Severe summertime flooding in Europe

Even as summers become drier, the incidence of severe precipitation could increase.

Using a high-resolution climate model, we are able to quantify the influence of greenhouse-gas-induced global warming upon heavy or extended precipitation episodes that inflict catastrophic flooding. We find that an increase in the amount of precipitation that exceeds the 95th percentile is very likely in many areas of Europe, despite a possible reduction in average summer precipitation over a substantial part of the continent. Our results indicate that episodes of severe flooding may become more frequent, despite a general trend towards drier summer conditions.

In the European Union project PRUDENCE (EVK2-CT-2001-00132; ref. 1), the high-resolution (50-km grid) regional climate model HIRHAM4 (ref. 2) created by the Danish Meteorological Institute has been applied to two of the emission scenarios, A2 and B2, drawn up by the Intergovernmental Panel on Climate Change (IPCC)[3]. Three 30-year time-slice experiments were carried out for periods representing roughly the present (1961–90) and two future scenarios (2071–2100), respectively. The large-scale controlling conditions originated from transient climate-change simulations using the coupled ocean–atmosphere global climate model (OAGCM) ECHAM4/OPYC (300-km grid; refs 4, 5).

Several studies with OAGCMs have indicated that precipitation in many regions of the Earth could change considerably in a warmer climate[6]. Simulations consistently predict that summer precipitation will be reduced in many mid-latitude regions, whereas at higher latitudes there will be little change or possibly an increase[6]. Although OAGCMs indicate an intensified global hydrological cycle in a warmer climate, evidence of changes in extreme precipitation at the regional scale remains unconvincing[7]. The low spatial resolution of OAGCMs precludes a realistic simulation of regional circulation and therefore of extreme precipitation.

We investigated the relationship between climate change and heavy precipitation episodes lasting for 1–5 days at high horizontal resolution during the late boreal summer (July–September). During this period, European climatic conditions occasionally favour very severe precipitation episodes, such as those that caused the recent flooding of the rivers Odra (1997), Elbe (2002) and of sub-catchments of the Rhone (2002).

Figure 1a shows the relative change in mean precipitation during July, August and September according to HIRHAM4 for the A2 scenario (the warmer of the two) with respect to present conditions. A two-sided *t*-test shows that all changes exceeding ±5–10% of the present-day mean are significant at the 95% level. The large-scale patterns of change are similar to those in the driving OAGCM model.

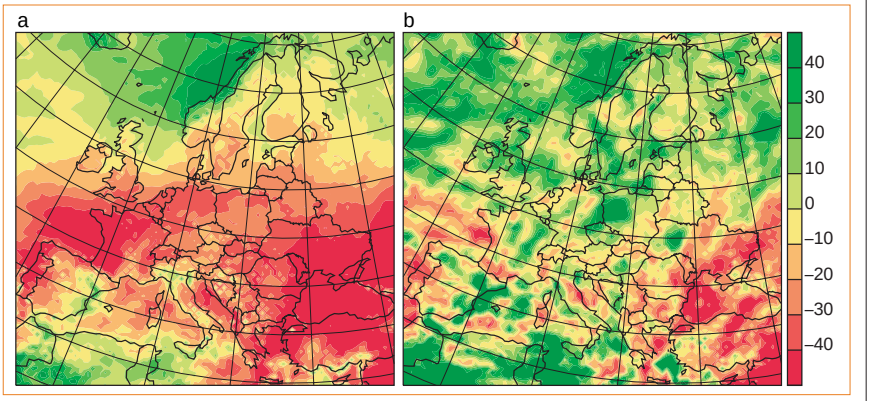

Figure 1 Relative percentage change in precipitation for July–September in the Intergovernmental Panel on Climate Change's A2 scenario with respect to the present day. Relative change is shown for **a**, the seasonal mean; and **b**, the five-day mean exceeding the 99th percentile.

