Global Lake Surface Water Temperatures

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1st Globolakes Scientific Workshop
The ‘what’ of ARC Lake

ARC = ATSR Reprocessing for Climate
• ATSR = Along Track Scanning Radiometer

• Original ARC project for sea surface temperature

• ARC Lake for “climate quality datasets of lake surface water temperature (LSWT)”

• Extracted from 17,000 billion radiance measurements
The ‘why’ of ARC Lake

LSWT remote sensing has generally used SST methods

• OK for some lakes

• For most, inappropriate
  – Cloud detection goes wrong
  – LSWT estimates are biased

• Strong requirements for LSWT
  – meteorology (weather forecasting)
  – climate (trends, feedbacks, prediction)
Along Track Scanning Radiometers

- Dual view
- Two-point high-quality black-body calibration
- Low noise detectors
- Accurately characterized spectral responses
  ➔ Supports physics-based approach
- 1 km spatial resolution (at best)
- 3 covering 1991 to 2012
ATSRs central to ARC / SST CCI

- CCI = Climate Change Initiative
  - ESA project to derive ECVs by EO
  - ECV = essential climate variable

- ATSRs define an independent reference for global SST

- ARC / SST CCI data from ATSRs
  - accuracy \( \sim 0.1 \) K (better than the validation data)
  - stable to 0.003 K / yr (tropics, 1995 – 2012)

- SST is an ECV, but LSWT is not!
ARC-Lake Background

• 263 Lakes

• ARC-Lake Database / metadata
  – Global Lakes and Wetlands Database (GLWD)
  – Herdendorf (1982)
  – ILEC, LakeNet, literature search ...

• ATSR Reprocessing for Climate – Lake
  – Lake Surface Water Temperature (LSWT)
  – Lake Ice Cover (LIC)
  – 1991-2011 in v2.0
    – extend soon to Apr 2012
Lake Selection / Definition

- Surface area > 500 km² [Lehner and Döll (2004) and Herdendorf (1982)]
- Exclusions:
  - intermittent / ephemeral
  - most reservoirs
  - lagoon areas (some large individual lagoons are included)
- Additions:
  - Lakes of scientific/validation interest
  - Some reservoirs the request of the user group

Lake Astray
ID = 115

Aral Sea

Polygon

NAVOCEANO + GLWD
Global Distribution
Algorithms

• Cloud detection and retrieval
  – use inverse methods based on physical modelling

• Bayesian inference of probability of clear sky

• Simplified optimal estimation

• Needs guess LSWT
  • Iterative EOF-based approach

Validation - LSWT

• Comparison with in situ data on 18 lakes
  – NDBC, FOC, SLU, GLEON, Wooster et al (2001), NIWA, USBC
  – Seeking more in situ data sources
  – Skin LSWT vs in situ

<table>
<thead>
<tr>
<th>Retrieval / Cloud Mask</th>
<th>Day / Night</th>
<th>N</th>
<th>Mean / K</th>
<th>RSD / K</th>
</tr>
</thead>
<tbody>
<tr>
<td>OE / Bayes</td>
<td>Day</td>
<td>3273</td>
<td>-0.34</td>
<td>0.41</td>
</tr>
<tr>
<td>OE / Bayes</td>
<td>Night</td>
<td>3220</td>
<td>-0.15</td>
<td>0.28</td>
</tr>
</tbody>
</table>
Data Products

- v2.0 released on 30th May 2012
  - http://www.geos.ed.ac.uk/arclake/
- 1991-2011
- NetCDF
- LSWT + uncertainty, number of cloud, ice, water pixels in cell, etc
- Land/water mask
- Lake Database (updated)

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Possible variants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coverage</td>
<td>Per-lake / Global</td>
</tr>
<tr>
<td>Source</td>
<td>Observations / Reconstructions</td>
</tr>
<tr>
<td>Time</td>
<td>Day / Night</td>
</tr>
<tr>
<td>Spatial Resolution</td>
<td>0.05 degree grid / Lake-mean</td>
</tr>
<tr>
<td>Temporal Averaging</td>
<td>None / Climatology / Timeseries</td>
</tr>
<tr>
<td>Temporal Averaging Period</td>
<td>Seasonal / Monthly / Twice-monthly / Daily</td>
</tr>
</tbody>
</table>
Data Tools

