ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Joint ICTP-IAEA Workshop on the Use of Cosmic Ray Neutron Sensor for Soil Moisture Management and Validation of Remote Sensing Soil Moisture Maps

10 May 2021 - 19 May 2021, virtual meeting

Lecture 2

Use of CRNS for supporting drought monitoring

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Alma Mater Studiorum – University of Bologna

Outline

1. What is (not) drought
2. Drought monitoring
3. CRNS and agricultural drought monitoring

Wrongly associated to dry and wet conditions

Too little = Drought?

Too much = flood?

Wrongly considered as water scarcity condition

"Drought" is a natural hazard, caused by large-scale climatic variability, and cannot be prevented by local water management.

"Water scarcity" refers to the long-term unsustainable use of water resources, which water managers can influence.

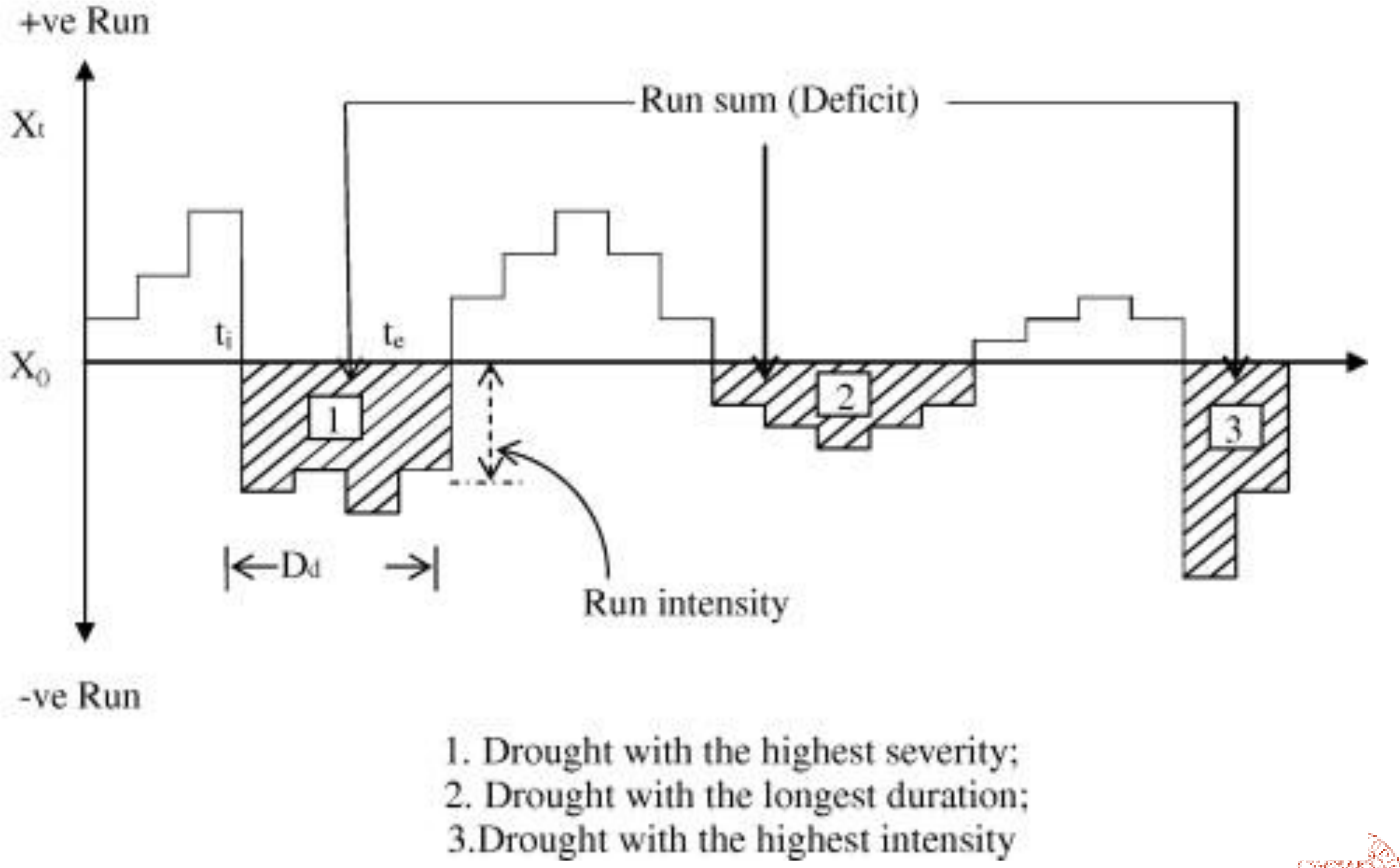
Making the distinction between drought and water scarcity is not trivial, because they often occur simultaneously.

Van Loon, A. F., and H. A. J. Van Lanen. "Making the Distinction between Water Scarcity and Drought Using an Observation-Modeling Framework." *Water Resources Research* 49, no. 3 (March 2013): 1483–1502. https://doi.org/10.1002/wrcr.20147.

What is drought?

Natural phenomena, mostly related to prolonged and abnormal water deficiency across an extended areas

Mishra, Ashok K., and Vijay P. Singh. "A Review of Drought Concepts." Journal of Hydrology 391, no. 1–2 (September 2010): 202–16. https://doi.org/10.1016/j.jhydrol.2010.07.012.



Drought anomaly from normal condition

But what is a normal condition? **Climate classification**

Climate is the long-term average of weather, typically averaged over a period of 30 years. In contrast **weather**: shorter time scale (year to daily)

Example of climate classification

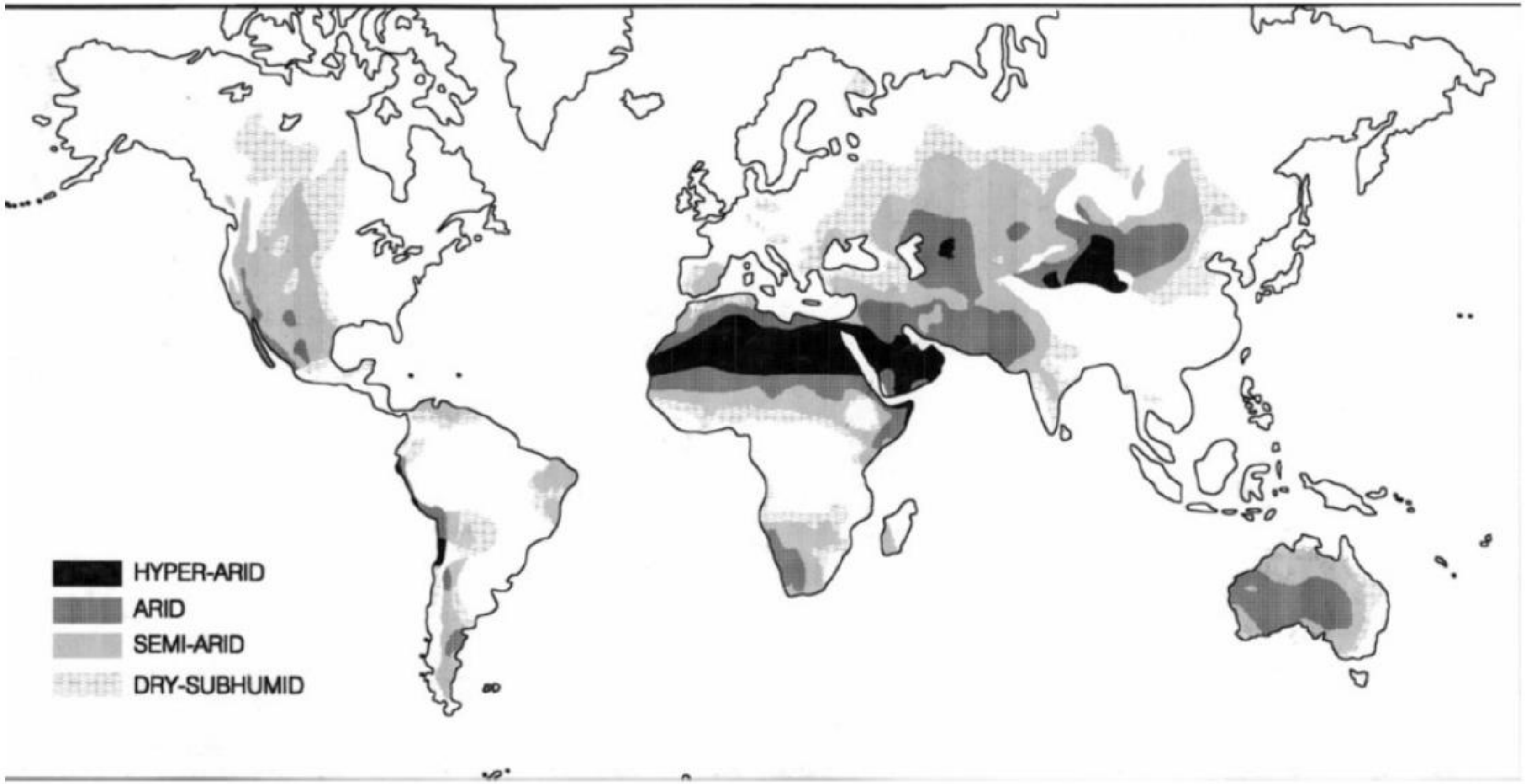
Rainfall aridity:

According to annual rainfall P_{ann}

hyper-arid:	$P_{ann} < 100$ mm/a
arid:	$P_{ann} < 200$ mm/a
semi-arid:	$P_{ann} < 500$ mm/a (winter rain)
	$P_{ann} < 800$ mm/a (summer rain)

Dry sub-humid: rainfall cycles are highly seasonal.

Climate classification



Distribution of arid climatic regions (UNEP 1992)

Climate classification

Improvements based on both precipitation and evapotranspiration

<u>Bio-Climatic aridity:</u>

Arid classified according the ratio: $\boldsymbol{P_{ann} / ETpot_{ann}}$

P_{ann} = annual Precipitation

$ETpot_{ann}$ = annual potential Evapotranspiration

UNESCO 1979 (ETpot according the Penman formula):

hyper-arid, if $P_{ann} / ETpot_{ann} < 0.03$

arid, if $0.03 < P_{ann} / ETpot_{ann} < 0.20$

semi-arid, if $0.20 < P_{ann} / ETpot_{ann} < 0.50$

sub-humid, if $0.50 < P_{ann} / ETpot_{ann} < 0.75$

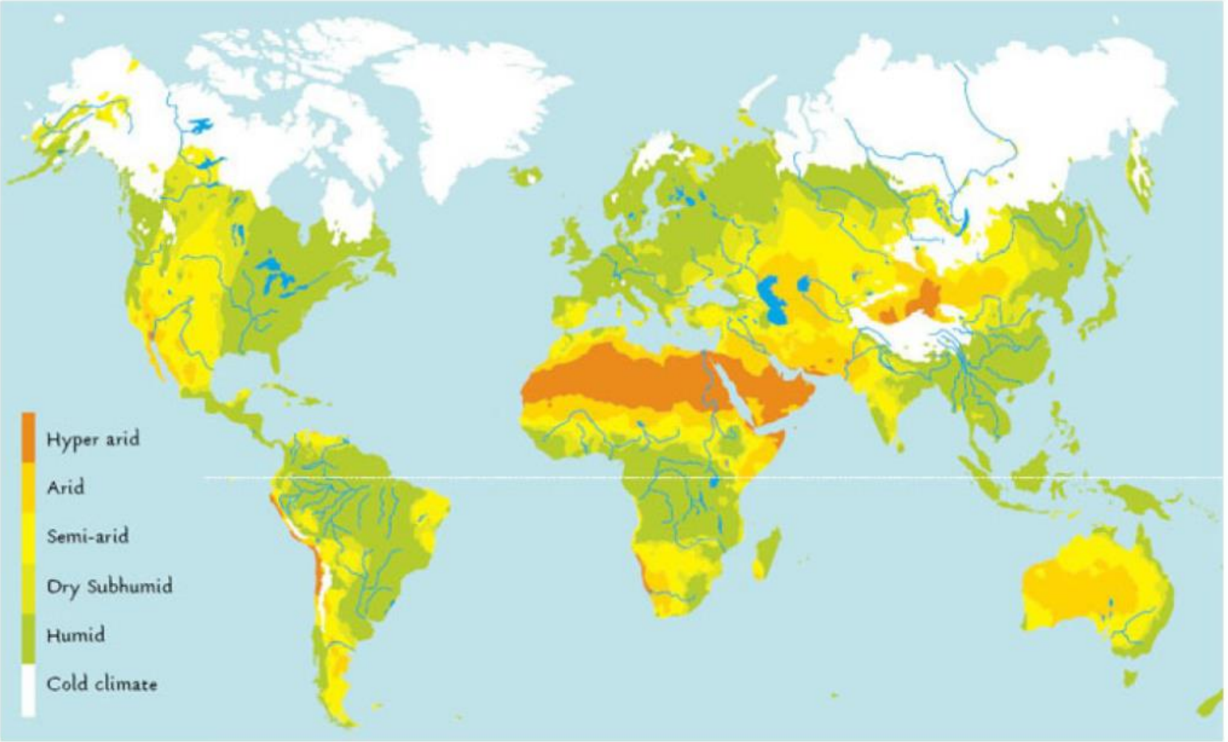
UNEP 1992: (ETpot according the Thornthwaite formula):

