STARDEX

STAtistical and Regional dynamical Downscaling of EXtremes for European regions

EVK2-CT-2001-00115

Deliverable D9

Trends in extreme daily precipitation and temperature across Europe in the 2nd half of the 20th century

FOREWORD

The STARDEX project on STAtistical and Regional dynamical Downscaling of EXtremes for European regions is a research project supported by the European Commission under the Fifth Framework Programme and contributing to the implementation of the Key Action "global change, climate and biodiversity" within the Environment, Energy and Sustainable Development.

STARDEX will provide a rigorous and systematic inter-comparison and evaluation of statistical and dynamical downscaling methods for the construction of scenarios of extremes. The more robust techniques will be identified and used to produce future scenarios of extremes for European case-study regions for the end of the 21st century. These will help to address the vital question as to whether extremes will occur more frequently in the future.

For more information about STARDEX, contact the project co-ordinator Clare Goodess (c.goodess@uea.ac.uk) or visit the STARDEX web site:
http://www.cru.uea.ac.uk/projects/stardex/

STARDEX is part of a co-operative cluster of projects exploring future changes in extreme events in response to global warming. The other members of the cluster are MICE and PRUDENCE. This research is highly relevant to current climate related problems in Europe. More information about this cluster of projects is available through the MPS Portal:
http://www.cru.uea.ac.uk/projects/mps/

STARDEX is organised into five workpackages including Workpackage 2 on 'Observational analysis of changes in extremes, their causes and impacts' which was responsible for the production of this deliverable (D9). Workpackage 2 is co-ordinated by András Bárdossy from the Institut für Wasserbau, University of Stuttgart, Germany.

STARDEX PROJECT MEMBERS

UEA	University of East Anglia, UK
KCL	King's College London, UK
FIC	Fundación para la Investigación del Clima, Spain
UNIBE	University of Berne, Switzerland
CNRS	Centre National de la Recherche Scientifique, France
ARPA-SMR	Servizio Meteorologico Regionale, ARPA-SMR Emilia-Romagna, Italy
ADGB	University of Bologna, Italy
DMI	Danish Meteorological Institute, Denmark
ETH	Swiss Federal Institute of Technology, Switzerland
FTS	Fachhochschule Stuttgart – Hochschule für Technik, Germany
USTUTT-IWS	Institut für Wasserbau, Germany
AUTH	University of Thessaloniki, Greece

D9 AUTHORS AND VERSION HISTORY

Lead author:
András Bárdossy, USTUTT-IWS

Contributing authors:
Christina Anagnostopoulou, AUTH
Carlo Cacciamani, ARPA-SMR
Hans Caspary, FTS
Christoph Frei, ETH
Clare Goodess, UEA
Malcolm Haylock, UEA
Yeshewatesfa Hundecha, USTUTT-IWS
Panagiotis Maheras, AUTH
Pavel Michna, UNIBE
Valentina Pavan, ARPA-SMR
Guy Plaut, CNRS
Jürg Schmidli, ETH
Evi Schuepbach, UNIBE
Eric Simonnet, CNRS
Konstantia Tolika, AUTH
Rodica Tomozeiu, ARPA-SMR

Version 1.0:	7 March 2003
Version 2.0:	19 March 2003
Version 3.0:	8 July 2003
Version 3.1:	26 September 2003
Version 3.2:	7 November 2003

CONTENTS

See also individual partner contributions from UEA (for Europe and UK), UNIBE, CNRS, ARPA-SMR, ETH, FTS, USTUTT-IWS and AUTH – available from http://www.cru.uea.ac.uk/cru/projects/stardex/.

1. Introduction

Many studies have revealed that significant changes in some climate variables have taken place over the last century. At a global scale, an increase of 0.6°C in the mean temperature has been reported (Nicholls *et al*., 1995). It has also been observed that the increase is mainly associated with the increase in the minimum rather than the maximum temperature (Easterling *et al*., 1997). This observation has been confirmed by other studies, which indicate that the number of frost days has decreased in different parts of the world including Europe (Heino *et al*., 1999), North America (Easterling *et al*., 2000) and Australia (Plummer *et al*., 1999). Similarly, it is reported that surface precipitation has increased in the mid- to high latitudes over the same period. An increase of 10 to 50% has been observed over Northern and Western Europe (Watson *et al*., 1998). Although it is difficult to associate the increase in the precipitation amount with the rise in the temperature, many climate model studies suggest an increase in the mean precipitation and the frequency of extremes due to an increase in the atmospheric temperature (Bony *et al*., 1995; Meehl *et al*., 2000).

