MINISTÉRIO DA CIÊNCIA E TECNOLOGIA
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

UNOOSA United Nations Office for Outer Space Affairs

United Nations/Austria Symposium on
"Space Weather Data, Instruments and Models:
Looking Beyond the International Space Weather Initiative (ISWI)"*

New products for monitoring and forecasting space weather in South America: regional magnetic indices and GNSS vertical error map

C. M. Denardini[1], H. Takahashi[1], J. E. R. Costa[2], O. Mendes Jr. [3],
N. SantAnna[4], R. Gatto[5], J. R. de Souza[1], A. L. Padilha[3], I. S. Batista[1]

[1] Aeronomy Div., National Institute for Space Research, S. J. Campos, SP, Brazil
[2] Astrophysical Div., National Institute for Space Research, S. J. Campos, SP, Brazil
[3] Geophysical Div., National Institute for Space Research, S. J. Campos, SP, Brazil
[4] Computer Lab. Div., National Institute for Space Research, S. J. Campos, SP, Brazil
[6] Ground System Div., National Institute for Space Research, S. J. Campos, SP, Brazil

Magnetic Measurement

Objectives:

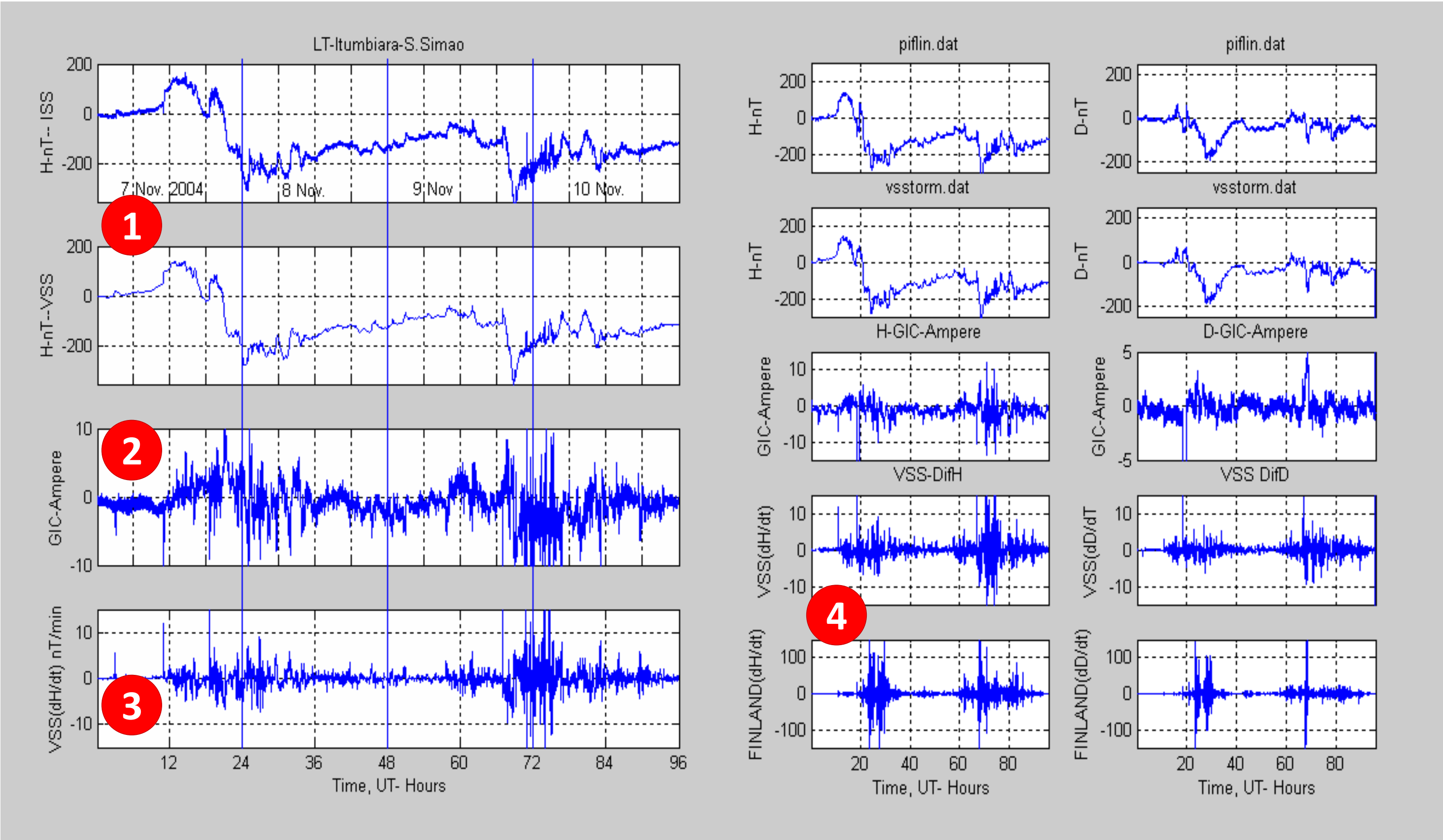
To monitor the Earth's magnetic fields variations along the eastern portion of the American sector to provide a toll to:

a. **estimate** the electric fields at E and/or F regions heights;
b. **provide** the ground induced effect of the EEJ (or CEJ);
c. **provide** the time derivative of the field (dB/dt); and
d. **monitor** the disturbance level based on the stations K-index

To achieve all the above variable it is crucial to have all the **EMBRACE Magnetometer Network** measuring with the same accuracy the variations of components since is need to have difference between measurements from different stations

GIC detected in Brazil

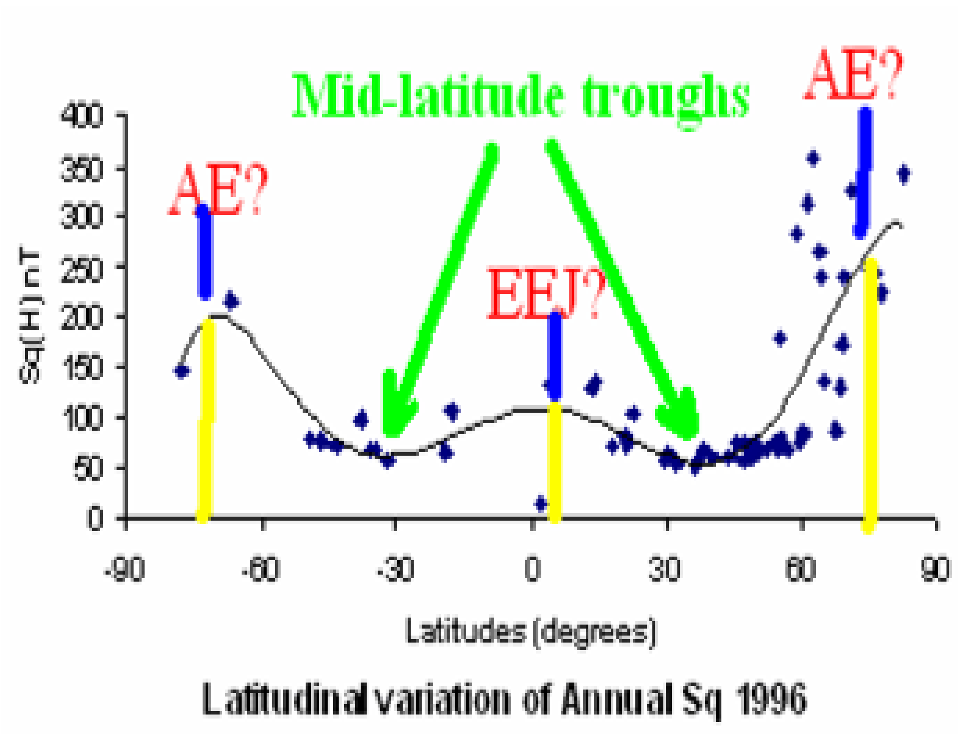
Courtesy:
Dr. Antonio Lopes Padilha

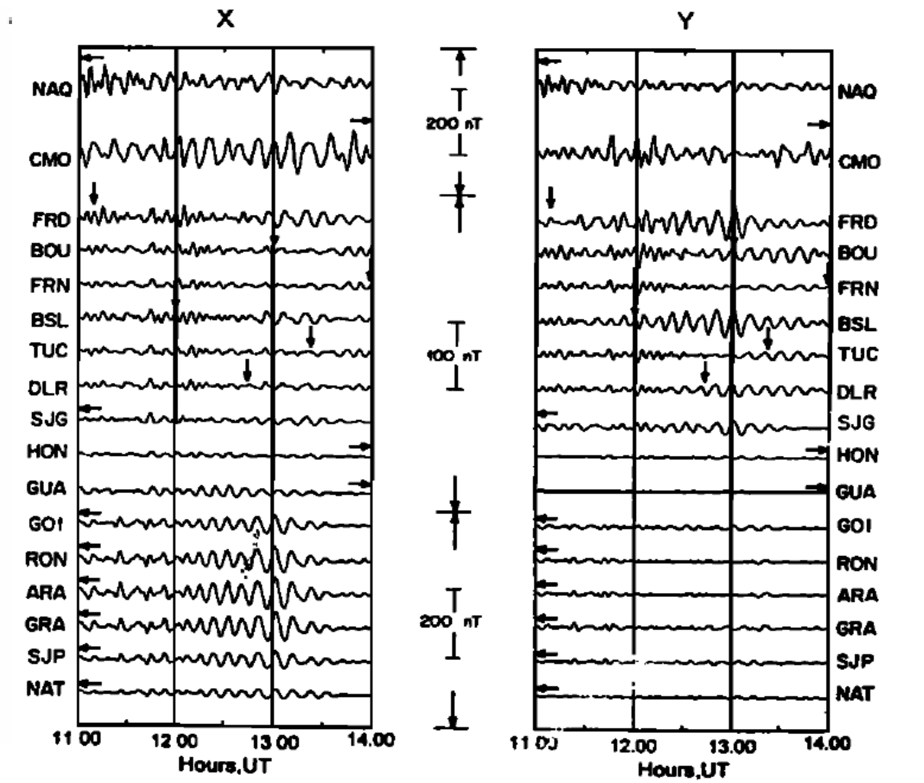


1. Magnetic variations measured at the Vassouras Observatory (RJ) and in Finland (ISS)
2. GIC on the ground of the transformer of a Electric Power Company
3. dB/dt derivative in VSS, which shown similarities with the GIC at the amperimeter
4. dB/dt at VSS is one order of magnitude lower than that measured in the auroral region (Finland)

