Monitoring Temperature changes in a Hypersaline Lake using MODIS-derived water temperatures (the case of Urmia Lake, Iran)

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ABSTRACT: Lake surface temperature is an important indicator of the lake state and a driver of regional weather and climate near large lakes. The objective of this study is to use thermal imagery from the MODIS on board the Earth Observing System Terra and Aqua platforms to assess the spatial and temporal variations in Urmia lake temperature. Urmia Lake, located in northwestern Iran is one of the largest permanent hypersaline lakes in the world. The surface temperature of Urmia Lake is examined between 2008 and 2009, as dry years. MODIS-derived lake SWT then was calibrated with monthly observations. MODIS-derived lake SWT exhibits a cool bias (–0.72°C) relative to in situ temperature observations in 2009.According to the results the diurnal SWT range is as large as 8°C while the annual cycle of UL SWT ranges from -3.2 °C in January to 26.6 °C in July 2008 and from 1.8 °C in January to 26.9 °C in July 2009.
Keywords: MODIS, Land-surface temperature, Hypersaline lakes, Urmia Lake.

1. Introduction

Lake surface temperature is an important indicator of the lake state and a driver of regional weather and climate near large lakes (Austin &Colman, 2007). In large lakes, spatial pattern of the temperature is of high importance since the metrological conditions over the lake may differ. Moreover, in shallow lakes vertical water temperature gradient is neglectible. So, knowing the water surface temperature the energy balance model of the lake can be developed. This in turn, leads to an accurate estimation of evaporation over lake which is a significant factor in the lake’s water balance. On the operational side, the study of temperature and evaporation from saline solutions is important for designing, constructing and operating saline and hypersaline shallow lakes for mineral extraction and energy production (Oroud, 1994). Satellite imagery has been used to understand spatial and temporal variation of SWT of lakes like Great Lakes (Plattner et al., 2006), Great Slave and Great Bear Lakes (Bussieres & Schertzer, 2003), Lake Tahoe (Hook et al., 2003), Lake Baikal (Mogilev & Gnatovsky, 2003), Wisconsin lakes (Becker & Daw, 2005), Salton Sea (Cardona et al., 2008), and the hypersaline Lake Eyre in Australia (Barton & Takashima, 1986). Several studies applied MODIS imagery to document lakes’ surface temperature including Swedish lakes (Reinart & Reinhold, 2008) and Great Salt lake (Crosman & Horel, 2009).

2.Study Area

Urmia Lake(UL), located in a closed basin in north-west Iran, is one of the largest (4750–6000 km^2) permanent hypersaline lakes in the world. The average depth of the lake is roughly 2.5 m (Fig.1a). Lake water is supplied from eighteen main rivers, mostly discharging to the south as well as direct precipitation. The average annual precipitation and evaporation over the lake is estimated about 1160 and 5700 MCM respectively. The lake is divided into north and south parts separated by a causeway, which has a gap that allows for a limited exchange of water between the two parts. Due to recent years of progressive dry climate, the water level has been dramatically dropped about 6m during the last 25 years. Simultaneously, the Lakes’ salinity has been increased considerably from 175g/L to 402g/L in a shoreline station. This level of salinity threatens the Lake’s unique wildlife, especially brine shrimp Artemia, with high economic value. Main factors which control the surface water temperature (SWT) of the UL at any particular time are water clarity, solar forcing, wind-driven mixing and lake. For example, Fig. 1b illustrates that the SWT can vary from one location to another by as much as 5°C.

