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Geomorphological Impacts of Extreme Weather

Case Studies from Central and Eastern Europe

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Foreword

Extreme weather events have always been with us, occupying the attention of scientists and land resource mangers over the years. Today, however, there is a real urgency for understanding such phenomena, for three main reasons. First, the increase in human population and associated rapid growth of fixed assets and infrastructure means the potential for loss and damage from extreme events has increased greatly in recent years. In addition, human modification of natural systems, through urbanisation, land use practices, and river regulation, has dramatically impacted the runoff regime in many catchments. Finally, the increasing evidence for both change and intensification of weather systems as a result of human-induced climate change suggests that we may experience changes to extreme events that we have neither experienced in the past nor made provision for in the future. Thus, this book offers a timely contribution to understanding the hydrological, geomorphological, and human impacts resulting from these rapidly changing processes.

The value of the geomorphological approach offered by this book is that it provides a holistic perspective to the problem. For example, the book demonstrates that an extreme rainfall event is not just an atmospheric phenomenon; rather, it is inevitably linked to earth surface processes (landslides, debris flows, channel degradation, soil erosion) and social process such as resource management, emergency management, and planning. Importantly, this book is a testimony of the geomorphologists of Carpatho–Balkan–Dinaric countries who have risen to the challenge of applying their science to one of the world's most pressing problems. This work sets a benchmark in applied geomorphology that will serve as an excellent example for geomorphologists around the world.

Wellington, New Zealand
10 December 2012

Michael Crozier
President
International Association of Geomorphologists

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Introduction

This collection of chapters aims at providing an overview of the most recent investigations into the short- and longer-term consequences of weather phenomena of unusual intensity – probably driven by global climate change (IPCC SREX 2012; see also Bartholy, Pongrácz – Chap. 1 in this volume). Although numerous previous events (for instance, those in the years 2002 and 2006) are also treated in the book, the main focus is on the diverse impacts of the 2010 rainfalls which affected most of Europe, particularly the Danubian macroregion and the neighbouring areas (ICPDR 2012 – Fig. 1). On raising the idea and 'screening' interests at a meeting in Ostravice, Czech Republic, in October 2011, first of all the authors of a previous Springer volume (Lóczy et al. 2012) were invited by the editor to explore the opportunities for compiling the most intriguing findings achieved in research in their own countries and summarise them for the international public in a series of selected brief case studies. Positive responses were received from 11 countries of eastern Central Europe, and they resulted in 21 chapters, each including case studies in different numbers (from 1 to 6). The spatial distribution of case studies (Fig. 2) is intended to reflect that of the events with the highest impact.

Starting with the hydrometeorological setting, the material in this book is partly arranged around topics (floods, landslides, and other impacts) and, within that framework, according to areas moving from north to south. Although in 2010 destructive floods were recorded even more to the north, in the Vistula drainage basin, the northernmost region treated in the volume is the Polish Carpathians. Several chapters deal with the only high mountains of Poland, where detailed investigations were launched to assess the impacts from many aspects. In the southernmost countries covered, in Bulgaria and Macedonia, similar research just began and the first inventories of natural hazards have been compiled only recently.

In each chapter the hydrometeorological background to geomorphological processes is assessed against the long-term trends. A reliable assessment, however, is hindered by the observation that the highest-intensity events are also the least frequent. If less data are available on them, these events are less suitable for a sound statistical analysis (Zhang 2011; Zhang et al. 2001). The 'moderate extremes' of higher frequency/probability, which occur in several years or in

