CLIMATE MONITORING AND MODELING LAKE AND RESERVOIR LEVEL

Stinger Ghaffarian Technologies

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LEGOS

Satellite Radar Altimetry Products

Satellite measurements of lake and reservoir water levels complement *in situ* observations by providing stage information for ungauged basins and by filling data gaps in gauge records. However, different radar altimeter-derived water level products may differ significantly owing to choice of satellites and data processing methods. To explore the impacts of these differences, a direct comparison between three different **altimeter-based surface water level estimates** (USDA/NASA GRLM, LEGOS and ESA-DMU) is presented, and products are validated with lake level gauge time series for lakes and reservoirs of a variety of sizes and conditions.

Product	LEGOS	GRLM	ESA-DMU
#Targets	160	75	750
Resolution	~30 days	10 days	35; 10 days
Altimeters	Merging 6 altimeters	T/P, Jason-1, OSTM/Jason2	Envisat, Jason-2
Reference	*Crétaux et al. 2011*	*Birkett et al. 2011*	*Berry and Wheeler 2009*

Validation of Altimetric Products with *In Situ* Observations

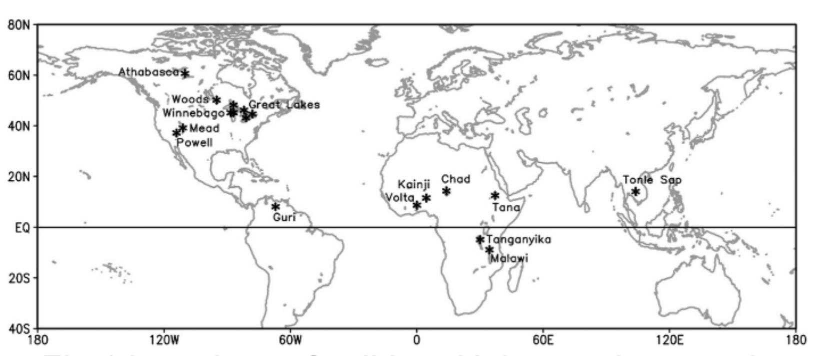

Fig.1 Locations of validated lakes and reservoirs.

Altimetry accuracy

- Smallest RMS errors: Great Lakes: 4-11 cm
- Lake Chad: 10-20 cm
- Largest RMS errors: Tonle Sap, Powell and Kainji: 74-92 cm

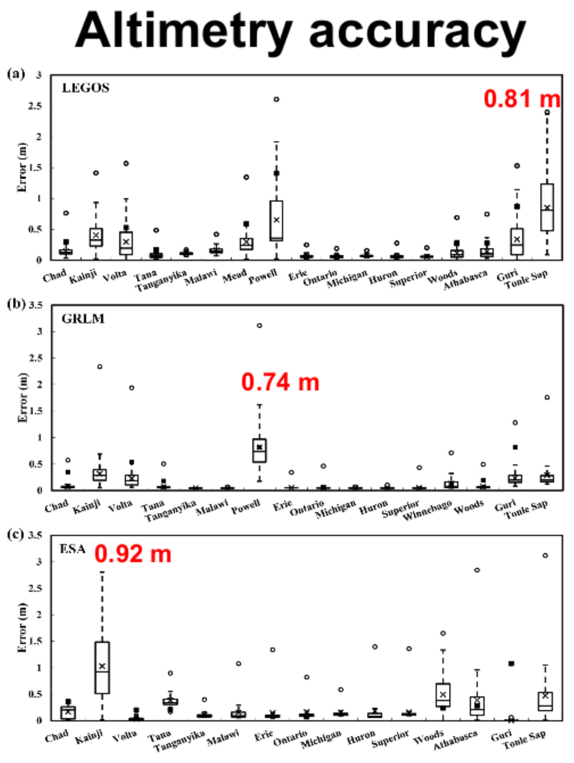

Fig.2 Lake level errors (m) for: (a) LEGOS, (b) GRLM, and (c) ESA-DMU with corresponding error means (crosses), farthest outlying errors ("whiskers"), outliers farther than 1.5x the interquartile range from the median (open circles), and observed RMS errors between the altimeter and gauge observations (black boxes).

