Global Lake Surface Water Temperatures

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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)"

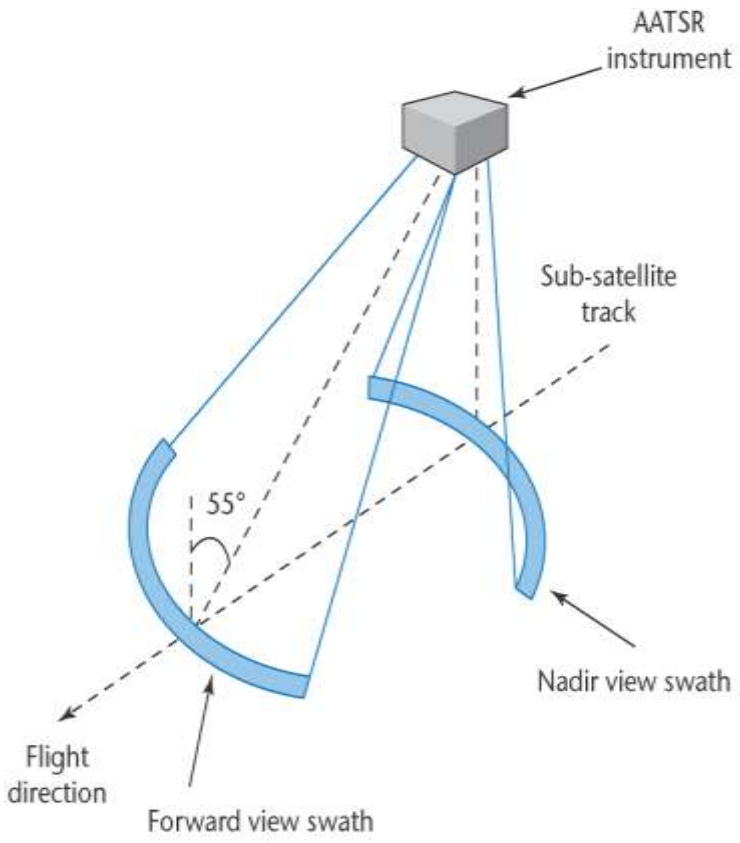
- Extracted from 17,000 billion radiance measurements

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 ~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!

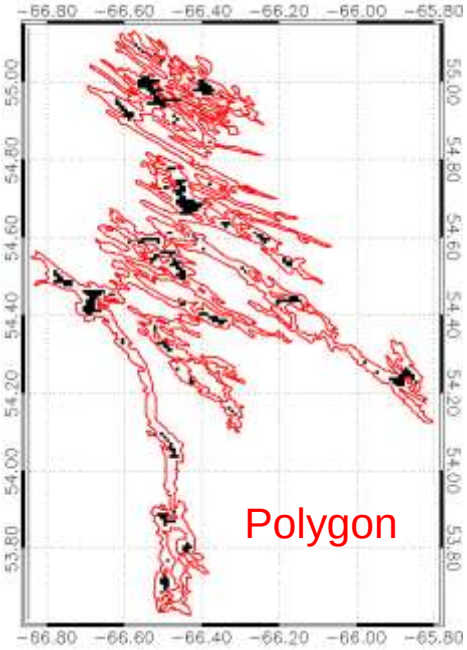
ARC-Lake Background

- 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 km^2 [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



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
  - Merchant et al, 2008, Rem Sens Environ
- Needs guess LSWT
  - Iterative EOF-based approach

MacCallum and Merchant (2012), Surface Water Temperature Observations of Large Lakes by Optimal Estimation, Can J Remote Sensing.

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

Retrieval / Cloud Mask	Day / Night	N	Mean / K	RSD / K
OE / Bayes	Day	3273	-0.34	0.41
OE / Bayes	Night	3220	-0.15	0.28

