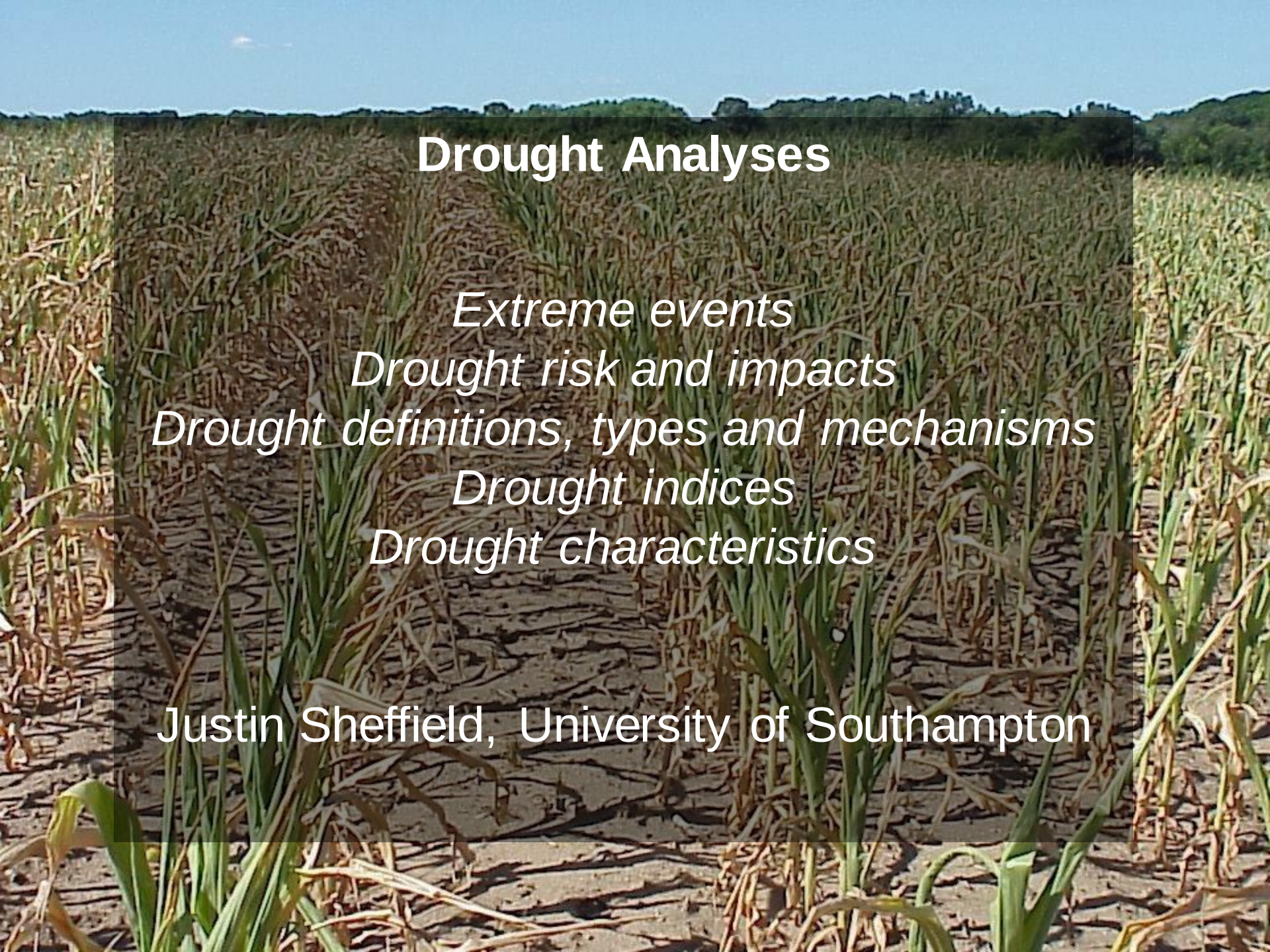

Drought Analyses

Extreme events
Drought risk and impacts
Drought definitions, types and mechanisms
Drought indices
Drought characteristics

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What is an Extreme Event?

- Multiple definitions
  - High impact (but potentially not really extreme)
  - Exceedance over a relatively low threshold e.g. 10^{th}, 90^{th} percentile of daily temperature or precipitation
  - Rare events (long return period)
  - Unprecedented events (in the available record)
  - (language used is not very precise)

- Very wide range of space and time scales
  - from very small scale (tornadoes, hail storms)
  - to large scale (drought, heat waves)

