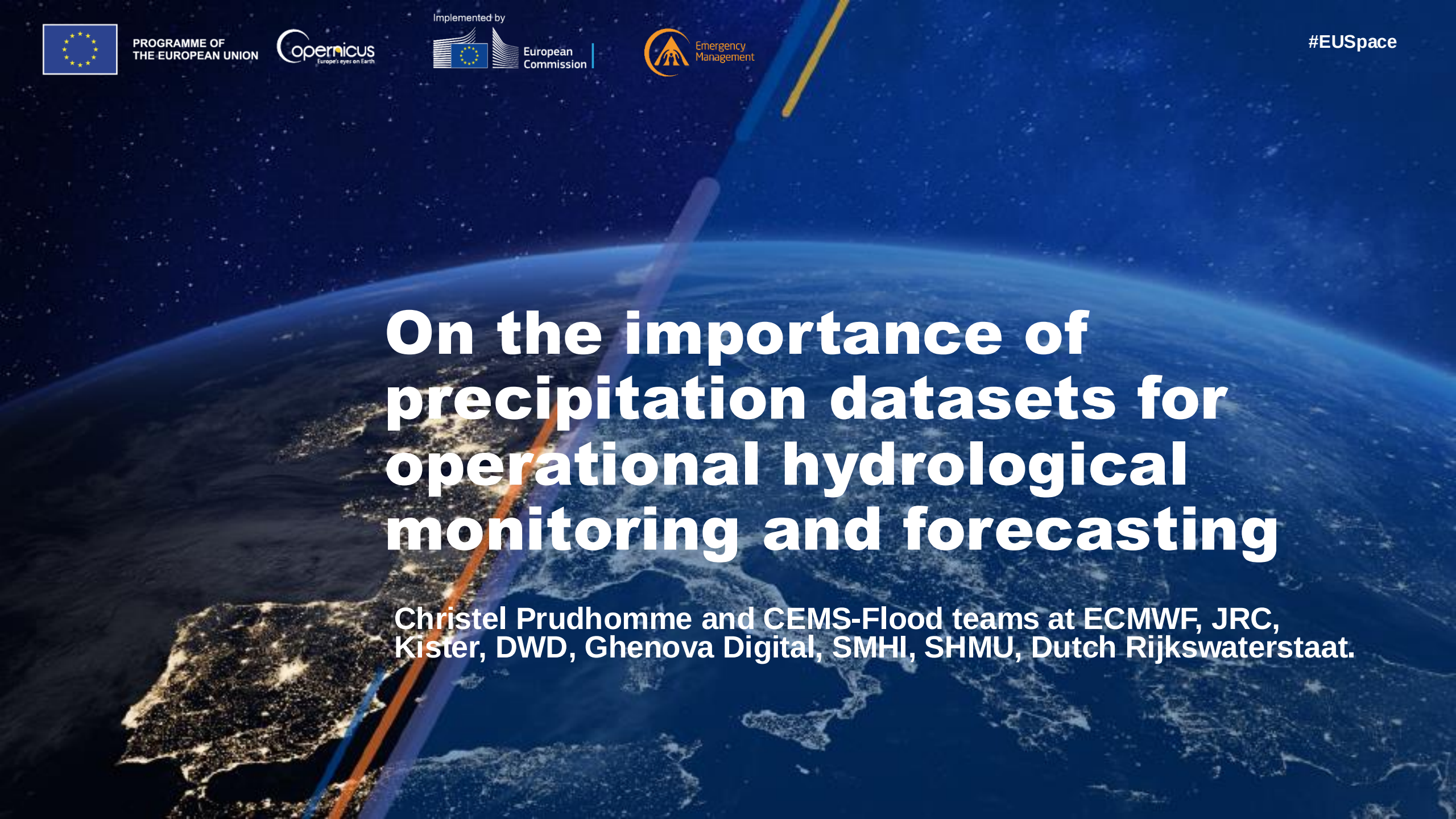



# On the importance of precipitation datasets for operational hydrological monitoring and forecasting

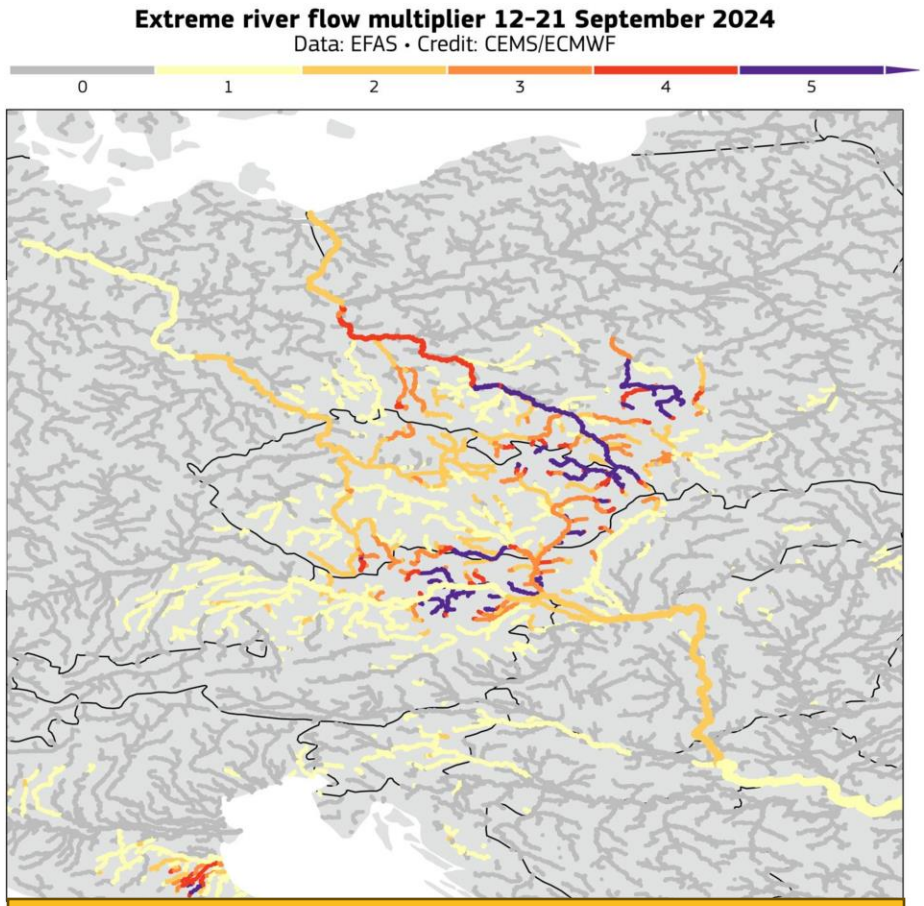
Christel Prudhomme and CEMS-Flood teams at ECMWF, JRC, Kister, DWD, Ghenova Digital, SMHI, SHMU, Dutch Rijkswaterstaat.

Czech Police

#EUSpace

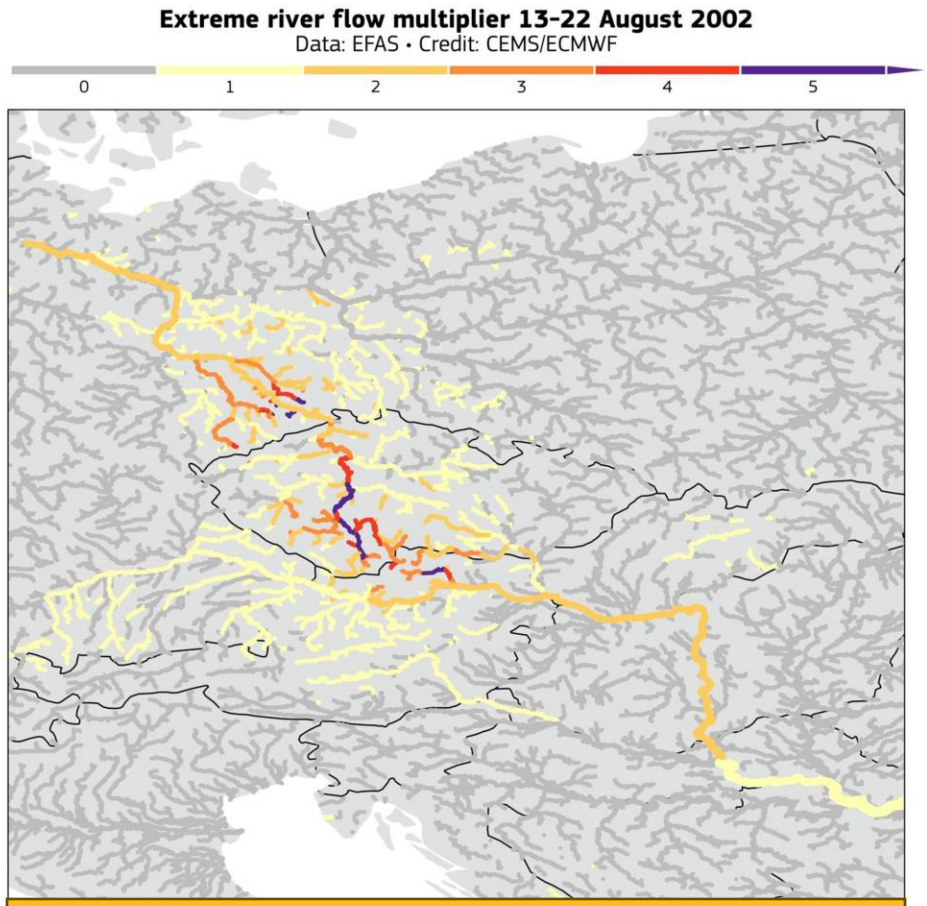
# The need for large-scale flood forecasting is growing

Storm Boris produced flood peaks beyond twice the average annual maximum along 8,500 km of rivers—**over double the extent of the 2002 floods**




**Storm Boris (September 2024)**

- 27 fatalities
- ~€2-3.5 billion damage
- Germany, Czechia, Austria, Poland, Slovakia, Hungary, Romania



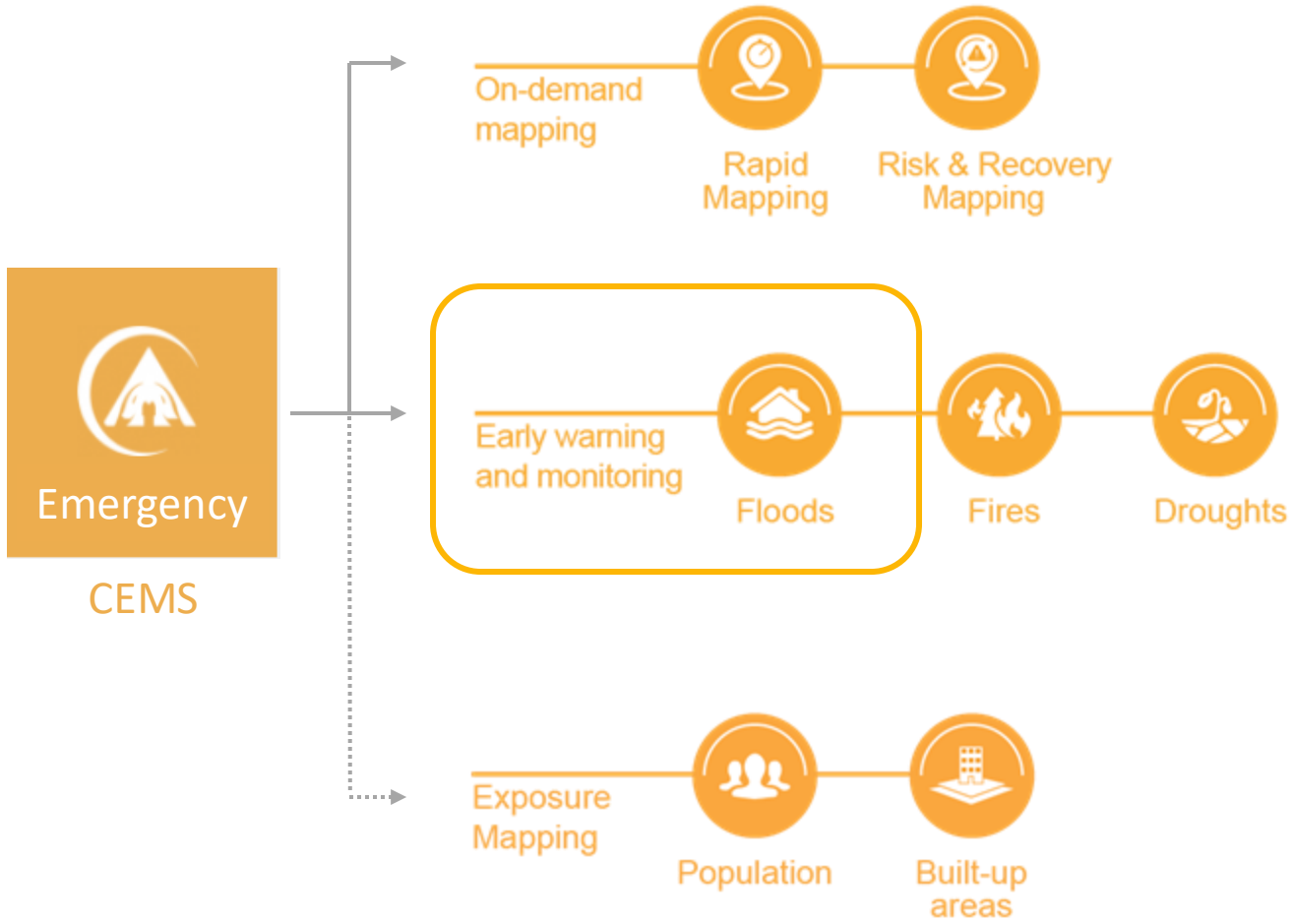

**August 2002 floods**

- 110 fatalities
- > €15 billion damage
- Germany, Czechia, Austria, Poland, Slovakia, Hungary

#EUSpace

Emergency Management

# The Copernicus Emergency Management Services




**Copernicus EMS On Demand Mapping**
provides on-demand detailed geospatial information for selected emergency situations that arise from natural or man-made disasters anywhere in the world.

**Copernicus EMS Early Warning and Monitoring**
provides critical geospatial information at European and global level through continuous observations and forecasts for floods, droughts and forest fires.

**Copernicus EMS Exposure Mapping**
provides highly accurate and continuously updated information on the presence of human settlements and population with the Global Human Settlement Layer (GHSL).

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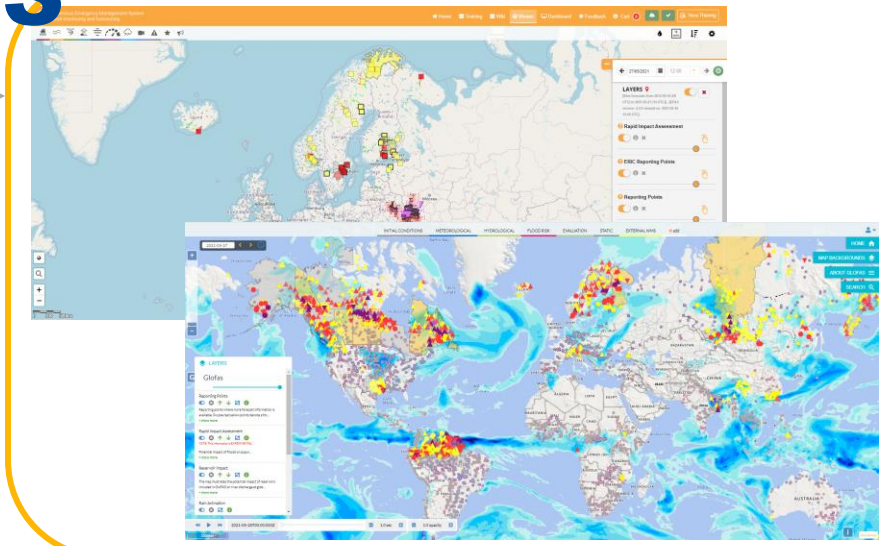
Emergency Management

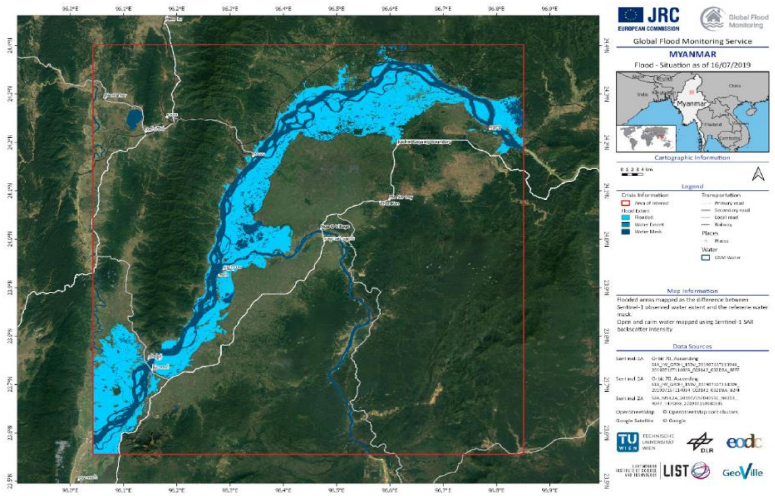
# CEMS FLOODS

Early warning and monitoring

Floods



The **European Flood Awareness Systems** (EFAS) and **Global Flood Awareness Systems** (GloFAS) provide **complementary** flood forecast information to relevant stakeholders that support flood risk management at the national, regional and global level.




The **Global Flood Monitoring** (GFM) Service offers an automated global monitoring of floods in near real-time.

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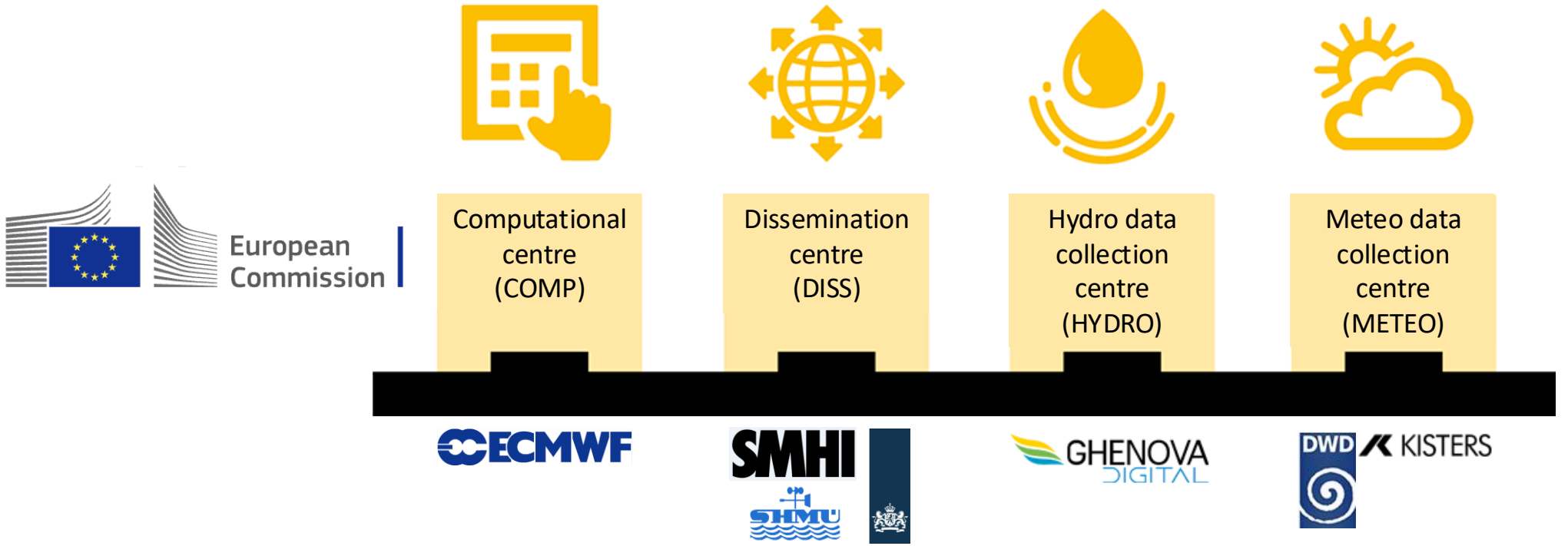
Emergency Management

# CEMS FLOODS SET-UP

Operational CEMS-Flood forecast EFAS is made of 4 centres executed by different consortia. The Joint Research Centre of the European Commission is the entrusted entity responsible of CEMS-FLOODS in terms of management, technical implementation and evolution.



