EUMETSAT H SAF SUPPORT TO OPERATIONAL HYDROLOGY AND WATER MANAGEMENT

Soil moisture and drought monitoring

EUMETRAIN event week,

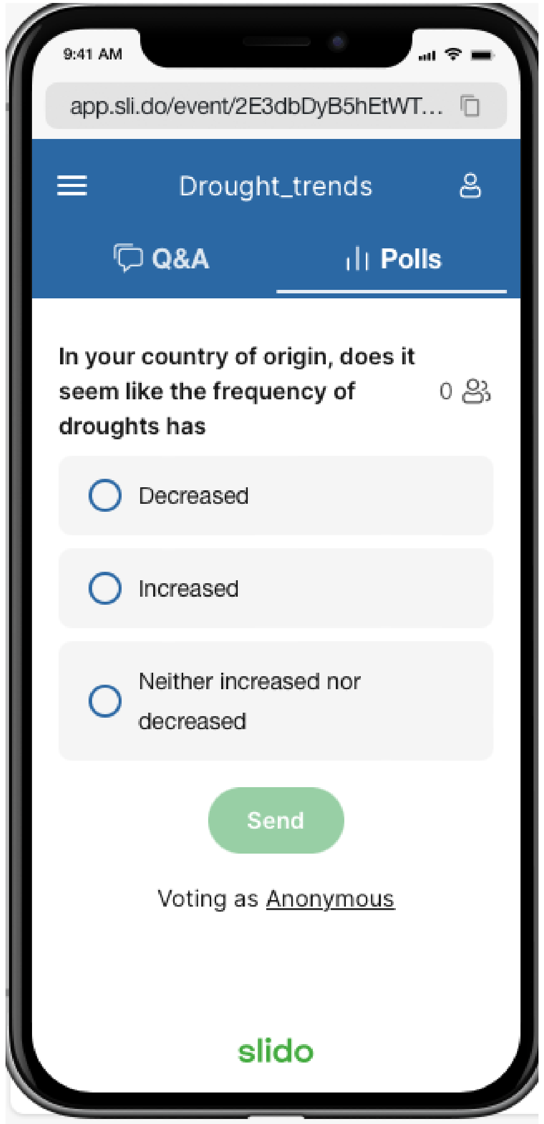
May 30th 2023

David Fairbairn (ECMWF), Patricia de Rosnay (ECMWF), Mariette Vreugdenhil (Tu Wien), Sebastian Hahn (Tu Wien), Apostolos Giannakos (Geosphere Austria), Luca Brocca (IRPI), Silvia Pucca (Italian civil protection)

Contents

Slido

Join us at #SMdrought



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1. Background

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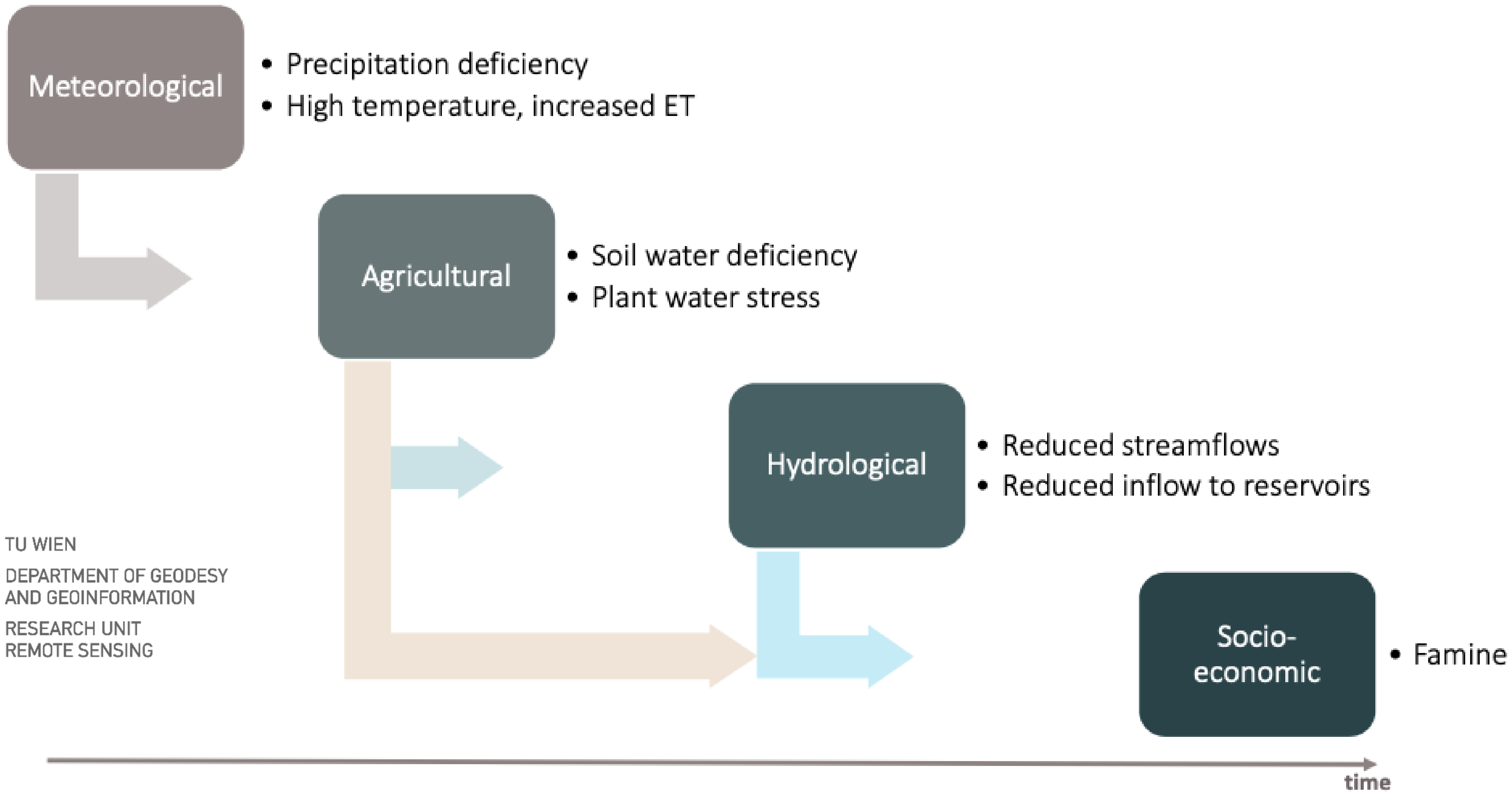
What is a drought?



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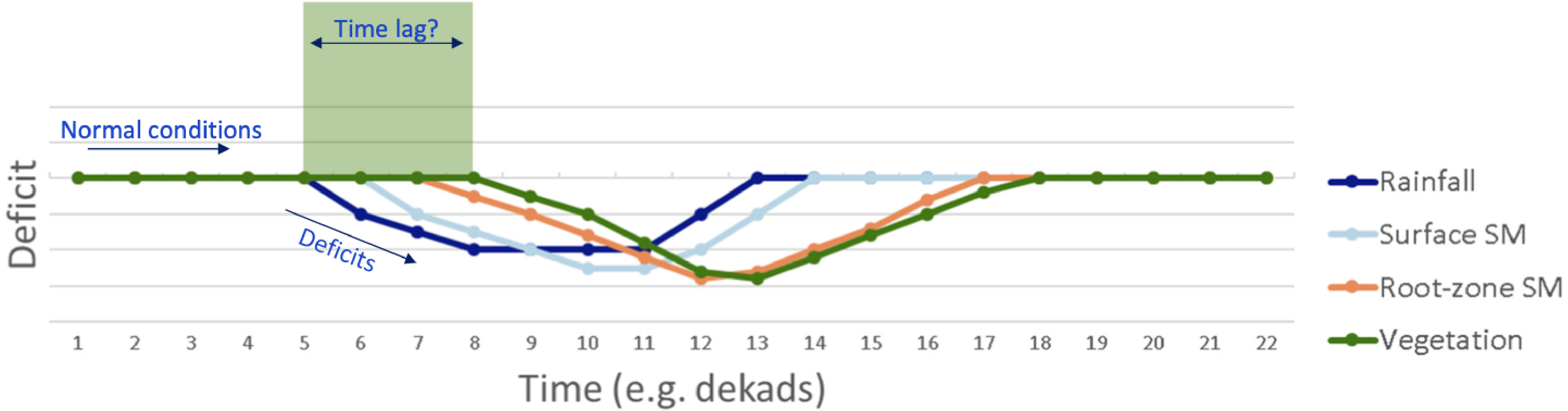
Slide from Mariette Vreugdenhil

Tracking rainfall deficits through the water cycle



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Slide from Mariette Vreugdenhil

H SAF SM data sets

Surface SM products

- ASCAT surface SM climate data records (12.5 km resolution)
  ASCAT SSM CDR v7 12.5 km (H119)
  ASCAT SSM CDR v7 EXT 12.5 km (H120)

- ASCAT CGLS 10-day product (12.5 km resolution)

Root-zone SM products

- ASCAT-derived root-zone SM near-real-time product (10 km resolution)
  RZSM-ASCAT-NRT-10km (H26) - operational

- ASCAT-derived root-zone SM climate data record (10 km resolution)
  RZSM-DR2019-10km (H145, 1992-2022) – available as demo product

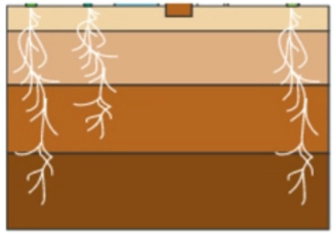
Simplified EKF analysis

$$\mathbf{x}^a(t_i) = \mathbf{x}^b(t_i) + \mathbf{K}_i\left[\mathbf{y}^o(t_i) - \mathcal{H}_i(\mathbf{x}^b)\right],$$

$$\mathbf{K}_i = \left[\mathbf{B}^{-1} + \mathbf{H}_i^T\mathbf{R}^{-1}\mathbf{H}_i\right]^{-1}\mathbf{H}_i^T\mathbf{R}^{-1},$$

$$\mathbf{H}_{mn,i} = \frac{\mathcal{H}_{m,i}(\mathbf{x}^b + \delta\mathbf{x}_n^b) - \mathcal{H}_{m,i}(\mathbf{x}^b)}{\delta x_n}.$$

SM analysed over first 3 layers in H-TESSEL:
Layer 1: 0-7 cm
Layer 2: 7-28 cm
Layer 3: 28-100 cm
Layer 4 (not analysed): 100-289 cm



Download and documentation

Downloading data
First register with H SAF: https://hsaf.meteoam.it/User/Register to obtain username and password
All H SAF data available to download via the H-SAF website (near-real-time) or the ftp (data records)

Documentation:
H SAF Website: https://hsaf.meteoam.it/Products/ProductsList?type=soil_moisture
ATBD (Algorithm theoretical baseline), PUM (Product user manual), PVR (Product validation report)

Training (Lecture notes and download/visualization examples)
H SAF github training page: https://github.com/H-SAF/5th_hsaf_user_Workshop
EUMETRAIN event week: https://eumetrain.org/index.php/event-weeks/h-saf-event-week-2019

