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Assessing Extreme Values for Water Management Purposes in the Context of Climate Change

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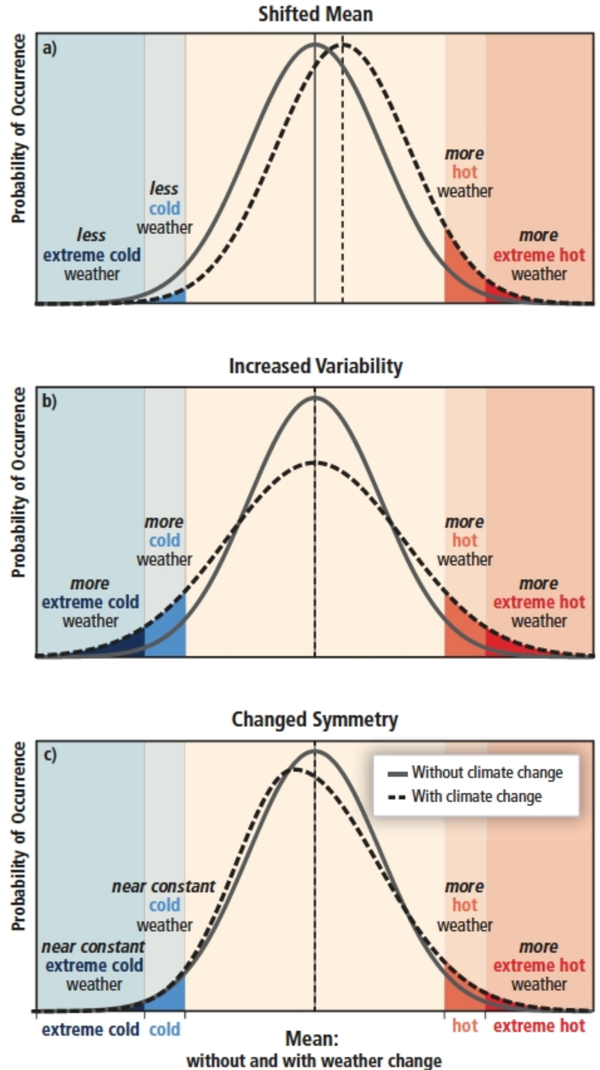
Why analyse Extremes and their Changes?

Adaptation to climate change needs to account for the decadal scale changes in extremes observed in the past decades as well as for projected future change in extremes.

Some infrastructure, e.g. some dyke systems, currently have little margin to buffer the impacts of climate change [Klein Tank et al., 2009].

- The distribution of extremes is in general asymmetric (Gumbel, Frechet, …) and not Normal,
- Changes in the mean values do not always correspond to changes in the extremes.



Field et al., 2012. Fig. SPM3

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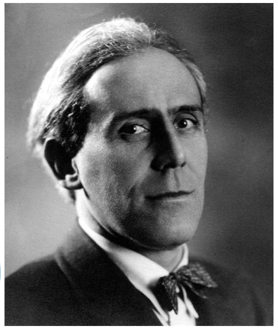
Extreme Value Assessment in Hydrology



