Temporal variations visible in induction arrows and their spatial distribution - preliminary results

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1 Introduction

Magnetotellurics is a passive sounding method using natural electromagnetic field variations of the Earth to determine the electrical resistivity structures beneath the Earth's surface. It means that in a geologically stable region transfer functions (which carry information about subsurface resistivity) should not change in time. However research has shown significant seasonal changes visible in induction arrows independent of geologic processes (see e.g., Ernst et al., 2019, Araya Vargas & Ritter, 2015, Brändlein et al., 2012). This suggests that source effects may cause that the plane wave assumption is not always fullfilled. The aim of this work is to analyze ground observatory data to find seasonal changes in the induction arrows along with the spatial distribution of such changes. For that purpose data from 30 permanent observatories were chosen. Observatories were selected based on their data quality and their location. Locations were chosen to provide representation of all main regions of the world and to investigate dependence on geomagnetic latitude.

2 Method

For this work one-minute data from 30 observatories collected from INTERMAGNET (www.intermagnet.org) were used (locations of selected observatories are listed in Table 1). A time range from 1995 to 2009, which corresponds to the 23rd solar cycle, was chosen to investigate solar activity as a possible source for seasonal changes. For each station data were divided into two groups – summer season (covering the time from June to August each year) and winter season (from December to February). For each data group (summer and winter) induction arrows were calculated using the standard magnetotelluric aproach by Egbert and Booker (1986). Then Difference Induction Arrows (DIA) were calculated as a difference between induction arrows obtained for summer season minus induction arrows obtained for winter season.

3 Results

Figure 1 shows summer, winter, and Difference Induction Arrows for observatories which represent typical DIA results for low-, mid-, and high geomagnetic latitudes. Stations

Table 1: Observatories location data. Geomagnetic coordinates from wdc.kugi.kyoto-u.ac.jp/igrf/gggm

station code	latitude	geomagnetic latitude	longitude	geomagnetic longitude	location	Country
ABK	68.358	66.04	18.823	114.05	Abisko	Sweden
BDV	49.08	48.52	14.015	97.71	Budkov	Czech Republic
BEL	51.837	50.07	20.792	10.21	Belsk	Poland
BFE	55.625	55.22	11.672	98.37	Brorfelde	Denmark
BNG	4.333	4.04	18.566	91.9	Bangui	Central African Republic
CBB	69.123	76.21	254.969	-53.68	Cambridge Bay	Canada
CLF	48.025	49.47	2.26	85.78	Chambon-la-Foret	France
CNB	-35.315	-42.04	149.363	-132.56	Canberra	Australia
DRV	-66.667	-73.87	140.007	-129.38	Dumont d'Urville	Antarctica
ESK	55.314	57.42	356.794	83.6	Eskdalemuir	United Kingdom
EYR	-43.422	-46.64	172.355	-105.93	Eyrewell	New Zealand
FUR	48.17	48.1	11.28	94.72	Fürstenfeldbruck	Germany
GDH	69.252	77.88	306.467	33.71	Qeqertarsuaq (Godhavn)	Greenland
GNA	-31.78	41.18	115.947	170.29	Gnangara	Australia
GUA	13.59	5.76	144.87	143.5	Guam	Guam
HER	-34.425	-34.0	19.225	85.27	Hermanus	South Africa
HON	21.32	21.65	202.0	-89.18	Honolulu	USA
KAK	36.232	27.76	140.186	-150.32	Kakioka	Japan
MBO	14.38	19.59	343.03	58.13	Mbour	Senegal
MEA	54.616	61.17	246.653	-51.89	Meanook	Canada
MMB	43.91	35.72	144.189	-147.76	Memambetsu	Japan
NCK	47.633	46.67	16.717	99.76	Nagycenk	Hungary
NGK	52.072	51.64	12.675	97.64	Niemegk	Germany
NUR	60.508	57.79	24.655	112.97	Nurmijarvi	Finland
OTT	45.403	54.88	284.448	-3.59	Ottawa	Canada
SIT	57.067	60.21	224.67	-77.69	Sitka	USA
SOD	67.367	63.95	26.663	119.57	Sodankyla	Finland
THL	77.483	87.01	290.883	14.84	Qaanaaq (Thule)	Greenland
WNG	53.743	53.85	9.073	94.94	Wingst	Germany
YKC	62.482	68.62	245.518	-58.23	Yellowknife	Canada

