baltic radar network

The Baltic sea experiment (BALTEX) radar network, BALTRAD, consists of 24 weather radars located in the Nordic countries Denmark, Finland, Norway and Sweden. Additionally

3 radar sites in Poland and 4 radar sites in Germany, both also contributing to CERAD, are merged in BALTRAD. Thus, BALTRAD consists of a total number of 31 radars (Table 2). These data, provided by the national weather services, are collected by the BALTEX Radar Data Centre (BRDC) and are merged to 500 m Pseudo Constant Altitude Plan Position Indicator (CAPPI) products (for a general description on weather radars see e.g. Collier (1996)). Overlapping radars are handled by pre-defined static and dynamic boundaries for each radar site. The overall objective of BALTRAD was to create radar composites containing homogenous radar products of radar reflectivity factors *Z* (in units dBZ) as a basis for higher-level products (Michelson et al., 2000). For the ELDAS study a constant *Z*–*R* relationship proposed by the BRDC was applied to calculate precipitation estimates, *R*, on a continuous scale. This is in opposite to CERAD, which gives by default categorical radar precipitation estimates of 7 classes. The spatio-temporal resolution of BALTRAD is 2 km/ 15 min, twice the resolution of CERAD.

2.3. Precipitation gauge networks

Until now no database containing dense measurements from precipitation gauges of the Europe Union is operationally available. While the Global Precipitation Climatology Centre (GPCC) assembles monthly area-wide values (Fuchs and Schneider, 2008), archives of daily measurements are mainly compiled to investigate long time series (Klein Tank et al., 2002; Auer et al., 2005). Area wide daily precipitation gauge networks are operated only by national meteorological or hydrological services. Sometimes two parallel driven networks exist, a hydrological and a meteorological as found, for instance, in Austria (here data from the denser hydrological network have been incorporated into the ELDAS data archive). Often solely small rain gauge networks at regional level are compiled (e.g. over Italy). Also a low willingness subsists in providing data for scientific projects at reasonable costs as also stated by Hulme (1992). Nevertheless a multitude of national data providers contributed to the ELDAS precipitation archive (period from Oct. 1999 to Dec. 2000) and made it possible to become an extensive database of daily precipitation measurements (Rubel, 2004). Most data have been collected from Austria (about 940 stations), Denmark (210), France (4300), Finland (400), Germany (4070), Great Britain (2830), Ireland (430), Netherlands (740), Poland (1200), Portugal (80), Spain (3560), Sweden (740), Switzerland (450) and Norway (730). It should be noted that in the foreground not the collection of long time series was aimed at, but the maximum in spatial coverage. For the presented study approximately half of the total number of about 21,600 collected stations (Fig. 2) cover the CERAD and BALTRAD regions and are used to adjust the radar estimates.

Table 2
BALTRAD specifications after Michelson et al. (2000).

Radar location	Lat. [°N]	Lon. [°E]	Height [m]	Band	Doppler	Since
Denmark						
Sindal	57.489	10.136	93	C	Yes	1994
Copenhagen	55.6	12.62	5	C	No	1986
Rømø	55.173	8.552	10	C	Yes	1992
Finland						
Korpo	60.128	21.646	61	C	Yes	1997
Vantaa	60.271	24.873	83	C	Yes	1993
Ikaalinen	61.767	23.080	154	C	Yes	1993
Kuopio	62.862	27.385	268	C	Yes	1995
Anyeslankoski	60.904	27.111	139	C	Yes	1993
Utajärvi	64.774	26.323	118	C	Yes	1997
Luosto	67.138	26.901	534	C	Yes	2000
Rovaniemi	66.610	24.840	209	X	No	1998
Germany						
Hamburg	53.623	9.992	46	C	No	1990
Rostock	54.172	12.056	36	C	Yes	1995
Berlin	52.474	13.386	80	C	Yes	1991
Dresden	51.122	13.768	262	C	Yes	2000
Norway						
Oslo	59.858	10.387	458	C	Yes	1992
Hægebostad	58.355	7.158	631	C	Yes	1999
Poland						
Legionowo	52.4	20.967	125	XS	No	1991
Katowice	50.142	18.726	357	C	Yes	1995
Bolkow	50.883	16.04	692	C	Yes	2000
Sweden						
Karlskrona	56.300	15.610	122	C	Yes	1990
Hemse	57.240	18.390	56	C	Yes	1990
Göteborg	57.720	12.170	164	C	Yes	1988
Norrköping	58.617	16.117	57	C	Yes	1983
Arlanda	59.660	17.950	75	C	Yes	1986
Leksand	60.723	14.880	458	C	Yes	1994
Hudiksvall	61.572	16.716	388	C	Yes	1992
Östersund	63.175	14.454	465	C	Yes	1995
Örnsköldsvik	63.640	18.400	522	C	Yes	1991
Luleå	65.550	22.133	35	C	Yes	1993
Kiruna	67.710	20.622	646	C	Yes	1996