hyper-arid, if $P_{ann} / ETpot_{ann} < 0.05$

arid, if $0.05 < P_{ann} / ETpot_{ann} < 0.20$

semi-arid, if $0.20 < P_{ann} / ETpot_{ann} < 0.50$

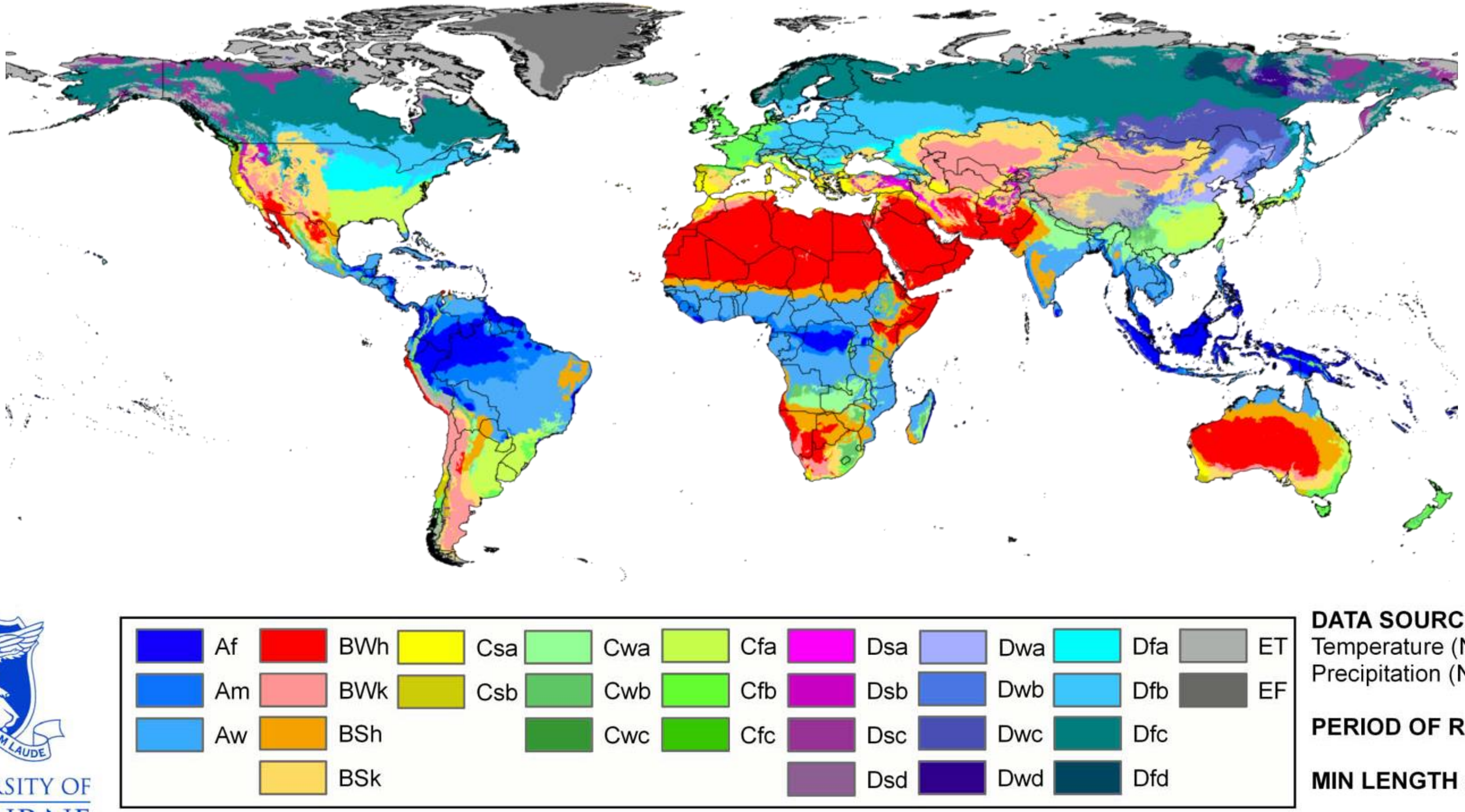
sub-humid, if $0.50 < P_{ann} / ETpot_{ann} < 0.65$



Distribution of arid climatic regions (CRU / UEA, UNEP / DEWA)

Climate classification

Köppen–Geiger climate classification map (1980–2016)



DATA SOURCE : GHCN v2.0 station data
Temperature (N = 4,844) and
Precipitation (N = 12,396)

PERIOD OF RECORD : All available

MIN LENGTH : ≥30 for each month.

RESOLUTION : 0.1 degree lat/long

Contact : Murray C. Peel (mpeel@unimelb.edu.au) for further information

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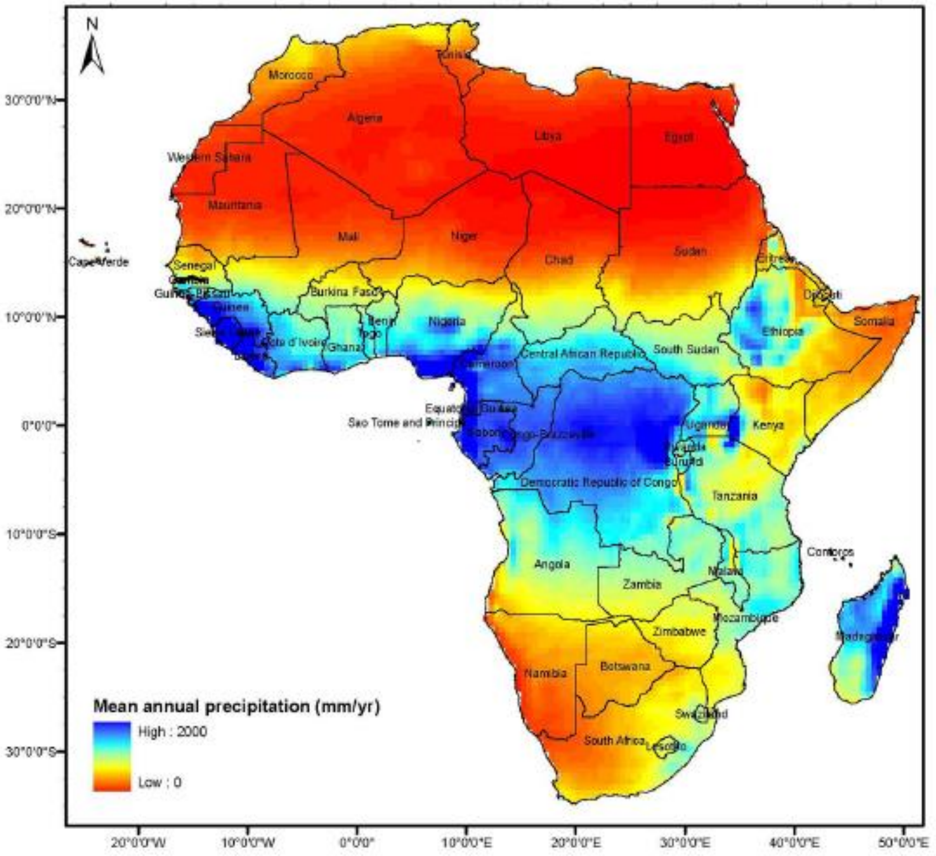
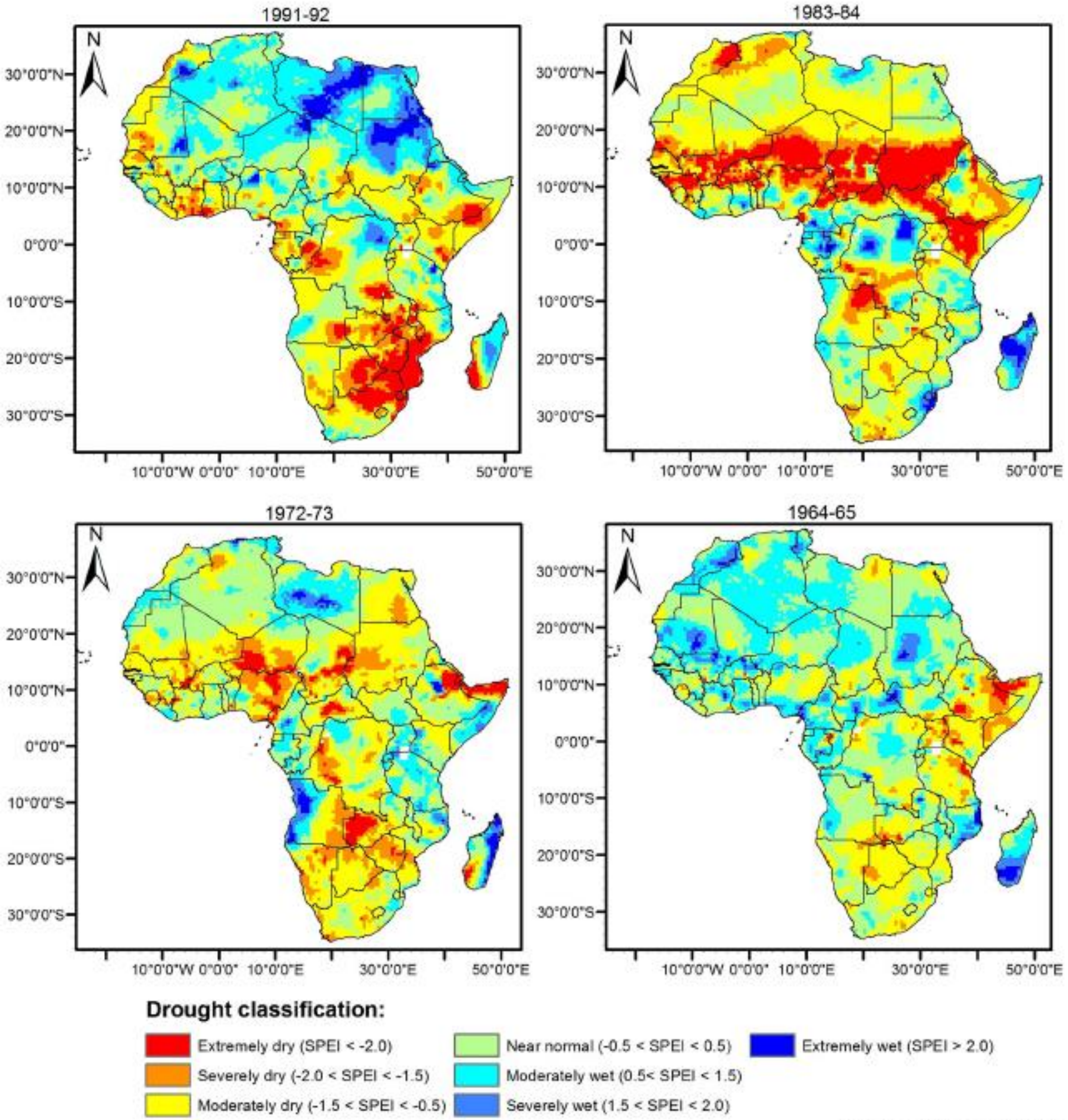
From base line (climate class) to drought, an example





Masih, I., S. Maskey, F. E. F. Mussá, and P. Trambauer. “A Review of Droughts on the African Continent: A Geospatial and Long-Term Perspective.” Hydrol. Earth Syst. Sci. 18, no. 9 (September 17, 2014): 3635–49. https://doi.org/10.5194/hess-18-3635-2014

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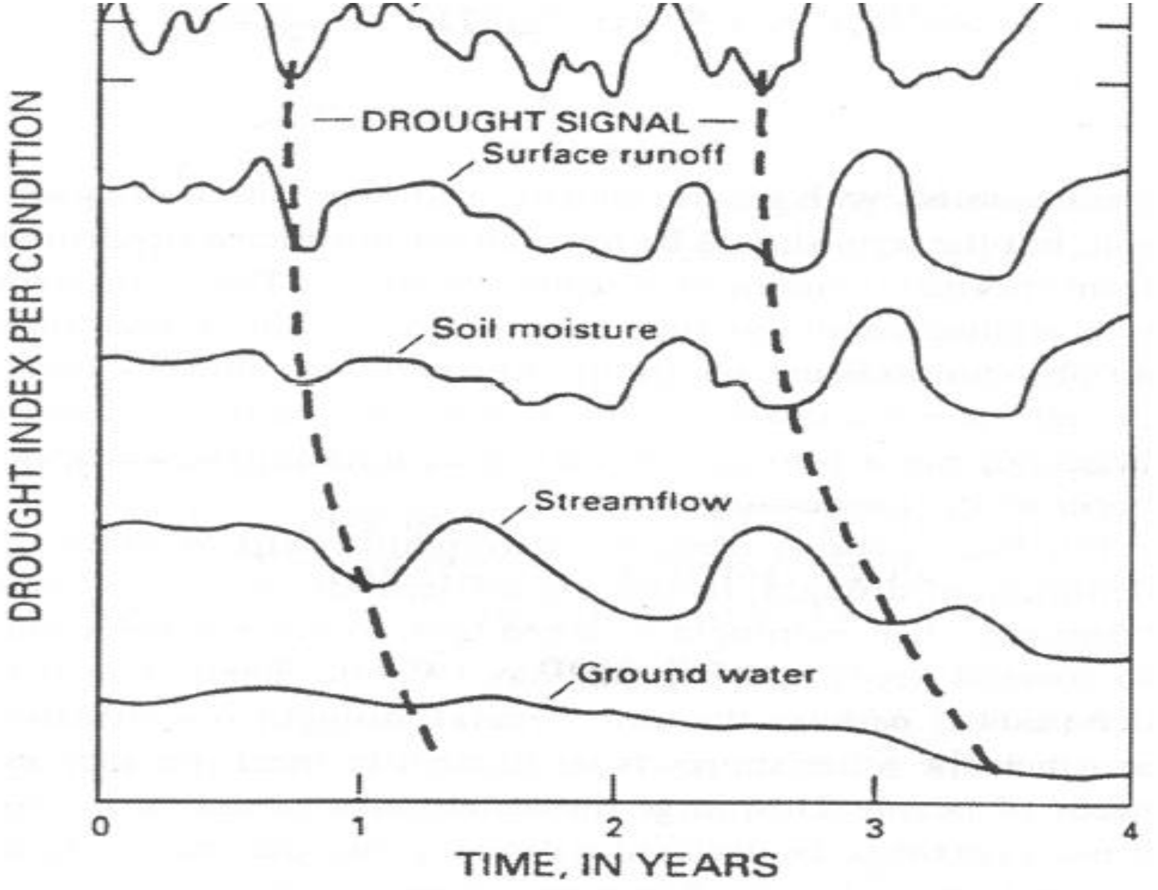
Drought types

Meteorological drought: period of months to years with below-normal precipitation

Agricultural drought: period with dry soils (below-average precipitation, less frequent rain events, or above-normal evaporation)

Hydrological drought: river streamflow and water storages in aquifers, lakes, or reservoirs fall below long-term mean levels.



