# A satellite-based climatology (1989–2012) of lake surface water temperature from AVHRR 1-km for Central European water bodies


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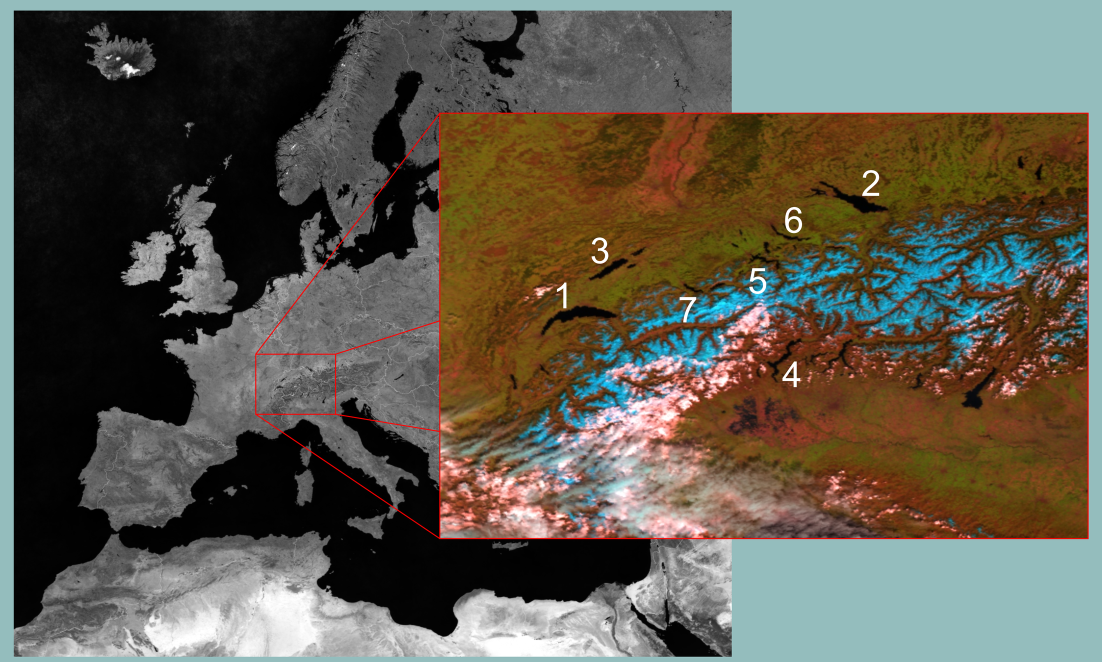
# Overview

## Introduction

The interest in lake surface water temperature (LSWT) is manifold. To name a few: Within the Global Climate Observing System (GCOS; WMO/GCOS, 2006), it is listed as an essential climate variable (ECV) reacting to changes in climate; focussing on shorter time scales, sufficiently large water bodies influence mesoscale weather development and LSWT can be assimilated into numerical weather prediction models (Balsamo et al., 2011). In contrast to in situ observations, satellite imagery offers the possibility to derive spatial patterns of LSWT variability. In addition, the temperature of many lakes is not monitored on a regular basis. Hence, the extensive Advanced Very High Resolution Radiometer (AVHRR) data record (1985–2012) of the Remote Sensing Research Group at the University of Bern (RSGB) will offer new insights into the temperature evolution of European lakes over the past three decades.

## Study region

GCOS-Switzerland (Seiz and Foppa, 2007) has initiated a project to generate a LSWT time series from the RSGB AVHRR 1-km data record for Switzerland. Within this project, it has been demonstrated that AVHRR and the proposed approach yield good results for lakes as small as Lake Sempach (~14 km$^2$).




