Remote Sensing of Environment 113 (2009) 73–81

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

MODIS-derived surface temperature of the Great Salt Lake

Erik T. Crosman *, John D. Horel

Department of Meteorology, University of Utah, United States

ARTICLE INFO

Article history:
Received 26 March 2008
Received in revised form 30 June 2008
Accepted 18 August 2008

Keywords:
MODIS
Land-surface temperature
Validation
Large lakes
Thermal infrared
Lake-effect precipitation
Hypersaline lakes
Great Salt Lake

ABSTRACT

The surface temperature of Utah's hypersaline Great Salt Lake is examined between 2000 and 2007 using 3345 images from the Moderate Resolution Imaging Spectroradiometer (MODIS) on board the NASA Earth Observing System Terra and Aqua platforms. This study shows the utility of using a multi-year record of the easily accessible and fully processed MODIS thermal imagery to monitor spatial, diurnal, seasonal, and annual variations in the surface water temperature (SWT) of lakes where long-term in situ measurements are rarely available. A cloud-free Terra image is available on average every day during the summer and early fall, every other day during spring and late fall, and every third day during the winter. MODIS-derived lake SWT exhibits a cool bias (~−1.5 °C) relative to in situ temperature observations gathered from three buoys and a slowly-moving watercraft.

The dominant SWT signal is the annual cycle (with a range of 26 °C and peak temperature in mid-July) while the diurnal range is as large as 4 °C during the spring season. Year-to-year variations in SWT are largest during the fall with over 1 °C anomalously warm (cold) departures from the 8-year monthly medians observed during fall 2001 (2006). The MODIS imagery provides an updated SWT climatology for operational weather forecasting applications (e.g., lake-effect snow storm prediction) as well as for input into operational and research numerical weather prediction models.

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; Burnett et al., 2003). The temperature of Utah's Great Salt Lake (GSL) responds within weeks to regional atmospheric forcing and contributes to the development of lake-effect snowstorms and lake-breeze fronts that affect the populace of northern Utah (Knievel et al., 2007; Onton & Steenburgh, 2001; Rife et al., 2002; Steenburgh et al., 2000; Stewart et al., 2002; Zumpfe & Horel, 2007).

As shown in Fig. 1a, the GSL is a hypersaline, terminal lake surrounded by desert playa to the west and mountain ranges to the south and east. The average (maximum) depth of the Lake is roughly 4.8 (10) m. The average surface elevation (area) of the lake is 1280 m (4404 km^2) and has ranged from 1278 to 1284 m (2460 to 6200 km^2) since the mid-1850s. A railroad earthen causeway that is indicated in Fig. 1a by the white dashed line severely restricts water exchange between Gunnison and Gilbert Bays. Most freshwater inflow empties into Gilbert Bay, resulting in lower salinity (8–15% by mass) in that portion of the lake compared to Gunnison Bay (25–28% by mass).

Water clarity and stability, solar forcing, wind-driven mixing and lake bathymetry are some of the factors controlling the surface water temperature (SWT) of the GSL at any particular time. For example, Fig. 1b illustrates that the SWT can vary from one location to another by as much as 5 °C. Specific features evident in Fig. 1b are numbered as follows: (1) higher temperature arising in part from decreased water clarity in that region as evident by the higher reflectivity in Fig. 1a; (2) a shallow freshwater lens undergoing intense solar heating; (3) advection of warm water into a counterclockwise eddy; and (4) lower temperature arising from vertical mixing.

While many large lakes have permanently-deployed buoys to monitor lake temperature, the variable level and hypersalinity of the GSL has hampered installation of such equipment. Twice-monthly shoreline observations from Saltair Boat Harbor (SBH; see Fig. 1a) between 1972 and 1989 were used by Steenburgh et al. (2000) to create a lake temperature climatology (Fig. 2). Recent changes to the operational numerical weather prediction North American Mesoscale Model of the National Centers for Environmental Prediction included specifying GSL SWT from the Steenburgh et al. (2000) climatology (G. DiMego, 2007, personal communication).

The objectives of this study are to use thermal imagery from the Moderate Resolution Imaging Spectroradiometer (MODIS) on board the Earth Observing System Terra and Aqua platforms to assess and update the Steenburgh et al. (2000) climatology (Fig. 2) and to improve understanding of spatial and temporal variations in lake

* Corresponding author.
E-mail address: Erik.Crosman@utah.edu (E.T. Crosman).