Propagation of rainfall anomalies through different comp
hydrological cycle (after Changnon, 1987)

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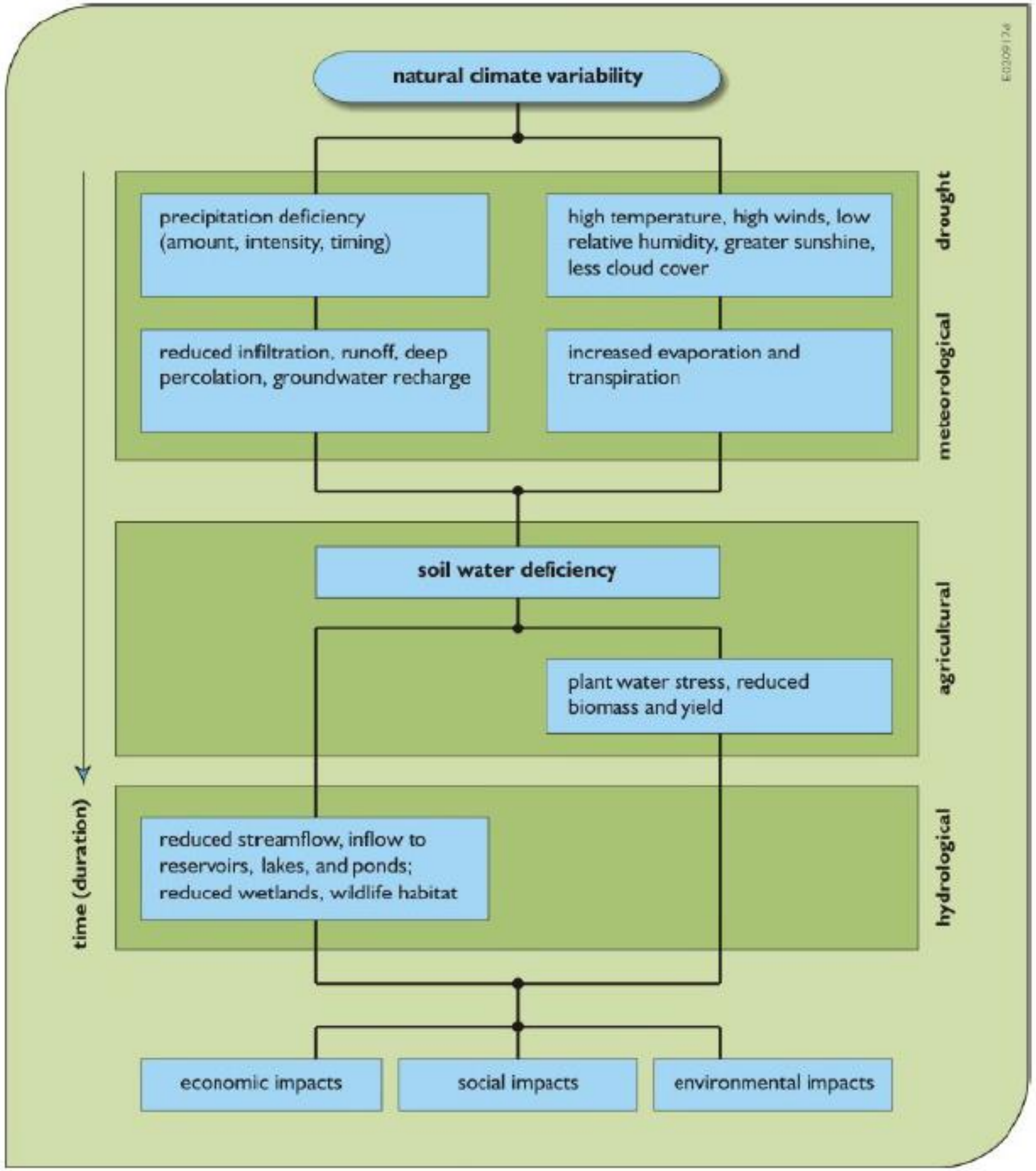
Why important?

Loucks, Daniel P., and Eelco van Beek. "Water Resources Planning and Management: An Overview." In Water Resource Systems Planning and Management: An Introduction to Methods, Models, and Applications, edited by Daniel P. Loucks and Eelco van Beek, 1–49. Cham: Springer International Publishing, 2017. https://doi.org/10.1007/978-3-319-44234-1_1



Why important?

Example: Drought, Not War, Felled Some Ancient Asian Civilizations. https://eos.org/articles/drought-not-war-felled-some-ancient-asian-civilizations

Toonen, Willem H. J., Mark G. Macklin, Giles Dawkes, Julie A. Durcan, Max Leman, Yevgeniy Nikolayev, and Alexandr Yegorov. "A Hydromorphic Reevaluation of the Forgotten River Civilizations of Central Asia." Proceedings of the National Academy of Sciences 117, no. 52 (December 29, 2020): 32982–88. https://doi.org/10.1073/pnas.2009553117.

By Richard J. Sima

Why important?

The Aral Sea basin in Central Asia was the center of advanced river civilizations over a period of more than 2,000 y. The region's decline has been traditionally attributed to the devastating **Mongol invasion** of the early-13th century CE.

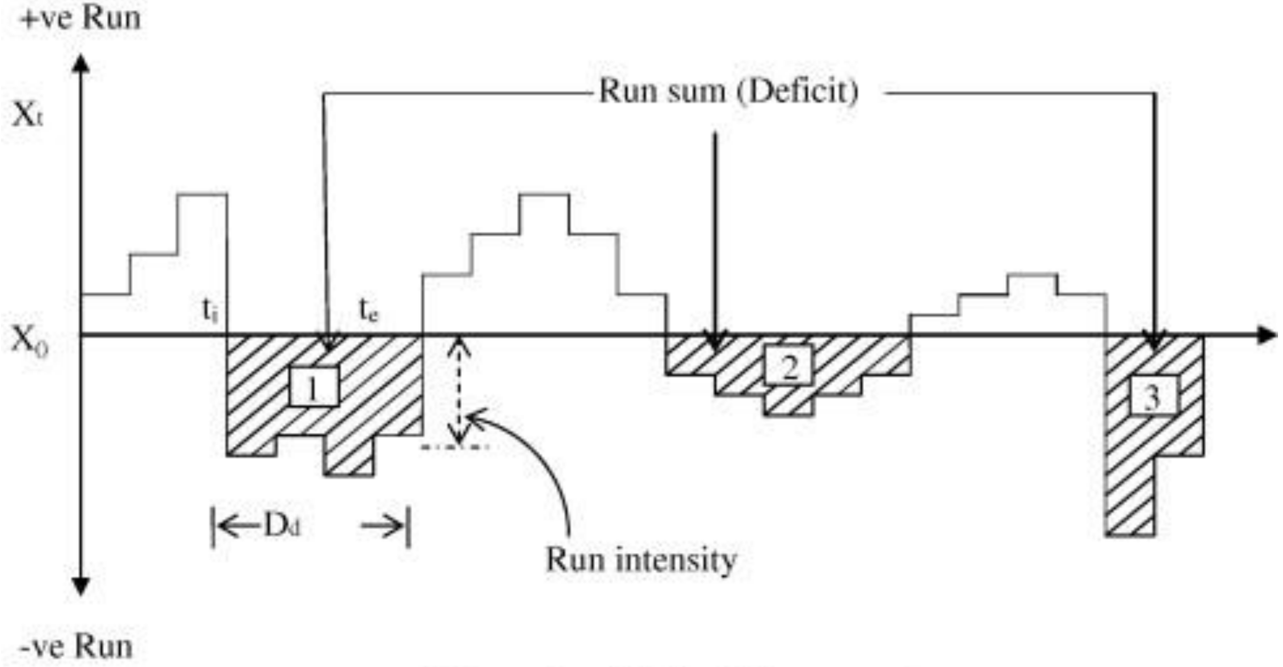
In this paper they report how major phases of fluvial aggradation coincide with economic flourishing of the oasis. Periods of abandonment of the irrigation network and cultural decline primarily correlate with fluvial entrenchment during **periods of drought**, instead of being related to destructive invasions.

Toonen, Willem H. J., Mark G. Macklin, Giles Dawkes, Julie A. Durcan, Max Leman, Yevgeniy Nikolayev, and Alexandr Yegorov. "A Hydromorphic Reevaluation of the Forgotten River Civilizations of Central Asia." Proceedings of the National Academy of Sciences 117, no. 52 (December 29, 2020): 32982–88. https://doi.org/10.1073/pnas.2009553117.

Drought monitoring

Drought monitoring and early warning systems are designed to identify water deficiencies in climatic or hydrologic variables. **They aim to detect emergence, probability of occurrence and the potential severity** of drought events (WMO 2006).

Drought is quantified based on different indices…



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

Mishra, Ashok K., and Vijay P. Singh. "A Review of Drought Concepts." Journal of Hydrology 391, no. 1–2 (September 2010): 202–16. https://doi.org/10.1016/j.jhydrol.2010.07.012.

Which indices?

More than 100 drought indices have so far been proposed, some of which are operationally used

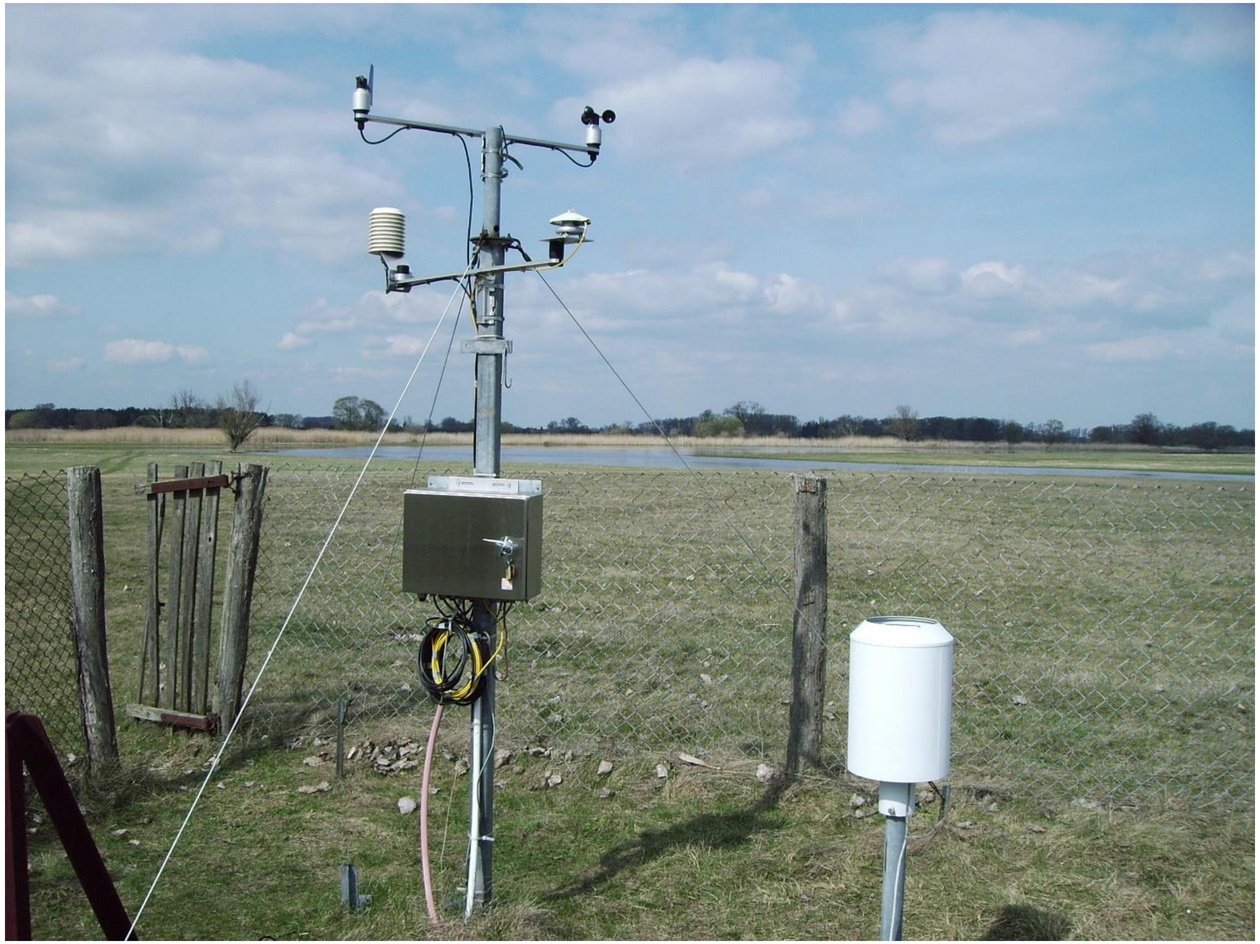
Heim, Richard R. "A Review of Twentieth-Century Drought Indices Used in the United States." *Bulletin of the American Meteorological Society* 83, no. 8 (August 1, 2002): 1149–66. https://doi.org/10.1175/1520-0477-83.8.1149.

Zargar, Amin, Rehan Sadiq, Bahman Naser, and Faisal I. Khan. "A Review of Drought Indices." *Environmental Reviews* 19, no. NA (September 13, 2011): 333–49. https://doi.org/10.1139/a11-013.