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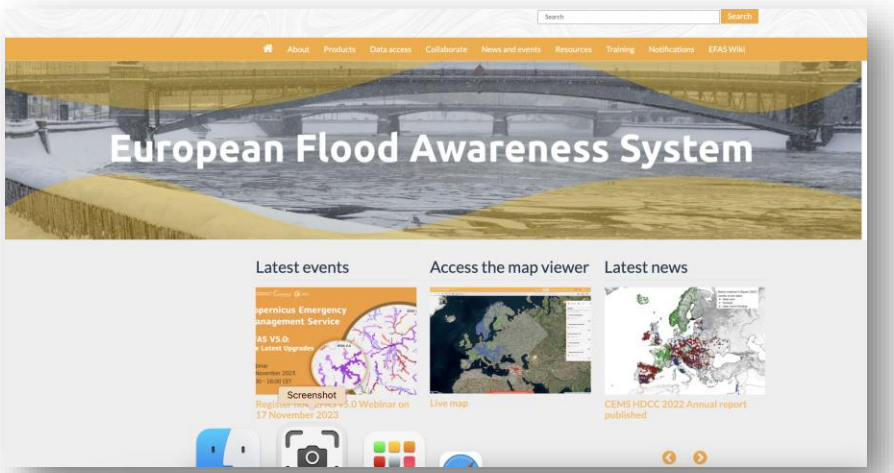
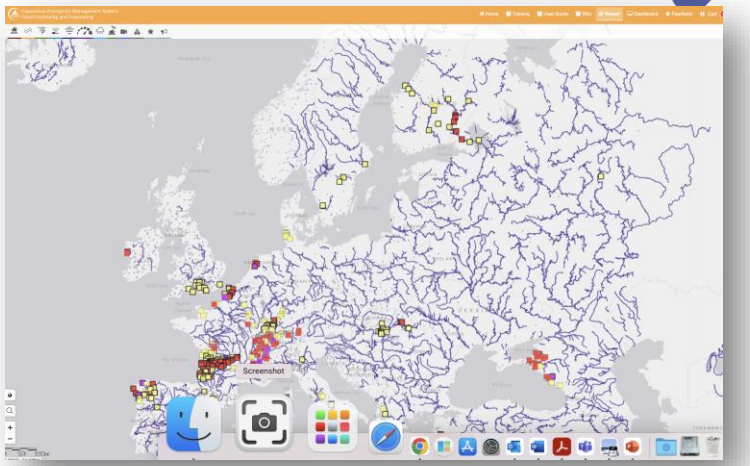
# What do EFAS and GloFAS offer?

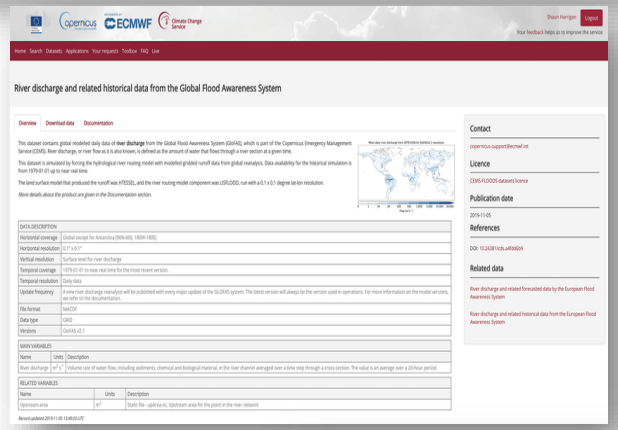



## EFAS website

www.efas.eu

Access to real-time maps only for EFAS partners

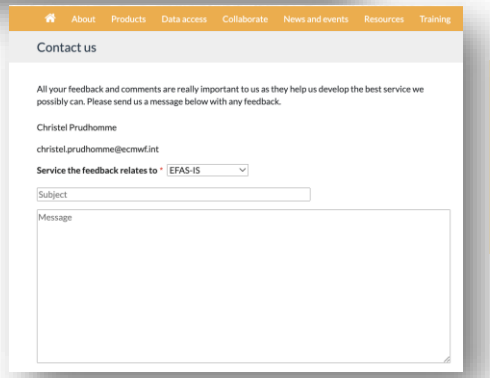



## EFAS data service (CDS)

## On-demand ftp service (EFAS partners)

- Password protected service
- Latest EFAS forecasts for fixed reporting points
- Available as netCDF files




## EFAS support

Wiki documentation

On-demand support service

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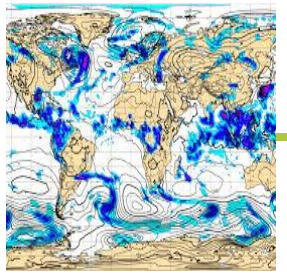
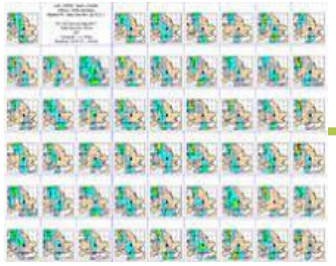
Emergency Management

# At the core: CEMS Flood processing chain



Weather OBS/ ERA5 to forecast date

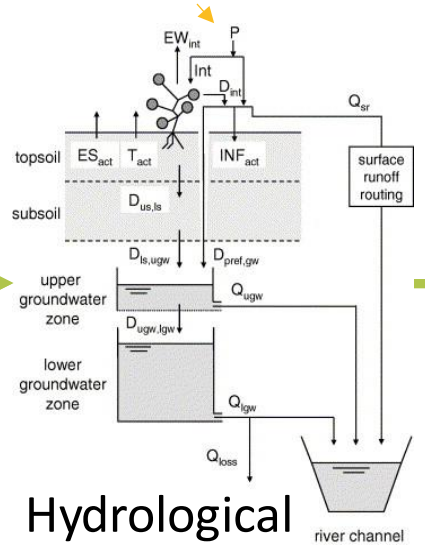


Weather forecasts up to 7 months

*ECMWF ENS*

Time-invariant data

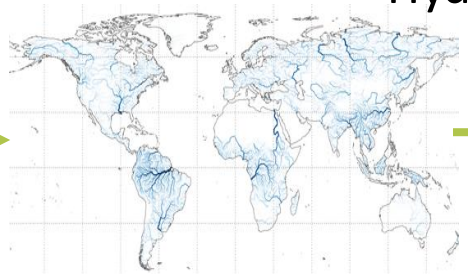
*Geo-spatial maps, parameters*




Hydrological Model

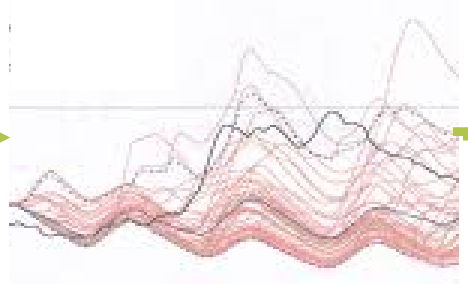
*LISVAP, LISFLOOD*

Surface fields at ~1.5/5km resolution
Calibrated ~2000 catchments (EFAS/GloFAS each)
Covering European/ Global domain
6hourly/ Daily



Hydrological status update

*River discharge, Soil moisture, etc…*

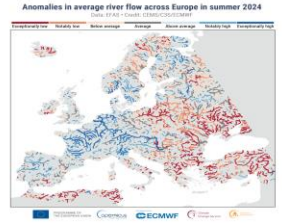


Ensemble hydrological forecast datasets

*River discharge, soil moisture, etc..*

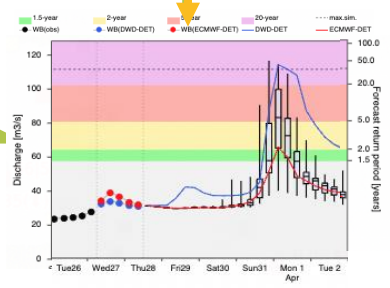
Hydrological monitoring lookback

*C3S ESoTC, seasonal lookback etc…*



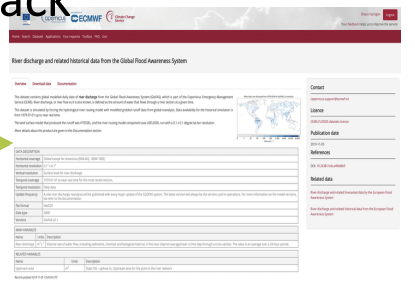
Climatology

*Flood thresholds*



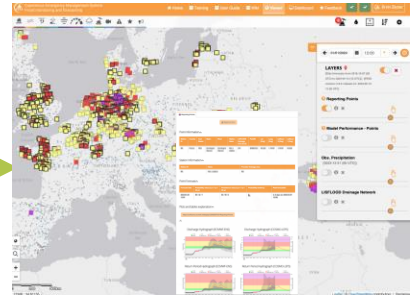

Hydrological forecast product generation

*Flood hydrographs, seasonal outlooks, etc…*



Data Service

*Copernicus Climate Data Store*

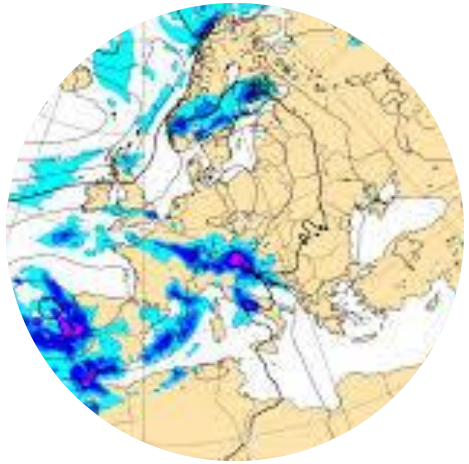


Web Service

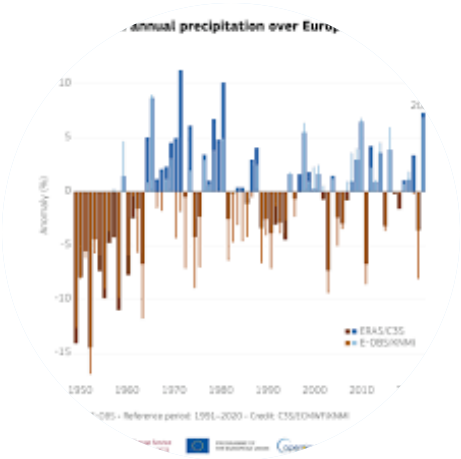
*CEMS EFAS*

# Key precipitation requirements

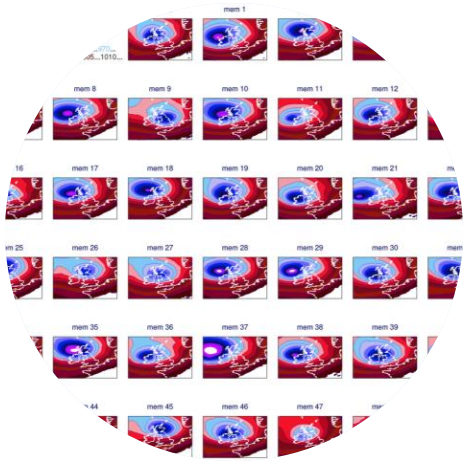
Continental/ global domain



Initial conditions

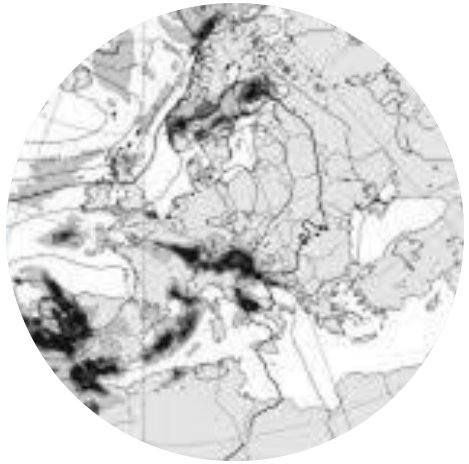


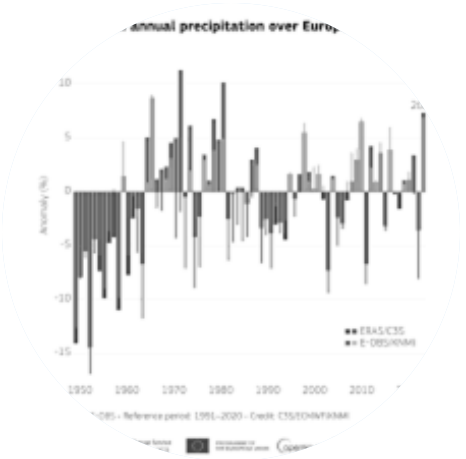
Historical records



Forecasts

# Continental/ global domain





**Continental/ global domain**

Coverage of full geographic domain at modelling time and spatial scale

Initial conditions

Historical records

Forecasts

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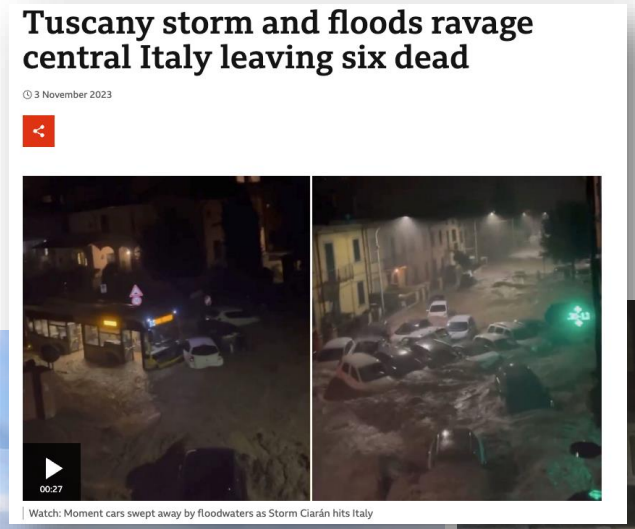
Emergency Management

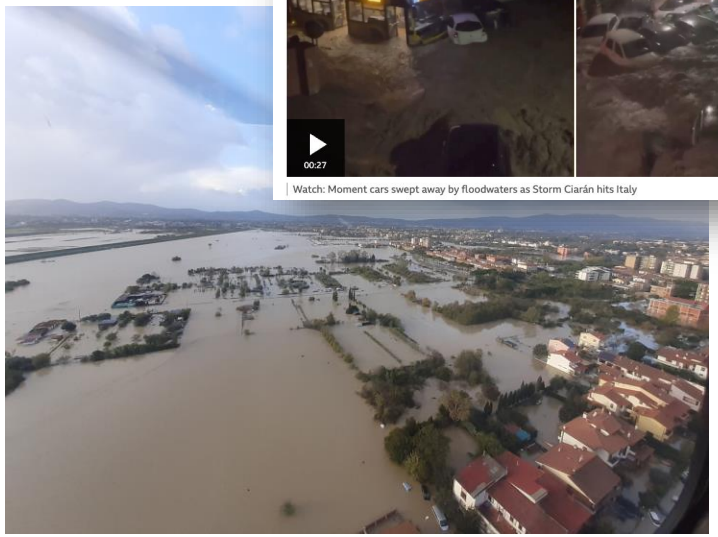
# Continental/global domain
# Limitation 1: Lack of in-situ measurements
# Example of missed flood event (2-3 Nov 2023, Tuscany)

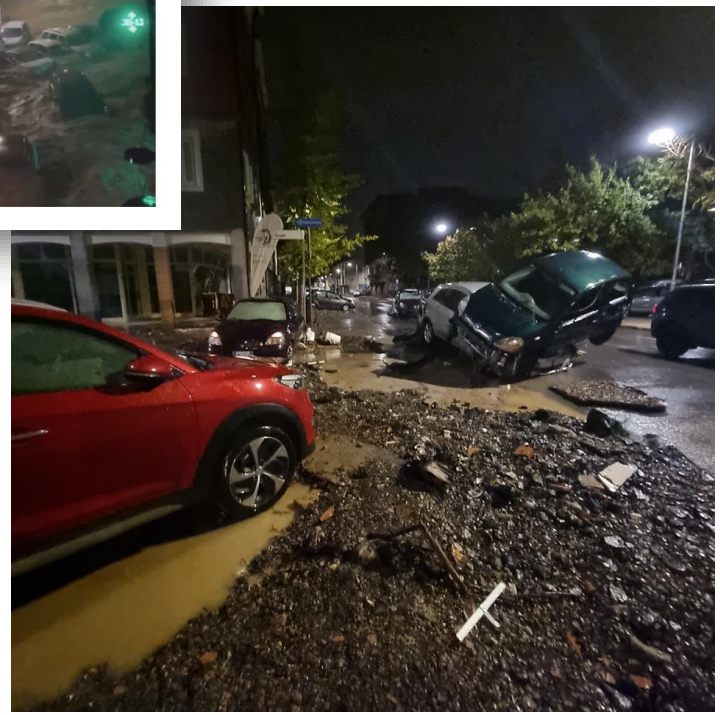

Tuscany storm and floods ravage central Italy leaving six dead

3 November 2023

00:27

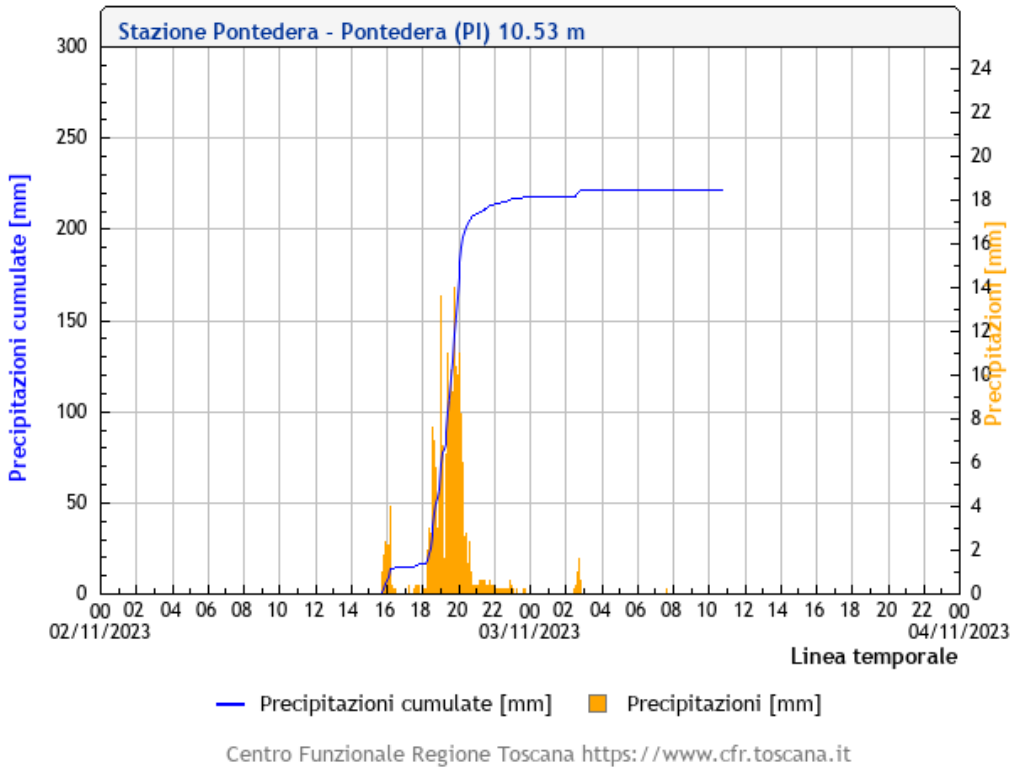
Watch: Moment cars swept away by floodwaters as Storm Ciarán hits Italy





