Global change in groundwater and lake storage over the past 21,000 years

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Our recently published article describing the WTM in full.

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The Water Table Model

We used the **Water Table Model (WTM)** to simulate water table over the past 21,000 years. The WTM couples groundwater with dynamically changing lakes to simulate changes in depth to water table at the continental scale. These simulations capture natural variability in the water table, based on topography, sea level, and climate.

The **groundwater model component** solves the 2D horizontal groundwater equation using the the Scalable Nonlinear Equations Solvers (SNES) component of PETSc (Portable, Extensible Toolkit for Scientific Computation).

The **dynamic lake model component, Fill-Spill-Merge (FSM)** makes use of a *depression hierarchy* to rapidly analyse the land surface and move surface water to lakes or to the ocean. As climate and topography change, lakes can grow or shrink. The presence of the lakes provide more precise head values at lake locations, which are important in the simulation of groundwater in surrounding regions. Cells are not pre-assigned to contain surface water; they can change dynamically and the depression heirarchy is recomputed if the topography changes (for example, due to Glacial Isostatic Adjustment (GIA)). The inclusion of this component also allows us to evaluate changes in pluvial and proglacial lakes over the deglaciation.

Our **data sources** for WTM inputs include TerraClimate for modern-day precipitation and evapotranspiration, ERA5 for present-day winter temperatures, and the TRACE-21K climate simulation for past climate parameters. Topography and slope are based on the GEBCO-2020 topographic dataset, modified due to glacial isostatic adjustment (GIA) based on the ICE-6G ice sheet reconstruction. Hydraulic conductivity and porosity, which are assumed to remain constant throughout our simulation, are based on the STATSGO/FAO soil texture database.

In this work, we simulated natural, climate- and topography-influenced water table globally over the past 21,000 years. We assumed that water table was at equilibrium at the LGM (21,000 calendar years before present) and then performed a transient simulation until the present day. Note that Eurasia has only been simulated until 5 ka.

