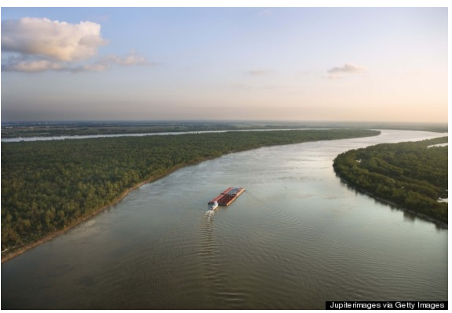
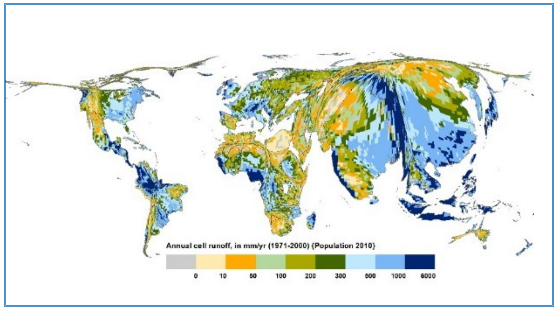
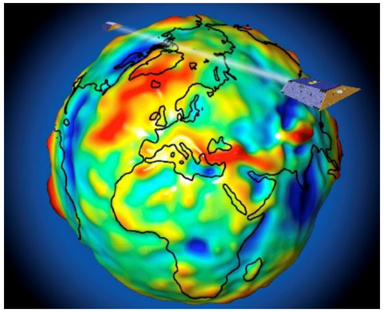
GRoW
WATER AS A GLOBAL RESOURCE

Globe Drought

What is hydrological drought (hazard) and how to generate informative hydrological drought hazard indicators