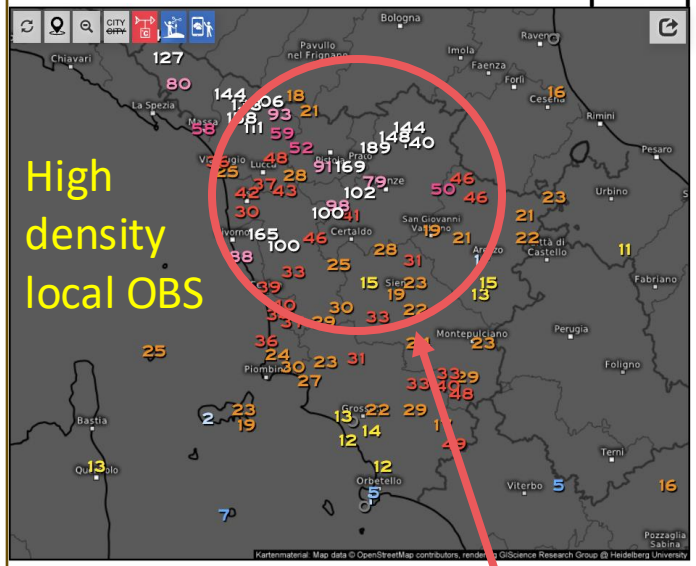
Aftermath flood 2-3 Nov 2023
Source: Government of Tuscany

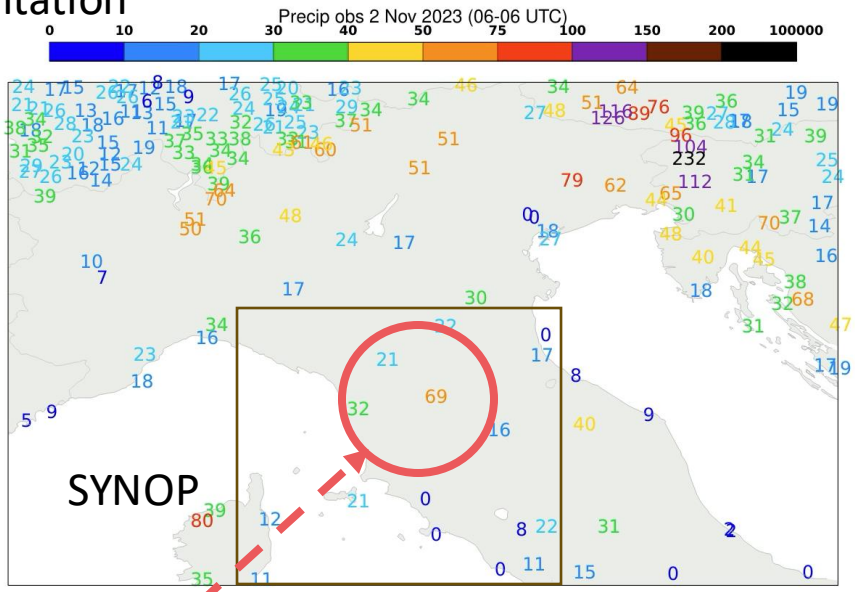
>200mm precipitation recorded 24 h



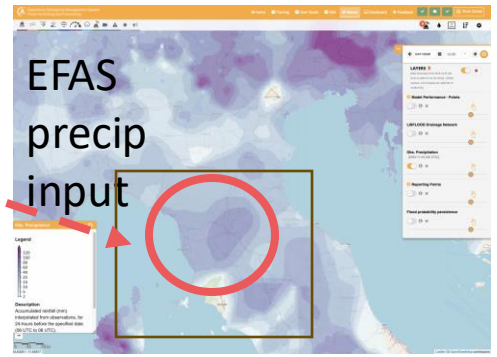
# Continental/global domain Limitation 1: Lack of in-situ measurements Example of missed flood event (2-3 Nov 2023, Tuscany)

2 Nov 2023 24h precipitation



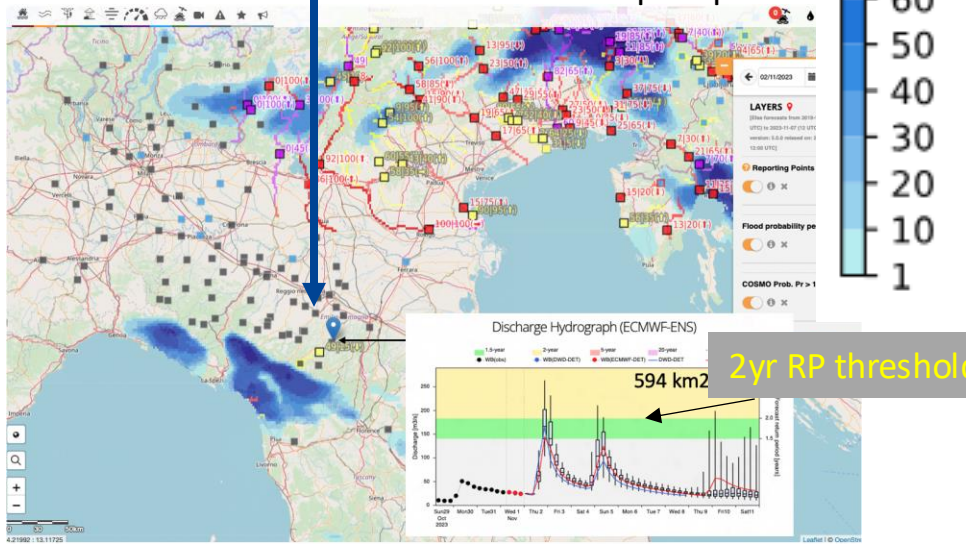

- Low density raingauge not capturing localized heavy rainfall
- EFAS meteo map underestimating rainfall totals




EFAS initial conditions underestimate river discharge

Forecasted total precipitation insufficient to generate flood

Probability of exceeding 150mm precipitation




EFAS forecast 2 Nov 2023 00UTC
Blue shades: precipitation forecast probability

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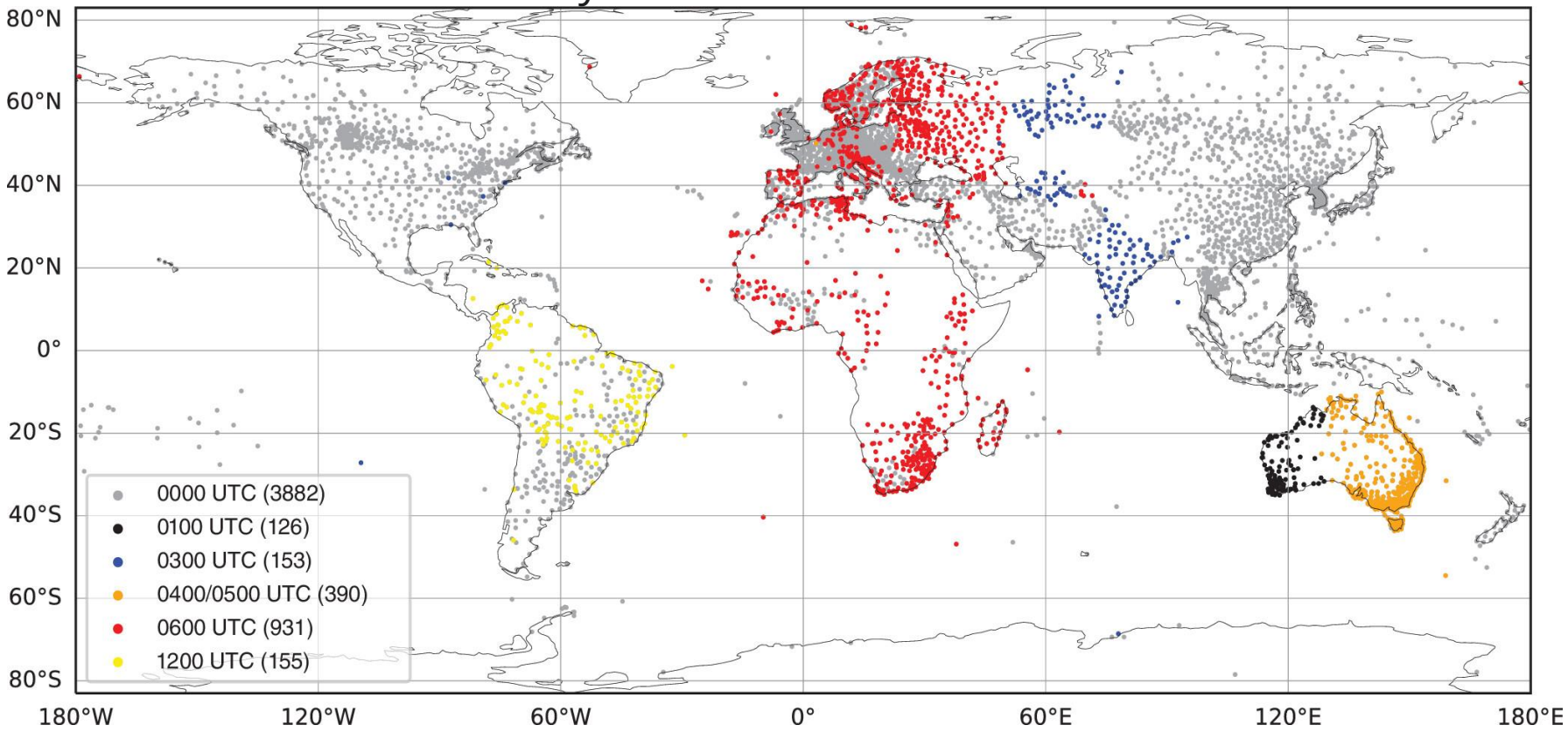
# Continental/global domain
# Limitation 1: Lack in-situ measurements
# Need for global alternative

Stations regularly reporting daily precipitation from WMO GTS system in 2001-2020




Gauge-based precipitation observations **not shared across full world domain**

Availability **at different times of day**

**Network density variable** across continents

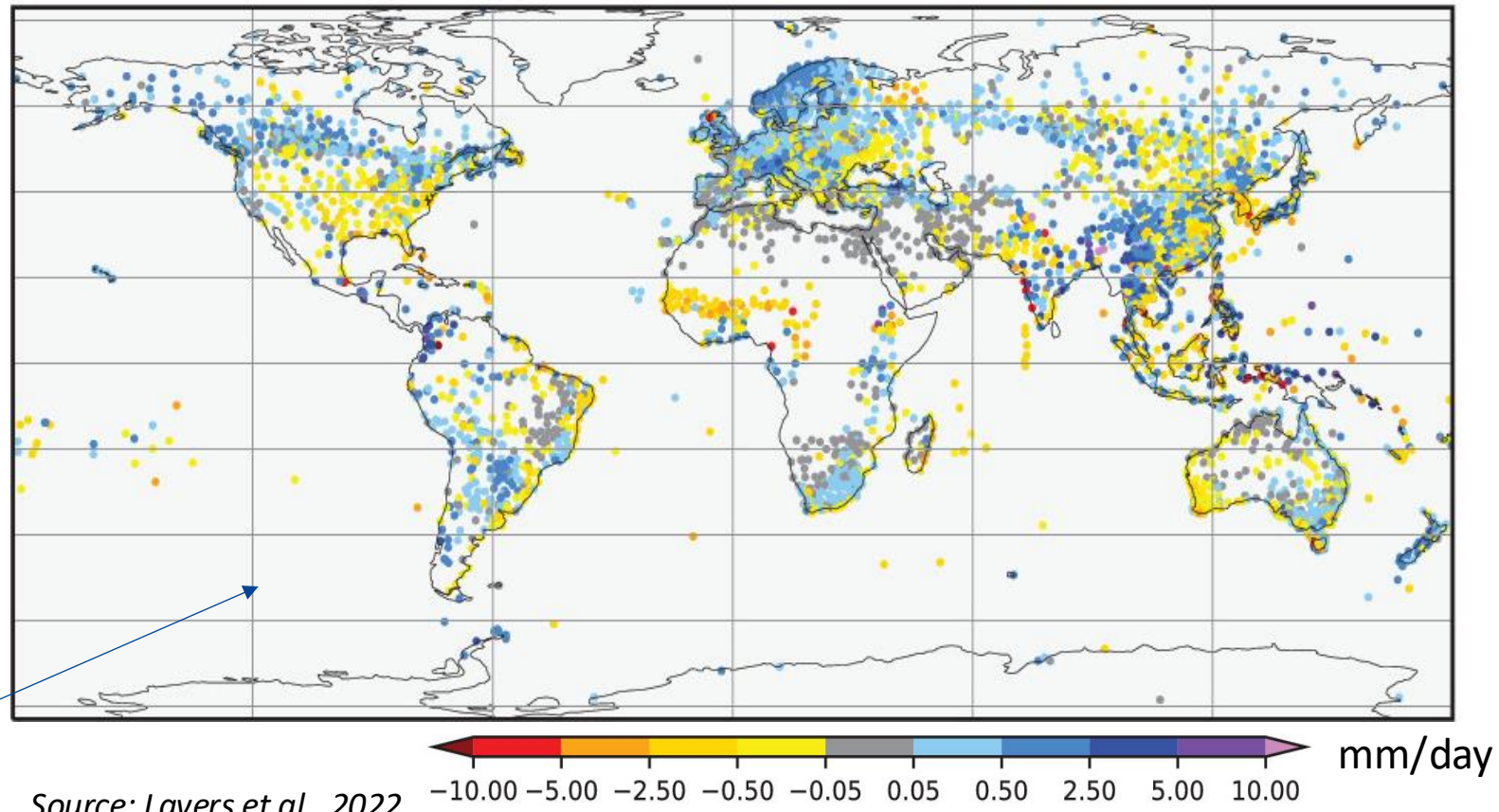
*Source: Lavers et al., 2022, https://rmets.onlinelibrary.wiley.com/doi/10.1002/qj.4351*

# Continental/global domain
# Limitation 1: Lack in-situ measurements
# Need for global alternative

**Precipitation requirements**
- Availability in (~few days latency)
- Consistent with multi-decadal historical records
- Spatial/ temporal resolution similar to model

**GloFAS pragmatic solution (since 2011)**
- Use of ERA5/ERA5T
- Available from 1950 with 3-5 days latency (timely version)
- But known **biases** impacting calibration and initial conditions

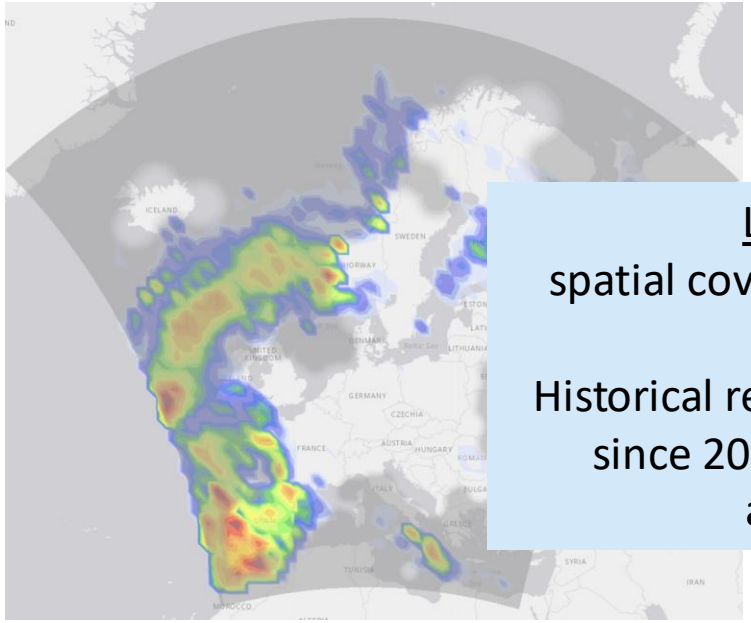
ERA5 precipitation bias in July (2001-2020)




*Source: Lavers et al., 2022, https://rmets.onlinelibrary.wiley.com/doi/10.1002/qj.4351*

# Continental/global domain
# Possible solutions to limitation 1

Initial conditions: radar-based precipitation?

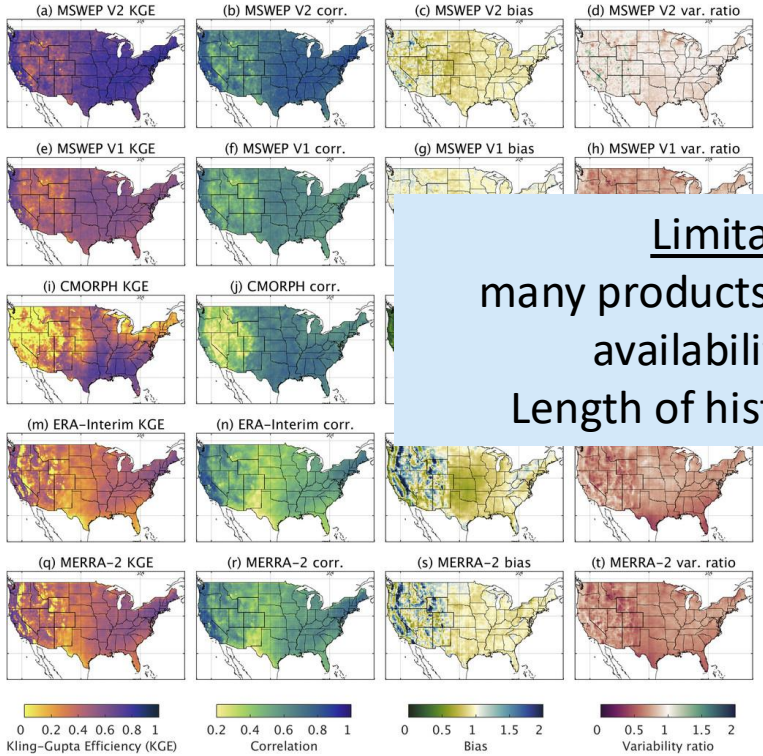


Opera radar composite precipitation (gauge corrected)
24h precipitation (valid 8-9 March 2025 00UTC)
(grey: NWP filled)

*Source: EFAS-IS/ EDERA project, https://edera-project.eu/*

Limitations:
spatial coverage (grey areas: no data)
Historical records (Europe Opera: since 2010; world: unequal availability)

Initial conditions + calibration: EO-based precipitation/ merged products?