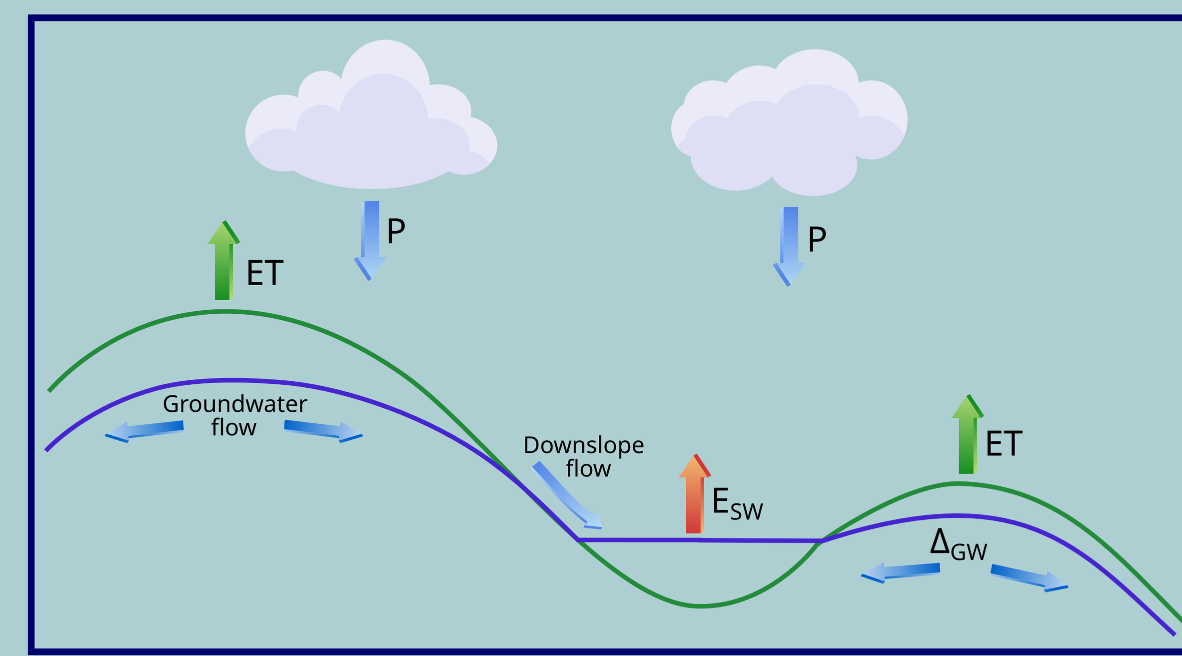


Figure 1: WTM schematic. The green line indicates the land surface and the blue line indicates the water table surface, including groundwater and lakes. The WTM uses topography, climate, sea level, and soil properties to compute either steady-state or transient water table.

