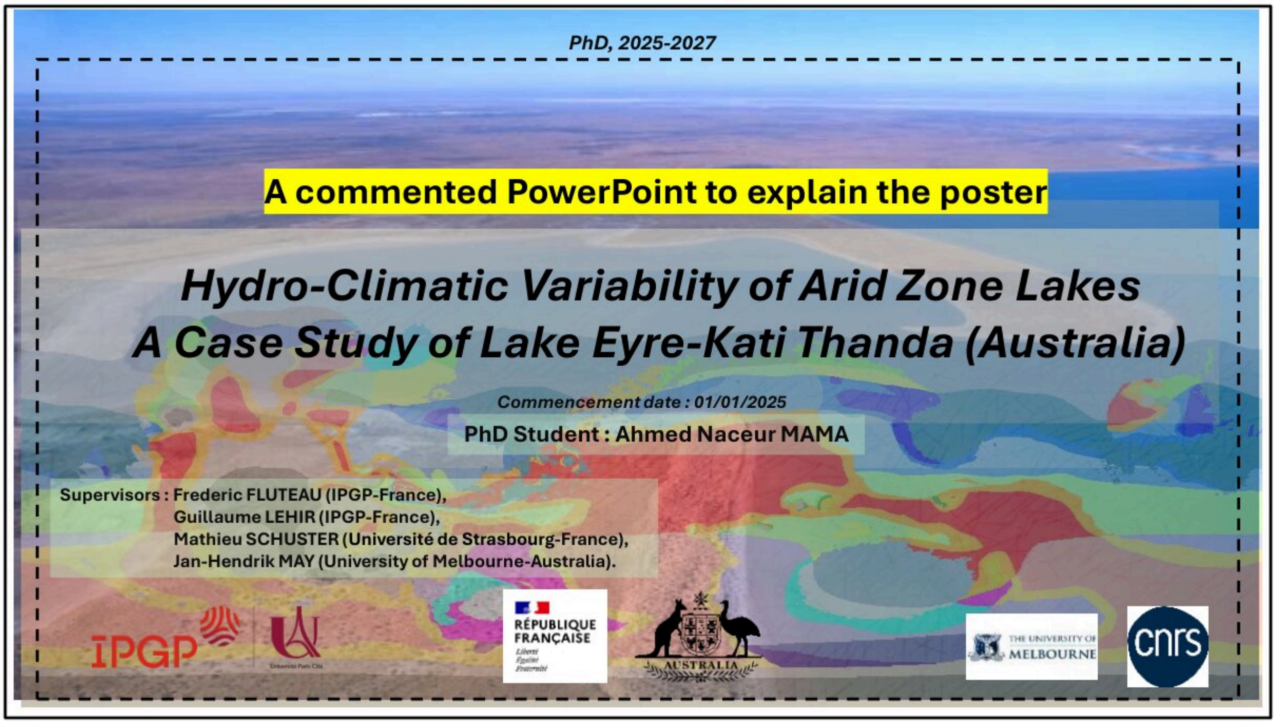


PhD, 2025-2027

A commented PowerPoint to explain the poster

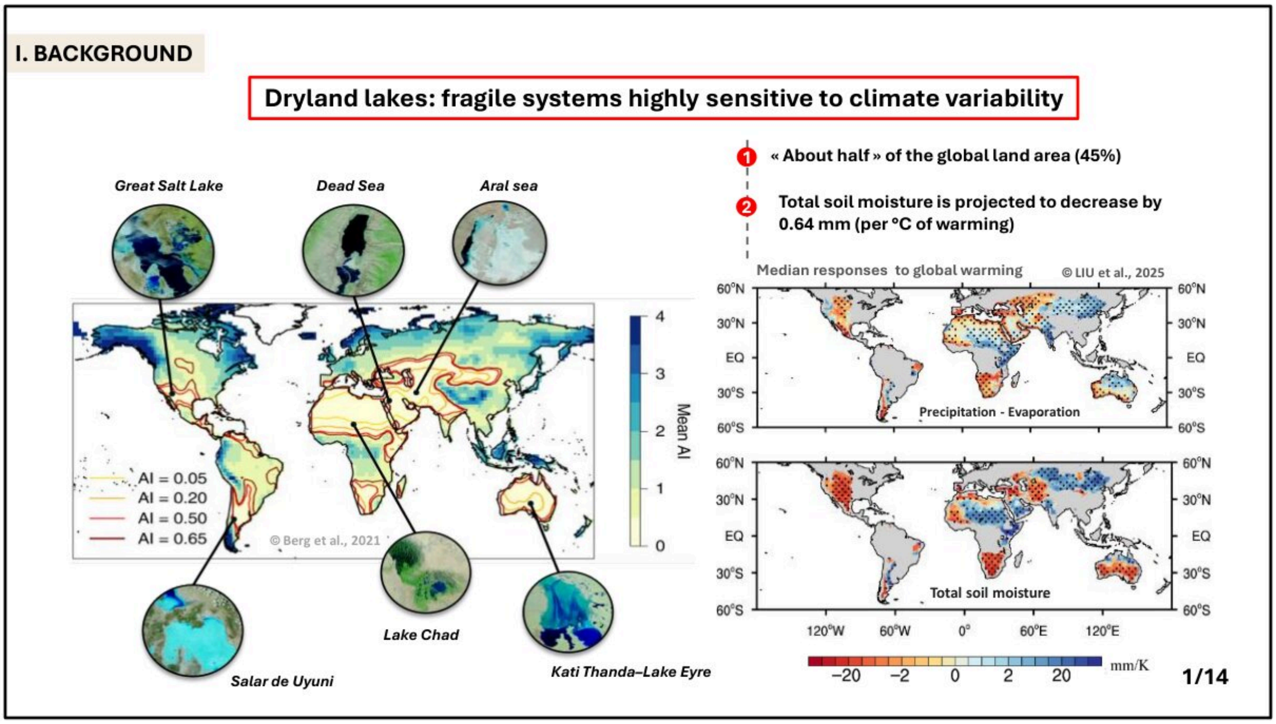
Hydro-Climatic Variability of Arid Zone Lakes A Case Study of Lake Eyre-Kati Thanda (Australia)

Commencement date : 01/01/2025

PhD Student : Ahmed Naceur MAMA

Supervisors : Frederic FLUTEAU (IPGP-France),
Guillaume LEHIR (IPGP-France),
Mathieu SCHUSTER (Université de Strasbourg-France),
Jan-Hendrik MAY (University of Melbourne-Australia).

Hi everyone, thank you for being here.
As a second-year PhD student, I will present my project, which focuses on understanding and modelling the hydroclimatic variability of dryland lakes. More specifically, this work explores how climate and hydrology control the rise and decline of water levels in Kati Thanda-Lake Eyre.
This is supplementary material intended to provide further explanation of what was presented during the poster session. All rights reserved. This document is private.



I. BACKGROUND

Dryland lakes: fragile systems highly sensitive to climate variability

① « About half » of the global land area (45%)

② Total soil moisture is projected to decrease by 0.64 mm (per °C of warming)

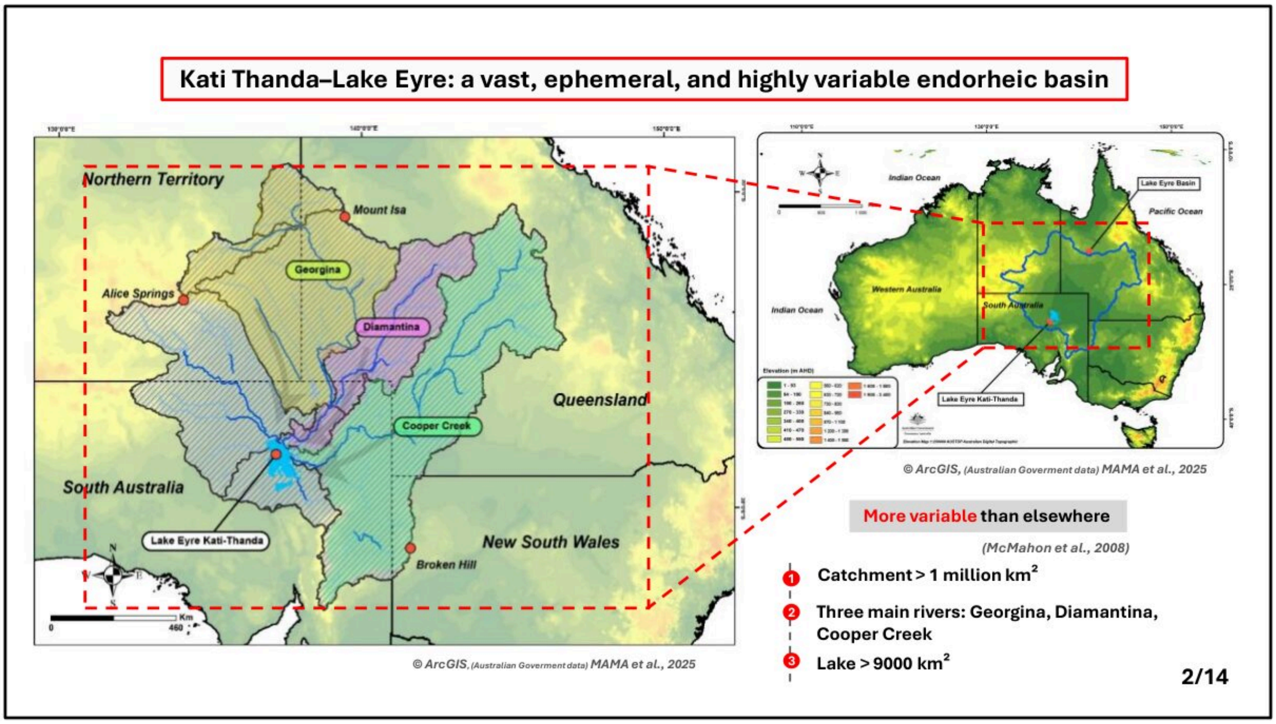
© Berg et al., 2021

Median responses to global warming

© LIU et al., 2025

1/14

When we think about lakes, we usually imagine wet regions, with a lot of water and permanent rivers. But in reality, many lakes are also located in dryland areas. Drylands cover almost half of the global land area, and they are among the regions most sensitive to climate variability and global warming. As the figures on your right show, changes in precipitation minus evaporation, and in soil moisture, are expected to be particularly strong in these regions. According to recent models, soil moisture is projected to decrease by about 0.64 mm for every 1°C of warming. For this reason, dryland lakes are very useful for studying how climate and hydrology interact in dry regions.



Kati Thanda–Lake Eyre: a vast, ephemeral, and highly variable endorheic basin

© ArcGIS, (Australian Goverment data) MAMA et al., 2025

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More variable than elsewhere

(McMahon et al., 2008)

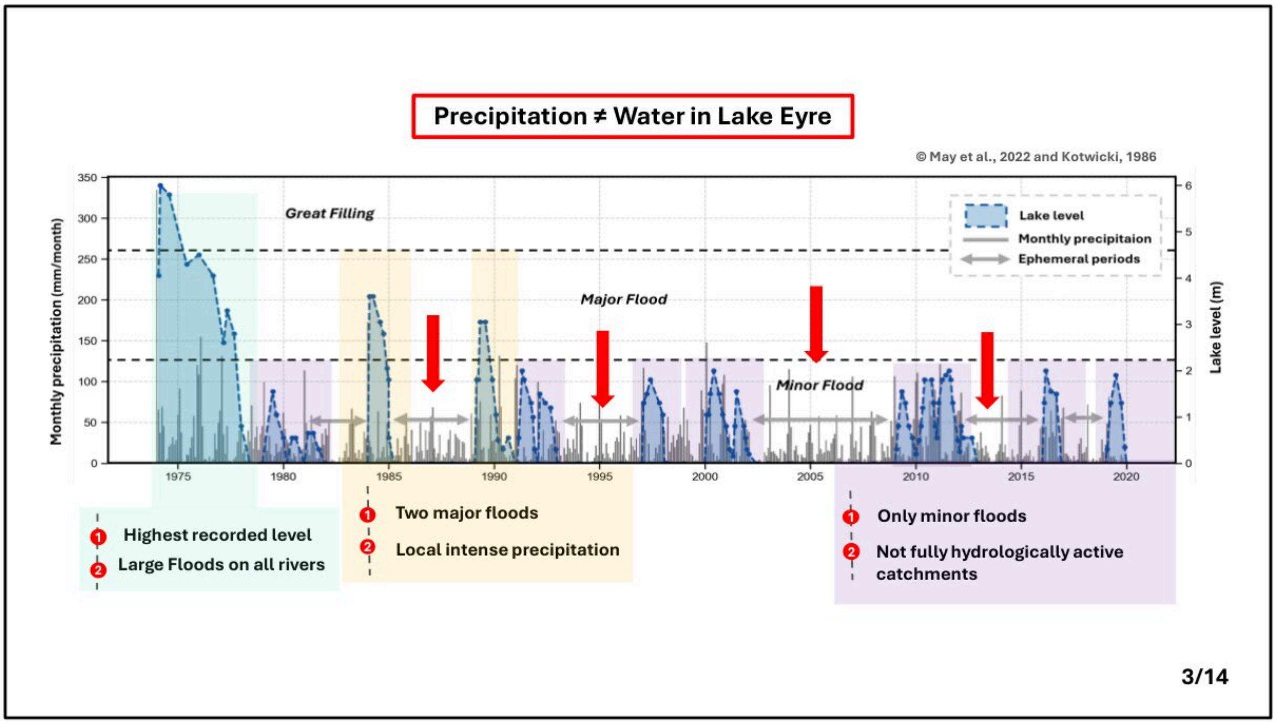
① Catchment > 1 million km²

② Three main rivers: Georgina, Diamantina, Cooper Creek

③ Lake > 9000 km²

2/14

Our case study is a lake located in the center of Australia, and it is called Kati Thanda-Lake Eyre. It is considered one of the largest ephemeral playas in the world, with a surface of more than 9,000 square kilometers, about the size of Cyprus. It has a huge basin area of more than 1 million square kilometers, about twice the size of France, with 70% of its surface below 250 m of altitude. Hydrologically, this lake is drained by three main ephemeral rivers that come from the north of the basin: the Georgina River, the Diamantina River, and Cooper Creek.



Precipitation ≠ Water in Lake Eyre

© May et al., 2022 and Kotwicki, 1986

① Highest recorded level
② Large Floods on all rivers

① Two major floods
② Local intense precipitation

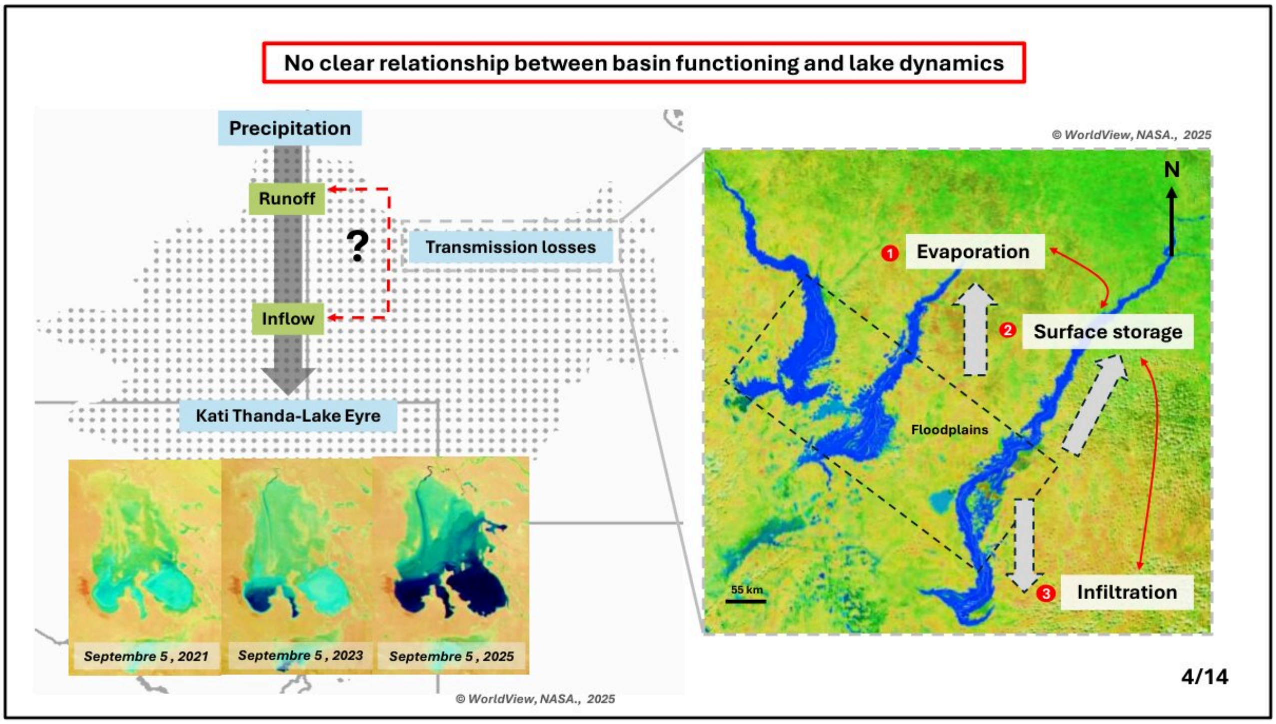
① Only minor floods
② Not fully hydrologically active catchments

3/14

The hydrological dynamics of this lake are highly unpredictable. As shown in this graph, Lake Eyre has completely filled only once, in 1974, when the water reached about 6 m depth. Since then, only two major floods exceeded 3 m, while most events have been minor floods, often associated with catchments that were not fully hydrologically active.

