The MAGDAS project
The past and next 10 years

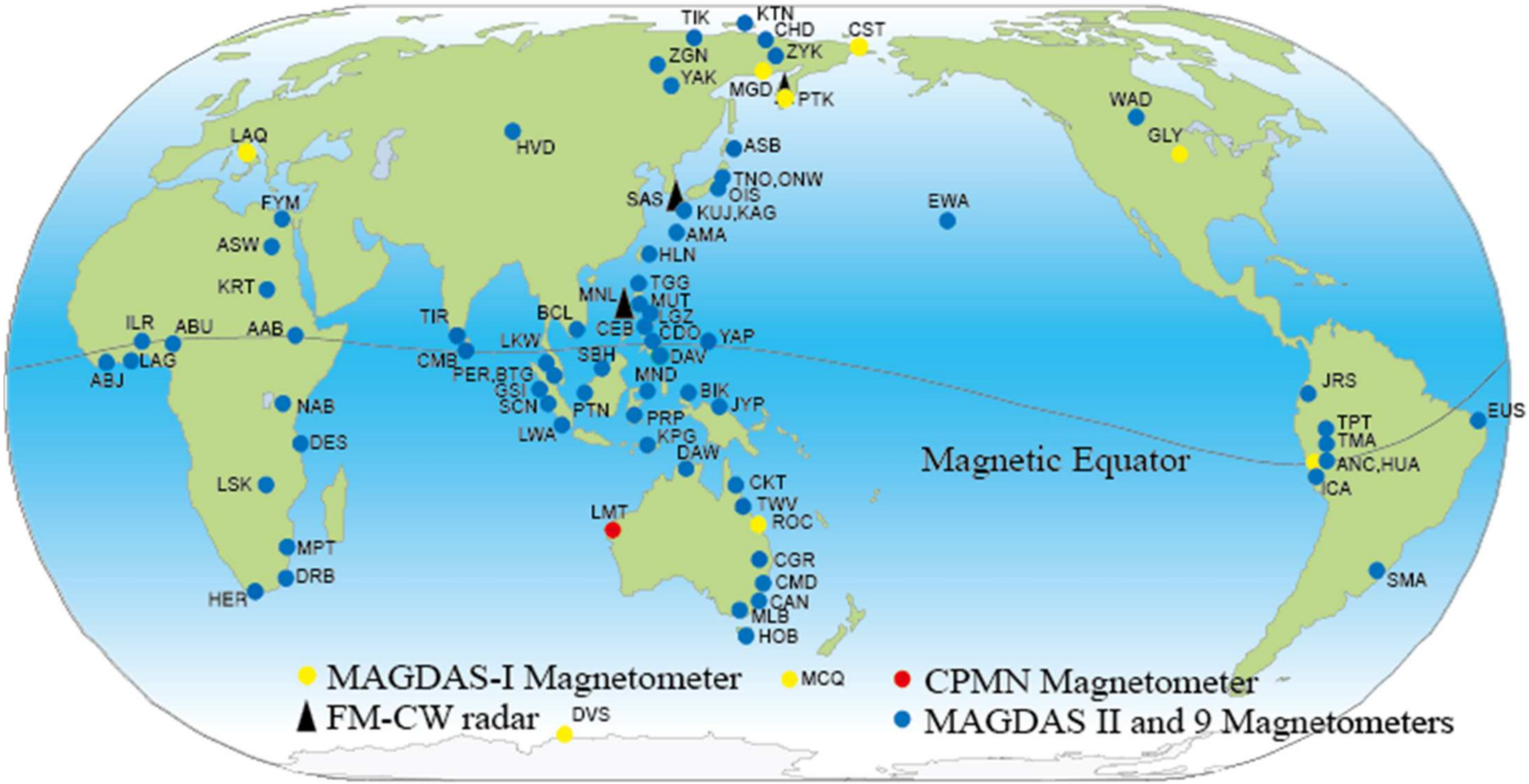
A. Yoshikawa and A. Fujimoto,

ICSWSE, Kyushu University

For Space environment monitoring

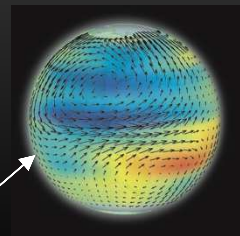
MAGDAS/CPMN

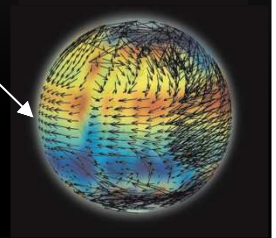
(MAGnetic Data Acqusition System/Circum-pan Pacific Magnetometer Network)



Why global network observations of geomagnetic field disturbances?

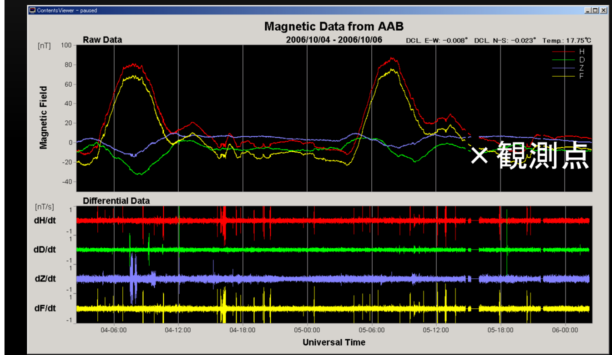
Magnetically quiet day

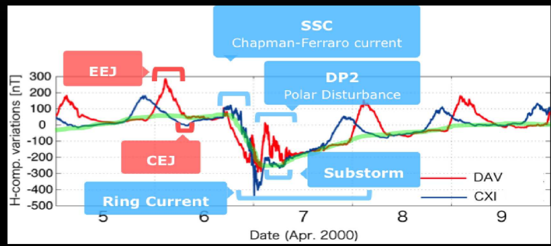


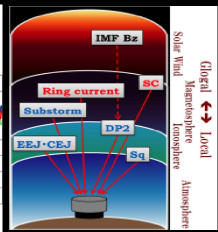


Start of magnetic

・Visualization of Space weather map from global magnetic field data







Magnetic field variations on the ground

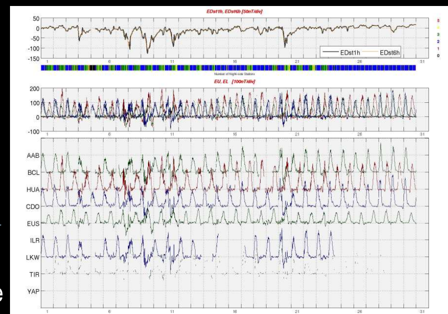
are generated by reflecting

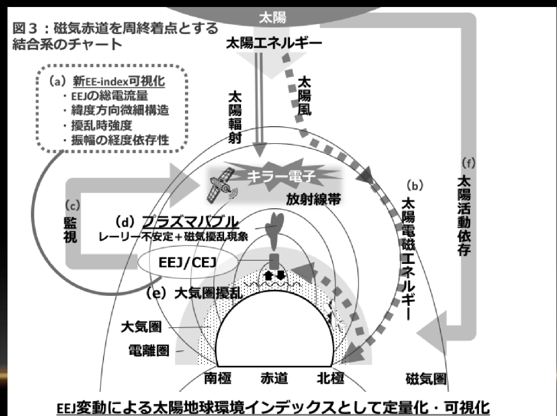
（１）「solar terrestrial coupling」
electromagnetic disturbances across the
magnetosphere and ionosphere

（２）「horizontal coupling 」
electromagnetic energy is distributed from
polar to equatorial ionosphere

（３）「atmospheric vertical coupling」
propagation of lower atmospheric
disturbances to upper atmosphere via
gravity wave and tidal waves

・space environment monitoring by using space weather index





We can investigate

・influences to Earth system caused solar eruptions

・relation between solar activity and climate phenomena and/or climate change

・global circulation of energy and material of upper atmosphere

・relations between seismic activity and solar activity?

これらを同時に且つ広域に調査できるデータは磁場変動データのみ

Super Multipoint Geomagnetic field Network Observation ：important tool for exploring of frontier of solar terrestrial coupling process

Recent update of MAGDAS stations (2015-2017)

(Enhancement of Equatorial Network : developed 15 new sites)

2015

Tingo Maria@Peru, December (New!)
Tarapoto@Peru, December (New!)
Colombo@Sri Lanka, February (New!)

2016

Wadena, Canada, September (replace of instrument)
Perak@Malaysia, October (New!)
Banting@Malaysia, October (New!)

2017

Johr Bahru@Malaysia, March (New!)
Terengganu@Malaysia, March (New!)
Penang@Malaysia, August(New!)
Kudah@Malaysia, August(New!)
Kamchatka@Russia, June (FM-CW repair)
Huancayo@Peru, September (FM-CW, New!)
YAP, Australia, November (maintenance)

ANGKASA MALAYSIA

Universiti Kebangsaan Malaysia
National University of Malaysia

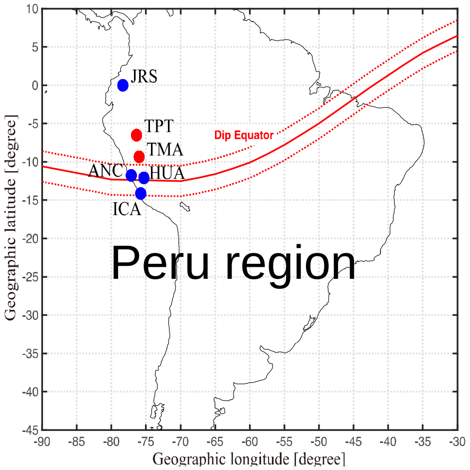
Universiti Teknologi MARA

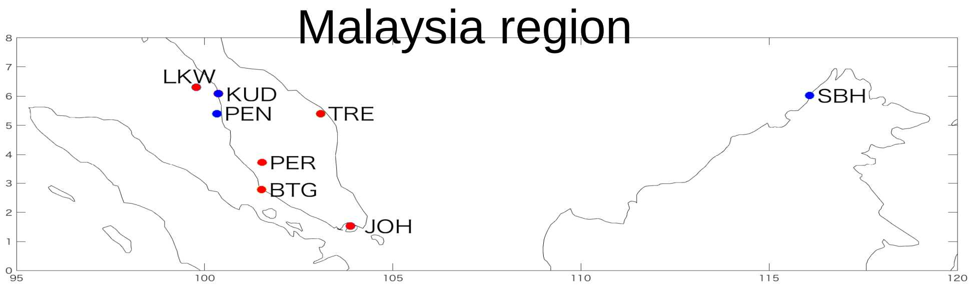
UniSZA Universiti Sultan Zainal Abidin

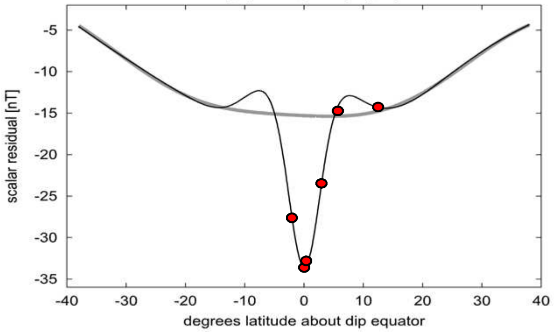
Kyushu University UI project Kyudai Taro,2014

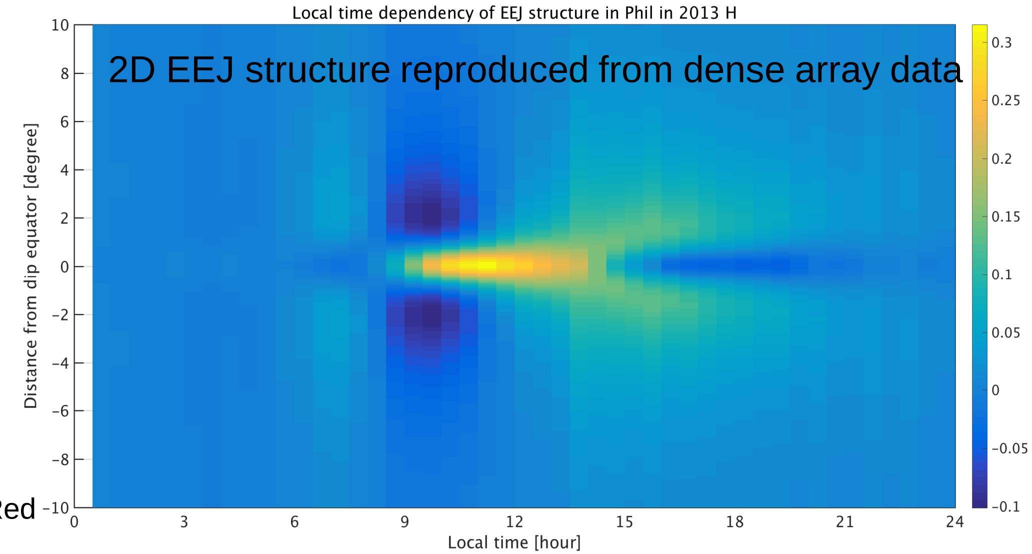
New 6-stations@Indonesia will be installed by BMKG (for seismic electromagnetics)

Development of dense array of EEJ across dip equator









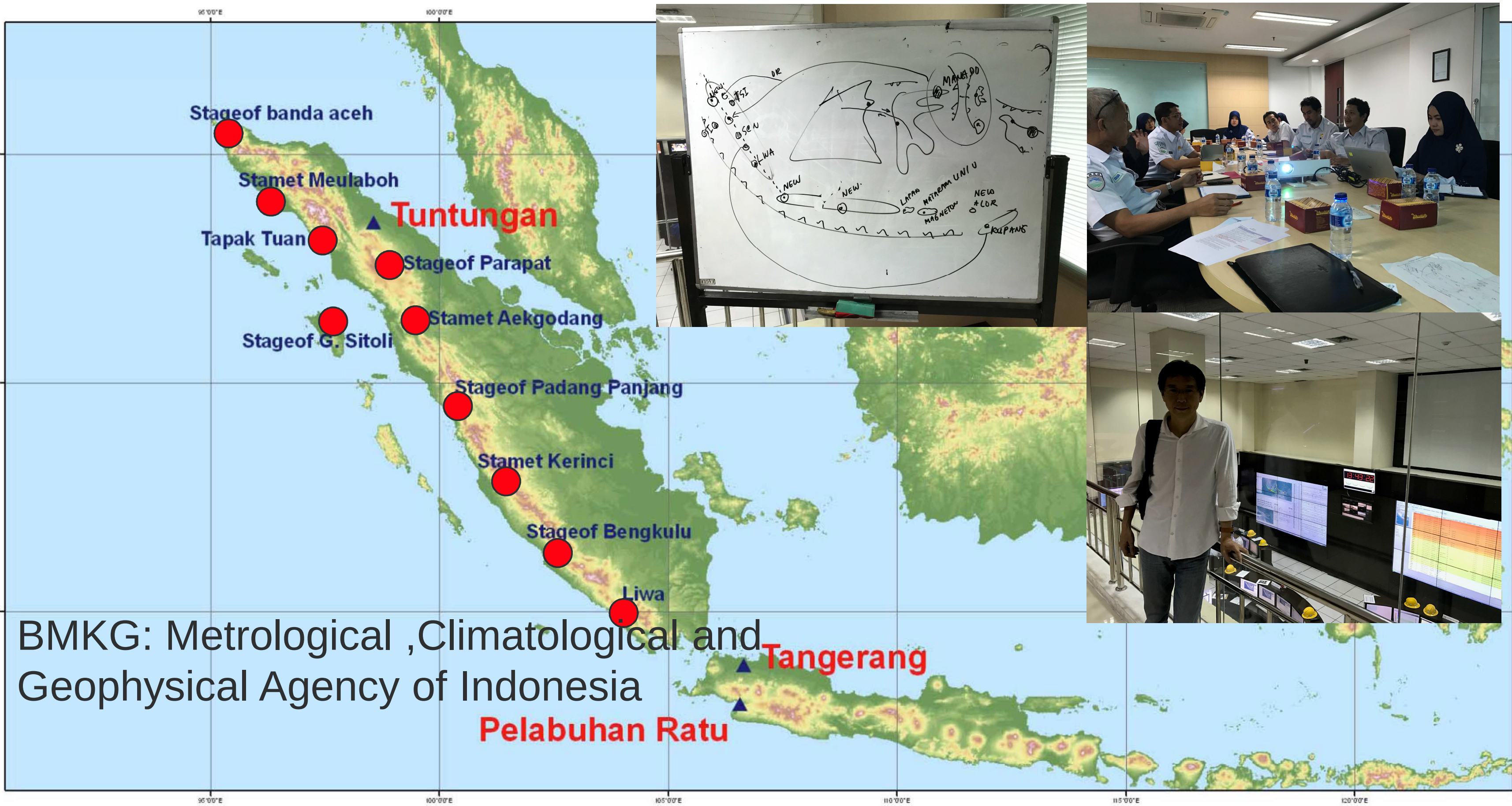
(Right) Noon time latitudinal variation of magnetic field change by ionospheric current (after Luhr et al., 2004). Red dots denote MAGDAS observatories in Peru.