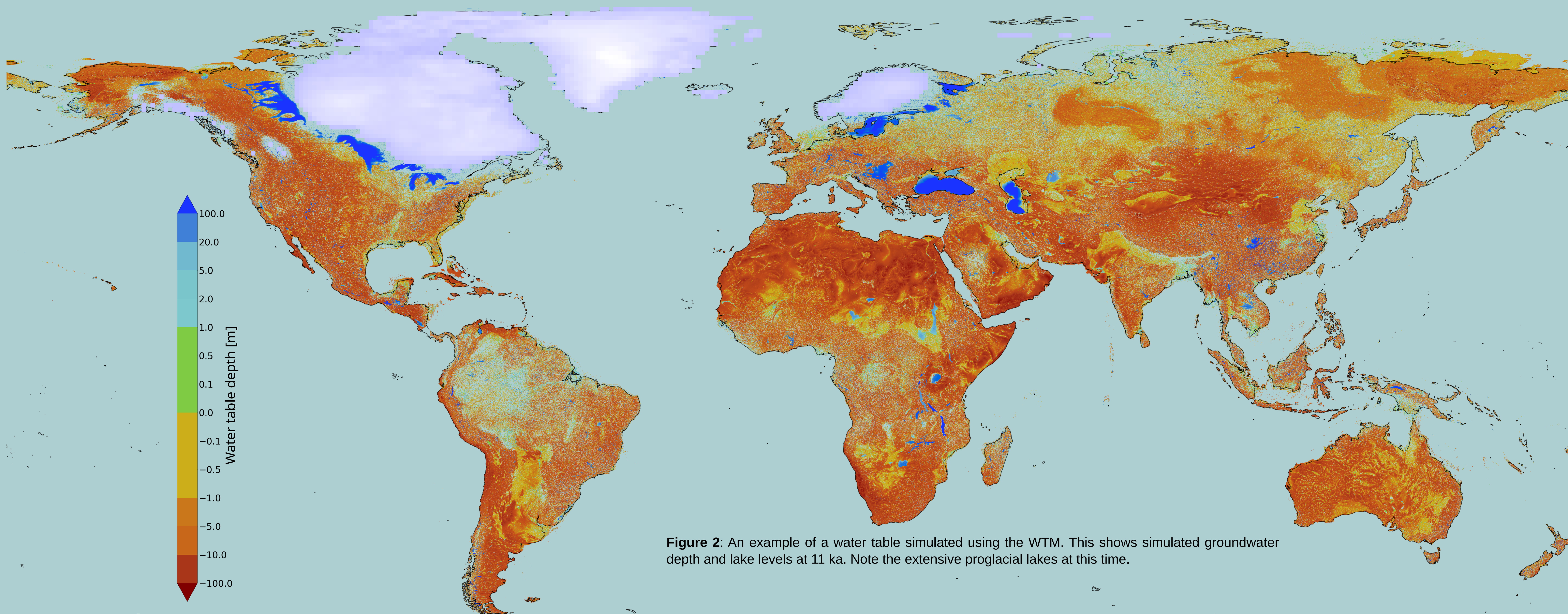
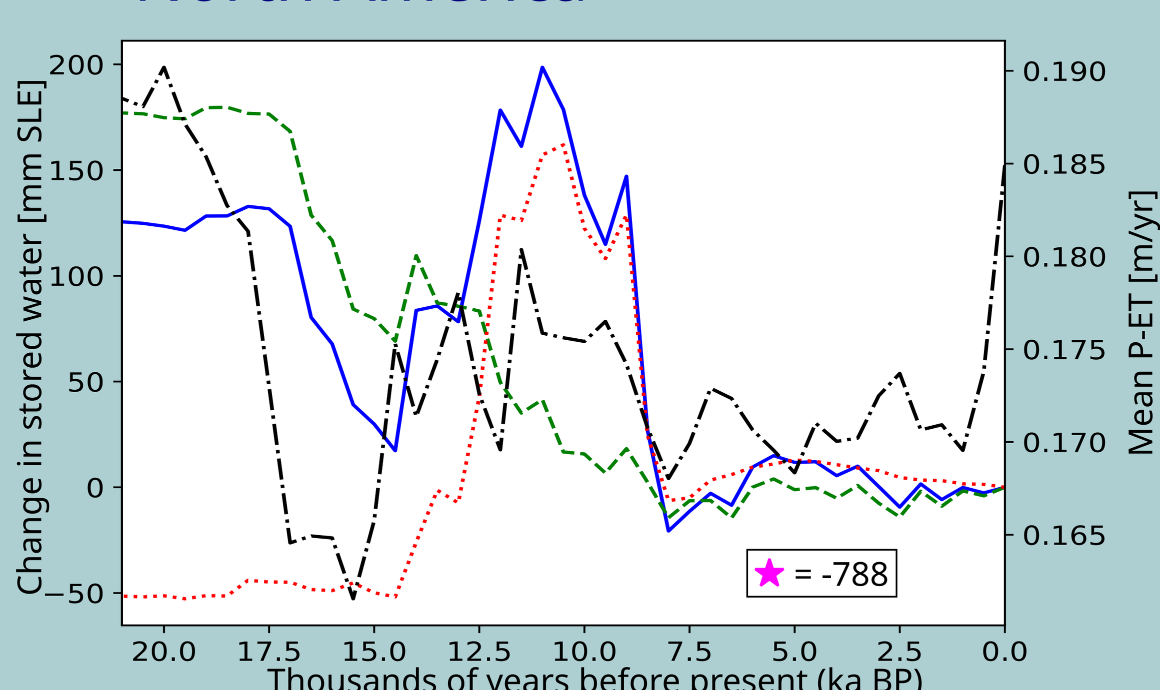
