PROGRAMME OF THE EUROPEAN UNION

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Emergency Management

#EUSpace

Improving hydrological forecasts at the global scale: the next major upgrade of CEMS GloFAS

Peter Salamon (1), Christel Prudhomme (2), Davide Bavera(3), Corentin Carton De Wiart (2), Jesus Casado Rodriguez(1), Robert Dill(4), Juliana Disperati(1), Andrea Ficchì(3), Goncalo Gomes(1), Stefania Grimaldi(1), Tomas Jacobson(5), Laura Jensen(4), Antonio Jimenez-Molina(5), Cinzia Mazzetti(2), Nikolaos Mastrantonas(2), Francesca Moschini(6), Carlo Russo(1), Alejandro Serratosa (5), Ervin Zsoter(2).

(1) CEMS Floods, EC JRC E1; (2) CEMS Hydrological Forecasts Computational Centre, ECMWF; (3) CEMS Drought – EC JRC E1; (4) GFZ Helmholtz Centre for Geosciences; (5) CEMS Hydrolological Data Collection Centre – GHENOVA Digital; (6) EC JRC D2

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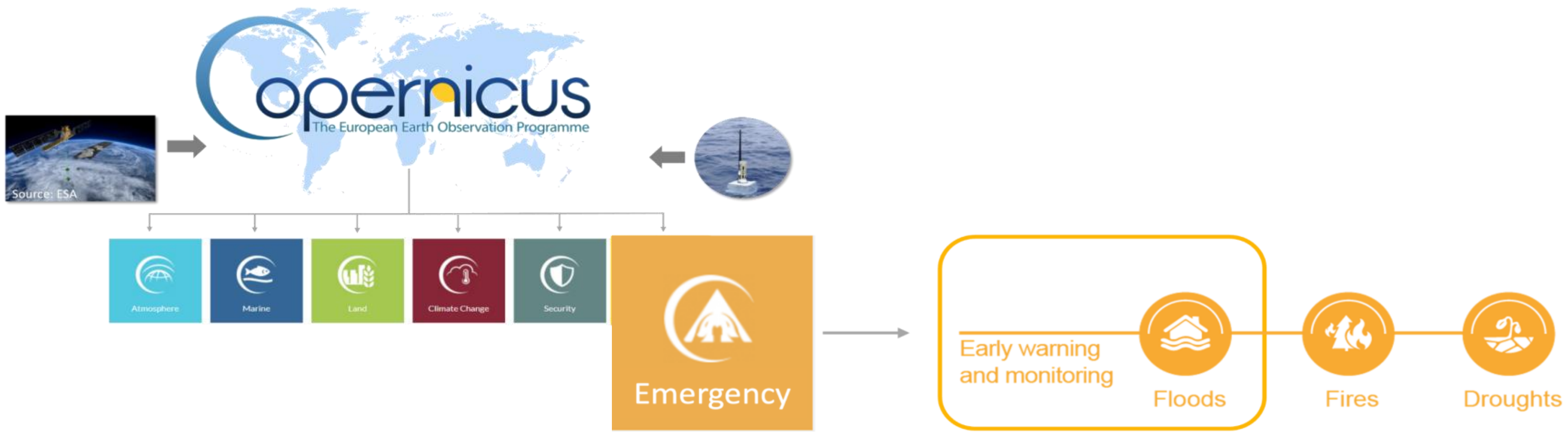
CEMS GloFAS



- **Copernicus Emergency Managment Service** (CEMS) provides timely and accurate geospatial information to support Disaster Risk Management, managed by EC JRC and operational since 2012.
- CEMS Global Flood Awareness System (GloFAS) is operational since 2018 and in **constant evolution**!
- Support **flood preparedness and response** globally by providing **complementary, probabilistic, harmonized** information to National and Regional Hydrological and Meteorological Services.
- Forecast products and data, hydrological model set-up, satellite-derived flood monitoring data **freely available.**

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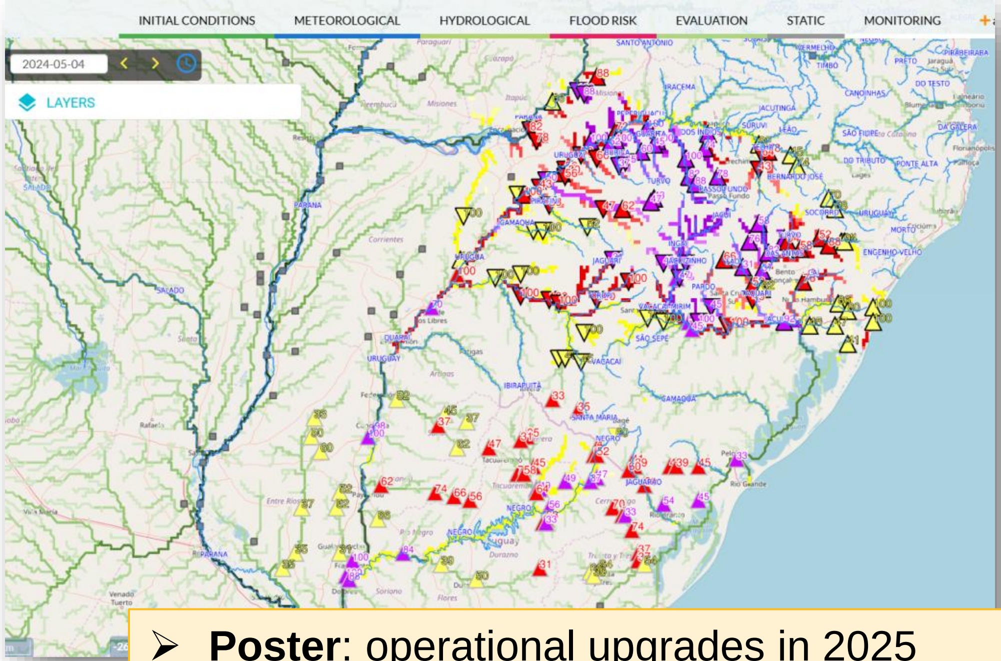
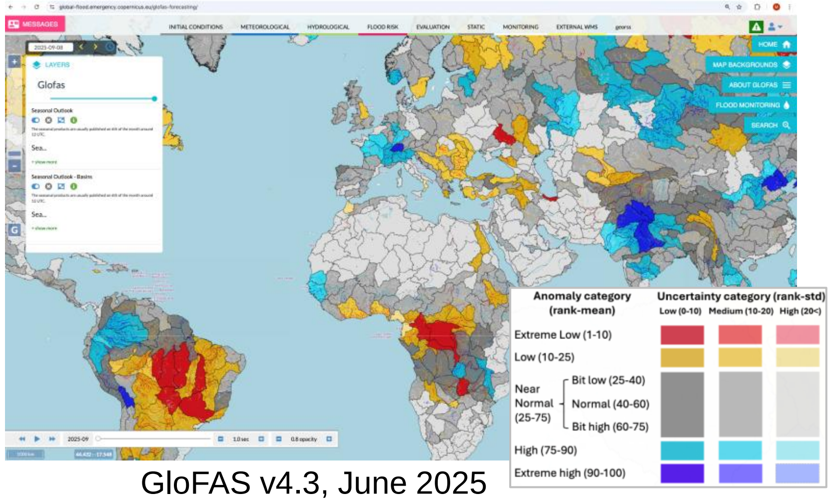
CEMS GloFAS portfolio

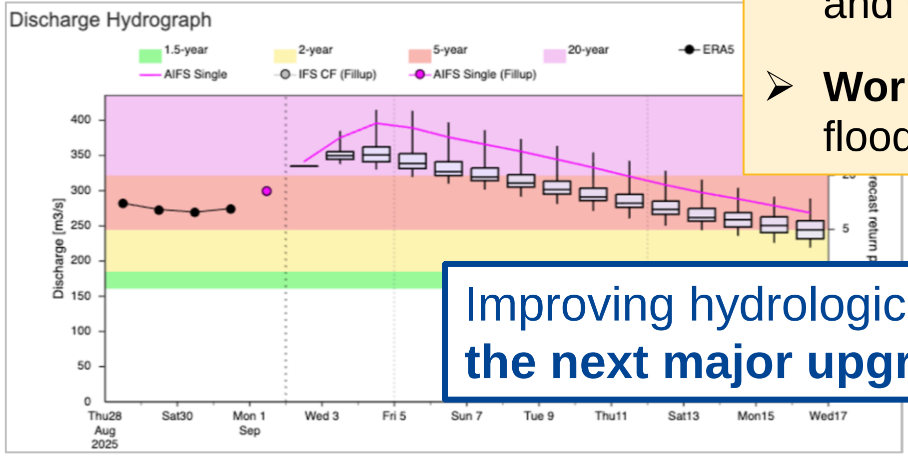
- Global **hydrological ensemble** (probabilistic) forecasts updated **daily**, for **each land pixel, at 0.05 degrees (~5km) resolution**.
- **Highlights** of expected flooding over next 15 days. Rapid flood mapping and rapid flood **impact assessment.**
- **Sub-seasonal and seasonal hydrological outlook** showing wet/dry anomalies over next 6 weeks and 7 months.
- **Additional information** as initial condition maps, soil moisture, snow water content anomalies, forecast consistency tables, performance layers to help interpret results.