- Average variation of EEJ, including current density and its structure, can be derived by satellite observation, but ground observations are necessary for monitoring EEJ activity every time.
- Dense array across EEJ enables real time monitoring of “breathing of EEJ”. that might be closely related to the scintillations caused by “Spread F” and /or “Plasma Bubble”.

Seismo-Eloctromagnetic Monitoring Network

Indonesia-Japan MAGDAS Project for Litho-Space Weather

MAP SCOUTING 10 POSSIBLE SITE FOR INSTALLATION



BMKG: Metrological ,Climatological and Geophysical Agency of Indonesia

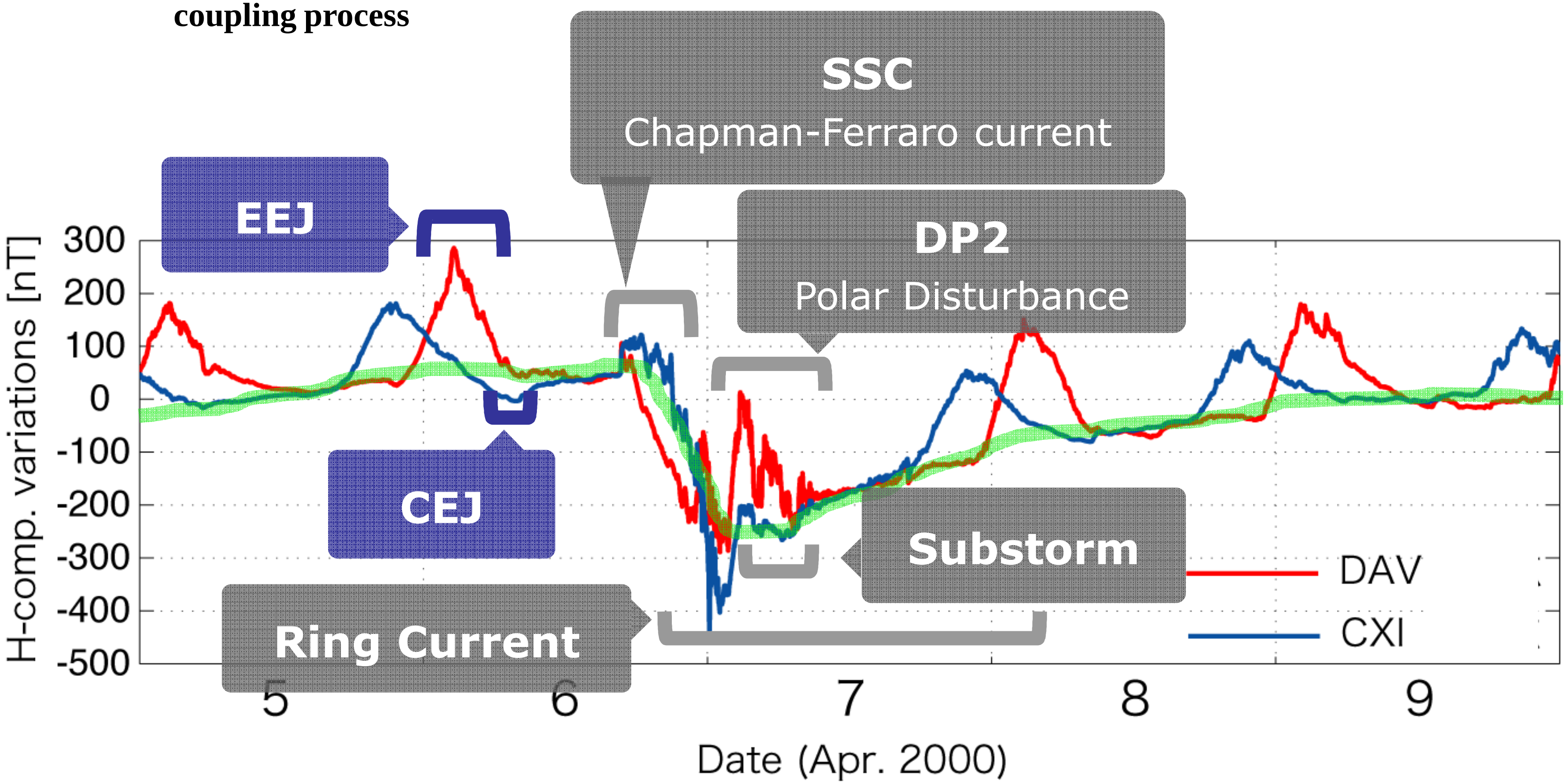
Legend :
- ● Planning Scouting 10 Possible Site
- ▲ Geomagnetic Observatory BMKG

ICSWSE, BMKG, Chiba U.

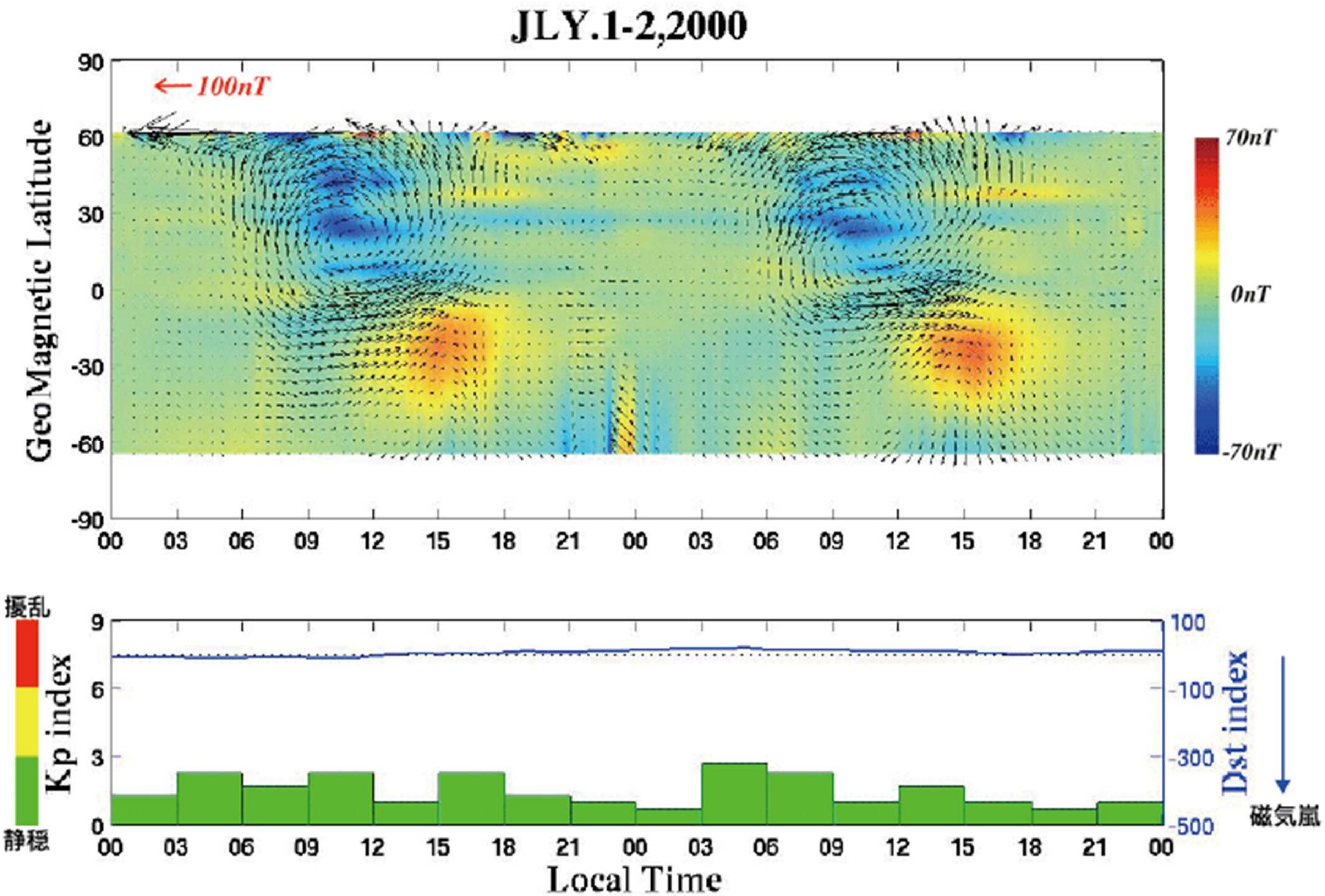
METEOROLOGICAL CLIMATOLOGICAL AND GEOPHYSICAL AGENCY

Why Equatorial Network ?

- magnetic dip-equator is a final destination of solar wind-magnetosphere-ionosphere coupling
- anomalously enhanced zonal conductance is aligned along the dip-equator by the Cowling effect and forming equatorial electrojet (EEJ)
- sensitive amplifier of atmospheric dynamo effect (long term variation)
- sensitive receiver of solar wind variation, storm and substorm disturbances (short term variation)
- very useful for monitoring magnetospheric , ionospheric , atmospheric disturbances and their coupling process

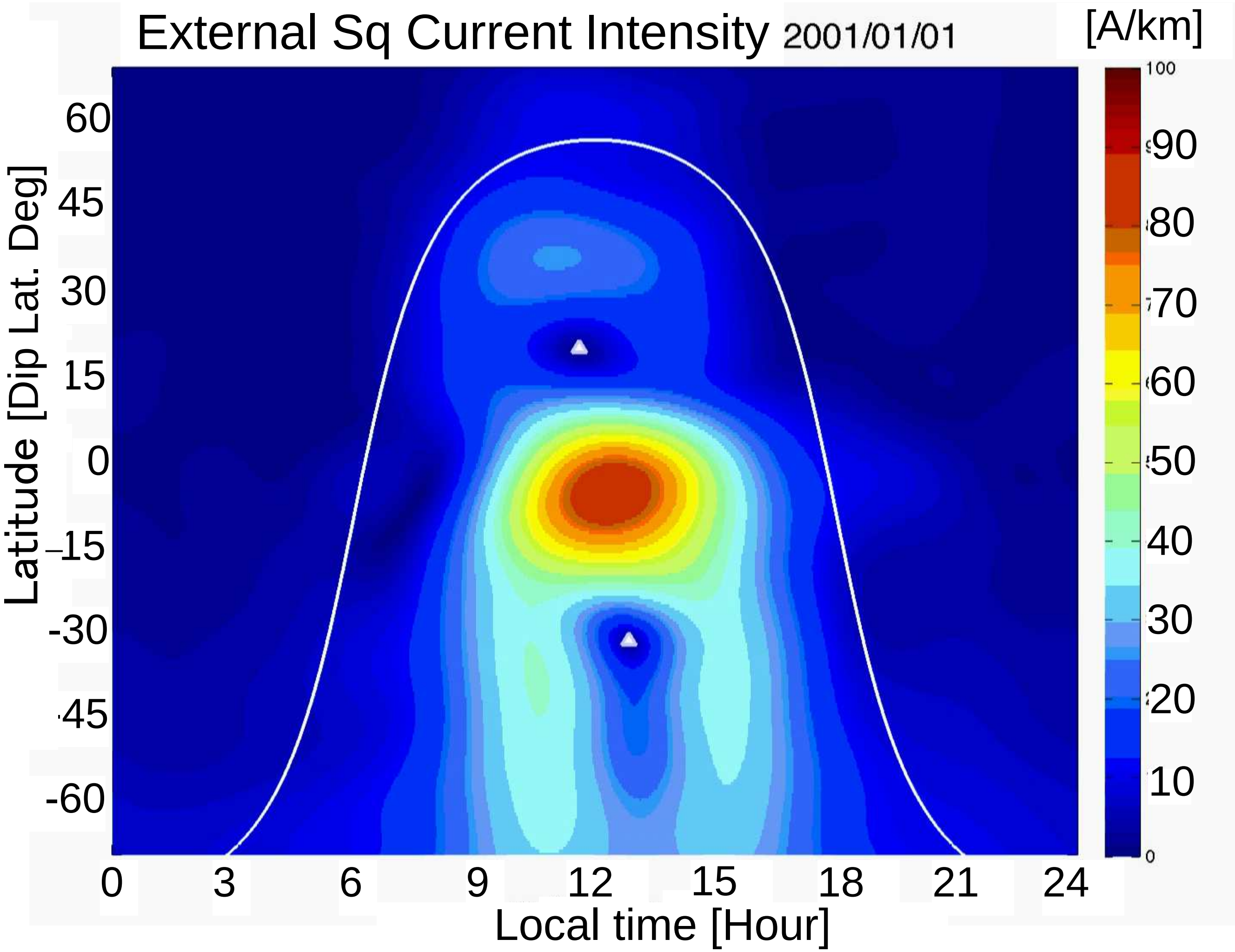


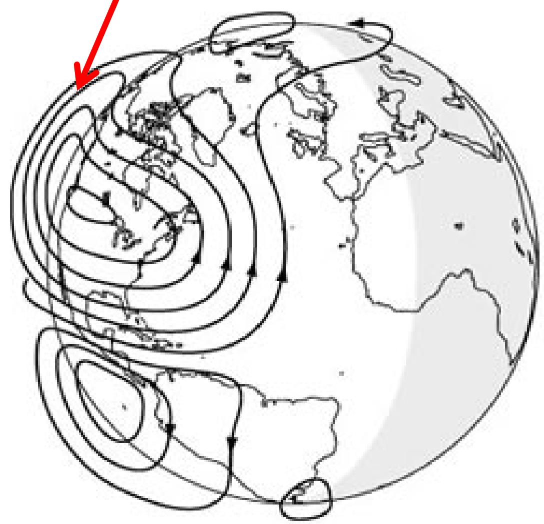
Visualization of Sq-Equivalent current in geomagnetically quiet days