3. Data analysis

As mentioned above, precipitation data have been collected and analysed for the ELDAS period from Oct. 1999 to Dec. 2000. The result of the analysis is a 3-hourly data set for Central and Northern Europe compiled on a 0.2°, grid equidistant in geographical latitude and longitude. Single steps of this data analysis comprise: (1) Software development to read and visualise the original CERAD and BALTRAD data files, (2) Reduction of radar specific artefacts, (3) Compilation of 3-hourly and daily accumulated radar precipitation estimates, merging of CERAD and BALTRAD precipitation estimates and interpolation onto the ELDAS grid, (4) Verification of radar precipitation with analysed ground measurements, (5) Adjustment of 3-hourly radar precipitation estimates by daily precipitation gauge estimates and compilation of a final precipitation product by filling the data gaps with ECMWF forecasts.

3.1. Reading and visualising of radar files

Traditionally, CERAD and BALTRAD precipitation data are different in data format, geographical projection, spatial and temporal resolution, scaling of precipitation values as well as data quality with respect to radar specific uncertainties. Therefore, the first step in handling both of the radar data sets was to develop software to read and de-compress the original radar data files. In a second step a visualisation software was developed and movies of animated radar pictures were archived to provide a quick view of the data. As

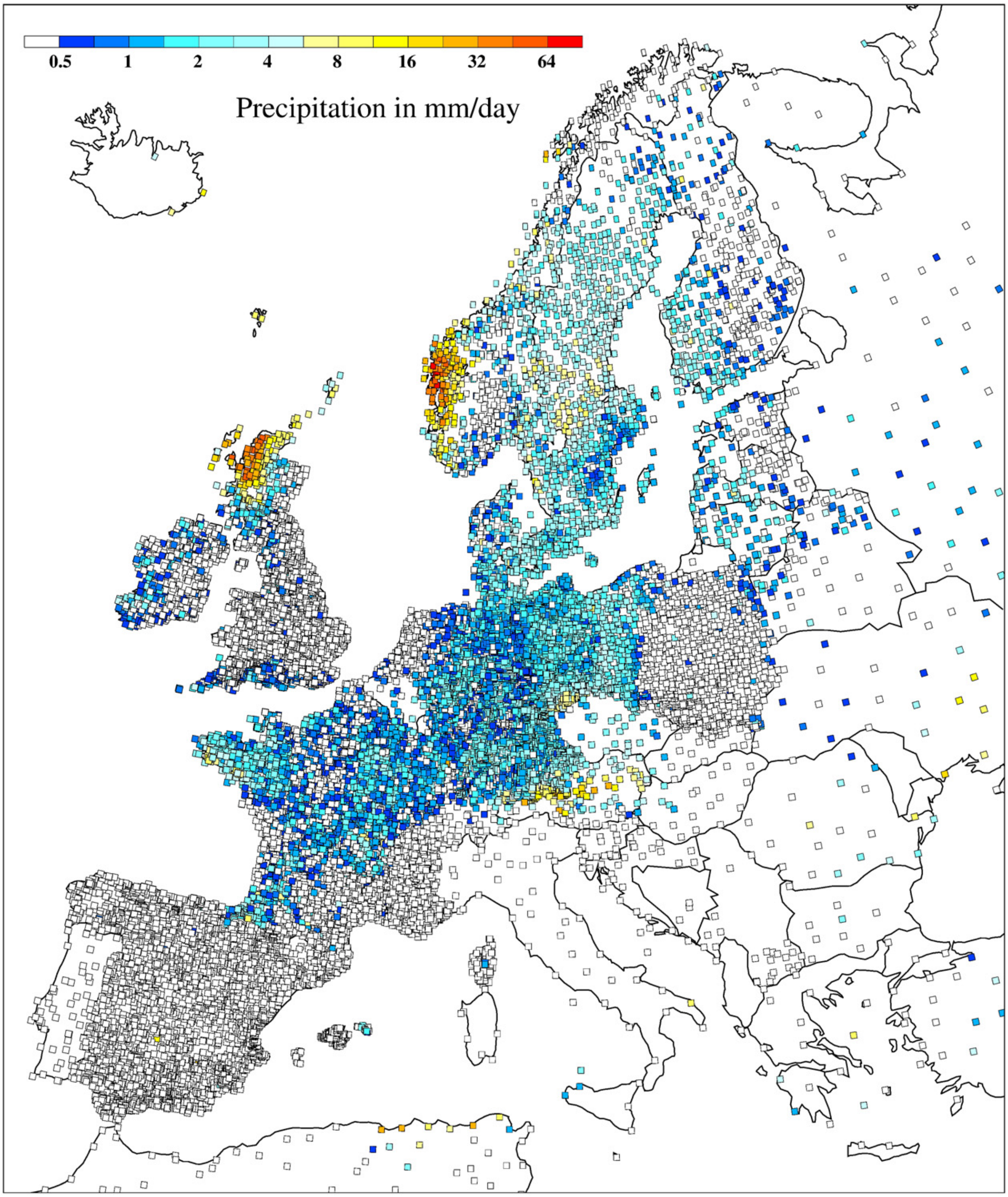

Fig. 2. ELDAS model domain with the locations of the collected precipitation gauges for the period from Oct. 1999 to Dec. 2000. Precipitation values correspond to daily observations of 1 January 2000, 6 UTC. Units mm/day.

