International Journal of Applied Earth Observation and Geoinformation 30 (2014) 247–250

Contents lists available at ScienceDirect

International Journal of Applied Earth Observation and Geoinformation

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

Short communication

Retrieving water surface temperature from archive LANDSAT thermal infrared data: Application of the mono-channel atmospheric correction algorithm over two freshwater reservoirs

R.N. Simon[a,*], T. Tormos[a,c], P.-A. Danis[b,c]

[a] IRSTEA, UR MALY, ONEMA/IRSTEA Rivers Hydroecology Research Unit, Centre de Lyon-Villeurbanne, 5 rue de la Doua-CS 70077, F-69336 Villeurbanne Cedex 69100, France
[b] IRSTEA, UR HYAX, ONEMA/IRSTEA Lakes Hydroecology Research Unit, F-13182 Aix-en-Provence, France
[c] French National Agency for Water and Aquatic Environments (ONEMA), France

ARTICLE INFO

Article history:
Received 16 October 2013
Accepted 15 January 2014
Available online 22 February 2014

Keywords:
Waterbodies
Remote sensing
Thermal infrared
Water surface temperature
LANDSAT 7 ETM+
Atmospheric correction
Mono-channel algorithm

ABSTRACT

Water surface temperature is a key element in characterizing the thermodynamics of waterbodies, and for irregularly-shaped inland reservoirs, LANDSAT thermal infrared images are the best alternative yet for the retrieval of this parameter. However, images must be corrected mainly for atmospheric effects in order to be fully exploitable. The objective of this study is to validate the mono-channel correction algorithm for single-band thermal infrared LANDSAT data as put forward by Jiménez-Muñoz et al. (2009). Two freshwater reservoirs in continental France were selected as study sites, and best use was made of all accessible image and field data. Results obtained are satisfactory and in accordance with the literature: r^2 values are above 0.90 and root-mean-square error values are comprised between 1 and 2 °C. Moreover, paired Wilcoxon signed rank tests showed a highly significant difference between field and uncorrected image data, a very highly significant difference between uncorrected and corrected image data, and no significant difference between field and corrected image data. The mono-channel algorithm is hence recommended for correcting archive LANDSAT single-band thermal infrared data for inland waterbody monitoring and study.

1. Introduction

Water surface temperature is a key waterbody parameter as it characterizes the energy fluxes taking place within the water–atmosphere interface (Alcântara et al., 2010; Sima et al., 2013). Satellite remote sensing has long been presented as a cost-effective, synoptic manner in which to monitor and study this parameter (Schneider and Mauser, 1996; Thiemann and Schiller, 2003).

Thanks to their good spatial resolution, significant temporal archive and straightforward accessibility, LANDSAT thermal infrared images have been widely used to retrieve waterbody surface temperature (*e.g.* Giardino et al., 2001; Lamaro et al., 2013), despite limitations in radiometric, spectral and temporal resolutions (Dekker and Peters, 1993; Schneider and Mauser, 1996).

Undoubtedly useful spatiotemporal surface temperature data are embedded within the 30-year LANDSAT image archive. But thermal infrared (TIR) data must be corrected for emissivity and atmospheric effects if it is to be quantitatively useful (see Li et al., 2013). Emissivity variations for water-only pixels of relatively small and calm inland waterbodies, however, are insignificant in most practical applications. Atmospheric correction, on the other hand, is required to compensate for atmospheric absorption and emission effects. In the absence of surface temperature field data for every image, which would allow for the use of simple empirical correction algorithms based on statistical regression models (*e.g.* Karakaya et al., 2011), image-based or radiative transfer modeling correction methods are required (Kay et al., 2005). Image-based methods such as split-window algorithms require two or more TIR bands (Sobrino et al., 2004), but archive LANDSAT data contain only a single TIR band.

Two possibilities are available for correcting single-band TIR images. The first is through the use of the radiative transfer equation (RTE) (*e.g.* Hook et al., 2004), in which transmissivity of the atmosphere, upwelling atmospheric radiance and downwelling atmospheric radiance are obtained through the use of radiative transfer modeling codes. This method, however, requires *in situ* radiosounding data obtained near the study area and near the acquisition time of the image as input (Jiménez-Muñoz and Sobrino, 2003). The second possibility is to apply mono-channel

* Corresponding author. Tel.: +33 4 72 20 87 65.
E-mail address: ricardo.simon@irstea.fr (R.N. Simon).

0303-2434/$ – see front matter © 2014 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.jag.2014.01.005