When comparing monthly basin-averaged precipitation with lake-level dynamics, there is no direct relationship (Red arrows). In other words, precipitation over the basin does not automatically translate into water in the lake.

This heterogeneity in filling makes Lake Eyre a relevant case study for investigating water vulnerability in dryland lakes and their catchment areas.



No clear relationship between basin functioning and lake dynamics

Precipitation

Runoff

?

Transmission losses

Inflow

Kati Thanda-Lake Eyre

Septembre 5 , 2021

Septembre 5 , 2023

Septembre 5 , 2025

© WorldView, NASA., 2025

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N

① Evaporation

② Surface storage

③ Infiltration

Floodplains

55 km

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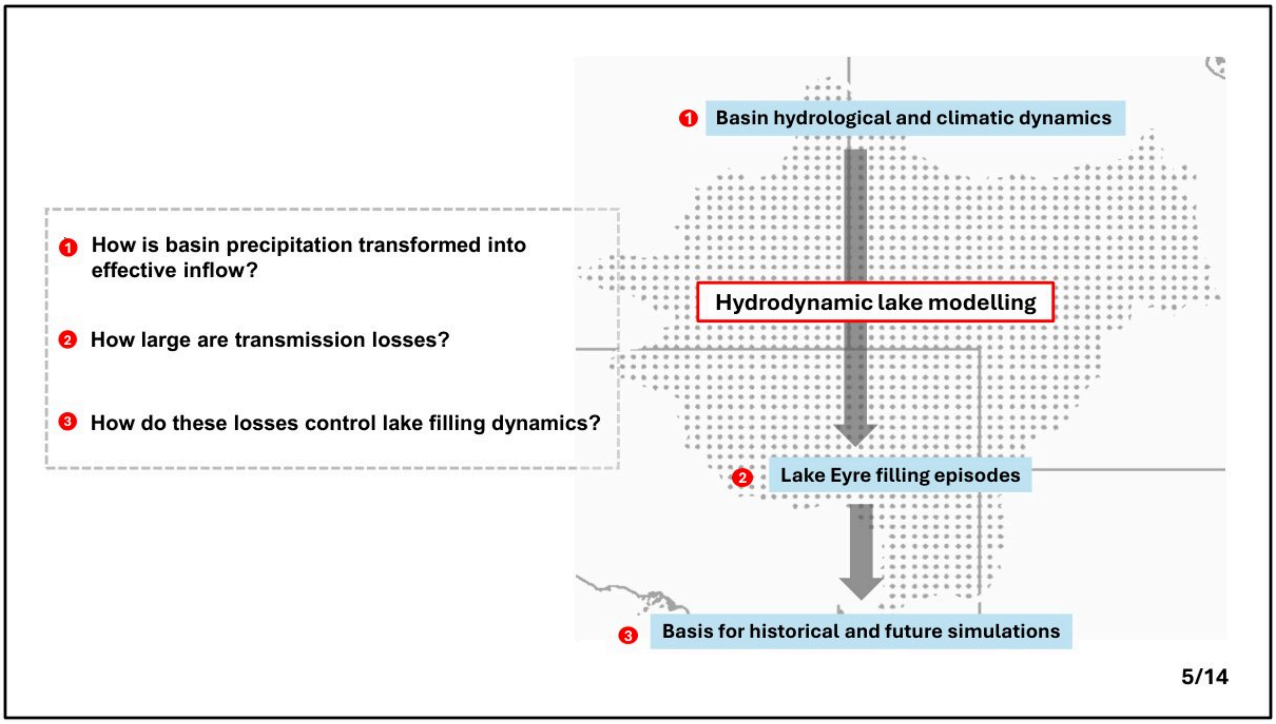
This process is widely known as transmission losses in such arid environments. Because our basin is very large, and precipitation mainly occurs in the north, water has to travel long distances through rivers and large floodplains before reaching the lake. During this transfer, part of the water is lost through evaporation, surface storage, and infiltration. This makes the relationship between basin functioning and lake dynamics non-linear and difficult to predict.



① How is basin precipitation transformed into effective inflow?

② How large are transmission losses?

③ How do these losses control lake filling dynamics?

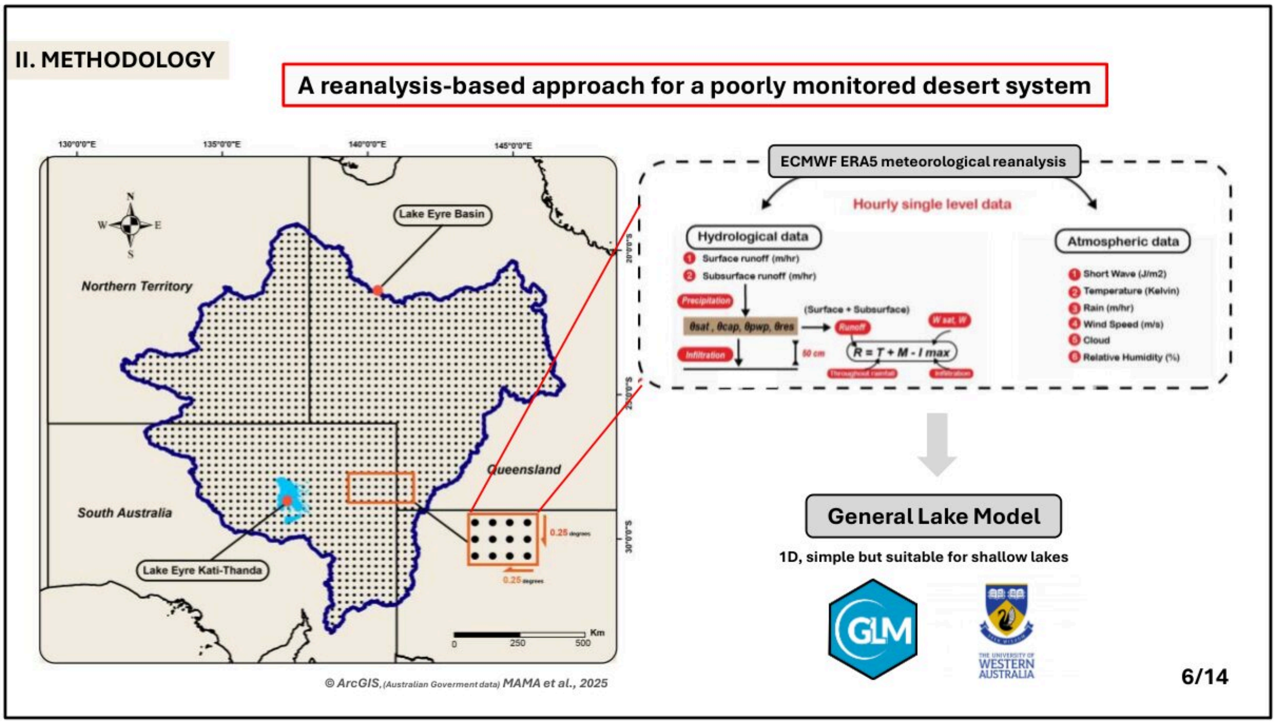
① Basin hydrological and climatic dynamics

Hydrodynamic lake modelling

② Lake Eyre filling episodes

③ Basis for historical and future simulations

And here we arrive at the main questions of the first part of my PhD: how is basin precipitation transformed into effective inflow, how large are the transmission losses, and how do these losses control lake-filling dynamics?



II. METHODOLOGY

A reanalysis-based approach for a poorly monitored desert system

ECMWF ERA5 meteorological reanalysis

Hourly single level data

Hydrological data

1. Surface runoff (m/hr)
2. Subsurface runoff (m/hr)

Atmospheric data

1. Short Wave (J/m2)
2. Temperature (Kelvin)
3. Rain (m/hr)
4. Wind Speed (m/s)
5. Cloud
6. Relative Humidity (%)

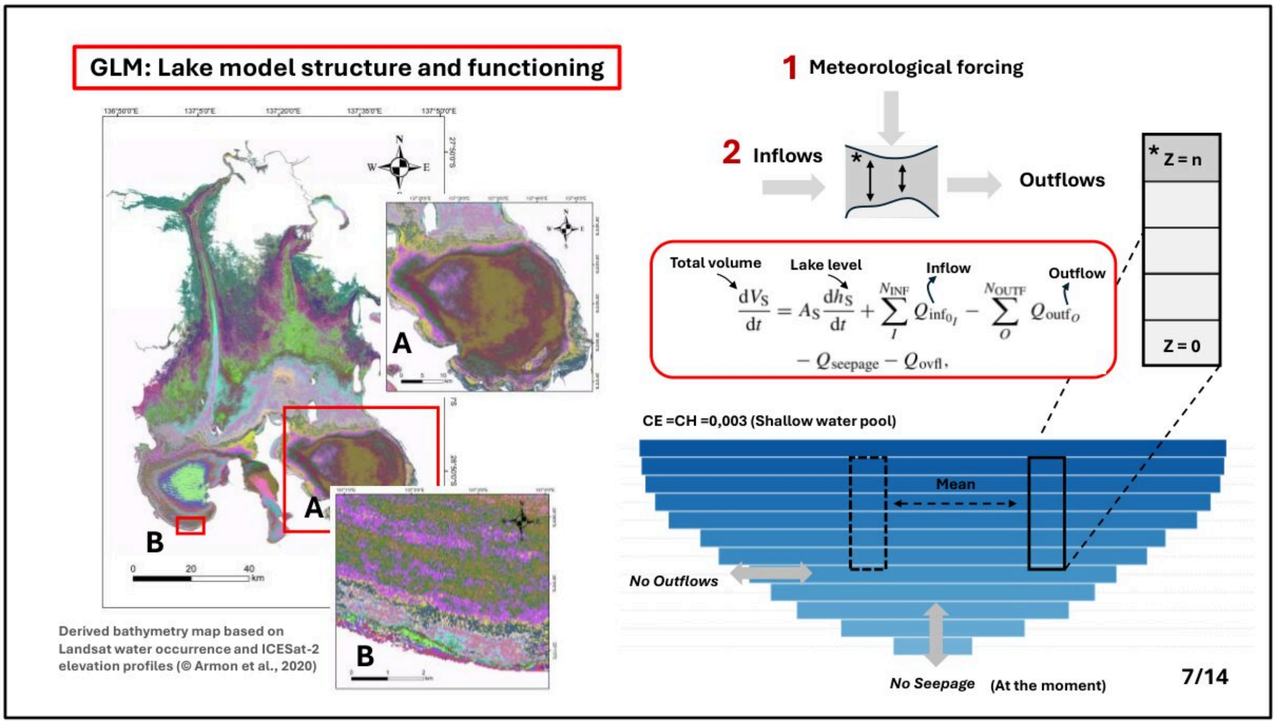
$R = T + M - I\,max$

General Lake Model

1D, simple but suitable for shallow lakes

© ArcGIS, (Australian Goverment data) MAMA et al., 2025

Now, to answer these questions, and because our large basin is poorly monitored across space and time, we decided to use both meteorological and hydrological data from the ERA5 reanalysis over the period 1974 to 2022. With a resolution of about 30 km between two points, we ended up with more than 1,000 points over the basin. For each point, we extracted hourly meteorological variables such as temperature, shortwave radiation, relative humidity, rainfall, cloud cover, and wind speed, together with two hydrological variables over the whole basin: surface runoff and subsurface runoff. These inputs were then used in an Australian lake model called GLM, the General Lake Model, to simulate the water balance of Kati Thanda-Lake Eyre.

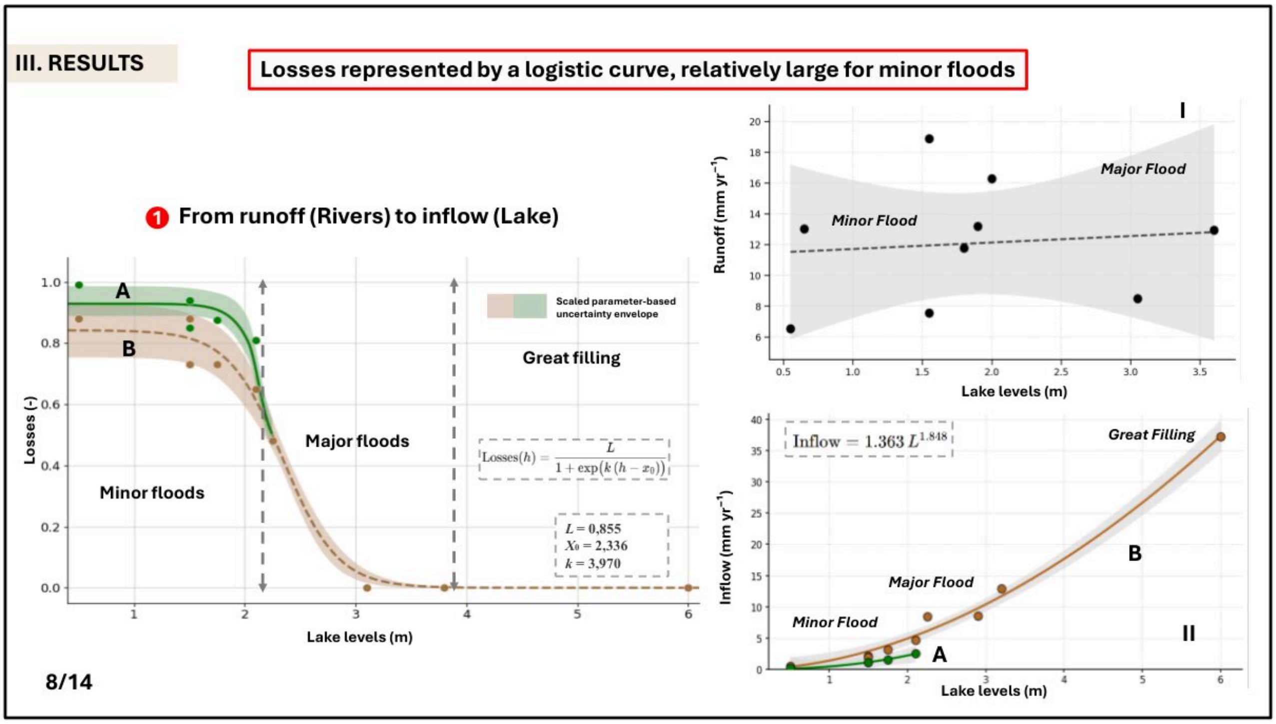


GLM: Lake model structure and functioning

$$\frac{\mathrm{d}V_S}{\mathrm{d}t} = A_S\frac{\mathrm{d}h_S}{\mathrm{d}t} + \sum_{I}^{N_{\mathrm{INF}}} Q_{\mathrm{inf}_{0_I}} - \sum_{O}^{N_{\mathrm{OUTF}}} Q_{\mathrm{outf}_O} - Q_{\mathrm{seepage}} - Q_{\mathrm{ovfl}},$$

Derived bathymetry map based on Landsat water occurrence and ICESat-2 elevation profiles (© Armon et al., 2020)

Even though this model is one-dimensional, it is still suitable for such shallow water systems. At its core, it solves a simple water balance, combining meteorological forcing and inflows to simulate changes in lake level and water volume. By using the hypsometric curve of the lake, it can simulate how the lake expands and shrinks depending on inflows and evaporation. Because Lake Eyre is an endorheic lake, no outflow was considered, and no seepage was included at this stage. This one-dimensional representation can then be projected into two dimensions using a high-resolution satellite-derived bathymetry, in order to show the areas that can be inundated according to the simulated lake level and water volume.



