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DAILY DATASET OF 20TH-CENTURY SURFACE AIR TEMPERATURE AND PRECIPITATION SERIES FOR THE EUROPEAN CLIMATE ASSESSMENT

A. M. G. KLEIN TANK,[1]* J. B. WIJNGAARD,[1] G. P. KÖNNEN,[1] R. BÖHM,[2] G. DEMARÉE,[3] A. GOCHEVA,[4] M. MILETA,[5] S. PASHIARDIS,[6] L. HEJKRLIK,[7] C. KERN-HANSEN,[8] R. HEINO,[9] P. BESSEMOULIN,[10] G. MÜLLER-WESTERMEIER,[11] M. TZANAKOU,[12] S. SZALAI,[13] T. PÁLSDÓTTIR,[14] D. FITZGERALD,[15] S. RUBIN,[16] M. CAPALDO,[17] M. MAUGERI,[18] A. LEITASS,[19] A. BUKANTIS,[20] R. ABERFELD,[21] A. F. V. VAN ENGELEN,[1] E. FORLAND,[22] M. MIETUS,[23] F. COELHO,[24] C. MARES,[25] V. RAZUVAEV,[26] E. NIEPLOVA,[27] T. CEGNAR,[28] J. ANTONIO LÓPEZ,[29] B. DAHLSTRÖM,[30] A. MOBERG,[31] W. KIRCHHOFER,[32] A. CEYLAN,[33] O. PACHALIUK,[34] L. V. ALEXANDER[35] and P. PETROVIC[36]

[1] Royal Netherlands Meteorological Institute, De Bilt, The Netherlands; [2] Central Institute for Meteorology and Geodynamics, Austria; [3] Royal Meteorological Institute of Belgium; [4] National Institute of Meteorology and Hydrology, Bulgaria; [5] Meteorological and Hydrological Service, Croatia; [6] Meteorological Service of Cyprus; [7] Czech Hydrometeorological Institute; [8] Danish Meteorological Institute; [9] Finnish Meteorological Institute; [10] Météo-France; [11] Deutscher Wetterdienst; [12] Hellenic National Meteorological Service, Greece; [13] Hungarian Meteorological Service; [14] Icelandic Meteorological Office; [15] Met Éireann, Ireland; [16] Israel Meteorological Service; [17] Ufficio Generale della Meteorologia, Italy; [18] Istituto di Fisica Generale Applicata, Italy; [19] Latvian Hydrometeorological Agency; [20] Division of Climatology of the Institute of Geography, Lithuania; [21] Service Meteorologique du Luxembourg; [22] Norwegian Meteorological Institute; [23] Institute of Meteorology and Water Management, Poland; [24] Instituto de Meteorologia, Portugal; [25] National Institute of Meteorology and Hydrology, Romania; [26] Russian Federal Service for Hydrometeorology and Environmental Monitoring; [27] Slovak Hydrometeorological Institute; [28] Environmental Agency of the Republic of Slovenia; [29] Instituto Nacional de Meteorologia Spain; [30] Swedish Meteorological and Hydrological Institute; [31] Department of Physical Geography and Quarternary Geology, Stockholm University, Sweden; [32] MeteoSwiss, Switzerland; [33] Devlet Meteoroloji Genel Müdürlüoü, Turkey; [34] Central Geophysical Observatory, Committee of the Hydrometeorology, Ukraine; [35] Met Office, UK; [36] Republic Hydrometeorological Institute of Serbia, Yugoslavia

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ABSTRACT

We present a dataset of daily resolution climatic time series that has been compiled for the European Climate Assessment (ECA). As of December 2001, this ECA dataset comprises 199 series of minimum, maximum and/or daily mean temperature and 195 series of daily precipitation amount observed at meteorological stations in Europe and the Middle East. Almost all series cover the standard normal period 1961–90, and about 50% extends back to at least 1925. Part of the dataset (90%) is made available for climate research on CDROM and through the Internet (at http://www.knmi.nl/samenw/eca).

A comparison of the ECA dataset with existing gridded datasets, having monthly resolution, shows that correlation coefficients between ECA stations and nearest land grid boxes between 1946 and 1999 are higher than 0.8 for 93% of the temperature series and for 51% of the precipitation series. The overall trends in the ECA dataset are of comparable magnitude to those in the gridded datasets.

The potential of the ECA dataset for climate studies is demonstrated in two examples. In the first example, it is shown that the winter (October–March) warming in Europe in the 1976–99 period is accompanied by a positive trend in the number of warm-spell days at most stations, but not by a negative trend in the number of cold-spell days. Instead, the number of cold-spell days increases over Europe. In the second example, it is shown for winter precipitation between 1946 and 1999 that positive trends in the mean amount per wet day prevail in areas that are getting drier and wetter.

Because of its daily resolution, the ECA dataset enables a variety of empirical climate studies, including detailed analyses of changes in the occurrence of extremes in relation to changes in mean temperature and total precipitation.

KEY WORDS: daily climate dataset; temperature and precipitation extremes; climate of Europe

* Correspondence to: A. M. G. Klein Tank, Royal Netherlands Meteorological Institute, PO Box 201, 3730 AE De Bilt, The Netherlands; e-mail: albert.klein.tank@knmi.nl

1. INTRODUCTION

There is a growing interest in extreme weather events, like food- or flood-producing rains, droughts, severe heat/cold spells, and gales (Easterling *et al*., 2000; Houghton *et al*., 2001). Identification of changes in the occurrence of these events requires accurate, complete and spatially consistent climatic time series with at least daily resolution (Jones *et al*., 1999; Folland *et al*., 2000), since only daily and higher-resolution series account for the sub-monthly time scale nature of extreme weather events. For the USA (Peterson *et al*., 1997), Canada (Vincent *et al*., 2000), the former Soviet Union (Razuvaev, personal communication) and Australia (Lavery *et al*., 1997; Trewin, 1999), datasets of daily temperature and precipitation have been developed. For Europe, such a dataset of daily station observations is not available, so far. Existing climatic datasets with satisfactory spatial coverage of Europe consist of monthly (mean) values only.

