Global Lake Surface Water Temperatures from ATSR

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1 Introduction

Lakes are a vital component of Earth's fresh water resources, and are of fundamental importance for terrestrial life. Lake water temperature is one of the key parameters determining ecological conditions within a lake and air-water heat and moisture exchanges. Lake surface water temperatures (LSWT) and lake ice cover (LIC) observations therefore have potential environmental and meteorological applications for inland water management and numerical weather prediction (NWP).

The European Space Agency (ESA) have established the ARC-Lake project (www.geos.ed.ac.uk/arclake) to adapt sea surface temperature (SST) techniques for cloud and ice detection and for surface temperature retrieval to the problem of lakes.

The ARC-Lake project considers "large" natural lakes (surface area > 500 km^2). A small number of additional lakes/reservoirs are included where they are of scientific interest and/or have validation data available or have been requested by the ARC-Lake User Group. The locations of these lakes are shown in Figure 1.

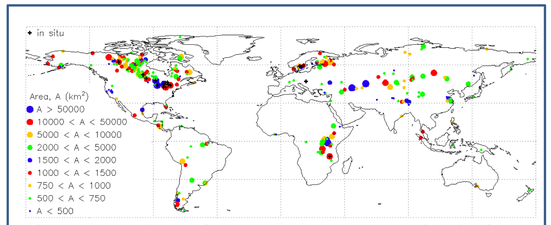

Figure 1. Location and area of 263 large target lakes in phase one of ARC-Lake. The location of lakes with sourced validation data are marked with + symbols.

2 Lake Mask

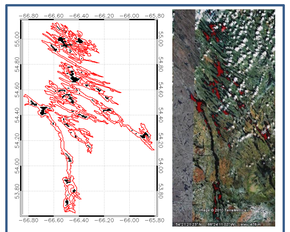

Figure 2. GLWD polygon for Astray Lake, Canada and resulting binary lake mask in Google Earth.

Attributing observations to individual lakes is not a trivial task. Lake-inflow, lake-outflow, lake-lake and/or lake-ocean boundaries need to be defined. Lakes may also have complex shapes, such as Astray Lake, Canada (Figure 2.). To overcome these issues, we defined a new lake mask based on existing land/water masks and individual lake polygons from the Global Lakes and Wetland Database (GLWD).

NAVOCEANO and Envisat masks were assessed a potential source. NAVOCEANO was selected as it offered higher levels of and accuracy of coverage. Figure 3. illustrates this for the example of Lake Abaya, Ethiopia, where the Envisat mask locates the lake to the east of its true location.

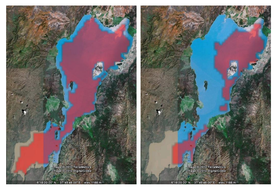

Figure 3. Envisat (left) and NAVOCEANO (right) masks for Lake Abaya, Ethiopia. Red overlay = correctly classed as water.

3 Cloud Detection and LSWT Retrieval

Cloud detection is a key element of LSWT retrieval, and inadequacies in detection give rise to significant uncertainties. In ARC-Lake we adopt a Bayesian approach informed by forward modelling, rather than a threshold based approach (e.g. SADIST).

Fig. 4. (a) and (b) illustrates the largely successful performance of this method, with all obviously cloudy areas flagged as cloud. Some clear-sky areas are incorrectly flagged as cloud. However, the rate of false positive detections is significantly less than with threshold based cloud screening.

ARC-Lake LSWT retrievals use optimal estimation (OE) methods. Again, this incorporates forward-modelling, for which RTTOV8.7 is used.

NWP data from ECMWF are used as the priors in the forward modelling, except for the LSWT field, due to inaccuracies in the NWP data for LSWT.

EOF-based methods are applied to the ARC-Lake observations to create a spatially complete prior LSWT field, demonstrated in Fig. 4. (c). Comparison with the subsequent night-time observations (Fig. 4. (d)) reveals these methods are able to accurately reconstruct the LSWT field.