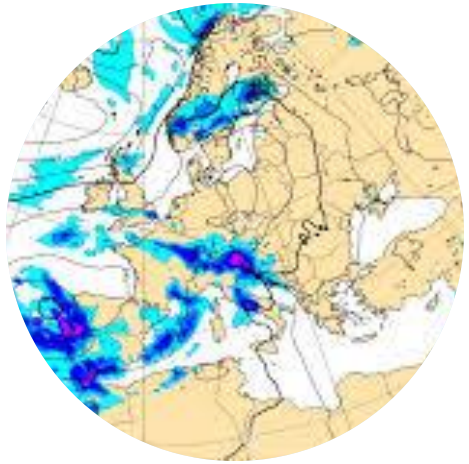

Limitations:
many products to chose from availability in NRT
Length of historical record

Comparison between stage IV gauge-radar reference datasets and EO-based precipitation products.

*Source: Beck, 2019 Bulletin of the American Meteorological Society 100, 3; 10.1175/BAMS-D-17-0138.1*

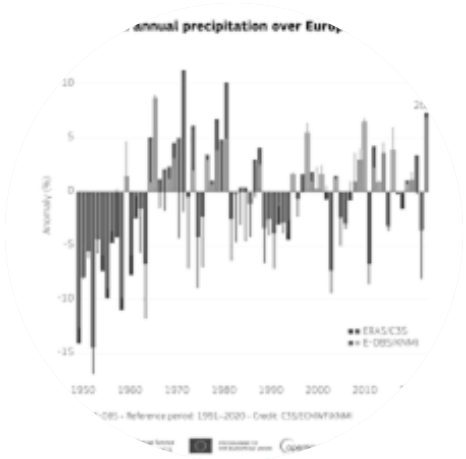
# Initial conditions

Continental/ global domain



**Initial conditions**

Quality Assured data available with 2-3 days latency maximum



Historical records

Forecasts

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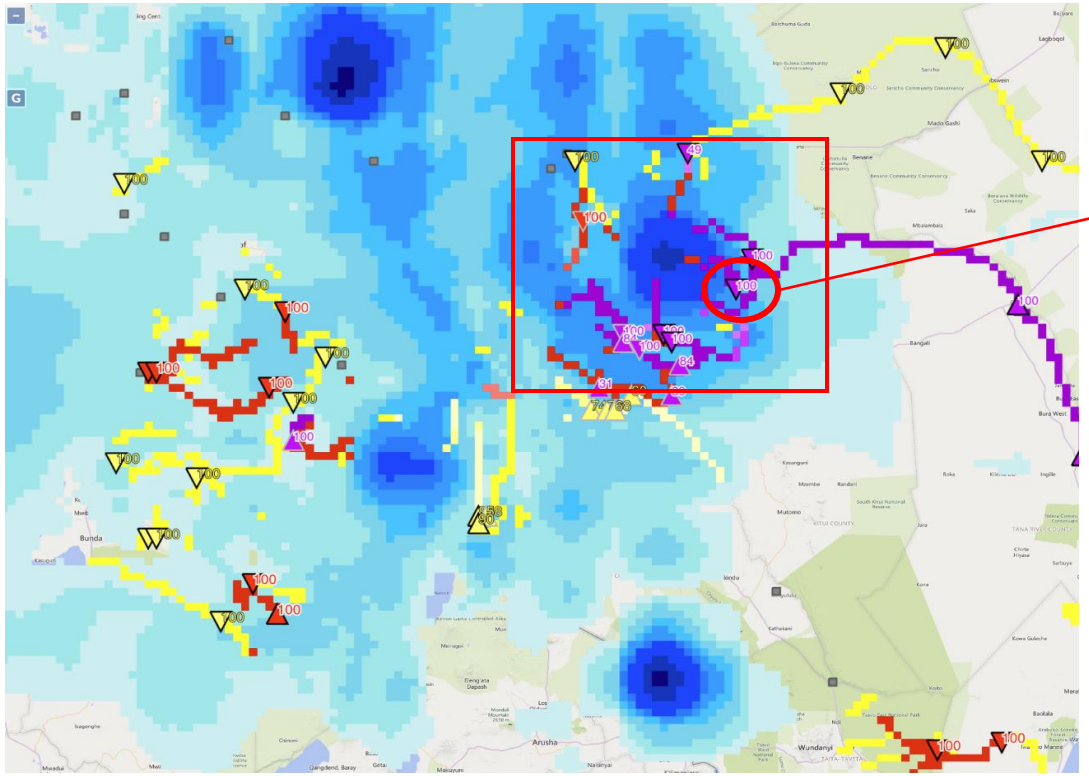
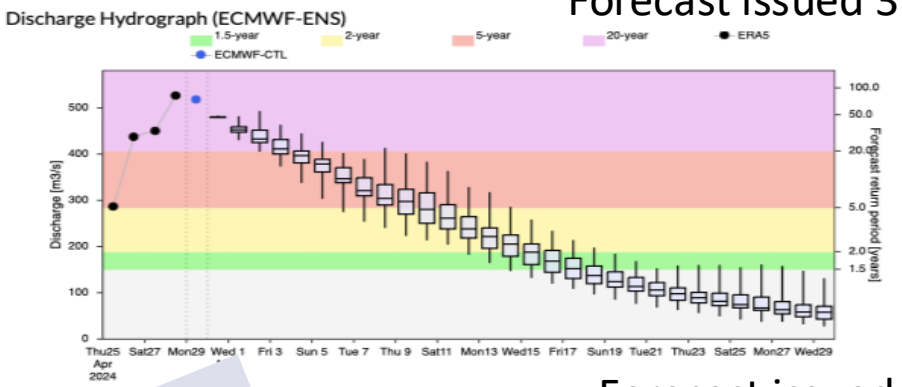
# Initial conditions
# Limitation 2: Localised extreme rainfall events
# Example of ERA5 rain bomb - Kenya April-May 2024



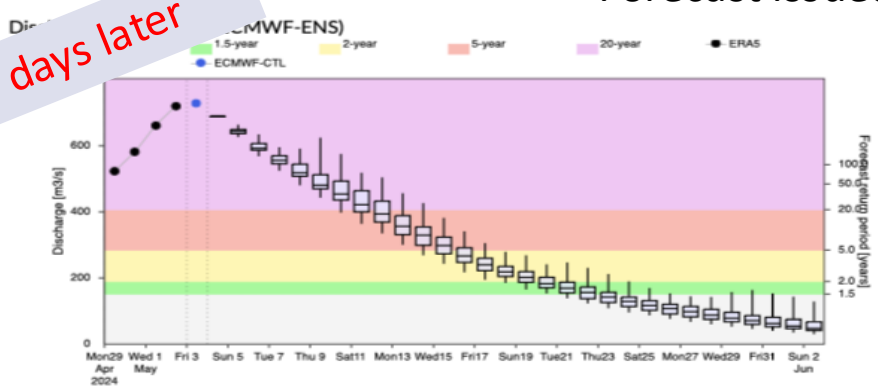
GloFAS 3-day precipitation (ERA5 interpolated, blue) and forecasted probability of flood events (yellow, red, purple) – 30 April 2024

Forecast issued 30 April 00UTC



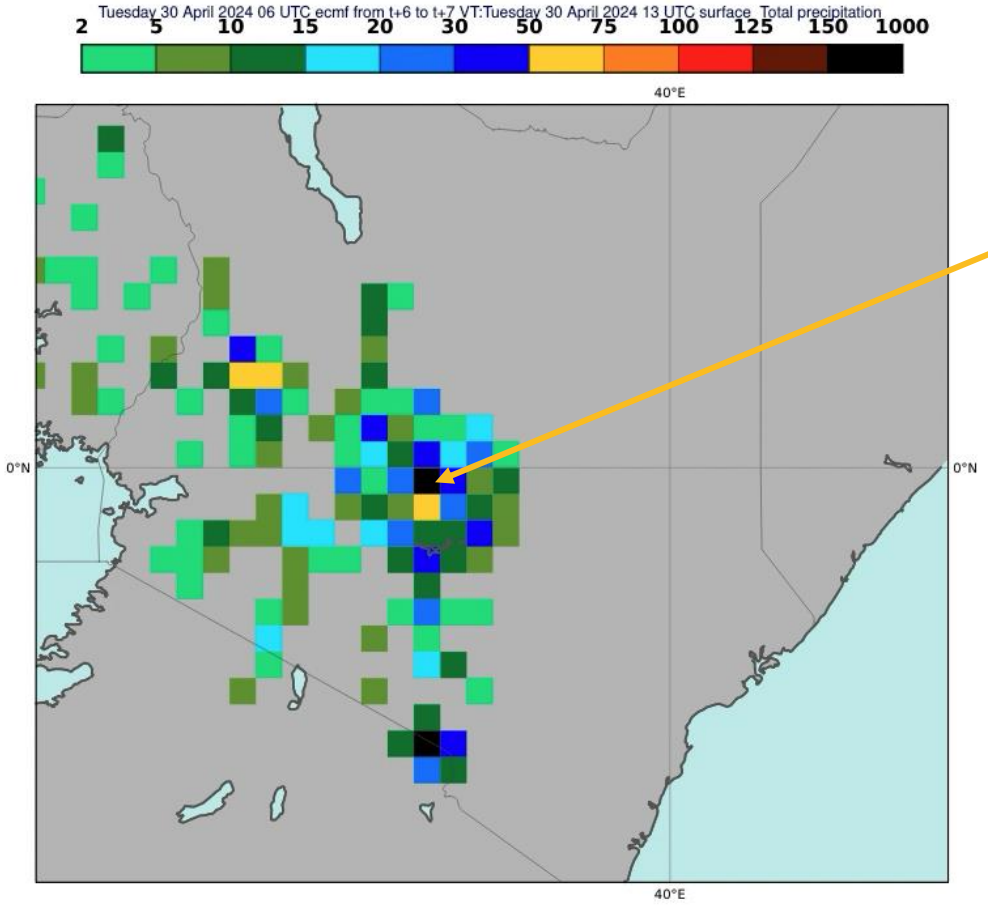

4 days later

Forecast issued 4 May 00UTC




Consistent severe (>20Y RP) flood signal in region from 27 April until 6 May 2024 always at start of forecast - due to initial conditions

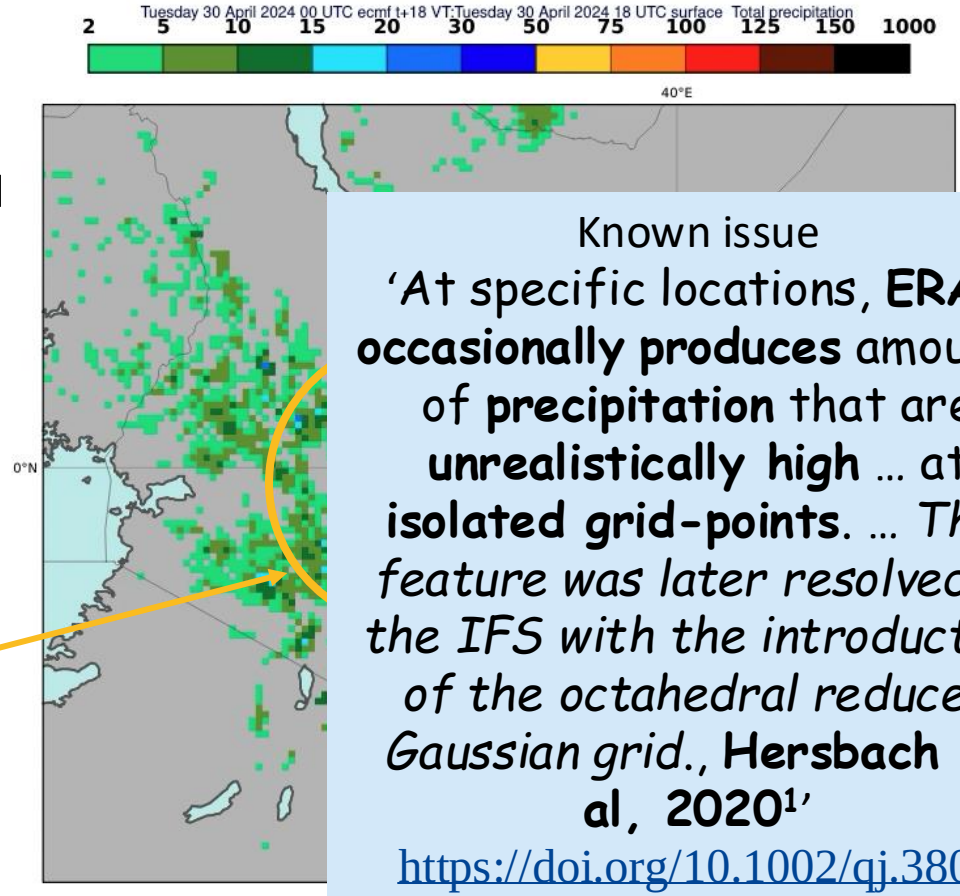
# Initial conditions
# Limitation 2: Localised extreme rainfall events
# Example of ERA5 rain bomb - Kenya April - May 2024




ERA5 18-h total precipitation 30 April 00UTC

Large precip total > 250 mm not seen in contiguous cells

No precipitation peak



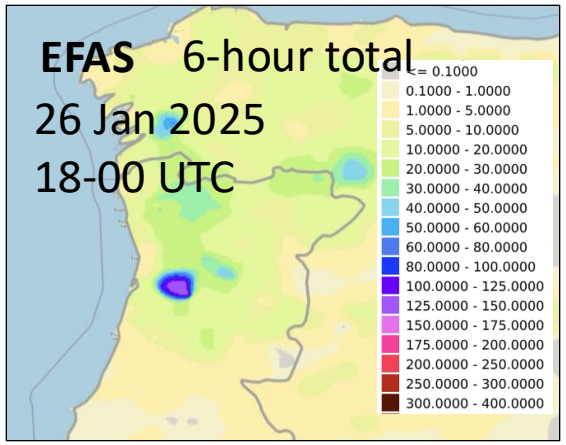

ECMWF HRES 18-h total precipitation 30 April 00UTC

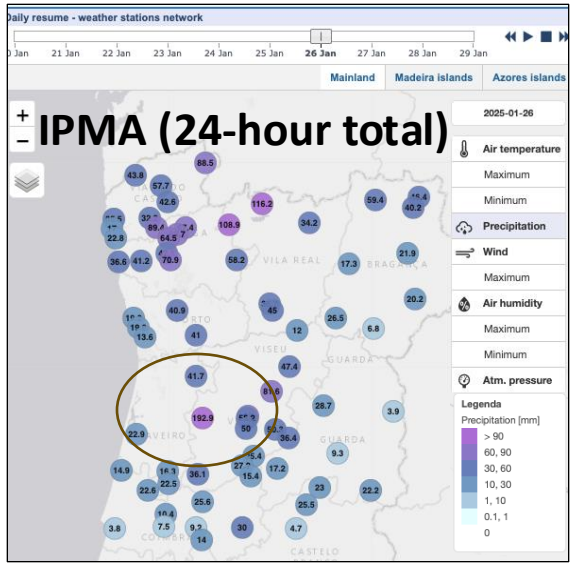
Known issue

'At specific locations, **ERA5 occasionally produces** amounts of **precipitation** that are **unrealistically high** … at **isolated grid-points**. … *This feature was later resolved in the IFS with the introduction of the octahedral reduced Gaussian grid.*, **Hersbach et al, 2020**[1]'

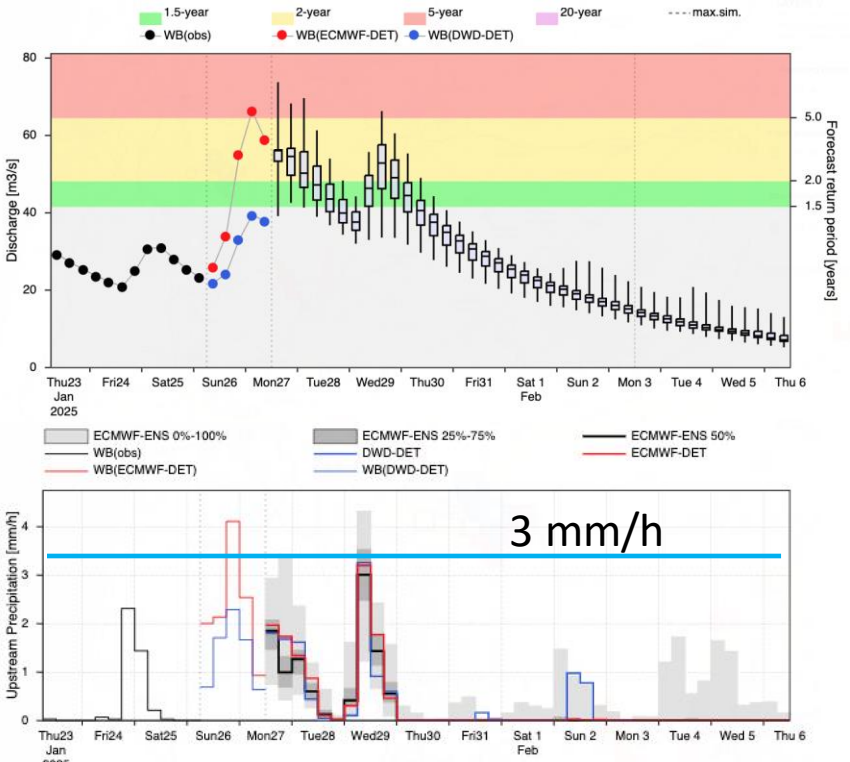
https://doi.org/10.1002/qj.3803

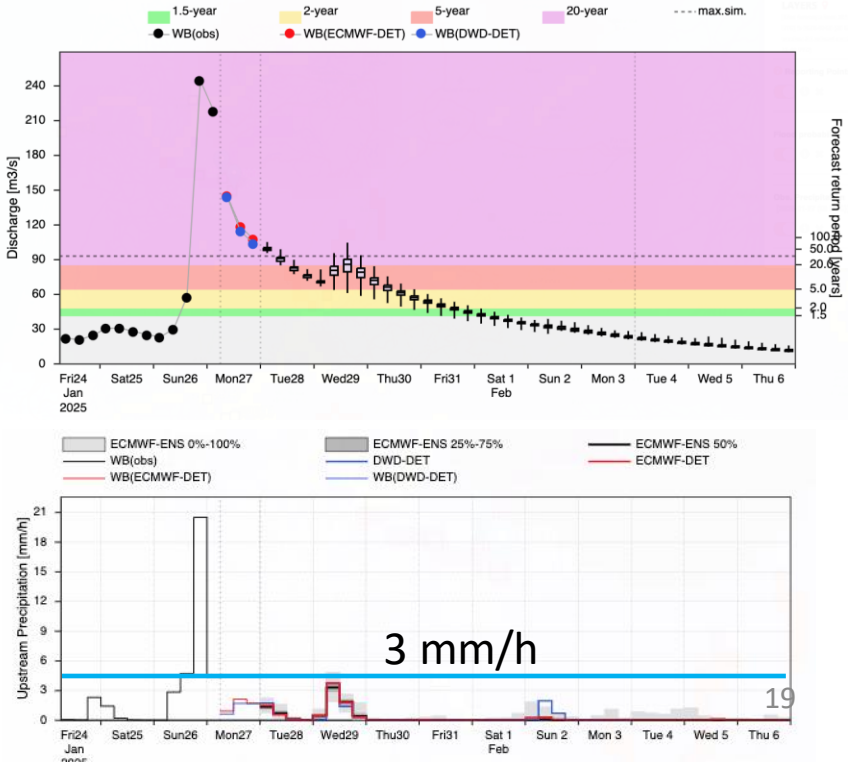
# Initial conditions
# Limitation 2: Localised extreme rainfall events
# Example of extreme rainfall – Portugal