Until now, studies on climate extremes that consider Europe have usually had a strong national signature (e.g. Herzog and Müller-Westermeier, 1997; Brunetti *et al*., 2001), or have had to make use of either a dataset with daily series from a very sparse network of meteorological stations (e.g. eight stations in Moberg *et al*. (2000)) or standardized data analysis performed by different researchers in different countries along the lines of agreed methodologies (e.g. Brazdil *et al*., 1996; Heino *et al*., 1999). The only other studies based on networks that cross national borders refer to the Nordic countries, where the National Meteorological Services developed a dataset that includes some sub-monthly information, like the absolute daily maximum temperature in a month and the maximum 1-day precipitation amount (Forland *et al*., 1998; Tuomenvirta *et al*., 2001). Owing to all these limitations, studies on European climate extremes so far suffer from inherent low spatial coverage, restricted information about daily extremes, and lack of standardization in the definition of extremes. It is obvious, therefore, that systematic analysis of changes in climate extremes requires a single European dataset with daily resolution.

Although Europe has a long history of routine meteorological observations, the compilation of a good quality dataset with daily resolution requires much effort. The main reasons are that archiving, maintaining and dissemination of daily climatic time series are the individual responsibility of more than 30 countries, each with its own storage system and data policy. Yet these multiple sources need to be opened up, as the alternative — collecting the daily data from synoptic observations transmitted on a routine basis over the global telecommunication system — has proven to result in a dataset of inferior quality (Folland *et al*., 1999).

We compiled a comprehensive European dataset consisting of daily temperature (minimum, maximum and/or daily mean) and precipitation series to address a whole range of questions of the type:

(1) Is the increase in mean temperature, as observed in many areas over the last few decades, accompanied by a decreasing number of frost days and a systematic advance in the start of the thermal growing season?
(2) Is the change in the number of very wet days more pronounced than the change in total annual precipitation, as in Groisman *et al*. (1999), who hypothesized that in many areas of the world only the scale of the daily precipitation distribution changes and not its shape, leading to an amplification of the changes in extreme precipitation relative to changes in the total amounts?

The objective of the current paper is to present and evaluate the contents of the dataset. As outlined in Section 2, the dataset was developed in the framework of the European Climate Assessment (ECA) project. Section 3 describes the quality-control procedure that was applied to the daily series in the dataset; and in Section 4 the ECA dataset is compared with existing (gridded) datasets with monthly resolution. Section 5 illustrates the potential of the ECA dataset in two examples: one on the relation between winter warming and trends in the number of days belonging to cold or warm spells, and the other on the relation between precipitation changes and wet-day trends.

2. DATA COLLECTION

In the ECA project the temperature and precipitation climate is analysed for WMO Region VI (Europe and Middle East: Lebanon, Syria, Jordan and Israel), putting particular emphasis on changes in daily extremes. The

ECA aims at applying uniform analysis methodologies to daily observational series from as many European meteorological stations as possible. So far, 34 countries participate in the ECA project (Figure 1; see also the authors' list), and the current version of the ECA dataset (December 2001) contains data from over 200 stations. Figure 2 shows the geographical distribution of stations for which daily time series have been collected. In the area covered by the participating countries, there are a total of 109 GCOS surface network (GSN) stations, assigned by the WMO for their importance for climate monitoring (Peterson *et al*., 1997). However, the participants included only 45 of these GSN stations in the ECA dataset.

The ECA project focuses on the 20th century from 1901 to 1999. For this time interval, station series with daily resolution have been collected where possible. Figure 3 indicates that most of the series cover the standard normal period 1961–90, and about 50% extends back to at least 1925. The strong decline in recent years in Figure 3 is due to the delay in archiving and quality-controlling meteorological data in the collaborating institutes and the time needed for collection in the ECA. There are 199 temperature series and 195 precipitation series; 172 stations have both temperature and precipitation series, 27 stations have temperature only, and 23 stations precipitation only. Of the stations having temperature series, 127 stations feature minimum, maximum and daily mean temperature, whereas 64 stations have minimum, maximum temperature only and eight stations daily mean temperature only. Respecting the data policies of the participants, a selection of the daily series in the ECA dataset (90%) is made available to the public on CDROM and through the Internet (at http://www.knmi.nl/samenw/eca). The list of station series at the website, which gives the start and end dates of each series in the dataset, includes a column indicating whether the series is available online. At the moment (December 2001), this is true for about 60% of the data; i.e. for 114 temperature series and 118 precipitation series from 20 countries. History metadata, like information on station surroundings, measuring instruments, observation times, and algorithms to calculate mean temperature, are not included in the December 2001 version. The release of an elaborated update of the ECA dataset is planned for 2002.

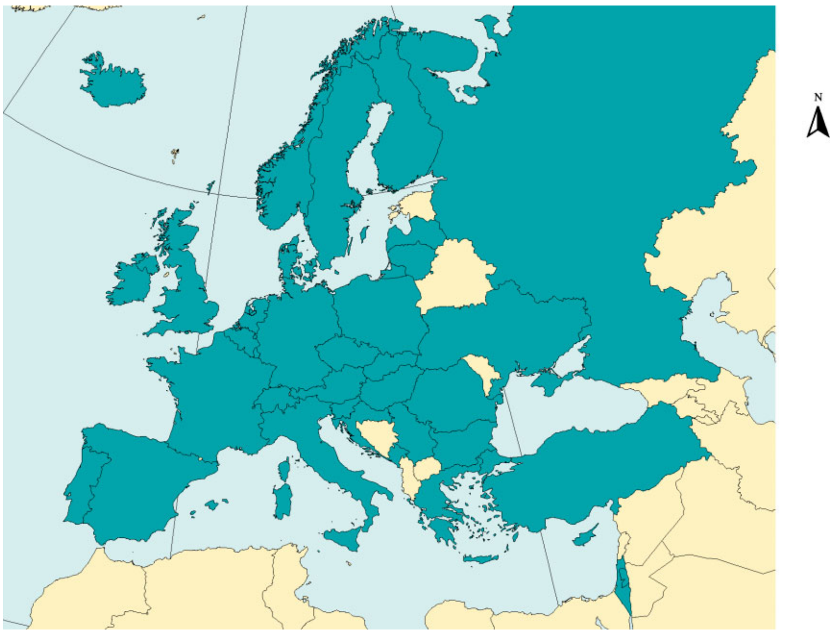

Figure 1. Participating countries in the ECA project that contributed daily climatic time series to the ECA dataset (status December 2001)