Amplitude vs Latitude

Courtesy:
Dr. Antonio Lopes Padilha



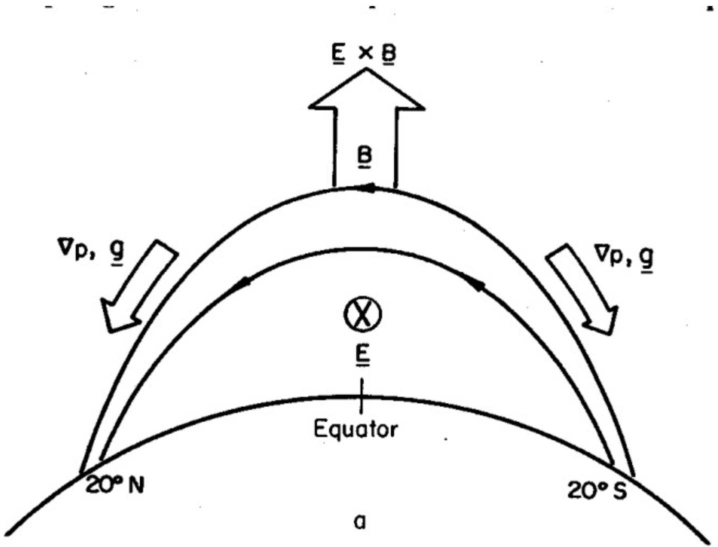


a. Low magnetic latitudes = Lower amplitudes of the geomagnetic variations

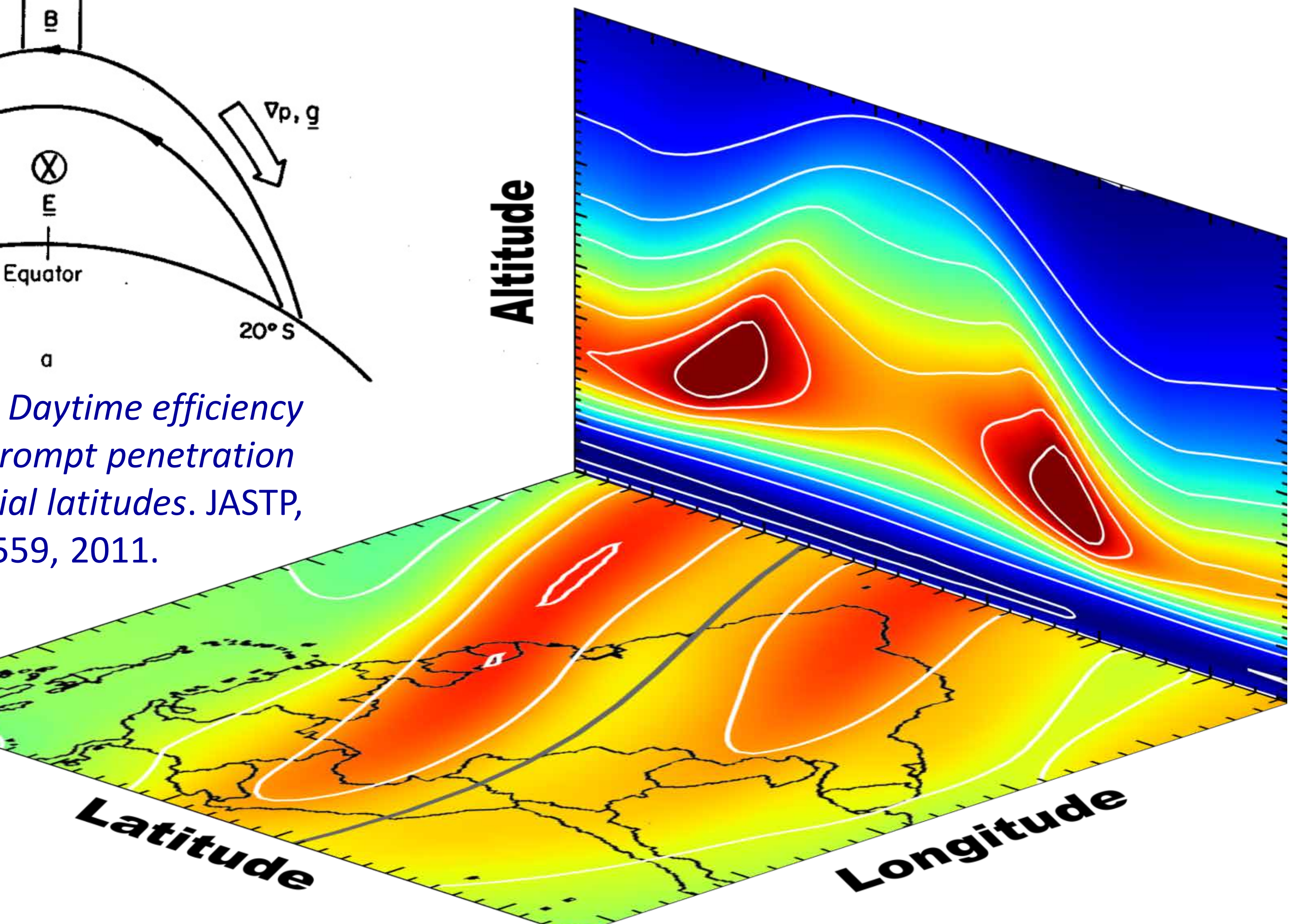
b. There is the well known diurnal amplification of the H component around the DIP equator

Electric Fields

Courtesy:
Dr. Jonas Rodrigues de Souza



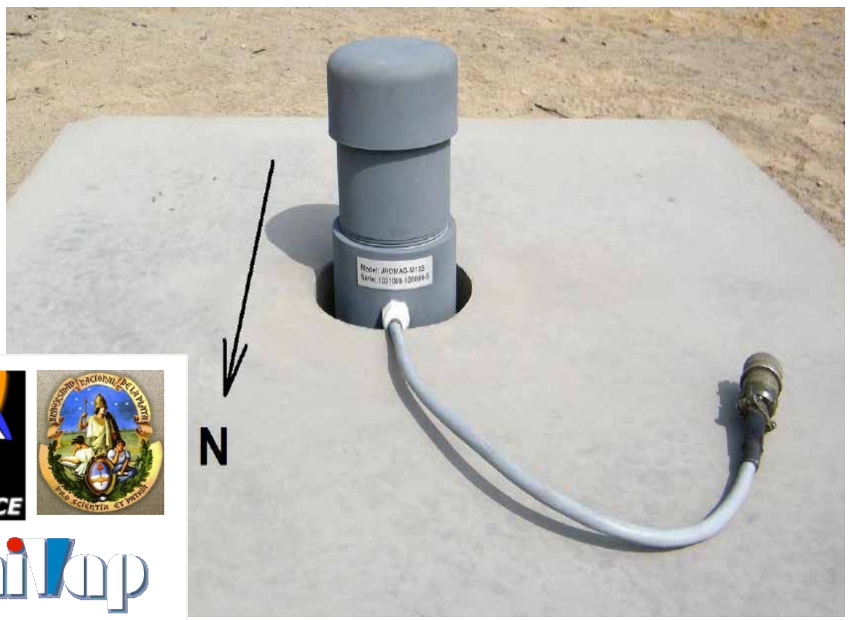
DENARDINI et al. (2011) *Daytime efficiency of different time scale prompt penetration electric fields to equatorial latitudes*. JASTP, v. 73, p. 1555-1559, 2011.



Transversal section of the ionospheric ionizations anomaly calculated by the SUPIM-INPE model.

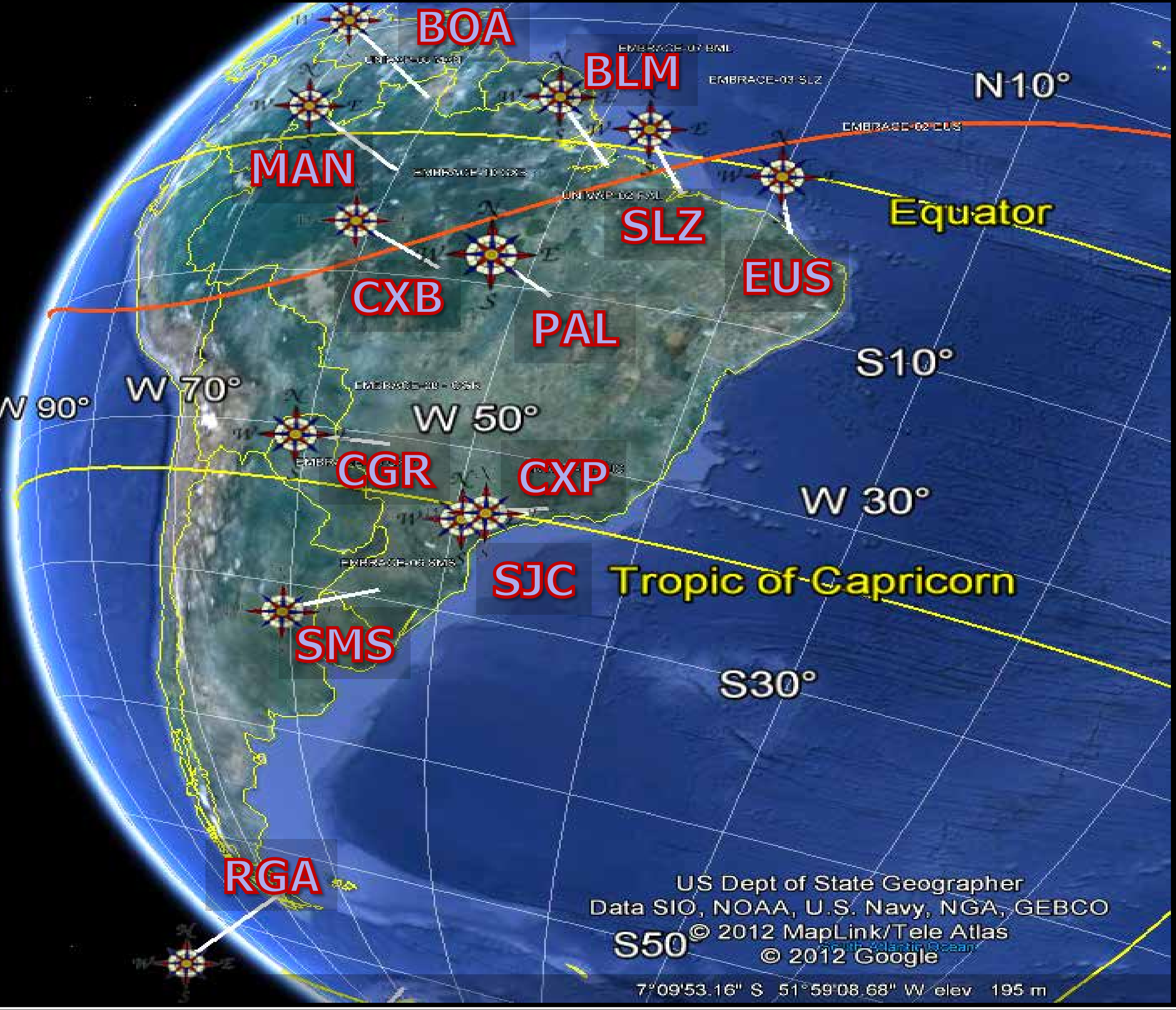
The Equipment

Measurement range	+/- 75000 nT
Dynamic range	+/- 250, 1000, 2500 nT
Resolution	0.1 nT
Accuracy	0.25%
Orthogonality	<0.5°
Offset at T=25 °C	<1 nT
Zero drift	<0.1 nT/C
Scaling temp. coeff.	+20 ppm/C, typ.
Supply voltages	+12 V
Current consumption	+220 mA

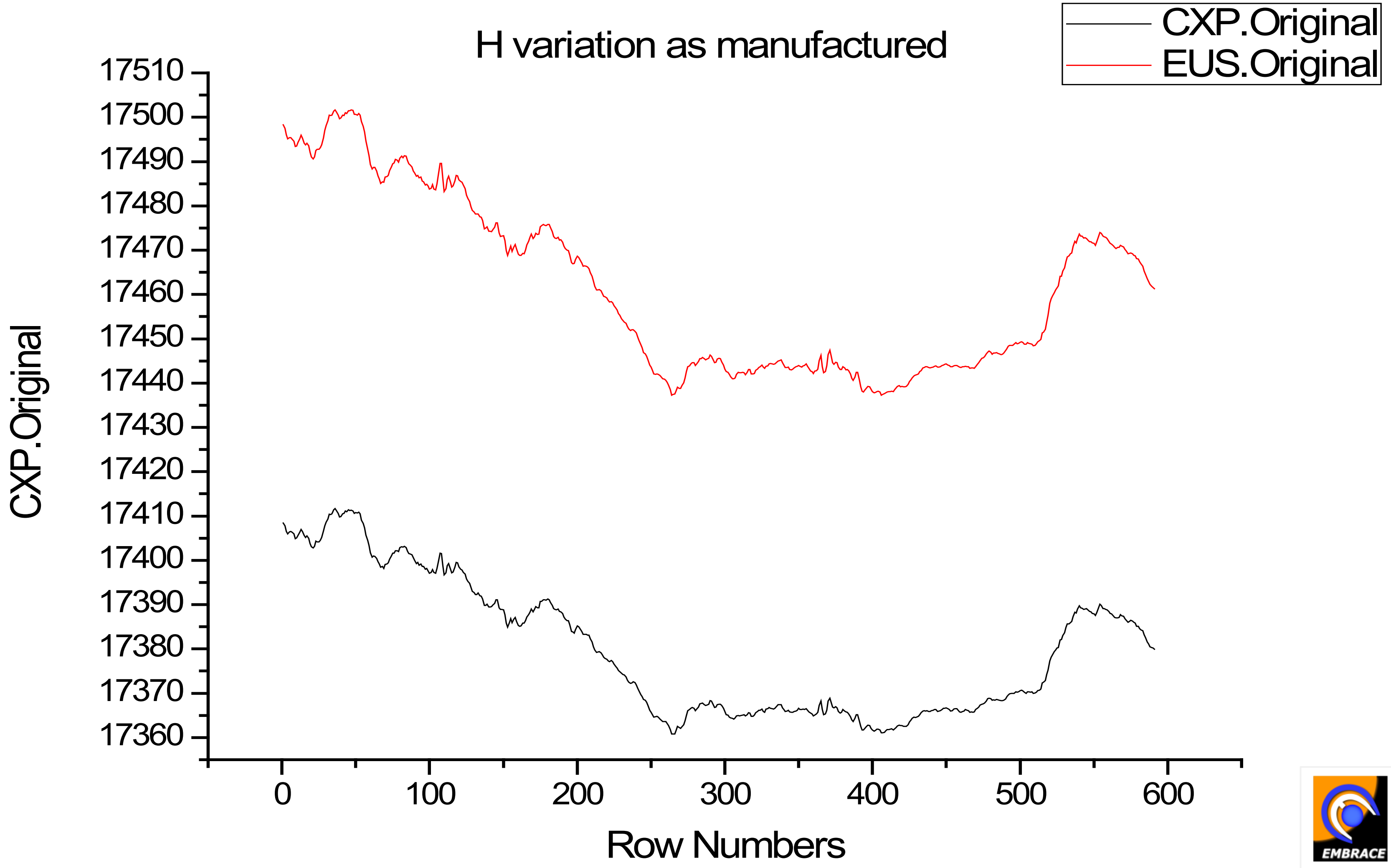


MINISTÉRIO DA CIÊNCIA E TECNOLOGIA
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