- **Poster**: operational upgrades in 2025
- **Market Place**: join us and explore GloFAS and GFM products and data
- **Workshop**: how to improve the usability of flood forecast information



GloFAS v4.3, June 2025



GloFAS v4.4, September 2025

Improving hydrological forecasts at the global scale:
the next major upgrade of CEMS GloFAS, v5.x

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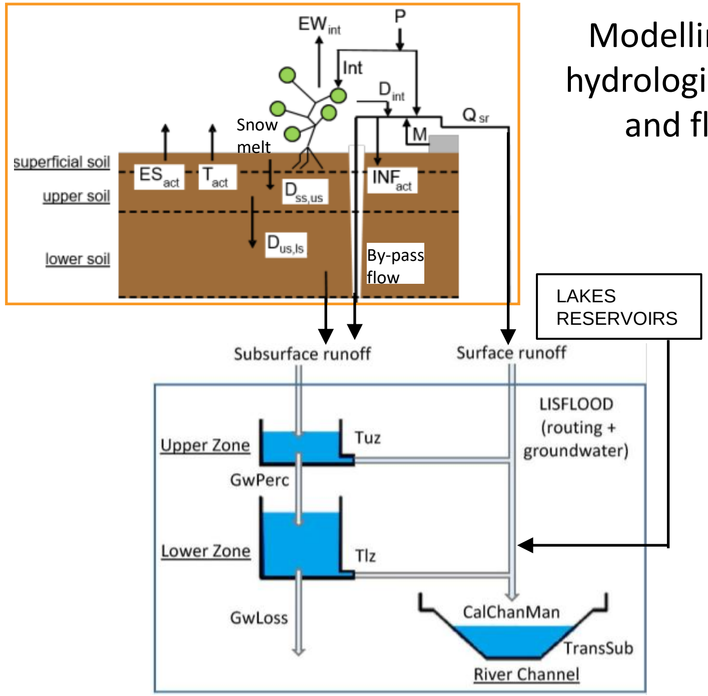
CEMS GloFAS hydrological modelling chain

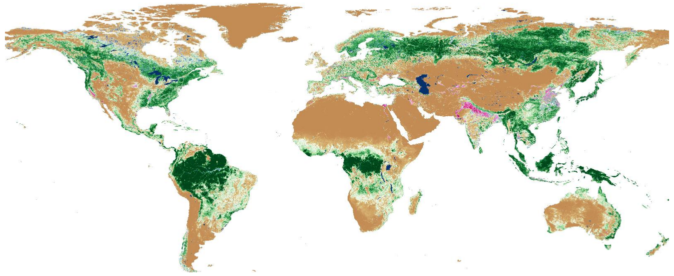
OS LISFLOOD Hydrological model :
Spatially distributed, physically based



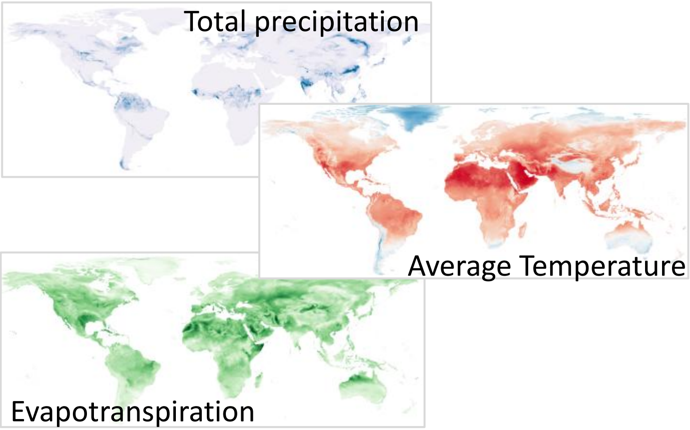
Modelling of all hydrological states and fluxes.

Open Source code and documentation:
https://github.com/ec-jrc/lisflood-code
https://ec-jrc.github.io/lisflood-model/

INFORMATION ON CATCHMENTS' PHYSICAL PROPERTIES



METEOROLOGICAL FORCINGS:



Climatology: ECMWF-C3S ERA5
Forecast: ECMWF Ens, AIFS, SEAS5

GloFAS v5.x:
3 arcmin spatial resolution
Daily temporal resolution

Model calibration

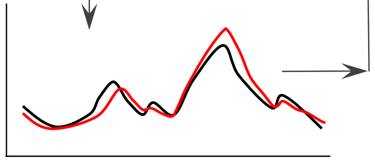
INPUTS

Parameters

OS LISFLOOD

Modelled time series

Observed time series

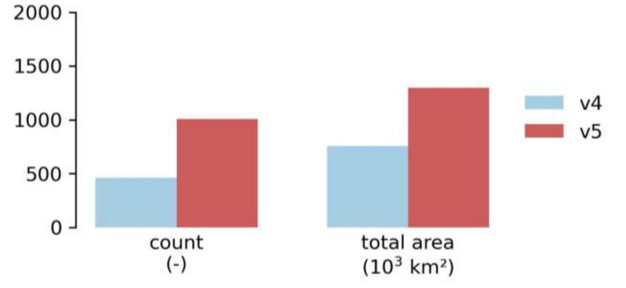


Can ungauged catchments learn parameters from gauged catchments?