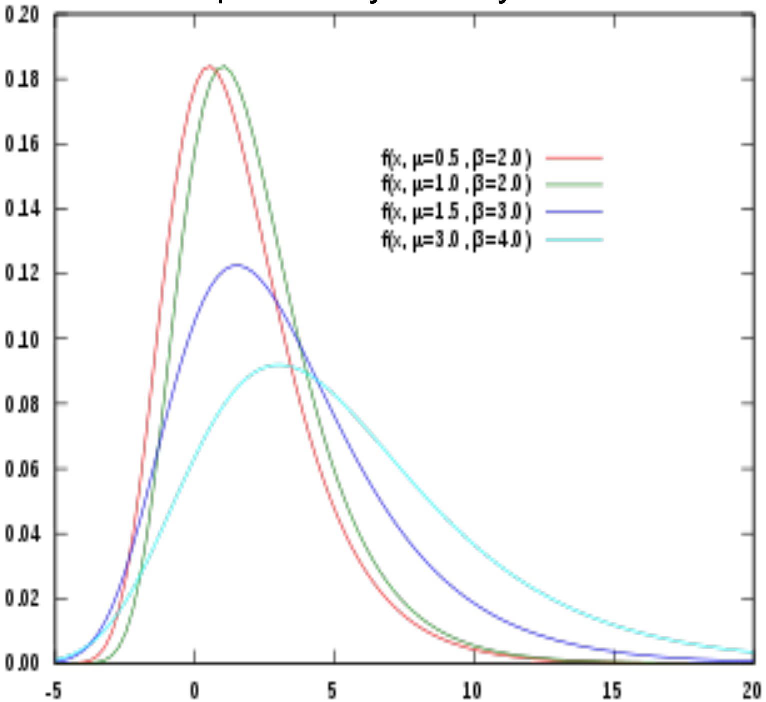
E. J. Gumbel

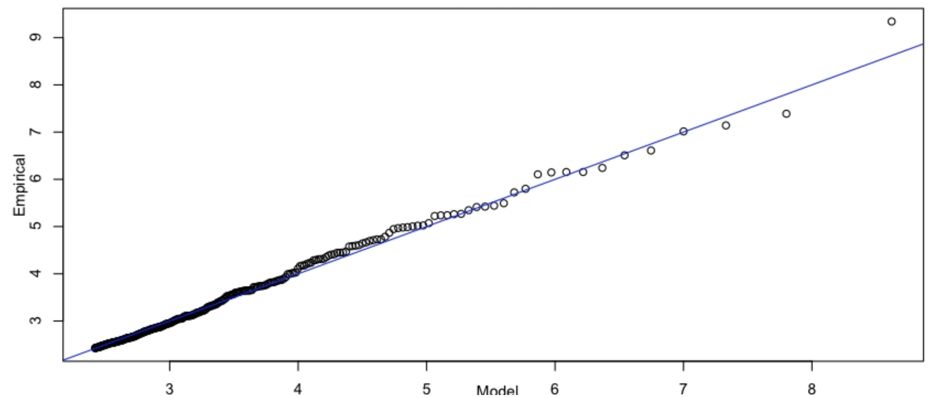
The Flood Problem. [Gumbel, 1958]

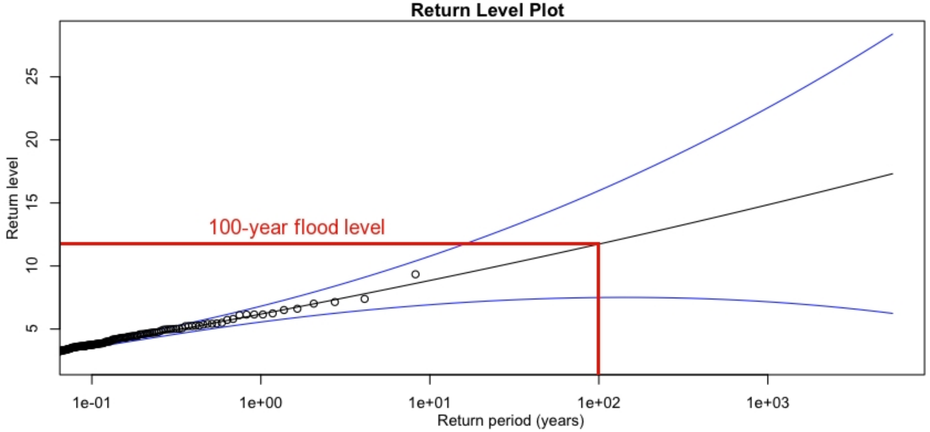
"However big floods get, there will always be a bigger one coming; so says one theory of extremes, and experience suggests it is true."

(PRESIDENT'S WATER COMM., p. 141.)

Gumbel probability density function



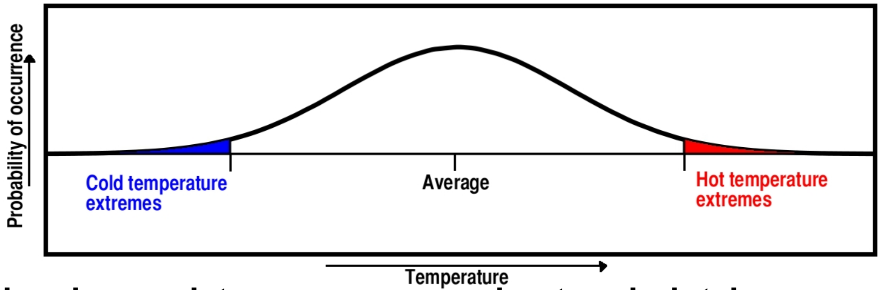




Extreme Value Assessment Methods

Indices: “moderate extremes”, e.g. 90th percentile. Such events lie well within the samples of observations.