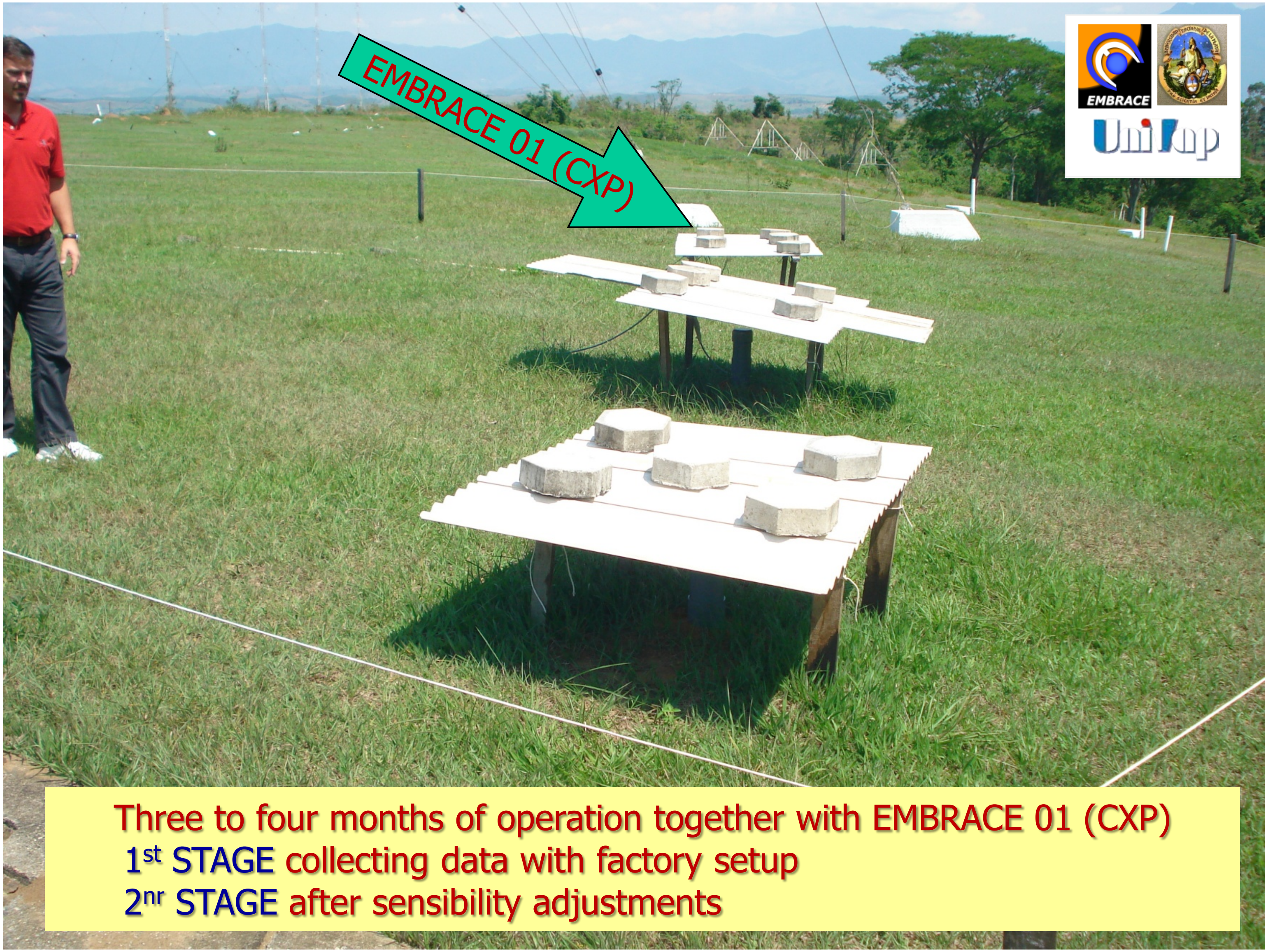
The Network



What we got is ...



How do we manage it ?



Three to four months of operation together with EMBRACE 01 (CXP)

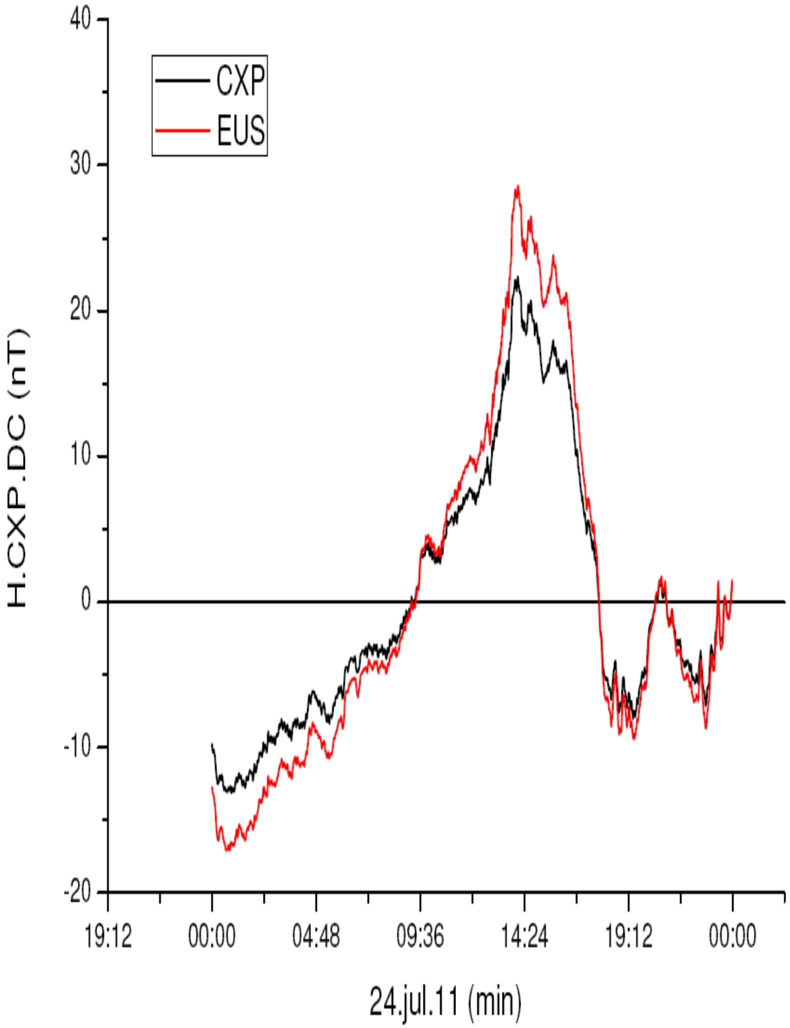
1st STAGE collecting data with factory setup

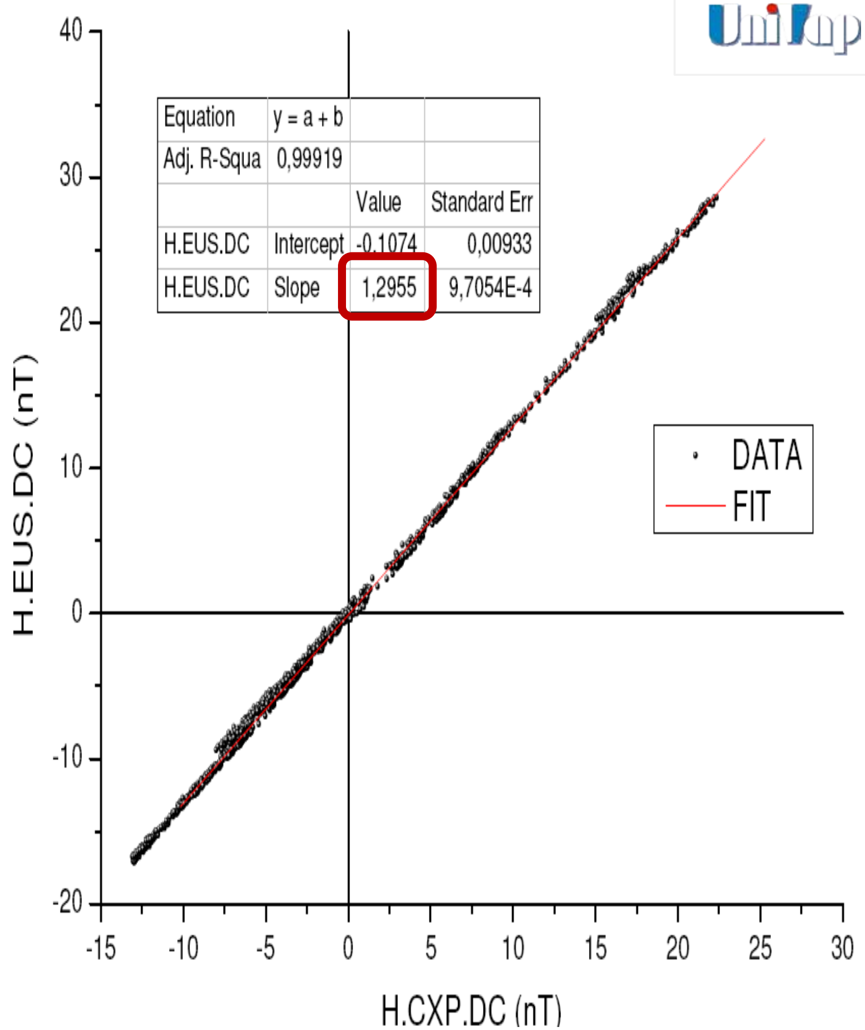
2nr STAGE after sensibility adjustments

How do we calibrate ?

5 Quietest Days in the Month (WDC @ Kyoto)

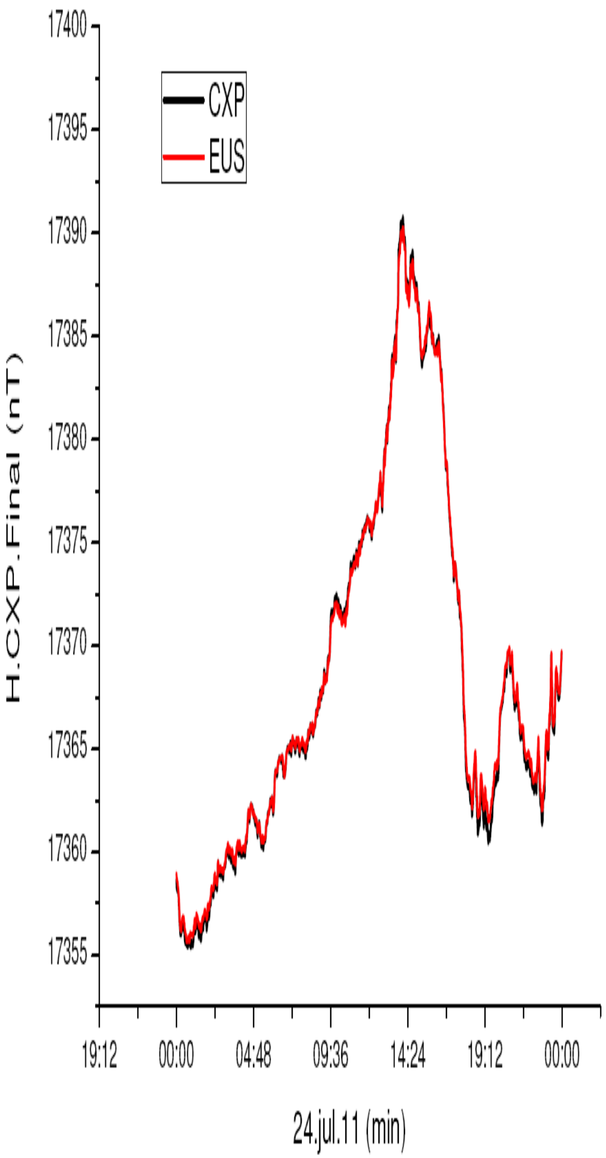
```
YYYY MM q1q2q3q4q5 q6q7q8q9q0 d1d2d3d4d5
2012 01 1419 43118 20 8 1 215 2224252316
```