Advanced Scatterometer (ASCAT) on-board Metop

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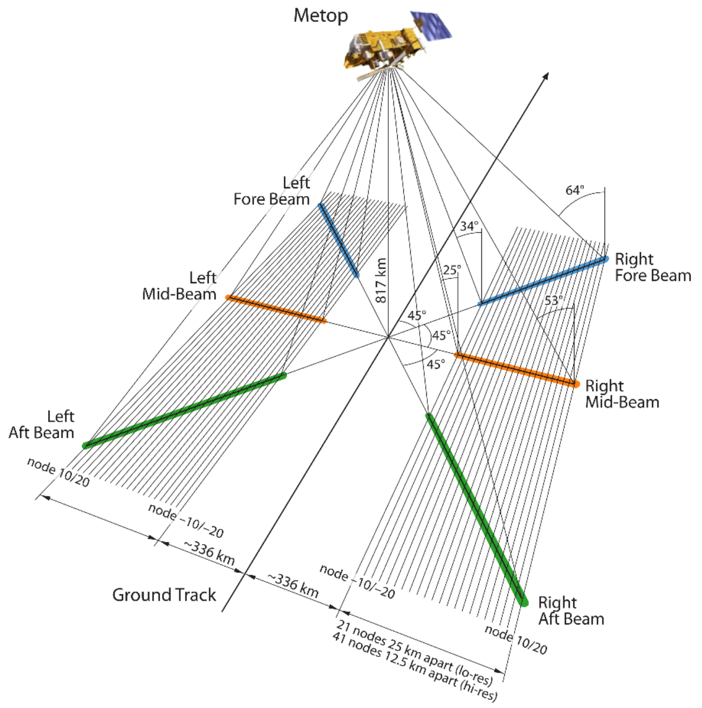
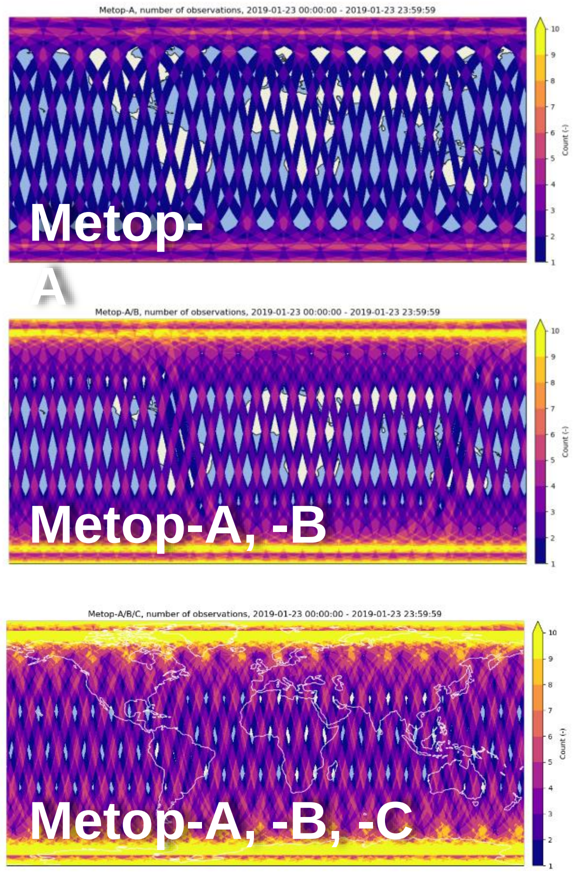
- Sensor characteristics
  - Active microwave scatterometer
  - Frequency: C-band, 5.255 GHz
  - Polarisation: VV
  - Spatial resolution: 25/50 km
  - Antennas: 2 x 3
  - Swath: 2 x 500 km
  - Multi-incidence: 25-65°
  - Daily global coverage: 82%



Figa-Saldana, et al., The advanced scatterometer (ASCAT) on the meteorological operational (MetOp) platform: A follow on for European wind scatterometers, Canadian Journal of Remote Sensing, 28(3), 404–412 (2002). http://dx.doi.org/10.5589/m02-035

Spatial coverage in 24 h



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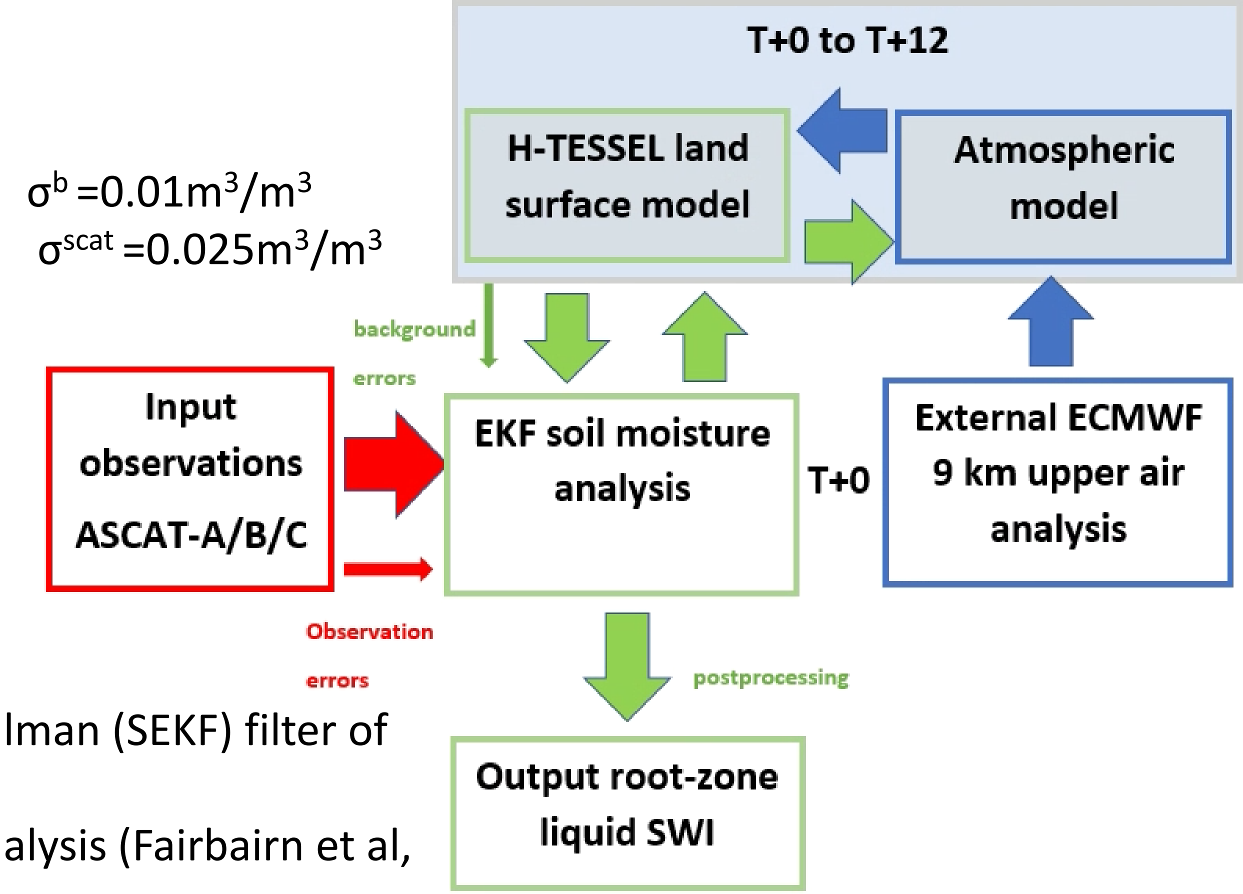
ZAMG

Slide from Sebastian Hahn

Root-zone SM NRT product

SSM derived from change-detection approach (Wagner et al., 1999)



- Simplified Extended Kalman (SEKF) filter of de Rosnay et al., 2013
- Stand-alone surface analysis (Fairbairn et al, 2019)

Simplified EKF analysis

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SM analysed over first 3 layers in H-TESSEL:
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- Daily (00 UTC) global root-zone liquid soil wetness index at 10 km sampling
- Operational since 23rd March 2022 with 12-hour latency
- Near-real-time product (identifier): RZSM-ASCAT-NRT-10km (H26)

New root-zone SM data record

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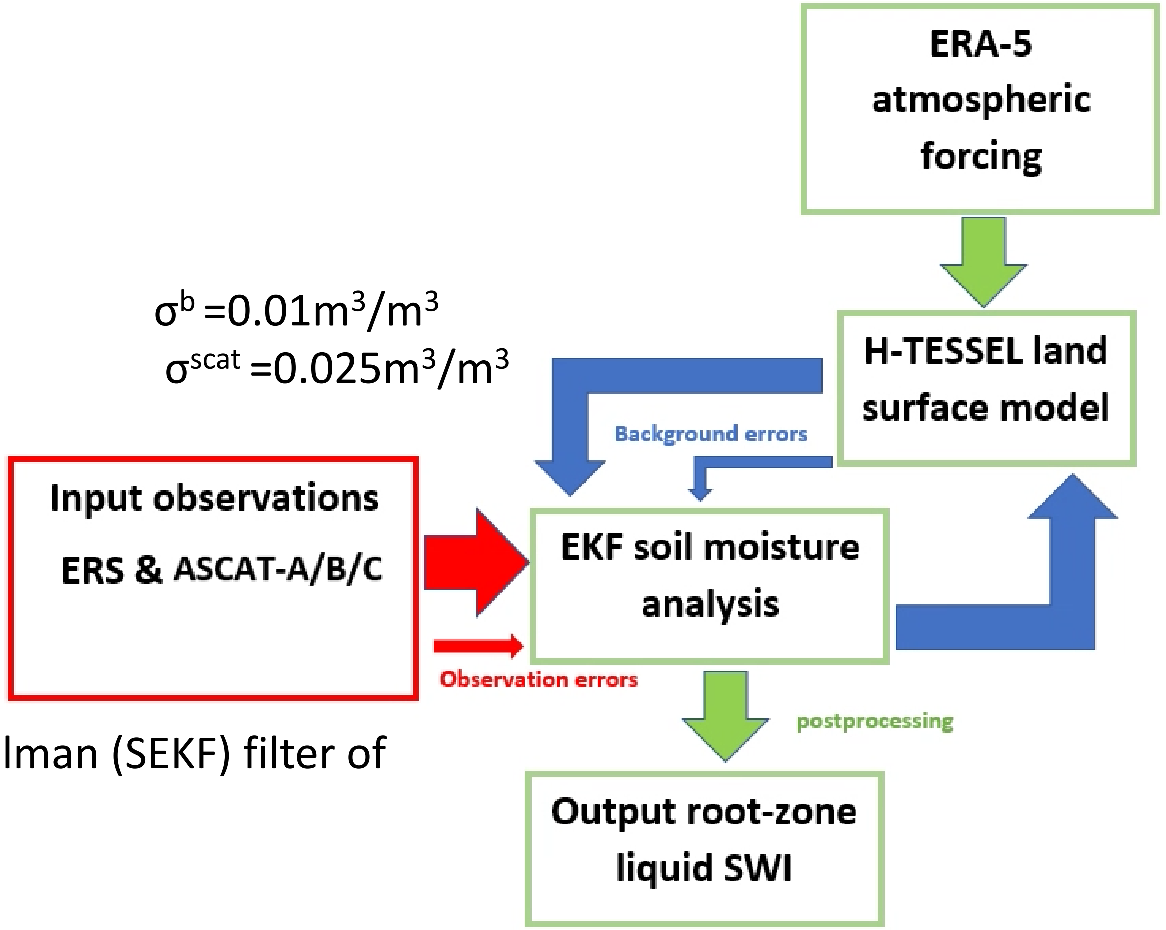
SSM derived from change-detection approach (Wagner et al., 1999)



Simplified Extended Kalman (SEKF) filter of de Rosnay et al., 2013

Simplified EKF analysis

$$\mathbf{x}^a(t_i) = \mathbf{x}^b(t_i) + \mathbf{K}_i\left[\mathbf{y}^o(t_i) - \mathcal{H}_i(\mathbf{x}^b)\right],$$

