Regional hydrological droughts in north-western Europe and associated weather types

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Bewl Reservoir in southeast England, February 2006. (Photo: Reuters)

Introduction

"Drought is a sustained and regionally extensive occurrence of below average natural water availability" (Tallaksen & van Lanen, 2004)

Hydrological drought = deficit in surface or ground water

Elbe in Dresden, April 2007 (spiegel.de)

Typical features

- develop slowly,
- become severe when they cover a large region and persist for an extended period.

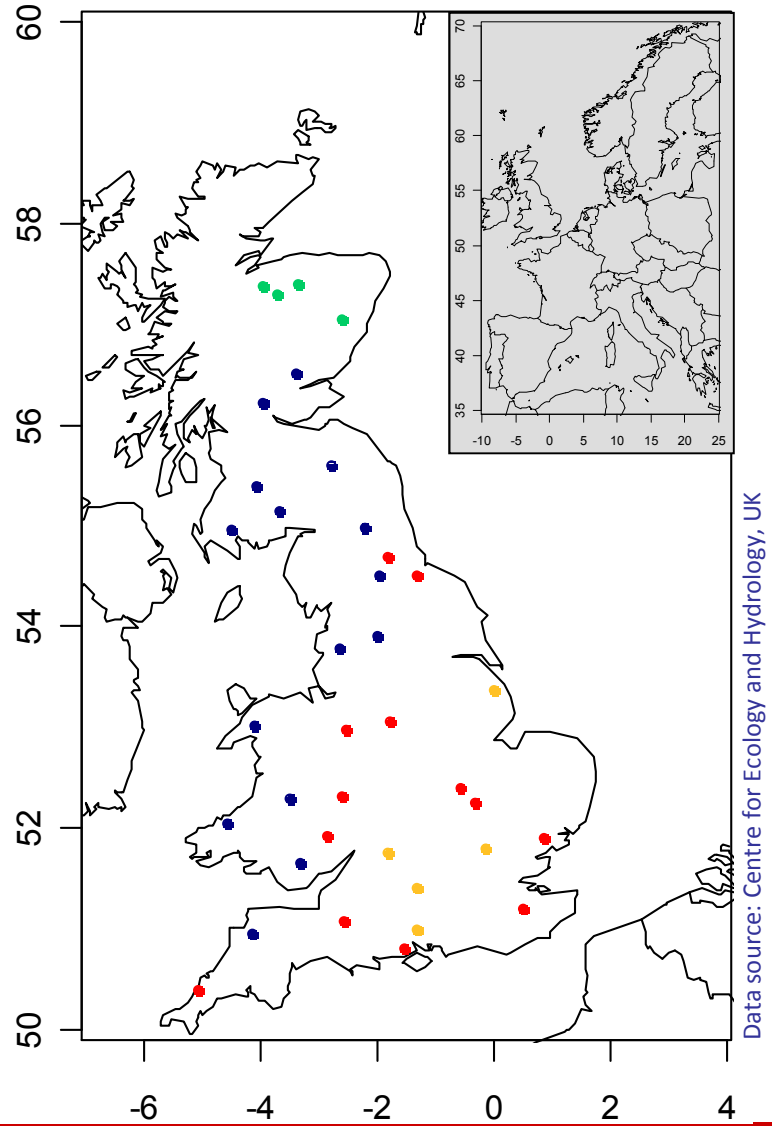
Objectives

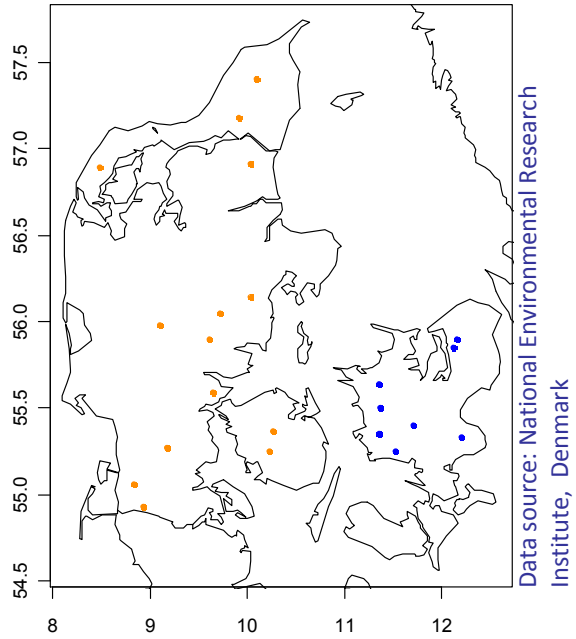
1. to study the characteristics of regional hydrological drought in north-western Europe, and
2. to investigate the mesoscale hydroclimatological processes leading to hydrological drought.

Focus

- on natural processes not under influence of human activities.

Hydrological drought in NW-Europe: Data





- 37 British and 22 Danish stations;
- natural or naturalized daily streamflow data for 1964–2001;
- threshold level method → at-site drought.

