A NEW RESOURCE FOR GLOBAL LAKE SURFACE WATER TEMPERATURE AND LAKE ICE-COVER DATA

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ABSTRACT
Optimal estimation (OE) and probabilistic cloud screening have been developed to provide lake surface water temperature (LSWT) estimates from the series of (Advanced) Along Track Scanning Radiometers (ATSRs). Variations in physical properties such as elevation, salinity, and atmospheric conditions are accounted for through the forward modelling of observed radiances. Therefore, the OE retrieval scheme developed is generic – i.e., applicable to all lakes. LSWTs have been obtained for 258 of Earth’s largest lakes from ATSR-2 and AATSR imagery from 1995 to 2009. Comparison to in situ observations from several lakes yields satellite-in situ differences of 0.3 ± 0.9 K for day-time and -0.3 ± 0.8 K for night-time observations (mean ± standard deviation). This compares to 0.6 ± 1.1 K for day-time and -0.2 ± 1.0 K for night-time observations for previous methods based on operational sea surface temperature algorithms. The new approach also increases coverage (reducing misclassification of clear-sky as cloud) and exhibits greater consistency between retrievals using different channel/view combinations. Empirical orthogonal function (EOF) techniques have been applied to the LSWT retrievals (which contain gaps due to cloud cover) to reconstruct spatially and temporally complete time series of LSWT. Visible reflectance channels are used to provide day-time observations of lake ice cover (LIC). Preliminary assessment of the LIC observations, through comparison with ice chart data, yields positive agreement for over 75% of cases assessed. The new LSWT observations, EOF-based reconstructions, and LIC observations offer benefits to numerical weather prediction (NWP), lake model validation, and improve our knowledge of the climatology of lakes globally.

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, as it influences both chemical and biological processes. In addition to the impact on lake ecology, lake water temperatures determine air-water heat and moisture exchanges, and are therefore vital for understanding the hydrological cycle. Lake surface water temperatures (LSWT) and lake ice cover (LIC) observations therefore have potential environmental and meteorological applications for inland water management, lake modelling and numerical weather prediction.

The series of Along Track Scanning Radiometers (ATSRs) are visible and infra-red imagers that provide excellent radiometric qualities (two-point on-board thermal calibration and low detector noise) and dual-view scanning capability. Because of this, the ATSRs have previously been exploited for sea surface temperature observations in the ATSR Reprocessing for Climate (ARC) project (i) with very accurate results (ii). The limitation of the ATSRs is the narrow swath, leading to relatively infrequent sampling (~3 day repeat cycle).

LSWT retrieval is a distinct problem from SST or land surface temperature (LST) estimation in many ways, yet previous studies have applied or adapted SST or LST schemes to LSWT retrieval, using a number of different instruments: (A)ATSR (iii), MODIS (iv, v), AVHRR (vi), Landsat (vii), ASTER (viii), and SEVIRI (ix).
The European Space Agency (ESA) have established the ARC-Lake project (www.geos.ed.ac.uk/arclake) to adapt SST techniques for cloud and ice detection and for surface temperature retrieval to the problem of lakes. In the ARC-Lake project, the specific challenges of LSWT retrievals (including lake-boundary definition, and variations in lake elevation and salinity) are addressed systematically for large lakes worldwide. This paper describes the LSWT and LIC retrieval methods developed and presents results from validation studies. The data products available from ARC-Lake and some potential science applications of the LSWT data are also discussed.

METHODS

The methodology of this study (1) can be broken down into five components: lake definition, LSWT retrieval algorithms, LSWT validation techniques, ice detection and validation, and data product generation. An outline of each of these components is given in the following sections.

Lake Definition

This study considers the world’s “large” natural lakes, conventionally taken to be those in excess of 500 km² in surface area (11, 12). In addition, some lakes slightly smaller have been included because they are of scientific interest and/or have validation data available. Three reservoirs have also been included at the request of a member of the ARC-Lake User Group (Environment Canada).

Fig. 1 shows the locations of the 263 lakes considered in this study and their size distribution. The distribution can be interpreted as a joint consequence of hydrological factors (availability of surface water) and geological factors (glaciation, rifting, etc). Lakes where in situ observations are freely available are also marked in Fig. 1. The number of such lakes is small and their geographic coverage limited. However, in situ observation campaigns have been identified for additional lakes and efforts to obtain further in situ data are ongoing.