1. Lake Geneva 580 km$^2$
2. Lake Constance 536 km$^2$
3. Lake Neuchâtel 215 km$^2$
4. Lake Lugano 210 km$^2$
5. Lake Lucerne 114 km$^2$
6. Lake Zurich 88 km$^2$
7. Lake Thun 48 km$^2$

Several smaller lakes: Lake Biel (40 km$^2$), Lake Zug (38 km$^2$), Lake Brienz (30 km$^2$), Lake Walen (24 km$^2$), Lake Murten (23 km$^2$), Lake Sempach (14 km$^2$)

## Data

- **AVHRR:** The current analysis includes data from the AVHRR/2 (NOAA-11/-14) and AVHRR/3 (NOAA-16/-17/-18/-19, Metop-A) instruments on board the National Oceanic and Atmospheric Administration (NOAA) and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) covering the period from1989 to 2012.
- **In situ** measurements for validation purpose:

| Sampling rate | Location |
|---|---|
| hourly | L. Geneva (2000–2011), L. Constance (1997–2009) |
| daily | L. Geneva (1991–2011), L. Constance (1987–1996), L. Zurich (2008–2012) |
| weekly/monthly | L. Neuchâtel, L. Lucern, L. Zurich, L. Thun, L. Biel, L. Zug, L. Brienz, L. Murten, L. Sempach |

- **ECMWF operational analysis and ERA-40 reanalysis:** The following meteorological data from the European Centre for Medium Range Weather Forecasts (ECMWF) daily at 12 UTC are used:
  1. Vertical profiles of T and RH (21 levels)
  2. Surface parameters ($T_{air}$, $T_{dew}$, $T_{skin}$, u, v, p)

# Methods

## Improving thermal calibration

- Calibration unit on board of AVHRR does not automatically guarantee high quality output signal
- Noise may arise from fluctuations in the instrument's thermal state, solar contamination or during digital conversion (Trishchenko, 2002)
- Especially NOAA-16 and prior satellites are prone to unwanted fluctuations

➔ Improvement of thermal data using multistage correction scheme introduced by Trishchenko (2002) (see Fig. 2 and 3)

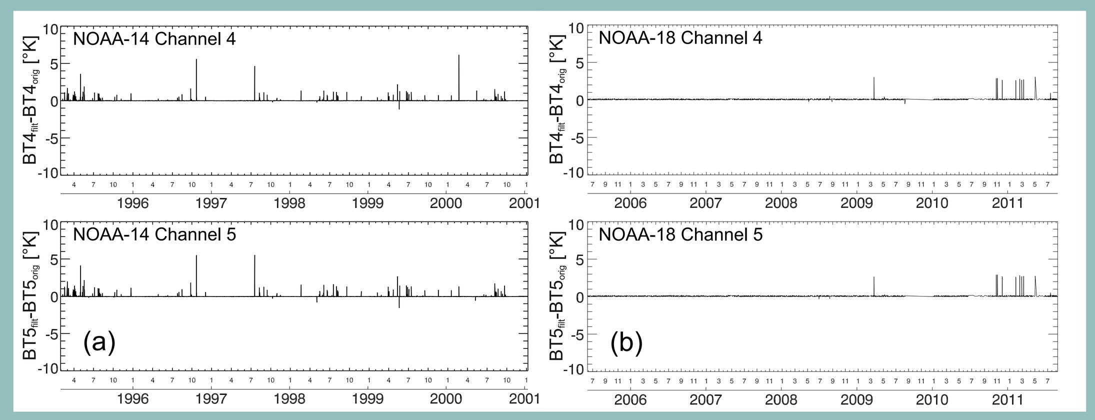



**Figure 2:** Difference of the scene average brightness temperature before and after filtering the calibration data shown for (a) NOAA-14 from 1995 to 2001 and (b) NOAA-18 from 2006 to 2011.