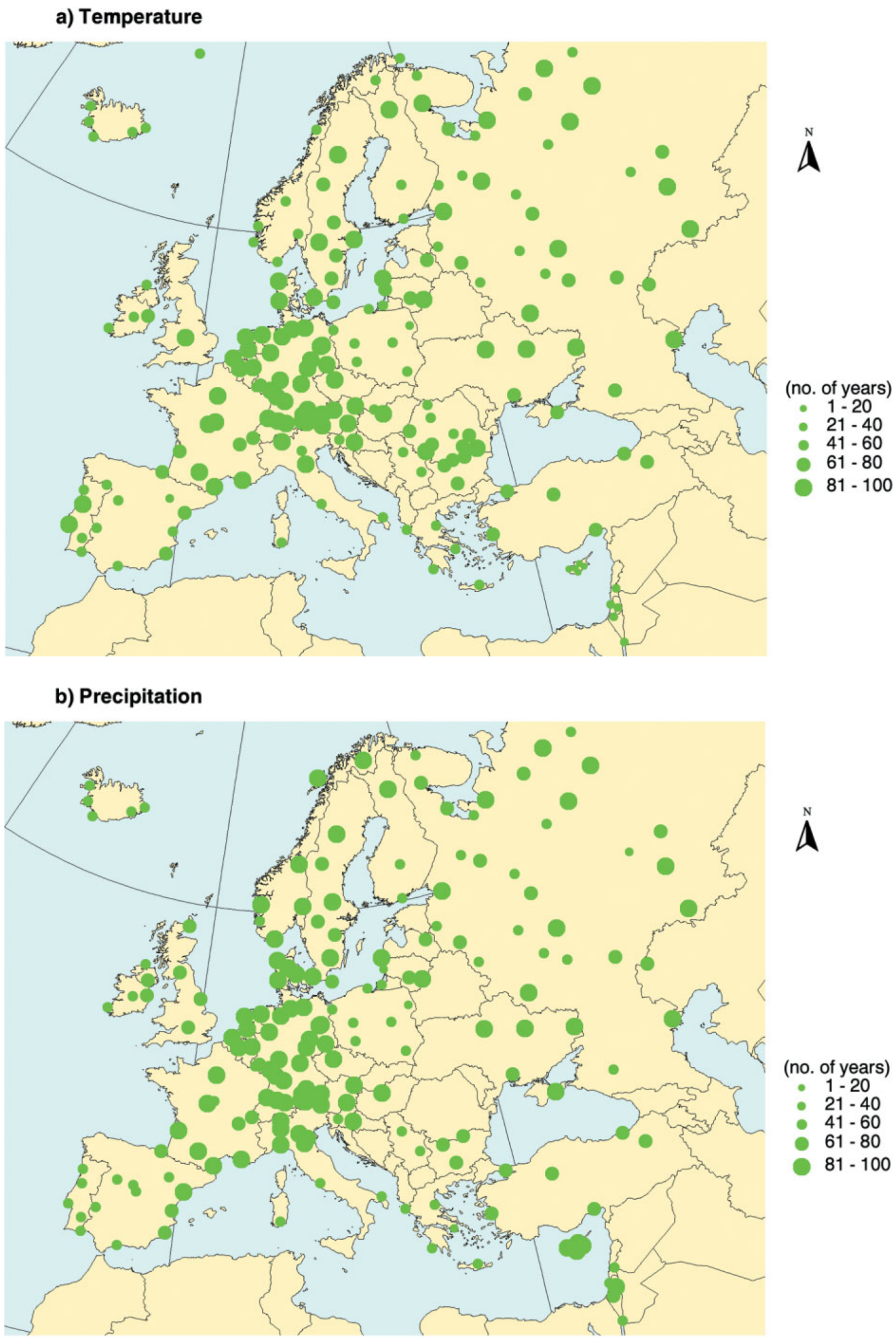

Figure 2. Stations with daily temperature (a) and daily precipitation (b) series in the ECA dataset. Station dots are scaled with the length of the time series. For details see the list of station series at http://www.knmi.nl/samenw/eca

3. DAILY TIME SERIES QUALITY CONTROL

Climatic time series typically exhibit spurious (non-climatic) jumps and/or gradual shifts due to changes in station location, environment, instrumentation or observing practices. In many daily resolution climatic time series, there is also a number of missing observation days. Because the degree of inhomogeneity and

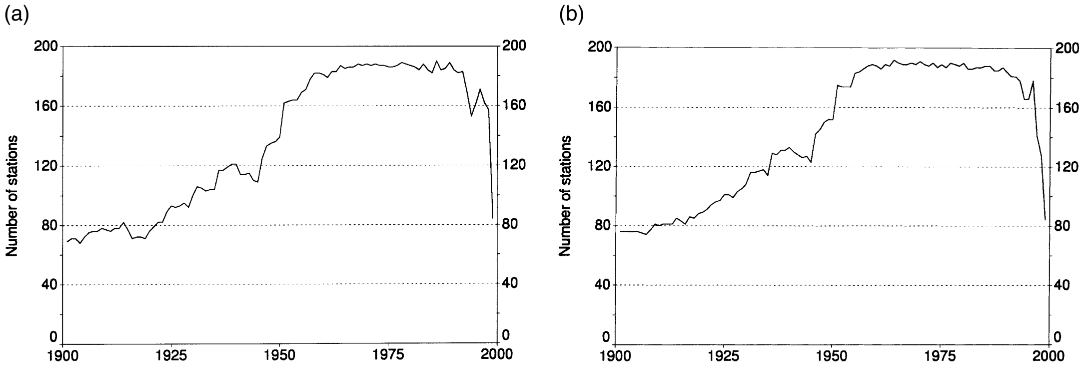

Figure 3. Number of stations with daily temperature (a) and daily precipitation (b) series in the ECA dataset

incompleteness of a daily resolution series determine the types of extremes analysis that can be undertaken, e.g. see Moberg *et al.* (2000) and Tuomenvirta *et al.* (2000), data quality control is an ongoing activity in the ECA project.

