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SEA SURFACE TOPOGRAPHY IN THE GULF OF PATRAS AND THE SOUTHERN IONIAN SEA USING GPS

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Abstract

The topography of the sea, which is changing continuously mostly due to tides, meteorological forcing and climatic changes, is very poorly known in both regional and global scale. In our work we apply a new method, "GPS-on boat", based on differential (DGPS) or kinematic GPS for the recording of the Sea Surface Topography (SST) in the Patras Gulf and the southern Ionian Sea. Analysis of data collected permitted to compile a first map of Sea Surface Topography in the study area. The application of the methodology that we present seems also quite promising for the accurate determination of the Geoid in coastal areas, in which other methodologies provide lower quality results.

***Key words:** GPS, Sea Surface Topography (SST), Geoid, GPS-no boat, Ionian Sea.*

1. Introduction

Sea Surface Topography (SST) roughly coincides with a surface of constant gravity, the geoid, representing the zero level for height measurement on land. The S.S.T. is usually poorly known, especially in closed gulfs and near-shore areas, which are not properly covered by satellite data merely focusing on oceans. The knowledge of the topography of the sea is important for various reasons, including geophysical (gravimetry-related) studies, meteorological models and climatic change studies. In the past, models of the geoid and the mean sea level for Hellenic area have been presented (Tziavos and Andritsanos, 1999; Andritsanos el al., 2000, Pavlis and Mertikas, 2004).

This paper summarizes results of a first attempt to measure SST along certain traverses in the Ionian Sea and the Patras Gulf using GPS, in particular the method GPS-on-boat. GPS have been widely used for geoid determination on land (Fotopoulos et al., 2000), but the on-boat application are new.The details and results of this technique, which may provide optimum results at coastal areas and semi-closed gulfs, are presented below.

2. Methodology

The method of 'GPS-on boat' is based on kinematic GPS (Smith, 1997), the simultaneous tracking of satellites by a moving ("rover") receiver and by one or more stable ("base") receivers on stable ground. The apparent changes of the position of the base receiver permit corrections to the computed coordinates of the rover receiver. This technique requires that both receivers are at relatively short distances, usually up to a few or a few tens of km, so that ambient conditions are quasi-similar, and

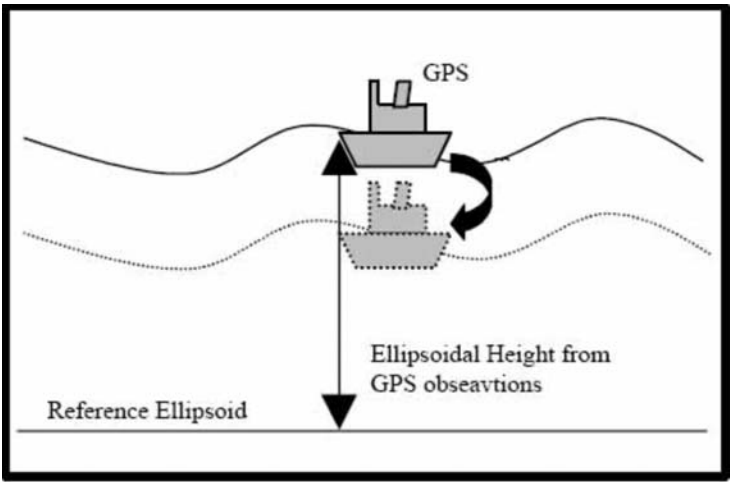

Fig. 1: The "*GPS- on boat*" methodology. The rover GPS receiver calculates directly the instantaneous elevation of the boat relative to the reference ellipsoid. Filtering of the short-term effects (fluctuations of the sea-level shown as two different levels) permits an accurate elevation of the SST along the boat track.

may permit up to mm level accuracies (Nickitopoulou et al., 2006). In longer distances, this error maybe of the order of tens of cm (Psimoulis et al, 2007), although there is the possibility of high accuracies at distances >100km (Kashani et al., 2005).

In our study the rover GPS was mounted on a boat which was sailing on the sea-surface, and the computed coordinates were corrected using recordings from base stations on land. Apparently, the elevation of the rover receiver was reflecting the instantaneous position of the rover receiver in reference to the ellipsoid (Fig. 1). This elevation represents the juxtaposition of the SST elevation along the boat track, noise introduced by waves and other meteorological events, elevation differences introduced by tilting of the boat and measurement errors.