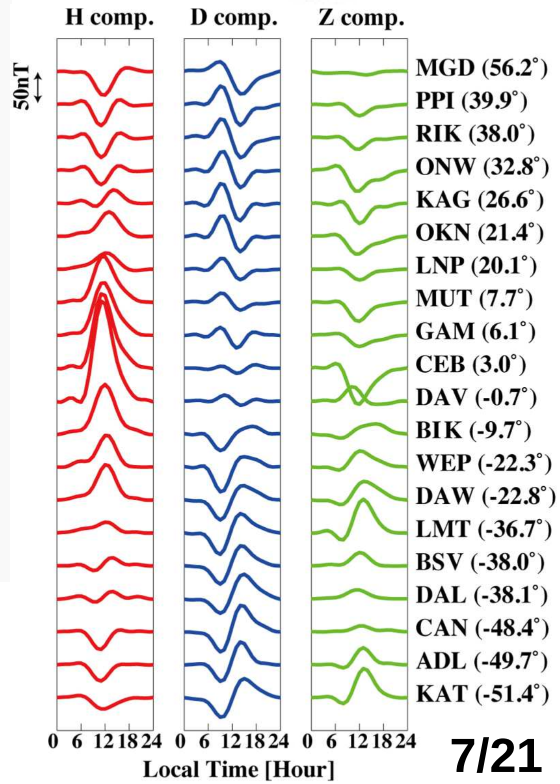


Sq Ionospheric Current

Sq Ionospheric Current

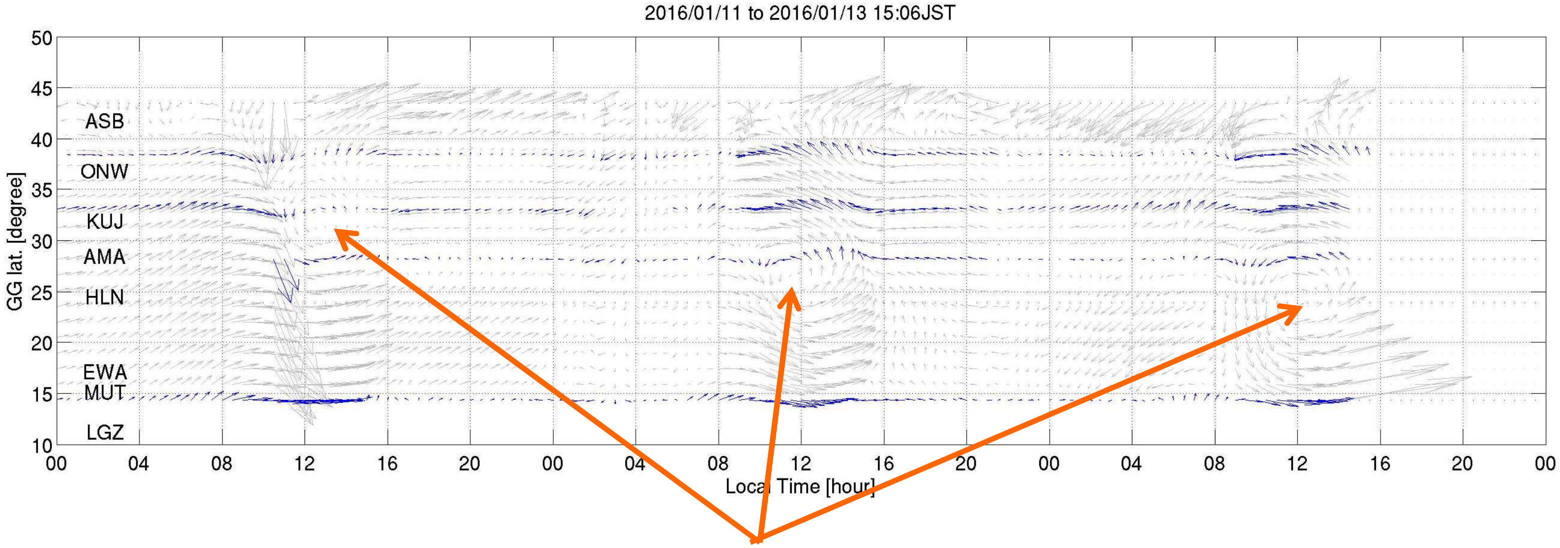






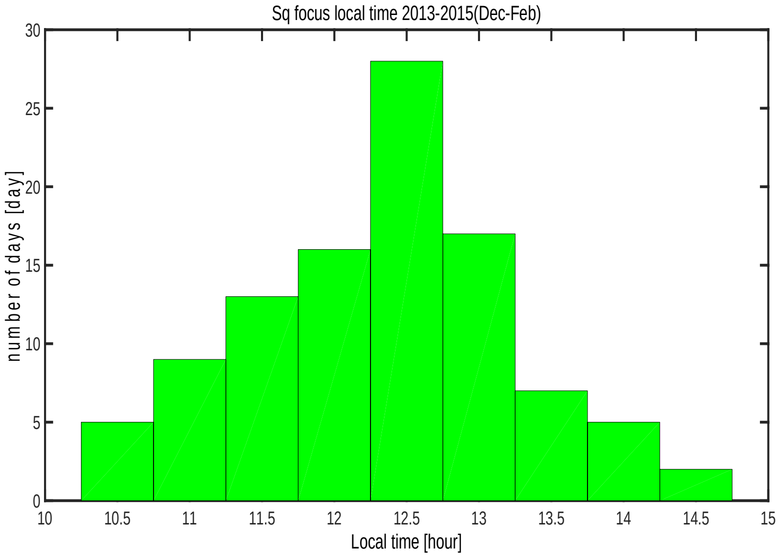
-Seasonal and day-to-day variations of global Sq ionospheric current produced by Solar Radiation.

Day to Day variations of Sq fields

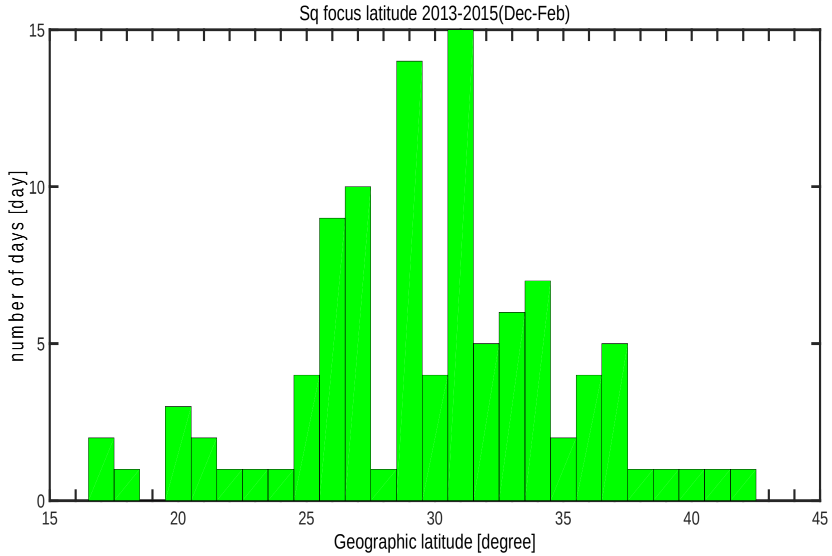


Day to day variation of focus of Sq vortex

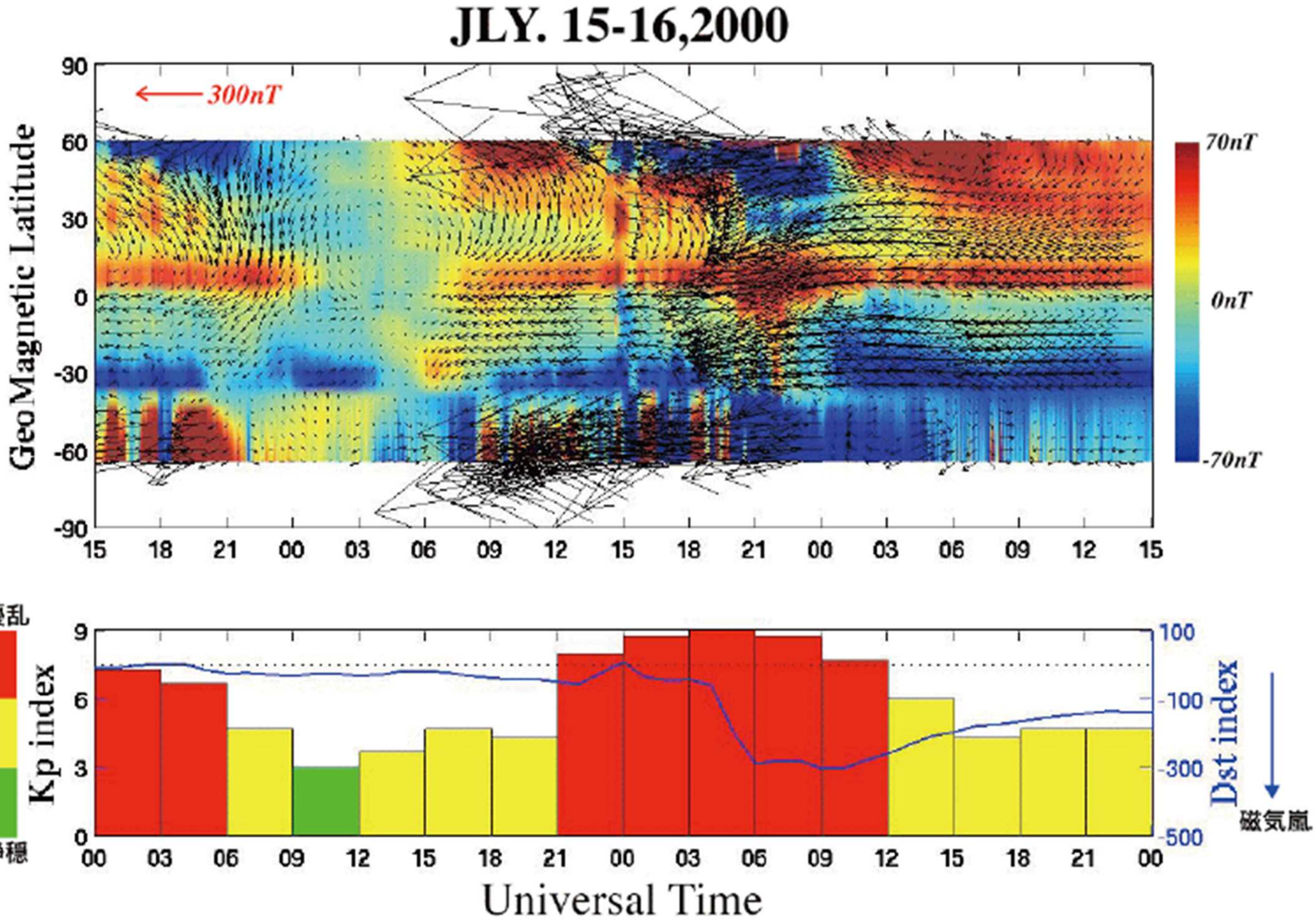
LT-distribution of Sq focus



Latitudinal-distribution of Sq focus

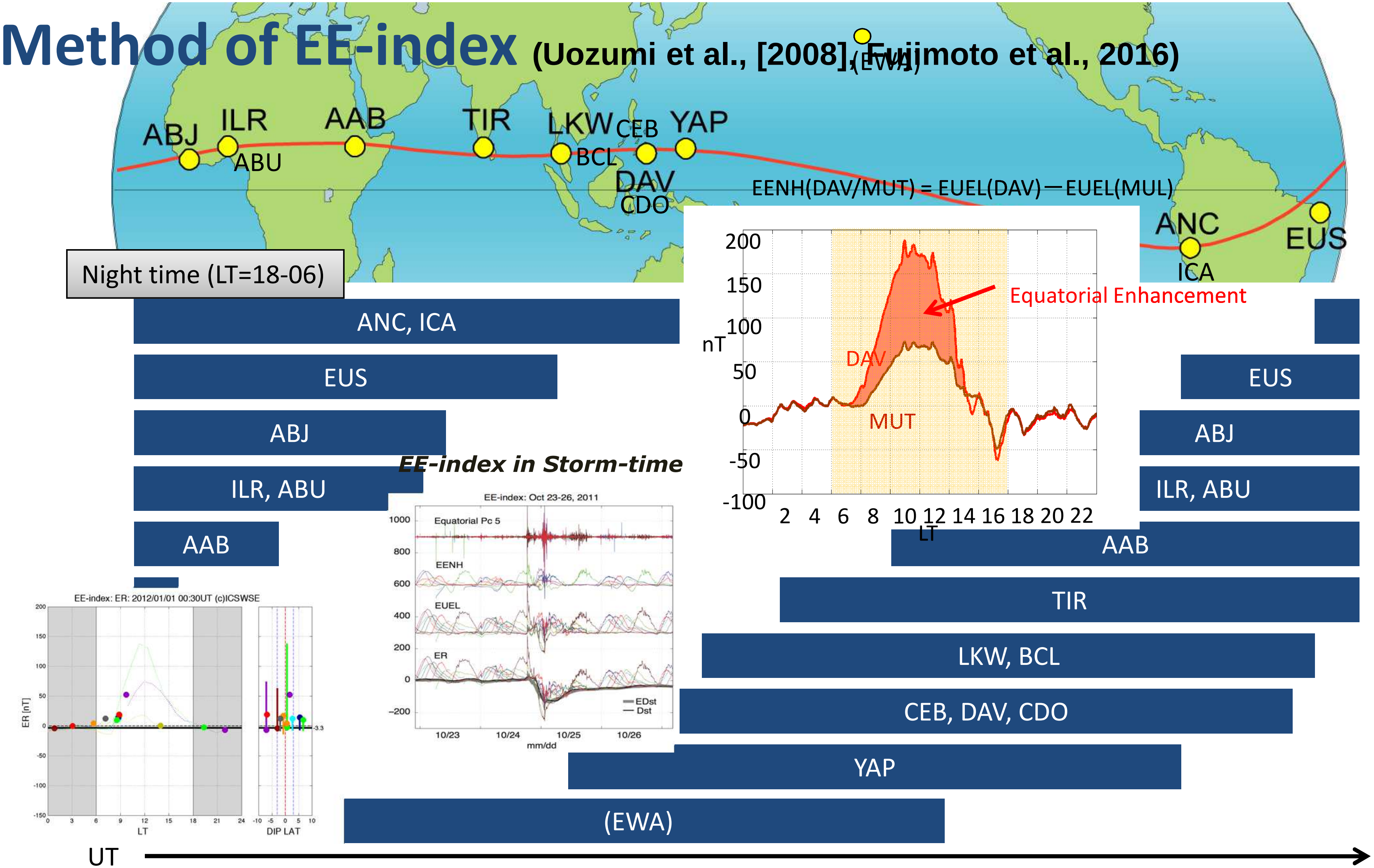


Visualization of Sq-Equivalent current in geomagnetically disturbances days



Monitoring of Equatorial Electrojet variations (Even for Magnetically disturbance)

Method of EE-index (Uozumi et al., [2008], Fujimoto et al., 2016)



