MINISTRY OF EDUCATION AND TRAINING

VIETNAM ACADEMY OF SCIENCE AND TECHNOLOGY

GRADUATE UNIVERSITY OF SCIENCE AND TECHNOLOGY

LE TRUONG THANH

STUDY OF THE EQUATORIAL ELECTROJET (EEJ) FROM CHAMP SATELLITE AND OBSERVATORIES DATA IN VIETNAM AND ADJACENT AREAS

SPECIALTY: GEOPHYSICS

CODE: 62 44 01 11

ABSTRACT OF DOCTORATE DISSERTATION

HANOI – 2015

The dissertation completed at: Graduate University of Science and Technology, Vietnam Academy of Science and Technology.

Academic Supervisors: Asc. Prof. Dr. Ha Duyen Chau
Dr. Le Huy Minh

Reviewer 1: Prof. Dr. Sc. Mai Thanh Tan

Reviewer 2: Asc.Prof. Dr. Dinh Van Toan

Reviewer 3: Dr. Hoang Van Vuong

This thesis is going to be defended at the council of doctorate thesis examiners of Graduate University at: ……………………………………….
………………………………………………………………………………..
on …….Date ……/…… / 2015.

The dissertation could be found at:

1. National Library, Hanoi.

2. Library of Vietnam Academy of Science and Technology.

3. Library of Graduate University of Science and Technology.

INTRODUCTION

1. Necessity of the thesis:

The magnetic field caused by Equatorial Electrojet (EEJ) only occupies a small part of the geomagnetic field recorded at Earth surface or at satellite orbit, but its daily variation can be up to hundreds nT in equatorial zone as in Vietnam and affects strongly to the geomagnetic field measurements. Previously, studies of EEJ mainly used the geomagnetic field data recorded at the observatories. Today, dozens of satellites measuring geomagnetic field gave us a lot of data to study EEJ on a global scale but using such satellite data have not been fulfilled in Vietnam.

Recently, in the paper of Doumouya et al. (2004), the authors used the geomagnetic data from CHAMP satellite in two months (August and September 2001) to study EEJ in global scale and noticed that: at longitude through Vietnam (105^0E) the amplitude of EEJ magnetic field has the maximum value. However, this study used too few data (only two months, in many areas there is no data) and in this period of strong solar activity, the separation of the magnetic field caused by EEJ from data profile with has many difficulties.

Therefore, in my doctoral thesis, we will use the geomagnetic data from CHAMP satellite and from some observatories of Vietnam and in the world during the 2002-2007 period to confirm that the amplitude of EEJ geomagnetic field is highest in the longitude through Vietnam and study some basic characteristics of EEJ system and its variations.

In addition, we use the magnetic data from CHAMP satellite on the nighttime to model the normal magnetic field (TTBT) for Vietnam and adjacent areas. It is very necessary, because from 2003 to now, in Vietnam no model of TTBT had been made.

2. The tasks of the thesis:

Basic tasks of the thesis are:

- Collect and process the magnetic data from CHAMP satellite and from the magnetic observatories within 6 years (from 2002-2007).

- Study the method to separate magnetic field caused by EEJ from the observed data. Identify some parameters of EEJ in all over meridians and study the variation of EEJ in space and time.

- Modeling the variation of EEJ in longitude, latitude and local time.

- Study and application of spherical cap harmonic analysis method (SCHA) for modeling the normal magnetic field and calculating magnetic anomaly for Vietnam and adjacent areas from CHAMP satellite data.

3. The news of the thesis:

- Use the magnetic data during the same long time span from both satellite and observatory to study EEJ.

- Use the different degree polynomial approximation of the crustal field to separate the EEJ magnetic field from CHAMP satellite data, study some basic characteristics of EEJ as well as its variability in global scale.

- In the first time in Vietnam we study and apply the spherical cap harmonic analysis method for modeling normal magnetic field for a country or a small area on the Earth surface.

4. Defensive theoretical poits:

- Using a combination of the magnetic data from CHAMP satellite and from magnetic observatories at Earth's surface to study the main characteristics of EEJ.

- Making confirmation that the current density of EEJ calculated from CHAMP satellite through Vietnam is strongest compared to other meridians.

- The normal magnetic field epoch 2007.0 for Vietnam and adjacent areas obtained by SCHA from CHAMP satellite data with high reliability could be used for other studies in Vietnam.

5. Scientific and practical significances of the thesis:

- Determine quantitatively the main parameters of EEJ.

- Provide a model of seven components of normal magnetic field and magnetic anomaly for Vietnam and adjacent areas (epoch 2007.0) by SCHA method. The results of this researches serve for other scientific research or economic and social developments. Nowadays, the SCHA method is more effective if using only the data from satellite without ground data, when the European Space Agency (ESA) is developing three SWARM satellites with high precision and reasonable distribution to research geomagnetic field in global scale or a region.

- Increase understanding how to construct and manager a project to launch Earth's observation satellites.

