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Extremes temperatures and enthalpy in Finland and Sweden in a changing climate

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Abstract

Though risks caused by harsh weather conditions are taken into account in the planning of nuclear power plants, some exceptional weather events or combination of different events may prevent normal power operation and simultaneously endanger safe shutdown of the plant. Extreme weather events could influence, for example, the external power grid connection, emergency diesel generators (blockage of air intakes), ventilation and cooling of electric and electronics equipment rooms and the seawater intake. Due to the influence of an intensified greenhouse effect the climate is changing rapidly during the coming decades and this change is expected to have an influence also on the occurrence of extreme weather events. In this report we have examined extreme temperatures. Enthalpy is a parameter that combines air temperature and air humidity and it is used in the design of air conditioning systems. Therefore, we have included also return levels of enthalpy in our analysis. The influence of climate change on extreme temperatures is analysed based on regional climate model simulations.

The reoccurrence times of high temperatures combined with high air humidity was analysed based on measurements made at five Finnish and three Swedish meteorological stations. Based on the observational records we find the 10 year return level of daily maximum temperature to be around 32°C and the 100 year return level around 35°C. If we look the return levels of warm and humid conditions then for example in Helsinki the 10 year return level of one week mean temperature in case mean air humidity is above 80% is 20.1°C. The 10 year return level of daily maximum enthalpy is around 60 kJ/kg and the 100 year return level almost 70 kJ/kg.

According to the climate model simulations the largest increase of 50-year return level of daily maximum temperature is found in southern Sweden and south-western Finland. By the end of this century the increase can be 3-5 °C. The largest change in the return levels of daily minimum temperature can be found in north-eastern Finland at the end of this century. This change can be even more than 10 degrees.

Key words

climate extremes, climate change, extreme temperature, extreme enthalpy

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1. Introduction and background

On the global scale the economical losses caused by natural catastrophes during 1980-2003 have been estimated to be about 1260 milliard US dollars of which 77.5% are estimated to be caused by weather (e.g. http://www.wmo.int/pages/prog/drr/). Due to the influence of a further intensified greenhouse effect the climate is expected to continue to change during the nearest decades and this change may have an influence also on the occurrence of extreme weather events (e.g. Christensen et al., 2007; Trenberth, 1999; Beniston and Stephenson, 2004). The discussion about the influence of climate change on extreme weather events has also drawn increased attention to the possible effects of extreme external events on nuclear power plants.

In the planning phase of nuclear power plants the risks caused by harsh weather conditions are taken into account. In spite of that, some exceptional weather events or combination of different events may prevent normal power plant operation and simultaneously endanger safe shutdown of the plant. Extreme weather events could affect, for example, the external power grid connection, emergency diesel generators (blockage of air intakes), ventilation and cooling of electric and electronics equipment rooms and the intake of cooling water. The nuclear power plants now in operation or under construction are planned to be operational several decades, up to end of the 21st century. According to present knowledge climate will change substantially within the coming decades (Christensen et al., 2007; Graham et al., 2008). In the climate change scenarios presented there it is evident that warm extremes get more severe in the future while cold extremes decrease in their intensity and that these changes are larger than the corresponding changes in mean temperatures. This will likely have an impact on the occurrence of extreme weather events relevant to nuclear power plants as well as on the most effective ways to operate the plants.

The Finnish Meteorological Institute (FMI) has made a few studies on the influence of weather on the safety of nuclear power plants (Venäläinen at al., 2007; Gregow et al., 2008). These studies have been commissioned by the Radiation and Nuclear Safety Authority of Finland (STUK), as well as, the nuclear power companies and The Finnish Research Programme on Nuclear Power Plant Safety 2007 – 2010 (SAFIR2010). In a recent study by Ljungberg (2009) extreme temperatures were studied with help of an atmospheric model. Her aim was to examine how warm or how cold it can be in Finland in most extreme conditions. According to the model simulations the highest measured temperatures around 35 °C measured in Finland can be reached only in very rare cases with exceptional warm air mass.

The Swedish Meteorological and Hydrological Institute (SMHI) has made studies for the Swedish Nuclear Fuel and Waste Management Company (SKB) concerning the climate impacts on safe management of spent nuclear fuel and radioactive waste generated within the Swedish nuclear power program both with a thousand-year perspective (Moberg et al., 2006) and on a 100.000-year perspective (Kjellström et al., 2009).

In the joint project Climate risks and nuclear power plants (WERISK) described in this report, FMI and SMHI investigate changes in temperature extremes, both as observed for the 20th century and as simulated by climate models for the 21st century. The aim of this study is to estimate probabilities of extreme values of air temperature and combinations of extreme values of air temperature and relative humidity and enthalpy. The study concentrates mainly in warm extremes as the ongoing climate change is foreseen to change them in an adverse direction. Estimated probabilities of extremes for all quantities are expressed in terms of T-year return values. The T-year return value is defined here as the threshold that is exceeded once every T years or in other words that is exceeded any given year with the probability $1/T$.

The study is partly based on long time series of air temperature, relative humidity and air pressure observations data (FMI and SMHI) and partly on data from climate model simulations.

Air temperature alone is not enough when the design values of air conditioning systems are defined, also air humidity is needed. That is why we have studied the return levels of maximum temperatures in different air humidity classes. Enthalpy is a parameter that combines air temperature and air humidity (e.g. Sarkomaa et al., 2002) and is used routinely for defining air conditioning systems and that is why we have included also the examination of return levels of this not so familiar parameter into our study.

The third part of the study contains an assessment of evolution of extreme air temperature from 1961 to 2100 in a changing climate in northern Europe as simulated with RCA3 climate model (Kjellström et al., 2005).

2. Datasets and methods

2.1 Observational data

The analyses were made for a number of observation station locations (Fig. 1).

Figure 1. Station used in the analyses.

The data used was the 3-hourly synoptic data including information about daily maximum and minimum temperatures. The data has passed the normal quality control routines. There has not been applied any homogenization routines. However, during the 50-year period there have not been such major changes in the observational methods nor in the station surrounding that would have had influence on the results.

In addition the long 1840-2001 time series from Uppsala was used for the examination of return levels of daily maximum temperature. The long time series data (e.g. Moberg, 1996) of air temperature data in Uppsala cover years from 1840 to 2001 and it was used for the examination of the influence of the length of timeseries for the extreme analyses. No homogenization was applied with this dataset either.

2.2 The regional climate model

The regional climate model RCA3 developed at the Rossby Centre (Kjellström et al., 2005) is used for the downscaling simulations in this report. It includes a land surface model and a lake model, PROBE (Ljungemyr et al., 1996). RCA3 builds on the previous version RCA2 which is described in Jones et al. (2004). RCA3 includes a completely new land surface scheme (Samuelsson *et al.*, 2006), as well as a number of differences compared to RCA2 in its radiation, turbulence and cloud parameterizations as described in Kjellström et al. (2005).

The set-up covers Europe with a rotated longitude-latitude grid with a horizontal resolution of 0.44° (approximately 50 km) and 24 vertical levels in the atmosphere. The domain covers Europe (see Fig. 2). The time step in the simulations was set to 30 minutes.

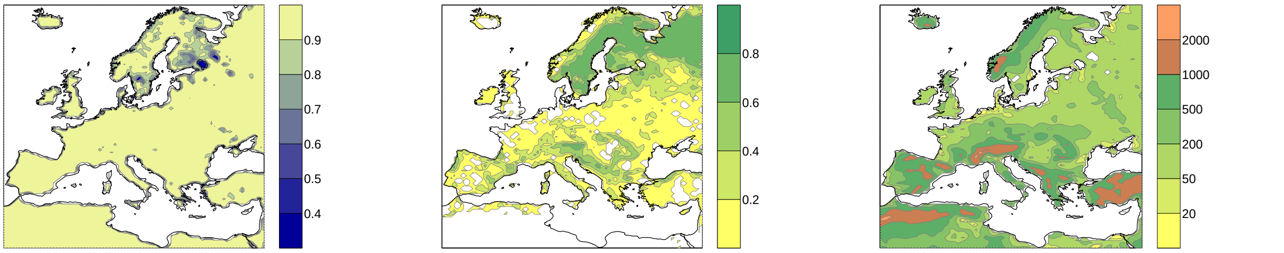


Figure 2. Land fraction with coastal regions and lakes shown in blue colours (left), forest fraction (middle) and orography in metres (right) in the current model setup.

Forcing global data

Data from a global climate model is needed to act as initial and boundary conditions for the regional climate model. Boundary conditions consist of lateral boundaries and sea ice/sea surface temperatures. These fields are taken from the global model every six hours in the simulations. We use driving data from three simulations with ECHAM5/MPI-OM (Roeckner et al., 2006; Jungclaus et al., 2006). All three use the SRES A1B emission scenarios from the Special Report on Emission Scenarios (SRES) by the Intergovernmental Panel on Climate Change (Nakićenović et al., 2000). The only difference between the three simulations are the initial conditions in 1860. There are two reasons for utilising several ensemble members; i) an ensemble samples a part of the natural variability in the climate and ii) the number of data increases significantly. Both factors contributes to a more robust analysis of the data. The external forcing during the 20th and 21st centuries is identical in the three simulations. All three simulations are contributions from the DKRZ and the Max-Planck Institute for Meteorology to the Climate Model Intercomparison Project 3 (CMIP3) used as input to the 4th Assessment Report from the IPCC. In a comparison with observations ECHAM5/MPI-OM has been shown to perform well in terms of surface pressure patterns in west-central Europe indicating that the large-scale circulation over Europe is realistic (van Ulden and van Oldenborgh, 2006). The simulation with the global model was performed at T63 resolution (1.875° × 1.875°). One of the downscaling simulations ECHAM5/MPI-OM with RCA3 has previously been documented in Persson et al. (2007).

2.3 Classification of temperature in different humidity classes

When we are estimating how suffocating the conditions are then air humidity is needed in addition to air temperature. That is why we have studied return levels of temperatures in different air humidity classes (below 40%, 40-60%, 60-80% and above 80%). For each humidity class we calculated 10, 100, 500 and 1000 year return levels for the temperature. The return periods can also be understood as likelihoods which in this case are equivalent to probabilities of 0.1, 0.01, 0.002

and 0.001. Temperatures that were studied were the daily maximum, 6 hour mean, 24 hour mean, 7 day mean and 14 day mean. In the analyses air humidity was taken as the mean value for the studied time span.

2.4 Enthalpy

Enthalpy is a parameter that combines air temperature and air humidity (e.g. Sarkomaa et al., 2002). It is routinely used for designing air conditioning systems which is our rationale for including it in our analysis. The observational data that is used for the calculation of enthalpy (H, kJ/kg) consists of instantaneous measurements taken every three hours. Weather parameters required for the calculation of enthalpy are air temperature (t, °C) and specific humidity (q, g/kg) (Eq .1).

$$H = (1.008 + q * 1.87) * t + q * 2501 \quad (1)$$

Specific humidity (q) can be estimated with Eq. (2).

$$q = 0.622 * E / (p - 0.378* E) \quad (2)$$

where E is the partial water vapor pressure (hPa) and p (hPa) air pressure. The partial water vapor pressure can be calculated from Eq. (3)

$$E = 0.01 * RH * ES \quad (3)$$

where RH (%) is the relative humidity and ES (hPa) the saturation vapor pressure. Finally the saturation vapor pressure can be calculated using Eq. (4).

$$ES = 6.11 * \exp (17.27 * t / (t + 237.3)) \quad (4)$$

The concept of extreme enthalpy is here understood as a state in which both air temperature and relative humidity of air reaches very high values at a certain time or continually during a given time span. The parameter studied here is the daily maximum, and the value above which enthalpy remained for 6 hours, 24 hours, 7 days or 14 days. These were calculated with Eq 1. using 3-hourly weather observations for the summer months May through September in every year (1956-2007). Like in the case of temperature the return levels of enthalpy were estimated for return periods of 10, 100, 500 and 1000 years.

2.5. Methods used in the extreme value analysis

Statistical modeling of extreme events deals with quantification of the stochastic behavior of a process at unusually large or small levels. Fitting a statistical model to the observed extreme events allows us to estimate the probability of events that are more extreme than any that have already been observed. The particular task is to estimate probabilities and related uncertainties for events which might occur once in, say 100 or 1000 years based on only 20 to 50 years of available data. Extreme value theory provides a framework that enables extrapolation of this type.

In frames of extreme value theory the concepts of return level and return period are commonly used to convey information about the likelihood of rare events. In this case the estimated probabilities of rare events are expressed in terms of T-year return values. The T-year return value is defined as the threshold that is exceeded once every T years. Or in other words the threshold that is exceeded any given year with the probability $1/T$. The time T is referred to as the return period.

In order to estimate the return values, a statistical distribution which describes stochastic behavior of extreme events should be defined. The choice of the distribution depends on what method that is used for sampling extreme events from observational or simulated data. Among several different approaches two general methods for sampling extreme events are the block maxima and peak over threshold. The generalized extreme value (GEV) distribution is the asymptotic distribution that describes the behavior of the block maxima while events above the specified threshold asymptotically follow the generalized Pareto (GPD) distribution.