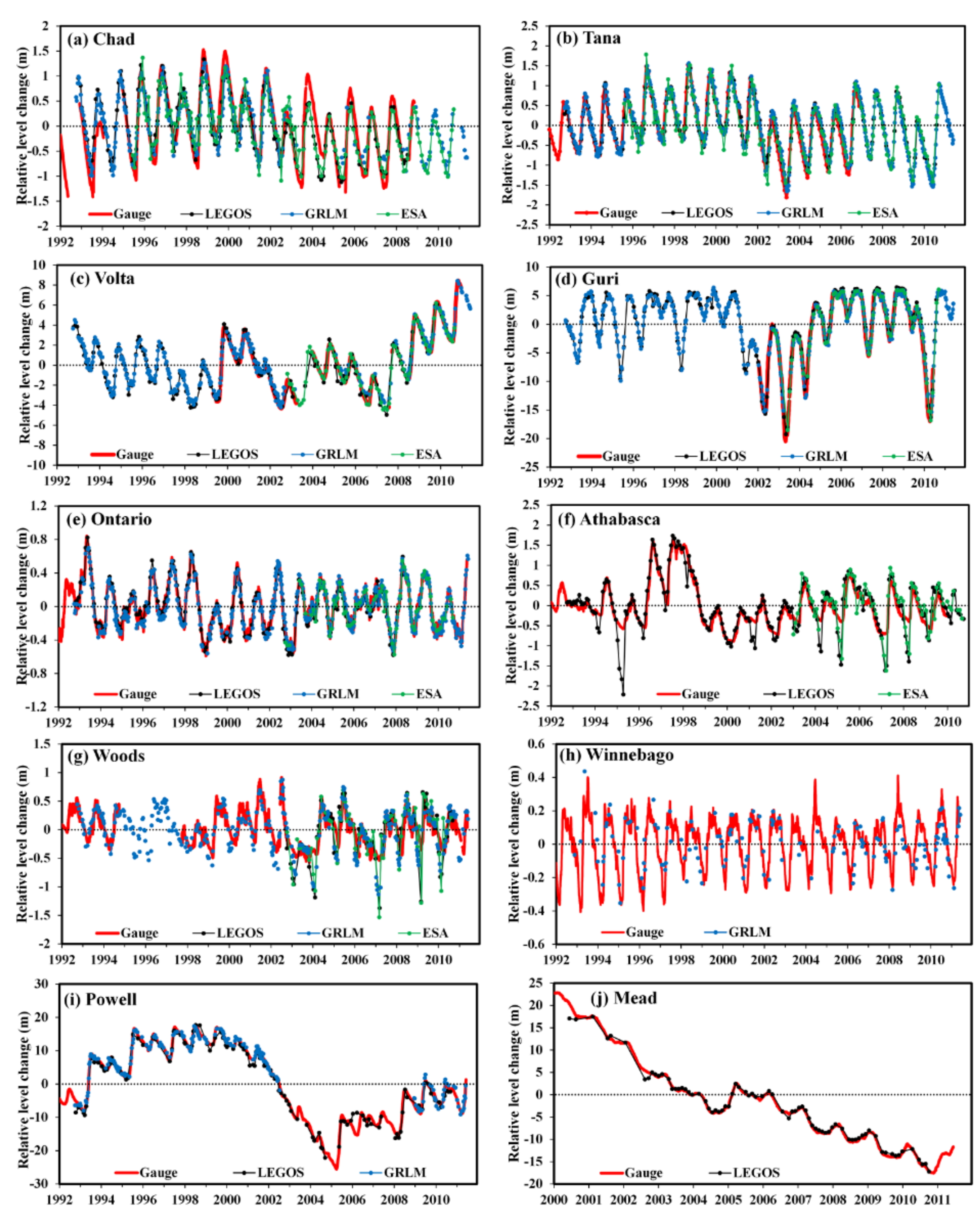

Fig.3 Filtered gauge and altimeter water level change (m) for 10 selected lakes and reservoirs during 1992-2011.