an example Fig. 3 (upper panel) depicts CERAD precipitation fields on the original projection with the provided scaling of 7 discrete precipitation intensities. Corresponding BALTRAD fields are depicted in Fig. 4 (upper panel). BALTRAD data were provided with a continuously scaling of *Z*-values, which were converted into precipitation *R* by a constant *Z*–*R*-relationship proposed by the BRDC (Michelson et al., 2000).

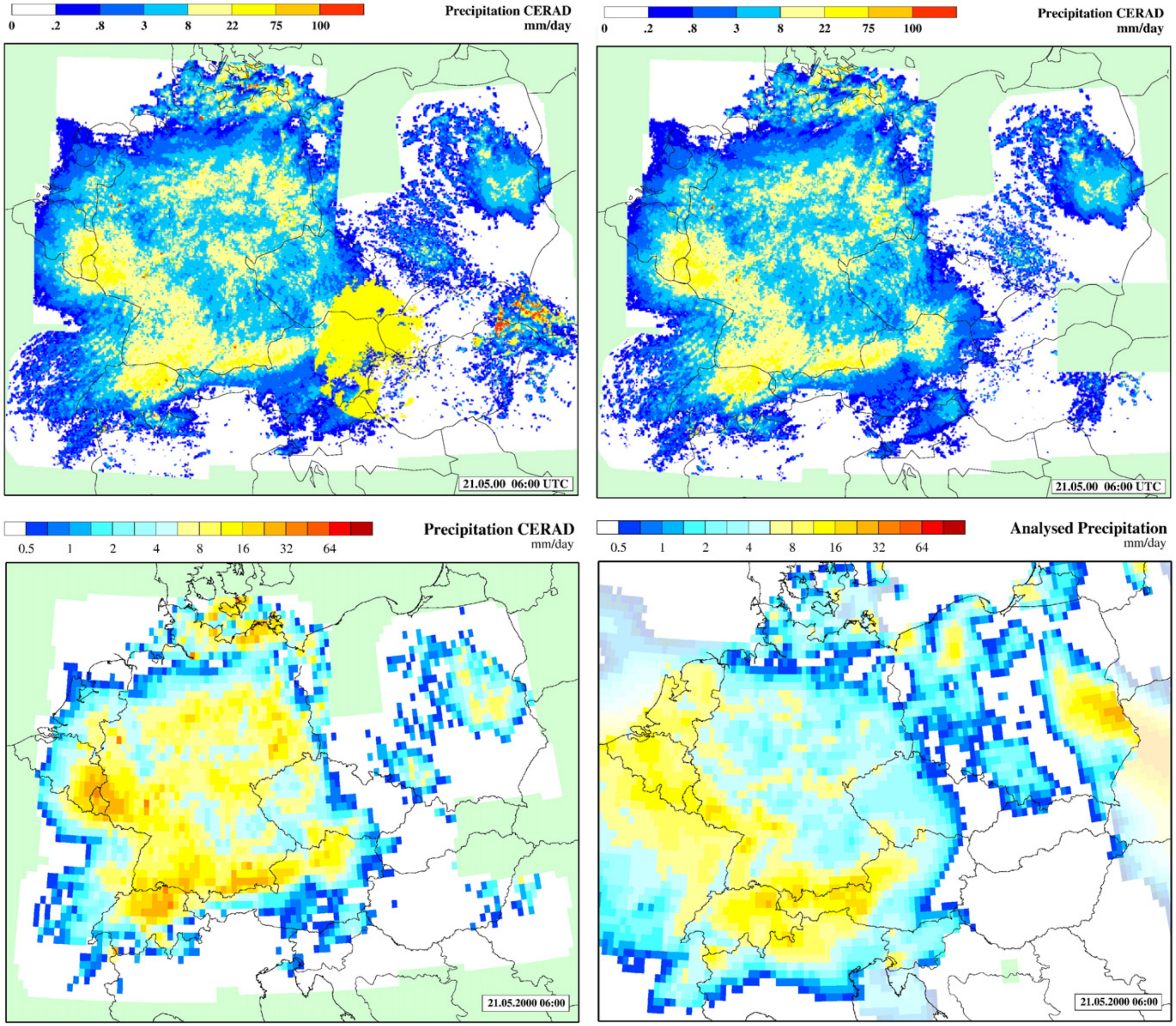

Fig. 3. CERAD processing line: daily precipitation estimated from original radar data (upper left panel), after correction (upper right), interpolated to the 0.2° ELDAS grid (lower left) and for comparison analysed rain gauge data on the ELDAS grid (lower right). Note that the different scaling for precipitation on the radar projection (upper panels) and the ELDAS grid (lower panels). Bright colors in the gauge analysis correspond to blended ECMWF forecasts. Date 21 May 2000, 06 UTC.