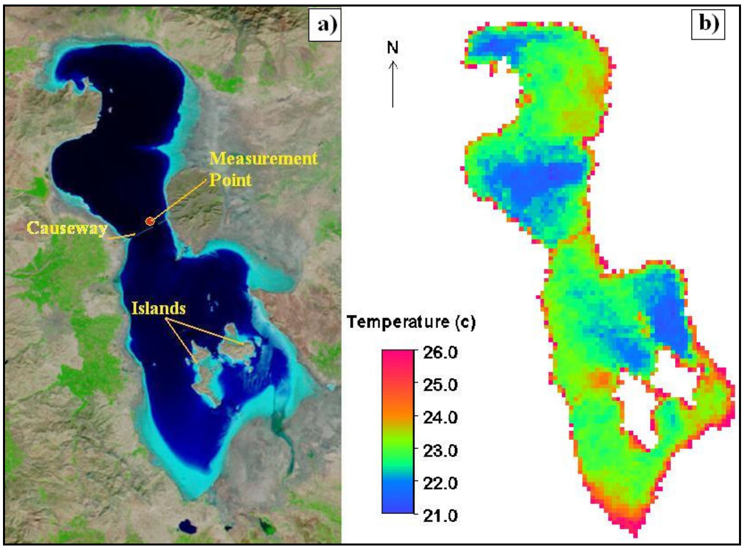

Figure 1. MODIS Aqua imagery of the UL from 12 September 2009 at 10:05 UTC: (a) color composite image (bands 7, 2,1) and (b) surface water temperature (SWT, °C) derived from bands 31 and 32.

In many large lakes permanently-deployed buoys are using for temperature monitoring. However, in UL there is no such equipment. Thus to gather in situ data for calibration, SWT has been measured in a fix point on the causeway since October 2009,twice a day at 12:00 and 14:00 local time.

3. Method

MODIS land-surface temperature (LST) level 2, 1-km nominal resolution data (MOD11L2, version 5) was obtained from the NASA Active Archive Center. MOD11L2 is produced from MODIS bands 31and 32 using a split-window algorithm designed for a wide variety of land cover types including inland water surfaces (Wan, 2006). Then using the HDF-EOS to GeoTIFF Conversion Tool (http://www.hdfeos.org/software/heg.php/) the MOD11L2 LST swath files were resampled to a 1×1 km grid. For pixels with lower than nominal (1-km) resolution, nearest neighbor interpolation was applied. Images potentially affected by significant cloud contamination were identified using visual inspection and then cloud-contaminated images were removed. Between all available clear-sky MODIS Terra and Aqua imagery, in the period of 2008-2009 one image in a week was used, resulting in a total of 43 and 67 clear-sky images for 2008 and 2009 respectively. An example of a daily cycle of Terra and Aqua clear sky images is given in Fig. 2a,b. Nominal local solar times of satellite overpasses over the UL are approximately 12:30 pm for Terra (Fig. 2a) and 14:20 pm for Aqua (Fig. 2b).Spatial variation larger than 5 °C are evident at this time of year in Fig. 2.

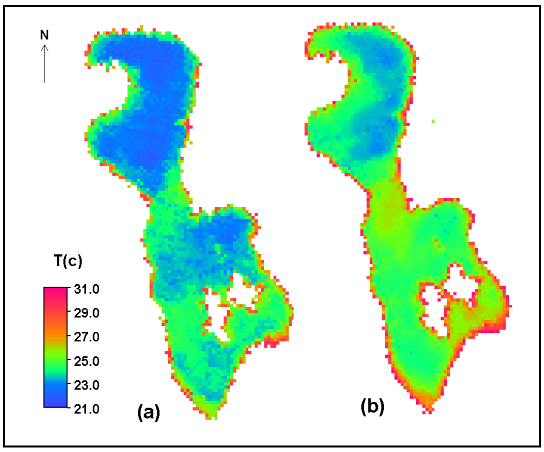

Figure 1. MODIS-derived surface water temperature, 13 August 2009 (a)Terra at 08:05 UTC (b)Aqua at 09:50 UTC.