EE=EUEL+ EDST

local component

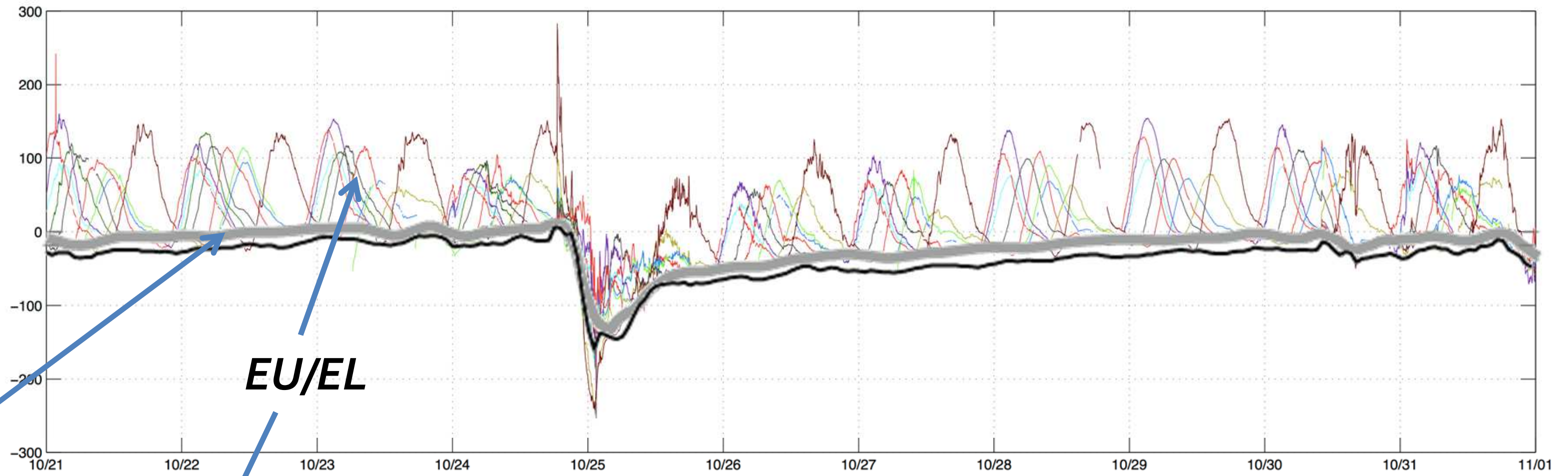
Global component

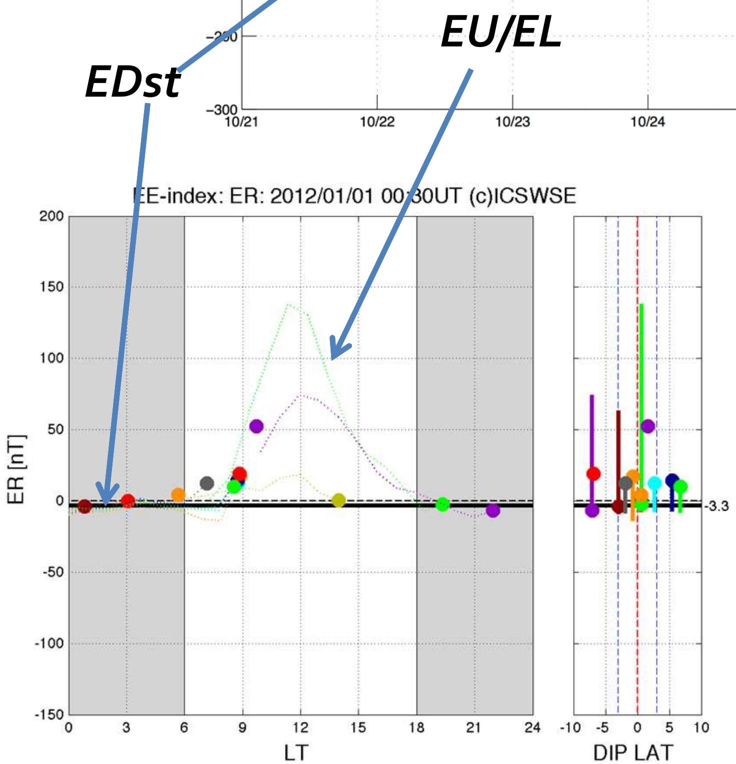
- monitor the equatorial magnetic field variations changing *from "moment to moment"* with the same ruler regardless of magnetospheric condition(quiet/disturbance)

"EE= +EUEL+EDst" calculated by MAGDAS

EDst **is defined as mean night time variation along Mag. Eq.**

EDst **shows similar variation as** ***Dst***





EDst **represents global magnetic variation**

EU/EL **represents local magnetic variation**

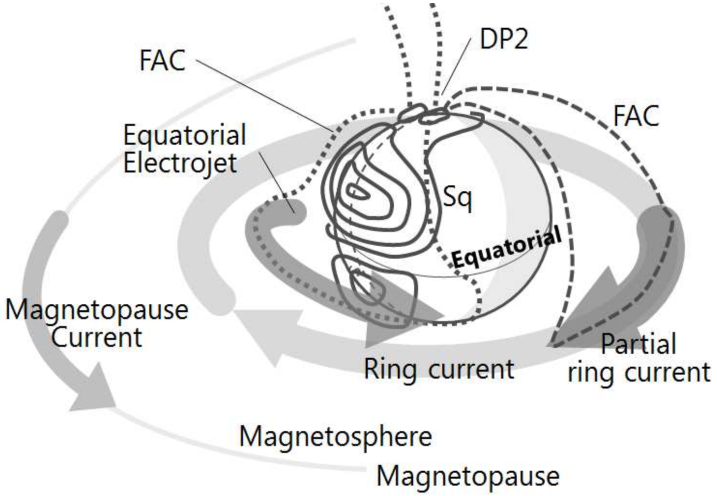
EDst **can be utilized as the base level for the EEJ and CEJ**

Space Weather Environment Index

Higher Freq. Variations

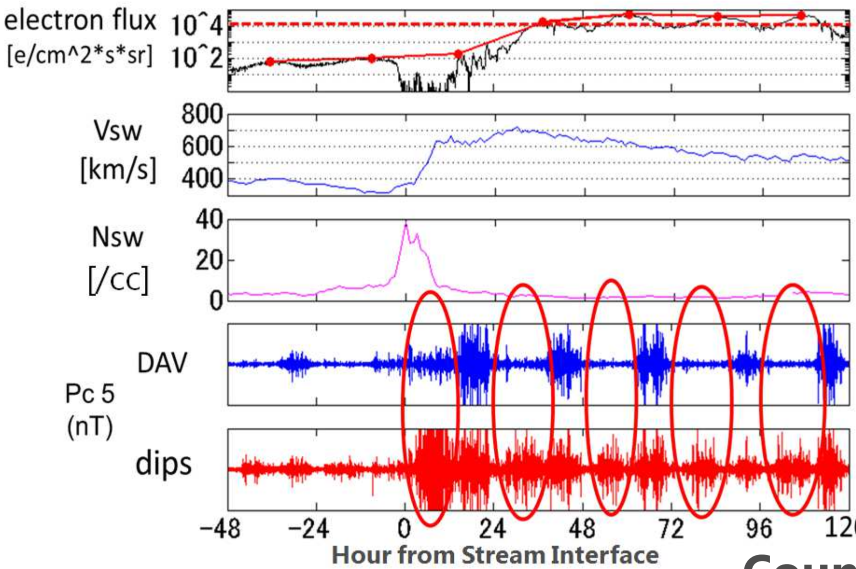
Pc5 ULF waves

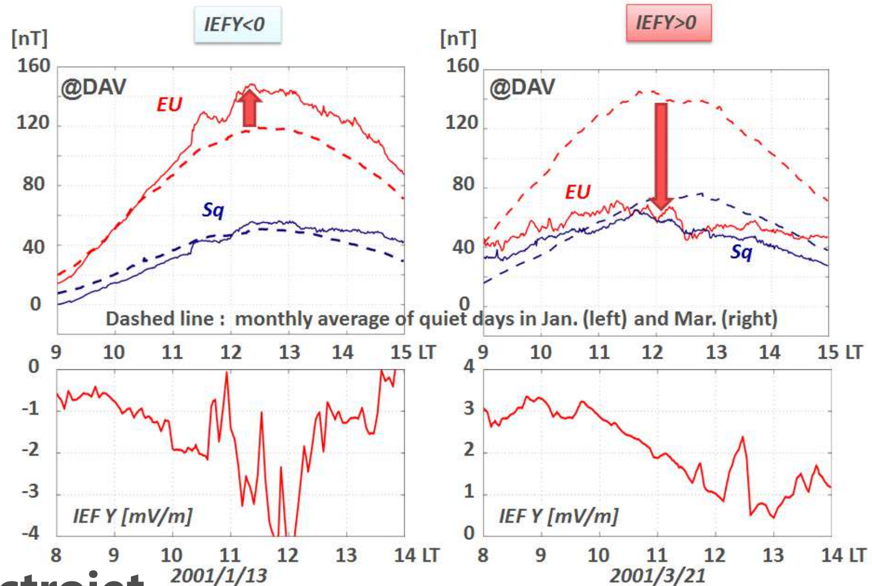
The proxy of the high energy electron acceleration in the radiation belt during magnetic storms



DP2

Penetration of solar wind energy (the Interplanetary Electric Field) into the equatorial ionosphere via the polar ionosphere





Counter Electrojet

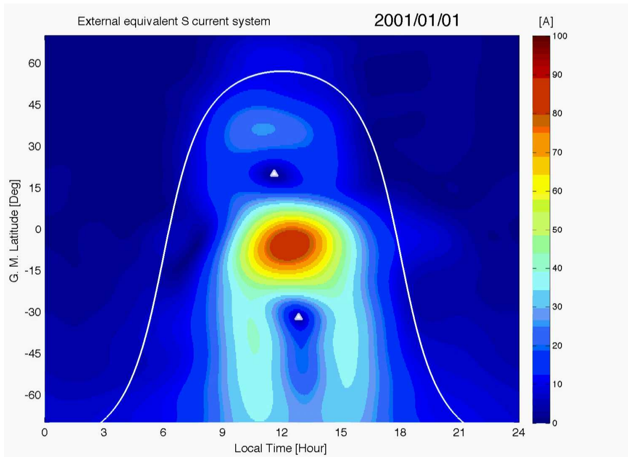
Polar disturbance effects to Equatorial Electrojet

Space Weather Environment Index

Lower Freq. Variations of EUEL

Solar cycle Variation

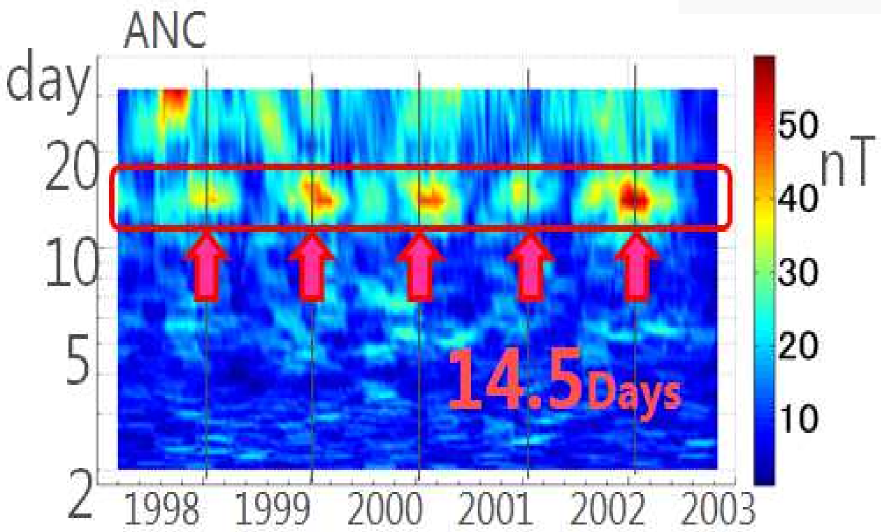
The dependence of the EEJ structure and the atmospheric motion related to EEJ on the solar activity/solar cycle