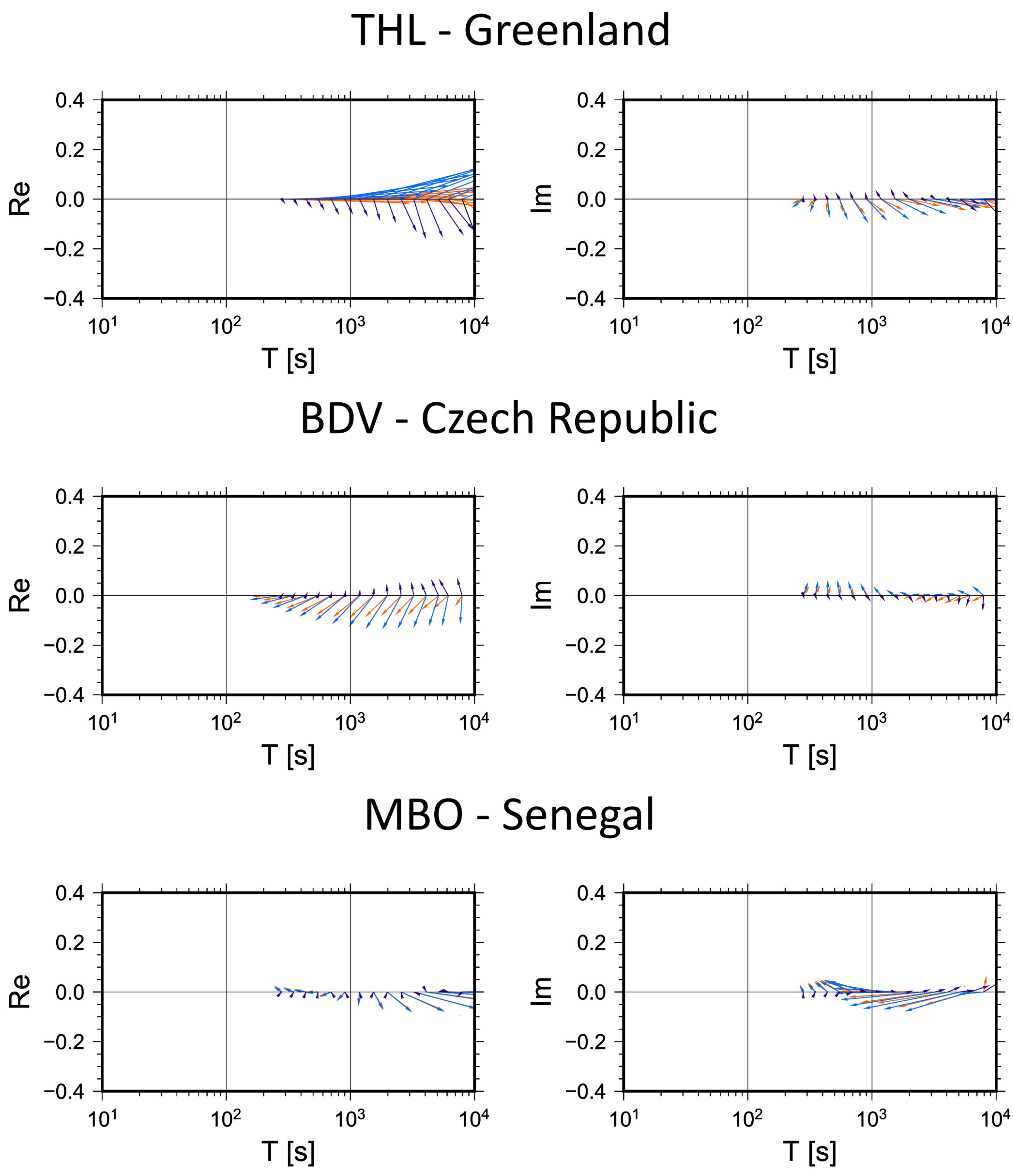

Figure 1: Typical results obtained for stations in high- (THL), mid- (BDV) and low-latitudes (MBO). Orange arrows are representing results obtained for summer season, blue are for winter season and purple arrows shows Difference Induction Arrows.

