Use of Weather Radar Data for Climate Data Records in WMO Regions IV and VI

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1) Introduction and scope of this paper

During the first meeting of the WMO CCl Task team on the Use of Remote Sensing Data for Climate Monitoring (TT-URSDCM) in 2014, the team recognized the increasing availability of radar data and emerging interest of Members to establish radar climatologies. Consequently, as part of the work plan of TT-URSDCM a task to create an overview of activities within Members on radar climatologies has been agreed.

This document provides the information which is available for WMO Region VI (Europe). The information has been compiled through personal communication and a literature survey, however it cannot guarantee completeness. The given examples provide a starting point in summarizing best practices of Member states to establish own climatologies. The authors are looking forward to further entrances and updates of list entries.

The document is structured as follows: After recalling the motivation in section 2, the challenges are shortly summarized in section 3, section 4 provides an example for Germany providing a few more details about the procedure followed and plans. Then section 5 gives an overview for several Members from Region VI. Finally, section 6 concludes this document.

2) Motivation for the Use of Weather Radar Data for Climatological Purposes

While weather radar data is widely employed for Numerical Weather Prediction, climatological use is still not common. And yet, radar data holds many advantages when compared to other sources of precipitation data. The high temporal and spatial resolution as well as coverage of radar-based data, for example, enables the study of small-scale atmospheric structures and dynamics (e.g. of convective systems) (e.g. Berg et al. 2015, Goudenoofdt & Delobbe 2013, Marra & Morin 2015, Tabary 2007). This implies that also in regions without observational network, area-wide coverage is attained and extreme events – which occur regional and temporary – are captured. Furthermore, the data is often provided in near real-time (Ruber & Brugger 2009).

In contrast to this, the oftentimes small density (and irregularity) of gauge networks results in point data with debatable reliability and representativeness for the surrounding area. The variability of precipitation is therefore not reflected in the spatially interpolated data, especially regarding regions with heterogeneous topography (e.g. Berndt et al. 2014, Goudenhoofdt & Delobbe 2013, Ruber & Brugger 2009, Rudolph et al. 2011, Tabary 2007, Tapiador et al. 2012). Until now, satellite-derived precipitation data is no suitable alternative for regional studies of precipitation climatology, as temporal and/or spatial resolutions are still too low (e.g. Goudenoofdt & Delobbe 2013, Tapiador et al. 2012).

Altogether, radar data holds large potential for climatological applications which is far from being fully exploited until now. Thus, this paper aims to provide an insight in the possibilities of climatological use of weather radar data.

3) Encountered Challenges

By now, many classic problems regarding weather radar measurements like e.g. ground clutters, shielding or non-uniform vertical profiles of reflectivity (see Figure 1, e.g. Fairman et al. 2015, Overeem et al. 2009, Yuter 2015), can be solved – particularly by using long time series as well as Doppler and polarimetric radars (cp. Tabary 2007, Tabary et al. 2007, Winterrath et al. 2015).

Concerning the climatological analysis of radar data, some other issues arise which, however, can also be overcome by proper processing of the data:

As with all other data sources, in the context of data harmonization, difficulties emerge from the removal or replacement of sensors as well as the change of sensor calibrations (Overeem et al. 2009). Furthermore, originally hidden systematic errors can be amplified when applying long-term means (Wagner et al. 2014). Hence pre-processing needs to be conducted before using the data (cp. Kronenberg & Bernhofer 2015).

To derive robust data, validation and calibration is essential. Unfortunately, many regions feature a lack of gauge data and especially during times of intense wind or rainfall errors occur in the gauge measurements (e.g. Fairman et al. 2015, Holleman et al. 2006). Additionally, calibrations as well as retrieval algorithms have to be harmonized and orographic corrections need to be performed to ensure data comparability (Berg et al. 2015, Fairman et al. 2015). Missing data must not be treated as zero precipitation as this would falsify climatological assertions but be amended in an adequate way (Fairman et al. 2015).