Since the demand on the quality and quantity of data required to investigate changes in climate extremes is high, many of the studies done so far were more on the mean values of the climate variables than on the extremes. However, the humanitarian and material losses that have resulted from extreme weather and climate events in recent years have instigated a close investigation of the evolution of such extremes over the past years. A number of recent studies have focused on regional changes in precipitation extremes for example, including work in North America (e.g., Karl and Knight, 1998), Europe (e.g., Klein Tank and Konnen, 2003), the UK (e.g., Osborn *et al*., 2000), Australia (e.g., Haylock and Nicholls, 2000), Central America (e.g., Peterson *et al*., 2002) and Southeast Asia and the Pacific (e.g., Manton *et al*., 2001). A near-global analysis of trends of indices of temperature and precipitation extremes has been undertaken by Frich *et al*. (2002). Thus the STARDEX work reported here adds to the growing body of work on extremes.

This study is aimed at investigating the evolution of extreme precipitation and temperature over the second half of the 20th century across Europe. Consistent statistical approaches were applied to observed daily precipitation and temperature data series from well selected observation stations across the entire region and from denser station networks in different sub-regions to find out whether there have been any changes in the extremes over the period under investigation. Whether the changes are significant and they have any seasonal dependence have also been investigated.

2. Data base and methodology

Analysis of extremes was carried out for selected sub-regions of Europe by STARDEX partners in their respective sub-regions. Changes in extreme precipitation were analyzed for the whole of Switzerland (ETH), part of Germany in the Rhine basin (USTUTT-IWS), Emilia-Romagna in Northern Italy (ARPA-SMR), Southeast and Northwest England (UEA), Greece (AUTH), and four sub-regions of the French Alps and surroundings: Savoy, Queyras, the Alps Maritimes, and Roussillon (CNRS). Trends in temperature extremes were also investigated for all the regions and for Switzerland, they were investigated by UNIBE. FTS examined changes in severe winter storms and flooding in a number of European sub-regions and their associated damages (economic and insured losses and fatalities).

Daily time series of precipitation and maximum and minimum daily temperatures were collected from a number of representative stations within the study areas. The time period for the study was set between 1958 and 2001, but for some of the study areas the period extended back to as early as the beginning of the 20th century, as in the case of Switzerland. In addition, both precipitation and temperature extremes were analyzed by UEA for Europe as a whole using data from 481 stations for the period 1958 to 2000.

As the study was focused mainly on the changes in extremes, a number of extreme temperature and precipitation indices were defined. Many of the indices are based on thresholds defined on the basis of statistical quantities such as the 90th or the 10th percentiles. The base period for the calculation of such quantities was set between 1961 and 1990. This makes the indices applicable to a wide variety of climates as no arbitrary threshold values are used. The only exception is a fixed threshold value of 0°C used to define frost days; which is, of course, applicable to all climates. The indices used in the study are listed in Table 1.

The seasonal and annual time series of each index were computed for all the stations used in the study using the STARDEX extreme indices software (available from the STARDEX web site: http://www.cru.uea.ac.uk/projects/stardex/). The magnitudes and directions of their trends were computed. The Kendall-tau test was used to test the statistical significance of trends. All trends were considered significant at the 95% level.

Table 1: STARDEX Diagnostic Extreme Indices analysed in the study

Designation	Description
	a) Precipitation related indices
Prec90p	90th percentile of rainday amounts (mm/day)
644R5d	Greatest 5-day total rainfall
646SDII	Simple Daily Intensity (rain per rainday)
641CDD	Max no. of consecutive dry days
691R90T	% of total rainfall from events > long-term 90th percentile
692R90N	No. of events > long-term 90th percentile of raindays
	b) Temperature related indices
Tmax90p	Tmax 90th percentile
Tmin10p	Tmin 10th percentile
125Fd	Number of frost days Tmin < 0 °C
144HWDI	Heat wave Duration

3. Summary of Results

Results of the analysis of observed trends both at the European-wide scale and at local scales for the different study areas are presented and discussed in detail in the separate reports contributed by partners on their respective sub-regions - available from the STARDEX web site. A general summary of the results, focusing on winter and summer, is presented in the following sections.