Model validation of extremes is generally limited by insufficient observational data: European daily-precipitation data, in particular, are not easily available. In two representative cases (Scandinavia and the Alps), however, the HIRHAM4 model can simulate relatively realistic precipitation frequencies, although it has a tendency to underrepresent the most extreme events[1,8,9].

The relative change in the mean five-day precipitation for July–September that exceeds the 99th percentiles in scenario A2 with respect to the control is shown in Fig. 1b. Even when a reduction in total mean precipitation is simulated, the amounts of precipitation in the intensive events are much less reduced, and even increase in many places. The higher the percentile considered, the larger are the areas that show a positive change. A standard Mann–Whitney test on a series of events that exceed different thresholds indicates that there is a significant change at the 95% level for events above the 95th percentile, but the small sample size precludes a general, unequivocal detection of change for the 99th percentile (or higher).

This, however, does not necessarily imply the absence of change. These changes are seen for a wide range of percentiles and for most European land points, with exceptions being mostly located on the Iberian Peninsula and over the Balkans. To illustrate the shift clearly while retaining a meaningful sample size, we show the 99th percentile in Fig. 1b, even though only those changes that exceed about ±10% are statistically significant.

We also carried out another similar analysis, averaging the precipitation data over several European river catchments. With few exceptions (involving rivers situated in a very dry environment), an increase in the amount of precipitation during extreme precipitation episodes is simulated in both scenarios (most prominent in A2).

Using the combined information from both simulations, we find that CO_2-induced warming can lead to a shift towards heavier intensive summertime precipitation over large parts of Europe; the warmer scenario (A2) gives the largest shift. This finding may be explained[10] by the fact that the atmosphere will contain more water in a warmer climate (according to the Clausius–Clapeyron equation), which will provide further potential for latent-heat release during the build-up of low-pressure systems, thereby possibly both intensifying the systems and making more water available for precipitation.

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Competing financial interests: declared none.

Ecology

Parthenogenesis in an outsider crayfish

It has been rumoured[1] that an unidentified decapod crustacean, a crayfish of marbled appearance and of uncertain geographical origin that was introduced into the German aquarium trade in the mid-1990s, is capable of unisexual reproduction (parthenogenesis). Here we confirm that this marbled crayfish ('*Marmorkrebs*') is parthenogenetic under laboratory conditions and use morphological and molecular analysis to show that it belongs to the American Cambaridae family. Although parthenogenesis is widespread among the Crustacea[2], and shrimp, lobsters, crayfish and crabs are otherwise versatile in their modes of reproduction[3–5], it has not been reported before in decapods, the largest and economically most important crustacean group. By virtue of its parthenogenetic reproduction, the marbled crayfish emerges not only as an interesting laboratory model but also as a potential ecological threat in that it could outcompete native forms should even a single specimen be released into European lakes and rivers.

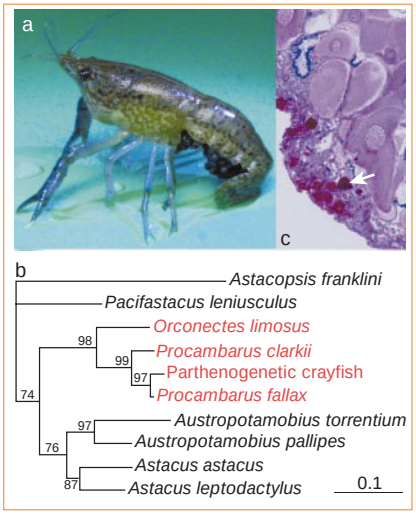

Figure 1 Characteristics of the marbled crayfish. **a,** Lateral view of the crayfish, showing the eggs attached to its pleopods. Adult specimens are 3–10 cm in length (rostrum to telson). The basic colour is brown–green, with light and dark spots. **b,** Phylogenetic relationships of the marbled crayfish based on a comparison of the partial sequences of two mitochondrial genes, *Cox1* and the gene encoding 12S ribosomal RNA; GenBank accession numbers, AY151515–AY151524, AY151525–AY151534. Maximum-likelihood analysis used the Hasegawa–Kishino–Yano model, assuming rate heterogeneity with a log likelihood of −3075.69; the reliability of branches is given as a percentage of puzzling steps where the appropriate node arises. Parsimony analysis produced similar results. The marbled crayfish belongs to the American Cambaridae (red) and is closely related to *Procambarus fallax* (only 2.2% of base positions different). Scale bar, 0.1 nucleotide substitutions. **c,** Azan-stained histological section of a gonad of a female with hatchlings exclusively composed of ovarian tissue. Arrow, pre-vitellogenic oocyte; arrowhead, primary vitellogenic oocyte.