In the December 2001 version of the ECA dataset, the daily series were subjected to a basic quality control procedure only. Every time series is checked for the occurrence of miscoding, like: precipitation <0 mm; minimum temperature > maximum temperature; non-existent dates; and erroneous outliers. Although the series have usually undergone routine quality control procedures by the supplying institutes, our additional checks identified a number of days with non-correctable mistakes. Such days are assigned 'missing values' in the ECA dataset. Currently, statistical homogeneity tests are being applied to the ECA series. The results of these tests will be included in the updated version of the ECA dataset.

4. COMPARISON WITH EXISTING (GRIDDED) DATASETS

An evaluation of the quality of the ECA dataset was carried out by comparing the 1946–99 annual averages of the daily series with those of existing datasets of lower temporal resolution. Mean temperatures were compared with grid box values in the Jones dataset of land air temperature anomalies (Jones, 1994; Jones *et al.*, 2001); precipitation amounts were compared with grid box values in the Hulme land precipitation dataset (Hulme, 1992; Hulme *et al.*, 1998). These two gridded datasets have been derived from quality-controlled monthly series of stations that may also be on the ECA list. But the percentage of common stations is small: 56% of the ECA stations make up only about 15% of the European stations in the gridded datasets (Jones, personal communication). Furthermore, sea surface temperature anomalies were merged into the grid box temperatures around coastal areas, whereas the ECA dataset contains station observations only.

For each ECA station, Figure 4(a) shows the correlation between the ECA temperature series and the temperature series of the nearest land grid box in the Jones dataset (1946–99). For the ECA stations where daily mean temperature is missing, but minimum and maximum temperatures are available, the average of minimum and maximum temperature was used. Time series with more than 20% of missing years were excluded from the analysis. In terms of the annual means, the daily ECA temperature series fit in well with the monthly series of the temperature grid. For 93% of the stations the correlation coefficient exceeds 0.8. A north–south gradient in correlation coefficients is apparent in Figure 4(a). Precipitation correlation coefficients (Figure 4(b)) exceed 0.8 at only 51% of the stations, despite of the higher density of the precipitation grid (2.5 °lat × 3.75 °lon) compared with the temperature grid (5 °lat × 5 °lon). This lower correspondence results from the inherent lower spatial coherence of precipitation fields. A northwest–southeast gradient in correlation coefficients is apparent in Figure 4(b).

Table I presents the European averages of temperature and precipitation trends in the ECA dataset and the gridded datasets. The 1946–99 period, its 30 year sub-period 1946–75, and the remaining sub-period 1976–99 are considered separately. European trends were calculated from grid box weighted average series,

