MONITORING WATER LEVEL AND WATER QUALITY OF LAKES MACRO PRESPA AND OCHRID USING RADAR ALTIMETRY AND MERIS DATA

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ABSTRACT

Having and maintaining suitable water quality is critical to sustain life on our planet. Various conventions have been established for the Protection and Use of Trans-boundary Watercourses and International Lakes. Monitoring of water quality / quantity using remote sensing, in conjunction with strategic in situ sampling can play a crucial role in determining the current status of water quality / quantity conditions and helps anticipate, mitigate and even avoid future water catastrophes. The objective of this work is to assess the performance of radar altimetry and MERIS data for the environmental monitoring (water level and water quality) of the lakes Macro Prespa and Ochrid. It is indicated that integrated satellite / GIS techniques can be used for spatiotemporal monitoring purposes of lakes.

1. INTRODUCTION

International conventions aim to strengthen national measures for the protection and ecologically sound management of trans-boundary surface waters and groundwater and establish concrete procedural obligations of cooperation between littoral states for the protection and management of these water bodies. They also include provisions for monitoring, research and development, consultations, warning and alarm systems, mutual assistance, institutional arrangements, and the exchange and protection of information, as well as public access to information.

The Prespa / Ochrid pilot project region is situated in the Balkan Peninsula, in southeastern Europe, at the borders between Albania, Greece, and the FYR of Macedonia, Fig. 1. The Macro & Micro Prespa Lakes, are shared between Albania, FYR of Macedonia and Greece and they are one of the most valuable lakes of Europe in terms of biodiversity. The entire Prespa basin has also been declared a trans-boundary protected area, with the establishment of the "Prespa Park" by the Prime Ministers of Albania, Greece and the FYR of Macedonia on 2 February 2000. According to the Strategic Action Plan for the sustainable development of the Prespa Park, which lays down the jointly agreed targets of trilateral cooperation in Prespa, gaps in knowledge of the system's main features and governing processes need to be filled as a matter of priority, while major and environmentally adverse past interventions or current practices need to be restored to the extent possible or changed [5]. Lake Ohrid is shared between Albania and FYROM. It is the oldest lake in Europe and one of the oldest in the world [6]. Its origin is tectonic, and it is suggested to be created 4-10 million years ago.

The pilot study area is quite mountainous and it includes the Micro / Macro Prespa lakes at an altitude of 850 meters and Ochrid lake at an altitude of 695 m a.m.s.l. [8]. A natural communication exists between the two Prespa Lakes where water flows from Micro to Macro Prespa Lake. The three lakes constitute a common hydraulic system. The elevation of the study area lies within 849 and ~2290 m with the highest elevations being observed in the NW part of the catchment. Mali i Thate mountain with the highest peak at 2287 m in Albanian territory and Galichitsa mountain with the highest peak 2251 m in FYR. of Macedonia territory are separating Ohrid from Prespa Lakes. These two mountains belong to the same geological system and are composed of carbonate karstic rocks.

Water resources management requires sufficient, long-term, frequent and reliable data. Accordingly, it is necessary to reorganize the existing networks, using new technologies. Available measurements of water levels, discharge, suspended solids and water quality no longer satisfy new demands, as they are subject to change. It is now necessary to collect data faster, more frequently and more reliably. An assessment of various remote sensing techniques has been included in the study.

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Figure 1. Overview of pilot study area of Prespa / Ochrid lakes.

Up to date information seems to be lacking or its access is difficult in the Prespa / Ochrid region. There are recommendations for priority data collection (meteorological data on higher elevations, snowfall data, flow gauges, sediment load, ground water level and water quality [5]). Remote sensing techniques have been applied in order to fill the existed lack of information. In order to achieve the purpose of the analysis various types of satellite data have been used that includes images from optical sensors in various resolutions as well radar satellite systems. Main objective of this study is the assessment of the performance of radar altimetry and MERIS data for acquiring selected parameters (water quality / quantity – water levels of lakes) that are related to the state of trans-national lake ecosystems. The methodology includes mapping and scientific processing and analysis of various data, and application of satellite image processing as well as radar altimetry techniques.