![Figure 1](image-url)

Figure 1. Location and area of 263 large target lakes considered in this study. Lakes where in situ observations are available to the study are marked with the + symbol.

Following the identification of the target lakes (the full list of which is available at www.geos.ed.ac.uk/arclake) a lake mask was developed, to enable satellite observations at a given location to be correctly attributed to an individual lake. This is a non-trivial problem due to complexities in lake shape and ambiguities in defining boundaries with inflows and lakes with connecting filaments of water.

A lake mask was derived through consolidation of the NAVOCEANO gridded land/water mask (from https://www.ghrsst.org/data/ghrsst-data-tools/ghrsst-land-sea-mask/) and level-1 polygons from the Global Lakes and Wetlands Database, GLWD (13). The resulting lake mask contains unique lake IDs (from the GLWD) on the 1° x 1° NAVOCEANO grid. It is hierarchically...
structured and is available from www.geos.ed.ac.uk/arclake.

The use of the GLWD polygons to provide unique lake IDs enables lakes with highly complex shapes to be represented, as demonstrated in Fig. 2. Here the mask is able to correctly associate multiple separate groups of water cells as belonging to the same lake, Lake Astray, Canada.

![Lake Astray (Canada) in the consolidated NAVOCEANO/GLWD land/water mask. White: land cells in mask. Black: water cells in mask. Red: polygon from GLWD. White cells within the red polygon contain both water and land, so are masked as land.](image)

Retrieval Algorithms

LSWT retrievals are performed using combinations of the three infra-red channels available on the ATSTs: 3.7, 10.8, and 12 µm. The ATSR infra-red radiometer is calibrated to high accuracy, achieved through: (a) on-board calibration using two reference targets, (b) a Stirling-cycle cooler (xii), and (c) a dual-view geometry that enables robust atmospheric correction (xiv). Global coverage is provided every three days in the tropics, with more frequent observation possible at higher latitudes. All ATSRs have flown on platforms with stable late-morning orbits, yielding consistent overlap periods to support their application to global climate monitoring. Spatial resolution is ~1 km at the nadir, and restricts the size of lake surface features (and indeed the minimum size of lakes) that can be observed. However, this is still fine enough to enable some spatial variations in temperature to be resolved, particularly in the larger lakes.

The LSWT retrieval algorithm consists of a cloud detection and temperature retrieval component, both of which depend upon forward modelling of clear-sky infra-red observations of the ATSRs. The radiative transfer model used is RTTOV8.7 (xv), driven by the nearest numerical prediction (NWP) profile for the state of the atmosphere from the European Centre for Medium Range Weather Forecasting (ECMWF).

A major motivation for this study is the relatively inadequate observational information available to NWP systems on lake water temperature, which is becoming more important as lake dynamics are increasingly included in land-atmosphere interactions schemes. A corollary of this is that NWP is not a good source of surface temperature for forward modelling of the infra-red satellite observations. Following initialisation using a combination of monthly climatology from MODIS observations (xvi) and lake-mean temperature climatology simulations from the lake model FLake (xvii), empirical orthogonal function (EOF) techniques (xviii) are used to reconstruct a spatially complete time-series of LSWT from the sparse ATSR observations. An iteratively updated version of this is used as the
source of prior LSWT in the forward modelling.

Brightness temperatures (BTs) seen for lakes by imagers such as the ATSRs are generally less than the true surface temperature. This deficit (known as the “atmospheric correction”) is caused by net absorption of IR radiance by the atmosphere (partially dependent on the total column water vapour) and by the surface emissivity being less than unity. The BT-LSWT relationships therefore depend on the altitude (affecting atmospheric impact) and salinity (affecting emissivity) of the lakes, both of which are highly variable across the target lakes. These variables are captured in the RTTOV8.7 forward model, providing strong motivation for employing forward modelling-based cloud detection and LSWT retrieval.

Inadequacies in cloud detection are linked to significant uncertainties. Typical threshold based cloud detection schemes for SST distinguish clear and cloudy skies through predefined tests on ranges for BTs and inter-channel BT differences. These threshold tests should ideally be dependent on parameters such as surface temperature, atmospheric profiles and satellite zenith angle. Pre-specifying thresholds that are successful across a wide set of circumstances is challenging, particularly so for lakes, where the range of circumstances is greater than for ocean surfaces (because of the range of elevations and the differences between maritime and continental air masses). Spatial coherence information is also used to distinguish clouds and water, and similar comments apply to determining these thresholds also.