Meteorological drought monitoring

Based on observations of climate variables like precipitation and evapotranspiration

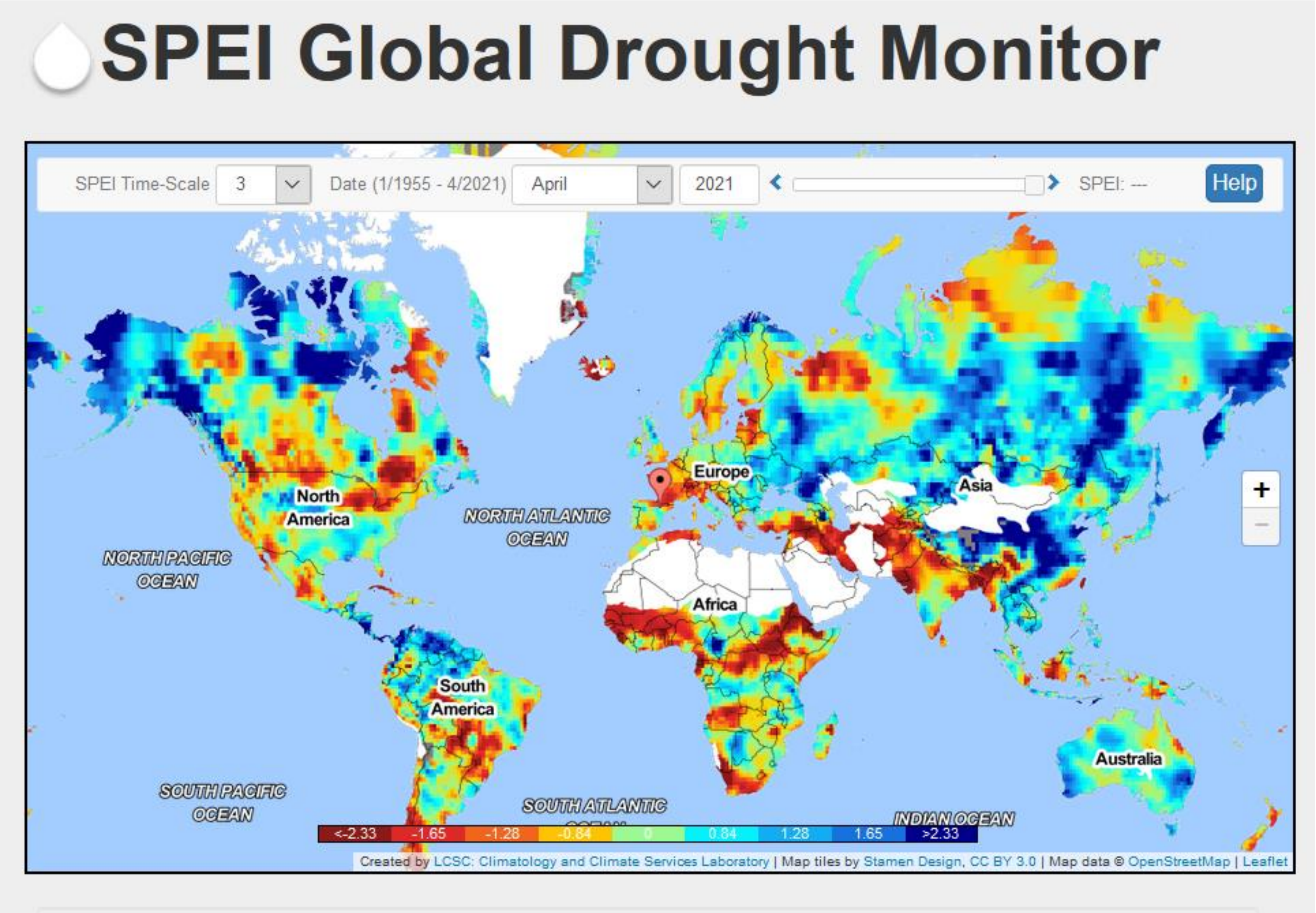
Long term observations systems (weather station and rain gauge) exists from which statistical analysis can be performed



Meteorological drought monitoring

e.g., the Standardised Precipitation-Evapotranspiration Index (SPEI) is a multiscalar drought index based on climatic data (precipitation and evapotranspiration).

https://spei.csic.es/map/maps.html

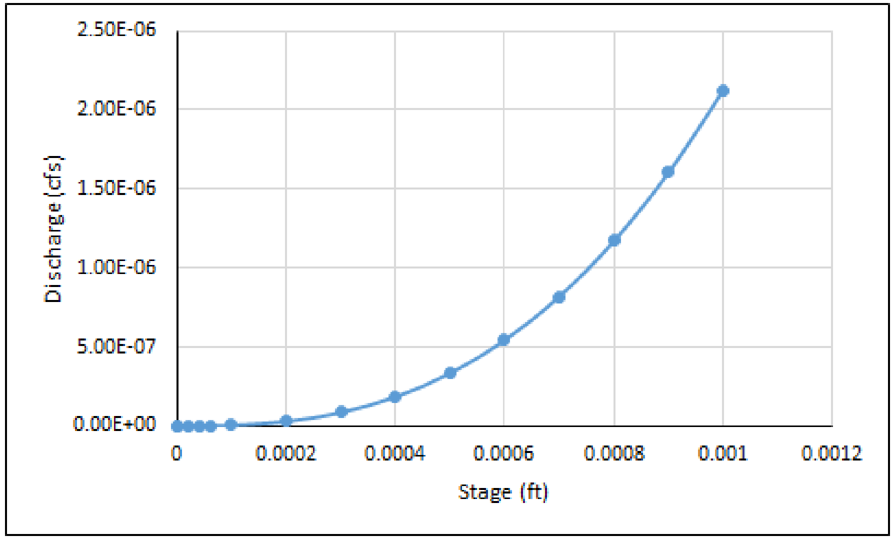


Hydrological drought monitoring

Based on measuring river discharge

Flow meters and stages (water depth)

Rating curve: is a graph of discharge versus stage for a given point on a stream, usually at gauging stations, where the stream discharge is measured across the stream channel with a flow meter.



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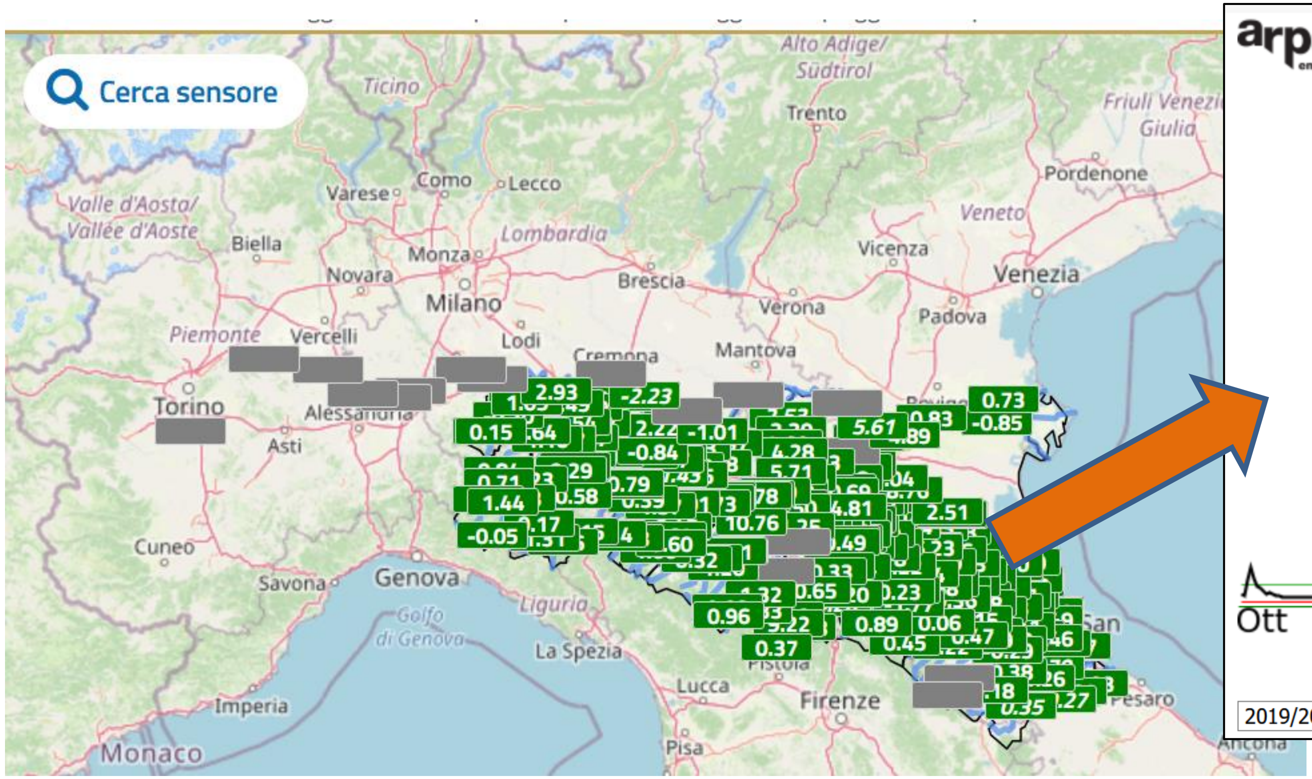
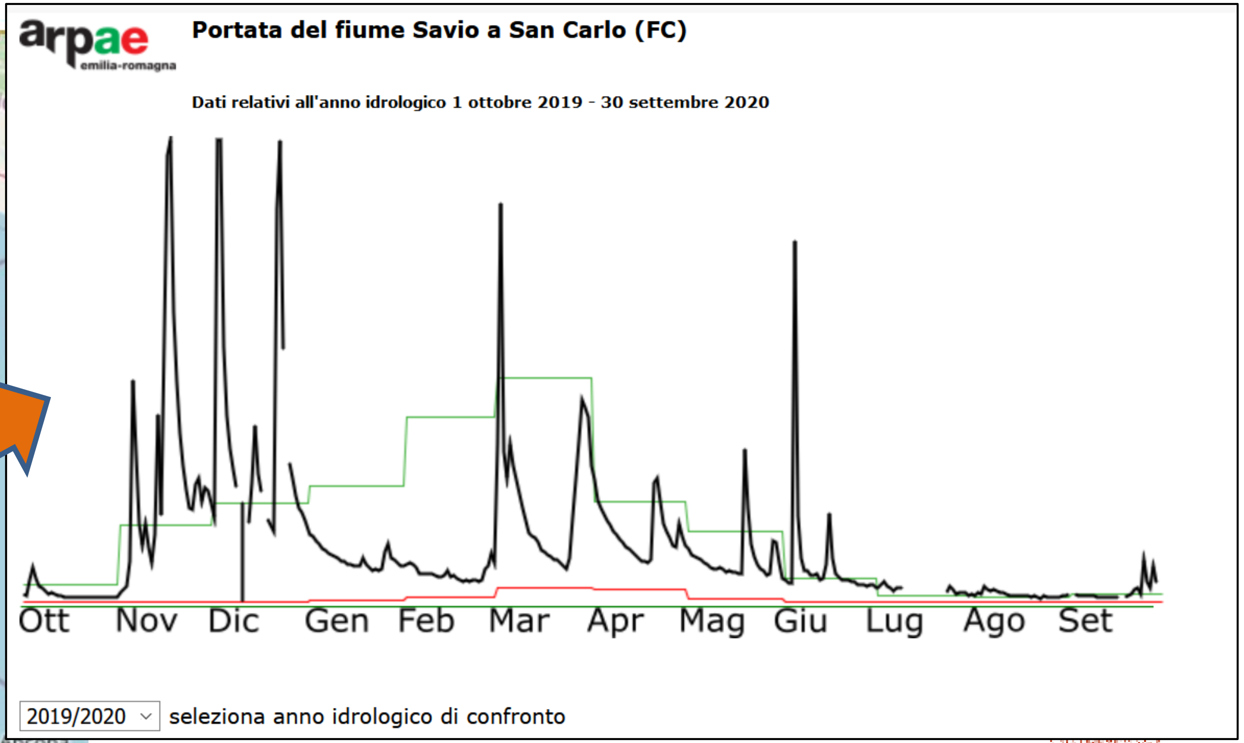
Hydrological drought monitoring

Several main streams are monitored allowing hydrological drought monitoring

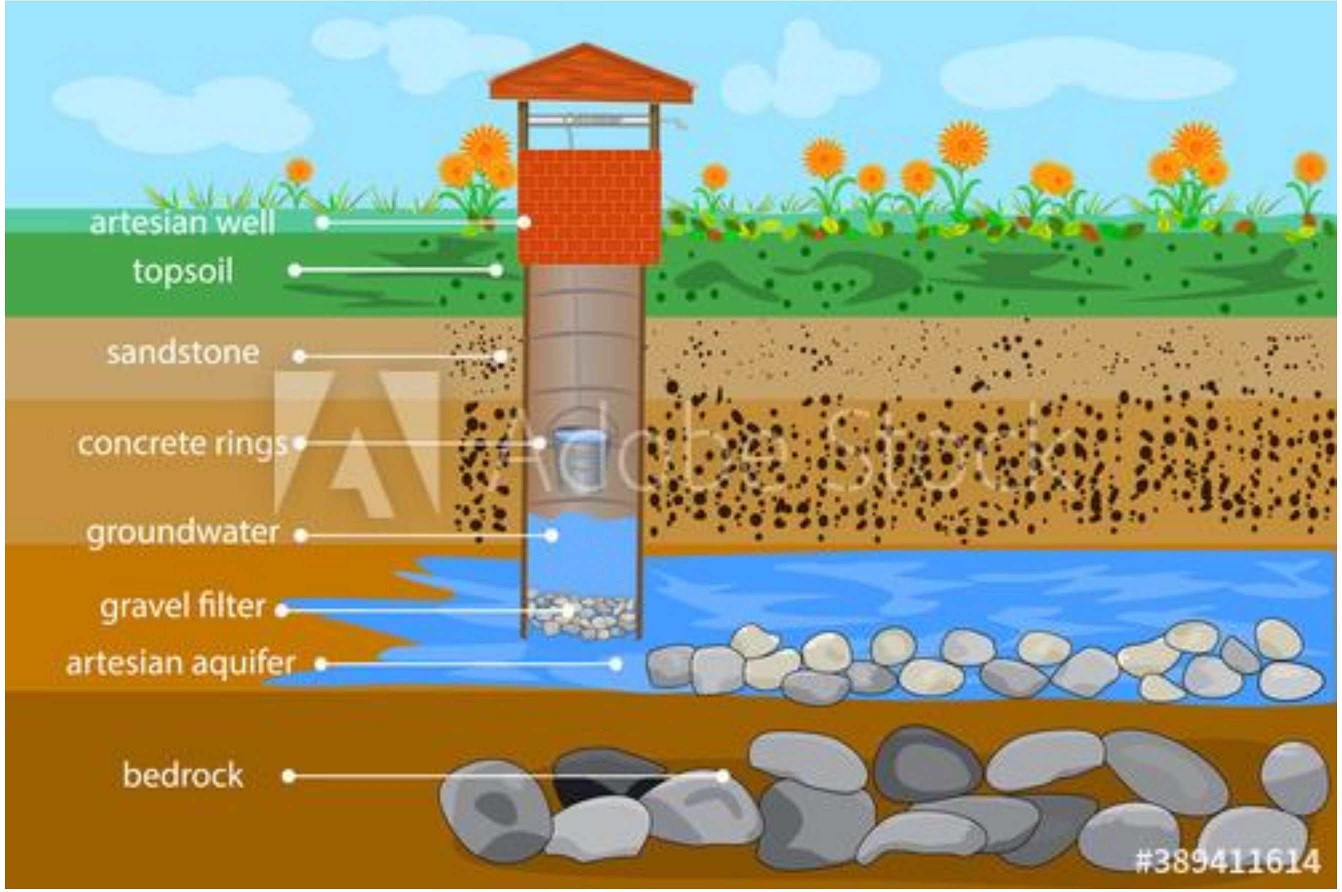
https://allertameteo.regione.emilia-romagna.it/web/zocca/home