Block maxima

The extreme types theorem (Coles, 2001), analogous to the central limit theorem, states that the maxima of sequences of size n of independent and identically distributed random variables converge to the generalized extreme value (GEV) distribution with the cumulative distribution function:

$$F(x,\mu,\sigma,\xi)=\begin{cases} \exp\left[-\exp\left(-\dfrac{x-\mu}{\sigma}\right)\right], & \xi=0 \\ \exp\left[-\left(1+\xi\dfrac{x-\mu}{\sigma}\right)^{-\frac{1}{\xi}}\right], & \xi\neq 0,\ \ 1+\xi\dfrac{x-\mu}{\sigma}>0 \end{cases} \quad (5)$$

Where x is the sampled maxima, μ is the location parameter, σ is the scale parameter (positive), and ξ is the shape parameter. The GEV distribution incorporates three types of distributions defined by the shape parameter ξ, namely: light-tailed Gumbel (ξ=0), bounded Weibull (ξ<0), and heavy-tailed Fréchet (ξ>0) distributions (Fig. 2a). In climatological applications the block length n is typically chosen to be equal to one year and the sampled extremes are annual maxima or minima in this case. There are two methods, L-moment (Hosking et al. 1995) and maximum likelihood (Coles, 2001), for fitting the GEV distribution to the annual extremes. Both methods show similar results (Kyselý, 2002) and here we use the L-moment method as it is more computationally efficient. After fitting the GEV distribution to a sample of annual extremes the T-year return values X_T are estimated by inverting the GEV cumulative distribution function (5):

$$X_T=\begin{cases} \mu-\sigma\ln\left[-\ln\left(1-\dfrac{1}{T}\right)\right], & \xi=0 \\ \mu-\dfrac{\sigma}{\xi}\left[1-\left\{-\ln\left(1-\dfrac{1}{T}\right)\right\}^{-\xi}\right], & \xi\neq 0. \end{cases} \quad (6)$$

Since the shape parameter ξ strongly defines the behavior of the right tail of the GEV distribution (Fig. 2a) the estimated return levels X_T for the GEV distribution with the same location μ and scale σ can easily differ by a factor of two depending on ξ (Fig. 3b).

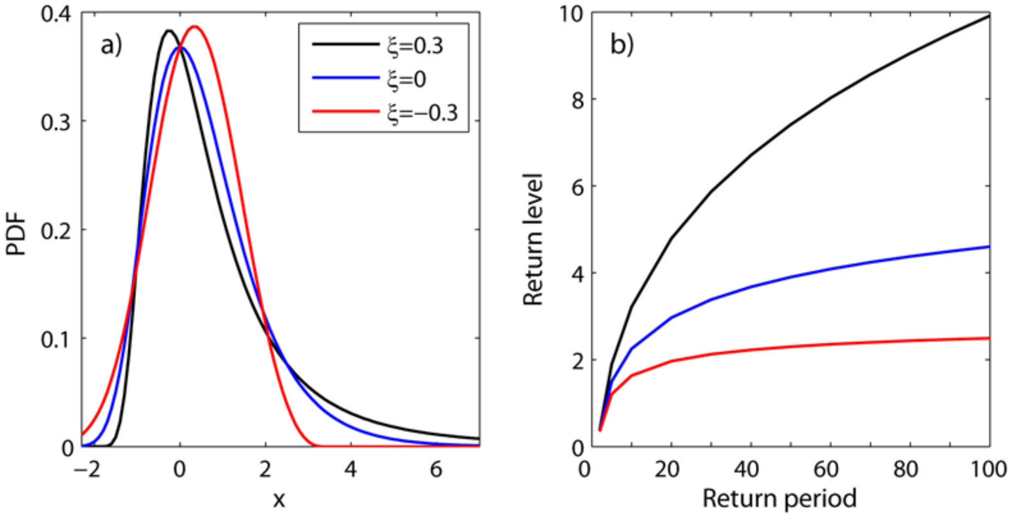


Figure 3. a) The probability density functions and b) return levels of the GEV distribution with the location parameter μ=0, the scale parameter σ=1 and three different shape parameter ξ=-0.3, ξ=0 and ξ=0.3.

Fitting the GEV distribution to annual maximum or minimum values assumes stationarity of the analyzed extremes, i.e. the distribution parameters (location, scale and shape) do not change with time. However, in transient climate simulations, when the greenhouse forcing gradually changes, the assumption of stationarity is not necessarily valid and the sampled extremes may be not identically distributed. In order to take into account the possible non-stationary nature of extremes in transient simulations we use a moving window approach. The parameters of the GEV distribution are estimated by applying the 21-year moving window and pooling three members of the ECHAM5-driven ensemble into one sample gives the total sample size 63 for each 21-year window. There is no unified criteria for how large the sample size of extremes should be but a larger sample size decreases uncertainties in the fitted GEV parameters and consequently in the estimated return values. In climatological practice a sample size of about 30 is common and assumed to be long enough for the GEV fitting. The GEV parameter estimates for the current moving window are attributed to the year in the centre of the window.

Beside the GEV distribution the generalized Pareto (GP) distribution is used frequently. Consistent with the point process representation, the "peaks over threshold" (POT) approach enables the use of more of the information available about the upper tail of the distribution. Compared with the GEV and its variates the GPD is superior by giving the flexibility to use solely the most pertinent data to its full extent by proper choice of the threshold value. However, the method is subjective due to the intervention of the user in choosing the threshold value. The choice of the value is not necessarily easy, although some general, objective guidance is available. The actual choice is always a trade-off between bias and variance,

In this study for the purposes of extreme value analysis of observed data the extRemes Toolkit (e.g. Katz et al., 2005) is used. The extRemes toolkit was designed to facilitate the use of extreme value theory in applications oriented toward weather and climate problems that involve extremes, such as the highest temperature over a fixed time period. The extRemes toolkit was used in this study to make a fit to the enthalpy and air temperature data. Then for given return periods we have calculated the return levels associated with the return periods. The extRemes toolkit software package includes a tool that helps to find the most appropriate thresholds to be used in the POT method, and also provides 95% confidence intervals for the return levels. The most appropriate threshold can be searched either using method know as “Mean residual plot” or by fitting data to GPD over a range thresholds. When using the “mean residual plot” or “mean excess plot” the idea is to find the lowest threshold where the plot is nearly linear. The other method for trying to find a threshold requires fitting data to the GPD distribution several times, each time using a different threshold. The stability is the parameter estimates can then be checked.

There was a large number of extreme value analyses made in this study based both on observed and modelled climate data. Summary of analyses is given in Table 1. In case of gridded climate data the analyses was made by fitting GEV distribution using L-moment. In case of the other analyses the fitted distribution was GPD and the method known as maximum likelihood.

Table 1. Summary of extreme value analyses made in the study.

Observed data

Location	Time period	Method	Parameter	Return levels
Uppsala	1840-2001	GPD	Tmax	10, 50, 100, 500, 1000 years
Helsinki-Vantaa	1957-2007	GPD	Tmax, T + RH, H	10, 50, 100, 500, 1000 years
Jokioinen	1957-2007	GPD	Tmax, T + RH, H	10, 50, 100, 500, 1000 years
Pori	1957-2007	GPD	Tmax, T + RH, H	10, 50, 100, 500, 1000 years
Kuopio	1957-2007	GPD	Tmax, T + RH, H	10, 50, 100, 500, 1000 years
Sodankylä	1957-2007	GPD	Tmax, T + RH, H	10, 50, 100, 500, 1000 years

Climate model RCA3, with ECHAM5 boundary

Location	Time period	Method	Parameter	Return levels
Helsinki-Vantaa	1961-2100	GPD	Tmax	10, 50, 100, 500, 1000 years
Jokioinen	1961-2100	GPD	Tmax	10, 50, 100, 500, 1000 years
Pori	1961-2100	GPD	Tmax	10, 50, 100, 500, 1000 years
Kuopio	1961-2100	GPD	Tmax	10, 50, 100, 500, 1000 years
Sodankylä	1961-2100	GPD	Tmax	10, 50, 100, 500, 1000 years

Climate model, 3-model ensemble

Location	Time period	Method	Parameter	Return levels
Europe 50 km grid	1970-2090	GEV	Tmax, Tmin	50 years

Tmax=daily maximum temperature, Tmin=daily minimum temperature, T= mean temperature, RH= relative humidity, H= enthalpy. In case of T, RH and H the calculations were made in addition to daily maximum also for 6 hour, 24 hour, one week and two week mean values.

3. Results

3.1 Long term variation in observed time series

For the Uppsala time series of daily maximum temperature we have analyzed return levels of air temperature for both the whole time series of yearly maximum air temperature for the years 1840 to 2001 and also separately for two (partly overlapping) one hundred years long time series; one period from 1843 to 1944 and the other one from 1902 to 2001. This approach was used to give an example of the influence of the length of the observational time series on the results (Table 2). It turns out that there are no visible diffrence in return levels of yearly maximum air temperatures for different return periods between the two 100 year time periods. So, there seem to be no obvious trends in return levels of yearly maximum air temperatures in Uppsala on the basis of the extreme value analyze.

The highest observed yearly maximum air temperature during 1840-2001 (158 years) in Uppsala was 37.4 ˚C and occurred in 1933. According to the extreme value analyzes air temperatures as high as 37,4 ˚C are assumed to be observed on average once in a century. This seems to be in line with the frequency deduced from the observations (Table 2 and Fig 4).

Table 2. Return levels of annual maximum temperatures (°C) based on Uppsala 1840-2001 observations. Mean indicates the most probable value and 95 %-column indicate confidence intervals.

	Years 1840-2001			Years 1843-1944			Years 1902-2001		
Return peiod (years)r	95 % low	Mean	95 % high	95 % low	Mean	95 % high	95 % low	Mean	95 % high
10	32.0	32.4	33.0	32.2	32.7	33.5	32.0	32.5	33.3
50	33.7	34.5	36.0	33.9	34.8	36.9	33.7	34.7	37.0
100	34.3	35.3	37.8	34.5	35.6	38.5	34.3	35.5	38.6
500	35.5	37.0	40.5	35.7	37.3	41.2	35.6	37.3	41.5
1000	35.9	37.7	41.6	36.1	37.9	42.2	36.0	37.9	42.6

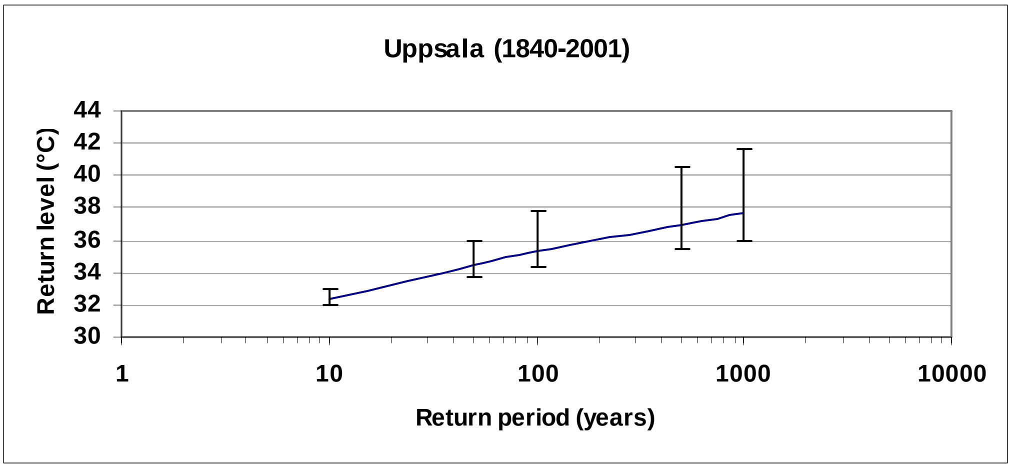


Figure 4. Return levels of yearly maximum air temperatures based on measurements made 1840-2001 in Uppsala. The continuous line indicates the best estimate and vertical bars the 95% confidence limits.

If we take a look at the diagram of yearly maximum air temperature data for 1840-2001 (Fig. 5) we see that there is actually no clear trend in the yearly maximum air temperature time series either. This is consistent with the results above.

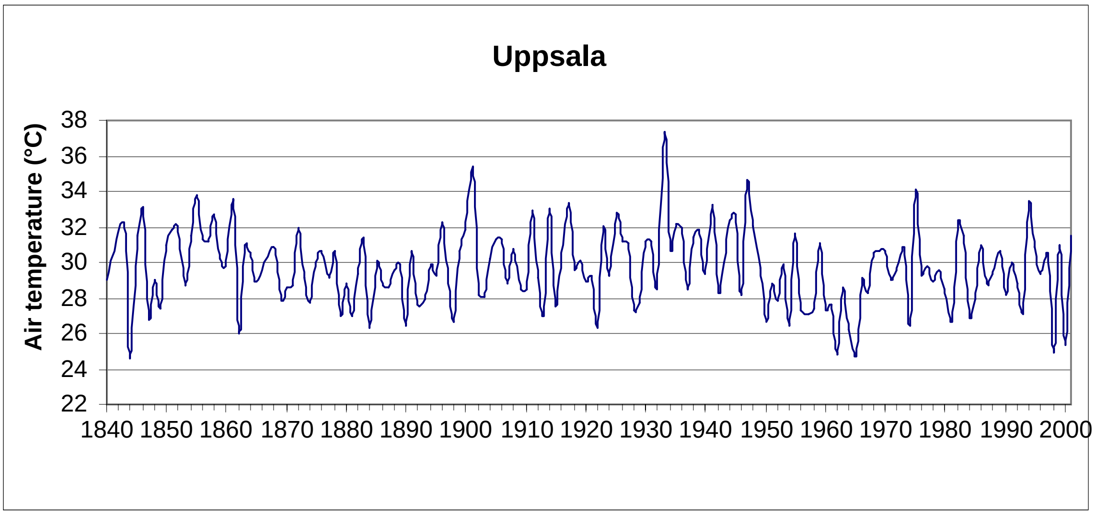


Figure 5. Annual maximum air temperatures from the longest available (1840-2001) daily maximum air temperature time series in Uppsala.