Applying cloud detection for SST to lake bodies gives a useful result in some cases – particularly for the largest lakes with altitudes near sea level. It also helps if they are saline and are at a temperature no too different from SSTs for their latitude. Thus, SST schemes often give sensible results for the Great Lakes, Caspian Sea, etc, at least for some seasons. However, more modest lakes can display greater spatial variability than is typical for the ocean, because of the effects of depth variations and thermal barring. This can trip tests for spatial coherence, leading to false detection of cloud. The BT-LSWT relationships are also changed by high elevation (less intervening atmosphere to affect IR radiance) and by continentality of air-mass. This can lead to false detection, and also failure to detect. Failures to detect cloud can cause large errors in retrieved LSWT.

For cloud detection in this study, we use a Bayesian approach informed by the forward modelling discussed above. This compares the expected (modelled) and observed BTs, and calculates in the context of various relevant uncertainties the probability the observation being clear-sky. The only threshold in the scheme is the threshold in the probability of clear sky above which LSWT retrievals are made.

Although the Bayesian approach adapts to the atmospheric conditions automatically (to the degree these are represented in NWP), the spatial coherence statistics currently used are still those developed for ARC SST (').

Earlier work established that LSWT retrieval using standard ATSR SST retrieval coefficients is prone, for some lakes, to retrieval biases of 0.5 K. (By retrieval bias, we mean the systematic offset between satellite and true LSWT that arises from imperfection in the retrieval algorithm. Occasional “biases” from failures in cloud detection can be larger.) This contrasts with a level of SST retrieval bias for ATSR that is generally <0.2 K. One solution could be to specify lake-specific retrieval coefficients. But this is not really a scalable solution as we look forward to later phases of the project, where more lakes will be tackled.

The Lake ST retrieval is therefore done by optimal estimation (OE). We use a simplified formulation of the inverse problem originally developed for SST observations from the Advanced Very High Resolution Radiometer (AVHRR) (x). This formulation includes only LSWT and total column water vapour as retrieved (state) variables (although full profile forward modelling is of course used). No radiance bias correction is yet derived for ATSR BTs, so the RTTOV8.7-simulated BTs are used "as is".
Validation Techniques

*In situ* observations from moored buoys located in 16 of the target lakes are used as reference temperatures for validation of the LSWT retrievals. Within this set of 16 lakes there are 52 observation sites. This dataset of *in situ* observations comprises those data that are freely available and is relatively limited in terms of number of lakes and geographic coverage (most of the available validation data are from the Great Lakes). The locations of the 16 lakes with available *in situ* data are shown in Figure 1.

Most sites provide hourly observations over time periods of years; however in some cases observations are only daily and/or more short lived or sporadic in their temporal coverage. At sites where the lake is frozen for considerable lengths of time, *in situ* observations are unavailable during the frozen period.

Clear-sky LSWT retrievals are averaged over a 5x5 pixel box, equivalent to the resolution of the ARC-Lake data products, centred on the buoy location. Matching against in situ observations is performed spatially (within 1 km) and temporally (within 3 hours). In total there are ~15500 match-ups for ATSR-2 and ~17500 for AATSR.

Retrieved OE LSWTs are validated against the *in situ* observations and also compared to equivalent validation of LSWTs from the operational ATSR cloud screening and retrieval scheme (designed principally for SST and labelled “ATS”). Assessment has been carried out for retrievals using the various standard channel combinations for both day and night time observations. Results for day time D2 (dual view, 11 µm and 12 µm channels) and night time D3 (dual view, 3.7 µm, 11 µm and 12 µm channels), using the Bayesian maximum channel-set cloud screening, are presented for AATSR in the Results section.

Ice Detection

The ARC-Lake project also provides observations of lake ice cover (LIC). This is based on the Normalized Snow Difference Index (NSDI) (xxiv) and is limited to daytime observations (as it uses visible reflectance channels). Preliminary assessment of the LIC product has been carried out through qualitative analysis of case study imagery and quantitative comparison with ice charts from the NOAA Great Lakes Ice Atlas (xxv) and the National Ice Center (www.natice.noaa.gov). Ice chart data are averaged to the $\frac{1}{20}^\circ \times \frac{1}{20}^\circ$ grid on which the ARC-Lake LIC product is output, and the fractional ice cover in each grid cell compared across the winter period. As for temperature observations, the availability of *in situ* ice cover observations is also limited to a small number of lakes and only cover the Great Lakes. Results of this preliminary validation exercise are presented in the Results section.

