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Investigating Regional Scale Reservoir Water Level Modeling

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Introduction

- The Global Reservoir and Lake Monitor (**G-REALM**) **multi-mission satellite radar altimetry** derived surface water level products are used to examine inland water level estimates for a set of lakes and reservoirs; and to complement *in situ* observations by providing stage information for un-gauged basins and filling data gaps in poorly gauged basins.
- Availability of both satellite-based rainfall and surface water level offers great opportunities to estimate and monitor additional hydrologic properties of the lake/reservoir systems. The applicability of a simple **hydrological model** (*Ricko et al., 2011*), together with the long-term altimeter records, is to provide longer record of surface water level increasing **the climate data record**.
- As instrument technology and data availability evolve, this method can be used to estimate the water level of greater number and much smaller targets. Such information can easily be incorporated into hydrologic descriptions and improve water balance estimation on local scales. It can also be utilized to assess **connections with climatic variations** on inter-annual to inter-decadal time-scales, with a focus on a future ability to predict changes in storage volume for water resources or natural hazards concerns.

Satellite Radar Altimetry Products

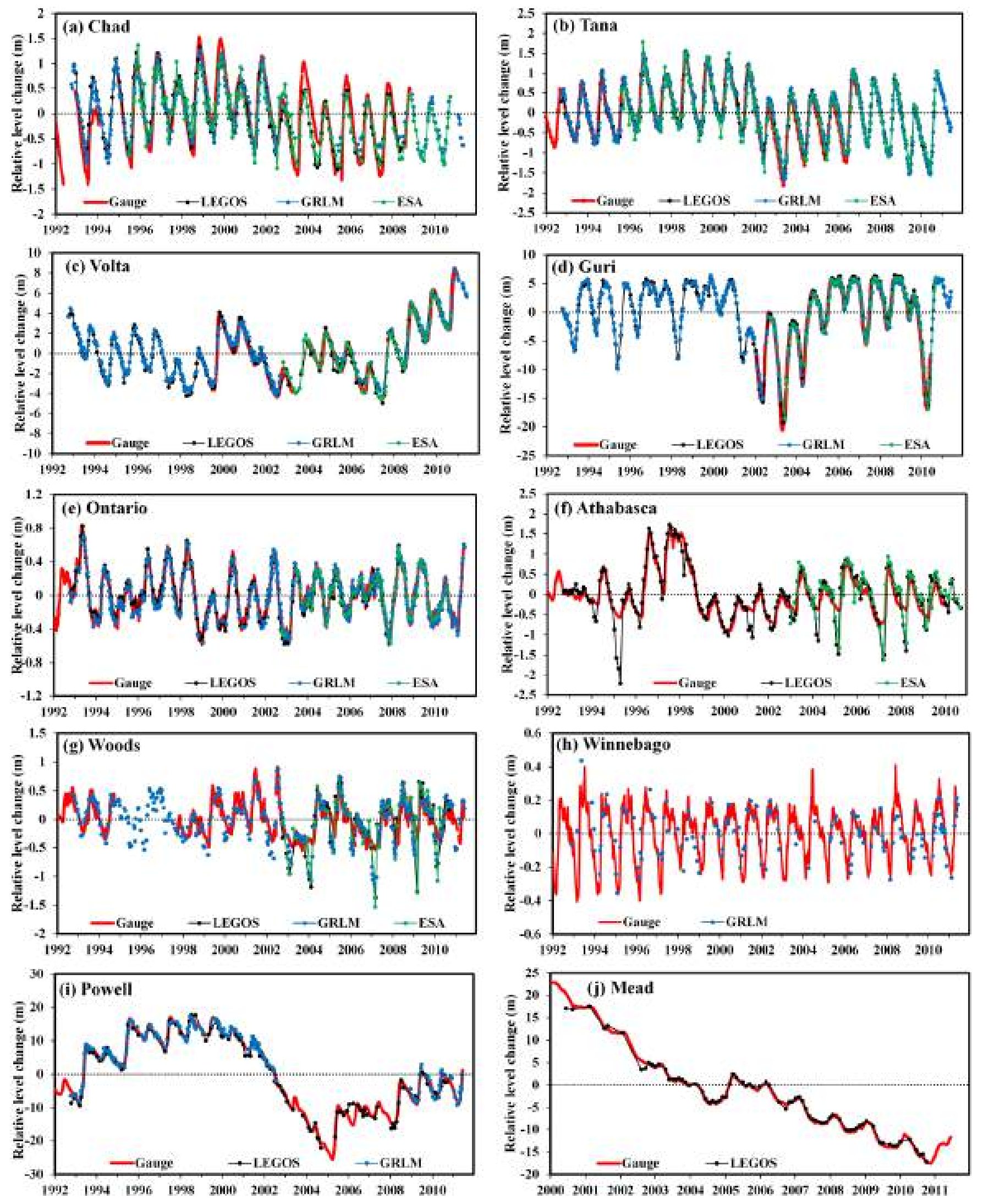
Validation of Altimetric Products with In Situ Observations

