Planning for extreme droughts: Current approaches for developing extreme drought scenarios and options for developing new methods

Exeter Workshop 23/1/2017

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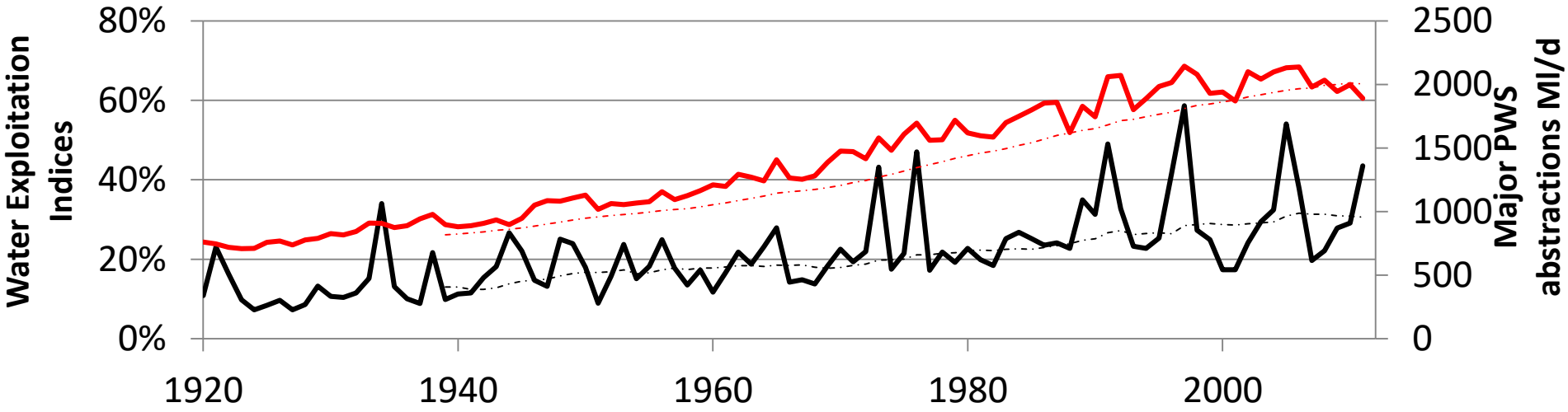
Acknowledgements: Water UK, Southern Water, Anglian Water, Welsh Water, South East Water, Atkins and Mott MaDonald

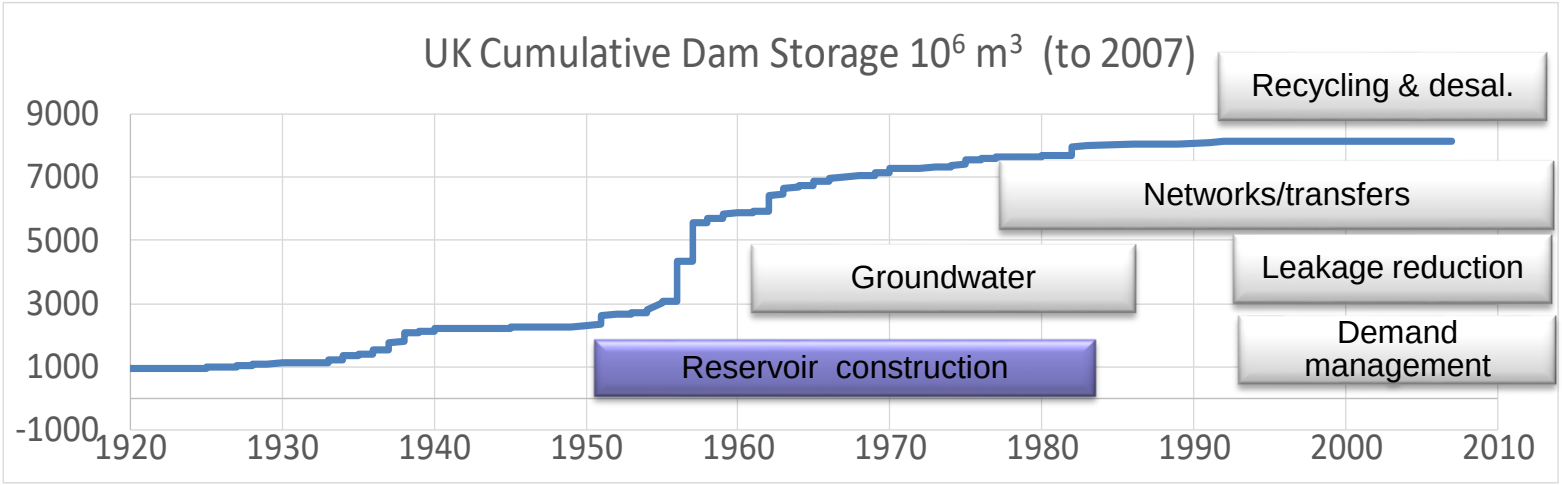
Outline

- Intro
  - Current approaches to water resources planning
- Climate variability and rainfall drought
  - Serinaldi and Kilsby Rainfall Generator
  - Water UK Resilience Study (Atkins)
  - Water Resources East Study (Anglian Water)
  - Welsh Water simulation of river flows
- Climate change
  - Application of UKCP09 and Future Flows
  - H++ climate change scenarios
  - UKCP18
  - Gaps between UKCP18 outputs and industry requirements

Development of UK water resources
(a) abstraction in London (b) UK dam construction



C19th Elan Valley Derwent Valley etc..



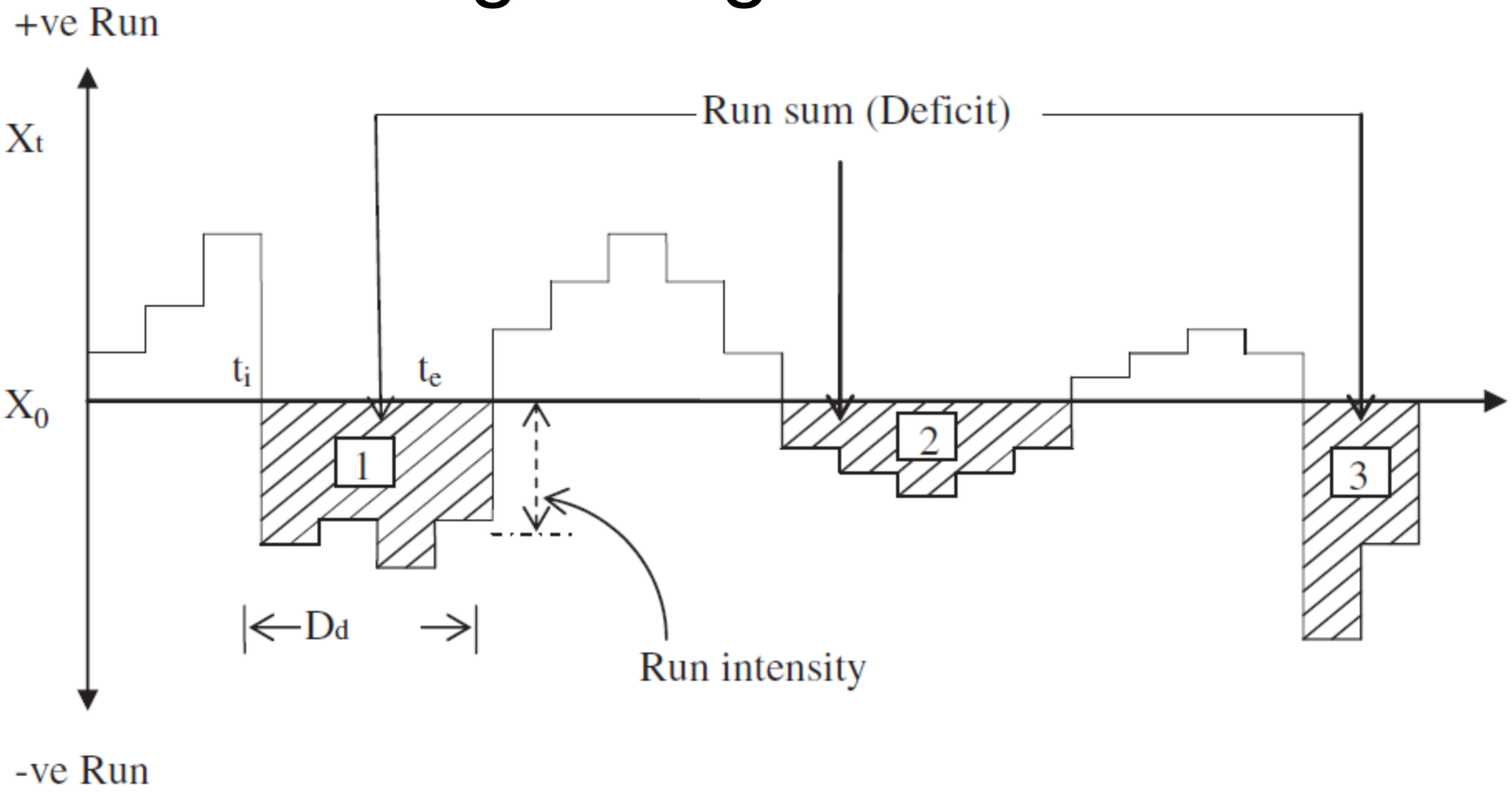
Understanding resilience

Now mainstream.....