• Data products searchable by variable via the ARC-Lake Database
  – e.g. Search for data within lat/lon bounds

• Visual geographic search using Google Maps

• Quick-look visualisation tools
  – Visualise ARC-Lake Database variables
    • e.g. Global map of lake elevations
  – Time series plots of lake-mean LSWT
    • e.g. Compare LSWT climatology across lakes
Climatology

Average Min.-Max. LSWT from lake-mean data

LSWT range, $dT$ (K)
- $dT > 25$
- $20 < dT < 25$
- $15 < dT < 25$
- $10 < dT < 15$
- $7.5 < dT < 10$
- $5 < dT < 7.5$
- $2.5 < dT < 5$
- $dT < 2.5$
Climatology of Lake Vattern

Annual LST Climatology (Lake 0029)

Lake Vattern (Sweden)
Climatology of Lake Winnipeg

Lake Winnipeg (Canada)

Annual LST Climatology (Lake 0013)
Climatology of Nam Co

Nam Co (Tibet)

Lake surface temperature ...
Climatology for N. America
Spatially complete reconstruction

- Lake Ladoga
Numerical Weather Prediction

• Comparison of ECMWF ST with ARC-Lake LSWT and in situ observations for Lake Malawi

![Graph showing Lake Mean LSWT (Lake 0010)]
Met Office Applications

• Operational LSWT observations in OSTIA from Nov. 2011
  – For 248 of lakes in ARC-Lake
    • Only Caspian Sea included prior to this
  – Uses ARC-Lake land/water mask on OSTIA grid
  – ARC-Lake climatology used for initialisation and relaxation climatology
  – ARC-Lake LSWT used as independent reference data for validation
  – Improved NWP (better weather forecasts)

• ARC-Lake also being used in regional climate modelling
  – African lakes esp. Lake Victoria
  – Aim to improve storm forecasting around inland waters
LSWT Trends

Lake Trend Validation

ARC-Lake Regional LSWT Anomalies
LSWT Trends

• Comparison of 20-year JAS trends with Inland Water Body Project (IWBP)
  – Schneider and Hook (2010)
  – ATSR, AVHRR and MODIS

• Results
  – Consistent relatively rapid warming in the lakes of N. America and Europe
  – Less consistent elsewhere

ARC Lake to GloboLakes

• New (to us) user community
• More, smaller lakes (~1000)
• Finer spatial resolution
  – ARC Lake 0.05 deg
  – GloboLakes 0.025 deg
• Adapt to Metop A/B AVHRRs in interim
• Use Sentinel 3 once available
Candidate lakes

- Target: apply global methods down to 80 km²
Candidate lakes

• Target: apply global methods down to 80 km$^2$
Candidate lakes

- Target: apply global methods down to 80 km$^2$
LSWT within GloboLakes

• Opportunity to define what thermal RS is useful for ecology and limnology
• Opportunity to share data e.g. GLEON for validating results on intermediate lakes
• Integrate our data with catchment, quality ...
• Challenge is 1000 lakes with global methods
  – basis in physics
  – SST and ARC Lake experience to build on
Data aspects

• Agnostic about collecting in one place vs distributed connected through web services

• For 1000+ lakes the following should be collected and unrestricted:
  – RS data (LSWT and Optical)
  – lake metadata
  – catchment parameters
  – meteorological data

• It seems validation data may need to be through agreement with providers

• GLEON virtual expeditions interesting re LSWT
Feedback from potential users of LSWT

• Are the current ARC Lake products fit for your purpose? (Formats, resolution, etc.)
• If not, are they readily adaptable?
• How important is short delay mode cf. off-line for your usage?
• Have you routine in situ data for validation of ARC Lake or GloboLakes lakes? Want to collaborate?
• Are online visualisations etc useful? Or would you just grab the datasets, O(1 - 10 GB)?
• [http://www.geos.ed.ac.uk/arclake/](http://www.geos.ed.ac.uk/arclake/)
  – for ARC Lake v2 data

• ARC Lake final meeting in 2013
