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Technical Note: Remote sensing of sea surface salinity using the propagation of low-frequency navigation signals

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Abstract

This paper introduces a potential method for the remote sensing of sea surface salinity (SSS) using measured propagation delay of low-frequency Loran-C signals transmitted over an all-seawater path between the Sylt station in Germany and an integrated Loran-C/GPS receiver located in Harwich, UK. The overall delay variations in Loran-C surface waves along the path may be explained by changes in sea surface properties (especially the temperature and salinity), as well as atmospheric dynamics that determine the refractive index of the atmosphere. After removing the atmospheric and sea surface temperature (SST) effects, the residual delay revealed a temporal variation similar to that of SSS data obtained by the European Space Agency's Soil Moisture and Ocean Salinity (SMOS) satellite.

1 Introduction

Sea surface Salinity (SSS) plays a fundamental role in the density-driven global ocean circulation and the water cycle. The latest remote sensing SSS products include the European Space Agency's Soil Moisture and Ocean Salinity (SMOS) satellite (Reul et al., 2013), NASA's Aquarius satellite (Lagerloef et al., 2013). This study attempts to explore a different approach, by measuring the propagation delay of low-frequency ground waves transmitted over a path that consists entirely of seawater. For an all-seawater path, we expect sea surface salinity (SSS) to have a predominant effect on the delay variations.

The 100 kHz Loran-C transmitters in Western Europe, primarily used for marine navigation in European and Arctic waters, have a long history of development. At the frequency used by these transmitters, the propagation of radio signals occurs in two ways. The surface wave component follows the curvature of the Earth, while the sky wave component propagates through multiple reflections between the ground and the ionosphere.

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The propagation velocity of the Loran-C surface wave may be influenced by the refractive index of the atmosphere and the electrical conductivity of the Earth's surface. The atmospheric delay, known as the primary factor (PF), is determined from the refractive index, η. The amount of time by which the delay is increased due to propagation over seawater is called the secondary factor (SF).

PF and SF are often computed with the assumption that η and the conductivity of seawater are both constant. By using the GPS as reference, it is possible to measure the actual variations in Loran-C delay over an all-seawater delay, which may be attributed to atmospheric and sea surface dynamics.

2 Analysis and results

The variations in Loran-C propagation delay between the Sylt Loran-C station in Germany and Harwich, UK, were computed by an integrated Loran-C/GPS receiver. The temporal resolution of this data is 30 min, and it was measured from February 2010 to July 2011. A 24 h filter was applied in order to remove any daily variations which are unlikely to be due to SSS.

Atmospheric data fields, including 2 m temperature, surface pressure and total column water vapor, were retrieved from the European Centre for Medium-Range Weather Forecasts (ECMWF) Interim Reanalysis at $1^\circ \times 1^\circ$ spatial resolution (Gaussian grid) and 24 h temporal resolution. These were used to compute the PF, whose variations were removed from the measured Loran-C delay variations. The equations used are as follows (Skolnik, 2008; Lo et al., 2009):

$$N = \frac{77.6p}{T} + \frac{e_s \times 3.73 \times 10^5}{T^2} \tag{1}$$

$$N = (\eta - 1) \times 10^6 \tag{2}$$

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$$\mathrm{PF} = \frac{d}{\left(\frac{c}{\eta}\right)} = \eta\frac{d}{c} \tag{3}$$

where N is the refractivity, T is the atmospheric temperature (in K), p is the pressure (in millibars), e_s is the partial pressure of water vapor (in mbar); d is the length of the propagation path and c is the speed of light in free space.

Sea surface temperature (SST) was retrieved from the ECMWF at the same spatial and temporal resolution. The SST delay shown in Fig. 2 is based on the assumption that across the 560 km path, a 1 K increase in SST represents a 5.6 ns decrease in Loran-C delay (i.e. $1\,\mathrm{ns}\,(100\,\mathrm{km})^{-1}\,\mathrm{K}^{-1}$). The SST delay was also removed from the measured Loran-C delay variations. This leaves a residual delay which shows a variation pattern similar to that in SSS observed by SMOS ($1^{\circ} \times 1^{\circ}$ Cartesian grid, monthly) during the same period. In Fig. 3, the residual Loran-C delay was inversed to reflect variations in the conductivity of seawater.

3 Conclusions

This paper describes a novel method which has the potential to provide SSS estimates. The idea is that across an all-seawater path, the variations in the propagation delay of low-frequency signals can reflect changes in atmospheric and sea surface properties. When the effects from the atmosphere and SST were removed from the measured Loran-C delay variations, the residual delay shows good agreement with satellite SSS observations.