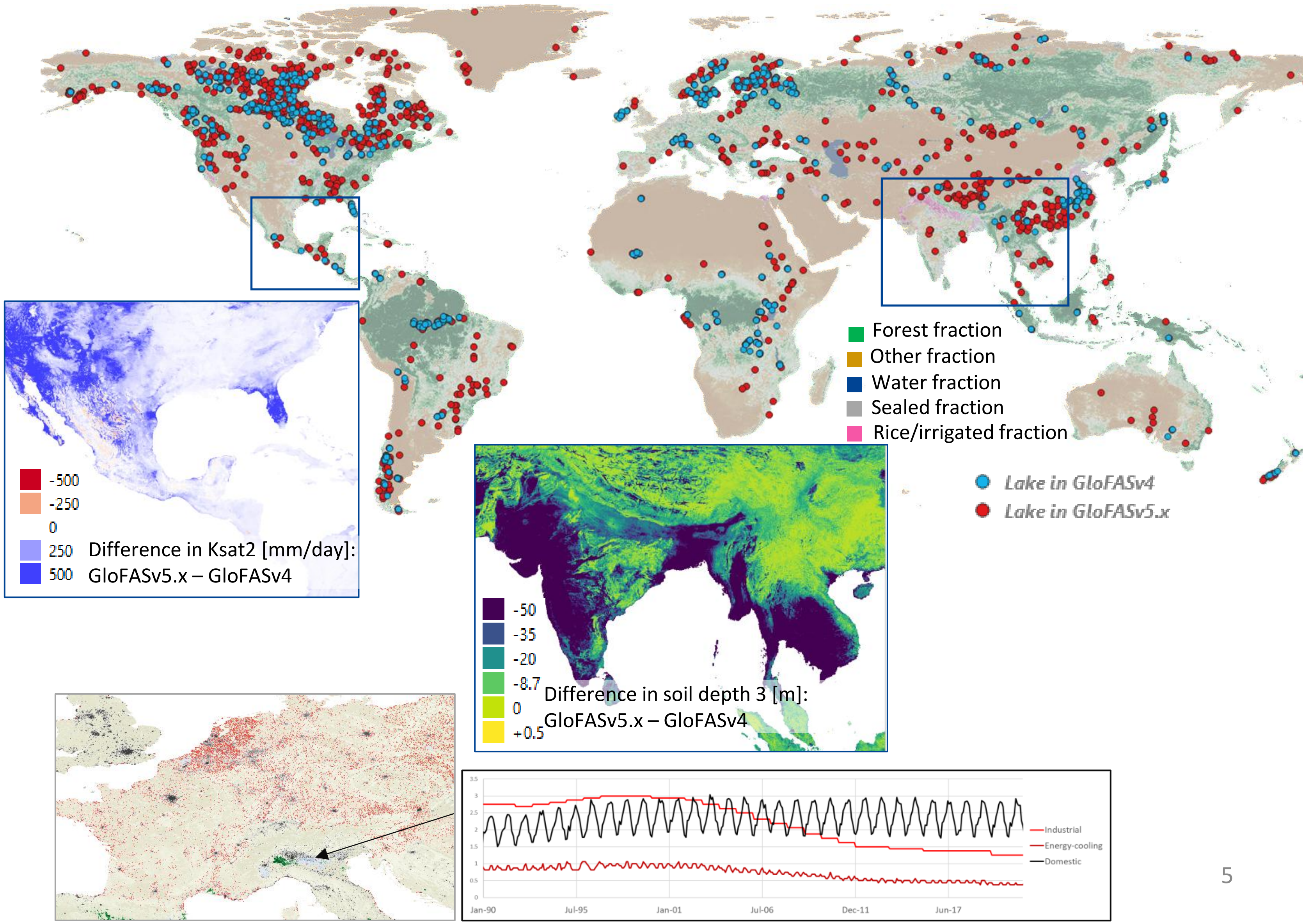
Improvements to model input data

~100 maps providing information on

- Morphology
- Land cover and land use
- Soil properties
  Maximum soil depth: depth to groundwater table or bedrock (Fan et al. 2013 [1]).
  Soil properties derived from ISRIC v2.0 [2].
- Water demand for human use [3] :
  domestic, livestock, industry, energy-cooling
- Lakes



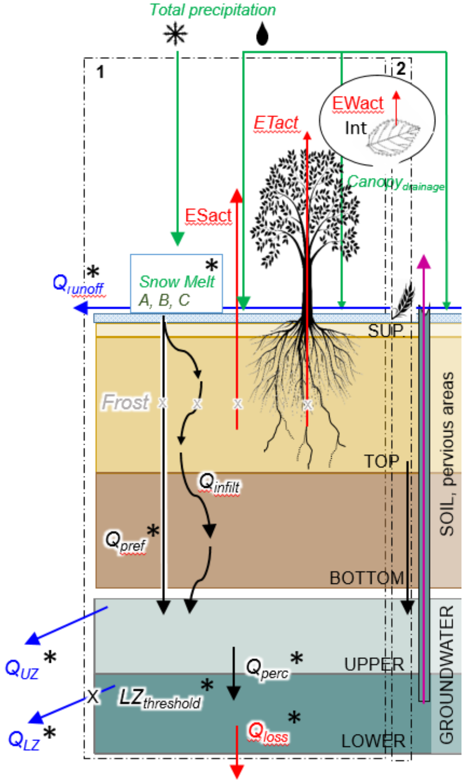
- Reservoirs ?



[1] https://www.science.org/doi/10.1126/science.1229881
[2] https://soilgrids.org/ [3] https://github.com/ec-jrc/lisflood-utilities

Improvements to the hydrological model

Model initialization

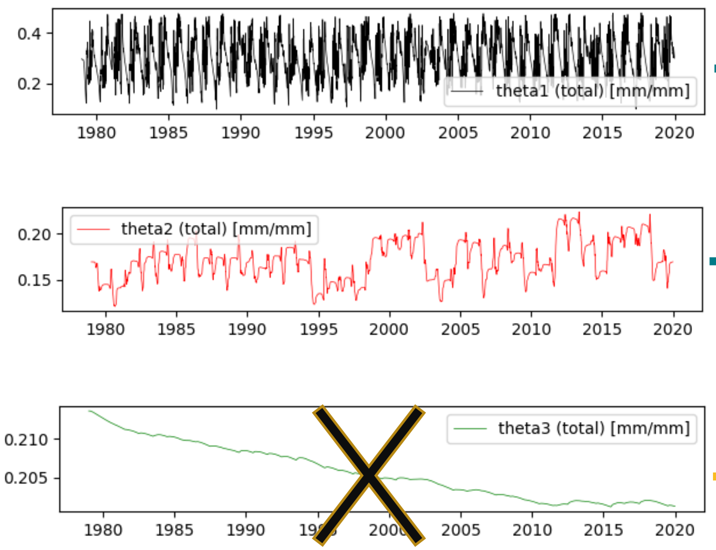


1 – Top 5cm

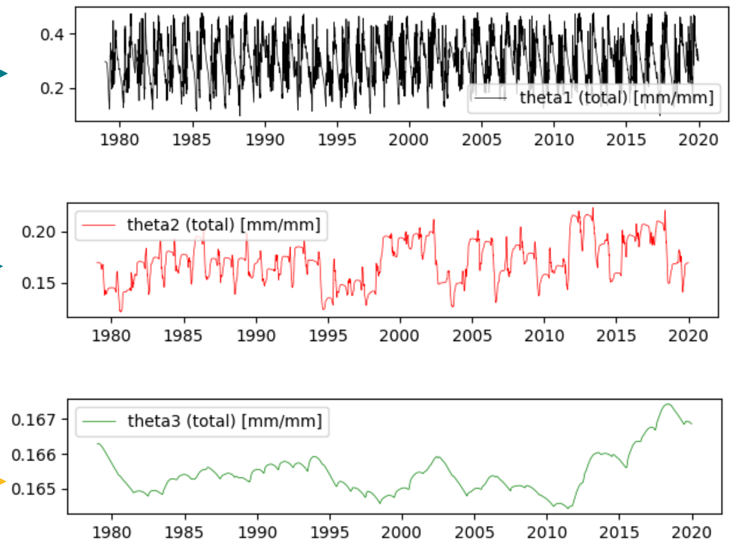
2 - Root depth

3 - Depth to bedrock/water table

Modelled soil moisture temporal series



Initial soil moisture state is computed analytically to account for area-specific soil properties and climate conditions.



In some areas (e.g. dry catchments, thick soils):

- Negative trend in third soil layer soil moisture.
- Not adequate interactions between storages.

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Improvements to the hydrological model

Open channel flow

One-dimensional (1-D) Saint-Venant

Continuity $$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0$$

Momentum $$\underbrace{\frac{\partial Q}{\partial t}}_{\text{Local acceleration}} + \underbrace{\frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right)}_{\text{Convective acceleration}} + \underbrace{gA\frac{\partial y}{\partial x}}_{\text{Pressure gradient}} - \underbrace{gA(S_o}_{\text{Gravity force}} - \underbrace{S_f)}_{\text{Friction}} = 0$$

Kinematic wave

Diffusive wave

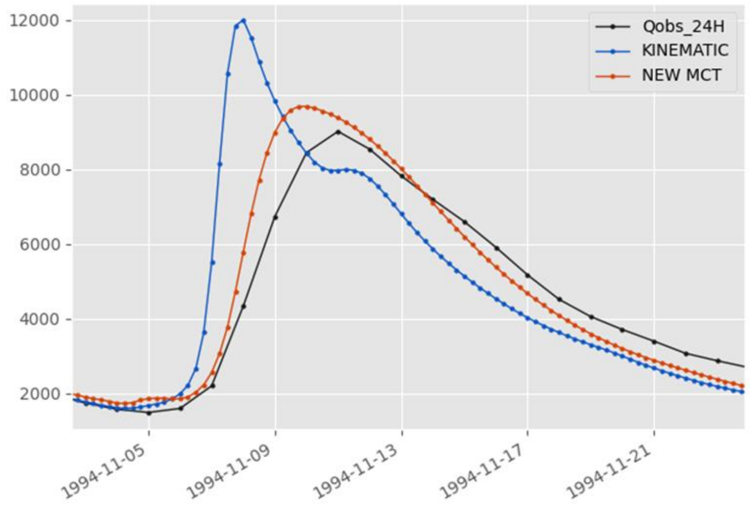
Dynamic wave

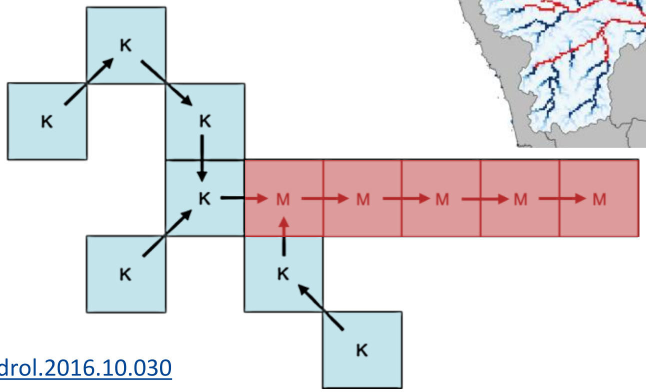
Kinematic wave routing

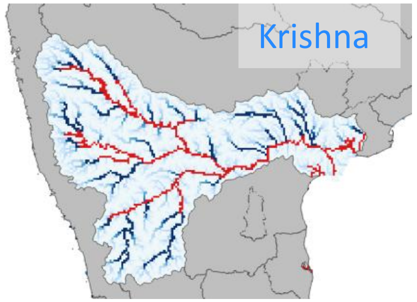
- works well in steep slope rivers,
- but it does not allow for physical attenuation.