3.2 Simulated air temperatures

3.2.1 Analyses for selected sites in Finland

There is an increasing trend both in the observed and in the simulated (RCA3) daily maximum temperature data (Fig. 6). The slope of the trend line for the observations data (0.0316°C/year) is to some extent higher than the slope of the trend line for the modeled data (0.0189 °C/year).

There is a substantial bias of about 8°C in the modeled time series of yearly maximum air temperature data. The bias is mainly due to inadequacies in cloud water and radiation fluxes in the model (Kjellström et al., 2005). The simulated linear trend shows an increase of about 2˚C in the annual extremes of air temperature from now (2007) until the end of the 21th century. Assuming that the model error does not change with time in the future we add this simulated trend to the observed conditions in the early 1960's to get a picture of a plausible evolution of yearly maximum air temperature in Helsinki-Vantaa for the rest of this century. In the beginning of the 1960's the annual extremes of air temperature were in Helsinki-Vantaa was on average 28˚C and according to the trend in the RCA3 simulations we find that these extremes would increase to about 31.5˚C by the end of the century.

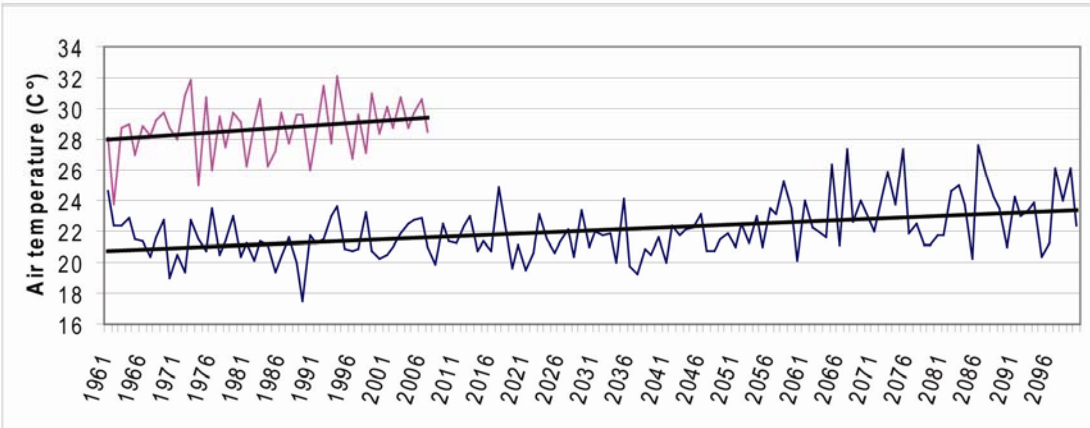


Figure 6. Yearly maximum air temperatures; observations 1961-2007 (red line) and simulated (blue line) 1961-2100 in Helsinki-Vantaa

The positive trend in maximum temperatures can be found also in case of Kuopio Observations (Fig. 7). The slope of the trend line for the observations data (0.0193) is just slightly higher than the slope of the trend line for the modeled data (0.0173). Then again as in the previous case of Helsinki-Vantaa, we can see that there is a substantial bias in the modeled air temperature data. The bias is here too about 8 ˚C. We add the simulated trend from RCA3 to the observed maximum in the beginning of the 1960's. RCA simulates an increase of about 1.6 ˚C in the annual extremes of air temperature from now (2007) until the end of the 21st century. The climate model RCA3 gives on average about 2.5˚C higher annual extremes of air temperature in Kuopio in the end of this century compared to the values in the beginning of 1960's. In the beginning of the 1960's the annual extremes of air temperature were in Kuopio on average 28˚C and according to the increase in the RCA3 simulations we find that the annual extremes of air temperature would increase to about 30.5˚C by the end of the century.

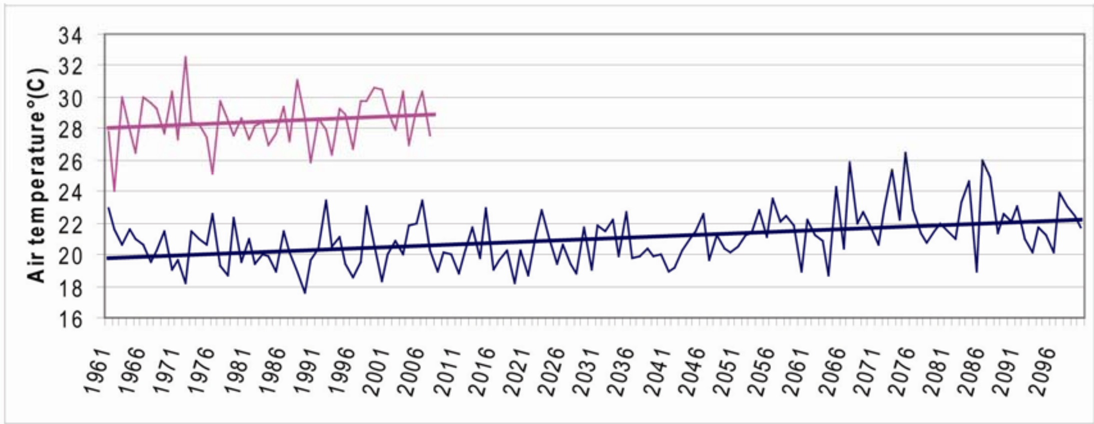
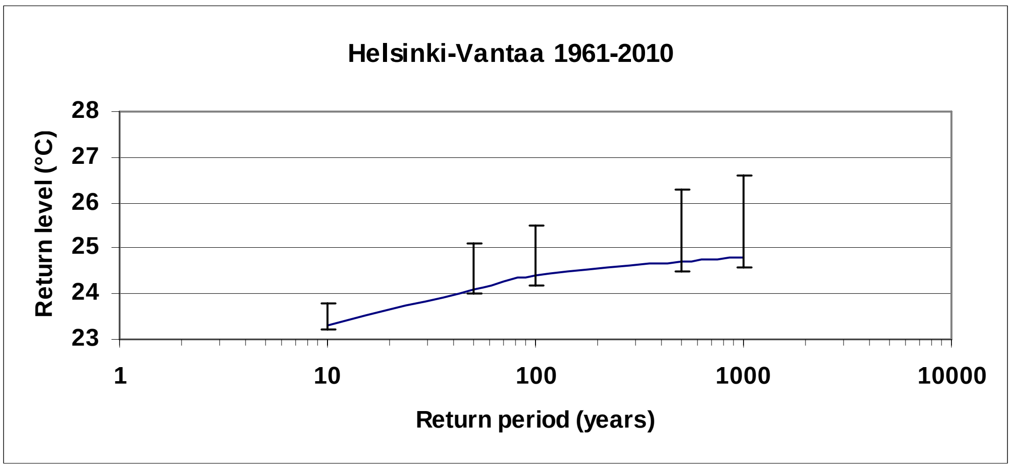


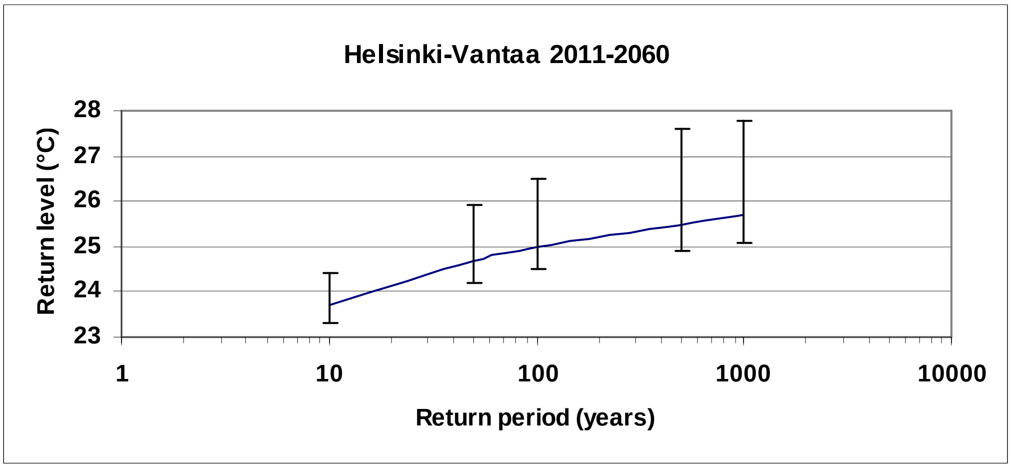
Figure 7. Yearly maximum air temperatures; observations 1961-2007 (red line) and simulated (blue line) 1961-2100 in Kuopio.

The positive trend in extreme temperatures that can be seen in Figs. 6 and 7 can be found also in the return values of extreme temperature (Table 3 and Fig. 8). In our analysis we use the simulated temperature time series for Helsinki Vantaa and perform the extreme value analysis for three 50 years long (partly overlapping) time periods; 1961-2010, 2011-2060 and 2051-2100.

Table 3. Return levels of annual maximum temperatures (°C) based on RCA3 model simulation made for the Helsinki Vantaa gridbox. Mean indicates the most probable value and 95 %-column indicate confidence intervals.

	Years 1961-2010			Years 2011-2060			Years 2051-2100		
Return period (years)	95 % low	Mean	95 % high	95 % low	Mean	95 % high	95 % low	Mean	95 % high
10	23.2	23.3	23.8	23.3	23.7	24.4	25.4	26.0	26.9
50	24.0	24.1	25.1	24.2	24.7	25.9	26.6	27.4	29.1
100	24.2	24.4	25.5	24.5	25.0	26.5	27.0	27.8	30.0
500	24.5	24.7	26.3	24.9	25.5	27.6	27.0	28.5	31.3
1000	24.6	24.8	26.6	25.1	25.7	27.8	27.2	28.7	31.5





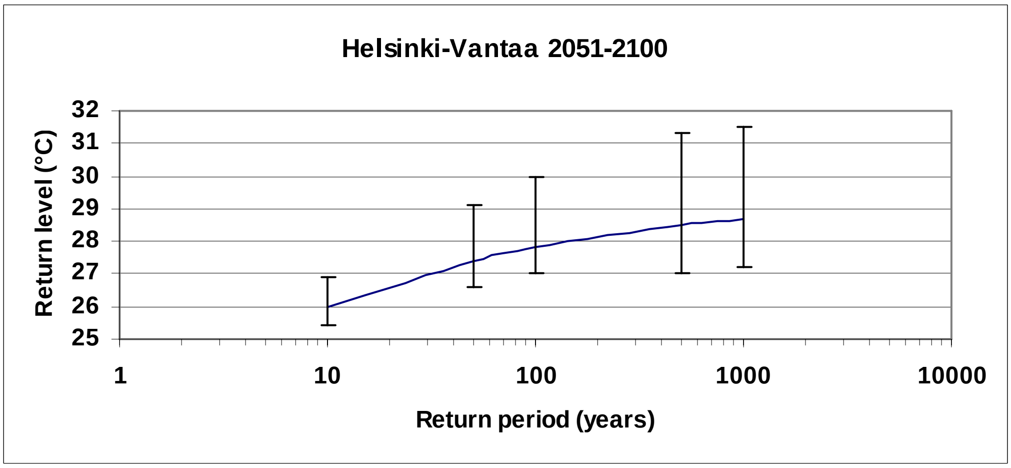


Figure 8. Return levels of yearly maximum air temperature data (simulated with RCA3 with A1B emission scenario) for three 50 years time periods (1961-2010, 2011-2060 and 2051-2100) in Helsinki-Vantaa. Note that the cold bias of about eight degrees in the modeled data has not been removed from these calculations. The continuous line indicates the best estimate and vertical bars the 95% confidence limits.

From 1961-2010 to 2011-2060 the one hundred year return level of yearly maximum air temperature rises with 0.6˚C and the corresponding upper level of 95 % confidence interval rises with 1.0 ˚C. The increase of the corresponding figures for the five hundred year return level are 0.8˚C and 1.3˚C. From 2011-2060 to 2051-2100 a one hundred year return level of yearly maximum air temperature rises with 2.8˚C and the corresponding upper level of 95 % confidence interval rises with 3.5˚C. The increase of the corresponding figures for the five hundred year return level are 3.0˚C and 3.7 ˚C. So, the increase in the return levels of yearly maximum air temperature is much larger between the two later fifty year periods than the increase between the two earlier ones.

<u>3.2.2 Spatial variation of return levels in daily extreme temperatures in a simulated future climate in northern Europe</u>

Based on the climate model simulations it is possible to analyse also the spatial variation of change in the return levels of extremes. In case of daily maximum temperature the largest increase in the 50-year return level is found in southern Sweden and in south-western Finland. By the end of this century the increase is 3-6 °C (Fig. 9). Closer in time, as for the 1990-2010 period, the increase in the 50-year return level of maximum temperature is in most of Sweden and in southern and central Finland 0-2°C.