Groundwater drought monitoring

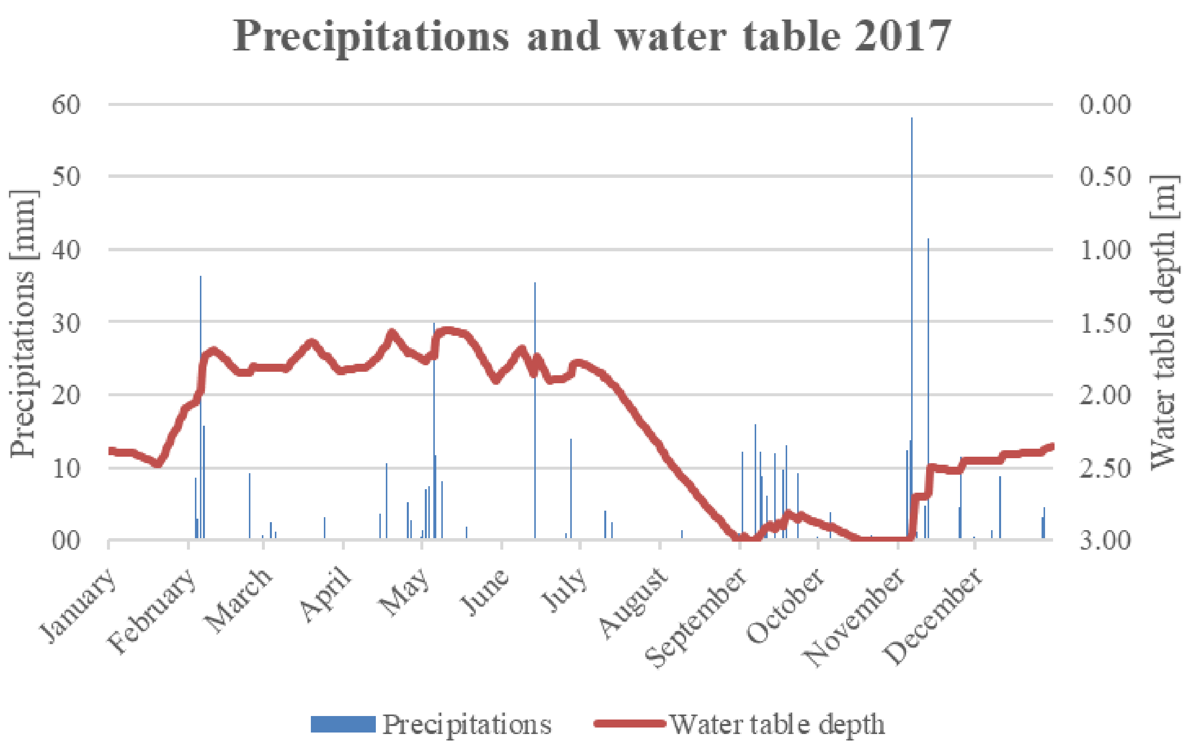
Piezometers and groundwater measuerments

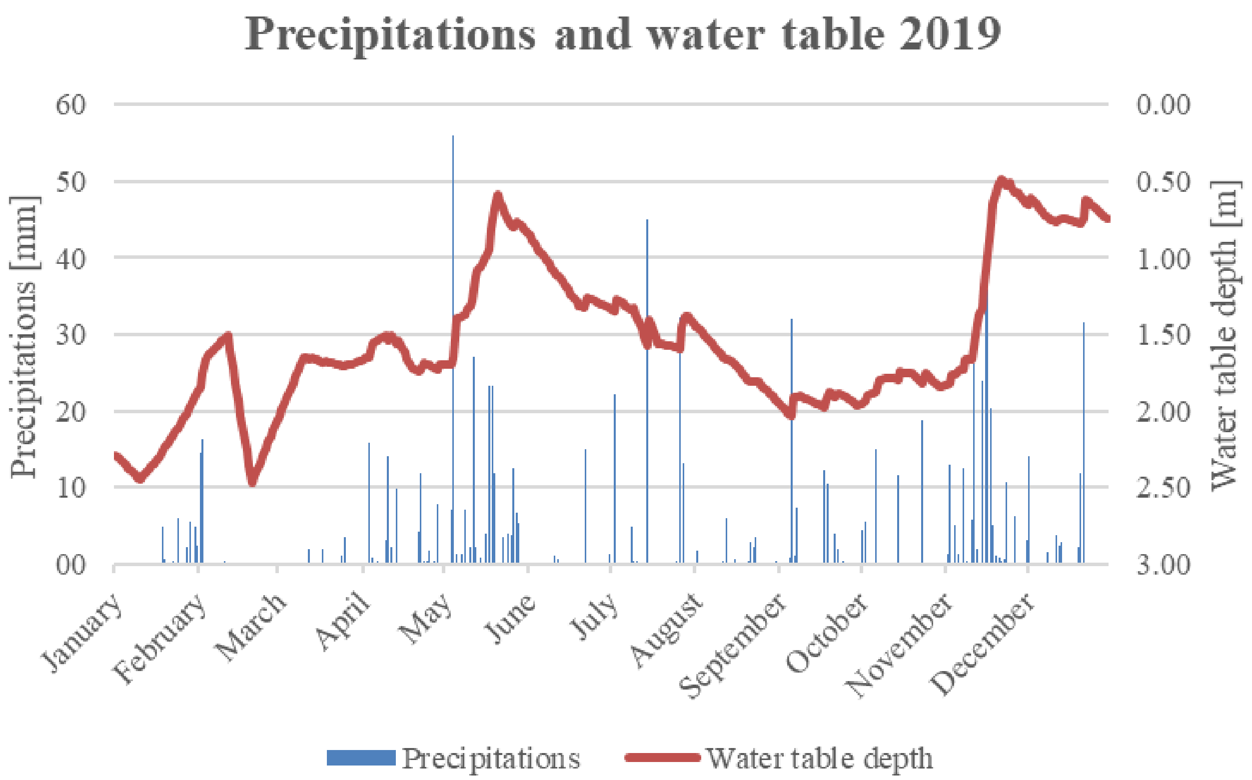


Groundwater drought monitoring

https://geo.regione.emilia-romagna.it/cartografia_sgss/user/viewer.jsp?service=ewater

Groundwater drought monitoring



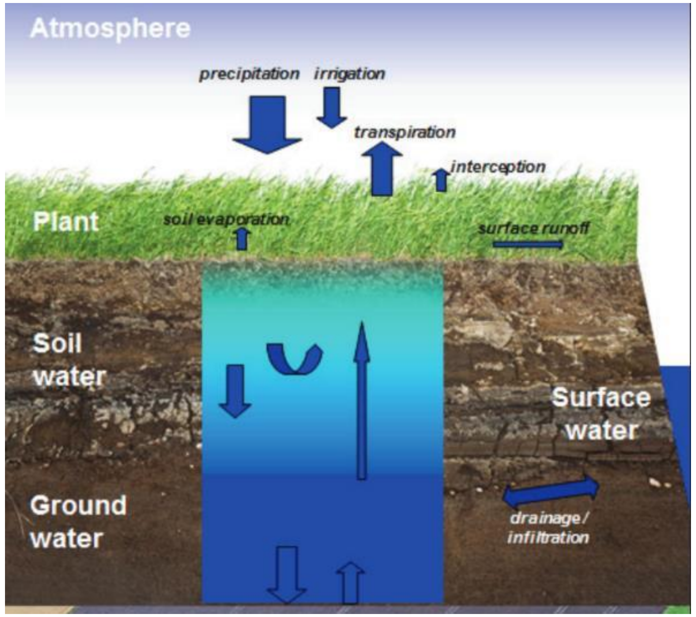


Agricultural drought monitoring

Hardly performed based on ground soil moisture observations

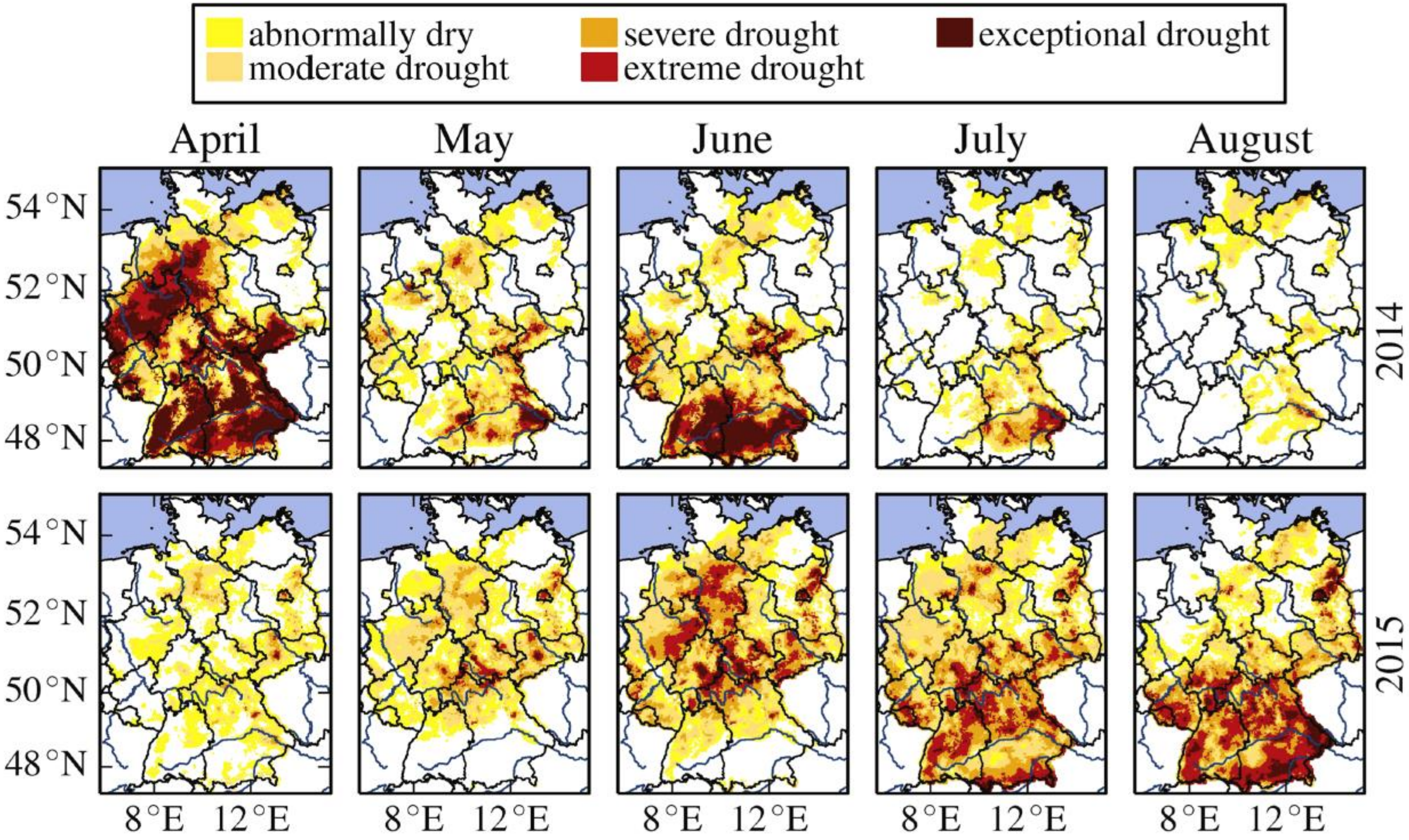
Soil moisture drought mainly based on modelling and remote sensing

https://www.swap.alterra.nl/



Example of agricultural drought monitoring

Zink, Matthias, Luis Samaniego, Rohini Kumar, Stephan Thober, Juliane Mai, David Schäfer, and Andreas Marx. "The German Drought Monitor." *Environmental Research Letters* 11, no. 7 (July 1, 2016): 074002. https://doi.org/10.1088/1748-9326/11/7/074002.