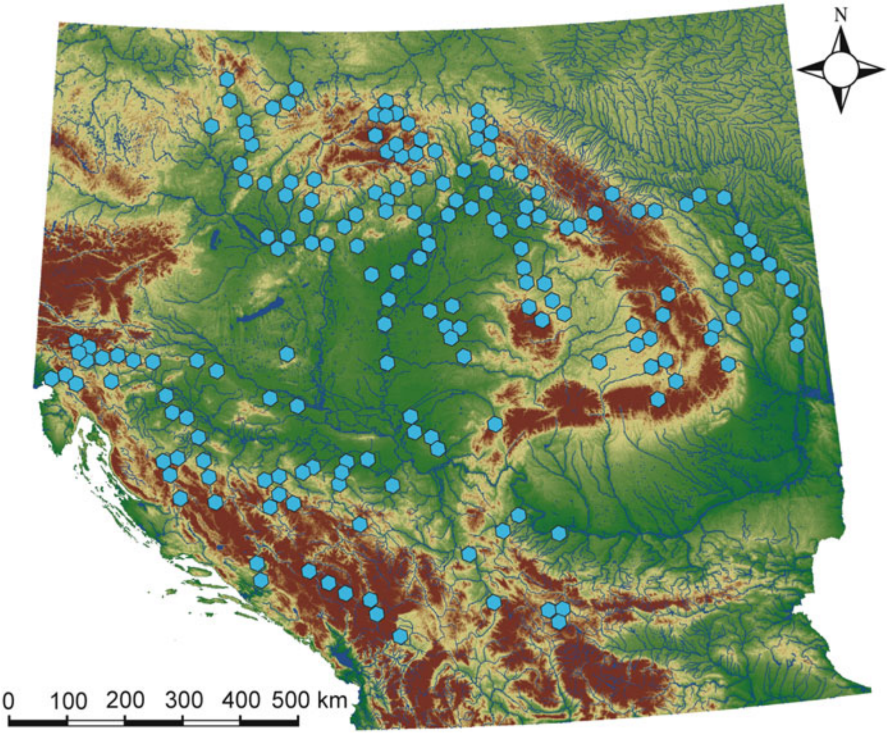

Fig. 1 Geographical distribution of the significant flood events in 2010 (*Source*: ICPDR 2012)

each decade, are easier to tackle statistically. Also their impact on geomorphic evolution is usually more clearly manifested. Notwithstanding, the derived indices of the frequency and intensity of climatic extremes (Frich et al. 2002) are generally suitable for spatial comparisons and pointing out long-term precipitation trends (related to the reference period 1961–1990): RX1D = annual or monthly maximum 1-day precipitation; RX5D = annual/monthly maximum consecutive 5-day precipitation; SDII (Simple Daily Intensity Index) = ratio of annual total precipitation to the number of wet days ($\geq$1 mm); RR1 = annual number of wet days (daily precipitation $\geq$1 mm); RR10 = annual number of days with heavy precipitation ($\geq$10 mm); RR20 = annual number of days with very heavy precipitation ($\geq$20 mm); R95p = very wet days (>95th percentile); and R99p = extremely wet days (>99th percentile). Although the indicators are interpreted slightly differently in the different countries, the editor has tried to make references to the above indices as common denominators of descriptions of precipitation events in the individual chapters. River discharges (and occasionally sediment yields) are described with the parameters routinely used by hydrologists (e.g. Q10, Q50, Q100 return period floods).

The 2009–2010 hydrological year was extraordinarily humid in most of the Danubian countries. Snow depths and rainfall amounts along the Middle and Lower

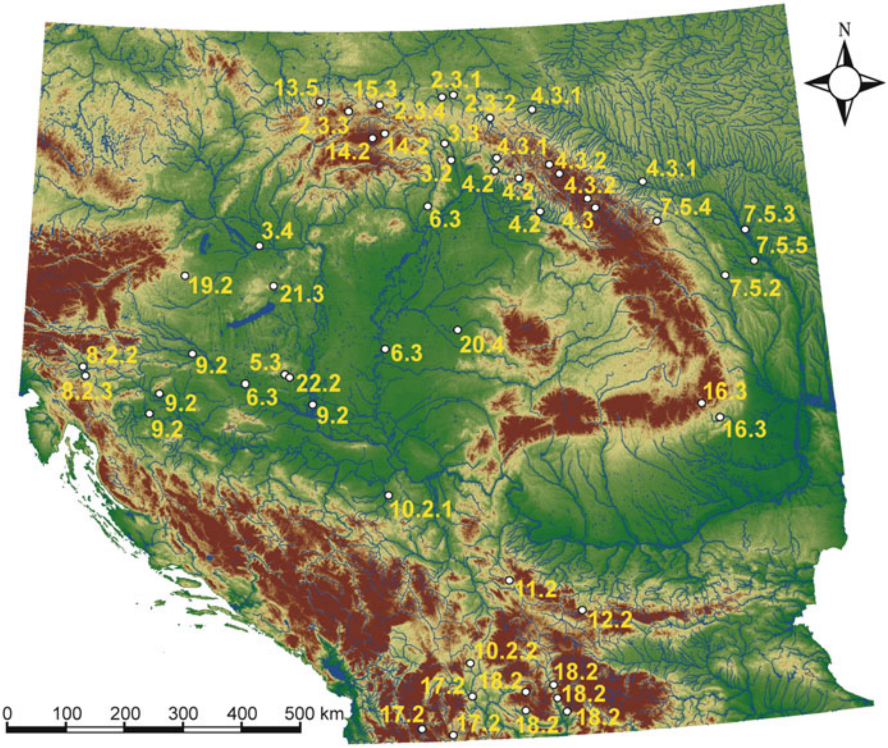

Fig. 2 Location of case studies in the chapters of this volume. The numbers refer to the subchapters where the study areas and the events are presented