- EFAS precip obs shows a ~200mm (>100mm in 6-hour) event causing 'sudden' flood
- Event present in local database (IPMA) but not confirmed by neighbouring gauges
- Event absent from previous NWP forecasts; Flood signal only appeared in system after simulated peak



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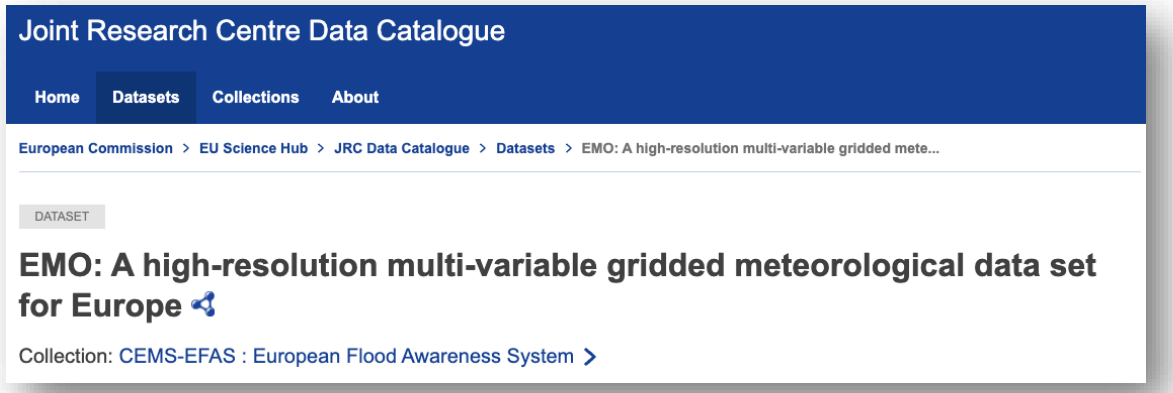
# Initial conditions
# Possible solution to limitation 2: automatic QC

## In-situ observations

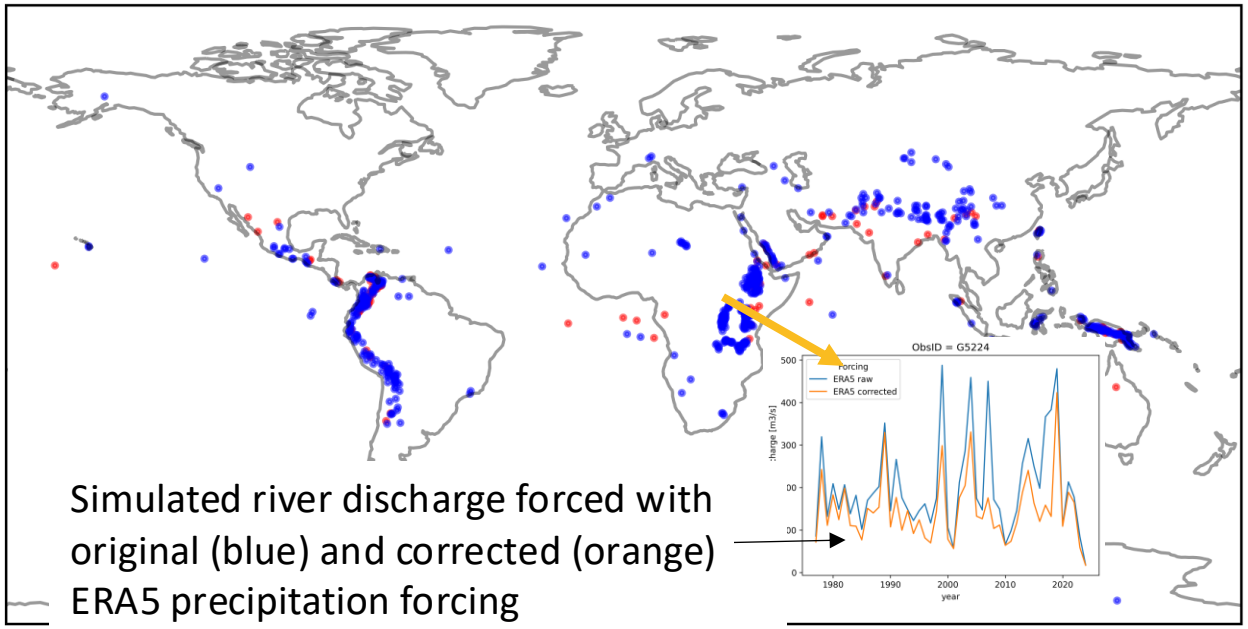
Temporal and spatial consistency checks → Removal of spurious data in historical database for generating historical grids → Algorithm to be applied in real-time when creating the gris for initial conditions




EMO-1 v3 (expected 2025)
To be implemented for EFASv6

## Gridded products

677 points with over 2% change in precip. after correction




Simulated river discharge forced with original (blue) and corrected (orange) ERA5 precipitation forcing

Average precipitation after corection (% of points)

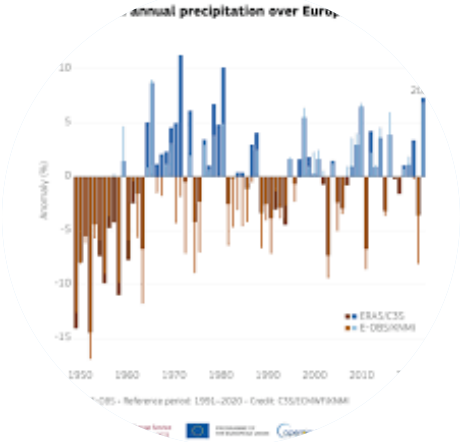
Filtering ERA5 1-cell heavy rainfall event
To be implemented for GloFASv5

*Mastrantonas, Zsoter et al., in preparation*

# Historical records

Continental/ global domain

Initial conditions




**Historical records**

Reference datasets several decades long at similar spatial and temporal resolution as model

Forecasts

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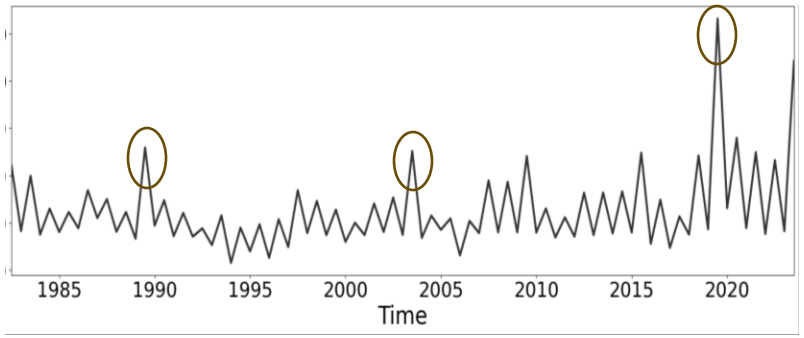
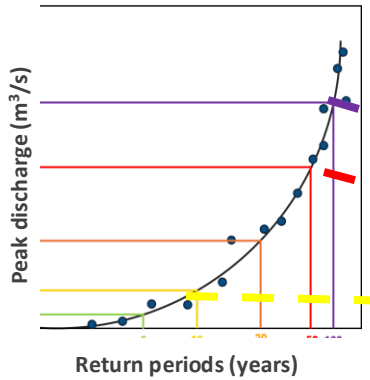
# Historical records
# Limitation 3: representativity of dataset
# Flood thresholds

Flood signal identification in CEMS-Flood
Algorithm run at every new forecast

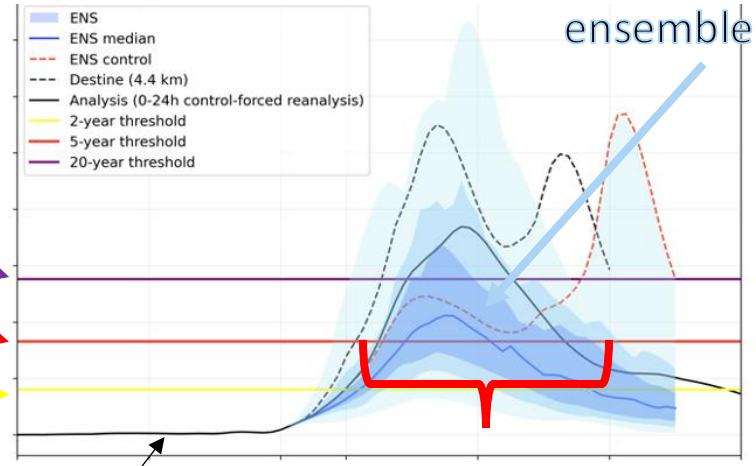
Extreme value analysis




Simulated historical river discharge time series




River discharge ensemble forecast




High flood event

Initial condition simulation

Definition of flood threshold
Updated once after each new hydrological model update

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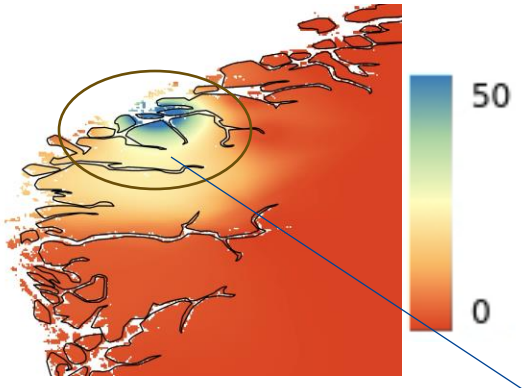
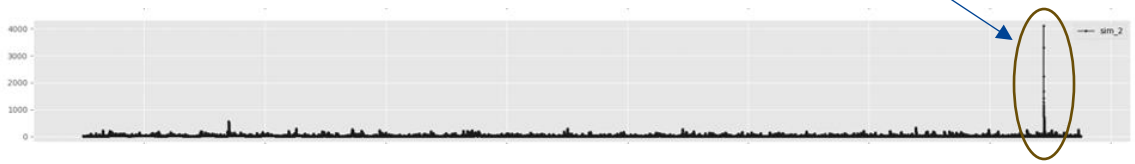
# Historical records
# Limitation 3: representativity of dataset
# Flood thresholds



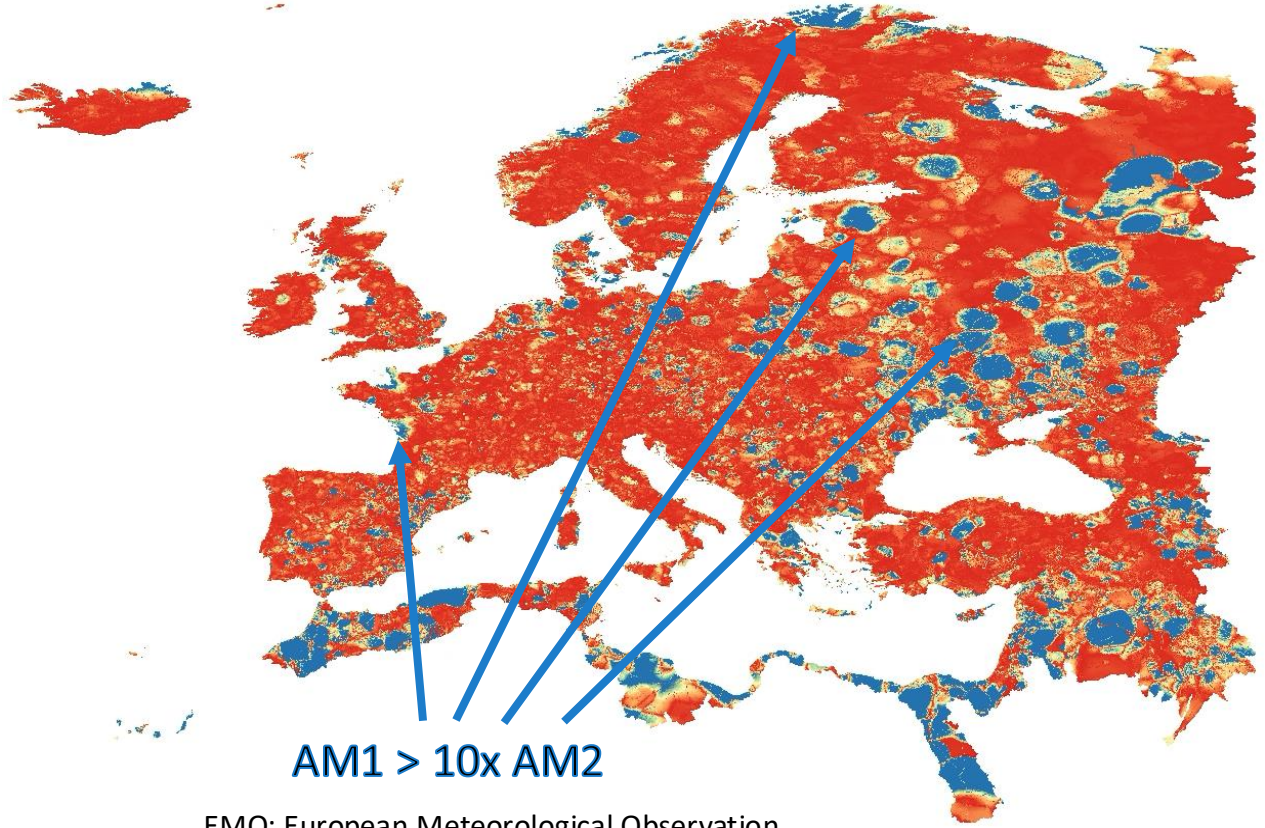

Example of localized precipitation event



Example of river discharge simulation with a spurious precipitation event

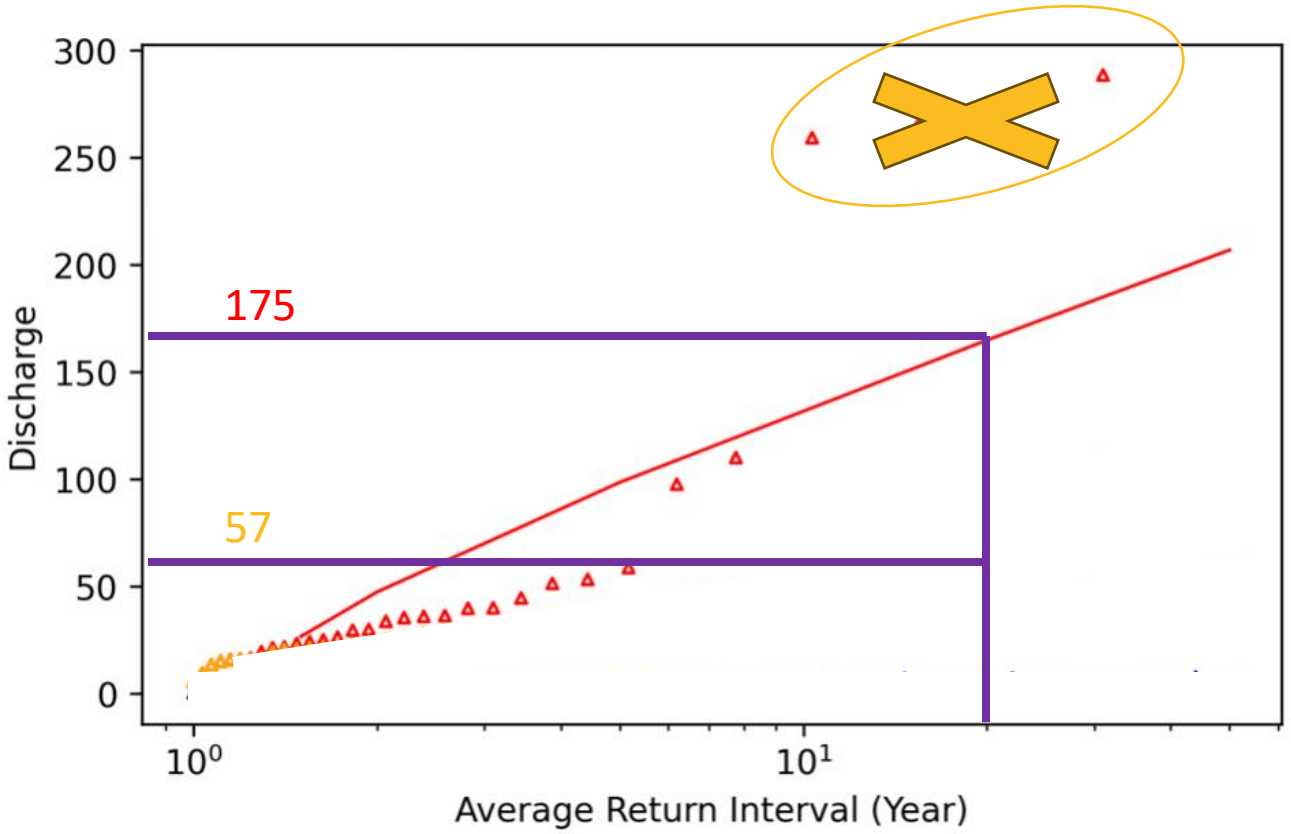
Standardised difference between largest and second largest annual maxima of EMO1 (blue: >10)

Based on simulations 1991-2017

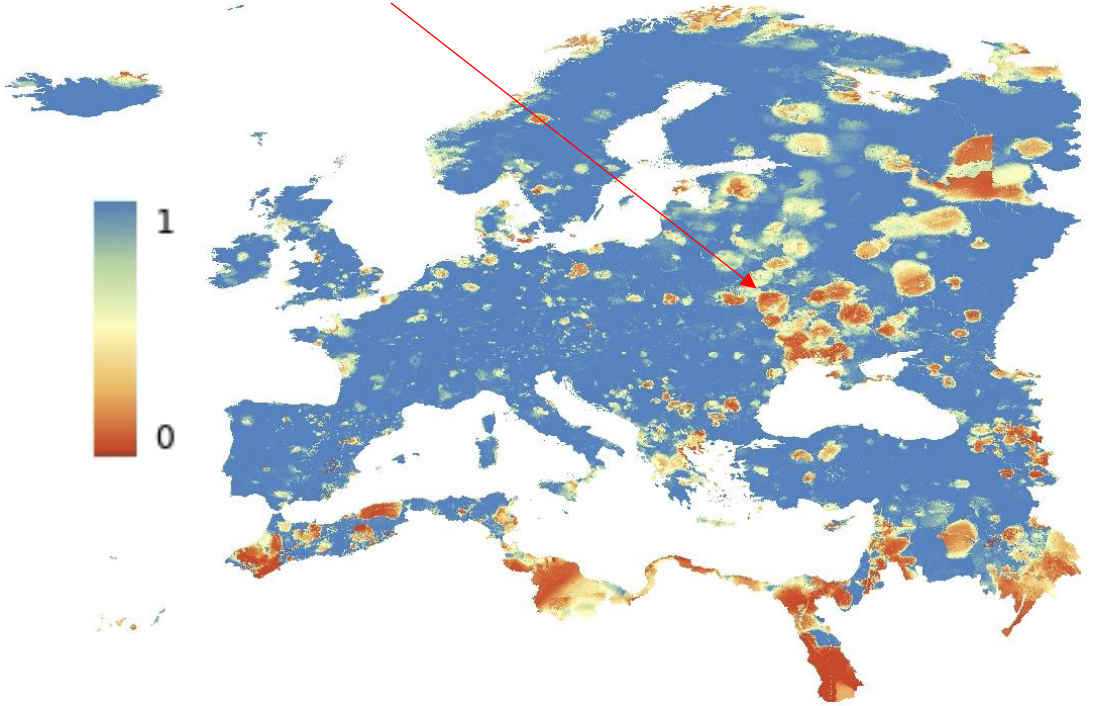



EMO: European Meteorological Observation
https://data.jrc.ec.europa.eu/dataset/0bd84be4-cec8-4180-97a6-8b3adaac4d26