located in low geomagnetic latitudes are characterized by the smallest values of Difference Induction Arrows, such that seasonal differences are practically absent. For stations representing mid geomagnetic latitudes real parts of the Difference Induction Arrows are small (< 0.1) but have a consistent character with a dominant North direction. This means that in summer time they contain an additional positive real X component. In contrast, real parts of the Difference Induction Arrows obtained for stations in high geomagnetic

latitudes have a dominant South direction and also have the biggest values. They can be such big that summer and winter induction arrows show a totally different picture.
The real parts of the Difference Induction Arrows for various periods were plotted on maps presented on Figure 2 and Figure 3. On these maps we can see that Difference Induction Arrows calculated for stations in Europe behave in a similar way and have a common North direction. However for stations located at geomagnetic latitudes higher than 60° behavior of the Difference Induction Arrows is more diversified, they have bigger values and more random direction, especially for the longer periods. Stations located close to the geomagnetic equator have the lowest values of the Difference Induction Arrows, which means that they are affected by the smallest seasonal changes.

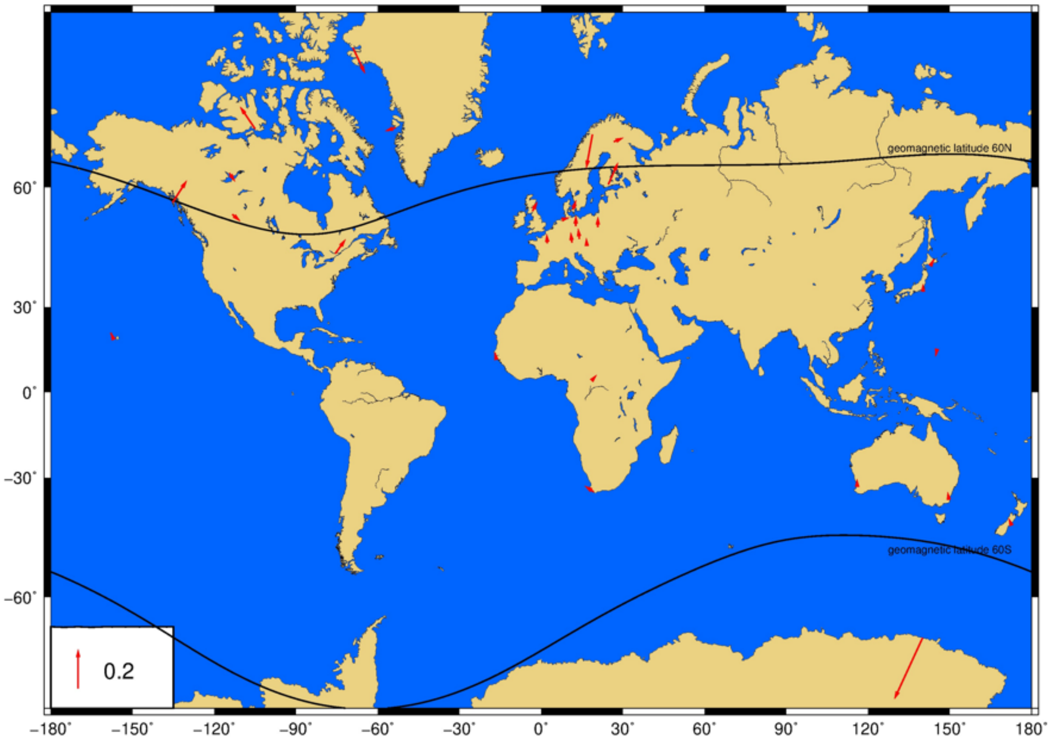

Figure 2: Difference Induction Arrows for a period of 2560 seconds.