Example of agricultural drought monitoring

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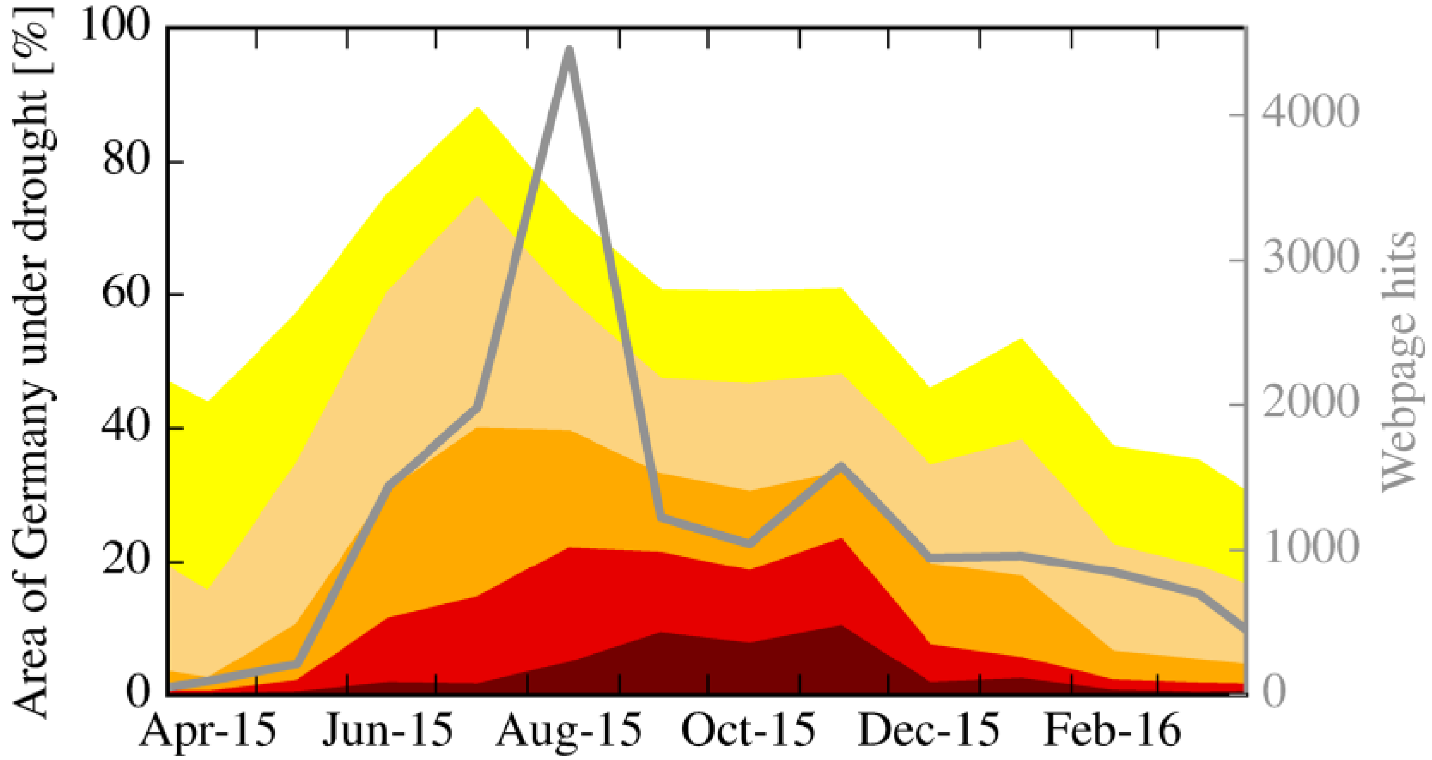

Figure 3. Percentage of area affected in Germany during the drought event in five drought classes (legend is show in figure 2) and total hits on our drought monitor webpage.

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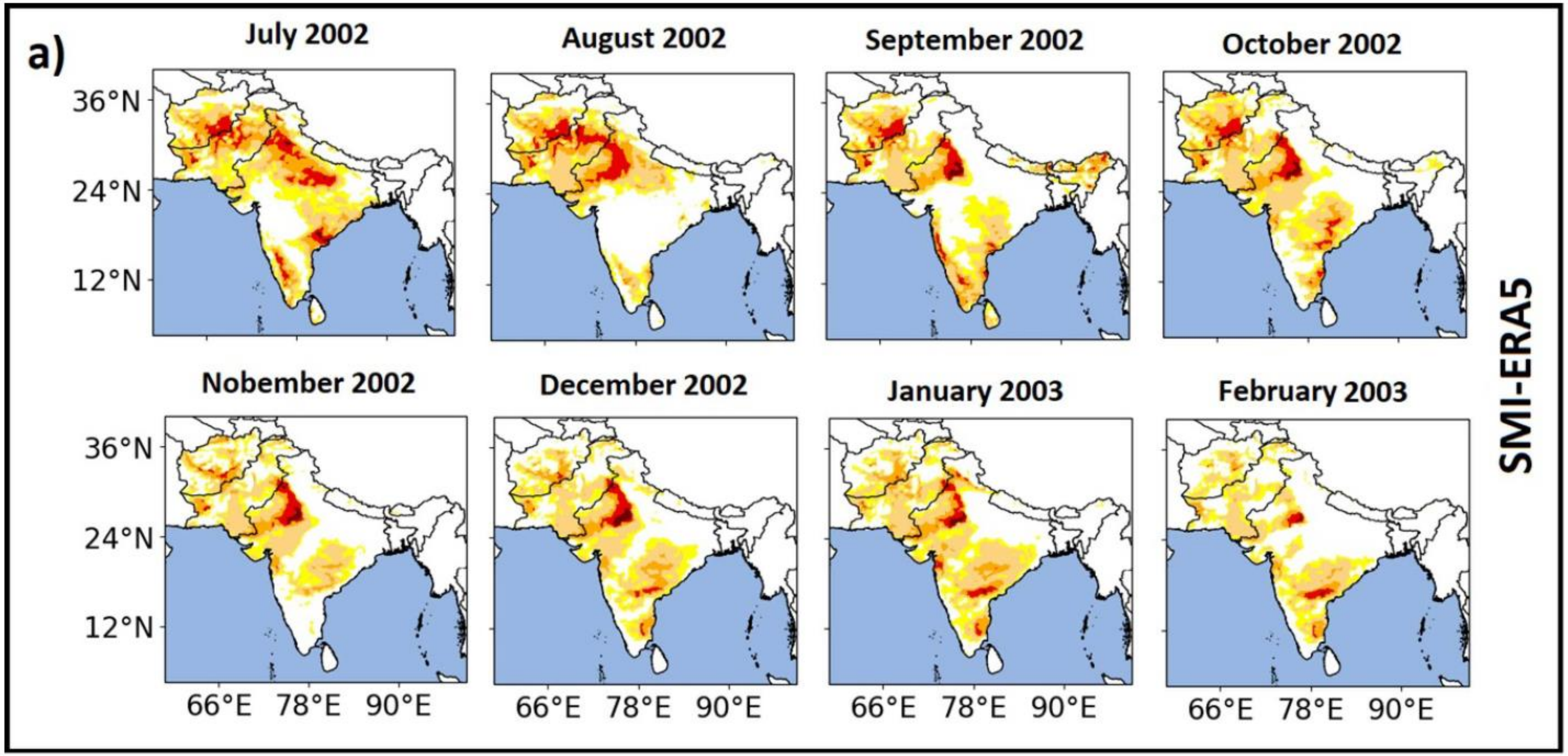
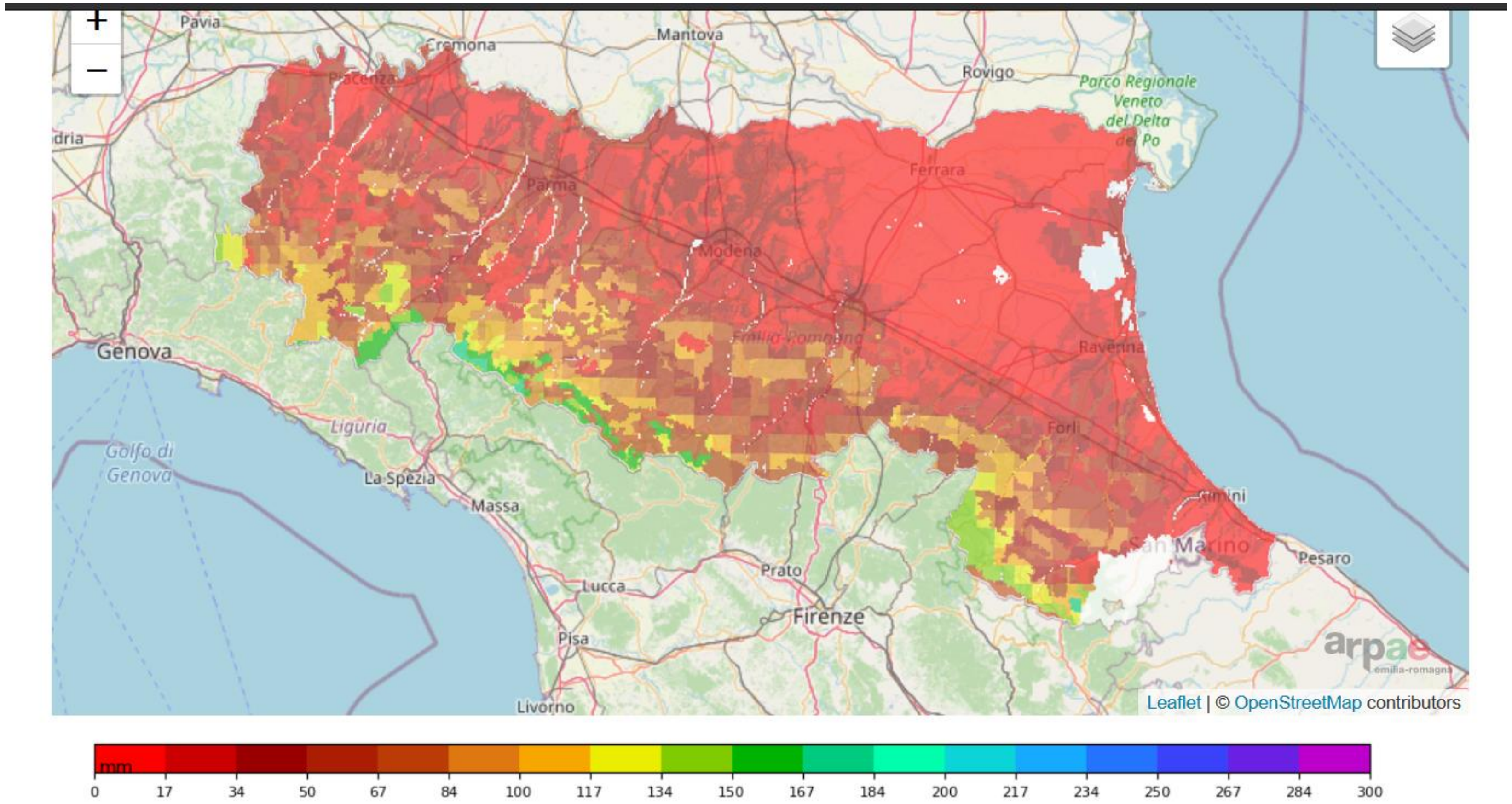
Example of agricultural drought monitoring

Saha, Toma Rani, Pallav K. Shrestha, Oldrich Rakovec, Stephan Thober, and Luis Samaniego. “A Drought Monitoring Tool for South Asia.” *Environmental Research Letters* 16, no. 5 (April 21, 2021): 054014. https://doi.org/10.1088/1748-9326/abf525.



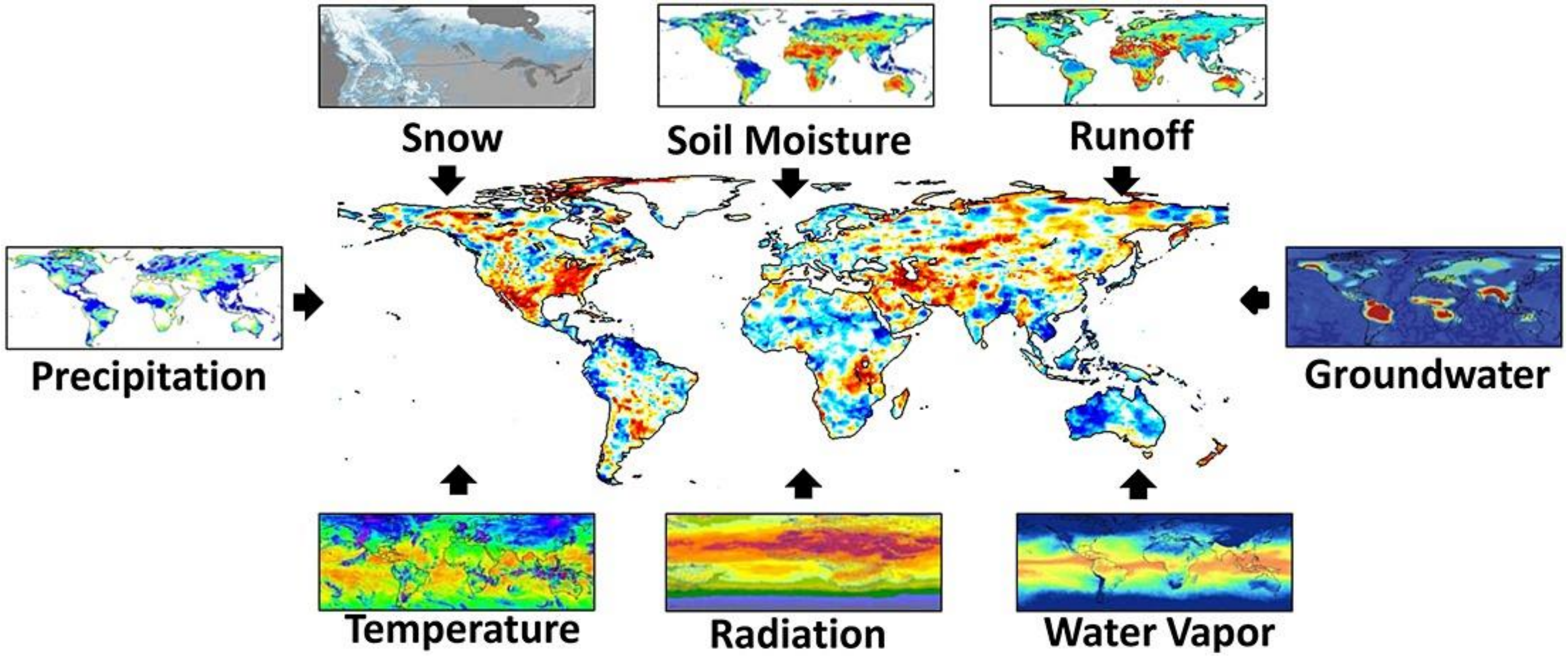
Example of agricultural drought monitoring



https://www.arpae.it/it/temi-ambientali/siccita/dati-e-indicatori/indicatori-di-siccita