- Extremes in one location may be normal in another

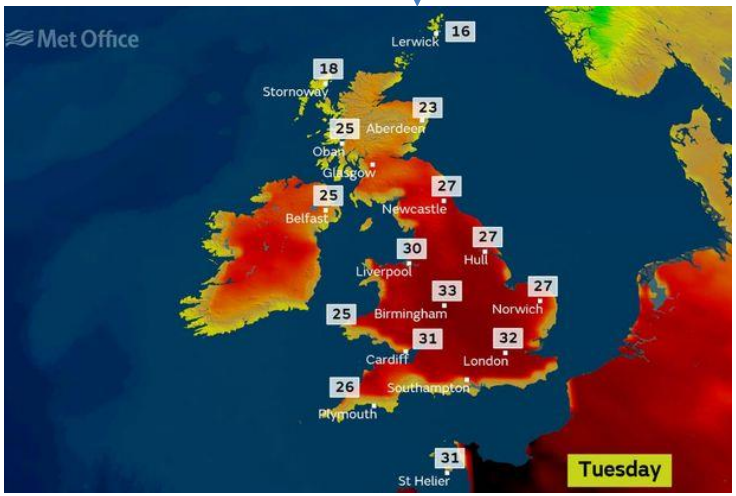
Extreme Events Relevant to Water Resources

Extreme precipitation

Droughts

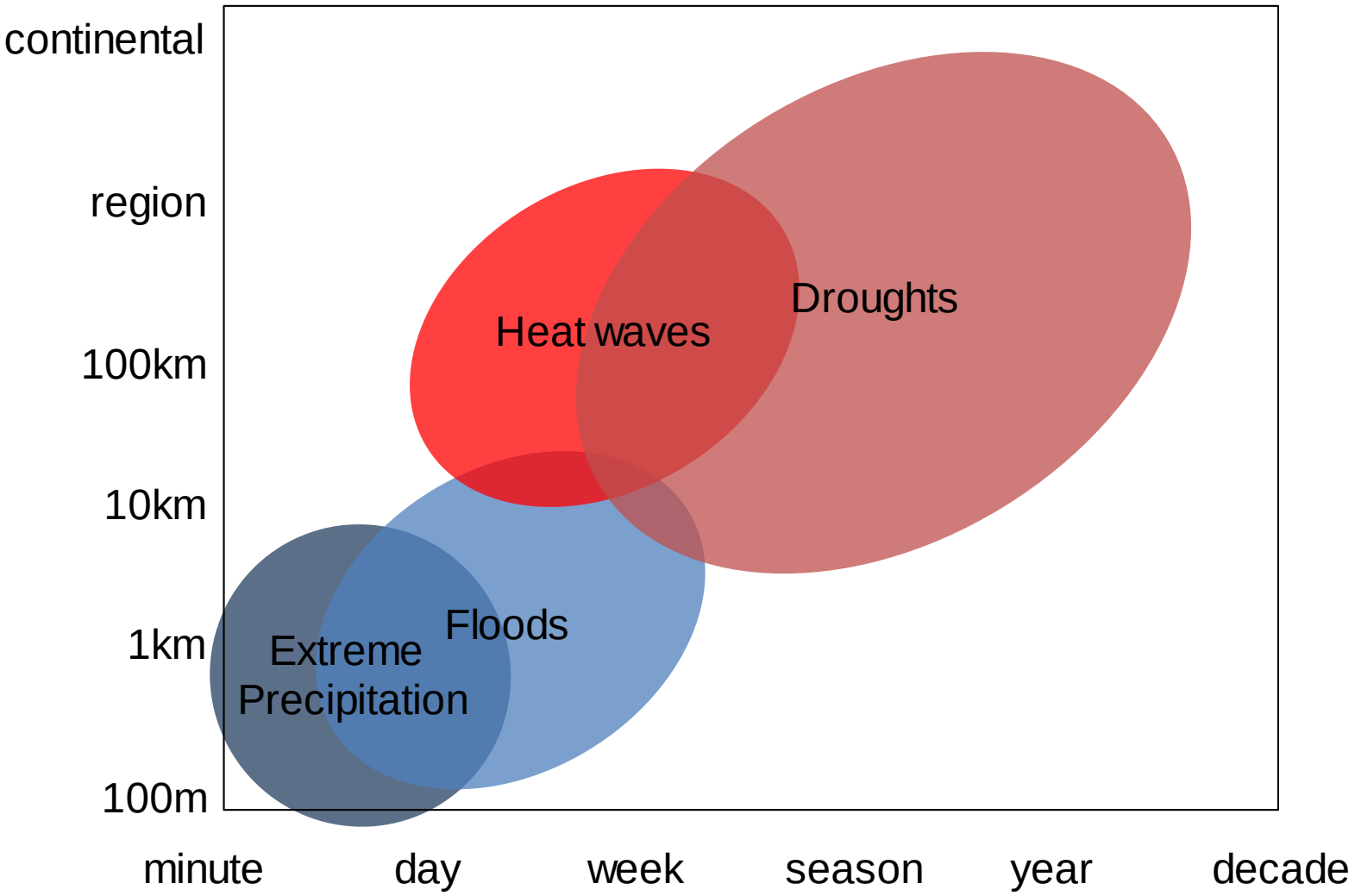
Connections

Floods



Extreme heat and Heat Waves

Scales of Extreme Events



Extreme Values and Extreme Value Analysis

- *Extreme values* are those of a process (e.g. precipitation or streamflow) that are *exceptionally* high or low

- *Extreme value analysis* is the statistical analysis of extreme values.
  - These values are generally analysed separately from the whole record
  - At a range of time (duration) and space (extent) scales.