The considered studies (see section 5) show the existence of a large number of techniques for the correction of systematic biases (e.g. Berndt et al. 2013, Fairman et al. 2015, Overeem et al. 2009, Wagner et al. 2014) as well as for radar-gauge merging respectively adjustment (e.g. Berndt et al. 2013, Goudenhoofdt & Delobbe 2009, Paulat et al. 2008, Winterrath et al. 2012). Regarding this, it is important to bear in mind that for using climatological radar data from different sources, comparable processing methods need to be applied to gain matchable results.

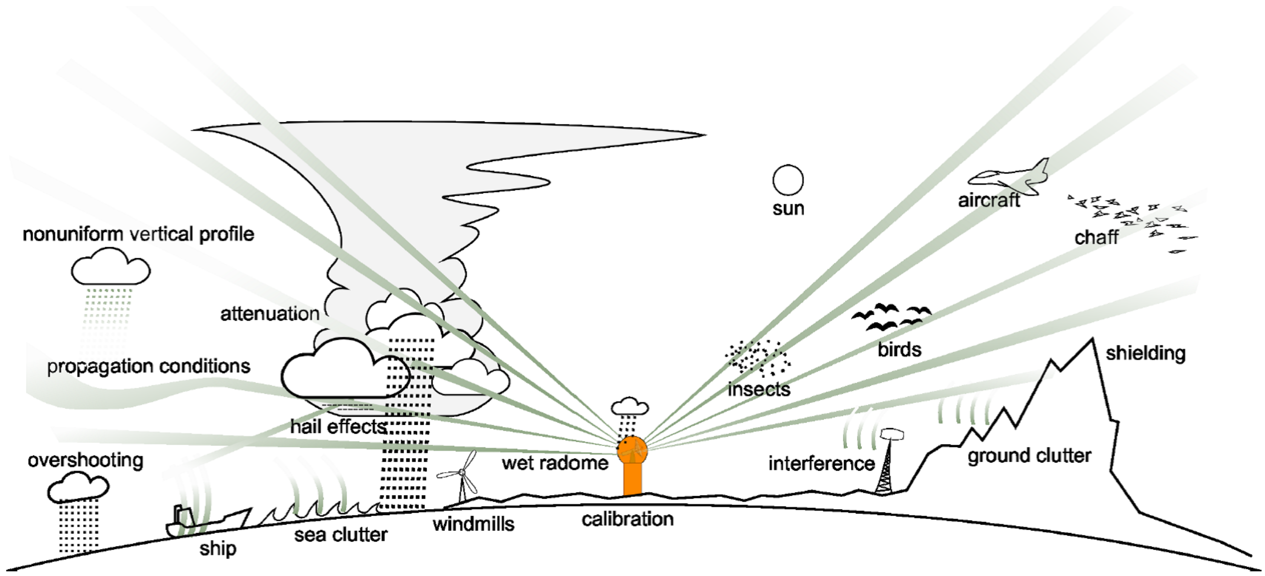

Figure 1: Phenomena Affecting Radar Data Quality (Holleman et al. 2006).

4) Activities and Experiences of Deutscher Wetterdienst (DWD)

The DWD radar network currently consists of 17 C-band Doppler radar systems. All but one of the former 16 single-polarization ones have been replaced by dual-pol ones between 2011 and 2015. In the RADOLAN (Radar-Online-Adjustment) project, methods for the production of hourly gauge-adjusted quality-controlled radar data based on five-minute terrain-following precipitation scans have been developed. For the real-time adjustment, approx. 1300 automatic gauges are available (Effective 2016). The project being finalized, processed data is now made available to DWD users every hour.

To analyze the radar-based precipitation data, a new project on the "Generation of a decadal radar-based high-resolution precipitation climatology for Germany for the retrieval of recent changes in precipitation extremes" has started in June 2014 and is ongoing until August 2016. In the course of this undertaking three project modules are elaborated. First, a complete reprocessing of the radar-based precipitation data is performed, second, a statistical analysis of the 15-year precipitation data is executed, and third, client-specific products are generated. The reprocessing of the data comprises the application of one software version to all the data to improve homogeneity, the usage of all available gauge data in the adjustment procedure, as well as the design and application of (automatic) procedures for different kinds of data corrections to remove or at least reduce errors arising from different kinds of sources (Winterrath et al. 2015, Winterrath & Schmitt 2015).