The content of the thesis has been published in 6 papers. The thesis consists of 148 pages, with 11 tables and 77 figures, 118 references. Besides the introduction, conclusion, and references, the dissertation is organized in 4 chapters as following:

Chapter 1: Overview of the research on EEJ abroad and in Vietnam; some models of normal geomagnetic field for Vietnam and the sources of data.

Chapter 2: Theory of ionospheric conductivity and EEJ formation process in the ionosphere; introduction to the spherical cap harmonic analytic (SCHA) method for modeling the normal geomagnetic field for a region.

Chapter 3: Results of calculation of the EEJ and its variation from CHAMP satellite and observatory data.

Chapter 4: Results of modeling the normal geomagnetic field for Vietnam and adjacent areas (epoch 2007.0) from CHAMP satellite data.

Below is a summary of the chapters in the thesis:

I. Brief review of the researches on EEJ, normal magnetic field model for Vietnam and used data

1. Research on EEJ abroad and in Vietnam

In 1951, Chapman explained the extraordinary increase of magnetic field at the magnetic equator because in the daytime at magnetic equator exists a current system running in eastward in the ionosphere. This current is generated by the heterogeneity conductivity in the ionosphere due to the impact of solar radiation and is called the equatorial electrojet (EEJ).

After the year of International Geophysics 1957-1958, many geomagnetic observatories around the world have been built, including the observatories at low latitude and at magnetic equator as in South America (Peru, Brazil), Africa, Asia (India and Vietnam).

Since 1970s, with the development of science and technology, a series of satellites for measuring geomagnetic field has been launched into orbit. The geomagnetic field data obtained on satellites have contributed to improve our understanding of the magnetic field of the Earth in general and of the equatorial electrojet in particularly. However, the data obtained from the satellites are able to study EEJ only when the satellite's orbit crosses the dip equator around local noon and the orbit must be low enough to record the magnetic field caused by EEJ.

Therefore, only the data of POGO, MAGSAT, Ørsted, CHAMP satellites and most recently SWARMs may be used to study EEJ. Until now, many studies about EEJ using satellite data have been published. Using the POGO satellite data there are studies of Cain (1973), Onwumechili (1980); and MAGSAT satellite data, one has papers of Yanagisawa's (1985), Cohen (1990) and Langel (1993). After 2001, when one has data obtained from CHAMP satellite with low orbit and orbit crossing the equator in the daytime, there are many studies on EEJ published as: Doumouya (2003, 2004) , Luhr (2004, 2008), Le Mouël (2006), Alken (2007, 2013)....

In Vietnam, the EEJ exists in the south of Vietnam, so many researchers are interested on EEJ, such as Truong Quang Hao (1987, 1998, 2001), Nguyen Thi Kim Thoa (1973, 1990), Nguyen Van Giang (1988), Tsvetkov (1989), Le Huy Minh (1998), Rotanova (1992), Luong Van Truong (2003).... These studies primarily use data recorded in the geomagnetic stations in Vietnam or India which are usually only in the short periods.

In addition, in the world in the study of EEJ, many authors have used different types of data, such as current density data recorded on the rocket or vertical component of the electric field obtained by VHF and HF Radar stations, ionospheric vertical sounding data…

However, the studies of EEJ published have usually several limitations such as: the irregular distribution of data along the magnetic equator or only in a short time of data, so still do not reflect the characteristics or variations of the EEJ currents, such as: seasonal variations, with solar activity…

2. About normal magnetic models in Vietnam and adjacent areas

The model of normal magnetic field for each country is important in mineral exploration and some other purposes. The normal magnetic field models in Vietnam from 1960 up to now are summarized as follows: the first map of normal magnetic field in Vietnam for epoch 1961.0 established by the General Department of Geology for the vertical component (Z) and total field (F) for North of Vietnam; Nguyen San (1970) has established a map of H, Z, F components based on 70 absolute measurement points; Le Minh Triet (1974) has established maps of normal magnetic field for north Vietnam epoch 1973.0 using an approximation by a second degree polynomial; Ha Duyen Chau (1979) used 69 points of absolute measurements to recalculate the normal magnetic field to the north of Vietnam at epoch 1973.0 by a second degree polynomial but using filtering high anomalous points; Nguyen Van Giang (1988) used the data from MAGSAT satellite and spherical harmonic analysis method (SHA) to obtain Gauss coefficients (degree n = 13) and from this coefficients, the model of normal magnetic field was calculated for the territory of Vietnam.

Nguyen Thi Kim Thoa (1992) established the map of normal magnetic field in Vietnam at epoch 1991.5 based on 56 points of absolute measurements and used an approximation of second degree polynomial; Ha Duyen Chau (1997) used data obtained from 56 repeat stations in Vietnam to model normal magnetic field at epoch 1997.5; Ha Duyen Chau (2003) continued to realize measurements at 58 points and has calculated normal magnetic field at epoch 2003.5 in Vietnam. This is also the last map of normal magnetic field for Vietnam using the ground data.