...must be prepared for natural hazards including more extreme events than previously planned for.

- The Civil Contingencies Act (CCA) 2004 sets out the roles and responsibilities for UK Authorities who are required to respond to incidents (including weather related incidents)
- The Climate Change Act (2008) promotes adaptation planning
- The Water Act 2014 adds a new duty to our primary duties: to 'further' the resilience objective (in England and Wales)
- Water UK 2016 "Water resources long-term planning framework" (2015-2065) – national minimum resilience standard

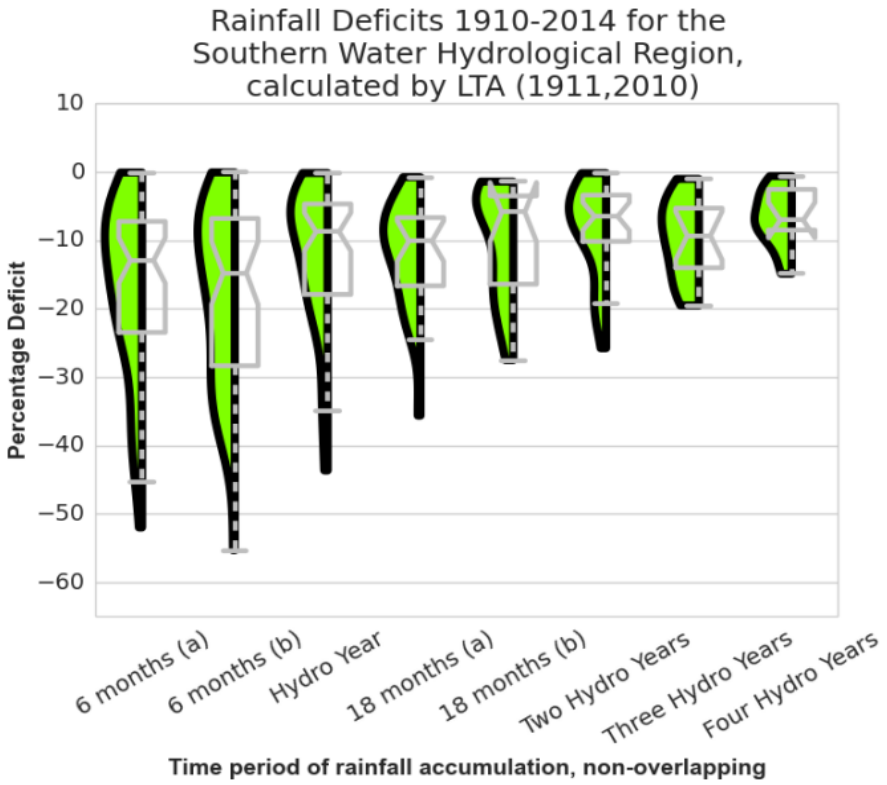
Defining drought

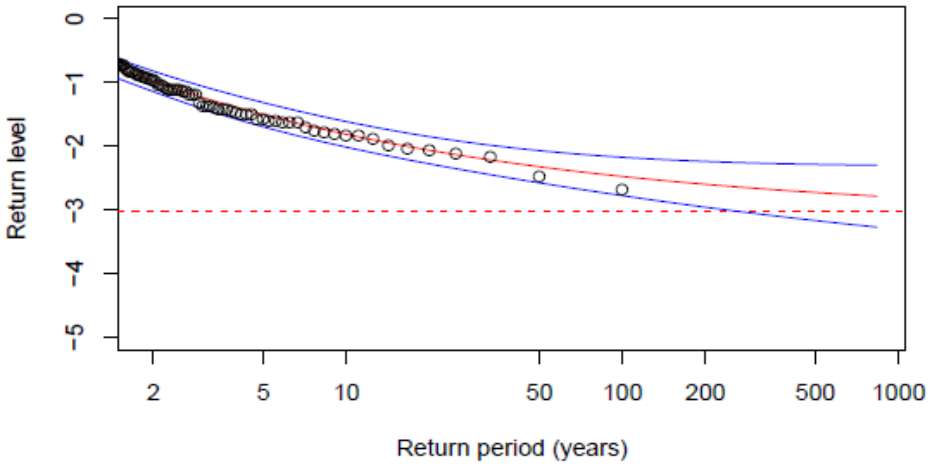


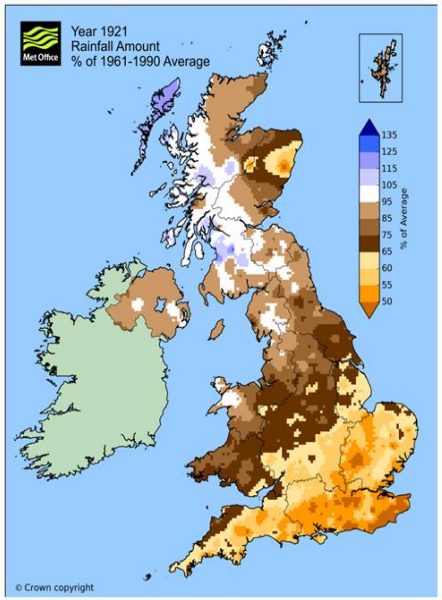
1. Drought with the highest severity;
2. Drought with the longest duration;
3. Drought with the highest intensity

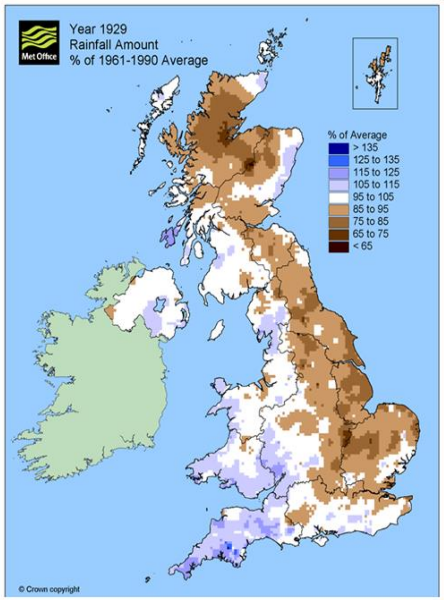
Fig. 1. Drought characteristics using the run theory for a given threshold level.

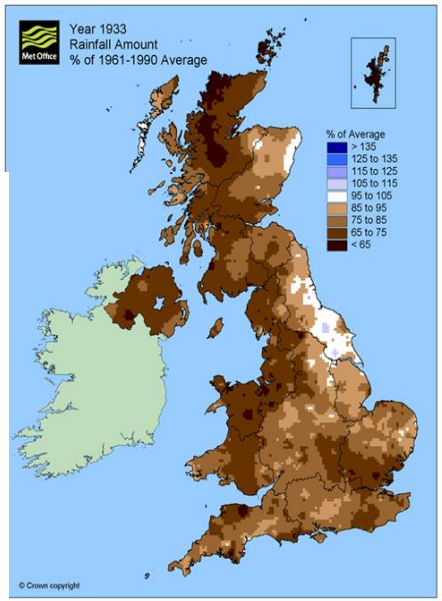
Low rainfall & rainfall drought.