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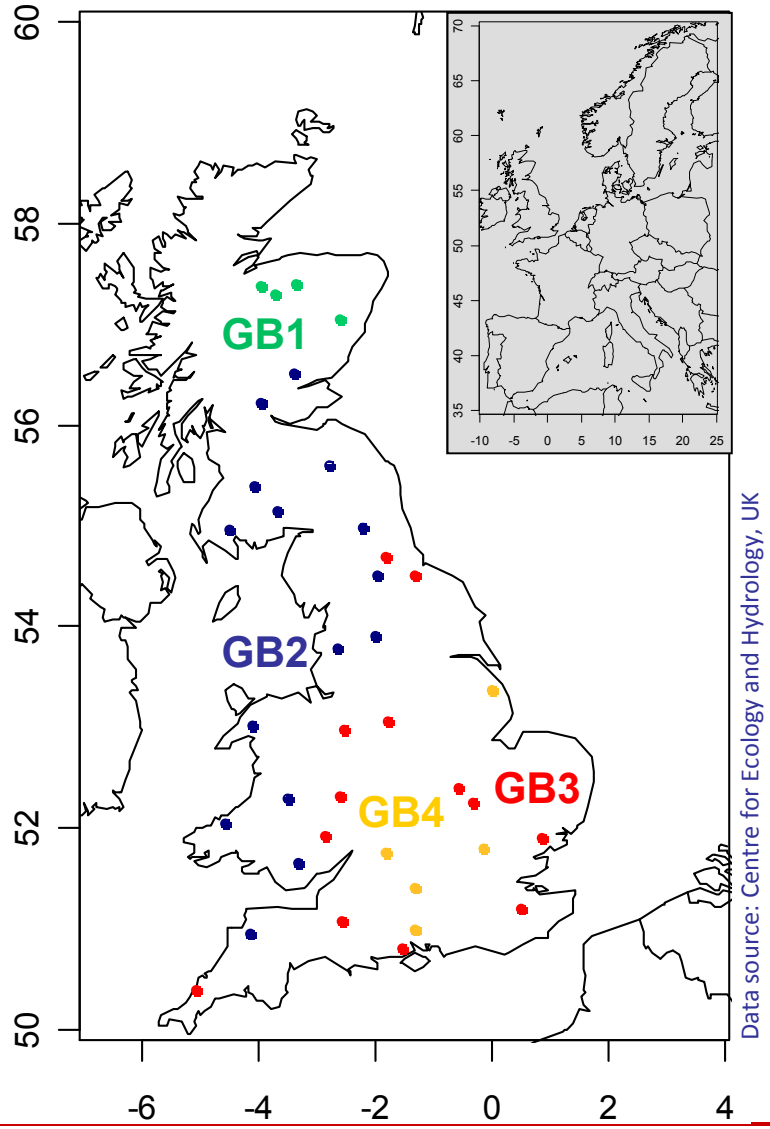

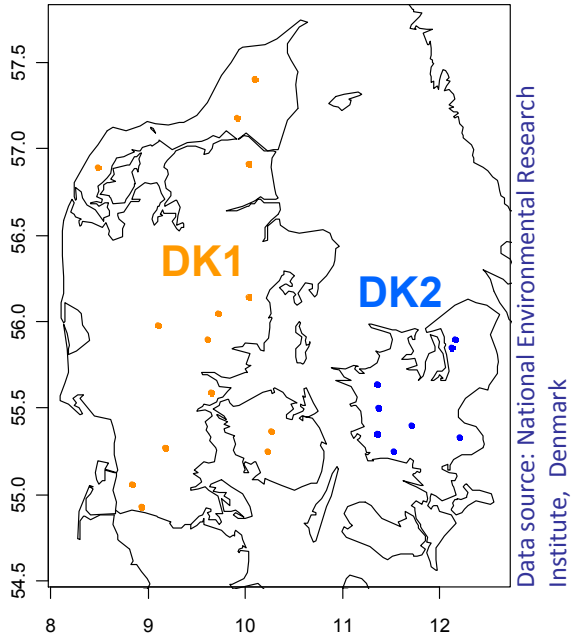

- 37 British and 22 Danish stations;
- natural or naturalized daily streamflow data for 1964–2001;
- threshold level method → at-site drought.
- cluster analysis → six regions.

Regional hydrological drought

Regional Drought Area Index (RDAI)

- daily series,
- drought affected proportion of the area within one region,
  total area = sum of catchment areas in the region,

→ RDAI: 0 – 1.

Regional drought definition

- RDAI > 0.7

Hydrological drought: Regional streamflow drought series

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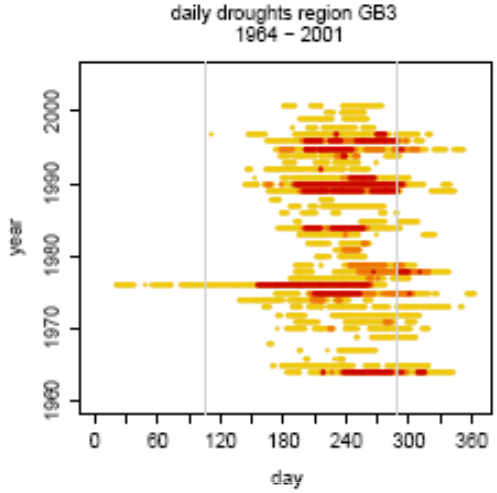