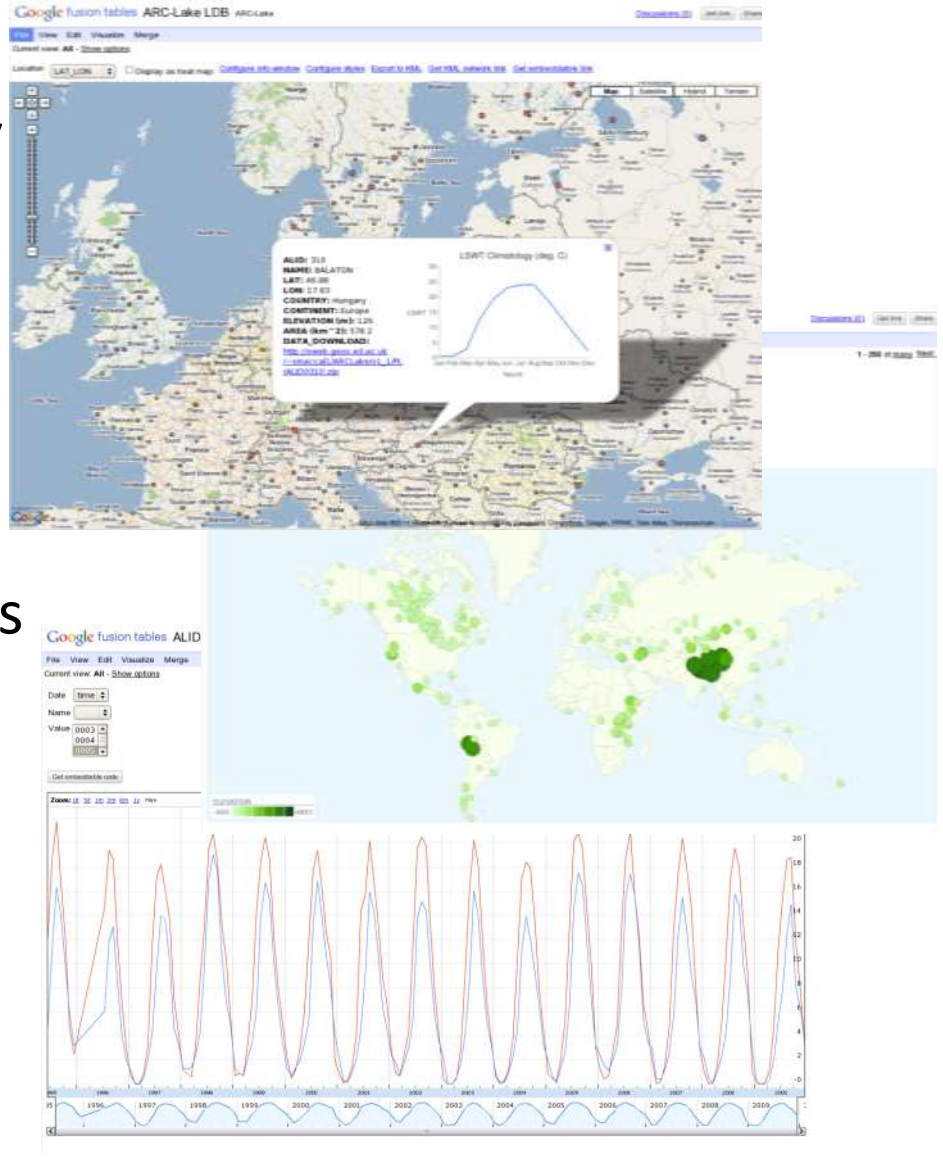
Data Products

- 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)

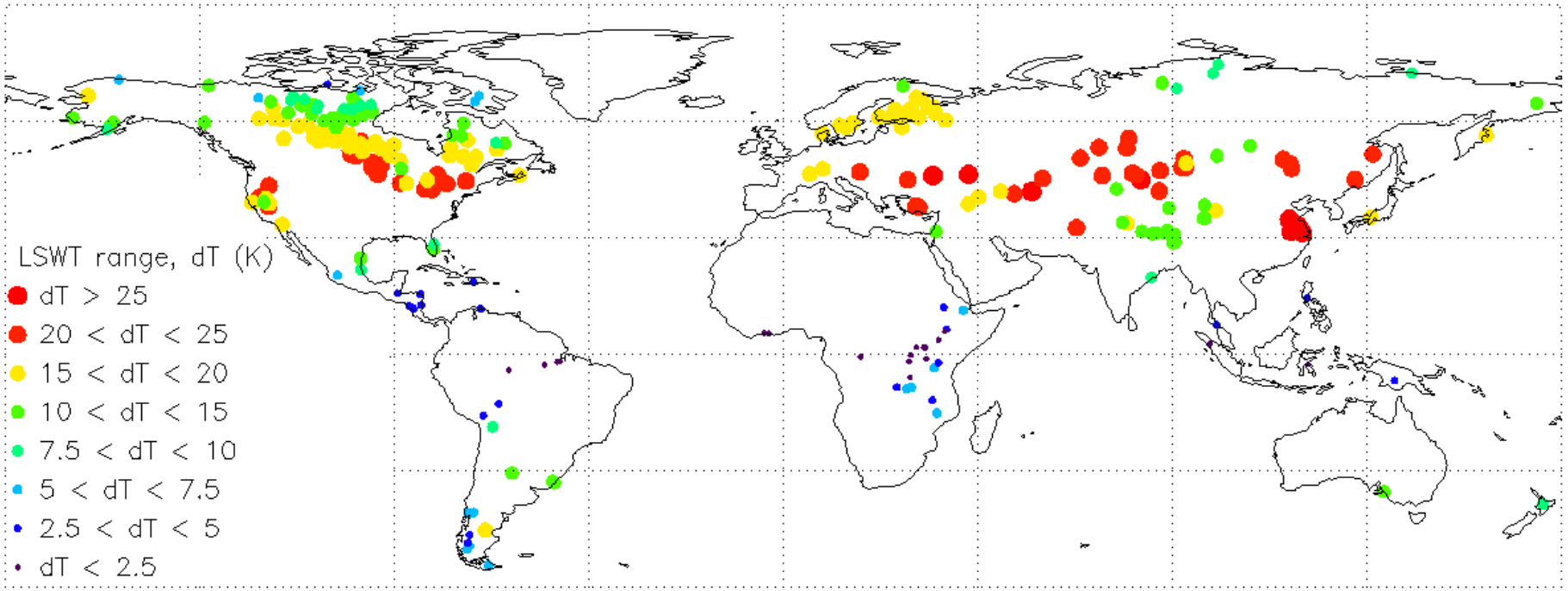
Attribute	Possible variants
Coverage	Per-lake / Global
Source	Observations / Reconstructions
Time	Day / Night
Spatial Resolution	0.05 degree grid / Lake-mean
Temporal Averaging	None / Climatology / Timeseries
Temporal Averaging Period	Seasonal / Monthly / Twice-monthly / Daily