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SMOS Ocean surface salinity was distributed in netCDF format by the Integrated Climate Data Center (ICDC, http://icdc.zmaw.de), University of Hamburg, Hamburg, Germany. We would also like to thank to ECMWF for the Interim Reanalysis data.

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Figure 1. Loran-C propagation path between Sylt and Harwich (image from Google™ Earth).

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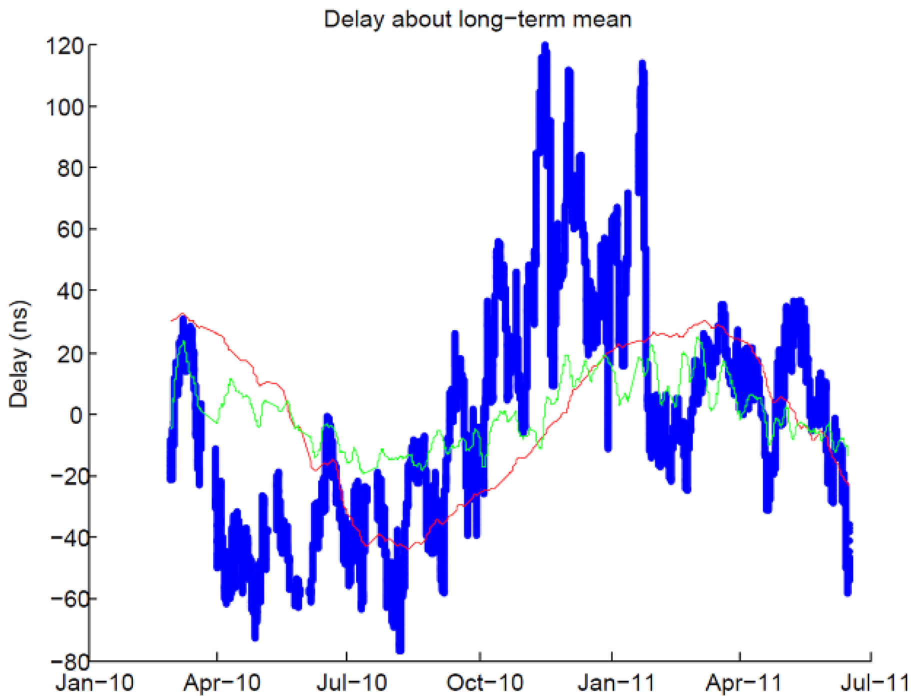

Figure 2. Measured Loran-C delay variations (blue), SST delay (red) and Atmospheric delay (green).

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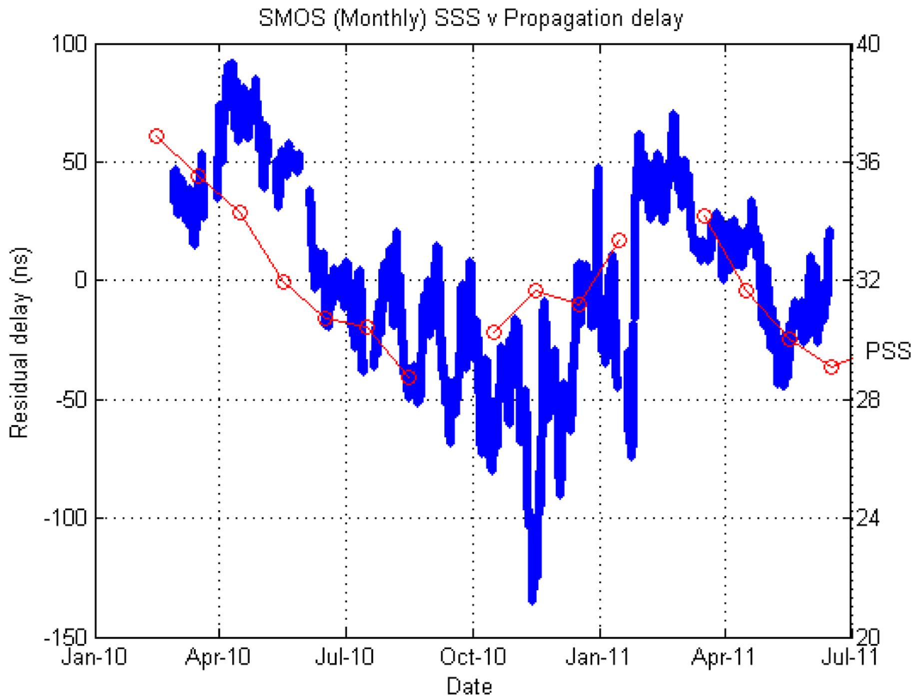

Figure 3. Comparison of the residual Loran-C delay (blue) with monthly SMOS SSS (red).

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