Danube River exceeded the multiannual average by 1.5–2.5 times, and maxima never observed since systematic instrumental weather observations have been recorded (Bálint and Liska 2010). The wet period started back in September 2009 and lasted in most of the broader Danubian region for more than a year (with 1 month interruption in March and for some weeks thereafter). The meteorological situation is summarised by Bartholy and Pongrácz (Chap. 1) for this volume.

In the lowlands widespread and lasting flooding was a direct consequence of snowmelt and rainfalls. In May 2010 the most severe damage resulted from *flash floods*, first reported from northern Italy, then from Slovenia (Komac, Zorn – Chap. 8 in this volume). The floods in September 2010 were even more disastrous in Slovenia. They affected 60% of Slovenian municipalities and caused over €240 million damage. The local high water levels accumulated into *riverine floods* on the major rivers of Croatia (see Biondić et al. – Chap. 9). Even the Croatian capital, Zagreb, is endangered by flash floods from Medvednica Mountain, where 52 detention basins are planned to be established (and 19 of them have already been completed – Petráš and Marušić 2009). In 2010 – as well as on previous occasions

(Gilja et al. 2010) – major floods passed on the Sava River. Some parts of Serbia were also heavily affected by riverine and flash floods. The extreme hydro-meteorological conditions and the resultant geomorphological processes in two catchments of Serbia, Kolubara and Pcinja River basins, are treated here (Dragićević et al. – Chap. 10). In eastern Serbia, the floods in the Nišava River basin and the suspended load transport of the rivers are presented by Mustafić et al. (Chap. 11). The cyclone soon reached Hungary, where damage was reported from 510 localities (see Czigány et al. – Chap. 5), and Slovakia with more than 900 localities affected. Lateral channel shifts and spatial variability of channel landforms have been studied using sedimentological techniques on the Ondava, Topl'a, and Danube rivers by Lehotský et al. (Chap. 3). Kiss et al. (Chap. 6) surveyed changes along the Hernád and Tisza rivers, where a couple of major flood waves occurred in 2010. On the Hernád River, a new maximum water stage was even recorded, while no significant flood was measured on the Dráva River. The huge cyclone extended over the Carpathians in Poland (Western Tatra, Bieszczady, and Beskid Niski mountains: Gorczyca et al. – Chap. 2) and Ukraine (the Tysa, Borzhava, Latorytsia, and Uzh watersheds: Kovalchuk et al. – Chap. 4) and even beyond that mountain arc. Large areas in Bosnia (where annual precipitation reached 1,836 mm at Bihać; floods on the Una, Sana, Vrbas, and Bosnia rivers – ICPDR 2012), Montenegro (rapid snowmelt as early as December 2009), and Bulgaria (Nikolova et al. – Chap. 12) have not been spared from devastation either. In Romania 3,000 houses, 4,130 km of national and regional roads, and 700 bridges were damaged (Bálint and Liska 2010). Flash floods induced by torrential rainfalls resulted in casualties mainly on the tributaries of the Mureş and Târnava rivers. The high water levels in the Siret and Pruth drainage basins are analysed by Romanescu (Chap. 7). The material damage was severe: the cost estimations of the individual countries affected add up to ca two billion Euros. In addition, the 2010 floods demanded a minimum death toll of 50 people (Bálint and Liska 2010) in the Carpathian (Middle Danube) Basin. (According to the ICPDR report (2010), there were only 34 victims).