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

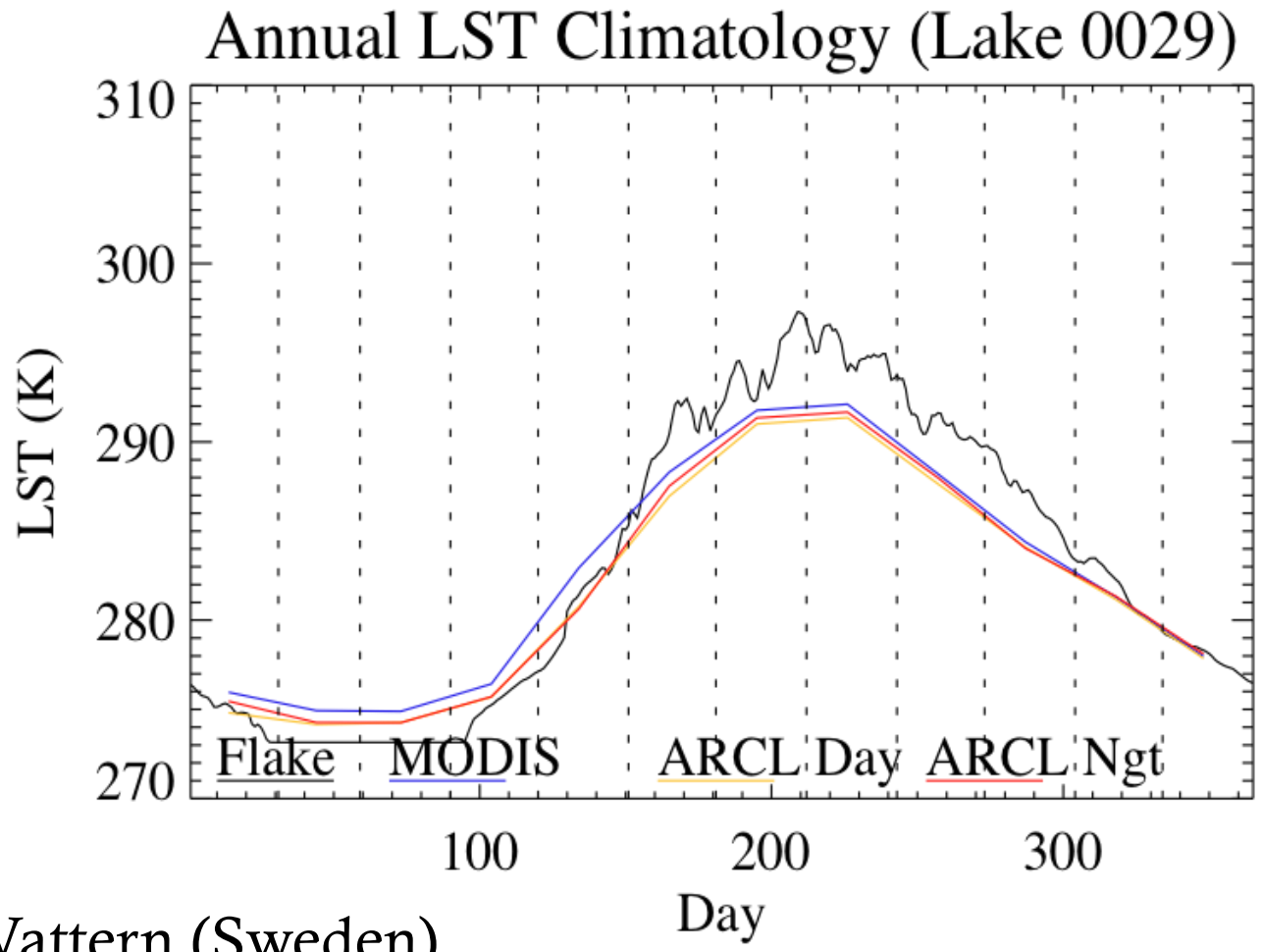


Climatology



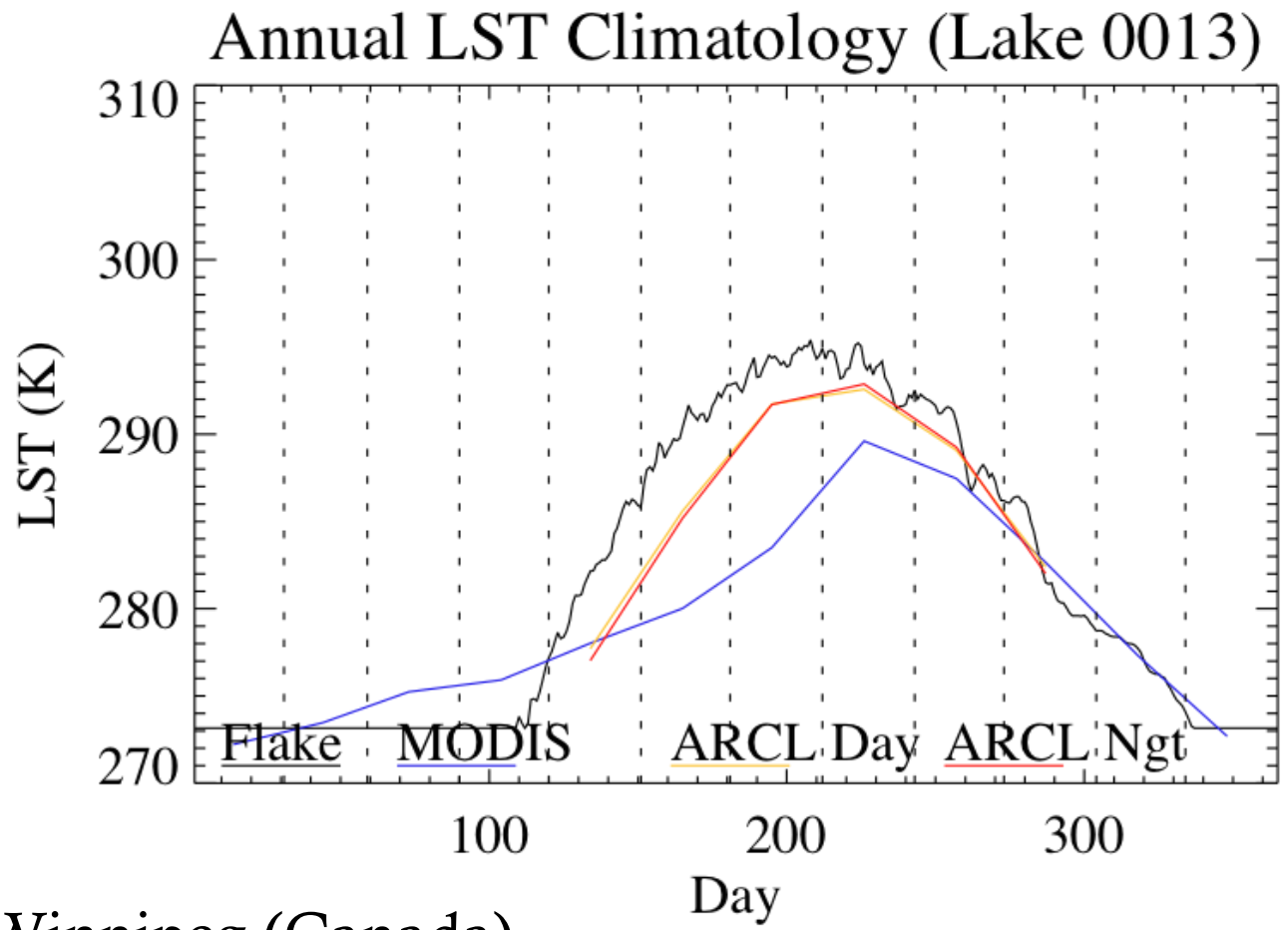
- Average Min.-Max. LSWT from lake-mean data