Extreme Value Statistics (EVT): rare and well defined values in the tail of the distribution (block maxima, threshold excesses).



- Originally designed to assess what might happen outside the range of the observed sample,
- Theoretical distribution used (e.g. Gumbel, GEV, GPD, …),
- Bears often the assumption of independent and identical distributed data,
- Uncertainty quantification of extrapolations (confidence bands).

These tools are increasingly used as well in the evaluation of extreme events simulated by climate models.

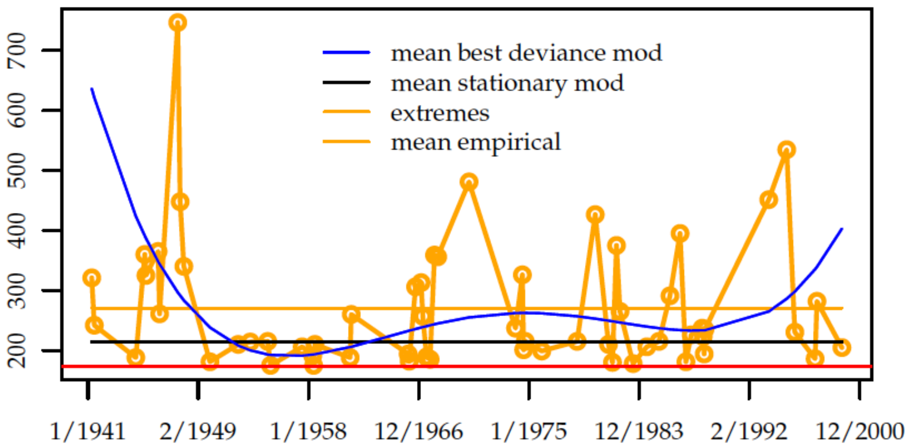
Climate Change/Climate Variability

1. Comparison of two time periods, or

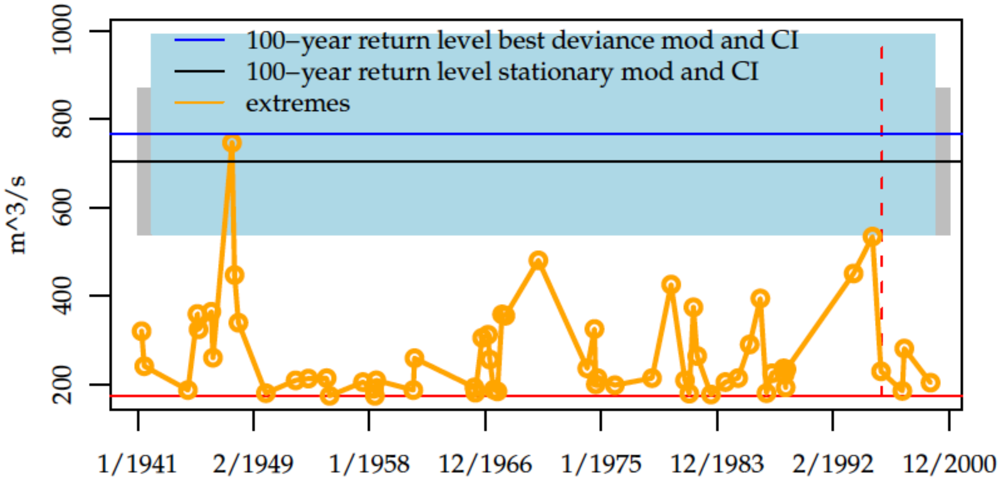
2. Inclusion of the non-stationarity in the modeling of extremes (e.g. time-dependent extreme value distributions).
   Model selection criteria available (e.g. likelihood ratio test).

