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Outstanding Student Poster Contest

A multi-sensor approach to monitor the desiccation of Lake Urmia in Iran

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Abstract

Lake Urmia, a hypersaline lake in northwestern Iran is under the threat of drying up. The high importance of the lake's watershed for agricultural purposes demands a comprehensive monitoring of the watershed's behaviour. Spaceborne sensors provide a number of novel ways to monitor the hydrological cycle and its interannual changes. The use of GRACE gravity data allows to determine continental water storage changes and to close the water budget on short time scales. Satellite altimetry can be used as a tool for monitoring inland water surface elevations. Optical satellite imagery provides the opportunity to monitor the spatial change in coastline, which can serve as a way to determine the water extent repeatedly in an appropriate time interval.

In this study, water storage change from GRACE, surface water level over different parts of the lake from satellite altimetry together with surface water extent estimation from optical imagery are used and assimilated to monitor the lakes hydrological cycle. In addition to the spaceborne data, in situ observation of precipitation is also employed for assimilation. A linear dynamic system consisting of a stochastic process model and observation equations is developed to assimilate the data from different sources. The dynamic system is solved by a Kalman filter to achieve an unbiased estimation with minimum variance. The results of the assimilation allow us to monitor the hydrological cycle over the lake.

1. Data

- Lake water level: ENVISAT, Hydroweb
- Surface water extent: MODIS, Hydroweb
- Precipitation: GPCCv06, in situ data from water research institute, ministry of Energy of Iran
- Mass storage changes: GRACE
- Moisture flux divergence ($\nabla \cdot \vec{Q}$): ERA Interim

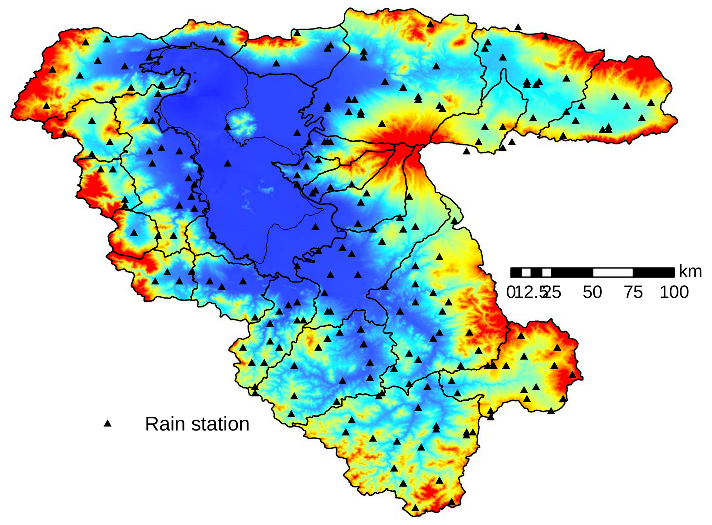

Figure 1: *Catchment and sub-catchments of Urmia Lake together with catchment's topography*

2. Surface water extent

Daily snapshots of MODIS (Moderate Resolution Imaging Spectroradiometer) images in Terra mode are used because of availability in different bands and its appropriate time interval. As the difference between water and soil in infrared bands is distinguishable, water body is easily determined by setting a threshold in infrared bands.