However, waves are transient effects usually with a period of a few seconds, the track of sailing boats is relatively smooth but with a zigzag pattern, while the tilt of the boat can be recorded during the sail. Hence, sampling of satellite signals at a rate of 15 second and filtering of the instantaneous coordinates of the rover using statistical approaches permit to minimize all these sources of noise and obtain filtered coordinates, with the vertical coordinate describing the SST with accuracy better than 15cm.

3. Data

The experiment was conducted from 25 June to 3 July 2008. A Topcon HipperPro type GPS receiver was mounted on a 43ft long sailing boat sailing has been used. The sampling rate of the rover and of base receivers was 15sec. In addition, weather data (intensity and wind direction, the atmospheric pressure, temperature and moisture), as well as the slope of the boat were systematically collected throughout the experiment.

4. Analysis

Kinematic coordinate recordings from each traverse were analyzed in combination with recordings from the nearest base stations using the PCCDU and Pinnacle software. In certain cases (boat in

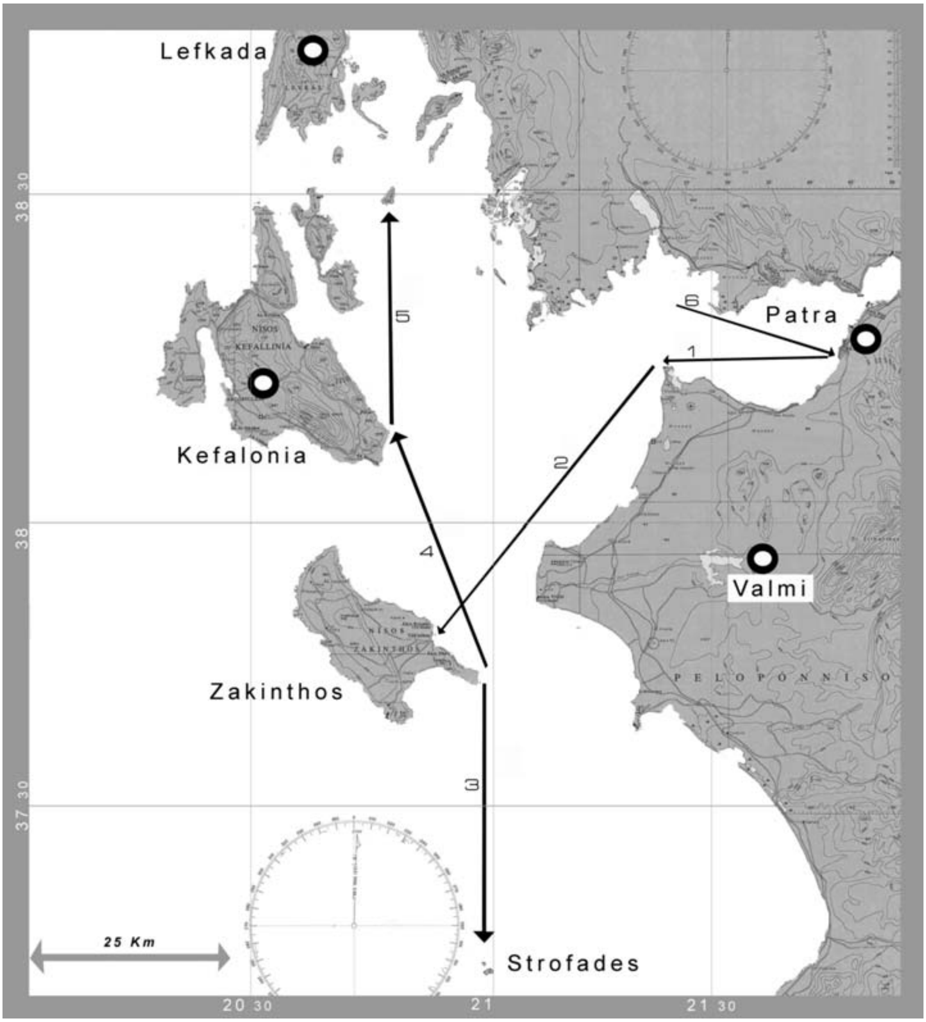

Fig. 2: General map illustrating six (6) different routes of scanning the surface of sea and geodetic GPS base stations. These stations are located at the University of Patras, the Village Valmi, Lefkada and Kefalonia.

harbour) mean values of sea-level elevations were obtained. Finally, the elevation of the rover receiver above the water was subtracted.