Petra Döll

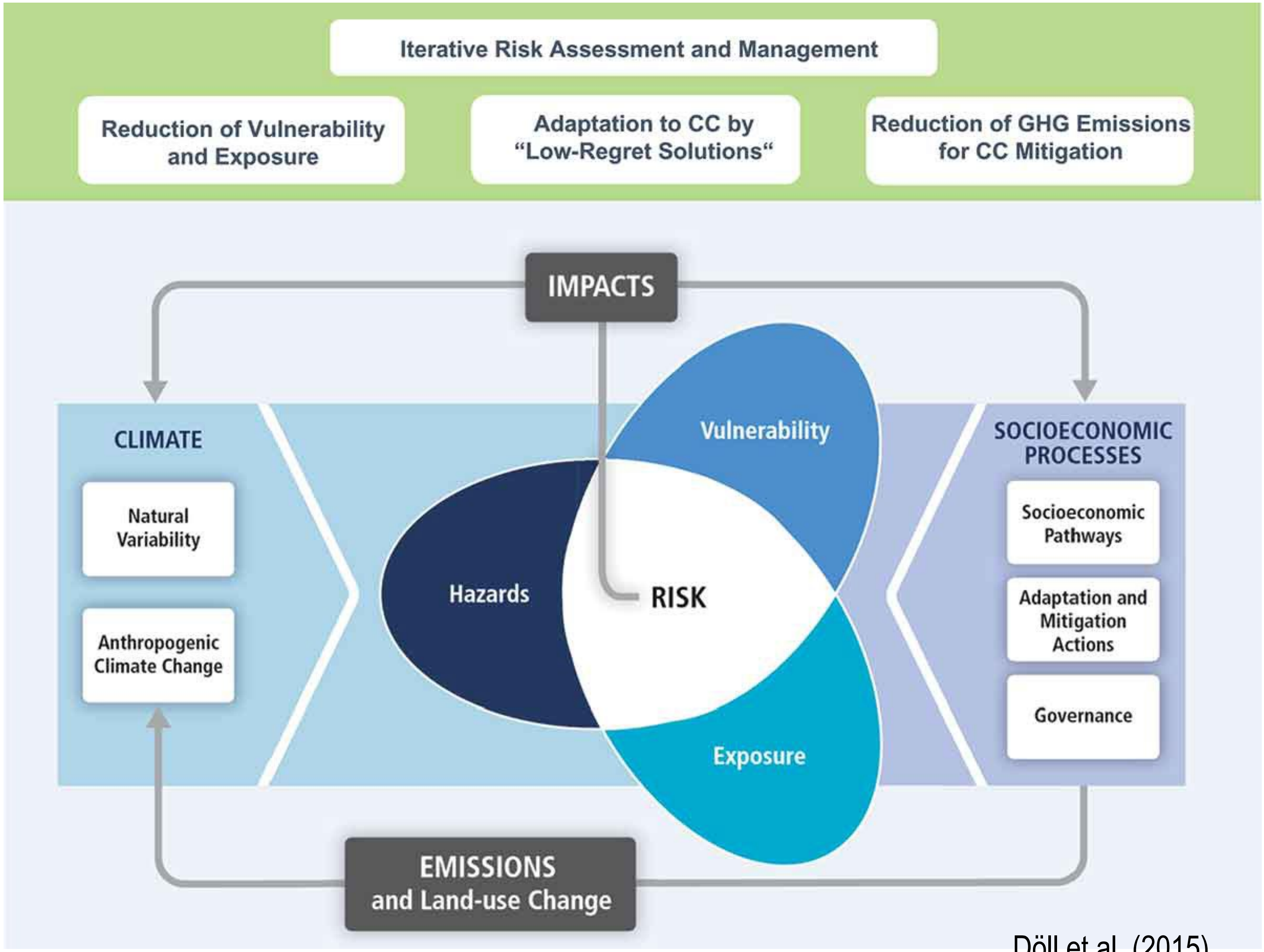
Goethe University Frankfurt

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

SPONSORED BY THE

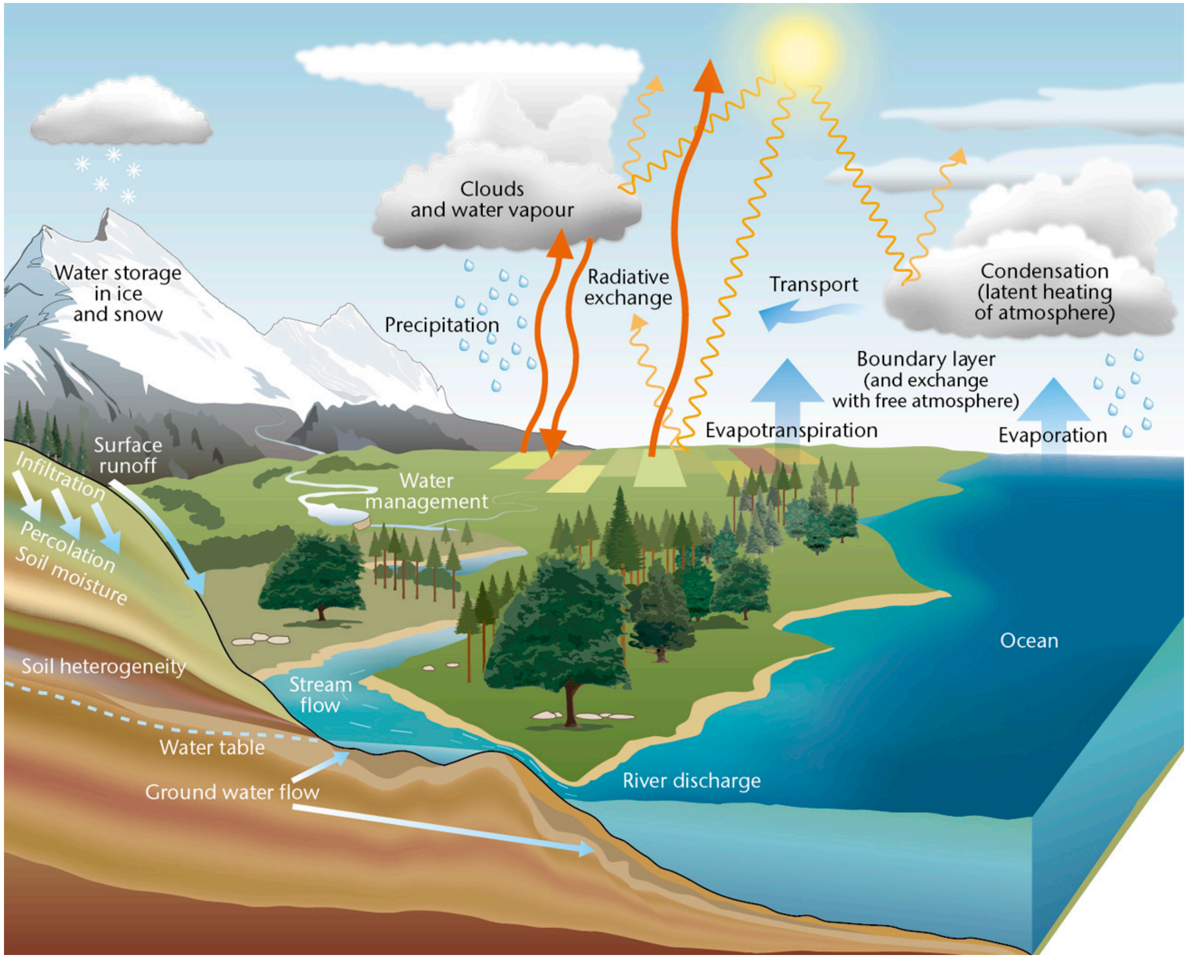
Federal Ministry of Education and Research

Climate-related risk assessment and management
(risks due to climate variability and change, thus applicable to drought risk)



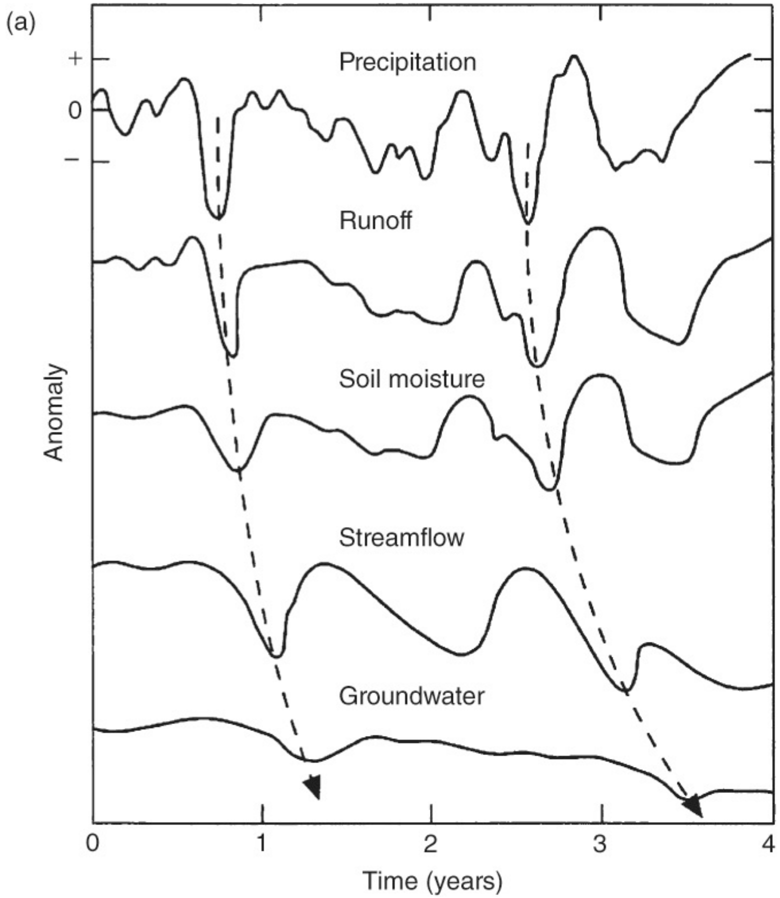
Döll et al. (2015)