As far as the indirect consequences of extreme weather events are concerned, geomorphologists in the eastern half of Europe – or at least the contributors to this volume – focus their attention on some *processes*, both spectacular in appearance and significant for the transformation of topography. Researchers seem to be most concerned with the corollaries of extreme rainfalls on river channel evolution, including *bank retreat* (Kiss et al. – Chap. 6), the influence of *excess water* inundations on soil properties (Gál, Farsang – Chap. 20), *urban flooding* attributed to improper stormwater management (Ronczyk, Czigány – Chap. 22), the various processes of *soil erosion* and *alluvial fan accumulation* generated by storm runoff in middle mountains and their foothills (Veress et al. – Chap. 19), and the modification of the morphometric parameters of *karst depressions* due to repeated extreme rainfalls (Veress – Chap. 21). The primary focus of interest, however, is understandably a wide range of mass movements, including *debris flows* (in the Tatra Massif, Kotarba (1997); Kotarba et al. (Chap. 14); in the Ukrainian

Carpathians, Kovalchuk et al. (Chap. 4); in the Stara planina (Balkan) mountains, Kenderova et al. (Chap. 18)) and *landslides* of different types, sizes, and mechanisms (in the Moravian–Silesian Beskids, Pánek et al. (Chap. 13); in the Polish Carpathians, Gorczyca et al. (Chap. 15); in the Curvature Carpathians of Romania, Micu et al. (Chap. 16); in the low mountains of Hungary, Czigány et al. (Chap. 5); and at much higher elevations in the mountains of the Republic of Macedonia, Jovanovski et al. (Chap. 17)).

Such diverse themes necessarily call for a wide range of *research methods*. Flood-prone areas are identified by geomorphological mapping and detailed land surveying aided by remote sensing image interpretation. River channel features developed during preceding events are described from the analyses of longitudinal profiles and cross sections of channels and valleys. In an optimal situation, data from surveys prior to floods are also available and the impacts are more reliably assessed. Sedimentological evidence (from grain-size distribution analysis) is often useful for the monitoring of hillslope erosion and river channel dynamics. For flow routing and simulations in watershed-scale studies, various hydrologic models are applicable with interface to connect to geographical information systems.

For flash floods *soil saturation* is a major precondition. To disclose its spatial distribution, a number of automated hydrometeorological stations are necessary, each equipped with soil moisture and temperature sensors. To determine soil depth (lower topsoil boundary, important for interflow detection and also to identify slip planes of landslides), vertical electrical sounding (VES) and hydraulic drilling are successfully employed.

Landslides are mapped in detail by GPS, in inaccessible areas; however, slope deformation is better studied on aerial photos. To reconstruct the temporal evolution of such landforms, radiocarbon and dendrogeomorphological datings are used (as in the case of the Girová landslide in the easternmost corner of the Czech Republic: Pánek et al. – Chap. 13). The inventory and monitoring of landslides (which is in Poland the responsibility of the Polish Geological Institute [PGI]) involves various techniques: terrestrial laser scanning (TLS) to create a detailed and accurate digital elevation model (DEM) and to trace landslide motion. Internal deformations can be registered by inclinometers.

The question arises whether the space devoted to the individual countries is proportional to the severity of hazards generated in them by extreme weather events. The answer is naturally not necessarily. A closer correlation can be found between the number of papers and the national traditions of hazards research. In some of the countries (Romania, Poland, and the Czech Republic), such investigations have recently become the leading topics of geomorphology. In Hungary the humid months of May and June, 2010, also provided a unique opportunity to study the impacts of rainfalls not only in fluvial geomorphology but also in other areas (soil science, karst morphology).

By their nature, the selected case studies are restricted to small areas and, consequently, cannot embrace all the consequences of the 2010 events in their entirety and spatial distribution, but, being representative, well illustrate the directions of research followed by hydrologists and geomorphologists in altogether 11 countries of the Carpatho–Balkan–Dinaric Region.

This collection of chapters is intended to be used by professionals specialised in the following theoretical or practical issues: impacts of climate change, geomorphological hazards (landslides), water management (flood and excess water control), and environmental planning. It can be used either as a reference book on the 2010 events or a handbook for research in a wide range of topics.

The spelling of geographical names follows national traditions for mountains (e.g. Beskid in Polish, Beskydy in Czech) and rivers (Tysa in Ukrainian, Tisza in Hungarian, Tisa in Serbian). The differences, however, are not so great that the reader would find it troublesome to identify the same geographical objects with different names in the individual chapters.

Finally, given the sensitivity of any issue concerning the Balkan countries, a remark is due on how political entities appear in the book. The editor has retained map representations and names of countries in the original form used by the contributors of the individual chapters (for instance, Republic of Srpska, Republic of Macedonia, Republic of Serbia incorporating Kosovo). He apologises if it hurt the national feeling of any reader.

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Part I
Hydrometeorological Background

Chapter 1
Spring and Summer Weather in 2010: Regular or Exceptional?