III. RESULTS

Losses represented by a logistic curve, relatively large for minor floods

❶ From runoff (Rivers) to inflow (Lake)

$$\text{Losses}(h) = \frac{L}{1+\exp\left(k\,(h-x_0)\right)}$$

$L = 0{,}855$
$X_0 = 2{,}336$
$k = 3{,}970$

$$\text{Inflow} = 1.363\,L^{1.848}$$

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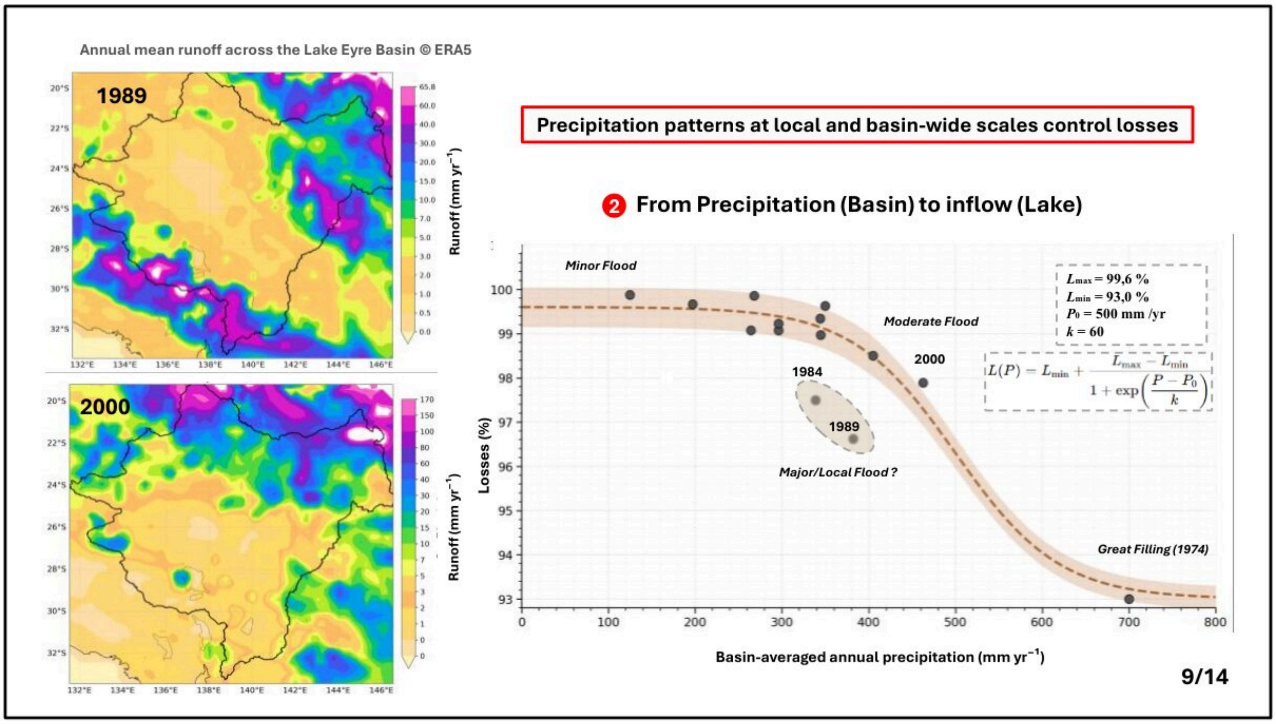
So, after calibrating the energy part of our model, we found that using ERA5 runoff directly as lake inflow leads to an overestimation of lake levels. On the upper right side, graph I shows that there is no clear relationship between runoff and lake levels. This means that a large part of the water is lost before reaching the lake. So, by applying an inflow factor to ERA5 runoff, we obtained the graph on the left. This graph shows how losses change with lake level. For minor floods, losses are high. The factor is around 0.8 when the lake fills more evenly, and more than 0.9 when water does not reach all parts of the lake equally. Then, for major floods and great filling episodes, losses become smaller. On the lower right side, when we include this logistic curve, we obtain a much clearer power relationship between inflow and lake level (Graph II).



Annual mean runoff across the Lake Eyre Basin © ERA5

Precipitation patterns at local and basin-wide scales control losses

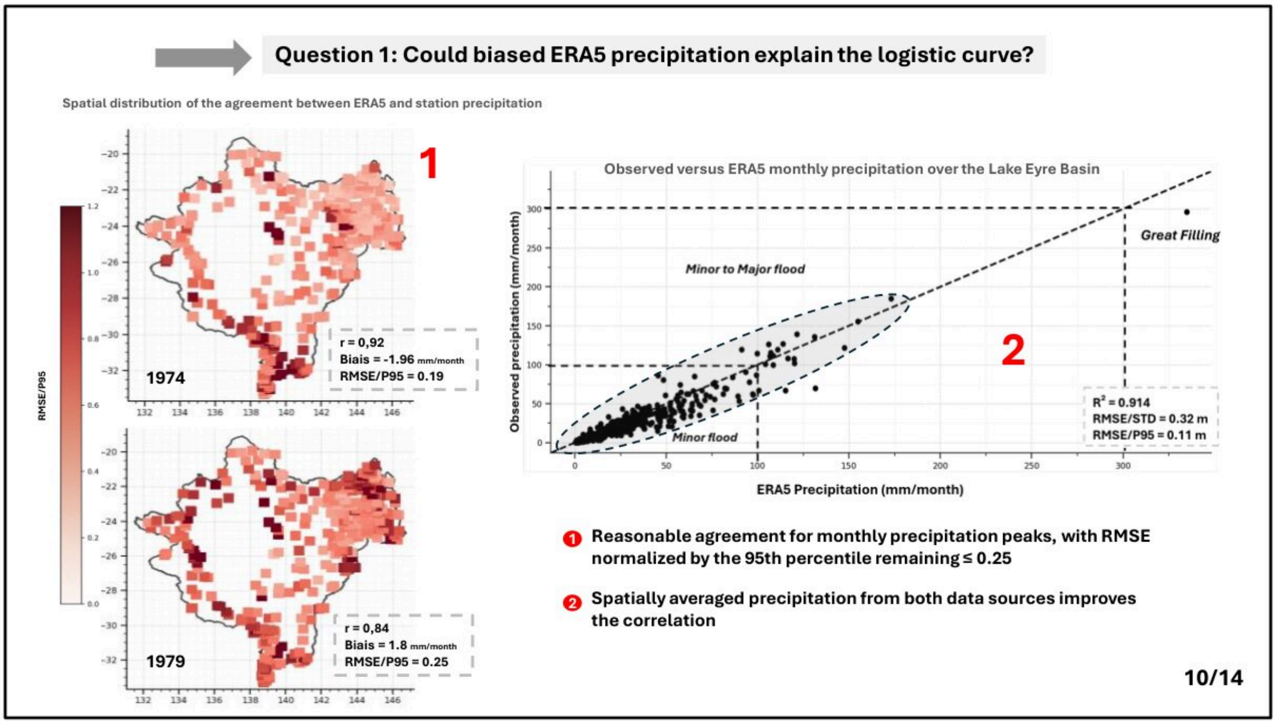
❷ **From Precipitation (Basin) to inflow (Lake)**

$L_{\max} = 99{,}6\ \%$
$L_{\min} = 93{,}0\ \%$
$P_0 = 500\ \text{mm /yr}$
$k = 60$

$$L(P) = L_{\min} + \frac{L_{\max} - L_{\min}}{1 + \exp\left(\frac{P - P_0}{k}\right)}$$

9/14

With the same logic, we also tried to describe the relationship between basin precipitation and the loss factor used to estimate the real inflow entering the lake. Globally, as flood magnitude increases, the relative percentage of losses decreases. Two years are clearly below the curve, and they actually correspond to the only two major floods, in 1984 and 1989. Spatially, as shown by the runoff distribution maps on the left, we can clearly see that precipitation did not come mainly from the north. This means that the main northern rivers were not fully active, and that part of the runoff and precipitation came from the southern part of the basin, closer to the lake. According to the literature, the Macumba River, in the south-western part of the basin, reached its highest level since 1938 during this flood. So, for a precipitation magnitude comparable to minor floods, losses were lower and more water was able to reach the lake. This again shows why considering the whole basin is important for understanding the real dynamics of the lake.



Question 1: Could biased ERA5 precipitation explain the logistic curve?

Spatial distribution of the agreement between ERA5 and station precipitation

r = 0,92
Biais = -1.96 mm/month
RMSE/P95 = 0.19

r = 0,84
Biais = 1.8 mm/month
RMSE/P95 = 0.25

Observed versus ERA5 monthly precipitation over the Lake Eyre Basin

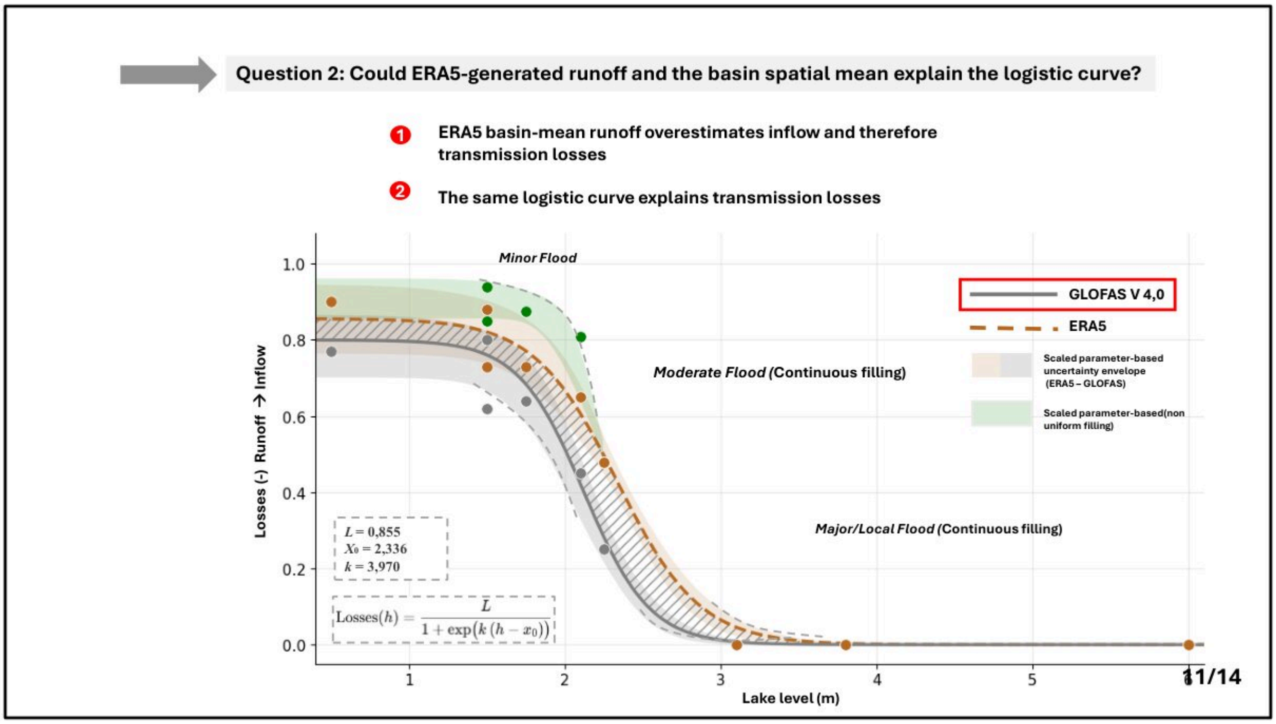
$R^2 = 0.914$
RMSE/STD = 0.32 m
RMSE/P95 = 0.11 m

❶ Reasonable agreement for monthly precipitation peaks, with RMSE normalized by the 95th percentile remaining ≤ 0.25

❷ Spatially averaged precipitation from both data sources improves the correlation

10/14

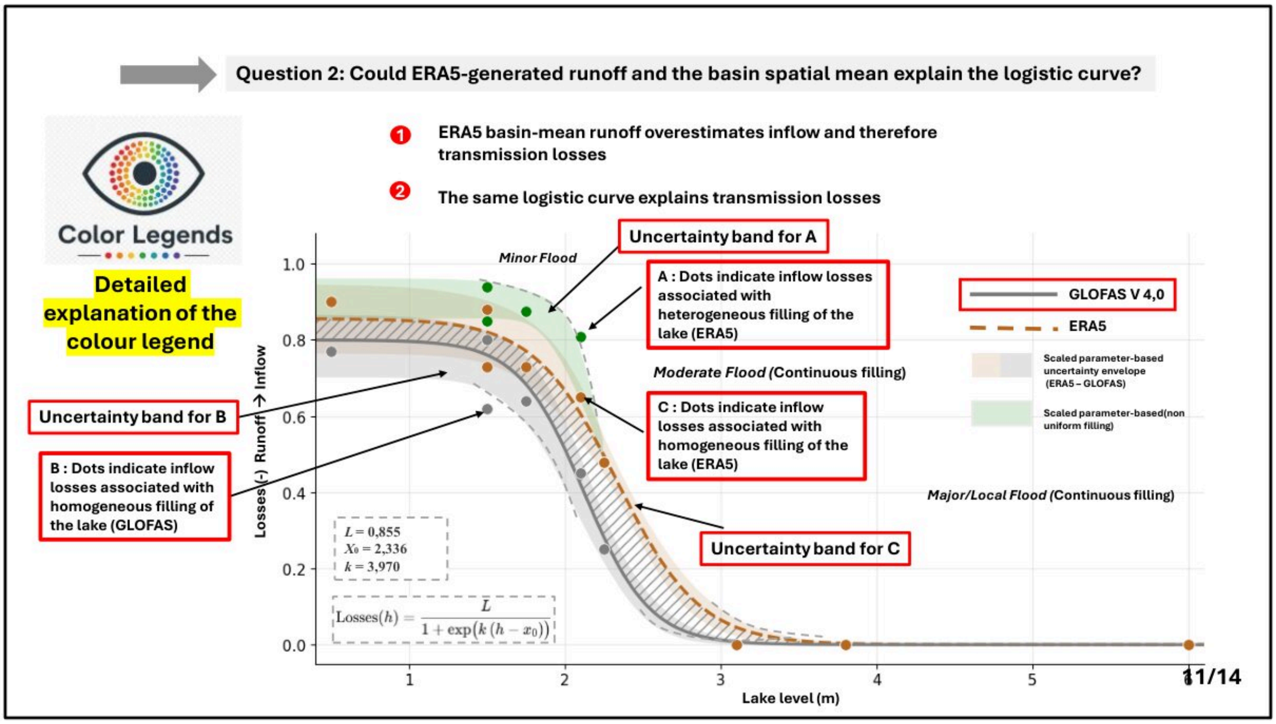
At this stage, we may ask a first important question: could biased ERA5 precipitation explain this logistic curve, rather than transmission losses? To answer this, we compared ERA5 precipitation with measurements from meteorological stations by calculating the correlation and the RMSE at each station. We found that the RMSE, normalized by the 95th percentile, remains below 0.25, which suggests that ERA5 is able to reasonably represent the main precipitation events linked to both minor and major floods. Then, when we compared basin-averaged precipitation from ERA5 with basin-averaged precipitation from all available stations, the agreement became even better, with a linear correlation greater than 0.9.



Question 2: Could ERA5-generated runoff and the basin spatial mean explain the logistic curve?

1. ERA5 basin-mean runoff overestimates inflow and therefore transmission losses
2. The same logistic curve explains transmission losses

The second question is this: if precipitation is reasonably well represented by ERA5, could an overestimation or underestimation of runoff generation explain this logistic curve? That is why we decided to use another model, called GLOFAS, which is driven by the same meteorological conditions as ERA5, but uses a different soil water balance model and a river routing system, avoiding the basin-averaged runoff approach we used with ERA5. So, in this figure, we added the grey curve, which represents the losses estimated using runoff from the second model. As you can see, transmission losses are still described by the same logistic curve evolution, but they are slightly lower than with ERA5. The interpretation is that, when we use basin-averaged runoff, we tend to overestimate runoff for minor and moderate floods. Then, as we move to major and great filling floods, the basin becomes more spatially connected and more saturated, so the ERA5 basin-mean runoff becomes closer to what is represented by a river-routing approach.



Question 2: Could ERA5-generated runoff and the basin spatial mean explain the logistic curve?