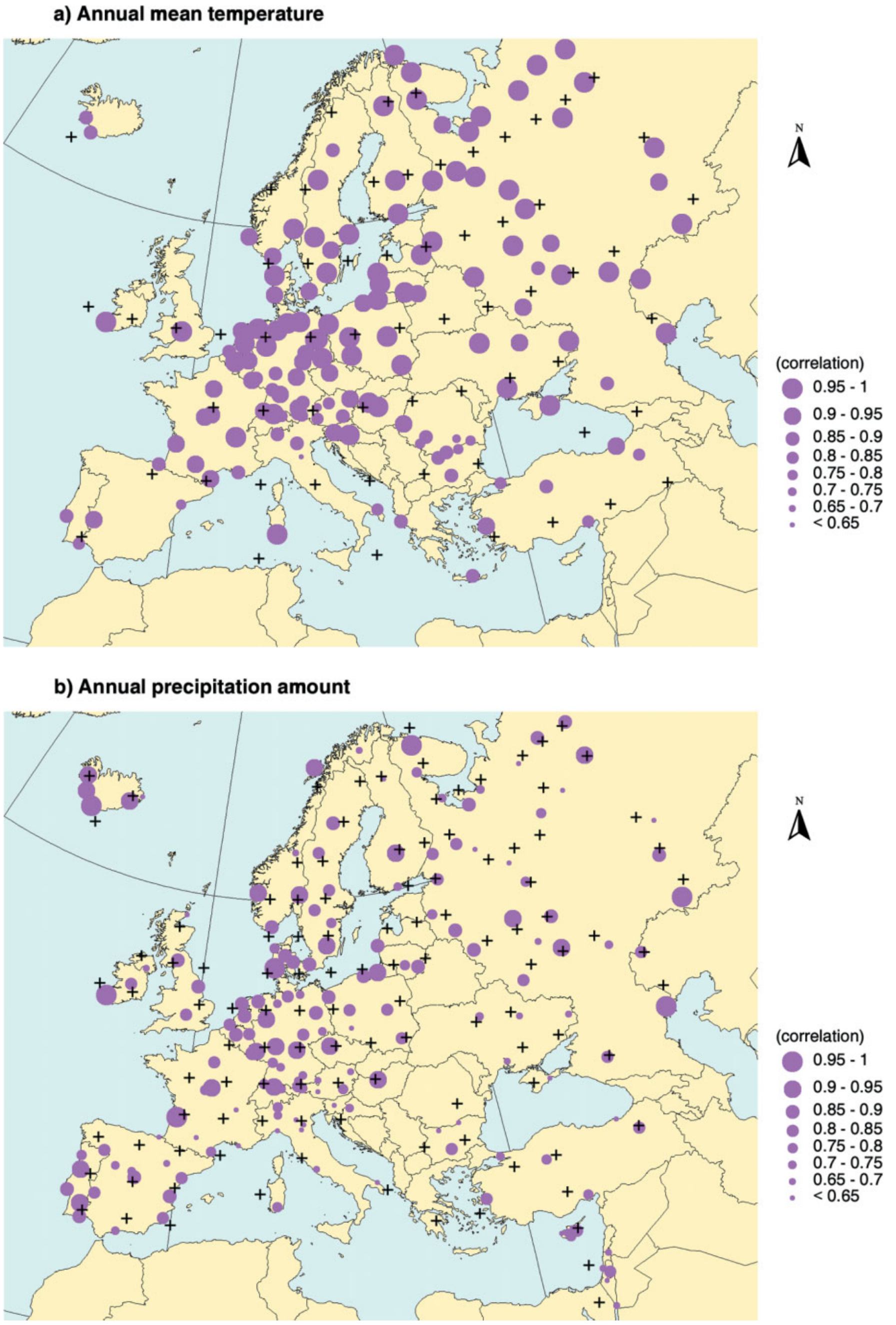

Figure 4. Correlation coefficients (1946–99) between annual mean temperature at stations in the ECA dataset and nearest land grid boxes of the Jones temperature dataset (a) and between annual precipitation amount in the ECA dataset and nearest land grid boxes of the Hulme precipitation dataset (b). The centres of the grid boxes used in the comparison with ECA are indicated

obtained as follows. For each Jones/Hulme grid box containing one or more ECA stations, the annual series of all stations in that grid box were arithmetically averaged. The resulting grid box series (41 for temperature and 97 for precipitation) were then averaged to derive the European ECA series. The corresponding European series for the gridded datasets were derived by arithmetically averaging the annual series of the same grid boxes as for ECA. Grid boxes without ECA stations, grid box series with more than 20% of missing years

Table I. Comparison of average trends in annual mean temperature and annual precipitation amount for stations in the ECA dataset and corresponding land grid boxes of the Jones and Hulme datasets. The trends for ECA stations were calculated from the time series obtained by first averaging the ECA station series in each Jones/Hulme grid box, and then averaging the series over these grid boxes (see text). The numbers n in the table header denote the number of grid boxes used in the comparison. The 95% confidence intervals are shown in parentheses. For none of the (sub-)periods did the trends for ECA stations and land grid boxes differ significantly at the 5% level (paired t-test)

	Temperature trend (°C/decade); $n = 41$		Precipitation trend (mm/decade); $n = 97$	
	ECA stations	Land grid boxes (Jones)	ECA stations	Land grid boxes (Hulme)
1946–99	0.04 (−0.04–0.08)	0.03 (−0.05–0.11)	11.1 (5.5–16.8)	6.4 (1.3–11.4)
1946–75	−0.04 (−0.24–0.16)	−0.03 (−0.21–0.15)	16.1 (2.1–30.1)	4.7 (−8.4–17.8)
1976–99	0.42 (0.10–0.74)	0.38 (0.08–0.68)	−2.8 (−20.0–14.4)	−0.2 (−15.0–14.6)

in a (sub-)period, and years in grid box series for which either the ECA or gridded value were missing were omitted. Also, the years in the European series whose values were based on fewer than 80% of the total number of grid boxes considered were assigned missing values. Table I shows that an agreement exists between the average magnitude of trends at ECA stations and land grid boxes.

5. TWO EXAMPLES OF DATASET APPLICATIONS

The potential of the ECA dataset is demonstrated in two examples, highlighting the benefits of the daily resolution of the climatic time series.

In the first example, the effect of increasing winter (October–March) temperature on the number of days belonging to cold or warm spells is explored for the rapidly warming period 1976–99. Analogous to the cold/warm days definition of Jones *et al.* (1999) and Horton *et al.* (2001), we defined cold/warm spells at a given site as periods of at least six consecutive days with daily mean temperatures below/above the lower/upper tenth percentile of the temperature distribution for each calendar day in the 1961–90 standard normal period. These calendar-day specific percentiles were calculated from 5 day windows centred on each calendar day. This gives a total sample size of 30 years × 5 days = 150 for each calendar day. The length of each spell is expressed in a single index that comprises the total number of days in that spell. For instance, a cold spell lasting 6 days yields 6; a cold spell of 7 days yields 7, etc., whereas a cold period of 5 days or less yields zero. The cold spell index of a winter is the sum of the indices of all spells in that winter, which equals the total number of days per winter that are members of any cold spell in that winter.

Trends in the number of cold/warm-spell days and in mean temperature were calculated for each individual ECA station and for Europe as a whole. Here, the European trends were calculated from European time series obtained by arithmetically averaging all 168 station series with no more than 20% of missing years in the 1976–99 period. In each year of the European series more than 80% of the total number of stations contributed to the European average.

The trends in winter mean temperature and cold/warm-spell days for stations in the ECA dataset between 1976 and 1999 are depicted in Figure 5. The figure shows that the winter warming is accompanied by an increase in the number of warm-spell days at nearly every ECA station. On the other hand, at less than 10% of the stations the winter warming is accompanied by a decrease in the number of cold-spell days. Averaged over all ECA stations, the increase in the number of warm-spell days of 3.0 days/decade is even accompanied by an increase in the number of cold-spell days of 0.2 days/decade, rather than a decrease in the number of cold-spell days (Table II). A similar, though weaker, asymmetric behaviour of warm- and cold-spell days is found for summer warming, with a five times larger trend in the number of warm-spell days than cold-spell days. Given the small climatological-mean number of cold- and warm-spell days per season in the 1961–90 standard normal period, the trends are really large and show that changes in the outbreak of cold and warm spells are not trivially related with changes in mean temperature. This non-triviality was also noted by Walsh