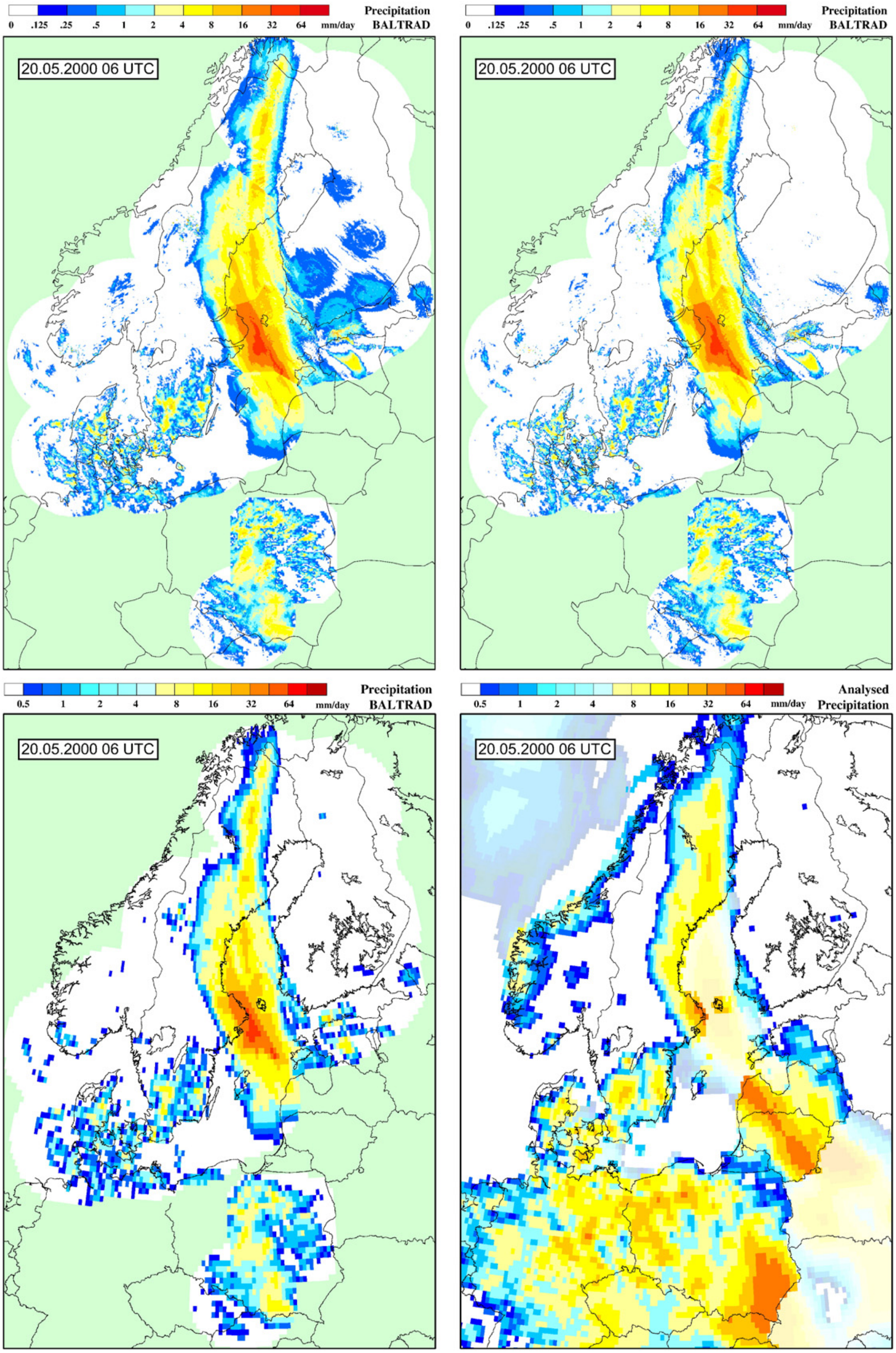

Fig. 4. BALTRAD processing line: Daily precipitation estimated from original radar data (upper left panel), precipitation with applied threshold of 0.2 mm/h (upper right), interpolated to the 0.2° ELDAS grid (lower left) and for comparison analysed rain gauge data on the ELDAS grid (lower right). Date 20 May 2000, 06 UTC.

Table 3
CERAD verification for 21 May 2000, precipitation in mm/day (see Fig. 3).