Climatology of Lake Vattern



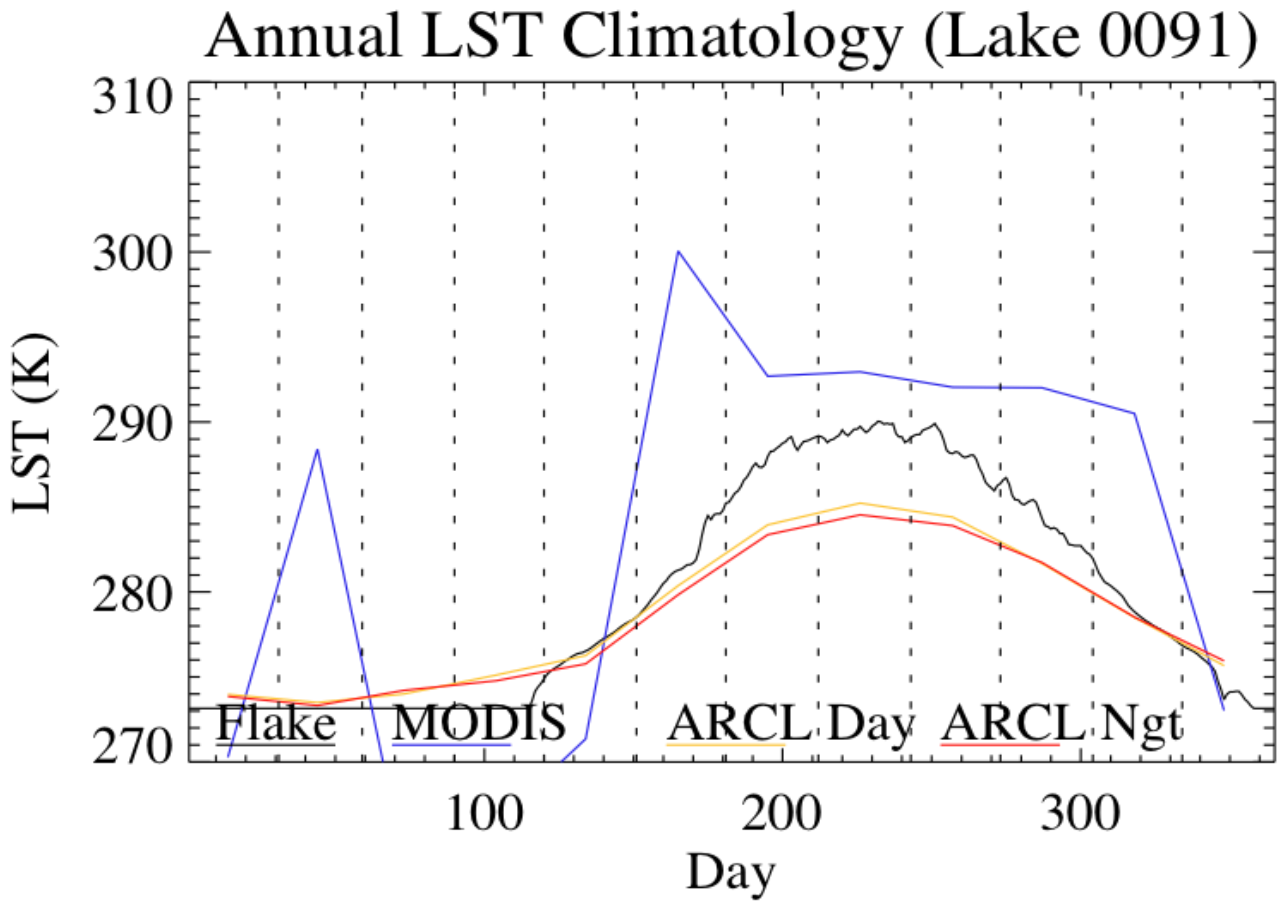
Lake Vattern (Sweden)

Climatology of Lake Winnipeg



Lake Winnipeg (Canada)

Climatology of Nam Co



Nam Co (Tibet)

