MAGNETIC FIELDS GENERATED BY THE INDIAN OCEAN TSUNAMI

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ABSTRACT

The devastating Sumatra Tsunami caused large scale movement of sea water in Indian Ocean. We simulate the magnetic fields generated by the Tsunami flow using a barotropic shallow water model with ETOPO5 bathymetry data in the Indian Ocean region. We use a global three-dimensional (3-D) electromagnetic induction code to simulate the magnetic fields. We consider two measurement scenarios for the predicted signals. At sea level, the predicted magnetic signal reaches up to 6 nT. We find that the magnetic fields track the leading wave of tsunami, and is observable only at observatories that in the coastal regions and also are close to the main flow of tsunami. We simulate the magnetic field effect for the first pass of CHAMP satellite above Indian Ocean, 215 minutes after the main earthquake, and the effect is within ±0.2 nT. We discuss the results in context with the possible use of magnetic measurements for tsunami monitoring.

1. INTRODUCTION

The largest earthquake of the past 40 years (seismic moment magnitude (Mw) = 9.1 to 9.3) in Indian Ocean on December 26, 2004 resulted in a devastating tsunami, which killed more that 280,000 people in the south-east Asian region [1]. Tsunamis can result in large scale wave motion in the ocean. Motional induction by the ocean has been studied for the last three decades and recently attracts renewed interest. This is primarily because of the availability of the high quality magnetic data and the sophisticated numerical simulations. In a breakthrough, [2] could identify the motional induction signals in CHAMP satellite data. The depth integrated velocities of ocean are directly related to the magnetic and electric field generation associated with ocean water movement. Reference [3] has demonstrated that tsunami related magnetic signals can achieve amplitudes of 4 nT at sea surface. He used a simple formulae connecting sea surface displacements with the magnetic field, and predicted the magnetic field at sea level due to motional induction from tsunami. He points out that these magnetic signals could possibly be detected in advance and may be useful in future tsunami monitoring systems. Some open questions about tsunami generated magnetic fields are 1) The temporal variation of such signals at the geomagnetic observatories; Can the observatories see the signals in advance ? 2) The signals at satellite altitude; Can magnetic satellites detect such signals ? To answer these questions, we use a barotropic tsunami model, constrained by the topography of Indian Ocean and a state-of-art three-dimensional (3-D) EM simulation code and simulate the magnetic fields generated by the Sumatra Tsunami at sea level and at satellite altitude. We will first describe the tsunami model, followed by the numerical simulations, and finally discuss the results of the simulation.

2. TSUNAMI MODEL

We use a barotropic model based on shallow water equations to simulate the sea level and circulation in the region. Model grid was 5 min in space and 10 sec in time. ETOPO5 bathymetry was used to simulate the Tsunami propagation in the Indian Ocean. The initial condition for the tsunami model was the vertical sea surface displacement as given in the U.S. Geological Survey [4]. The model output (vertically integrated transport) was stored at every 0.5 x 0.5 deg grid and at every one min time step.

3. NUMERICAL SIMUALTION

To predict the electric and magnetic fields due to the tsunami wave motion, we adopt the numerical solution described by [5], and successfully applied by [6,7] to study the EM fields from tide flow and ocean circulations. The solution allows simulating the EM fields, excited by a current, $\mathbf{j}^{ext}$, in 3-D spherical models of electric conductivity. The 3-D model consists of a surface spherical shell of conductance $S(\vartheta,\varphi)$, underlain by radially symmetric conductor, and $\mathbf{j}^{ext}$ simplifies to the sheet current density, $\mathbf{J}_\tau^{ext}$, which is calculated as,

$$\mathbf{J}_\tau^{ext} = \sigma_w(\mathbf{U}\times\mathbf{e}_r B_r^m)\,, \qquad (1)$$

where σ_w is the mean conductivity of sea-water (3.2 S/m), $\mathbf{U}$, the depth-integrated velocities derived from the tsunami model and B_r^m is the geomagnetic main field is derived from POMME 1.4 [8].