2. APPLICATION OF GIS TECNHIQUES

GIS techniques are used in processing multiple data that are of concern to a lake water assessment project. The application of GIS techniques includes the formulation of a data inventory after the acquisition of topographic maps, compilation of geological and hydro-geological maps based on analysis of relevant data, compilation of digital elevation model for the area of interest based on satellite data and available maps. It also includes the acquisition of various hydro-meteorological data when available. On the basis of available maps and satellite data, digital elevation models are used in order to delineate the basic sub-catchments of the Prespa basin as well as the irrigation network in the area, Fig. 2. The characteristics of the basin as well as the statistical quantities of its hydrographic network have also been estimated. Finally the Corine land cover map for the whole of the basin has been included in the inventory.

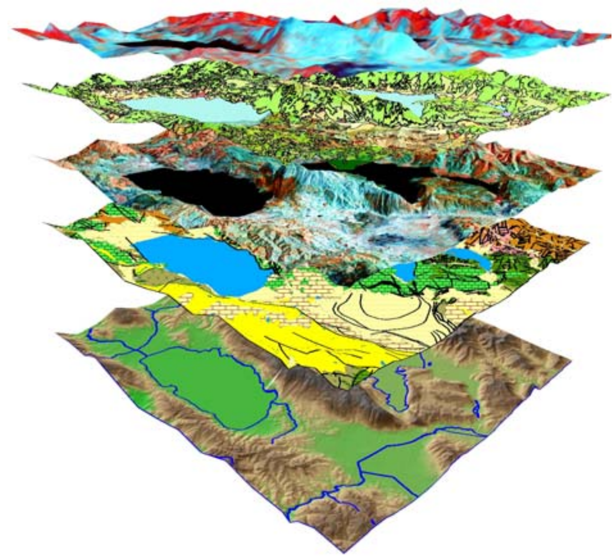


Figure 2 Selected GIS maps of Prespa / Ochrid lakes

Processing techniques that have been applied include integrated image processing / GIS vector data techniques. The BEAM software has been used to read and process the MERIS images and to export data into Geo-Tiff format. All data have been imported to TNTmips V 7.4 which supports fully integrated GIS, image processing, CAD, TIN, Desktop cartography and geospatial database management tools. Geometric and radiometric corrections were performed on the satellite images in order to prepare them for further processing and analysis. When necessary, data have been re-projected into the local Greek Geodetic system georeference-Egsa 87. For MERIS data georeferencing has been made using the tie-points provided with the images. Combination of different resolution data using data fusion techniques proved to be effective as far as the land cover and the interpretation of geologic features are concerned because complementary information for the same target is combined. The optical satellite data are used for mapping land cover / use and the assessment of land cover changes as well as monitoring water quality parameters. Up to date information of land use, land cover, vegetation status and their changes over time (e.g. seasonally) is important for the understanding and modeling of hydrological processes such as infiltration, water needs etc. Space borne sensors can provide such information, at different levels of spatial and thematic details-resolution, [4]. A land use/cover classification for the broader area of the Macro Prespa lake is performed using ENVISAT MERIS Full Resolution data. Land cover changes are detected due to forest fires and change of land use Fig. 3.