- For example
  - extreme precipitation at the daily time scale, at a point
  - annual daily maximum streamflow for a catchment
  - extreme drought at the annual scale for a country.

Why is it important for water resources?

- Understanding the occurrence of extreme high values (floods) and extreme low values (droughts) helps us
  - to better manage water resources to ensure enough supply
  - to mitigate impacts of floods
  - → disaster risk reduction

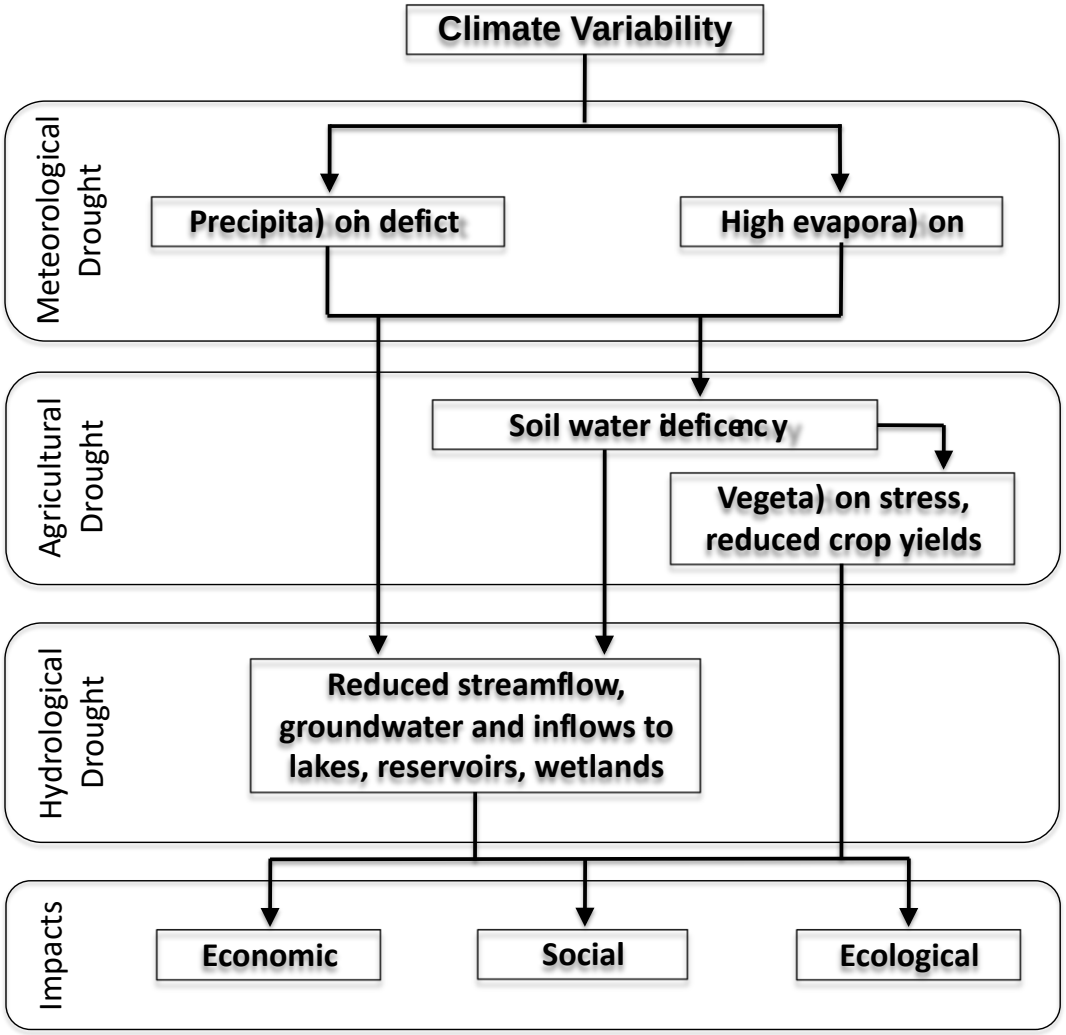
- For example:
  - knowing how often an extreme flood will happen on average every 25 years (return period) allows us to design how big to build flood defenses or dams.
  - knowing how severe a drought could be, helps planning in agriculture.

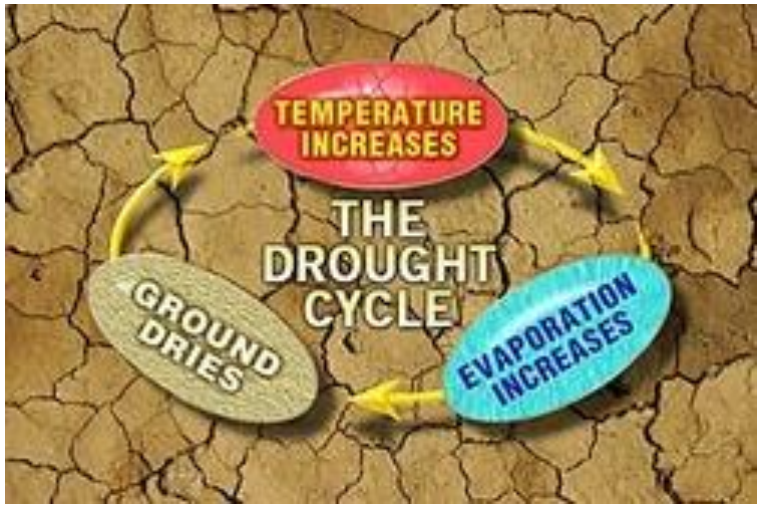
- Some concepts from engineering hydrology
  - Design rainfall, design flood, Intensity-Duration-Frequency (IDF) curves