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SM analysed over first 3 layers in H-TESSEL:
Layer 1: 0-7 cm
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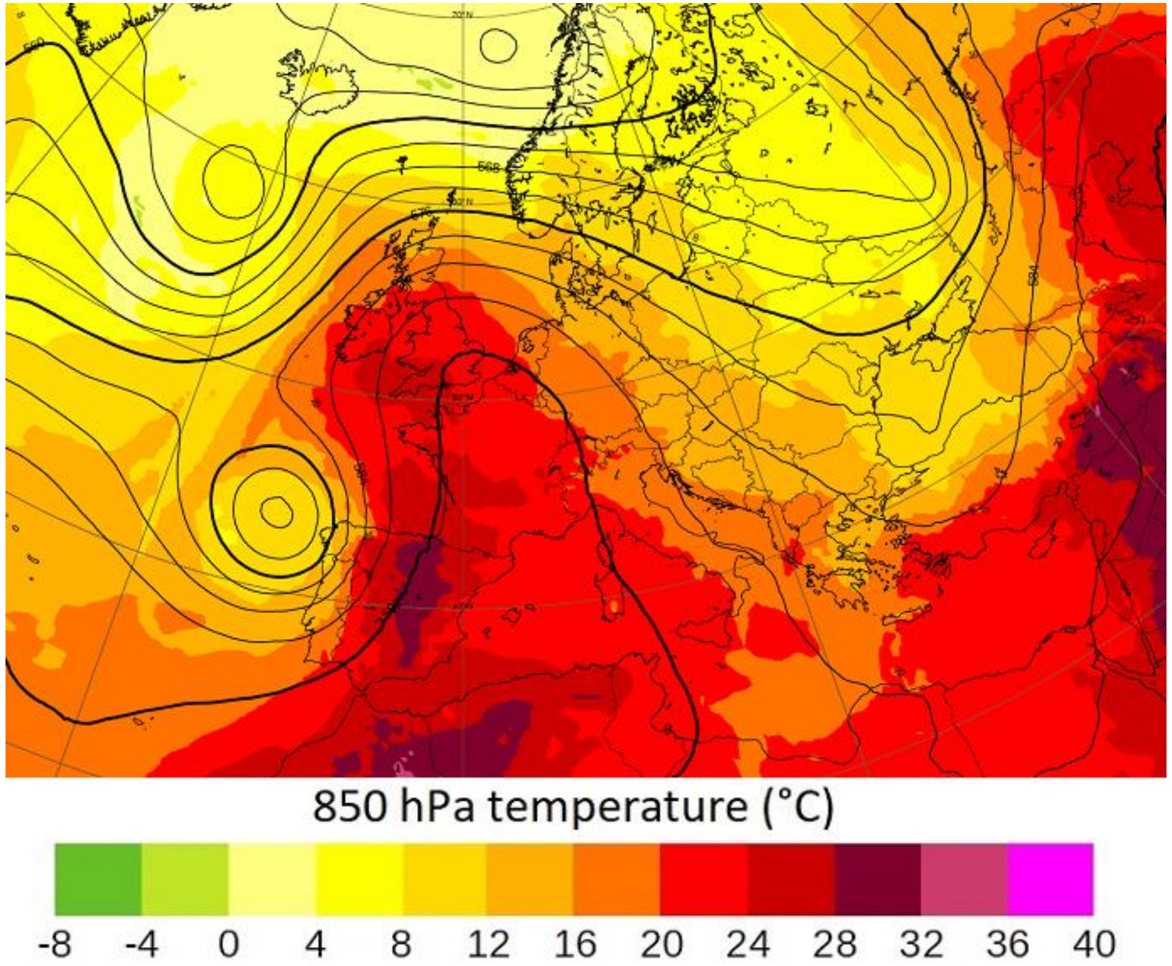
Layer 3: 28-100 cm
Layer 4 (not analysed): 100-289 cm

- Daily (00 UTC) global root-zone liquid soil wetness index at 10 km sampling over 1992-2022
- Data record product (identifier): RZSM-DR2019-10km (H145) covers 1992-2022
- Available as demonstrational product (subject to review)

2. Case study: 2022 summer drought in Europe

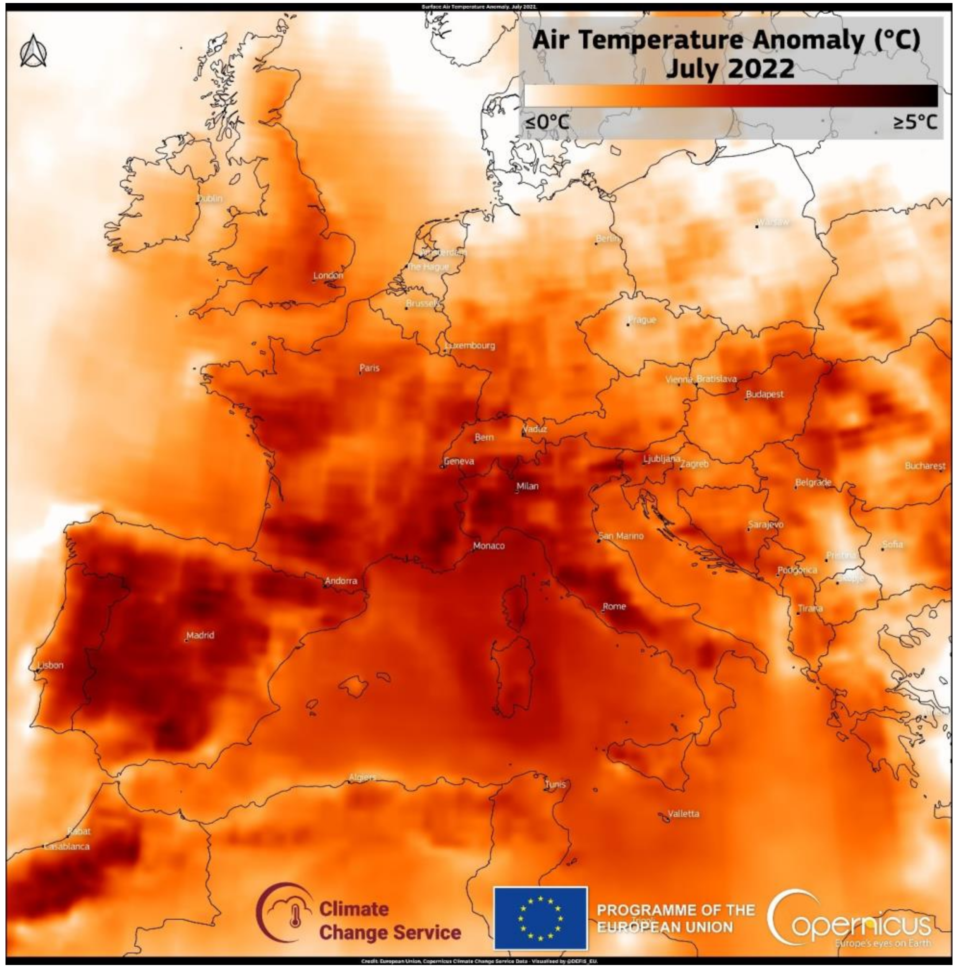
Synoptic setup and air temperatures

High pressure dominated most of Europe during the period, bringing with it drier than usual conditions.



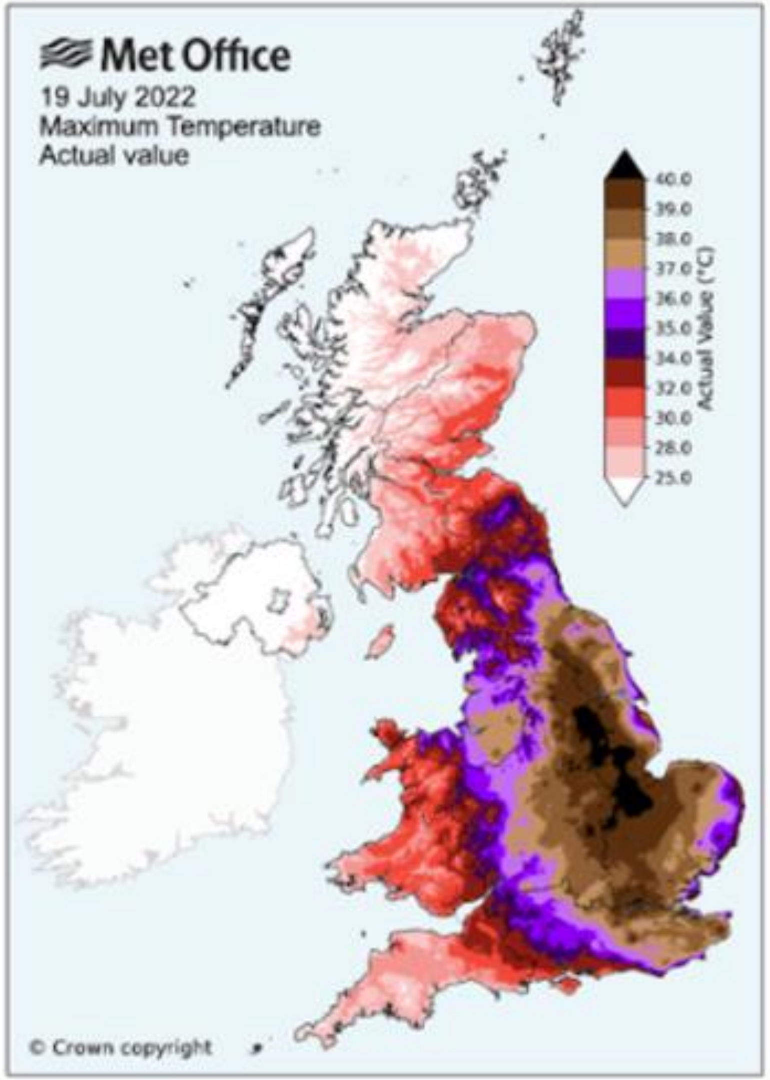
https://www.ecmwf.int/en/about/media-centre/focus/2022/update-european-heatwave-july-2022

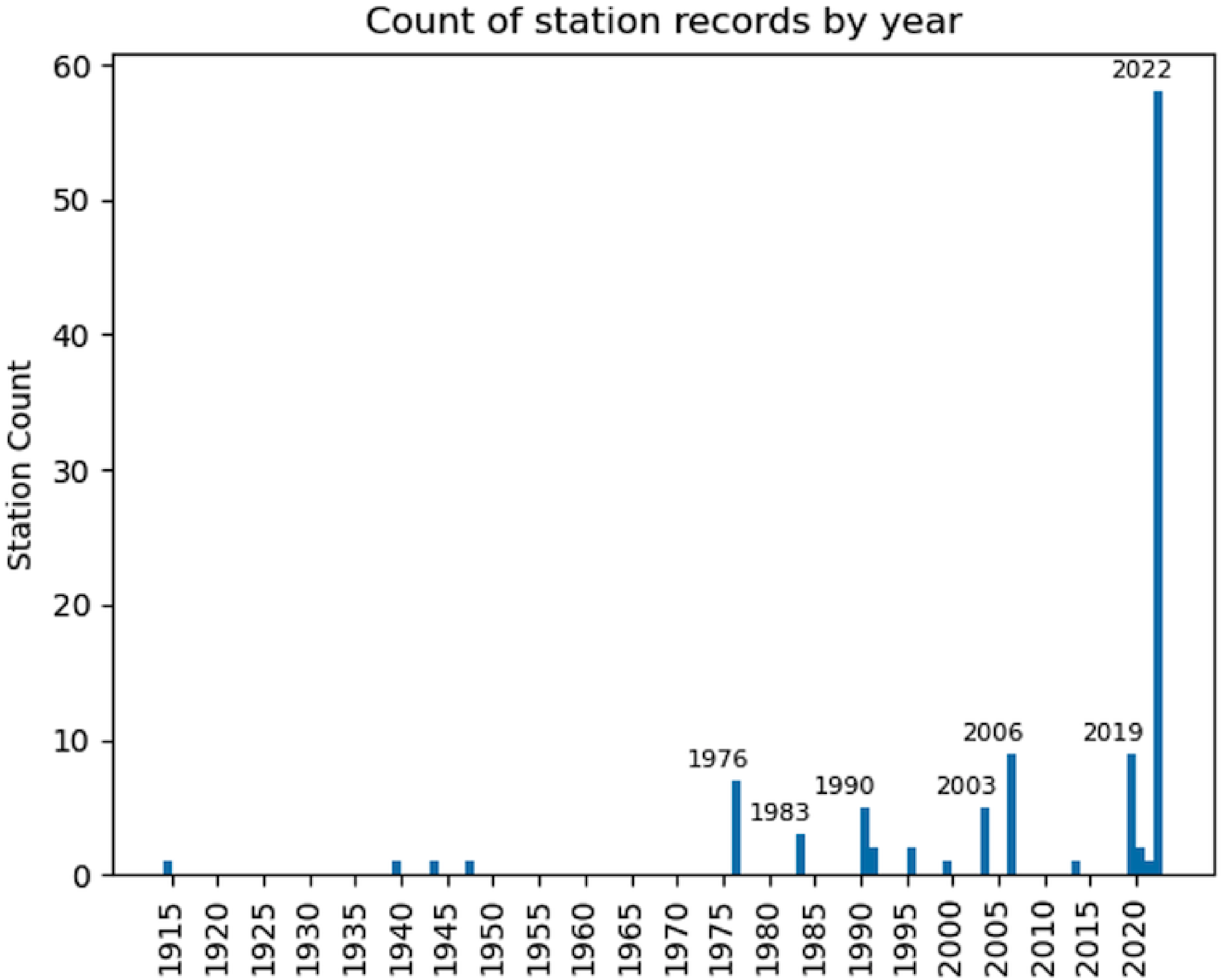
Air temperatures anomalies reached 3-5℃ over many parts for July and August