Recent Altimeter-derived Lake Level Products

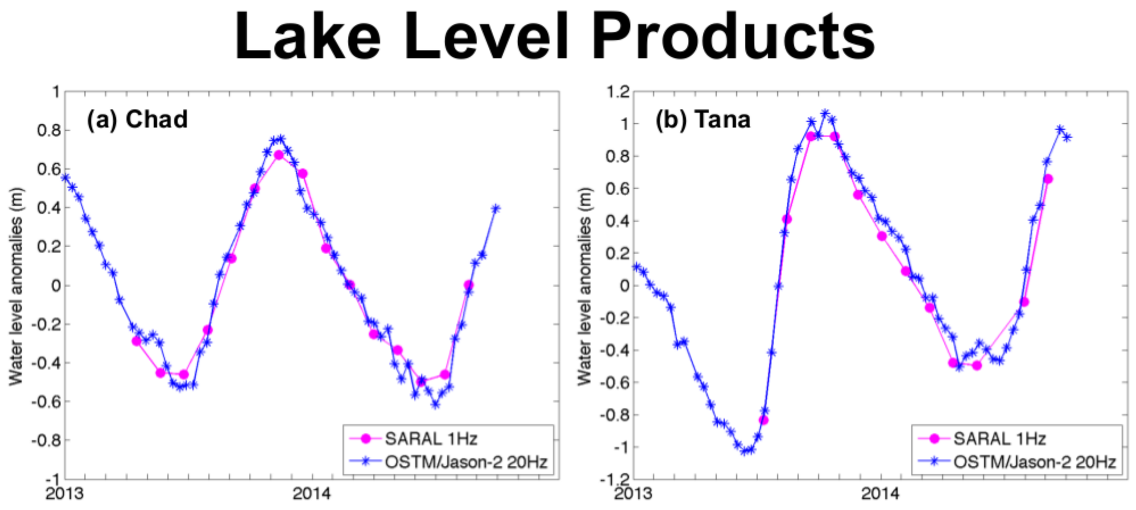

Fig.4 Altimeter water level anomalies (m) derived from OSTM/Jason-2 20 Hz (GRLM, TPJO.2 version; magenta) and SARAL 1 Hz (blue) for (a) Lake Chad and (b) Lake Tana during 2013-2014.

Hydrologic Model

Availability of **satellite-based rainfall** (i.e., GPCP and TRMM) and **satellite-based lake level** offers great opportunity to estimate and monitor the hydrologic properties of the lake systems. Here, a simple water balance model is utilized to relate net freshwater flux on a catchment basin to lake level. Focused on tropical lakes and reservoirs, 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):

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

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

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 studied lakes (*Ricko et al., 2011*).