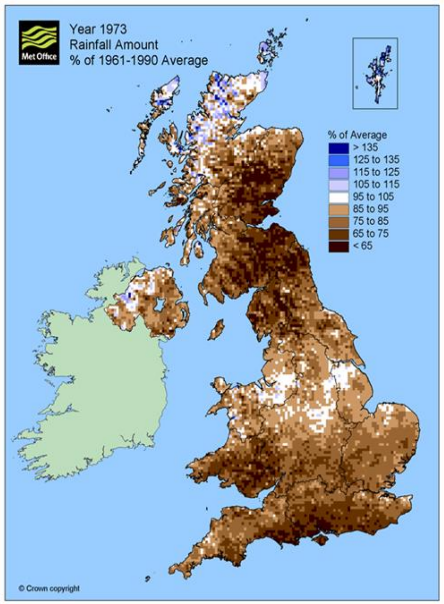






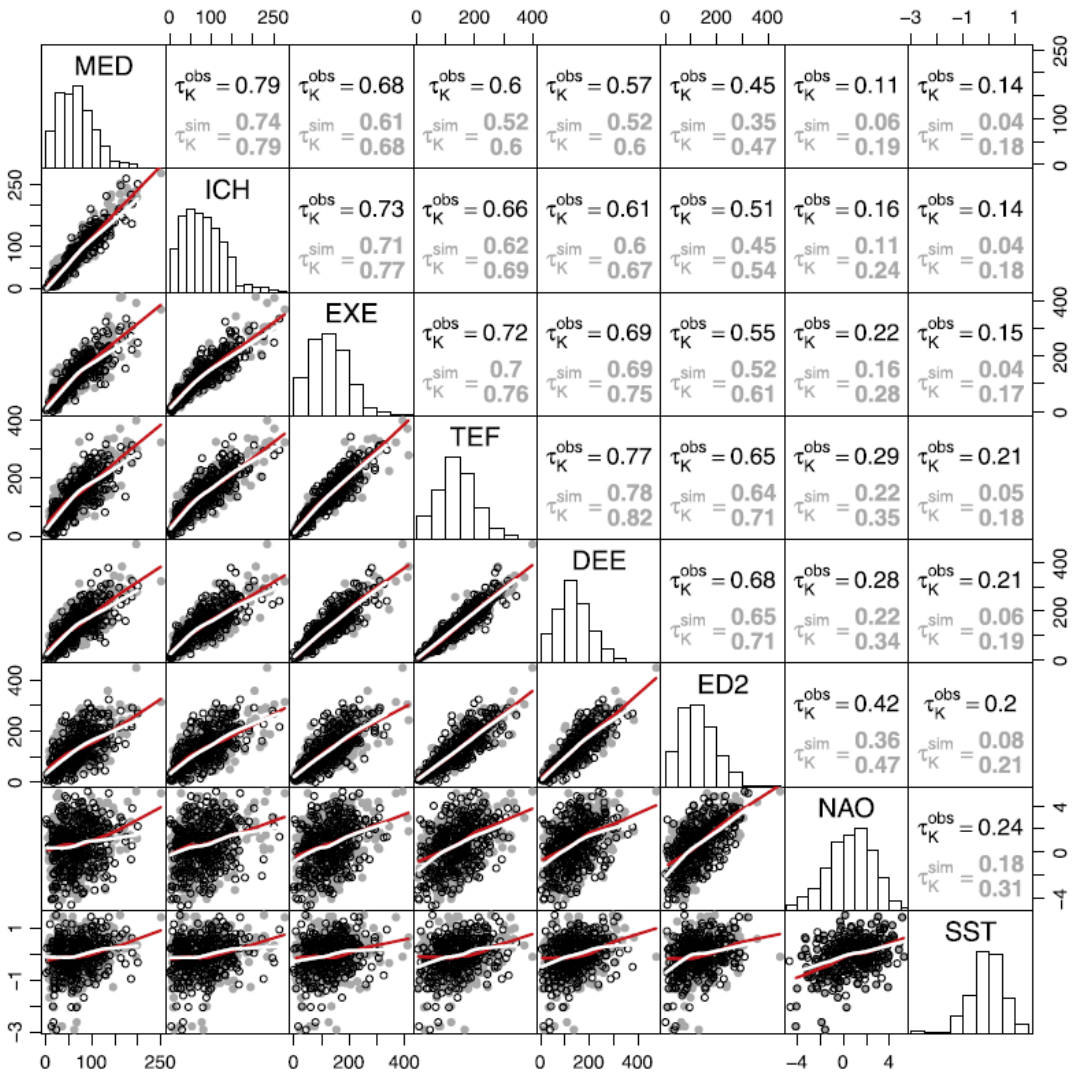




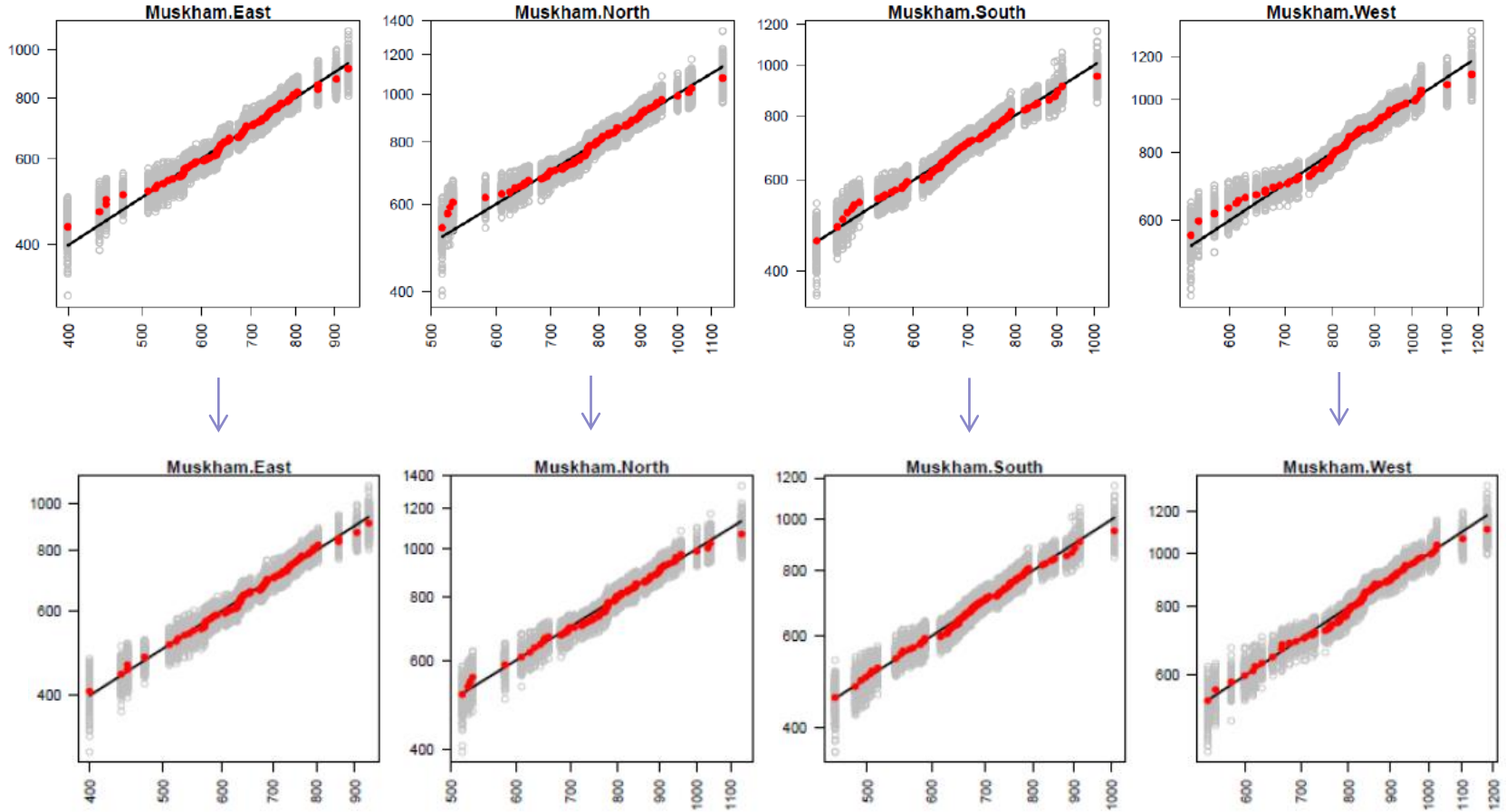


Rainfall generation

- Rainfall simulation to assess risks of long droughts
- Multi-site, linked to North Atlantic Oscillation (NAO) and sea surface temperatures (SSTs)
  - Serinaldi F, Kilsby CG (2012). A modular class of multisite monthly rainfall generators for water resource management and impact studies. Journal of Hydrology 464-465, 528-540.