https://www.copernicus.eu/en/news/news/observer-2022-year-extremes

Temperature records in the UK

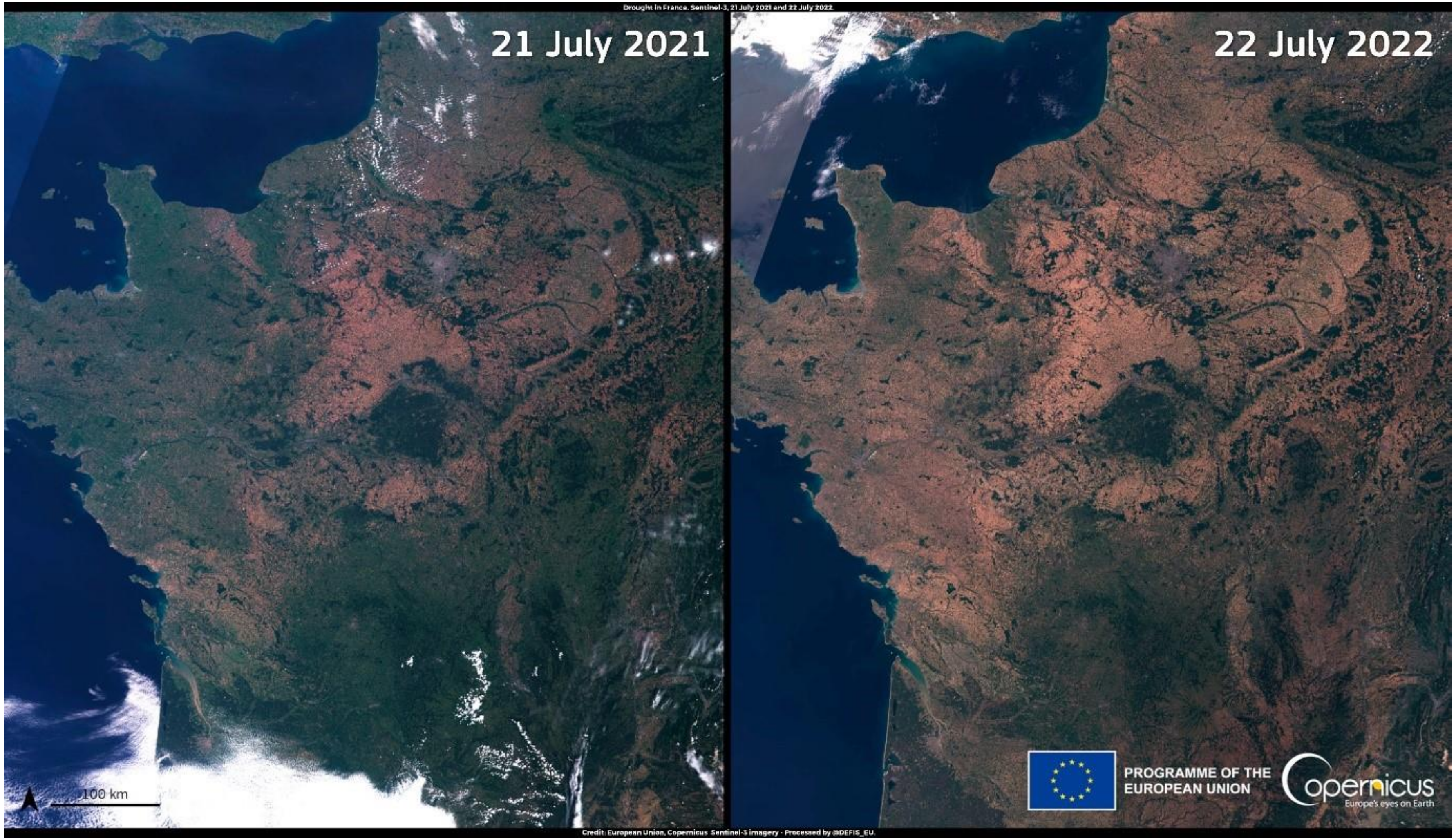




https://www.carbonbrief.org/guest-post-a-met-office-review-of-the-uks-record-breaking-summer-in-2022/

Impact on vegetation

- The drought conditions were evident from satellite images, such as the comparison of France from July 2021 with July 2022
- In France, 90 out of the 96 administrative “*départements*” were affected by water restrictions
- Other countries saw similar water restrictions, which lasted into the winter

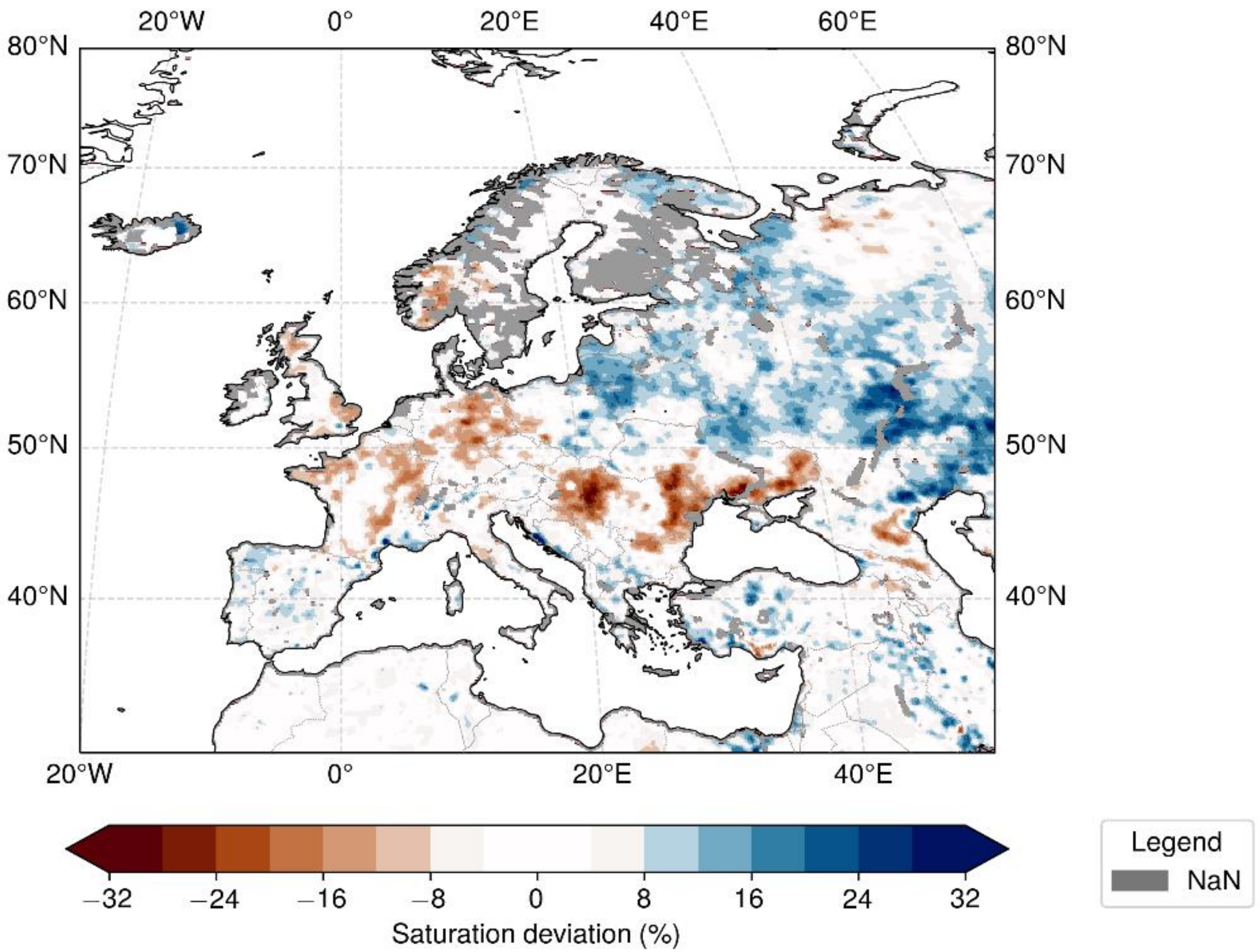


https://www.copernicus.eu/en/news/news/observer-2022-year-extremes

H SAF surface soil moisture anomaly

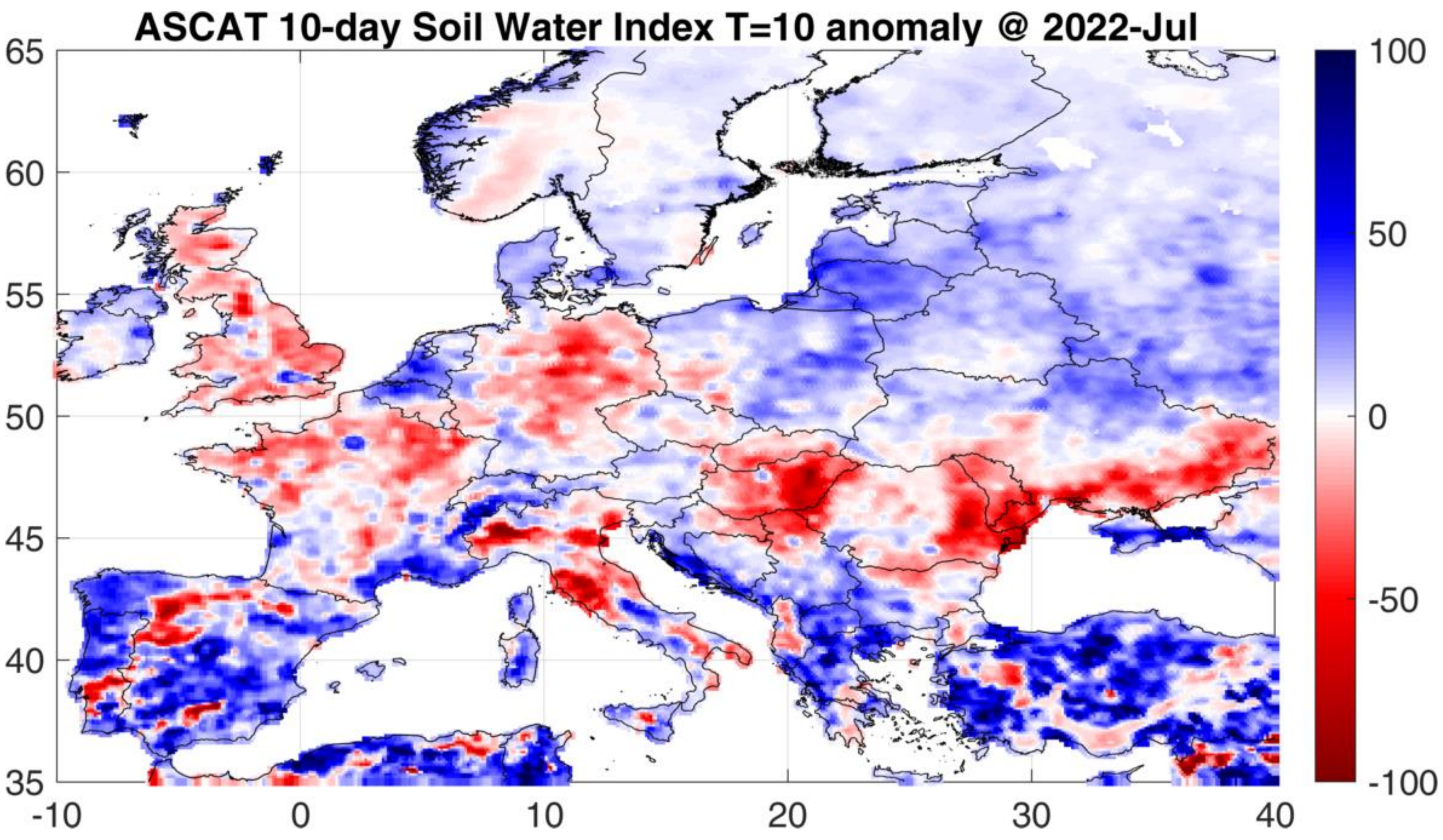
- Highly negative surface soil moisture anomalies (deviation < -10%) were present over many parts of Europe during July and August.
- Wetter than usual conditions were present over parts of eastern Europe and Scandinavia