Color Legends

Detailed explanation of the colour legend

❶ ERA5 basin-mean runoff overestimates inflow and therefore transmission losses

❷ The same logistic curve explains transmission losses

Uncertainty band for A

A : Dots indicate inflow losses associated with heterogeneous filling of the lake (ERA5)

Uncertainty band for B

B : Dots indicate inflow losses associated with homogeneous filling of the lake (GLOFAS)

C : Dots indicate inflow losses associated with homogeneous filling of the lake (ERA5)

Uncertainty band for C

$L = 0{,}855$
$X_0 = 2{,}336$
$k = 3{,}970$

$$\text{Losses}(h) = \frac{L}{1 + \exp\left(k\,(h - x_0)\right)}$$

11/14

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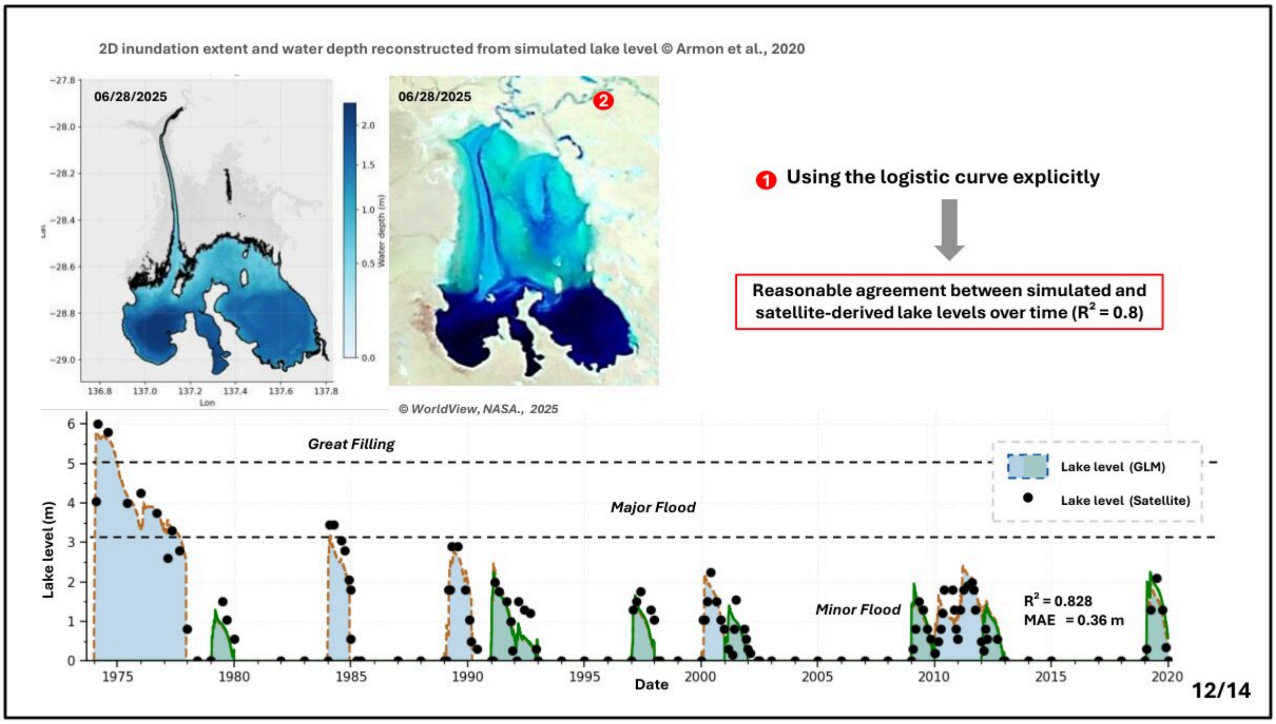

2D inundation extent and water depth reconstructed from simulated lake level © Armon et al., 2020

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① Using the logistic curve explicitly

Reasonable agreement between simulated and satellite-derived lake levels over time (R^2 = 0.8)

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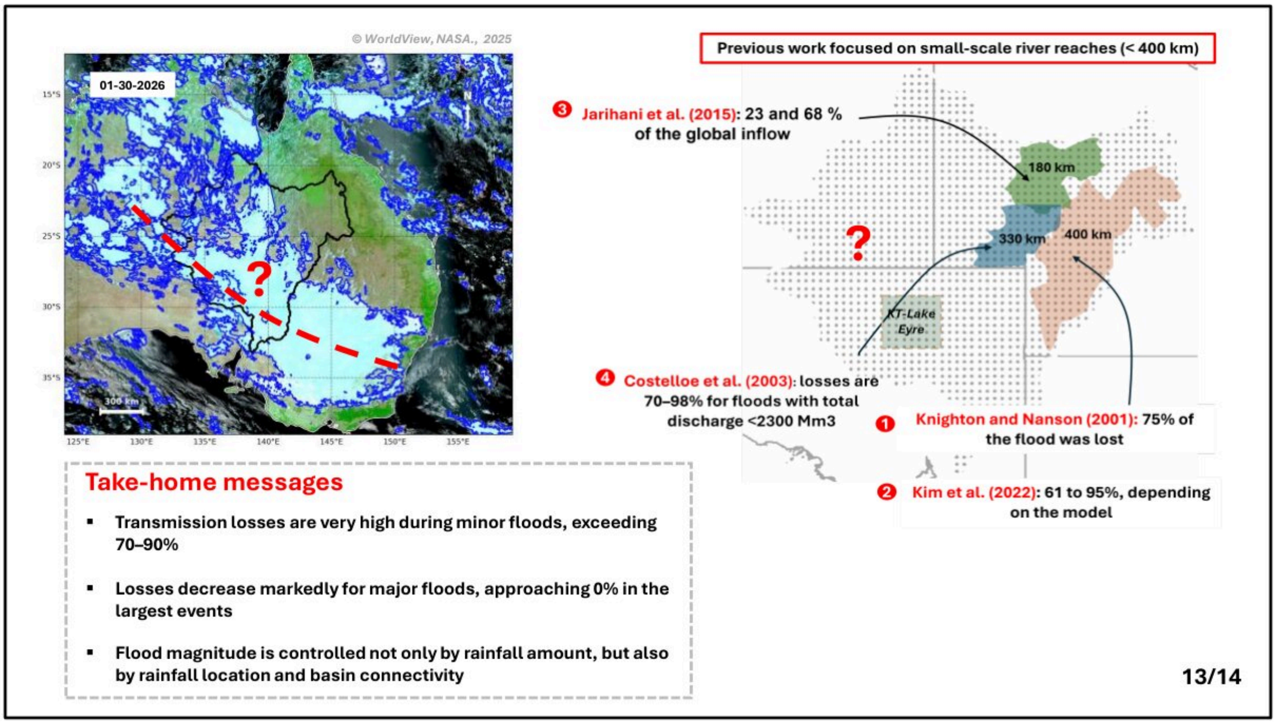
Now, using this orange curve and its equation, we simulated lake levels for all years from 1974 to 2020. The black points are satellite-derived lake levels, and the blue and green curves are our simulated lake levels, depending on whether the filling over the lake was homogeneous or not. Overall, we found a reasonable agreement, with a correlation of about 0.8 and an error of 0.36 m. Part of this difference may be linked to direct precipitation over the lake.

In 2025, the lake reached about 2.2 m in both bays, corresponding to around 70% of losses, as predicted by our logistic curve. When we projected this filling into 2D, we found a reasonable match between the simulated inundation and the satellite image. This also supports the good quality of the satellite-derived bathymetry map produced by Armon et al. in 2020.



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01-30-2026

Previous work focused on small-scale river reaches (< 400 km)

③ **Jarihani et al. (2015)**: 23 and 68 % of the global inflow

④ **Costelloe et al. (2003)**: losses are 70–98% for floods with total discharge <2300 Mm3

① **Knighton and Nanson (2001)**: 75% of the flood was lost

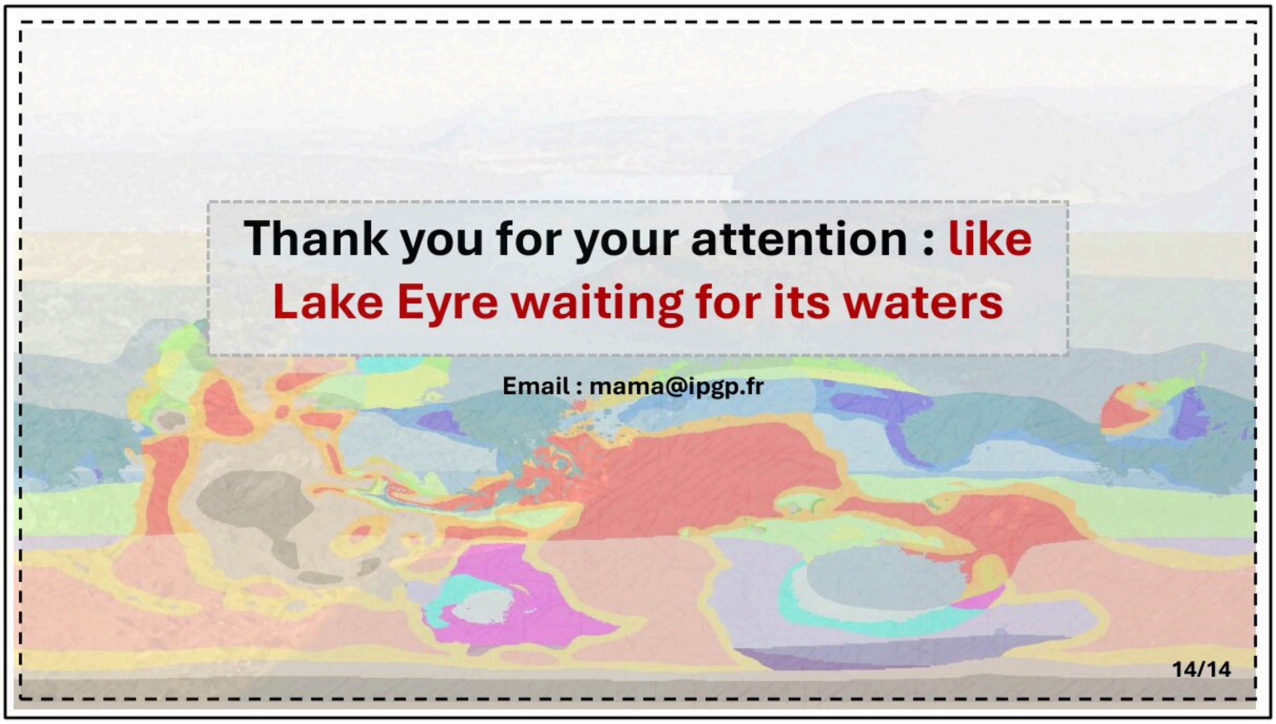
② **Kim et al. (2022)**: 61 to 95%, depending on the model

Take-home messages

- Transmission losses are very high during minor floods, exceeding 70–90%
- Losses decrease markedly for major floods, approaching 0% in the largest events
- Flood magnitude is controlled not only by rainfall amount, but also by rainfall location and basin connectivity

13/14

To finish with the take-home message, I would like to say that only a few studies have tried to understand transmission losses, and most of them focused on small reaches of the three main rivers, as you can see here. The main thing we know from the literature is that losses are very large, ranging from about 60% to more than 90%. Our approach is different because it considers the whole basin as one system. Finally, 2026 seems very promising, because water is currently coming mainly from the southern part of the basin, just like in 1989. This confirms that flood magnitude is controlled not only by the amount of rainfall, but also by rainfall location and basin connectivity.



Thank you for your attention : like Lake Eyre waiting for its waters

Email : mama@ipgp.fr

Most of the water comes from the western part of the basin. A lake level of 2 m at Kati Thanda–Lake Eyre was achieved only because of local precipitation over the southern part of the basin.

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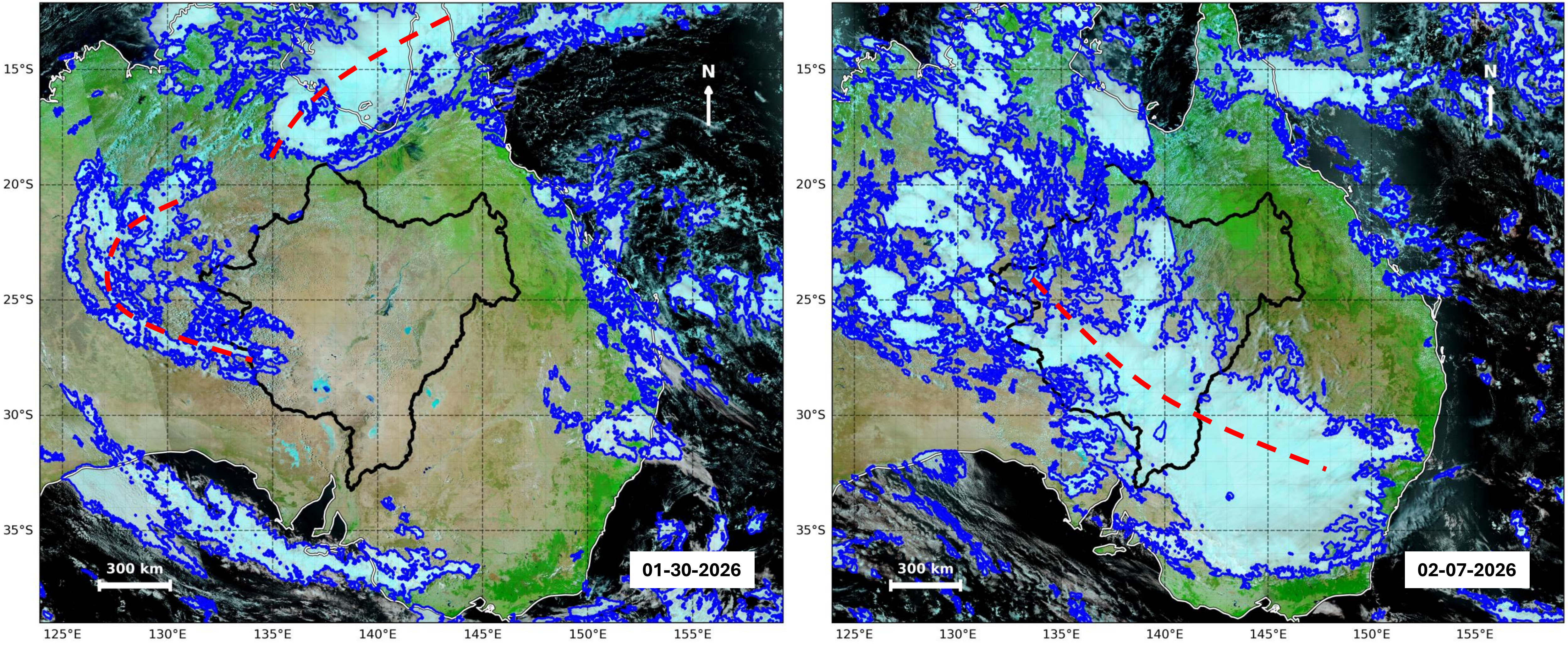

Most of the water comes from the western part of the basin. A lake level of 2 m at Kati Thanda–Lake Eyre was achieved only because of local precipitation over the southern part of the basin.