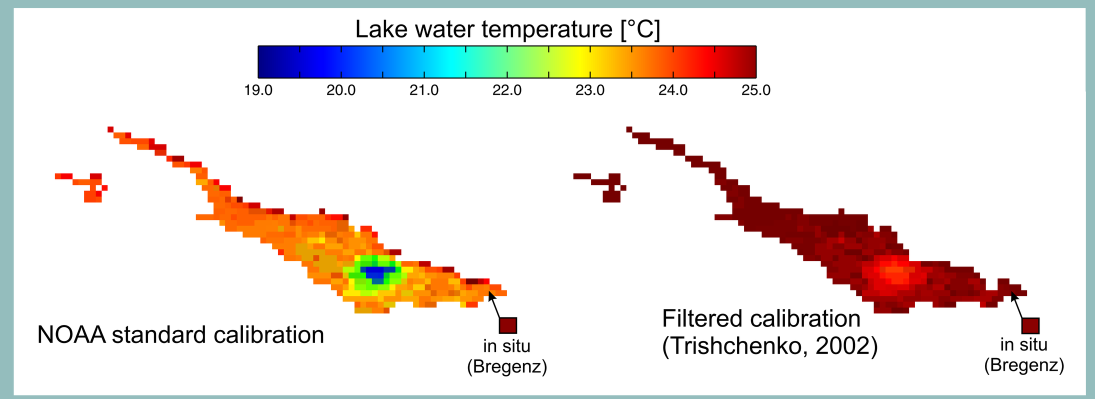



**Figure 3:** Influence of calibration on resulting LSWT shown for NOAA-17 on 17 August 2003 for Lake Constance. The map on the left shows the LSWT based on the original (NOAA standard) calibration, the map on the right after applying the multi-stage correction scheme.

## Optimized LSWT retrieval

- Split-window approach using the multi-channel SST algorithm similar to Oesch et al. (2005) and Hulley et al. (2011)

$$T_s = a_0 + a_1T_4 + a_2(T_4-T_5) + a_3(T_4-T_5)(1-Sec(\theta_v))$$

*a_i ... coefficients derived from least squares linear regression*
*$T_4$, $T_5$ ... brightness temperature of AVHRR channel 4 and 5*
*$\theta_v$ ... sensor view angle*

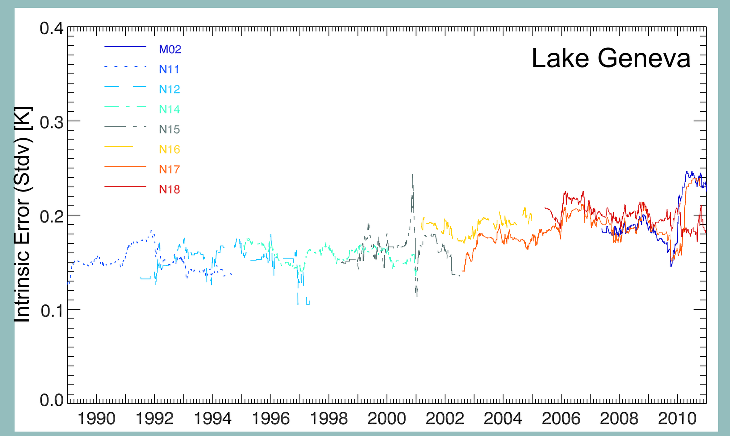



**Figure 4:** Intrinsic error (standard deviation) of the simulation-based model to retrieve the LSWT for the various satellites. The intrinsic bias equals zero for all satellites.

- Simulated brightness temperatures using Radiative Transfer for TOVS (RTTOV) Version 10 (Saunders et al., 2012) together with ECMWF analysis and reanalysis data:
  - $T_s = T_s$-10 K:$T_s$+10 K in increments of 5 K
  - $\theta_v$ = [0, 15, 30, 40, 45, 50, 55, 60 deg.]
- Skin-to-bulk temperature conversion using wind dependent parameterization (Minnett et al., 2011)
- Weighted, robust linear regression using a running time window of 360 days

**References:**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# Results

## Validation

- Simulation-based LSWTs have been compared with in situ measurements from various lakes
- Operational global NOAA National Environmental Satellite, Data, and Information Service (NESDIS) and Pathfinder SST algorithms have been applied