Drought Definitions

- The simplest definition is "a deficit of water relative to normal conditions"
- More specifically as a low amount of water in one or a combination of these stores (river, lake, reservoir, snowpack, soil water and groundwater) or fluxes (precipitation, evapotranspiration and run-off).
- This definition may be further qualified by adding that a drought occurs when the lack of water is sustained and spatially extensive, and is a deficit below a threshold that has adverse impacts.
- Many other definitions….
- Note:
  - Drought is a normal, recurrent feature of climate that occurs in virtually all climate zones, from very wet to very dry.
  - Drought is different than aridity, which is a permanent feature of climate in regions where low precipitation is the norm, as in a desert.

Drought Types and Mechanisms





Drought Types

In the scientific literature, droughts are typically classified into four major types:

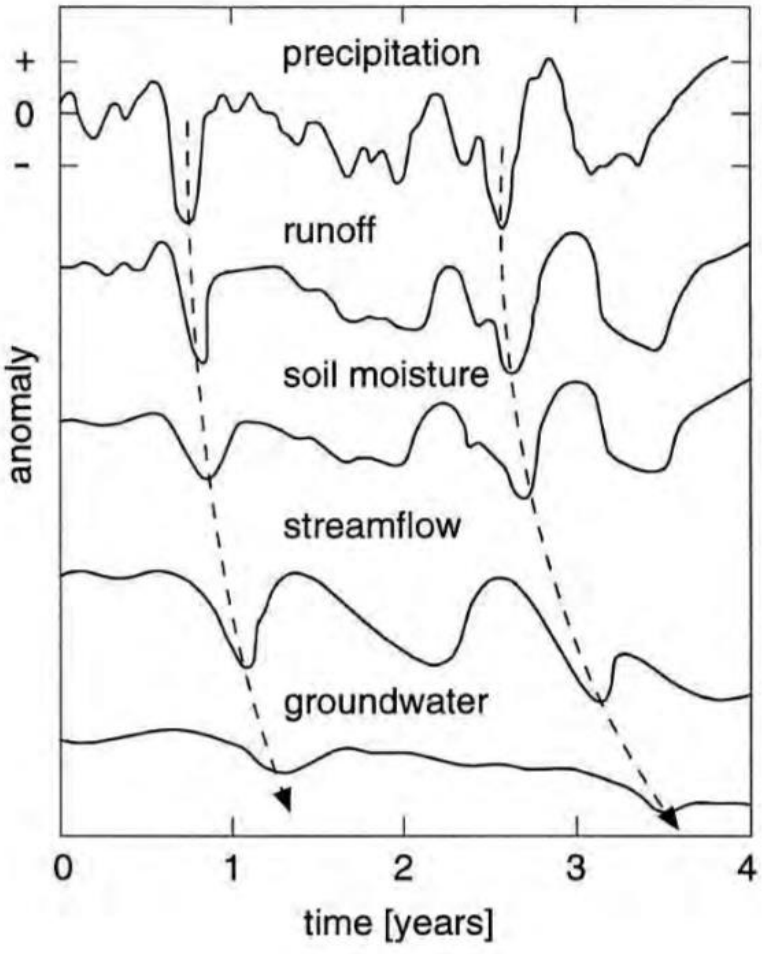
1. *meteorological drought*, a significant negative deviation from mean precipitation;
2. *hydrological drought*, a deficit in the supply of surface and subsurface water;
3. *soil moisture* or *agricultural drought*, a deficit in soil moisture, driven by meteorological and hydrological drought, reducing the supply of moisture for vegetation;
4. *socio-economic drought*, a combination of the above three types leading to undesirable social and economic impacts.

These classifications of drought are not rigid, since the definitions incorporate many different physical, biological and socio-economic variables. Further definitions may apply, based on environmental impacts.