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

Model-derived Lake Level Products

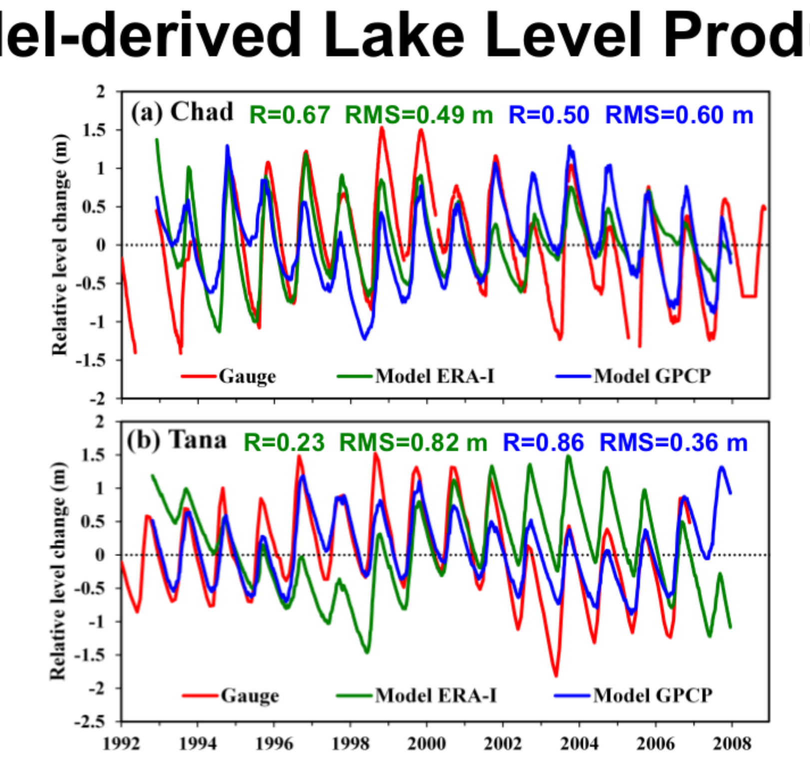

Fig.5 Gauge and modeled water level change (m) for (a) Lake Chad and (b) Lake Tana.

