What methods can be used to make projections about future changes in the occurrence of extreme weather events in Europe?

This information sheet provides an introductory overview to a series of regional information sheets describing how the frequency and intensity of extreme weather events may change by the end of the 21st century in response to global warming. The regional information was obtained using state-of-the-art climate modeling and regional downscaling techniques developed during the STARDEX European Union-funded research project. These methods are outlined here.

Scenarios of extremes

Recent events, such as the August 2002 floods in Central and Eastern Europe and the severe heatwaves experienced across many parts of Europe in August 2003, together with the severe drought affecting Spain and Portugal in summer 2005, graphically illustrate the losses of life and high economic damages which can be caused by extreme weather events. According to estimates by the Munich Re reinsurance company, for example, the August 2002 floods were responsible for economic losses of 21.1 billion Euro and insured losses of 3.4 billion Euro, together with over 100 deaths. Such events demonstrate the need for information about how the occurrence of weather extremes may change in the future in response to global warming. Thus there is a need for scenarios of extremes as well as for mean climate. Scenarios provide coherent, internally consistent and plausible descriptions of possible future states of the world.

Regional downscaling

Global climate models (GCMs) provide the starting point for constructing climate scenarios. However, their relatively coarse spatial resolution (e.g., 300 km x 300 km over Europe), means that downscaling is required to the finer spatial scales relevant for studying the impacts of climate change. Two major approaches to downscaling can be used: dynamical (using physically-based Regional Climate Models (RCMs)) and statistical downscaling. State-of-the-art RCM scenarios for Europe (at a 50 km resolution) have been produced by the EU-funded PRUDENCE project. STARDEX has focused on the development and assessment of improved statistical downscaling methods for Europe with emphasis on their ability to provide reliable scenarios of extremes for point locations. Comparisons with the PRUDENCE RCM grid-point scenarios have also been undertaken.

Statistical downscaling

Statistical downscaling involves the application of relationships identified in the observed climate, between the large-scale and smaller-scale, to GCM output. It is based on two major assumptions. First, that the observed relationships are applicable to a future warmer climate (the stationarity assumption). Second, that the large-scale patterns are better represented than the local in the GCMs. Although the first assumption cannot be fully tested, STARDEX has put considerable effort into developing and evaluating many different methods. The most reliable and robust statistical downscaling methods have the following characteristics:

- Strong, stable and physically-meaningful predictor-predictand relationships
- Stationary predictor-predictand relationships
- Uniformity of performance
- Predictors well simulated for the present day by the GCM

The STARDEX methods

In all, 22 different statistical downscaling methods were developed and tested by STARDEX. These are grouped into the following categories:

- multiple linear regression
- canonical correlation analysis
- artificial neural networks
- multivariate autoregressive models
- conditional resampling and other analogue-based methods
- methods based on a 'potential precipitation circulation index' and 'critical circulation patterns'
- a conditional weather generator
- local scaling and dynamical scaling

The methods range from fairly standard linear regression methods, through methods focusing on spatial patterns, to non-linear neural network methods and other novel methods, including some analogue-based methods. In the case of neural network methods, STARDEX provides the most systematic evaluation of these downscaling approaches to date.

The methods can be divided into 'indirect' methods, where daily time series are downscaled and indices of extremes calculated, and 'direct' methods where the seasonal indices of extremes are downscaled directly.

STARDEX indices of extremes

Many different definitions of extremes are available. A set of 10 core indices of extremes (6 for rainfall and 4 for temperature) was used in STARDEX. Many of them are based on thresholds defined using percentile values rather than fixed values. This makes them transferable across the range of climatic regimes experienced across Europe. In order to ensure statistical robustness (i.e., to ensure sufficient data points), the indices are rather moderate. Although defined primarily from a climatic perspective, they are still highly relevant in terms of the impacts of extremes. This is reflected in the user-friendly names for the indices used in these information sheets. A software package for calculating these indices (and more than 40 others) is available from the STARDEX web site.