Diffusive wave routing should be used in mild slope rivers, but hydraulic routing methods are generally computationally expensive.

Muskingum-Cunge-Todini method (MCT)
is an **analogue of the diffusion wave equation,**
simple and accurate, suited for **large-scale hydrologic modelling**.







Todini, E (2007), https://doi.org/10.5194/hess-11-1645-2007, 2007
Reggiani, P., Todini, E., & Meißner, D. (2016). https://doi.org/10.1016/j.jhydrol.2016.10.030

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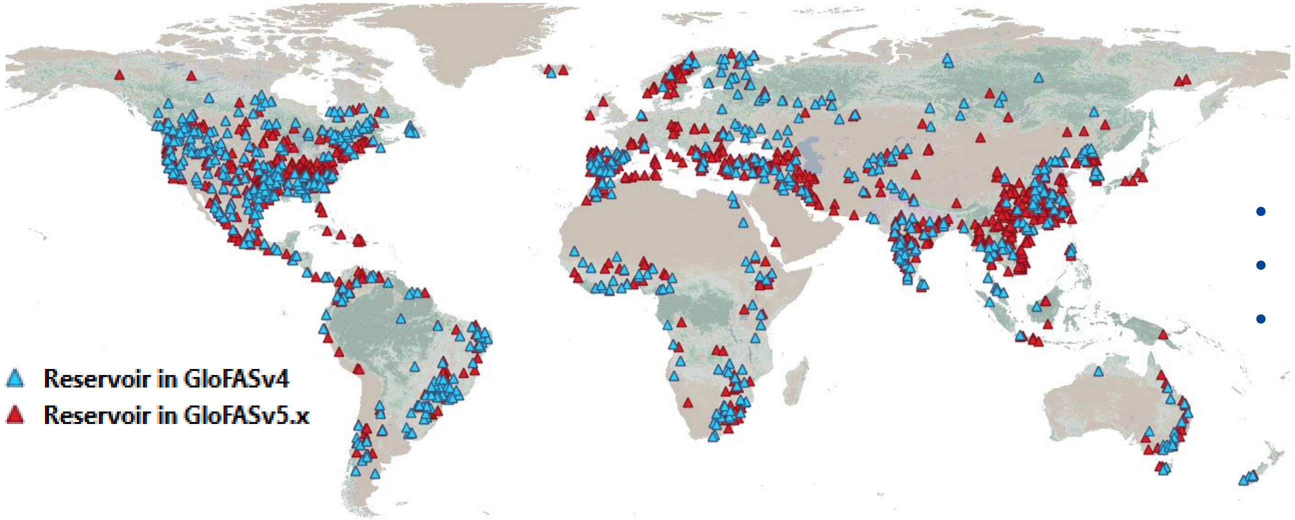
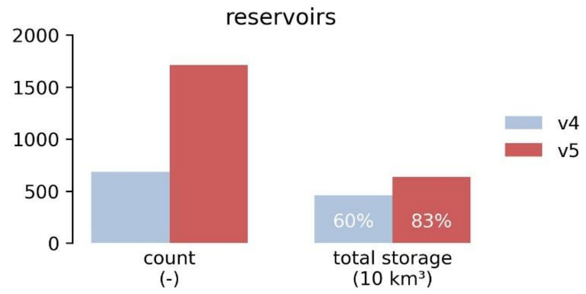
Improvements to the hydrological model

Reservoir modelling

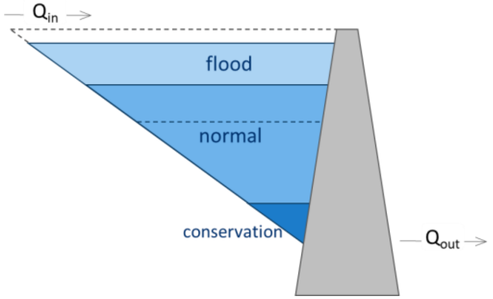


- GRanD / GlobalDamWatch
- Capacity ≥ 100 hm^3
- Catchment ≥ 500 km^2



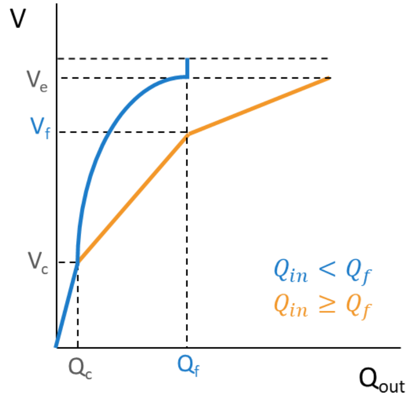
Reservoir modelling routing in GloFASv4:

- Outflow is a function “only” of storage
- In the simulation, reservoirs tend to fill up (limited flood control).



In GloFAS v5.x:

- Hanazaki et al. (2022) [1]
- Outflow is a function of both inflow and storage
- Enhanced simulation of both storage and outflow



[1] Hanazaki, R., Yamazaki, D., & Yoshimura, K. (2022) https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2021MS002944

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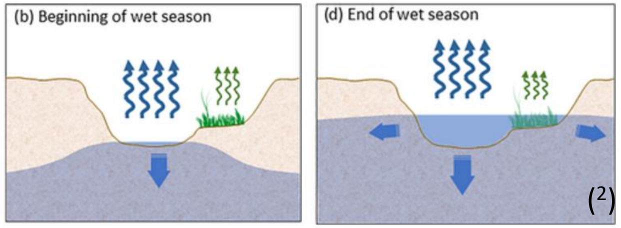
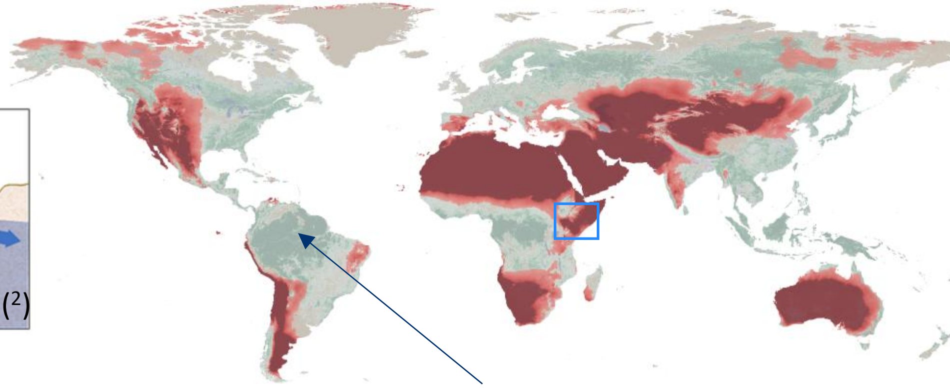
Improvements to the hydrological model

Transmission losses

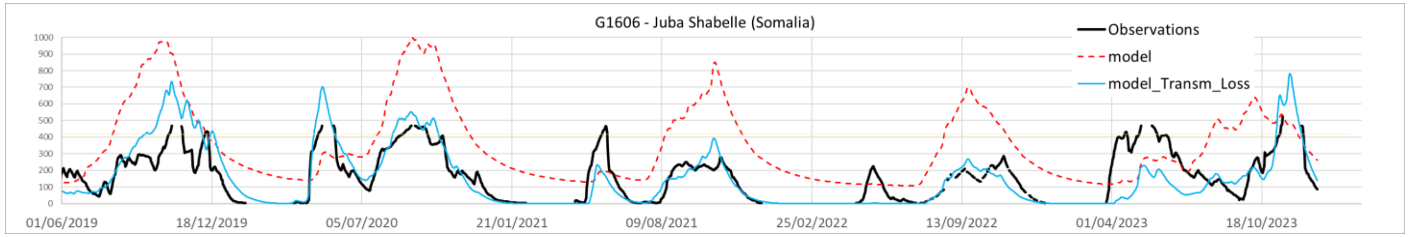
Loss in the flow volume of a river as water moves downstream: evaporation, transpiration by riparian vegetation, and **groundwater recharge.**
Where? Arid areas, karstic systems, but not only ([1]).