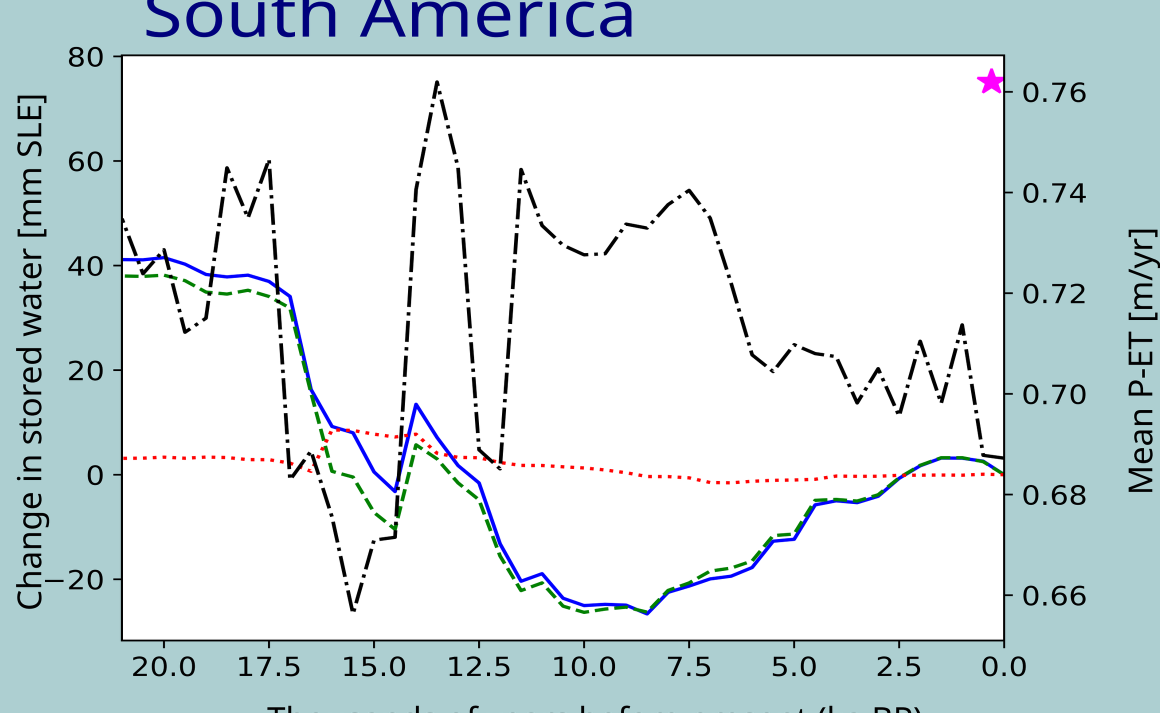