21.05.2000 06 UTC	Uncorr.	Corr.		Uncorr.	Corr.
Continuous statistics			Categorical statistics		
Analysed	3.79		Hit rate, HR	0.79	0.76
Radar prec.	5.81	3.61	Critical success index, CSI	0.77	0.73
Mean error	2.02	−0.19	Prob. of detection, POD	0.81	0.76
Mean absolute error	5.10	3.05	False alarm ration, FAR	0.07	0.05
RMS error	10.71	4.92	Bias score, BIAS	0.87	0.80
Rank–order correlation	0.48	0.62	True skill statistics, TSS	0.45	0.55

3.2. Reduction of radar specific artefacts

The visual control of the original radar data showed, that especially CERAD precipitation was tainted with high amount of radar specific artefacts (Fig. 3, upper panel, left). These comprise ground and sea clutter, geometrical artefacts produced by solar radiation or temporal malfunction of radar sites. Furthermore, missing distinction between *not measured* and *no precipitation* have been detected in early CERAD files (before 2000), errors based on the composing algorithm, on the *Z*–*R*-relationship and on screening by the topography. Further problem are data gaps due to missing composite images or even missing data for single radar sites.

For the reduction of radar specific artefacts a semi-automatic algorithm was implemented. This algorithm is based on a simple automatic multi-temporal method to detect clutter or other artefacts and a manual step to remove those artefacts which were not automatically detected (Brugger, 2004). For the latter all radar images were verified visually and unrealistic patterns were replaced by missing values.

In opposite to CERAD, major radar specific artefacts were removed from BALTRAD by the data provider. This has to be attributed to the considerable work done in the framework of BALTEX (Koistinen and Michelson, 2002; Bennartz and Michelson, 2003; Michelson, 2004; Michelson et al., 2005). Therefore in the BALTRAD precipitation data set only minor adjustments were applied. Values below a threshold of 0.2 mm/h in the 15 min composite image were removed, because they yield unrealistic precipitation values in the 3- and 24-hourly accumulations. Selected results of the reduction of radar specific artefacts are depicted for CERAD in Fig. 3 (upper panel) and for BALTRAD in Fig. 4 (upper panel).

3.3. Accumulation and interpolation onto the ELDAS grid

After the reduction of radar specific artefacts in the original CERAD and BALTRAD data both datasets were accumulated to 3-hourly and daily precipitation sums. Following the *maximum intensity display* philosophy of CERAD, the maximum radar values are used in regions covered by both datasets. Subsequently, these radar derived precipitation fields were interpolated onto the ELDAS grid (0.2°regular lat/lon grid) by simply averaging all radar pixels within an ELDAS grid area. The interpolation on the coarser ELDAS grid and the temporal accumulation also result in the transfer of the discreet scaled CERAD data to a continuous precipitation scale.

Figs. 3 and 4 depict the processing lines for analysing CERAD and BALTRAD data, respectively. The processing lines begin with the original radar data and end with the final radar analysis on the ELDAS grid. In Figs. 3 and 4 daily accumulations are shown. They may be compared with ground analyses on the same temporal and spatial resolution, which is essential for a fair verification (Göber et al., 2008).

3.4. Verification of radar precipitation estimates

As depicted in the case studies (Figs. 3 and 4) radar derived precipitation fields correspond quite well with those of the daily surface analysis. The quality of radar data processing was quantified by objective measures as for example were applied to verify NWP models (Ebert and McBride, 1997; Rubel et al., 2002). CERAD verification results for uncorrected and corrected daily QPEs of 21 May 2000 are given in Table 3. Corrected scores correspond to radar data with reduced radar specific artefacts and errors. The significance of the correction is evident. While an areal precipitation value of 5.81 mm/day was estimated from uncorrected radar data, 3.61 mm/day were estimated from corrected data. The latter is closer to the gauge analysis of 3.79 mm/day which is considered as ground truth (mean error −0.19 mm/day). Also the rank–order correlation increases after correction from 0.48 to 0.62. Similar results for the BALTRAD verification of 20 May 2000 are depicted in Table 4. While the mean error due to the correction slightly increases, QPEs from corrected radar data results in significantly higher scores of rank–order correlation and true skill statistics.

Other days showed similar verification results, whereas radar performs generally better in observing precipitation rather than snow, which frequently occurs in the BALTRAD region. This becomes visible when verifying longer time periods. Verification of the entire year 2000 (Brugger, 2004) yields a significantly underestimation of BALTRAD precipitation due to frequent snow events (gauges 2.40 mm/day, BALTRAD 0.79 mm/day), whereas the QPEs from corrected CERAD data are of same order as observed (gauges 2.48 mm/day, CERAD 2.19 mm/day). Also the correlation coefficient (CERAD 0.63, BALTRAD 0.57) and the true skill statistics (CERAD 0.50, BALTRAD 0.42) are higher for CERAD. On the other hand, BALTRAD performs better in scores of mean

Table 4
BALTRAD verification for 20 May 2000, precipitation in mm/day (see Fig. 4).

