Deriving Lake Surface Temperature Variations of an Alpine Lake using NOAA – AVHRR Data

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Abstract – An operational near real-time processing chain for NOAA-AVHRR data is used, from which lake surface water temperatures (LSWT) measurements based on a nonlinear sea surface (NLSST) algorithm are derived. The method used has been widely examined and the bias of the algorithm is around 0.5-1°C. As one of the potential applications, LSWT temperature variations for Lake Geneva situated for the year 2002 is presented. The result shows strong surface temperature variations on the annual time scale. Knowledge of these facts gives new insights and possibilities for modeling local scale meteorological phenomena like heat flux, energy budget and evapotranspiration. Using operational satellite-derived lake surface temperature can also improve numerical weather prediction models on local scales.

Keywords: Lake surface temperature, NOAA – AVHRR, operational application.

1. INTRODUCTION

Water temperature has a profound influence on the entire aquatic ecosystems as well as on a wide variety of human activities located around waterbodies. Continental lakes, such as those in the alpine region, contain a sufficient large volume and areal extent of water to exert a significant influence on local weather patterns (Livingstone, 2001). In addition, monitoring of climatological temperature conditions, temporal and spatial distribution of the lake surface temperature can be extremely valuable for different applications (Alsdorf, 2003). Up to now, there is no area-wide consistent temperature data set for the alpine lakes available. Only a few insitu measurements at points of opportunity are existing, which are not suitable to derive the temperature pattern properties of the entire lake surface.

Infrared sensors onboard the meteorological satellites NOAA – AVHRR are successfully used to monitor lake surface of the Great Lakes in North America (Schwab, 1999). In this paper we show a possible application of the NOAA – AVHRR sensor for operational LSWT mapping for a lake in the European Alps. This requires an advanced processing scheme with focus on automated geocoding with sub – pixel accuracy, including orthorectification to account for the complex topography.

2. METHOD

2.1 Data

Full resolution AVHRR data are read out in High Resolution Picture Transmission (HRPT) format at the receiving station of the University of Bern. These data are the starting point for the LSWT processing. The derived Level-1B data are then further radiometrically-corrected and calibrated in physical units at full instrument resolution as acquired. An orthorectification of the imagery is essential in an alpine region to overcome the displacement errors introduced by the topography. An automated procedure, which uses a terrain model based on the GTOPO30, was developed and implemented. To detect and estimate the LSWT of small lakes with a spatial extent of a few square kilometers, a feature-matching algorithm is used to geocode the satellite imagery with subpixel accuracy. Using piecewise linear mapping functions throughout the whole image carries out the rectification process.

2.2 Algorithm

In this paper the NOAA-16 sensor counts of noon passes in channels 4 (10.3-11.3μm) and 5 (11.5-12.5μm) are transformed to units of "brightness temperature", using the Planck black body function. The LSWT algorithm used is essentially the nonlinear SST (NLSST) according to (Walton, 1998), as modified by (Li, 2001) and described at (Oesch, 2003a):

$$\begin{aligned} NLSST &= a_1(ch4) + a_2(ch4 - ch5)(MCSST) + a_3(ch4 - ch5)(q) - a_4 \\ MCSST &= b_1(ch4) + b_2(ch4 - ch5) + b_3(ch4 - ch5)(q) - b_4 \end{aligned} \quad (1)$$

where NLSST, MCSST = nonlinear and multichannel SST
ch4, ch5 = Channel 4 and 5 brightness temperatures in K
a_1-a_4, b_1-b_4 = Coefficients according to NOAA's National Environmental Satellite Data and Information Service
q = ((secant of satellite zenith angle) –1)

Validation and feasibility of the AVHRR data for alpine regions is discussed in (Oesch, 2003b)

A lake - land mask according to the Pan-European Land Use and Land Cover Monitoring (PELCOM)(Mücher, 2000) dataset is used to determine the water bodies. To avoid mixed land and water pixel, an additional buffer distance of the size of one AVHRR pixel is applied to the shoreline.

To maintain high accuracy of LSWT algorithm, pixel viewed with an satellite zenith angle greater than 53° are omitted, since larger atmospheric path lengths leads to greater attenuation of surface emitted radiance. A day (sun zenith less than 75°) and night (sun zenith greater than 75°) threshold scheme is used to mask out cloud

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contaminated pixel additionally to the cloud mask as defined by CASPR (Key, 2002). During daytime, a gross IR test and visible cloud threshold test is performed: Pixels with channel 4 temperatures lower than 0°C or if the corrected albedo (albedo value divided by the cosine of the solar zenith angle) is greater than 10 percent are considered as cloud contaminated. The gross IR test is also used for night satellite imagery together with a test for low stratus clouds: The difference obtained when subtracting channel 3 temperature from channel 5 temperature must be less or equal -0.6°C. Finally, as (Schwab, 1999) suggested, pixel representing a standard deviation greater 3°C of the neighboring pixel and completely surrounded pixel by non valid data are rejected. The result is filtered with a 9x9 average filter to smooth any high frequency noise in the image.

3. RESULTS

The LSWT processing scheme discussed above was applied to 214 NOAA – 16 noon passes of the year 2002. As an example, the mean, minimum and maximum temperatures for Lake Geneva were determined. Lake Geneva is one of the major waterbodies in the European Alpine region. Covering an area of 581 km^2 and with a max depth of 310m, he has a significant influence on regional climatic conditions. As the southeast shore of Lake Geneva is surrounded by a mountain range with altitudes up to 2200 m.a.s.l., the orthorectification has to be accurate. In Fig. 1 the annual average temperature cycle for Lake Geneva is shown. From 214 data sets, the 89 covering more than 80% of the lake surface, are used for this study.