A realistic model of the shell conductance $S(\vartheta,\varphi)$ is obtained by considering contributions both from sea-water and from sediments [9]. The 1D conductivity model is essentially the same as the one used by [6].

The time series of U (600 minutes) were converted to frequency domain at each grid point and the numerical simulations were performed independently for each of the 300 frequencies. Finally an inverse Fourier transform of the fields gives the time series of predicted magnetic signals at each grid points.

4. RESULTS

We envisage two measurement scenarios for analyzing the results. 1. The magnetic signals at geomagnetic observatories 2. The magnetic signals, as would be observed by a CHAMP satellite.

4.1 Predicted magnetic fields at sea level

Fig. 1 shows the maximum amplitude of the predicted magnetic signals at sea level due to the tsunami waves. The maximum amplitude of the signal is seen in the south Indian Ocean, as the major flow is directed towards the SW direction. As the vertical component of the main field, B_r^m is minimum near the geomagnetic dip-equator, the observed signals show least strength here (Eq. 1). The maximum amplitude of the signal reaches up to 6 nT. The bathymetry control of the flow is also reflected in the predicted magnetic signals. The two stripes in the southern Indian Ocean are clearly due to the effect of the NS trending 90ºE ridge in the Indian Ocean. The predicted fields at the geomagnetic observatories are smaller in amplitude. The signals at the observatories in Indian region have amplitudes less than 0.5 nT, which is less than the accuracy of the most of the land based geomagnetic observatories. In addition, such small signals would be difficult to be separated from the geomagnetic variations from other sources.

On the other hand, if observatories are placed along the possible regions of major flow, the chances of detecting the signals are higher. We present the time series as would have been observed in two islands in Indian Ocean, along the main flow region. The time series of the vertical component of the geomagnetic fields predicted for Diego Garcia and Maldives islands are given in the Fig. 2. The magnetic signals at these islands are predicted to be up to ±3 nT, which is clearly a detectable signal from the observatory measurements. No high amplitude signals are observed at Diego Garcia before the onset of the tsunami waves, i.e., during the first 200 minutes. The onset of tsunami is marked by a positive peak in the magnetic fields. The variations in the predicted magnetic field decay with time, and within 100 minutes, the signal variation are reduced to ± 1 nT. Though Maldives Island is located in the main flow region, the predicted magnetic field variations are within ± 1 nT. The reduced amplitude is obviously due to the Island's proximity to the geomagnetic dip-equator.

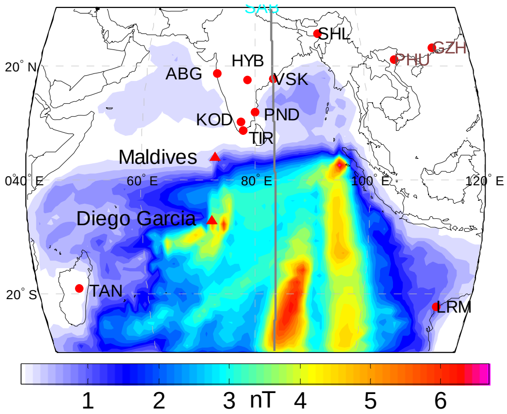

Figure 1. The predicted maximum amplitude of the vertical magnetic field component (B_r) at sea level. The red circles are the magnetic observatories. The unit is nT. The solid (grey) line indicates the path of CHAMP satellite, which passed the region 215 minutes after the main shock.

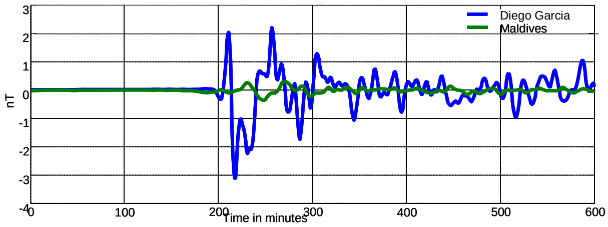

Figure 2. The predicted time series of B_r at Diego Garcia and Maldives Islands.