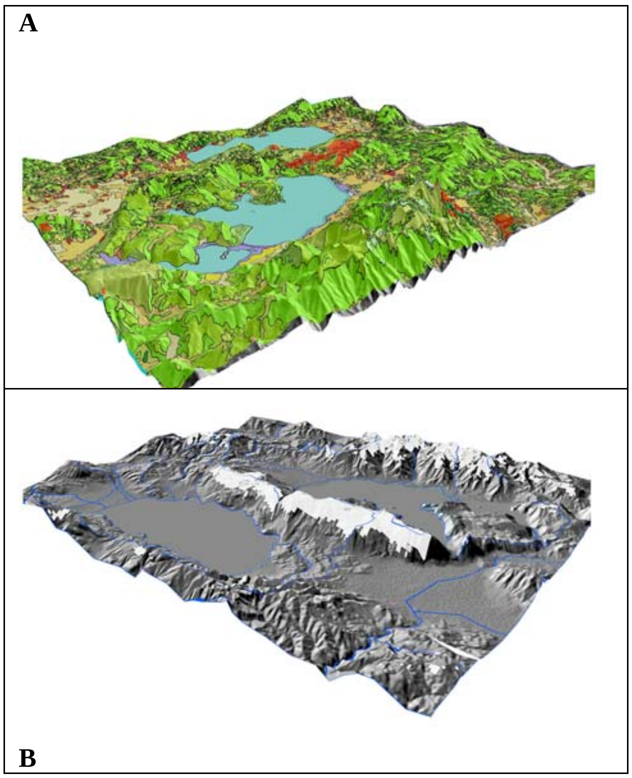


Figure 3 Land cover information extracted from MERIS data: A. Burned areas from forest fires. B. Snow cover

Different estimates of the surface area of Macro Prespa lake are provided in various publications [8]. We performed a satellite based surface lake estimation, Table 1.

Source	Macro Prespa	Micro Prespa	Ochrid lake
Landsat TM (1998)	273.70 km^2	40.13 km^2	355.6512 km^2
Landsat ETM (2000)	265.26 km^2	40.13 km^2	355.5853 km^2

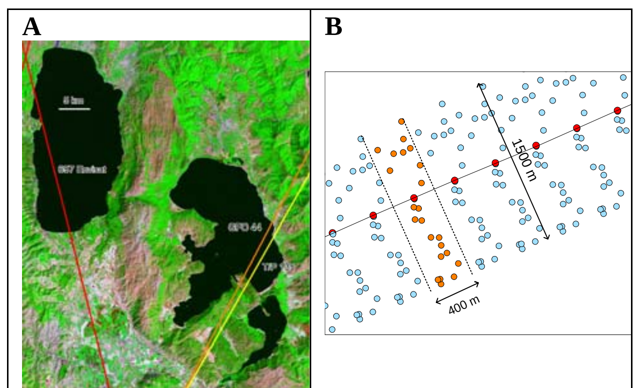
Table 1 Surface area estimation based on the analysis of satellite images

The Macro Prespa lake has lost nearly 10 Km^2 of its surface due to a drop of the water level during the last 20 years. The GIS database has been informed by the land cover classification of MERIS data. Temporal changes can be detected.

3. RADAR ALTIMETRY

Lake water level data appears to be the only parameter with ample availability of measurements in the specific case study area and it should be kept as consistent as possible. However, almost constant differences are noted when Greek and Albanian records were compared, indicating disparities in the associated datum [5]. Access to measurements is not well established. An experiment has been completed for the characterization of the quality of water level time series reconstructed from sampled satellite measurements observed by TOPEX/Poseidon New Orbit (TPNO) and by ERS-2 or Envisat.

We have used ENVISAT track 657 (cycles 10 to 68, October 2002 to May 2008) for Ochrid lake and Geosat Follow-On (GFO) track 44 (cycle 37 to 201, September 2000 to May 2007) and TOPEX/Poseidon new orbit (TPNO) track 135 (cycles 368 to 445, September 2002 to October 2004) for Macro Prespa lake (Fig. 4).



A: Overview map of Ochrid and Macro Prespa lakes. Red line - ENVISAT track, Orange - GFO and yellow - T/P. Background - Landsat image circa 1990 (MrSID image server)

B: Sample of spatial distribution of 18 Hz Envisat measures (cycles 10 to 36). Data from cycle 20 have been chosen as reference points (red dots). Dashed line – boundaries for one reference point.