The use of spherical cap harmonic analysis method (SCHA) with satellite data for modeling magnetic field for each country or for one region has been performed for many regions and has obtained good results such as: Haines (1986) used data from MAGSAT satellite, airborne magnetic survey and ground data to build maps of normal magnetic field for Canada at epoch 1980.0; Santis (1990) used MAGSAT satellite data to model magnetic field for Italy; Kotzé (2001) used Ørsted satellite data to model magnetic field for South American region at epoch 2000.0; Qamili (2007) used the data collected on the CHAMP, Ørsted satellites and at repeat measurements points to calculate normal geomagnetic field for eastern Albania and Italy at epochs 1990.0; 1995.0; 2010.0… The model of normal geomagnetic field must reflect not only the main Earth's magnetic field, but also represent the magnetic field of the Earth's crust appropriate to wavelengths of a few hundred kilometers; this is an advantage of the SCHA method compared with conventional spherical harmonic analysis method.

3. Data for research

For nearly a half century, nearly 20 satellites measuring the geomagnetic field has been launched into orbit. In the period 1960-1980, due to the technological limitations, the satellites usually measured only total field (F) and the equipment is very of low precision. After 1980, the satellites simultaneously measure three components of the magnetic field and the total field together. Up to now, geomagnetic field data obtained on the low orbit satellites as: MAGSAT, Ørsted, CHAMP and SAC-C with high density and with good space resolution. However, only the CHAMP satellite with high accuracy, low orbit, provided continuous sequence data in the long time span.

CHAMP standard data consists of 5 levels equivalent to the processing of data as following:

- Level 0: Raw data received from CHAMP satellite.

- Level 1: Raw data compressed and added documents about temperature, satellite operations and notifications.

- Level 2: The original data with corrected time, the document vector and total field averaged at a resolution of 1 second. Document vector is treated with a set of parameters which are updated regularly.

- Level 3: The data at this level includes the time sequence of magnetic components in NEC coordinates based on information from the flight reference measurements and modeling. This level provides vector data with a resolution of 5 seconds and the total field data with a resolution of 1 second.

- Level 4: Main magnetic field models represented as a spherical harmonic expansion to n=14 derived from the combination of spacecraft and ground-based data, updated once per month; lithospheric magnetic field model derived from the coefficients of the spherical expansion for degree and order 15 to 60, separation into a constant and a time varying part by comparison of consecutive models; and magnetic activity indices indicating the ring current activity, the polar electrojet activity and the global magnetic activity.

In this study as well as in other studies published in the world, one used data at level 3 which were checked and calibrated about coordinates and time.

In addition, besides the geomagnetic data from CHAMP satellite, we also used data recorded at some stations in over the world to compare. Data at 6 geomagnetic stations selected for three meridian zones as: two stations of Vietnam: Bac Lieu (BCL) and Phu Thuy (PHU) in Asian sector; Huancayo (HUA) and Fuquence (FUQ) in the American sector, Addis Ababa (AAE) and Qsaybeh (QSB) in the African-European sector. All the stations have used a numerical recording system in the frame of INTERMAGNET or MAGDAS program. This system is of high resolution: 0.1 nT for the tri-dimensional magnetometer.

II. The formation of EEJ in the ionosphere

The process of formation of EEJ system can be summarized as follows: at low latitudes, the vectors of electric field and magnetic field are almost horizontal, Earth's atmosphere is revealing the most, thus most of electromagnetic radiation of the Sun can arrive to the ionosphere layer at equator, increases ionization and creats an conductive environment leading to the formation of a narrow current at the solar hemisphere running from west to east and called Equatorial Electrojet. Thus, the EEJ system depends on the solar activity and on the electric and magnetic fields in the region. Basing on the data from magnetic observatories over the world, Rishbeth (1969) indicated that the latitudinal variation of EEJ has affected by Pedersen and Hall conductivities in the ionosphere and these conductivities depend on the intensity of geomagnetic field (F) and magnetic dip angle (I).

III. Results of study on EEJ from CHAMP satellite and Earth’s surface data

1. The magnetic field of EEJ calculated from CHAMP satellite and observatory data

To research on EEJ, we use the total geomagnetic field (F) obtained on CHAMP satellite during the period from 2002 to 2007. The first step is selection of data, one just selects data for the quiet geomagnetic periods (am<20nT, $K_P \leq 3^+$) and around local noon. A total number of about 9695 profiles of data are used.

The residual field (F_{res}), after removing the main geomagnetic field (using the model IGRF-11, with n = 13) consists of: crustal field and external field whose sources locate in the magnetosphere and the ionosphere. F_{res} have amplitudes in the range from -80nT to 150nT.

The residual field F_{res} includes a base "signal" with long-wavelength overlaping on "signals" with short-wavelengths. The short wavelength signal corresponds to the depression of the signal and overlap the magnetic equator so the depression of the signal represents the magnetic field of EEJ current. In this study, to separate these depression parts, we use polynomial filters whose degrees are selected from 6 to 12 depending on the shape of the curve and its amplitude. From that, we can obtain the magnetic field of EEJ (ΔF) in every data profile.