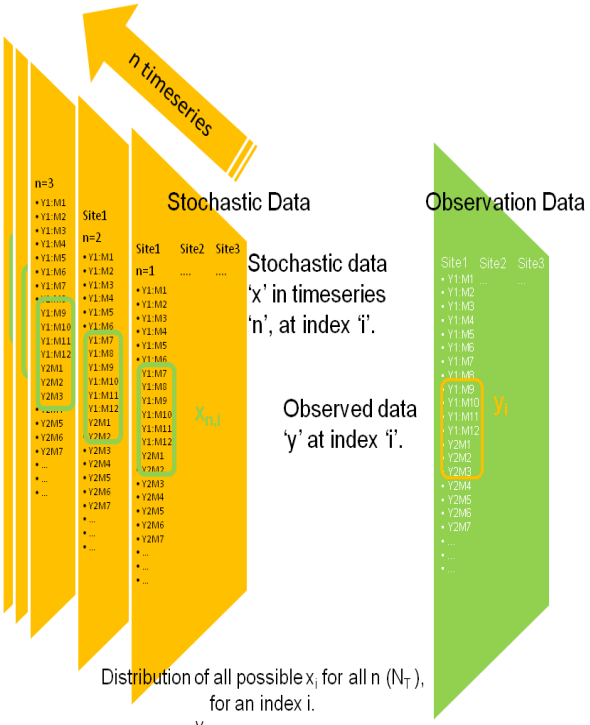


Example of original fit and post-processing bias correction

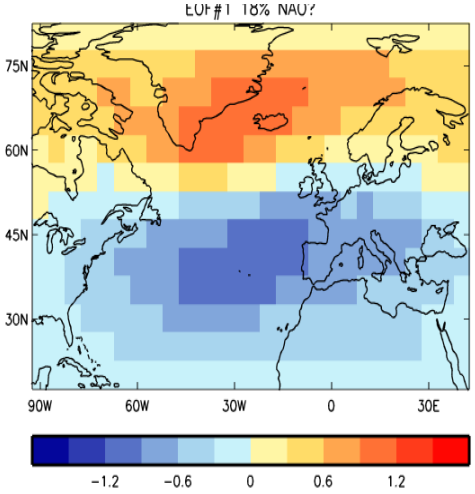


Link with WRE project: Development of rainfall generator and EA index

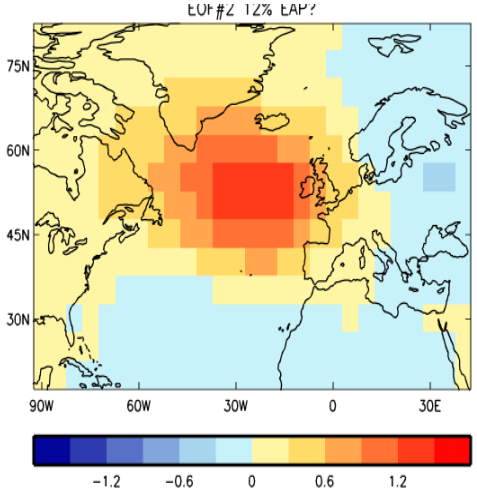
Rainfall Generator Configurations	Periods used to test Rainfall Generator Accuracy				
	3HydroYears(Oct-Sept) (Average Δmm)	2HydroYears(Oct-Sept) (Average Δmm)	HydroYear(Oct-Sept) (Average Δmm)	6months(October-March) (Average Δmm)	6months(April-Sept) (Average Δmm)
Baseline_Dep_EA	-1.414	-0.864	1.003	1.468	-1.043
Baseline_EA	-2.885	-1.820	0.689	2.301	-2.305
Baseline_Dep	5.632	4.562	2.729	0.194	1.239
Baseline	4.345	3.702	2.376	0.672	0.327
In2SeasonsDep_EA	4.863	4.500	2.343	0.413	0.341
In2SeasonsDep	5.678	4.998	2.367	0.421	0.478
In2Seasons_EA	5.231	4.193	2.671	1.017	0.284
In2Seasons	6.279	4.779	2.933	-0.865	2.448
In4SeasonsDepEA	6.397	4.821	2.975	1.843	-0.169
In4SeasonsDep	8.987	6.456	3.665	-0.040	2.429
In4SeasonsEA	5.012	4.068	2.605	1.386	-0.146
In4Seasons	6.236	4.740	2.914	-0.703	2.273



NAO



EA



Absolute Value, measure of spread of data

$$\sum_{sites}^{Total_{sites}} \left[\frac{\sum_{i=1}^{i=i_{total}} \left[\frac{\sum_{n=1}^{N_T} |x_{n,i} - y_i|}{N_T} \right]}{i_{total}} \right]$$

Instantaneous Value, measure of accuracy of data

$$\sum_{sites}^{Total_{sites}} \left[\frac{\sum_{i=1}^{i=i_{total}} \left[\frac{\sum_{n=1}^{N_T} (x_{n,i} - y_i)}{N_T} \right]}{i_{total}} \right]$$

Welsh Water example

Met Office Hadley Centre

Taf Fawr (Llwynon, Cabtref & Beacons)

Taf Fechan (Pontsticill & Neuadd)

Crai

Usk

Usk 56014

Elan

Ddol Farm 55026 ~ 609 Ml/d

Talybont

LCB

P&N

57002

57001

Senni 56007 ~ 89 Ml/d

Yscir 56013 ~ 167 Ml/d

Usk

Grwyne 56012

Wye

Redbrook 55023 ~ 6926 Ml/d

Trostrey ~ 2500 Ml/d

Chainbridge 56001

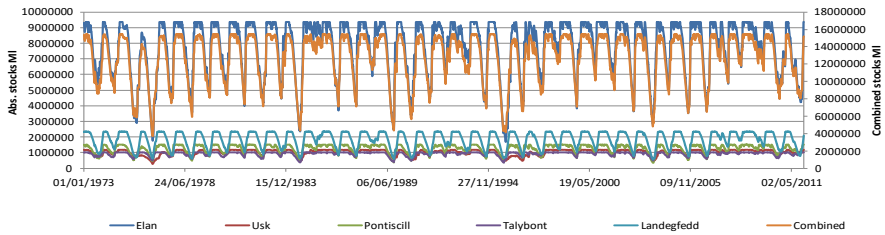
Pumped storage reservoir

Landegfedd

Prioress Mill Q > 445 Ml/d?

Key:
NRFA gauge
Key DCWW Q site
DCWW mass balance
DCWW reservoir
DCWW abstraction

Qnat



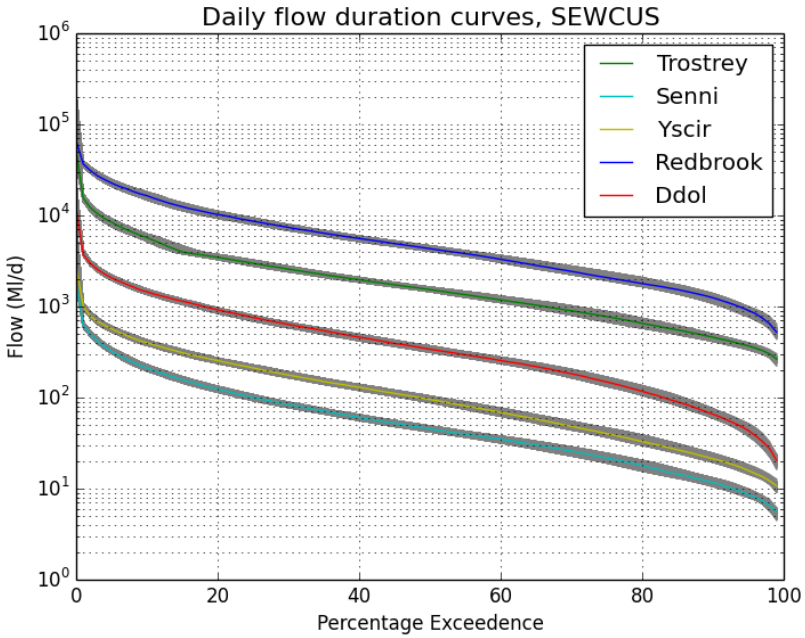
Multi-site stochastic generation of river flows