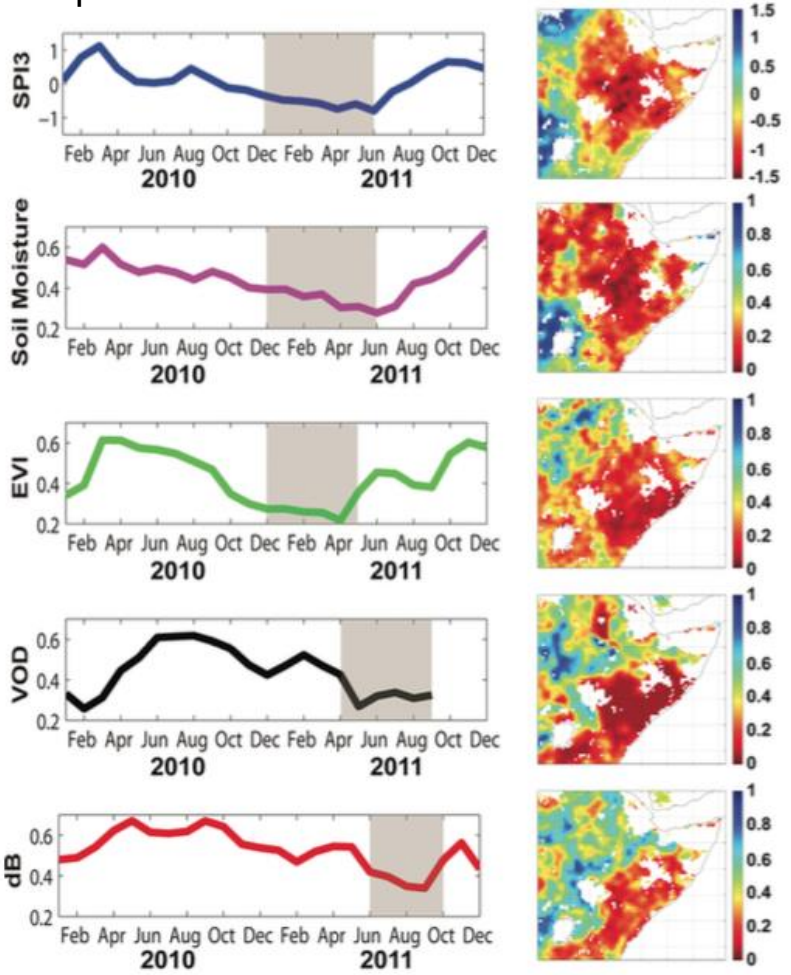
Drought Propagation

- A drought event generally begins with a deficit of precipitation
- The drought signal propagates through the rest of the hydrological system
- The signal is filtered and often becomes more persistent