ASCAT SSM DR v7 12.5 km (H119) and ASCAT SSM DR EXT v7 12.5 km (H120)
Jul 2022



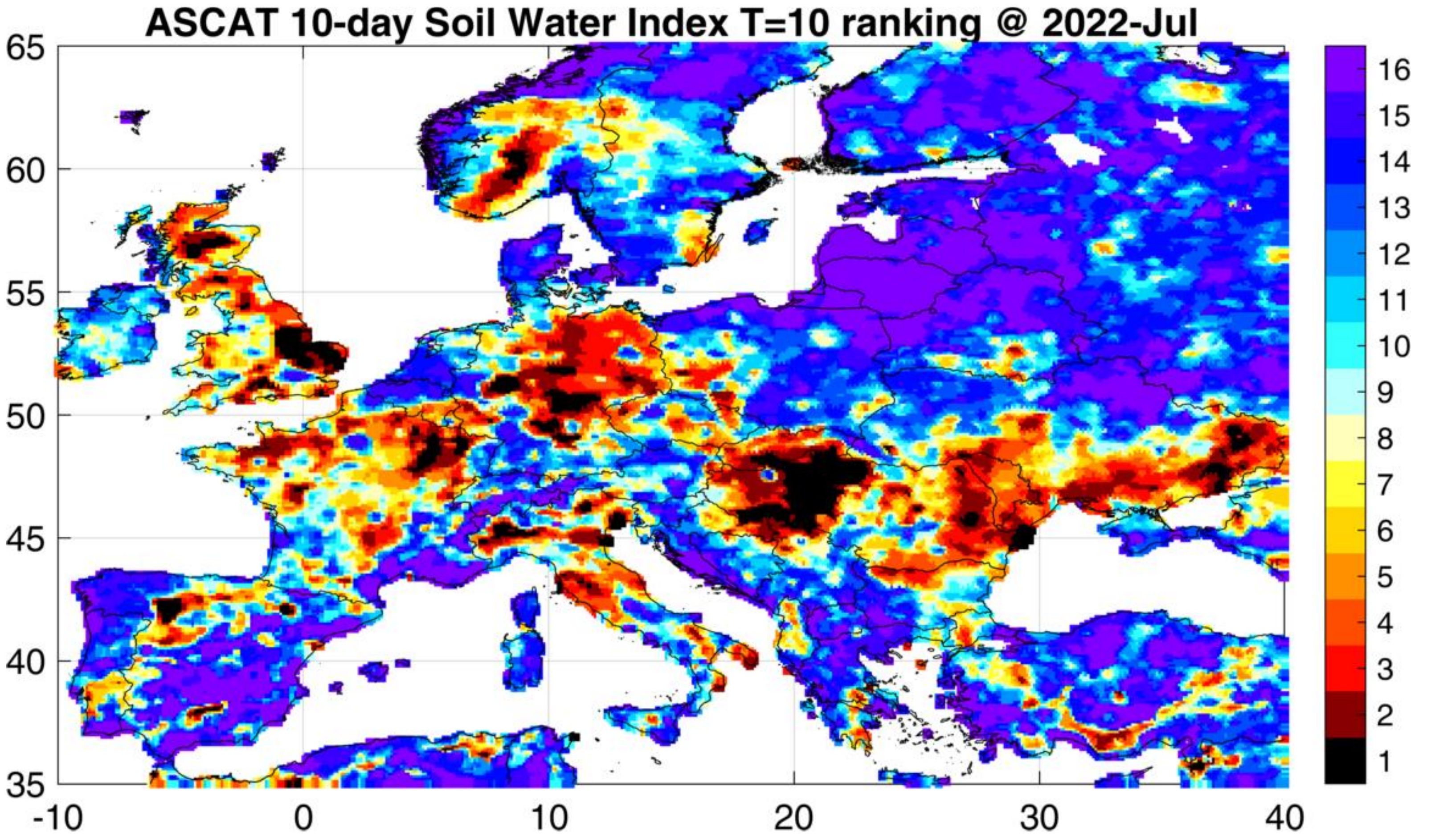
CGLS soil moisture

- The Copernicus Global Land Service (CGLS) Soil Water Index 10-daily SWI 12.5km V3 (SWI10) product is shown, which takes H SAF ASCAT NRT SSM products as input.
- The SWI10 anomalies for July 2022 shows dry conditions in deeper soil layers.



CGLS soil moisture

- Map plot shows the ranking of the SWI10 anomaly based on the past 16 years (2007-2022) is given in Figure 5. A ranking of 1 (16) indicates the driest (wettest) July during the period.
- Several parts of Europe were ranked as 1, highlighting the severity and extent of the drought
- This is even more remarkable given that several dry European summers were recorded during the 16-year ranking period (e.g. 2015, 2018, 2019).



H SAF Root-zone SM anomaly

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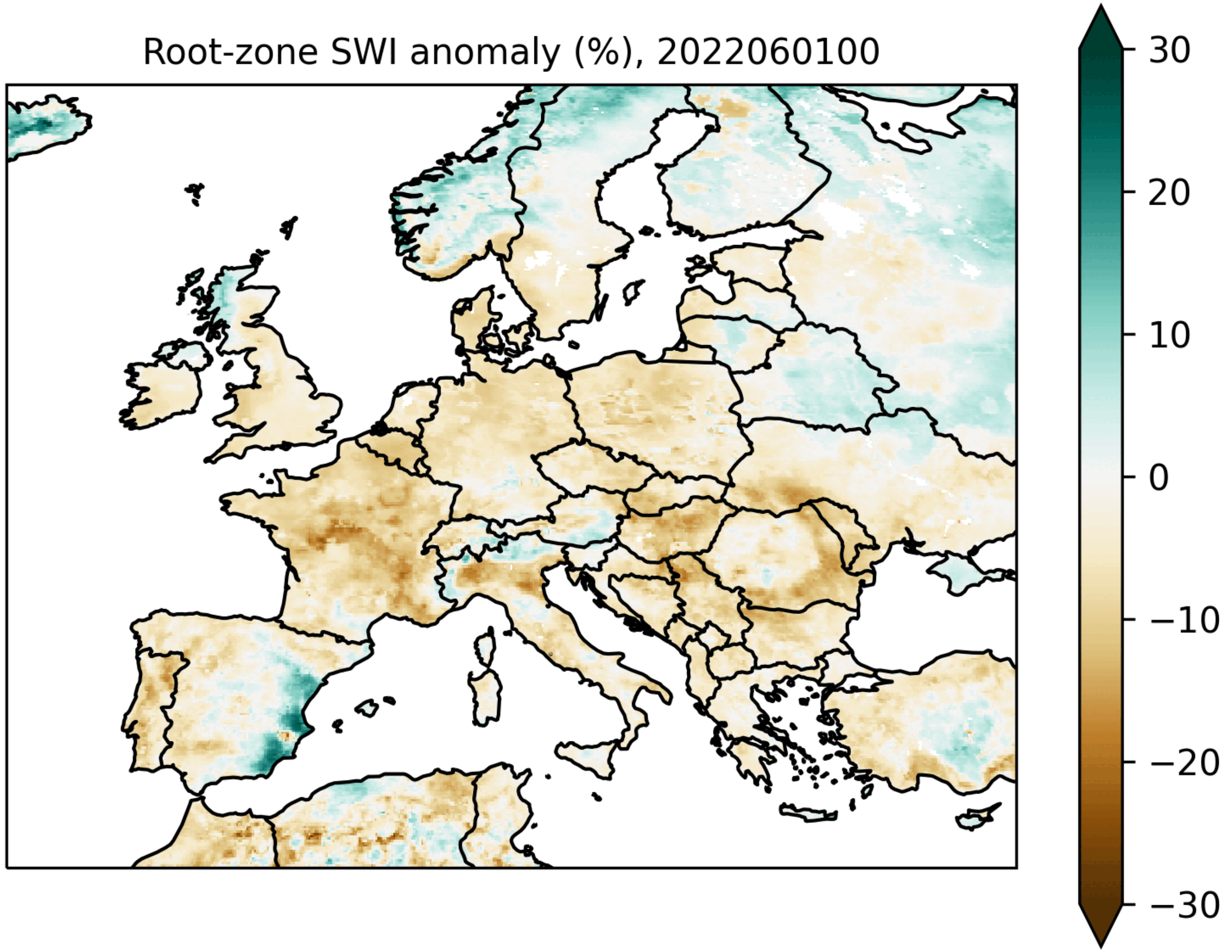
- Data record (H145) available from 1992-2022
- SM layer 3 (28-100 cm) approximates the root-zone
- Daily anomaly (%) for June-August 2022, relative to centred 10-day (dekad) rolling mean (1992-2021)

$$(SM_i - \overline{SM})*100.0$$

- Extremely dry anomalies develop over most of Europe (<-20%)
- Dipole effect, with wet anomalies over parts of Scandinavia and eastern Europe

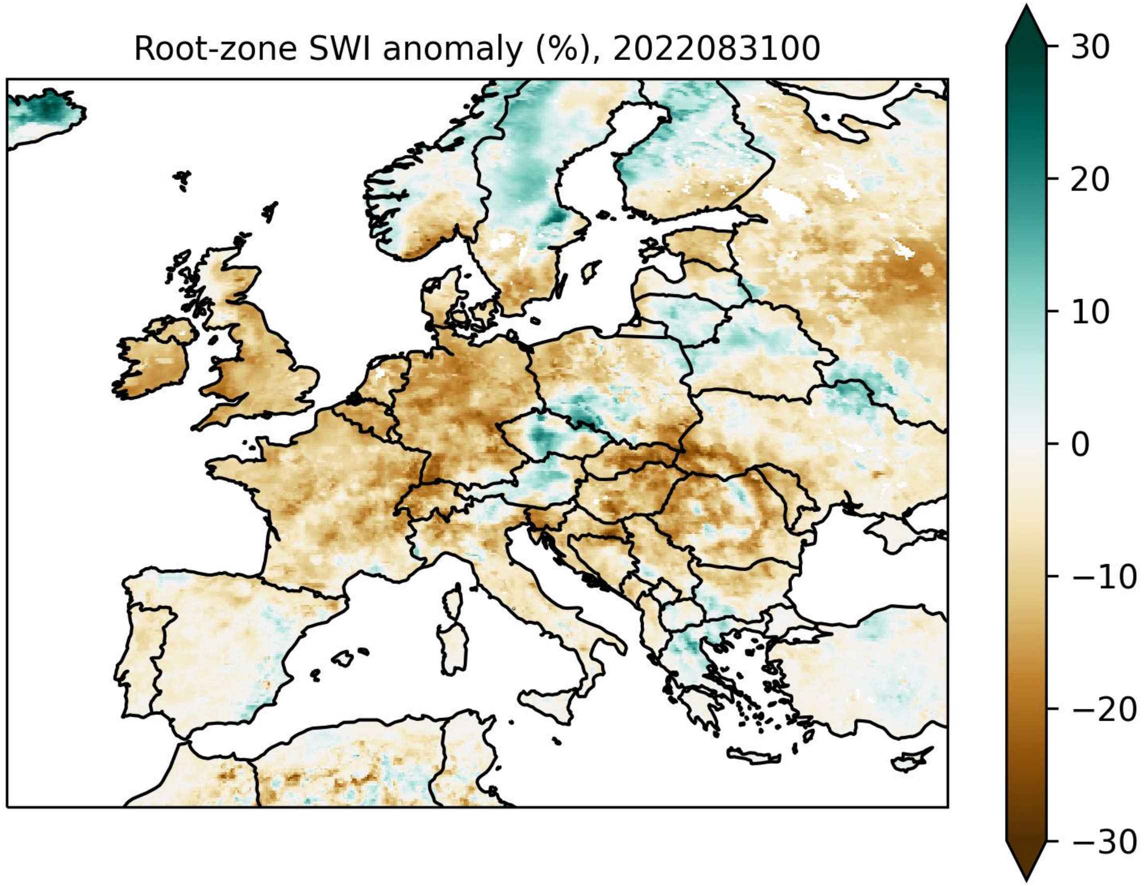
H145 layer 3 (28-100 cm depth) anomaly with respect to 1992-2021 mean