Non-Stationary Extremes

$$Z_t = \mathrm{GEV}(\mu_t, \sigma_t, \xi) = \exp\left\{ -\left[1 + \xi\left(\frac{z_t - \mu_t}{\sigma_t}\right)\right]^{-1/\xi} \right\}$$

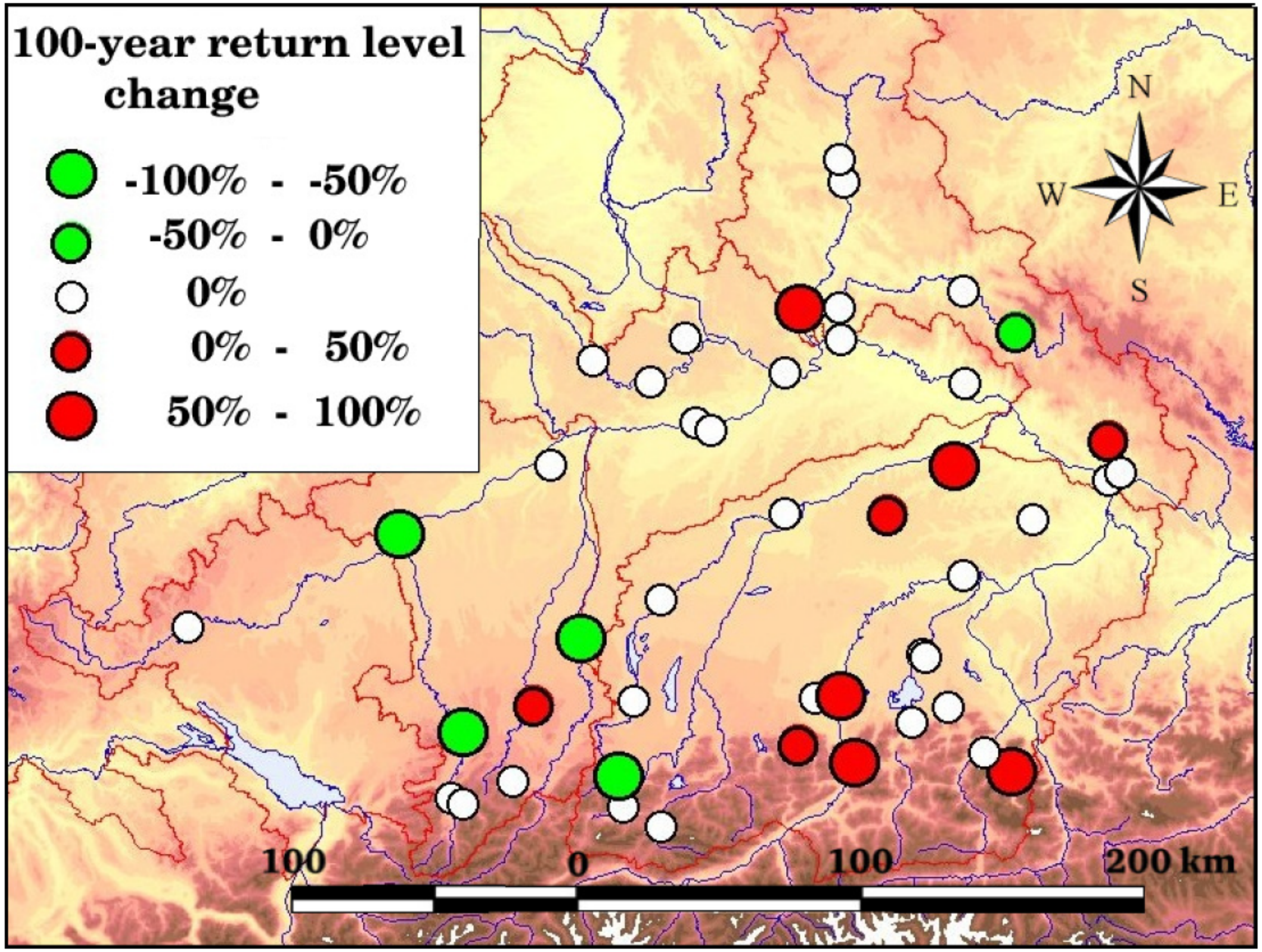


Extremes (excesses over 173m³/s) of Naab River runoff at Heitzenhofen in Germany (orange). Estimates of mean value with a stationary model (black) and best-suiting non-stationary model (blue).



100-year return levels of stationary model (black) and best-suiting non-stationary model (blue, at time point 01.01.1996) with 68% confidence intervals.

Non-Stationary Extremes II



Comparison of 100-year return levels of stationary and non-stationary model at time point 01.01.1996 (return levels for daily river runoff in Southern Germany of time period 1941 – 2000).

M. Kallache, H. W. Rust, H. Lange, and J. P. Kropp. *In Extremis*, chapter Extreme Value Analysis for Non-Stationary Data. Springer Verlag, Berlin, 2011a. ISBN 978-3-642-14862-0.