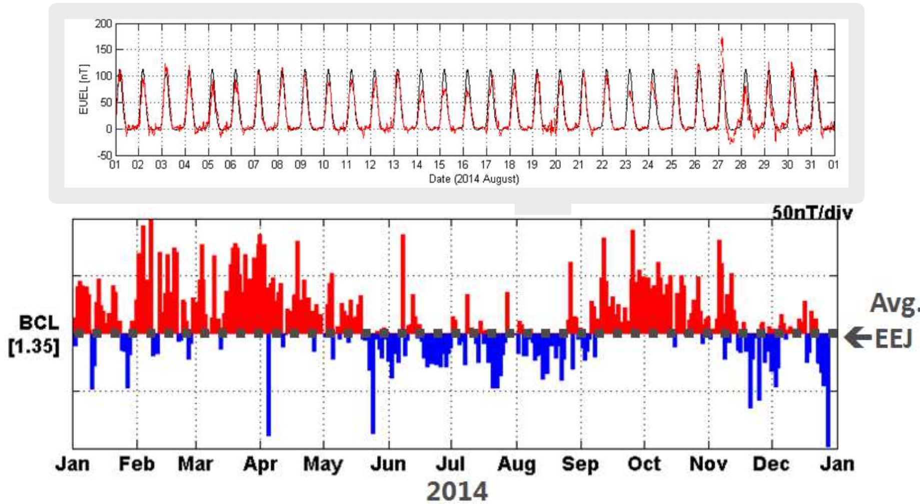


Day-to-day variation

The atmospheric disturbances affecting ionospheric dynamics

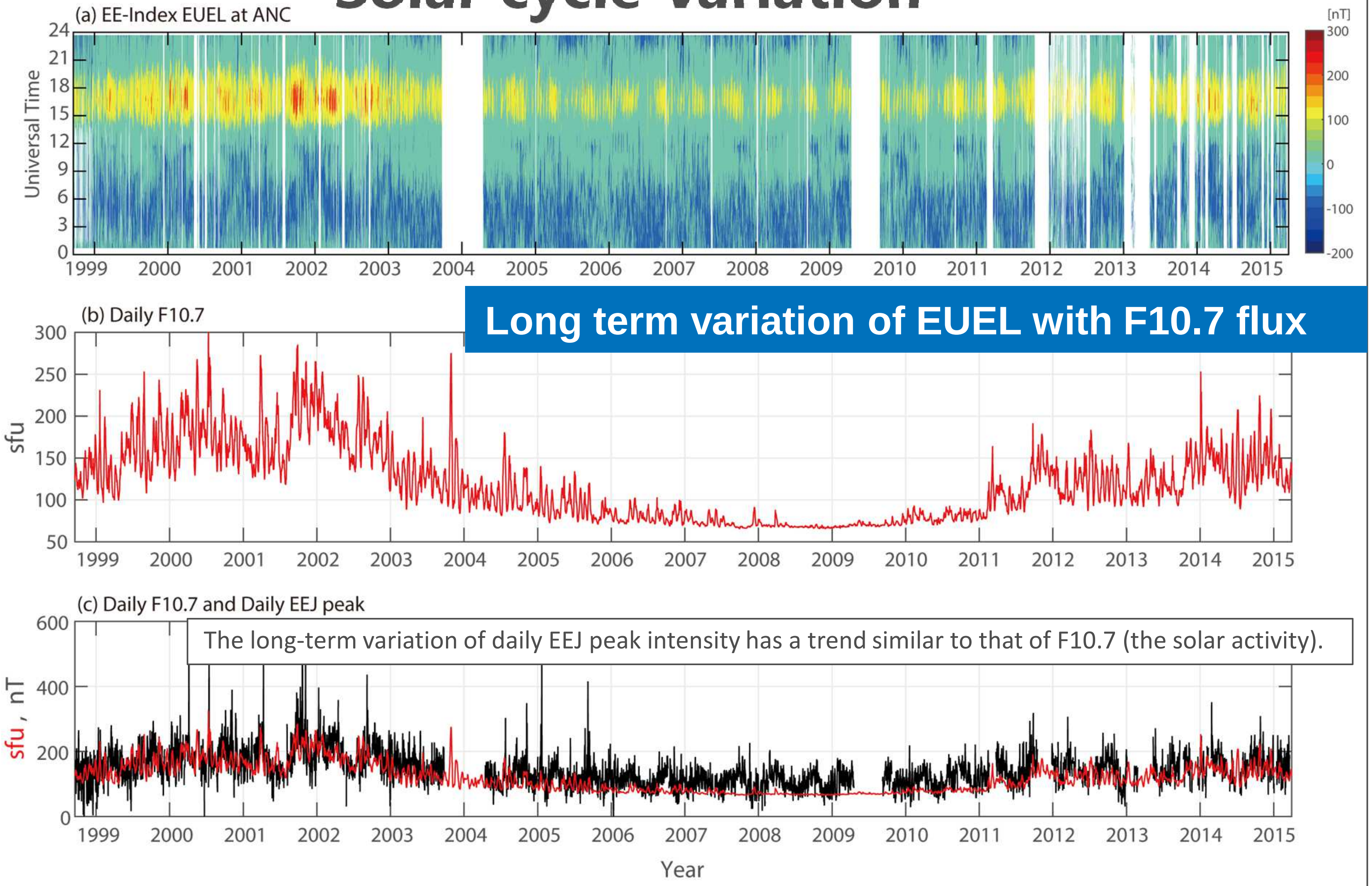
Avg. EUEL@DAV





Long term Variations of EUEL

Solar cycle Variation



Long term variation of EUEL with F10.7 flux

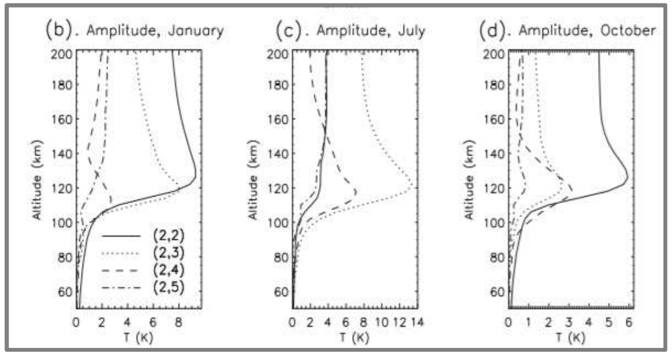
The long-term variation of daily EEJ peak intensity has a trend similar to that of F10.7 (the solar activity).

After Fujimoto et al., 2016

Seasonal dependence of ΔEUEL (semidiurnal variation)

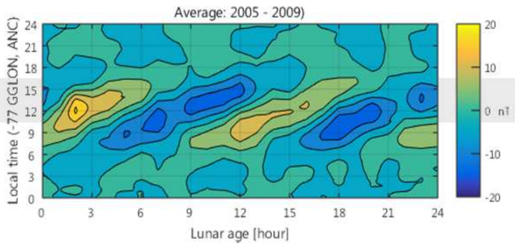
The seasonal dependence of semidiurnal variation agrees with the seasonal profile of atmospheric neutral wind (2.2) mode corresponding to the lunar tide.

The mean behavior of ΔEUEL is consist of the result of Rastogi (1973). We demonstrated the monthly mean behavior of ΔEUEL, for the first time based on the time-series magnetometer data.



[Forbes et al., 2013]

(a) Mean behavior of all ΔEUEL



(b) Monthly Mean behavior of ΔEUEL

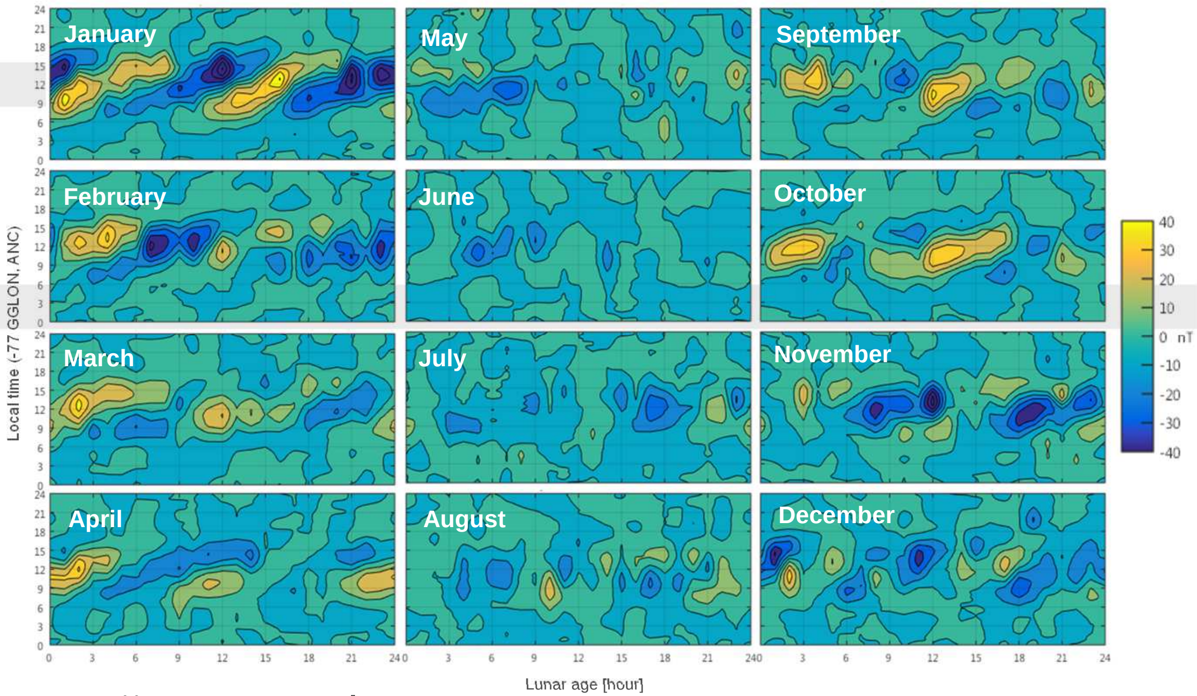


Fig. 6

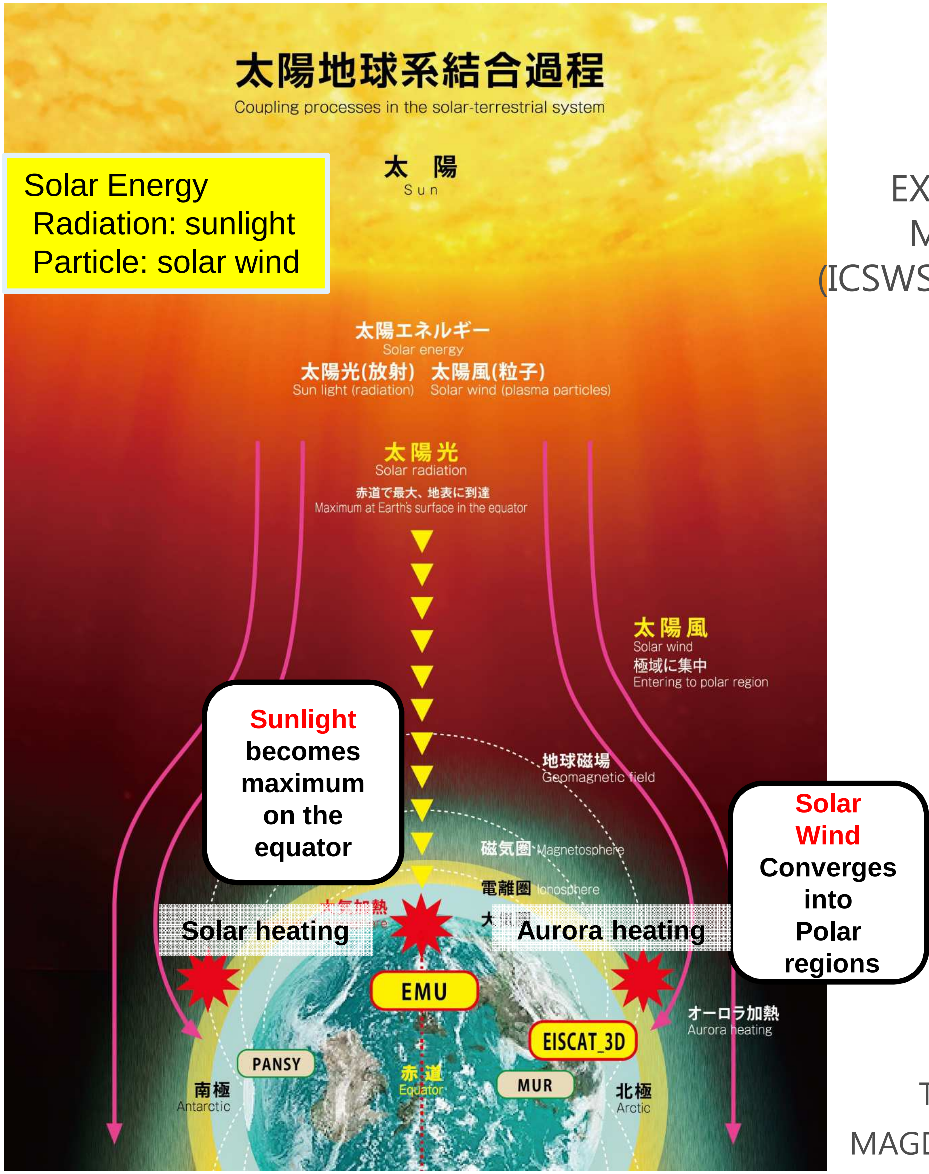
(a) Average of ΔEUEL during the all analyzed period, as the function of the lunar age (hour) to the local time (= solar time at Ancon). The lunar time = 0 and 12 indicate the new moon and the full moon, respectively.

(b) Monthly of averaged ΔEUEL, as the same manner of (a). The significant semidiurnal variation appears in January. The weaker semidiurnal variations are found in February, March, April, September and October. In May, June, July and August, the semidiurnal variation is unclear.

After Fujimoto et al., 2016

MAGDAS project for next 10 year

"**Coupling process in the solar-terrestrial system**" aims to study the solar energy inputs into the Earth, and the response of Geospace (magnetosphere, ionosphere and atmosphere) to energy input.



Polar region

EISCAT3D, (NIPR)

Global coupling

EXTENDED MAGDAS (ICSWSE, Kyushu-U)

EXTENDED OMTIs (ISEE, Nagoya-U)

EMU (RISH, Kyoto-U)

Equator region

Global network observation of E-field by New digital type FM-CW radar system (1-transmitter, 3-reciver)

Global Poynting vector map!!
(electromagnetic energy flow inside F-region)

Global network observation of B-field by MGADAS

Total budget: 100,000,000 USD for 2018-2027

MAGDAS budget: 13,000,000 USD

Capacity Building (2015-2017)

- MAGDAS training@ Malaysia and Peru (4x @ Malaysia, 2x @Peru)

- SCOSTEP School@Peru(2015), @ India(2016)
- COSPAR School@Russia(2016)
- JSPS Core to Core School@ Nigeria(2017), Indonesia(2018)
  (PI: Prof. Shiokawa-san)
- MAGDA-WS@ Malaysia(2017)
- UN/USA WS for the ISWI (2017)

- 1 Master student from Korea (2017-)
- 2Ph.D students from Malaysia (2017-)
- Visiting Researcher from Egypt (2016-2017)
- Employment of Foreign Associate Prof.
  2015-2016 from Russia
  2016-2017 from Philippine
  2017-2018 from Finland

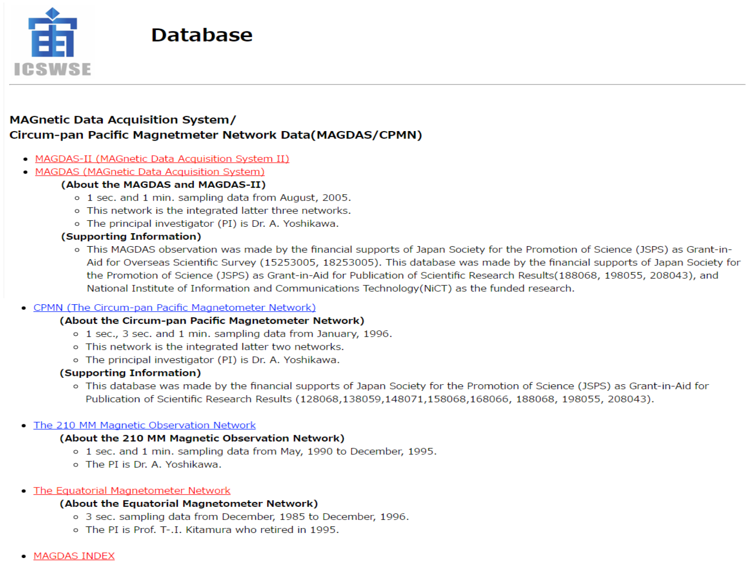
Data distribution

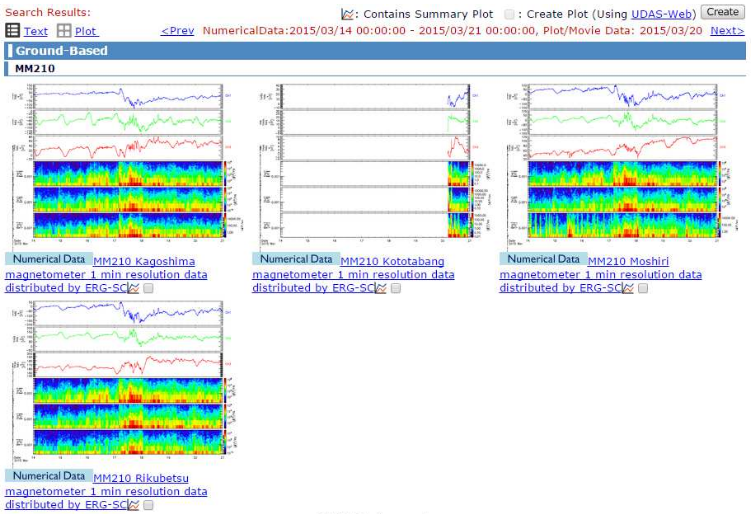
- The realtime quick-look plot (ordinary and time derivative) are available at http://data.icswse.kyushu-u.ac.jp/.