While well-known radar-specific false enhanced signals, e. g. clutter, are clearly visible in single real-time products, signal reductions become visible only in the long-term totals. Therefore, besides applying the state-of-the-art real-time correction methods, DWD develops specific climatological correction algorithms. For artefacts originating from beam blockage by (permanent) obstacles and also distant-dependent signal enhancement, which is a permanent feature, long term means can be used for corrections. More complex climate-data corrections which are to be developed and applied in the future concern non-permanent periodic spokes as well as season- or intensity-dependent distance effects, the latter one being associated with deep convection (Winterrath et al. 2015). Furthermore, it is planned to perform a statistical analysis of the 15-year radar climatology for Germany and to examine extreme events by the use of objective indices. Additionally, the results are combined with non-meteorological data for impact and vulnerability studies.

The radar-based precipitation climatology is planned to be extended on an annual basis. Based on the dual-pol technology, new data products will be included in the future.

5) Use of Weather Radar for Climate Data Records in WMO Region VI

The following statements on the recent state of weather radar use for climatological data records in the WMO Region VI is based on an examination of the webpages of the Region VI Members' national meteorological and hydro-meteorological services (NMHSs) (as listed online at WMO 2016), the WMO World Radar Database (WRD 2016) as well as a review of literature. Until now, little activity can be observed in terms of the use of radar for the establishment of precipitation time series sufficiently long for the use in climate research. Most of the Region VI countries employ radar data merely for weather observation and forecasting. Climate applications by means of weather radar data are pursued by ten countries (Belgium, Denmark, France, Germany, Ireland, Italy, Netherlands, Sweden, Switzerland, and United Kingdom of Great Britain and Northern Ireland).

Use of radar data for the compilation of climatologies of high precipitation events, convective events or hail is mainly listed for countries with no available information on radar precipitation climatologies, showing that multi-annual time series of radar data are existent. No claim to completeness is raised.

A summary is given in Table 1 and in Figure 2, while the following paragraphs present the situation for the different countries in more detail:

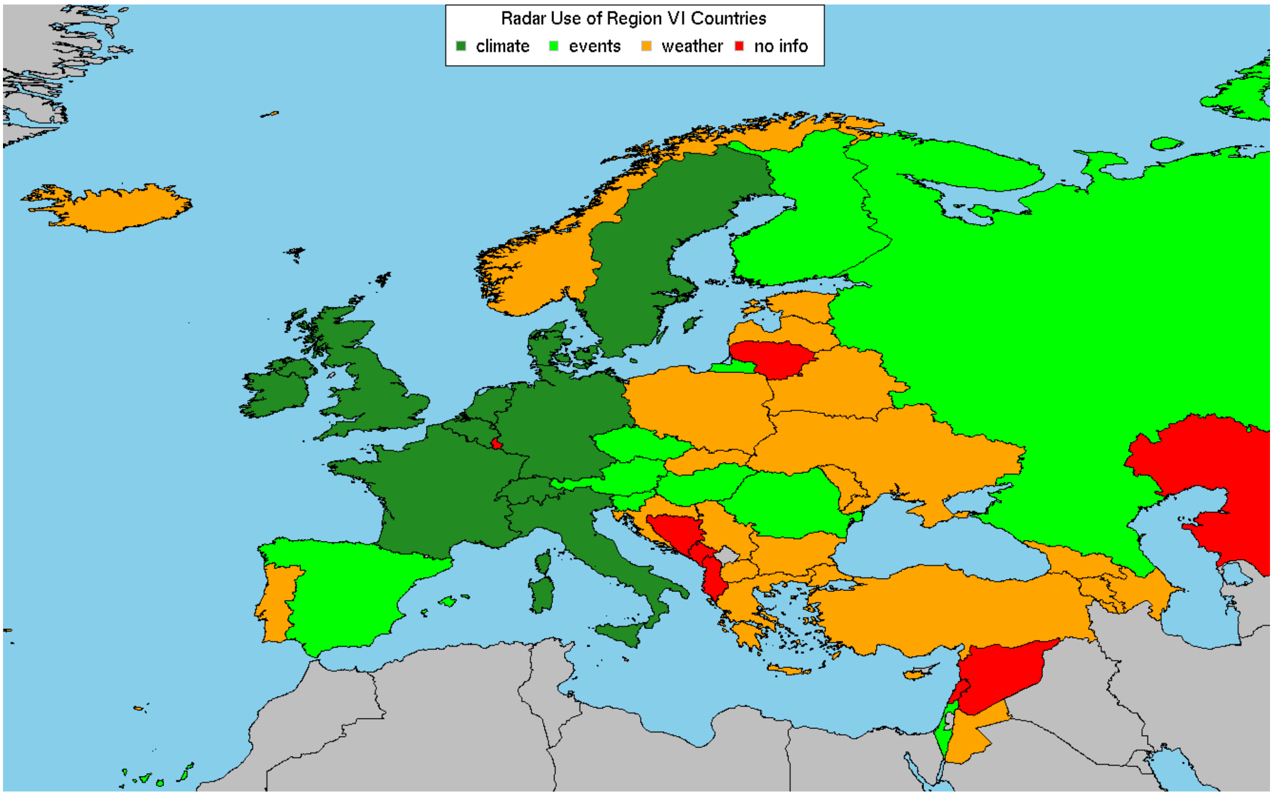

Figure 2: Use of Weather Radar Data in WMO Region VI Countries. Climate: multi-annual time series produced – events: climatologies of hail, convective or high precipitation events compiled but no information on radar-based precipitation climatologies – weather: only information on radar use for weather purposes – no info: no information on weather radar use at all.

Austria. Kaltenboeck & Steinheimer (2015) examine intensive convective events of the warm seasons 2008–2012 using C-band weather radar in combination with ERA-Interim Reanalysis data over Austria. Separating Austria in three different regions, they analyze severe storm occurrence regarding the different combinations of deep layer wind shear and CAPE strength.

Belgium. In their study, Goudenhoofdt & Delobbe (2009) examine and perform various radar-gauge merging methods and contrast the results with independent gauge data. The work is based on radar data from the Wideumont Radar in south-western Belgium, covering the years 2005 to 2008. Records of the same radar station but for 2002–2011 are also used by Goudenhoofdt & Delobbe (2013) for the analysis of convective storms. Furthermore, a reprocessing of the QPE (quantitative precipitation estimation) for the 2005–2015 period including different correction techniques and gauge-merging is conducted by Goudenhoofdt & Delobbe (2016a) (using DWD RADOLAN Z-R relationships), leading to a marked enhancement of the data when compared to (independent) rain gauge measurements. Extreme values are also analyzed (cp. Goudenhoofdt & Delobbe 2016b).

Czech Republic. Bližňák et al. (2016) examine the gauge-merged data of two radar stations for the warm seasons 2002–2011. Besides the derivation of a MJJAS total precipitation climatology, sub-daily extreme events as well as small-scale differences in precipitation amounts are investigated. Seven algorithms for hail detection from single-polarisation radar data are examined by Skripniková & Řezáčová (2014) regarding hail events in the Czech Republic and SW Germany evidenced by data from insurance companies and other sources. From this, criteria are defined to delineate hail occurrence and thus construct a 2007–2011 hail climatology for the Czech Republic.

Denmark. A ten year radar-based precipitation climatology (2002–2012) for Denmark is derived by Thorndahl et al. (2014). Using data from the Stevns C-band radar, various bias adjustment methods are examined revealing better results for hourly compared to daily adjustment. Additionally, it is shown that at least 10 to 20 randomly distributed rain gauges are necessary for valid mean field bias adjustment.