Table II. Average change in summer (April–September) and winter (October–March) mean temperature, number of warm-spell days and number of cold-spell days for stations in the ECA dataset between 1976 and 1999. The changes refer to increases in temperature and number of warm-spell days, but to *decreases* in number of cold-spell days, so that positive numbers refer to warming throughout. The 95% confidence intervals are shown in parantheses. The climatological means (1961–90) for the number of warm/cold-spell days are shown in square brackets. All numbers were calculated from European time series obtained by arithmetically averaging over 168 ECA stations. The European trend in annual temperature according to this method is 0.45 (0.15–0.75); cf. Table I

	Temperature increase (°C/decade)	Warm-spell days increase (days/decade)	Cold-spell days decrease (days/decade)
Summer (April–September)	0.46 (0.24–0.68)	3.6 (2.5–4.6) [2.9]	0.7 (0.0–1.4) [1.9]
Winter (October–March)	0.47 (0.01–0.93)	3.0 (1.1–4.8) [2.4]	−0.2 (−1.9–1.4) [3.8]

et al. (2001) in the relation between cold outbreaks and temperature in the National Centers for Environmental Prediction reanalysis data for 1948–99. Unravelling these kinds of relations is only possible with the aid of daily resolution observations, like those collated in the ECA dataset.

The second example deals with precipitation changes. Figure 6 shows that the station trends in the winter (October–March) total precipitation amount between 1946 and 1999 should not only be attributed to changes in the number of wet days ≥1 mm. For most stations the percentage changes in total amounts are different from the percentage changes in the number of wet days. This is caused by the accompanying changes in the mean precipitation amounts per wet day, i.e. the average rain intensity per wet day. This rain intensity index predominantly increases over Europe, both at stations with positive trends and at stations with negative trends in total winter precipitation amount.

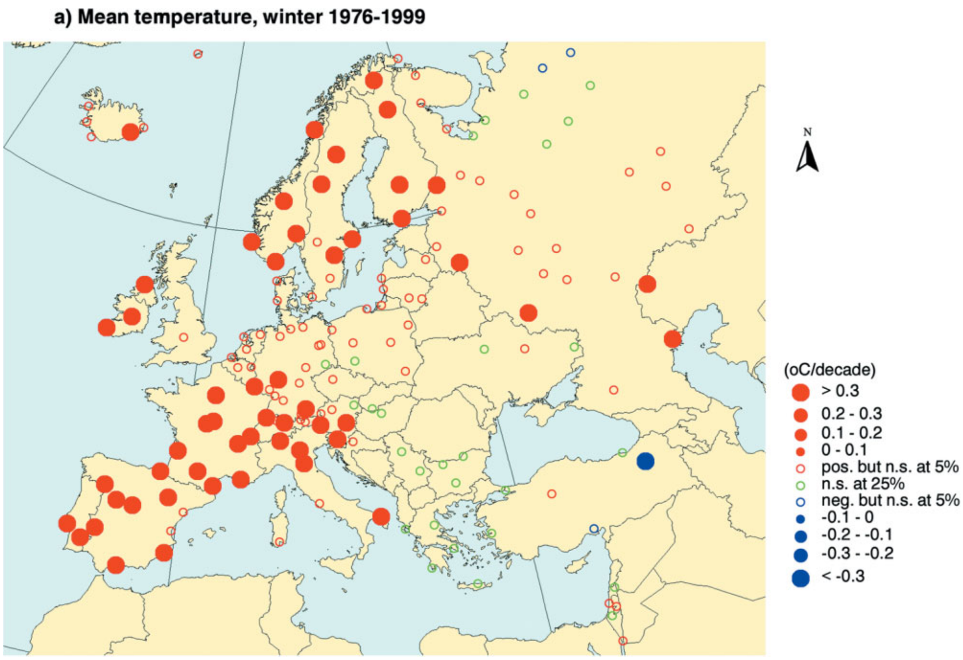

Figure 5. Trends in winter (October–March) mean temperature (a), number of cold-spell days (b) and number of warm-spell days (c) between 1976 and 1999. For trends significant at the 25% level, but not at the 5% level (Student's *t*-test), only the sign of the trend is given and not its magnitude. Colour coding is applied: blue corresponds to cooling, red to warming. Green is used for trends that are not significant at the 25% level. No warming effect is seen in the number of cold-spell days

