Variations of the induction vector, worldwide study

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SUMMARY

Real (in phase) and imaginary (out of phase) induction vectors (vertical response functions) were obtained for every day in the time interval from 1991 to 2014 years on 137 observatories of the global network «Intermagnet» for 5 intervals of periods: 150-300 c, 300-600 c, 600-1200 c, 1200-2400 c, 2400-3600 c. To reduce scatter and make it easier to work with great amount of data, the daily values were averaged to monthly mean values. Such global material from $+87^0$ to -88^0 geomagnetic latitudes was obtained for the first time and its analysis yields new scientific results. The annual variation with a period 1 year is visible at about 2/3 of the observatories (At the rest observatories it is below background of shorter period variations and/or noise). Its amplitude depends of geomagnetic latitude and sometimes attains such a high value as 0.4-0.5 (peak-to-peak) in high ($>65^0$) latitudes and varies within 0.01-0.15 in middle and low latitudes. Previous studies in middle latitudes led to conclusion that induction vector's northern component A_u is everywhere positive (maximum in June, minimum in December) and proposed a global source model for its description. This study states that in high latitudes A_u is negative. 11-years variation found in ≈30% of observatories distributed in all latitudes but more frequently in aurora zones. Non-periodic transient variations of the induction vector also occur, in particular before strong earthquakes. In common, the behavior of the induction vector variations is complex with many local exceptions and irregularities that leads to supposition that they are not a simple «source effect», but contain information from the Earth interior and its environment including interactions in the system Earth-Sun-Moon-planets.

Keywords: geomagnetic field, geomagnetic variations, annual variation, magnetic variation profiling.

Introduction

The Induction vectors were introduced by Parkinson (1959), Wiese (1965) and Schmucker (1970) for the study of strong conductivity contrasts like sea-land and looking for electrical conductivity anomalies in the Earth crust. To obtain an induction vector, three components of natural geomagnetic field **B**(t) are necessary.

Method

In the geoelectromagnetic studies of the Earth's interior natural source field $\mathbf{B}(t)=B_x\mathbf{e_x}+B_y\mathbf{e_y}+B_z\mathbf{e_z}$ (where $\mathbf{e_x}$, $\mathbf{e_y}$, $\mathbf{e_z}$ are unit vectors directed to North, East and downward) is used. **B**(t) contains rich information both from external source in ionosphere and magnetosphere and from the Earth interior. To clean out external influence and focus on the Earth interior study special processing transforms **B**(t) time series into Response Functions (RF) time series. Induction vector **C** is one of RF (response of the Earth to applied external field):

$$\mathbf{C}=A\mathbf{e_x} + B\mathbf{e_y} \quad (1)$$

where A and B determined from the linear equation

$$B_z = AB_x + BB_y \quad (2)$$

The quantities A and B are complex numbers, and a pair of induction vectors is determined: real $\mathbf{C_u}$ and imaginary $\mathbf{C_v}$ (Rokityansky 1982).
Real induction vector $\mathbf{C_u} = A_u\mathbf{e_x} + B_u\mathbf{e_y}$ possess an important property: in the Wiese notation used here, it is directed away from a good conductor.

Processing technique

The processing of the data recorded in the time interval ΔŦ=t2-t1 (usually 1 day in this work) is a transformation from 3 synchronous time series Bx, By, Bz with a discreteness Δt (1 min – data Intermagnet) into the time series of the induction vector components for the set of obtained periods Tn (n=1-5) with discreteness ΔŦ. Obviously, Δt«Tn«ΔŦ.
Processing was carried out by programs of Varentsov (2007) and Klimkovich (2009) based on FFT, calculation of cross- and auto-correlation energy spectra between magnetic components, partial estimator procedure in a set of overlapping windows, and a multi-stage selection of acceptable estimators according to coherence criteria.

Data and results

Digital Intermagnet worldwide data **B**(t) (http://www.intermagnet.org/) with the discreteness of 1 min have been processed since 1991 to 2014 year and for every day the components A_u, B_u, A_v, and B_v of real and imaginary induction vectors were obtained for the intervals of periods 2,5-5 min, 5-10 min, 10-20 min, 20-40 min and 40-60 min. The daily components of the induction vector are characterized by a considerable scatter. For their smoothing and compact presentation of long-term data, the monthly mean values were calculated and used. This limited the resolution of the obtained time series to 2-3 months.