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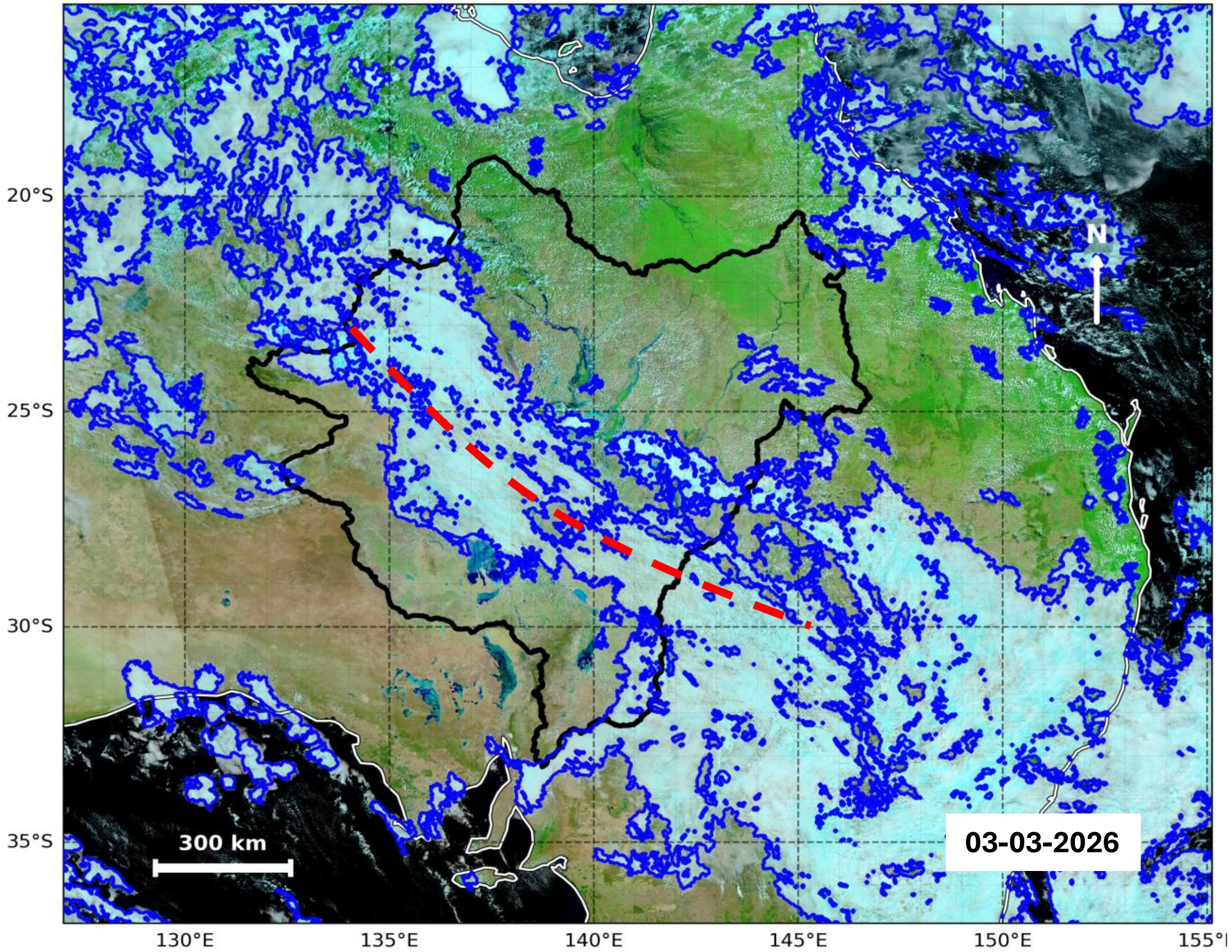

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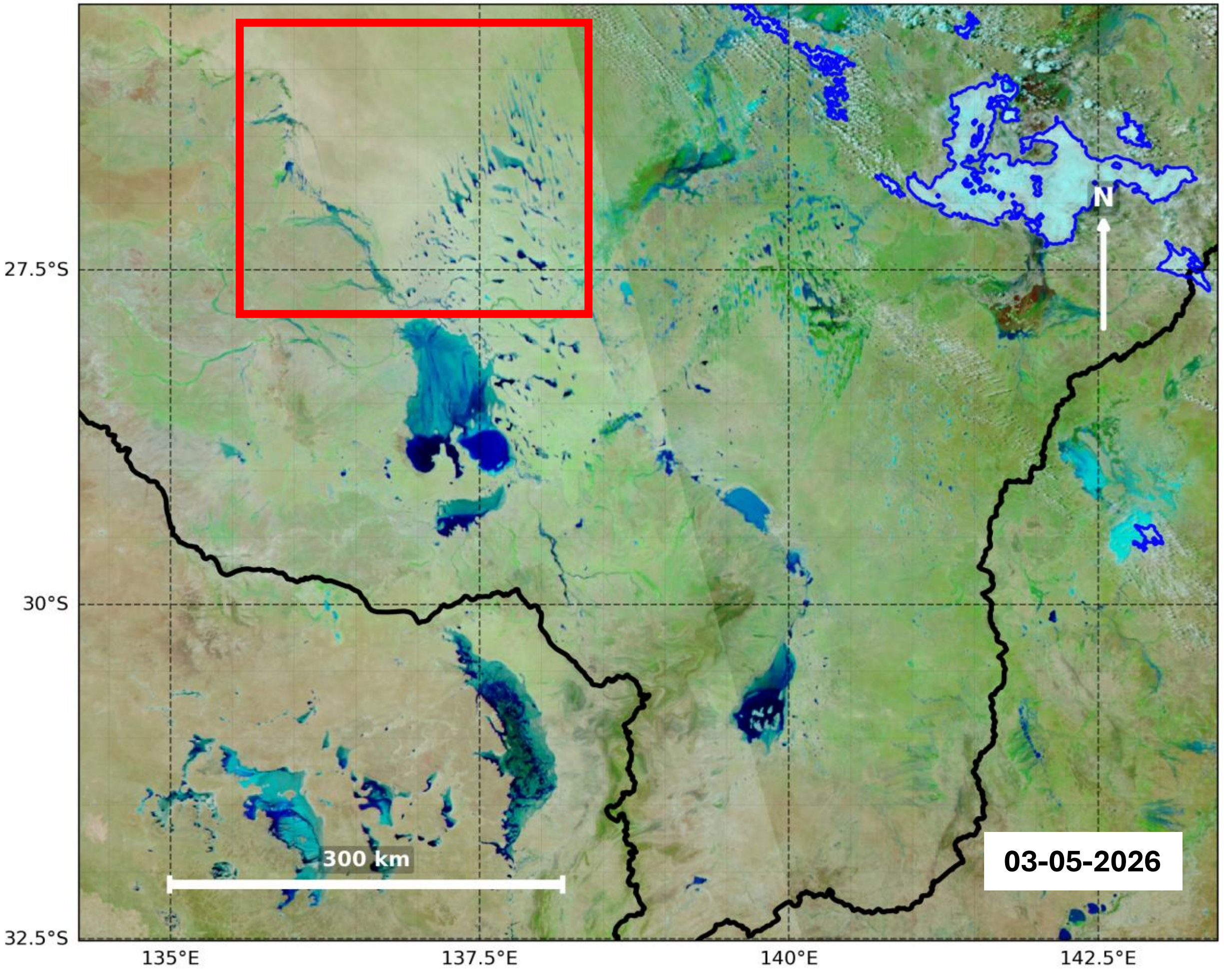
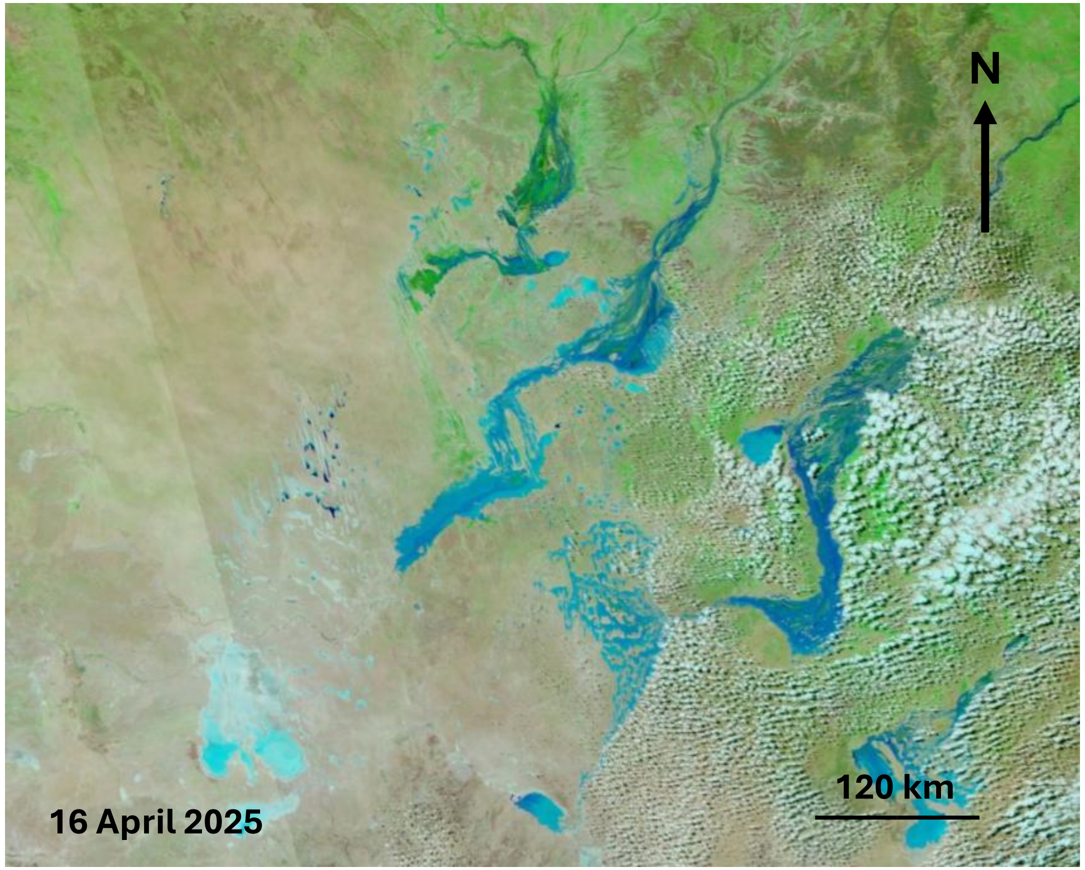


In 2025 and 2026, Lake Eyre reached about 2 m water level. However, the hydrological causes were different, with local precipitation likely playing an important role.



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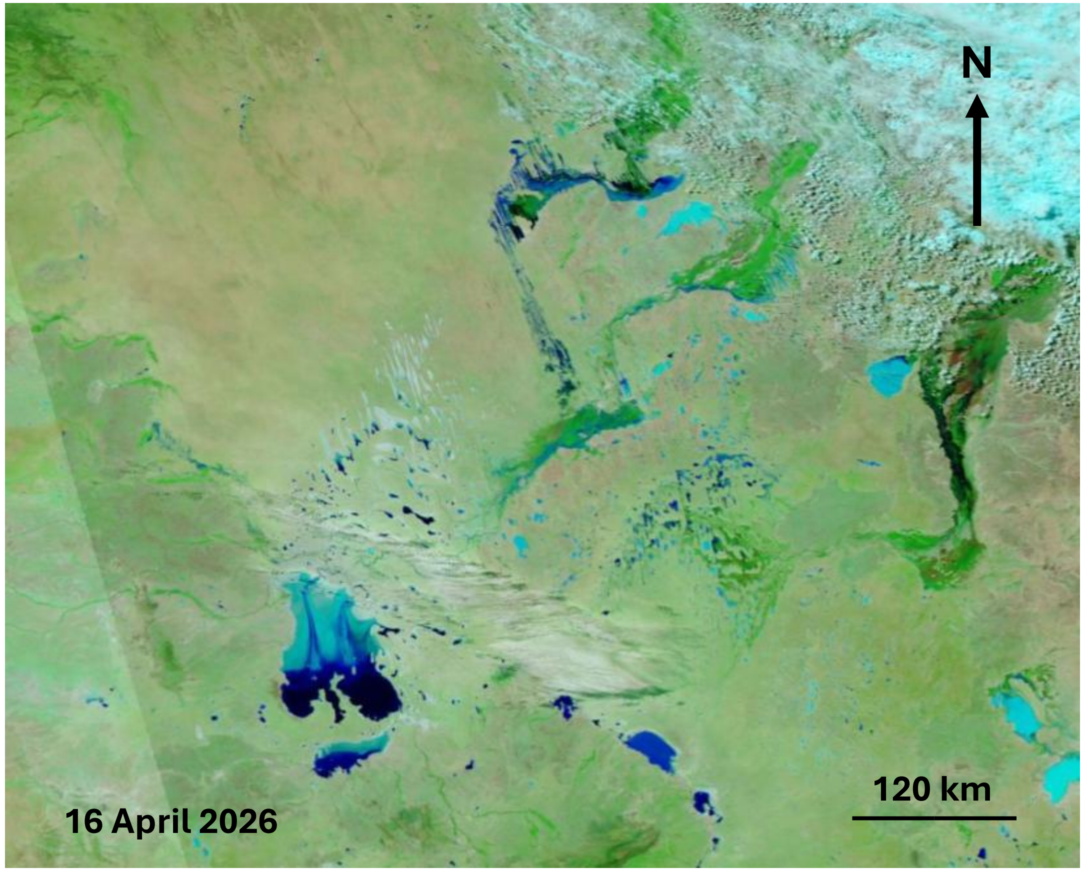

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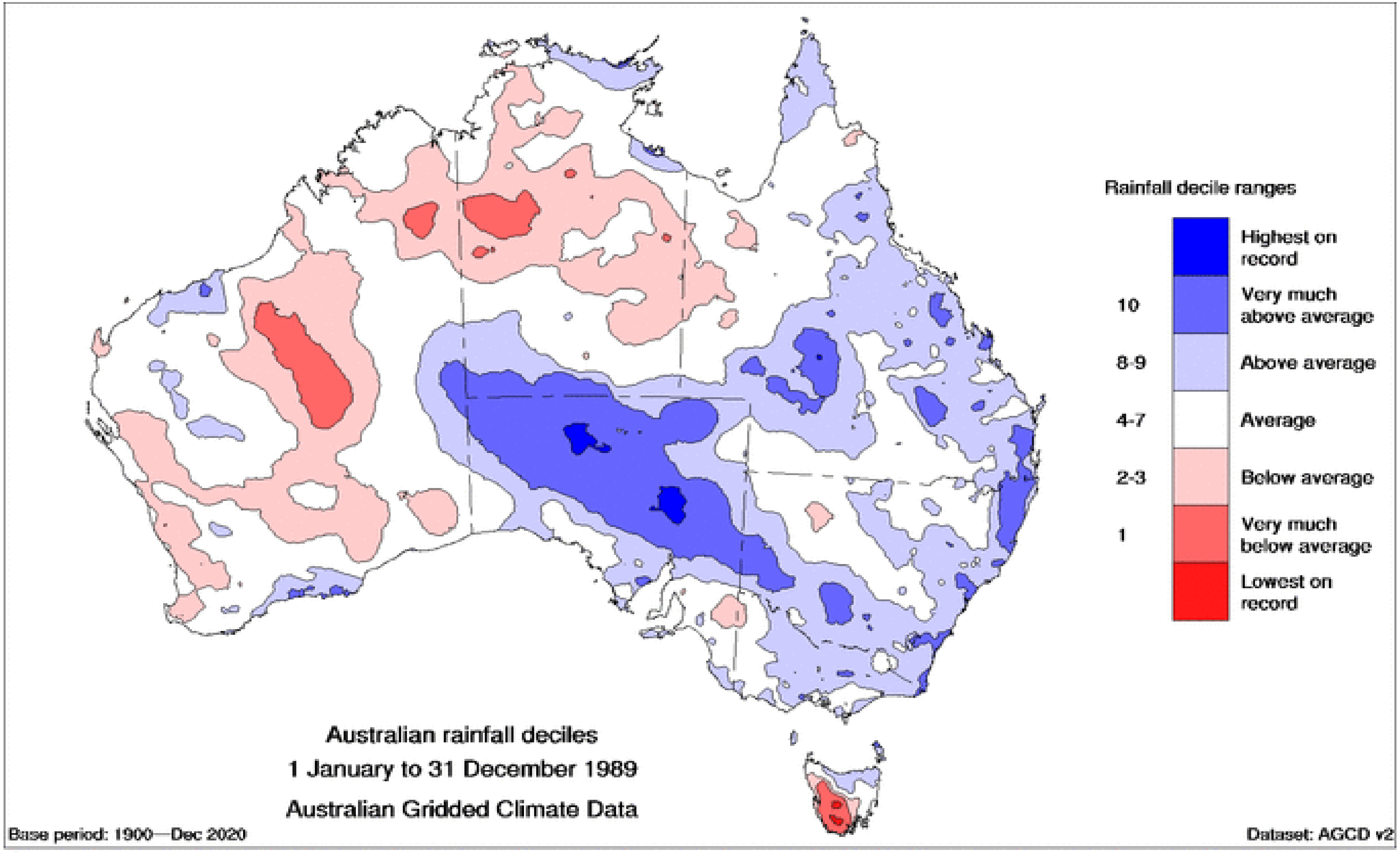

Australian rainfall deciles
1 January to 31 December 1989
Australian Gridded Climate Data

Base period: 1900—Dec 2020

Dataset: AGCD v2

Issued: 15/02/2021

Abstract + Supplementary Material

A modeling perspective on hydroclimatic variability in dryland lakes

What is the impact of hydroclimatic variability on the filling and drying dynamics of Kati Thanda-Lake Eyre?