Conceptual figure of drought propagation through the hydrological system

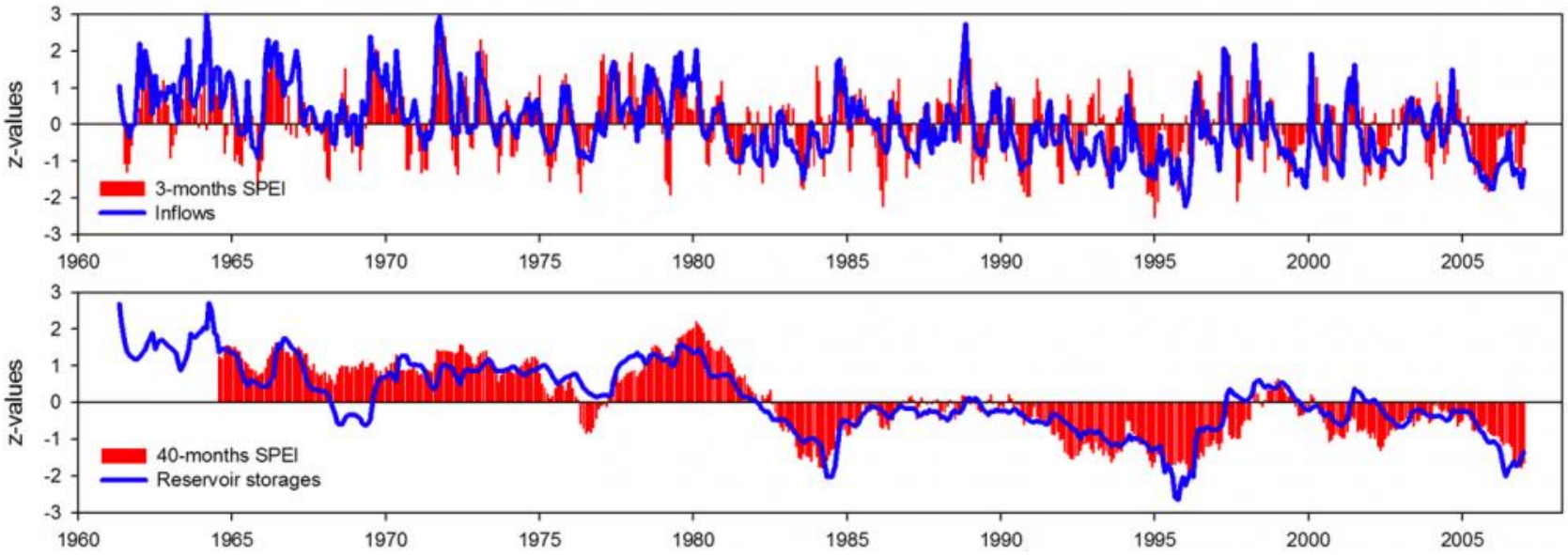


Propagation of drought signal through multiple independent RS variables

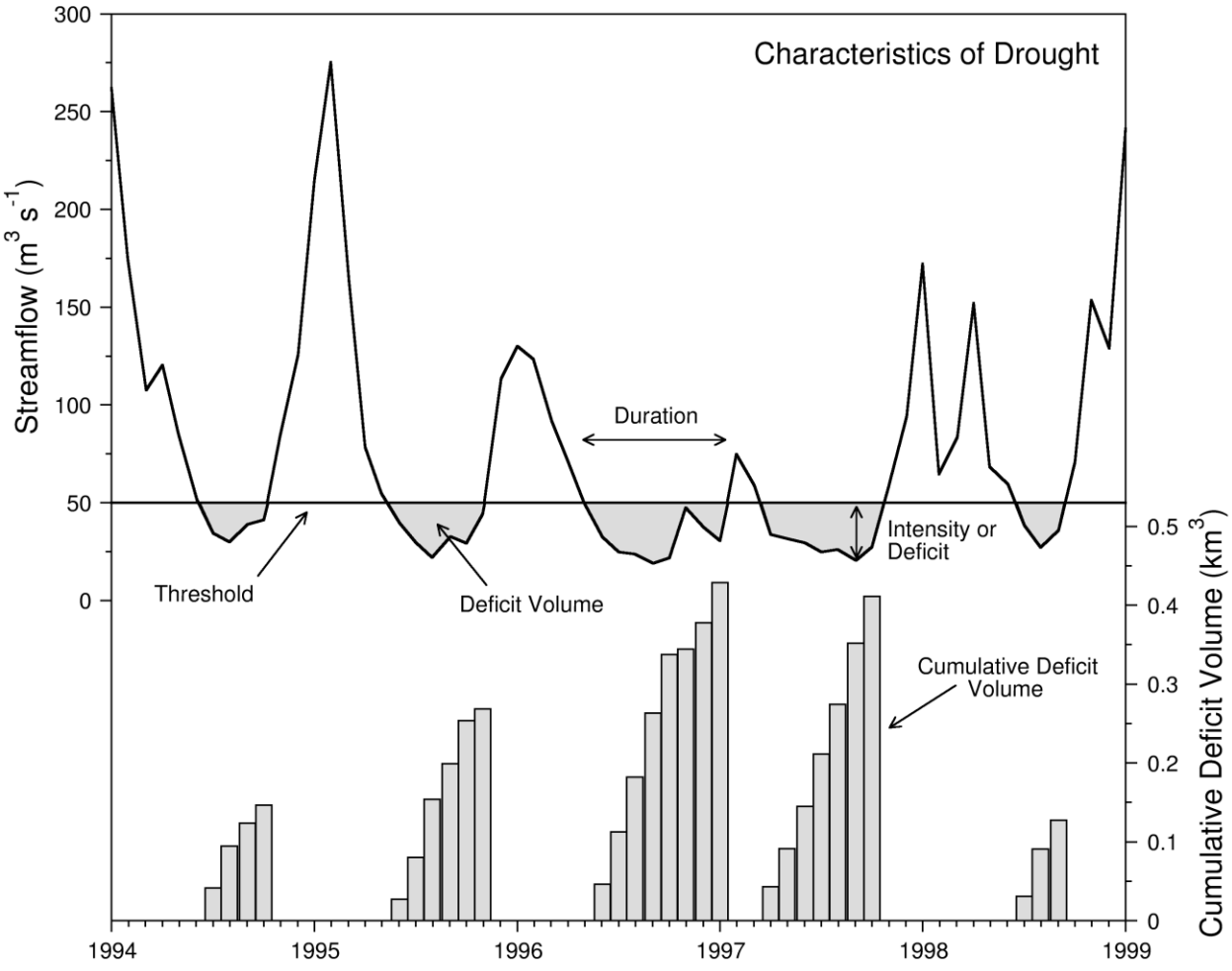


Drought Indices

- A quantitative expression for the state of drought is generally required to understand current conditions, and how it compares with past droughts and with other regions
- This is usually called a drought index and allows a scientist, farmer, manager or policy-maker to objectively analyse a system and make quantitative management and policy decisions.
- There are many different types of index, but they are generally a rescaled version of a meteorological or hydrological variable at a time step of weekly/monthly or longer (e.g. percentile, Z-score, …).