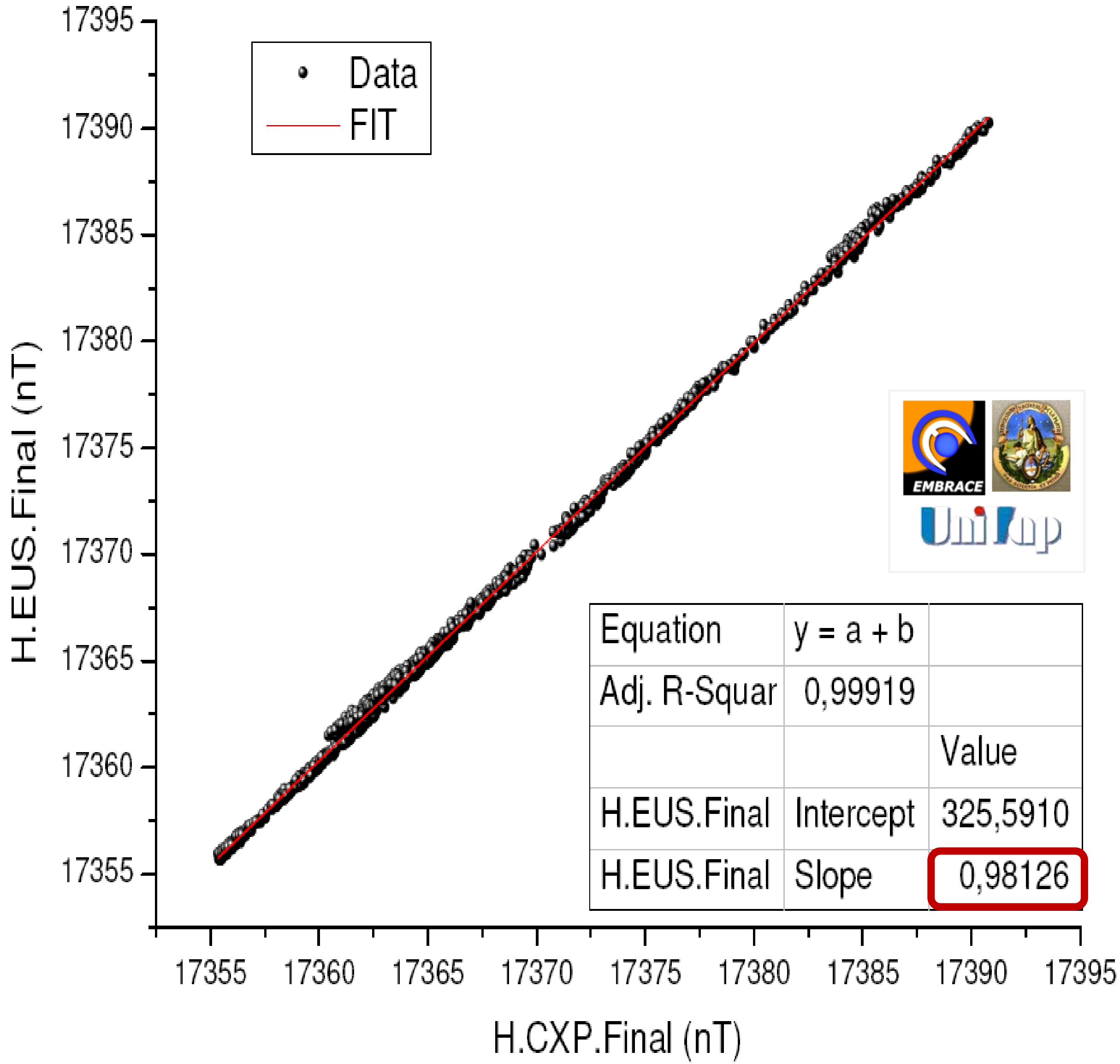




Equation	y = a + b		
Adj. R-Squa	0,99919		
		Value	Standard Err
H.EUS.DC	Intercept	-0,1074	0,00933
H.EUS.DC	Slope	1,2955	9,7054E-4

After Sensibility Adjustments





EMBRACE Magnetometer Network

CXP

EMBRACE-05 CXP

EMBRACE Magnetometer Network

SLZ

EMBRACE-03 SLZ

EMBRACE Magnetometer Network

EUS

EMBRACE-02 EUS

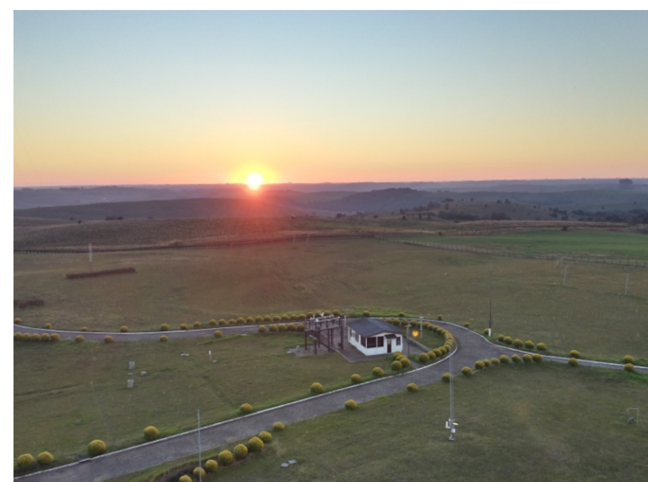
EMBRACE Magnetometer Network

SJC

UNIVAP-01 SJC

SMS

EMBRACE-06 SMS

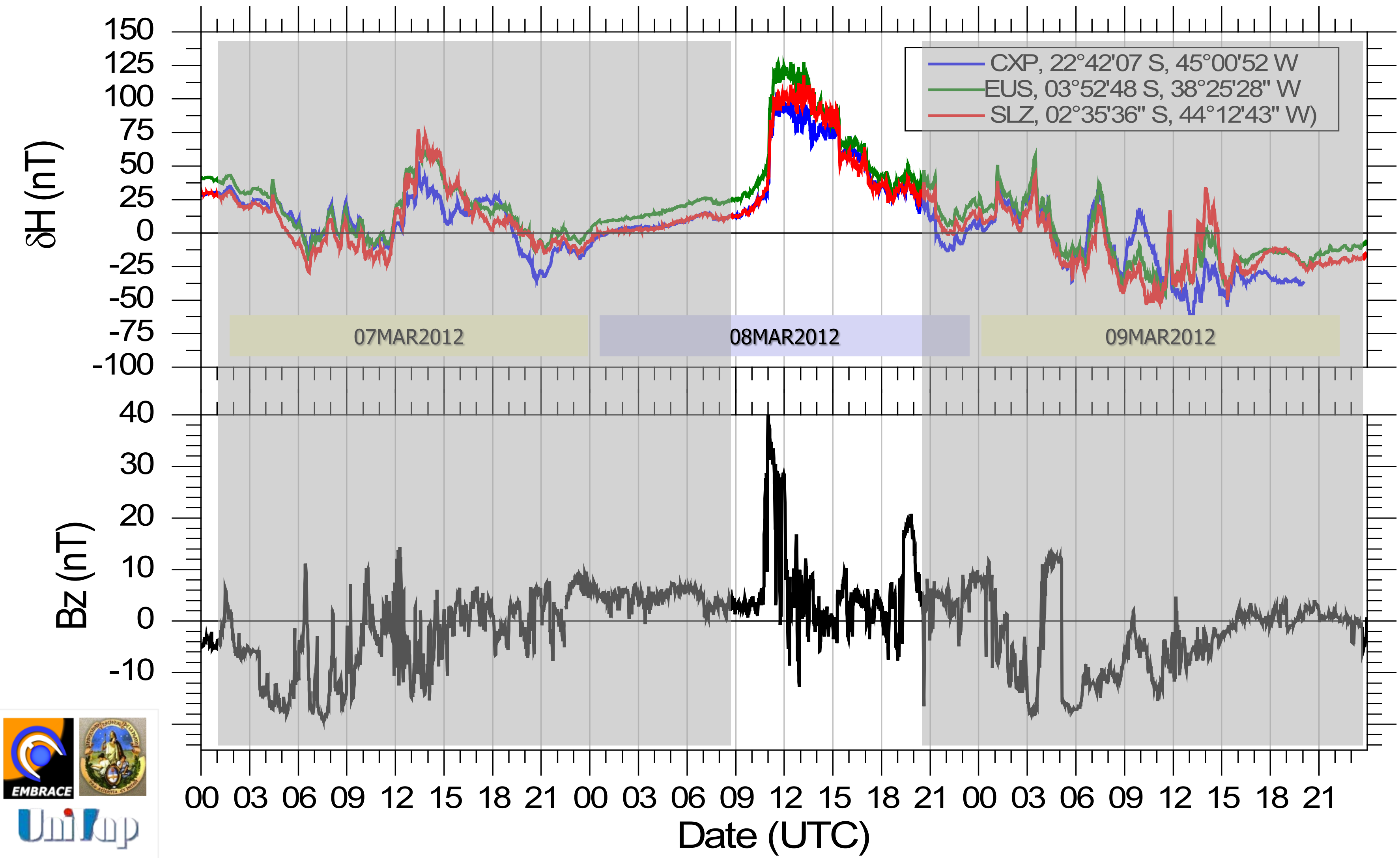


EMBRACE Magnetometer Network

RGA

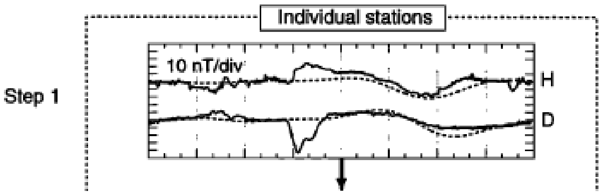
EMBRACE-04 RGA

Data from EMBRACE MagNet



ACE Data is from NOAA / Space Weather Prediction Center

The K Index



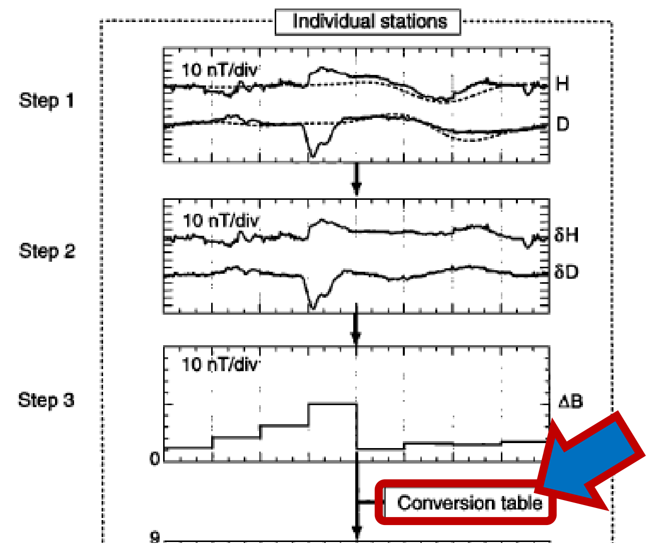
1. Define the regular part or QDC of the variations in the northward (H) and eastward (D) components of the magnetic field recorded at each station, as illustrated in the top panel. The solid lines indicate the 1-min data; the smooth dashed lines are the QDCs. In the literature the QDC is sometimes referred to as solar regular variation of the day, S_R [Mayaud, 1980], meaning regular variations that are fixed with respect to the direction of the Sun. The definition of the term "regular" is subjective, but in concept the regular part should not contain disturbances generated by storms or substorms. According to Mayaud [1967], there are established rules that should be followed in defining QDC [see also Menvielle et al., 1995].

2. Remove the QDC from the original records and define the residual time series δH and δD, as shown in the second panel.

3. Find the range (the difference between the maximum and minimum) of δH and δD in each of the 3-hour bins 0000-0300, ... 2100-2400 UT. Identify the larger of the δH and δD ranges (denoted ΔB). By definition, ΔB is zero or positive. ΔB represents the "raw" geomagnetic disturbance in the 3-hour bins, as illustrated in the third panel.

The K Index

4. Convert ∆B to the station K index using a conversion table, as illustrated in the fourth panel. The K index has 10 levels, 0 through 9. The K9 threshold refers to the limit of ∆B above which K is 9. For other stations, the limits for the n^{th} level, K_n, can be defined by adjusting the K9 threshold according to the corrected geomagnetic latitude of the stations and dividing K_n for a reference station by the redefined K9 threshold.
5. Standardize the K index into Ks so that the occurrence distribution of the value of Ks is consistent among all the stations, as illustrated in the fifth panel. The Ks index, like the Kp index, is expressed in a scale of thirds (28 values):0o, 0+, 1-,1o, 1+, 2-, 2o, 2+ ..... 8o, 8+, 9-, 90. For each station, separate tables are defined for different seasons for converting from K to Ks.
6. Obtain Kp by averaging Ks from all the stations as illustrated in the sixth panel.

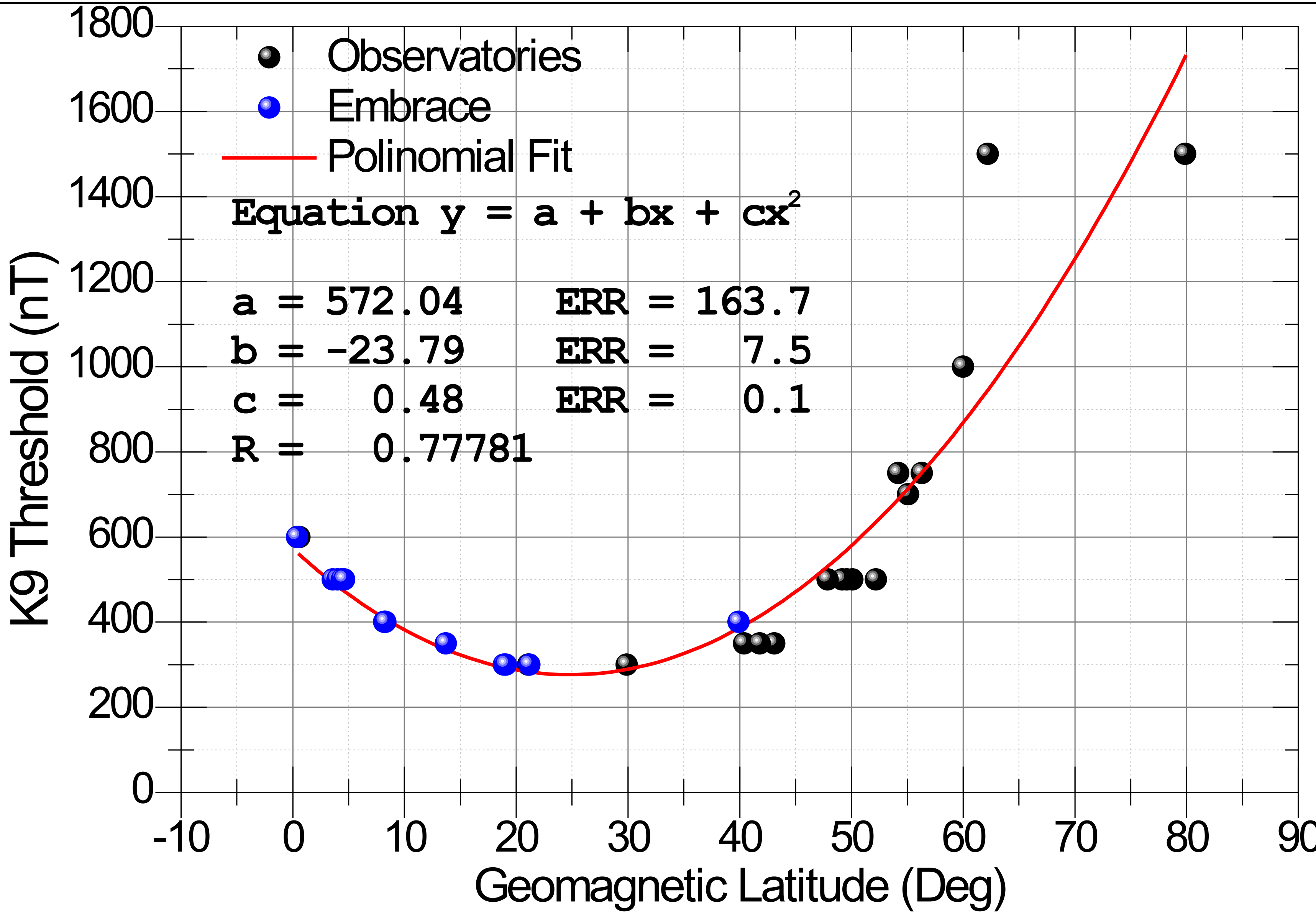


For the historical development and evaluation of various techniques for deriving the QDC, readers are referred to Mayaud [1980], Menvielle and Bertbelief [1991], and Menvielle et al. [1995].