3.1 Regional trends

3.1.1 Extreme Precipitation

The spatial pattern of the trends in extreme precipitation indices can be seen from the analysis of extremes from the stations distributed across the region. It has, in general, been found that there are spatially coherent regions of both increases and decreases in seasonal extreme rainfall. Not only the trends, but also the spatial structure show seasonal variability.

In winter, the indices related to heavy precipitation show an increase for most of the stations in central Europe, the UK, and Scandinavia, while most of the stations in Eastern Europe, Greece, and western Iberian Peninsula show the opposite trend. The number of stations showing an increase is generally greater than those showing a decrease. The maximum number of consecutive dry days shows an increase in the southern part of the region and a decrease in the north, with the increase generally greater than the decrease.

In summer, most of the indices related to heavy precipitation show four NW-SE oriented regions of coherent change: positive trends across northern Scandinavia and Russia, negative across the UK and NE Europe, positive through SW Europe and negative across the northern Iberian Peninsula. In general, the number of stations showing increases and decreases are balanced with the average trend across the entire region near zero. Although a less coherent signal was found for the maximum consecutive dry days, most of the stations in the central part, southern Scandinavia and the UK show an increase. Table 2 summarises the numbers of stations showing positive/negative trends and the numbers of significant trends for all the precipitation indices in all seasons. Their spatial patterns in summer and winter are also shown in the figures included in the UEA partner contribution.

Table 2: Number of precipitation stations with positive/negative trends and the corresponding no. of significant ($p < 5\%$) trends for precipitation indices across Europe (481 stations)

Index	Winter				Spring				Summer				Autumn				Annual			
	+	sig +	-	sig -	+	sig +	-	sig -	+	sig +	-	sig -	+	sig +	-	sig -	+	sig +	-	sig -
prec90p	324	65	157	12	295	32	186	17	243	20	193	11	305	27	173	8	315	62	166	17
641CDD	253	17	228	15	246	20	235	12	316	25	165	6	199	12	282	20	238	16	243	14
644R5d	299	60	182	15	290	34	191	13	231	19	250	13	326	34	155	5	299	41	182	13
646SDII	315	80	166	16	292	43	189	16	258	28	223	16	301	32	180	11	314	83	167	19
691R90T	310	58	171	12	284	34	197	14	261	20	220	15	303	26	178	4	300	59	181	14
692R90N	283	71	197	20	283	40	197	25	242	24	237	15	316	40	164	10	292	78	189	25

3.1.2 Extreme Temperature

Analysis of the station data over the entire European region showed that winter extreme maximum temperature has increased over most of the region except in the SE - including stations in Greece and the Baltic area. In summer, more stations located in northern Scandinavia, Eastern Europe and Russia have shown a decrease. In the remaining regions, most of the stations have shown an increase.

The winter extreme minimum temperature has increased to a larger degree than the corresponding extreme maximum temperature, having increased over the entire region apart from small decreases in parts of Greece, the Iberian Peninsula and Scandinavia. Also in summer, it has increased over most of the region, but to a lower degree than in the winter.

The number of frost days has decreased in winter for most stations except a few in the southern part of the region. In summer, only stations in the alpine and northern parts of the region had sufficient frost days for the calculation of trends and most of them have shown a decrease.

The heat wave duration index has increased at most stations in winter, with a few stations in the south showing a decrease. In summer, stations in central Europe have generally shown an increase while those in northern Scandinavia have shown a decrease. But the increases are generally stronger than the decreases.

The numbers of stations that show positive or negative trends for each of the above temperature indices in all seasons are summarised in Table 3. Trend maps for winter and summer are shown in the UEA partner contribution.

Table 3: Number of temperature stations with positive/negative trends and the corresponding no. of significant (p < 5%) trends for temperature indices across Europe (481 stations)

Index	Winter				Spring				Summer				Autumn				Annual			
	+	sig +	-	sig -	+	sig +	-	sig -	+	sig +	-	sig -	+	sig +	-	sig -	+	sig +	-	sig -
tmax90p	425	200	56	15	385	84	95	6	376	115	104	9	233	15	247	21	382	144	99	7
tmin10p	438	81	43	5	423	160	58	8	401	159	80	9	198	9	283	46	418	158	63	12
125Fd	66	6	412	143	71	8	402	123	52	4	153	31	231	30	229	21	75	6	403	175
144HWDI	398	151	48	7	345	70	111	13	316	76	133	10	242	21	179	15	401	162	73	9

3.2 Local trends

3.2.1 Precipitation

In Switzerland, the indices related to heavy precipitation generally show significant increases in winter and autumn, while they show weak positive trends in the summer and spring. The results are summarised in Table 4. No significant change was obtained for the maximum number of consecutive dry days.