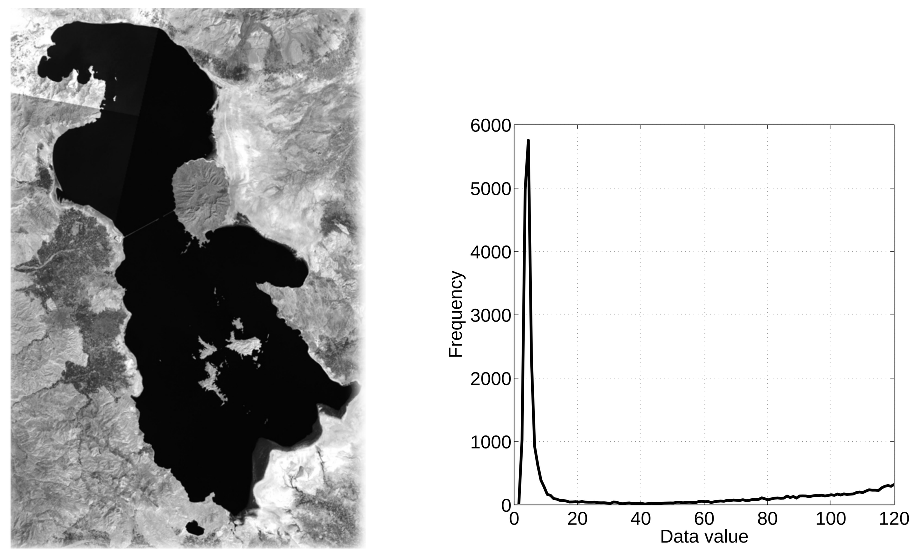

Figure 2: *Left) A sample of image over Lake Urmia Right) histogram of returned power*

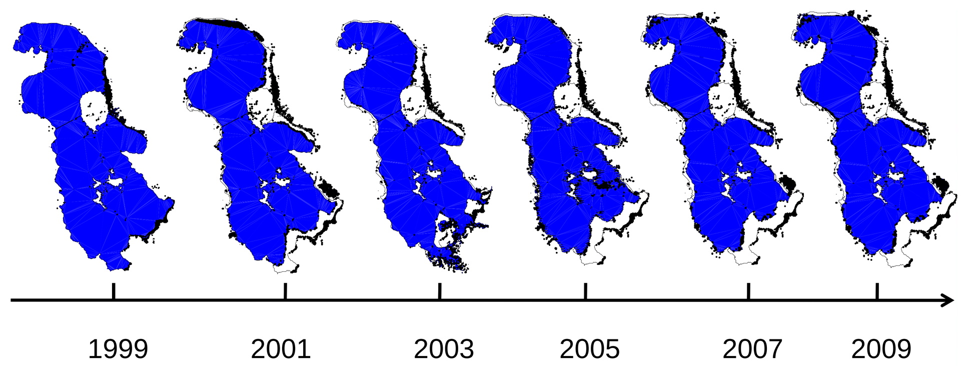

Figure 3: *Surface water extent obtained from MODIS imagery from 1999 to 2009*

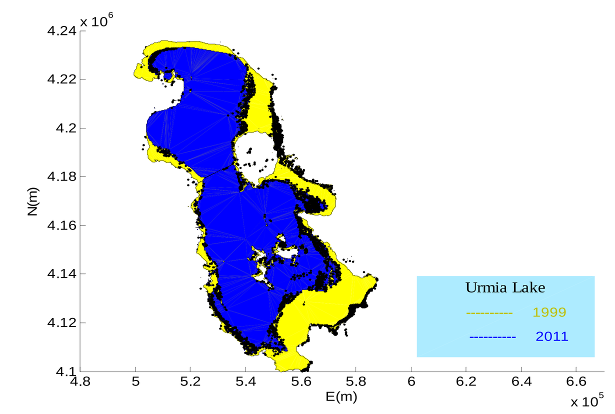

Figure 4: *Emphasis on the decline of Lake Urmia surface water extent from year 1999 to 2011*

3. Multi-sensor approach

Multi-sensor approach provides the opportunity to monitor the hydrological cycle over Lake Urmia