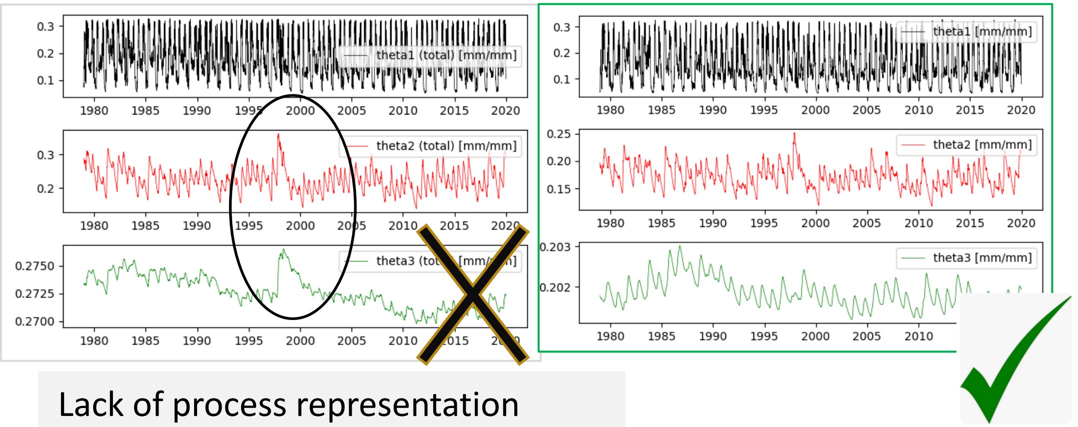


(1) https://www.nature.com/articles/s41467-024-54370-3

Modelling of transmission losses:
simplified approach for modelling seepage from channels to deep groundwater - one parameter relationship([2]).



SOIL MOISTURE – 40y CLIMATOLOGY



Lack of process representation leads to detrimental compensation effects of model parameters!

[2] Rao, C. X., & Maurer, E. P. (1996). A Simplified Model for Predicting Transmission Losses in a Stream Channel. *Water Resources Bulletin*. http://scholarcommons.scu.edu/ceng/66

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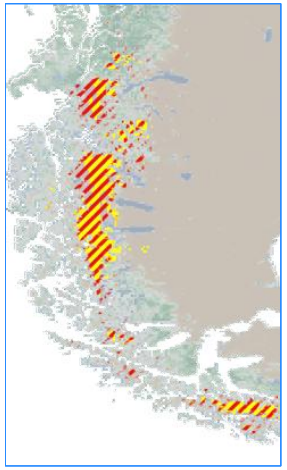
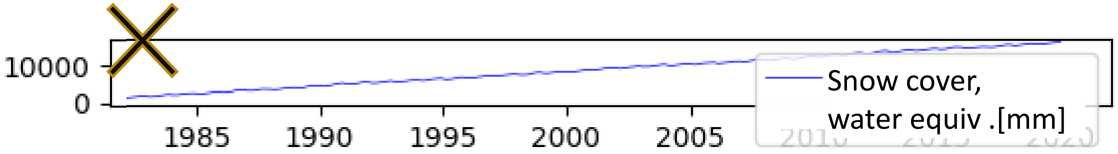
Improvements to the hydrological model

Bug-fixes

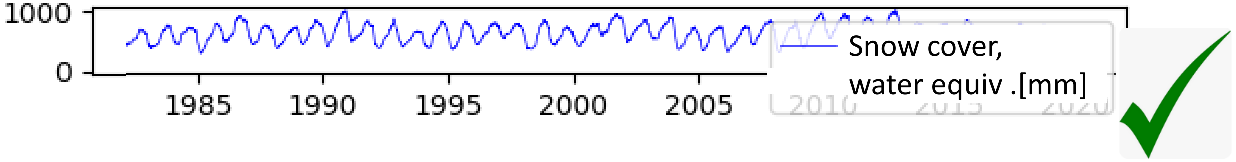


Adjusted snowmelt for high altitude pixels – solution proposed by GFZ



Constant increase of snow accumulation in some pixels of the global domain, not consistent with observed Total Water Storage.

Snow ablation from highest to middle, to lowest elevation of each pixel; increased snow melt in the lowest elevation.

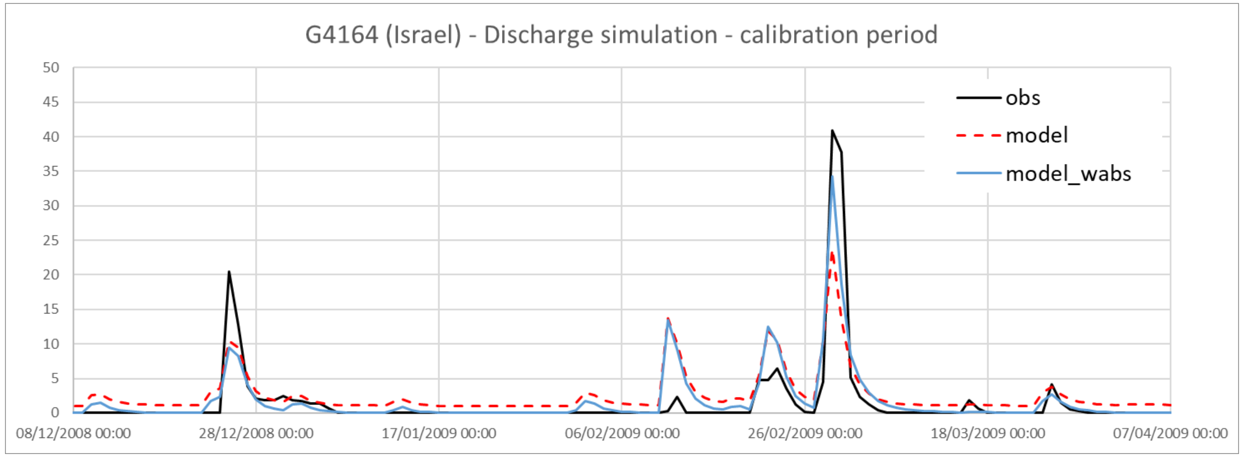


GloFASv4 accumulated snow water equivalent in level A

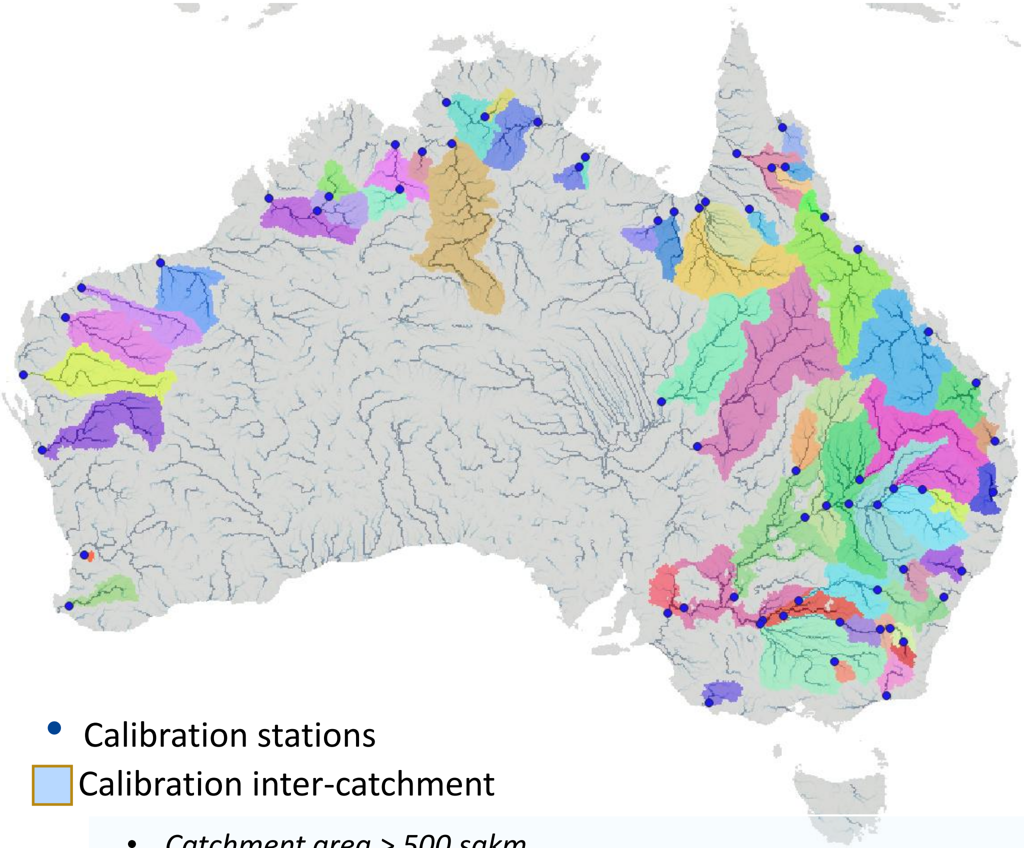
GLIMS glaciers outline (https://www.glims.org/)

More consistent management of water abstraction

OS LISLFOOD currently does not model horizontal groundwater fluxes. More consistent management of water consumptive use and water demand to avoid spurious effects on river flow and groundwater storage.