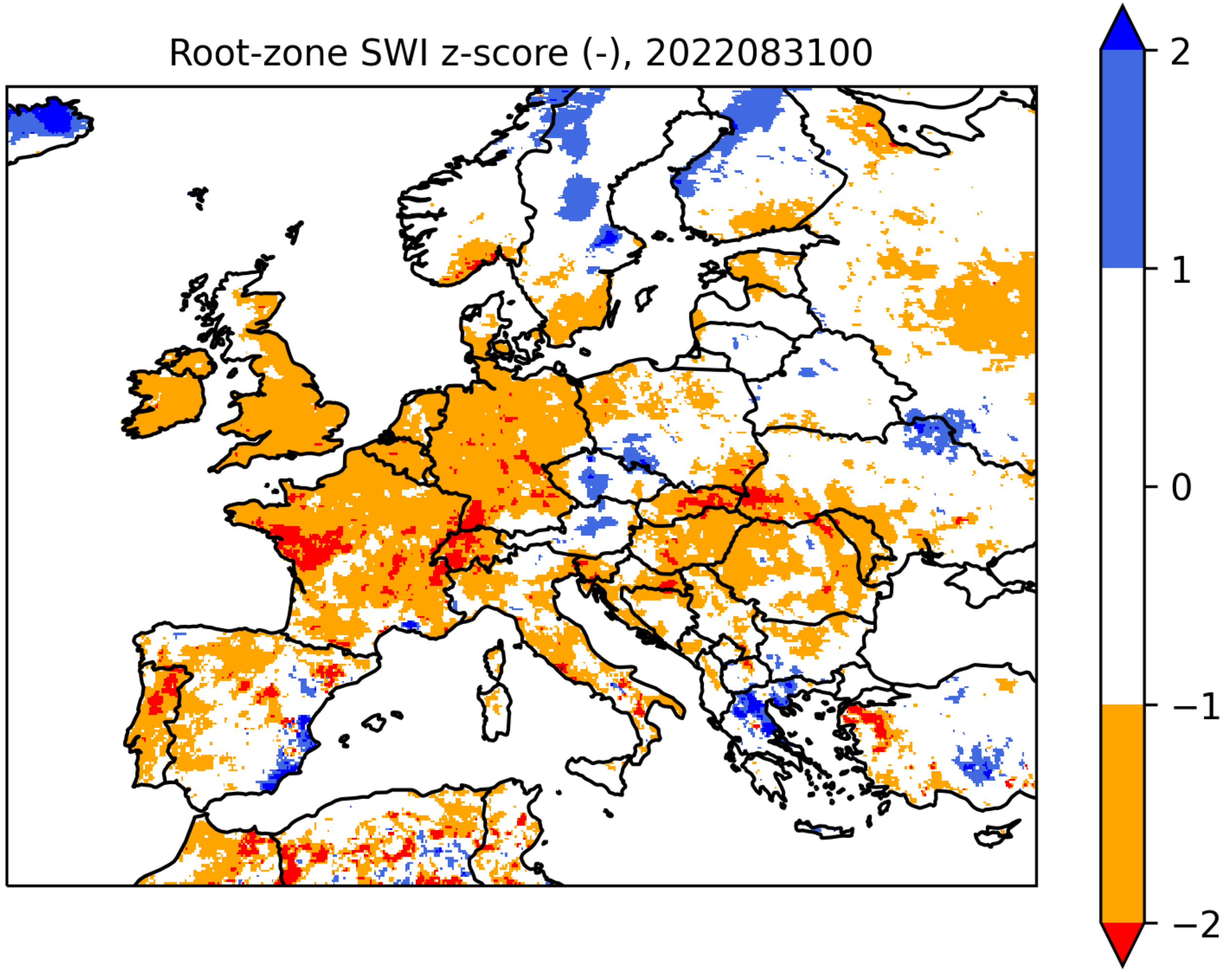
H SAF Root-zone SM anomaly

- Z-score based on dekad anomaly relative to 1992-2021 $\frac{SM_i - \overline{SM}}{\sigma}$
- Drought conditions (<-1), Severe drought (<-2)
- Widespread drought by the end of August

Root-zone SWI anomaly (%), 2022083100

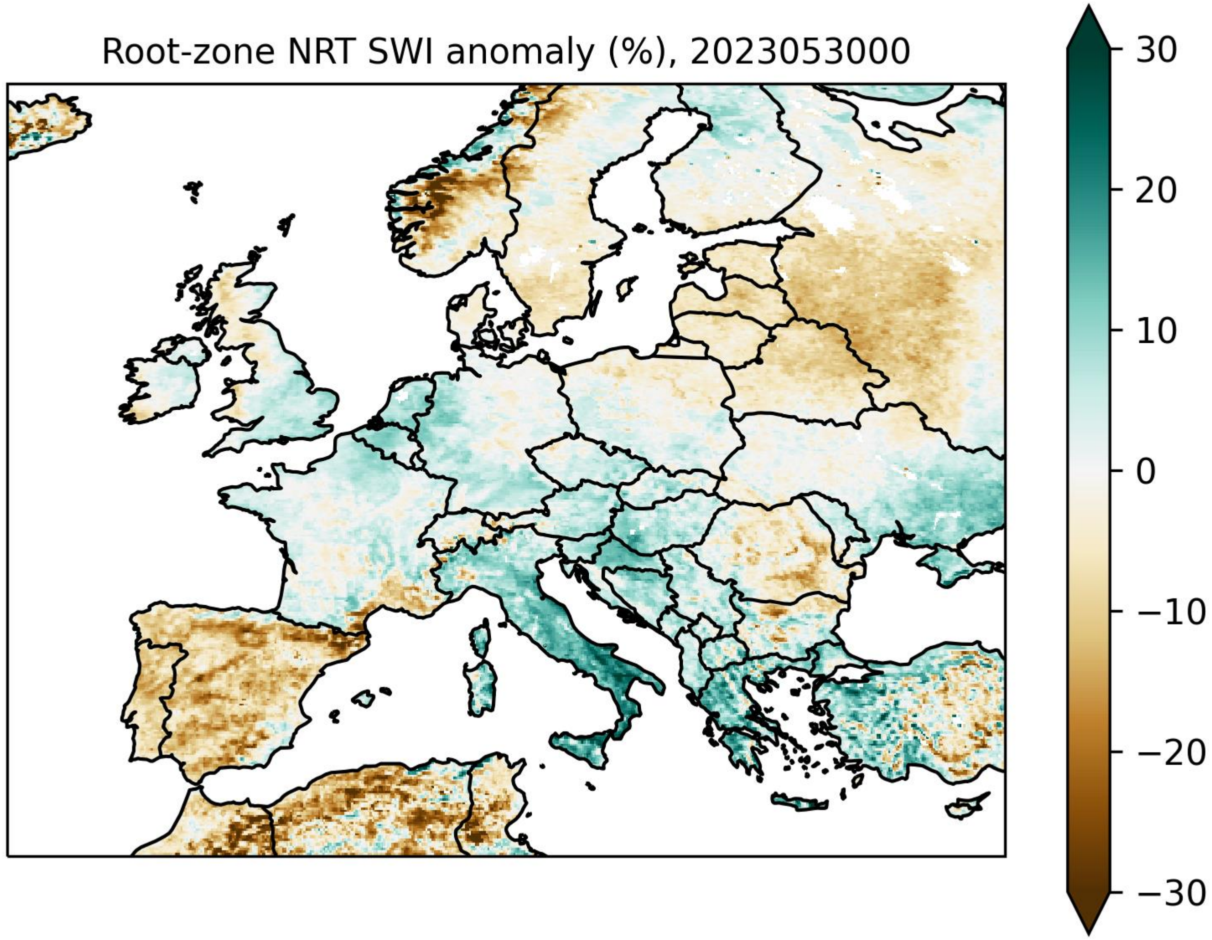


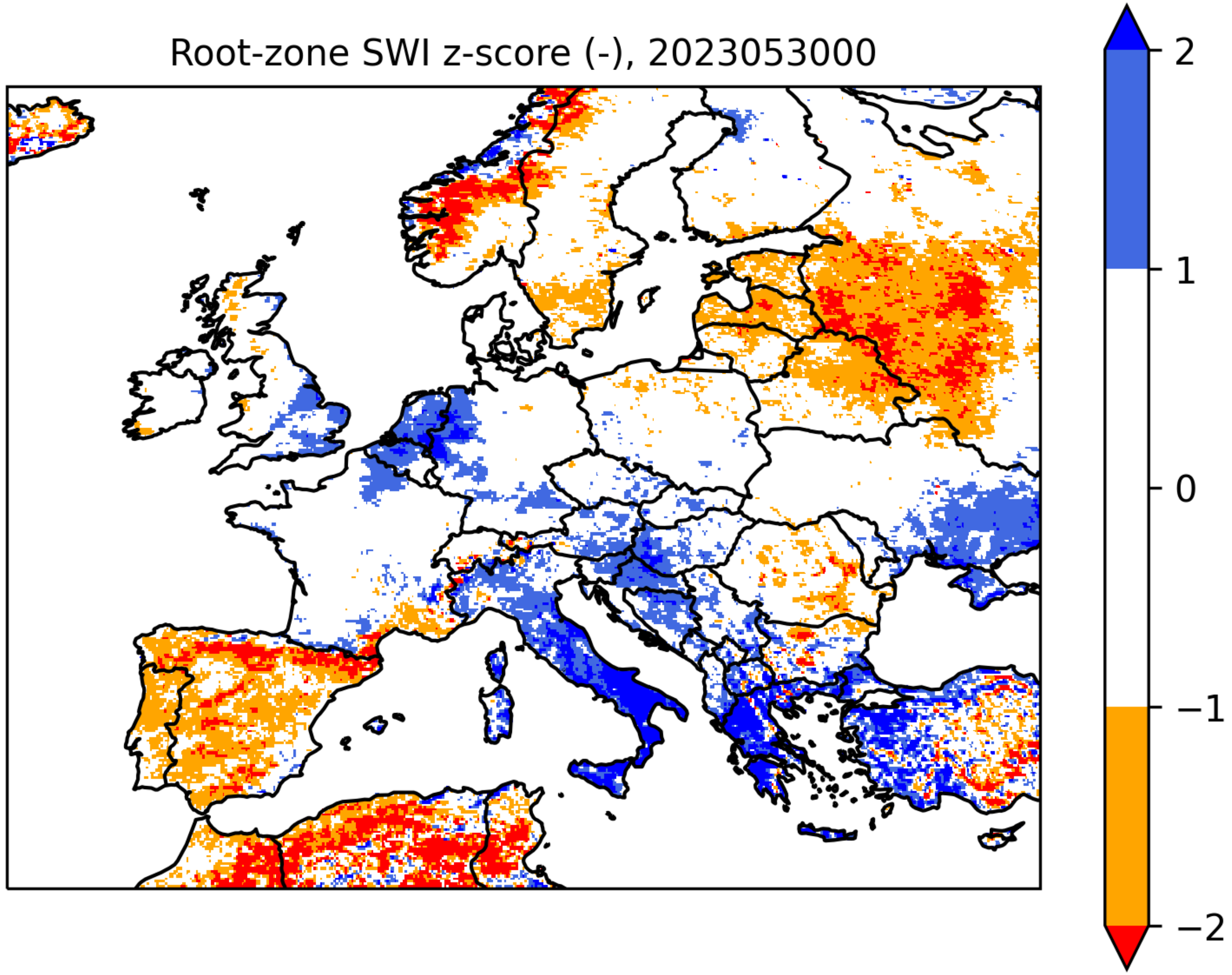
Root-zone SWI z-score (-), 2022083100



Near-real-time SM anomaly

- For recent anomalies (from 2023), the NRT root-zone SM product (H26) is available
- Comparison of H26 near-real-time SM (12-hour latency) with H145 SM data record (1992-2021)
- Drought conditions captured over the Iberian peninsula (z-score<-1)





Slido question:

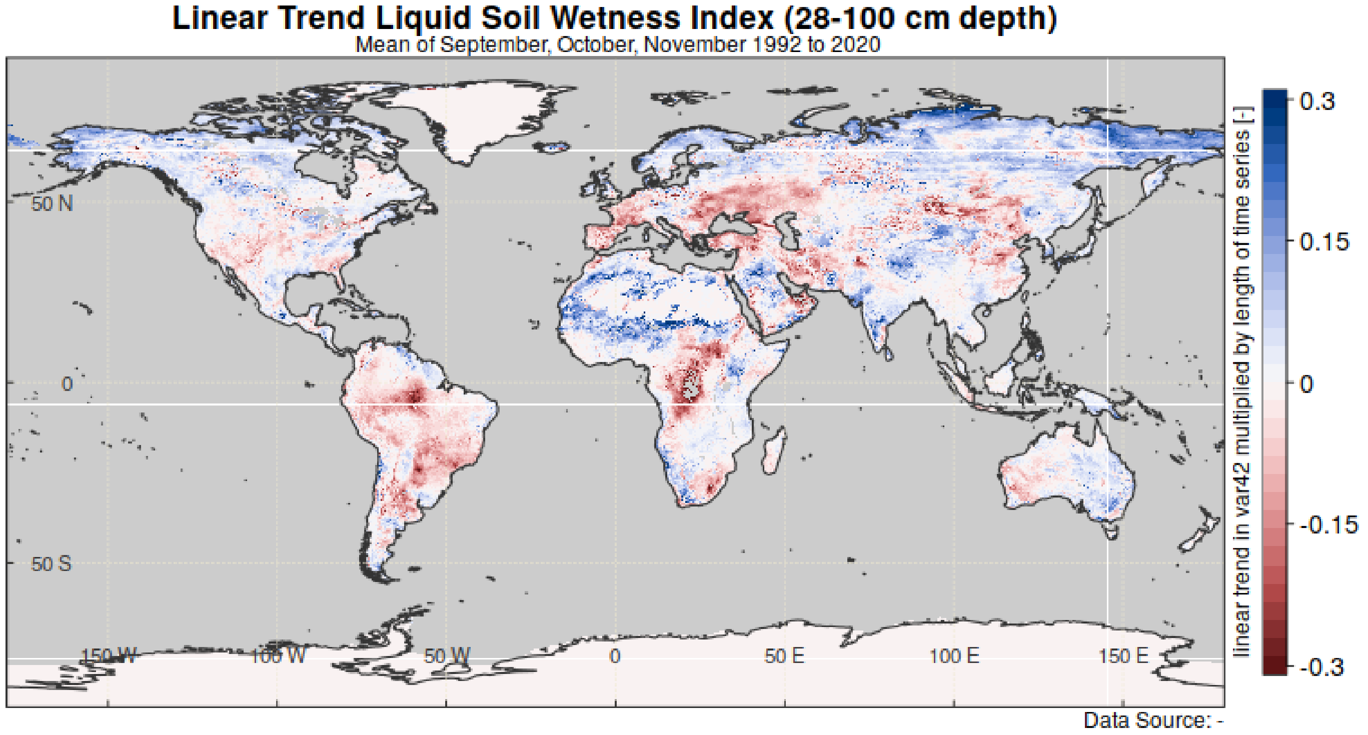
#SMdrought

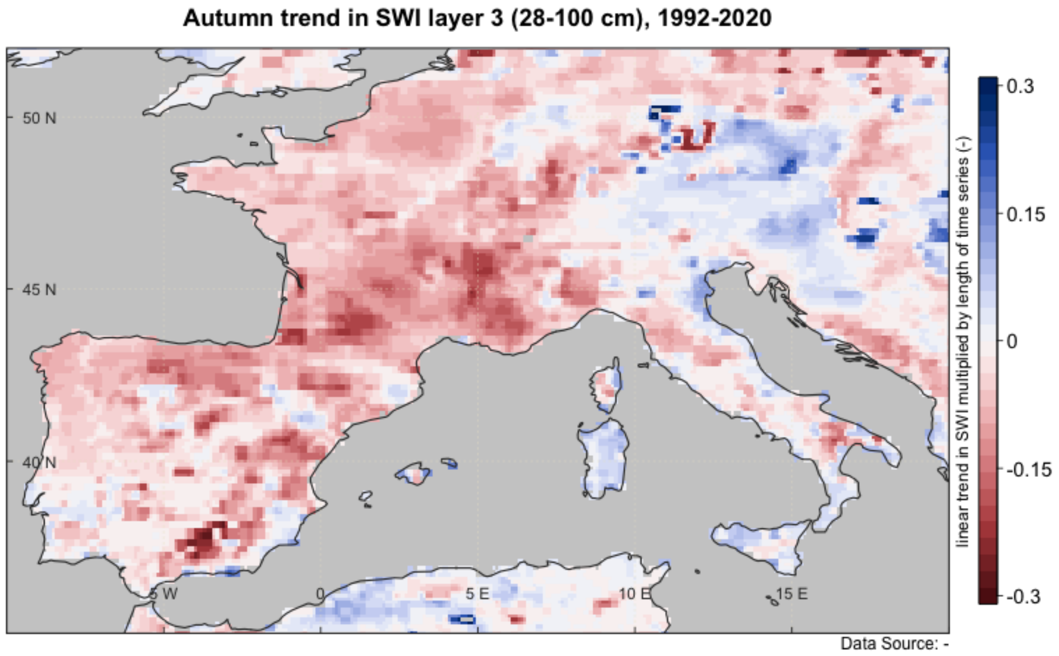
In your country of origin, does it seem like the frequency of droughts has

1. Decreased
2. Increased
3. Neither decreased nor increased

https://app.sli.do/event/2E3dbDyB5hEtWTs5qe7dvB

Data record trends (1992-2020)



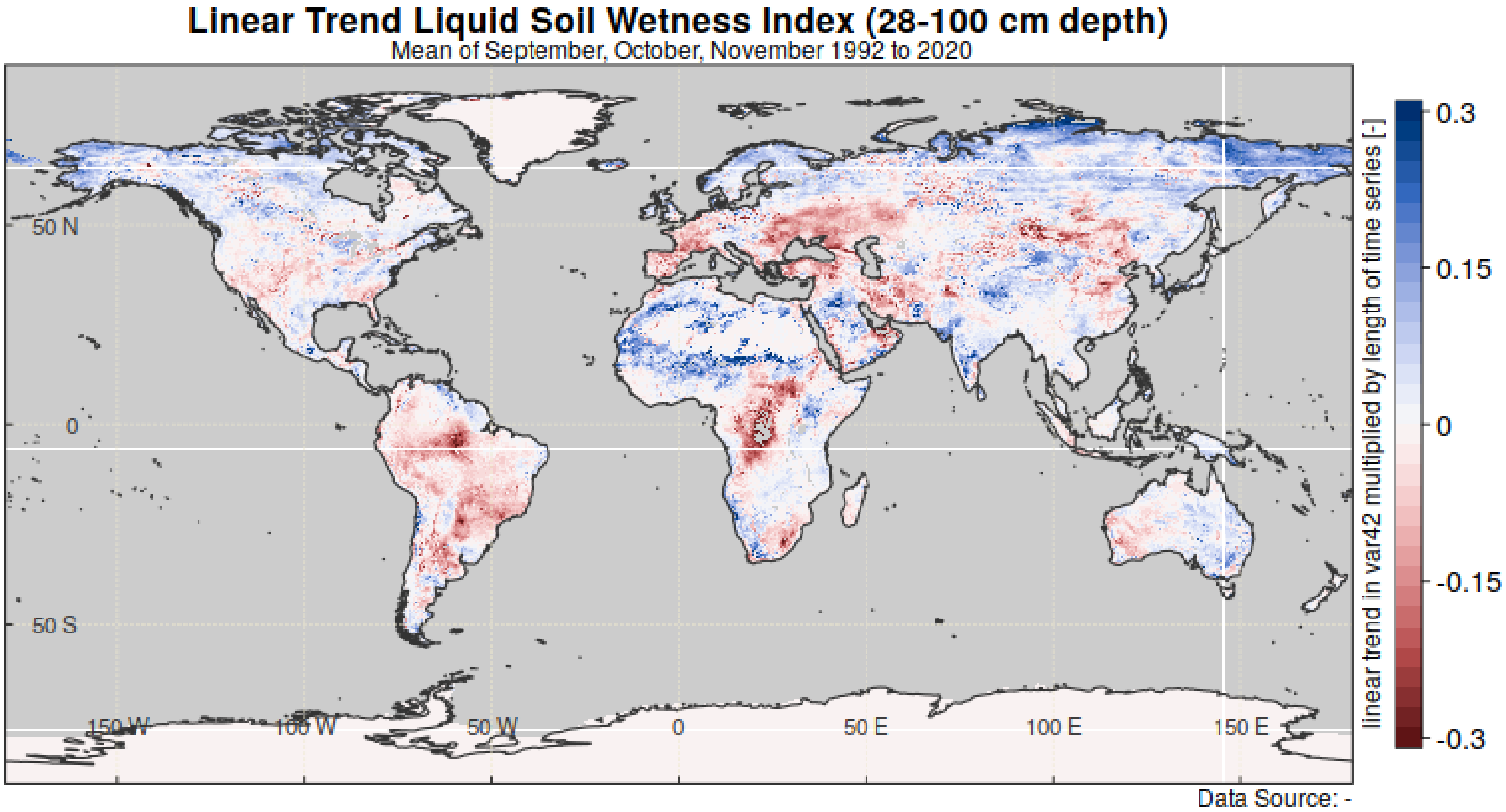


Trends calculated using CMSAF toolbox software (Kothe et al., 2019)

- Soil moisture has decreased by up to 30% in midlatitude summer/autumn months, especially Europe
- Trends suggest that summer droughts are becoming more likely in midlatitudes and some low-latitude regions

Data record trends (1992-2020)

- Slido (#SMdrought): Does your perception of the drought trend in your country of origin agree with the SM trend on the map (assuming negative trend implies drought more likely)?



3. Building drought indices

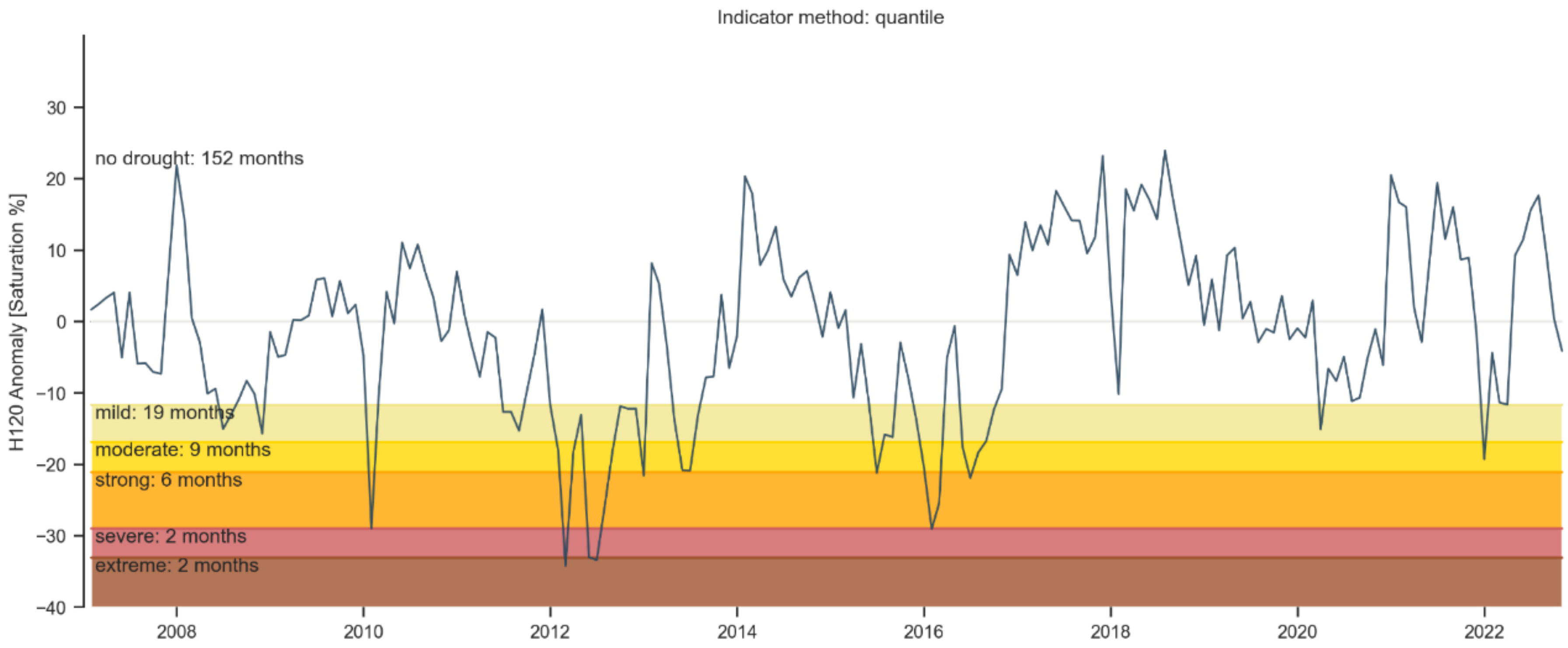
Anomaly indicators:

Vreugdenhil et al. 2022

Indicator	Equation	Common thresholds	
Anomalies and percentiles (Champagne et al., 2011; Nicolai-Shaw et al., 2017; van Hateren et al., 2021; Vroege et al., 2021)	$SMA_{k,i} = SM_{k,i} - \overline{SM_i}$	No drought	20% or more
		Mild	10–20%
		Moderate	5–10%
		Significant	2–5%
		Severe	1–2%
		Extreme	Lower than 1%
Z-scores (Cammalleri et al., 2017)	$Z_{k,i} = (SM_{k,i} - \overline{SM_i})/\sigma_i$	Mild	More than −1
		Moderate	−2 to −1
		Severe	Lower than −2
Standardized Soil Moisture Index (SSI, ESSI, SSMI) (Carrão et al., 2016; Xu et al., 2018; Ford and Quiring, 2019; Modanesi et al., 2020)	Monthly average soil moisture; Fitted statistical distribution function with Kernel Density Estimator; Percentile value transformed to standard normal cumulative probability distribution function	No drought	−0.84 or more
		Mild	−0.84 to −1.00
		Moderate	−1.01 to −1.50
		Severe	−1.51 to −2.00
		Extreme	Lower than −2.00
Soil Moisture Anomaly Percentage Index (SMAPI) (Liu et al., 2019)	$SMAPI_{k,i} = \frac{SM_{k,i} - \overline{SM_i}}{\overline{SM_i}} \times 100\%$	No drought	−5% or more
		Mild	−15 to −5%
		Moderate	−30 to −15%
		Severe	−50 to −30%
		Extreme	More than −50%
Soil Moisture Deficiency Index (SMDI) (Pablos et al., 2017; Xu et al., 2018; Fang et al., 2021)	$SMDI_{k,i} = 0.5 \cdot SMDI_{k,i-1} + \frac{SD_{k,i}}{50}$ $SD_{k,i} = \frac{SM_{k,i} - SM_{median,i}}{SM_{max,i} - SM_{median,i}} \cdot 100 \; if \; SM_{k,i} > SM_{median,i}$ $SD_{k,i} = \frac{SM_{k,i} - SM_{median,i}}{SM_{median,i} - SM_{min,i}} \cdot 100 \; if \; SM_{k,i} < SM_{median,i}$	No drought	0 or more
		Mild	−1 to −0.01
		Moderate	−2 to −1.01
		Severe	−3 to −2.01
		Extreme	−4 to −3.01
Soil Water Deficit Index (SWDI) (Martínez-Fernández et al., 2016, 2017; Mishra et al., 2017; Pablos et al., 2017; Paredes-Trejo and Barbosa, 2017; Bai et al., 2018; Fang et al., 2021; Paredes-Trejo et al., 2021; Zhou et al., 2021; Cao et al., 2022; Chatterjee et al., 2022; Wu et al., 2022)	$SWDI = \frac{SM - SM_{FC}}{SM_{FC} - SM_{WP}} \cdot 10$	No drought	0 or more
		Mild	−2 to −0.01
		Moderate	−3 to −2.01
		Severe	<-3
		Extreme	
Soil Moisture Agricultural Drought Index (SMADI) (Sánchez et al., 2016; Mercedes-Salvia et al., 2021; Souza et al., 2021)	$VCI = \frac{NDVI_i - NDVI_{max}}{NDVI_{max} - NDVI_{min}}$ $MTCI = \frac{LST_i - LST_{max}}{LST_{max} - LST_{min}}$ $SMCI = \frac{SM_{max} - SM_i}{SM_{max} - SM_{min}}$ $SMADI_i = SMCI_i \frac{MTCI_i}{VCI_{i+1}}$	No drought	0 to1
		Mild	1.01 to 2
		Moderate	2.01 to 3
		Severe	3.01 to 4
		Extreme	More than 4

Quantiles for Mozambique

Surface SM % anomaly for H119/H120



Slide from Mariette Vreugdenhil

Z-score for Mozambique

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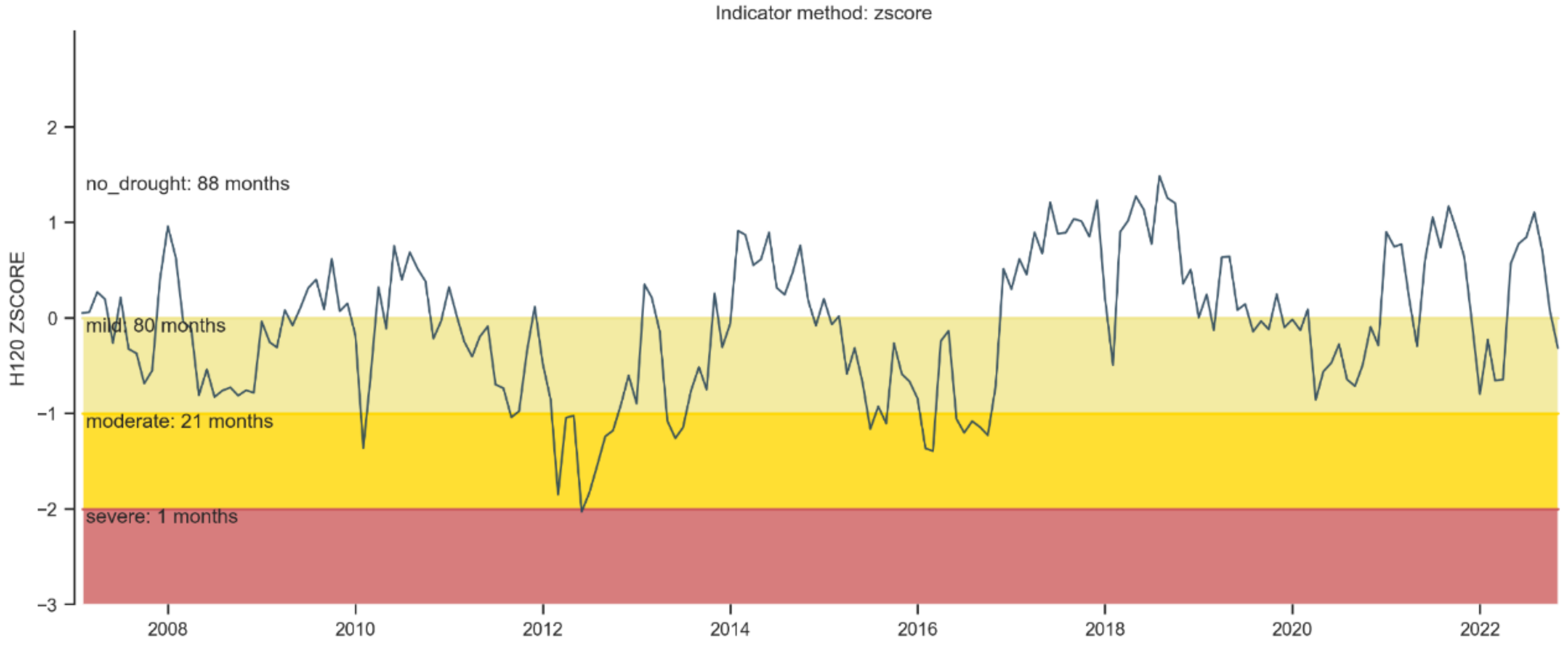
Z-score (-) for H119/H120



Slide from Mariette Vreugdenhil

Soil Moisture Anomaly % Index

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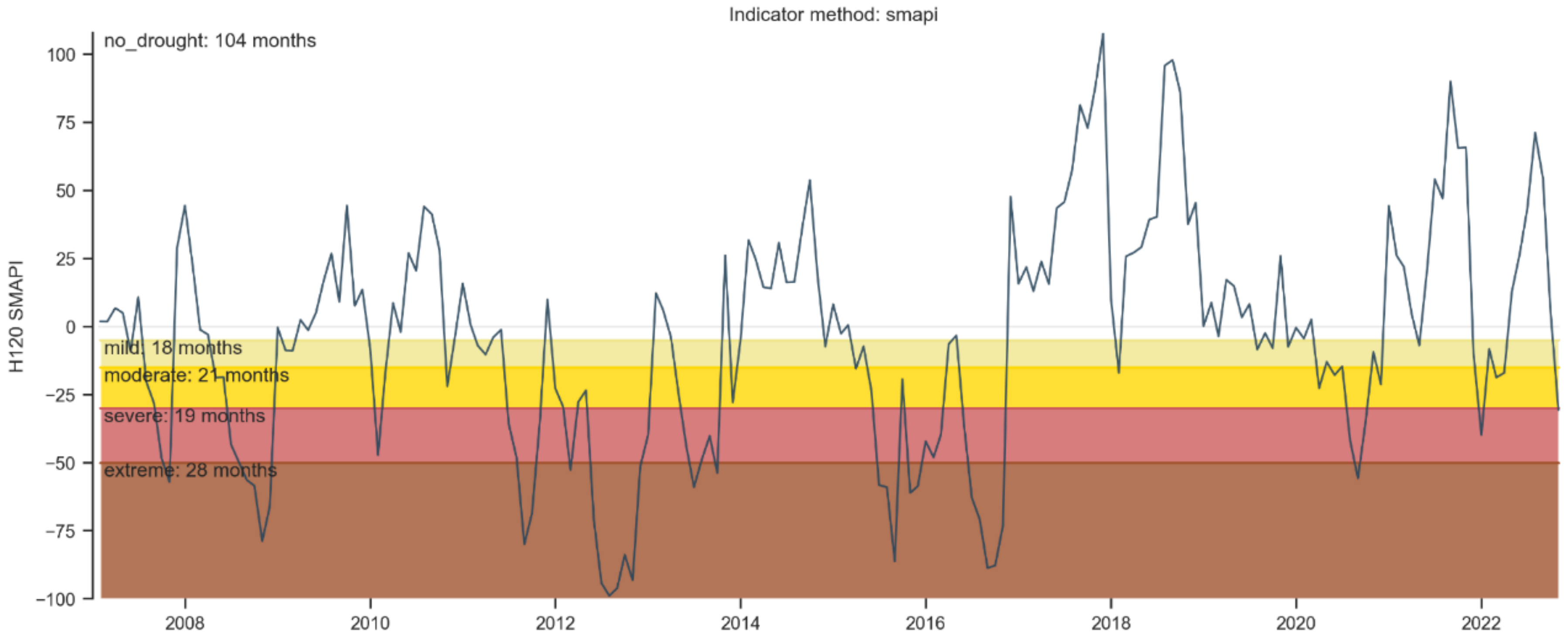
SM % index for H119/H120



Slide from Mariette Vreugdenhil

VS/AS Activity – Soil moisture anomaly workflows

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- Cluster: Soil Moisture
- Host institute: TU Wien
- VS Supervisors: M. Vreugdenhil W. Wagner, S. Hahn

Motivation

- Weather-related disasters have increased in frequency and severity in the past decades
- Condensation of large volume of satellite soil moisture data to relevant information for the public and decision maker to raise awareness of imminent drought and flood events
- Request by SAF Network

Objectives

- Investigate state-of-the-art methods to compute soil moisture anomalies
- Create multiple soil moisture anomaly maps using H SAF ASCAT soil moisture products and compare them against historic drought and flood events
- Make recommendations on which anomaly metrics are best suited for highlighting drought and flood events
- Develop a workflow that produces soil moisture anomaly maps from H SAF soil moisture products
- Provide workflow as open source sharing it with users

Summary

Summary

- SM products can be used to monitor droughts. The surface SM is more sensitive to the meteorological conditions, whilst the root-zone SM has a long memory and is more related to vegetation stress.
- Long-term climate data records (CDRs) demonstrated the exceptional severity and extent of the 2022 summer drought over Europe
- Near-real-time root-zone SM anomalies capture the current drought over the Iberian Pensinsula
- CDR trends in Europe indicate that soil moisture has become up to 30% drier in summer/autumn over the last 30 years
- Different indices exist for drought monitoring, including the % anomaly, z-score and SM anomaly % index.
- Although all the metrics capture droughts, they may differ in severity for individual events
- SM is an important drought indicator, but other variables are important too (next presentation gives more details)

References

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