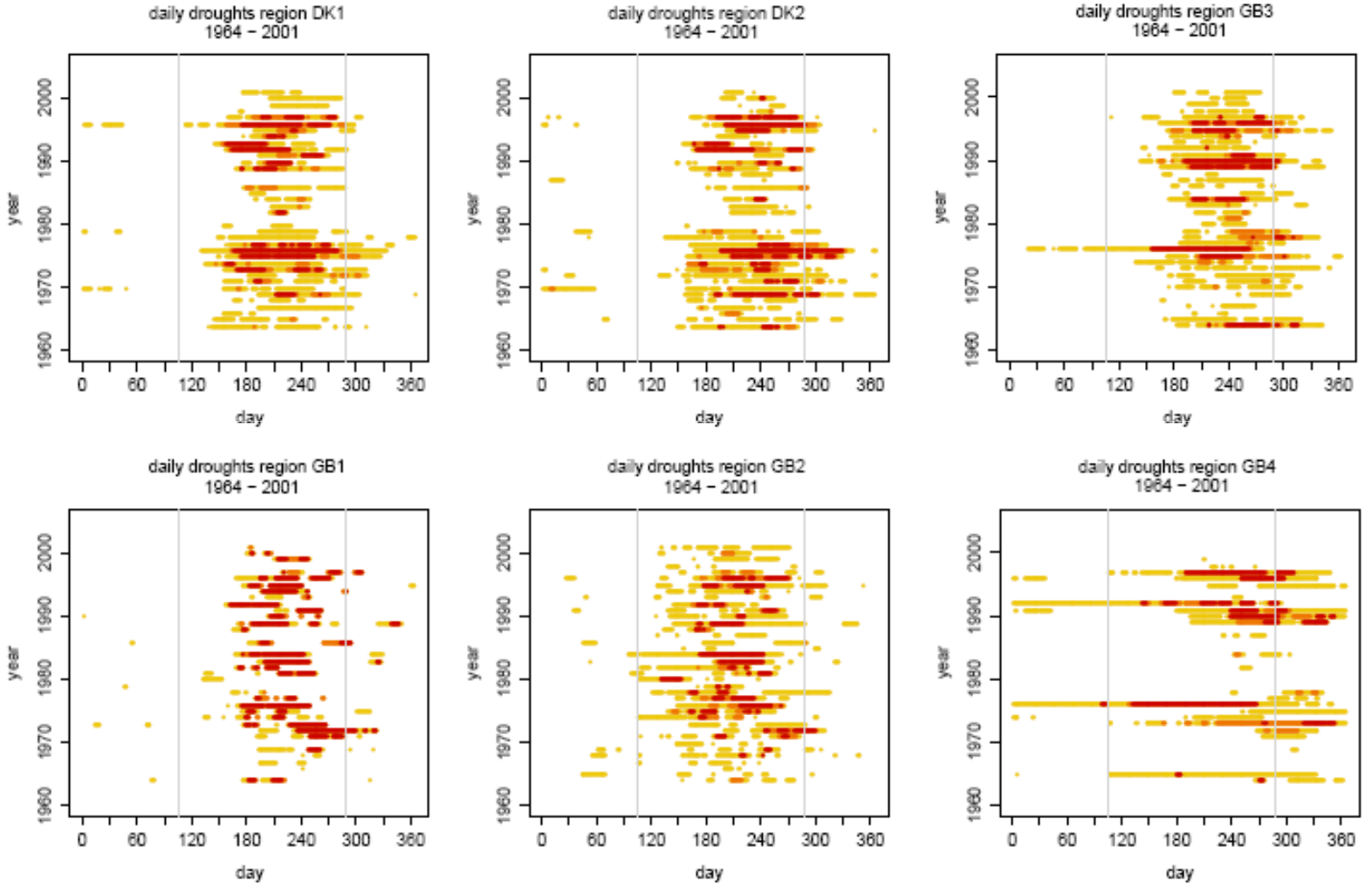
RDAI > 0

RDAI > 0.4

Drought =

RDAI > 0.7

Hydrological drought: Regional streamflow drought series



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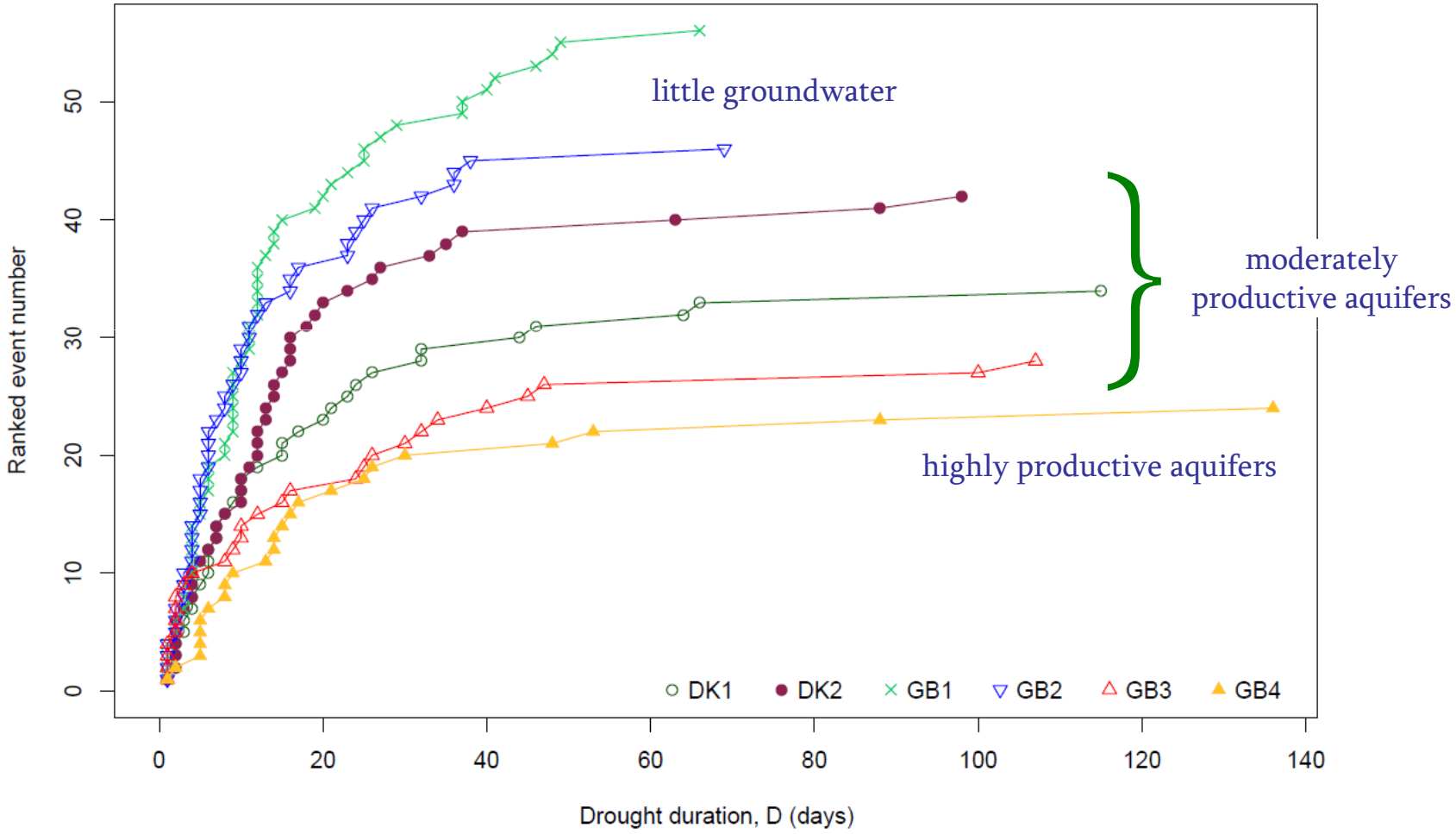
Regional hydrological drought



Fleig et al. (2010)