4. Validation

4.1. Sources of error

There are limited studies on validation of MODIS-derived sea surface temperature and LST products over lakes (e.g.Hook et al., 2007; Wan et al., 2004). Possible sources of error are instrument noise and drift, sun glint, residual cloud contamination, misspecification of atmospheric attenuation and surface emissivity effects (Crosman & Horel, 2009). Different researches report a typical temperature difference from 0.10–0.50 °C between satellite derived and in situ water surface temperature. However, it can be up to several °C (Hook et al., 2003). This difference arises from two important components: the cool skin and the warm layer (Minnett, 2003).The first one refers to a systematic cool bias of the SWT at the air–water interface while the latter is associated with strong daytime warming (0.5–5.0 °C) of the top 5–50 cm of the water column in light winds (Merchant et al., 2008). Since the spatial and temporal variation of wind speed over the UL is unknown, combined effects of the cool skin and warm layer couldn't be considered in this study.

4.2. In situ temperature versus MODIS SWT

In situ temperature measurement was done at a depth of 0.5 m in a fix point in the Causeway twice a day (at 12:00 and 14:00 local time) during October-December 2009 located by a red circle in Fig. 1a.Then multiple in situ lake temperature samples were used for validation against each satellite pixel, resulting in 36 total match-ups. Only in situ measurements taken within 1 h of the satellite retrieval were used. The scatter plot of MODIS derived SWT versus in situ measurements in 2009 (Fig.3) has a cool bias (SWT_in situ) of −0.72 °C and a root mean squared difference (RMSD) between SWT and in situ observations of 0.99 °C. After calculating the cool bias from this validation, SWT of the year 2009 has been adjusted upward by 0.72 °C. Unfortunately, there was no in situ measurement to validate SWT of 2008. However, MODIS Derived SWTs are still valuable as they can be used to show the spatial and temporal pattern of the lake temperature.

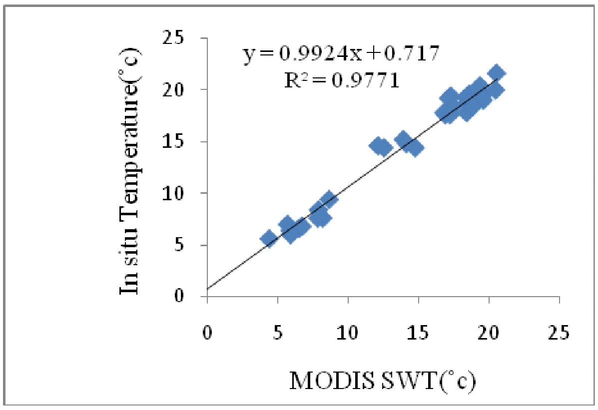

Figure 2. Scatter plots of MODIS Aqua and Terra SWT versus in situ measurements (°C) in Shahid Kalantary Causeway (October-December 2009)

5. Results and discussion

Monthly lake-mean MODIS SWT in 2008 and 2009 was computed using both Terra and Aqua imagery. Results are illustrated in Fig. 4,5 respectively. Unfortunately, there was no clear sky image in April 2008. Then the minimum, maximum, mean and standard deviation of the lake temperature in monthly mean images was calculated as shown in Table1. According to the results, monthly mean SWT in 2009 varies from -3.2 °C in January to 26.6 °C in July after the 0.72 °C bias correction (Fig 6). Moreover, maximum surface variation of the lake temperature has occurred in May while the minimum variation happens in November and January for the year of 2008 and 2009 respectively. Maximum variation of the surface temperature can be up to 8 ˚C which shows the importance of considering the spatial variation in the lake evaporation estimation in dry season. The monthly standard deviation of the lake temperature about the

mean value ranges from 0.4 °C in January to 1.9 °C in May 2009 (Table.1). The high spatial variability during May reflects the stronger seasonal warming evident from May through July.
According to the spatial pattern of the lake surface temperature, three different temperature zones can be recognized: the coast, north and south part of the lake. Clearly coastal zone of the lake has the highest temperature because of the lower water depth. Near the causeway and islands similar pattern is evident. As the lake is deeper in the north part, in dry seasons when the inflows to the south is near zero temperature is often lower in this part. However, wind effect can violate this conclusion by influencing flow circulation in the lake.