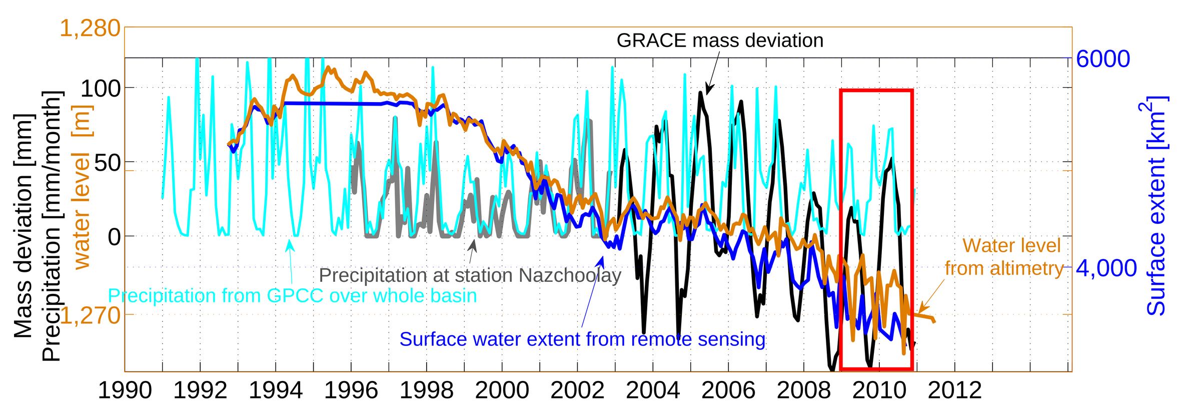

Figure 5: *All in one: Time series of mass deviation from GRACE, precipitation from GPCC, precipitation of Nazchoolay station, surface water extent from remote sensing approach and water level from satellite altimetry*

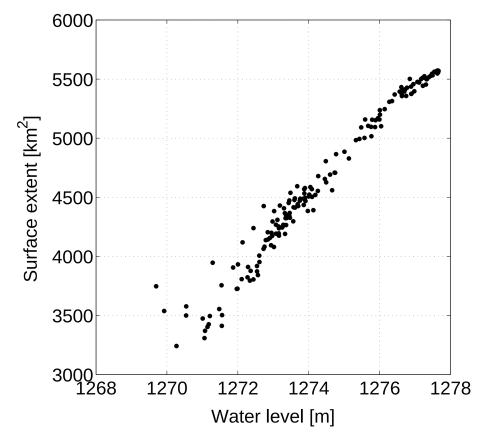

Figure 6: *Relationship between water level from satellite altimetry and surface water extent from MODIS imagery*

4. Methodology

From the hydrological water balance, the following model can be inferred:

$$\frac{dM}{dt} \times a = \Delta H \times a_{\mathrm{L}} + (P - ET_{\mathrm{a}}) \times (a - a_{\mathrm{L}}) \qquad (1)$$

where $\frac{dM}{dt}$ is the monthly rate of mass change from GRACE, a is the catchment area, a_{L} is the lake's water extent, ΔH is the lake level height variation in a month and $P - ET_{\mathrm{a}}$ is the recharge including precipitation P minus actual evapotranspiration ET_{a}.

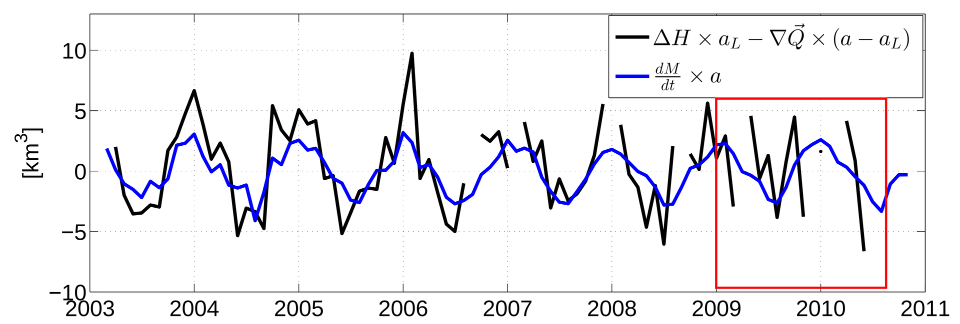

Figure 7: *Comparison between the left and right hand side of above model (1), here $\nabla \cdot \vec{Q}$ is used for recharge*

Table 1: *Statistical comparison between the left and right hand side of model*

Time period	Correlation [ ]	σ of diff. $[\mathrm{km}^3]$
2003–2008	0.79	2.3
2003–2010	0.65	2.7