In case of minimum temperatures the spatial distribution is different (Fig. 10). As the simulated warming is larger in the north also the largest change in the return levels of daily minimum temperature can be found in parts of northern Sweden and Finland by the end of this century. The change may exceed 10 degrees. This means that very cold temperatures would become much more rare in Lapland. Also in the other areas the change in the annual lowest temperatures is predicted to be larger than in the case of annual highest temperatures. These results are consistent with previously reported results for means and extremes in this area (cf. Kjellström, 2004, Kjellström et al., 2007).

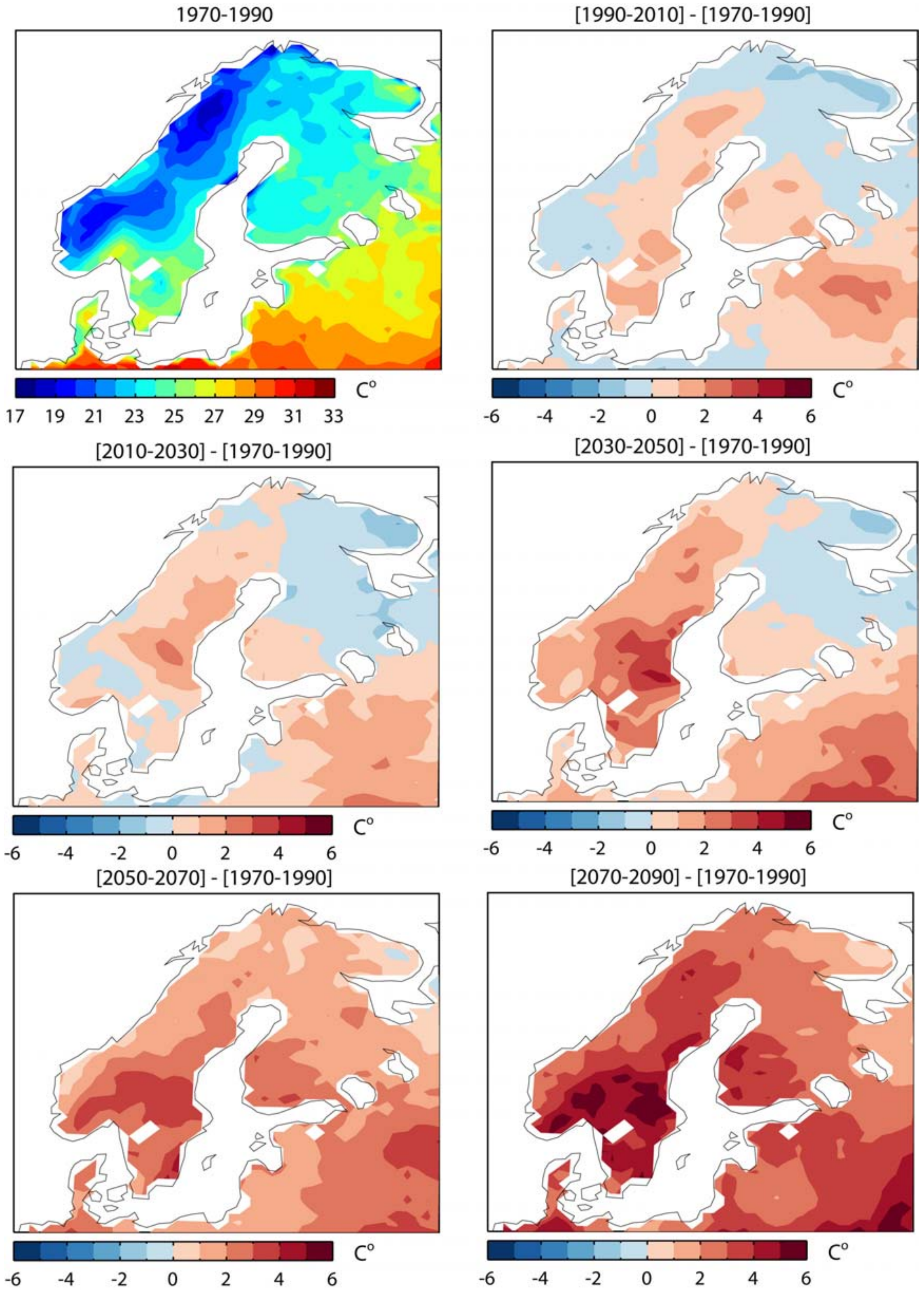


Figure 9. The change in the 50 year return level of daily maximum temperature. Comparison is done between the 1970-1990 period (upper left corner figure). The periods are 20-year long starting from 1990-2010 (upper right corner figure). The last period is 2070-2090. The parameter shown in the maps is the difference between the reference period and the studied period.

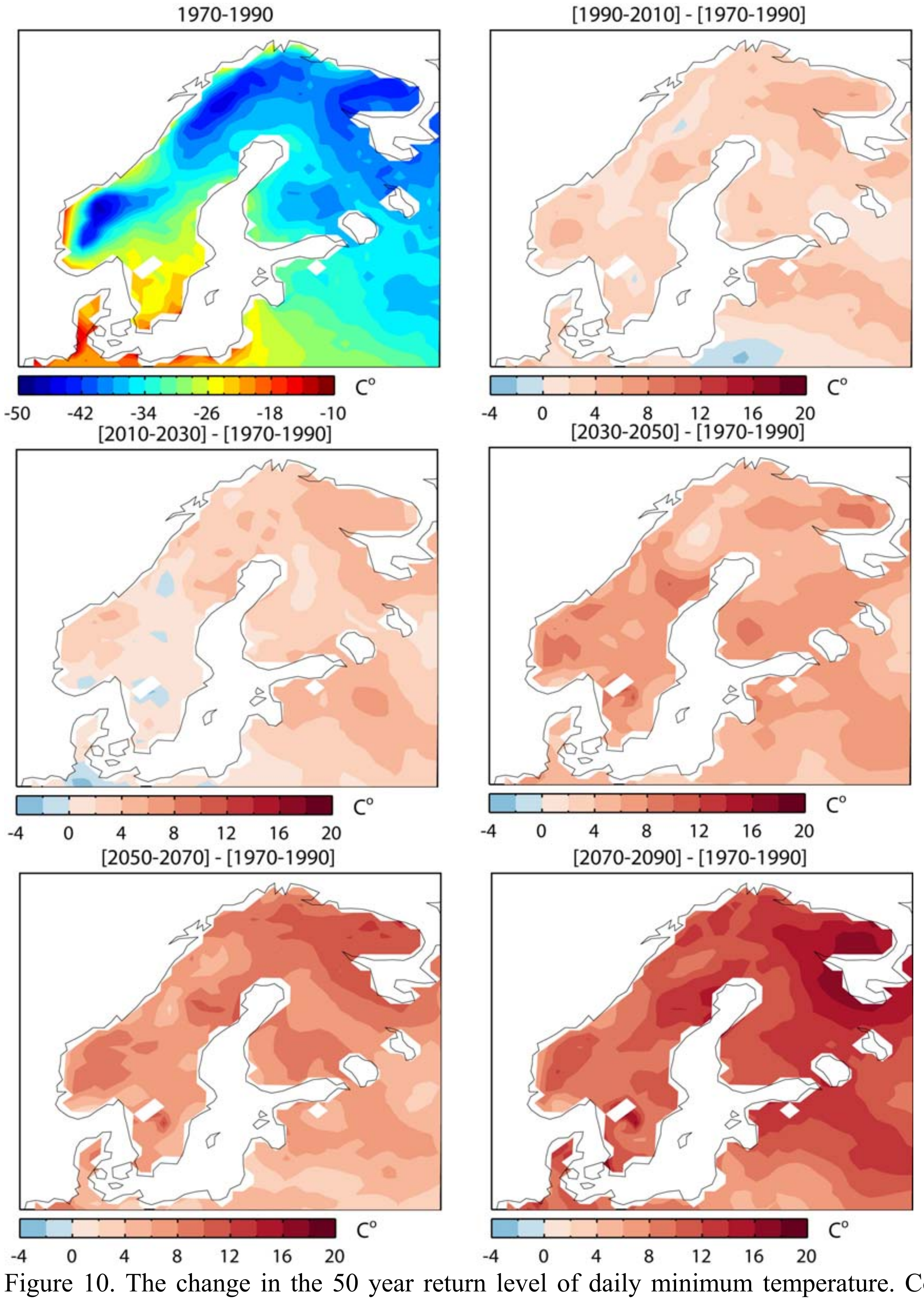


Figure 10. The change in the 50 year return level of daily minimum temperature. Comparison is done between the 1970-1990 period (upper left corner figure). The periods are 20-year long starting from 1990-2010 (upper right corner figure). The last period is 2070-2090. The parameter shown in the maps is the difference between the reference period and the studied period.

3.3. Enthalpy

The results of extreme value analysis and return level assessments of enthalpy are shown in Appendix 1. In these tables we find return levels of enthalpy for four different return periods of 10, 100, 500 and 1000 years. In case of a changing climate the probability is a more informative parameter than the return period. Return period 10 years means probability 1/10, 100 year return period 1/100 etc.

The minimum enthalpy, derived from observations of temperature and humidity, in summer at Helsinki-Vantaa airport is about 20 kJ/kg and the maximum values around 60 kJ/kg (Fig. 11). As a comparison, in a warmer and more humid climate, like in Miami in the USA the maximum values can be around 90 kJ/kg. In Falsterbo and Uppsala in Sweden the values are very similar to values in Helsinki. During midsummer months June and July when the most extreme values are observed there is no major difference between Helsinki and Uppsala. In Falsterbo the values are somewhat higher possibly due to more maritime climate.

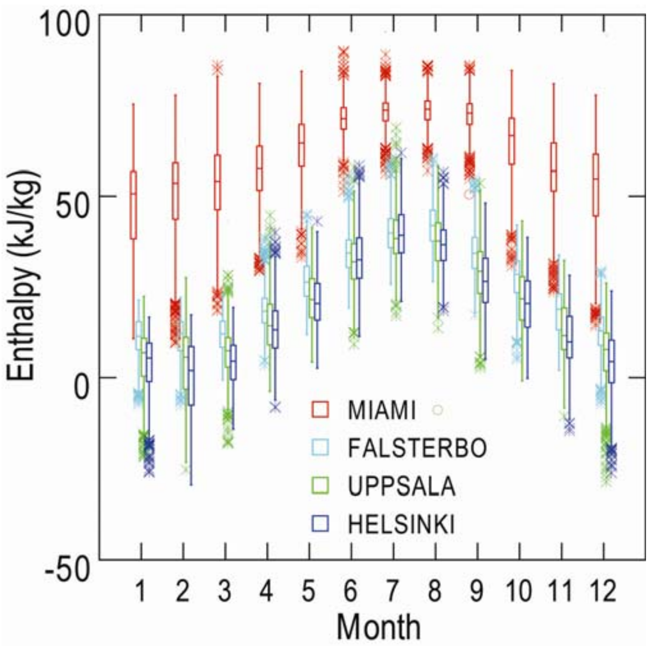


Figure 11. The variation of enthalpy (kJ/kg) calculated using hourly 1996-2001 observations from Helsinki-Vantaa airport, Miami (USA), Falsterbo and Uppsala. The horizontal line within the box corresbonds to the median, the ends of the box to the interquartile range and the “whiskers” to ±1.5 times the interquartile range.

In case of *daily extremes* the 100 year return level (or probability = 0.01) of enthalpy range from 65.1 kJ/kg (in Jokioinen) to 69.4 KJ/kg (in Helsinki-Vantaa). Considering the 95%-confidence intervals, a 100 year return level value of enthalpy lies between 63.4 kJ/kg (in Jokioinen) and 76.1 kJ/kg (in Pori). A 1000 year return period (or probability = 0.001) gives a return level of enthalpy ranging from 67.2 kJ/kg (in Jokioinen) to 72.8 kJ/kg (in Helsinki-Vantaa). Taking into consideration the limits in 95%-confidence intervals, a 1000 year return level varies between 64.8 kJ/kg (in Jokioinen) and 82.4 kJ/kg (in Sodankylä).

For a *14 days* time span the 100 year return level (or probability = 0.01) of enthalpy range from 31.1 kJ/kg (in Sodankylä) to 44.5 kJ/kg (in Kuopio). Considering the 95%-confidence intervals a 100 year return level of enthalpy for *a 14 days* time span lies between 29.4 kJ/kg (in Sodankylä) and 53.9 kJ/kg (in Kuopio). For a 14 days time span of a 1000 year return period (or probability = 0.001) of enthalpy we find that a return level of enthalpy ranges from 32.8 kJ/kg (in Sodankylä) to 47.3 kJ/kg (in Kuopio). Taking into consideration the limits in 95%-confidence intervals, a 1000 year return level of enthalpy for a *14 days* time span lies between 30.8 kJ/kg (in Sodankylä) and 58.8 kJ/kg (in Kuopio).

Selected results in Appendix 1 are visualized in Figs. 12.-16. The diagrams show return levels of enthalpy for a number of sites.