Judit Bartholy and Rita Pongrácz

Abstract Large rainfall within a relatively short time (a few hours or days) may lead to severe environmental consequences, including floods and landslides. In 2010 numerous precipitation-induced events were reported from Central and Eastern Europe. In order to objectively assess regional precipitation in this particular year, gridded data sets compiled from long-term measurements starting in 1951 are analyzed in this chapter with special focus on the period from May to September 2010. Furthermore, Central/Eastern European extreme values are compared to world records from different geographical regions. In addition to the detected precipitation, projected regional trends for the 21st century are also discussed including precipitation-related climate indices (e.g., number of wet days: when daily precipitation exceeds 1 mm; number of very wet days: when daily precipitation exceeds 20 mm). For this purpose, precipitation outputs from 11 regional climate model simulations are analyzed, taking into account the widely used intermediate global emission scenario (A1B), where the global concentration of carbon dioxide is estimated at 1.9 and 2.6 times the preindustrial atmospheric level by 2050 and 2100, respectively.

Keywords Precipitation distribution • Climate change • Modeling • Wet days • Central and Eastern Europe

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Table 1.1 The highest multiannual average precipitation amounts in different continents

Continent	Precipitation amount (mm)	Geographical location (country)	Elevation (m)	Length of period (years)
Africa	10,287	Debundja (Cameroon)	9	32
Australia	8,636	Bellenden Ker (Queensland)	1,555	9
Asia	11,872	Mawsynram (India)	1,401	38
South America	10,790	Quibdo (Colombia)	37	16
Europe	4,648	Crkvica (Bosnia–Herzegovina)	1,017	22
North America	6,502	Henderson Lake (Canada)	6	14
Oceania	11,684	Mt. Waialeale (Hawaii)	1,569	30

Data source: http://www.satelliten-bilder.de/

1.1 Introduction

Precipitation is among the most variable meteorological elements, both in time and space. Therefore, in order to reliably monitor and analyze its distribution, a much denser network of rain gages is necessary than in the case of temperature measurements. In addition to the global atmospheric circulation, the distance from large water bodies (i.e., ocean, large sea) and the orographic effects determine the geographical distribution of annual precipitation.

Since the beginning of regular precipitation measurements, the highest 1-year precipitation sum (26,461 mm) was observed in the monsoon region of India, in Cherrapunji (elevation: 1,313 m), during the period 1 August 1860–31 July 1861. In the case of four continents (Asia, Oceania, South America, and Africa), precipitation extremes exceed 10,000 mm (Table 1.1), with the lowest of them (4,648 mm) observed in Europe.

In the European regions, however, temporal variability is quite large. In Hungary, for instance, the highest annual precipitation amount (1,554 mm) was observed in 2010 at Jávorkút. It is more than twice as large as the climate normal of the country-wide annual average precipitation (Fig. 1.1). The largest monthly amount (444 mm) was detected in Dobogókő in June 1958. On a finer temporal scale, maximum daily precipitation (203 mm) was observed in Gyömrő on 8 September 1963.

1.2 World Precipitation in 2010

The World Meteorological Organization (WMO) regularly prepares annual statements on the status of the global climate, including globally averaged land *precipitation*. The highest-ever *annual* amount (1,085 mm) occurred in 2010, while for the period 1961–1990, global average was 1,033 mm (WMO 2011). The second and the third highest annual amounts occurred in 1956 and 2000, respectively.

The year 2010 was particularly wet in Central and Southeastern Europe, in the western part of Australia, and in Indonesia (Fig. 1.2). For instance, in Hungary 2010 was the wettest year since 1901, with a spatial average precipitation of