Covariates, "Regression" for Extremes

Extremes, whose distribution changes with time. However, dependence on covariates (possibly model outputs):

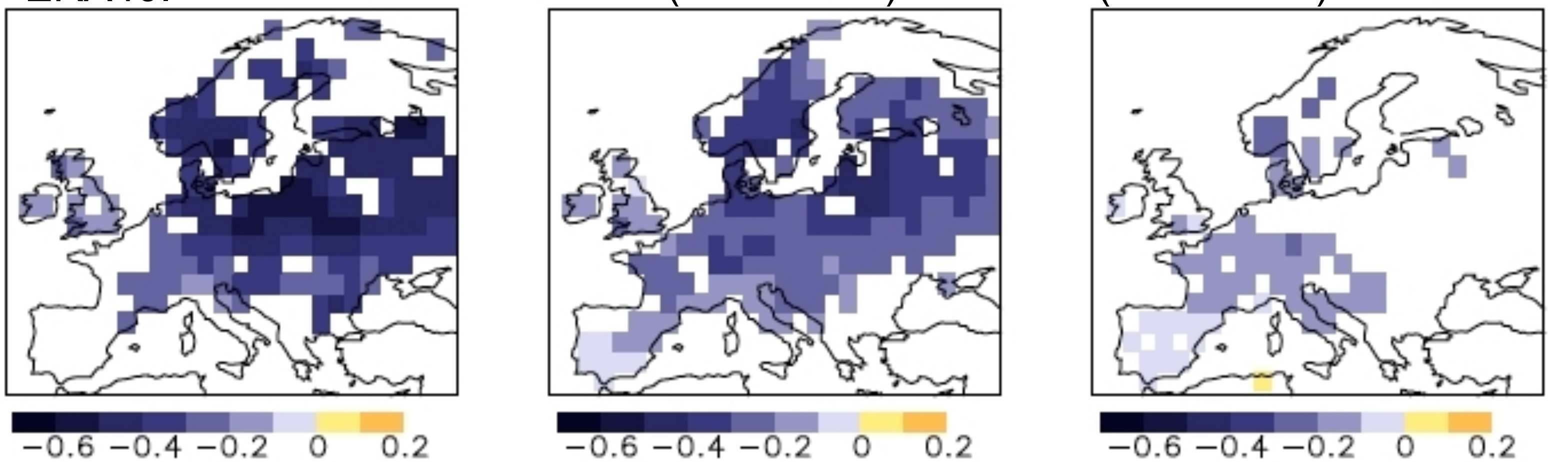
- Verification of the model projections necessary, e.g. by comparison with observations or reanalysis data in a historical time period.
- Model selection criteria for the choice of covariates (e.g. likelihood ratio test).

Projections of Extremes with Covariates

Assessment of evolution of monthly winter temperature minima in Europe. Blocking index $B(t)$ as additional information (covariate) in case the non-stationary model improves results.

Slope c of location parameter $\mu(t) = a + c\,B(t)$ of a non-stationary GEV model.

ERA40. | Concatenated ECHAM5/MPI-OM ensemble members of the 20C (1961-2000). | ECHAM5/MPI-OM A1B simulations (2160-2199).



Result: Persistent negative relation between winter temperature minima and atmospheric blocking events. In the future, blocking looses influence on winter temperature minima in some regions.

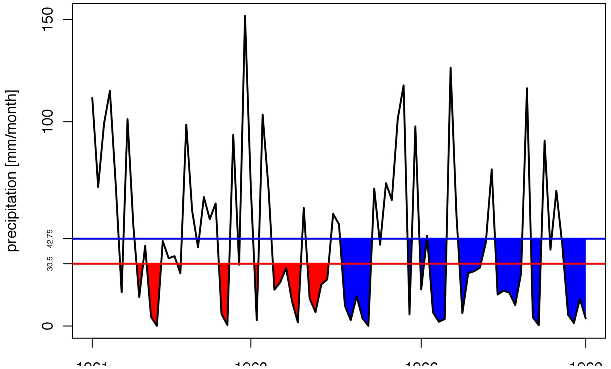
J. Sillmann, M. Croci-Maspoli, M. Kallache, and R.W. Katz. Extreme cold winter temperatures in Europe under the influence of North Atlantic atmospheric blocking. *Journal of Climate*, 24 (22):5899–5913, 2011. doi: 10.1175/2011JCLI4075.1.