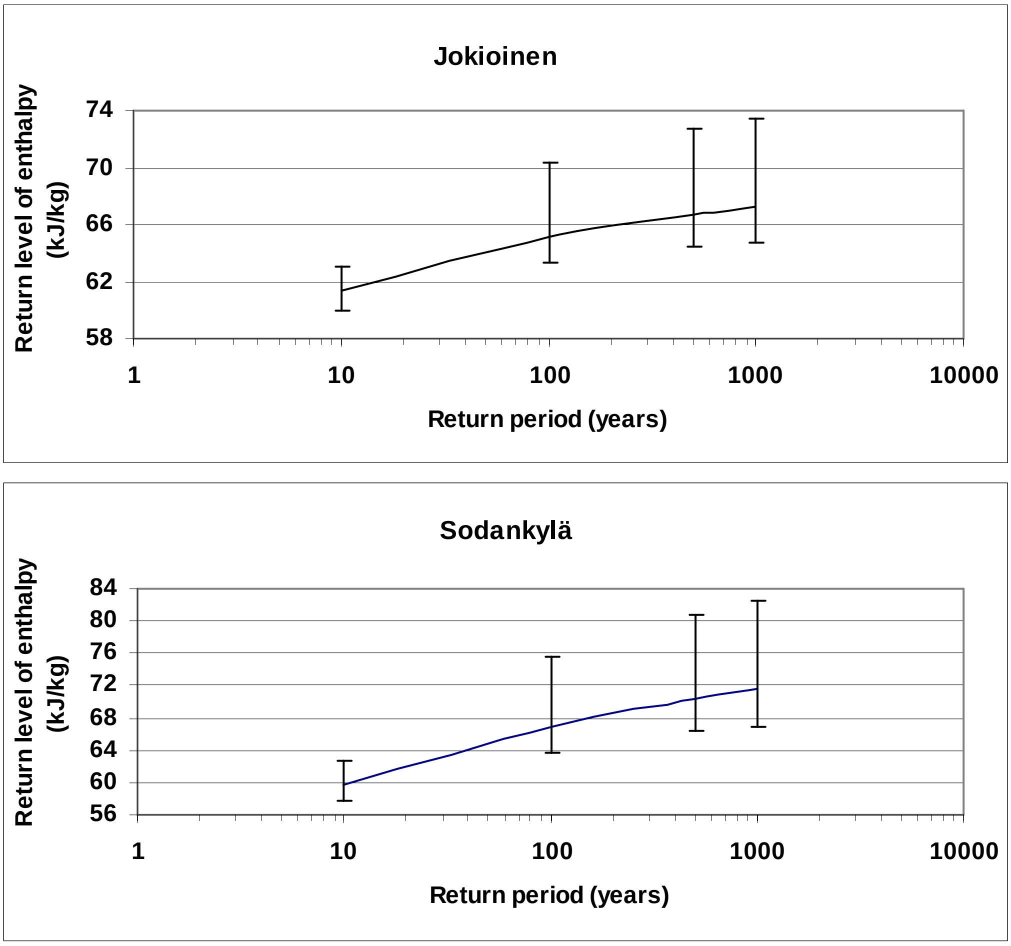


Figure 12. Return levels of daily extreme enthalpy at Jokioinen and Sodankylä. The continuous line indicates the best estimate and vertical bars the 95% confidence limits.

For a 6-hour time period (Fig. 13) the lowest return levels of enthalpy (for 100, 500 and 1000 year return periods) are found in Jokioinen. However, the differences in the lowest values between Jokioinen and Sodankylä are very small (not shown). The highest return level values of enthalpy are found in Kuopio.

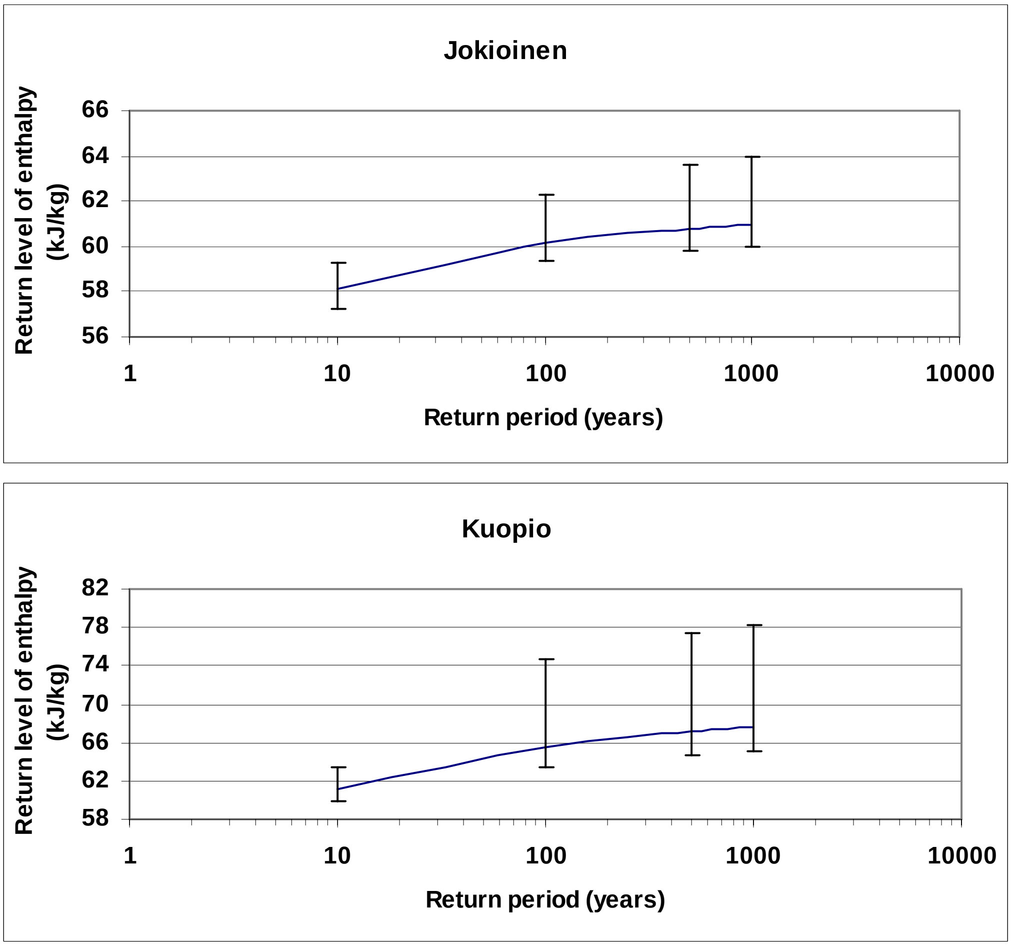


Figure 13. Return levels of 6 hours extreme enthalpy at Jokioinen and Kuopio. The continuous line indicates the best estimate and vertical bars the 95% confidence limits.

For a 24-hour time period (Fig. 14) the lowest return levels of enthalpy (for 100, 500 and 1000 years return periods) are found in Sodankylä but differences in the values in Jokioinen and Sodankylä are again very small (not shown). The highest values are found in Kuopio. For a 24-hour time period we see that the return level values of enthalpy in Pori were not possible to define (Appendix 1). This is due to the input data, it was not possible to fit GPD into this data sample.

For a 7-day time period (Fig. 15) the lowest return levels of enthalpy (for 100, 500 and 1000 years return periods) are found in Sodankylä. Differences in the values in Jokioinen and Sodankylä are again very small, especially if we focus on the values on the upper level of confidence interval. The highest values are found in Kuopio.

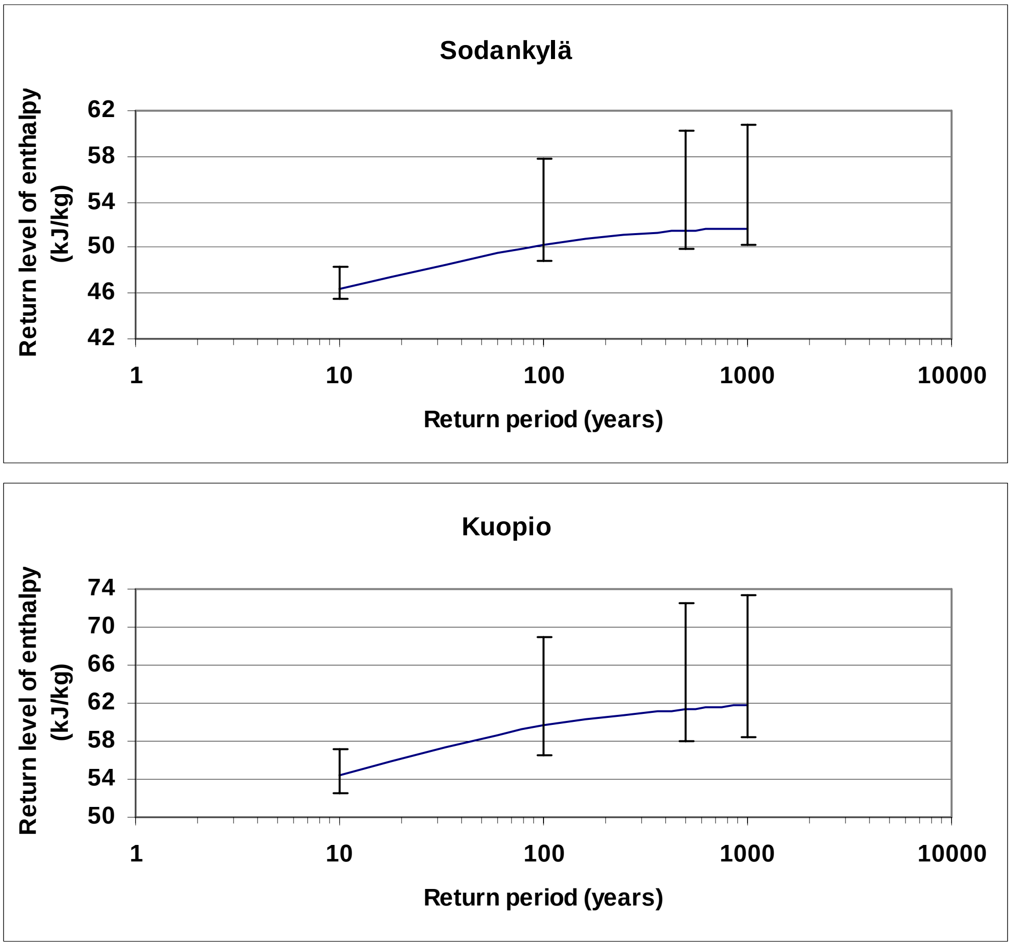
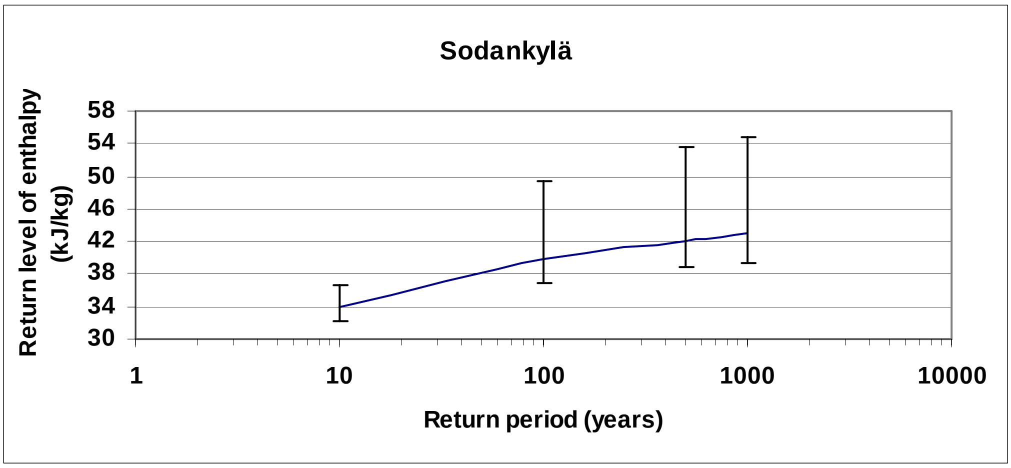


Figure 14. Return levels of 24-hour extreme enthalpy at Sodankylä and Kuopio. The continuous line indicates the best estimate and vertical bars the 95% confidence limits.