With the use of our filters, instead of using the fixed degree 12 filter of Doumouya (2004), we realize the maximum value of magnetic field due to EEJ in our method greater than about 4nT; In areas with low amplitude of EEJ (Atlantic, Pacific and Brazil) where the calculation by Doumouya gives ΔF almost zero, the meridian distribution of ΔF is more continous and ΔF has greater values.

Applying this algorithm for all data of CHAMP satellite, we has some conclusions:

- ΔF is in range about from 20nT to 67nT, its maximum value in the longitude through Vietnam (105^0E) in every year.

- In the south America, the central Pacific Ocean and the west of the Central Africa, ΔF is about 30-55nT.

- In the east Africa region, western of Indian Ocean, Atlantic and north western Brazil, ΔF is only about 20nT- 30nT.

The center of EEJ is defined as the position in latitude where the value of ΔF is lowest in every data profile obtained from CHAMP satellite. With the data for 2002-2007 period, we found that: the center of EEJ lies almost around the magnetic equator at epoch 2005.0 within a band of $\pm 1^0$. In the area with longitudes from 20^0W to 60^0W, the position of the center of the EEJ deviates the most from the magnetic equator, with the deviation reaches approximately $\pm 2^0$. This area coincides with the area where satellites orbit is not perpendicular to the equator or where the values of amplitude ΔF are lower. In the areas with longitudes from 90^0E to 180^0E and from 60^0W to 180^0W, the center position of EEJ is almost identical to that at the equator. In the areas with longitudes from 20^0W to 50^0W, the center of EEJ is located at the north of equator. In the areas with longitudes from 20^0E to 90^0E, the center of the EEJ is in the south of equator.

Besides using CHAMP satellite data, in this study we also select data from 3 pairs of stations (one station near magnetic equator and another located outside) on Earth's surface. Three pair of stations represents the 3 regions in the world as mentioned above: BCL and PHU; HUA and FUQ; AAE and QSB. The hourly average values of diurnal variation of H component (ΔH) are used. We consider that: ΔH from equatorial station includes magnetic field caused by EEJ and Sq current; ΔH from station located outside of magnetic equator is caused only by the magnetic field of Sq current. So, one can easily calculate the magnetic field of EEJ current at the equatorial magnetic stations.

2. Comparison of current density of EEJ obtained from two kinds of data

When we know the amplitude of the magnetic field caused by EEJ, using an expression given by Doumouya (2003), we can calculate the current density of EEJ at the centre of the EEJ (j_0) from both kinds of data. Table 3.4 summarizes the average value of the current density j_0 at locations of three stations (HUA, AAE, BCL) from ground and CHAMP satellite data in the corresponding locations. The table includes also the differences of current densities (Δj_0) calculated from the two kinds of data. And then one can make some important remarks:

- j_0 calculated from CHAMP satellite data has the values between 40 to 140A/km, while j_0 from stations data are in the range 70A/km – 150A/km. In all over the meridian, there exist 4 maximum peaks and 4 minimum peaks and it is called the wavenumber 4 longitudinal structure. The appearance of the 4 peaks of j_0 is concordant with the results in the study of England (2006) and Brahmanandam (2011). The wavenumber 4 longitudinal structure is generated by the E-region dynamo fields and associated with upward drifts occurring in the dayside ionosphere and its maximum peak at the longitude 105^0E is the largest.

Table 3.4: Average value j_0 calculated from the observatories (Obs.) and CHAMPsatellite data at the same locations.

Year	j_0 at HUA (A/km)			j_0 at AAE (A/km)			j_0 at BCL (A/km)		
	Obs.	CHAMP	Δj_0	Obs.	CHAMP	Δj_0	Obs.	CHAMP	Δj_0
2002	149	111	**38**	123	64	**59**	129	132	**-3**
2003	134	109	**25**	115	59	**56**	125	125	**0**
2004	112	107	**5**	99	61	**38**	121	119	**2**
2005	108	102	**6**	98	56	**42**	117	121	**-4**
2006	97	94	**3**	93	56	**37**	112	123	**-11**
2007	94	98	**-4**	85	52	**33**		117	

- Normally, the maximum of j_0 calculated from observatory data reached maximum at about local noon.

- j_0 calculated from observatories tends to decrease from 2002-2007. j_0 calculated from CHAMP satellite data changes with the same tendency, but not completely linear variation across in every meridian.

- Δj_0 almost have positive value, that means j_0 calculated from observatory data is usually greater than that calculated from satellite data.

- At the location of AAE station, j_0 calculated from observatory data is greater than that calculated from CHAMP one. This may be due to the fact that j_0 calculated from CHAMP data in this area has low value, further more the distance from QSB to AAE is so far (about 29.94^0 dip-latitude) so the calculation of the magnetic field caused by EEJ from this pair of stations is not exact to with respect to from other pair of stations.

- Excluding 2002-2003, j_0 calculated from both types of data at BCL location is greater than at HUA and AAE.