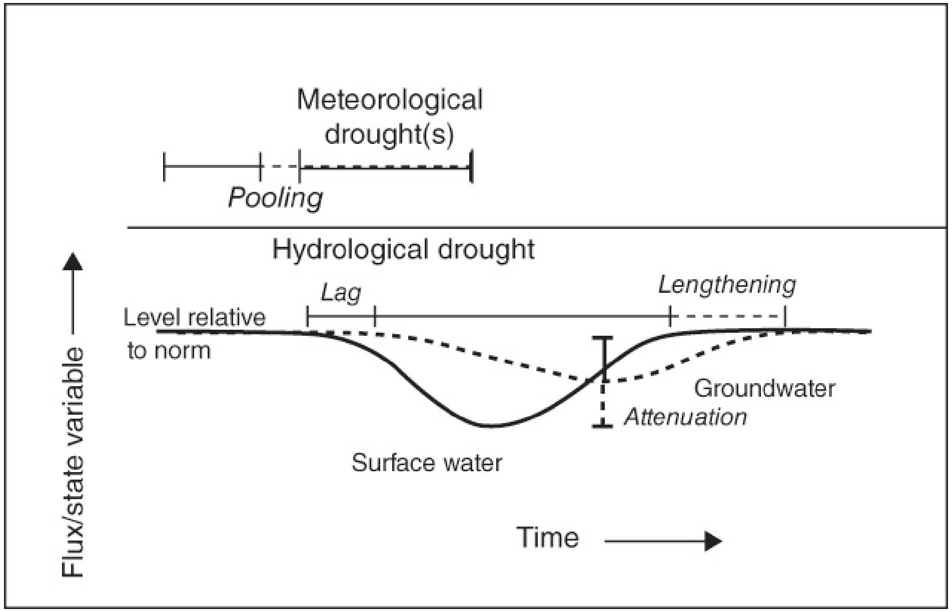
Water flows and storages to consider for assessing hydrological drought



https://www.metoffice.gov.uk/weather/learn-about/weather/how-weather-works/water-cycle

Drought propagation





Van Loon (2015)

Drought risk assessment

Characterize each type of risk by combining suitable indicators of the risk components hazard, exposure and vulnerability

	Drought risk for rainfed agriculture	Drought risk for hydropower production
Risk of which adverse drought impacts for whom	Risk of reduced crop production for farmers	Risk of reduced electricity production for energy supply companies
Hazard	Anomalously high soil water storage deficit as compared to optimal growing conditions	Anomalously low streamflow and reservoir storage
Exposure	Rainfed cropland area	Hydropower production
Vulnerability		
Ecosystem susceptibility	Crop yield decline due to soil water deficit	Not applicable
Societal susceptibility	Dependence of farm income on rainfed crop production	Share of total electricity production from hydropower
(Lack of) Coping capacity	Capacity to invest in irrigation	Capacity to increase hydropower production efficiency

Drought hazard

- Hazard is the potential for a physical event (or trend) that may lead to a negative impact.
- Regarding drought, hazard refers to an event with less water than normal that poses a risk of negative impacts on humans and other biota.
- Is drought
  - a) just a (prolonged) abnormally dry period? or
  - b) “a prolonged abnormally dry period when the amount of available water is insufficient to meet our normal use”? (Australian Government Bureau of Meteorology)
- So should we analyze as droughts abnormally low values(e.g. of soil moisture) (a) or abnormally high deficits (e.g. of field capacity minus actual soil moisture) (b)

Drought risks of what and for whom and related hazard variables

Risk directly caused by not enough water		Computable drought-related hazard variable	
Risk of what	**Risk for whom**	**Primary**	**Secondary**
Reduced crop/livestock production	farmers, consumers	soil WS (rainfed), Q, GWS (irrigated), AET/PET	
Reduced hydropower production	energy companies, consumers	Q, reservoir storage	
Reduced thermal power production	energy companies, consumers	Q, reservoir storage (GW storage limited to very dry regions)	temperature
Reduced industrial production	industry	Q, GWS, reservoir storage	
Restrictions in public water supply	water suppliers, consumers	Q, GWS, reservoir storage	
Reduced water quality	water suppliers, consumers, freshwater biota	Q, lake, reservoir and wetland storage	temperature
Change in habitat condition in rivers	freshwater biota	Q	temperature
Change in habitat condition in wetlands and lakes	freshwater biota	lake, reservoir and wetland storage	temperature
Reduced health of terrestrial ecosystems including forests	terrestrial ecosystems (forestry, nature conservation	soil WS, AET/PET	
Wildfires	terrestrial ecosystems (forestry, nature conservation), humans	soil WS, AET/PET	temperature
Impaired waterborne transportation	shipping industry	water level (Q)	

Soil WS: soil water storage, Q: streamflow, GWS: groundwater storage, AET: actual evapotranspiration ET, PET: potential ET

How can hydrological models be best used to indicate hydrological drought hazard?