Climatology for N. America

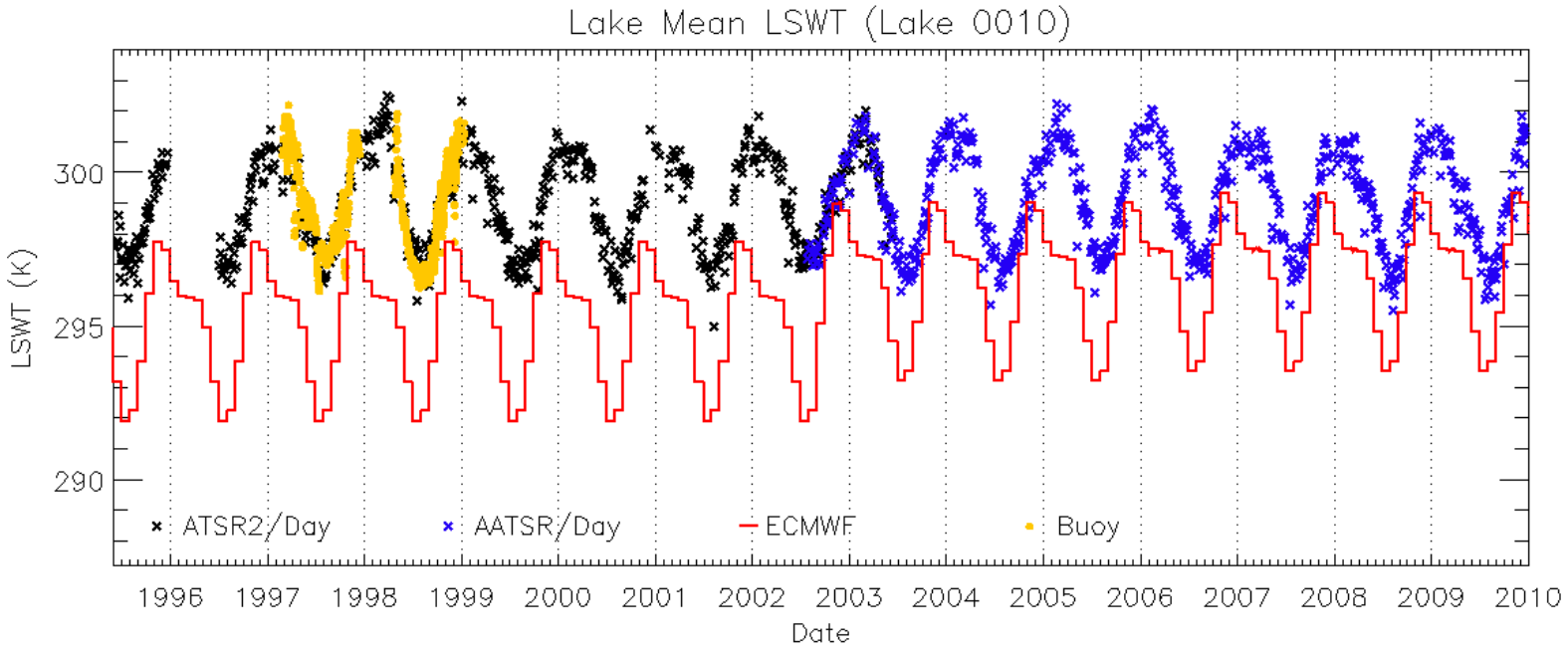
Spatially complete reconstruction

- Lake Ladoga

Numerical Weather Prediction

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

ATSR2
AATSR
In situ
ECMWF ST

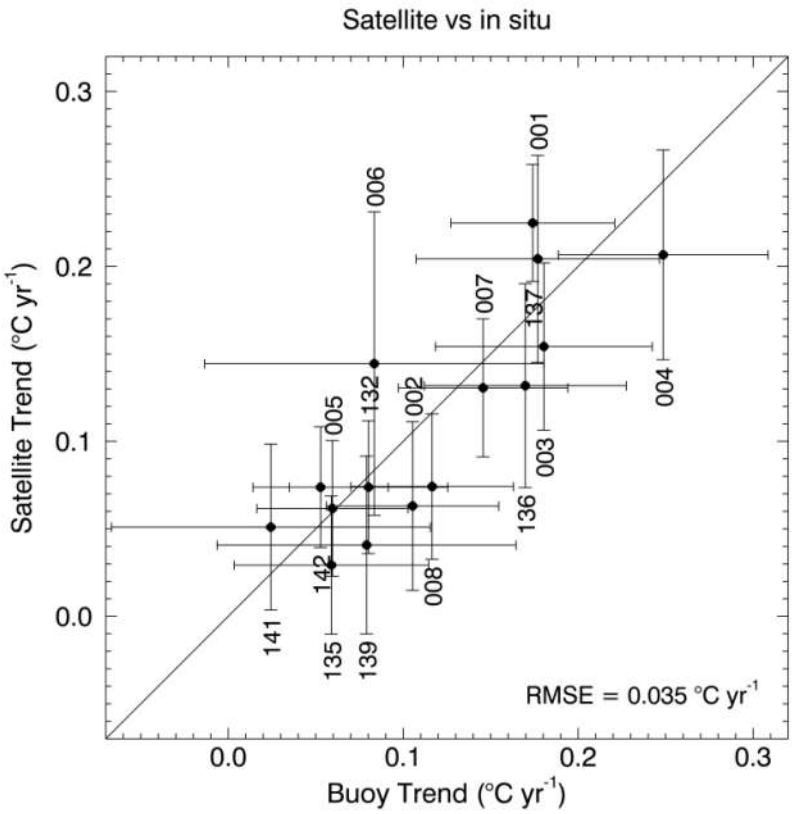


Met Office Applications

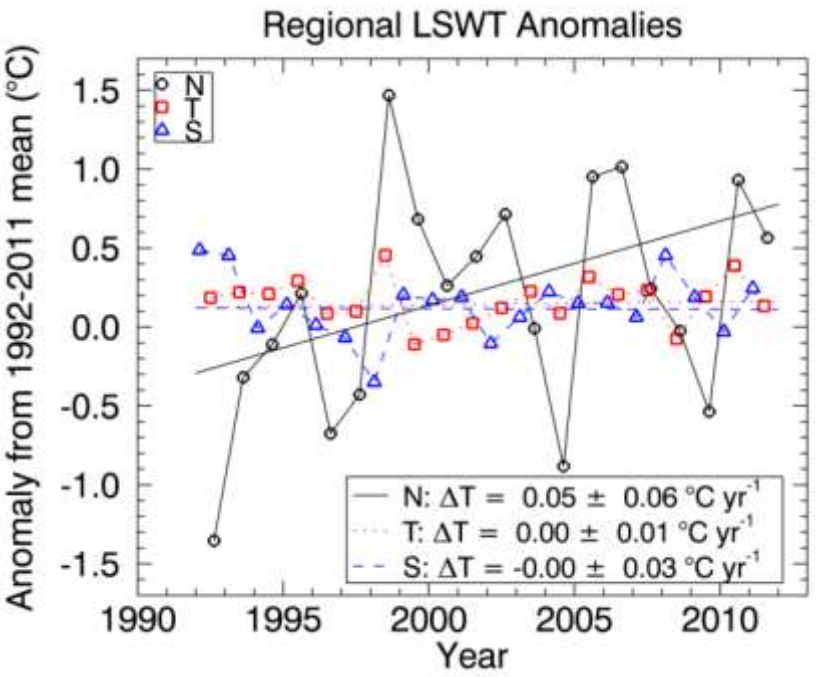
- Operational LSWT observations in OSTIA from Nov. 2011
  - For 248 of lakes in ARC-Lake
    - Only Caspian Sea included prior to this
  - Uses ARC-Lake land/water mask on OSTIA grid
  - ARC-Lake climatology used for initialisation and relaxation climatology