With 72 months of continuous data collected from CHAMP satellite and at 3 equatorial stations, we can study seasonal variation of EEJ. As one knows geomagnetic seasons are defined as follows: Summer (May, June, July, August); Winter (November, December, January, February); Spring equinox (March, April) and Autumn equinox (September, October). After the calculation, we give the following remarks:

- j_0 at two equinoxes and summer shows four maximum peaks and four minimum peaks as the annual average value of the current density of EEJ, known as wavenumber 4 longitudinal structure. In particular, the peak through Vietnam (105^0E) is the highest.

- j_0 in winter shows only three maximum peaks and three minimum peaks, also known as wavenumber 3 longitudinal structure. Kil (2010) studies globally the ionosphere plasma density and confirmes that the vertical ($\vec{E} \wedge \vec{B}$) drift (or E-region dynamo electric field) creates wavenumber 3 or wavenumber 4 longitudinal structures and showed that the eastward movements of atmospheric tides are the source of wavenumber 3 longitudinal structure in the ionosphere.

- j_0 calculated from both types of data showed that: in spring equinox the value of j_0 is highest, smaller in autumn equinox and then in summer, in winter j_0 is weakest. Tarpley (1973) suggested that the seasonal movements of the Sq foci can explain seasonal variation of amplitude of EEJ. Amplitude of EEJ is inversely proportional to the distance between the centers of the Sq foci. In winter, two centers of the Sq foci move toward the poles, so this reduce the magnitude of EEJ and inversely in the equinoxes.

- j_0 calculated from station data at HUA is greater than that at BCL during equinoxes and have equal amplitude as in the summer. But j_0 calculated from CHAMP data at HUA location is smaller than that at BCL in all seasons.

With six years of continuous data (2002-2007) corresponding to ½ cycle of solar activity, we can also study the variation of EEJ with the solar activity. As result, with the data obtained from 3 geomagnetic stations, the EEJ current density is direct proportional to the sunspot number. But with the EEJ current density calculated from CHAMP data, this relationship is more complicated, in some meridian regions this proportion is not correct. This reflects the longitudinal heterogeneity of the EEJ density.

The results of this study shows that the exterior EEJ current is directly related not only to the solar activity, but also affected by the many different electrodynamic processes in the ionosphere and thermal processes in the atmosphere. Thus, we can see that the EEJ current density at a global scale is affected by many complex physical processes in the ionosphere and low atmosphere so the EEJ research still has been interested by international scientific community.

3. Modeling EEJ from CHAMP satellite data

The observed EEJ parameters from the satellite data, we can represent the their changes as a function of time and coordinates. Among the common EEJ models, only 3EM model of Doumouya (2004) can represent well the variation of EEJ in function of longitude, latitude and local time.

According to 3EM model, the function **$j(x,\phi,t)$** is the current density of EEJ (at longitude x; latitude ϕ; local time t) including three independent functions together: **$j(x,\phi,t) = j_0(\phi).G(t).j(x)$.**

where **$j_0(\phi)$** is a function of current density at the center EEJ at local noon and at longitude (ϕ); it represents the change in the meridian of current density j_0;

$G(t)$ is a function of local time t; it describes the change in time (a day) of EEJ;

$j(x)$ is a function of current density j in latitude (x), describes the change of EEJ in latitude. The independent functions will be determined theoretically or empirically basing on observations of magnetic field or current density j_0 of EEJ.

When knowing the current density j values, applying Biot- Savart law we easily calculate the magnetic component (ΔH and ΔZ) caused by EEJ current at any point. After the calculation process, one gives the following remarks:

- EEJ model of 3EM type permits pretty good description of EEJ depending on longitude, latitude and local time. The root-mean-square deviations (RMS) between the observation data and calculated from the model are smaller than 5.4nT for 6 years of data. These deviations are also show complex variation of EEJ globally due to the effects of many different causes as discussed in the first part of this study. In addition, it can be due to satellite data quality, due to its orbital altitude, due to method to separate the magnetic field caused by EEJ from observation data...

- In areas with large amplitude of EEJ (at longitude 105^0E), the RMS values obtained are smaller than in others. In general, the value of models is often smaller than observed value.

- With this model, we can calculate the components of the magnetic field of EEJ at any location or at any time. Normally, the maximum value of EEJ is reached at about 5 UT or 12LT. In the Southeast Asian sector (at 105^0E), the maximum value of ΔH is about 60nT and ΔZ = 0 at the magnetic equator.

IV. Normal geomagnetic field model and magnetic anomaly in Vietnam and adjacent areas

The geomagnetic field recorded at the Earth's surface or at the altitude of orbit of satellites includes magnetic field of several sources: internal fields, produced in the outer core of the Earth (known as main field) or by the magnetization of the rocks in the crust (known as crustal field); external fields, due to electric currents flowing in the magnetosphere and ionosphere. The normal geomagnetic field of an area includes the magnetic field of Earth's core, lithospheric field and regional field. The magnetic anomaly field as the local geomagnetic field, is caused by the magnetic rocks in the local area of the Earth's crust.