Conversion Table (observatories)

Observatory	IAGA Code	Country	Geographic		Geomag. Lat. (°)	Altitude (m)	DIP (°)	Limits of ranges for the corresponding K									
			Lat. (°)	Lon. (°)				0	1	2	3	4	5	6	7	8	9
Huancayo	HUA	PE	-12.05	284.66	-0.6	3313.0	-02.10	0	6	12	24	48	85	145	240	400	600
Honolulu	HON	US	21.32	201.94	21.1	4.0	39.14	0	3	6	12	24	40	70	120	200	300
San Juan	SJG	RQ	18.38	293.88	29.9	424.0	52.60	0	3	6	12	24	40	70	120	200	300
Tucson	TUC	US	32.25	249.17	40.4	946.0	59.84	0	4	8	16	30	50	85	140	230	350
Watheroo	WAT	AS	-30.32	115.88	-41.8	200	-64.49	0	4	8	16	30	50	85	140	230	350
Fresno	FRN	US	37.09	240.28	43.1	331.0	61.73	0	4	8	16	30	50	85	140	230	350
Hartland	HAD	UK	51.00	355.52	47.9	95.0	66.32	0	5	10	20	40	70	120	200	330	500
Boulder	BOU	US	40.14	254.76	49.2	1682.0	67.45	0	5	10	20	40	70	120	200	330	500
Fredericksburg	FRD	US	38.21	282.63	49.6	69.0	68.28	0	5	10	20	40	70	120	200	330	500
Cheltenham	CLH	US	38.73	283.16	50.1	70.0	71.49	0	5	10	20	40	70	120	200	330	500
Niemegk	NGK	GE	52.07	12.68	52.2	78.0	67.25	0	5	10	20	40	70	120	200	330	500
Saint Johns	STJ	CA	47.59	307.32	54.2	100.0	68.60	0	7,5	15	30	60	105	180	300	500	750
Newport	NEW	US	48.26	242.88	55.1	770.0	71.49	0	7	14	28	56	98	168	280	462	700
Ottawa	OTT	CA	45.40	284.45	56.3	75.0	72.19	0	7,5	15	30	60	105	180	300	500	750
Sitka	SIT	US	57.05	224.67	60.0	24.0	74.57	0	10	20	40	80	140	240	400	660	1000
Meanook	MEA	CA	54.62	246.67	62.2	700.0	76.96	0	15	30	60	120	210	360	600	1000	1500
Godhavn	GDH	GL	69.24	306.48	79.9	69.0	81.77	0	15	30	60	120	210	360	600	1000	1500

K9 Threshold (our stations)

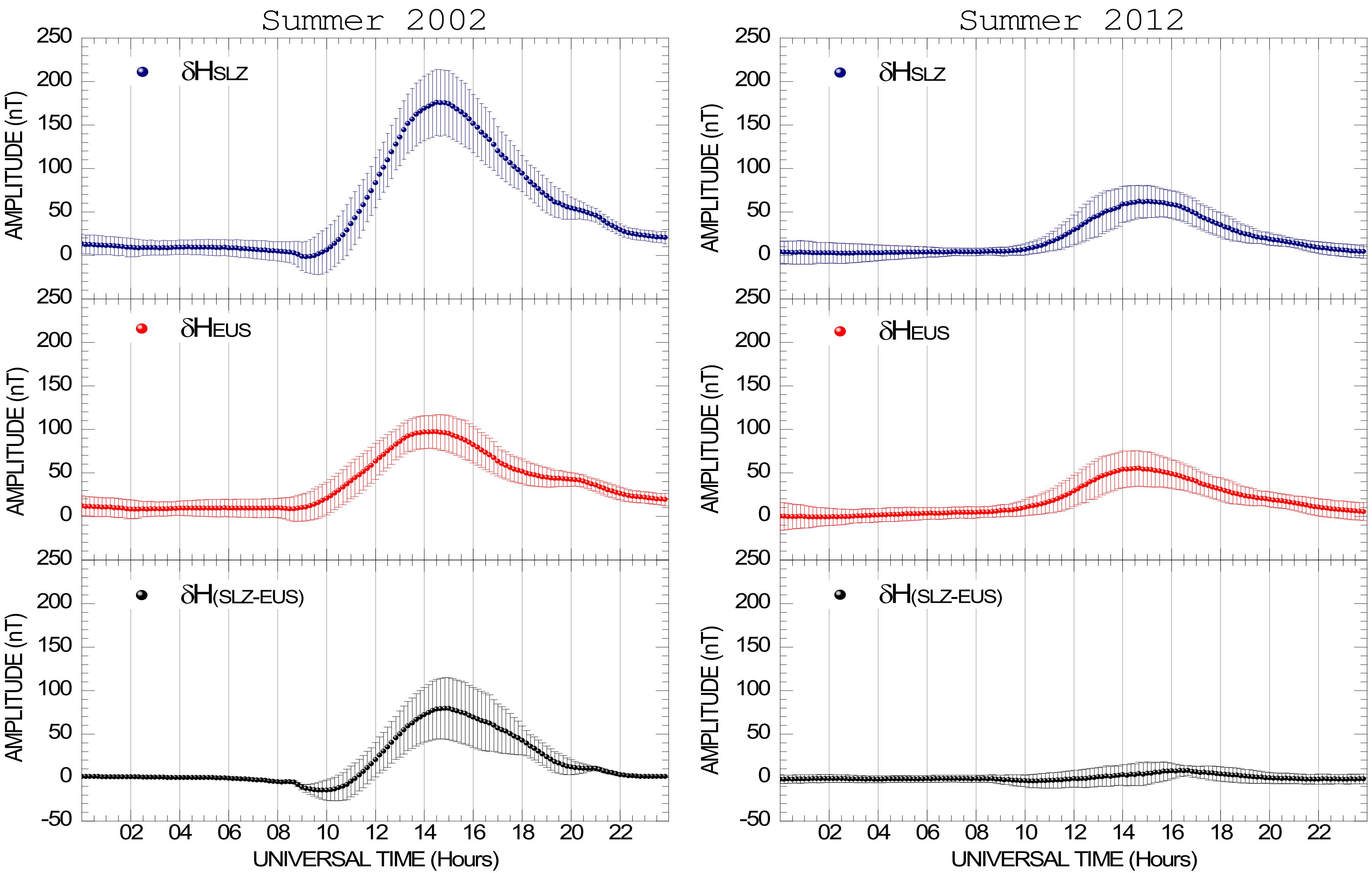


Conversion Table (our stations)

$$R_{max} = 0.48(\text{GeomLat})^2 - 23.79(\text{GeomLat}) + 572.04$$

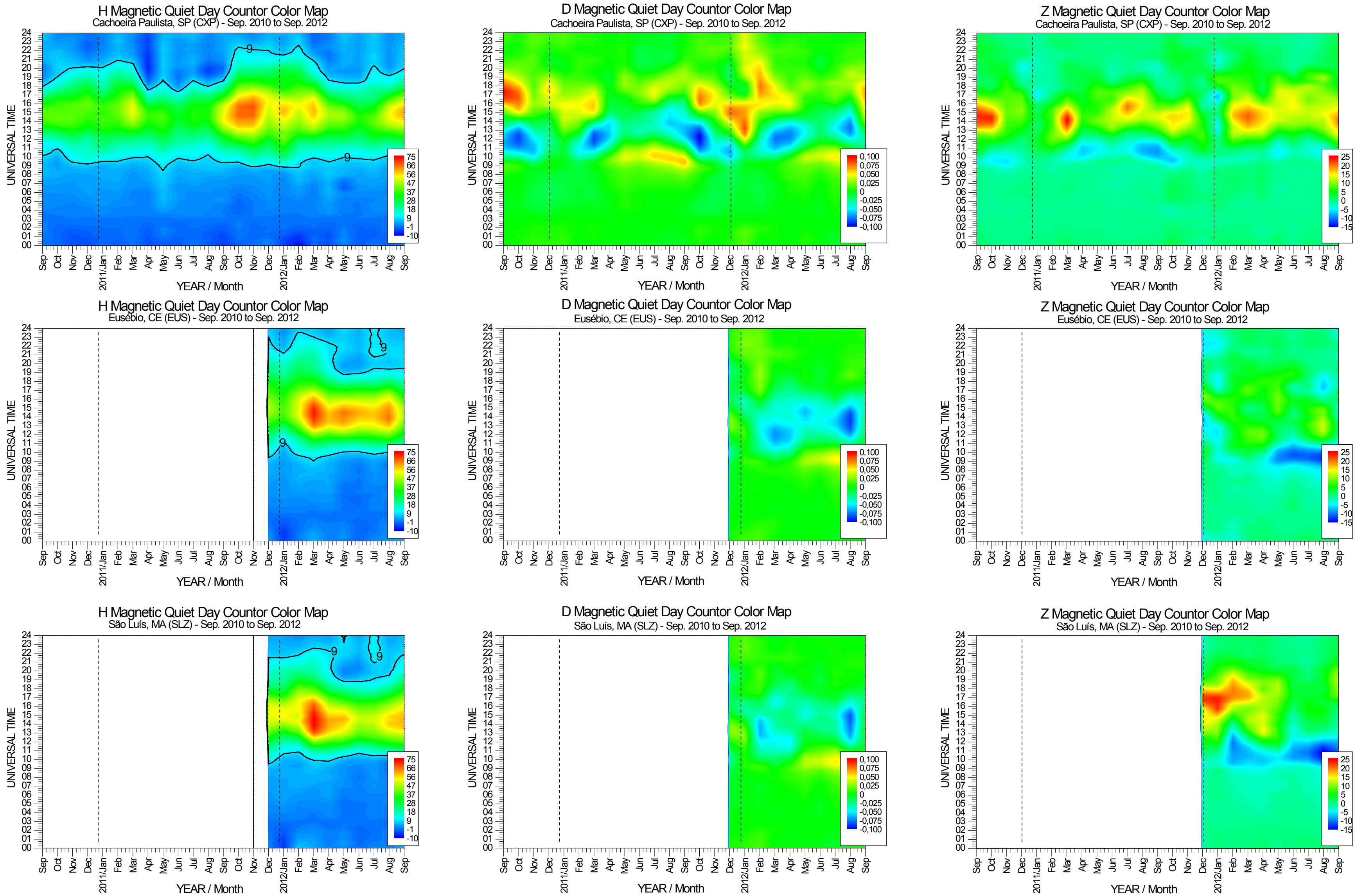
Magnetic Station	Geomag. Lat. (°)	DIP (°)	Limits of ranges for the corresponding K										R_{max}
			0	1	2	3	4	5	6	7	8	9	
Belém-PA	-00.4	-00.80	0	6	12	24	48	85	145	240	400	600	563
São Luís-MA	-03.6	-07.26	0	5	10	20	40	70	120	200	330	500	493
Cachimbo-PA	-04.0	-07.99	0	5	10	20	40	70	120	200	330	500	485
Manaus-AM	-04.4	08.75	0	5	10	20	40	70	120	200	330	500	477
Boa Vista-RR	-04.6	-09.22	0	5	10	20	40	70	120	200	330	500	473
Eusébio-CE	-08.2	-16.51	0	4	8	16	32	56	96	160	265	400	409
Palmas-TO	-08.3	-16.52	0	4	8	16	32	56	96	160	265	400	408
C. Grande-MS	-13.7	-26.29	0	4	8	16	30	50	85	140	230	350	336
C. Paulista-SP	-18.9	-36.43	0	3	6	12	24	40	70	120	200	300	294
São J. Campos-SP	-19.1	-36.64	0	3	6	12	24	40	70	120	200	300	293
São Martinho-RS	-21.2	-36.48	0	3	6	12	24	40	70	120	200	300	283
Rio Grande-TF	-39.9	-50.03	0	4	8	16	32	56	96	160	265	400	387