Stochastic Analysis, Modeling, and Simulation (SAMS) Version 2007

USER's MANUAL

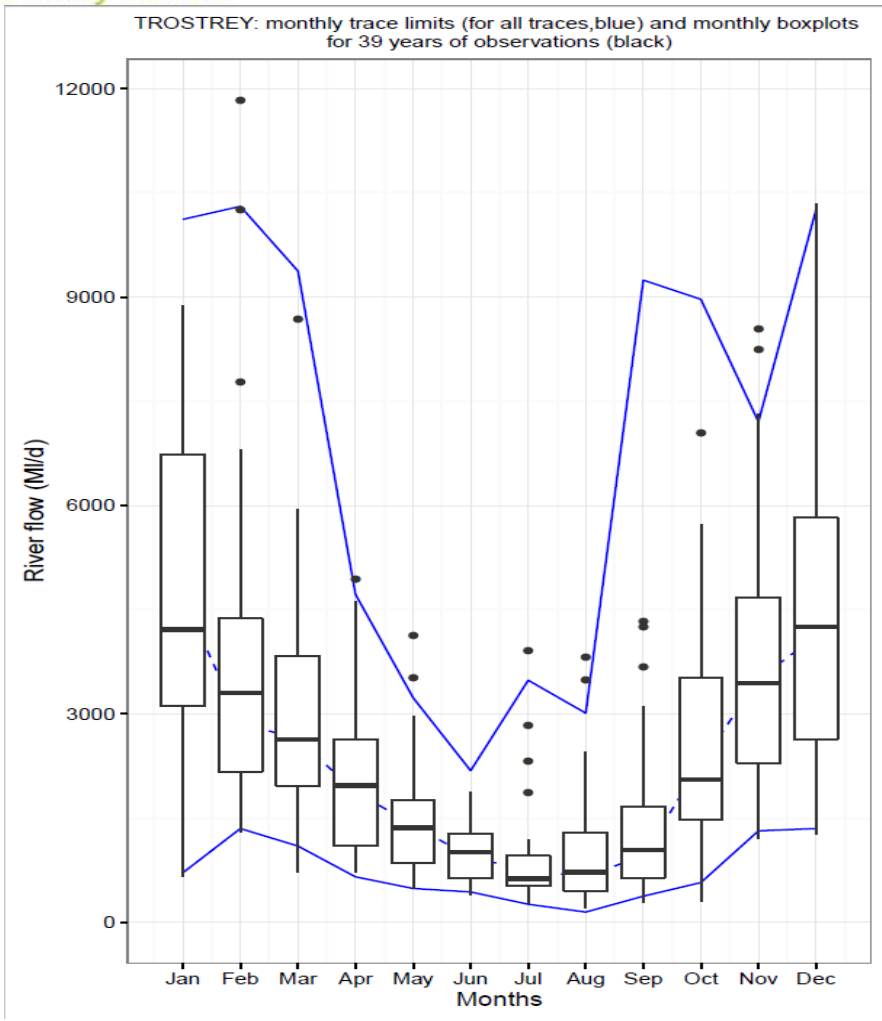
O. G. B. Sveinsson, J. D. Salas, W. L. Lane, and D. K. Frevert