The modeling normal geomagnetic field for each region and each country is very important. It is used in the navigation, aviation or detecting geomagnetic field anomaly for serving to study the geological structure, mineral resources...

In this study we use the spherical cap harmonic analysis methods (SCHA) to model normal geomagnetic field for Vietnam and adjacent areas using vectorial data (X, Y, Z) and total field data (F) obtained from CHAMP satellite within 2 years (2006-2007).

The studied area is limited for longitudes from 90^0E to 130^0E, latitudes from 15^0S to 25^0N. This area includes some countries in the region such as: Vietnam, Thailand, Malaysia, Philippines, Indonesia ...and the Vietnam East sea. Geomagnetic data obtained from CHAMP satellite on this region are selected on quiet geomagnetic days (index am<20nT, $K_P \leq 3^+$) and in period of around local midnight (from 22pm to 5am). With such selection of data, the magnetic field of the currents outside of Earth are minimum.

All the geomagnetic data collected from CHAMP satellite satisfy the above conditions within 2 years including 612.002 measurement points. With sampling rate of 1sec and inclination of satellite orbit of about 87.3^0, the selected data covers almost all studied areas.

To remove the effects of time-varying of geomagnetic field, we deduce all the data to epoch 2007,0 (0h00 LT of 1st January 2007), by using the coefficients of IGRF-11 model (International Geomagnetic Referrence Field) with n=13 for the field and n = 8 for the secular variation.

According to Haines (1985), before applying SCHA method, it is recommended to remove the main field from IGRF model.

Geomagnetic data collected from CHAMP satellite are of very high density, thus at the same point may have multiple data which have different values and at different altitude, as well as by the size of the input data to inverse is too large for the computer system. Therefore, before calculating, we choose the data in a grid. The area covered 612002 data points (corresponding to 2448008 of 3 components and total field), is gridded with grid size 0.1^0x0.1^0 for longitude and for latitude. This grid size selection ensures that in each cell there is at least one data point. The value at the center of each cell is the average value of all the data points in the cell. The data in each cell which have the deviation >2nT than the average value in the cell are removed. After the such gridded process, the remaining number of data points used to calculate is of 160.801.

Next, one selects the parameters for SCHA method in accordance with studied area and to reduce the calculation time:

- Selection of half-angle θ_0 of spherical cap: the studied areas are spread about 40^0 in longitude and latitude, so one chooses half-angle of $\theta_0=20^0$, enough to cover studied areas. The center of the cap is chosen at the position of coordinates: 5^0N and 110^0E.

- Using degrees $K_{ext}=2$ for external potential, model coefficients obtained of the external field are presented in the Table 4.1. With these coefficients, it's easy to calculate the magnetic field of the current system outside the Earth for the studied area. For this study, the total external field is about ±18nT (for epoch 2007.0) at the Earth's surface. The origin of this magnetic field may be caused by Sq current and by current systems in the magnetosphere...

Table 4.1: The coefficients g_k^{me}, h_k^{me} for external magnetic field

k	**m**	**n_k(m)**	g_k^{me}	h_k^{me}
1	0	6.3832	12.032	
1	1	4.8432	-4.493	-3.721
2	0	10.4885	-5.650	
2	1	10.0815	0.932	1.107
2	2	8.3553	-0.076	-0.180

- Using degrees $K_{int}=8$ for internal potential, corresponding to the geomagnetic field inside of the Earth, the obtained coefficients are represented on the Table 4.3. With the selected $K_{int}=8$ and a half-cap angle $\theta_0=20^0$, minimum wavelength of the internal field is of about 1000 km.

From calculated coefficients of SCHA, we can calculate the values of the components of magnetic field for studied area. Finally, all the components of the normal magnetic field for studied area are obtained by adding the geomagnetic field components calculated from the model IGRF to the geomagnetic field calculated by SCHA method, so we obtain the maps of the components of the normal geomagnetic field for studied areas. From such obtained maps, we give some remarks on the normal geomagnetic field for studied areas as follows:

Table 4.3: The coefficients g_k^{mi}, h_k^{mi} *for internal magnetic field*

k	m	$n_k(m)$	g_k^{mi}	h_k^{mi}
0	0	0	217.03	
1	0	6.3832	-126.1	
1	1	4.8432	-43.31	55.478
2	0	10.489	191.16	
2	1	10.489	78.385	-46.21
2	2	8.3553	-27.96	22.023
3	0	15.311	-208.7	
3	1	14.793	-112.1	47.909
3	2	14.255	45.331	-30.81
3	3	11.686	15.284	-9.601
4	0	19.604	201.95	
4	1	19.604	105.69	-31.67
4	2	18.754	-83.79	-6.185
4	3	17.858	31.574	22.01
4	4	14.933	20.093	7.336
5	0	24.289	-150.2	
5	1	23.967	-75.46	13.533
5	2	23.64	84.257	9.389
5	3	22.535	-32.33	-29.22
5	4	21.361	-19.45	-14.24
5	5	18.13	-0.012	8.542

