Available online at www.sciencedirect.com

SCIENCE DIRECT®

Global and Planetary Change 46 (2005) 9–27

GLOBAL AND PLANETARY CHANGE

www.elsevier.com/locate/gloplacha

Variation in Lake Baikal's phytoplankton distribution and fluvial input assessed by SeaWiFS satellite data

Birgit Heim[a,*], Hedi Oberhaensli[a], Susanne Fietz[b], Hermann Kaufmann[a]

[a]*GeoForschungsZentrum Potsdam GFZ, Telegrafenberg, 14473 Potsdam, Germany*
[b]*Leibniz Institute of Freshwater Ecology and Inland Fisheries, 12587 Berlin, Germany*

Received 1 November 2004; accepted 1 November 2004

Abstract

The current behaviour of selected climate proxies in Lake Baikal was assessed by remote sensing analyses of 'Sea viewing Wide Field of view Sensor' (SeaWiFS) satellite data. Suitable proxies include optically visible water constituents such as phytoplankton, suspended terrigenous matter and yellow substance. These limnological parameters reflect the present-day climate bioproductivity and the river discharge in the catchment area.

A biological and geochemical ground truth data set for Lake Baikal was established with the help of members of the paleoclimate project 'high-resolution CONTINENTal paleoclimate record in Lake Baikal' (CONTINENT). For processing the SeaWiFS satellite data, the atmospheric correction was adapted to the case of Lake Baikal. Chlorophyll as a proxy for phytoplankton was quantified using global NASA ocean colour algorithms OC2 and OC4. In cases of no optical interferences by terrigenous input, the calculated chlorophyll concentrations in clear pelagic waters were within ±30% accuracy with the CONTINENT cruise data during the summers of 2001 and 2002. Within this range of accuracy, the SeaWiFS time series will be able to show the seasonal variations of chlorophyll of specified bio-optical provinces of Lake Baikal and of CONTINENT sites. In this study, the suspended matter as a proxy for the terrigenous input was calculated according to an empirical algorithm using ground truth data in the time frame of flooding events in summer 2001. The approach chosen correlates the suspended matter concentration with the remotely sensed parameter of 'attenuation coefficient' to account for the organic-rich terrigenous input that originates from the swampy watersheds.

Seasonal and spatial information that is provided by the analyses of the SeaWiFS satellite data will assist paleoclimate researchers to interpret the autochthonous and allochthonous influences at the CONTINENT coring sites.

Keywords: Lake Baikal; Remote sensing; SeaWiFS; Chlorophyll; Suspended matter

1. Introduction

Within the 'high-resolution CONTINENTal paleoclimate record in Lake Baikal' (CONTINENT) Proj-

* Corresponding author. Tel.: +49 331 288 1191; fax: +49 331 288 1192.
E-mail address: biggi.heim@web.de (B. Heim).

0921-8181/$ - see front matter © 2004 Elsevier B.V. All rights reserved.
doi:10.1016/j.gloplacha.2004.11.011

ect, funded by the European Union, sedimentary records from several locations in Lake Baikal are exploited for high-resolution paleoclimate studies. The record of the CONTINENT sediment cores (spanning potentially 150,000 years) at three sites within the lake (Charlet et al., 2005-this issue) and the multiproxy approach of the project provide unique opportunities to understand the Late Quaternary climate history of the Earth. However, in order to interpret the biogenic and silico-clastic records in the paleosediments more comprehensively, the present-day formation of these climate proxies within Lake Baikal needs to be investigated. The interdisciplinary approach allows the examination of the present-day bio-limnological and geochemical conditions of Lake Baikal, as well the processes occurring in the water column and the catchment. Sequential sediment trap data from the South and North Basins, as well as field data provide information on the lake's phytoplankton and bioproductivity, on the terrigenous input into the lake and on the geochemistry.

The goal of this study is to show the potential of high spectral resolution satellite data to map the phytoplankton distribution and the terrigenous input into Lake Baikal.

Previous investigations on water clarity and suspended matter using operational satellite data were carried out, e.g. by Bukata et al. (1974), Klemas et al. (1974), Munday (1974), Munday and Alfoeldi (1979), or Lillesand et al. (1983). They used Landsat-Multispectral Scanner (MSS) data, but their research was restricted to turbid, eutrophic lakes. The challenge then was to extract not only relative turbidity, but to estimate the main phytoplankton pigment (chlorophyll; (chl-*a*)) from the satellite data of the Landsat sensors MSS, TM, and ETM+ (Yacobi et al., 1995; Mayo et al., 1995). While these land-focused sensors provide high spatially resolved information, the limited radiometric and spectral resolution of these sensors in the visible wavelength range are not suitable for analysing clear water bodies. The average errors of chlorophyll derivation in the case of land-focused sensors are high for existing algorithms, from ± 10 up to ± 20 $\mu g\ l^{-1}$ chl-*a* (Burgess, 2003). In cases that use advanced techniques such as the spectral unmixing method in the Mecklenburg Lake district (Germany) (Thiemann and Kaufmann, 2000), the accuracy range is about ± 10 $\mu g\ l^{-1}$ chlorophyll.

Due to the limited spatial resolution (1 km^2 per pixel) of the first ocean colour sensor, the Coastal Zone Scanner (CZCS), launched in 1987 by NASA, water quality monitoring strategies for inland water bodies are mainly based on hyperspectral airborne scanner data. Hyperspectral approaches provide lake maps of water clarity, suspended matter concentration, chlorophyll, and dissolved organic carbon (DOC) concentration (Dekker, 1993; Heege, 2000; George and Malthus, 2001; Kallio et al., 2001; Keller, 2001; Koponen et al., 2002; Thiemann and Kaufmann, 2002; Kloiber et al., 2002). The chlorophyll algorithms for these generally eutrophic inland water bodies are principally based on the stable and significant reflectance features in the red and the near-infrared wavelengths. In contrast, the water-leaving radiances of clear water bodies are naturally restricted to the blue and the green wavelength range due to the reduced contribution of scattering processes on particles (i.e. phytoplankton, detritus, minerogenic particles). The red to near-infrared algorithms used for water quality investigations of eutrophic lake water bodies are therefore not applicable for clear water bodies, such as Lake Baikal.

The marine chlorophyll algorithm development for oligotrophic, pelagic waters (Morel and Gordon, 1980; Gordon and Morel, 1983; Stumpf and Tyler, 1988; Gitelson et al., 1994) is performed with radiometrically highly resolved ocean colour satellite data, supported by high spectral resolution in the blue and green spectral regions. The chlorophyll algorithms were designed for clear pelagic 'case 1 waters' (Jerlov, 1978), in which the phytoplankton is the main optically relevant component, and other water constituents such as suspended matter and yellow substances are low in concentration and directly correlated with the chlorophyll concentration. New powerful generations of high spectral resolution satellite sensors with a very high radiometric sensibility (SeaWiFS (NASA), MODIS (NASA), MERIS (ESA)) were launched in the late 1990s. Recent investigations (e.g. Moore et al., 1999; Ruddick et al., 2000; Koponen et al., 2002) focused on the optically more complex waters, 'case 2 waters' (Jerlov, 1978), in which the optically important water constituents may not be correlated, such as in coastal waters and semi-enclosed seas and large inland water bodies. So, while experimental