Set up hydrological model of region of interest, driven by climate data, to estimate time series of various water flows and storages at the required (or possible) spatial resolution, to compute

- streamflow
- water storage anomalies (groundwater, lakes, reservoirs, wetlands, snow, soil moisture, or sum of all storages total water storage anomaly TWSA)
- AET/PET
- Deficits in soil water storage as compared to e.g. field capacity, or deficit in streamflow as compared to water demand

Select, compute, evaluate and visualize informative drought hazard indicators using the above variables or deficits

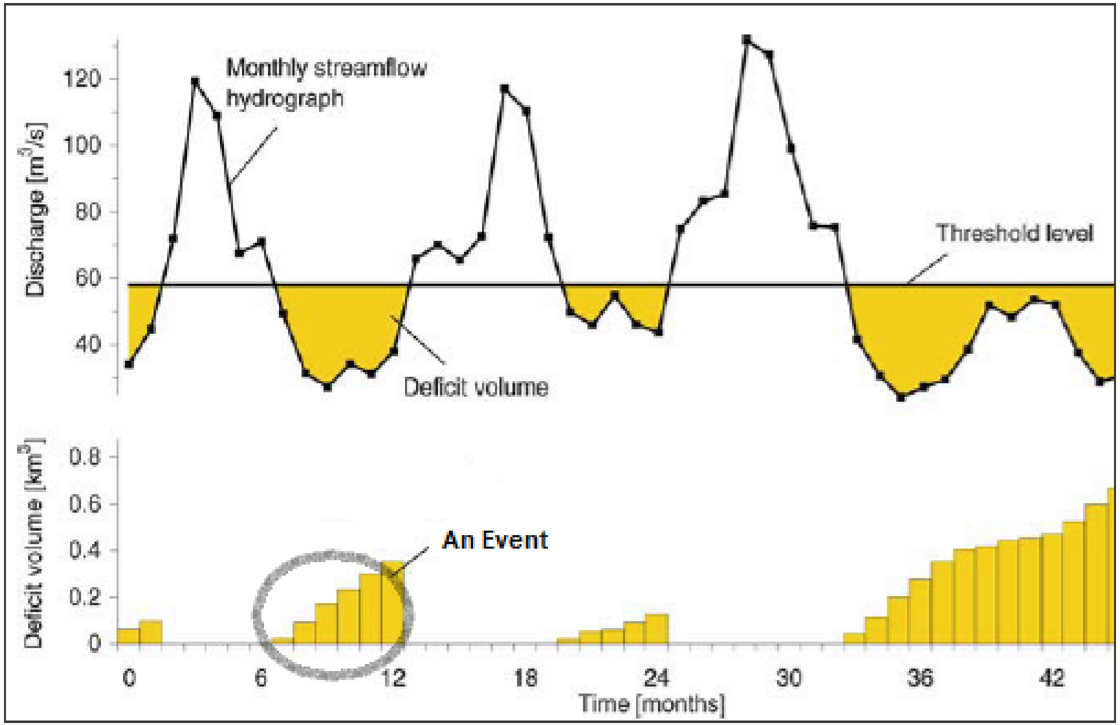
- that are suitable for the specific drought risk to be considered and
- for which quantification is as reliable as possible.

Determination of drought condition at a certain point in time (e.g. month)

- Standardized drought indicators like SPI (precipitation) (McKee et al. 2003) or SSI (streamflow) have fixed accumulation periods. Longer accumulation periods for SPI (3, 6 or 12 months) reflect delayed and smoothed rainfall drought propagation through soil and groundwater to streamflow. Requires fitting of distribution functions to variable values during reference periods, and transformation to a normal distribution
  - e.g. to determine SSI-3 for July 2014 streamflow is first aggregated over the last three months and compared to the three-months aggregated values of all July's in the reference period (the normal). SSI-3 for July 2014 of -1 means that streamflow of the last three month was one standard deviation lower than normal.
- Define percentile (e.g. median, 20%) of time series during reference period as threshold (e.g. median of July monthly streamflow) and define difference between threshold value and actual value in July 2014 as deficit.