K	m	$n_k(m)$	g_k^{mi}	h_k^{mi}
6	0	28.649	84.355	
6	1	28.649	65.285	-35.11
6	2	28.089	-54.46	-27.02
6	3	27.516	44.944	24.604
6	4	26.2	31.31	15.149
6	5	24.794	-10.64	-8.431
6	6	21.292	8.537	-6.179
7	0	33.279	-28.33	
7	1	33.044	-12.24	31.249
7	2	32.807	18.917	22.661
7	3	32.055	-5.129	-12.99
7	4	31.282	-0.99	-9.902
7	5	29.783	1.009	4.496
7	6	28.176	-5.509	-8.026
7	7	24.429	-2.1	4.964
8	0	37.673	5.545	
8	1	37.673	2.382	-0.528
8	2	37.252	-2.952	0.078
8	3	36.825	2.119	2.277
8	4	35.909	-1.407	0.786
8	5	34.965	-0.948	0.731
8	6	33.304	1.7	-1.044
8	7	31.519	-0.388	-0.417
8	8	27.546	1.392	-1.319

- Total geomagnetic field (F): The value of the total intensity F varies from 38600nT to 49500nT. The isoporic curves are denser in the north and south, sparser in the center of area and minimum peaks located in the east of the Philippines with minimum value of about 38624nT.

- The horizontal component (H): The value of H is in the range of 31600nT to 41500nT. The isoporic curves are denser in the north, south of area. The highest value of H is about 41460 nT at the location (9.2^0N-98.3^0E).

- The north component (X): The value of X is in the range of 31300nT to 41500nT in the area. The shape of the isoporic curves of X is similar to that H, with the highest value of about 41458 nT at the location (9.1^0N, 97.8^0E).

- The east component (Y): The value of Y is in the range of -3820nT - 2130nT in the area. At the north of Vietnam, the isoporic curves have the concavity toward the north, while in the south of Vietnam having the concavity toward the south. At the north of Thailand there is the intersection of four major geomagnetic field anomalies of Asia.

- The vertical component (Z): The value of Z is in the range of 37000nT - 28400nT in the area. The isoporic curves tend to be nearly straight lines, parallel, spaced. The area with highest value of Z is located in the north of Vietnam, then values of Z decrease as one goes to the south of the region. The zero isoline is a nearly straight line laying around latitude 8^0N, then Z become negative.

- The declination (D): Absolute values of D on the whole area are small in the range of -7^0 to 3.5^0. The isoporic curves of D are similar to those of Y. The values of D on the whole territory of Vietnam are negative. The zero isoline is locate at east-south of Vietnam

- The inclination (I): The values of I are in the range of -49^0 to 7^0 in the studied area. The isoporic curves tend to be nearly straight lines, parallel, spaced as Z component. The zero isoline is locate at around latitude 8^0N, then I become negative.

To confirm the accuracy of SCHA method, we compare the magnetic field obtained by SCHA method with data obtained at Bac Lieu and Phu Thuy geomagnetic observatories of Vietnam (Two stations used the numerical recording systems with high resolution). After removing the time variation, the deviation of three components of the geomagnetic field (X,Y,Z) are: at the location of Phu Thuy: ΔX=1.3nT; ΔY=-2.4nT; ΔZ=-2.8nT. At Bac Lieu: ΔX=1.7nT; ΔY=-2.1nT; ΔZ=-3.0nT. The value of the deviations is quite small and confirms the accuracy of the model.

Next, we compare the field intensity (F) calculated by SCHA methods with that calculed from the model IGRF-11 at the same epoch 2007.0 and at the Earth's surface. We found that, the morphologies of the isoporic curves are almost quite similar but the amplitudes have a little difference. This proves that, the model of normal magnetic field calculated by SCHA method represent the main field and the part of crustal one. The differences ($\Delta F_{ĐL}$) between the total magnetic field from the SCHA and from IGRF is in the range -90 nT÷98 nT. In the studied area, almost the values of ΔF are negative, excepting only two areas where $\Delta F_{ĐL}$ are positive: north of Philippines, southern Taiwan and southeast of Indonesia. Thus, the values of the total magnetic field intensity $\Delta F_{ĐL}$ represent the field of Earth's crust in the region, which the field from IGRF can not do.

The error of a model includes: Error of measurements δ_1 (by equipment, in the determination of the coordinates, of time…) with CHAMP satellite data, δ_1= ±3 nT. Error in the reduction of the variation in the data about δ_2 = ± 6nT. Error of field transformations from the satellite altitude of about 400km to the surface δ_3 = ±30 nT. Therefore, the total error with this model is about δ = ±39 nT. This value is smaller than that in the research of Haines (1985) with δ = ±75 nT; or in the research of Nguyen Van Giang (1988) with δ = ±60 nT.