France. For France, Tabary et al. (2012) report about the production and validation of a decadal time series of radar-gauge merged precipitation spanning 1997–2006, intended to be used as a reference database. Weckwerth et al. (2011) study convection in parts of France and Germany (Vosges Mountains, Rhine Valley, Black Forest Mountains, Swabian Mountains) in the May to August periods 2000–2006 as well as 2008 based on radar data. This work is conducted in relation to the COPS (Convective and Orographically-induced Precipitation Study) field campaign in summer 2007.

Germany. As the current approach at DWD has been described in detail above (see section 4), here only additional work is cited. Hourly RADOLAN-QPEs of the German Free State Saxony covering the 4.2004–12.2009 period are processed by Kronenberg & Bernhofer (2015) to be suitable for analyses of annual or bigger timescales of precipitation. Error accumulation is prevented by a detection and elimination of outliers, adaption by means of elevation data and bias-adjustment using independent gauge data. The resulting dataset is then compared with two datasets covering the same domain. The utilization of the applied method for other study areas is limited as it is only valid for regions with high correlations between precipitation and elevation. Wagner et al. (2014) examine the 2005–2009 period of the German radar composite RX. Long-term means are used to detect systematic biases, and the susceptibility of the data regarding climatologically amplified formerly minor systematic errors is highlighted. Three different geostatistical interpolation techniques are employed by Berndt et al. (2014) for the merging of radar and rain gauge data at different spatial and temporal resolutions. The study is based on radar data of the Hanover station from 2008 until 2010. Using a so-called disaggregation technique, Paulat et al. (2008) construct a combined gauge-radar dataset of precipitation in Germany (2001–2004). Additionally, COSMO-7 model forecasts are studied regarding their representation of the findings.

A hail climatology for the summer half-years 2002–2011 (continuation intended) is compiled by Junghänel et al. (2016) employing pre-processed single-polarized C-band Doppler radar data, lightning data, observations from weather stations and volunteers as well as insurance data. The resulting frequency map shows the annual average number of hail days per square kilometer.

Finland. Based on five years of corrected summer rainfall intensity data of seven C-band Doppler radars (MJJAS 2000–2005), return periods of rainfall intensities are derived from probability respectively (complementary) cumulative density functions by Koistinen et al. (2008). Two-minute point values – which show higher intensities than gauge-based results – as well as different combinations of area-time accumulations are studied, revealing the necessity for “post detection quality filtering”. Saltikoff et al. (2010) use adjusted radar data of the summer seasons 2001–2005 in combination with ECMWF MARS temperatures as well as 70 years of hail reports to derive a hail climatology for Finland yielding partially differing results.

Hungary. Based on the TITAN method and data from three C-band radars, thunderstorm activity in Hungary between 2004 and 2012 is studied by Seres & Horváth (2015). Three different intensity types of “thunderstorm ellipses” are defined and occurrence frequencies as well as spatial and temporal differences are examined.

Ireland. *See United Kingdom of Great Britain and Northern Ireland*

Israel. Weather radar QPE data from October 1990 to September 2013 are employed by Marra & Morrin (2015) to deduce Intensity-Duration-Frequency curves covering the different climates of Israel. Several adjustments are applied before examining the data and the results are compared to rain gauge-based ones, showing overestimations of the radar with respect to the gauge data.

Italy. The convective activity during the warm seasons 2005–2007 in the Veneto region in northern Italy is documented in a radar-based time series by Calza et al. (2008). Stanzani et al (2000) match raw as well as gauge-calibrated radar precipitation estimates from a radar station in Bologna against (independent) gauge network data for 1997–1998 (except from 11/97 to 03/98 with no data available). The results show underestimations in terms of the raw data and good results regarding the calibrated data.

Netherlands. Based on the data of the two Dutch Radar stations, a 10-year (1998–2007) precipitation climatology is constructed by Overeem et al. (2009) comprising several – separately deployed and compared – adjustment techniques, partially involving gauge data. When compared to gauge-based data, a newly developed adjustment method combining mean-field bias and spatial adjustment yields the best results, also regarding variance differences. On the KNMI web page, daily precipitation maps based on radar data are available from 2009 on (KNMI 2016).

Norway. There are activities to compile radar climatologies which were reported on in a presentation, but there are no hints in the literature.