4.1 Assimilation and Kalman filtering

$$X(t) = \begin{bmatrix} (P - ET_{\mathrm{a}})(t) \\ \delta ET_{\mathrm{a}}(t) \end{bmatrix} \qquad (2)$$

where $\delta ET_{\mathrm{a}} = ET_{\mathrm{a}} - \overline{ET_{\mathrm{a}}}$. $\overline{ET_{\mathrm{a}}}$ is the monthly mean of actual evapotranspiration

The stochastic process model can be formed as:

$$X(t) = AX(t-1) + e, \qquad (3)$$

where,

$$A = \Sigma_{\Delta}\Sigma^{-1} \qquad (4)$$

and

$$C\{e\} = \Sigma - \Sigma_{\Delta}\Sigma^{-1}\Sigma_{\Delta}^{T} \ . \qquad (5)$$

The observation equation:

$$\begin{bmatrix} l_1 \\ l_2 \\ l_3 \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 1 & 1 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} (P - ET_{\mathrm{a}})(t) \\ \delta ET_{\mathrm{a}}(t) \end{bmatrix} + \epsilon \qquad (6)$$

$\epsilon \sim \mathcal{N}(0, Qx)$ where

$$l_1 = P - ET_{\mathrm{a}} = \frac{\frac{dM}{dt} \times a - \Delta H \times a_{\mathrm{L}}}{a - a_{\mathrm{L}}} \qquad (7)$$

$$l_2 = P + \overline{ET_{\mathrm{a}}} \qquad (8)$$

$$l_3 = P - ET_{\mathrm{a}} = -\nabla \cdot \vec{Q} \qquad (9)$$

The dynamic system comprising above process model and observation equation is solved by Kalman filtering.

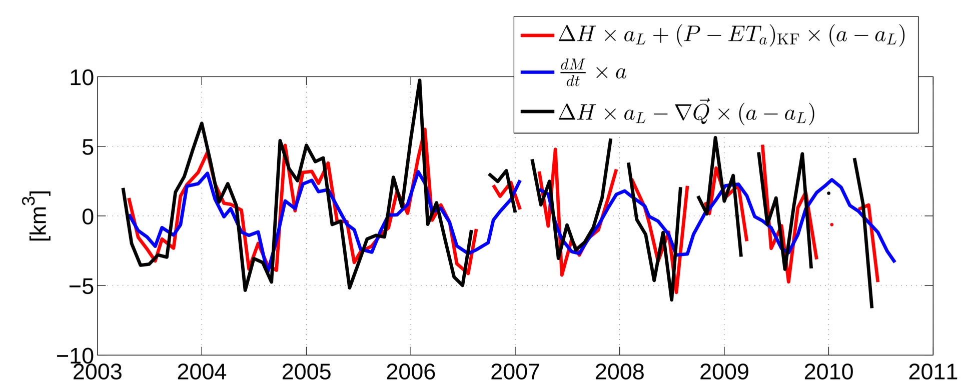

Figure 8: *Comparison between the left and right hand side of model when estimated recharge from Kalman filter approach is used*

Table 2: *Statistical comparison between the left and right hand side of model when recharge from Kalman filter estimation is ussed*

Time period	Correlation [ ]	σ of diff. $[\mathrm{km}^3]$
2003–2008	0.81	1.6
2003–2010	0.69	1.9

5. Conclusion

Given the obtained results in this study, spaceborne geodetic sensors and optical satellite imagery designed for altogether different purposes, can be introduced as valuable tools for monitoring the hydrological behaviour and desiccation of Lake Urmia. Kalman filter estimation allows us to assimilate the observations from different sensors with their respective error budget.

References

[1] Crétaux, J.-F., Jelinski, W., Calmant, S., Kouraev, A., Vuglinski, V., Bergé-Nguyen, M., Gennero, M., Nino, F., Rio, R. A. D., Cazenave, A., and Maisongrande, P.: SOLS: A lake database to monitor in the Near Real Time water level and storage variations from remote sensing data, Advances in Space Research, 47, 1497–1507, 2011.

[2] Moritz, H.: Advanced physical geodesy, Wichmann, 1989.

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