QDC for the Magnetic Stations



MINISTÉRIO DA CIÊNCIA E TECNOLOGIA
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

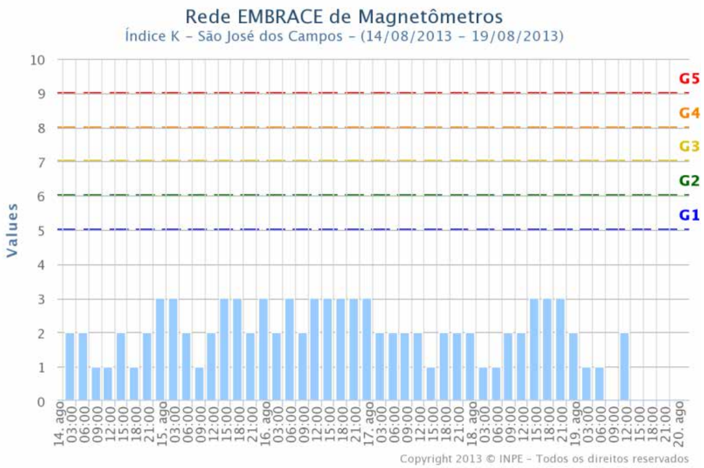
QDC for the Magnetic Stations

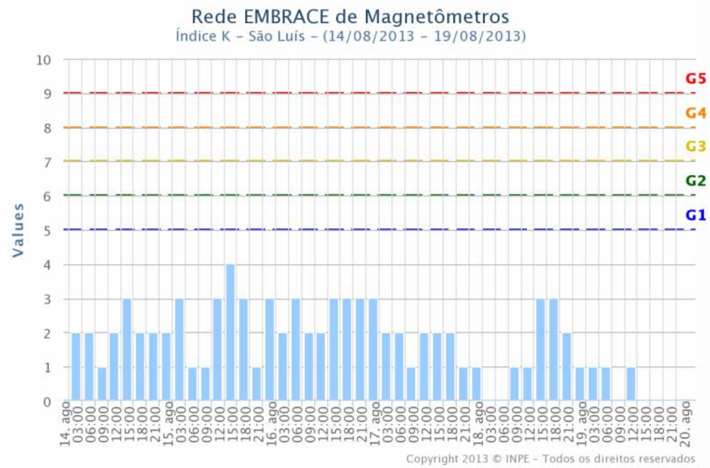


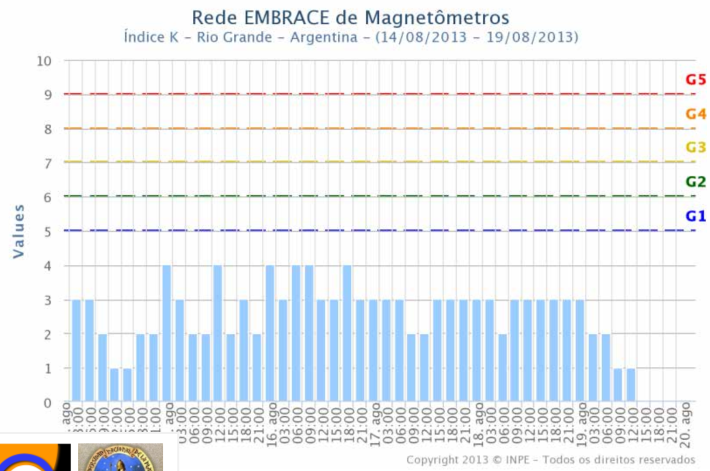
MINISTÉRIO DA CIÊNCIA E TECNOLOGIA
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

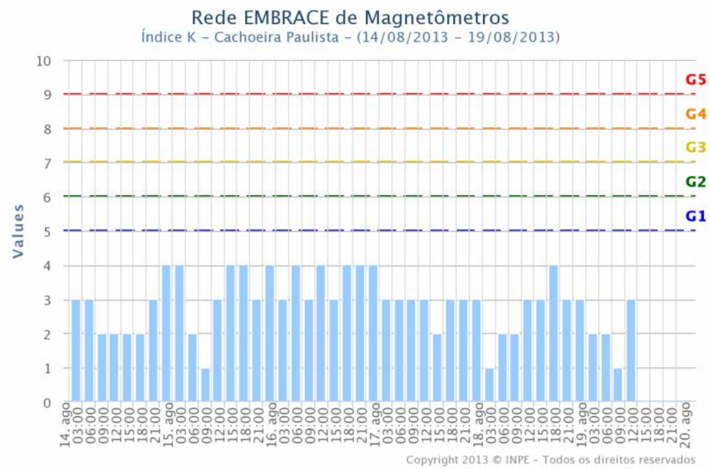
The Station K Index

www.inpe.br/spaceweather









Localização dos Magnetômetros

Listagem

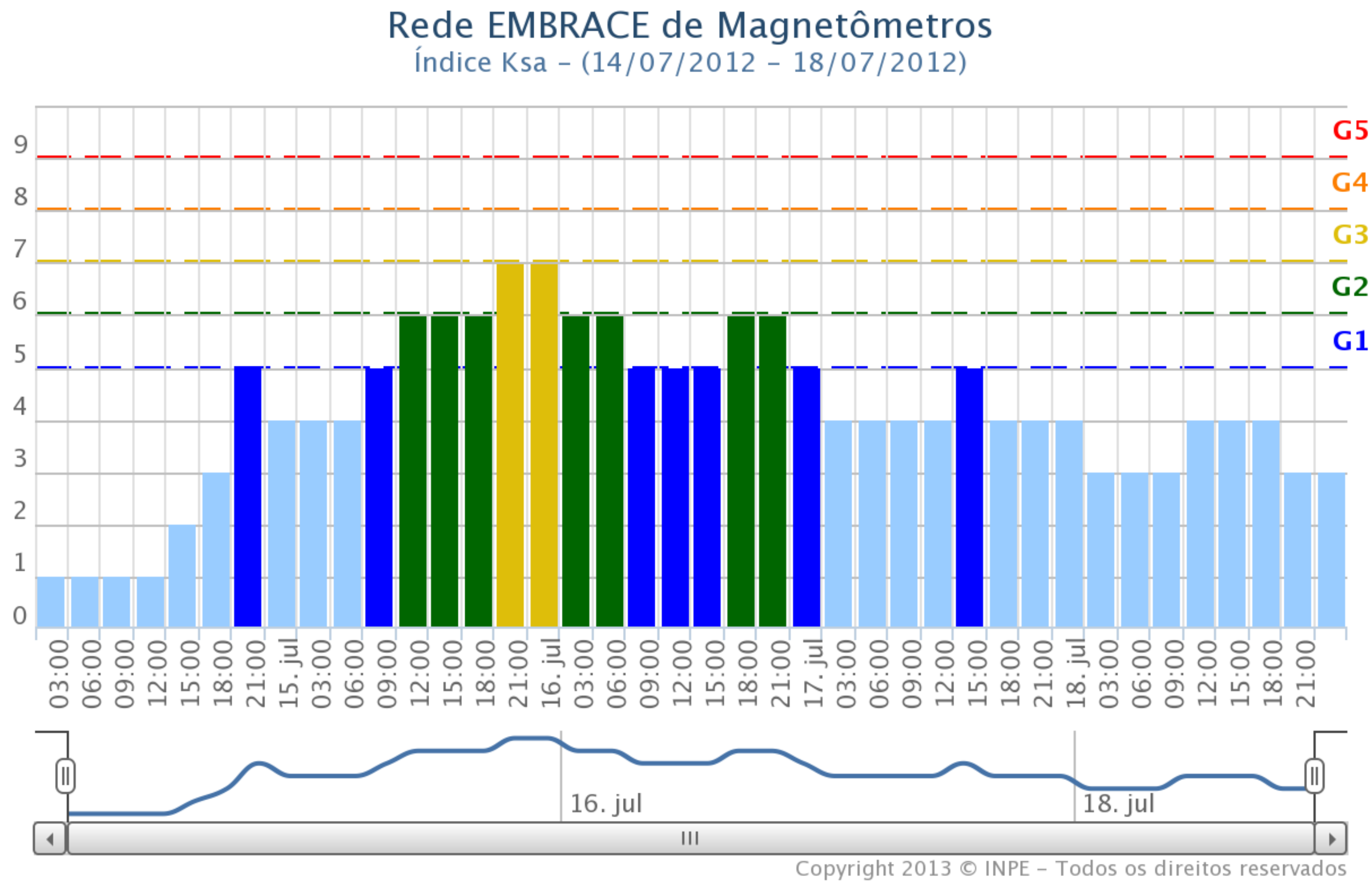
- Cachoeira Paulista, CXP
- Eusébio, EUS
- São Luís, SLZ
- Rio Grande - Argentina, RGA
- São José dos Campos, SJC
- São Martinho da Serra, SMS

EMBRACE

UniFap

The South American K Index

www.inpe.br/spaceweather



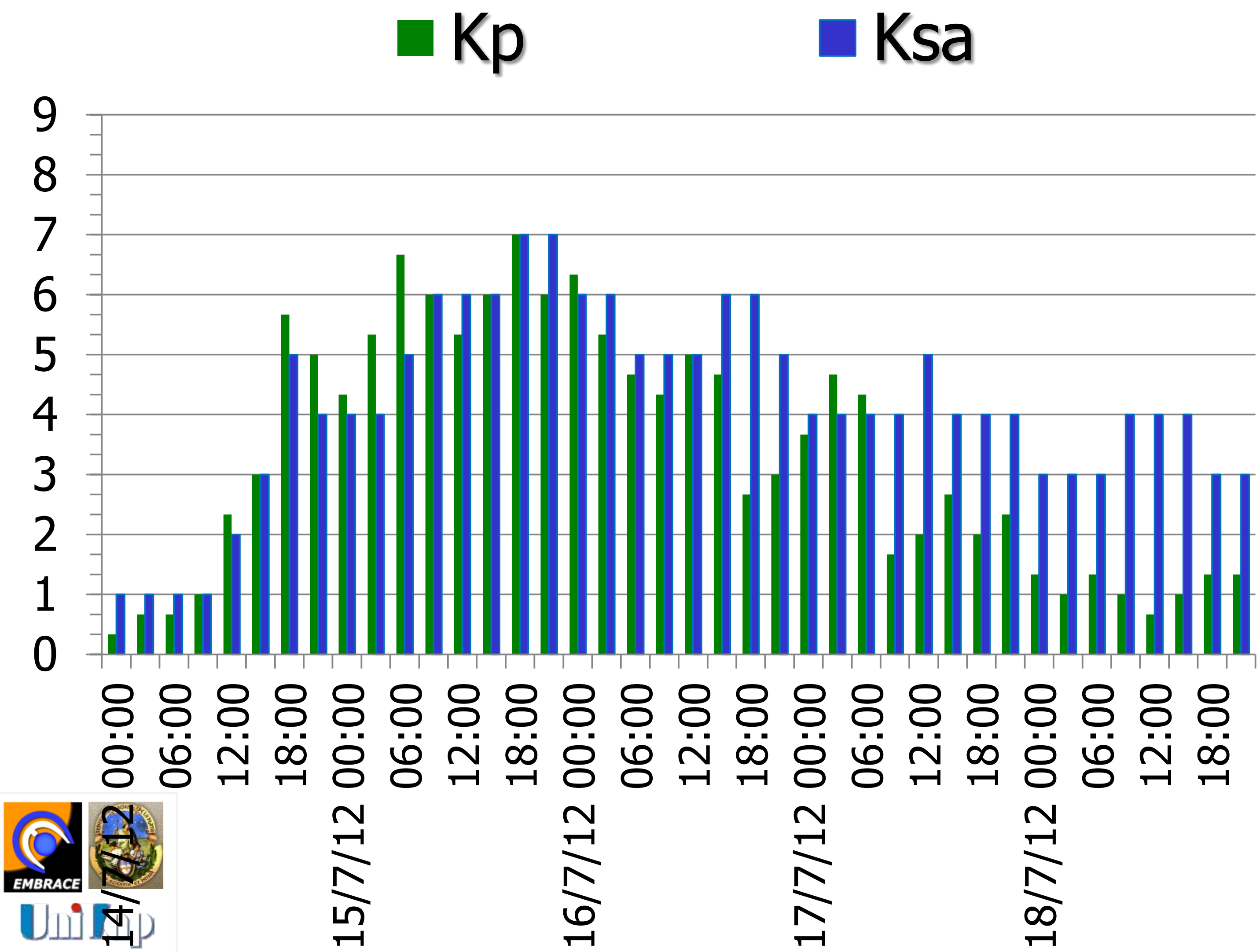
Localização dos Magnetômetros

Listagem

- Cachoeira Paulista, CXP
- Eusébio, EUS
- São Luís, SLZ
- Rio Grande - Argentina, RGA
- São José dos Campos, SJC
- São Martinho da Serra, SMS