Improvements to model calibration and regionalization



- Calibration stations
- Calibration inter-catchment
    - *Catchment area > 500 sqkm.*
    - *At least 365x4 of daily discharge observations from 01/01/1980.*
    - *Discharge time series has acceptable quality (e.g. outliers)*
- "Ungauged" area

Observations: discharge in-situ measurements.

Gauged catchments

Hierarchical (top-down), catchment by catchment approach.

Distributed Evolutionary Algorithm for Python (DEAP, Fortin et.al 2012 [1]).

Enhanced open-source calibration tool:

- Pre-selection of the relevant parameters (e.g. parameters related to lakes or snow melt can be excluded)
- Use of longer time series of observations [2]
- More restrictive stopping criteria for the selection of the best individual
- Evaluation based on 'KGE incl. Jensen-Shannon Divergence, accounting for *both high flows and low flows* [3].

Parameter regionalization

GloFAS v4: simple parameter transfer, from 1 donor to 1 target catchment

GloFAS v5.x: can we learn from all calibrated catchments?

Derive model parameters for ungauged catchments using parameter learning Neural Network

[1] https://jmlr.org/papers/volume13/fortin12a/fortin12a.pdf - [2] https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2021WR031523 - [3] https://meetingorganizer.copernicus.org/EGU25/EGU25-16423.html

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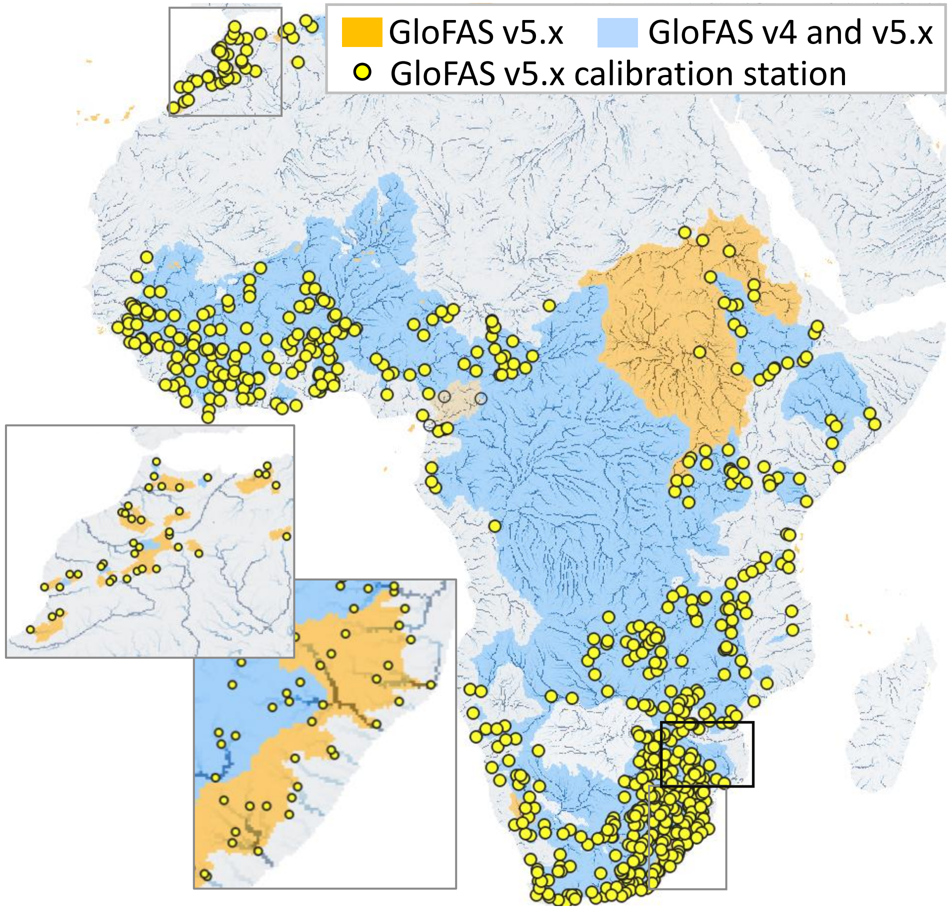
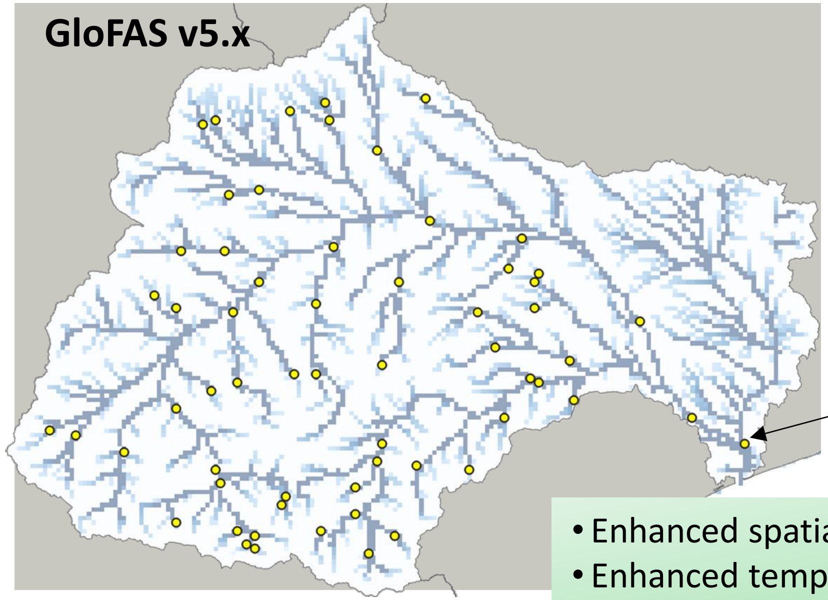
A sneak preview! Updated calibration stations

GloFAS v4 used 1995 calibration stations. Estimated number for GloFAS v5.x 5000

Africa: GloFAS v4: 420 calib. Stations
GloFAS v5.x: 650



Example - Limpopo basin

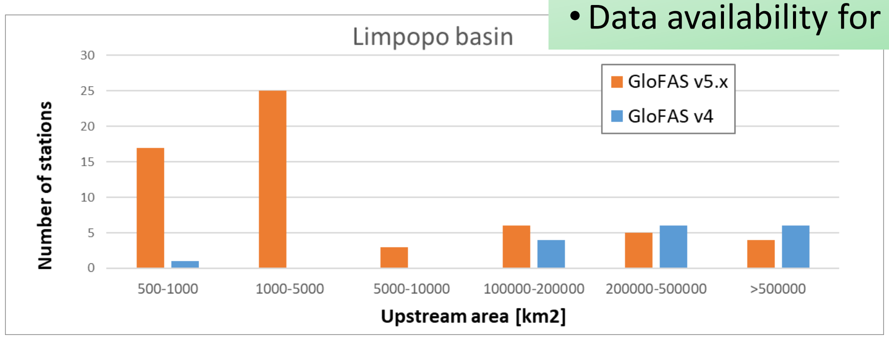


Calibration stations:

- GloFAS v4: 17
  GloFAS v5.x: **62**
- Same area coverage
- Analysis of smaller catchments

Calibration Station

- Enhanced spatial coverage
- Enhanced temporal coverage
- Data availability for smaller catchments