RDAI: Regional characteristics

Years of the five most severe drought events per region

Year	DK1	DK2	GB1	GB2	GB3	GB4
1964						
1972						
1973						
1975						
1976						
1983						
1984						
1989						
1990						
1991						
1992						
1993						
1995						
1996						
1997						

1976

1996

Weather types (WTs)

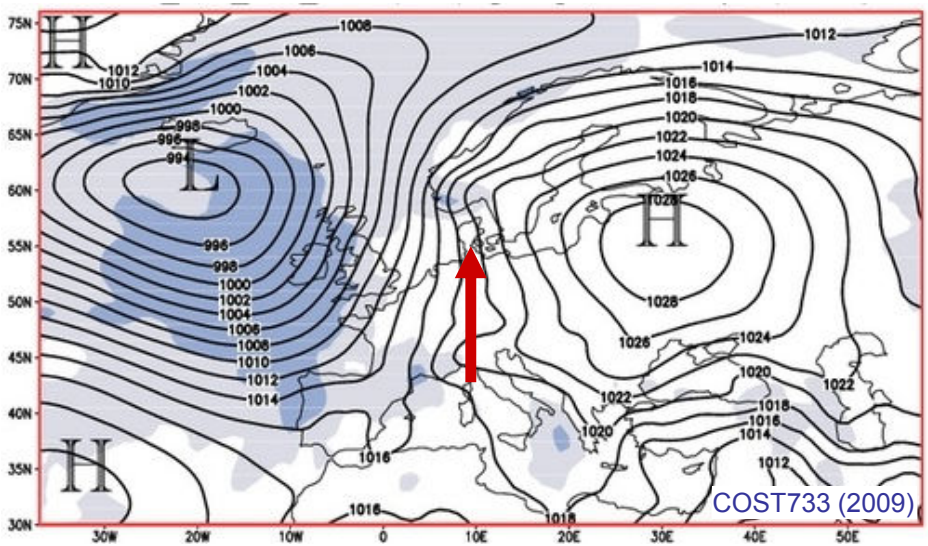
- simple, discrete characterization of the current atmospheric conditions over a region on the nominal scale;
- may be based on one or several meteorological variables.
- Weather type classification (WTC): the set of WTs describing (all) common atmospheric situations over a region.

Advantages

- simple,
- consider the whole region,
- strongly correlated with several, local meteorological variables,
- if based on air pressure data only:
  - better represented in climate models than precipitation.

OGWL: Objective Grosswetterlagen

- Objective WTC based on Hess-Brezowsky Grosswetterlagen,
  - developed for central Europe using expert knowledge,
- input data: MSLP and Z500 (geopotential heights),
- 29 WTs,
- WTs are characterised by flow direction (W, NW, N, NE,...) and cyclonicity (anticyclonic, cyclonic).

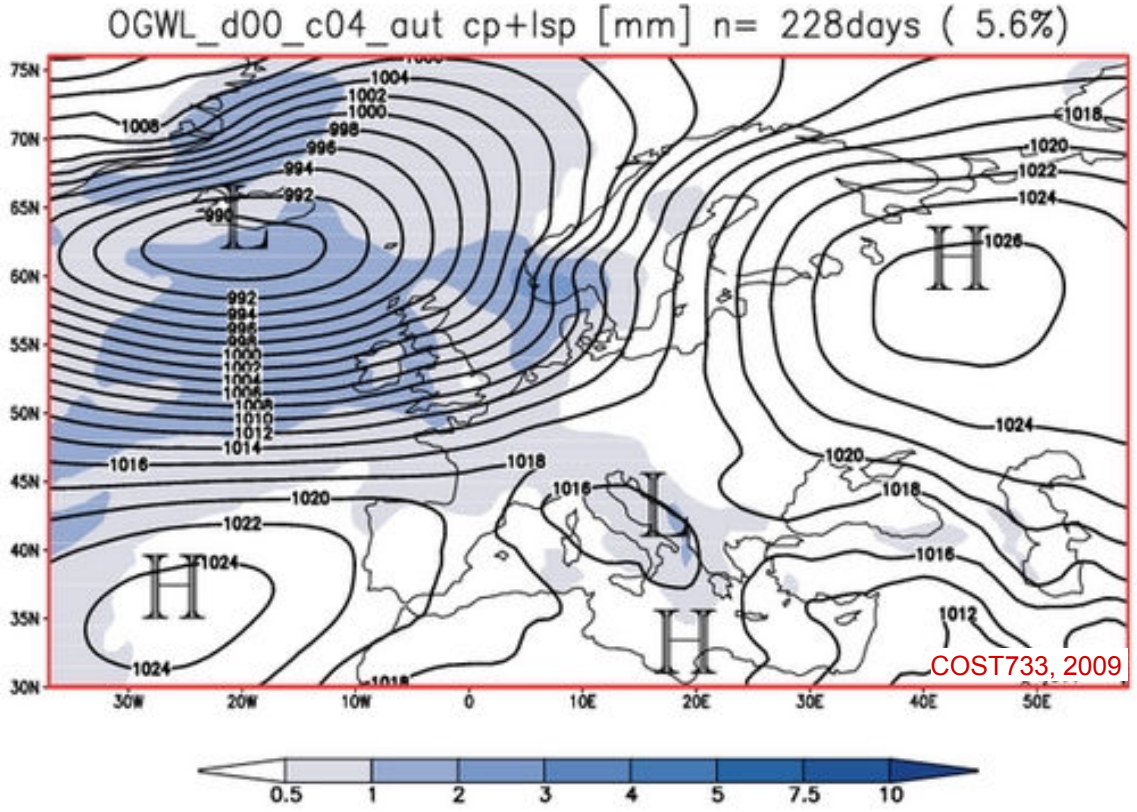


southernly, anticyclonic (high pressure system)

Determination of the period of influence: d_{reg}

- subjective selection of WTs;
- based on composites of precipitation amounts.