# Historical records
# Possible solution to limitation 3: outlier removal




Circular features linked to localized precipitation outliers




Ratio of EFAS severe flood threshold after/before outlier removal

Blue: no change

Red: new threshold <<< original threshold

New threshold implemented in EFASv5.1

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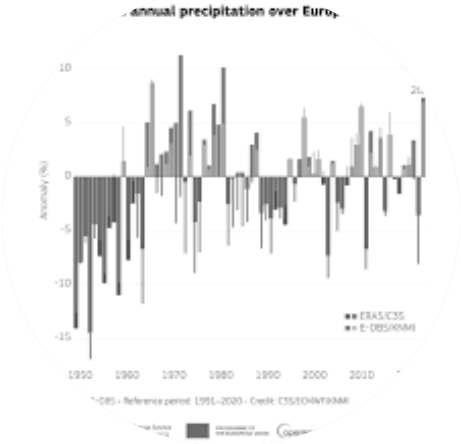
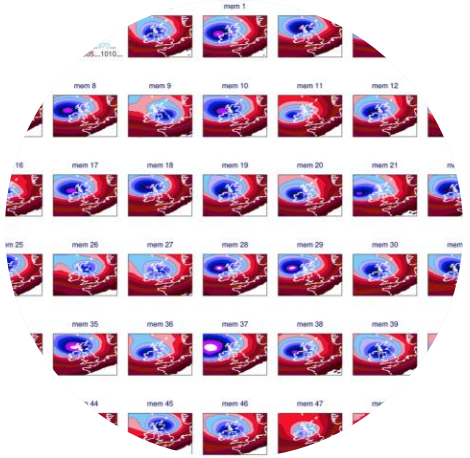
# Forecast uncertainty

Continental/ global domain

Initial conditions




Historical records



Forecast uncertainty

Consistency reference and forecast datasets

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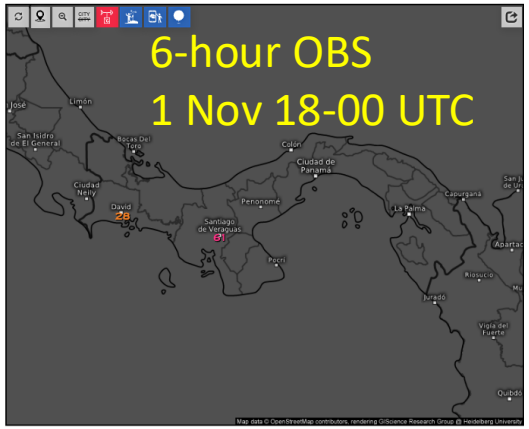
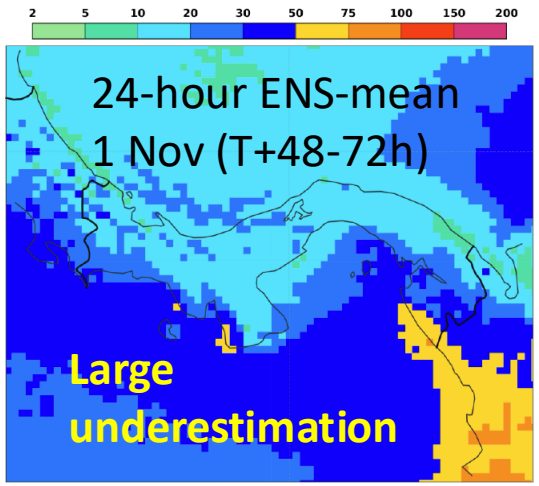
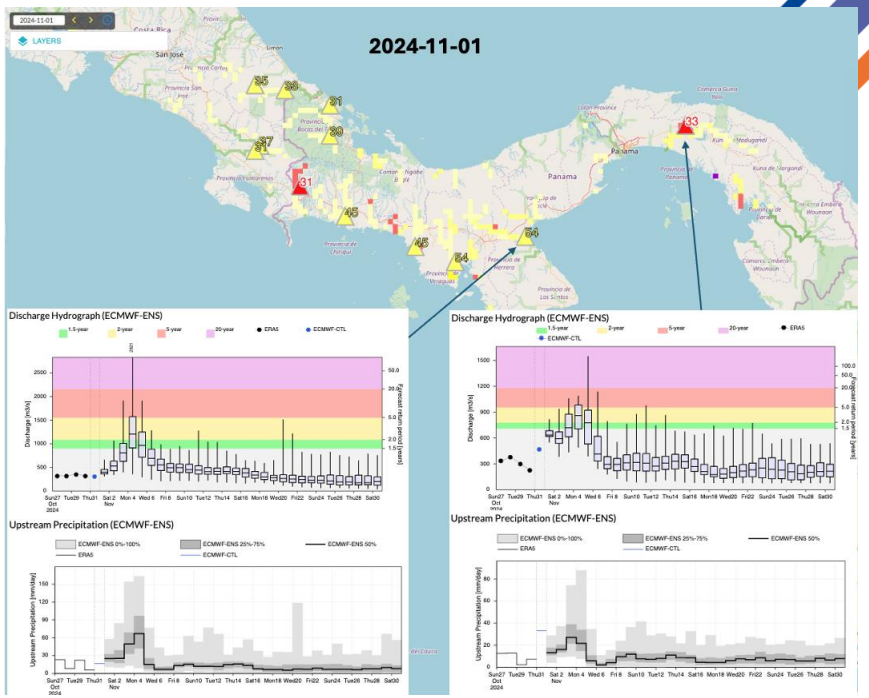
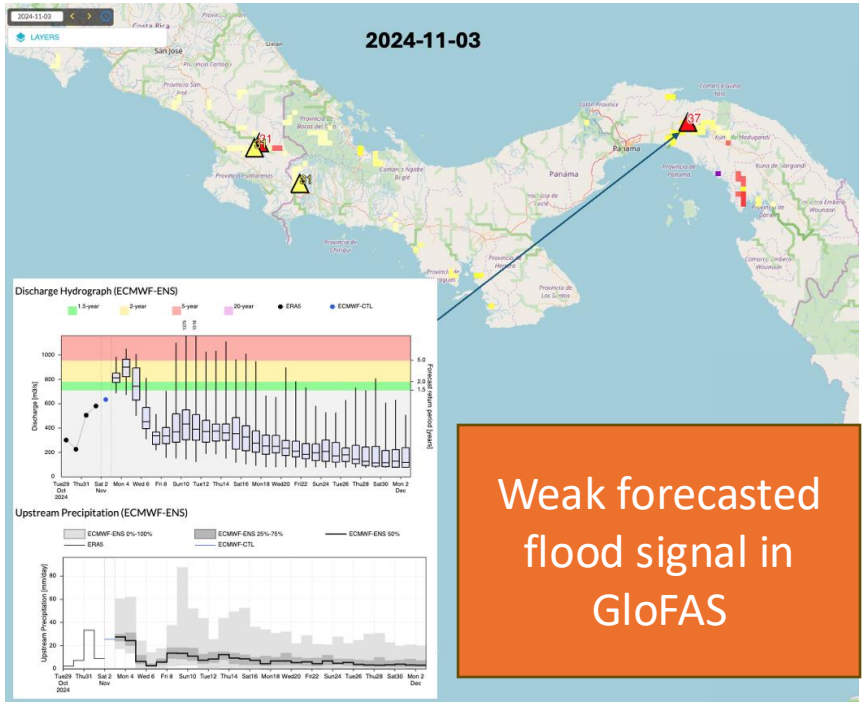
# Forecast uncertainty
# Limitation 5: underestimated events
# Example of Panama Nov 2024




Limited precipitation observation
NWP precipitation too low




Weak forecasted flood signal in GloFAS

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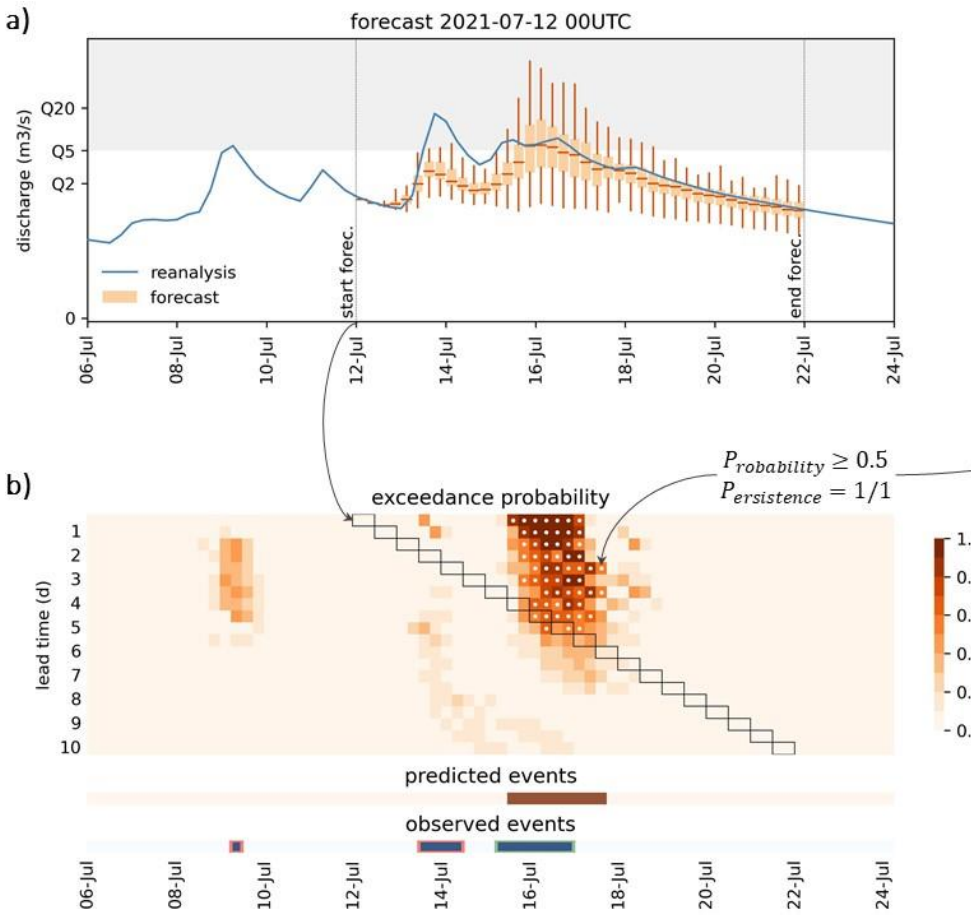
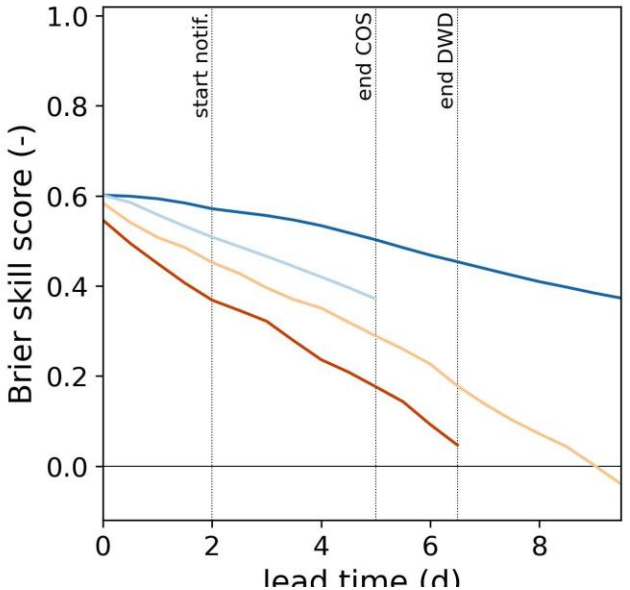
# Forecast uncertainty
# Possible solution to limitation 5: ensemble forecasting

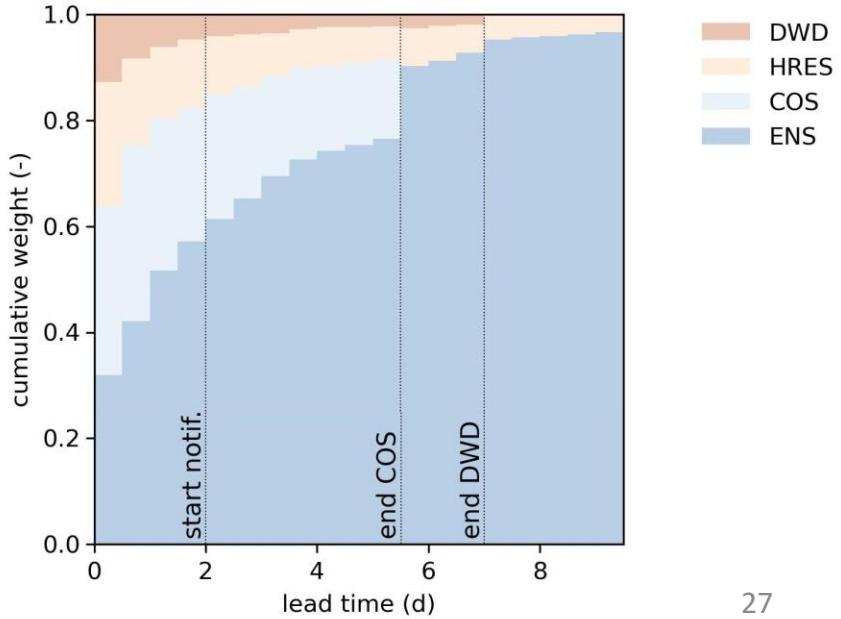


Brier skill score for every meteorological model and lead time. The reference (BSS=0) is a model that never predicts an event.
Blue -> probabilistic
Orange -> deterministic

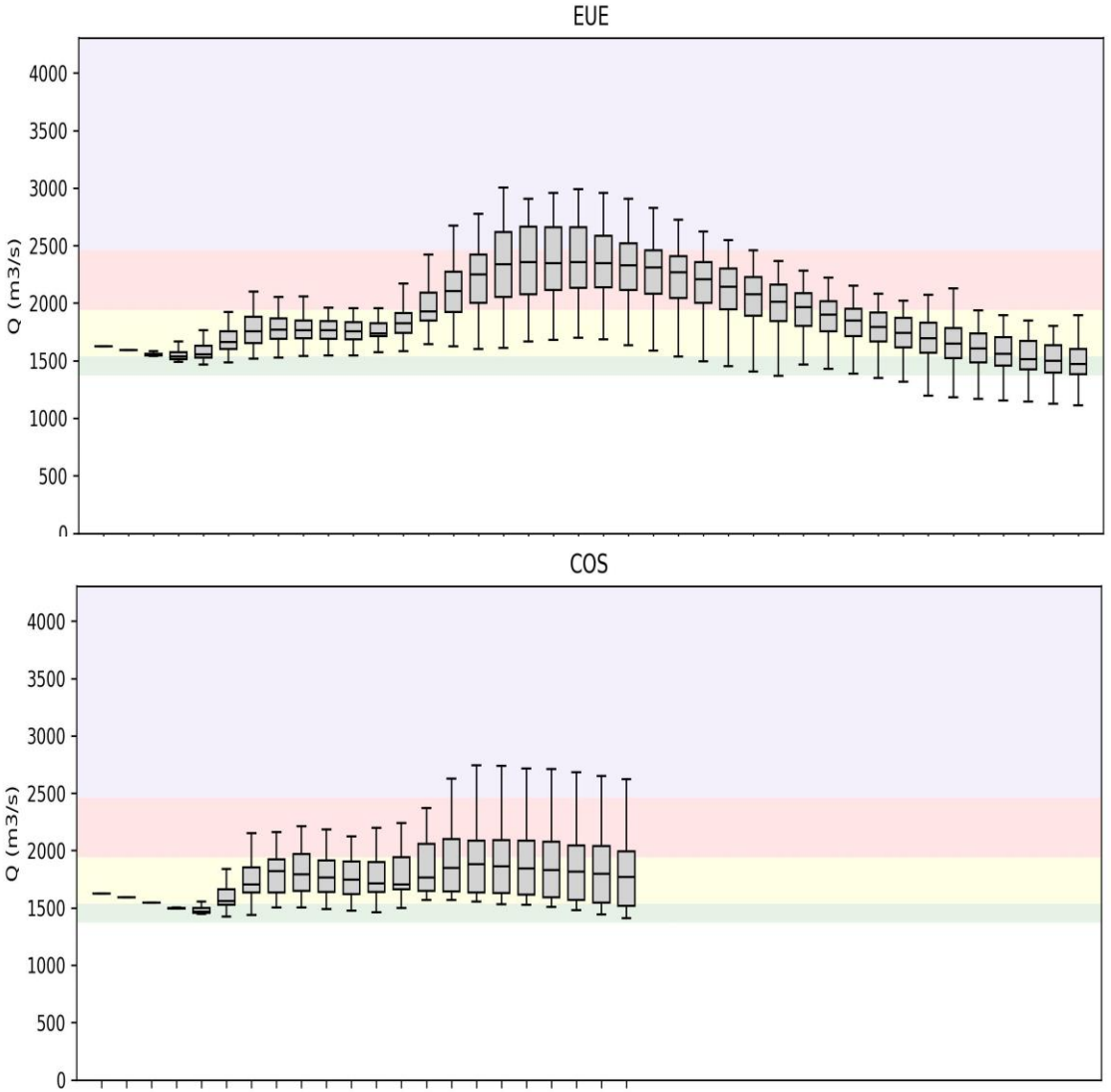
Distribution of weights over NWP models and lead time for the Brier weighted combination.