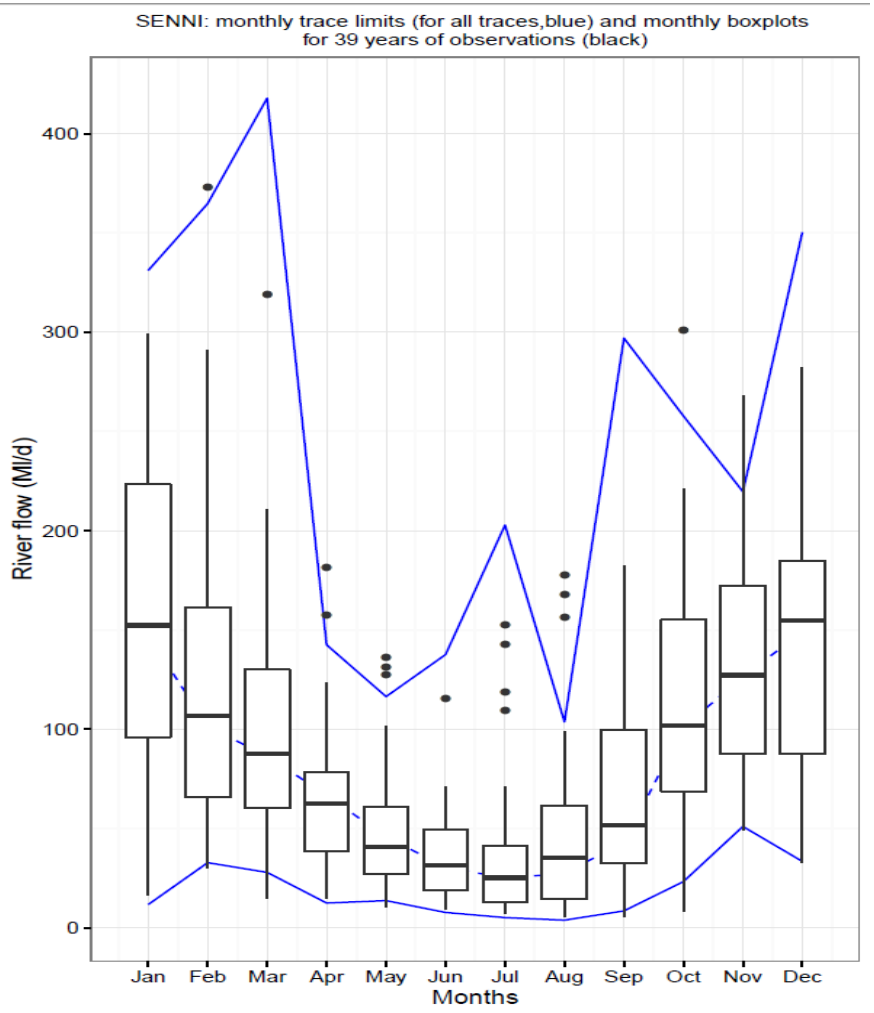
December. 2007



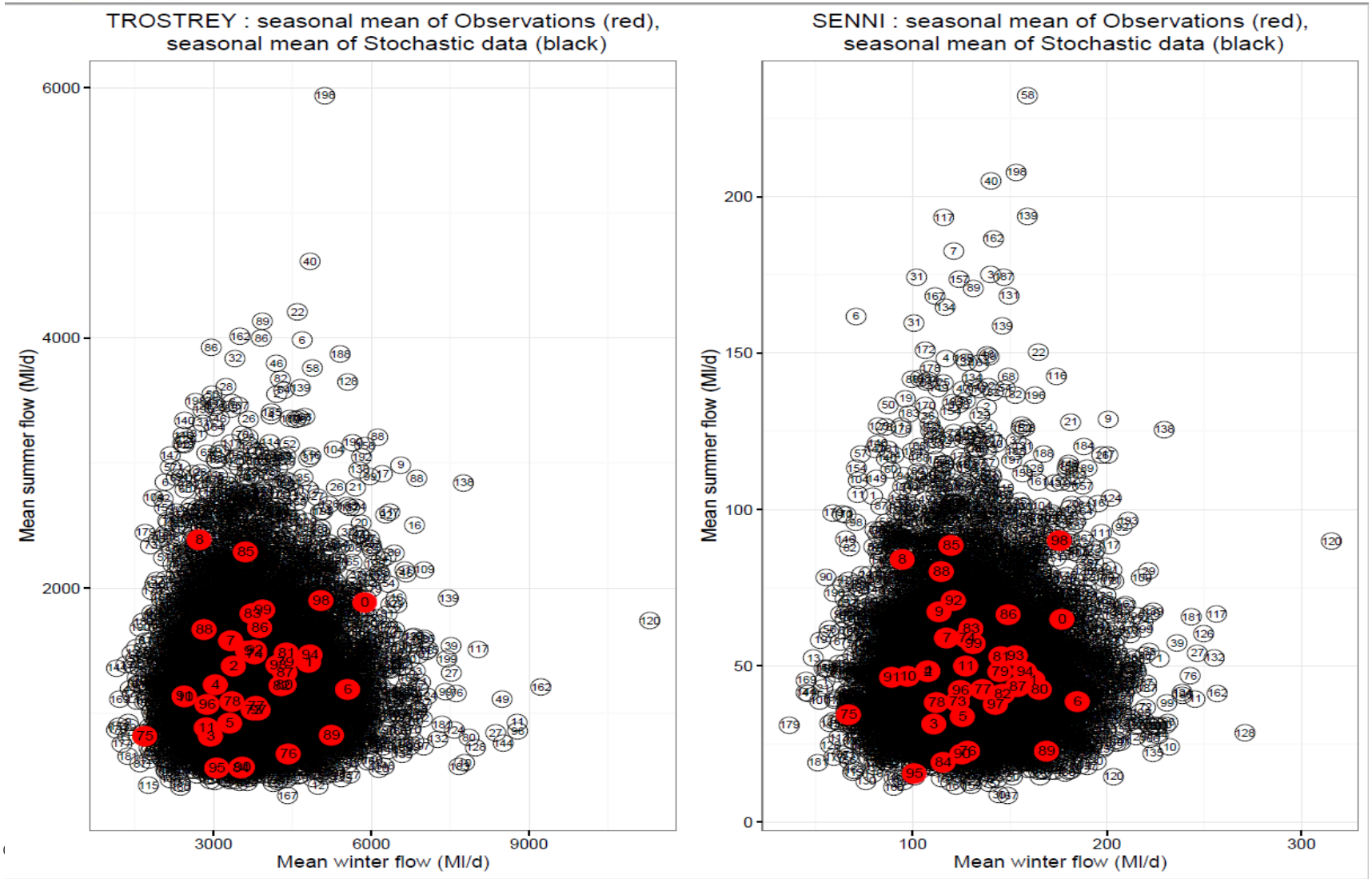
1. Pre-processing, QA to create observed monthly data
2. SAMS: Statistical Analysis, transformation and fitting distributions
3. SAMS: Model fitting (e.g. MPAR or CARMA model)
4. SAMS: Flow generation (100+ time series)
5. Post-processing to check model fit (iterate back to step 3, if required)
6. Post-processing to demonstrate plausibility
7. Post-processing: Dissaggregation to daily data
8. Post-processing: Selection of scenarios

Box-plots of monthly observed flows and median, 2.5% and 97.5%iles of 200 traces of 100 years