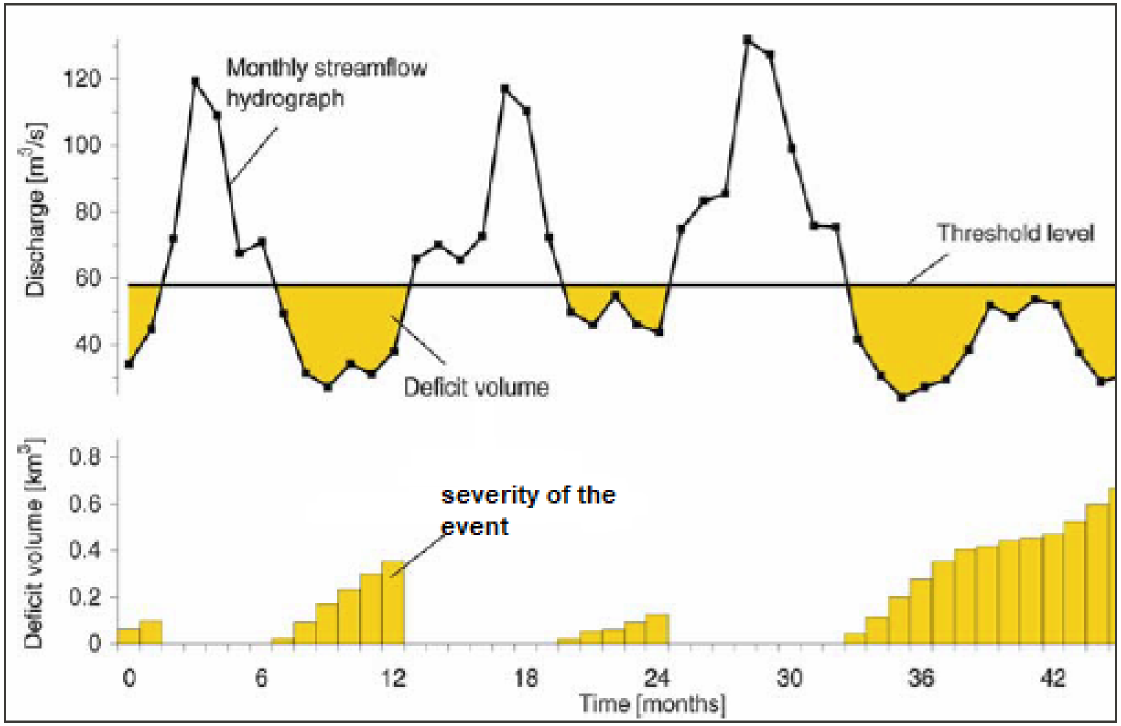
Determination of drought events

- To identify and quantify drought events, their start and end conditions have to be defined. For example, a drought event starts if SPI/SSI etc. drops below -1 (similar to McKee et al. 1993) or if the actual variable value drops below the percentile threshold. It ends as soon as the value exceeds the threshold.



Determination of severity and probability of drought events

- **Severity** of each event is the accumulated deficit of the last month of the drought event.
- By fitting a distribution to all drought events, the **probability** of occurrence of drought events of certain severity can be computed.

