Global Lake Surface Water Temperatures from ATSR

Stuart N MacCallum, Christopher J Merchant, and Aisling Layden

School of GeoSciences, The University of Edinburgh (s.maccallum@ed.ac.uk)

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) funded ARC-Lake project (www.geos.ed.ac.uk/arclake) adapts sea surface temperature (SST) techniques for cloud and ice detection and for surface temperature retrieval to the problem of lakes.

Initially, ARC-Lake considered 263 predominantly "large" natural lakes (surface area > 500 km^2). In phase-3 of ARC-Lake the techniques developed will be adapted and applied to smaller lakes (surface area < 100 km^2). The final list of target lakes is expected to be of order 1000 lakes, giving improved global coverage (Fig.1).

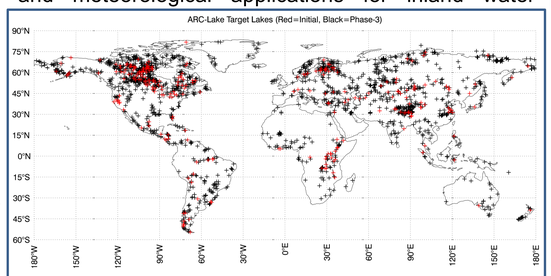

Figure 1. Locations of initial ARC-Lake target lakes (red) and additional potential targets for ARC-Lake phase-3 (black).

2 Lake Mask

Attributing observations to individual lakes is not trivial, requiring the definition of lake-inflow/outflow and lake-lake/ocean boundaries, and handling of complex shapes, such as Astray Lake, Canada (Figure 2.). To overcome these issues, we defined a new lake mask for the initial set of target lakes, based on an existing land/water mask and individual lake polygons from the Global Lakes and Wetland Database (GLWD).

This temporally static mask does not capture long term or seasonal changes in lake extent and in some cases does not provide an accurate representation of the lake area. Lakes with known highly variable extent were excluded from the initial targets.

A new lake mask, accounting for changes in lake extent, is under development in ARC-Lake. We use the visible channels of the ATSRs in a water detection algorithm (based on normalised difference tests) to derive a temporally varying lake mask. Fig. 3 shows improved representation of the Aral Sea and the Kara-Bogaz-Gol for 2008, relative to GLWD.

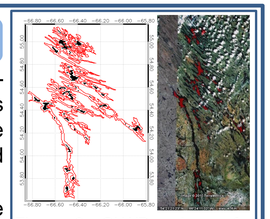

Figure 2. GLWD polygon for Astray Lake, Canada and resulting binary lake mask in Google Earth.

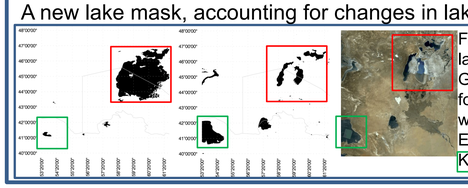

Figure 3. Comparison of lake masks. Left to right: GLWD, provisional mask for phase-3 based on water detection, Google Earth image. Aral Sea Kara-Bogaz-Gol

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.

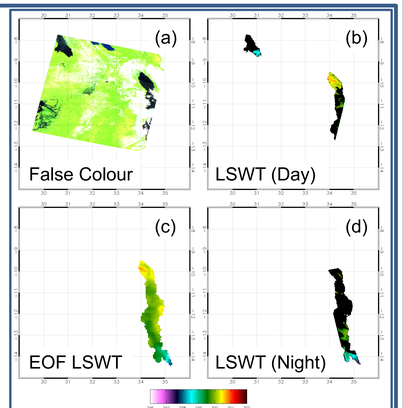

Figure 4. Example of cloud detection, LSWT retrieval and EOF-based reconstruction for Lake Nyasa. Black = pixels flagged as cloud.

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

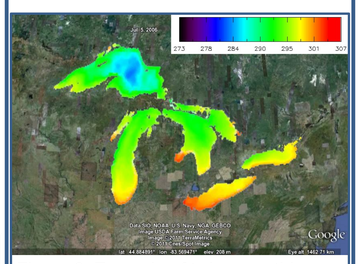

Figure 6. Example of twice-monthly spatially resolved LSWT product over the Great Lakes for 1st – 15th June 2006.

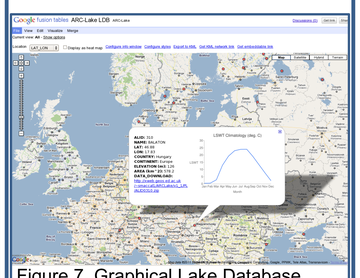

Figure 7. Graphical Lake Database search facility, showing basic information for Lake Balaton, Hungary.