4.2 Predicted magnetic signals at satellite altitude

The amplitudes of the magnetic signals generated by tsunami are close to that predicted for ocean circulation (cf. [7]). The predicted magnetic signals were then upward continued to 400 km to study the amplitude and structure of the fields at satellite altitude. The range of the signals at satellite altitude is however less than 0.2 nT. Compared to the magnetic signals generated by the ocean circulation and tidal flows, whose signal strength at satellite altitude are about ±1.5 nT, the tsunami generated magnetic signals have smaller amplitudes. One reason could be that the spatial scales of the flow, though reaches up to 100s of kilometers, is still less when compared to the ocean circulation or tides. CHAMP satellite passed the region, 215 minutes after the main shock. The track was almost along 84 E (see Fig. 1). Fig. 3 shows a snapshot of the magnetic signals at satellite altitude, at 215 minutes after the main shock. The tsunami wave front has reached up to 20 S by then. The largest signals, as observed above the leading wave front have strength of about -0.15 nT. All the three components of the predicted signals show this anomaly.

The scalar data from this CHAMP pass over Indian Ocean was corrected for the internal [8] and the external [10] geomagnetic contributions. The residual scalar data still has a range of ±10 nT which are obviously from the un-modeled external sources. Further treatment of satellite data is outside the scope of the present paper.

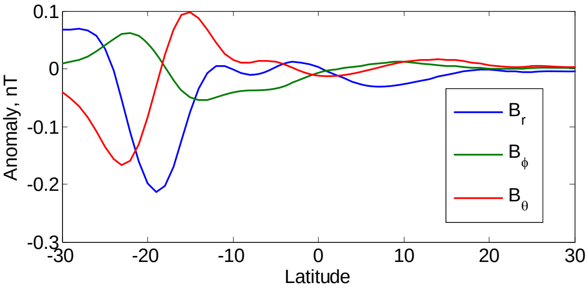

Figure 3. The predicted magnetic signals at 400 km altitude and 215 minutes after the main shock, along the track of CHAMP satellite.

5. DISCUSSION AND CONCLUSION

The amplitude of the predicted magnetic signals from the Sumatra Tsunami reaches up to 6 nT at sea level. This estimation is slightly larger than a previous prediction by [3] who reported maximum amplitude of 4 nT. We find that the predicted magnetic signals at sea levels are limited to the main flow regions. Only the leading wave produces magnetic signals of large amplitudes in the ocean, and the magnetic signals track the leading wave. So most of the land based observatories will not see the magnetic signals, unless they are close to the coast and are in the region which is close to the main flow path. Thus, monitoring of the tsunami generated magnetic signals requires a network of magnetometer, preferably in ocean islands. Diego Garcia, which is in the Indian Ocean region, and located away from the dip-equator, is a preferable location for the monitoring of the Tsunami magnetic signals.

At satellite altitude, all the three components of the magnetic signals show the effect from the leading wave. Though the signal amplitude is within ±0.2 nT, the spatial structure of the signal probably can be exploited to detect the signal in satellite magnetic data. A challenge, however, is to extract the signals due to tsunami from background variations of the Earth's magnetic field. With the better understanding of geomagnetic fields and its temporal variations from the magnetic-satellite missions like CHAMP, we are now able to see the ocean tidal signals in satellite magnetic readings [3]. Swarm mission, which aims at mapping the Earth's magnetic fields with very high accuracy, thus gives hope to find out magnetic signals from other oceanographic contributions like circulation and tsunami.

6. SUMMARY

Using a shallow water, barotropic tsunami model, along with a 3D global EM simulation code, we predicted the magnetic signals due to the Dec. 26 Indian Ocean Tsunami. We find that the predicted magnetic signals reach an amplitude of 6 nT at ground. The magnetic fields track the leading wave of tsunami, and are observable only at observatories that in the coastal regions and also are close to the main flow of tsunami. At satellite altitude, the fields are within the range ±0.2 nT. Though the monitoring of tsunami generated magnetic signals by satellite measurements is a distant possibility, the ground magnetic observatories can detect the tsunami flow, if installed in Ocean Islands.

7. REFERENCES

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