20.05.2000 06 UTC	Uncorr.	Corr.		Uncorr.	Corr.
Continuous statistics			Categorical statistics		
Analysed	1.78		Hit rate, HR	0.76	0.79
Radar prec.	1.16	1.03	Critical success index, CSI	0.61	0.61
Mean error	−0.62	−0.75	Prob. of detection, POD	0.72	0.66
Mean absolute error	1.27	1.26	False alarm ration, FAR	0.20	0.10
RMS error	2.91	2.93	Bias score, BIAS	0.90	0.72
Rank–order correlation	0.69	0.74	True skill statistics, TSS	0.53	0.58

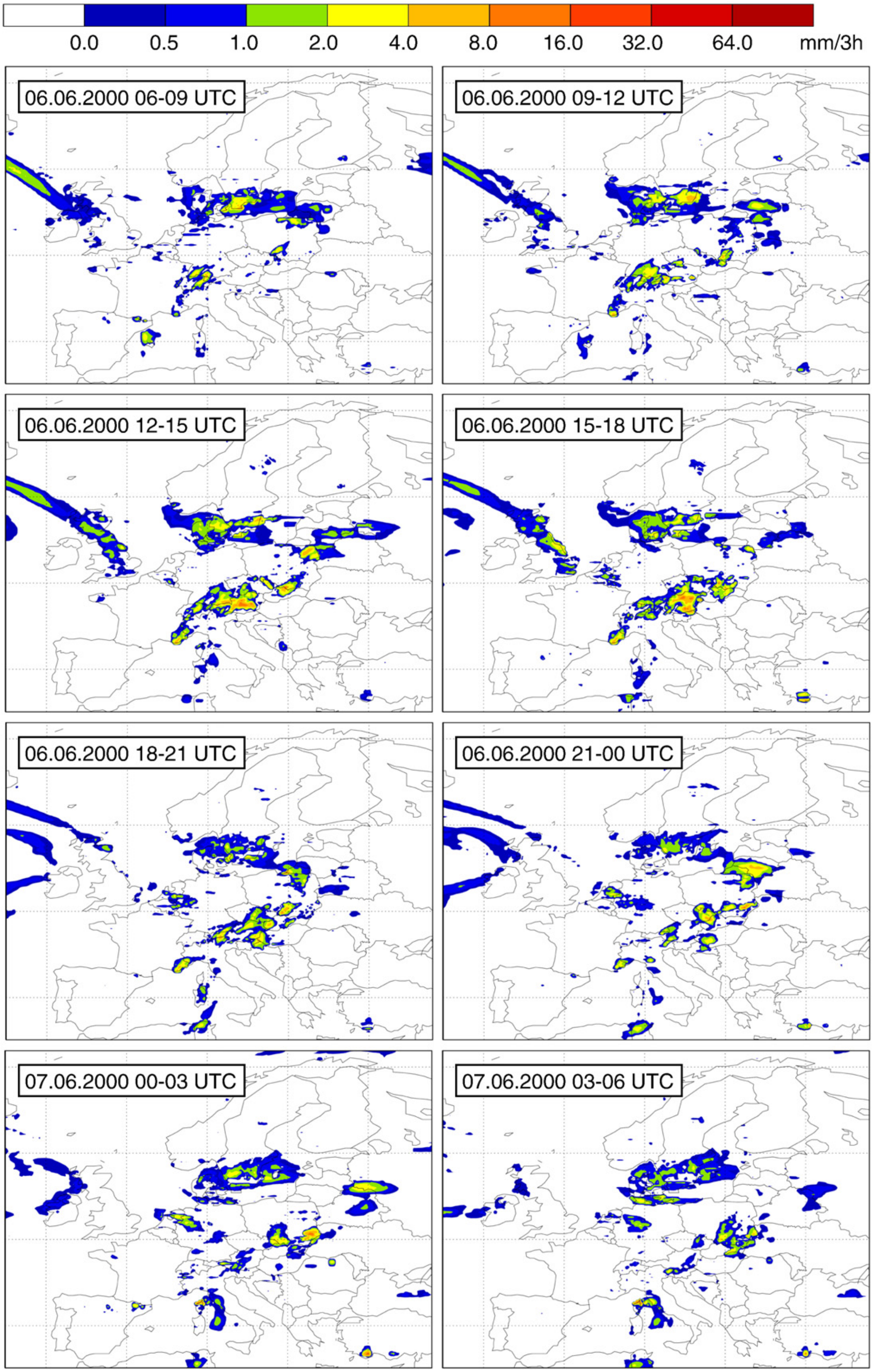

Fig. 5. Example of 3-hourly ELDAS precipitation estimates for 6 July 2000, 6 UTC to 7 July 2000, 6 UTC.

absolute error, RMS error and false alarm ratio. Finally, the completeness of BALTRAD is much higher than those of CERAD (missing dates CERAD 14%, BALTRAD 0.16%).