https://confluence.ecmwf.int/display/CEMS/Share+your+data+with+GloFAS

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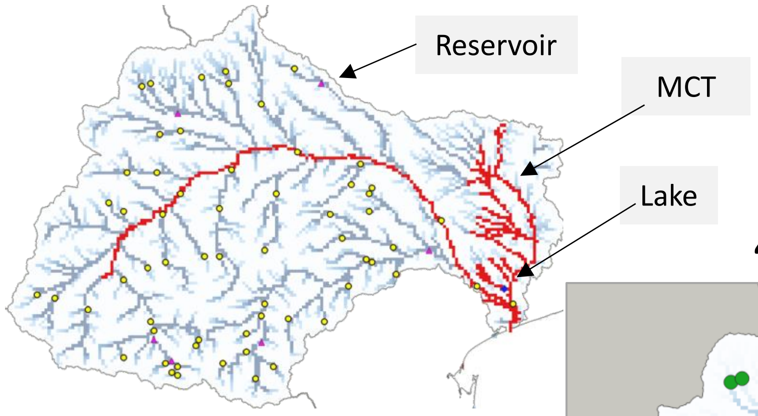
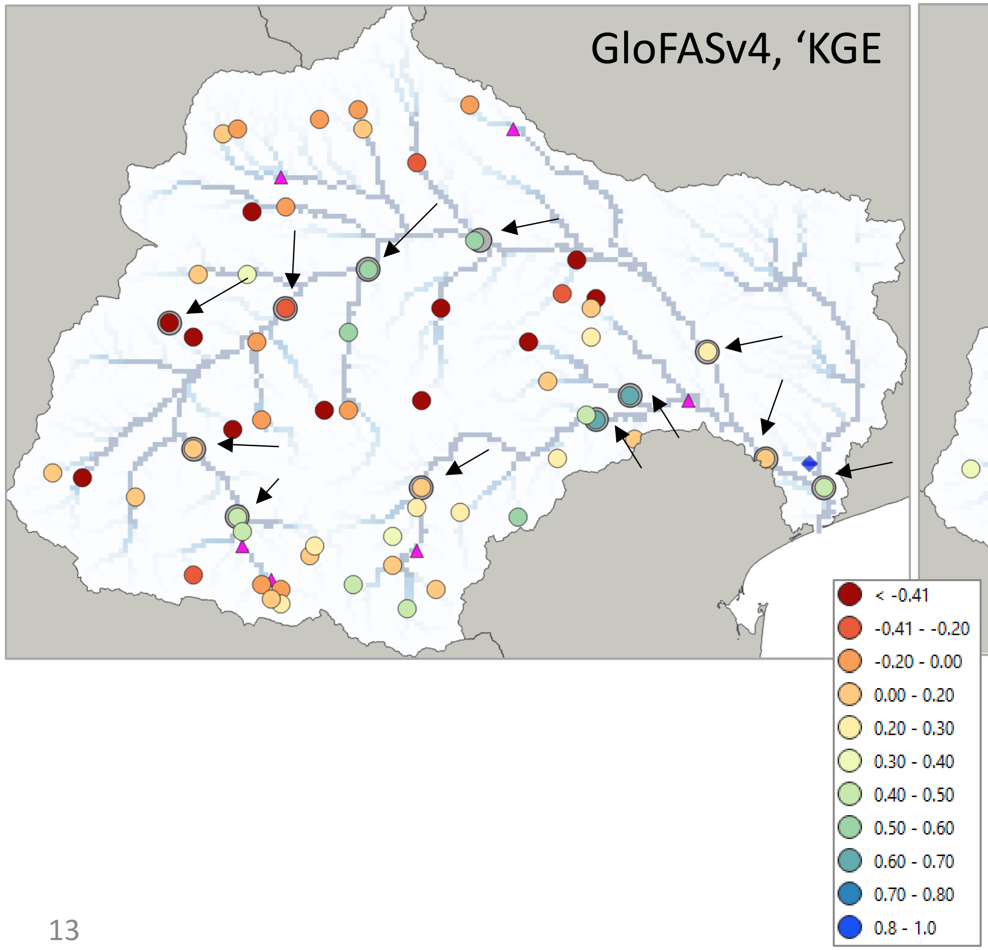
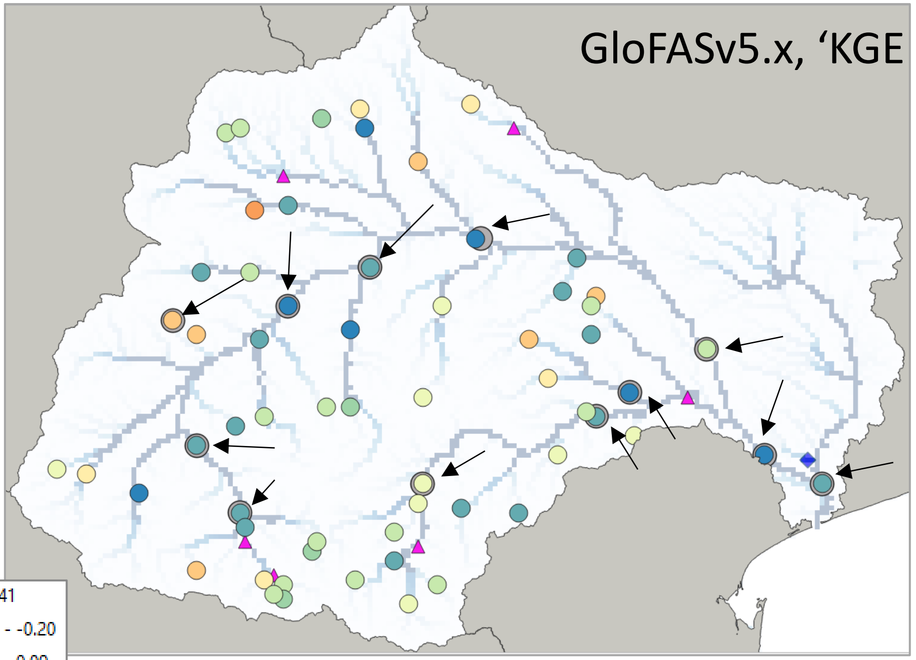
A sneak preview! Results