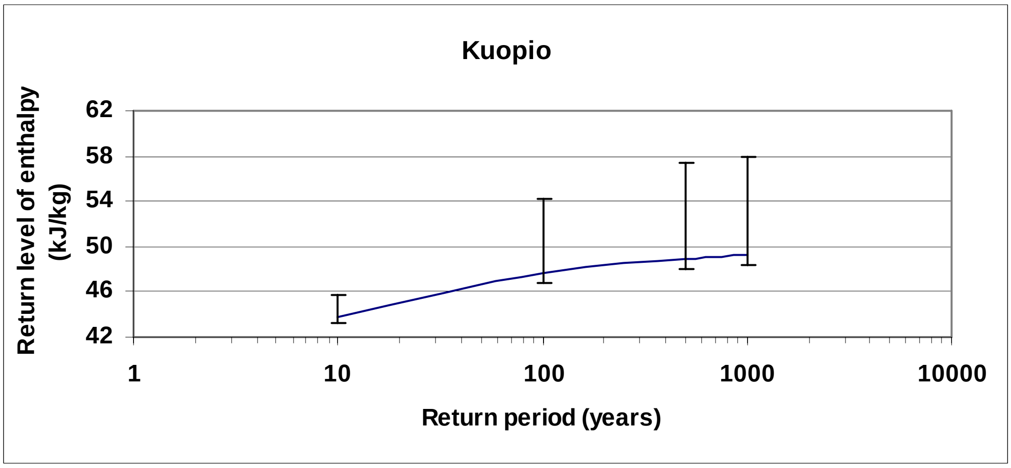
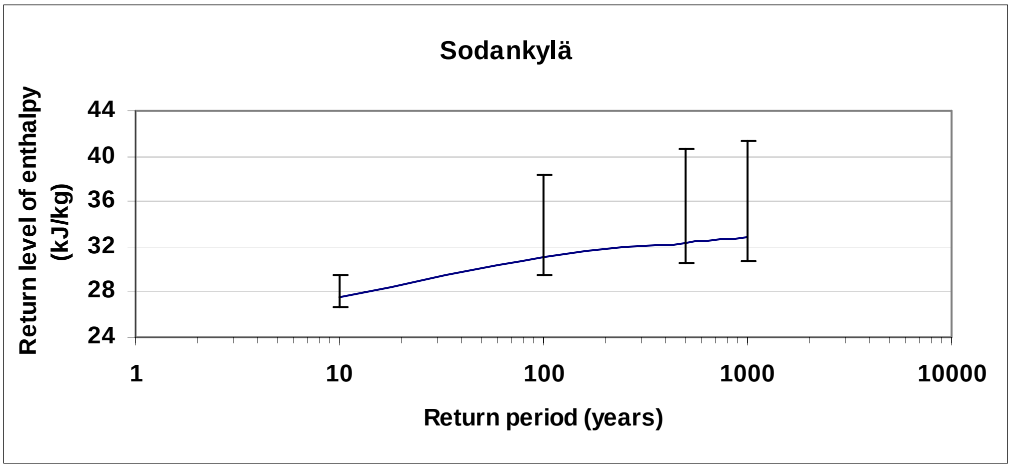


Figure 15. Return levels of 7 days extreme enthalpy for Sodankylä and Kuopio. The continuous line indicates the best estimate and vertical bars the 95% confidence limits.

For a 14 days time period (Fig. 16) the lowest return levels of enthalpy (for 100, 500 and 1000 years return periods) are found in Sodankylä. The highest values are found again in Kuopio.



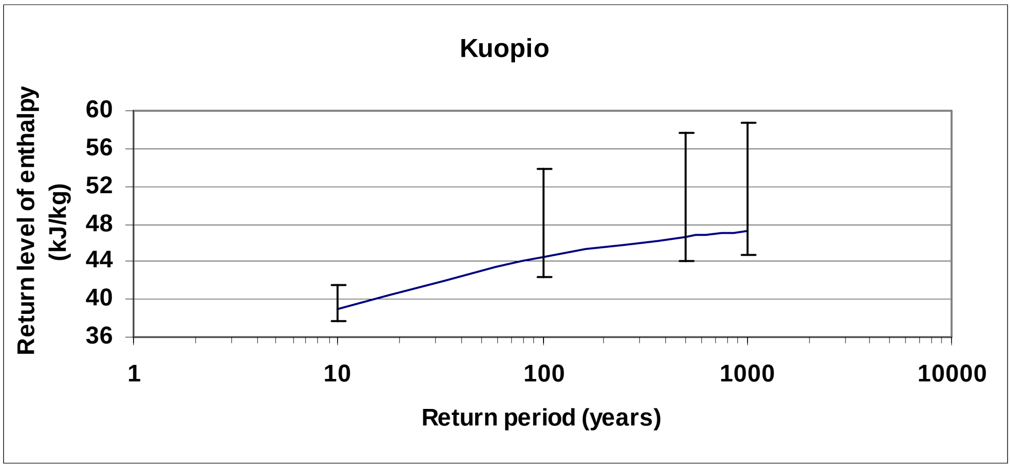
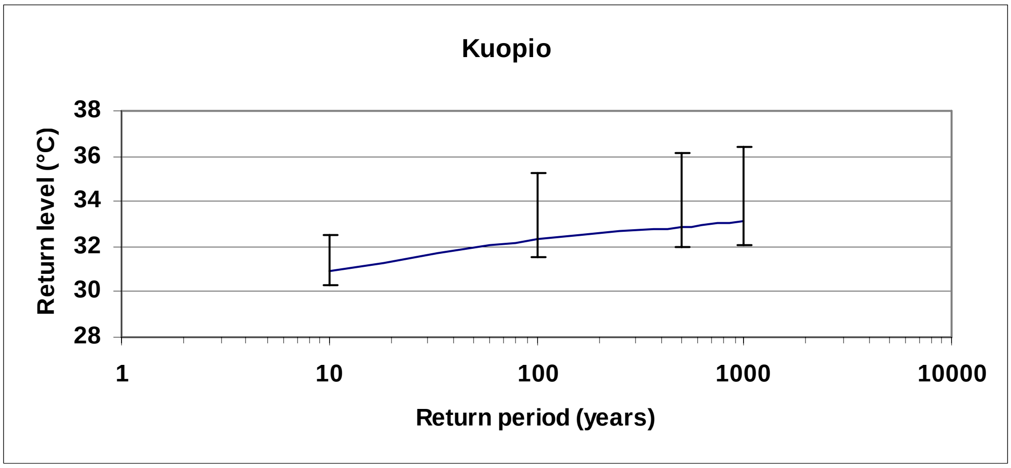


Figure 16. Return levels of 14 days extreme enthalpy for Sodankylä and Kuopio. The continuous line indicates the best estimate and vertical bars the 95% confidence limits

3.4 Return levels of air temperature in different relative humidity classes

In Appendix 2- 6 return levels (or probabilities) of air temperature are given for four different relative humidity classes (<40%, 40-60%, 60-80% and >80%) calculated for return periods of 10, 100, 500 and 1000 years. In these tables there are some unreliable values of return levels due to an unsuccessful GPD-fit of some of the temperature data. These unreliable values are marked in *italics* in the tables.

We take a closer look at a couple of results in these tables. For daily extremes the highest return levels of temperature in relative humidity class <40% are found for Kuopio (Appendix 5) which we have illustrated with a diagram (Fig. 17). In the same picture we have drawn a diagram for the lowest return level values of temperature in relative humidity class <40% and these values we find in Sodankylä (Appendix 6). Air temperature for a 100 year return level is 2.3˚C higher in Kuopio than in Sodankylä and 4.9˚C higher if we compare the corresponding temperature values on the upper limit of the 95% confidence interval. Air temperature for a 1000-year return level is 2.7˚C higher in Kuopio than in Sodankylä and 5.5˚C higher if we compare the corresponding values on the upper limit of the 95% confidence interval.



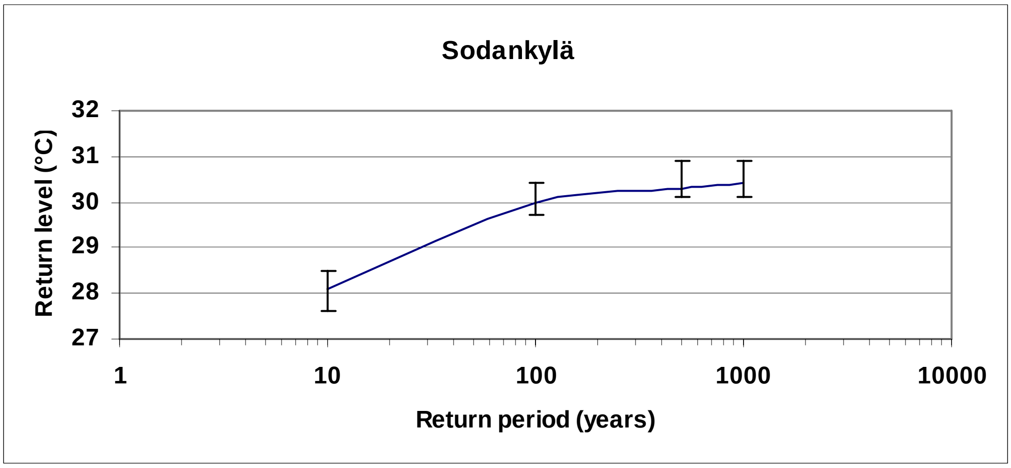
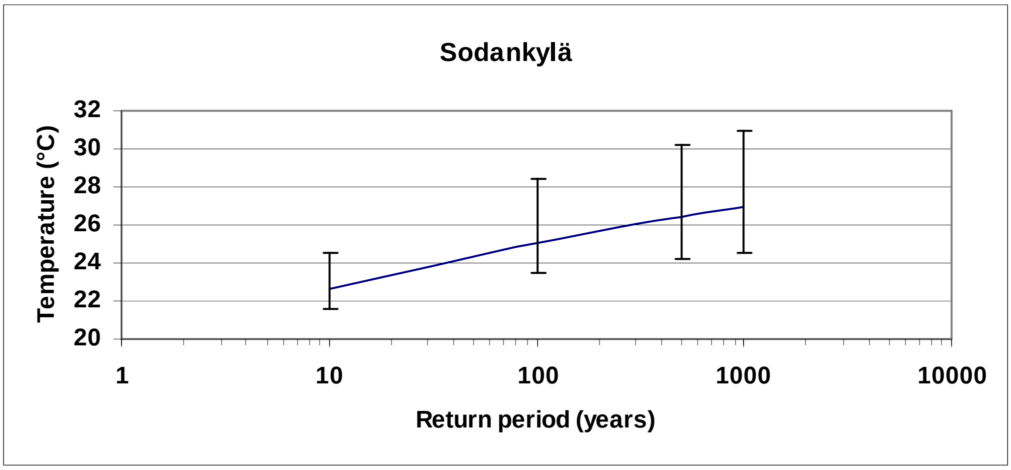


Figure 17. The return levels of daily maximum temperature at Kuopio and Sodankylä in case relative humidity is less than 40 %. The continuous line indicates the best estimate and vertical bars the 95% confidence limits.

For daily extremes we see that the highest return level values of temperature in relative humidity class of greater than 80% are found in Sodankylä (Appendix 6) which we have illustrated with a diagram (Fig. 18). However, the values at Helsinki-Vantaa (Appendix 2) are very close to the values in Sodankylä. The lowest return level values of temperature in relative humidity class of greater than 80% are found in Kuopio (Appendix 5) and the diagram over these values is found in Fig. 18. The return level of air temperature for a 100 year return period is 5.5˚C higher in Sodankylä than in Kuopio and 6.6˚C higher if we compare corresponding values on the upper limit of the 95% confidence interval. The return level of air temperature for a 1000 years return period is in Sodankylä 7.2 ˚C higher than in Kuopio and 8.5˚C higher if we compare corresponding values on the upper limit of the 95% confidence interval.



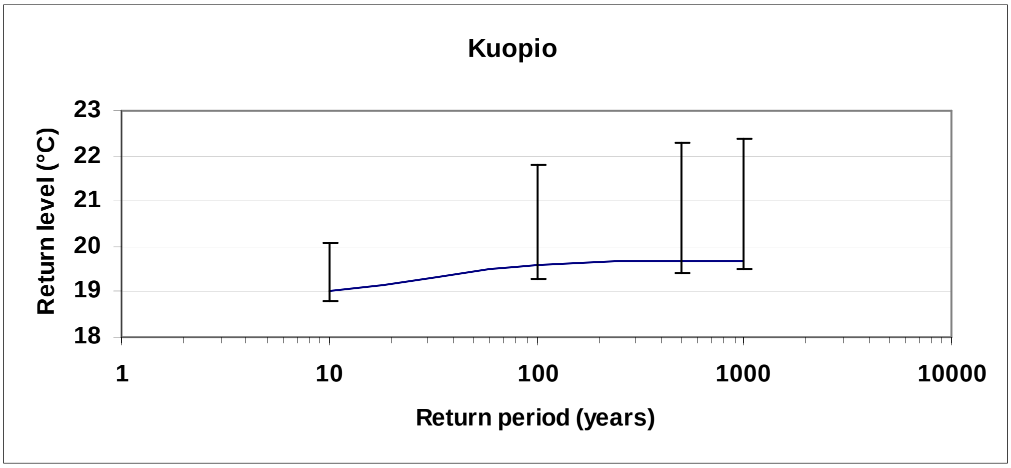


Figure 18. The return levels of daily maximum temperature at Sodankylä and Kuopio in case relative humidity is more than 80 %. The continuous line indicates the best estimate and vertical bars the 95% confidence limits.

4. Discussion and conclusions

The use of relatively short observational time series makes the reliable estimation of return levels of rare phenomena very difficult. No statistical method can give reliable estimates of for example a once in a 1000 year phenomena if there is only 100 years, or even less, of observational data available. This difficulty can be seen in the relatively large confidence limits produced by the applied statistical method. In some cases it was even impossible to fit any distribution into the available data. However, this is the best that can be achieved based on the available data.