The anomalous magnetic field obtained by subtracting from data obtained from the satellite CHAMP the normal magnetic field calculated by SCHA method at same altitude and location. The magnetic anomalies are generated by the magnetization contrast of rocks in the Earth's crust in the region. The establishment of magnetic anomaly maps for an area or one country is very important, they allow to study the geological structures or to search for mineral resources. From the magnetic anomaly maps for ΔX_a, ΔY_a, total ΔF_a from CHAMP satellite data (altitude about 350km) for studied area, we give some following remarks:

- The north component (ΔX_a): in the range of -13nT - 8nT; the east components (ΔY_a) in the range of -8nT - 10nT; the vertical component (ΔZ_a) in the range of -8nT - 10nT. The magnetic anomaly fields has the nearly symmetrical amplitudes.

- The magnetic anomalies in the studied region are quite complex, the positive and negative anomalies are alternate.

However, due to obtained at the high orbit altitude of about 350km, the anomalous magnetic fields reflect only major anomalies, such as the contacts between tectonic plates or large basalt blocks.

CONCLUSION AND SUGGESTION

*** Conclusion:**

From the results of this study, we have some conclusions:

1. Using the polynomials with different degrees of 6 to12 we can separate the magnetic field caused by EEJ from the CHAMP satellite data. The amplitude of EEJ field is between 20nT to 67nT. With 6 years of data from 2002 to 2007, the EEJ at longitude 105^0E is highest.

2. In all over the meridian, the current density of EEJ calculated from CHAMP satellite data is between 40A/km to 140A/km. The EEJ represents a clear seasonal variation, which in summer and equinox has 4 maximum peaks and 4 minimum peaks, but in winter has only 3 maximum peaks and 3 minimum peaks. Comparison of the EEJ calculated from satellite and observatory data as well as study of the variability of EEJ showed that the EEJ system has both local and global properties, the EEJ directly relate to the solar activity and is affected by many electrodynamics processes in the ionosphere and in the atmosphere.

3. The amplitude of the EEJ calculated from observatory data is proportional to the sunspot number, but the one of EEJ calculated from CHAMP satellite data depend on the sunspot number in different manner at every longitudinal sector.

4. Model of 3EM type allows us to have a general view on the variation of EEJ along longitude, latitude and local time. The mean deviation between model and observation data is smaller than 5.4nT, that is quite small.

5. It's first time, in Vietnam one has studied and applied spherical cap harmonic analysis method for modeling normal geomagnetic field for Vietnam and adjacent areas. The maps of 7 elements of normal geomagnetic field at the epoch 2007.0 for area present not only the main geomagnetic field of the Earth but also the crustal field with high reliability. The total error of this normal magnetic field model is quite small (<±39nT).

6. The magnetic anomaly maps obtained from CHAMP satellite for studied area is quite small, only in a range of about ±10nT at the altitude of 350km. But they reflect quite well the large magnetic anomalies such as magnetic contacts boundary between tectonic plates or large basalt blocks.

*** Sugestion:**

1. One need to continue to study of EEJ to confirm and explain the anomaly of EEJ at longitude of Vietnam by using more geomagnetic data from SWARM satellite and from observatories; using the global models such as TIECGM in order to model the EEJ and to describe the process of electrodynamics in the ionosphere and atmosphere affecting this current.

2. Using the SCHA method for combined geomagnetic data such as: data from observatories, from repeat station points, and from geomagnetic measurements in the air, sea... to improve the reliability of the normal magnetic field model.

List of related papers published by author:

[1] V. Doumbia, Le Truong Thanh, Le Huy Minh, Y Cohen, Amory-Mazaudier, On the estimation of the equatorial electrojet magnetic signature and peak current density from polar orbiting satellite magnetic measurements, *International Association of Geomagnetism and Aeronomy 11*, **2009**, Vol 41(42).

[2] Le Truong Thanh, V. Doumouya, Le Huy Minh and Ha Duyen Chau, The equatorial electrojet model with CHAMP satellite data, *Journal of the Earth's Sciences*, **2010**, Vol T32(1), pp 48-56.

[3] Le Truong Thanh, Le Huy Minh, Ha Duyen Chau, V. Doumouya, Y. Cohen, Anomaly of equatorial electrojet (EEJ) and its seasonal variation, *Journal of the Earth's Sciences*, **2011**, Vol T33(1), pp 29-36.

[4] M. Yamamoto, T. Tsugawa, T. Nagatsuma, Ha Duyen Chau, Le Truong Thanh, S. Kaloka, P. Baki, Study of equatorial spread-F with GNU radio beacon receiver (GRBR) network over Asia, Pacific and Africa, *International Union of Geodesy and Geophysics*, **2011,** M12_29PP145.

[5] H.D. Chau, L.T. Thanh, N.T. Dung, Vietnam magnetic and ionospheric observatories are ready to be integrated in the geoss, *International Union of Geodesy and Geophysics XXIV General Assembly in Melbourne*, Australia, **2011**, JG05_3PP028.

[6] Ha Duyen Chau, Le Truong Thanh, Nguyen Thanh Dung, Results of magnetic – ionospheric studies in Vietnam, *The proceedings of the international scientific conference, to commemorate the 55th anniversary of the Geophysics of Vietnam*, **2012**, Publishing house for Natural Science and Technology.