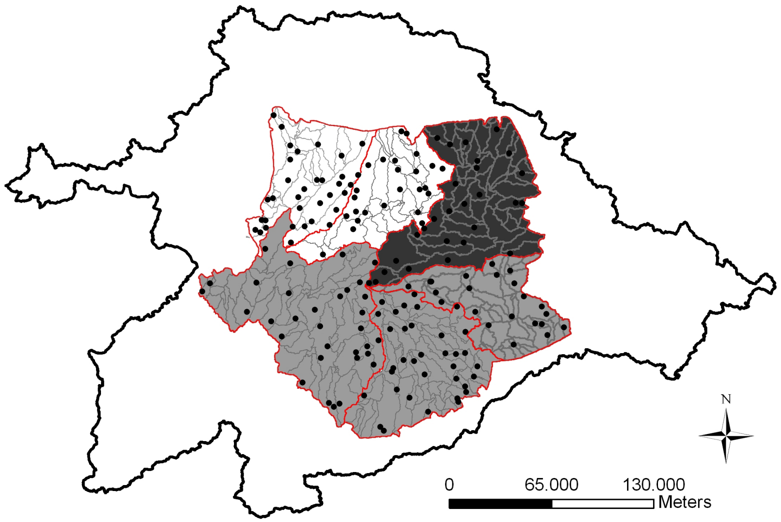
Dependence of Multivariate Extremes

$$\bar{F}(x_1, \ldots, x_k) = P(X_1 > x_1, \ldots, X_k > x_k) = \frac{\mathcal{L}(x_1, \ldots, x_k)}{(x_1 \times \ldots \times x_k)^{1/(k\eta)}}$$

Meteorological droughts in the Duero basin (Central Spain).

- Droughts: cumulative monthly precipitation deficits below a level,
- Multivariate EVT model to describe extreme droughts and their dependence,
- Station drought series are aggregated to represent 6 sub-basins in crop regions,
- Examine dependence of extremes by analysing parameters of the M-EVT model [cf. Ramos and Ledford, 2009].





Dependence between regions in irrigation season (Mai to October) for level 42.7mm/month. Same colors for regions with *fragility index* > 1.5.

Observed Changes of Hydrological Extremes

[IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation, Fields et al., 2012]

extreme	changes	region
number of heavy precipitation events	**changes** (sigificant), more increase than decrease (likely)	strong regional and subregional variations
droughts	**more intense and longer** (medium confidence)	Southern Europe and West Africa
	less intense or shorter	central North America and northwestern Australia
floods	changes, but low agreement and low confidence on a global scale (limited to medium evidence because of limited gauge station data and confounding effects of changes in land use and engineering).	

There is evidence that some extremes have changed as a result of anthropogenic influences, including increases in atmospheric concentrations of greenhouse gases.

Changes of Hydrological Extremes in the 21th Century

[IPCC special report, Fields et al., 2012]

extreme	changes	region
number of heavy precipitation events **proportion of total rainfall from heavy falls**	**increase** (likely). In some regions despite projected decrease in total precipitation (medium confidence)	high latitudes and tropical regions, northern mid-latitudes (winter)
droughts	**more intense and longer** (medium confidence)	Southern and Central Europe, the Mediterranean region, central North America, Central America, Mexico, northeast Brazil, and southern Africa
floods	changes due to projected precipitation and temperature changes (low confidence due to limited evidence and complexity of regional changes)	

Adaptation and Management Measures

[IPCC special report, Fields et al., 2012]

•**Attention to the temporal and spatial dynamics of exposure and vulnerability is important.**
Adaptation and disaster risk management can reduce risk in the short term, but may increase exposure and vulnerability over the longer term**.**
Example: *dike systems can reduce flood exposure by offering immediate protection, but also encourage settlement patterns that may increase risk in the long term*.