The real parts of the Difference Induction Arrows in North direction (X) and in East direction (Y) were analyzed in dependence of geomagnetic latitude of the observatories (shown in Figure 4). The obtained results show that there is a dependence of Difference Induction Arrows on geomagnetic latitude which can be described as follows:

- There is visible a trend between 30 – 60° of geomagnetic latitude where the real part in North (X) direction of Difference Induction Arrows is growing with latitude.
- For mid-latitudes the real part of the Difference Induction Arrows in North direction (X) is growing with period and closer to 10^4 seconds is much bigger than the real part in East direction (Y), this is also visible on Figure 1 for BDV station.

- 60° of geomagnetic latitude seem to constitute a boundary for the behavior of Difference Induction Arrows. There is visible a rather sharp jump at this latitude (Figure 4, this applies also to other periods). This latitude is consistent with the southern boundary of the region where the polar electrojet is observed (Hill, 2019).

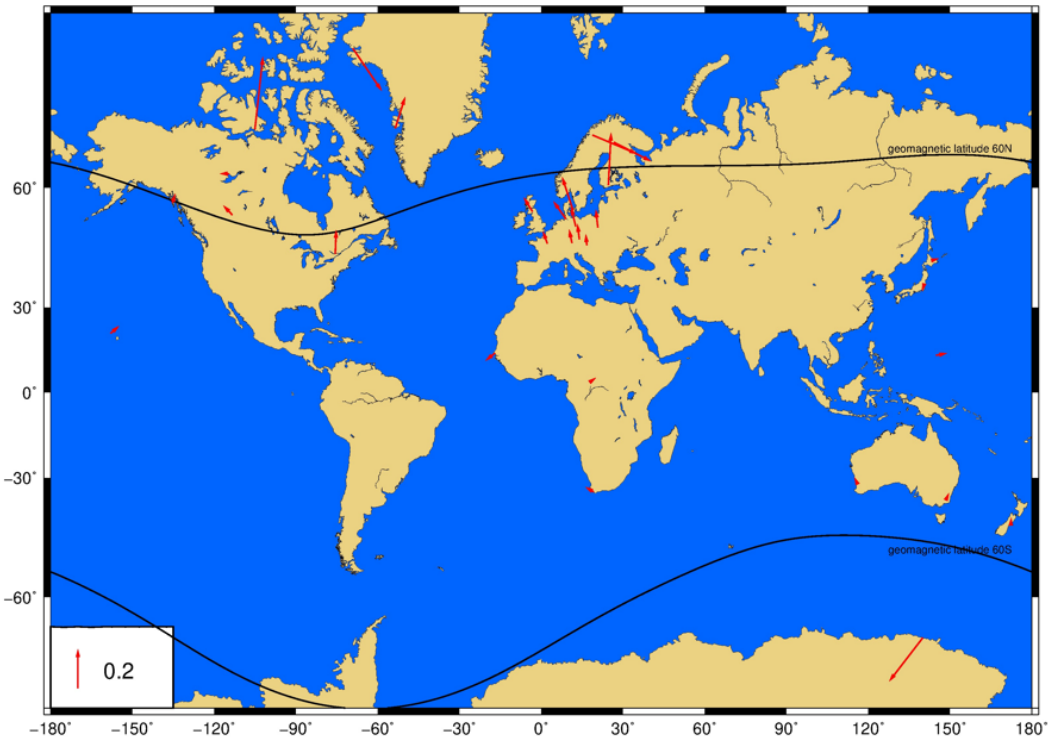

Figure 3: Difference Induction Arrows for a period of 10240 seconds.

4 Outlook

The aim of this research is to analyze the ground observatory data to find seasonal changes visible in the induction arrows and their spatial distribution. This research will be continued by investigating year by year seasonal changes (and maybe with a yet higher time resolution) visible in induction arrows. Comparison with data of solar activity will be conducted to describe the influence of solar cycles to induction arrows. The author hopes to identify source effects also by inspection of geomagnetic time series.