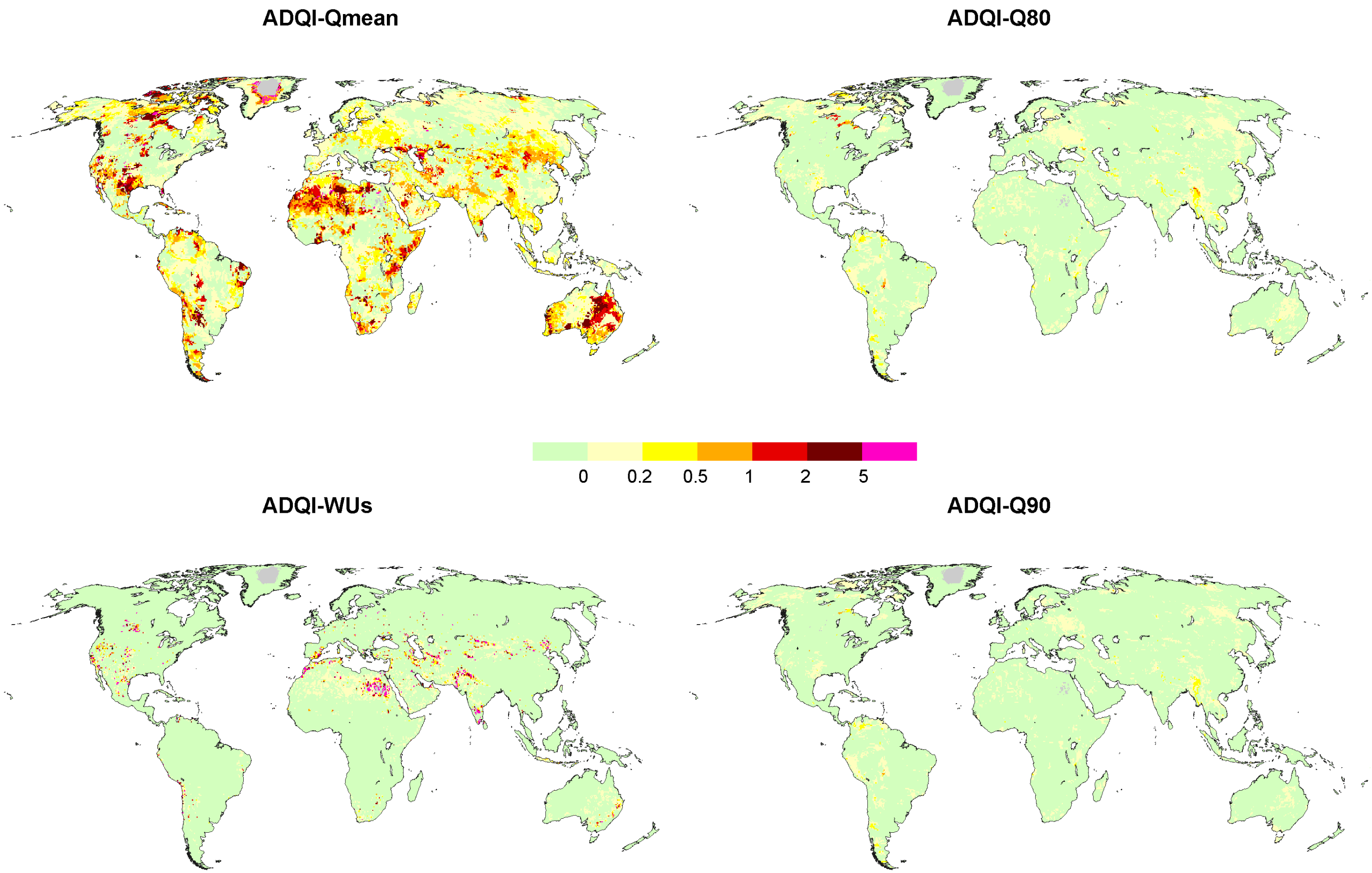


Preliminary results: streamflow hazard indicator

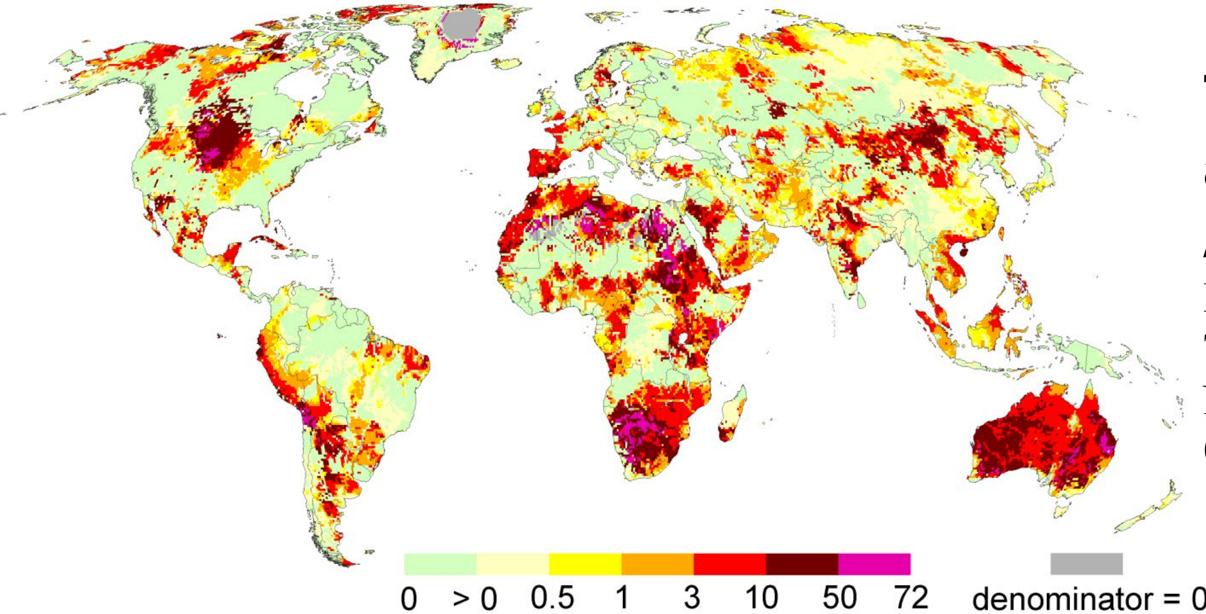
Threshold-based accumulated deficit volume October 2014, in units of mean annual streamflow

Reference period: 1985-2014, four different thresholds, per calendar month

Normalization: annual mean



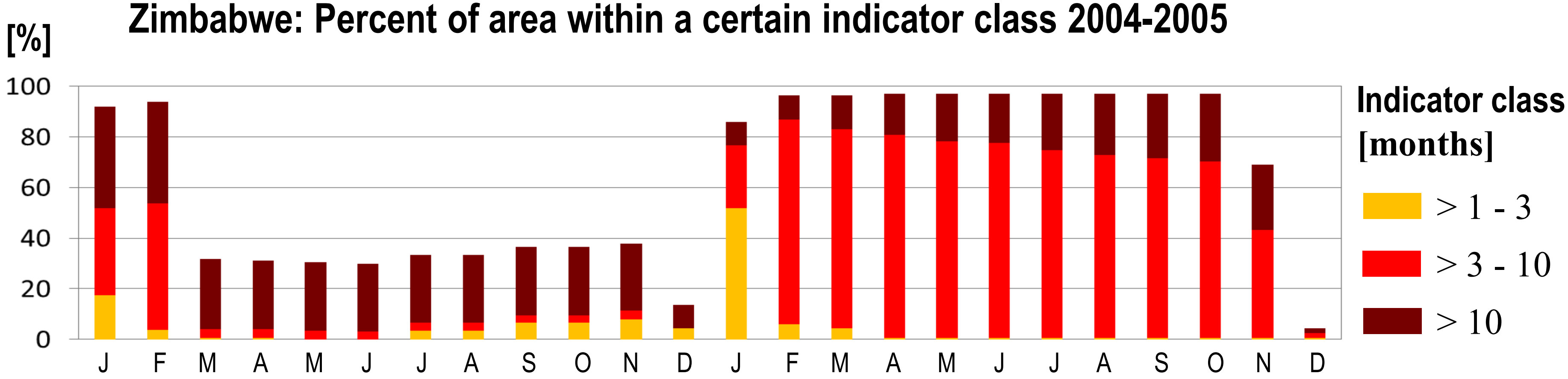
Preliminary results: streamflow hazard indicator



Threshold-based accumulated deficit volume April 2005 [months]

Reference period: 1985-2014
Threshold: monthly mean
Normalization: annual mean
CDPM not applied