Table 4: Number of precipitation stations with positive/negative trends and the corresponding no. of significant (p < 5%) trends for precipitation indices in Switzerland (104 stations)

Index	Winter				Spring				Summer				Autumn			
	+	sig +	-	sig -	+	sig +	-	sig -	+	sig +	-	sig -	+	sig +	-	sig -
prec90p	96	43	8	0	78	11	26	1	67	11	37	5	95	32	9	0
644R5d	98	30	6	0	77	9	27	2	77	11	27	2	89	17	15	1
646SDII	93	51	11	0	77	15	27	2	69	11	35	3	95	31	9	0
691R90T	88	32	16	0	67	9	37	0	75	15	29	1	95	34	9	0
692R90N	91	53	13	1	67	9	37	1	61	12	43	3	97	34	7	0

In the UK (i.e., NW and SE England), heavy precipitation indices show an increase in winter and a decrease in summer. The maximum number of consecutive dry days shows negative trends in winter and positive trends in summer. Table 5 summarises the numbers of stations with different trend patterns and significances for the precipitation related indices in each season.

In Germany, heavy precipitation indices show significant increases in winter and significant decreases in summer. They show more positive trends in spring and autumn, with many stations having significant trends. But there are also a lot of stations with negative trends, although not significant. The maximum number of consecutive dry days shows a strong negative significant trend in autumn and a positive trend in summer. In spring, positive and negative trends are balanced, with few significant station series. In winter there is no significant change, although the trends tend to be negative. These are summarised in Table 6.

Table 5: Number of precipitation stations with positive/negative trends and the corresponding no. of significant (p < 5%) trends for precipitation indices in the UK (i.e., NW and SE England - 40 stations).

Index	Winter				Spring				Summer				Autumn				Annual			
	+	sig +	-	sig -	+	sig +	-	sig -	+	sig +	-	sig -	+	sig +	-	sig -	+	sig +	-	sig -
prec90p	37	7	3	0	20	0	20	1	3	0	37	6	24	0	16	1	27	2	13	2
641CDD	16	0	24	0	38	4	2	0	34	0	6	0	18	0	22	0	28	1	12	2
644R5d	37	11	3	0	16	0	24	0	4	0	36	3	16	1	24	1	20	1	20	0
646SDII	39	8	1	0	20	1	20	2	7	0	33	4	23	1	17	1	27	1	13	1
691R90T	35	6	5	0	21	0	19	0	3	0	37	5	18	1	22	1	21	2	19	3
692R90N	37	7	3	0	17	0	22	0	5	0	35	9	21	1	19	0	26	0	14	1

Table 6: Number of precipitation stations with positive/negative trends and the corresponding no. of significant (p < 5%) trends for precipitation indices in Germany (611 stations)

Index	Winter				Spring				Summer				Autumn				Annual			
	+	sig +	-	Sig -	+	sig +	-	sig -	+	sig +	-	sig -	+	sig +	-	sig -	+	sig +	-	sig -
Prec90P	546	107	65	1	407	42	204	5	203	10	408	67	422	55	189	3	390	87	221	18
644R5D	599	121	12	0	415	21	196	0	149	5	462	54	446	53	165	2	403	59	208	10
646SDII	589	172	22	1	391	48	220	7	176	13	435	95	395	48	216	9	396	130	215	27
641CDD	122	0	489	2	395	11	216	3	496	65	115	0	8	0	603	122	69	0	542	50
691R90T	560	97	51	2	426	35	185	2	209	9	402	44	373	38	238	7	366	65	245	24
692R90N	541	86	70	1	461	37	150	2	122	4	489	82	534	121	77	2	417	83	194	11

In Greece, the indices related to heavy precipitation show more negative trends annually and in winter, with regions of significant trend varying for different indices. The maximum number of consecutive dry days has shown positive trends in all seasons. The trend pattern for all the indices is summarised in Table 7.