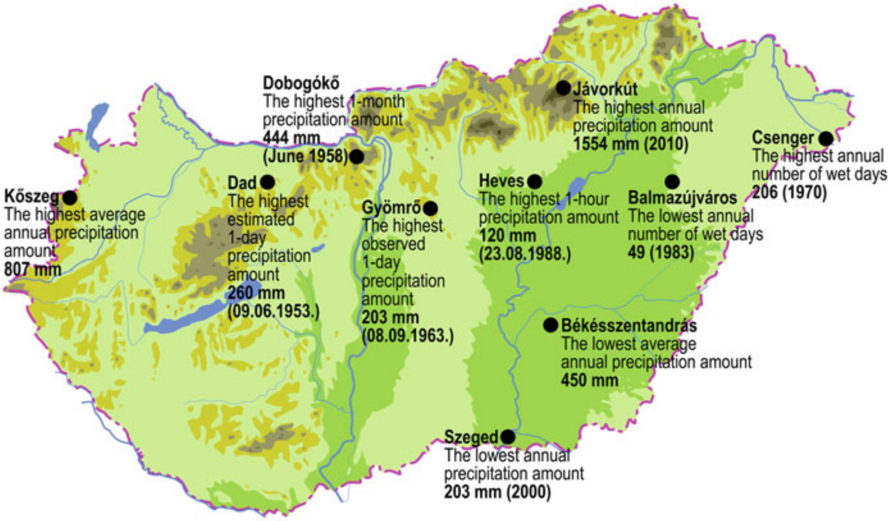

Fig. 1.1 Precipitation-related extremes in Hungary (*Source*: Hungarian Meteorological Service)

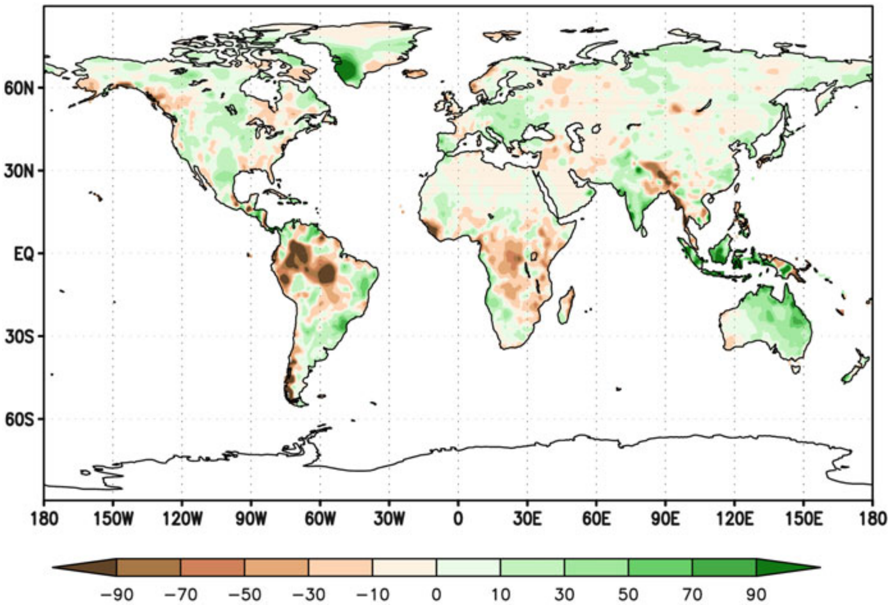

Fig. 1.2 World map of annual precipitation anomaly (mm) in 2010 (reference period: 1979–2000) (*Data source*: Global Precipitation Climatology Centre, Deutscher Wetterdienst (GPCC, DWD))

959 mm (Móring 2011), which is 130 mm more than the previous record (set in 1940). Furthermore, the year 2010 was the most humid on record in Novi Sad, Serbia, and several stations in Moldova (WMO 2011). High precipitation generated intensive runoff processes in Central and Southeastern Europe. Severe *floods* were reported in May–June from southern Poland (IMGW 2010), the Czech Republic, Slovakia, Hungary, Croatia, Bosnia and Herzegovina, Bulgaria, and southern and eastern Germany (Bissolli et al. 2011). In December another series of major floods hit Montenegro, Bosnia and Herzegovina, and Serbia, caused by heavy precipitation in early December when the 3-day precipitation totals reached 100–200 mm (WMO 2011).

1.3 Analysis of Precipitation Time Series for Central/Eastern Europe

The map series of *annual precipitation anomalies* in 2010 for the entire European continent and the Central/Eastern European region (the area between 10°E and 30°E longitudes and between 40°N and 55°N latitudes) compared to the previous 4 years (Fig. 1.3) shows remarkable positive anomalies in Central/Eastern Europe and in the western Iberian Peninsula. For instance, in Portugal and southwestern Spain, the year 2010 was 20 and 50% wetter than normal, respectively (WMO 2011). The spatial extension of the other high positive anomaly is larger for Eastern Europe than in the case of the Iberian Peninsula. The highest annual anomalies occurred near the Adriatic coast; however, annual precipitation was higher than usual in most of Eastern Europe, including Poland, Slovakia, Hungary, and Romania.

