Abstract

The availability of satellite estimates of rainfall and lake levels offers exciting new opportunities to estimate the hydrologic properties of lake systems. Combined with simple basin models, connections to climatic variations can then be explored to focus on a future ability to predict changes in storage volume for water resources or natural hazards concerns. This study examines the possibility of a simple basin model in estimating variations in water level and also examines model-derived lake level sensitivity to precipitation fluctuations. With focus on 12 tropical lakes and reservoirs, model-derived estimates of net surface freshwater flux and lake levels during a 16-year remotely-sensed observation period (1992-2007) form the basis for an initial study. The model is constructed so that freshwater flux is related to lake level via two empirical parameters: effective catchment area and time delay between freshwater flux and lake level response. Both are determined based on correlation analysis of remotely-sensed contemporaneous freshwater flux and lake level data sets. The initial data themselves are also explored and cross-checked. Here, rainfall data sets include one reanalysis product and two satellite-sensed contemporaneous freshwater flux and lake level data sets. The initial data sets are also examined based on corelating analysis of remotely-sensed contemporaneous freshwater flux and lake level data sets. Two radar altimeter-derived lake levels data sets are compared.

Tropical Lakes

Altimeter validation

Satellite radar altimeter data:

- GRLM (USDA) (Crétaux et al 2009)
- LEGOS (Crétaux et al 2009)

Rainfall validation

Fig. 2. LEGOS vs. GRLM lake level estimates during 1993-2007.

Fig. 4. Rainfall and evaporation estimates averaged over Lake Malawi’s catchment area.

Fig. 3. Altimeter ground tracks (ENVISAT and Envisat). Horizontal axes span January – December.

Table 1. Ground truth data for LEGOS

<table>
<thead>
<tr>
<th>Name</th>
<th>Ground truth</th>
<th>Modelled</th>
<th>A/L</th>
<th>Time delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake Malawi</td>
<td>0.5</td>
<td>0.5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Lake Victoria</td>
<td>0.5</td>
<td>0.5</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Lake Kivu</td>
<td>0.5</td>
<td>0.5</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Lake Tana</td>
<td>0.5</td>
<td>0.5</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Lake Kainji</td>
<td>0.5</td>
<td>0.5</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

Fig. 5. LEGOS vs. modeled lake level. Rainfall from (a) ERA-Interim and (b) GPCP during 1993-2007. Modelled vs. observed Lake Malawi level, with months indicated.

Model

A hydrologic model (Calder et al 1995) is defined as a lake level anomaly from its time mean (H), lake area (A), catchment area (A_c), anomalous net freshwater flux (P-E), and anomalous water loss (ε) through a variety of processes, at any given time (t) and space (x,y):

\[ \frac{\partial H(x,y,t)}{\partial t} = \nabla \cdot \left[ \frac{A}{A_c} \left( P(x,y,t) - E(x,y,t) \right) \right] + \varepsilon(t,x,y) - H(t) \]

Assumptions:

1. A_c/A is obtained from maximum amplitude fit determined by minimizing RMS values of initial model and altimetric height lake level, and
2. time delay of freshwater input and level rise is determined based on a maximum correlation value between initial model and altimetric lake level height.

Model inputs:

Rainfall: ERA-Interim, GPCP, TRMM.

Evaporation: ERA-Interim.

Results

Lake Malawi

Fig. 6. Observed LEGOS (black) and modeled (ERA-Interim, red, GPCP blue) height lake level for 12 lakes and reservoirs. Displacement between horizontal lines is 3 m. Levels for two Turkana and Shihui have been reduced in amplitude by a factor of three and two. A quadratic trend has been removed from each time series.

Fig. 7. Similar to Fig. 6, with the annual and semiannual Fourier harmonics filtered out. Displacement between horizontal lines is 2 m. Levels for Turkana, Tanganyika, Samburu, 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 Nino periods (1997, 2002-3).

Conclusions

We find that overall GPCP is higher than ERA-Interim rainfall over most tropical lakes. Good agreement is observed between the two remote sensing-derived lake level data sets with the lowest correlations occurring for lakes Kainji and Tana (0.87 and 0.89). This study demonstrates the use of a simple model in estimating lake level. The model formed a set of A_c/A, and delay time values ranging from 2-27 and 0-105 days among lakes and different data sets. Utilizing the model-derived parameters, we find that the different rainfall products produce slightly different results: for nine of the twelve lakes the observational products provide a better fit to the observed altimetry record of lake levels than the reanalysis product (with median correlation 0.78 vs 0.70).

Future Work

- Assessment of short intraseasonal climate variability of tropical lake levels (tropical cyclones and hurricanes; Madden-Julian Oscillation)
- Future climate forecasting of height lake levels.
- Hindcasting the past events of height lake levels.

References


Acknowledgments

We gratefully acknowledge support from the NASA’s Woods Program and the NASA’s OSTM and Decision Support Programs.