Enthalpy is a new parameter to be studied the way it was done in this project. Hopefully this new analyses can be used to help in the design of air conditions equipments. Another way of estimating hot and humid conditions is to combine these two parameters in different classes and to calculate return levels for these conditions as was done in this study. This gives new information also for the estimation of frequency of conditions that may be harmful for elderly or sick persons and who may suffer due to excess humid and hot weather. For people adapted to temperate regions, the comfort zone has air temperatures of 20-25°C and relative humidity between 25 and 75 %. According to this study mean six hourly air humidity above 80% and air temperature above 25 degrees occurs only once in every 100 years in Helsinki. However, as people in this area are used to cooler temperatures even temperatures above 20°C combined with high air humidity may be difficult.

Climate change is regarded as one of the largest threats. The large magnitude and rapidness of the change can be seen also from the results of this study. According to the results there will be more hot summer days and less very cold winter days within this century. The largest increase of 50-year return levels of daily maximum temperature can be found southern Sweden and south-western Finland. Until the end of this century the increase can be 3-6 °C. In case of minimum temperatures the spatial distribution is different. As the warming of climate is estimated to be larger in the north also the largest change in the return levels of daily minimum temperature can be found at the end of this century in parts of northern Sweden and Finland. The change can be more than 10 degrees.

When we make the calculations in changing climatological conditions we have to note that some values that have been considered extreme may become quite common during the coming decades.

Finally we note that the presented results for future extremes are based on just a few simulations with climate models. We are aware that such a small set of experiments only sample a small part of the uncertainty related to climate change. In particular, the three ensemble members do sample some of the uncertainties related to natural variability. A larger ensemble that also sample uncertainties related to emissions (different emission scenarios) and choice of boundary conditions (different GCMs) would be preferable. Some results of that kind have been obtained within the European PRUDENCE and ENSEMBLES projects (e.g. Beniston et al., 2007). Also, other RCMs should be used in such a context as much of the uncertainties in the extremes and higher order variability is related to the choice of RCMs (Kjellström et al., 2007).

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Appendix 1. The return levels of enthalpy (kJ/kg) based on observations made at five locations in Finland 1956-2007. Daily extreme indicates the instantaneous highest value, 6-hours the highest value that lasts at least six hours and 24-hours a value that lasts at least 24-hours, 7-day value lasts one week and 14-days value two weeks.. The figures in brackets are the 95% confidence limits.

Daily extreme

Return period	Probability	Hki-Vantaa	Jokioinen	Pori	Kuopio	Sodankylä
10	0.100	64.0 (62.4-66.2)	61.3 (60.0-63.1)	64.2 (61.4-66.7)	64.3 (62.9-66.5)	59.8 (57.8-62.7)
100	0.010	69.4 (67.2-75.2)	65.1 (63.4-70.3)	68.8 (65.0-76.1)	68.3 (66.3-74.8)	66.9 (63.8-75.5)
500	0.002	72.0 (69.2-78.8)	66.7 (64.5-72.7)	70.7 (66.5-78.7)	69.8 (67.6-77.4)	70.4 (66.3-80.7)
1000	0.001	72.8 (69.9-80.0)	67.2 (64.8-73.5)	71.2 (66.9-79.6)	70.2 (67.9-78.0)	71.6 (67.0-82.4)

6 hours

Return period	Probability	Hki-Vantaa	Jokioinen	Pori	Kuopio	Sodankylä
10	0.100	60.2 (59.8-61.9)	58.1 (57.2-59.3)	60.8 (60.3-62.8)	61.2 (59.8-63.5)	55.1 (53.9-57.1)
100	0.010	63.6 (62.9-69.8)	60.2 (59.4-62.3)	64.8 (64.0-70.9)	65.5 (63.4-74.7)	59.2 (57.4-66.4)
500	0.002	64.8 (64.0-72.1)	60.8 (59.8-63.6)	66.2 (65.3-74.2)	67.1 (64.7-77.4)	60.7 (58.6-69.2)
1000	0.001	65.1 (64.2-72.7)	61.0 (60.0-64.0)	66.5 (65.6-74.8)	67.5 (65.0-78.2)	61.1 (58.9-69.8)

24 hours

Return period	Probability	Hki-Vantaa	Jokioinen	Pori*)	Kuopio	Sodankylä
10	0.100	52.2 (50.5-54.7)	49.7 (49.0-51.2)		54.5 (52.6-57.1)	46.4 (45.5-48.3)
100	0.010	57.5 (55.1-65.6)	52.6 (51.6-58.4)		59.6 (56.6-69.0)	50.2 (48.8-57.8)
500	0.002	59.8 (57.0-69.4)	53.6 (52.4-60.2)		61.3 (58.1-72.5)	51.4 (49.9-60.3)
1000	0.001	60.6 (57.6-70.6)	53.8 (52.6-60.6)		61.8 (58.5-73.3)	51.7 (50.2-60.8)

7 days

Return period	Probability	Hki-Vantaa	Jokioinen	Pori	Kuopio	Sodankylä
10	0.100	39.9 (39.3-41.6)	38.6 (37.4-40.9)	39.2 (37.8-41.7)	43.7 (43.2-45.8)	34.0 (32.3-36.7)
100	0.010	43.3 (42.2-50.0)	43.2 (41.2-50.9)	44.1 (41.9-53.7)	47.7 (46.8-54.2)	39.8 (36.9-49.5)
500	0.002	44.4 (43.1-51.9)	44.8 (42.6-53.8)	45.9 (43.4-56.8)	48.9 (48.0-57.4)	42.1 (38.8-53.5)
1000	0.001	44.6 (43.3-52.4)	45.3 (42.9-54.6)	46.4 (43.8-57.6)	49.2 (48.3-58.0)	42.9 (39.4-54.7)

14 days

Return period	Probability	Hki-Vantaa	Jokioinen	Pori	Kuopio	Sodankylä
10	0.100	35.3 (34.0-37.4)	32.0 (31.5-33.7)	33.8 (32.6-35.6)	38.9 (37.6-41.5)	27.6 (26.6-29.4)
100	0.010	38.8 (36.9-43.9)	35.2 (34.4-41.7)	37.4 (35.4-45.4)	44.5 (42.3-53.9)	31.1 (29.4-38.4)
500	0.002	40.2 (37.6-48.0)	36.2 (35.4-43.6)	38.6 (36.3-47.6)	46.7 (44.1-57.6)	32.4 (30.5-40.7)
1000	0.001	40.6 (37.8-49.5)	36.5 (35.7-44.1)	38.9 (36.5-48.3)	47.3 (44.7-58.8)	32.8 (30.8-41.3)

*) due to the quality of input data it is not possible fit the GPD using extRemes-software

Appendix 2. Return levels of air temperature (°C) in different relative humidity classes at Helsinki-Vantaa airport. Daily extreme is the highest daily value calculated using 3-hourly synoptic observations. The longer periods (6 and 24 hours, 7 and 14 days) are the mean values calculated for that period using the same synoptic observations. In case of 24 hours and longer periods mean relative humidity is so seldom below 40% that analyses is not possible. The cases where fitting of distribution was difficult are given in *italics.*

Helsinki-Vantaa airport

Daily extreme

		Rel.Humidity (%)			
Return period	Probability	<40	40 - 60	60 - 80	>80
10	0.100	30.6 (30.1-31.6)	30.2 (29.7-31.0)	27.1 (26.9-27.8)	24.1 (23.5-25.4)
100	0.010	31.4 (30.9-33.7)	31.2 (30.6-33.0)	27.8 (27.6-29.8)	25.6 (24.7-28.2)
500	0.002	31.7 (31.1-34.2)	31.6 (30.9-33.8)	28.0 (27.8-30.3)	26.3 (25.2-29.1)
1000	0.001	31.8 (31.2-34.3)	31.7 (31.0-34.0)	28.1 (27.8-30.4)	26.6 (25.3-29.4)

6 hours

		Rel.Humidity (%)			
Return period	Probability	<40	40 - 60	60 - 80	>80
10	0.100	30.5 (30.3-32.7)	29.4 (29.2-30.0)	27.0 (26.5-28.1)	23.5 (22.8-24.9)
100	0.010	31.3 (31.0-31.3)	30.0 (29.7-31.1)	28.1 (27.6-30.4)	25.1 (24.0-27.6)
500	0.002	31.5 (31.2-31.5)	30.2 (30.0-30.2)	28.5 (27.9-31.0)	25.9 (24.5-28.8)
1000	0.001	31.6 (31.3-31.6)	30.2 (30.0-30.2)	28.6 (28.0-31.2)	26.2 (24.7-29.2)

24 hours

		Rel.Humidity (%)			
Return period	Probability	<40	40 - 60	60 - 80	>80
10	0.100		25.6 (25.3-26.7)	25.2 (24.7-26.0)	22.5 (22.1-23.4)
100	0.010		26.3 (25.9-28.7)	26.1 (25.5-27.8)	23.5 (23.0-25.2)
500	0.002		26.5 (26.1-29.1)	26.4 (25.8-28.6)	23.9 (23.4-26.1)
1000	0.001		26.6 (26.1-29.2)	26.5 (25.9-28.7)	24.0 (23.5-26.2)

7 days

		Rel.Humidity (%)			
Return period	Probability	<40	40 - 60	60 - 80	>80
10	0.100		*23.3 (23.2-25.5)*	23.5 (23.3-24.4)	20.1 (19.7-21.4)
100	0.010		*23.5 (23.5-23.8)*	24.5 (24.3-26.3)	21.1 (20.6-23.6)
500	0.002		*23.6 (23.5-23.9)*	24.9 (24.6-27.2)	21.5 (20.9-24.1)
1000	0.001		*23.6 (23.5-23.9)*	25.0 (24.7-27.4)	21.6 (21.0-24.3)

14 days

		Rel.Humidity (%)			
Return period	Probability	<40	40 - 60	60 - 80	>80
10	0.100	0	20.6 (20.1-21.0)	22.2 (21.7-23.1)	19.8 (19.5-21.2)
100	0.010	0	21.4 (21.2-21.8)	23.0 (22.5-24.8)	20.7 (20.4-23.1)
500	0.002	0	21.5 (21.4-22.0)	23.3 (22.7-25.5)	21.0 (20.7-23.9)
1000	0.001	0	21.6 (21.4-22.0)	23.4 (22.8-25.6)	21.1 (20.8-24.1)

Appendix 3. Return levels of air temperature (°C) in different relative humidity classes at Jokioinen. Daily extreme is the highest daily value calculated using 3-hourly synoptic observations. The longer periods (6 and 24 hours, 7 and 14 days) are the mean values calculated for that period using the same synoptic observations. In case of 24 hours and longer periods mean relative humidity is so seldom below 40% that analyses is not possible. The cases where fitting of distribution was difficult are given in *italics.*

Jokioinen Observatory

Daily extreme

		Rel Humidity (%)			
Return period	Probability	<40	40 - 60	60 - 80	>80
10	0.100	31.1 (30.6-32.4)	29.1 (28.9-29.7)	26.2 (25.8-27.1)	22.5 (22.2-23.2)
100	0.010	32.1 (31.5-34.8)	29.7 (29.4-31.2)	27.1 (26.6-29.2)	23.2 (22.8-24.9)
500	0.002	32.5 (31.8-35.4)	29.9 (29.6-31.7)	27.4 (26.9-29.7)	23.5 (23.1-25.3)
1000	0.001	32.6 (31.9-35.5)	30.0 (29.7-31.7)	27.5 (26.9-29.8)	23.6 (23.1-25.5)

6 hours

		Rel Humidity (%)			
Return period	Probability	<40	40 - 60	60 - 80	>80
10	0.100	30.7 (30.5-31.7)	28.8 (28.6-29.5)	*25.8 (25.7-27.3)*	22.7 (22.5-23.4)
100	0.010	31.5 (31.3-33.6)	29.3 (29.1-31.0)	*26.3 (26.1-26.4)*	23.4 (23.2-24.9)
500	0.002	31.8 (31.5-34.2)	29.5 (29.2-31.3)	*26.4 (26.2-26.5)*	23.7 (23.5-25.6)
1000	0.001	31,9 (31.6-34.3)	29.5 (29.2-31.3)	*26.5 (26.3-26.5)*	23.8 (23.6-25.7)

24 hours

		Rel Humidity (%)			
Return period	Probability	<40	40 - 60	60 - 80	>80
10	0.100		25.0 (24.4-26.2)	24.4 (24.1-25.3)	21.8 (21.5-22.5)
100	0.010		25.7 (25.1-28.2)	25.1 (24.8-27.1)	22.5 (22.1-23.9)
500	0.002		25.9 (25.3-28.5)	25.3 (24.9-27.7)	22.7 (22.3-24.6)
1000	0.001		26.0 (25.3-28.6)	25.4 (25.0-27.7)	22.7 (22.4-24.8)

7 days

		Rel Humidity (%)			
Return period	Probability	<40	40 - 60	60 - 80	>80
10	0.100		20.4 (19.9-21.0)	22.2 (22.1-23.0)	20.0 (19.6-21.1)
100	0.010		21.9 (21.5-22.9)	23.0 (22.8-24.6)	20.7 (20.3-23.0)
500	0.002		22.3 (21.9-23.5)	23.2 (23.0-25.3)	20.9 (20.5-23.6)
1000	0.001		22.4 (22.0-23.6)	23.3 (23.1-25.4)	21.0 (20.5-23.6)

14 days

		Rel Humidity (%)			
Return period	Probability	<40	40 - 60	60 - 80	>80
10	0.100		19.4 (18.9-19.8)	21.1 (20.9-21.9)	19.4 (18.7-21.1)
100	0.010		20.1 (20.0-20.4)	21.8 (21.5-23.5)	20.5 (19.6-23.6)
500	0.002		20.2 (20.1-20.6)	22.0 (21.7-24.0)	20.8 (19.9-24.1)
1000	0.001		20.2 (20.2-20.6)	22.0 (21.8-24,1)	21.0 (20.0-24.3)

Appendix 4. Return levels of air temperature (°C) in different relative humidity classes at Pori Airport. Daily extreme is the highest daily value calculated using 3-hourly synoptic observations. The longer periods (6 and 24 hours, 7 and 14 days) are the mean values calculated for that period using the same synoptic observations. In case of 24 hours and longer periods mean relative humidity is so seldom below 40% that analyses is not possible.