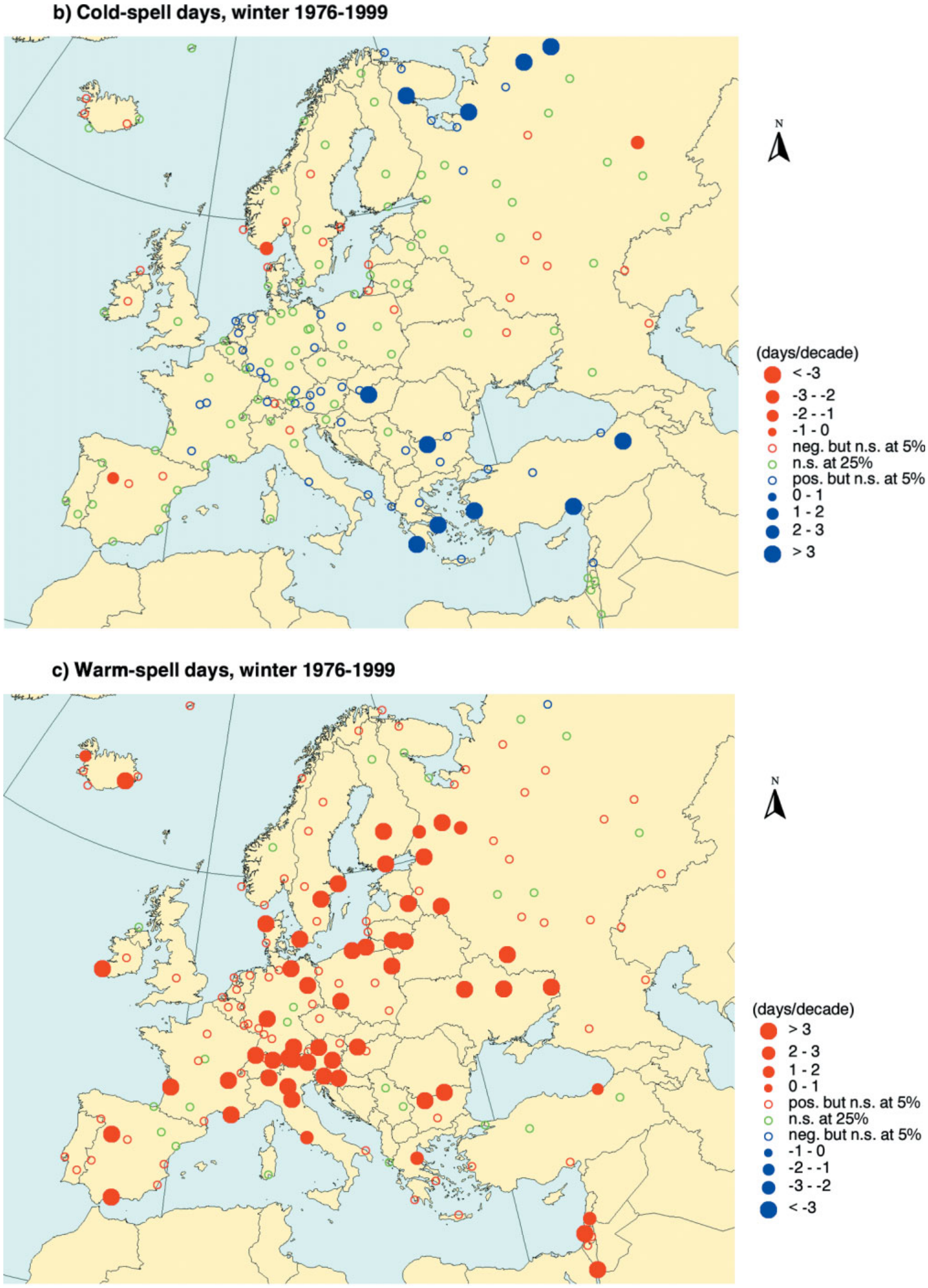

Figure 5. (*Continued*)

6. CONCLUSIONS AND DISCUSSION

With a total of 199 station series of daily temperature and 195 station series of daily precipitation in the ECA dataset, we accomplished an important initial step towards the development of a high-resolution dataset for Europe and the Middle East that is suitable for the analysis of changes in climate extremes and allows for a variety of other climate studies. Although this daily dataset is made available for climate research on

CDROM and through the Internet, it cannot yet be guaranteed that every temperature and precipitation series in the December 2001 version will be sufficiently homogeneous in terms of daily mean and variance for every application. It is clear that, at some stations, changes in instruments have led to discontinuities. It is also clear that the time series of some city stations include urban heating effects, as well as discontinuities resulting from station relocations to out-of-town airports. At the moment, there are no established methods to determine and adjust such inhomogeneities in daily resolution time series, although some techniques are under development, e.g. see Vincent *et al*. (2000) and Brandsma (2001). Within the ECA project, Wijngaard and Klein Tank (2001) explored the application to the ECA dataset of established statistical techniques that have been developed for homogeneity testing of lower time resolution series, e.g. see Szalai *et al*. (1999).

In this paper, we have restricted ourselves to a first quality assessment of the ECA dataset by comparing the temperature and precipitation series to existing gridded datasets of monthly resolution. It may be argued that this comparison is biased, because the gridded datasets are based on monthly series from stations that partly overlap the list of ECA stations. However, the fact that the ECA stations make up only a small part of the gridded datasets and that the correlation coefficients between the annual values of the ECA series and the grid box series are generally higher than 0.8 strengthens our confidence in the ECA dataset. Besides, in terms of the average magnitude of temperature and precipitation trends, there is also a fairly good correspondence between the ECA dataset and the gridded datasets. Deviations between individual station trends and nearby grid box trends may correspond with suspect station series, but may also represent local climate anomalies that cannot be captured by the grid. However, it is not *a priori* clear that the gridded series can act as a homogeneous baseline. Differences might also originate from flaws in the gridded datasets (Moberg and Alexandersson, 1997).

The potential of the ECA dataset is demonstrated in two examples: (1) the observed counter-intuitive trends in the number of cold-spell days over Europe that accompany the warming trends in mean winter temperature between 1976 and 1999; and (2) the predominant increasing trends in mean precipitation amount per wet

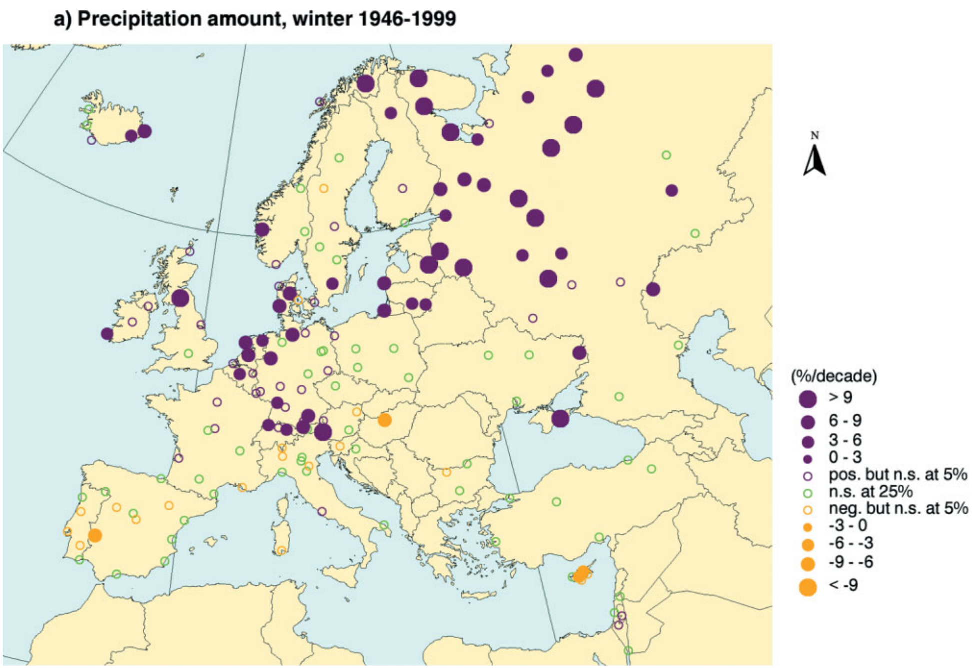

Figure 6. Trends in winter (October–March) precipitation amount (a), number of wet days ≥1 mm (b) and mean precipitation amount per wet day (c) between 1946 and 1999. Precipitation amount and number of wet days were calculated as percentage anomalies with respect to the 1961–90 means. Statistical significance is as in Figure 5. Colour coding is applied: yellow corresponds to drier conditions, violet to wetter conditions. Green is used for trends that are not significant at the 25% level. In contrast to the total winter precipitation amounts and the number of wet days, the mean precipitation amount per wet day increased throughout Europe