Table 7: Number of precipitation stations with positive/negative trends and the corresponding no. of significant (p < 5%) trends for precipitation indices in Greece (22 stations)

Index	Winter				Spring				Summer				Autumn				Annual			
	+	sig +	-	sig -	+	Sig +	-	sig -	+	sig +	-	sig -	+	sig +	-	sig -	+	sig +	-	sig -
prec90p	8	0	14	3	7	1	15	3	7	1	15	1	12	2	10	2	6	2	16	3
641CDD	21	5	1	0	20	6	2	0	17	5	5	0	20	7	2	0	19	8	3	0
644R5d	2	0	20	6	6	1	16	6	8	0	14	3	13	1	9	1	8	1	14	4
646SDII	5	0	17	3	8	1	14	3	10	1	12	3	10	2	12	3	8	2	14	6
691R90T	11	0	11	1	10	1	12	2	10	0	12	1	12	1	10	2	8	1	14	3
692R90N	2	0	20	7	9	0	13	2	9	1	13	1	8	0	14	3	4	1	18	8

In Northern Italy, the indices related to heavy precipitation show negative trends in winter and spring, while they show opposite trends in summer. The maximum number of consecutive dry days increased only in winter, with no change observed in other seasons. Table 8 summarises the trend pattern of the stations investigated.

Table 8: Number of precipitation stations with positive/negative trends and the corresponding no. of significant (p < 5%) trends for precipitation indices in Northern Italy (55 stations)

Indices	Winter				Spring				Summer				Autumn				Annual			
	-	sig-	+	sig+	-	Sig-	+	sig+	-	sig-	+	sig+	-	sig-	+	sig+	-	sig-	+	sig+
Prec90	26	2	18	1	38	7	15	0	10	1	42	4	19	0	29	3	20	4	32	6
R5d	26	1	23	0	46	7	4	0	8	0	42	6	25	0	25	0	18	1	29	3
SDII	23	3	30	0	40	9	14	0	9	2	44	8	9	1	34	4	22	4	30	7
CDD	3	0	50	5	22	0	31	1	33	0	21	0	24	0	30	1	14	0	39	10
R90T	20	0	34	2	41	11	13	0	14	1	39	7	22	0	31	3	21	1	30	9
R90N	38	7	16	1	41	11	13	0	9	0	44	5	18	0	35	2	33	5	20	2

For France, investigation was made on one station series for each of the regions Queyras, Alps maritime, and Roussillon and additionally gridded precipitation time series for the alpine region synthesised by the ETH. For Savoy, only precipitation from the gridded series was used. In Savoy, all heavy precipitation related indices show an increasing trend in all seasons with significant increase in winter. The maximum number of consecutive dry days shows weak positive trends in all seasons. In the Alps maritime, many of the indices show a significant decrease in spring and summer, while they show poorly significant changes in winter. In autumn, a few significant positive trends are observed. In Queyras, signals of significant increase in some heavy precipitation indices are noticed in spring and winter. The total accumulated precipitation shows a slight increase in spring and autumn. The maximum number of dry days also increases in spring and decreases in autumn. In Roussillon, decreasing trends are noticed for a few indices in spring. Generally, stations located in the north of the Alps get more intense precipitation in all seasons except summer and the corresponding increase in the extreme indices was found to be highly significant, especially in winter. In the south of the Alps, significant increases in some of the extreme indices were obtained only in autumn.

3.2.2 Temperature

In France, detailed investigation was made at three stations: Nice (Alps maritime), Embrun (Queyras), and Perpignan (Roussillon). Twenty more French stations in other parts of France were also investigated to see whether the observations made in the Alpine area are similar with those of the other regions. At Nice, the maximum temperature shows an increase in all seasons, but a highly significant increase was observed in summer. The minimum temperature shows a significant increase in all seasons except in autumn, where the increase is not significant. At Embrun, except for a significant increase of the maximum temperature in summer, only winter indices show a significant warming signal. They show no change in autumn. At Perpignan, little sign of warming was obtained. The observations for the 20 French stations indicate that the trend pattern for the maximum extreme temperature is more like the observations at Embrun and for the extreme minimum temperature, it is more like those at Nice.

In Greece, the maximum temperature shows a significant negative trend in winter and a positive trend in the other seasons. The minimum temperature shows a decreasing trend in spring and autumn and a significant increase in summer, while a balance between the number of stations showing an increase and a decrease is established in winter. The heat wave duration index, on the other hand, shows an increase in summer and spring and a decrease in the other seasons (Table 9).

In Germany, the maximum temperature has increased significantly in all seasons except in autumn, where the increase is balanced by the decrease. The minimum temperature has also displayed a significant positive trend in spring and summer, while a balance between positive and negative trends is observed for the other seasons with little statistical significance. The number of frost days has shown a significant decrease in winter and spring, while a balance between an increase and a decrease was noticed in other seasons. The heat wave duration index has also increased in all seasons, with the strongest significant increase in winter. These trends are summarised in Table 10.