0034-4257/$ – see front matter © 2008 Elsevier Inc. All rights reserved.
doi:10.1016/j.rse.2008.08.013

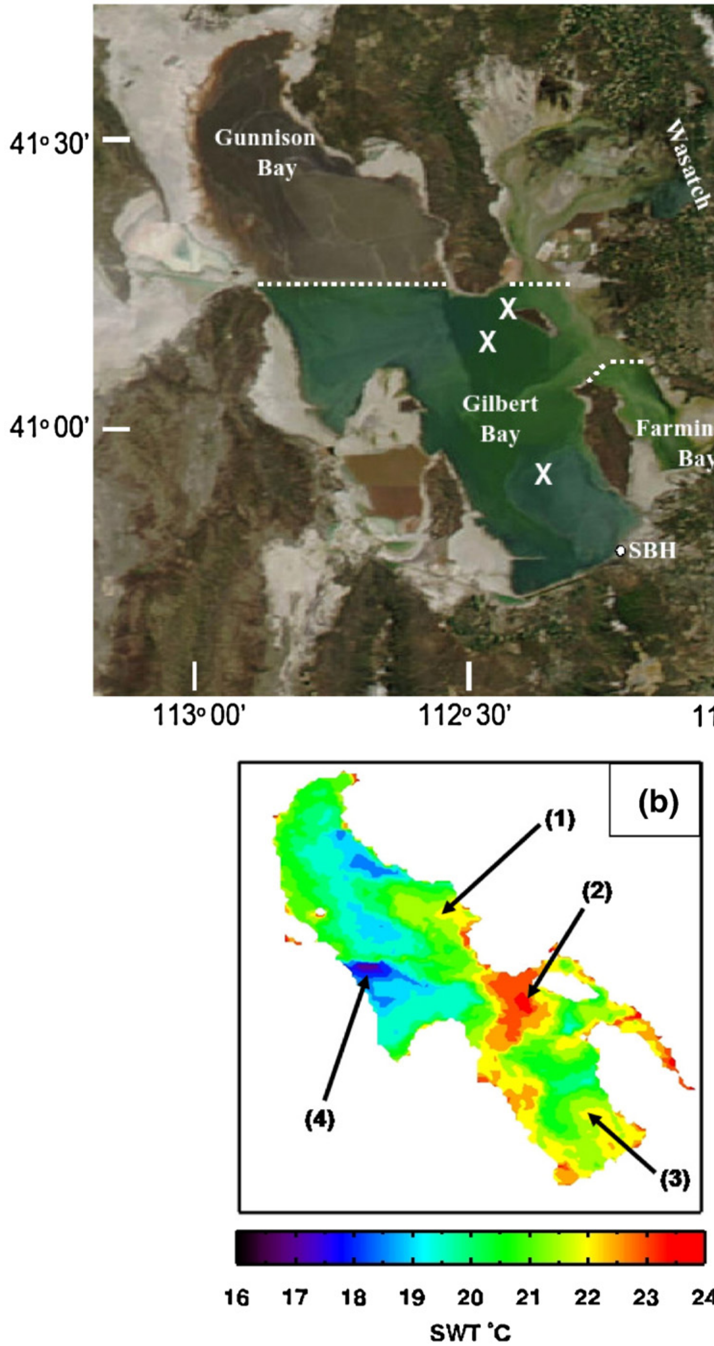

Fig. 1. MODIS Aqua imagery from 24 May 2005 at 2010 UTC: (a) true color (bands 1–4–3) and (b) bias-corrected surface water temperature (SWT, °C) derived from bands 31 and 32. Landmarks in (a) and numbered regions in (b) are explained in the text.

temperature, which affect a wide range of physical and biological processes that have considerable economic impact (Gwynn, 2002).

Many studies have used satellite imagery to document the SWT of lakes, including the Great Lakes (Li et al., 2001; Plattner et al., 2006), Great Slave and Great Bear Lakes (Bussieres & Schertzer, 2003), Lake Tahoe (Hook et al., 2003; Steissberg et al., 2005), Lake Baikal (Bolgrien et al., 1995; Mogilev & Gnatovsky, 2003), various high-elevation European lakes (Oesch et al., 2005), Wisconsin lakes (Becker & Daw, 2005), Salton Sea (Cardona et al., 2008), and the hypersaline Lake Eyre in Australia (Barton & Takashima, 1986). Reinart and Reinhold (2008) used MODIS thermal imagery to study Swedish lakes between 2001 and 2003. Our study is the first to our knowledge to use the MODIS period of record (2000–2007) to document the surface temperature of a lake on diurnal to interannual time scales.

2. MODIS imagery

MODIS land-surface temperature (LST) level 2, 1-km nominal resolution data (MOD11L2, version 4 and version 5) was obtained from the National Aeronautics and Space Administration Land Processes Distributed Active Archive Center (Wan, 2008). MOD11L2 is generated with MODIS bands 31 (11 µm) and 32 (12 µm) using a split-window algorithm designed for a wide variety of land cover types including inland water surfaces, satellite viewing angles, and atmospheric