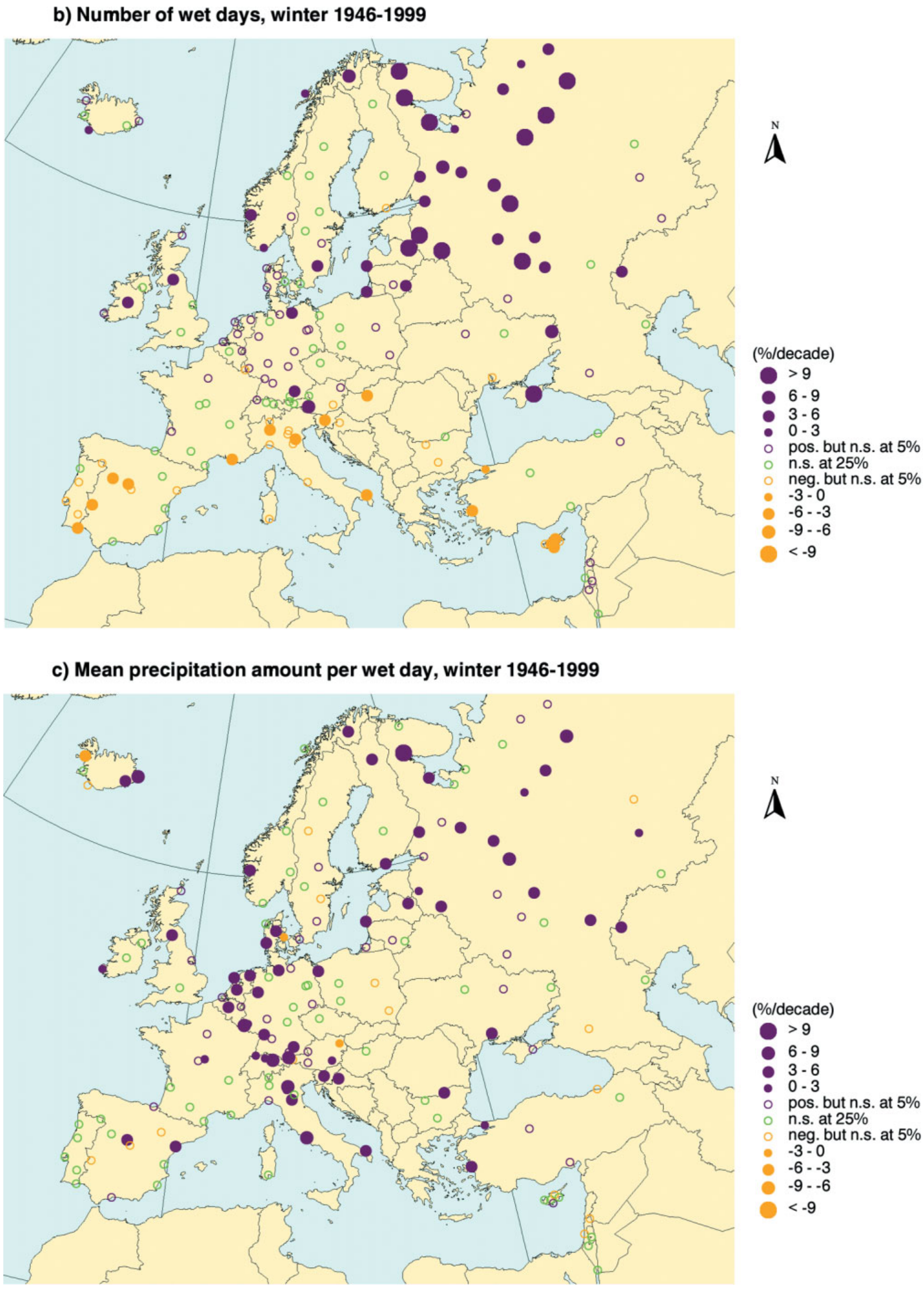

Figure 6. (*Continued*)

winter-day in Europe, inclusive of regions where the total precipitation amounts decrease (1946–99). These two examples illustrate that there need not be a trivial relation between the change in the mean (or total) of a climatic parameter and the change in other statistical characteristics, such as the extremes. The ECA dataset with daily time resolution facilitates the consistent analysis of such relationships for Europe and the Middle East.

The first study on climate extremes based on the ECA dataset (Frich *et al.*, 2002) proves that the dataset serves its initial purpose of climate change detection and analysis of sub-monthly climate extremes. In order to make the dataset fully applicable for systematic monitoring of changes in climate extremes, regular updates are required, together with concentrated and enhanced efforts on data quality control and daily time series homogenization.

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The Jones temperature dataset is available from the Climatic Research Unit at http://www.cru.uea.ac.uk/cru/data/temperature. The Hulme precipitation dataset is available from the Climatic Research Unit at http://www.cru.uea.ac.uk/~mikeh/datasets/global. The dataset 'gu23wld0098.dat' (Version 1.0) is constructed and supplied by Dr Mike Hulme at the Climatic Research Unit, University of East Anglia, Norwich, UK (supported by the UK Department of the Environment, Transport and the Regions, contract EPG 1/1/48).

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