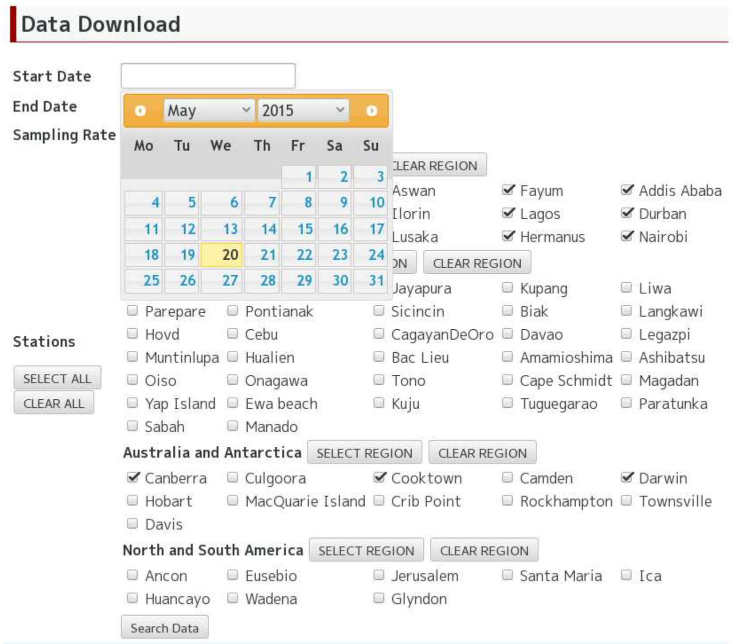
- All MAGDAS data are available on request. We are developing web-based data sharing system, and will be opened in near future.

- A part of MAGDAS data have been opened through the ERG Science Center (for more details, http://ergsc.isee.nagoya-u.ac.jp/) as CDF format.

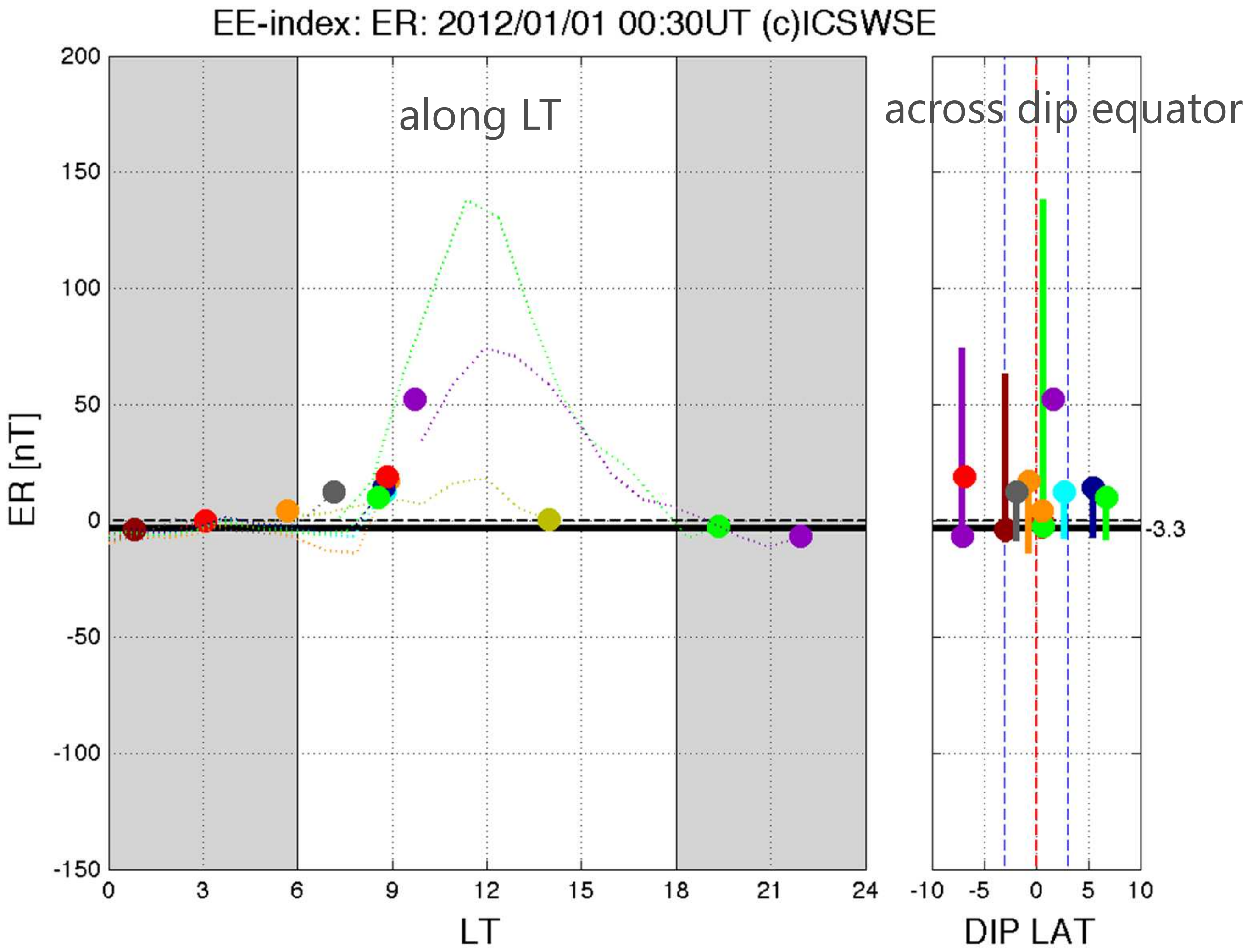
- Metadata of MAGDAS data have been opened through the IUGONET.







Dynamical monitoring of EEJ by using EE-index



KYUSHU UNIVERSITY

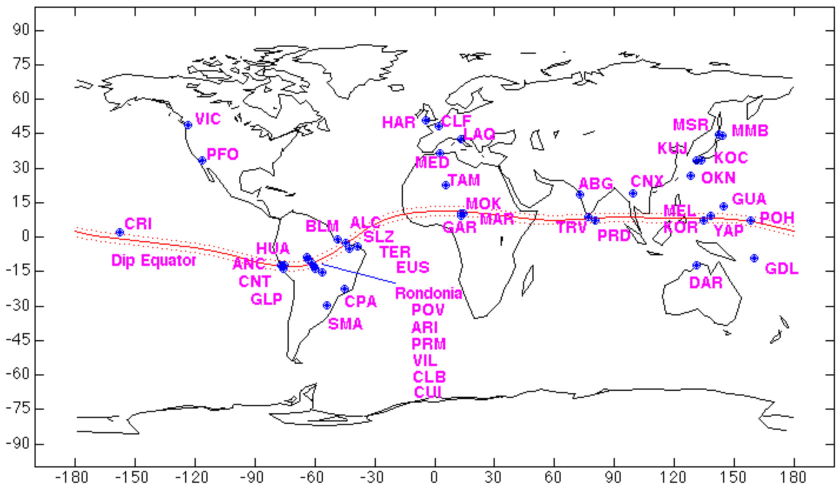
Treasure trove for space weather monitoring

- Especially EEJ (equatorial electrojet) is an extremely interesting phenomenon from the view of connecting the ionosphere to the atmosphere, which have different physical backgrounds caused by the sun and the magnetosphere. Recently many researchers are trying to comprehensively understand the interaction/coupling among these different regions by analyzing simultaneously whole regions. The consecutive monitoring of equatorial magnetic variations requires an indicator not affected by the magnetospheric environment.

- In 2008, International Center for Space Weather Science and Education, Kyushu University (ICSWSE) proposed the EE-index (Uozumi et al., 2008; Fujimoto et al., 2015), which is an index to monitor quantitatively various equatorial geomagnetic phenomena in real time.

- EE-index separates the magnetic disturbances in the equatorial region into the global (EDst) and local (EUEL) magnetic variations. The derivative indies of EUEL, "MAGDAS Space weather environment index", provide the quantitative and visible information in order to reveal the electromagnetic phenomena affecting the fundamental structure of EEJ, In terms of the space weather and space climate. In this paper, we present the method and concept of "MAGDAS Space weather environment index", an application example (the dependence of EUEL on the solar cycle) and the project of the equatorial ICSWSE magnetometer Network.

The Equatorial Magnetometer Network(1985–1996)



3 sec. sampling data from December, 1985 to December, 1996.

The Kyushu magnetometer system consists of
(1) Tape unit.
(2) System controller "Super Digit-Kun".
(3) Magnetometer amplifier.
(4) Power supply.
(5) Magnetometer sensor.
(6) Radio antenna.
(7) Sensor cable.

See picture below for their detailed structure.

CPMN Project (1996-2004)

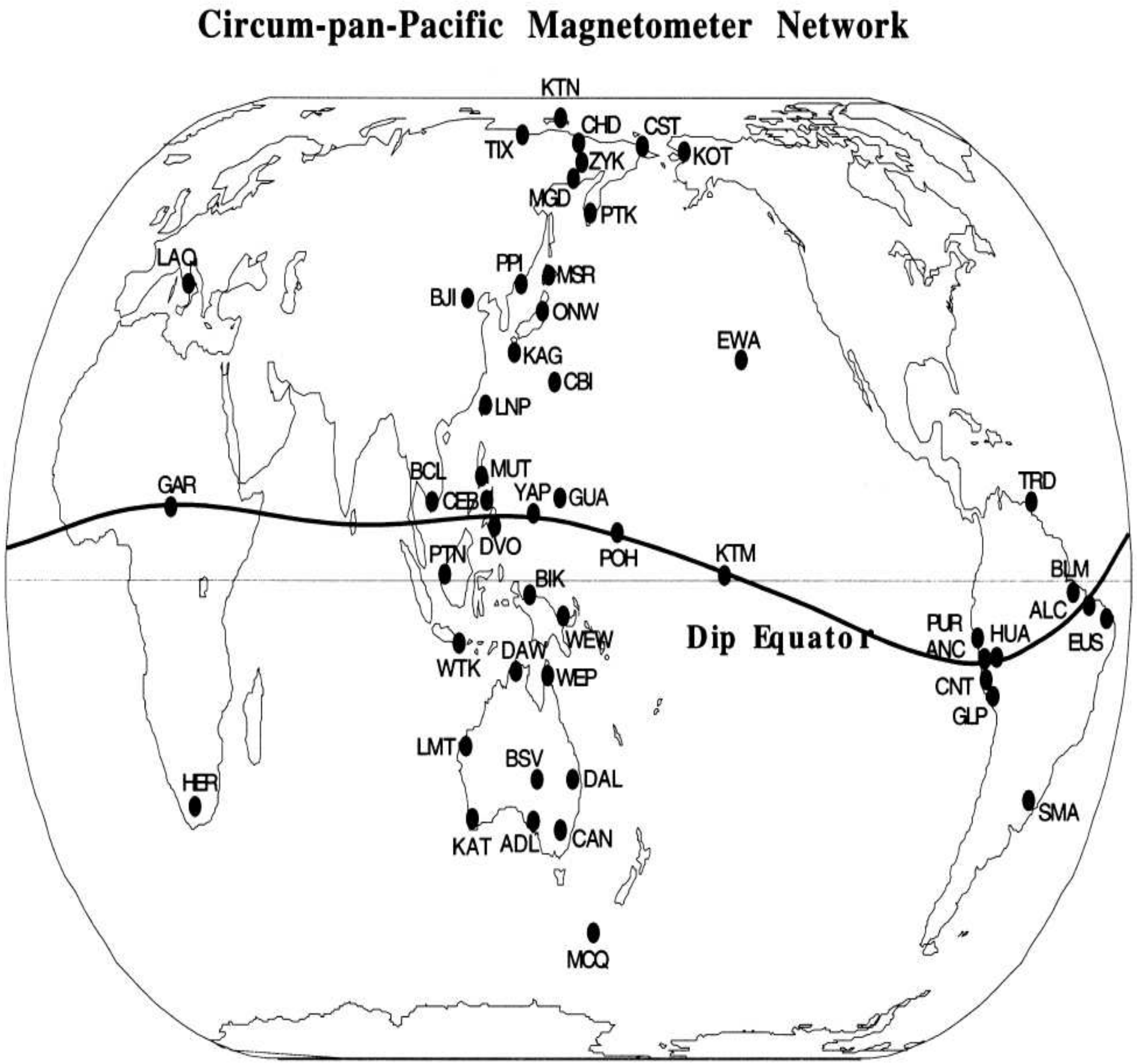


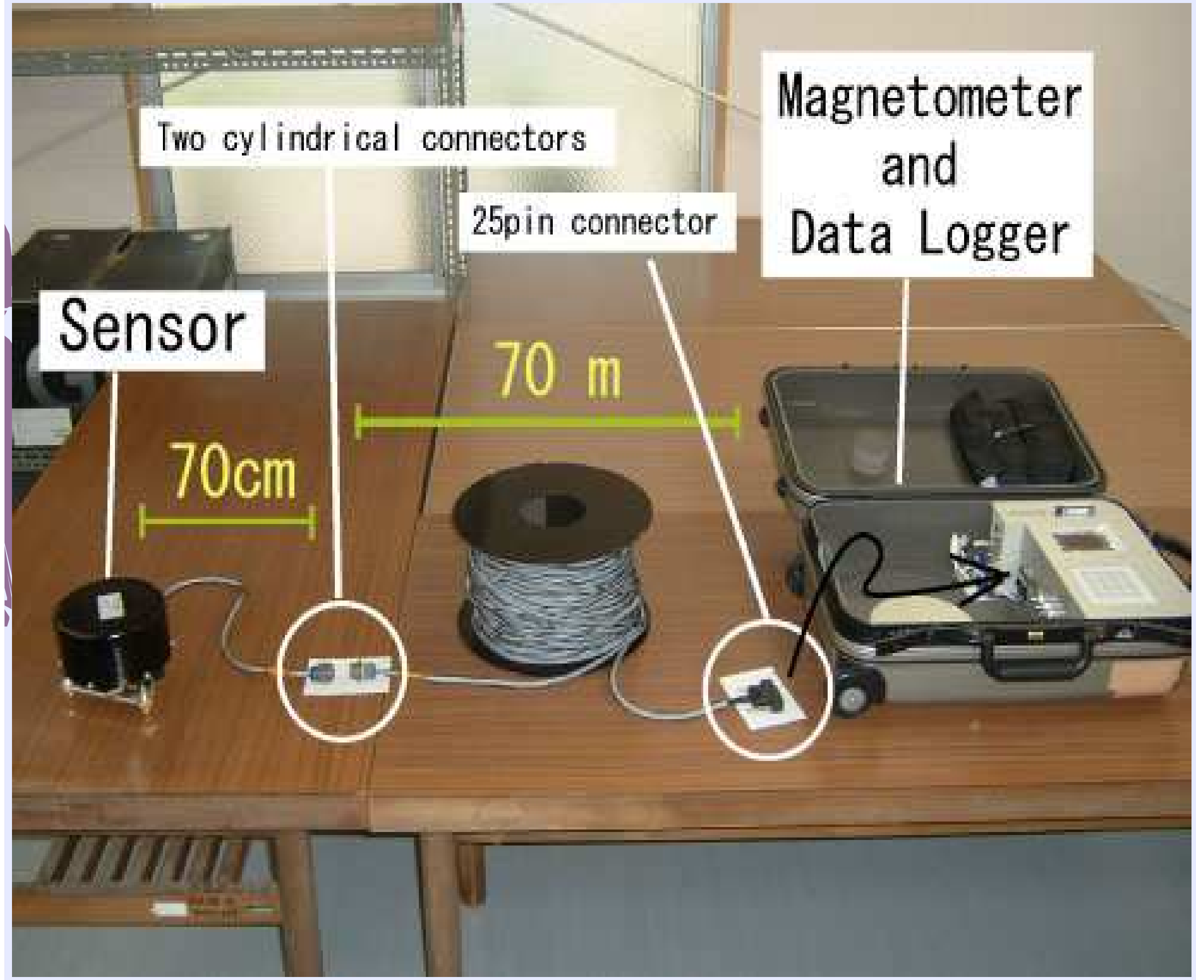
Fig. 1. A station map of the Circum-pan-Pacific Magnetometer Network (CPMN).