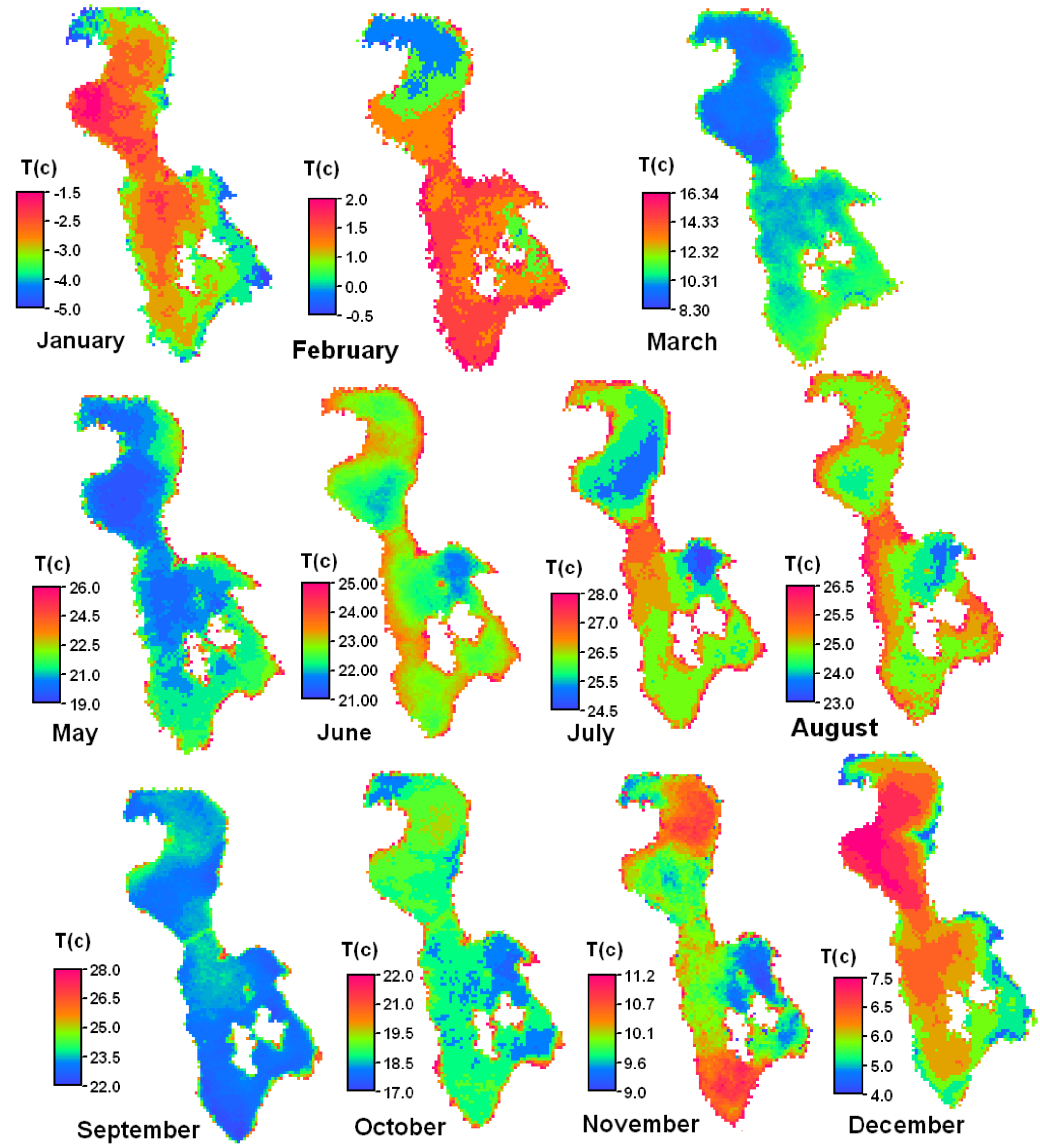

Figure 3. Temperature anomaly (SWT, °C) in median monthly SWT from MODIS Terra/Aqua 2008.