  - ARC-Lake LSWT used as independent reference data for validation
  - Improved NWP (better weather forecasts)
  - Fiedler et al (2012). Lake Surface Water Temperature in the operational OSTIA system.
- 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

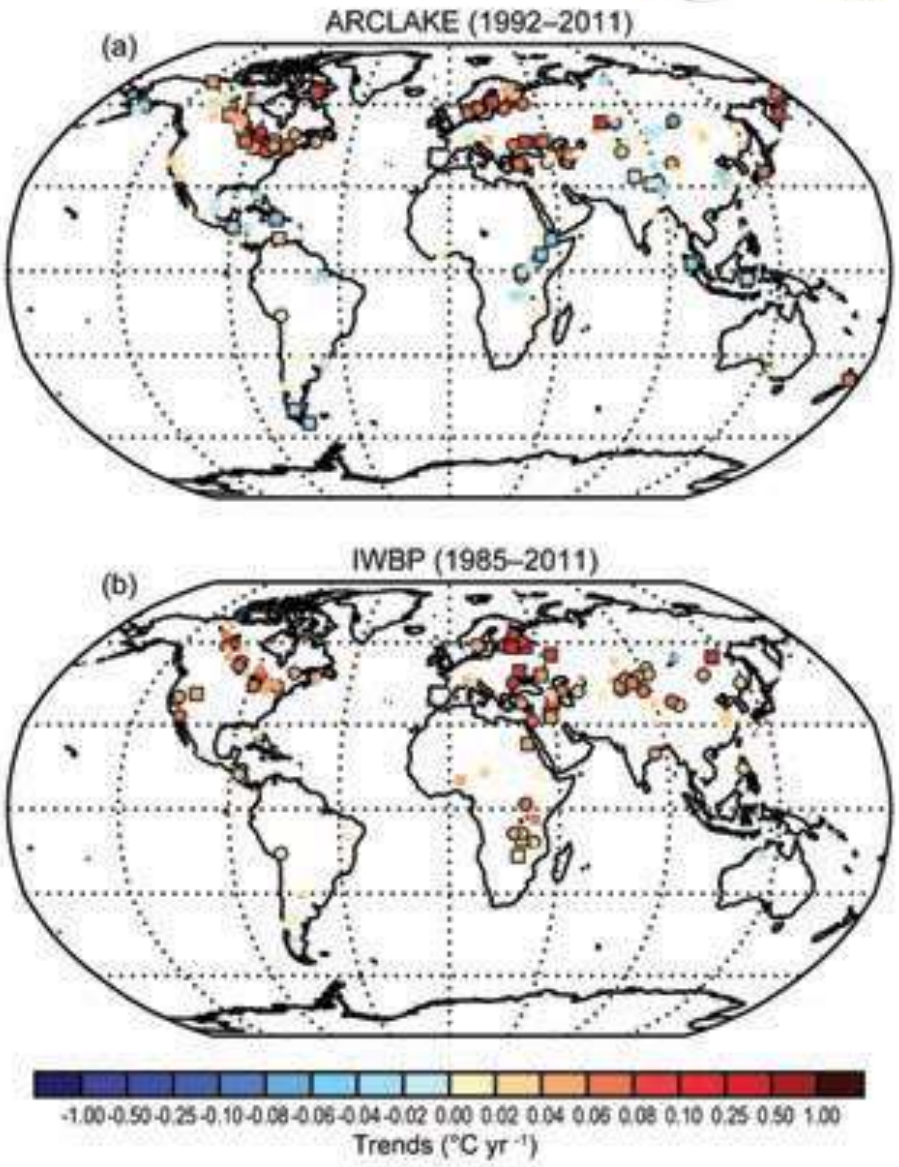


ARC-Lake Regional LSWT Anomalies



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
- Hook, S., R. C. Wilson, S. MacCallum and C. J. Merchant (2012), [Global Climate] Lake Surface Temperature [in "State of the Climate in 2011], Bull. Amer. Meteorol. Soc., 93 (7), S18-S19.