Observatories with induction vectors at period 1800 s are presented in Figure 1, the time series for 25 observatories at the same period are given in Figure 2, the time series at 4 periods are published in (Babak et al 2017) for 8 observatories. *When reading the following text, it is recommended to look at the mentioned figures.*

The annual variation (AV) with a period 1 year is visible at about 2/3 observatories of world (at the rest observatories it is below background of shorter period variations and/or noise). Its amplitude depends of geomagnetic latitude and sometimes attains such a high value as 0.4-0.5 (peak-to-peak) in high (>65^0) latitudes and varies within 0.01-0.15 in middle and low latitudes. AV amplitude as a rule increases with the period.

Previous works (Araya and Ritter 2016 and others referred in it) studied AV only in middle latitudes and found that northern component A_u is always positive, i.e. A_u has the maximum in June. Studies in high latitudes yield: polarity of A_u is usually negative (maximum in December) with few exceptions. All this clearly seen in Figure 2 at northern observatories THL and RES and in the southern one DRV, but in the most southern SBA A_u is positive (an «exception»). It means that annual variations are not only global source field effect but also effect of local factors.

Consider the results of 3 observatories:

THL (geomagnetic latitude 87.31^O, northwest of Greenland). AV is most intense at the longest period of 3000 s, sometimes reaching an amplitude of 0.5 on A_u and B_v components. With the period decrease, AV amplitude decreases to values of the order 0.2-0.05. AV is unstable, its amplitude at some components/periods changes by 1.5-2 times during 23 years. Also, there is an «overflow» of AV from one component to another. So, at periods 5-10 min at A_v in THL and at B_v in NAQ annual variation in 1991-2004 was rather intensive, then it was halved, and at A_u and B_u of both observatories AV amplitude was doubled. The same AV enhancement from 2005-2007 to 2011-2014 was observed in HLP (Poland), KOU (Guyana) … and Japan where it was supposed to be middle-term precursor of the Tohoku earthquake (Rokityansky et al. 2019).

RES (north of Canada), the induction vector is on average 0.2 directed to the north. The AV is slightly smaller in amplitude than in THL, but with a similar distribution over the components. Intense variations with a period little less than half of year are imposed on the AV. They deviate the shape of AV from a sinusoid and make the upper extremum of AV blunt and the lower extremum pointed (and similar form is observed also at observatories THL, DRV, SBA on A_u and B_v components); in other cases, vice versa, the upper one is pointed, the lower one is blunt (THL, SBA - on the B_u component).

NAQ (geom. latitude 69.46^0, south of Greenland). Marine currents of deep ocean create a significant real induction vector Cu≈0.9 at periods 20-60 min. The imaginary vector Cv at periods 450, 900, 1800 and 3000 s is equal to +0.3, +0.15, 0 and -0.15 respectively which is in full agreement with the theory and empirical formula (7.1) for the coast effect developed in [Rokityansky, 1982, p. 313]. In NAQ large annual (0.1-0.3) and 11-year variations (0.1-0.2 in all periods). And quite unusual thing - a large trend ≈0.2 over 23 years. Glaciers are melting in Greenland. May be the anomalous behavior of vectors in NAQ related with global warming?

11-years variation found in ≈30% of observatories distributed in all latitudes, more often in aurora zones.