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[2] School of Geography, Earth and Atmospheric Sciences, University of Melbourne, Australia
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*Corresponding authors

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I. INTRODUCTION AND OBJECTIVES

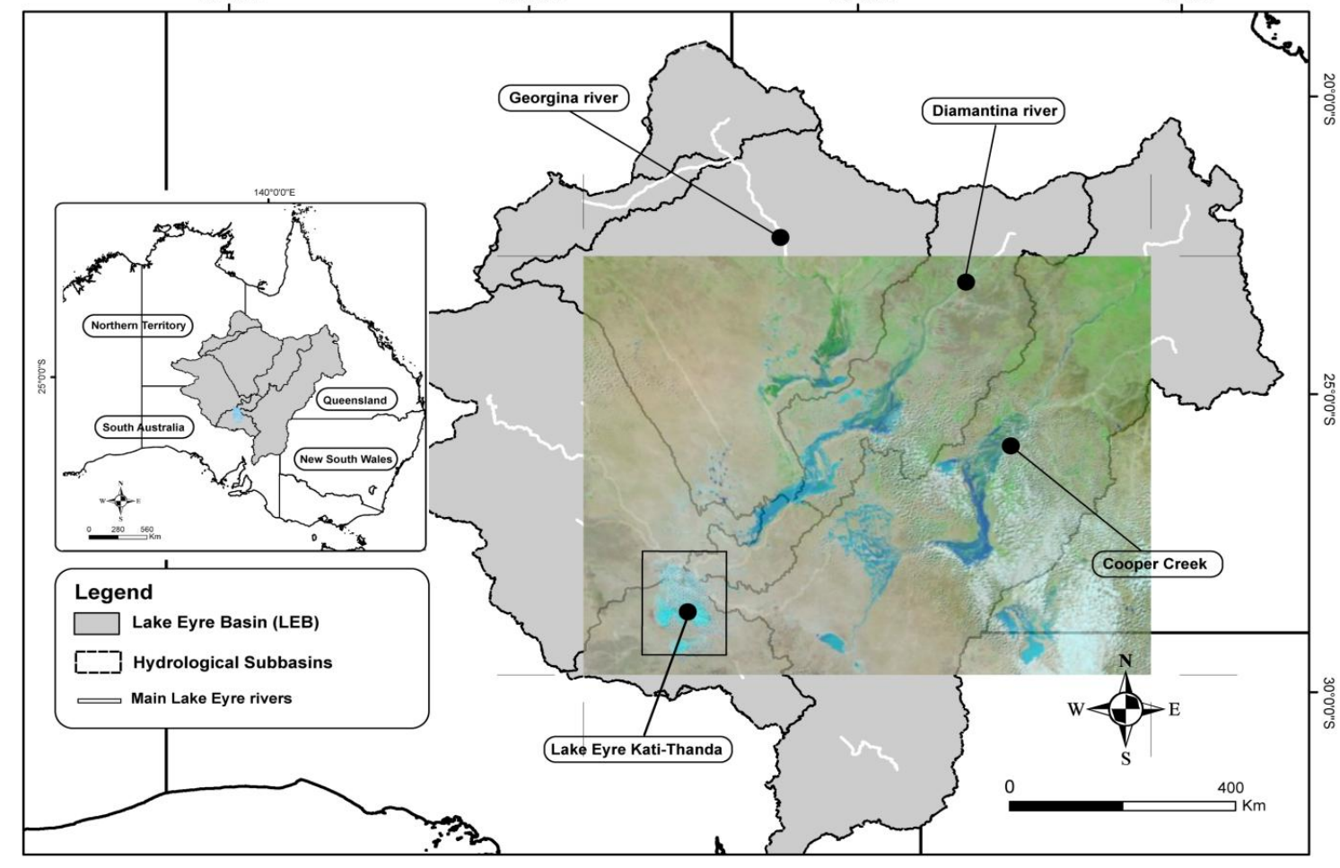


Fig.1: Study area: Lake Eyre Basin and main river systems (Australia)

❶ Kati Thanda-Lake Eyre (Australia) is one of the world's largest ephemeral playa lakes, covering 9,000 km^2 with a depth of only 6 m (Only in 1974) (Fig. 1–2),

❷ Lake-level variations cannot be explained by precipitation alone (Fig.2) because catchment response is highly variable and transmission losses along the main rivers can exceed 70% [1–2].

An integrated reanalysis-driven one-dimensional lake model helps assess the vulnerability of continental water resources in arid environments.

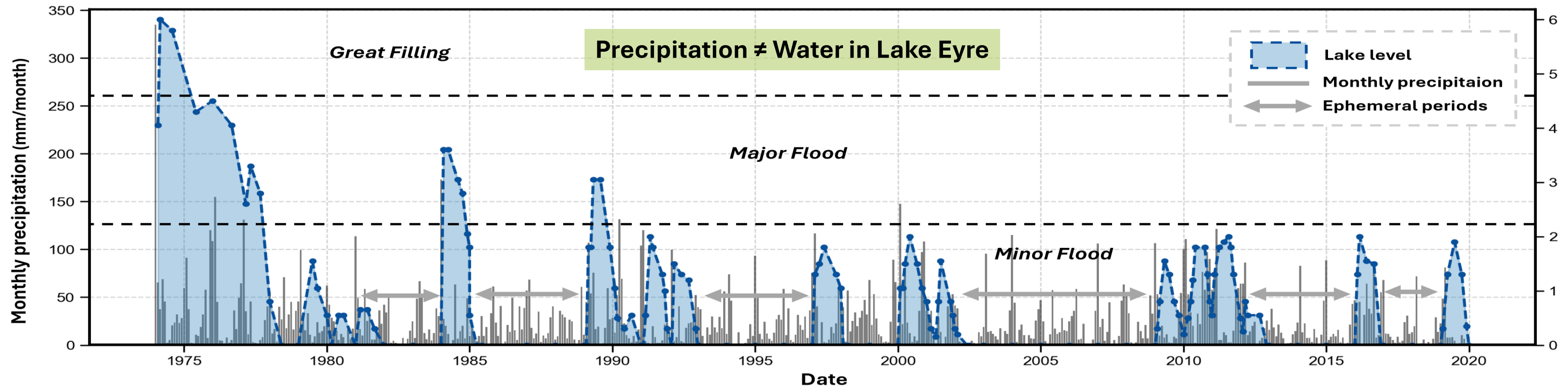


Fig. 2: *Basin-averaged monthly Bureau of Meteorology precipitation and satellite-derived Belt Bay lake level for Kati Thanda–Lake Eyre North* [3]

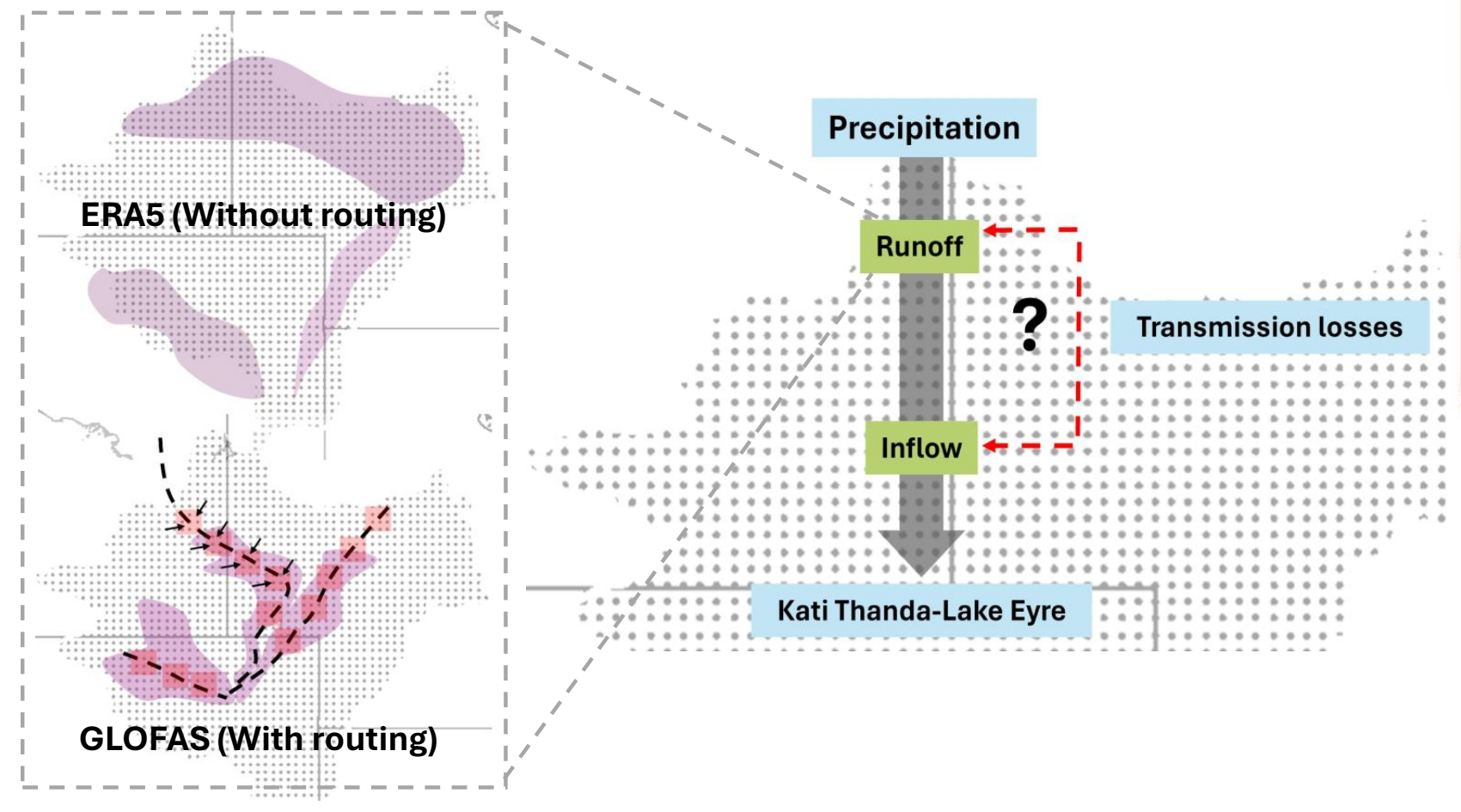
II. METHODOLOGY

❶ Forcing data

Hourly ERA5 atmospheric inputs were extracted over the Lake Eyre Basin at 30 km resolution,

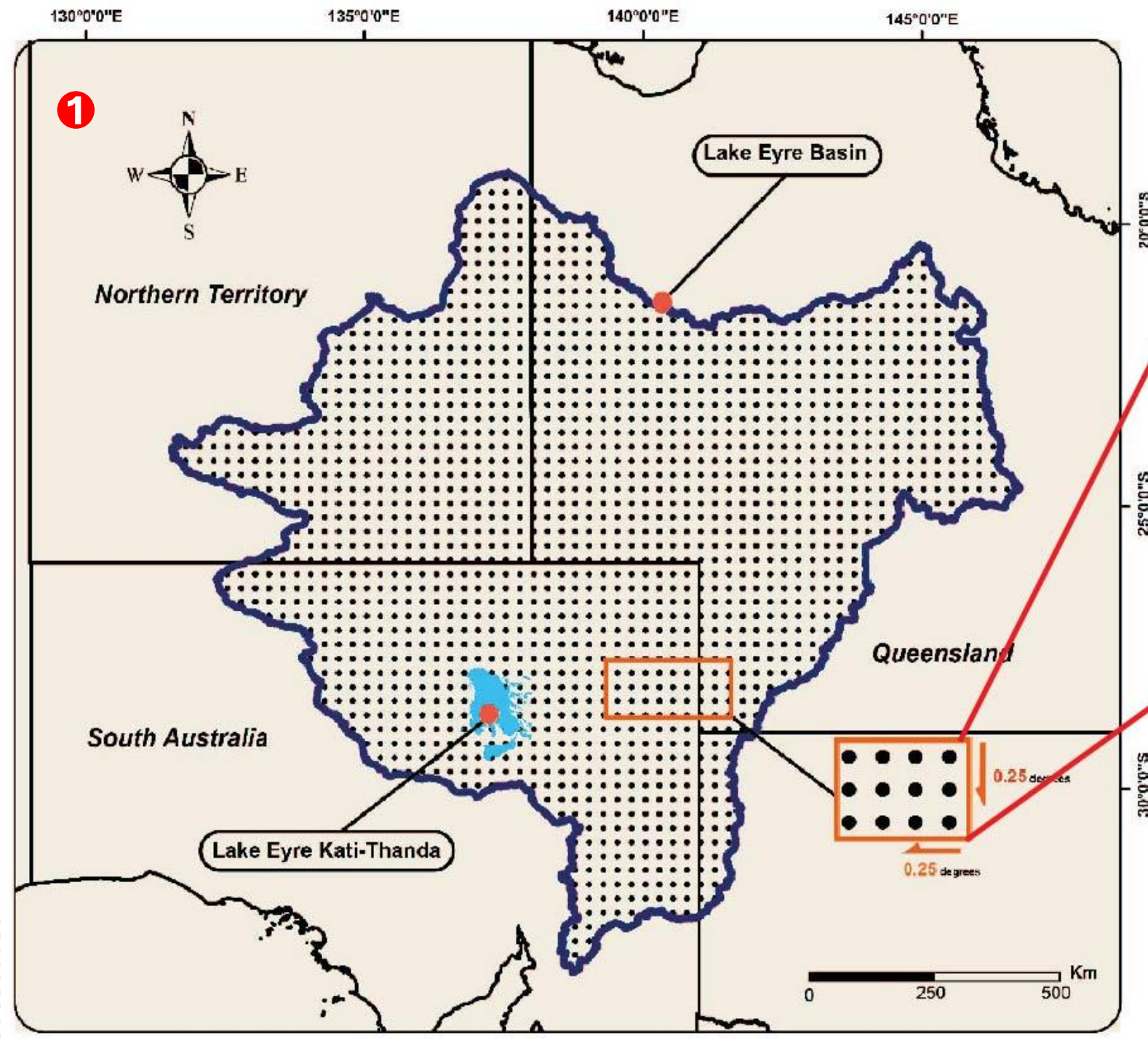
❷ Hydrological inputs & GLM (General lake model)

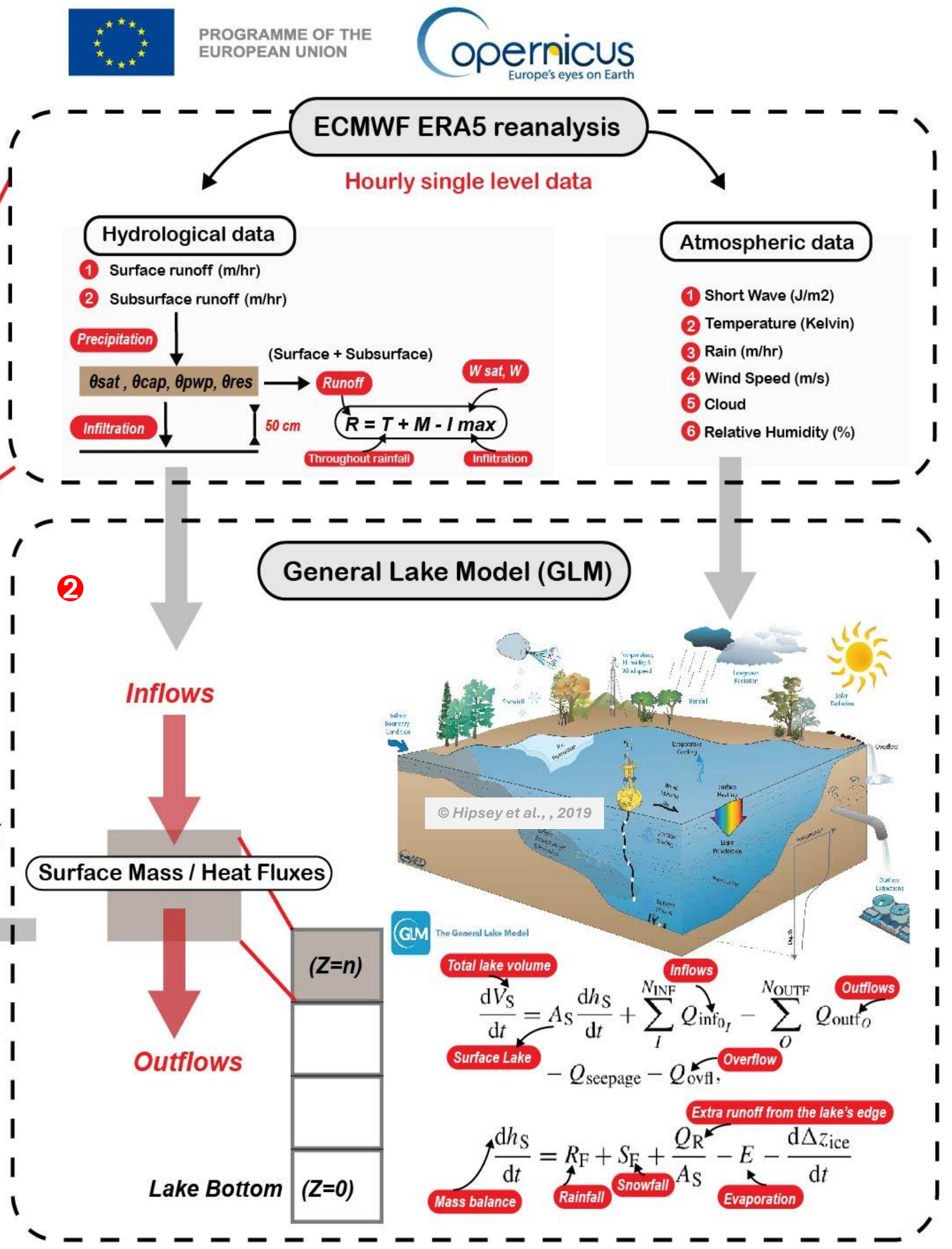
Runoff inputs were derived from ERA5 and GloFAS-LISFLOOD land-surface models under the same meteorological conditions,