Drought Characteristics



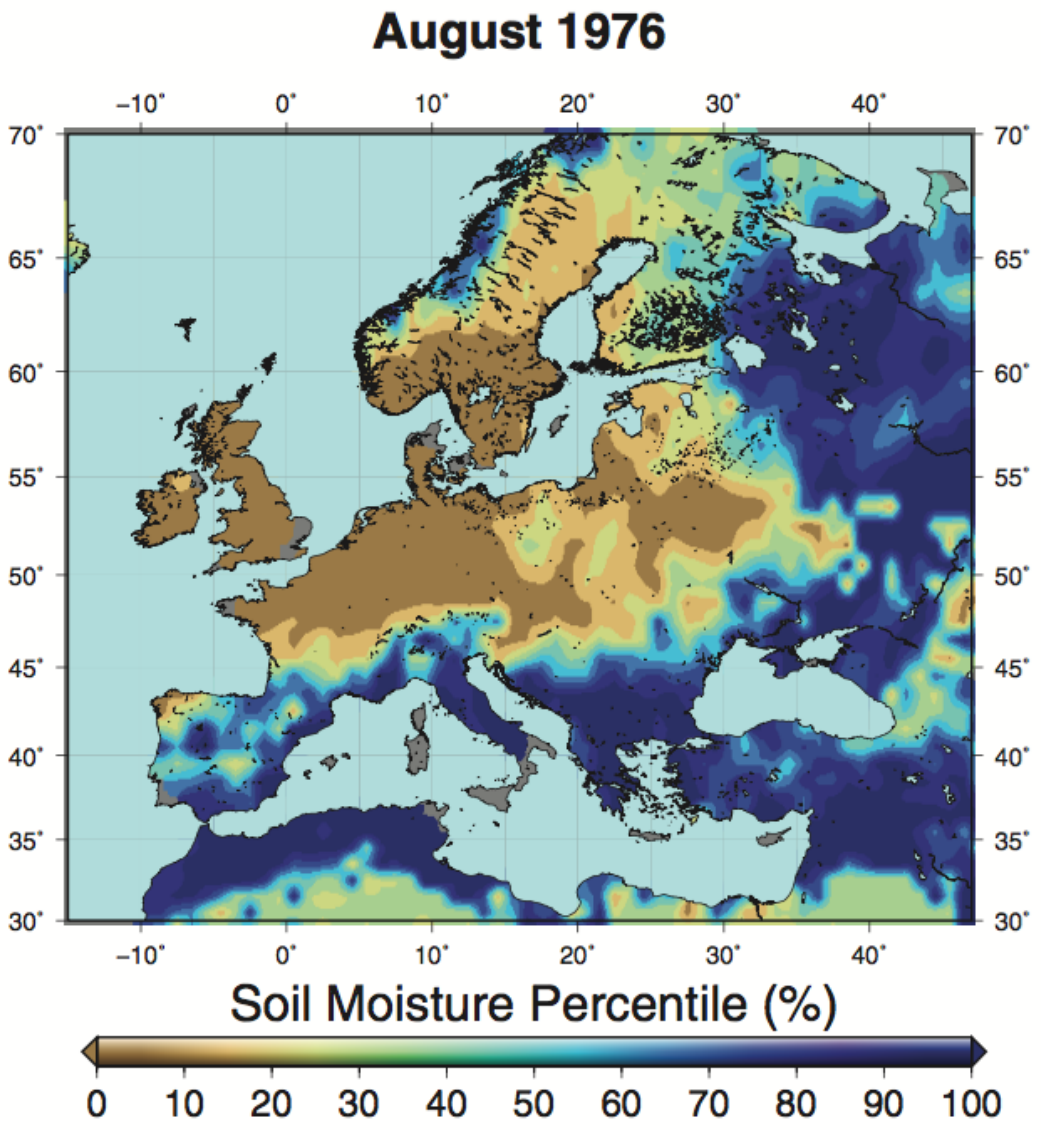
- A drought is defined when the quantity drops below a threshold level.
- The time that the index is below the threshold is the duration of the drought.
- The level below the threshold at any particular time is the deficit, magnitude or intensity of the drought.
- The severity describes the combined duration and intensity/magnitude of the drought, calculated as the intensity multiplied by the duration. This is also often referred to as the deficit volume for hydrological drought.

Popular Drought Indices

Index	Description	Advantages	Disadvantages
Meteorological Drought			
Precipitation percent of normal	Actual precipitation divided by the average annual value	Simple and effective for single locations and seasons	Concept of normal is different to the general concept of normal weather
Standardized Precipitation Index (SPI)	Based on the probability of precipitation	Can be computed for different timescales. Adopted by World Meteorological Organization (WMO)	Values may change as new data are incorporated. Reflects only precipitation
Agricultural Drought			
Palmer Drought Severity Index (PDSI)	Departure of moisture from normal using a simple water balance model. Used by US agencies	Takes into account precipitation inputs and outputs from evaporation and run-off	May lag behind emerging droughts; does not handle frequent climatic extremes; complex
Soil moisture percentile index (SMI)	Calculated from modelled or observed soil moisture data	Provides a statistically robust measure of soil moisture, reflecting inputs and outputs	Usually calculated from complex hydrological models; requires detailed input data
Hydrological Drought			
Mean annual minimum n-day flow	Calculated from the time series of annual minima of the *n*-day average flow	Can be used to estimate the retum period of low flows	Requires long time series and is difficult to apply in intermittent or ephemeral streams
Baseflow index	Ratio of baseflow to total flow	Quantifies flow from stored water in the basin	Long records required to separate baseflow from total flow
Ecological Drought			
Normalized Difference Vegetation Index (NDVI)	Difference between maximum absorption of visible and near-infrared radiation	A measure of general vegetative condition. Satellite data provide large areal coverage and high spatial resolution	Requires data from airborne or spaceborne sensors. Difficult to discern other influences on vegetative health
Regional Drought			
Regional Drought Area or Deficit Area	Percentage area in drought within a region	Quantifies the spatial extent of drought	Requires spatially continuous or regional data

Spatial Characteristics of Drought

- Droughts can further be characterized by their spatial extent
- For example, by identifying connected regions of low index values, such as soil moisture from models/satellite retrievals, or measured streamflow at various gauging sites.
- Indices can be defined based on the area in drought (e.g. % or fraction) or the average severity over the region.