3.5. Adjustment of radar estimates by gauge measurements

Following the good verification results of daily QPEs from radar data a similar performance of 3-hourly accumulated radar data is assumed. Nevertheless, an adjustment with daily gauge analyses will produce additional accuracy. Thus, the 3-hourly QPEs from radar data have been adjusted for each grid point so that their daily sum equals the value estimated from gauges. The simplest possible method, linear temporal interpolation, was therefore used. The gauge analysis is based on a correction procedure to reduce the systematic measurement errors (Rubel and Hantel, 1999) and a kriging method to interpolate the irregularly spaced gauge measurements to the ELDAS grid (Rubel and Hantel, 2001). Grid points at which neither radar estimates nor gauge estimates are available are handled as missing values. Because the NWP community expects observed precipitation fields without missing values, in the final 3-hourly precipitation product ECMWF T512 operational precipitation forecasts were blended at these grid points. A mask provides information whether a grid point provides a QPE from radar and gauge observations or a background value from ECMWF prediction.

4. Results and discussion

The 3-hourly QPEs are available for the ELDAS reference period from Oct. 1999 to Dec. 2000. An example of a daily series of 3-hourly precipitation fields for 6 June 2000 is depicted in Fig. 5. Both, temporal and spatial resolutions were defined by the NWP community in accordance with the resolution of models used in ELDAS. The goal was to demonstrate that high-resolution precipitation and radiation forcing improves the skill of recent NWP models, especially in regions with strong coupling between soil moisture and precipitation such as Central Europe (Koster et al., 2004), which may be characterized by Cfb-climate (warm temperate, fully humid with warm summer) after Köppen (Kottek et al., 2006). Results of the ELDAS data assimilation simulations using the precipitation data presented here as well as radiation data provided by Meetschen et al. (2004) have been published by van den Hurk et al. (2008) and Hess et al. (2008). A verification of ELDAS NWP products using in-situ observations was presented by Jacobs et al. (2008).

It was demonstrated that continental-scale weather radar data may be used together with high resolution gauge networks to compile QPEs for Central and Northern Europe. Today more than 10 years of historical weather radar data covering the major part of the European Union are archived by national radar providers. This offers the possibility to compile high-resolution QPEs based on radar and gauge data for climate research. Recent developments within the framework of OPERA will support real-time as well as climate applications of weather radar data.

The data set presented in this paper is stored in GRIB format in the ECMWF MARS archive. Alternatively, it is available on request from the authors.

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References

Auer, I., Böhm, R., Jurkovic, A., et al., 2005. A new instrumental precipitation dataset for the greater alpine region for the period 1800–2002. Int. J. Climatol. 25, 139–166.

Bengtsson, L., 2001. Numerical modelling of the energy and water cycle of the Baltic Sea. Meteorol. Atm. Phys. 77, 9–17.

Bennartz, R., Michelson, D., 2003. Correlation of precipitation estimates from spaceborne passive microwave sensors and weather radar imagery for BALTREX PIDCAP. Int. J. Remote Sens. 24, 723–739.

Brugger, K., 2004. Areal Precipitation over Central and Northern Europe Estimated from Weather Radar Data (in German). Master's Thesis, University of Vienna, 97 pp.

Collier, C.G., 1996. Applications of Weather Radar Systems, 2nd ed. John Wiley & Sons, Chichester.

Ebert, E.E., McBride, J.L., 1997. Methods for Verifying Quantitative Precipitation Forecasts: Application to the BMRC Laps Model 24-Hour Precipitation Forecasts. BMRC Technical Development Report No. 2, Melbourne, Australia, 87pp.

Fuchs, T., Schneider, U., 2008. The Global Precipitation Climatology Centre (GPCC) — precipitation monitoring and mapping on national, regional and global scale. 8th Annual Meeting of the EMS / 7th ECAC Abstracts, vol. 5. EMS2008-A-00414, 2008.

Göber, M., Zsoter, E., Richardson, D.S., 2008. Could a perfect model ever satisfy a naive forecaster? On grid box mean versus point verification. Meteorol. Appl. 15, 359–365.

Hess, R., Lange, M., Wergen, W., 2008. Evaluation of the variational soil moisture assimilation scheme at Deutscher Wetterdienst. Q.J.R. Meteorol. Soc. 134, 14991512.

Holleman, I., Delobbe, L., Zgonc, A., 2008. Update on the European Weather Radar Network (OPERA). Proc. 5th Europ. Conf. on Radar in Meteorology and Hydrology (ERAD), 30 June–4. July 2008, Helsinki, Finland.

Huffman, G.J., Adler, R.F., Morrissey, M.M., Bolvine, D.T., Curtis, S., Royce, R., McGavock, B., Susskind, J., 2001. Global precipitation at one-degree daily resolution from multi-satellite observations. J. Hydrometeorol. 2, 36–50.

Hulme, M., 1992. The cost of climate data — a European expertise. Weather 49, 168–174.

Jacobs, C.M.J., Moors, E.J., Ter Maat, H.W., Teuling, A.J., Balsamo, G., Bergaoui, K., Ettema, J., Lange, M., Van den Hurk, B.J.J.M., Viterbo, P., Wergen, W., 2008. Evaluation of European Land Data Assimilation System (ELDAS) products using in situ observations. Tellus Ser. A 60, 1023–1037.