Figure 2: An example of a water table simulated using the WTM. This shows simulated groundwater depth and lake levels at 11 ka. Note the extensive proglacial lakes at this time.

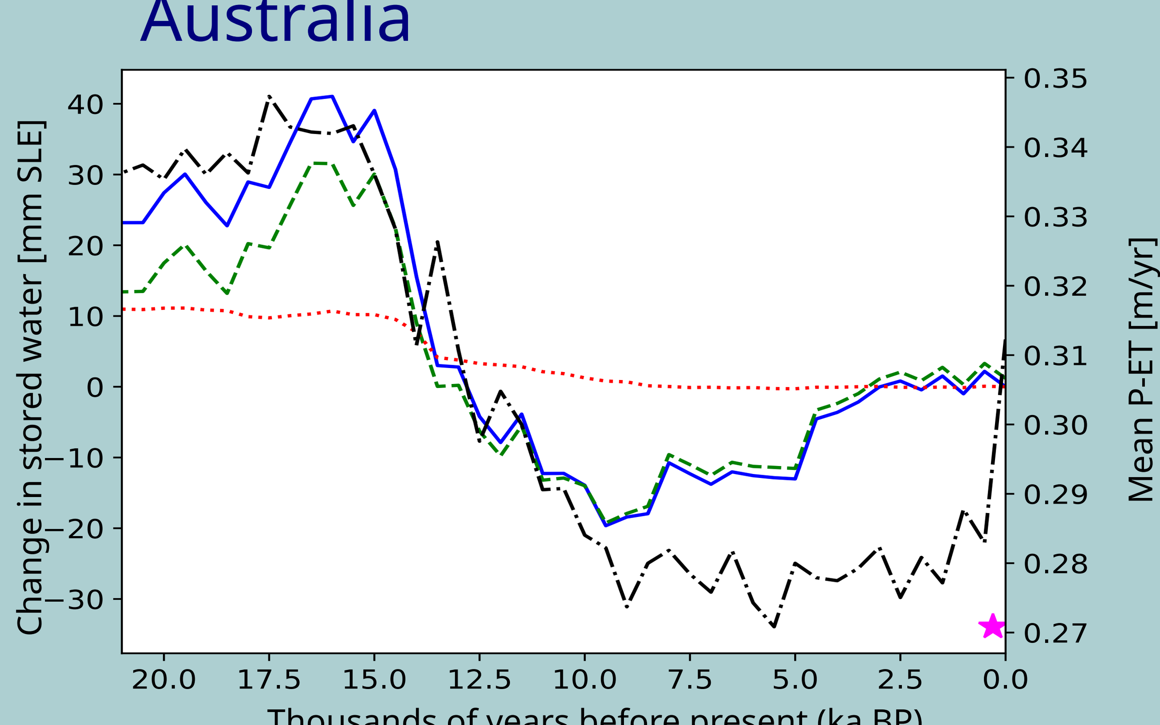
North America



South America



Australia



Discussion

Although groundwater and lakes are vital freshwater reservoirs, little is known about how their storage volumes and regional distributions change in the long term. Our transient simulation of global water table over the past 21,000 years is the first of its kind, allowing us to evaluate large-scale fluctuations in terrestrial water storage.
Our results highlight the impact of well-known climatic intervals – such as the Younger Dryas and the Bølling–Allerød – on continental-scale water tables, and indicate that changes in groundwater and lake storage can modify global sea level by several decimeters at a millennial time scale.
Groundwater levels commonly follow changes in P-ET at the continental scale, but sometimes regional changes are more dominant. Lake-level changes can be rapid and are more closely related to changing topography and ice extent.

Figure 3: All graphs. Changes in lake and groundwater volume stored within each continent over the last deglaciation, relative to the present day. Mean P-ET over this time period is also shown. Groundwater change typically follows changing P-ET, while lake volume is controlled by changes in the ice sheet and topography.

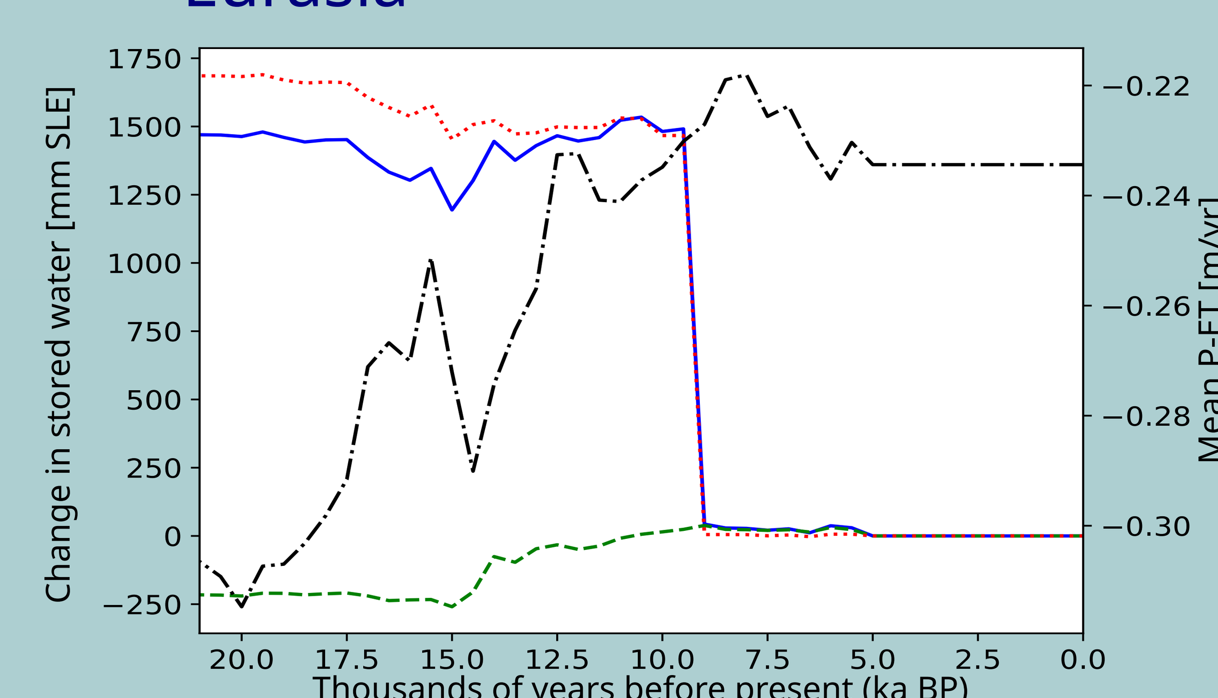
Ongoing work

Water table and GIA:
Changing lake and groundwater distributions can result in GIA, just like changing ice volumes do. Adding these lake and groundwater mass changes into calculations of GIA can modify local topography by tens of metres over the course of the deglaciation. In ongoing work, we are updating topography inputs to take the impact of water-induced GIA into account. This could lead to both more accurate GIA fields for the past, and improved simulations of past and present water table depth.