Climate Effects on Lake Basins

- ✓ 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

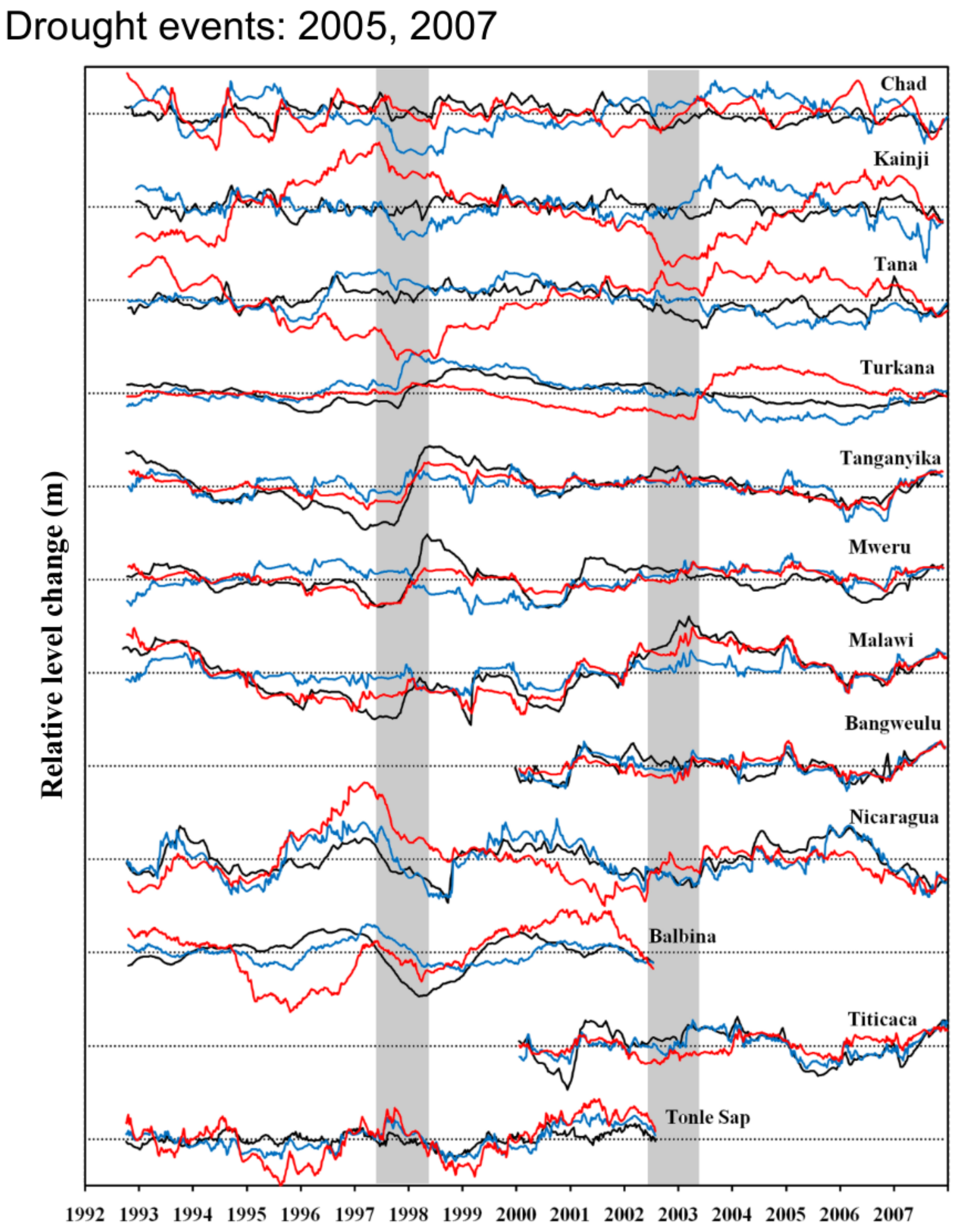

Fig.6 Observed LEGOS (black) and modeled (ERA-Interim, red; GPCP, blue) water level for 12 lakes and reservoirs (quadratic trend, annual and semiannual Fourier harmonics filtered out). Displacement between horizontal lines is 2 m. Levels for Turkana, Tanganyika, Mweru, and Balbina have been reduced in 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).

Lake Level Forecasts

Current coupled climate forecast models still do not have sufficient resolution to support full hydrologic system models. *Can we introduce a simple developed hydrologic model into the climate forecast models to forecast water levels in lakes on a seasonal time scale?*

The combined use of model, satellite-based rainfall, and rainfall-evaporation information from reanalysis products, can be used to output **seasonal water level forecasts**. Such a tool is fundamental for understanding present-day and future variations in lake/reservoir levels, and enabling a better understanding of **climatic variations** on inter-annual to inter-decadal time-scales.