Table 1. Statistic of the mean monthly MODIS derived temperature of the UL in 2008 and 2009.

year	Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2008	Min	-5.5	-0.5	8.7	-	19.2	21.5	24.5	23.2	22.0	17.4	8.5	3.7
	Max	-0.9	3.3	15.2	-	27.3	26.1	29.7	28.1	27.5	23.1	11.5	7.5
	Mean	-3.2	1.1	11.6	-	22.8	23.4	26.6	25.3	24.3	19.9	10.1	5.7
	Std	1.2	0.9	1.7	-	2.2	1.1	1.3	1.2	1.4	1.5	0.8	1.1
2009	Min	0.8	4.6	8.5	15.6	18.4	21.9	24.1	22.5	21.0	17.2	10.8	2.7
	Max	2.7	9.4	13.7	20.5	27.1	29.5	30.6	28.9	25.5	20.9	14.5	8.3
	Mean	1.8	6.8	11.1	17.7	22.8	24.8	26.9	25.4	23.0	18.9	12.8	6.1
	Std	0.4	1.1	1.3	1.2	1.9	1.7	1.7	1.7	1.1	1.0	0.8	1.0

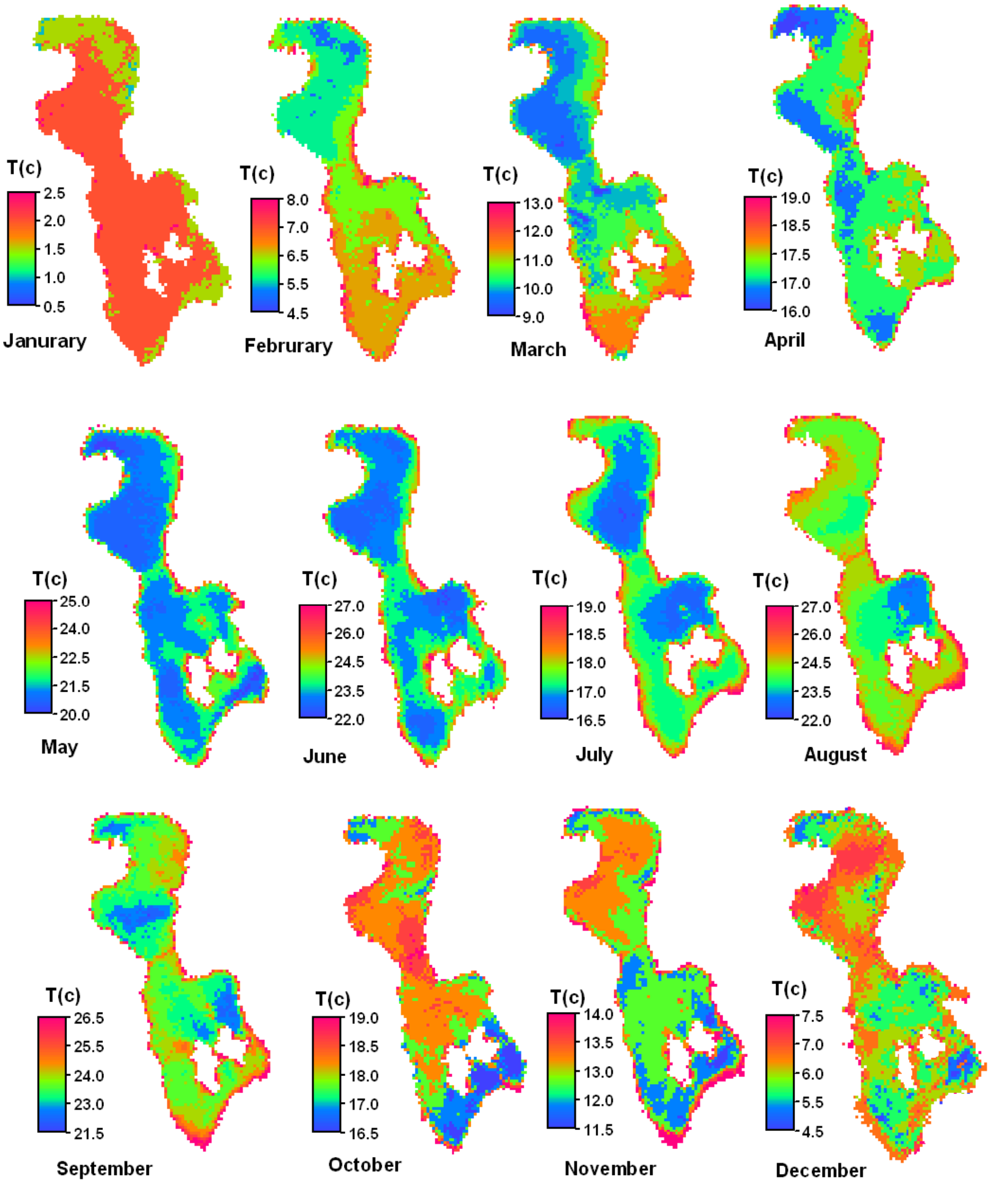

Figure 4.Mean monthly MODIS derived (bias-corrected) SWT of the UL during 2009.

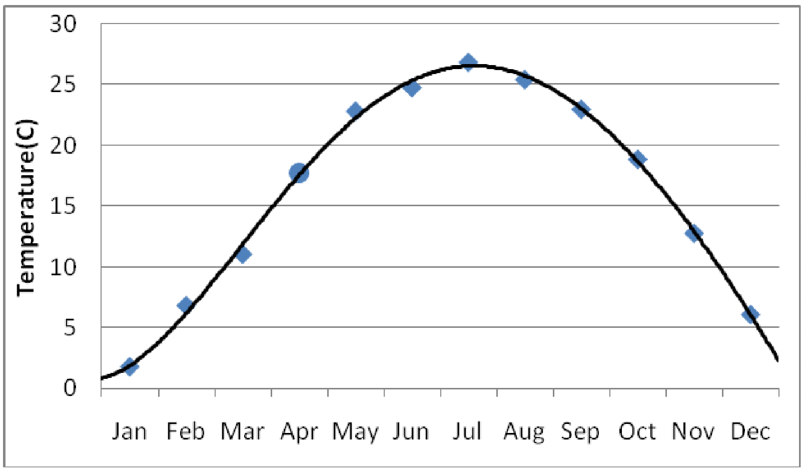

Figure 5. Monthly mean water surface temperature (MODIS Derived) variation of the UL in 2009.

6. Summary and conclusions

Temperature is a determining factor in closed lakes especially shallow lakes, as it controls many phenomena like evaporation, water quality and biological process. In large lakes, knowing the spatial pattern of the temperature as well as the temporal pattern is essential. However, as the long-term in situ measurements are rarely available for such great lakes, it is a difficult task. The utility of using MODIS level 2 LST products (MOD11) to monitor spatial, diurnal, seasonal and annual variations in the SWT of Urmia Lake has been investigated in the present study. In total 110 clear sky MODIS Terra and Aqua imagery were used in the period of 2008-2009.A cool bias (−0.72°C) was observed for MODIS-derived SWT relative to in situ observations during 2009. The annual cycle of UL SWT ranges from -3.2 °C in January to 26.6°C in July 2008 and from 1.8 °C in January to 26.9 °C in July 2009. Three temperature zones were distinguished from the mean monthly SWT maps: coastal, north and south parts. In the coastal zone, the temperature is higher due to the lower depth, while the north part of the lake which is the deepest part has lower temperature in the dry season when the inflows to the south is near zero.

7.References

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