G-REALM Altimetry products:

- *10-day resolution*:
  T/P, Jason-1, Jason-2/OSTM, Jason-3
- *27-day resolution*:
  Sentinel-3A
- *35-day resolution*:
  ENVISAT, SARAL

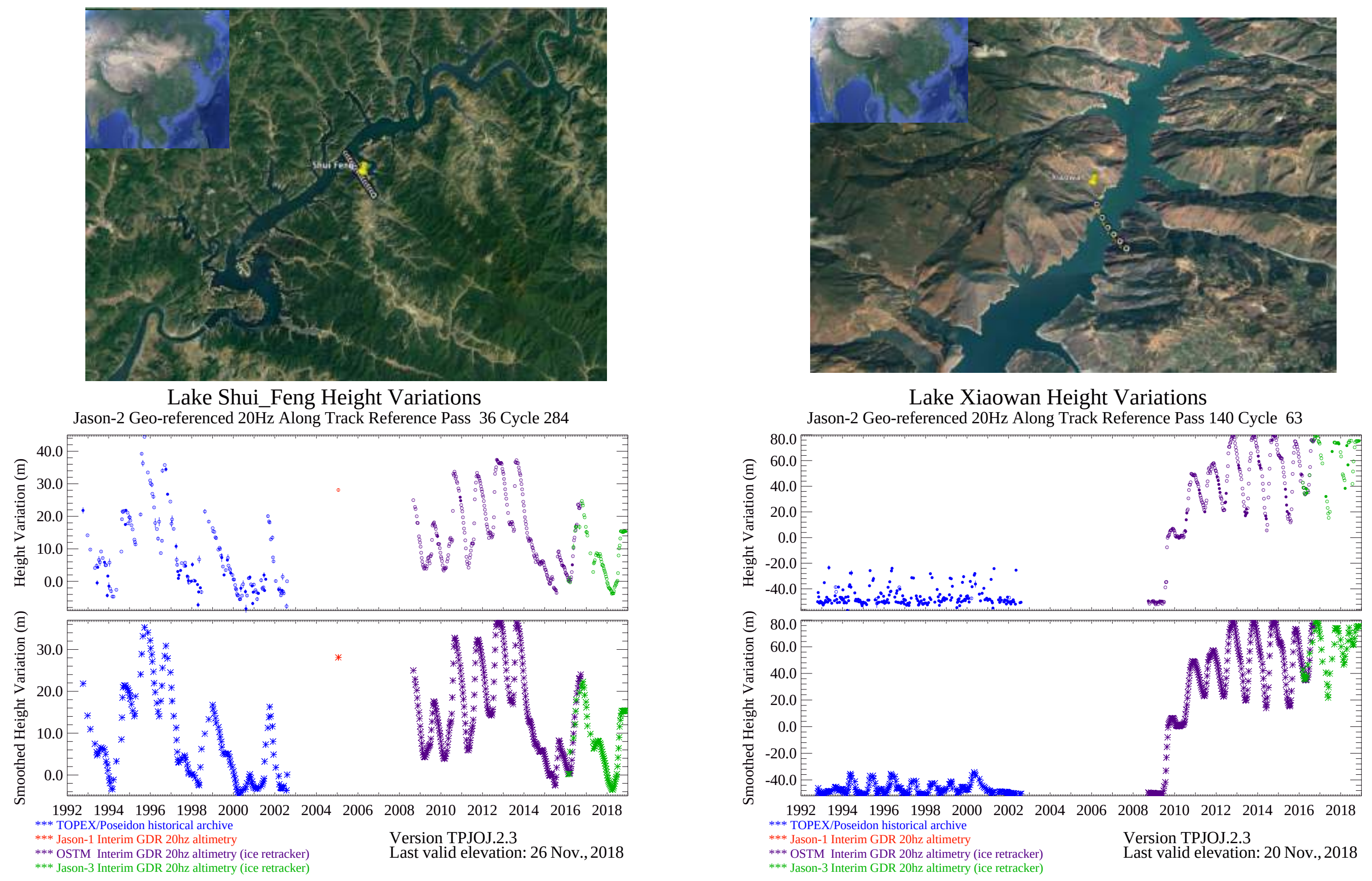
Altimetry accuracy (RMS error)**:**

- Smallest errors: Great Lakes 4-11 cm
- Lake Chad 10-20 cm
- Largest errors: Powell and Kainji reservoirs 74-92 cm



(Right) Filtered gauge and altimeter water level change (m) for 10 selected lakes and reservoirs.

Recent Altimetry Reservoir Water Level Products



T/P, Jason-1,2,3 *Altimeter-derived water level change over Shui Feng and Xiaowan dams.*

Hydrologic Model

Here, a simple water balance model is utilized to relate net freshwater flux on a catchment basin to lake level. It allows a comparison of the flux to altimetric lake level estimates.

A hydrologic model is defined as a lake level anomaly from its time mean (H), with corresponding lake area (A_L), catchment area (A_C), anomalous net freshwater flux (P-E), and anomalous water loss (ε_t) through a variety of processes at any given time (t) and space (x,y):

$$\frac{d}{dt}\left(\oiint H(x,y,t)\,dA_L\right) = \oiint [P(x,y,t-\delta t) - E(x,y,t-\delta t)]\,dA_C - \varepsilon_t$$