From 2000, GPS antenna was available freely for time signal generator.

Digital Recorder with MO, CF card

- Time Accuracy; msec

MAGDAS magnetometer(2005)



- **Tiltmeter of sensor**
  Range: ±1°,
  Resolusion: 0.2 arc-sec
- **Thermometer of sensor**
  Range: ±60℃,
  Resolusion: 0.002℃
- **Observation ranges**
  ±1000nT, ±2000nT,
  (±65000nT)
- **16bit A/D converter**
  0.031nT/dig, 0.061nT/dig
- **Sampling rate**
  1-sec, 1-min
- **Estimated noise level**
  0.02nTp-p
- **Total weight**
  14.5 kg

MAGDAS-A:
磁力計、データロガー、転送装置のall-in one unit.

MAGDAS−II system (2008)

MAGDAS-II: 古い磁力計をリアルタイムデータ転送に対応させたもの

Field Site

(W x D x H mm) or
(φ x H mm)

Specified cable

CPMN-Amplifier

(200x230x160 mm)

CPU BOX for Internet

(100x100x21 mm)

Analog

Serial

CPMN-Sensor

(200x200 mm)

A/D + Logger

(130x180x30 mm)

Internet (FTP or SSH)

ICSWSE

Data Acquisition Server

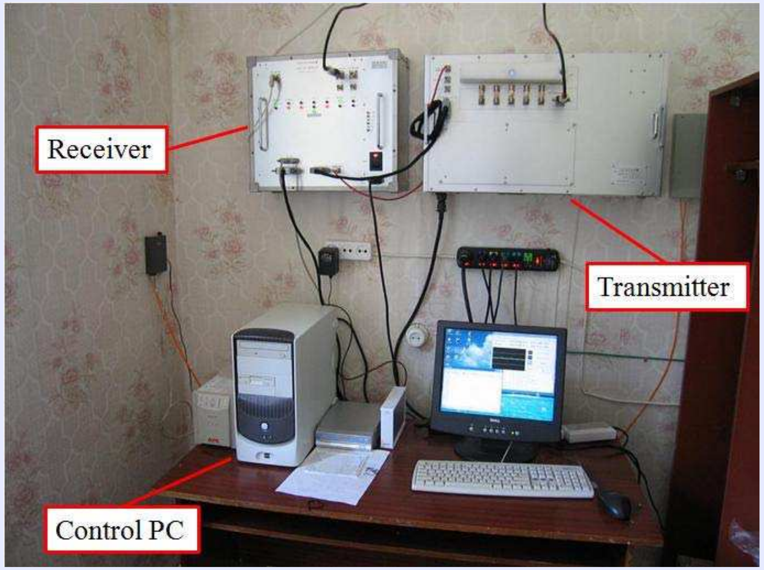
Latest MAGDAS (2011)

- Sensor + 7 m cable; 2.9 kg + 1.7 kg
- Amplifier; 2.9 kg
- 70 m cable; 4.5 kg
- GPS antenna + cable; 0.85kg
- Data Logger; 2.6 kg

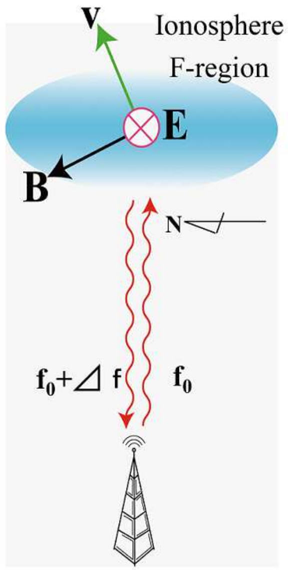
Total 15.5 kg

- (H,D,Z,F)-comp magnetic fields, ±70,000nT,0.01nT, 2 tilt meter, 0.1”; 32bits 250Hz sampling, 10Hz, 1Hz averaged data
- Temperatures at sensor and amplifier;0.01℃ 24 bits 10Hz sampling
- Power consumption; 12Vx400mA
- Data card; 2 Gbyte, 10Hz data logging

FM-CW radar(2002～)



Ionospheric Observation

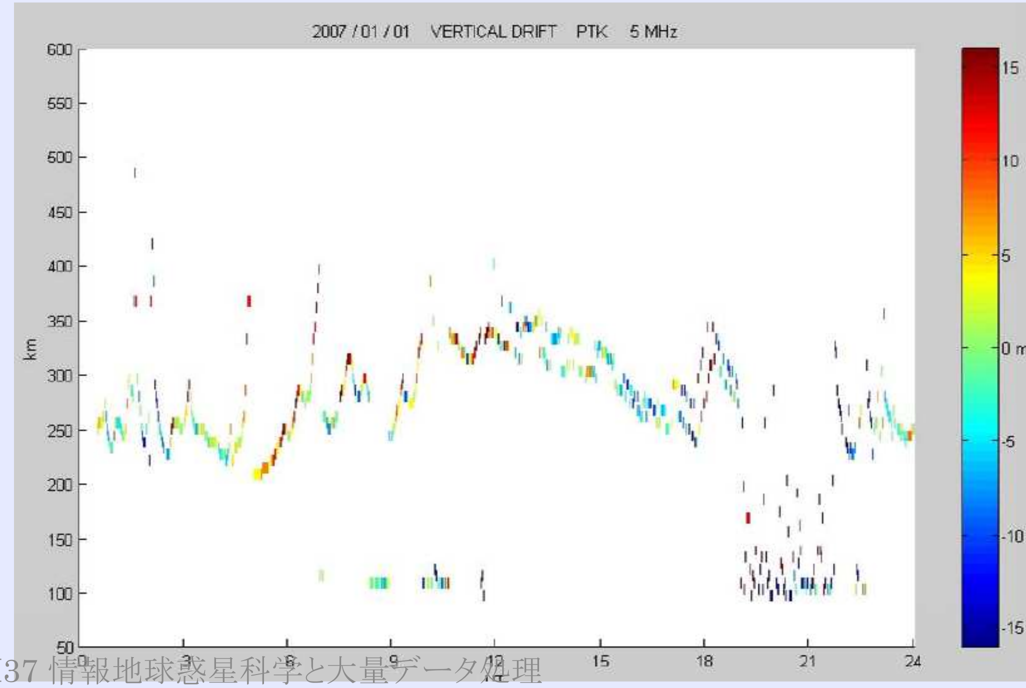


When the eastward electric field penetrates into the low-latitude ionosphere, it drifts upward owing to the frozen-in effects (**E** × **B** effects).

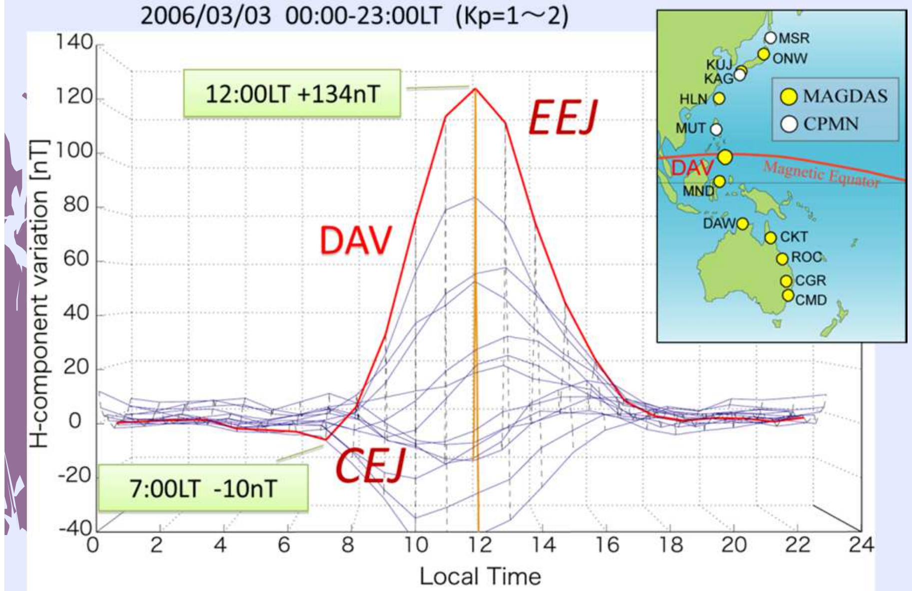
$$\boldsymbol{E} = -\boldsymbol{v} \times \boldsymbol{B}$$

Therefore we can measure the vertical drift velocity v from the observed Doppler frequency Δf which is the difference of transmitting frequency (f_0) and receiving frequency ($\Delta f + f_0$) because of the Doppler effect responsible for the vertical movement of the ionosphere. The relational expression is

$$\Delta f = -\frac{2v}{c} f_0 \quad (c = 3.0 \times 10^8 m/s)$$



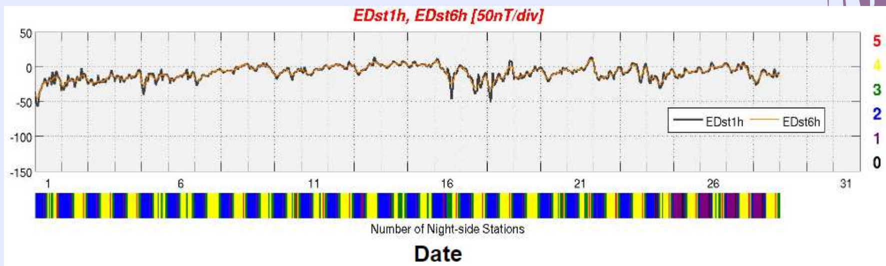
EE-index



EE-index：EDst and EUEL

EEJ：EUELのpositive変動成分
CEJ：EUELのnegative変動成分
→ あらゆる周波数帯の対流侵入モニター
EDst：代替Dst10分更新版にもなる指数

ウェブにてリアルタイムデータ公開



Space Environment Research Center, Kyushu University
EDst1h (Realtime Ver.)
Unit: nT

February 2017

Universal Time

DAY	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	-36	-48	-57	-55	-40	-34	-30	-25	-24	-17	-20	-28	-24	-15	-20	-26	-7	-24	-25	-7	-8	-16	-17	-20
2	-34	-28	-34	-23	-28	-27	-12	-20	-20	-17	-17	-20	-30	-23	-14	-18	-20	-20	-2	-17	-10	-10	-16	-21
3	-25	-22	-21	-17	-22	-27	-25	-24	-23	-12	-23	-23	-21	-22	-18	-22	-23	-17	-17	-17	-12	-5	-11	-14
4	-21	-16	-13	-13	-14	-22	-13	-19	-22	-22	-16	-16	-16	-11	-14	-17	-14	-15	-15	-14	-10	-6	-5	-5
5	-21	-32	-40	-34	-18	-14	-21	-9	-12	-9	-13	-9	-18	-26	-22	-19	-11	-11	-3	-20	-13	-12	-12	-10
6	-14	-17	-25	-17	-17	-21	-18	-17	-15	-15	-15	-13	-13	-15	-10	-11	-10	-3	-19	-13	-16	-12	-8	-8
7	-12	-22	-27	-24	-18	-19	-17	-13	-12	-12	-13	-12	-15	-12	-10	-10	-7	-8	-7	-7	-5	-5	-5	-3
8	-6	-7	-9	-7	-7	-6	-6	-6	-6	-6	-6	-10	-6	-2	0	-4	0	-1	0	1	2	3	3	4
9	4	0	-3	1	-2	-3	-6	-6	-6	0	2	0	3	1	5	2	0	5	-1	0	-1	-4	-7	-9
10	-10	-12	-18	-15	-13	-9	-8	-9	-6	-5	-5	-4	-1	-3	-10	-15	-19	-15	-9	-7	-7	-4	-3	-7
11	-2	-7	-10	-1	-5	-10	-12	-12	-11	-13	-11	-9	-5	-4	-3	-4	-5	-4	-4	-4	-3	0	2	1
12	0	-2	-3	0	1	1	2	3	3	3	2	3	2	0	0	-2	-3	-4	-2	8	3	3	1	1
13	2	-4	-7	-9	-13	-10	-7	-6	-5	-4	-5	-3	0	2	5	3	2	2	14	9	6	5	4	3
14	1	3	1	1	1	-1	-2	1	2	3	5	8	7	6	5	3	2	2	2	7	7	6	6	5
15	2	0	-2	-1	2	5	7	7	2	1	2	2	3	3	3	2	3	1	0	3	2	-1	1	5

http://data.icswse.kyushu-u.ac.jp/eeindex/EDst/201702.html

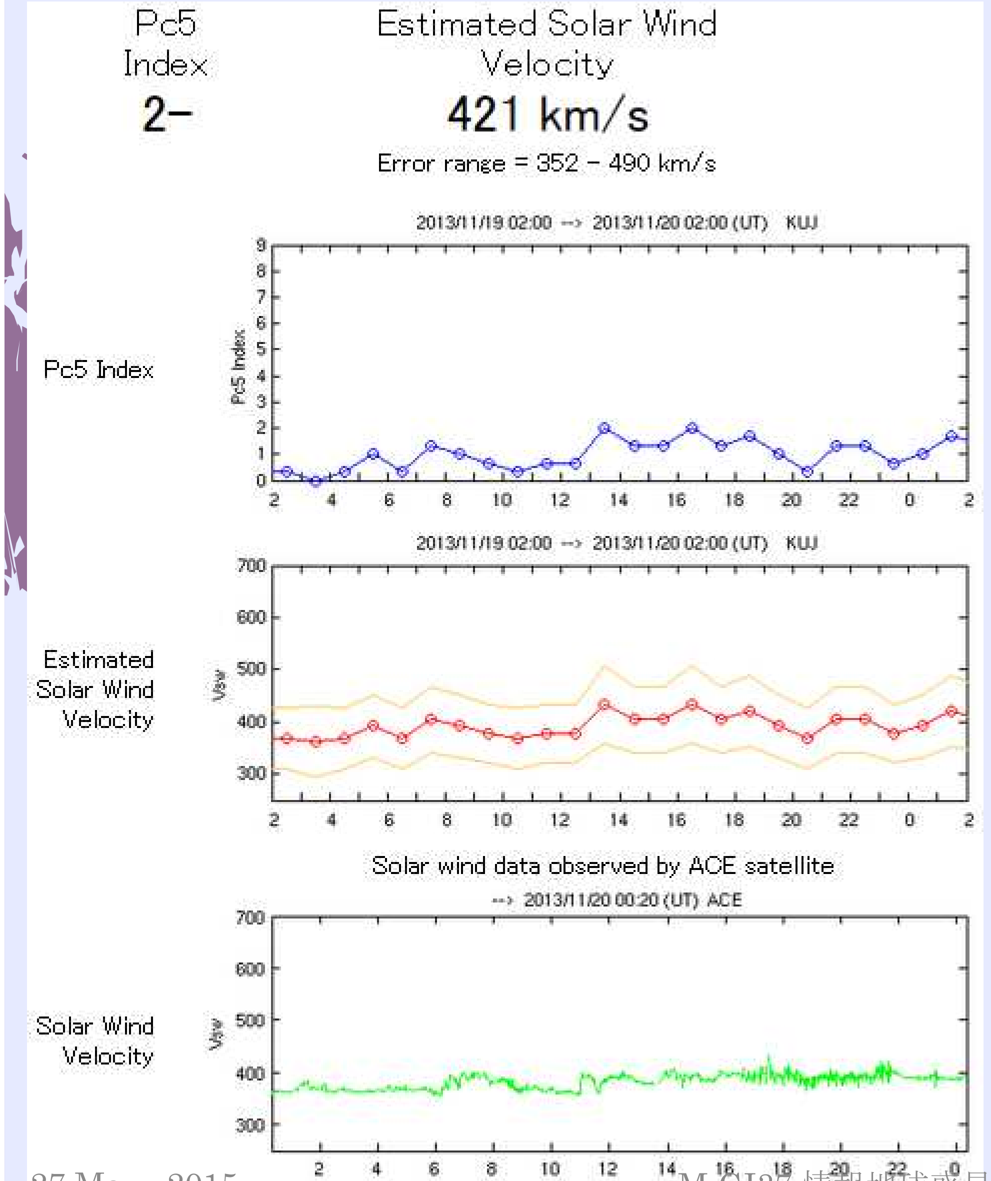
九大では現在、緯度方向稠密構造観測網の構築による**EE**指数のアップグレードを推進中。
併せて、ウェブサイトをアップデート予定。