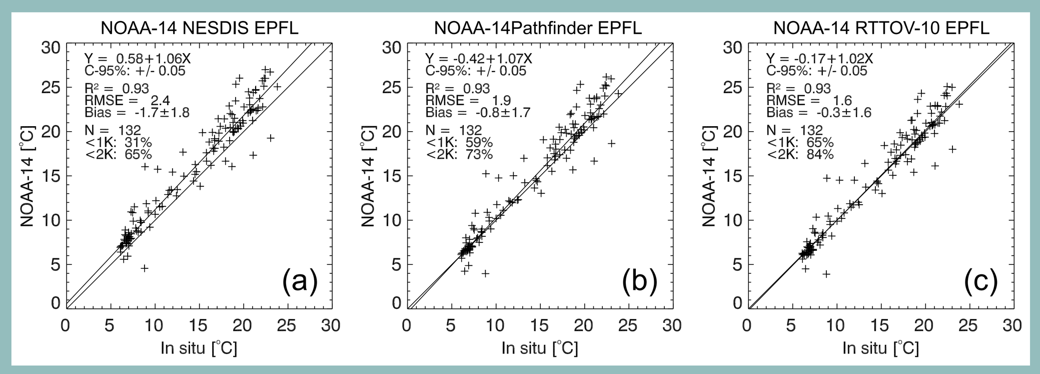


**Figure 5:** Validation of NOAA-14 LSWT at Lake Geneva. Displayed are in situ measurements from the École Polytechnique Fédérale de Lausanne (EPFL) versus the (a) NOAA NESDIS, (b) NOAA Pathfinder, and (c) optimized RTTOV-10 LSWT algorithms.

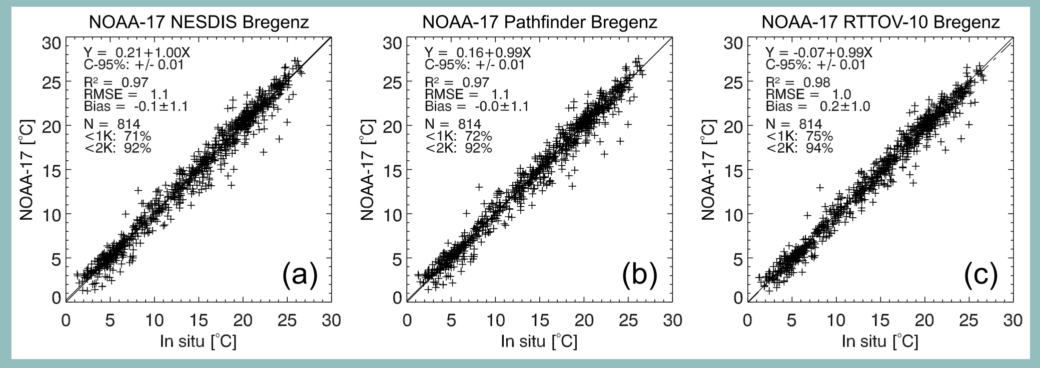


**Figure 6:** Validation of NOAA-17 LSWT at Lake Constance. Displayed are in situ measurements from the Environmental Agency of Vorarlberg (Bregenz) versus the (a) NOAA NESDIS, (b) NOAA Pathfinder, and (c) optimized RTTOV-10 LSWT algorithms.

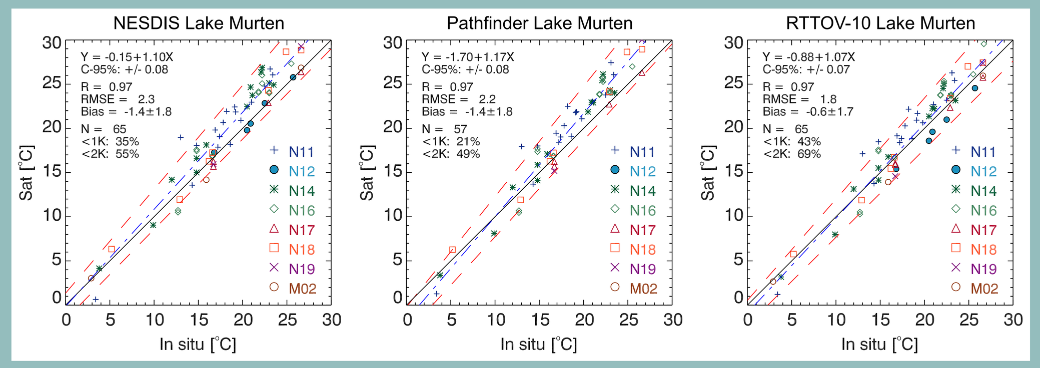


**Figure 7:** Validation of all available satellites at Lake Murten. The in situ temperature at this lake is typically observed once per month (vertical profile). The red dashed lines indicate the 95% confidence intervals of the linear fit.