Obtained records were characterized by various types of noise, as shown in Fig. 3. This noise was removed adopting the following procedures:

(1) outliers were removed.
(2) systematic offsets with amplitude of tens of cm, sometimes characterizing GPS data for intervals of up to 10min long (see Nickitopoulou et al., 2006), were corrected.
(3) scatter in data revealing random noise was removed using a moving average filter.

In addition, tidal corrections, of small magnitude in the area (<10cm) were also made, and mean values of elevation along straight lines (instead of zigzagged lines of the boat track) were computed.

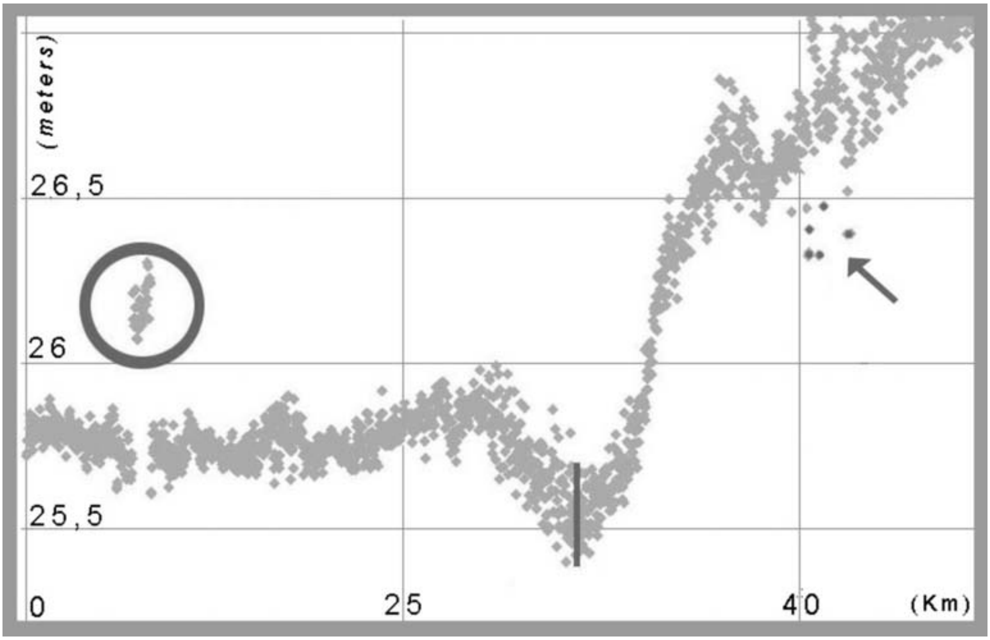

Fig. 3: Recordings of the boat elevation relative to the ellipsoid indicating several types of noise: random (a spread of data), systematic (a systematic offset marked by a circle) and outliers (marked by an arrow). Extract from the June 28th 2008 record.

Following this filtering and correction process, a final set of coordinates of the boat position was available. These coordinates indicate the SST elevation along the traverses. The mean sea surface elevation error was smaller than 15cm. This is due to the imperfections of the atmospheric model as well as to the large distance of GPS base stations from the mobile GPS (Genrich and Bock, 2006) and the multi-reflection of the signal (Leandro, 2009). This analysis is, however, preliminary, and can be repeated using data from additional base stations and different atmospheric models (Kashani et al., 2005) to obtain accuracies one order higher.

5. Sea Surface Topography Maps

Figure 4 illustrates the mean elevation of the sea along six traverses. The contours define the Sea Surface Topography around the traverses. These results indicate a smooth drop of the topography and the geoid in the Patras gulf and the southern Ionian Sea. Moreover, these are consistent with the geoid maps of the broader regions derived using other methods (Andritsanos et all, 1995; Cocard et all, 2002).