Data Product Generation

A key aim of the ARC-Lake project is to provide spatially and temporally resolved data products of LSWT and LIC. Clear-sky LSWT retrievals and LIC estimates are averaged over $\frac{1}{20}^\circ \times \frac{1}{20}^\circ$ longitude/latitude grid cells for each day/night of observations. These averaged observations are stored (along with ancillary information) in NetCDF files on both a per-lake basis (covering all years of observations) and a global basis (covering all lakes for a single day).

Further spatial and temporal averaging is also applied, to generate spatially-resolved ($\frac{1}{20}^\circ \times \frac{1}{20}^\circ$) and lake-mean climatology and time-series over a range of averaging intervals (daily, monthly, twice-monthly, and seasonal). Equivalent data products are also generated from the spatially complete EOF-based LSWT reconstructions. All data products are freely available via the ARC-Lake project website (www.geos.ed.ac.uk/arclake). A summary of the possible variants of data products is given in Table 1.
Table 1. Overview of the types of data product available through ARC-Lake.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Variants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
<td>Observations / Reconstructions</td>
</tr>
<tr>
<td>Coverage</td>
<td>Per-lake / Global</td>
</tr>
<tr>
<td>Time</td>
<td>Day / Night</td>
</tr>
<tr>
<td>Spatial Resolution</td>
<td>0.05° grid / Lake-mean</td>
</tr>
<tr>
<td>Temporal Averaging Type</td>
<td>Climatology / Time-series</td>
</tr>
<tr>
<td>Temporal Averaging Period</td>
<td>Seasonal / Monthly / Twice-monthly / Daily</td>
</tr>
</tbody>
</table>

RESULTS

LSWT Validation

The results of the validation study, where OE LSWT retrievals are compared with in situ observations and operational retrievals, are presented in Figure 3 and Tables Table 2 and Table 3 for AATSR. Statistics for the ATSR-2 validation are also provided in Tables Table 2 and Table 3. All results are for direct comparison of satellite and buoy observations: no adjustment is made for the skin-bulk effect.

Figure 3. LSWT-Buoy differences against buoy temperature for AATSR. (a) and (b) operational day and night, (c) and (d) OE scheme, day and night. Trend lines are marked on the plots and their gradient, \( m \) (K K\(^{-1}\)), and intercept, \( C \) (K) are given.

Biases from the operational and OE retrievals are of the order expected for skin-bulk comparisons. RSDs are also comparable across the retrieval schemes. However, the Bayesian cloud screening used in ARC-Lake returns a greater number of observations than the operational method (44-69% more match-ups). The increased number of match-ups mainly arises from the lower end of the temperature range, where the operational threshold tests seem most likely to return false detection of clouds. This increased number of observations coupled with no increase in retrieval uncertainty
gives us confidence that the Bayesian cloud screening offers consistently improved cloud masking.

For the operational retrievals using different channel combinations, the mean satellite-in situ differences range from 0.12 K to 0.88 K (day) and -0.52 K to 0.18 K (night) for AATSR, with robust standard deviations (RSDs) of the order 0.5-0.6 K. The spread of mean differences is reduced to 0.18 K to 0.23 K (day) and -0.46 K to -0.31 K (night) when the OE retrievals and Bayesian cloud mask are used. RSDs are similar to or lower than those from the ATS retrieval for all retrieval types, with the RSD for the N2 day-time case ~0.15 K lower. SDs from the OE scheme are also lower for all retrieval types, indicating a reduction in outliers compared to the operational scheme, despite passing a greater fraction of matches as clear. The consistency of biases and RSDs across retrieval schemes is of particular importance for extending the new LSWT retrievals to include ATSR-1, in the light of the early failure of the 3.7 µm channel on this instrument.