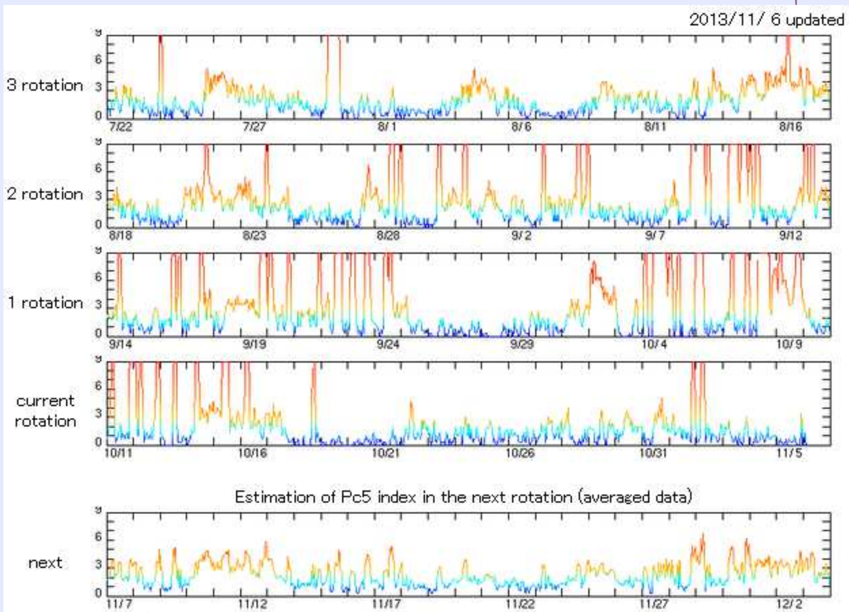
ULF index

ULF- Index：
全球全周波数帯(EMICからULFまで)のインデックス化

現在: PC5 indexのみ
1観測点による太陽風速度推定
ウェブにてリアルタイム公開中
http://data.icswse.kyushu-u.ac.jp/pc5index/index_e.html

拡張予定
A. 中緯度帯全球モニター
  globalとlocalの分離：複数観測網の連携
B. 磁気赤道全球モニター
  対流侵入タイプ型PC5
→高エネルギー電子flux増加のindicator

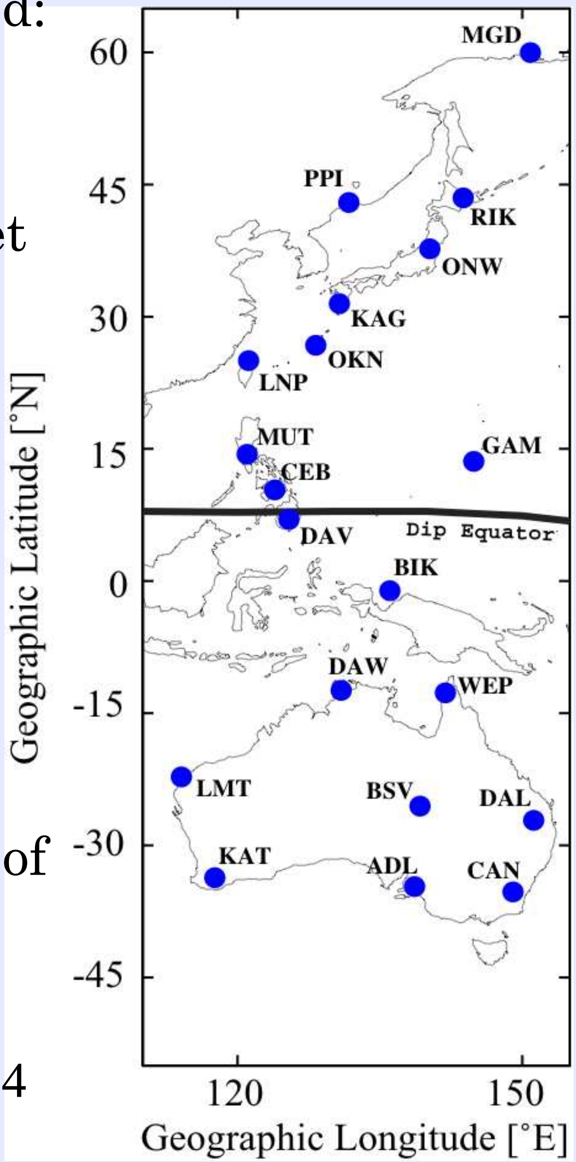


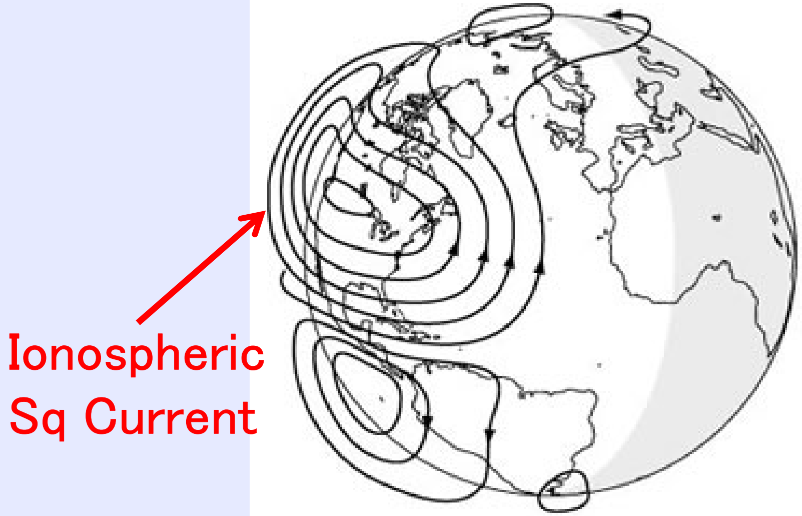


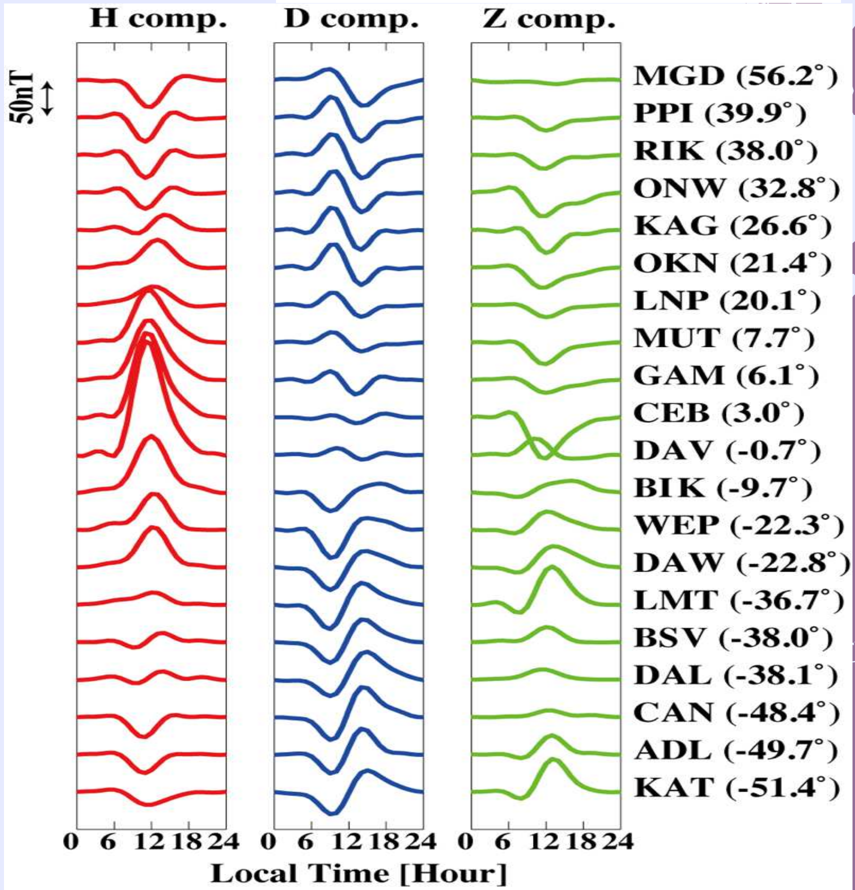
Ionospheric Sq Current by MAGDAS/CPMN Data

- Analysis Period: 1996 - 2007
- Magnetic Quiet Days: Kp≤2+
- 21 Stations: (Yumoto et al., 2001)
- Hourly Value of Horizontal Sq Amplitude:

$$\sum_{i=1}^{24}\sqrt{H_i^2 + D_i^2} / 24$$







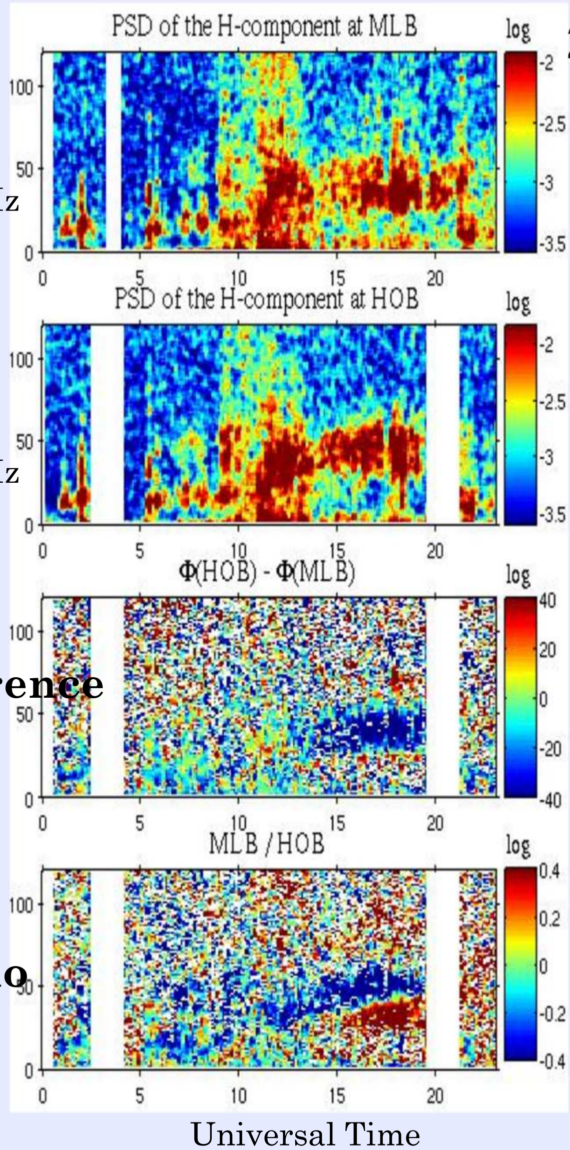
Estimation of FLR frequency and plasma mass density by MAGDAS ULF Pulsation Data

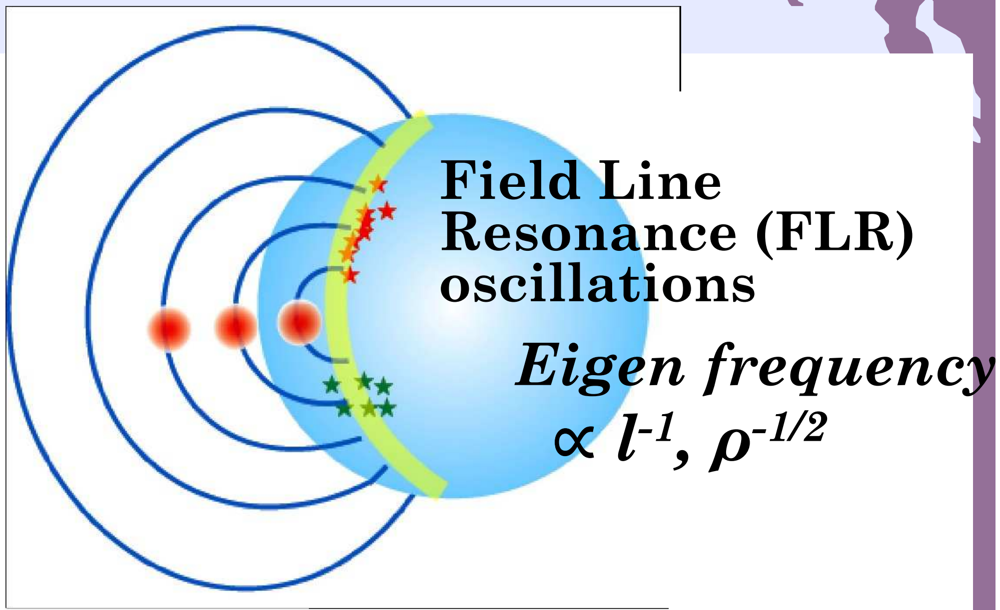
MLB
Power spectra

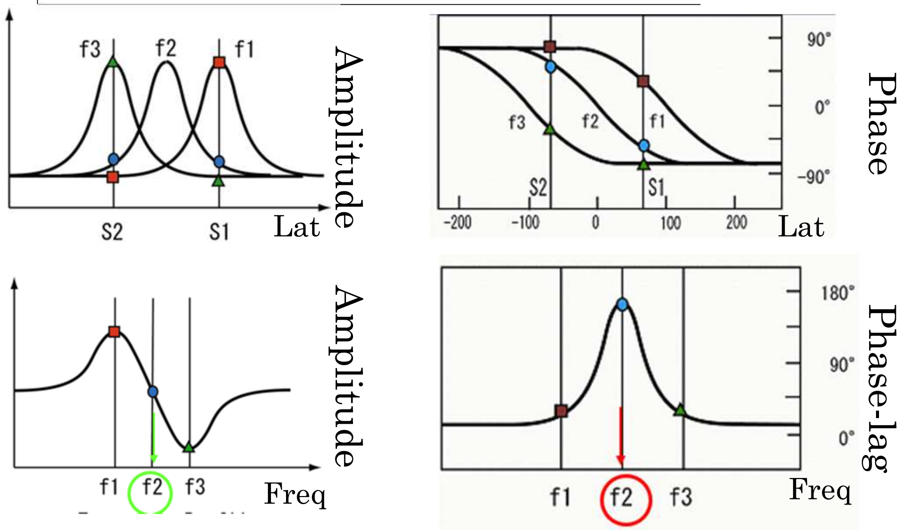
HOB
Power spectra

Phase difference
(HOB)-(MLB)

H-amplitude
Power ratio
(MLB)／(HOB)







The amplitude-ratio method (Baransky et al.,[1985]) and the cross-phase method(Waters et al., [1990])