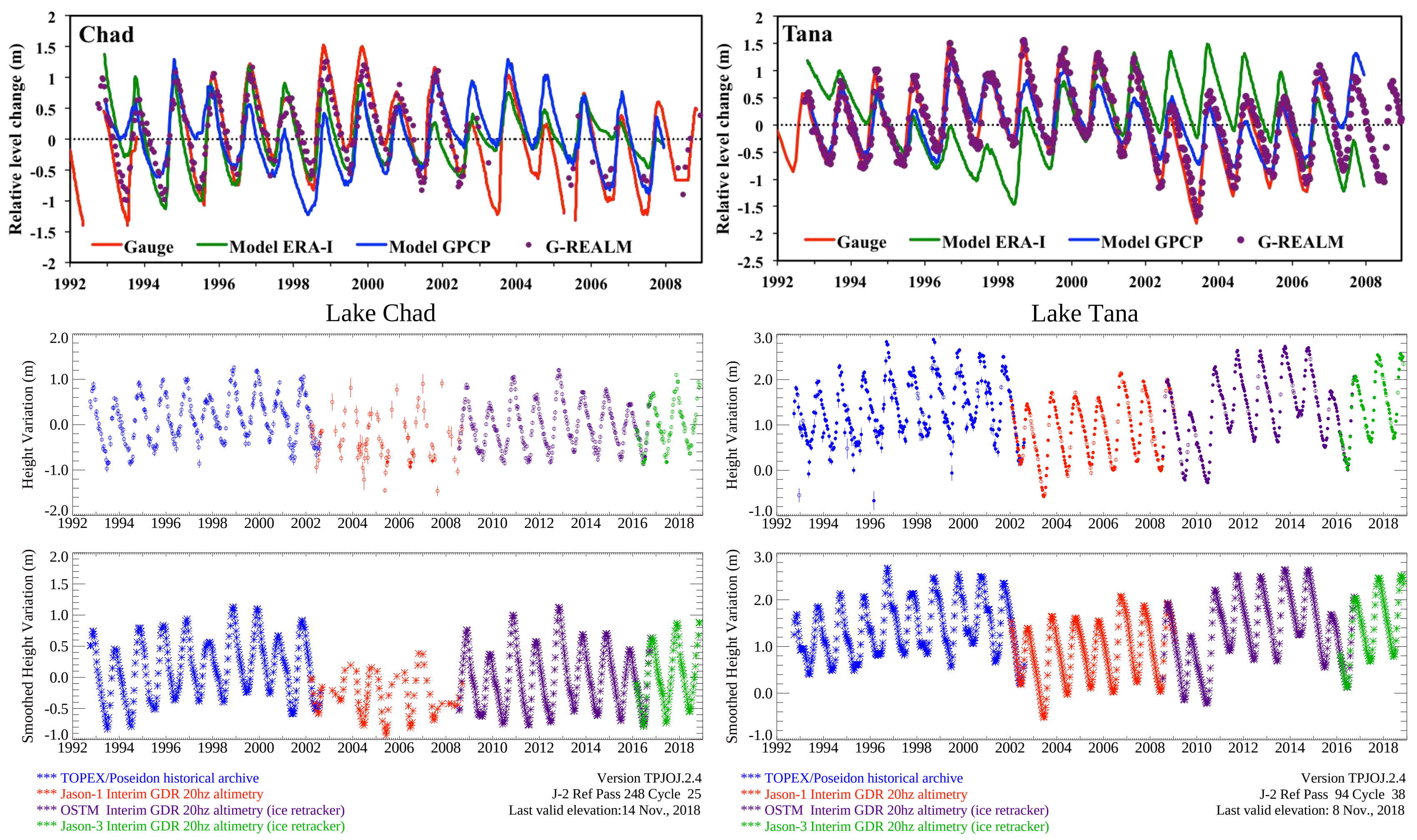
Assumptions: a single constant delay between the time of freshwater flux and the accumulation of water in the lake and a constant A_C/A_L; water level does not vary spatially within the lake; thermal expansion effects and the effects of changing salinity on evaporation rates, water loss and anthropogenic effects are neglected.