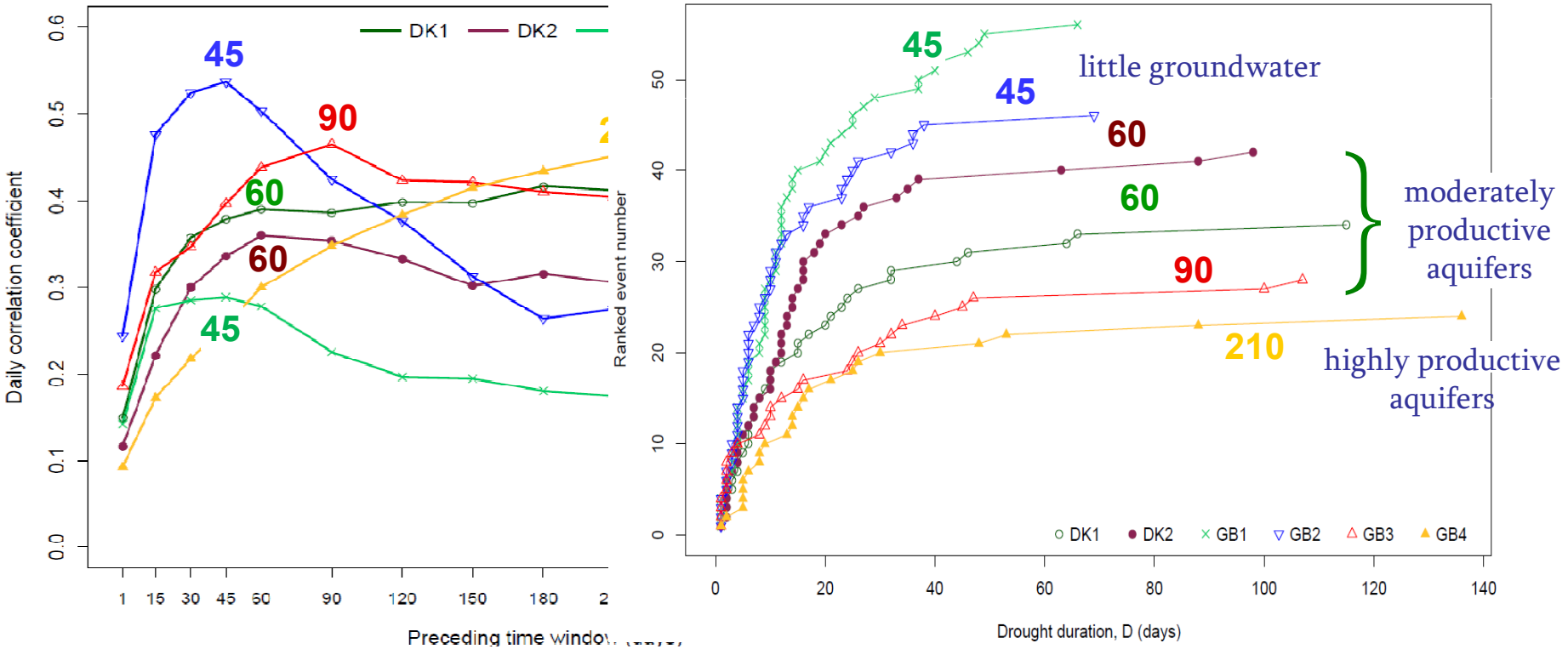
➔ 14 – 22 potentially drought supporting WTs per region



Determination of the period of influence: d_{reg}

Correlations between

- daily RDAI,
- cumulative WT-frequencies of potentially drought-supporting WTs over previous *n* days (*n* = 1, 15, 30, 45, 60, 90, 120, ... 330).



Identification of WTs related to severe drought events

Frequency anomalies (FA_{WT})

- for the five most severe droughts in each region;

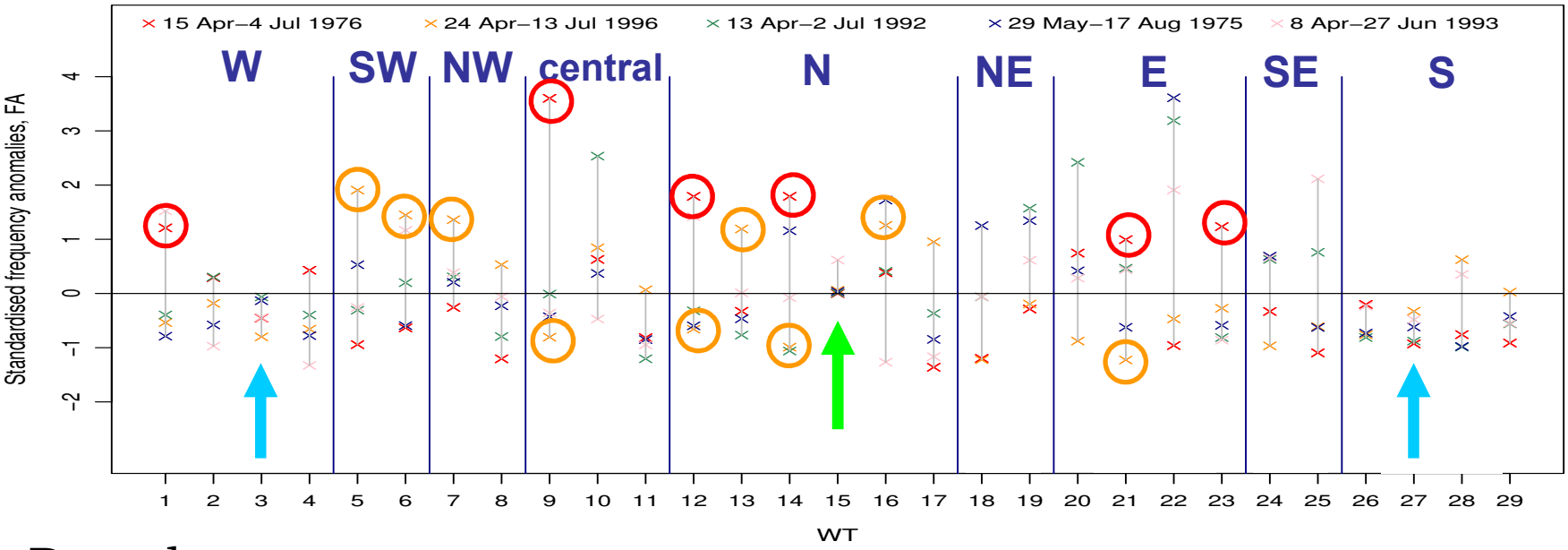
$F_{e,WT}$ frequencies of a given WT prior to and during (d_{reg}) drought event e