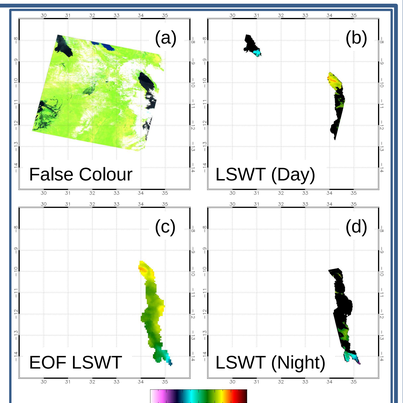

Figure 4. Example of cloud detection, LSWT retrieval and EOF-based reconstruction for Lake Nyasa. Black = pixels flagged as cloud.

5 Data Products

- V2.0 released in May 2012
- ATSR-1, ATSR-2 and AATSR (1991-2011)
- NetCDF
- Land/Water Mask
- Lake Database
- Simple analysis tools
- www.geos.ed.ac.uk/arclake

Attribute	Possible variants
Coverage	Per-lake / Global
Source	Observations / Reconstructions
Time	Day / Night
Spatial Resolution	0.05 degree grid / Lake-mean
Temporal Averaging	None / Climatology / Time-series
Temporal Averaging Period	Seasonal / Monthly / Twice-monthly / Daily

Table 2. Summary of data products available from ARC-Lake

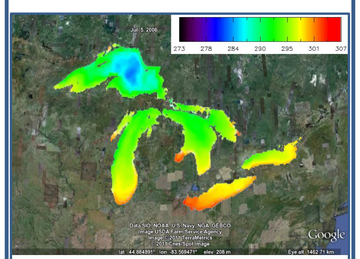

Figure 6. Example of twice-monthly spatially resolved LSWT product over the Great Lakes for 1st – 15th June 2006.

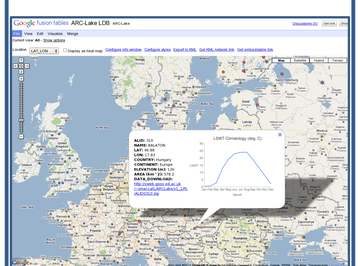

Figure 7. Graphical Lake Database search facility, showing basic information for Lake Balaton, Hungary.

4 Validation

OE LSWT retrievals are compared with *in situ* observations at 54 locations across 18 lakes (Fig. 1) and with the operational retrieval and cloud mask (SADIST). Some results of this validation study are shown in Fig. 5. and Table 1. Consistency in OE retrieval bias and uncertainty is observed across ATSR instruments and retrieval types (e.g. dual-view 3-channel and dual-view 2-channel).

Fig. 5	Retrieval / Cloud Mask	Day / Night	N	Mean	RSD
(a)	Operational / SADIST	Day	1694	-0.58	0.41
(b)	Operational / SADIST	Night	1652	-0.24	0.27
(c)	OE / Bayes	Day	2866	-0.33	0.41
(d)	OE / Bayes	Night	2739	-0.15	0.28

Table1. Validation statistics corresponding to Fig. 5.

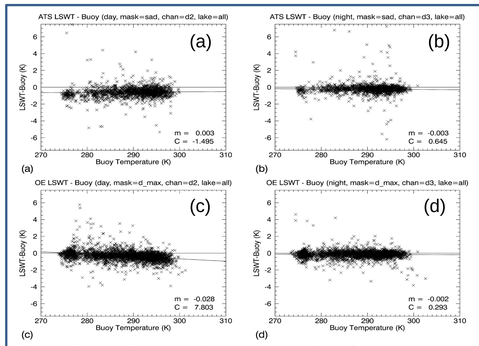

Figure 5. LSWT-Buoy differences against buoy temperature for (a) and (b) SADIST day and night, (c) and (d) ARC-Lake day and night, for AATSR.