Zimbabwe: Percent of area within a certain indicator class 2004-2005



Questions

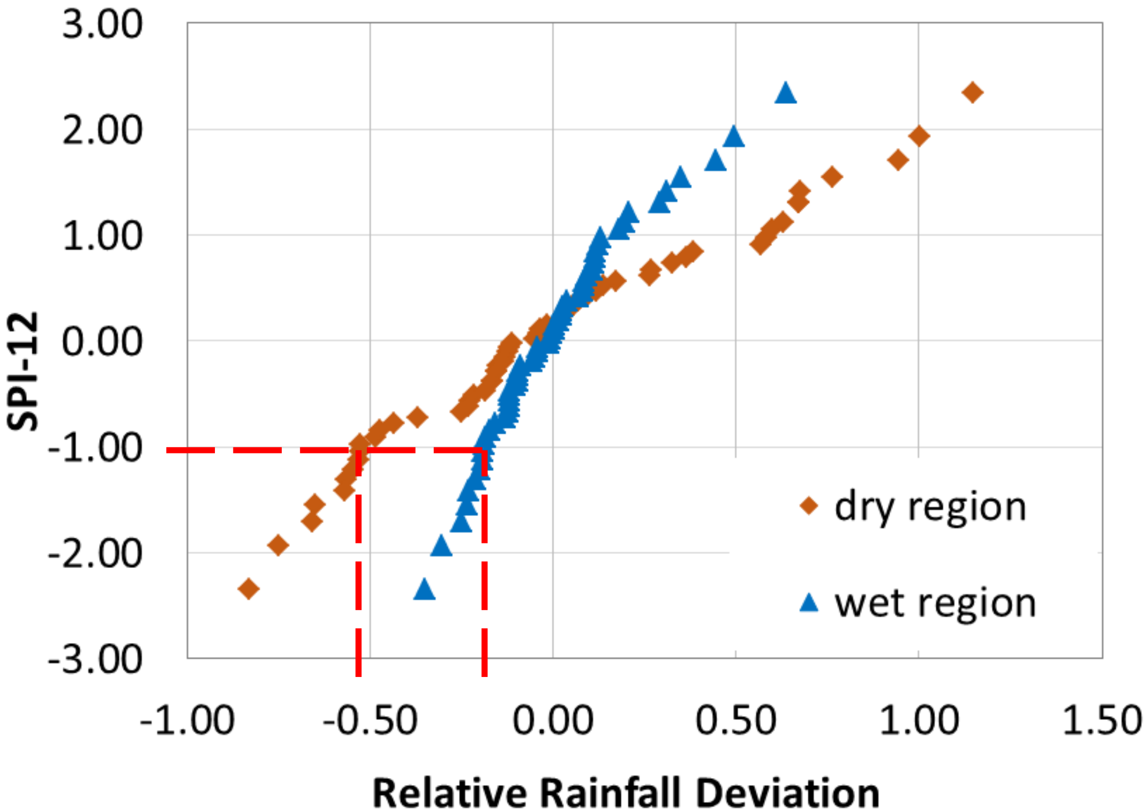
Drought hazard being defined as occurring when water flows or storages are less than normal: What is the best defined as "normal"?

Question 1. Are people/other biota used to **mean seasonality** of rainfall, streamflow etc., such that mean monthly values can be considered normal?

Question 2. Are people/other biota used to **interannual variability** of rainfall, streamflow etc.?

Then, drought hazard can be expressed in units of standard deviation, as done in case of Standardized Precipitation Indicator SPI or defined to occur if e.g. streamflow is lower than the 20th percentile of the mean calendar month streamflow. (SPI = (P – Pmean)/sd(P)

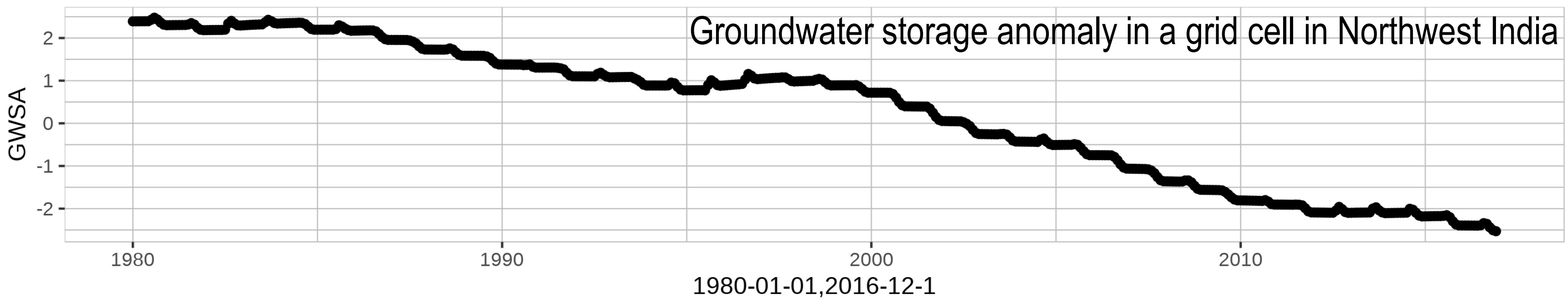
Under what conditions are relative deviations from mean conditions better suited to quantify the hazard than SPI/SSI (or indicator with percentile other than 50) as threshold?