Table 9: Number of temperature stations with positive/negative trends and the corresponding no. of significant ($p < 5\%$) trends for temperature indices in Greece (22 stations)

Index	Winter				Spring				Summer				Autumn				Annual			
	+	sig +	-	sig -	+	sig +	-	sig -	+	sig +	-	sig -	+	sig +	-	sig -	+	sig +	-	sig -
tmax90p	3	0	19	14	16	3	6	0	19	9	3	0	14	3	8	1	19	6	3	0
tmin10p	10	5	12	5	2	0	20	9	18	13	4	0	4	1	18	9	6	1	16	10
125Fd	7	3	11	4	15	3	1	0	-	-	-	-	9	1	-	-	4	2	14	3
144HWDI	3	0	19	6	13	3	9	1	20	13	2	1	5	1	17	1	14	3	8	3

In the UK (i.e., SE and NW England), a clear warming signal was obtained in all seasons. Both the maximum and minimum temperatures have increased with a corresponding increase in the heat wave duration index. The number of frost days in winter has also shown a significant decrease (Table 11).

Table 10: Number of temperature stations with positive/negative trends and the corresponding no. of significant (p < 5%) trends for temperature indices in Germany (232 stations)

Index	Winter				Spring				Summer				Autumn				Annual			
	+	sig +	-	sig -	+	sig +	-	sig -	+	sig +	-	sig -	+	sig +	-	sig -	+	sig +	-	sig -
Tmax90p	217	128	15	1	201	81	31	3	198	97	34	9	76	14	156	24	201	102	31	7
Tmin10p	139	20	93	8	225	86	7	1	223	93	9	2	90	7	142	8	201	44	30	3
125Fd	47	18	185	86	21	9	211	76	30	10	130	23	84	14	148	22	30	18	202	96
144HWDI	189	88	22	1	198	26	33	3	199	29	33	4	186	2	46	4	203	66	28	3

Table 11: Number of temperature stations with positive/negative trends and the corresponding no. of significant (p < 5%) trends for temperature indices in the UK (i.e., SE and NW England – 21 stations).

Index	Winter				Spring				Summer				Autumn				Annual			
	+	sig +	-	sig -	+	sig +	-	sig -	+	sig +	-	sig -	+	sig +	-	sig -	+	sig +	-	sig -
tmax90p	21	13	0	0	20	1	1	0	21	8	0	0	3	0	18	0	21	7	0	0
tmin10p	21	5	0	0	21	6	0	0	19	9	2	0	16	1	5	0	21	16	0	0
125Fd	0	0	21	12	0	0	21	8	3	0	6	0	3	0	18	5	0	0	21	17
144HWDI	15	1	0	0	18	3	2	0	18	0	2	0	0	0	13	1	20	4	0	0

In Northern Italy, a warming signal is evident in all seasons, with both the maximum and minimum temperatures displaying positive trends. The number of frost days has also decreased in winter and spring, although not significantly. No trend was obtained in autumn for this index. The heat wave duration index has also increased, with the most intense increase observed in summer. Table 12 shows a summary of the trends.

Table 12: Number of temperature stations with positive/negative trends and the corresponding no. of significant (p < 5%) trends for temperature indices in Northern Italy (30 stations)

Indices	Winter				Spring				Summer				Autumn				Annual			
	-	sig-	+	sig+	-	sig-	+	sig+	-	sig-	+	sig+	-	sig-	+	sig+	-	sig-	+	sig+
Tmax90	2	0	28	12	5	0	25	15	3	0	27	19	6	1	24	3	3	0	27	23
Tmin10	5	0	25	11	12	0	18	5	10	3	20	10	23	7	7	0	10	2	20	11
125Fd	21	8	10	0	20	5	11	0	0	0	0	0	7	0	24	4	20	11	11	0
HWDI	3	0	25	13	9	2	20	11	0	0	28	19	10	0	18	6	4	0	25	20

In Switzerland, there is a clear increase in the minimum extreme temperature in all seasons except autumn. The increase was found to be significant in western and southern Switzerland. In autumn, there is a balance between the number of stations showing an increase and a decrease. The maximum extreme temperature shows an increase at almost all stations in winter, half of them significant. A nearly similar pattern is observed for spring, but fewer stations show a significant increase. Most stations show an increasing trend in summer, although non significant. In contrast, most stations show a negative trend in autumn. Correspondingly, the number of frost days shows a negative trend for most stations in winter and spring, though the number of significant decreases in spring is less. In autumn, the number of stations with a positive trend is greater than those showing a negative trend. No clear pattern was obtained in the trend of the heat wave duration index. Generally, most stations show an increasing trend in summer and winter and a decreasing trend in spring and autumn. Table 13 summarizes the seasonal trends and their significances for the indices.