F_{WT} average (normal) frequencies of a WT during the same period of the year for 1964–2001

$FA_{e,WT}$ $$\mathrm{FA_{e,WT}} = \frac{\mathrm{F_{e,WT}} - \mu \mathrm{F_{WT}}}{\sigma \mathrm{F_{WT}}}$$

WTs related to severe drought events

Region DK1



Drought events are:

- associated to several WTs;
- mostly including different flow directions;
- different events by different WTs;
- only in DK1 and GB3 a WT is related to all five events;
- 1 – 5 WTs have a negative FA for all five events in one region;

Results: WTs related to severe regional droughts

WTs with a mean FA > 0 over all five drought events

	W				SW		NW		central			N						NE		E				SE		S			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
cyclonicity	A				A		A		A	A		A		A		A		A		A		A		A		A			
DK1																													
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➔ six WTs are included for all regions:
mostly northern high pressure centres;

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➔ six WTs are related to drought in all regions:
mostly northern high pressure centres;

➔ most important flow directions: N, E, and central;
(with respect to central Europe)

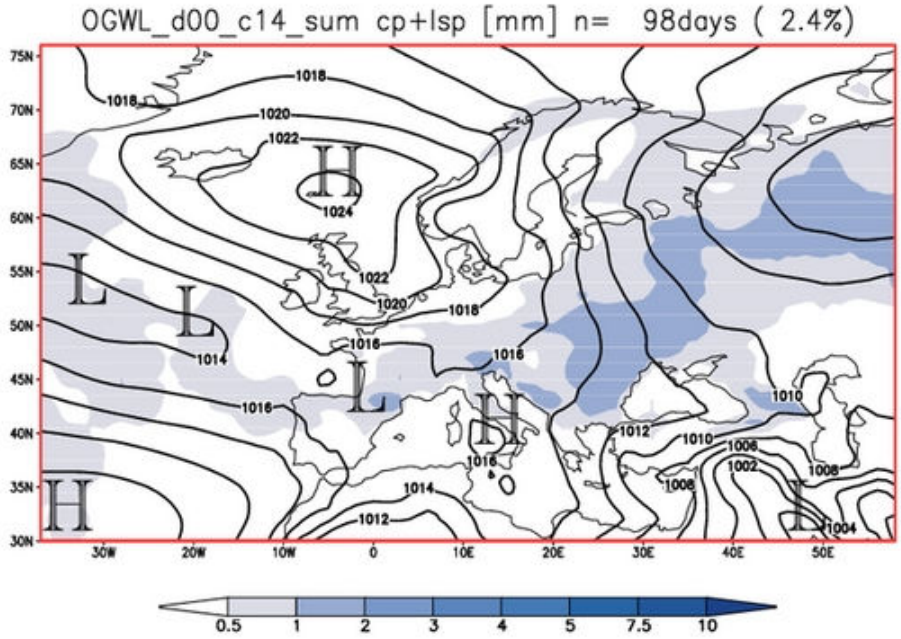
Results: WTs related to severe regional droughts

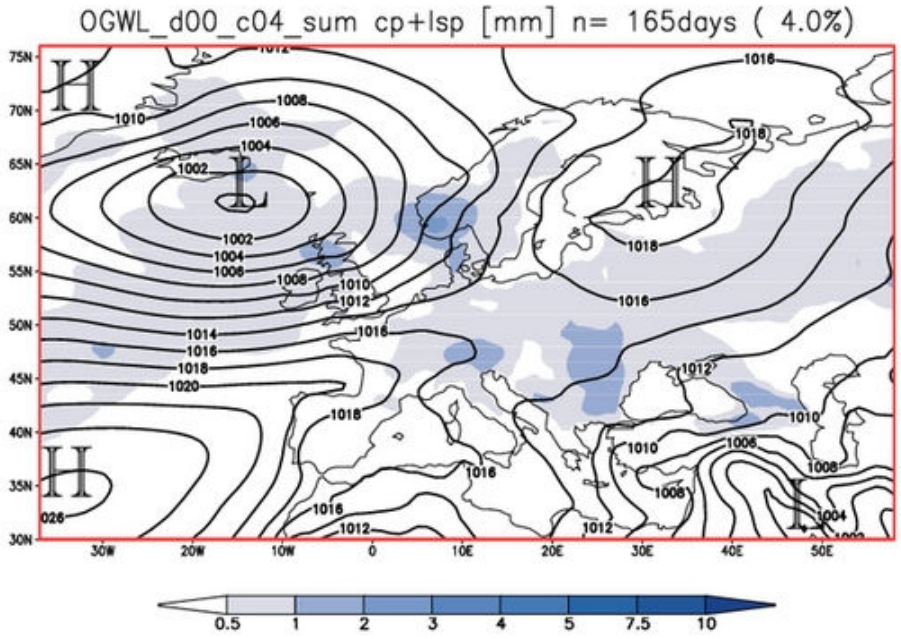
Regional flow direction

➔ differ between regions:
Denmark: N, NE, NW
Great Britain: S, SE, SW

all regions: central high,

Regional flow direction over Denmark





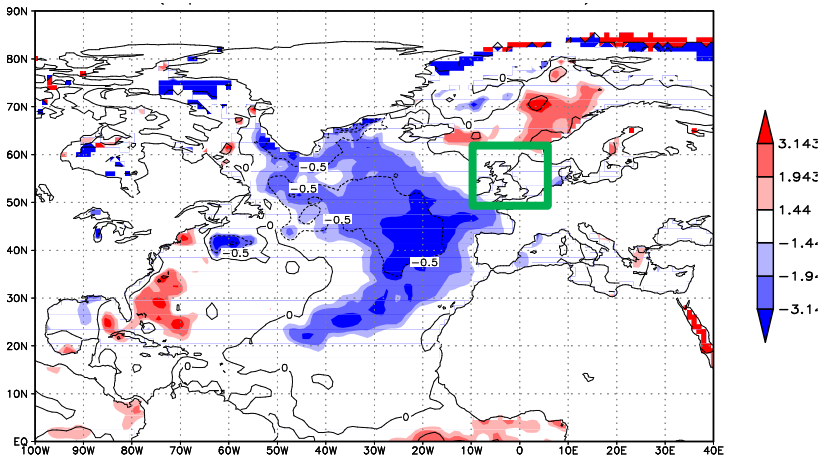
Outlook: Longer term relations

Composite analysis of ocean and atmospheric fields during drought years: composites: average anomalies of a variable for a given month during drought years as compared to the long-term mean for that month.