<table>
<thead>
<tr>
<th>Day / Night</th>
<th>View / Channels</th>
<th>ATSR-2</th>
<th>AATSR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean Diff.</td>
<td>SD</td>
</tr>
<tr>
<td>Day</td>
<td>D2</td>
<td>812</td>
<td>0.24</td>
</tr>
<tr>
<td>Night</td>
<td>D3</td>
<td>1529</td>
<td>-0.32</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Day / Night</th>
<th>View / Channels</th>
<th>ATSR-2</th>
<th>AATSR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean Diff.</td>
<td>SD</td>
</tr>
<tr>
<td>Day</td>
<td>D2</td>
<td>1179</td>
<td>0.42</td>
</tr>
<tr>
<td>Night</td>
<td>D3</td>
<td>2184</td>
<td>-0.18</td>
</tr>
</tbody>
</table>

**Ice Validation**

Reflectance channel imagery and the ARC-Lake ice mask are shown in Figure 4 for Lakes Erie and Huron. Ice is clearly visible in the false colour image as mid-blue regions (darker than the land) with adjacent black areas being open water. The ice mask (red in the right-hand image of Figure 4) captures most of the clearly visible ice cover, with only a region (with partial cloud cover) on Lake Erie not detected. Good correspondence between the ARC-Lake ice mask and the ice chart data is also observed for this case study.
Overall results of the quantitative comparison between the LIC product and ice charts for ATSR-2 and AATSR combined are presented in Table 4. Ideally the diagonal elements of this table should be large, particularly so for open water (0%) and ice-covered (>85%), where there should be less ambiguity about the surface type. Reasonable levels of agreement are observed between the LIC product and the ice charts, with the same classification given in over 75% of the matches, and agreement to within one class exceeding 90%.

<table>
<thead>
<tr>
<th>Ice Charts</th>
<th>ARC-Lake</th>
<th>0 %</th>
<th>1-15 %</th>
<th>15-85 %</th>
<th>&gt;85 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 %</td>
<td>64.0</td>
<td>0.84</td>
<td>0.77</td>
<td>0.19</td>
<td></td>
</tr>
<tr>
<td>1-15 %</td>
<td>8.84</td>
<td>0.62</td>
<td>0.65</td>
<td>0.65</td>
<td></td>
</tr>
<tr>
<td>15-85 %</td>
<td>2.48</td>
<td>0.88</td>
<td>2.25</td>
<td>2.56</td>
<td></td>
</tr>
<tr>
<td>&gt;85 %</td>
<td>2.47</td>
<td>1.02</td>
<td>3.25</td>
<td>8.64</td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Results of comparison of ARC-Lake LIC product from ATSR-2 and AATSR with ice charts over all the Great Lakes. Values are the percentage of cells matching each surface classification pair between ARC-Lake LIC and the ice charts.

Science Applications
Perhaps the most obvious application of the ARC-Lake data products is in improving our knowledge of basic lake climatological information. As shown in Figure 1, most lakes are poorly monitored in situ, therefore ATSR observations offer a potentially far more globally complete picture of lake climatology, since 1991. Figure 5 and Figure 6 provide examples of the type of climatological information that can be determined from the ARC-Lake data products. Figure 5 shows the lake-mean seasonal LSWT range (from reconstructions) for the 258 target lakes, where enough valid LSWT observations were made to enable the reconstruction to be derived, and illustrates the global nature of the coverage provided. Low temperature ranges are observed in the tropics, with the peak temperature ranges occurring at around 45° N. Moving to higher latitudes the temperature range generally decreases again as the lakes do not receive sufficient heating following the frozen period to reach such high temperatures. Figure 6 shows the lake-mean seasonal trend in
Lake ST for Lake Balaton (Hungary) and compares ARC-Lake climatology to that from MODIS and from the online lake model, Flake (xxx). Broadly good agreement is observed for this case but for some other lakes ARC-Lake provides a more reasonable seasonal climatology than MODIS.

Figure 5. Example of basic climatological information available from ARC-Lake. Mean max.-min. LSWT over the ATSR2/AATSR lifetime (1995-2009), derived from EOF-based reconstructions.

Figure 6. Example of seasonal LSWT climatology derived from ARC-Lake EOF-based reconstructions for Lake Balaton, Hungary.