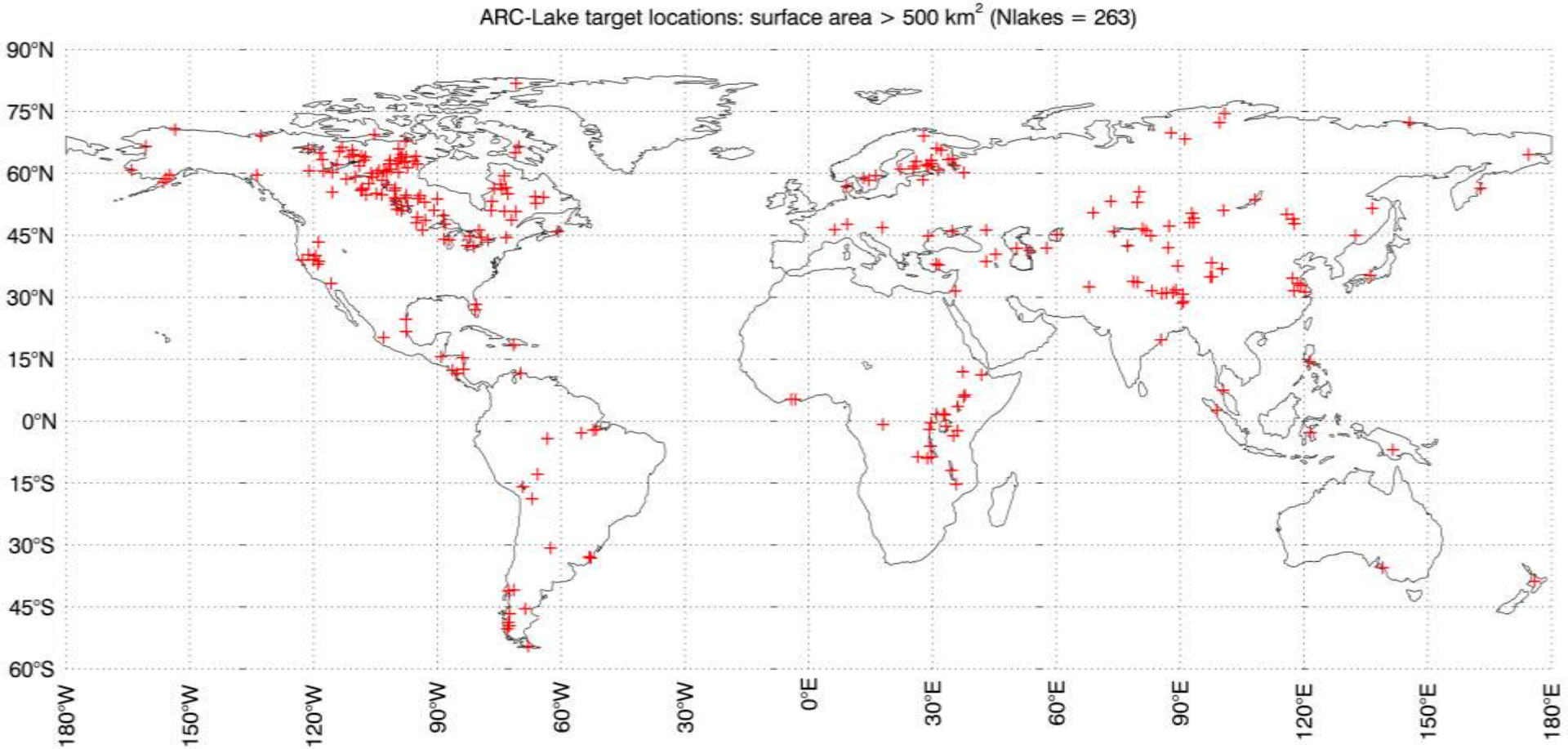


ARC Lake to GloboLakes

- 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 km^2



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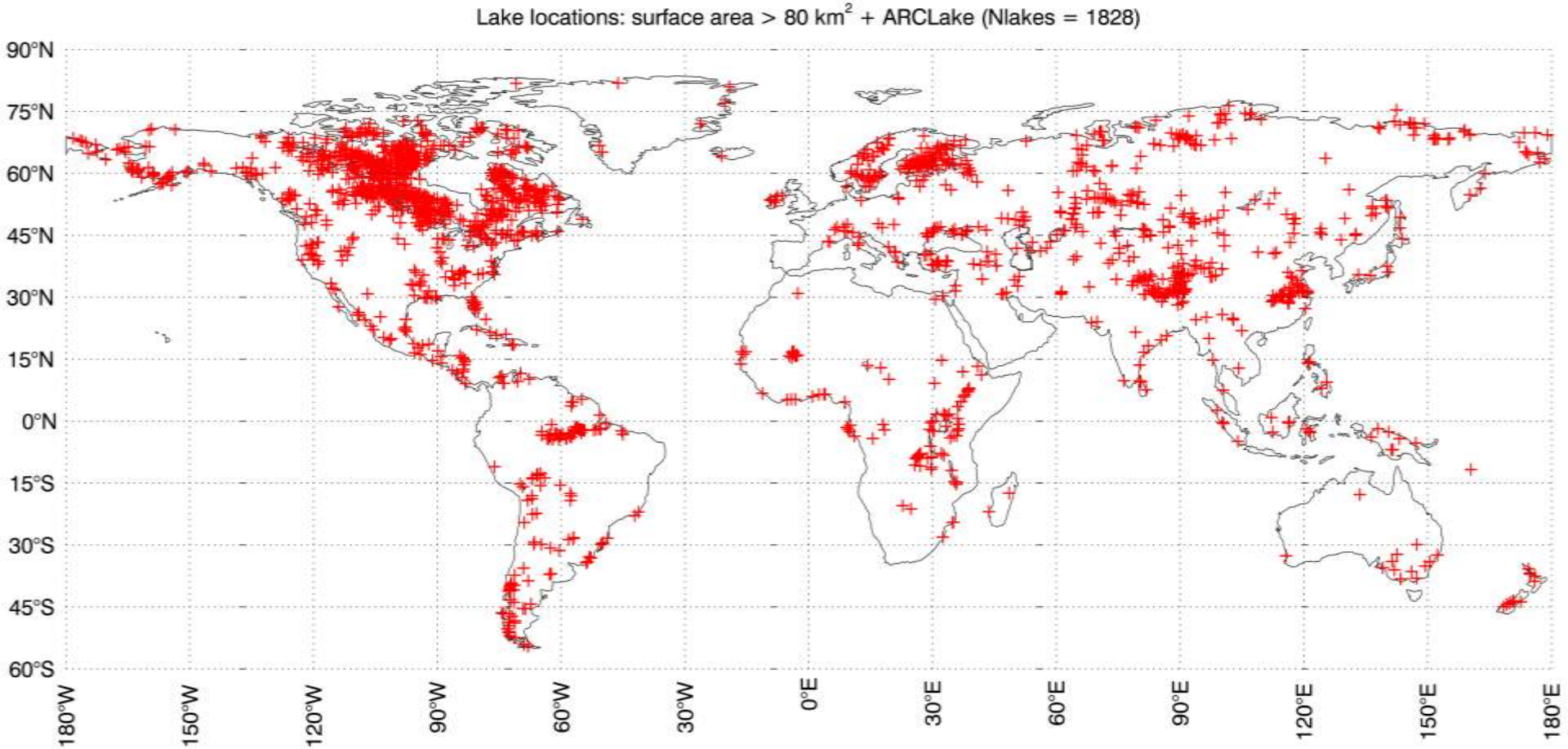