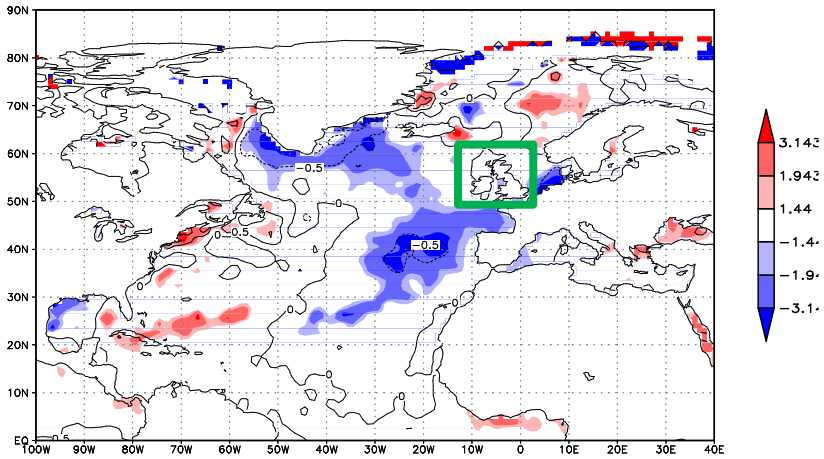
SST anomalies in preceding months

- month with strongest SST anomaly for each region,
- difference in lag time according to regional drought response time.