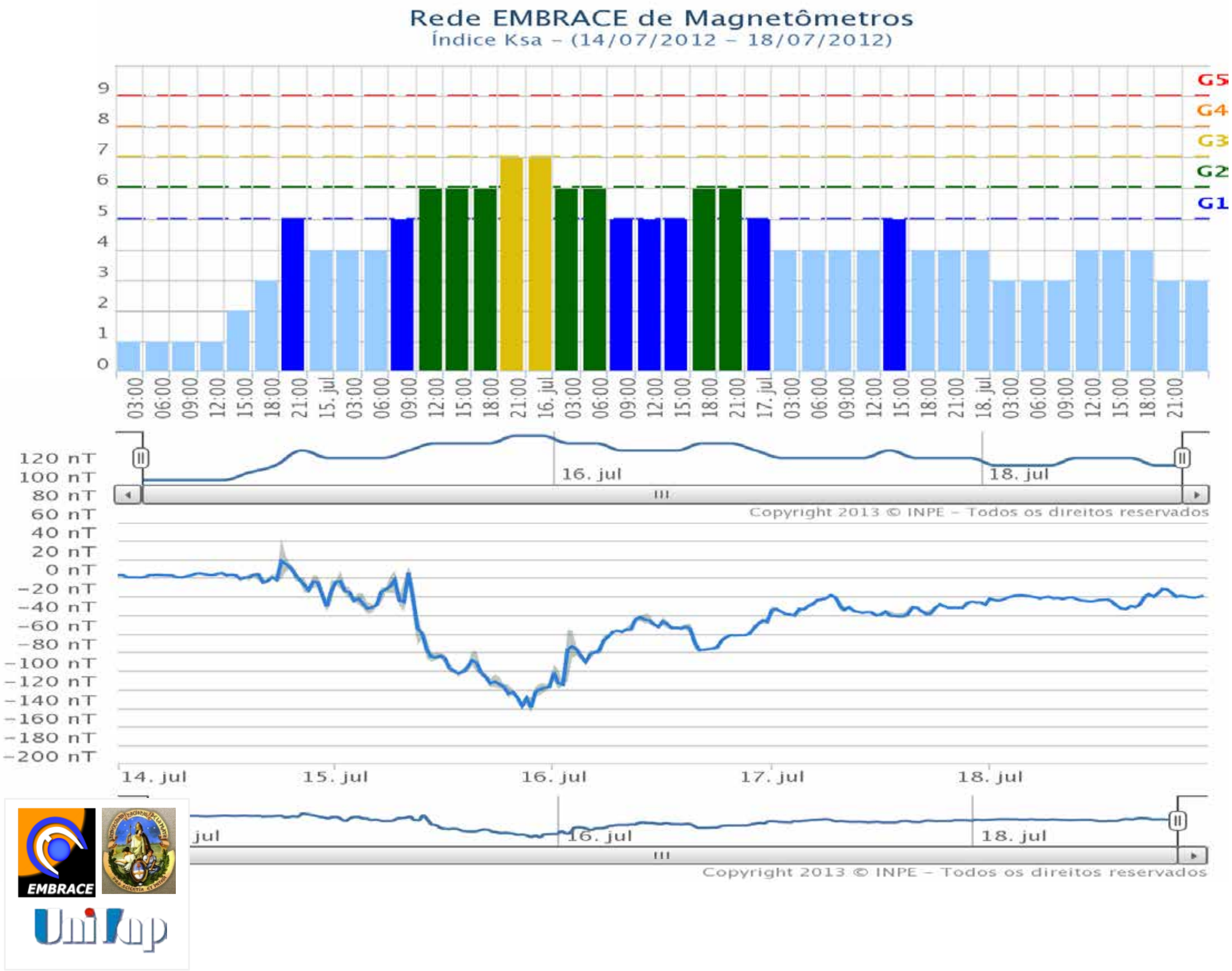
EMBRACE
UniFap

Is Kp really planetarische ?



The South American K Index

www.inpe.br/spaceweather

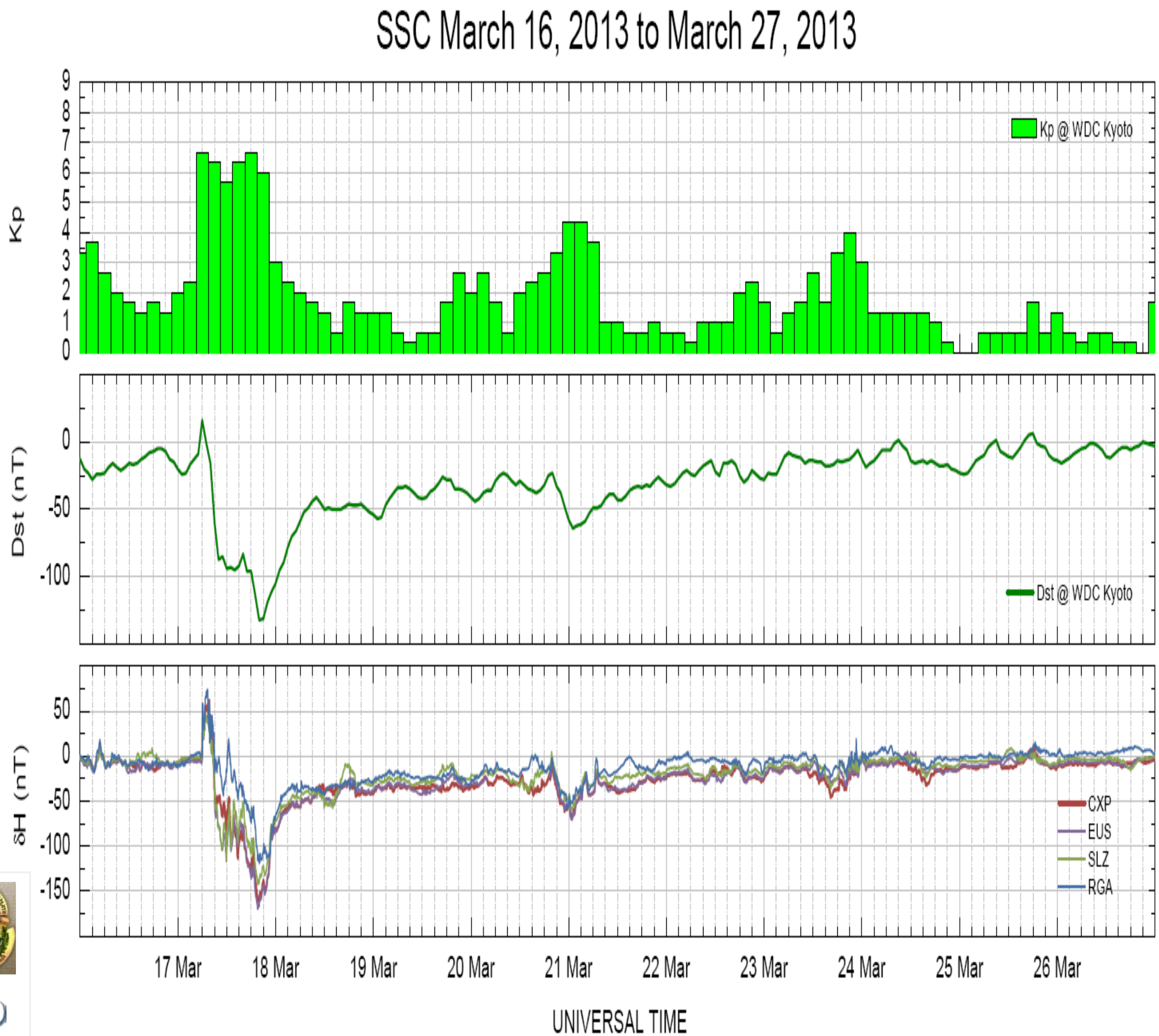


Listagem

- Cachoeira Paulista, CXP
- Eusébio, EUS
- São Luís, SLZ
- Rio Grande - Argentina, RGA
- São José dos Campos, SJC
- São Martinho da Serra, SMS

A New Dst Proxy

www.inpe.br/spaceweather



Listagem

- Cachoeira Paulista, CXP
- Eusébio, EUS
- São Luís, SLZ
- Rio Grande - Argentina, RGA
- São José dos Campos, SJC
- São Martinho da Serra, SMS

GNSS Data Processor

Objectives:

To monitor the ionized atmospheric environment over the South American to provide a toll to:

a. **provide** a reliable GNSS data processor for the community
b. **provide** the current TEC over the South America;
c. **estimate** the vertical error [m] over the South America;
d. **estimate** the horizontal error [m] over the South America; and

To achieve all the above variable it is crucial to have all the **EMBRACE Data System** fully duplicate in two or three different location around South America to assure redundancy and continuity.

The GNSS Sensor Networks

www.inpe.br/spaceweather

Phase delay in the ionosphere

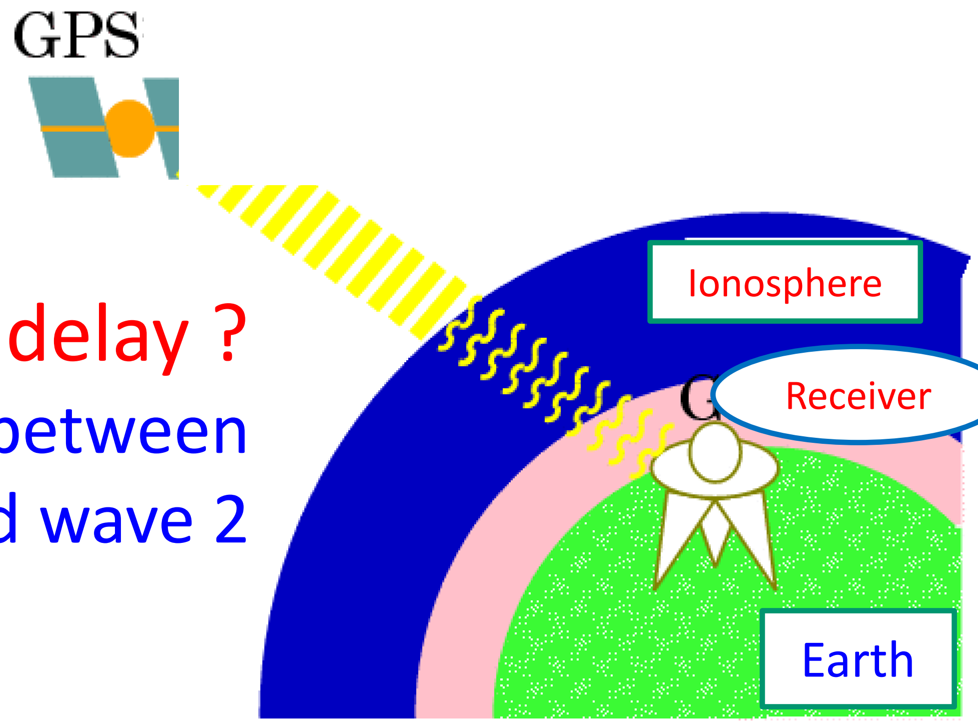
$$d\Phi = \frac{40.3 * TEC}{f^2} \ [m]$$

1 TECU: $d\Phi \sim 0.2$ m

$d\Phi$: Phase delay in [m]

TEC: TEC unit in 10^{16} Electrons/m2 col.

f : Wave frequency in [cycles)



How to get the phase delay ?

Using path difference between the wave 1 and wave 2

From phase delay to TEC

Using path difference between the wave 1 and wave 2

1. Using the Pseudo range (*) difference from CODE

$$TECp = 9.52(P_2 - P_1) + A, \quad [m]$$ (noisy but absolute)

,where $P_{1,2}$ are pseudo distance of wave 1 and 2, A is instrumental factors.