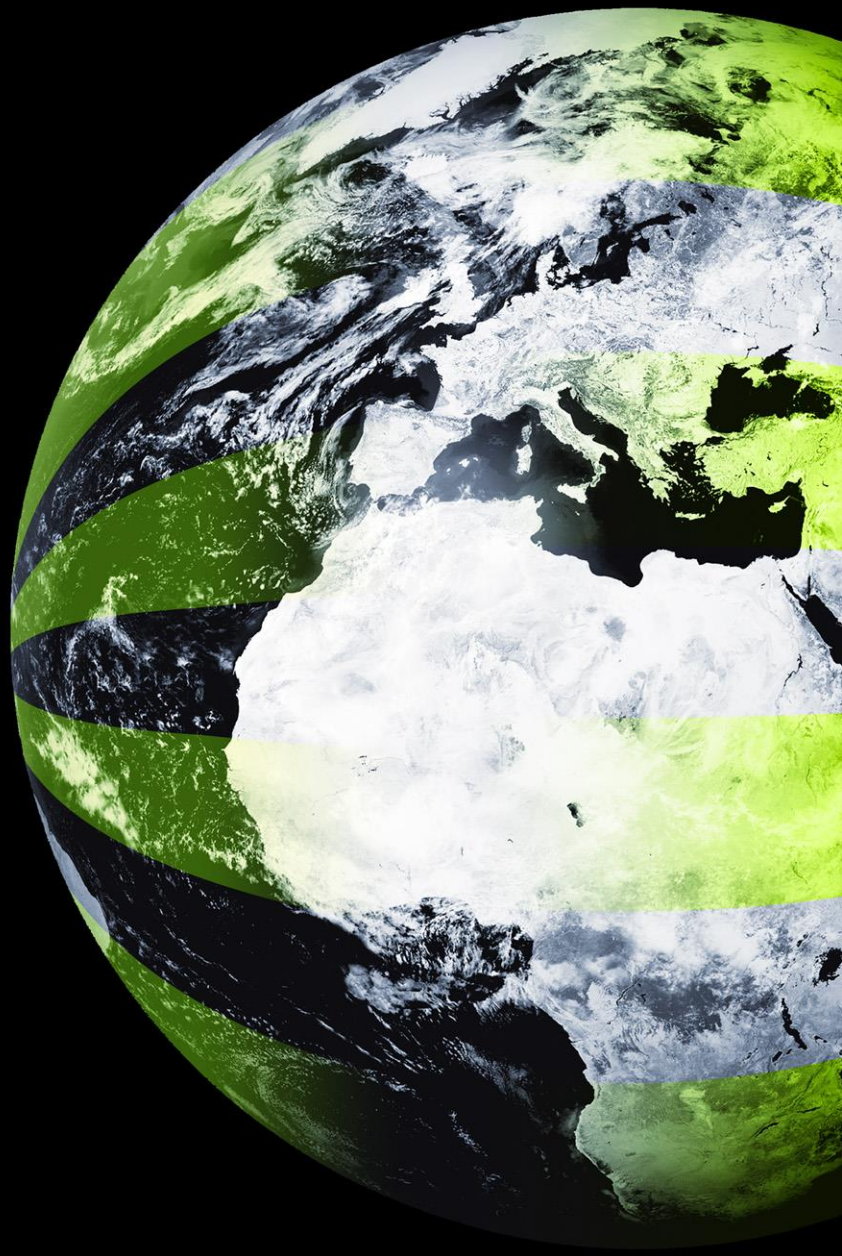




Summer (y) and winter (x) flows with observed (red) and stochastic flows



Impacts of climate change

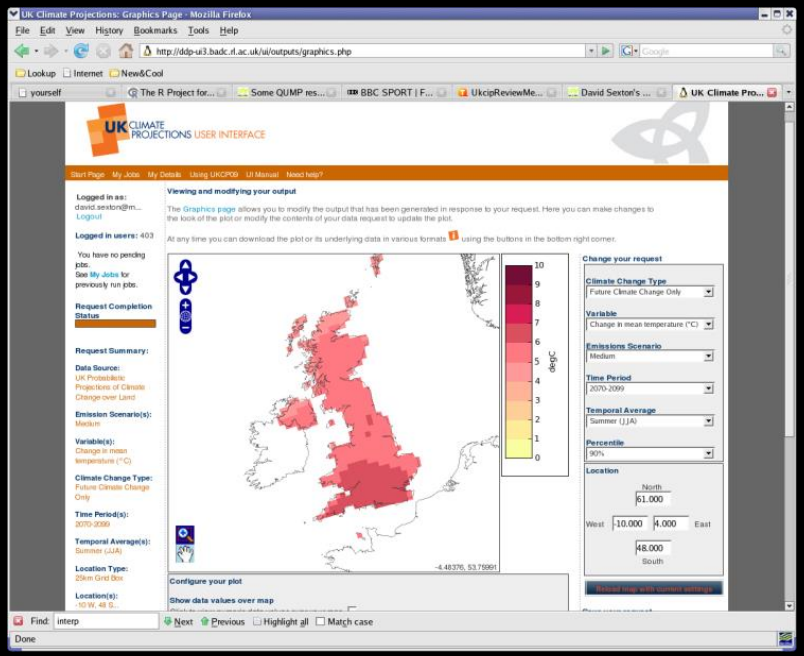


Understanding the future
United Kingdom Climate Projections 2009

Met Office Hadley Centre

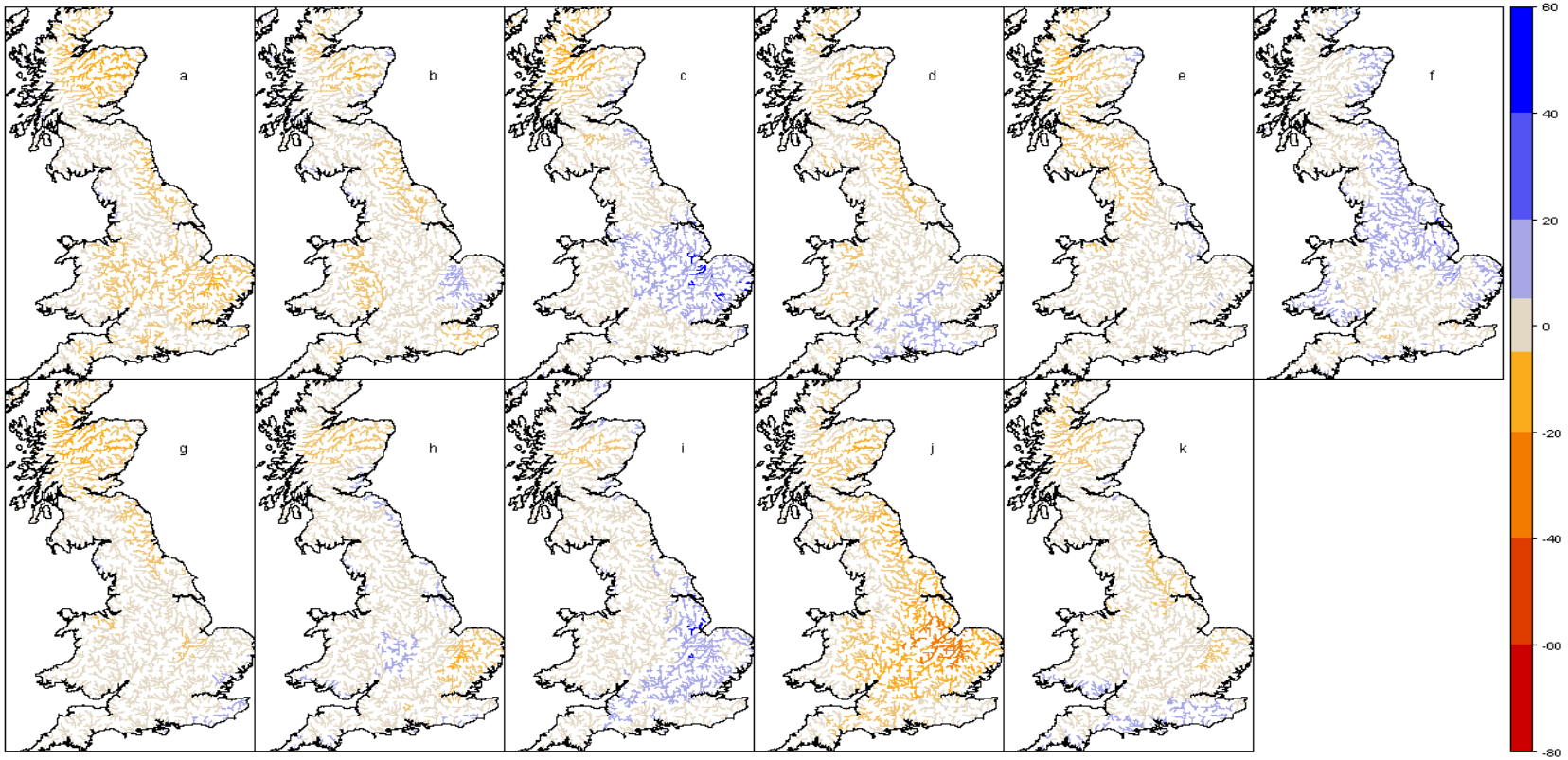
Reports

User Interface



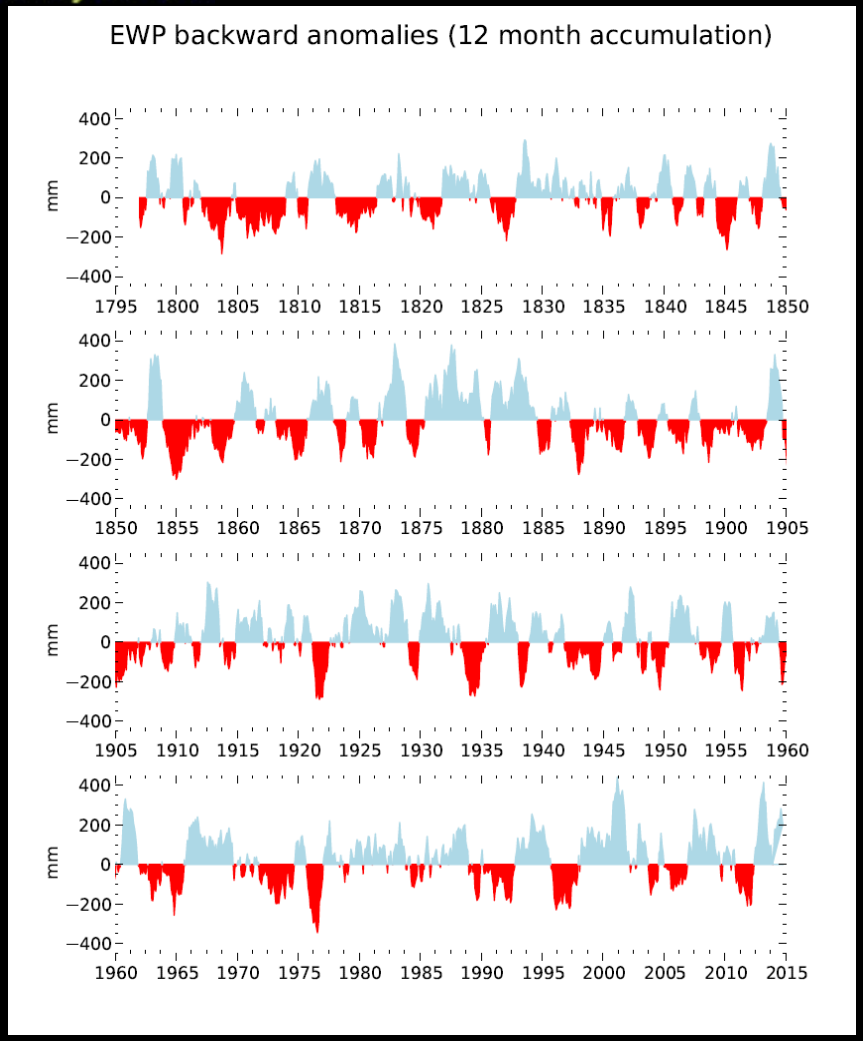
http://ukclimateprojections.metoffice.gov.uk/
http://ukclimateprojections.metoffice.gov.uk/24125

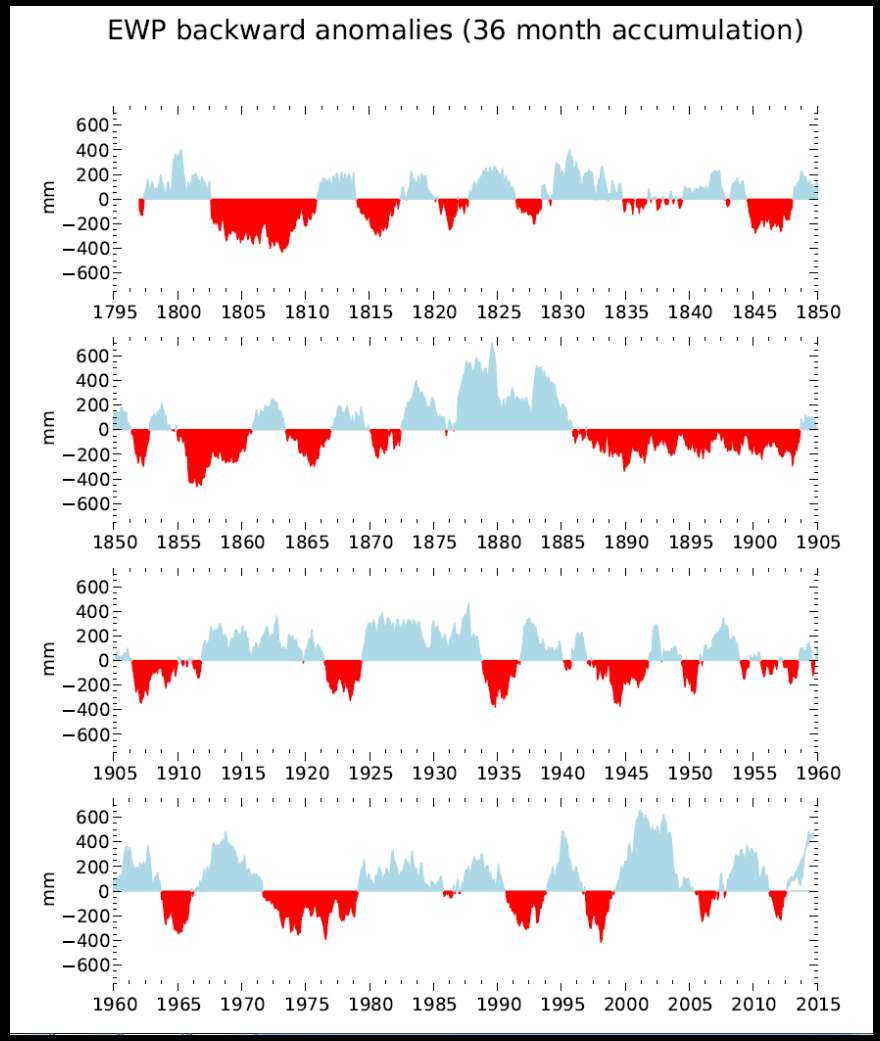
The Future Flows project



Future Flows change in summer flows (JJA) 2050s ME (Prudhomme et al., 2012)