Pori airport

Daily extreme

		Rel.Humidity (%)			
Return period	Probability	<40	40 - 60	60 - 80	>80
10	0.100	30.9 (30.2-32.2)	30.1 (29.6-31.1)	27.5 (26.3-28.8)	23.5 (22.9-24.8)
100	0.010	31.7 (31.0-34.5)	30.9 (30.3-33.0)	28.6 (27.2-31.3)	24.5 (23.8-27.2)
500	0.002	32.0 (31.2-34.8)	31.1 (30.5-33.6)	29.0 (27.5-31.9)	24.9 (24.1-27.8)
1000	0.001	32.1 (31.2-34.9)	31.2 (30.6-33.7)	29.1 (27.6-32.1)	25.1 (24.4-28.0)

6 hours

		Rel.Humidity (%)			
Return period	Probability	<40	40 - 60	60 - 80	>80
10	0.100	30.2 (30.0-31.3)	30.0 (29.7-30.9)	26.9 (26.6-27.6)	23.3 (23.1-24.2)
100	0.010	30.9 (30.5-32.9)	30.8 (30.4-32.4)	27.4 (27.2-29.0)	24.2 (23.9-26.0)
500	0.002	31.1 (30.7-33.7)	31.0 (30.6-33.2)	27.6 (27.3-29.6)	24.5 (24.2-26.8)
1000	0.001	31.2 (30.7-33.8)	31.1 (30.7-33.4)	27.6 (27.3-29.8)	24.6 (24.3-26.9)

24 hours

		Rel.Humidity (%)			
Return period	Probability	<40	40 - 60	60 - 80	>80
10	0.100		25.2 (25.0-26.3)	24.9 (24.7-25.8)	22.3 (22.0-23.2)
100	0.010		26.0 (25.7-27.9)	25.8 (25.5-27.5)	23.0 (22.6-24.8)
500	0.002		26.2 (25.9-28.5)	26.1 (25.8-28.3)	23.2 (22.8-25.6)
1000	0.001		26.3 (26.0-28.7)	26.1 (25.9-28.4)	23.3 (22.9-25.6)

7 days

		Rel.Humidity (%)			
Return period	Probability	<40	40 - 60	60 - 80	>80
10	0.100		20.1 (19.4-20.9)	22.8 (22.5-23.7)	20.8 (20.2-22.1)
100	0.010		22.0 (21.4-23.5)	23.6 (23.4-25.5)	21.8 (21.1-24.3)
500	0.002		22.6 (21.9-24.6)	23.9 (23.7-26.4)	22.1 (21.4-25.1)
1000	0.001		22.8 (22.1-24.9)	24.0 (23.7-26.5)	22.2 (21.4-25.2)

14 days

		Rel.Humidity (%)			
Return period	Probability	<40	40 - 60	60 - 80	>80
10	0.100		19.1 (18.2-20.2)	21.3 (20.8-22.3)	21.6 (20.3-24.4)
100	0.010		20.7 (20.0-22.2)	22.1 (21.6-24.1)	24.2 (22.4-28.6)
500	0.002		21.0 (20.4-23.1)	22.3 (21.8-24.6)	25.5 (23.3-30.5)
1000	0.001		21.1 (20.5-23.3)	22.4 (21.9-24.7)	26.0 (23.6-31.2)

Appendix 5. Return levels of air temperature (°C) in different relative humidity classes at Kuopio Airport. Daily extreme is the highest daily value calculated using 3-hourly synoptic observations. The longer periods (6 and 24 hours, 7 and 14 days) are the mean values calculated for that period using the same synoptic observations. In case of 24 hours and longer periods mean relative humidity is so seldom below 40% that analyses is not possible. The cases where fitting of distribution was difficult are given in *italics.*

Kuopio airport

Daily extreme

		Rel.Humidity (%)			
Return period	Probability	<40	40 - 60	60 - 80	>80
10	0.100	30.9 (30.3-32.5)	30.7 (30.1-31.8)	27.7 (27.2-28.8)	19.0 (18.8-20.1)
100	0.010	32.3 (31.5-35.3)	31.8 (31,1-34.3)	28.7 (28.0-31.3)	19.6 (19.3-21.8)
500	0.002	32.9 (32.0-36.1)	32.3 (31.5-34.9)	29.0 (28.3-31.9)	19.7 (19.4-22.3)
1000	0.001	33.1 (32.1-36.4)	32.4 (31.6-35.1)	29.1 (28.4-32.1)	19.7 (19.5-22.4)

6 hours

		Rel.Humidity (%)			
Return period	Probability	<40	40 - 60	60 - 80	>80
10	0.100	30.9 (30.6-32.3)	*29.9 (29.6-31.9)*	27.5 (26.8-28.5)	23.3 (23.1-24.2)
100	0.010	32.1 (31.8-34.9)	*30.4 (30.2-30.5)*	28.3 (27.6-30.7)	24.1 (23.8-25.9)
500	0.002	32.5 (32.2-35.8)	*30.6 (30.3-30.6)*	28.6 (27.8-31.4)	24.3 (24.1-26.6)
1000	0.001	32.6 (32.3-35.9)	*30.6 (30.3-30.6)*	28.7 (27.8-31.5)	24.4 (24.1-26.7)

24 hours

		Rel.Humidity (%)			
Return period	Probability	<40	40 - 60	60 - 80	>80
10	0.100		26.0 (25.7-26.9)	26.0 (25.6-27.2)	22.5 (22.1-23.4)
100	0.010		26.5 (26.2-28.4)	27.1 (26.5-29.7)	23.5 (23.0-25.6)
500	0.002		26.6 (26.3-29.1)	27.5 (26.9-30.3)	23.9 (23.4-26.2)
1000	0.001		26.7 (26.3-29.1)	27.6 (27.0-30.5)	24.0 (23.5-26.4)

7 days

		Rel.Humidity (%)			
Return period	Probability	<40	40 - 60	60 - 80	>80
10	0.100		23.7 (23.4-25.4)	23.8 (23.0-25.0)	*20.6 (20.3-23.1)*
100	0.010		24.6 (24.2-27.9)	24.7 (23.9-27.4)	*21.2 (20.9-21.2)*
500	0.002		24.8 (24.5-28.3)	25.0 (24.1-28.0)	*21.4 (21.0-21.4)*
1000	0.001		24.9 (24.5-28.4)	25.1 (24.2-28.2)	*21.4 (21.1-21.4)*

14 days

		Rel.Humidity (%)			
Return period	Probability	<40	40 - 60	60 - 80	>80
10	0.100		20.2 (19,7-20.7)	22.8 (22.0-24.0)	19.0 (18.8-20.1)
100	0.010		21.1 (20.9-21.5)	24.0 (23.0-26.5)	19.6 (19.3-21.8)
500	0.002		21.2 (21.1-21.7)	24.5 (23.4-27.2)	19.7 (19.4-22.3)
1000	0.001		21.3 (21.1-21.7)	24.6 (23.5-27.4)	19.7 (19.5-22.4)

Appendix 6. Return levels of air temperature (°C) in different relative humidity classes at Sodankylä Research Centre. Daily extreme is the highest daily value calculated using 3-hourly synoptic observations. The longer periods (6 and 24 hours, 7 and 14 days) are the mean values calculated for that period using the same synoptic observations. In case of 24 hours and longer periods mean relative humidity is so seldom below 40% that analyses is not possible. The cases where fitting of distribution was difficult are given in *italics.*

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Daily extreme

		Rel.Humidity (%)			
Return period	Probability	<40	40 - 60	60 - 80	>80
10	0.100	28.1 (27.6-28.5)	28.7 (28.5-29.4)	26.0 (25.1-27.7)	22.6 (21.6-24.5)
100	0.010	30.0 (29.7-30.4)	29.5 (29.3-31.4)	28.5 (27.2-31.6)	25.1 (23.5-28.4)
500	0.002	30.3 (30.1-30.9)	29.8 (29.5-32.0)	29.7 (28.0-33.2)	26.4 (24.2-30.2)
1000	0.001	30.4 (30.1-30.9)	29.9 (29.6-32.1)	30.1 (28.3-33.8)	26.9 (24.5-30.9)

6 hours

		Rel.Humidity (%)			
Return period	Probability	<40	40 - 60	60 - 80	>80
10	0.100	29.7 (29.6-30.3)	*29.0 (28.7-31.2)*	25.1 (24.5-26.2)	22.0 (21.3-23.4)
100	0.010	30.0 (29.9-31.2)	*29.9 (29.6-29.9)*	26.1 (25.4-28.5)	23.4 (21.9-26.4)
500	0.002	30.1 (30.0-31.4)	*30.1 (29.8-30.1)*	26.4 (25.7-29.4)	24.0 (22.3-27.2)
1000	0.001	30.1 (30.0-31.5)	*30.2 (29.9-30.2)*	26.5 (25.8-29.5)	24.1 (22.4-27.4)

24 hours

		Rel.Humidity (%)			
Return period	Probability	<40	40 - 60	60 - 80	>80
10	0.100		*24.6 (24.5-26.9)*	23.8 (23.4-24.8)	20.4 (19.9-21.6)
100	0.010		*25.0 (24.8-25.1)*	24.6 (24.2-26.5)	21.6 (20.9-24.2)
500	0.002		*25.1 (24.9-25.2)*	24.9 (24.4-27.3)	22.0 (21.3-24.8)
1000	0.001		*25.1 (24.9-25.2)*	24.9 (24.5-27.6)	22.1 (21.4-24.9)

7 days

		Rel.Humidity (%)			
Return period	Probability	<40	40 - 60	60 - 80	>80
10	0.100		23.0 (22.0-26.2)	21.6 (20.8-23.0)	15.2 (14.7-15.6)
100	0.010		24.5 (23.3-29.5)	23.2 (22.3-26.1)	16.9 (16.6-17.6)
500	0.002		25.0 (23.7-30.4)	23.8 (22.8-27.0)	17.4 (17.0-18.2)
1000	0.001		25.1 (23.8-30.6)	24.0 (23.0-27.3)	17.5 (17.1-18.4)

14 days

		Rel.Humidity (%)			
Return period	Probability	<40	40 - 60	60 - 80	>80
10	0.100		21.7 (20.4-25.7)	20.7 (19.5-22.2)	13.7 (13.1-14.6)
100	0.010		23.1 (21.5-28.5)	22.4 (20.9-25.4)	16.3 (15.4-18.4)
500	0.002		23.6 (21.9-29.3)	23.2 (21.5-26.4)	17.3 (16.2-20.3)
1000	0.001		23.7 (22.0-29.6)	23.4 (21.7-26.7)	17.6 (16.3-21.0)

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Title	Extremes temperatures and enthalpy in Finland and Sweden in a changing climate
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Abstract	Though risks caused by harsh weather conditions are taken into account in the planning of nuclear power plants, some exceptional weather events or combination of different events may prevent normal power operation and simultaneously endanger safe shutdown of the plant. Extreme weather events could influence, for example, the external power grid connection, emergency diesel generators (blockage of air intakes), ventilation and cooling of electric and electronics equipment rooms and the seawater intake. Due to the influence of an intensified greenhouse effect the climate is changing rapidly during the coming decades and this change is expected to have an influence also on the occurrence of extreme weather events. In this report we have examined extreme temperatures. Enthalpy is a parameter that combines air temperature and air humidity and it is used in the design of air conditioning systems. Therefore, we have included also return levels of enthalpy in our analysis. The influence of climate change on extreme temperatures is analysed based on regional climate model simulations. The reoccurrence times of high temperatures combined with high air humidity was analysed based on measurements made at five Finnish and three Swedish meteorological stations. Based on the observational records we find the 10 year return level of daily maximum temperature to be around 32°C and the 100 year return level around 35°C. If we look the return levels of warm and humid conditions then for example in Helsinki the 10 year return level of one week mean temperature in case mean air humidity is above 80% is 20.1°C. The 10 year return level of daily maximum enthalpy is around 60 kJ/kg and the 100 year return level almost 70 kJ/kg. According to the climate model simulations the largest increase of 50-year return level of daily maximum temperature is found in southern Sweden and south-western Finland. By the end of this century the increase can be 3-5 °C. The largest change in the return levels of daily minimum temperature can be found in north-eastern Finland at the end of this century. This change can be even more than 10 degrees.
Key words	climate extremes, climate change, extreme temperature, extreme enthalpy

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