Table 13: Number of temperature stations with positive/negative trends and the corresponding no. of significant (p < 5%) trends for temperature indices in Switzerland (21 stations)

Indices	Winter				Spring				Summer				Autumn				Annual			
	-	sig-	+	sig+	-	sig-	+	sig+	-	sig-	+	sig+	-	sig-	+	sig+	-	sig-	+	sig+
Tmax90	1	0	20	9	4	0	17	5	4	1	17	6	15	3	6	1	4	1	17	11
Tmin10	0	0	21	9	0	0	21	7	1	0	20	10	11	1	10	1	0	0	21	8
125Fd	18	10	3	0	19	8	2	0	7	2	0	0	8	2	13	0	18	11	3	0
HWDI	2	1	19	6	12	2	9	3	7	1	14	1	14	0	7	0	9	0	12	3

4. Discussion

As summarised in the previous sections and shown in more detail in the partner contributions, the trends for most of the investigated indices show spatial variation. Analysis of stations distributed over the entire European region indicates that stations showing an increase and a decrease in the extreme precipitation indices show coherent spatial structure across Europe, with consistent trends in the indices describing similar extreme conditions. On average, heavy precipitation conditions have increased in winter, while little change has been observed in summer. Although the spatial coherence of the trends in the extreme temperature indices is not as clear as that of the extreme precipitation indices, it has, in general, been found that both the extreme maximum and minimum temperatures have increased across the European region, with the minimum showing more increase than the maximum. This is in agreement with global scale observations (Easterling *et al*., 1997).

Generally, precipitation shows strong temporal and spatial variability, even within a given area. Therefore, it is worthwhile to investigate whether the trends in the extremes are different for different spatial scales. This was done for the German part of the study region by USTUTT-IWS by examining the trends for interpolated precipitation time series at different grid sizes. The location of highly concentrated significant trends did not show any change for different scales. However, pockets of significant trends at a lower scale were noticed to disappear at larger scales due to the resulting aggregation of the spatially varied precipitation.

The core set of ten indicators of extremes used here was selected from the full set of more than 50 indices calculated by the STARDEX software because it provides a good mix of measures of intensity and frequency. Many of the indices are based on percentiles, making them applicable to all climates. However, the version of the heat wave duration index (HWDI) used in this study is not percentile based, but rather the number of days per period when temperatures are more than 5° above average for at least six consecutive days. More recent analyses have indicated that this index is not appropriate for oceanic climates such as experienced in western Europe. Hence, a percentile-based measure of heat waves will be used in future STARDEX work.

In this study, carried out during the early stages of the STARDEX project, only the trends of observed extremes and their spatial structure were investigated and, apart from some work undertaken by FTS, no attempt was made to explain their causes. FTS examined links between severe winter storms and flooding in several European regions and "critical" circulation patterns associated with the extremes, together with the damages (insured and economic losses and fatalities). Investigation of the potential causes is an objective of ongoing and future STARDEX work. It would, for example, be worthwhile to consider potential predictor variables for statistical downscaling and to try to look for their relationship with the extremes and their own evolution within the investigation period. It could, for example, be possible that circulation patterns associated with heavy precipitation have become more frequent through time. USTUTT-IWS has made an attempt to investigate this for precipitation extremes in Germany. Circulation patterns associated with extreme precipitation events were identified and the direction of their trends was found to be consistent with that of the observed trends in the extreme precipitation indices for most of the stations. However, the magnitudes of the trends were found to be very low and none of them are significant. This work and additional studies by the STARDEX partners on the causes of the observed changes in extremes, focusing on relationships with potential predictor variables, will be reported in future project deliverables including D10 on 'Recommendations on the best predictor variables for extreme events' and D12 on 'Downscaled extremes based on NCEP Reanalysis data (1958-2000)'.