6. Discussion

The technique presented above provide high accuracy results and resolution maps of the geoid and of the Sea Surface Topography, especially in closed waters not covered by satellite data. The accuracy claimed of 15cm is an upper level of the method, and it can be reduced using data from other GPS base stations (e.g. Strophades islands) and more refined models. The method proposed is rather expensive because it requires data collected by boats. However, its accuracy can be much higher and using interpolations may provide detailed maps of the SST for different users.

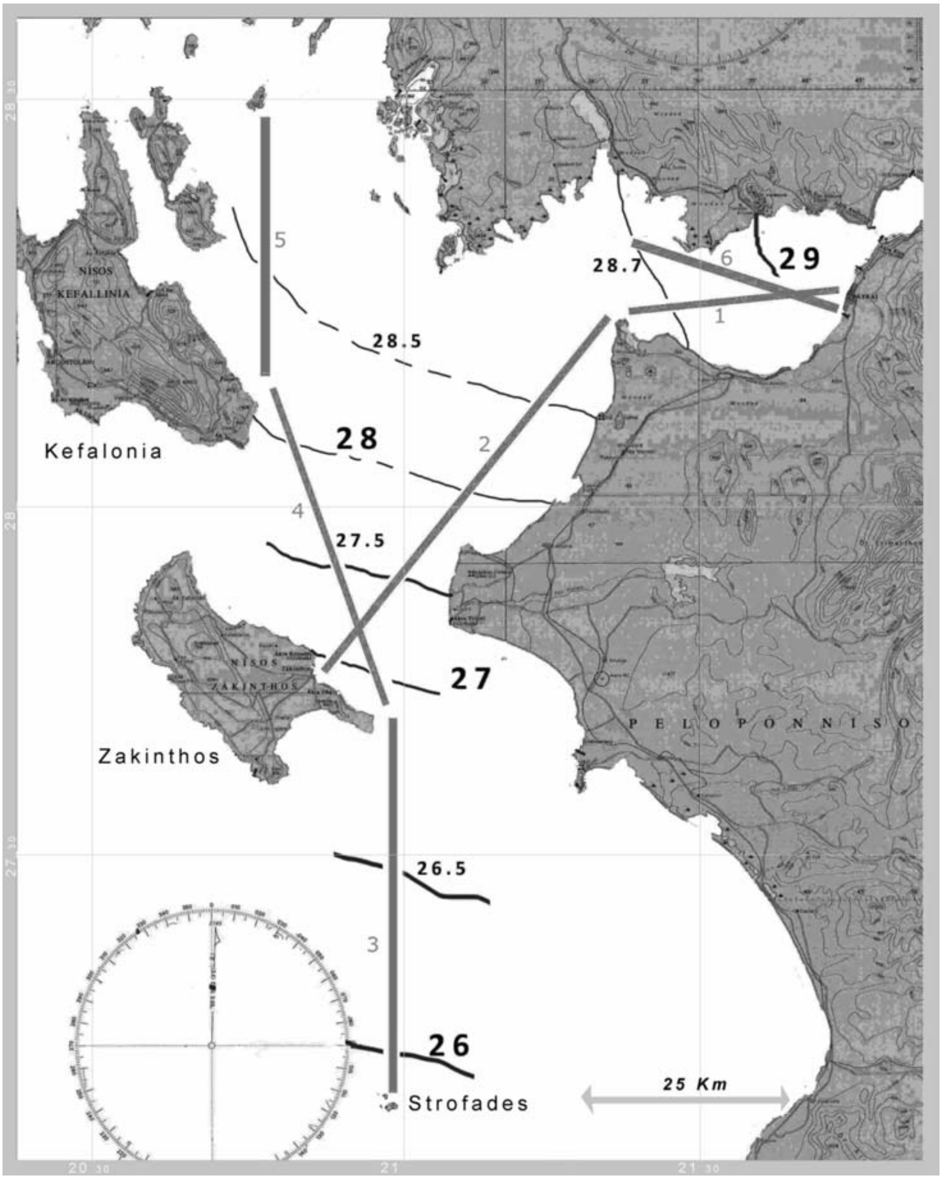

Fig. 4: Sea Surface Topography contours along six traverses.

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