6 Applications

- Basic lake climatological information
- Verification for lake physics models
- Driver for hydrological and ecological models
- Climate trend analysis
- Data for NWP re-analysis (not real time yet)

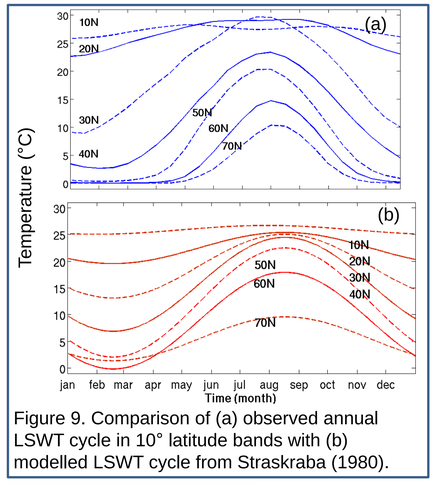

Figure 9. Comparison of (a) observed annual LSWT cycle in 10° latitude bands with (b) modelled LSWT cycle from Straskraba (1980).

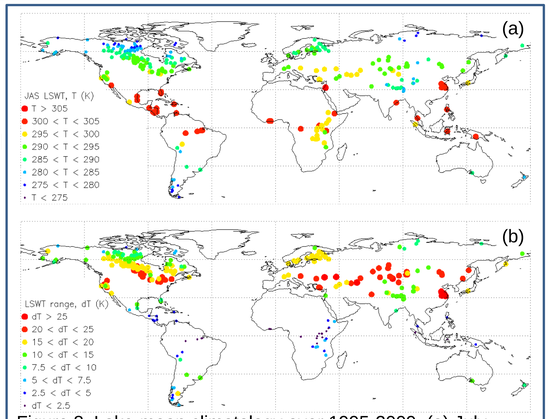

Figure 8. Lake-mean climatology over 1995-2009. (a) July-August-September LSWT. (b) Annual LSWT range.

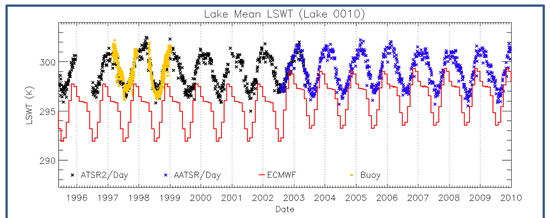

Figure 11. Comparison of ECMWF ST (red) with ARC-Lake LSWT (black and blue) and in situ observations (orange) for Lake Malawi.

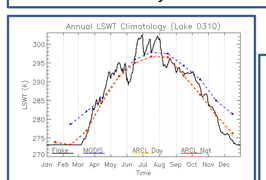

Figure 10. Comparison of annual mean LSWT from monthly ARC-Lake climatology with MODIS climatology and FLake simulations, for Lake Balaton.

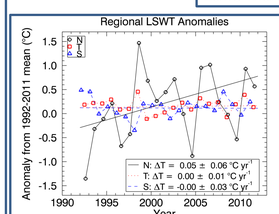

Figure 12. Time-series of seasonal LSWT anomalies from 1992 to 2011.

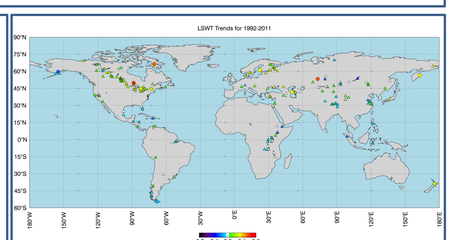

Figure 13. Global trends in LSWT from 1992-2011.

7 Further Work

ARC-Lake
- Extend to smaller lakes for ATSRs
- Time-dependent land/water mask

New NERC project - GloboLakes
- Providing LSWT component of ecological and physical lake observation system
- Application of ARC-Lake methods to operational instruments

Beyond
- Seek project to deliver LSWT operationally in Sentinel-3