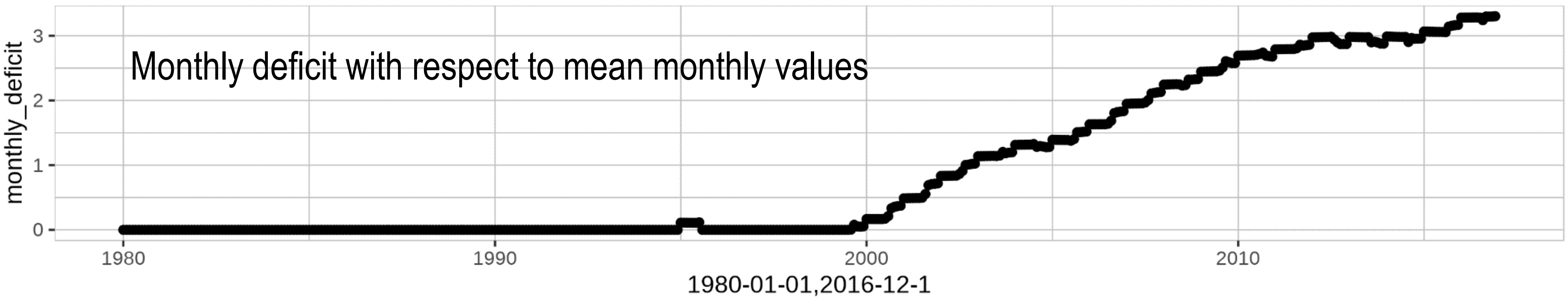


Data from two Iranian sites provided and analyzed by Mohammad Hosseini

Question 3. Should "normal conditions"

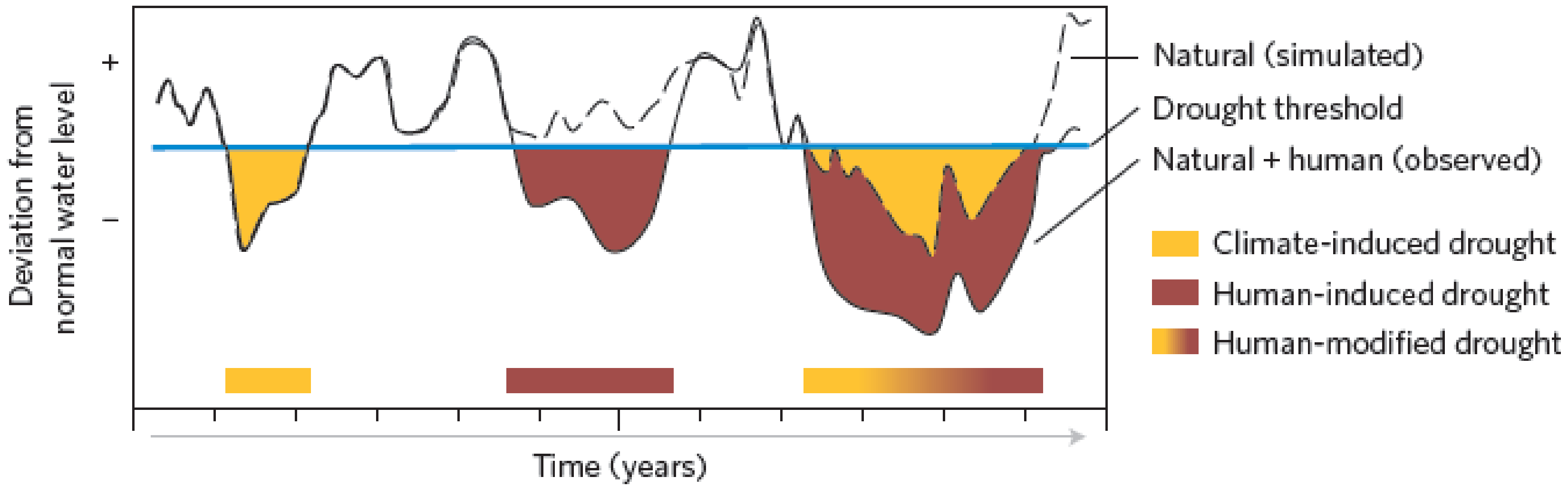
- take into account human alterations *(necessarily the case if observations of streamflow or groundwater levels are used to define normal)*
- refer to virtual natural conditions that are not affected by humans *(e.g. as computed by hydrological models that are driven only by climate and e.g. do not consider the impact of human water use on streamflow or groundwater levels)*?





Question 3 continued

To use naturalized conditions as normal has recently been proposed by Van Loon and Van Lanen (2013) and Van Loon et al. (2016) and could help to distinguish purely climate-induced drought from human-induced water scarcity/human-induced drought (?).



Should drought hazard be identified not only as a function of the deviation from normality but also with respect to the deviation of water availability from a demand?

Question 4. Regarding soil water and streamflow:

Should anomaly of deficit (field capacity minus actual soil water content, human water use minus streamflow) be analyzed rather than soil water content and streamflow themselves?

References

- Australian Government Bureau of Meteorology (without year). http://poama.bom.gov.au/climate/drought/#tabs=About-drought
- Döll, P., Jiménez-Cisneros, B., Oki, T., Arnell, N., Benito, C., Cogley, G., Jiang, T., Kundzewicz, Z.W., Mwakalila, S., Nishijima, A. (2015): Integrating risks of climate change into water management. Hydrol. Sci. J., 60(1), 3-14. doi: 10.1080/02626667.2014.967250.
- McKee, T. B., N. J. Doesken, J. Kleist (1993): The relationship of drought frequency and duration of time scales. Eighth Conference on Applied Climatology, American Meteorological Society, Jan17-23.
- Van Loon, A. F. and van Lanen, H. A. J. (2013): Making the distinction between water scarcity and drought using an observation-modeling framework, Water Resour. Res., 49, 1483–1502, doi:10.1002/wrcr.20147.
- Van Loon, A. F. (2015): Hydrological drought explained, WIREs Water, 2, 359–392, doi:10.1002/wat2.1085.
- Van Loon, A. F. et al. (2016): Drought in the Anthropocene, Nature Geosci, 9, 89–91, doi:10.1038/ngeo2646.