（ 続紙 1 ）

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論文題目	Magnetic fields generated by tsunamis: Case studies on the 2009 Samoa and 2010 Chile earthquake tsunamis （津波が作る磁場: 2009 年サモアおよび 2010 年チリ地震津波に関する事例解析）		

（論文内容の要旨）

Tsunami magnetic fields are generated by conductive sea water movement by tsunamis in the presence of the geomagnetic main field. Recent studies have revealed that the arrival of tsunami magnetic fields is earlier than tsunami sea level changes themselves. Moreover, the wave height of tsunamis as well as their propagation directions can also be estimated by the tsunami magnetic fields. These characteristics make the tsunami magnetic fields have two potential applications: 1) tsunami early warning and 2) a new data source of tsunami wave heights. However, the early arrival of the tsunami magnetic fields and their promising potentials to estimate not only propagation directions but also wave heights have not been confirmed by a direct comparison of the simultaneously observed tsunami magnetic fields and sea level changes. In other words, the characteristics of the tsunami magnetic field still need examination before applying them to practical problems such as disaster mitigation and/or tsunami early warning. We, therefore, used the simultaneously observed vector magnetic and pressure data on a deep seafloor for the 2009 Samoa and 2010 Chile tsunamis. Those data were from the “Tomographic Investigation by seafloor ARray Experiment for the Society hotspot (TIARES)” project. This study focuses on examining the possible applications of the tsunami magnetic fields to tsunami early warning, which includes the sensitivity of the tsunami magnetic fields to the tsunami sea level change and the accuracy of both propagation direction and wave height estimated by the tsunami magnetic field.

The ocean bottom electromagnetometer array and a differential pressure gauge at the 4000-5000m depth seafloor maintained by the TIARES project captured the tsunami magnetic and sea level change signals during the 2009 Samoa and 2010 Chile tsunamis. The tsunami magnetic signals were extracted from the observed vector tsunami magnetic data by adopting band-pass filters as well as external field correction. The tsunami sea level changes were obtained from the observed ocean bottom pressure data

by a combination of deconvolution and band-pass filters. Comparison of these two different and independent tsunami quantities has revealed not only the indisputable presence of the tsunami magnetic fields but also the early arrival of the vertical tsunami component, b_z. Estimation of tsunami propagation directions were also examined by two different methods. One using the tsunami first waves observed by the entire array gave a more accurate direction estimate several minutes after the tsunami arrival at the array, while the other based on the two tsunami horizontal components, b_x and b_y, provided less accurate directions at each observation site on arrival. However, accuracy of the direction estimates depends naturally on signal-to-noise ratios of the tsunami magnetic fields and the activity of the background geomagnetic field of external origin. Tsunami sea level changes converted from the observed tsunami magnetic fields were proved to have very high accuracy by comparing them with the direct observation of seafloor pressure as well. The comparison indicated that both long-wave and linear-dispersion approximations are applicable to the accurate conversion of the tsunami magnetic data to the sea level change on the deep seafloor, provided that the tsunamis in concern are two-dimensional enough with weak dispersion in pelagic environments. The new evidence revealed by this study suggests that the tsunami magnetic field is useful for improvement of the existing global tsunami early warning system.

To further explain the observed tsunami magnetic field well, 3-Demensional time domain tsunami magnetic simulations were conducted. The calculations of tsunami velocity and magnetic fields in the TIARES area were achieved by open-source numerical simulation codes of JAGURS and TMTGEM, respectively. The simulations clarified, for the first time, that the discrepancy between the observed and simulated tsunami magnetic fields stems not from JAGURS or TMTGEM but from inaccurate tsunami source models. The clarification was also made possible by virtue of the simultaneous observation of both tsunami magnetic and sea level changes. An attempt to explain the converted tsunami wave heights from the magnetic signals was conducted to clarify whether they were applied to existing tsunami source model inversion schemes. The result showed us that we were able to incorporate the converted wave heights so as to yield satisfactory fits to the TIARES data. However, it also turned out that the new initial sea surface displacements were incompatible with the tsunami data outside the TIARES region, which implies that more comprehensive inversions are required to construct optimized tsunami source models for both far-field tsunamis using magnetic data.

（続紙　２　）

（論文審査の結果の要旨）

導電性流体の地球主磁場の下での運動により起電力が生じ電流が流れることを初めて示唆したのは，電磁誘導現象の発見者ファラデーその人であった（Faraday, 1832）。その後，海底ケーブルを用いた電場観測や低軌道衛星高度における磁場観測により，西岸境界流や海洋潮汐といった地球規模での海水運動の速度場に観測可能な電磁場が伴っていることが確認された。

津波は西岸境界流や海洋潮汐とは異なり，空間スケールは地球規模であるが，時間的には数日程度の過渡的現象であるという特徴がある。地球電磁気学的には，支配方程式である磁場の誘導方程式において自己誘導項が有意に働くという点に面白さがある。

津波が作る磁場については，磁場変化の位相が津波による水位変化より進んでいるのではないか，また，磁場と津波波形との相関が高いことを利用して磁場から水位変化への定量的変換が可能ではないかという理論的予想がなされていたが，磁場と水位変化の同時観測データを直接比較検証した例はこれまでになく，これらの予想は実証も定量化もなされていなかった。

申請者はこの点に着目し，タヒチ周辺の南太平洋海域で同時に観測された海底圧力と磁場データの詳細な解析から，2009年のサモアおよび2010年のチリ地震津波が作った微少な磁場変化を捉え，（１）津波磁場の鉛直成分の位相が水位変化より進んでいること，（２）ベクトル量である磁場の観測から津波の伝播方向が精度良く推定できること，（３）津波磁場の鉛直成分・水平成分どちらを用いても水位変化への精密変換が可能であることなどを明らかにしている。これらの成果は，地球惑星科学分野における著名な学会である米国地球物理学連合が発行するインパクトファクターの高い学会誌に掲載されると共に，2021年12月には同学会から記者発表対象論文にも選定された。

申請者はまた，既存の波源モデルを用いて津波磁場の三次元時間領域シミュレーションも行ない，観測との食い違いは波源モデルの不正確さが一因になっていることも明らかにしている。これを踏まえ，津波磁場から変換した水位を用いて，当該海域の津波磁場観測値をよく説明する初期水位分布も求めている。

このように本論文は，海底圧力計原記録の正確な逆畳み込みによる津波水位変化の復元や，海洋島遠隔磁場観測点に準拠した外部磁場補正といった精密なデータ解析に基づいており，津波研究分野に対して新たに重要な知見を与えるものとして高く評価できる。さらに，既存の概念にとらわれることなく，オープンソースソフトウェアを複数組み合わせ，研究目的に最も適した三次元時間領域シミュレーションを実行するなど，当該分野の学際的発展にも大きく寄与するものである。

よって、本論文は博士（理学）の学位論文として価値あるものと認める。また、令和4年7月25日、論文内容とそれに関連した事項について試問を行った結果、合格と認めた。

要旨公表可能日：　　年　　月　　日以降