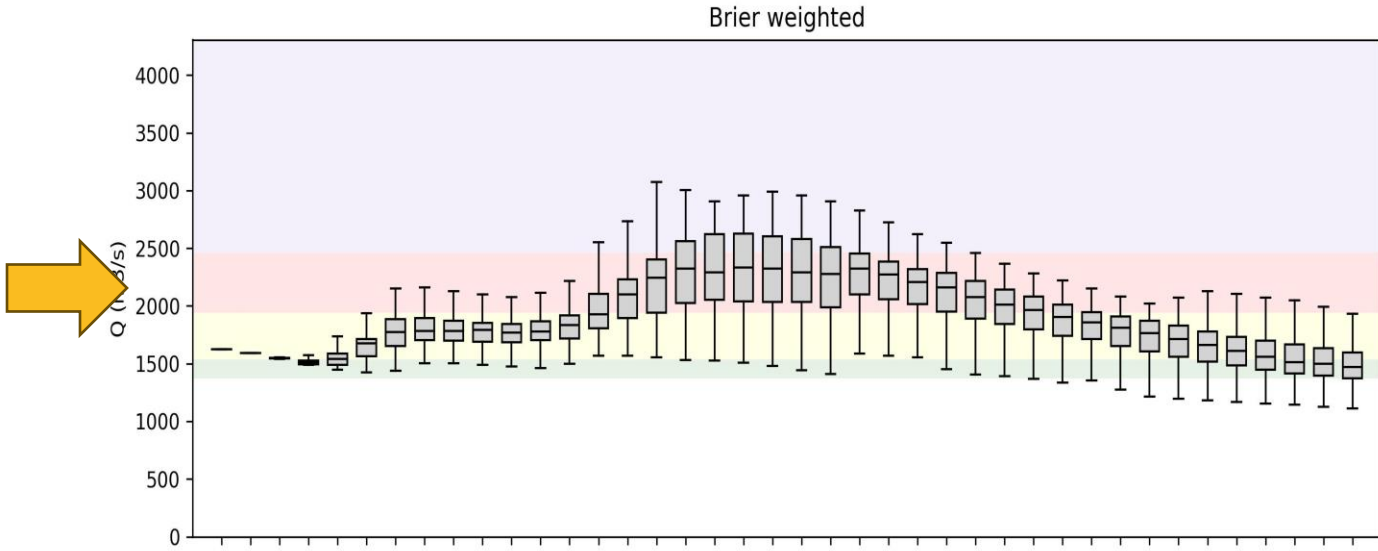
DWD stands for DWD-ICON, HRES for ECMWF-HRES, COS for COSMO-LEPS and ENS for ECMWF-ENS.




*Work by Casado-Rodriguez et al., in press*

# Forecast uncertainty
# Possible solution to limitation 5: ensemble forecasting



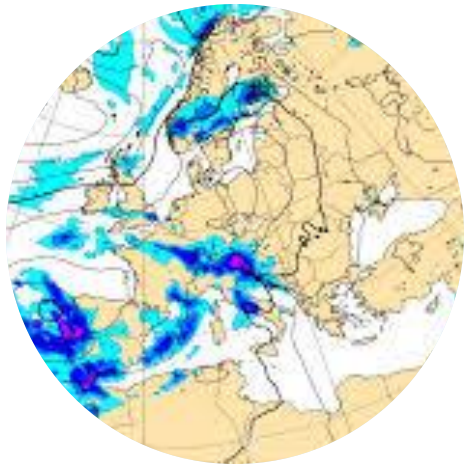




Ensemble flood hydrograph weighted according to individual model skill
Implementation: EFASv5.2 (August 2024)

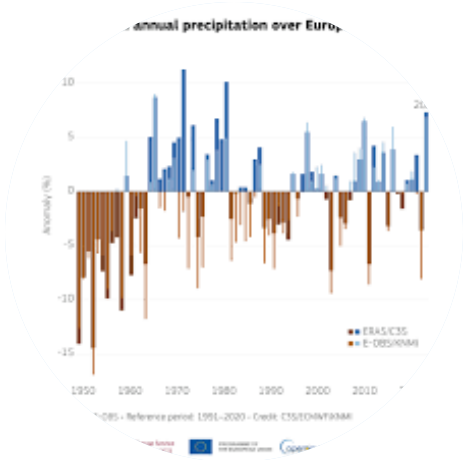
*Work by Casado-Rodriguez et al., in press*

# Conclusion

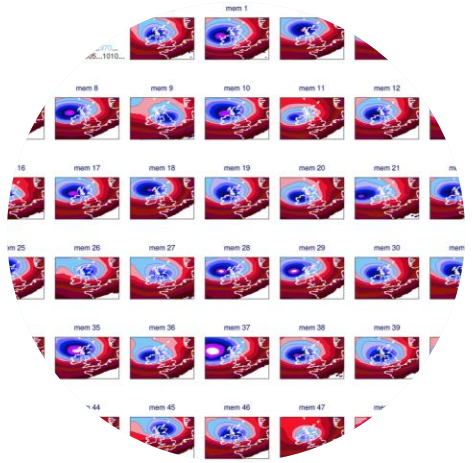
**Continental/ global domain**



**Initial conditions**




**Historical records**



**Forecasts**

Precipitation critical along the hydrological forecasting value chain
Complex requirements regarding spatial and temporal availability
Quality of observations and derived data products critical for forecasting flood events
Any improvement in precipitation quality will have direct impact on the quality of EWS for floods

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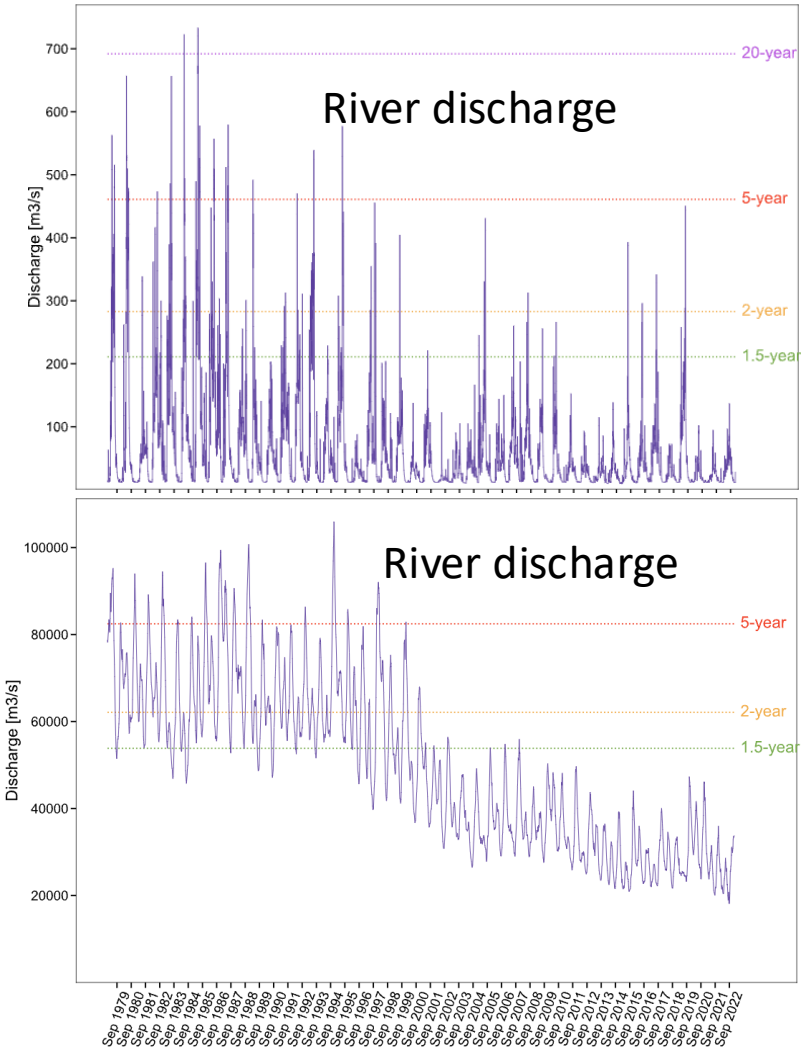
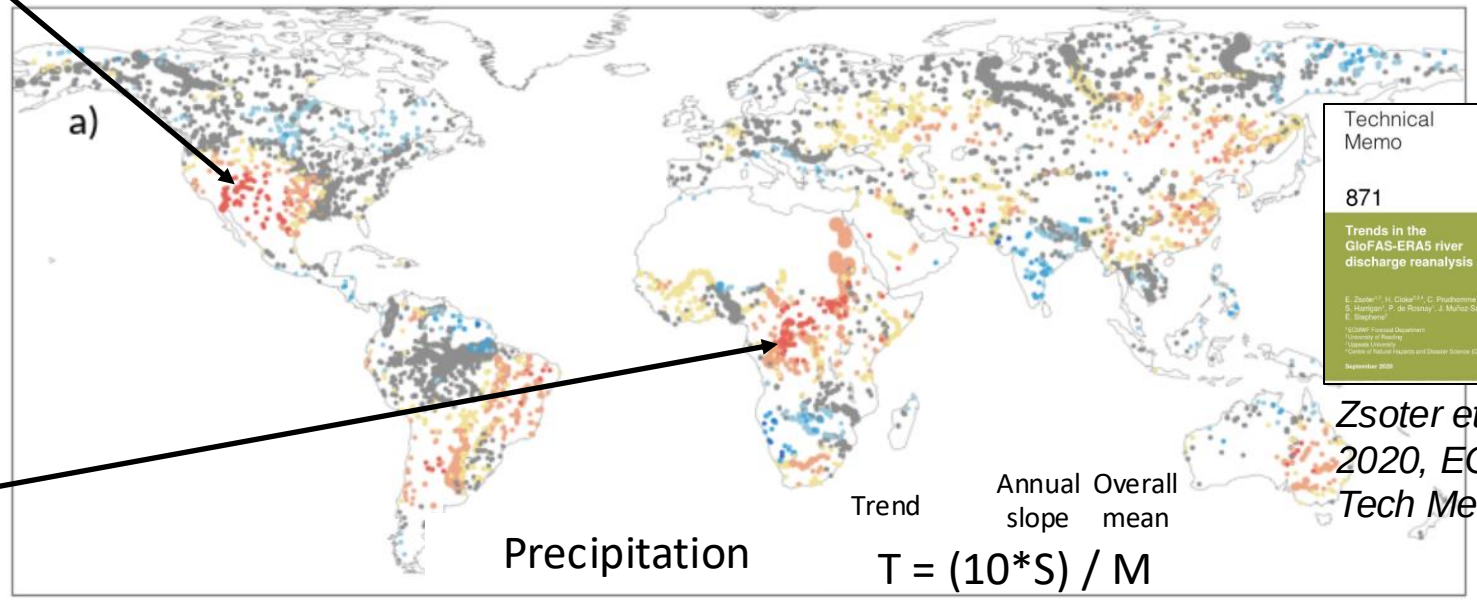
# Thank you!

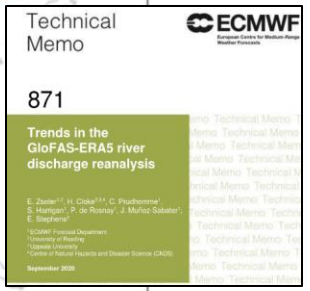
# Additional slides

# Continuous simulation over multiple decades Limitation 3: representativity of dataset Trends




- ERA5 has some major non-stationarity features
- Most noticeable precipitation trends in Central Africa and western USA
- Large decrease in river discharge can lead to underestimated flood signal
- Large increase can lead to overestimated flood signal
- ERA5-based thresholds will potentially be non-representative of forecast behaviour



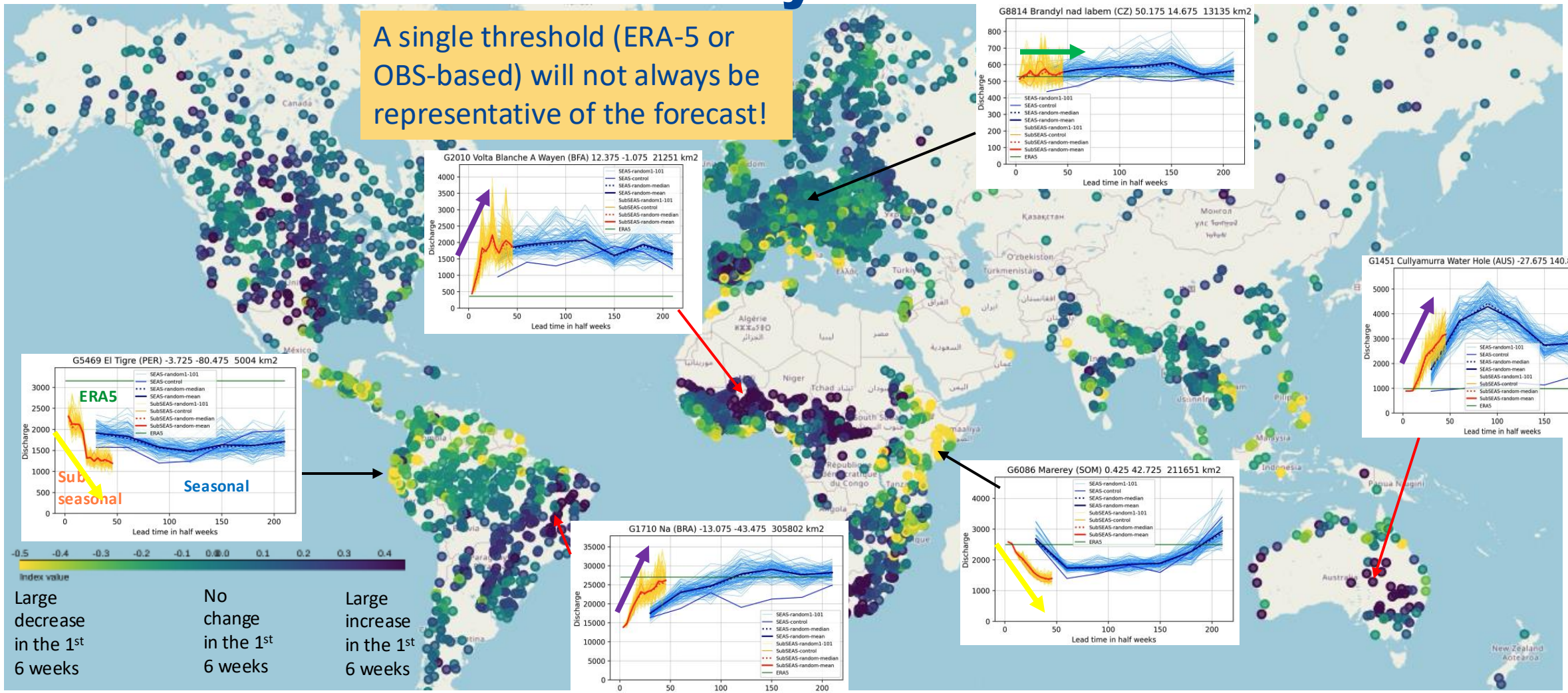

*Zsoter et al., 2020, ECMWF Tech Memo 871*

# Forecast uncertainty
# Limitation 4: long-range forecast drifts
# Flood threshold consistency

Change in flood threshold value between week1 and week 6

Needs of range-dependent flood threshold

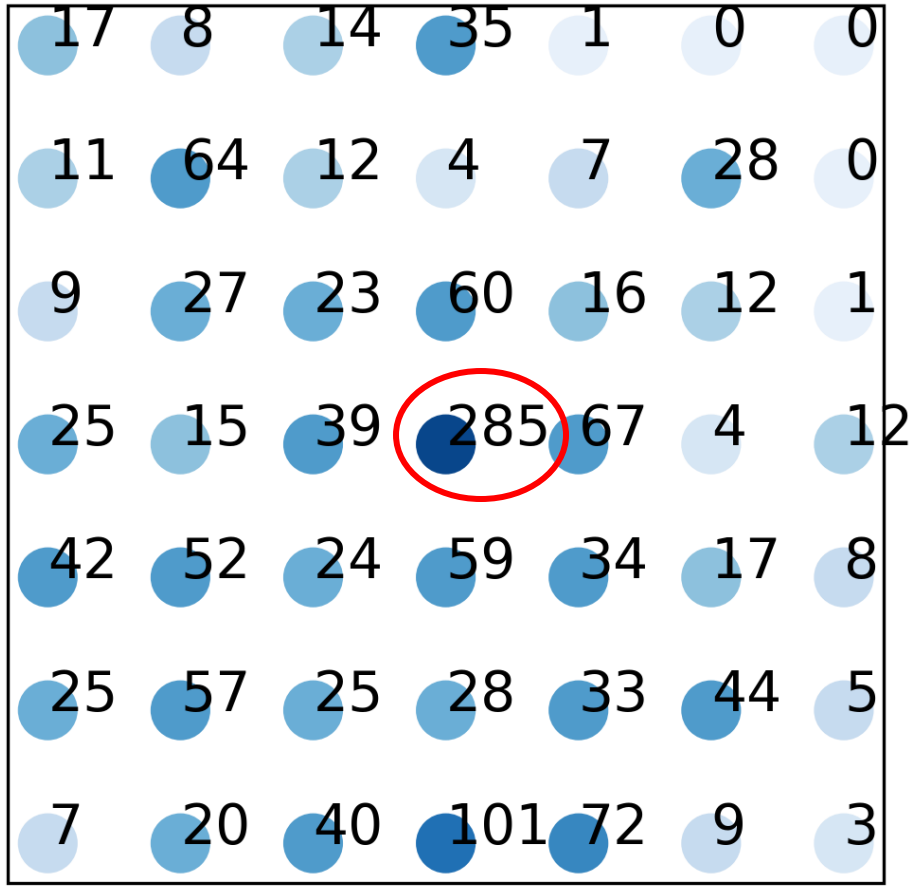
A single threshold (ERA-5 or OBS-based) will not always be representative of the forecast!



# The problem

**Kenya, 2024/04/20**

ERA5 (~31 km resolution), daily precip.