Romania. Data of two Doppler radars are used by Maier & Haidu (2011) to produce a climatology of hail for the summer seasons of 2004 to 2009 over the Apuseni Mountains in Romania. The derived maps show a high spatial variability of hail frequency and severity related to the prevailing topography.

Russian Federation. Hail activity in two Russian regions is investigated by Zharashuev (2012) studying convective cells in the periods 2002–2008 (Stavropol radar) respectively 2004–2009 (Kirovskoe radar Crimean Paramilitary Service).

Slovenia. Stržinar & Skok (2016) construct a hail climatology for Slovenia for the period 2002–2010. In doing so, they apply and compare different algorithms.

Spain. García-Ortega et al. (2011) use data from a C-band radar near Zaragoza to identify hail days in the Middle Ebro Valley between 2001–2008, which are confirmed by observers. Afterwards, the atmospheric conditions during those days is examined using reanalysis data.

Sweden. Based on radar and gauge data, Berg et al. (2015) generate a time series of precipitation over Sweden spanning 2009–2014. They point out the need for inter-radar calibration as well as gauge-independent radar composite adjustments.

Switzerland. While Rudolph et al. (2009) focus on high precipitation events in the Alps of Switzerland and the adjacent countries during the 2000–2007 period using radar data, the ongoing MeteoSwiss project "CombiPrecip" goes beyond this. It aims at the construction of hourly gauge-radar merged precipitation fields from 2005 on by means of geostatistical combination methods. Data from all Swiss radar stations, covering and exceeding the Swiss territory, is employed (MeteoSwiss 2013, 2014).

United Kingdom of Great Britain and Northern Ireland. Including several corrections and adjustments, Fairman et al. (2015) compile an eight-year time series of precipitation over Great Britain and Ireland. Comparisons against annual totals reveal high overestimations in some and underestimations in other parts of the study area. Besides poor radar data quality regarding Ireland, errors concerning the gauge-based data are assumed.

United States. Nelson et al. (2003) produced a high-resolution precipitation data set climatology based on NEXRAD radar estimates for a five-year period (1996-2000) over the Mississippi River basin – nearly 2/3 of the continental United States (CONUS). Nelson et al. (2010) also produced a reanalysis of radar-based precipitation estimates for a five-year period over the southeastern United States. Recently Ortega et al. (2015) have produced a 10-year climatology of severe weather based products based on the NEXRAD operational level-II products. The Multi-Year Reanalysis of Severe Storms (MYRORSS) data set consists of some 18 severe weather based products at high resolution. In addition Nelson et al (2016) have produce the companion QPE climatology for the same time period over CONUS.

Central and Northern Europe. Data from the border-crossing CERAD (Central European Radar) and BALTRAD (Baltic Radar) networks adjusted by in-situ observations provides the basis for the 10/1999–12/2000 precipitation time series over Central and Northern Europe compiled by Rubel & Brugger (2009).

6) Conclusion

When compared to other data sources, the large potential of weather radar data for climatological application arises from its high spatial as well as temporal resolution and coverage, implying that also small scale differences in precipitation and extreme events can be captured.

During the last decade solutions for a lot of general problems in terms of radar measurements (see Figure 1) were found. Some specific issues arise when analyzing radar data for climatological purposes. These include e.g. sensor modifications over time, amplification of originally minor systematic errors, lacking validation data (lacks and errors in gauge data). Nevertheless, even most of them can be handled by adequate processing. To use radar observation for climate monitoring, there is in addition a need for harmonized calibrations and retrievals, for comparable methods regarding bias correction and radar-gauge adjustments, as well as for an adequate treatment of missing data. As an example, Deutscher Wetterdienst has started to reprocess and analyze the radar-based reflectivity measurements of the German radar network starting in 2001. Currently, the compilation of decadal gauge-adjusted radar precipitation climatology is ongoing until August 2016. It comprises the design and application of various correction schemes spanning different levels of complexity. A statistical analysis of the 15-year radar climatology as well as a studyof extreme events will be performed.