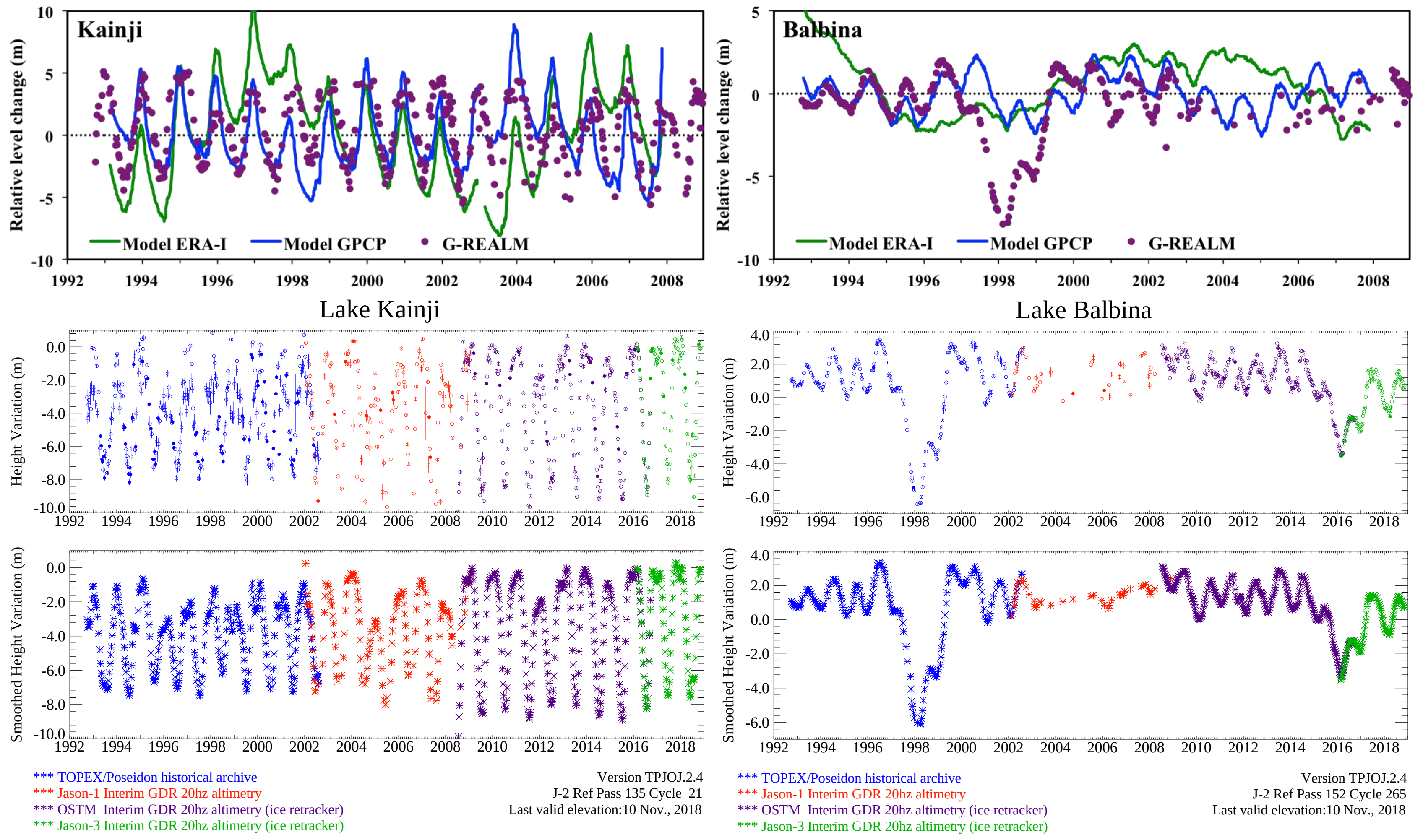
Model equation: $$H(t) = \frac{A_c}{A_L} \int_{t=-\delta t}^{t-\delta t} e^{\frac{\lambda}{A_L}(t+\delta t-\tau)} [\tilde{P}(t) - \tilde{E}(t)]\,dt + H(t=0)$$

Model parameters: **1.** ***Effective size of catchment area (A_C/A_L)*** is obtained from a maximum amplitude fit determined by minimizing RMS values of initial model and altimetric height lake level; **2.** ***Time delay (δt)*** of freshwater input and level rise is determined based on a maximum correlation value between initial model and altimetric height lake level. Parameter values range from 2-27 and 0-105 days among selected lakes (*Ricko et al., 2011*).