Figure 4. Geographic selection and spatial referencing of altimetry data

In order to minimise potential contamination of the altimetric signal by land reflections, and at the same time to retain a sufficiently large number of altimeter measurements on water, we performed a geographical selection of the data. We used GeoCover™ Landsat Thematic Mapper orthorectified mosaics with 28.5 m pixel size available from the MrSID Image Server to select the most appropriate intersections of water bodies and satellite tracks. We use data that provide the highest possible along track ground resolution, such as 10 Hz data for T/P and 18 Hz for ENVISAT (distance between adjacent altimetric observations is about 600 and 400 m, correspondingly)

In order to precisely analyse spatial and temporal variability of altimetric measures, we need to refer all altimetric measures to the common spatial reference points. As orbit changes across track are much larger than the distance between high-frequency altimetric measures (for example, for ENVISAT across-track changes are 1500 m, while distance between 18 Hz measures is about 400 m, Fig. 4), use of latitude or longitude values for study of temporal and spatial changes would be misleading. A viable solution is to choose a set of unique reference points. This is done by arbitrarily choosing one cycle and defining all high-frequency points in this cycle as the reference points for all other cycles (see Fig. 4). By choosing boundaries as lines located halfway between reference points and perpendicular to the satellite track, we refer all points that fall between these two boundaries, to the chosen reference point.

Both lakes are surrounded by terrain with highly variable topography and mountains with height more than 2000 m. The behaviour of radar altimeter in these conditions often become unstable, and this requires rigorous quality control of the obtained measures. After performing initial geographical selection we have then selected only those reference points that are not affected by mountains and have low dispersion of observations (difference between 3rd and 1st quartiles, or IRQ lower than 900 mm). Then median values for each cycle and for each reference point has been estimated. For ENVISAT we have used range estimates using ice2 retracker that is more robust for the complicated tyes of terrain. We have used in situ observations from Ochrid (693.17 m asl) hydrological station in Ochrid lake and PUSTEC (Liqenas) – Albania and STENjE (847,68 m asl) – FYROM hydrological stations in Macro Prespa lake [1, 5].

For Macro Prespa lake GFO observations were not regular, and provided too high temporal variability (up to 5 m). As a result, they were all discarded as not reliable (GFO data has in general poor quality over small continental water bodies). For TPNO situation is better that for GFO , but nevertheless there are many cycles with very few (2-4) observations. T/P uses only one retracker - Ocean - which is not adapted to continental surfaces. Though in general TPNO observations follow the same pattern as Stenje data, even after geographical selection and quality control, they still look noisy with variations of up to 1.2 meter and difference from in situ observations up to 40-60 cm, Fig. 5. For Ochrid lake (Fig. 6) ENVISAT data provide much reliable observations. This is partly related to longer intersection between satellite track and water surface than for Macro Prespa lake, but mostly to higher sensitivity and robustness of Ice 2 retracker. For some ENVISAT cycles estimates of water level have not been made due to quality control. Difference between the two time series can be up to 15-20 cm, apparently due to land influence on altimetric signal, but in general both in situ and altimetric observations are in very good agreement.

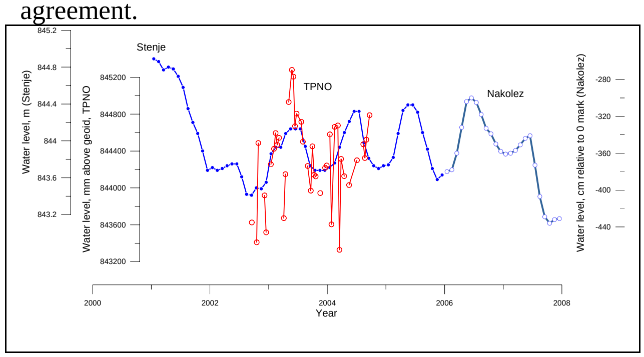


Figure 5**.** *In situ (blue line and small dots for Stenje station and dark blue line and open circles for Nakolez station) and altimetric TPNO (red line with open circles) water level time series for Macro Prespa lake. Though absolute values differ for Y axis, vertical scales are identical.*