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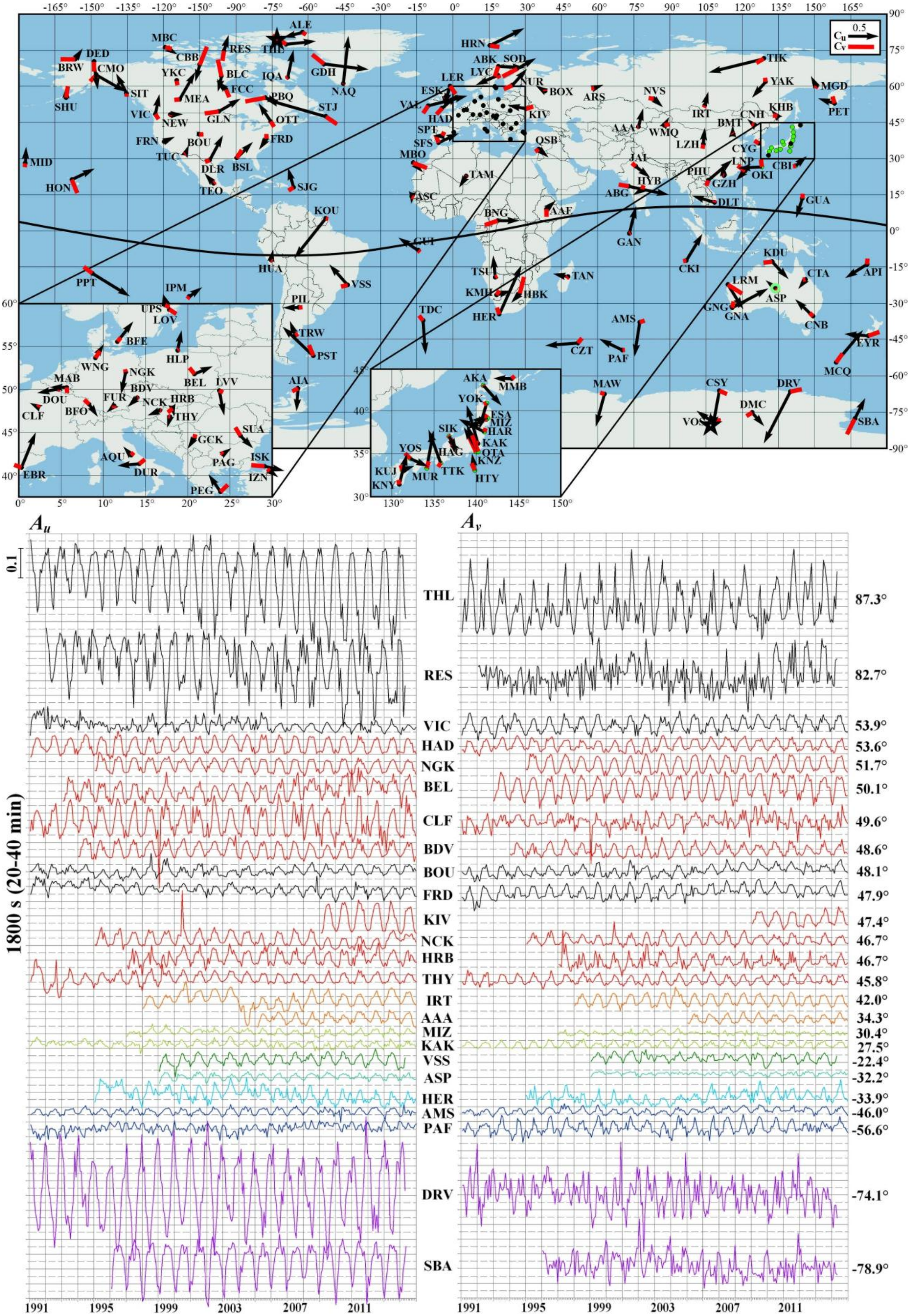

C_u
C_v
0.5
A_u
A_v
0.1
1800 s (20-40 min)
THL 87.3°
RES 82.7°
VIC 53.9°
HAD 53.6°
NGK 51.7°
BEL 50.1°
CLF 49.6°
BDV 48.6°
BOU 48.1°
FRD 47.9°
KIV 47.4°
NCK 46.7°
HRB 46.7°
THY 45.8°
IRT 42.0°
AAA 34.3°
MIZ 30.4°
KAK 27.5°
VSS -22.4°
ASP -32.2°
HER -33.9°
AMS -46.0°
PAF -56.6°
DRV -74.1°
SBA -78.9°
1991
1995
1999
2003
2007
2011