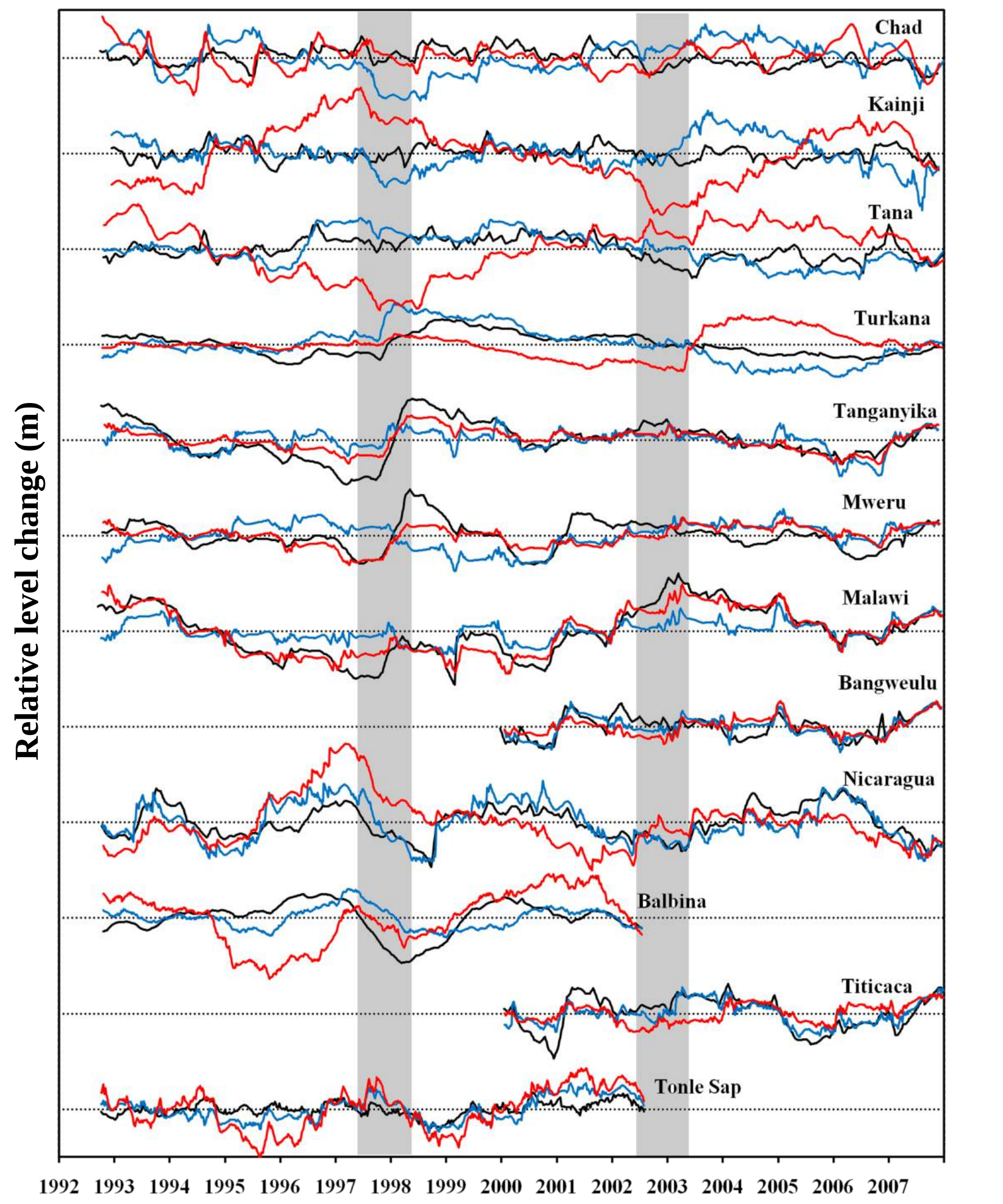
Model input data: Rainfall (e.g., ERA-Interim, GPCP, TRMM) and Evaporation (ERA-Interim).