## Time series

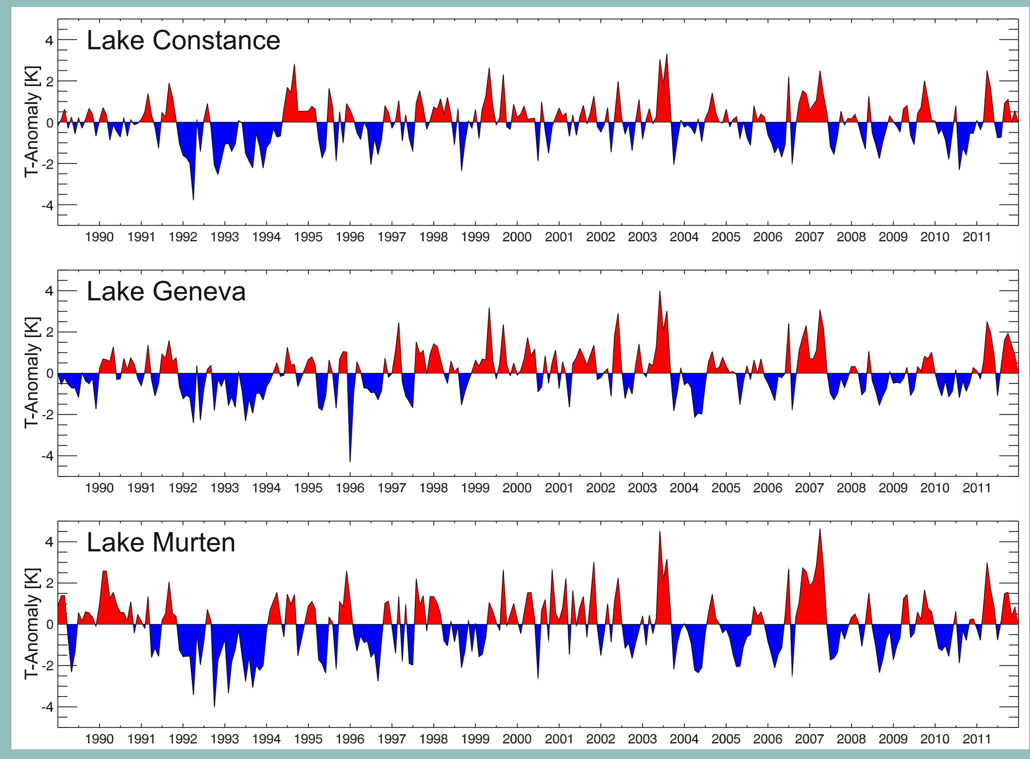


**Figure 8:** Time series of monthly temperature anomalies at Lake Constance (536 km$^2$), Lake Geneva (580 km$^2$), and Lake Murten (23 km$^2$) from 1989 to 2011. The LSWT records were built by extracting a 3 x 3 pixel array from the center of each lake. Individual overpasses were then aggregated to monthly means making use of a robust locally weighted regression technique (Cleveland, 1979) to eliminate outliers and fill data gaps (periods with high cloud coverage). The anomalies were calculated as the deviation from the monthly mean temperatures of the whole record.

## Conclusions and outlook

- Simulation-based split-window approach, which accounts for local atmospheric variability, clearly improves accuracy of LSWT retrieval (compared to global SST products)
- Satellites and locations not displayed in figures show similar results
- Removing noise from thermal calibration data is a prerequisite of time series processing for NOAA-16 and prior satellites
- Time series (Switzerland) from 1989 – 2011 is available at http://rsgb.unibe.ch
- Expand presented approach to European lakes (within recorded swath)


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