For the purpose of the temporal evaluation of precipitation, 60-year *gridded time series* has been analyzed for Central/Eastern Europe with 0.5° horizontal resolution. Maximum, minimum, and spatial average of the annual precipitation grid point anomalies relative to the reference period 1979–2000 have been calculated for the Central/Eastern European region (Fig. 1.4). Also here the record year is undoubtedly 2010, but in the past decade very dry years (2003 and 2000) also occurred in Central/Eastern Europe.

A similar analysis has been accomplished for all countries of the region (Fig. 1.5). The *ranked* country-based *time series* suggests that 2010 was the wettest not only in the broader region but also in the subregions. Spatial mean precipitation *anomalies* were mostly *positive* during the 1951–2010 period in most of the countries, except Hungary and Slovakia. In Slovakia (not shown) the positive and negative anomalies are nearly balanced. Hungary is the only country in the region where negative annual precipitation anomalies dominate the entire period; more specifically, 40 years were drier and 20 years wetter than usual (reference period: 1979–2000).

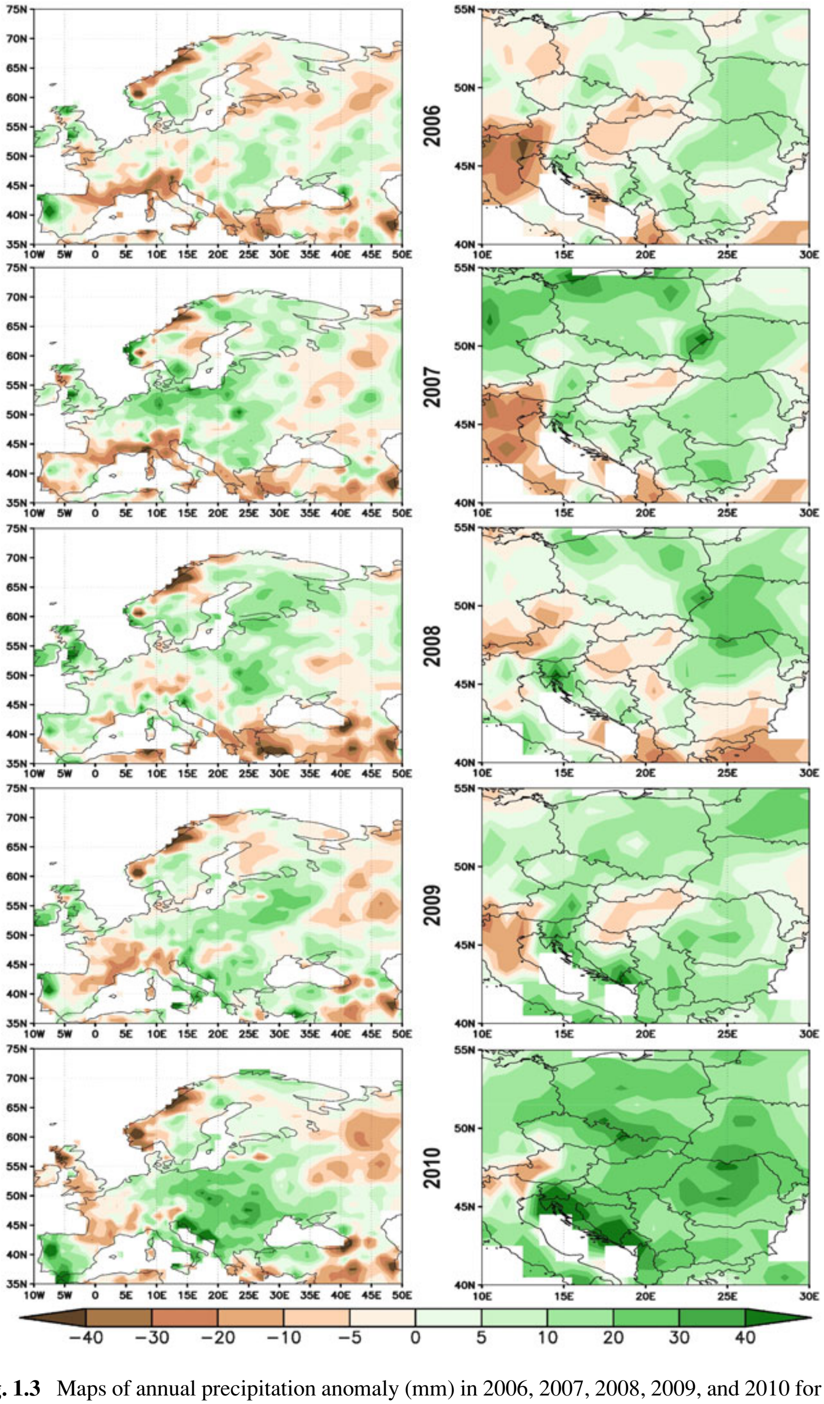

Fig. 1.3 Maps of annual precipitation anomaly (mm) in 2006, 2007, 2008, 2009, and 2010 for the European continent and the Central/Eastern European region (reference period: 1979–2000) (*Data source*: GPCC, DWD)