It is important to mention here the data issues associated with the analysis of extremes. Unlike the investigation of the means, analysis of extreme events puts a high demand on data, both in terms of quantity and quality. The data to be used should be complete, as incomplete data could lead to exclusion of important extreme events. Conventional precipitation measuring devices tend to underestimate precipitation and the degree of underestimation varies depending on whether the event is coupled with strong wind. This also has the potential to induce a bias in the trends of extremes. It would therefore, for example, be interesting to augment the precipitation rain-gauge measurements with observations of flood heights in streams. Nonetheless, all the station series used in the work reported here, have been subject to varying degrees of reliability and homogeneity testing.

5. References

Bony, S., J.P. Duvel, and H. LeTreut, 1995. Observed dependence of the water vapour and clear-sky greenhouse effect on sea surface temperature. *Climate Dynamics* **11**, 307-320.

Easterling, D. R., B. Horton, P.D. Jones, T.C. Peterson, T.R. Karl, D.E. Parker, M.J. Salinger, V. Razuvayev, N. Plummer, P. Jamason, and C.K. Folland, 1997. Maximum and minimum temperature trends for the globe. *Science* **277**, 364-367.

Easterling, D.R., J.L Evans, P.Ya. Groisman, T.R. Karl, K.E. Kunkel, P. Ambenje, 2000. Observed variability and trends in extreme climate events: A brief review. *Bulletin of the American Meteorological Society* **81**, 417 - 425.

Frich, P., Alexander, L.V., Della-Marta, P., Gleason, B., Haylock, M., Klein Tank, A.M.G. and Peterson, t. 2002. Observed coherent changes in climatic extremes during the second half of the twentieth century. *Climate Research* **19**, 193-212.

Haylock, M. and Nicholls, N. 2000. Trends in extreme rainfall indices for an updated high quality data set for Australia, 1910-1998. *International Journal of Climatology* **20**, 1533-1541.

Heino, R., R. Brazdil, E.J. Førland, H. Tuomenvirta, H. Alexandersson, M. Beniston, C. Pfister, M. Rebetez, S. Roesner, G. Rosenhagen and J. Wibig, 1999. Progress in the study of climatic extremes in Northern and Central Europe. *Climatic Change* **42**, 151-181.

IPCC, 1998. *The Regional Impacts of Climate Change: An Assessment of Vulnerability*. (Eds: Watson, R.T., M.C. Zinyowera, and R.H. Moss), Intergovernmental Panel on Climate Change, Working Group II. Cambridge University Press, 517 pp.

Karl, T.R. and Knight, R.W. 1998. Secular trends of precipitation amount, frequency and intensity in the United States. *Bulletin of the American Meteorological Society* **79**, 231-241.

Klein Tank, A.M.G. and Konnen, G.P. 2003. Trends in indices of daily temperature and precipitation extremes in Europe, 1946-1999. *Journal of Climate*, **16**, 3665-3680.

Manton, M.J. and 26 others, 2001. Trends in extreme daily rainfall and temperature in Southeast Asia and the South Pacific: 1961-1998. *International Journal of Climatology* **21**, 269-284.

Meehl, G.A., F. Zwiers, J. Evans, T. Knutson, L. Mearns, and P. Whetton, 2000. Trends in Extreme weather and climate events: Issues related to modelling extremes in projections of future climate change, *Bulletin of the American Meteorological Society* **81** 427-436.

Nicholls, N., G.V. Gruza, J. Jouzel, T.R. Karl, L.A. Ogallo, and D.E. Parker, 1996. Observed climate variability and change, *in Climate Change 1995: The Science of Climate Change*, (Eds: J.T. Houghton, L.G.M. Filho, B.A. Callander, N. Harris, A. Kattenberg, and K. Maskell), 133-192, Cambridge University Press, Cambridge, UK.

Osborn, T.J., Hulme, M., Jones, P.D. and Basnett, T.A., 2000. Observed trends in the daily intensity of United Kingdom precipitation. *International Journal of Climatology* **20**, 347-364.

Peterson, T.C. and 16 others. 2002. Recent changes in climate extremes in the Caribbean region. *Journal of Geophysical Research – Atmospheres* **107**, art. no.-4601.

Plummer, N., M.J. Salinger, N. Nicholls, R. Suppiah, K.J. Hennessy, R.M. Leighton, B.C. Trewin, C.M Page, and J.M. Lough. 1999. Changes in climate extremes over the Australian region and New Zealand during the twentieth century. *Climatic Change* **42**, 183-202.