•**Low-regrets measures might provide benefits today and in the future** (early warning systems; risk communication between decisionmakers and local citizens, irrigation and drainage system, …)

Managing the Risks of Extreme Events. Example: Droughts [IPCC special report, Fields et al., 2012]

Example	Exposure and vulnerability at scale of risk management in the example	Information on Climate Extreme Across Spatial Scales			Options for risk management and adaptation in the example
		GLOBAL Observed (since 1950) and projected (to 2100) global changes	REGIONAL Observed (since 1950) and projected (to 2100) changes in the example	SCALE OF RISK MANAGEMENT Available information for the example	
Droughts in the context of food security in West Africa	Less advanced agricultural practices render region vulnerable to increasing variability in seasonal rainfall, drought, and weather extremes. Vulnerability is exacerbated by population growth, degradation of ecosystems, and overuse of natural resources, as well as poor standards for health, education, and governance. [2.2.2, 2.3, 2.5, 4.4.2, 9.2.3]	Observed: *Medium confidence* that some regions of the world have experienced more intense and longer droughts, but in some regions droughts have become less frequent, less intense, or shorter. Projected: *Medium confidence* in projected intensification of drought in some seasons and areas. Elsewhere there is overall *low confidence* because of inconsistent projections. [Table 3-1, 3.5.1]	Observed: *Medium confidence* in an increase in dryness. Recent years characterized by greater interannual variability than previous 40 years, with the western Sahel remaining dry and the eastern Sahel returning to wetter conditions. Projected: *Low confidence* due to inconsistent signal in model projections. [Table 3-2, Table 3-3, 3.5.1]	Sub-seasonal, seasonal, and interannual forecasts with increasing uncertainty over longer time scales. Improved monitoring, instrumentation, and data associated with early warning systems, but with limited participation and dissemination to at-risk populations. [5.3.1, 5.5.3, 7.3.1, 9.2.3, 9.2.11]	Low-regrets options that reduce exposure and vulnerability across a range of hazard trends: • Traditional rain and groundwater harvesting and storage systems • Water demand management and improved irrigation efficiency measures • Conservation agriculture, crop rotation, and livelihood diversification • Increasing use of drought-resistant crop varieties • Early warning systems integrating seasonal forecasts with drought projections, with improved communication involving extension services • Risk pooling at the regional or national level [2.5.4, 5.3.1, 5.3.3, 6.5, Table 6-3, 9.2.3, 9.2.11]

Summary

- Extreme Value Theory (EVT) approaches are an important part of the assessment of characteristics and changes of hydrological extremes (heavy precipitation, droughts, floods, …),
- Benefits of EVT are:
  - Attribution of changes in the likelihood of extreme events, indicated by e.g. changes of return levels, to external causes (event attribution),
  - Potential to account for spatial dependence of extremes (e.g. max-stable processes [Schlather, 2002]),
- EVT approaches can be useful tools to develop low-regret water management measures, which are beneficial today and in the future.

References

- C. B. Field, V. Barros, T. F. Stocker, D. Qin, D. J. Dokken, K. L. Ebi, M. D. Mastrandrea, K. J. Mach, G.-K. Plattner, S. K. Allen, M. Tignor, and P. M. Midgley, editors. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, 2012. 582 pp.
- H. J. Fowler, D. Cooley, S. R. Sain, and M. Thurston. Detecting change in UK extreme precipitation using results from the climateprediction.net BBC climate change experiment. *Extremes*, **13**:241-267, 2010. Doi: 10.1007/s10687-010-0101-y.
- E. J. Gumbel. *Statistics of Extremes*. Dover Publications, New York, USA, 1958.
- M. Kallache, H. W. Rust, H. Lange, and J. P. Kropp. In Extremis, chapter Extreme Value Analysis for Non-Stationary Data. Springer Verlag, Berlin, 2011a. ISBN 978-3-642-14862-0.
- M. Kallache, M. Vrac, P. Naveau, and P.-A. Michelangeli. Nonstationary probabilistic downscaling of extreme precipitation. *Journal of Geophysical Research (Atmospheres)*, **116**:D05113, 2011b. Doi: 10.1029/2010JD014892.
- A. M. G. Klein Tank, F. W. Zwiers, and X. Zhang. Guidelines on analysis of extremes in a changing climate in support of informed decisions for adaptation. Technical Report WCDMP-72, WMO-TD 1500, WMO, 2009. 56 pp.
- A. Ramos and A. Ledford. A new class of models for bivariate joint tails. *Journal of the Royal Statistical Society B*, **71**(1):219-241, 2009.
- M. Schlather. Models for stationary max-stable random fields. *Extremes*, **5**(1):33-44, 2002.
- J. Sillmann, M. Croci-Maspoli, M. Kallache, and R.W. Katz. Extreme cold winter temperatures in Europe under the influence of North Atlantic atmospheric blocking. *Journal of Climate*, **24** (22): 5899-5913, 2011. doi: 10.1175/2011JCLI4075.1.

Thank you for your attention!