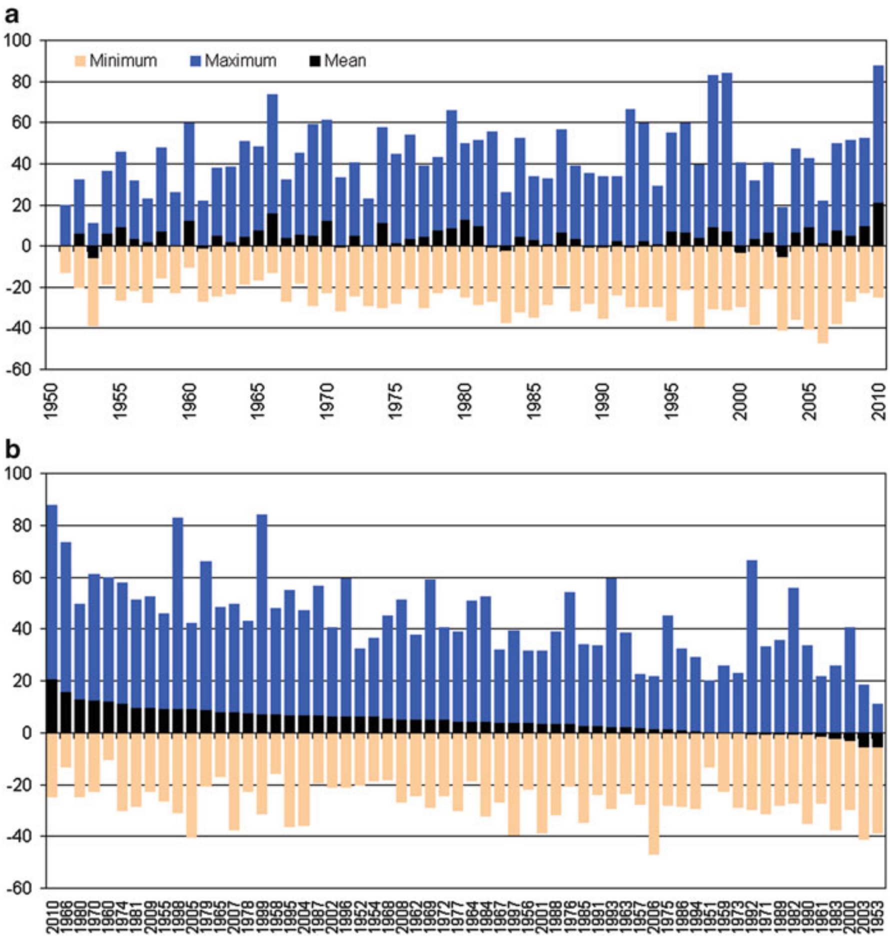

Fig. 1.4 Minimum, mean, and maximum annual precipitation anomalies (mm) for Central/Eastern Europe, 1951–2010 (reference period: 1979–2000. (**a**) Original time series; (**b**) ranked time series based on mean spatial anomalies) (*Data source*: GPCC, DWD)

On the map of *monthly precipitation anomalies* of the Central/Eastern European region for 2010 (Fig. 1.6), remarkably wetter-than-usual conditions can be recognized for May over the entire region with the highest anomalies in southern Poland, northern Slovakia, and the eastern part of the Czech Republic. The high precipitation in May and later in June was caused by two consecutive events resulted from an upper-air low pressure synoptic system over southern Poland, which later became stationary over Southeast Europe (Bissolli et al. 2011).

In most of the months in 2010, *both dry and wet* conditions occurred in different parts of the region. In January, March, and October, the northern subregions were drier than usual, while the southern and southeastern subregions received above-average rainfalls. In July, August, September, November, and December, most of Central/Eastern Europe experienced positive precipitation anomalies, and only