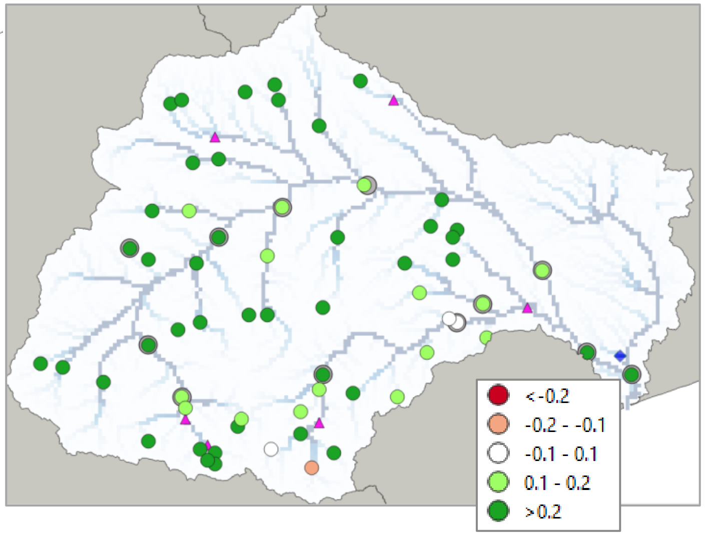
The Limpopo basin



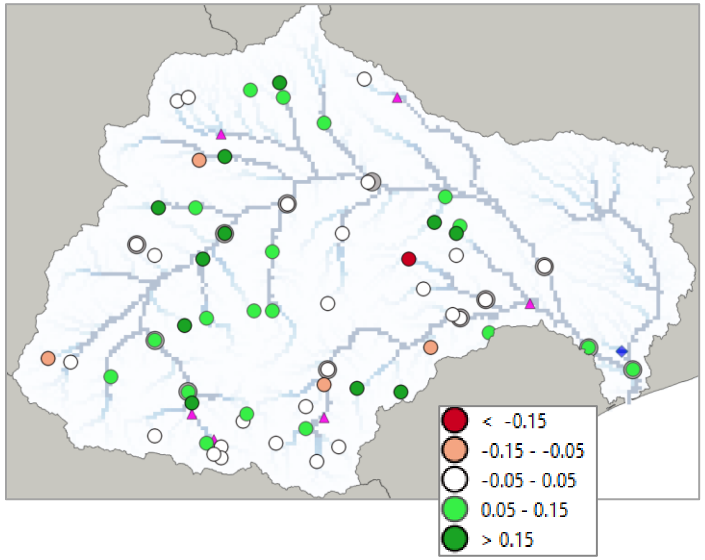




'KGE difference



Correlation difference



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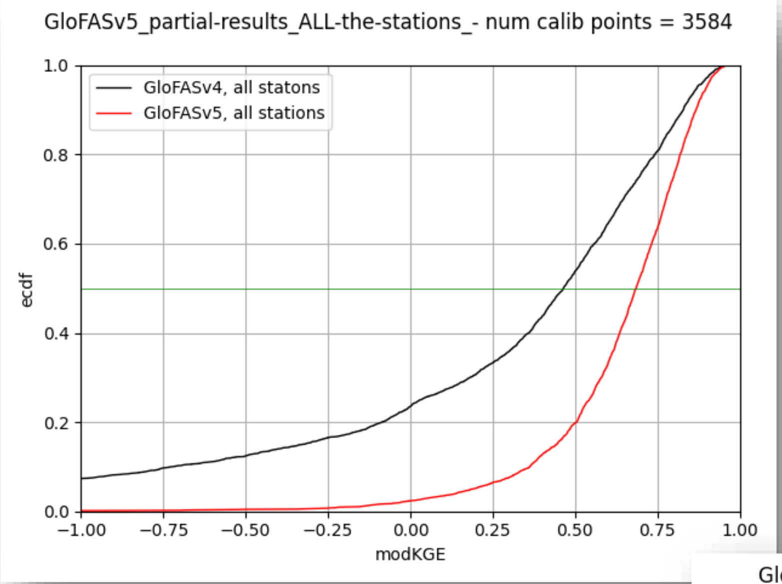
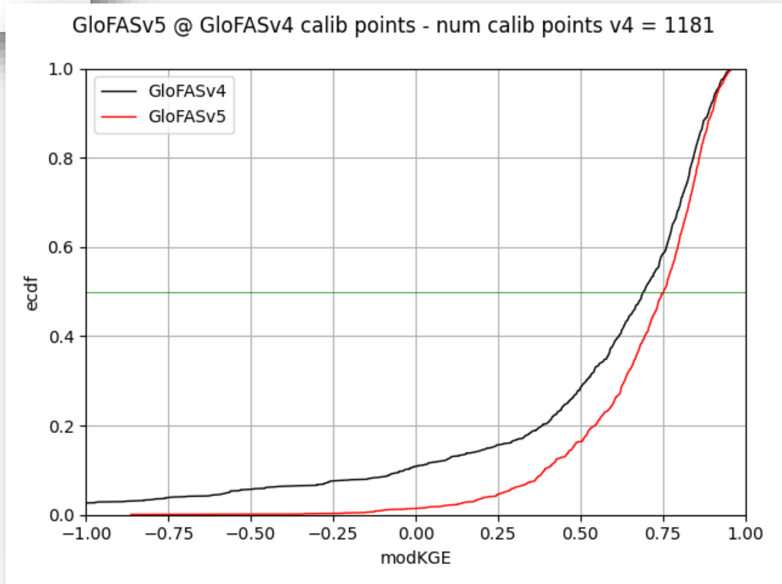
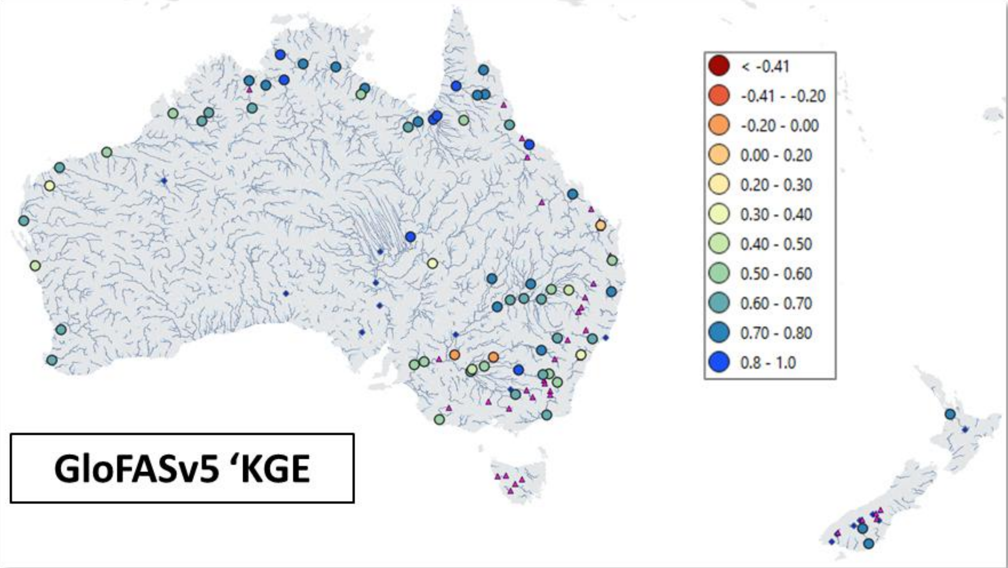
A sneak preview! Results

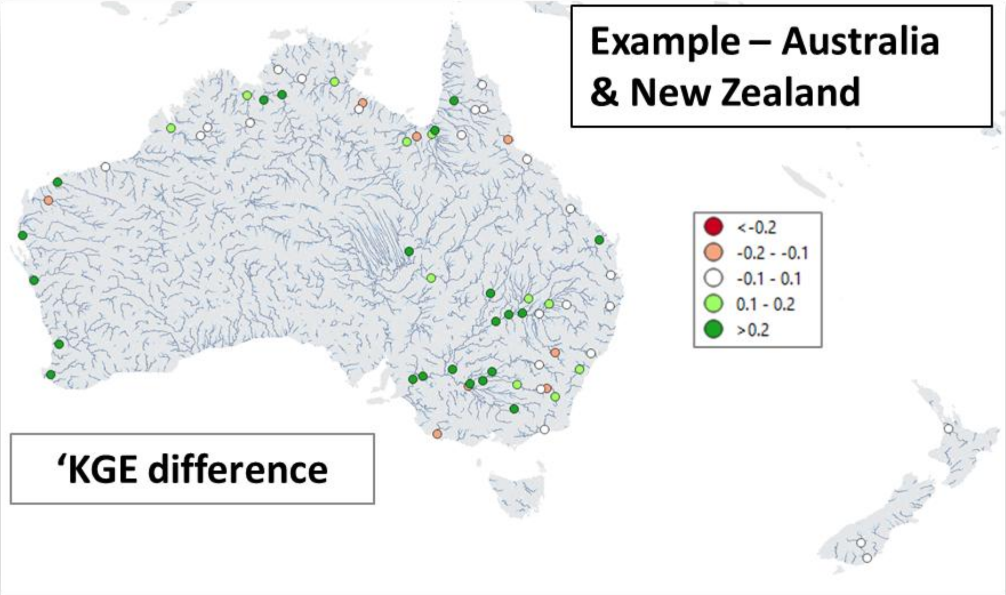


3500 calibrated stations as of today!
- ✓ Africa,
- ✓ Asia,
- ✓ Oceania,
- ✓ Central and South America

In progress: North America, Europe







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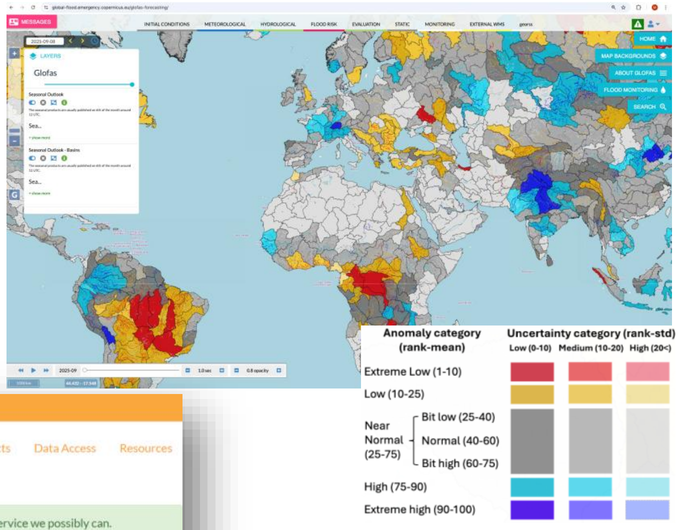
What’s next?

1. GloFAS v5.x calibration and computation of GloFAS v5.x climatology
2. Publication of the GloFAS v5.x climatology in the CEMS Early Warning Data Store
3. Pre-operational release of GloFASv5.x on stage (https://stage.globalfloods.eu/), 1 month before operational release
4. **GloFAS v5.x operational release – 2026**

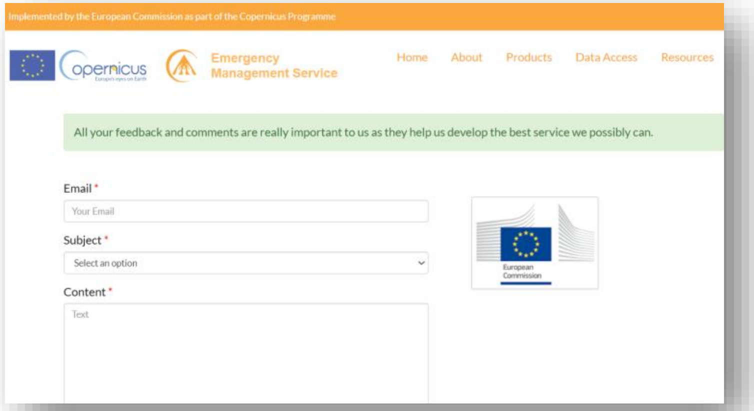
Looking forward to in-depth conversations!

- **Poster** operational upgrades in 2025
- **Market Place**: join us and explore GloFAS and GFM products and data!
- **Workshop**: How to improve the usability of flood forecast information



Please contact us at

https://global-flood.emergency.copernicus.eu/contact-us/



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Thank you

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