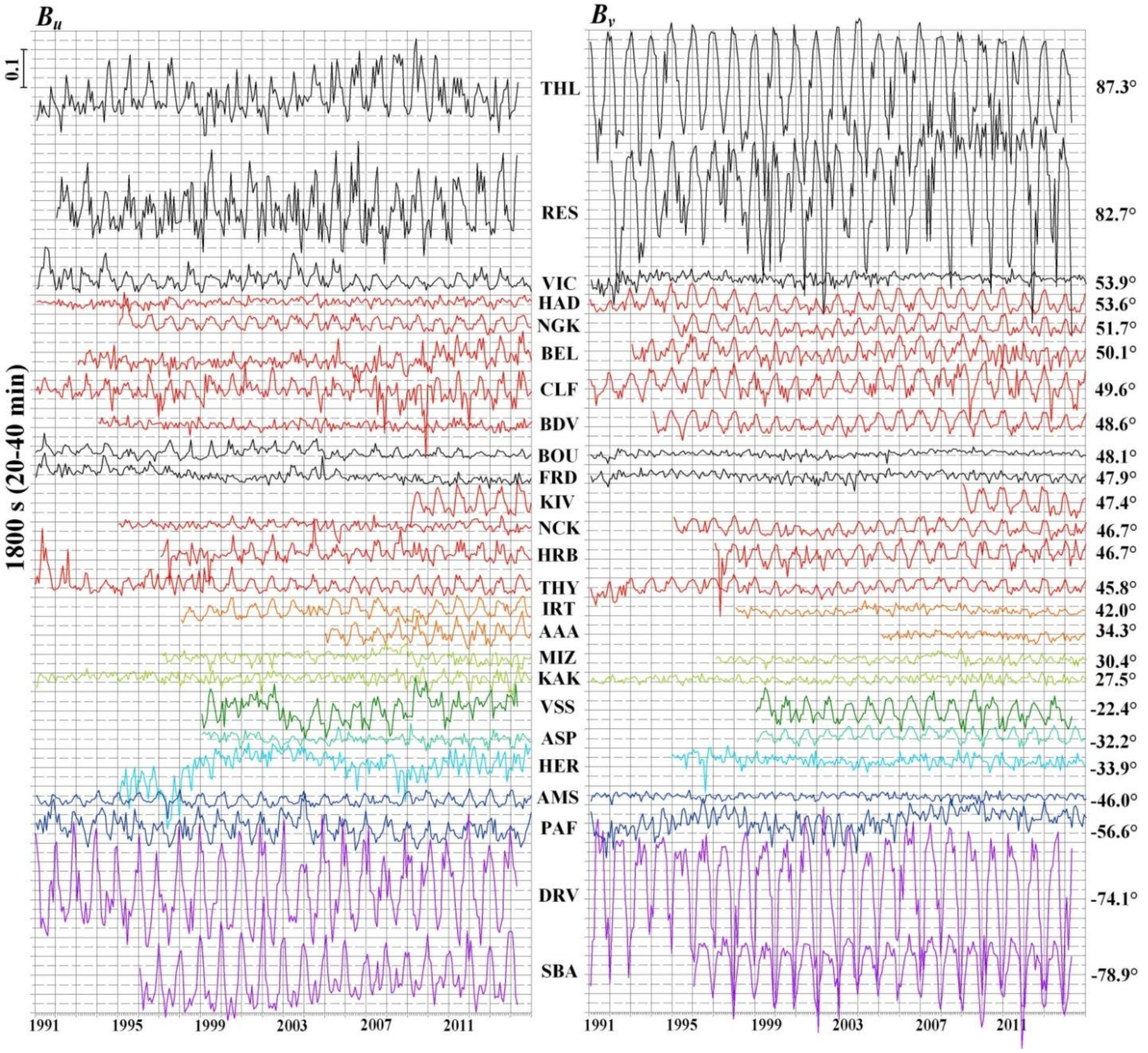

Figure 1. Map of 137 Intermagnet + 14 Japanese observatories with real $\mathbf{C_u}$ and imaginary $\mathbf{C_v}$ induction vectors for the period 1800 s (20-40 min), averaged for the entire observation period. Geomagnetic poles for epoch 2010 are marked by 5-ray stars, geomagnetic equator is also drawn.

Figure 2. Monthly average components A_u and A_v (upper graph), B_u and B_v (lower graph) in 1991-2014 for a period 1800 s (20-40 min) at 25 observatories selected with clearly visible annual variations. The geomagnetic latitudes of each observatory are inscribed on the right. The scale for all observatories is the same, the level is not saved. The color of the curves depends on the location: black - North America, red - Europe, faded red - Asia, light green - Japan, green - South America, green-blue - Australia, blue - South Africa, dark blue - Indian Ocean, orange - Antarctica.

Conclusions

Real and imaginary induction vectors were calculated for every day and month in the time interval from 1991 to 2014 on 137 observatories of the global network «Intermagnet» for 5 intervals of periods: 150-300 c, 300-600 c, 600-1200 c, 1200-2400 c, 2400-3600 c. Such global material was obtained for the first time and its analysis yields new results so far using only monthly mean values. The annual variation is visible at about 2/3 of the observatories. In high (>65^0) latitudes its amplitude attains such a high value as 0.4-0.5, in middle and low latitudes it varies within 0.01-0.15. Northern component of annual variations in low and middle latitudes is positive (maximum in June, minimum in December), in high latitudes - negative. 11-years variation found in 30% of observatories distributed in all latitudes but more frequently in aurora zones. Non-periodic transient variations of the induction vector also occur, in particular before strong earthquakes. Dependence of the induction vector variations on the magnitude and direction of the vector itself is not found in this study.