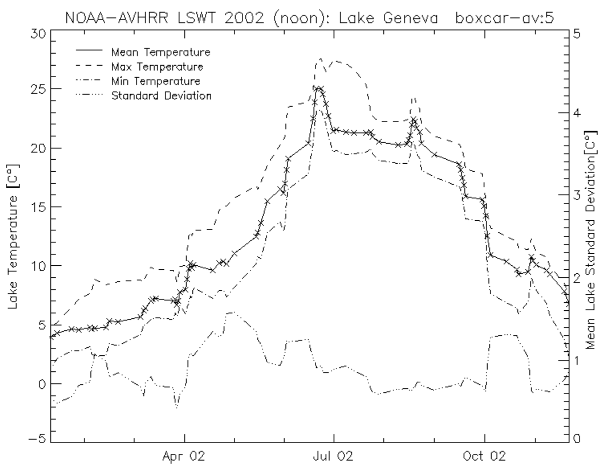

Figure 1. Lake Geneva mean, minimum and maximum average temperature for the year 2002. The spatial temperature variation is expressed by the mean lake standard deviation. The satellite data is smoothed with a boxcar average of the width of 5.

The cloud free lake-wide average temperatures curve in Fig. 1 is smoothed with a moving window filter of the size of 5. Maximum temperatures are reached at mid – June with values of 25°C for the lake wide mean and 27°C for the lake –wide maximum respectively. Absolute minimum temperatures are below 5°C in January, resulting in a LSWT oscillation of about 20° for the year 2002 for Lake Geneva. Rapid warming of the water body begins in April at a time when the temperature variation within the 581 km^2 of the lake surface is at the minimum of the year. The various parts of the lake are responding different to the warming period: the temperature inhomogeneity of Lake Geneva surface reaches its yearly maximum at the beginning of May, expressed by the standard deviation about 1.5°C. Another time period of strong non-uniform temperature distribution can be observed in fall, at the beginning of October. This can be explained with the weather system dominating this region usually at this period of year: autumn storms and alternate sunny days are influencing the upper layer of the waterbody.

The other process assumed to influence the temperature cycle is related to the internal annual circulation pattern, which is inherent to each lake. The Lake Geneva is situated in a temperate climatic zone, and therefore has a dimictic behavior: it usually mixes twice annually in the spring and in the fall. This mixing process, partly driven by global radiation and strong winds, alters the energy transfer process in the uppermost layer of the waterbodies, and can explain in this case strong variation of the LSWT.

4. CONCLUSIONS

One purpose of the implementation of a LSWT algorithm for NOAA - AVHRR imagery as stated above, is to gather information about the annual cycle of the water surface temperature for lakes. As discussed and shown above, concerning the spatial coverage and the consistency of AVHRR data, satellite images offer new possibilities to monitor LSWT phenomena.

Additional long-term LSWT analysis is necessary to understand the properties of the various lakes, such as the Lake Geneva, and determine the use of the AVHRR LSWT measurements. Especially to derive the diurnal development of the LSWT needs to take advantage of the temporal resolution of the NOAA - AVHRR. A composite technique has to be established to provide a continuous dataset throughout the year. Based on this, the derivation of climatological LSWT for lakes covering areas greater than 1km^2 can be done using AVHRR imagery. Taking advantage of the near real-time capabilities of the processing scheme, an implementation for assimilation in NWP is possible.

5. REFERENCES

D. Alsdorf, D. Lettenmaier and C. Vörömarty, “The need for global, satellite based observations of terrestrial surface waters” EOS Transactions American Geophysical Union, vol 84, no29, p269,275, 2003.

J.R Key, “The Cloud and Surface Parameter Retrieval (CASPR) System for Polar AVHRR - User's Guide,” Cooperative Institute for Meteorological Satellite Studies University of Wisconsin, 1225 West Dayton, Madison, WI 53562, 2002.

X. Li, W. Pichel, P. Clemente-Colón, V. Krasnopolsky, and J. Sapper, "Validation of coastal sea and lake surface temperature measurements derived from NOAA/AVHRR data," International Journal of Remote Sensing, vol22, no7, p.p.1285 – 1303, 2001.

D. M. Livingstone and M. T. Dokulil, "Eighty years of spatially coherent Austrian lake surface temperatures and their relationship to regional air temperature and the North Atlantic Oscillation," Limnology and Oceanography, vol46, no5, p.p.1220-1227, 2001.

C. A. Mücher, K. T Steinnocher, F. P. Kressler and C. Heunks, "Land cover characterization and change detection for environmental monitoring of pan-Europe," International Journal of Remote Sensing, vol21, no6&7, p.p.1159-1181, 2000.

Oesch, D., 2003a. "NOAA / AVHRR RSGB Sea & Lake Surface Temperature Data Set", Remote Sensing Research Group, Departement of Geography, University of Bern. http://saturn.unibe.ch/rsbern/noaa/dw/realtime/RSGB_AVHRR_SST.pdf

D. Oesch, A. Hauser and S. Wunderle, "Operational processing of NOAA - AVHRR data for mapping lake surface temperatures in an alpine environment: feasability and validation," SPIE International Symposium Remote Sensing 2003. SPIE, Barcelona, Spain, 2003b, *submitted*..

D. J. Schwab, G. A. Leshkevich and G. C. Muhr, "Automated Mapping of Surface Water Temperature in the Great Lakes," Journal of Great Lakes Research, vol25, no3, p.p468-481, 1999.

C. C. Walton, W. G. Pichel, J. F. Sapper and D. A. May, "The development and operational application of nonlinear algorithms for the measurement of sea surface temperatures with the NOAA polar-orbiting environmental satellites," Journal of Geophysical Research, vol103, noC12, p.p.27999-28012, 1998.