Validation of Model-derived Lake Level Products





Monitoring Climate Effects



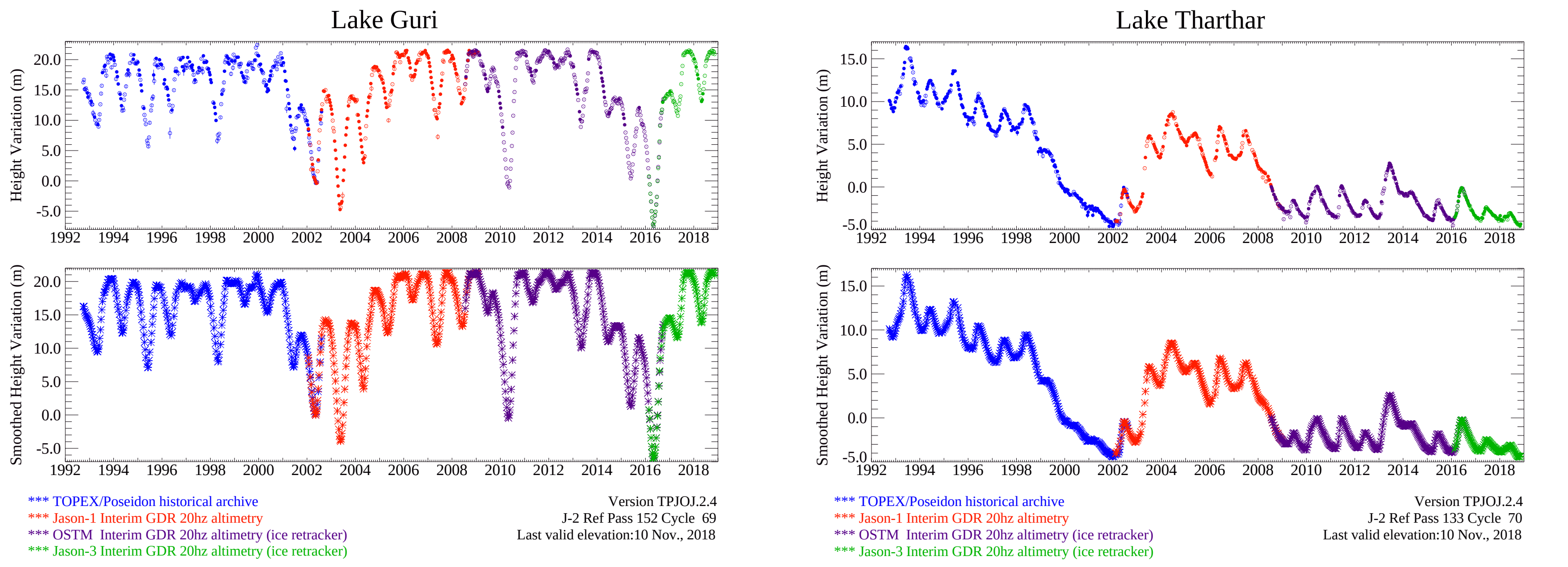
Observed climate change events:

✓Northern Africa:
Tropical cyclones (Sept 1994, Jul 2006)
✓African Rift Valley:
Tropical cyclones (Feb 1996, Mar 1999, Jan 2005, Mar 2006)
✓Nicaragua:
Hurricane Mitch (Oct 1998)
✓Balbina: Min water (Mar 1998)
✓**El Niño events**: 1997-8, 2002-3
✓**Drought events**: 2005, 2007

(Left) Observed altimetric (black) and modeled (ERA-Interim, red; GPCP, blue) water level for 12 lakes and reservoirs (quadratic trend, annual and semiannual Fourier harmonics filtered out). Displacement between horizontal lines is 2m. Levels for Turkana, Tanganyika, Mweru, and Balbina have been reduced in amplitude by a factor of 5, 1.5, 1.5, and 2.5. Grey shaded areas identify two El Niño periods (1997-98, 2002-03).

Monitoring severe drought events

✓ Lake Guri: drought (2010)
✓ Lake Tharthar: drought (1999-2001)



Summary

- **The altimeter-derived water level products perform well** for a great sample of lakes and reservoirs of varying latitude, size, surface roughness, and surrounding terrain (*Ricko et al., 2012),* including smaller lakes, dams, river systems, and wetlands, especially with recent improvements of satellite orbits, atmospheric corrections, etc.
  - ✓ Large lakes show the smallest errors <10 cm, while the largest errors are validated for smaller targets and the northern latitudes lakes that freeze (i.e., Lake Athabasca).
  - ✓ Even large errors >1 m for the reservoirs (e.g., Powell and Mead) are sufficiently low to detect climate variability and monitor water level changes.
- **A simple hydrological model effectively derives lake level estimates**.
  - ✓ While large uncertainties in model applications exist, they can offer reasonable assessment of surface water availability in large river basins, especially for science-based investigations.
  - ✓ This physically based modeling is also useful to **fill in time gaps** in the observed altimetric time series and for basins **where no ground-based or satellite-based data are available**, enabling the construction of a longer climate data record of surface water level.
  - ✓ It can be used by climate modelers and water management community (contribution to earth system climate modeling!) to explore connections to **climatic variations** (e.g. extreme events) on regional to global scales.

References

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