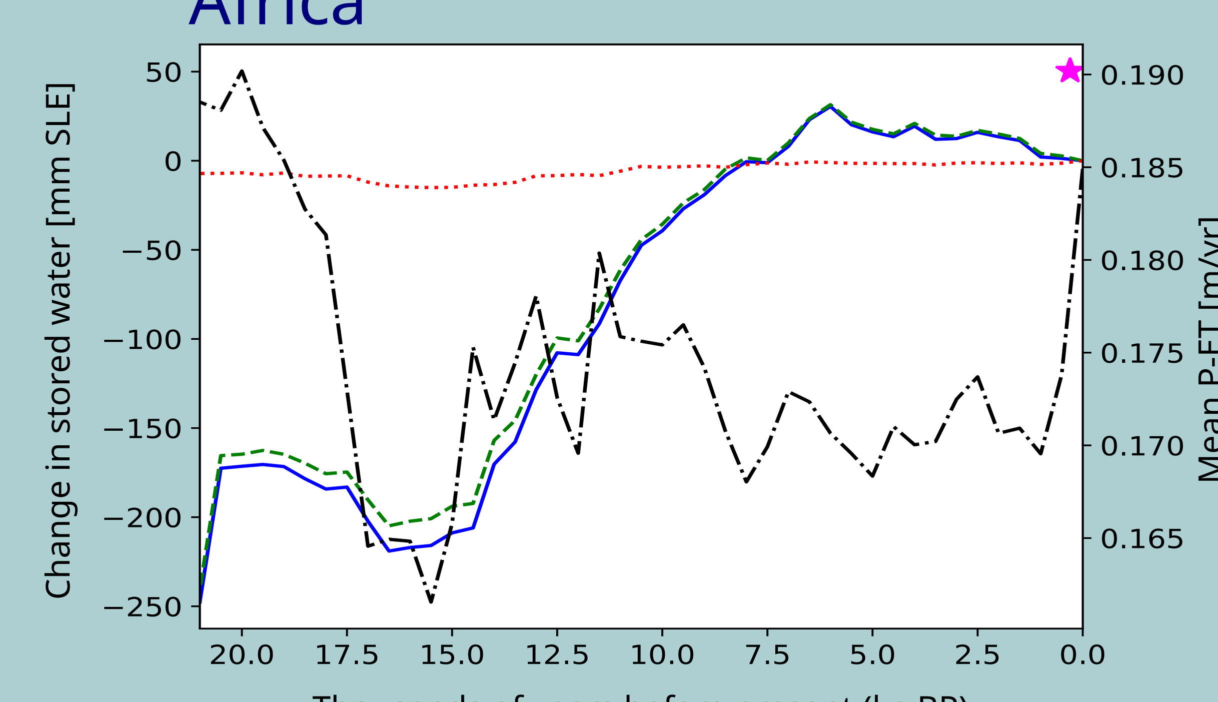
Present and future water table:
Most global-scale simulations of water table are at steady-state. Our long-term transient simulation of water table provides a transient present-day water table and also allows us to simulate seasonal changes in the water table - *see the poster tomorrow*! In addition, we are working to simulate future fluctuations in water table based on various possible climate futures.

Prediction of future drought:
Although meterological drought frequency can be determined from climate models, hydrological drought is more complex. By simulating changing water table in the recent past and future, and comparing this with drought proxies such as NDVI, we can determine how hydrological drought frequency and severity will change in the future. *See the poster right now*!

Eurasia



Africa



Global