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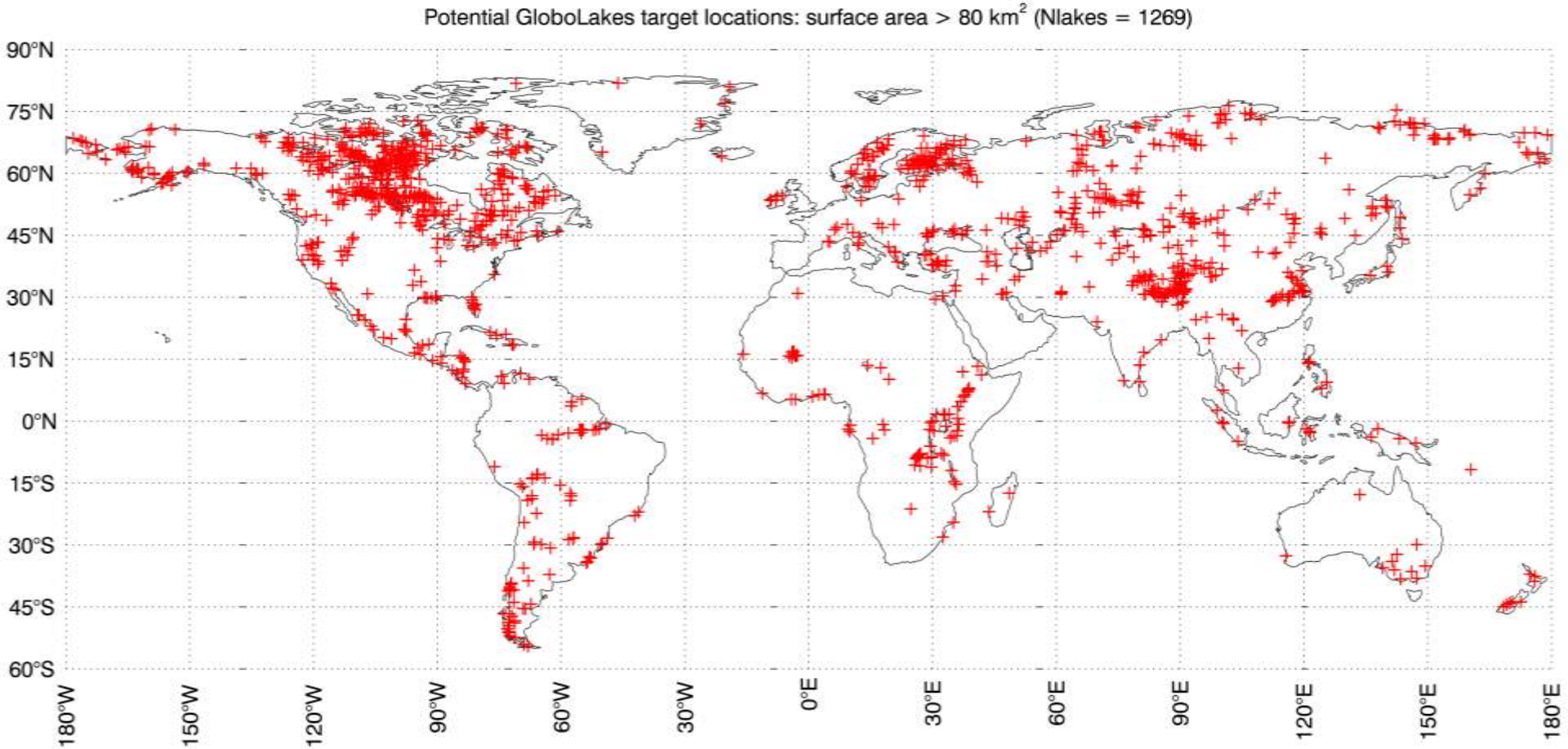

LSWT within GloboLakes

- 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/
  - for ARC Lake v2 data
- ARC Lake final meeting in 2013

- MacCallum, S. N. and C. J. Merchant (2012), Surface Water Temperature Observations of Large Lakes by Optimal Estimation, Can J Remote Sensing, 38(1), 25 - 45. doi:10.5589/m12-010.
- Hook, S., R. C. Wilson, S. MacCallum and C. J. Merchant (2012), [Global Climate] Lake Surface Temperature [in "State of the Climate in 2011], Bull. Amer. Meteorol. Soc., 93 (7), S18-S19.