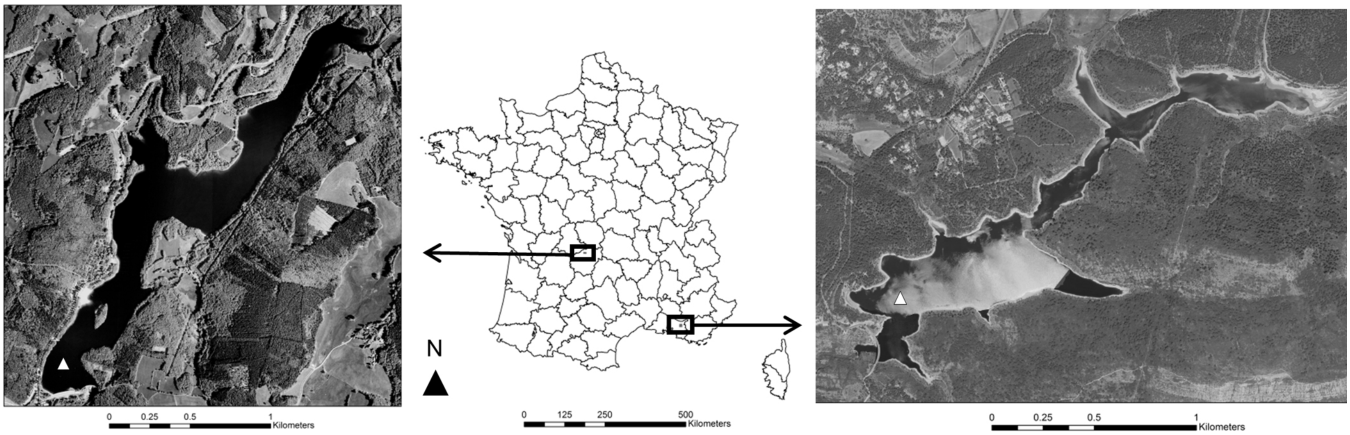

Fig. 1. Geographical location of the two study sites, Lake Bariousses (left) and Lake Bimont (right). White triangles represent the location of field temperature measurement points (Lake Bariousses: 45.556° latitude and 1.813° longitude; Lake Bimont: 43.543° latitude and 5.539° longitude).
Source of images: the French National Institute of Geography (IGN) BDOrtho®.

correction algorithms which are based on approximations of the RTE. Despite being less accurate, these algorithms crucially avoid dependence on *in situ* radiosounding data and are therefore better suited for satellite imagery archive studies (Sobrino et al., 2004). Jiménez-Muñoz and Sobrino (2003), in particular, have developed an operational algorithm which relies solely on atmospheric water vapor content as ancillary data.

The main objective of this study is hence to apply and validate the updated mono-channel algorithm as published in Jiménez-Muñoz et al. (2009). In order to do so, two artificial freshwater reservoirs in continental France, Lake Bimont and Lake Bariousses, were selected as study sites.

2. Study area

Lake Bimont (14 hm^3 in volume, 1.187 km^2 in area, 14.88 km in perimeter, 27 m average depth and 55 m maximum depth) is located near the city of Aix-en-Provence in southeastern France, while Lake Bariousses (7.48 hm^3 in volume, 0.857 km^2 in area, 8.7 km in perimeter, 7.4 m average depth and 22.5 m maximum depth) is located near the town of Treignac in the central-south part of the country (Fig. 1). Both are stream impoundments characterized by a warm monomictic thermal regime.

3. Materials

Table 1 provides the characteristics of the field and LANDSAT data used.

All field data were provided by the French Company of Electricity (EDF), the French National Office for Water and Aquatic Ecosystems (ONEMA) and the French National Research Institute of Science and Technology for Environment and Agriculture (IRSTEA). Field water surface temperature data were available for a single spatial point per reservoir per date (white triangles in Fig. 1). Vector files of metric precision of the two reservoirs were obtained from the BDTopo® database of the French National Geography Institute (IGN).

LANDSAT Climate Data Records (CDR) data, which consist of surface reflectance products from the LANDSAT archive (Masek et al., 2006), are freely available from the United States Geological Survey (USGS). TIR data is provided as top-of-atmosphere (TOA) brightness temperature images resampled *via* cubic convolution to a pixel size of 30 m. Useful mask layers for clouds, cloud shadows, adjacent clouds, snow, land and water, and quality flags are also provided.

Total column water vapor data solely of analysis origin and produced at 12:00 for the period spanning from June 2009 to May 2013 was downloaded from the ERA Interim dataset produced by the European Centre for Medium-Range Weather Forecasts (ECMWF) (Dee et al., 2011). Grid cell size was set to 0.25° by 0.25°.

4. Methods

Fig. 2 provides an overview of the preprocessing and processing chain in the form of a workflow. The chain was automated through Python® programming language and GIS software ArcGIS® version 10. Vector files and land-water mask layers were used to produce water-only images of each reservoir, and the remaining mask layers were applied to eliminate inappropriate pixels. Images were then visually inspected and those containing insufficient data (less than 20 or so valid pixels) were eliminated.

Processing of images consisted in applying the mono-channel algorithm as proposed by Jiménez-Muñoz and Sobrino (2003) and specifically adapted for LANDSAT by Jiménez-Muñoz et al. (2009). The algorithm is based on a linear approximation between the water surface temperature T_S and a temperature value T_O which is near to T_S, combined with the use of simulated atmospheric profile data and water vapor data to account for atmospheric transmissivity, upwelling atmospheric radiance and downwelling atmospheric radiance. All five atmospheric profile databases presented in the

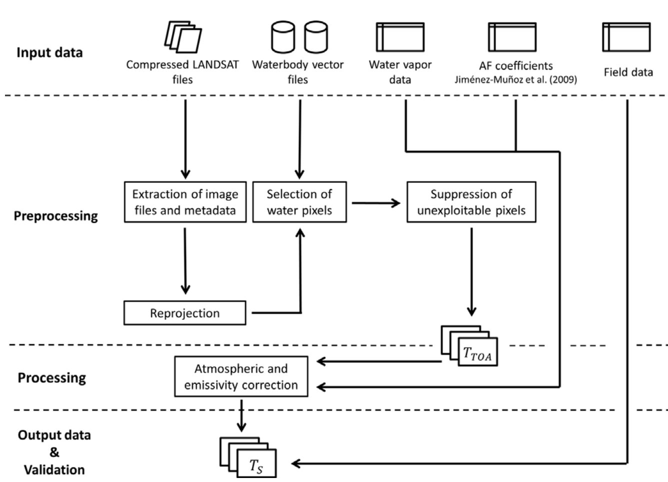

Fig. 2. Workflow of the image preprocessing and processing chain. Field data: *in situ* water surface temperature measurements. Unexploitable pixels are those affected by clouds, cloud shadows, adjacent clouds and quality flags. T_{TOA}: top-of-atmosphere brightness temperature. T_S: surface temperature.