Drought monitoring based on remote sensing

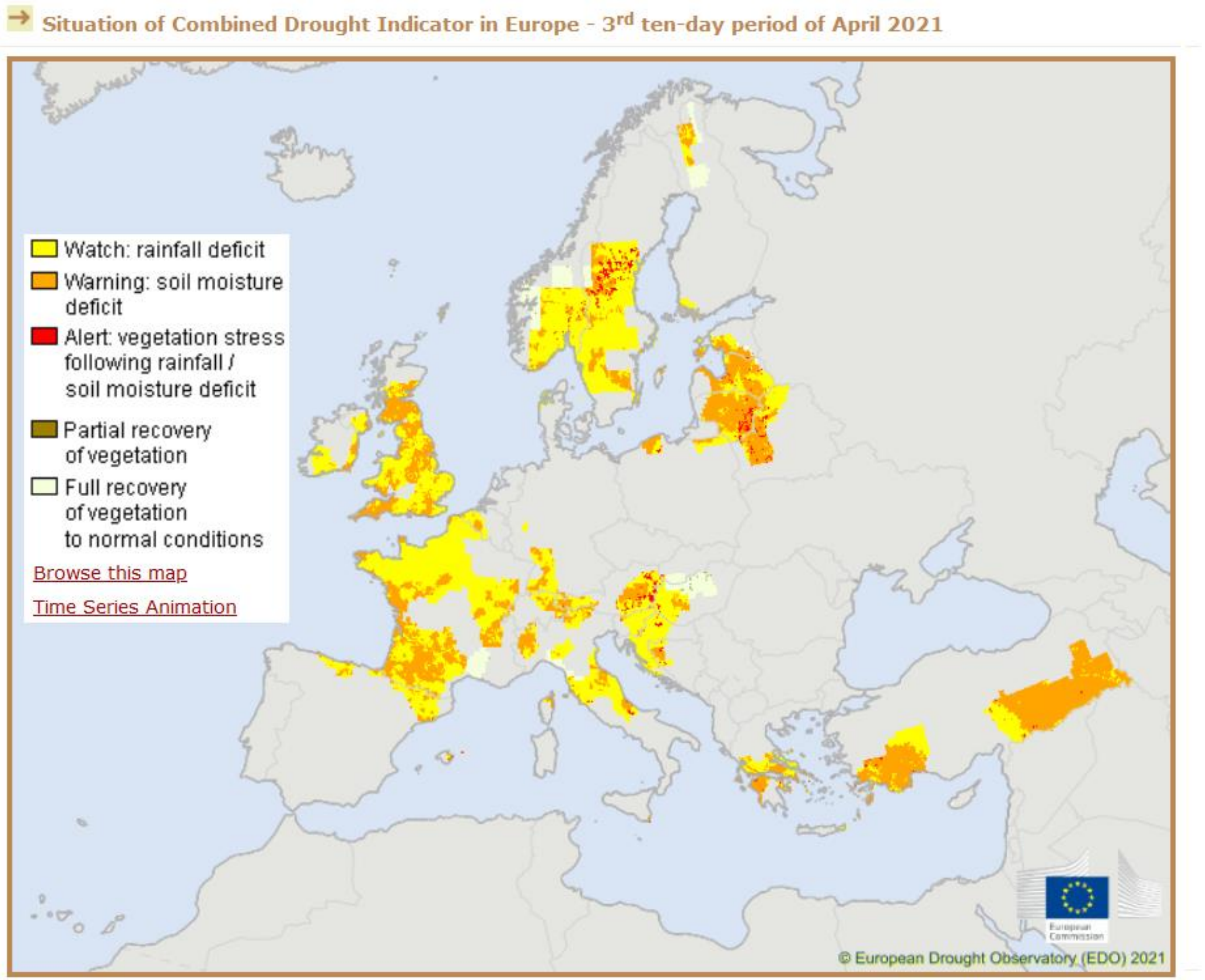
AghaKouchak, A., A. Farahmand, F. S. Melton, J. Teixeira, M. C. Anderson, B. D. Wardlow, and C. R. Hain. "Remote Sensing of Drought: Progress, Challenges and Opportunities." *Reviews of Geophysics* 53, no. 2 (2015): 452–80. https://doi.org/10.1002/2014RG000456.



Combined drought monitoring

https://edo.jrc.ec.europa.eu/edov2/php/index.php?id=1000

The European Drought Observatory pages contain drought-relevant information such as maps of indicators derived from different data sources (e.g., precipitation measurements, satellite measurements, modelled soil moisture content).



Modelling…uncertainty and reliability

They provide a nice overview of the spatial extend

Uncertainty due to the assumptions on the modelling tools, input and parameters

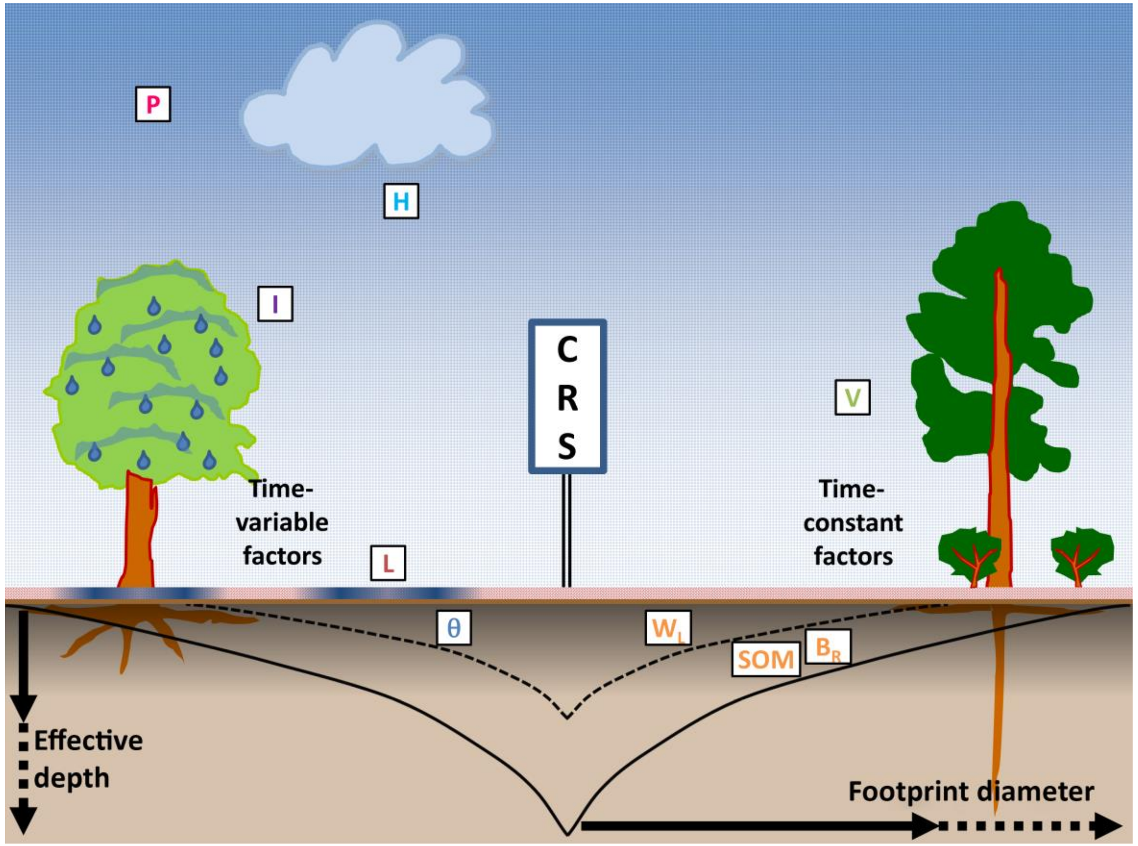
In several cases also meteorological and hydrological drought monitoring is based on modelling but several observations are available for calibration and the assessment

In contrast, models and remote sensing are assessed based on few soil moisture locations. This is even more critical in agricultural sites where long-term observations lack

CRNS and agricultural drought monitoring

CRNS provides the opportunity to establish a long-term agricultural drought monitoring

- Standardized measurements
- Non invasive
- Large scale and not affected by small scale soil variability
- Low maintenance



Heidbüchel, Ingo, Andreas Güntner, and Theresa Blume. "Use of Cosmic-Ray Neutron Sensors for Soil Moisture Monitoring in Forests." *Hydrology and Earth System Sciences* 20, no. 3 (March 30, 2016): 1269–88. https://doi.org/10.5194/hess-20-1269-2016.

CRNS and COSMOS network

CRNS networks are being implemented under the acronym of COSMOS (the COsmic-ray Soil Moisture Observing System).

- The first network was established in the USA by the University of Arizona and has already deployed more than 60 CRNS sensors at various locations across the USA (Zreda et al., 2012).
- The Australian network was supported by the CSIRO research institute and consists of nine sensors distributed across the continent under different environmental conditions (Hawdon et al., 2014).
- A network has also been established in the United Kingdom by the UK Centre for Ecology and Hydrology (CEH) (Evans et al., 2016).
- Similar initiatives have been started in Sothern Africa (Vather et al., 2019) and India (Upadhyaya et al., 2021).

COSMOS network

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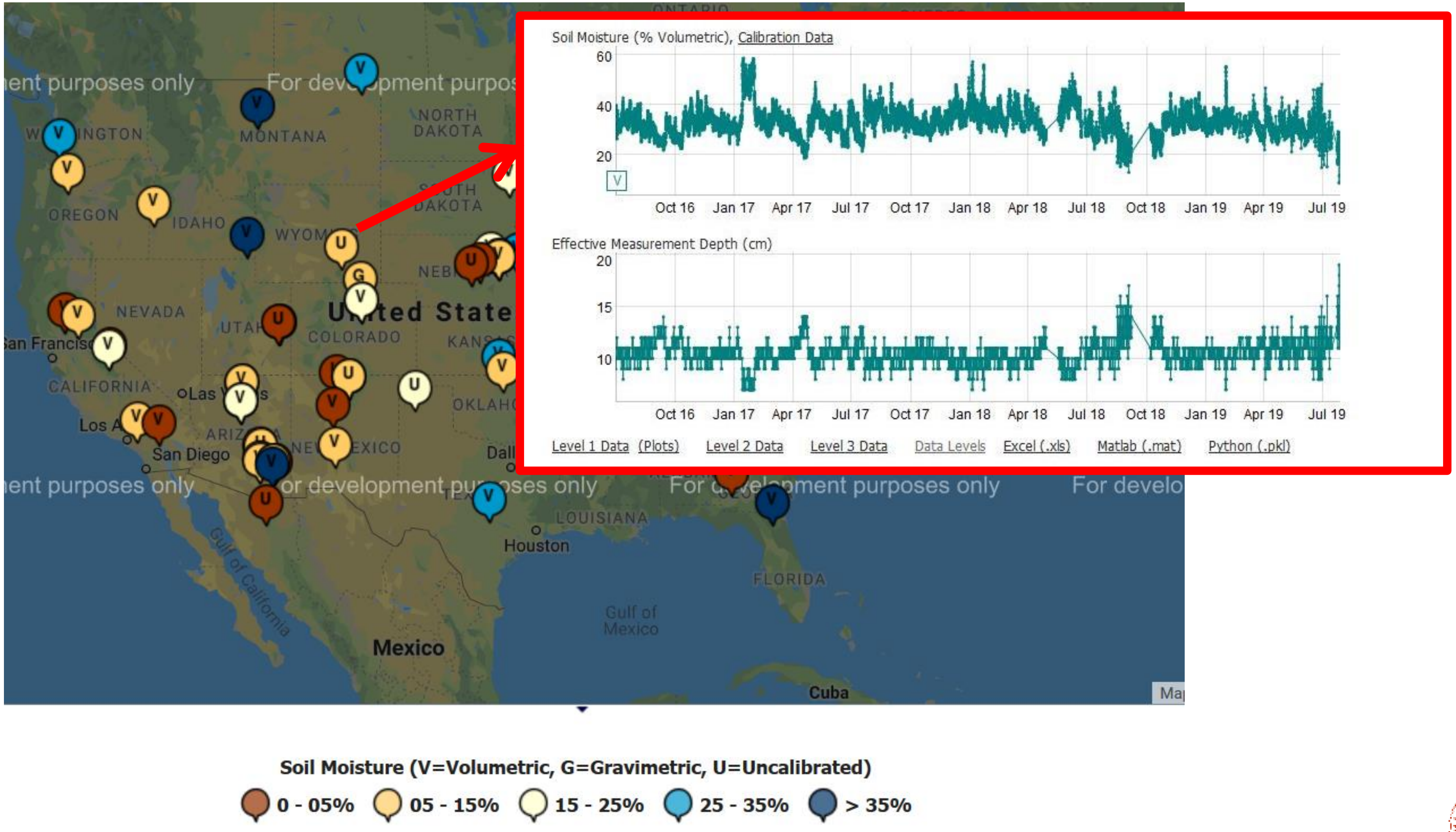
COSMOS network