❸ Calibration & evaluation

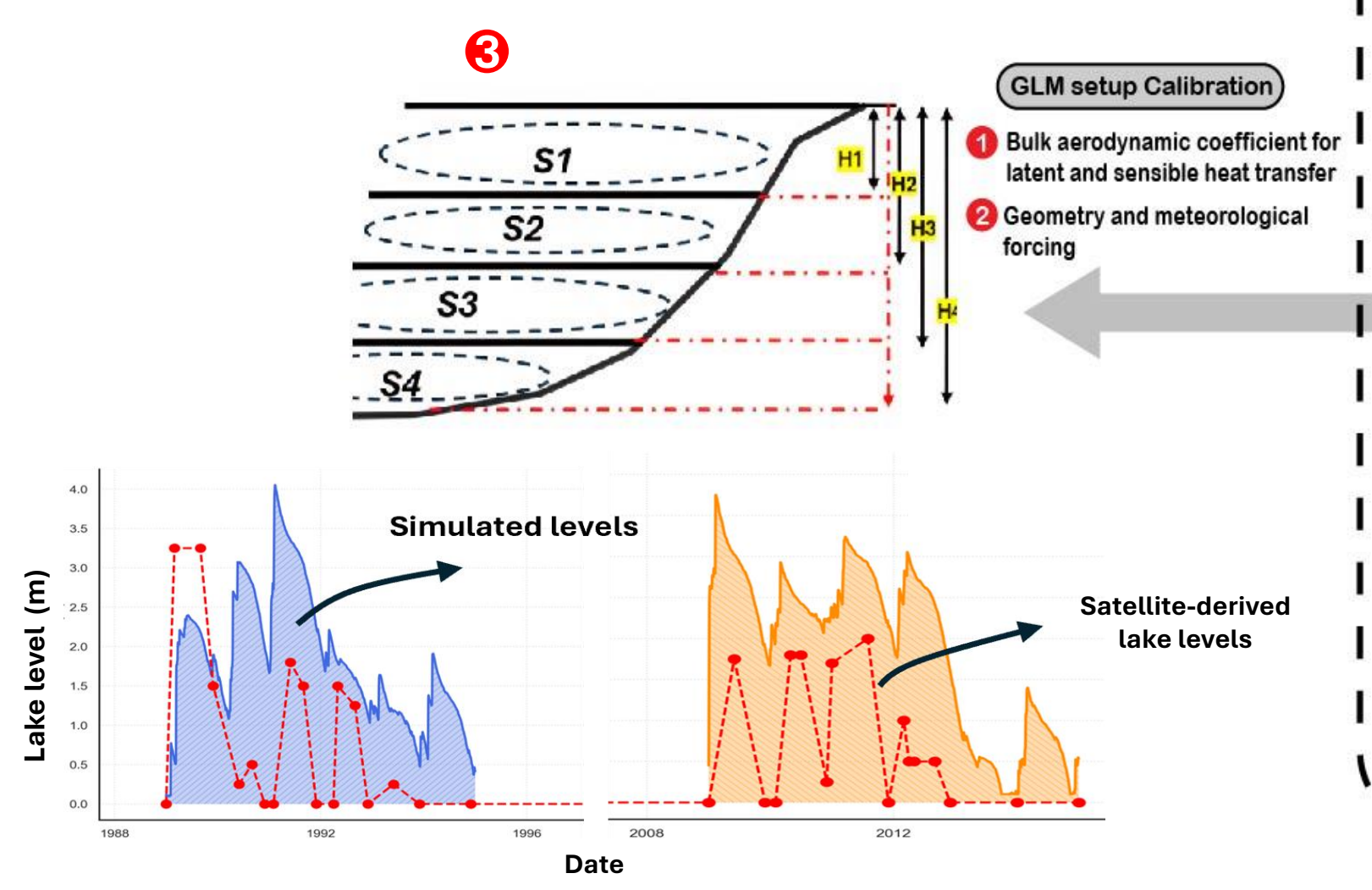
GLM was calibrated with heat-exchange and runoff factors to reproduce lake levels and estimate transmission losses.





$$\frac{dV_S}{dt} = A_S\frac{dh_S}{dt} + \sum_{I}^{N_{INF}} Q_{inf_I} - \sum_{O}^{N_{OUTF}} Q_{outf_O} - Q_{seepage} - Q_{ovfl}$$

$$\frac{dh_S}{dt} = R_F + S_F + \frac{Q_R}{A_S} - E - \frac{d\Delta z_{ice}}{dt}$$



III. RESULTS AND VALIDATION

Main forcing factors controlling lake filling

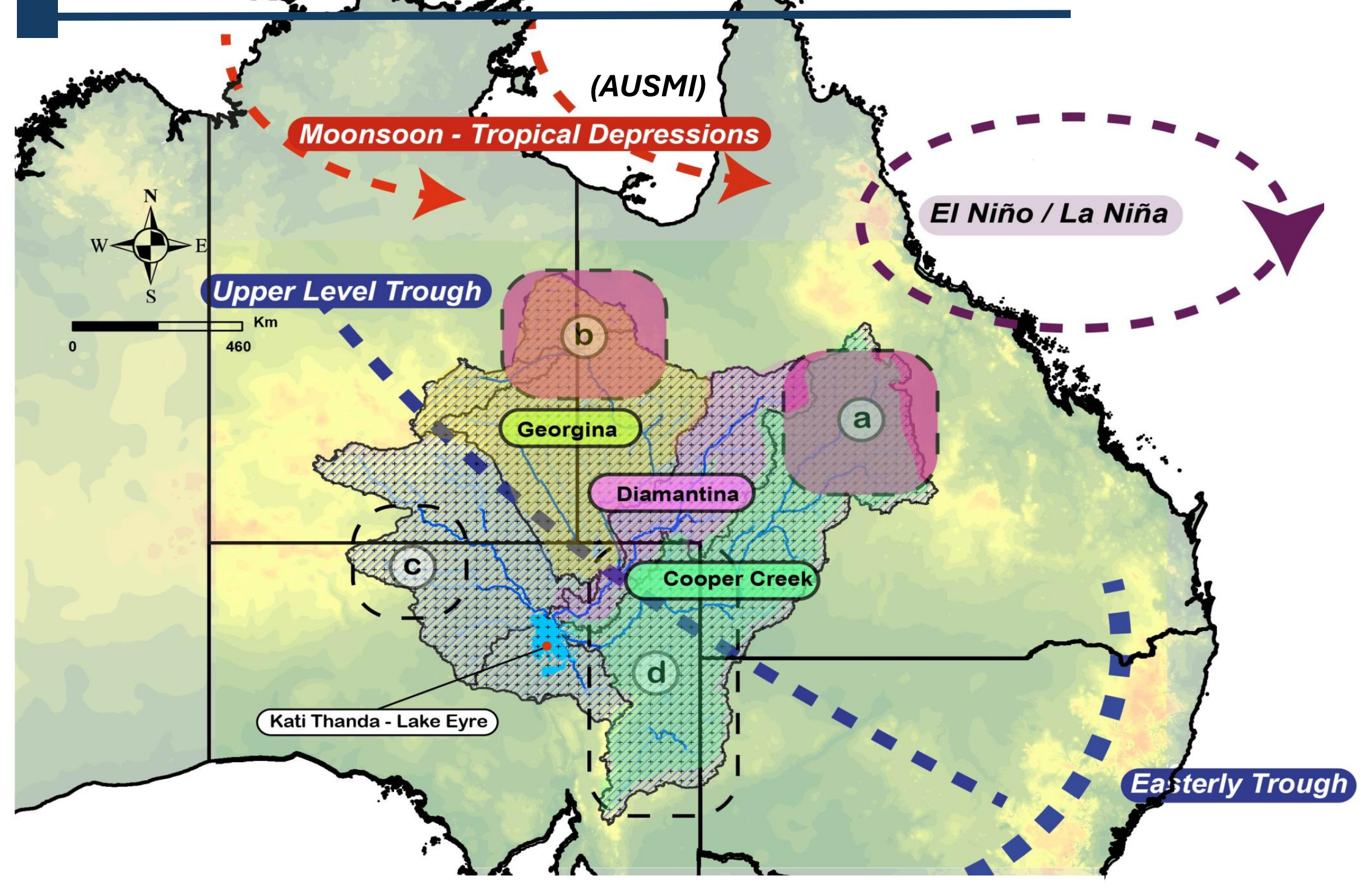


Fig. 3 : Main climatic synoptic systems affecting the Lake Eyre watershed and major rivers feeding Kati Thanda–Lake Eyre [Bureau of meteorology, 2010].

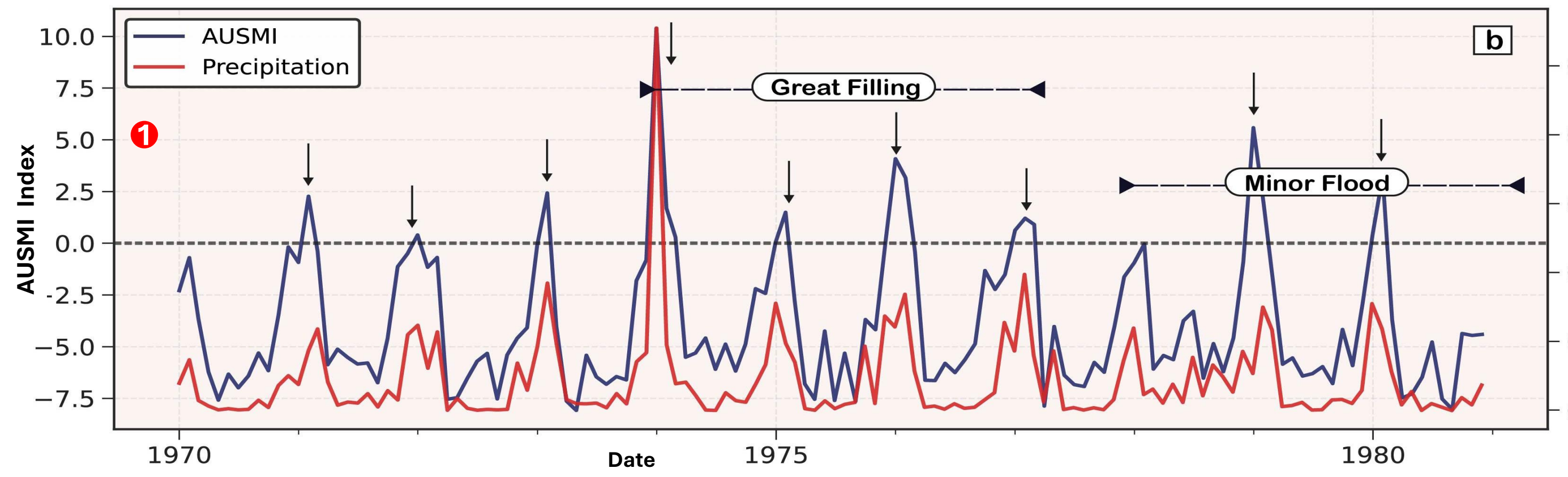


Fig. 4: AUSMI Peaks and Basin Precipitation Variability

❶ AUSMI (Australian Monsoon Index) is based on low-level zonal wind anomalies averaged over northern Australia. Its highest peaks generally occur when water is present in Lake Eyre.

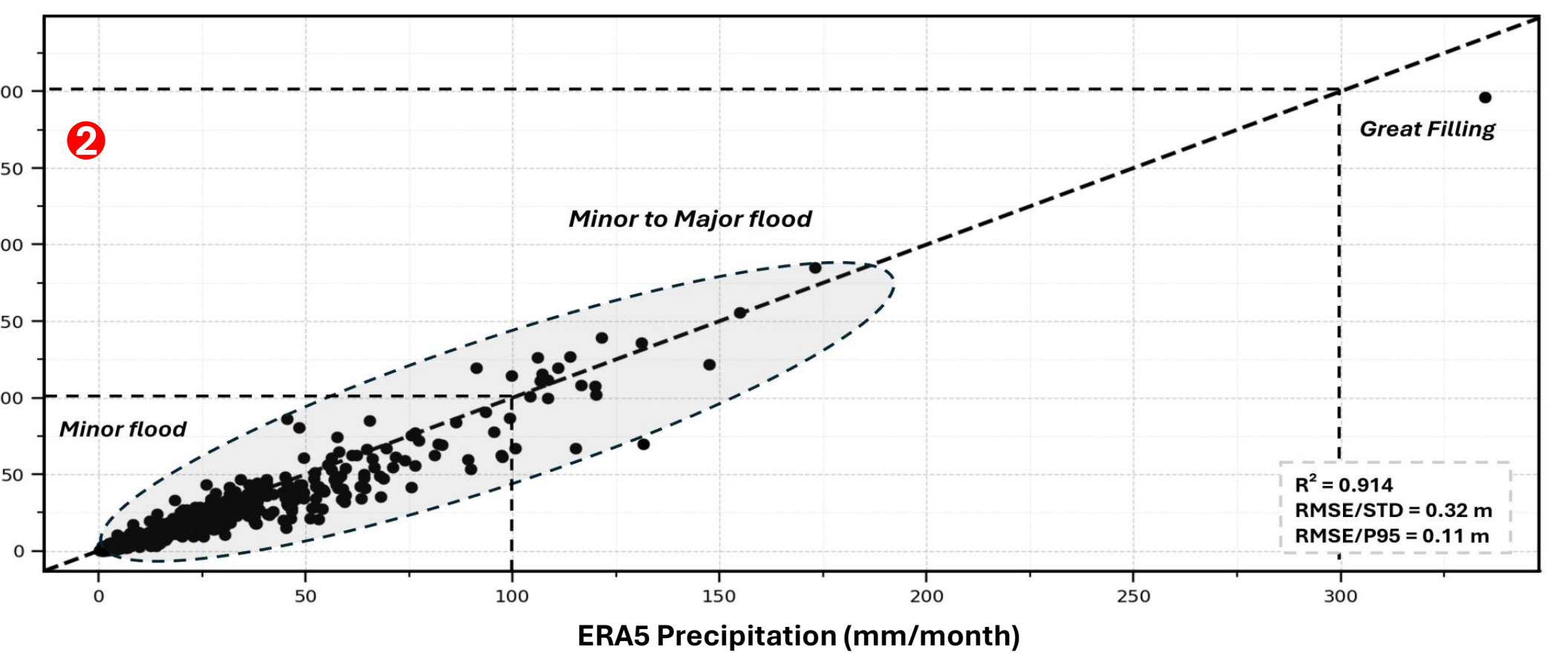


Fig. 5 : Linear correlation between basin-averaged observed BoM and ERA5 monthly precipitation

❷ Strong agreement with observations (R^2 = 0.914) for basin-averaged precipitation (1974–2025), with slightly larger dispersion at high water levels.