Drought Threshold and Drought Triggers

- Usually a threshold (fixed or fuzzy gradation) is chosen below which there is drought and above which there is not.

- Often a drought threshold will be used to declare an official drought in a region and trigger a set of management responses or implement a drought plan
  - municipal water-use restrictions
  - a cessation of reservoir releases to maintain water supplies
  - government aid or insurance payments to farmers
  - in vulnerable regions the build-up of food aid to tackle potential future shortages or famine

How to choose a threshold?

- When there is an impact to plant health, sustainable water supply, etc
- An event that happens every 10 or 20 years (10 or 20-year event)
- A low percentile value (e.g. 10^{th} or 20^{th} percentile)
- A low flow value

Example of Drought Categories used in the US

Category	Description	Possible Impacts	Soil Moisture Percentile Index	Weekly Streamflow Percentiles	SPI
D0	Abnormally Dry	Going into drought: • short-term dryness slowing planting, growth of crops or pastures Coming out of drought: • some lingering water deficits • pasture/crop not fully recovered	21 to 30	21 to 30	-0.5 to -0.7
D1	Moderate Drought	• Some damage to crops/pasture • Streams, reservoirs, wells low, some water shortages developing • Voluntary water-use restrictions requested	11 to 20	11 to 20	-0.8 to -1.2
D2	Severe Drought	• Crop or pasture losses likely • Water shortages common • Water restrictions imposed	6 to 10	6 to 10	-1.3 to -1.5
D3	Extreme Drought	• Major crop/pasture losses • Widespread water shortages or restrictions	3 to 5	3 to 5	-1.6 to -1.9
D4	Exceptional Drought	• Exceptional and widespread crop/pasture losses • Shortages of water in reservoirs, streams, and wells creating water emergencies	0 to 2	0 to 2	-2.0 or less

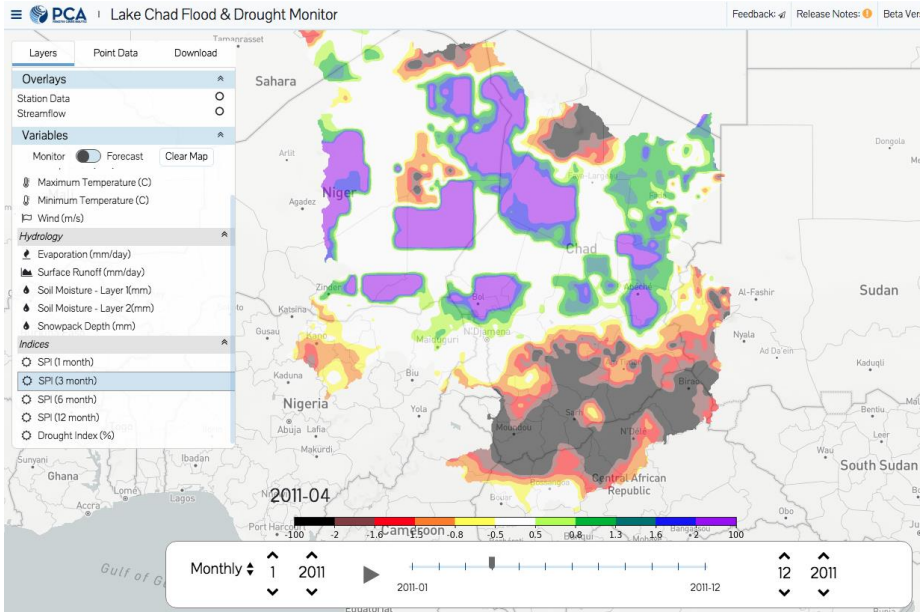
Summary

- There are multiple types and definitions of extreme events, which can be analyzed in terms of extreme event analysis
- Droughts as one example of a natural hazard have tremendous impacts which can potentially be reduced through early warning
- There are many definitions of drought and associated types (meteorological, agricultural, hydrological, …), with associated causes and connections.
- These are quantified using many different indices, which can be used to identify and characterize droughts.
- Drought thresholds are used to identify, monitor and warn of drought droughts, which can then be used for official drought declarations, which can trigger a set of management responses or drought plan

Questions?

Practical Exercises

Use data from the CHAD-FDM to identify droughts using multiple drought indices and estimate the impacts on agriculture in terms of the area affected.



- Use the CHAD-FDM to examine time series of drought indices for the past 10 years to identify a drought event.
- Examine the regional extent of the drought with CHAD-FDM spatial maps of the various indices
- Import data into ArcMap, and estimate the area in drought for different severities
- Estimate the area of agriculture affected by drought.