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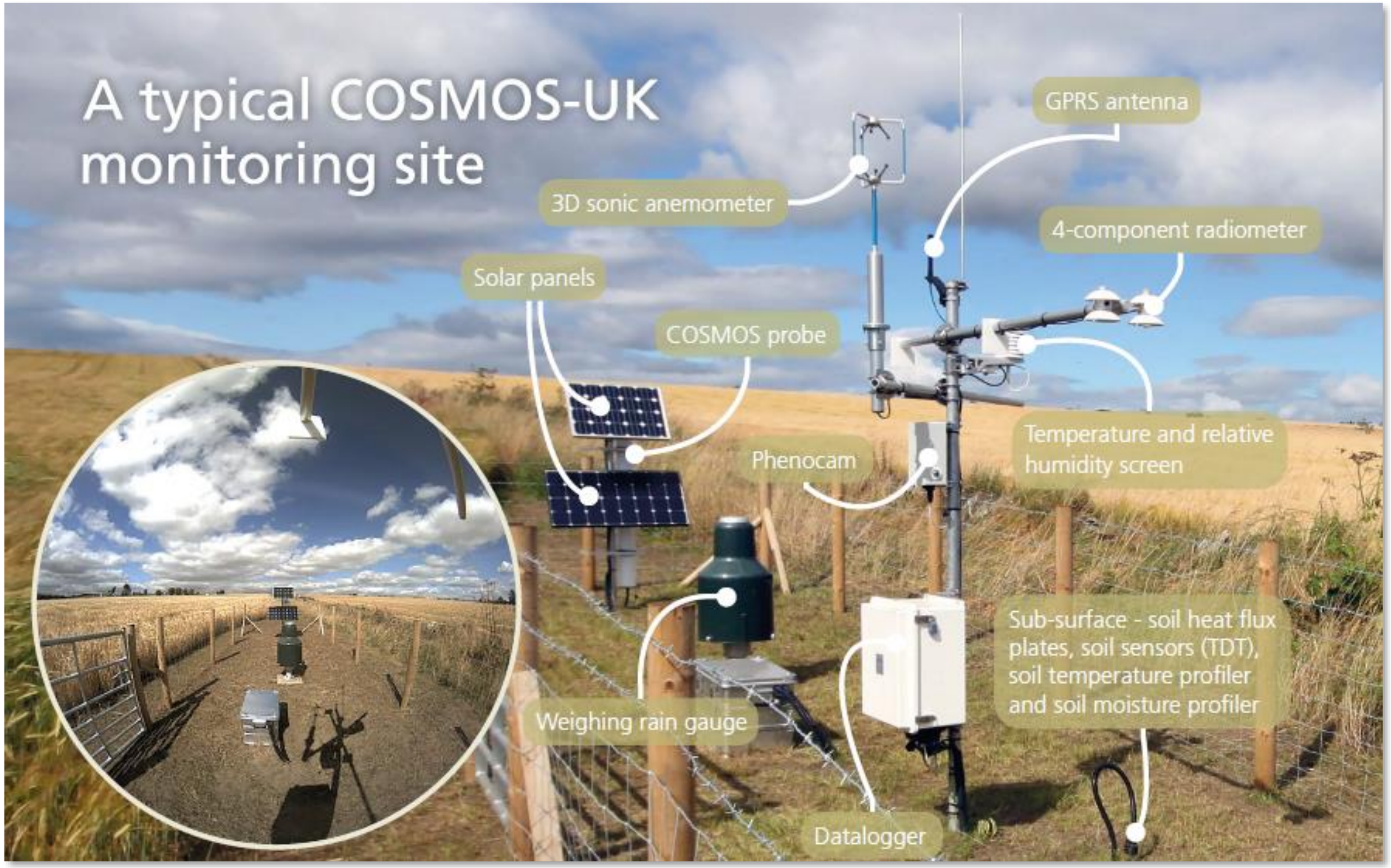
COSMOS-UK

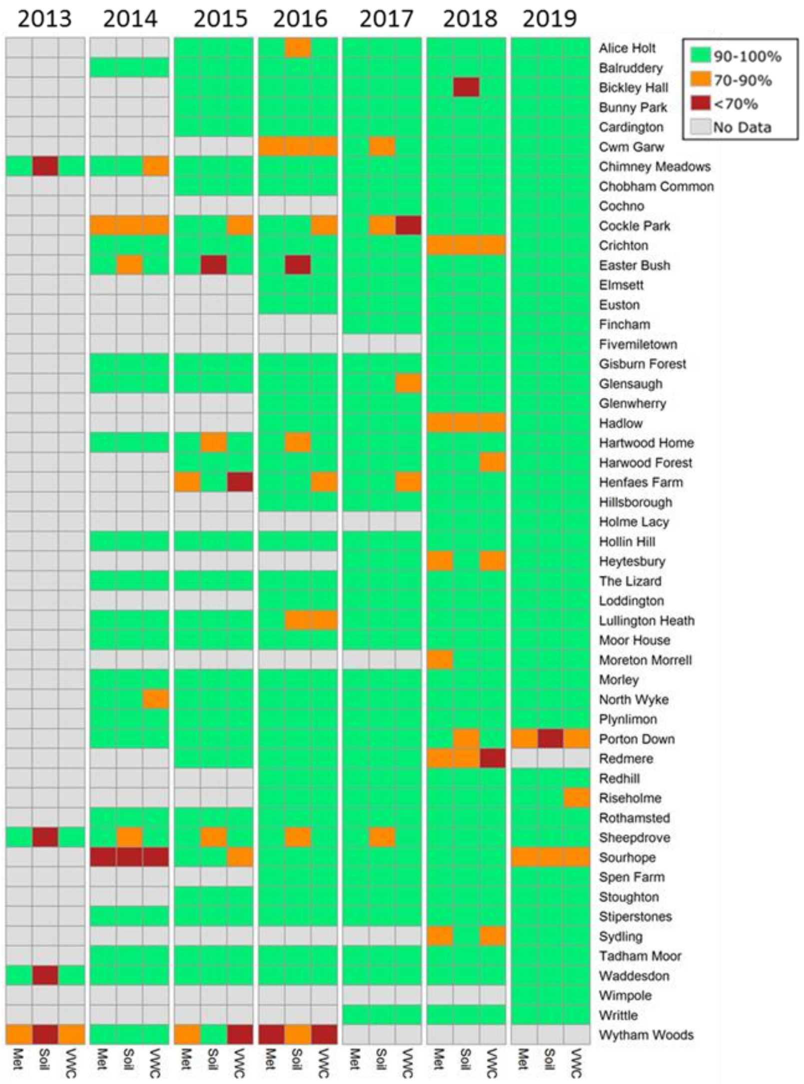
Evans, J. G., H. C. Ward, J. R. Blake, E. J. Hewitt, R. Morrison, M. Fry, L. A. Ball, et al. "Soil Water Content in Southern England Derived from a Cosmic-Ray Soil Moisture Observing System - COSMOS-UK: Soil Water Content in Southern England - COSMOS-UK." *Hydrological Processes*, May 2016. https://doi.org/10.1002/hyp.10929.



COSMOS-UK

From presentation of David Boorman

COSMOS workshop (Hidelberg, Germany, 2020)



UK Centre for Ecology & Hydrology

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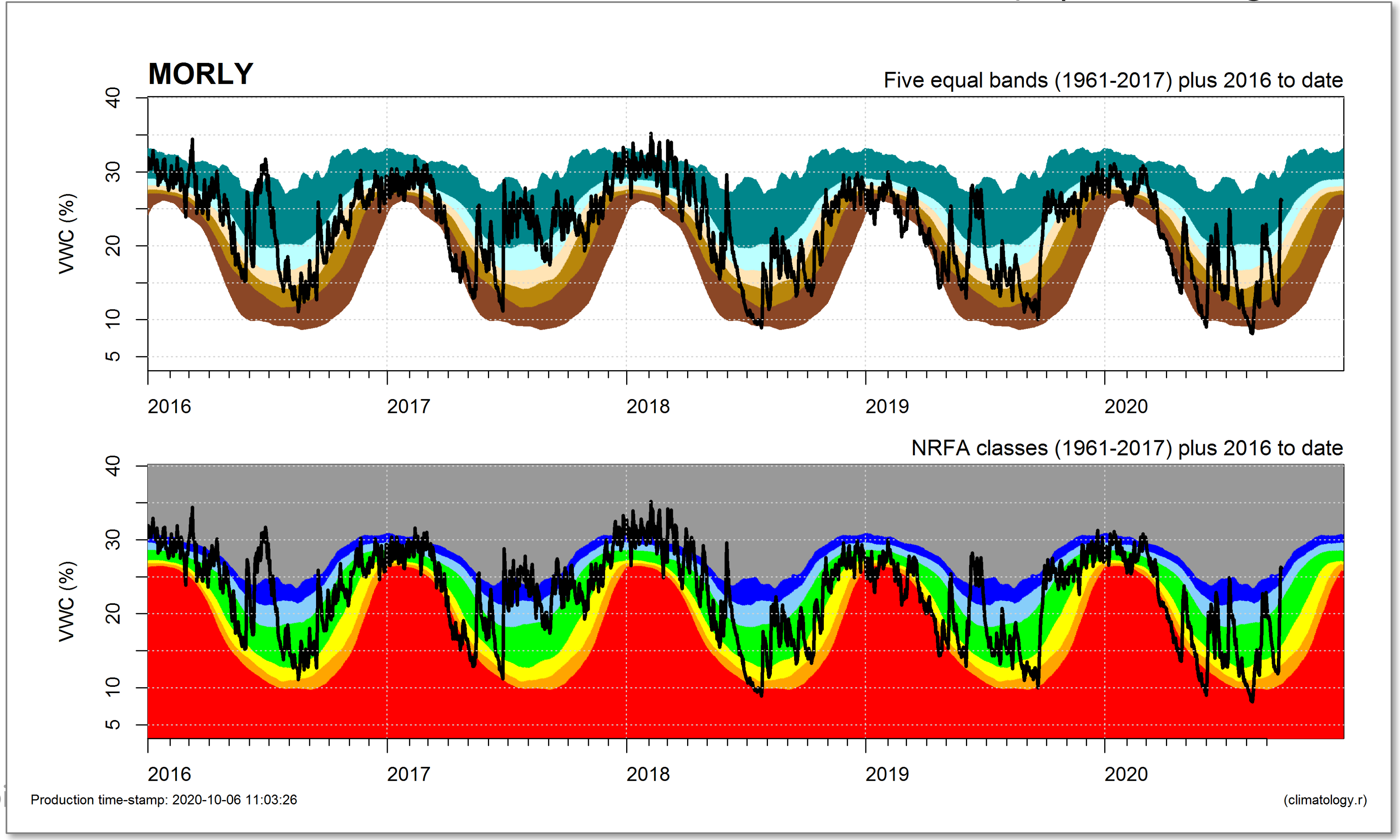
COSMOS-UK

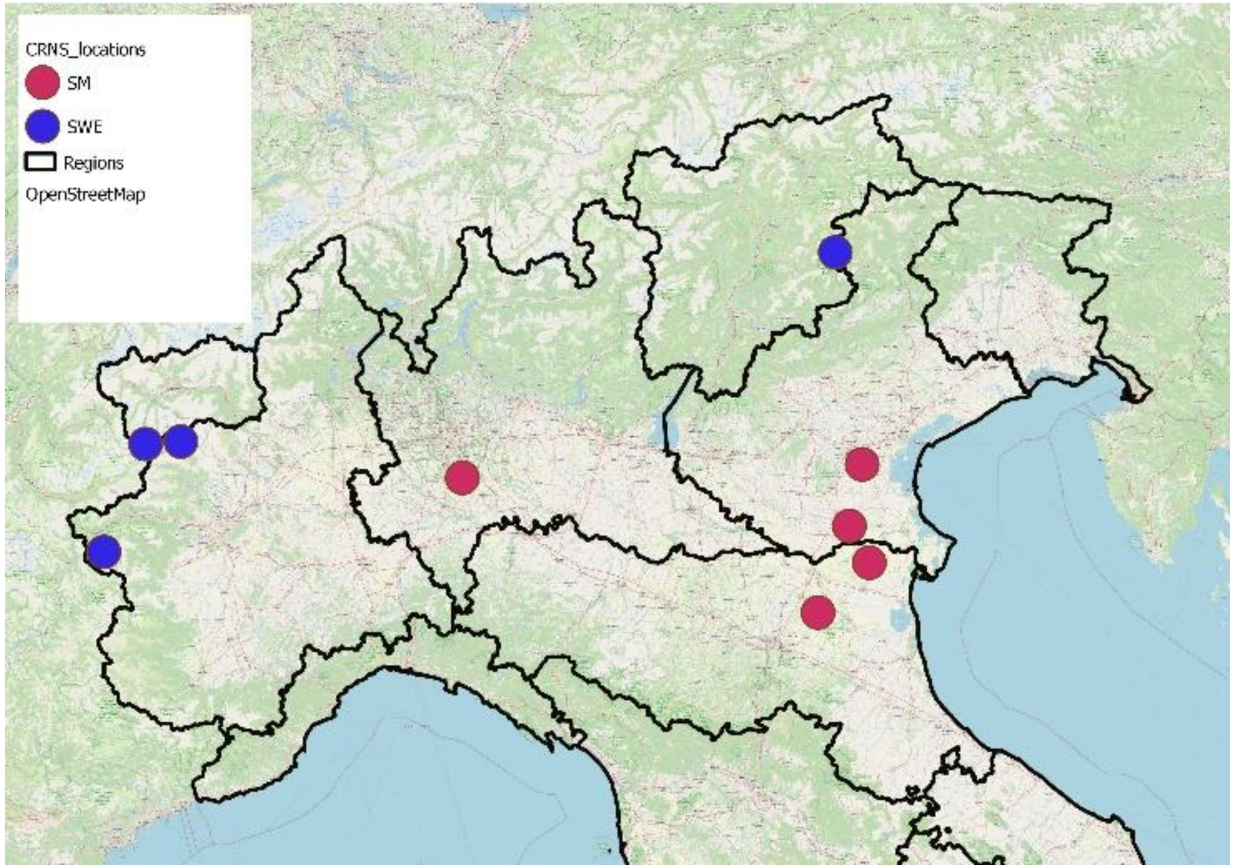
https://eip.ceh.ac.uk/hydrology/water-resources/

COSMOS-UK

From presentation of David Boorman, COSMOS workshop (Hidelberg, Germany, 2020)



Current activities in Italy



Test sites for innovative CRNS in collaboration with FINAPP.srl and several environmental agencies and private companies

Aim to establish long-term observatory for agricultural drought monitoring

Example of field site

- 17 February 2021

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