Recent work (iii) has found dramatic warming trends in Lake surface temperatures over a number of North American lakes. For Lake Tahoe, warming trends of > 1 K decade-1 are shown over the ATSR lifetime. Unfortunately the data available to this study (iii) did not include the overlap periods between ATSR instruments and was also missing ATSR-2 data in the late 90s. ARC-Lake observations for ATSR-2 and AATSR (Figure 7) do not yield the same dramatic warming trend as found in (iii) when all available data are considered. The difference between “AL” and “SC” warming trends in Figure 7 suggests that much of the 0.9 K yr⁻¹ difference in warming trends between (iii) and this study may be accounted for by the relatively warm years (1996-1998) not available to (iii). ATSR-1 has not yet been processed in ARC-Lake and relatively low LSWT observations for these years (1991-1994) are also expected to contribute to the difference in observed trends. Differences between the ATSR sensors have been accounted for in the ARC-Lake results but due to the limited time period of analysis, these results should be interpreted with caution.
LSWT observations of the form available from ARC-Lake, if made operational, have potential to improve NWP, through assimilation. This is demonstrated in Figure 8, where ARC-Lake observations are compared with NWP data and *in situ* observations for Lake Nyasa. A climatological cycle is represented in the NWP data but the magnitude of the NWP temperatures are significantly different to those observed in ARC-Lake. There is good agreement between ARC-Lake and *in situ* observations, giving confidence that the ARC-Lake observation provide accurate LSWTs.

**CONCLUSIONS**

Optimal estimation (OE) LSWT temperature retrievals and Bayesian cloud screening have been applied successfully to 258 of the 263 target large lakes. No empirical tuning of retrievals has been used, so that the new satellite LSWTs are independent of in situ observations, being based on the physics of radiative transfer. The new LSWT retrievals have been validated against *in situ* observations.
tions, and, relative to operational retrievals using techniques designed principally for SST observation, provide improved coverage (by ~50% overall), reduced biases (within ~0.2 K of the expected mean difference from in situ at night), and reasonable precision (~0.8 K).

Validation of the LSWT product against in situ observations shows good consistency across different channel/view combinations, with satellite-in situ mean differences agreeing to within ~0.15 K across all combinations (considering day and night, and each ATSR separately). Uncertainties are also consistent across retrievals, with RSDs within 0.1 K. The statistics of difference from in situ observations across both ATSR-2 and AATSR are 0.3 ± 0.9 K for daytime and -0.3 ± 0.8 K for night-time. The night time mean difference of -0.3 K needs to be interpreted in the light of the cool skin effect that makes the radiometric temperature of a water body a few tenths of kelvin cooler that the temperature below the surface. The robust SD of differences is of the order 0.5 K for both day and night.

The problem of inaccurate NWP for lake surface temperatures has been illustrated for Lake Nyasa. In order to provide a reasonable prior LSWT for cloud detection and retrieval, an EOF technique has been used to fill data gaps to create a spatially complete LSWT field from the ATSR observations. A by-product of applying these techniques is the creation of spatially and temporally complete time-series for > 50% of the target lakes (equivalent climatologically averaged products are derived for the remaining lakes). These data have potential use in NWP systems that include lake temperature in their land-atmosphere interaction scheme, and for lake model validation. Moreover, the new LSWT time series will be useful in quantifying the recent climatology and variability of many lakes where other data are sparse or absent. Trends in LSWT in the data need to be treated with caution until LSWT data are available for all ATSR sensors and until differences between the ATSR sensor calibration and observation times (which differ by 30 minutes) are accounted for.

An ice detection algorithm has also been implemented. This has been demonstrated to provide good correspondence (>75% agreement) to ice chart data for the Great Lakes. The ice detection algorithm uses visible reflectance imagery and is therefore only available for daytime observations. LSWT and LIC data products are now available from the ARC-Lake project (www.geos.ed.ac.uk/arclake), covering a variety of spatial and temporal averaging scenarios. Several improvements are planned for future data releases. Look-up tables used in cloud detection that are based on ocean observations will be replaced with lake-specific tables. Provision for lakes with boundaries evolving over time will be made via an automated water detection algorithm. Methods for lake ice-detection and discrimination from ice-clouds will be improved. Overlaps between sensors will be used to inter-calibrate the LSWTs for different ATSRs. Most fundamentally, the time series will be extended back to 1991 by including ATSR-1.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge that this work is funded by the European Space Agency under contract 22184/09/I-OL. The lake processor is a modification of the processor built during the ATSR Reprocessing for Climate (ARC) project, that was funded by the UK Natural Environment Research Council (NE/D001129/1) and the Department of Energy and Climate Change (CPEG 31).

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