The examination of the WMO World Radar Data Base, RA VI NHMSs' web pages and a search for literature reveals some activity in terms of climatological use of radar-based precipitation data which is listed in Table 1 and displayed in Figure 2. It is evident that only a few Members of RA VI (Germany, Switzerland) are currently performing projects regarding generating, provision and archiving of long time series of adjusted radar precipitation.

Even though the number of countries deriving radar-based precipitation climatologies is still small, the examples listed in this paper are encouraging.

Table 1: Countries with Information Regarding Multiannual Radar Data Use.

Country	Details	Time	Reference
Austria	Intensive convective cores	2008–2012	Kaltenboeck & Steinheimer 2015
Belgium	Convective events (SW Belgium)	2002–2011	Goudenhoofdt & Delobbe 2013
	Radar-gauge merging methods (SW Belgium)	2005–2008	Goudenhoofdt & Delobbe 2009
Czech Republic	Total precipitation MJJAS, sub-daily extreme events, small scale differences	2002–2011	Bližňák et al. 2016
	Hail climatology	MJJA 2007–2011	Skripniková & Řezáčová 2014
Denmark	Bias adjustment methods	2002–2012	Thorndahl et al. 2014
Finland	Rainfall intensity return periods	MJJAS 2000–2005	Koistinen et al. 2008
	Hail climatology	MJJAS 2001–2005	Saltikoff et al. 2010
France	Radar-gauge precipitation time series as reference database	1997–2006	Tabary et al. 2011
	Convective events (NE France and SW Germany)	MJJA 2000–2006, 2008	Weckwerth et al. 2011
Germany	Radar-gauge precipitation time series	2001+ (ongoing)	Winterrath et al. 2015 Winterrath & Schmitt 2015
	Processed climatology for at least annual means (Saxony, E Germany)	4/2004–12/2009	Kronenberg & Bernhofer 2015
	Bias detection	2005–2009	Wagner et al. 2014
	Radar-gauge merging, Hanover station	2008–2010	Berndt et al. 2014
	Radar-gauge combination	2001–2004	Paulat et al. 2008
	Hail climatology	2002–2011	Junghänel et al. 2016
Hungary	Hail climatology	2004–2012	Seres & Horváth 2015

Country	Details	Time	Reference
Ireland	Radar-gauge precipitation time series	2006–2013	Fairman et al. 2015
Israel	Intensity-Duration-Frequency curves	10/1990–09/2013	Marra & Morrin 2015
Italy	Convective events (N Italy)	MJJAS 2005–2007	Calza et al. 2008
	Radar-gauge comparison (N Italy)	01–10/1997, 04–12/1998	Stanzani et al. 2000
Netherlands	Radar-gauge precipitation time series	1998–2007	Overeem et al. 2009
	Daily radar precipitation maps	2009+ (ongoing)	KNMI 2016
Romania	Hail climatology (NW Romania)	JJA 2004–2009	Maier & Haidu 2011
Russian Federation	Hail climatology (two Russian regions)	2002–2008 / 2004–2004	Zharashuev 2012
Slovenia	Hail climatology	2002–2010	Stržinar & Skok 2016
Spain	Hail climatology and atmospheric conditions in the (NE Spain)	2001–2008	García-Ortega et al. 2011
Sweden	Radar-gauge precipitation time series	2009–2014	Berg et al. 2015
Switzerland	Radar-gauge precipitation time series (CombiPrep)	2005+ (ongoing)	MeteoSwiss 2013, MeteoSwiss 2014
	High precipitation events (Alps)	2000–2007	Rudolph et al. 2009
United Kingdom	Radar-gauge precipitation time series	2006–2013	Fairman et al. 2015
United States	Radar-gauge Climatology Radar-Gauge Reanalysis Radar-Gauge QPE Climatology Multi-Year Reanalysis of Severe Storms	1996-2000 2002-2007 2002-2011 2002-2011	Nelson et al. 2003 Nelson et al. 2010 Nelson et al. 2016 Ortega et al. 2015
C & N Europe	Radar-gauge precipitation estimation	10/1999–12/2000	Rubel & Brugger 2009

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