4 Validation

OE LSWT retrievals are compared with *in situ* observations at 54 locations across 18 lakes 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.

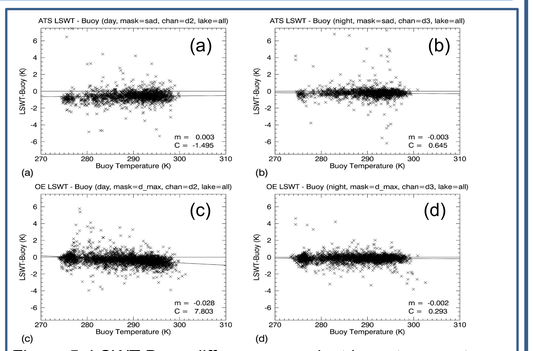

Figure 5. LSWT-Buoy differences against buoy temperature for (a) and (b) SADIST day and night, (c) and (d) ARC-Lake day and night, for AATSR.

6 Lake Model Tuning

Tuning of the *FLake* model with ARC-Lake data using an optimum combination of only 3 model parameters; depth, albedo and light extinction coefficients, substantially improves the LSWT output of ~245 lakes (Fig. 8). Table 3 summarises the pre and post–tuning metrics of trial lakes, resulting in an overall improvement of ~75% in the temperature bias and spread of errors.

Seasonally ice covered trial lakes (21)	Pre-tuning	Post-tuning	Non-seasonally covered trial lakes (14)	Pre-tuning	Post-tuning
Mean Absolute Difference (°C)	3.07 ± 2.25	0.84 ± 0.51	Mean Absolute Difference (°C)	3.55 ± 3.20	0.96 ± 0.63
Mean JAS bias (°C)	+3.71 ± 3.51	-0.12 ± 1.09	Max. monthly bias (°C)	+1.92 ± 5.05	-0.44 ± 1.52
Ice-on bias (days)	12.0 ± 39.6	-1.6 ± 12.8	Min. monthly bias (°C)	+3.71 ± 4.33	-0.03 ± 1.48
Ice-off bias (days)	-27.1 ± 29.7	-0.2 ± 10.7			

Table 3. Pre and post *FLake* model tuning metrics

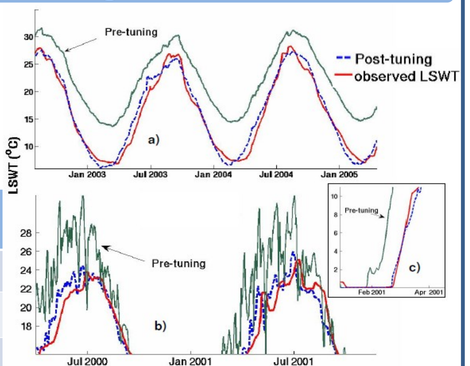

Figure 8. Pre and Post tuning vs observed LSWT for a) Lake Biwa (36 ºN) and b) Lake Balaton (47 ºN) and c) insert of ice-on for Lake Balaton

7 Other Applications

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

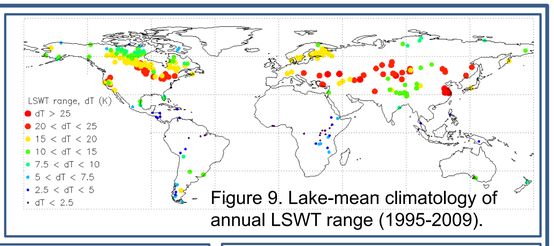

Figure 9. Lake-mean climatology of annual LSWT range (1995-2009).

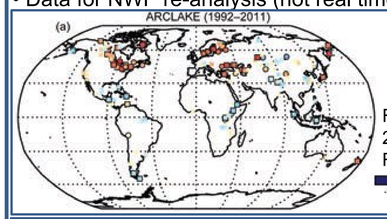

Figure 10. LSWT trends for 1992-2011 (BAMS State of the Climate Report, 2011).

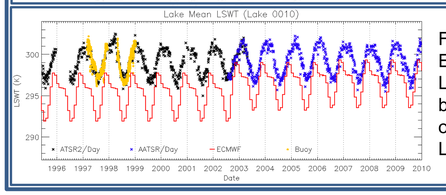

Figure 11. Comparison of ECMWF ST (red) with ARC-Lake LSWT (black and blue) and in situ observations (orange) for Lake Malawi.

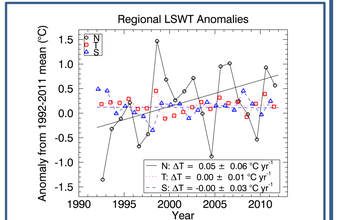

Figure 12. Time-series of seasonal LSWT anomalies (1992-2011). T = Tropics, N/S = N/S latitudes.

8 Ongoing and Future 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