Klein Tank, A.M.G., Wijngaard, J.B., Können, G.P., et al., 2002. Daily datasets of 20th century surface air temperature and precipitation series for the European climate assessment. Int. J. Climatol. 22, 1441–1453.

Köck, K., 1999. Nationale und internationale Wetterradarnetzwerke und ihre Kalibrierung mittels Regenmesserdaten für quantitative Verwendung (in German). Ph.D. thesis, Graz University of Technology, 143 pp.

Köck, K., Leitner, T., Randeu, W.L., Divjak, M., Schreiber, K.-J., 2000. OPERA: operational programme for the exchange of weather radar information. First results and outlook for the future. Phys. Chem. Earth (B) 25, 1147–1151.

Koistinen, J., Michelson, D.B., 2002. BALTEX weather radar-based precipitation products and their accuracies. Boreal Env. Res. 7, 253–263.

Koster, R.D., Dirmeyer, P.A., Guo, Z., Bonan, G., Chan, E., Cox, P., Gordon, C.T., Kanae, S., Kowalczyk, E., Lawrence, D., Liu, P., Lu, C.-H., Malyshev, S., McAvaney, B., Mitchell, K., Mocko, D., Oki, T., Oleson, K., Pitman, A., Sud, Y.C., Taylor, C.M., Verseghy, D., Vasic, R., Xue, Y., Yamada, T., Team, G.L.A.C.E., 2004. Regions of strong coupling between soil moisture and precipitation. Science 305, 1138–1140.

Kottek, M., Rubel, F., 2007. Global daily precipitation fields from bias-corrected rain gauge and satellite observations. Part I: design and development. Meteorol. Z. 16, 525–539.

Kottek, M., Grieser, J., Beck, C., Rudolf, B., Rubel, F., 2006. World map of Köppen–Geiger climate classification updated. Meteorol. Z. 15, 259–263.
Meetschen, D., van den Hurk, B.J.J.M., Ament, F., Drusch, M., 2004. Optimized surface radiation fields derived from Meteosat imagery and a regional atmospheric model. J. Hydrometeorol. 5, 1091–1101.
Michelson, D.B., 2004. Spurious weather radar echo identification and removal using multisource temperature information. Meteorol. Appl. 11, 1–14.
Michelson, D., Anderson, T., Koistinen, J., Collier, C., Riedl, J., Syturc, J., Gjertsen, U., Nielsen, A., Overgaard, S., 2000. BALTEX Radar Data Centre Products and their Methodologies. Tech. Rep. 90, SMHI Report Meteorlogy and Climatology.
Michelson, D.B., Jones, C.G., Landelius, T., Collier, C.G., Haase, G., Heen, M., 2005. "Down-to-Earth" modelling of equivalent surface precipitation using multisource data and radar. Q.J.R. Meteor. Soc. Part A 131, 1093–1112.
OPERA, 2008. Operational Programme for Exchange of Weather Radar Information. online available at http://www.knmi.nl/opera/.
Paulat, M., Frei, C., Hagen, M., Wernli, H., 2008. A gridded dataset of hourly precipitation in Germany: its construction, climatology and application. Meteorol. Z. 17, 1–14.
Raschke, E., Meywerk, J., Warrach, K., et al., 2001. The Baltic Sea Experiment (BALTEX): a European contribution to the investigation of the energy and water cycle over a large drainage basin. Bull. Amer. Meteor. Soc. 82, 2389–2413.
Rubel, F., 2004. European precipitation dataset for NWP model verification and data assimilation studies. Research Activities in Atmospheric and Oceanic Modelling Report No. 34, WMO/TD, Section, vol. 2, pp. 15–16.
Rubel, F., Hantel, M., 1999. Correction of daily rain gauge measurements in the Baltic Sea drainage basin. Nord. Hydrol. 30, 191–208.
Rubel, F., Hantel, M., 2001. BALTEX 1/6 degree daily precipitation climatology 1996–1998. Meteorol. Atmos. Phys. 77, 155–166.
Rubel, F., Skomorowski, P., Rudolf, B., 2002. Verification scores for the operational GPCP-1DD product over the European Alps. Meteorol. Z. 11, 367–370.
Rubel, F., Brugger, K., Skomorowski, P., Kottek, M., 2004. Quantitative precipitation estimates from CERAD, BALTRAD and gauges. Proc. 3rd Europ. Conf. on Radar in Meteorology and Hydrology (ERAD), 6 to 10 Sept. 2004, Visby, Sweden.
Ungersböck, M., Rubel, F., Fuchs, T., Rudolf, B., 2001. Bias correction of global daily rain gauge measurements. Phys. Chem. Earth (B) 26, 411–414.
van den Hurk, B.J.J.M., 2002. European LDAS established. GEWEX News 12 (2), 9-9.
van den Hurk, B.J.J.M., Ettema, J., Viterbo, P., 2008. Analysis of soil moisture changes in Europe during a single growing season in a new ECMWF soil moisture assimilation system. J. Hydrometeorol. 9, 116–131.