Calibrating, including transmission losses to convert runoff into inflow

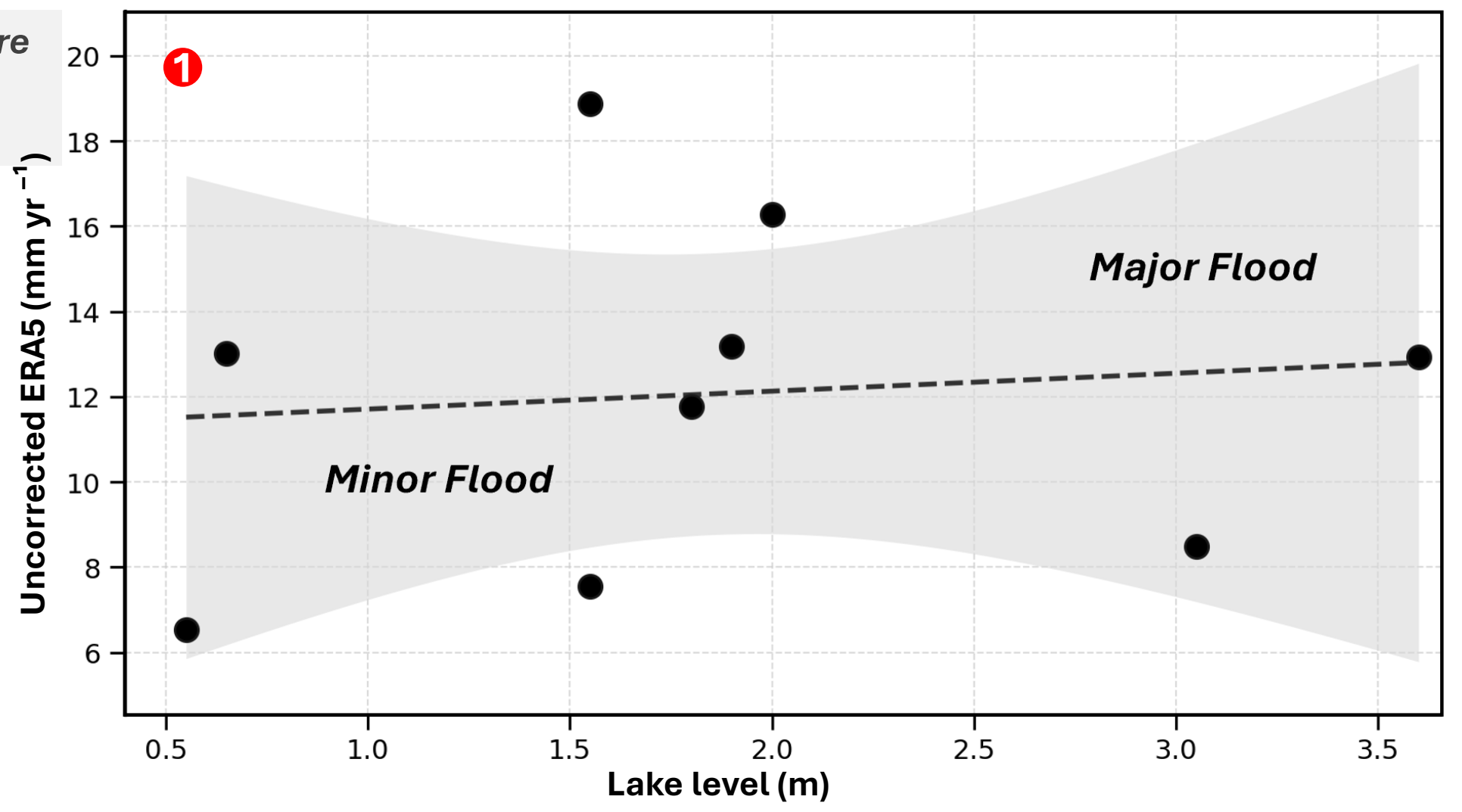


Fig. 6 : Annual basin runoff (mm/yr) before applying the losses factor, plotted against lake level (m).

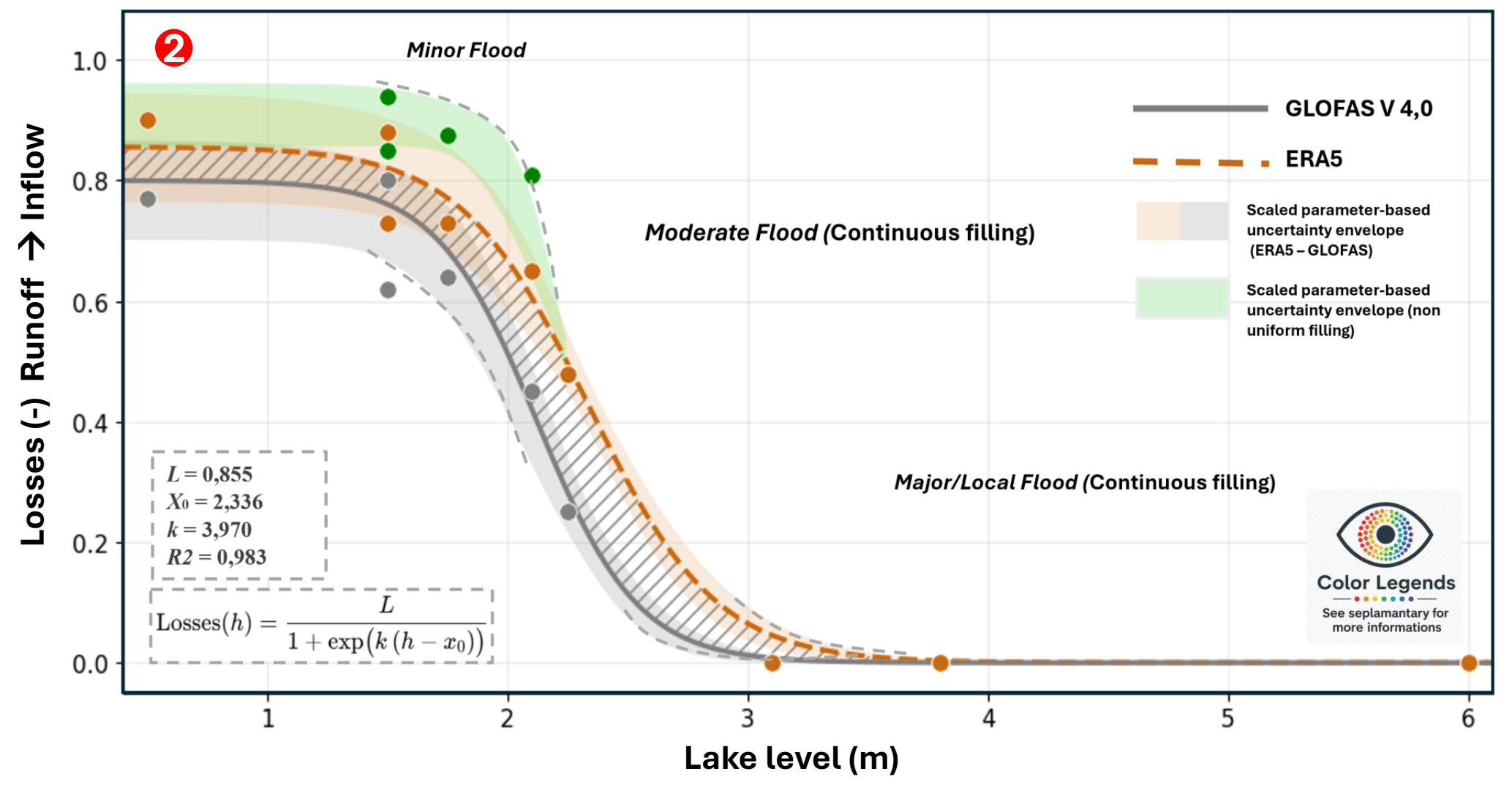
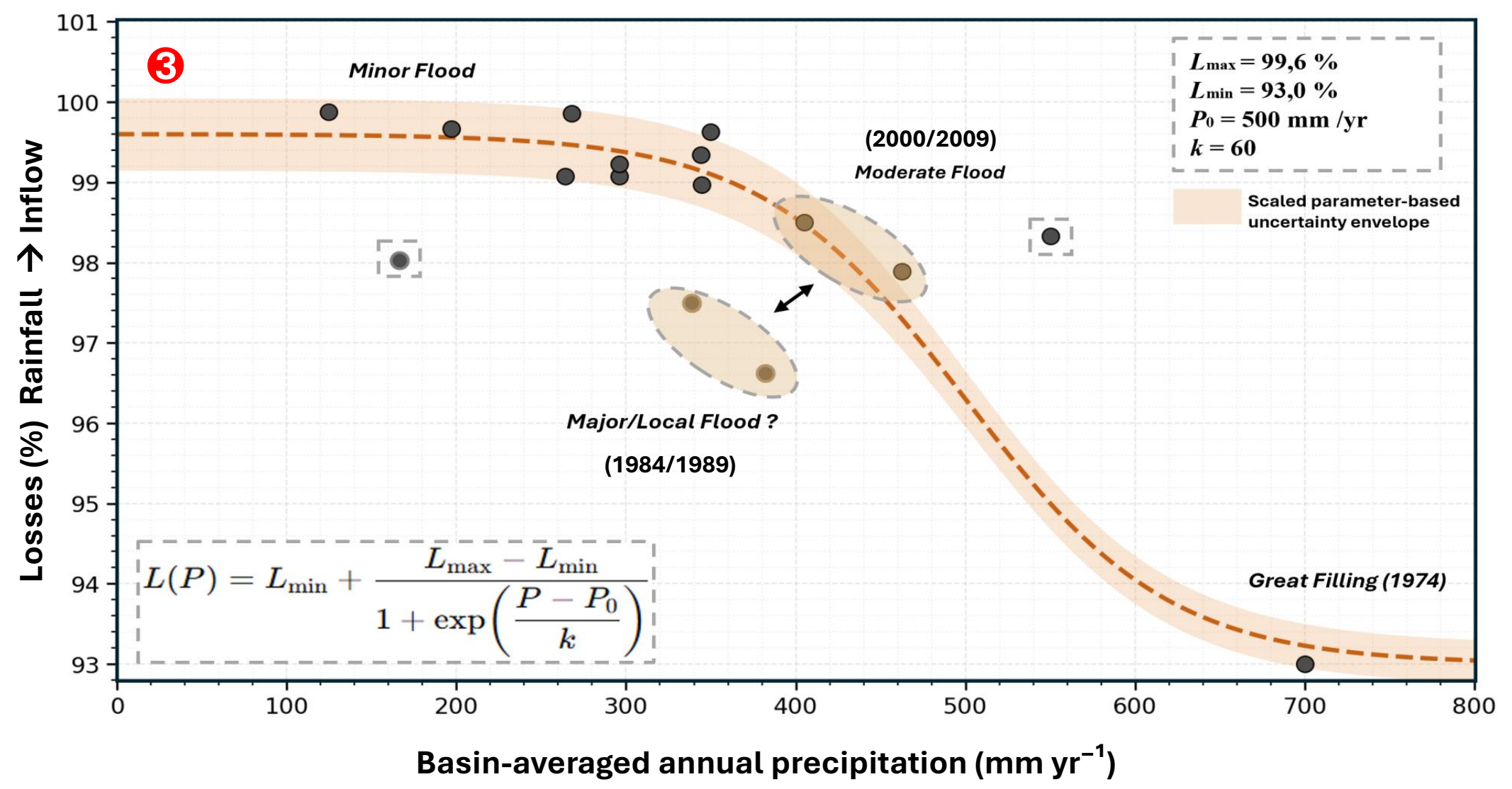


Fig.7 : Relationship between losses (runoff to inflow) and effective Belt Bay lake level for Kati Thanda–Lake Eyre North.



$$L(P) = L_{\min} + \frac{L_{\max} - L_{\min}}{1 + \exp\left(\frac{P - P_0}{k}\right)}$$

Fig.8 : Relationship between losses (% rainfall to inflow) and basin-averaged annual precipitation.

❶ No clear relationship was found between runoff/precipitation and lake levels (Fig.6),

❷ Losses exceed 80% during minor floods and decrease sharply during major floods as the basin becomes more interconnected (Fig. 7),

❸ Two major floods (1984 and 1989) lie below the curve, indicating more efficient inflows despite similar precipitation to some minor floods [1] (Fig. 8).

Simulating Lake Eyre water levels from 1974 to 2020 and validating with observations

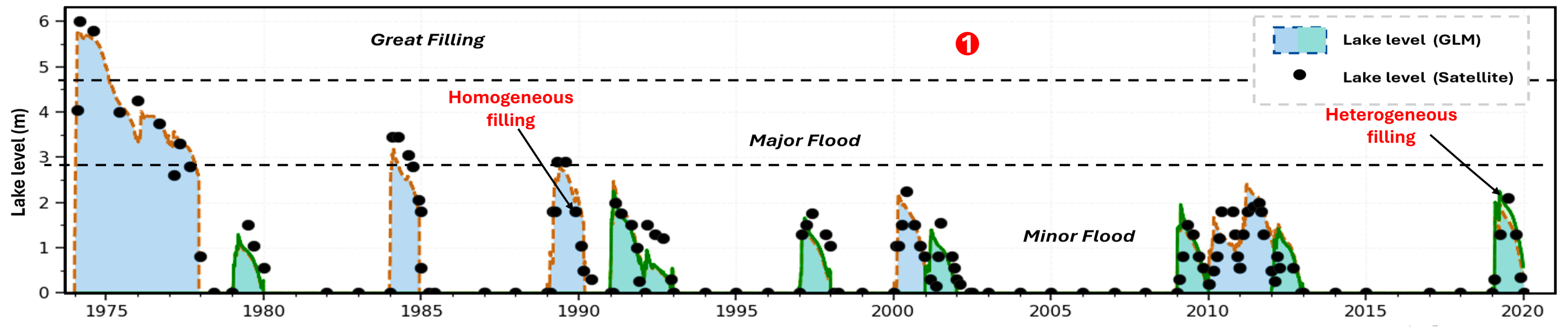


Fig.9: Lake-level evolution (1974–2020) at Kati Thanda–Lake Eyre North: GLM simulations versus satellite-derived Belt Bay observations

❶ Applying the logistic curve to inflows from 1974 to 2020 produced a good agreement between simulated and satellite-derived lake levels (R^2 = 0.828), with a mean absolute error of 0.36 m (Fig.9),

❷ Reasonable inundation patterns of the 2025 flood (2.2 m), using Armon's (2022) high-resolution 2D bathymetry [4] (Fig. 10).

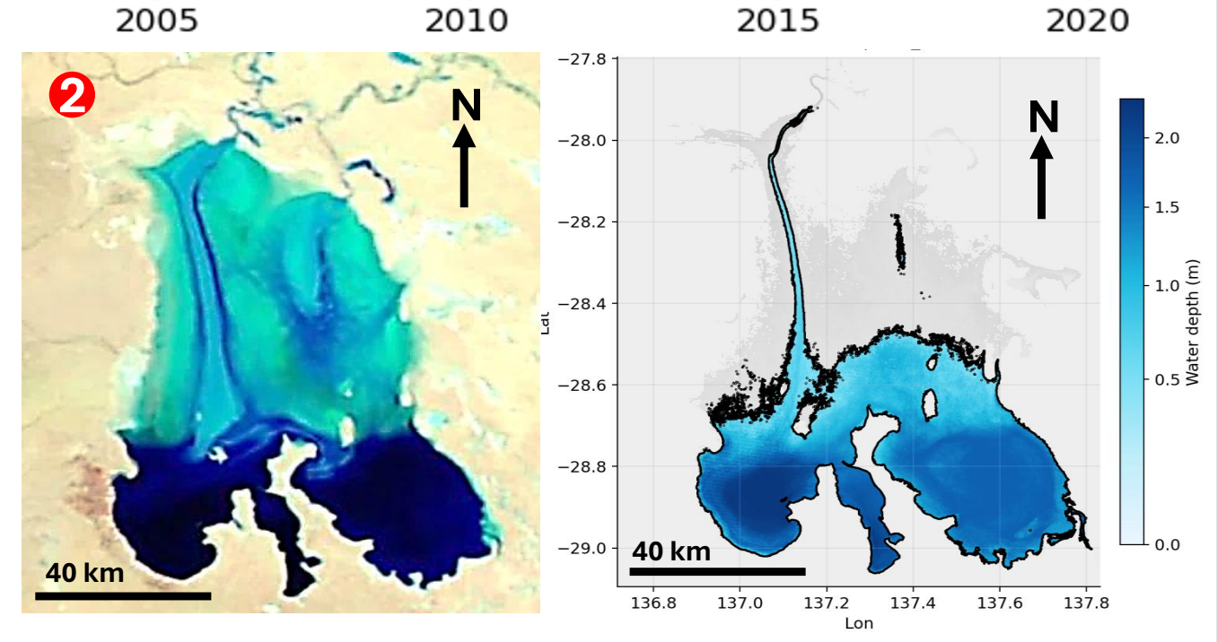


Fig.10: Observed and Simulated 2025 Flood extent Using Armon High-Resolution Bathymetry

IV. CONCLUSIONS

❶ No clear direct relationship was found between precipitation and lake levels. Transmission losses, represented by a logistic curve, link the basin water balance to the Lake Eyre water balance. They vary strongly with initial soil moisture, precipitation magnitude, and rainfall distribution, from >80% during minor floods to <10% during major and great filling events,

❷ Ongoing work with the ORCHIDEE land surface model aims to better represent floodplains and provide a physical explanation for this logistic curve across the basin.

KEY REFERENCES

[1] Costelloe et al. (2003). *Modelling the flow regime of an arid zone floodplain river, Diamantina River, Australia*. Environmental Modelling & Software, 18, 693–703. https://doi.org/10.1016/S1364-8152(03)00071-9

[2] Jarihani et al. (2015). Where does all the water go? Partitioning water transmission losses in a data-sparse dryland river system using modelling and remote sensing. Journal of Hydrology, 529, 1511–1529. https://doi.org/10.1016/j.jhydrol.2015.08.030

[3] May et al. (2022). *Transactions of the Royal Society of South Australia*, 146(1), 59–89. https://doi.org/10.1080/03721426.2022.2050506

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