At specific locations, **ERA5 occasionally produces** amounts of **precipitation** that are **unrealistically high** … at **isolated grid-points**. … *This feature was later resolved in the IFS with the introduction of the octahedral reduced Gaussian grid.*, **Hersbach et al, 2020**[1]

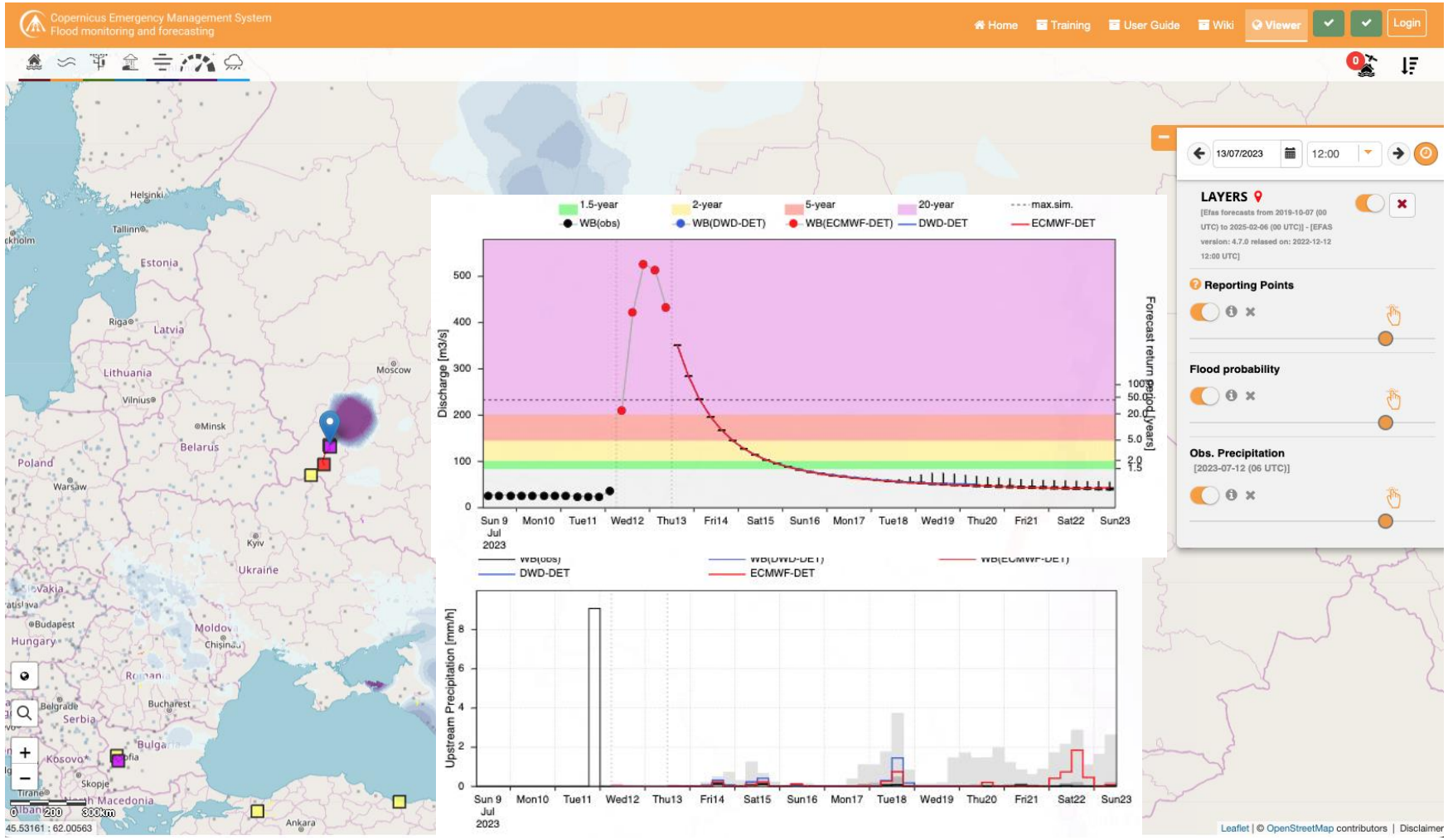
More information:

1 https://doi.org/10.1002/qj.3803

2 https://www.ecmwf.int/en/elibrary/80059-new-grid-ifs

# Initial conditions
# Limitation 2: spurious rainfall events
# Europe – QC of extreme rainfall

- Another very large observation causing huge flood
- Very sparse observation network
- Subsequently, very large Impact radius of the error in the EFAS meteo input map



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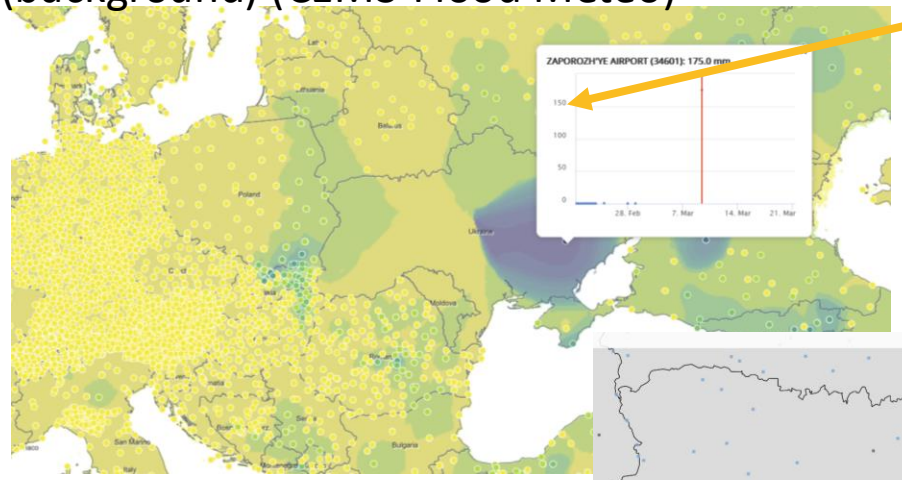
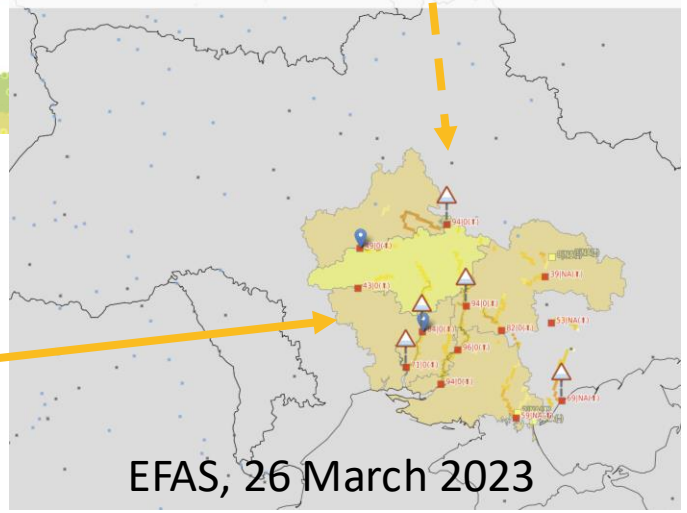
# Full domain
# Limitation 1: Lack of in-situ measurements
# Need for extrapolation (Ukraine war)

Raingauge stations (circles) and interpolated precipitation (background) (CEMS-Flood Meteo)

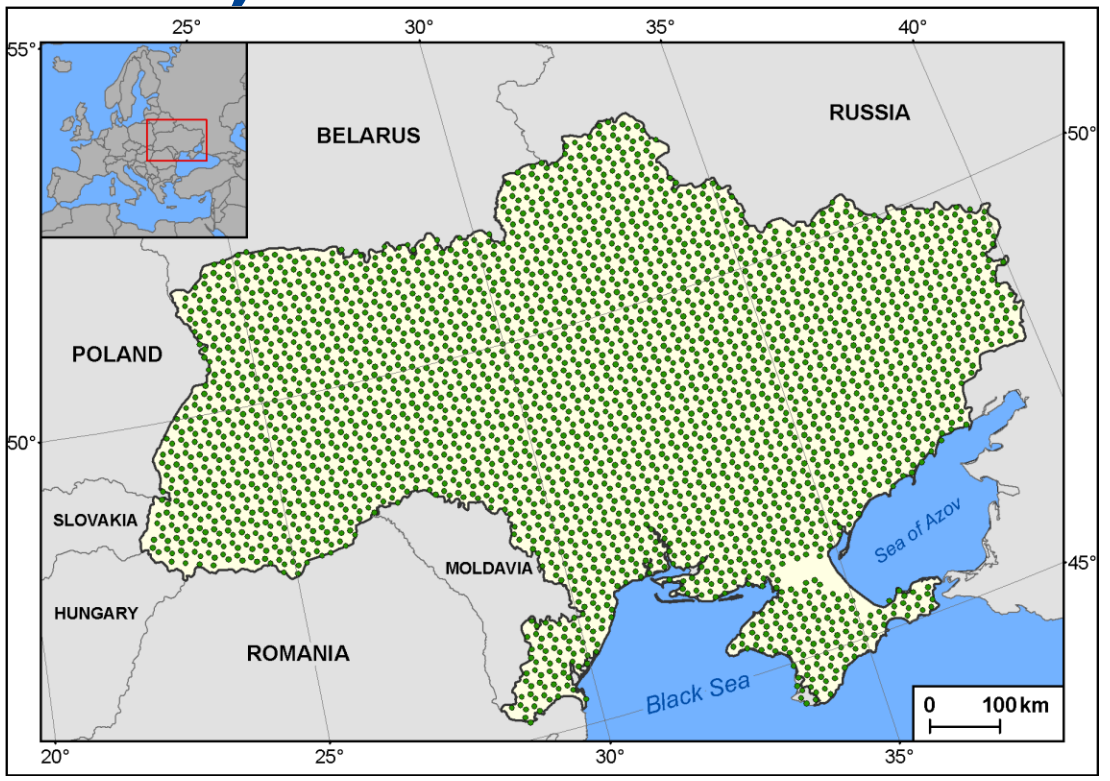



Single erroneous record on 9 March 2023



EFAS, 26 March 2023

Wrong EFAS flood impact (yellow/ orange regions) due to simulated snow melt




Use of NWP data from DWD Icon to compensate for lack of precip data from Ukraine (equivalent to 3374 stations)

https://european-flood.emergency.copernicus.eu/en/news/cems-mdcc-integrated-nwp-data-dwds-icon-model-cover-data-gaps-ukraine-during-war

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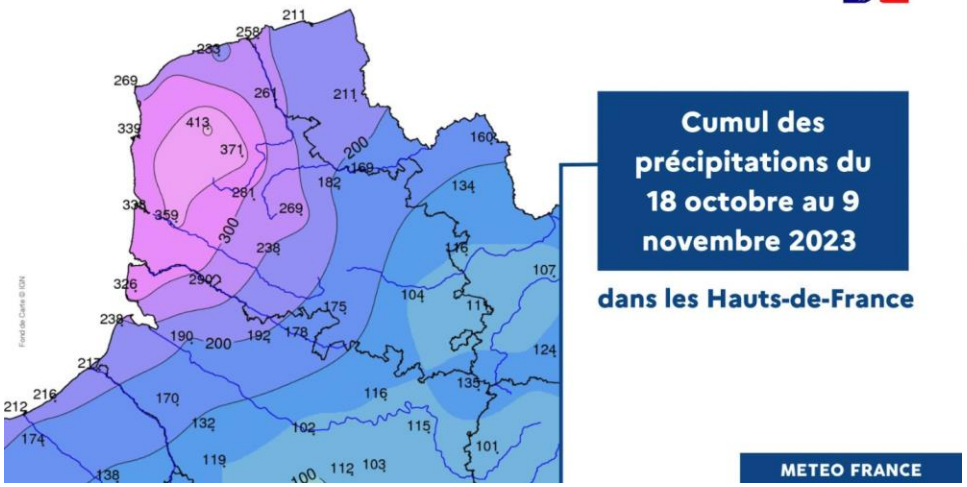
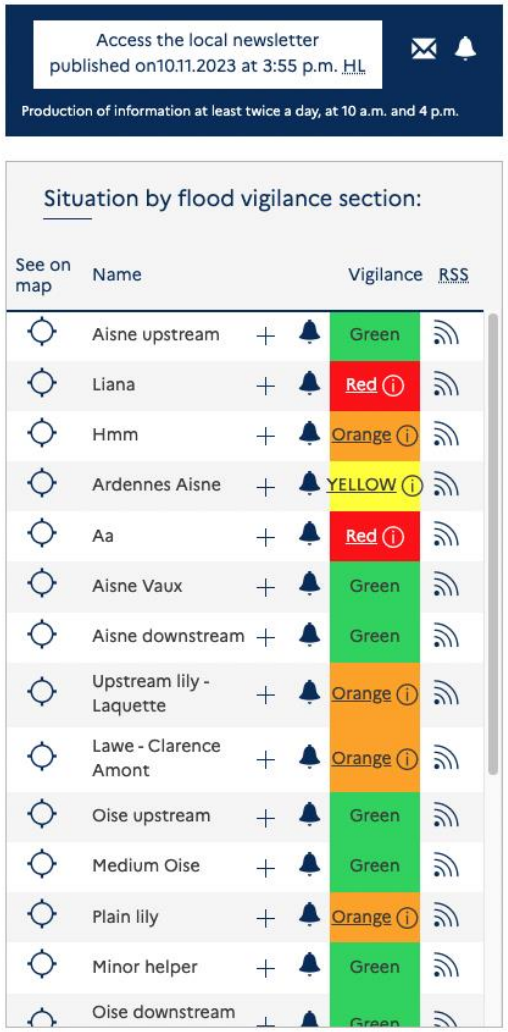
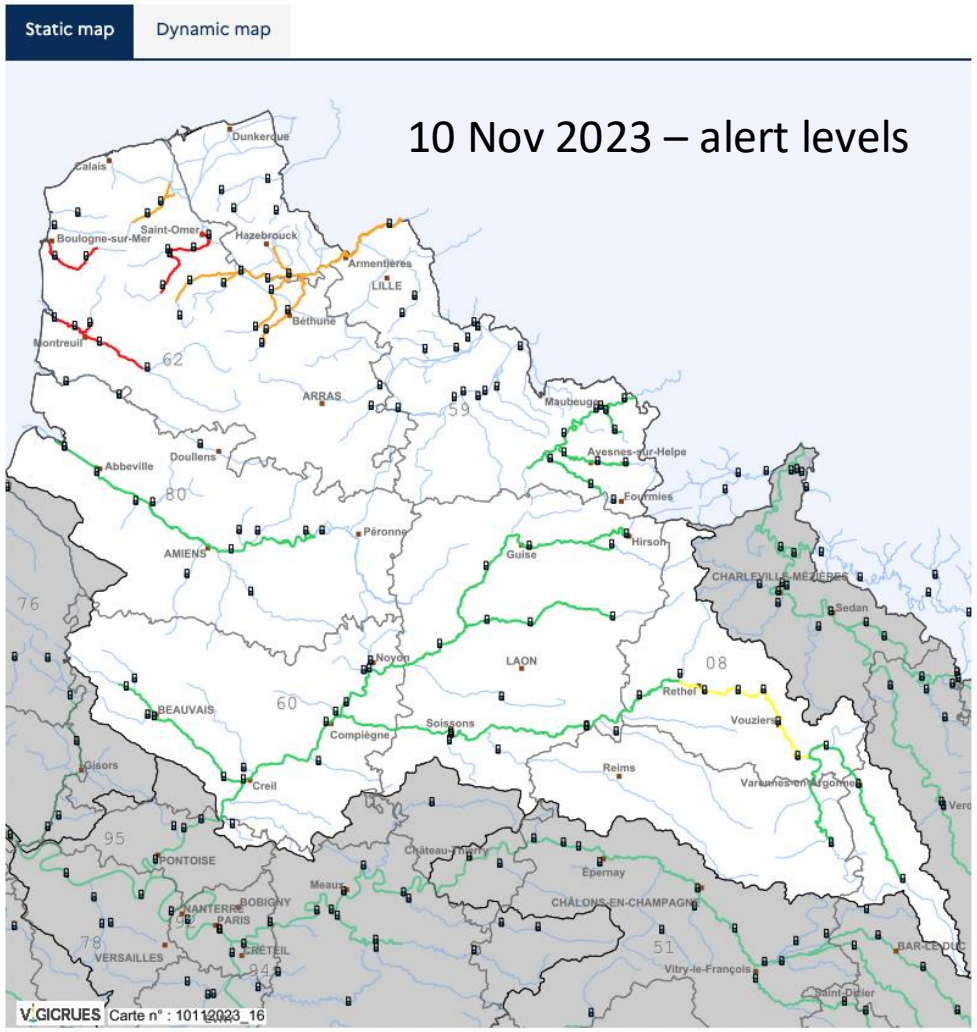
# Forecast quality
# Limitation 5: missed event




State of emergency declared in parts of France after record rainfall

Floods force evacuation of homes, schools and town halls in Calais region and in the Alps



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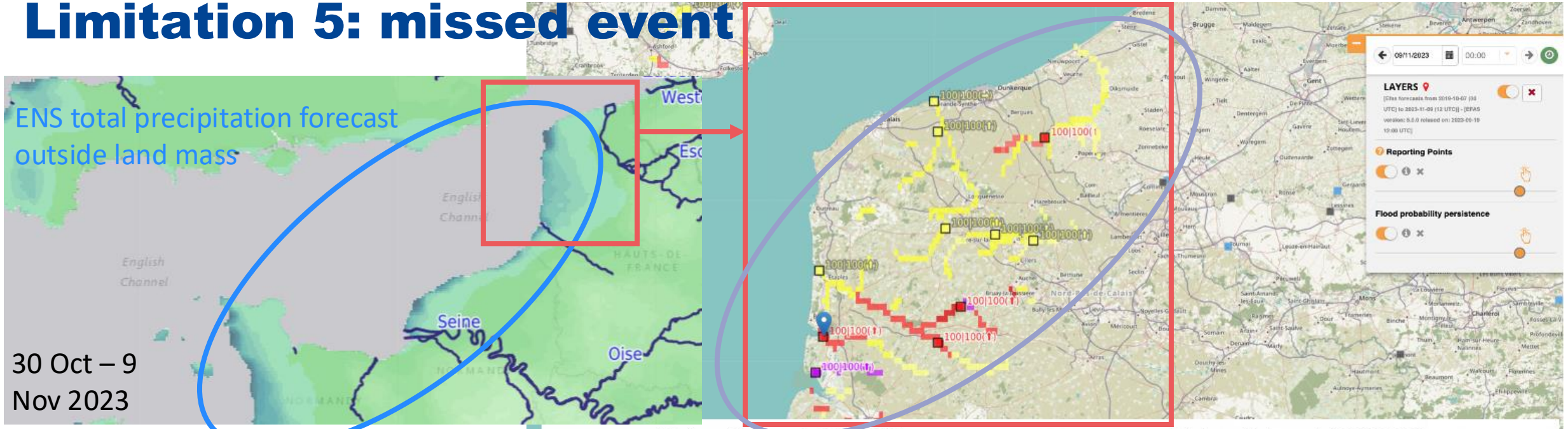
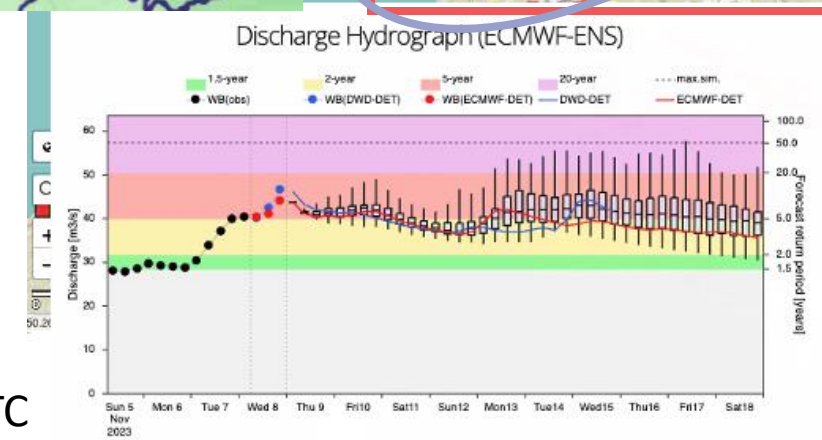
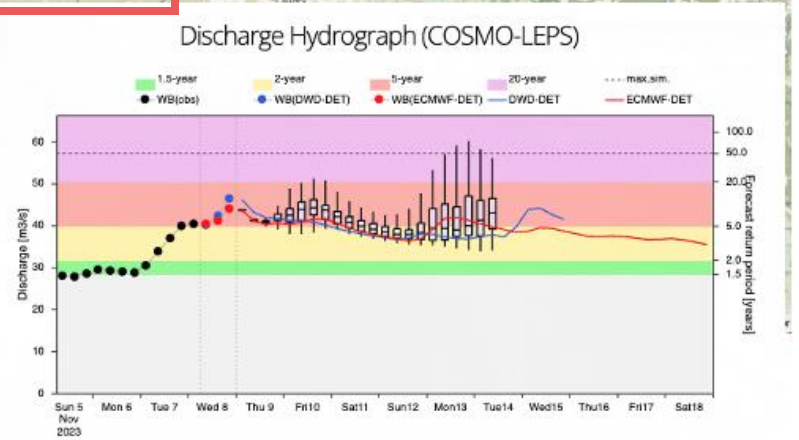
Limited flood forecast signal

# Forecast quality
# Limitation 5: missed event




Green: Probability to exceed 50mm
Blue: Probability to exceed 150mm




EFAS forecast 9 Nov 00UTC

#EUSpace

Emergency Management

# Thank you

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