The STARDEX study regions

STARDEX used a range of statistical downscaling methods suitable for different applications. Some provide information for multiple sites for example, and are therefore more applicable to denser regional station networks than European wide. Thus is was not appropriate to use a single region for assessing the methods. Instead, STARDEX focused on six regional case-studies: the Iberian Peninsula, Greece, the Alps, German Rhine, the UK and Northern Italy. Scenario information sheets are available for these regions, as well as for Europe as a whole. The latter scenarios are based on a data set of almost 500 daily station records, while the regional scenarios are based on denser station networks. Each method was tested in two different regions, thus ensuring that multiple results are available for each region.

Scenario uncertainties

A major STARDEX recommendation is to use a range of the better statistical downscaling methods for the construction of scenarios of extremes, just as it is recommended good practice to use a range of GCMs and RCMs in order to reflect a wider range of the uncertainties.

While STARDEX has undertaken a comprehensive assessment of the uncertainties due to choice of statistical downscaling method, the scenarios are based on output from a single GCM (HadAM3P from the UK Hadley Centre, which has a spatial resolution of about 150km over Europe) and two greenhouse gas emissions scenarios (the IPCC SRES A2 and B2 scenarios with concentrations of 715 and 562 ppmv at 2100 respectively). HadAM3P output was also used to drive many of the PRUDENCE RCM simulations, thus allowing direct intercomparison of PRUDENCE and STARDEX scenarios (e.g., for the Alps).

Another STARDEX information sheet discusses scenario uncertainties in more detail.

References and further reading

Goodess, CM and 13 others, 2005: An intercomparison of statistical downscaling methods for Europe and European regions – assessing their performance with respect to extreme temperature and precipitation events. *Climatic Change*, submitted.

Wilby, RL, Charles, SP, Zorita, E., Timbal, B, Whetton, P. and Mearns, LO, 2004: Guidelines for use of climate scenarios developed from statistical downscaling methods. IPCC guidance material, see http://ipcc-ddc.cru.uea.ac.uk/

The scenarios presented in this series of information sheets are underpinned by extensive analyses undertaken during the STARDEX project. The following deliverable reports provide supporting technical information:

D9: demonstrates that coherent changes in European extremes have occurred over the last 40 years

D10: describes how the best predictor variables were selected for the statistical downscaling models

D11: demonstrates the need for regional downscaling from GCMs

D12: provides detailed evaluation of the performance of the statistical downscaling models for the present day

D13: demonstrates that the large-scale predictors used by STARDEX are generally well simulated by the GCM

D15: describes the statistical downscaling models developed by STARDEX

D16: provides guidelines for those wishing to undertake downscaling, in particular how to assess the reliability and robustness of statistical methods. Also provides summary documentation on the methods used to construct the STARDEX scenarios

They are all available from the STARDEX web site, together with the scenario data – http://www.cru.uea.ac.uk/cru/projects/stardex/.

PRUDENCE RCM scenario data are available from http://prudence.dmi.dk/

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The STARDEX precipitation related indices of extremes		*User-friendly name*
pq90	90th percentile of rainday amounts (mm/day)	Heavy rainfall threshold
px5d	Greatest 5-day total rainfall	Greatest 5-day rainfall (amount)
pint	Simple daily intensity (rain per rainday)	Average wet-day rainfall (amount)
pxcdd	Maximum number of consecutive dry days	Longest dry period
pfl90	% of total rainfall from events > long-term 90th percentile	Heavy rainfall proportion
pnl90	Number of events > long-term 90th percentile of raindays	Heavy rainfall days
The STARDEX temperature related indices of extremes		
txq90	Tmax 90th percentile (ºC) – the 10th hottest day per season	Hot-day threshold
tnq10	Tmin 10th percentile (ºC) – the 10th coldest night per season	Cold-night threshold
tnfd	Number of frost days Tmin < 0 °C	Frost days
txhw90	Heat wave duration (days)	Longest heatwave
STARDEX mean indices		
pav	Precipitation average (mm/day)	Average daily rainfall (amount)
txav	Average Tmax (ºC)	Average daily high temperature
tnav	Average Tmin (ºC)	Average daily low temperature