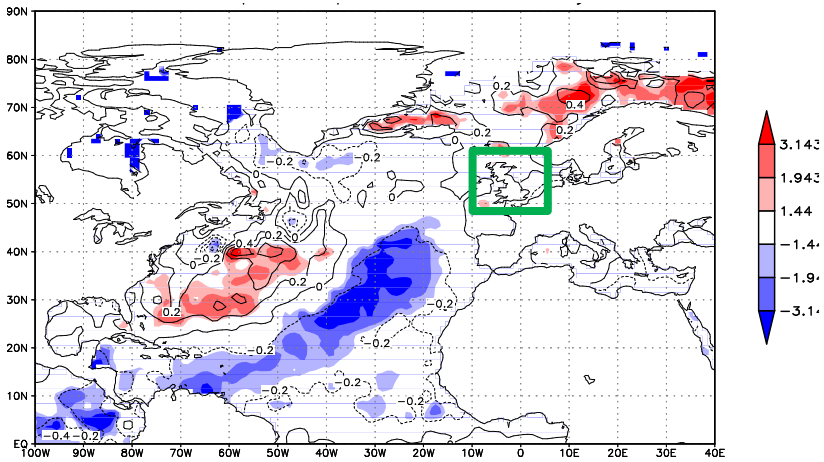
GB1: May



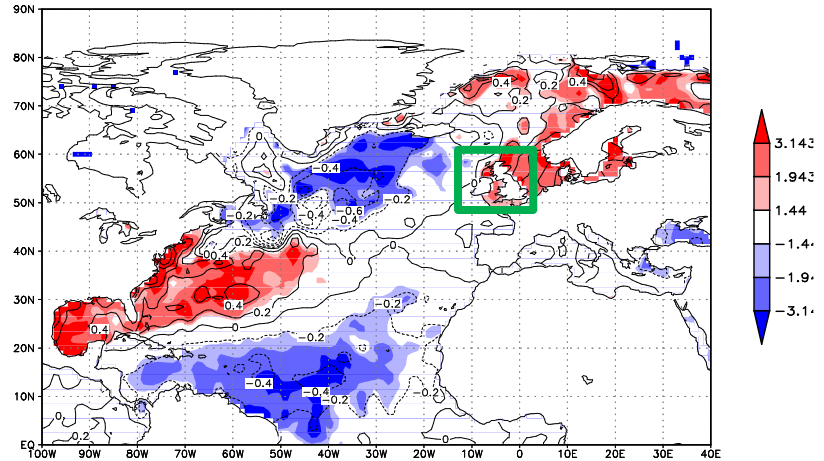
GB2: May



GB3: April

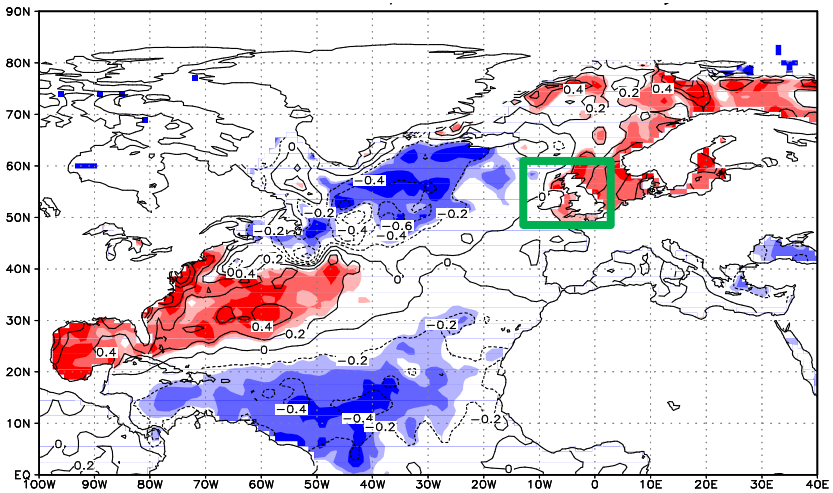


GB4: March

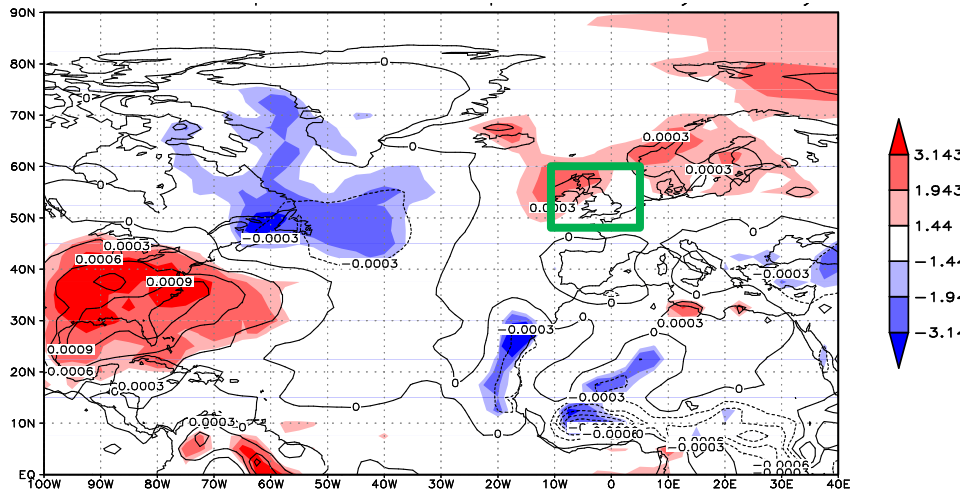


Atmospheric anomalies in preceding months

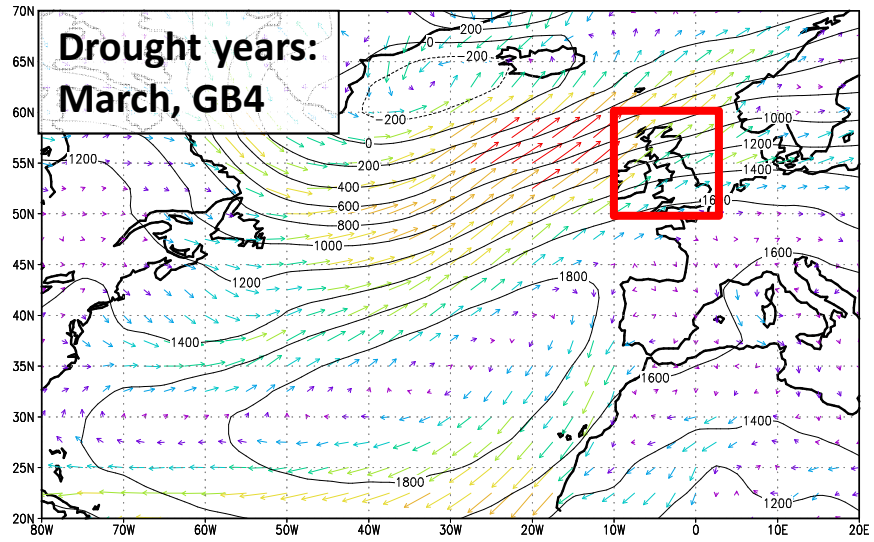
GB4: March, SST



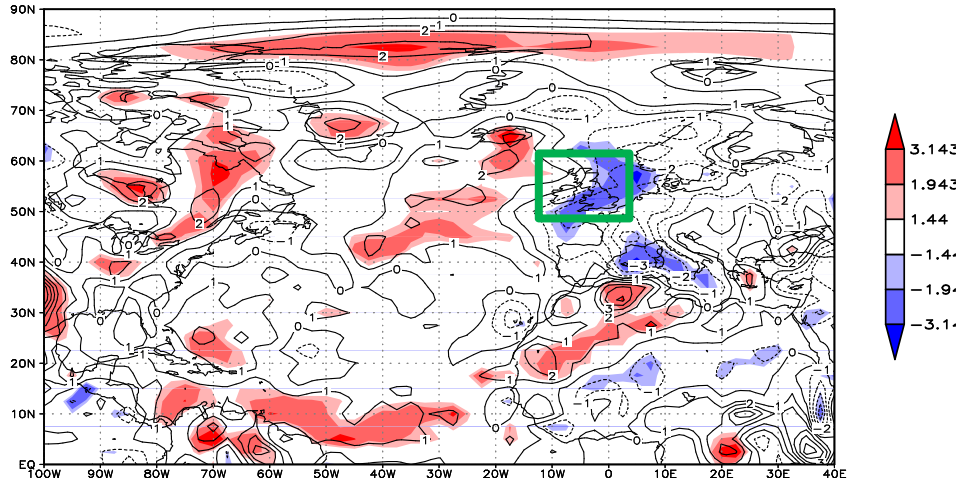
GB4: March, specific humidity



Drought years: March, GB4



GB4: Apr, relative humidity



Summary & Conclusions

- Regional hydrological drought characteristics vary considerably within the study region according to regional hydrogeological properties;
- regional hydrological response time, d_{reg} varies and is related to drought characteristics and hydrogeology;

  → consideration of the regional hydrological response time is important;
- Drought causing hydroclimatological processes are complex, i.e. vary between regions and individual events;
- Meridional air flow (N, S) and central highs are most frequently related to drought development.

Conclusions & Outlook

The methodology and results may be valuable for:

- the study of the hydroclimatology of historical droughts over the whole of Europe;
- monthly or seasonal drought forecasting based on large-scale ocean-atmosphere patterns by investigating possible relations between drought related WTs and larger-scale teleconnections;
- the study of future drought characteristics by analysing frequencies of drought related WTs in climate scenarios;
  - advantage of WTs: pressure is better modelled than precipitation.
  - prerequisite: hydrothermal properties of pressure based WTs are stationary during changing climatological conditions.

Acknowledgements

- the COST733 Action and Paul James, Hadley Centre Met Office, for the weather type data;
- the UK National River Flow Archive, CEH, for the British river flow data;
- the National Environmental Research Institute in Denmark for the Danish data (provided for applications in the Nordic Energy Research funded project Climate and Energy Systems to which this study is a contribution).

Thank you!

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