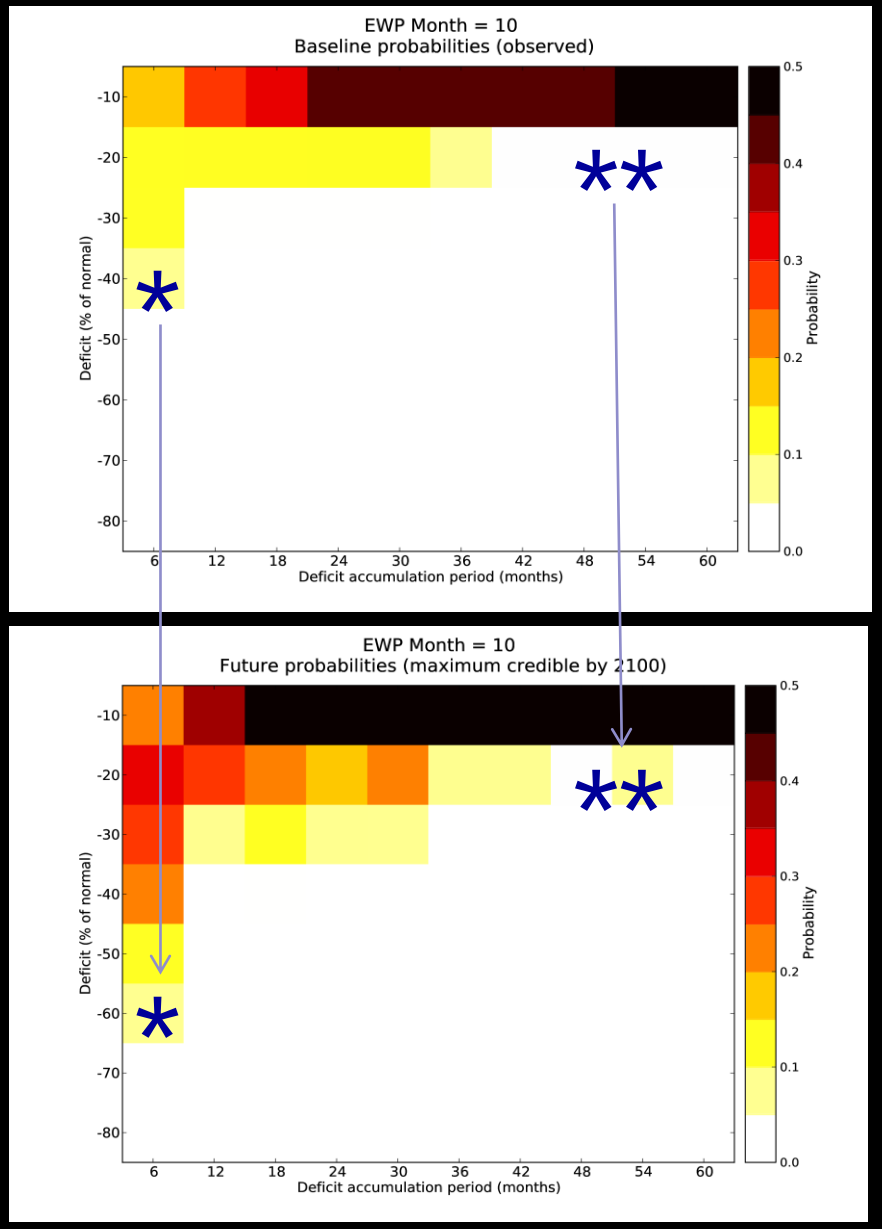
H++ analysis (with Ben Lloyd-Hughes) Low rainfall – notable dry periods in the historical record





H++ analysis: Low rainfall

- Summer droughts may decrease or increase in severity by 2080s
- For H++ ~ an increase in magnitude and frequency of short summer droughts *
- Many droughts terminated by heavier winter rainfall
- Still potential for severe long rainfall droughts (>3 years) **



Headline risk multipliers for H++ scenarios

Hazard	Scenario & direction of change		Scenario description	Main basis
Heat waves	**H++**	⇧	Annual average summer maximum temperatures exceeding **30°C over most of the UK and 34°C over much of central and southern England. Hottest days would exceed 40°C, with 48°C being reached in extreme cases.**	Historical data, particularly anomalies related to the hot summers of 1976 and 2003; UKCP09 High emissions scenario, 90% probability level. Explicit consideration of the Urban Heat Island effect was excluded.
	UKCP09 High Emissions	⇧	Average summer maximum temperatures in most of England and Wales are around 14 to 22 ºC (1961-1990). Under the UKCP09 2080s High emissions scenario, at the 90% probability level and regional scale, summer 30-year mean maximum temperatures are projected to be 8-9°C warmer than 1961-1990. (22 to 31 ºC in most of England and Wales), but the hottest day could be 10-12°C warmer (24 to 34 ºC in most of England and Wales).	UKCP09 Trends Report Figure 2.12 gridded data. UKCP09 projections (This report Section 3.3) administrative regions http://ukclimateprojections.metoffice.gov.uk/23673?emission=high
	H++	⇧	**A 6 month duration summer drought with rainfall deficits of up to 60% below the long term average (1900-1999).** Longer dry periods spanning several years with rainfall deficits of up to 20% below the long term average (1900-1999) across all of England and Wales, similar to the most severe and extensive long droughts in the historical record.	Historical data, particularly the UK regional precipitation series (HadUKP); selected Coupled Model Inter-comparison Project (CMIP5) climate models; calculation of rainfall deficits over a range of time periods from 6 months to 5 years.
Low rainfall	CMIP5 range	⇳	UKCP09 does not provide drought indices. The CMIP5 baseline indicates maximum 6 month summer rainfall deficits across England and Wales of 50% below normal. CMIP5 future projections indicate a wide spread in possible 6 month summer drought severities. These may increase up to a maximum reduction of 60% below normal, or decrease to a maximum reduction of 30% below normal. No change in winter or longer duration droughts.	England and Wales Precipitation (EWP). See Figure 4.4. Selected CMIP5 models. See Section 4 and Figure 4.10. The baseline is 1900-1999 rather than 1961-90. These scenarios cannot be compared directly to deviations from a 1961-1990 baseline or data for smaller areas or maps with gridded data. A large average deficit across England and Wales indicates the potential for much larger local deficits.

UKCP18 – Some improvements on UKCP09

- Time series of probability distribution functions at the monthly resolution and/or with a user-defined baseline period.
- Improved weather types in the UK from the global coupled climate model.
- Climate model data at the global scale.
- Very high resolution climate model products.
- Sea-level and storm surge projections

Possible options for developing rainfall drought scenarios

- Alternative multi-site or gridded rainfall or multivariate generators?
- Decadal forecasting systems, such DePreSys that now uses the latest version of the Met Office coupled climate model, HadGEM3.
- Climate models that produce large ensembles e.g. MARIUS project?
- Combining UKCP with additional simulation tools

Conclusions

- Water industry approaches have developed to include more risk based planning.
- Current tool set requires some improvement
- UKCP18 will provide new information but possibly too few ensemble members（?）and no weather generator.
- Requirement for tools to provided multivariate and multi-site weather scenarios that incorporate UKCP18 (pdfs, weather types)
- Opportunities to work on the global data set for international water resources projects