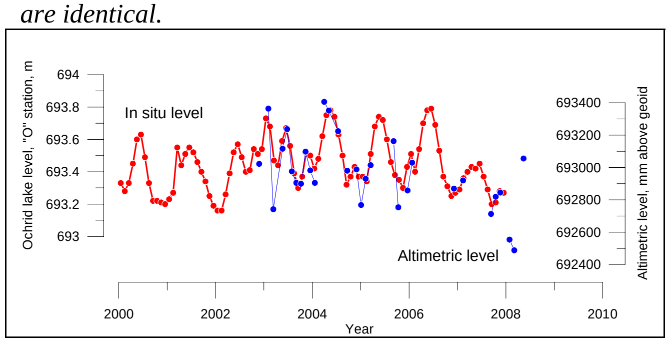


Figure 6. In situ (red line and dots) and altimetric (blue line and dots) water level time series for Ochrid lake. Though absolute values differ for Y axis, vertical scales are identical for both.

4. WATER QUALITY OF LAKES

Traditional monitoring of water quality as well as other environmental parameters involves specialized personnel and both on site and laboratory analysis. Such procedures impose considerable implementation budget and data are not always accessible by the public. Water quality parameters of the lakes can be retrieved from remote sensing. In this work MERIS Data area have been used for the assessment of spatio-temporal variability of selected water quality parameters like turbidity, suspended solids and algae or chlorophyll concentration. Using the BEAM VISAT software various water quality parameters have been calculated [2] and results are shown in Fig. 7.

Trophic state of Lake Prespa during 1992 alternated between oligotrophic and mesotrophic state [7]. For the ten years period, trophic state of the Lake was significantly changed and all of the investigated parameters indicated that Lake Prespa is in process of eutrophication [6]. It has been observed that both the development of anoxic conditions in the bottom water and the increases in sedimentary P, as well as the linear lake phosphorus balance, point towards a eutrophication of Lake Prespa. The main anthropogenic factor influencing Lake Prespa is agricultural development and in particular the abstraction of water, application of fertilizers, and increasing soil erosion. Lake Ochrid is classified as oligotrophic but this condition is threatened due to uncontrolled discharge of urban wastewaters and nutrients, especially phosphorous. The agriculture activities in the watershed are also the biggest potential contributors of nitrogen, and pesticides, discharged in the lake. Even there are no systematic studies, pesticides are found in the livers and fish tissues of different fish species of Lake Ohrid [7].

Chlorophyll *a* concentration and Secchi depth are the most significant measures of the lake trophic state. A highly significant, strong inverse correlation between Secchi depth and chlorophyll *a* concentration has been determined in the surface water of Lake Prespa [6]. It has been indicated that lake transparency mostly depends on chlorophyll *a* content in other words on phytoplankton biomass. Also in Lake Prespa a significant inverse correlation between chlorophyll a and TN:TP ratio has been determined [3]. It indicate that TN:TP ratio is related with the lakes trophic state and it decreases if the lake is in process of eutrophication.

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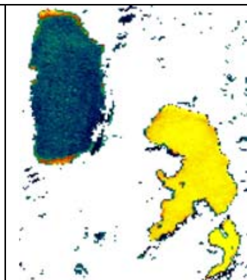

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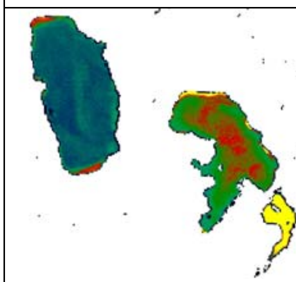

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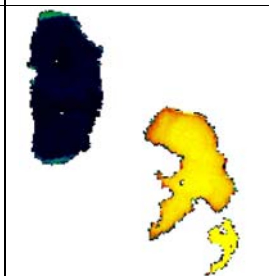