Seasonal Lake Level Prediction

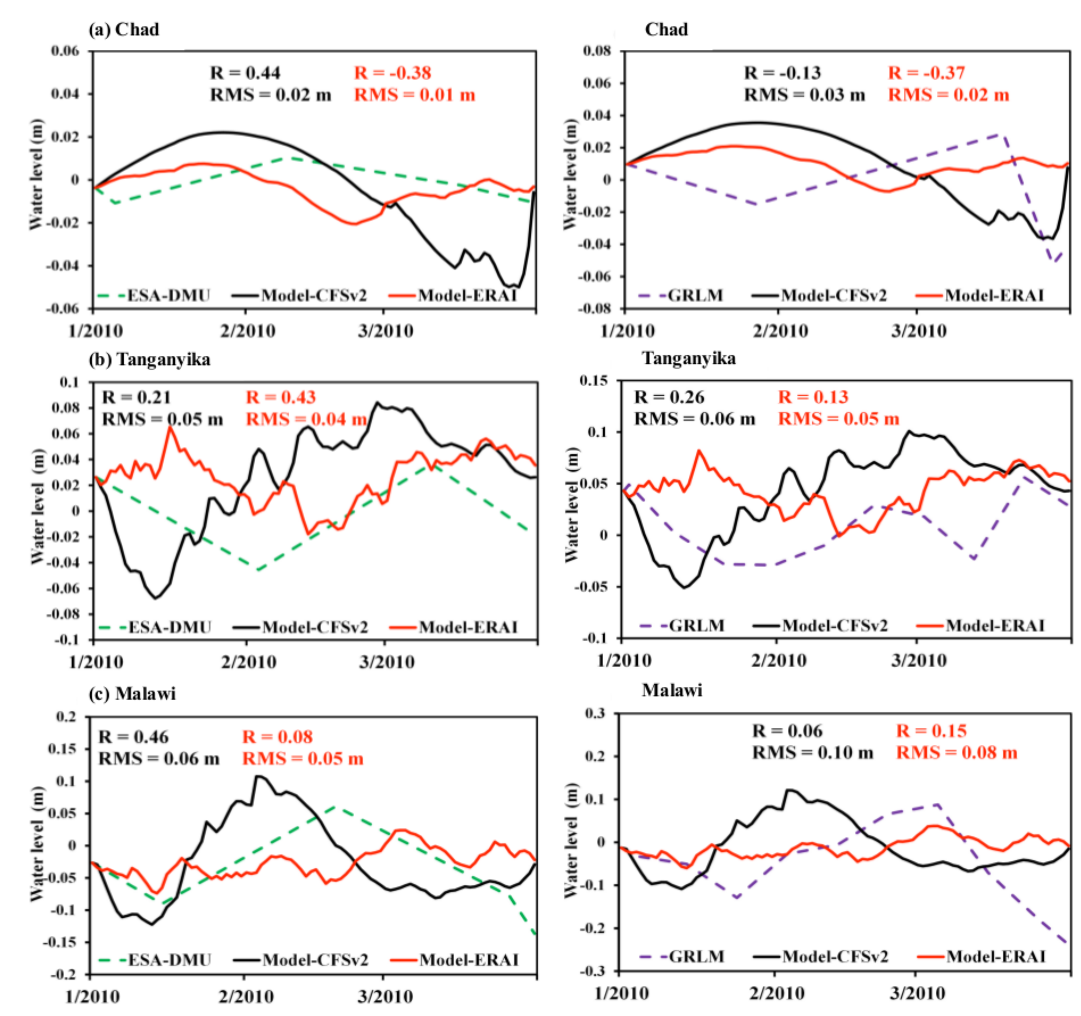

Fig.7 Comparison of seasonal water level forecast (m) model derived using the NCEP retrospective forecast CFSv2 rainfall and evaporation (black), validated with model derived water levels using ERA-Interim reanalysis (red) and altimetric products (ESA-DMU, green, and GRLM, purple) for lakes: (a) Chad, (b) Tanganyika, and (c) Malawi.

Summary and Conclusions

- **The altimeter-derived lake level products** differ in methodology but **perform well** for a sample of lakes and reservoirs of varying latitude, size, surface roughness, and surrounding terrain (*Ricko et al., 2012).* The North American Great Lakes show the smallest errors (<10 cm), while the largest errors are validated for the lakes that freeze (Lake Athabasca and Lake of the Woods).

  Significance:
  - (1) Even for the reservoirs (i.e., Powell and Mead), **the error levels** (>1 m) **are sufficiently low** to detect climate variability.
  - (2) Variations in the trends observed in different products appear to be due to differences in satellite coverage, ground track position, and corrections applied. **For climate purposes** these **variations in trend estimates are acceptably small**.

- **A simple hydrological model can effectively derive lake level estimates from a net freshwater flux** observations. Two model parameters provide useful information regarding the hydrological properties of lake basins.

  Significance:
  - (1) **Model can provide water level estimates for basins where no ground-based or satellite-based data are available.**
  - (2) 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.
  - (3) **Seasonal forecasts of future lake levels** and **hindcasts of past lake levels.**

References

Berry, P.A.M., and J. L. Wheeler, 2009: Jason2-ENVISAT exploitation, development of algorithms for the exploitation of Jason-2-ENVISAT altimetry for the generation of a river and lake product, Product Handbook, *Internal Report DMU-RIVL-SPE-03-110*, De Montfort University **3** (5).

Birkett, C.M., C. Reynolds, B. Beckley, and B. Doorn, 2011: From research to operations: The USDA global reservoir and lake monitor. Ch. 2, in *Coastal Altimetry*, pp. 19–50, Springer-Verlag, Berlin Heidelberg.

Crétaux, J-F., et al., 2011: SOLS: A lake database to monitor in the near real time water level and storage variations from remote sensing data. *Adv. Space Res.* **47** (9), 1497–1507.

Ricko, M., J. A. Carton, and C. Birkett, 2011: Climatic effects on lake basins. Part I: modeling tropical lake levels. *J. Climate*, **24**, 2983-2999.

Ričko, M., C. M. Birkett, J. A. Carton, and J.-F. Crétaux, 2012: Intercomparison and validation of continental water level products derived from satellite radar altimetry. *J. Appl. Remote Sens.* **6** (1), 061710.