To determine the origin and phylogenetic position of the marbled crayfish (Fig. 1a), we compared the sequences of sections of two mitochondrial genes with those of other related species, with particular reference to a similar-looking cambarid species, *Procambarus fallax*, from Florida. The sequences in both genes of the marbled crayfish differ at only a few positions from those of other cambarids, which supports their morphological similarity (the presence of a spermatheca)[6]. Our phylogenetic analysis indicates a particularly close affinity with *P. fallax*, although the marbled crayfish's species identity remains to be verified (Fig. 1b).

We tested whether *Marmorkrebs* could be parthenogenetic by studying a mature female from a laboratory population in Berlin whose spermatheca contained no evidence of spermatophores from copulation, but which repeatedly laid eggs. Between two broods, this crayfish moulted, a procedure that clears any remnants of sperm from the spermatheca. We also sexed laboratory populations in Berlin (93 specimens from 7 mothers of two generations) and Heidelberg (39 specimens), beginning at the earliest stage at which sex can be determined. We found that all specimens (body length, 0.8–8.0 cm) showed female morphology, which excludes protandric hermaphroditism as the mode of reproduction. No spermatophore was detected in our study.

To rule out internal autogamy, we studied the histology and ultrastructure of the reproductive system of all 39 specimens of the Heidelberg population from juvenile (1.9 cm) to post-brooding (6.8 cm) stages. All gonads were normal ovaries with oviducts, and there was no evidence of ovotestes or male gonoducts (results not shown), which are usually present in hermaphroditic crayfish[7]. Azan staining of some adult gonad sections revealed an abundance of large, primary vitellogenic oocytes, and proliferating clusters of small pre-vitellogenic oocytes in the presence of hatchlings, indicating that a new reproductive cycle was already under way (Fig. 1c). These results provide convincing evidence for parthenogenesis in the marbled crayfish.

Our findings have several practical implications. This marbled crayfish will be useful in the laboratory for physiological, ecological, evolutionary, developmental and genetic studies, having the advantages of fitness, high fertility, fast growth, unisexuality and isogenic progeny[8]. The large oocytes are easily accessible for genetic manipulation, making this species a candidate model for transgenesis[9] in decapod crustaceans. The rapid reproduction of this crayfish might also be of interest for commercial farming purposes.

Last but not least, this crayfish, which is now widespread in Europe's aquaria, could become a menace to European freshwater ecosystems, as the release of even one specimen into the wild would be enough to found a population that might outcompete native crayfish. As an American species, it is a potential transmitter of the infectious crayfish plague that almost caused the extinction of the native European crayfish and which still threatens wild and farmed populations[10].

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Competing financial interests: declared none.

correction

Ultrahard polycrystalline diamond from graphite
T. Irifune, A. Kurio, S. Sakamoto, T. Inoue, H. Sumiya
Nature **421,** 599–600 (2003)

In the legend to Fig. 1a of this communication, the diameter of the transparent polycrystalline diamond shown is 1 mm, and not 0.1 mm as published; the scale divisions represent 0.1 mm. Also, the first full paragraph in the second column on page 600 should read: "Recent chemical-vapour deposition techniques provided pure polycrystalline diamonds, but these diamonds are not sintered and have poor intergrain adhesion. Accordingly, they have been reported to have a hardness of ~80–100 GPa (ref. 10), which is significantly lower than the highest value (~120 GPa; ref. 4) for single-crystal diamonds."