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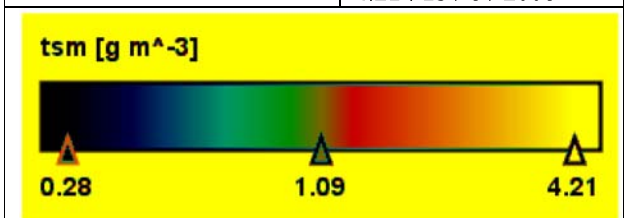
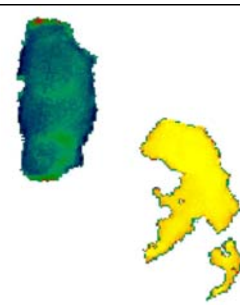
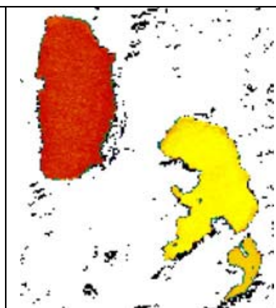




A Chl_Conc [mg m^]$^{-3}$0.07 to 6.67: 21 / 8 / 2007



B Chl_Conc [mg m^]$^{-3}$ 0.02 to 13.56 : 15 / 2 / 2008

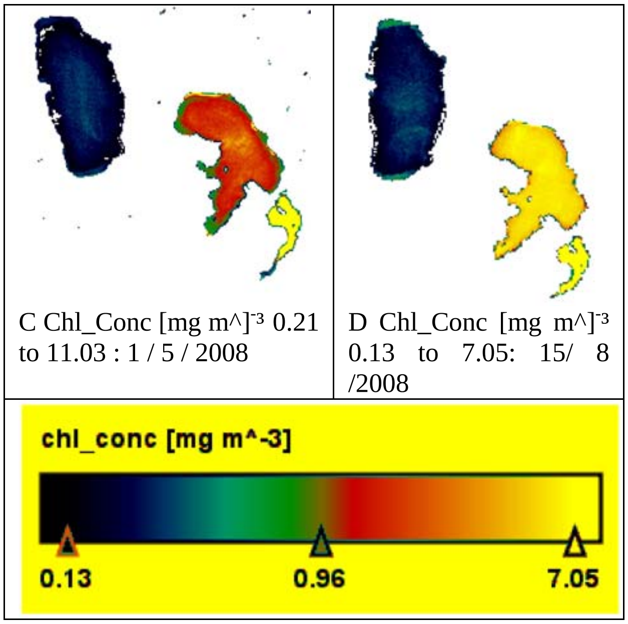


Figure 7 Water quality parameters of the lakes of the pilot study area.

Water quality parameters can be obtained after the processing of MERIS data and this is in accordance to reference measurements available. The oligotrophic state of Ochrid lake as it is contrasted to the nearly eutrophic state of Prespa lakes can be interpreted in images of Fig.7. Also annual / seasonal temporal variations can be interpreted, Fig 7. Cloud cover has limited the application of monitoring the water quality parameters while another limiting factor is the coarse sensor resolution.

DISCUSSION

All data provided by the satellite observations have been used to update information stored in the GIS data base. Remote sensing provides valuable information concerning different hydrological parameters of interest to a transnational river basin assessment project. Monitoring is supported due to the multi-temporal character of the data. Water quantity / quality assessments can also be performed. The methodology is cost effective and if it is to be used in conjunction with in situ observations and hydrological modelling, these observations from space have the potential to significantly improve the understanding of hydrological processes affecting lake basins in response to climate variability. The combination of data from different sources linked by the powerful prospects of new Earth Observation techniques can be used for supporting policies like the EU 2000/60 Water Framework Directive which, as agreed by the three countries, the integrated water management in the Prespa Park area as a whole, has to be built on its principles. It is indicated that integrated satellite / GIS techniques can be used for spatiotemporal monitoring purposes of lakes.

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