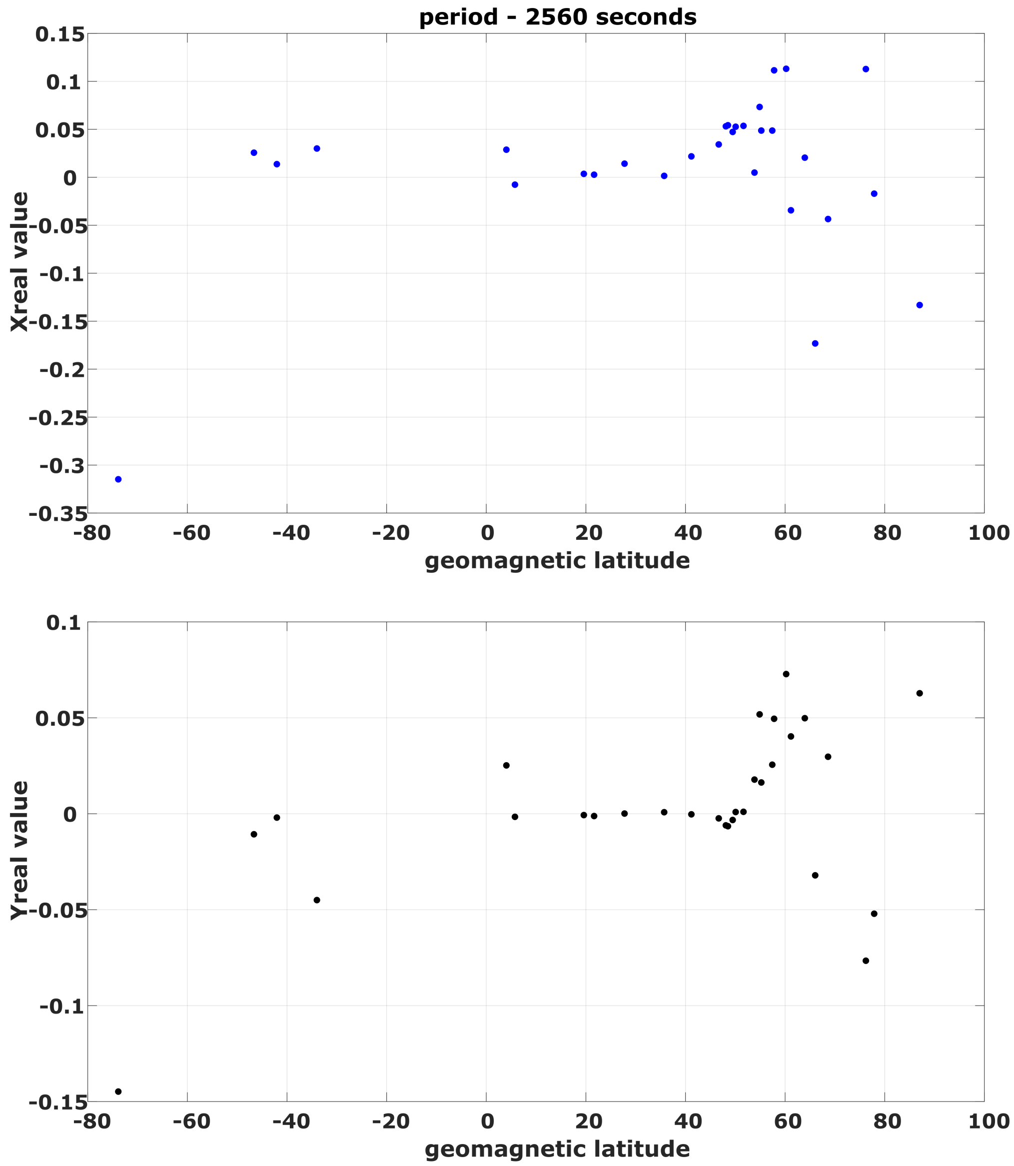

Figure 4: Dependence of real part of Difference Induction Arrows in North (Xreal) and East (Yreal) direction on geomagnetic latitude for a period of 2560 seconds.

Acknowledgements

The results presented in this paper rely on data collected at magnetic observatories. We thank the national institutes that support them and INTERMAGNET for promoting high standards of magnetic observatory practice (www.intermagnet.org). I would like to thank Anne Neska and Krzysztof Nowożyński for providing necessary codes. This work was partially financed as a part of the statutory activity from the subvention of the Ministry of Science and Higher Education in Poland.

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