2. Using a phase difference of carrier wave 1 and wave 2 and taking a factor of ambiguity B*

$$TEC_{\Phi} = 9.52\{(\Phi_1 - \Phi_2) - B^*\} + A, \quad [m]$$

,where $\Phi_{1,2} = L1/f_{1,2} * c$ in [m], where c: light velocity in [m]

(*) Pseudo range **P:** (Code delay: Precise satellite orbit, Clocks of satellite and Ground-receiver)

TEC Calculation Procedure

BEGIN

1 GPS data in RINEX Format
2 Time series of CODE: P1 and P2 (Pseudorange in meters)
3 Time series of Phase values: L1 and L2 (wave numbers)
4 Difference of pseudorange: Dr = P2-P1 [m]
5 Difference of L1 and L2: Dp = (L1/f1-L2/f2)*c (c is the speed of light)
6 Ambiguity: B=Dp-Dr for each time series
7 Bavg: using > 1 hour of time series
8 Slant TEC: Tr = F*(Dp - Bavg) F=9.52
9 Instrumental Bias: Bi for each site/satellite
10 Absolute Slant TEC: Ta= Tr + Bi
11 Elevation angle: θ from Navigation data
12 Vertical TEC: Tva= Sθ*Ta Sθ: geometrical factor

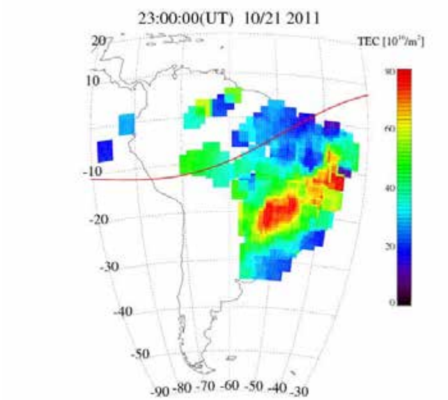
END

MINISTÉRIO DA CIÊNCIA E TECNOLOGIA
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

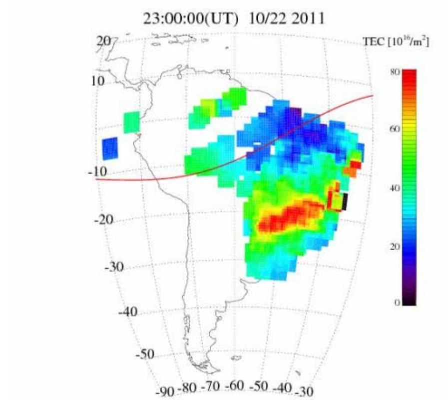
www.inpe.br/spaceweather

Climatology of the EIA

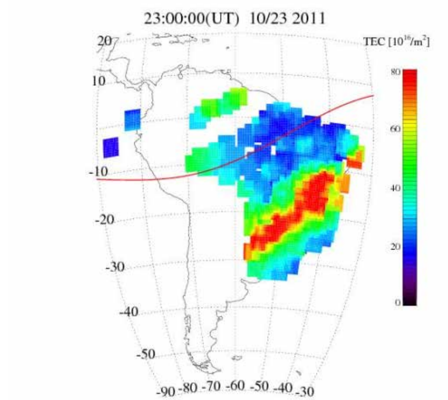
October 21, 2011
ΣKp = 8-



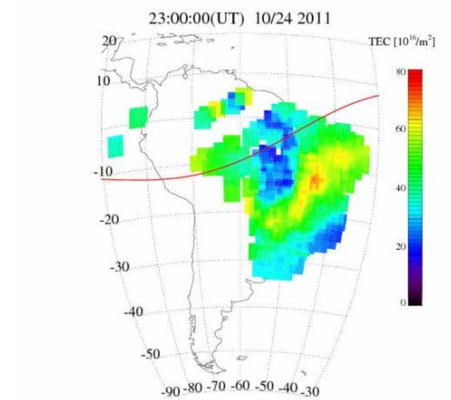
October 22, 2011
ΣKp = 2+



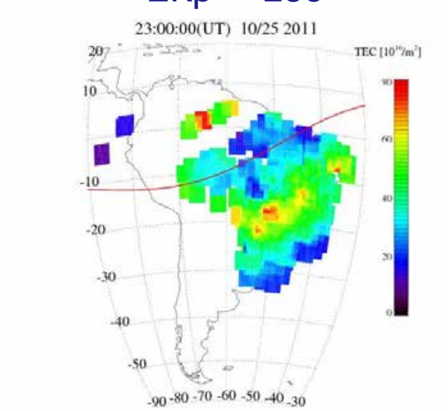
October 23, 2011
ΣKp = 4o



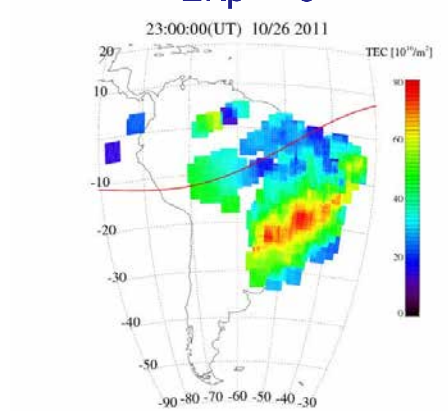
October 24, 2011
ΣKp = 18o



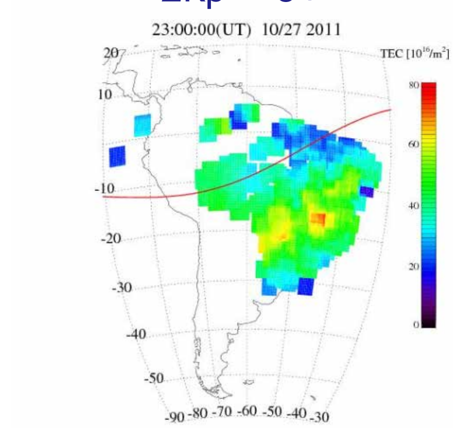
October 25, 2011
ΣKp = 28o



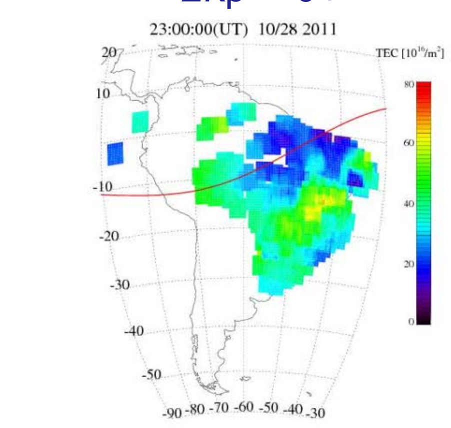
October 26, 2011
ΣKp = 8-



October 27, 2011
ΣKp = 8+



October 28, 2011
ΣKp = 0+

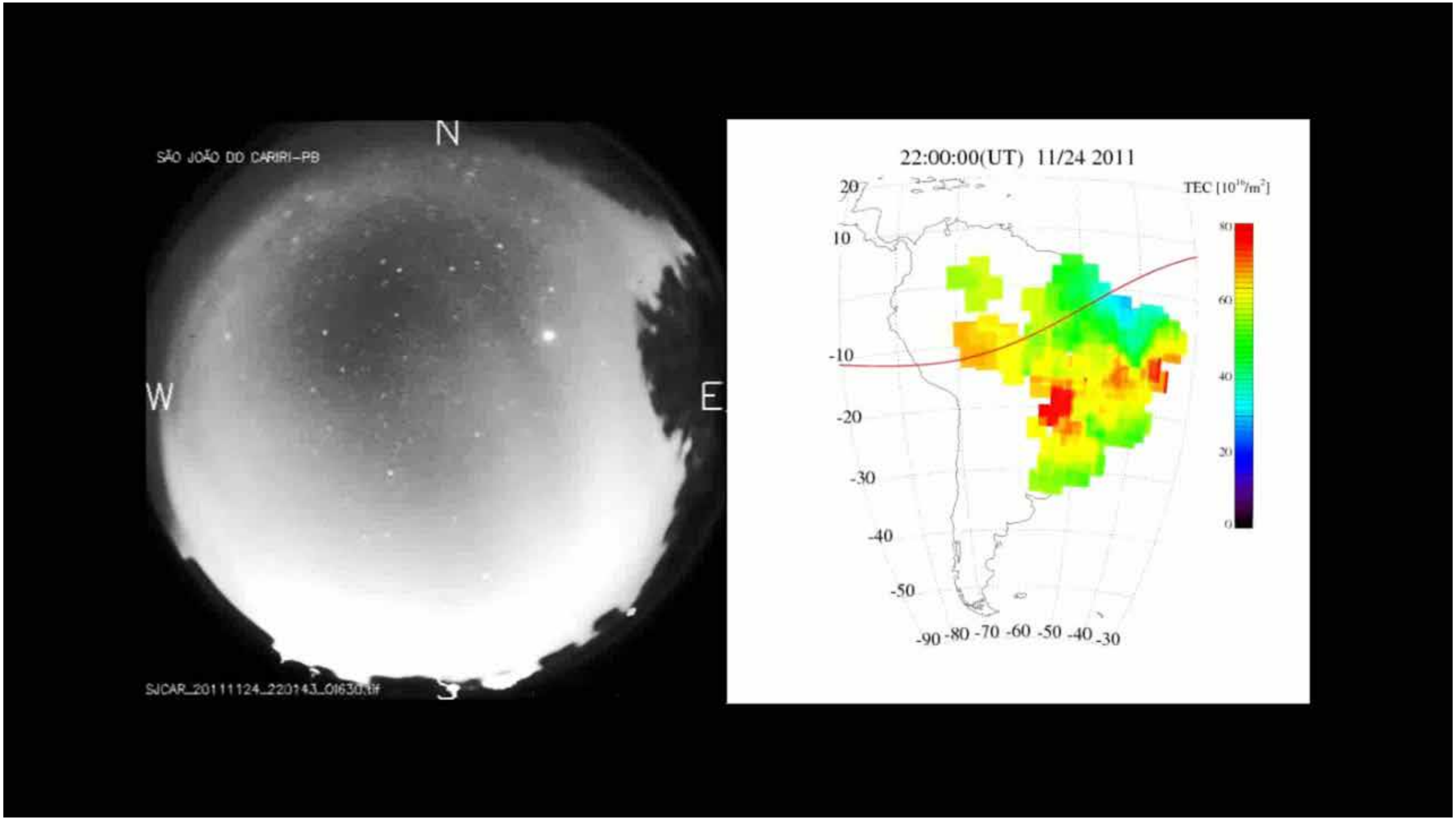


Daily variability of evening EIA between October 21 and 28, 2011 at 23:00 UT (8:00 PM at 45W)

A Bubble detected in TEC + Glow

MINISTÉRIO DA CIÊNCIA E TECNOLOGIA
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

Simultaneous Observation of the bubble by TECMAP and IMAGE (Cariri, PB - Brazil) from 22:00 to 01:30 UT (3.5 hours) on Nov. 24-25, 2011

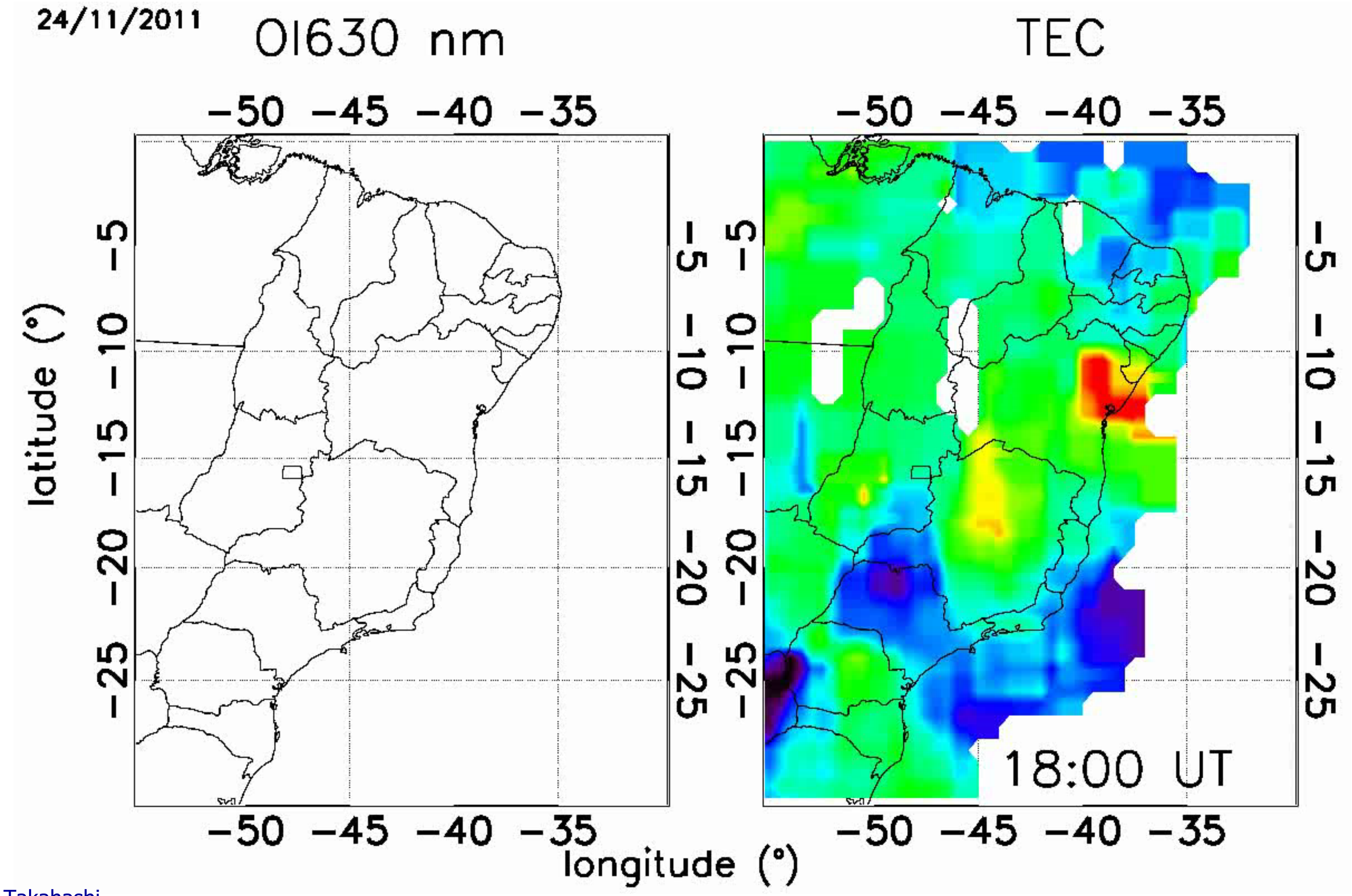


Courtesy:
Dr. Hisao Takahashi

A Bubble detected in TEC + Glow

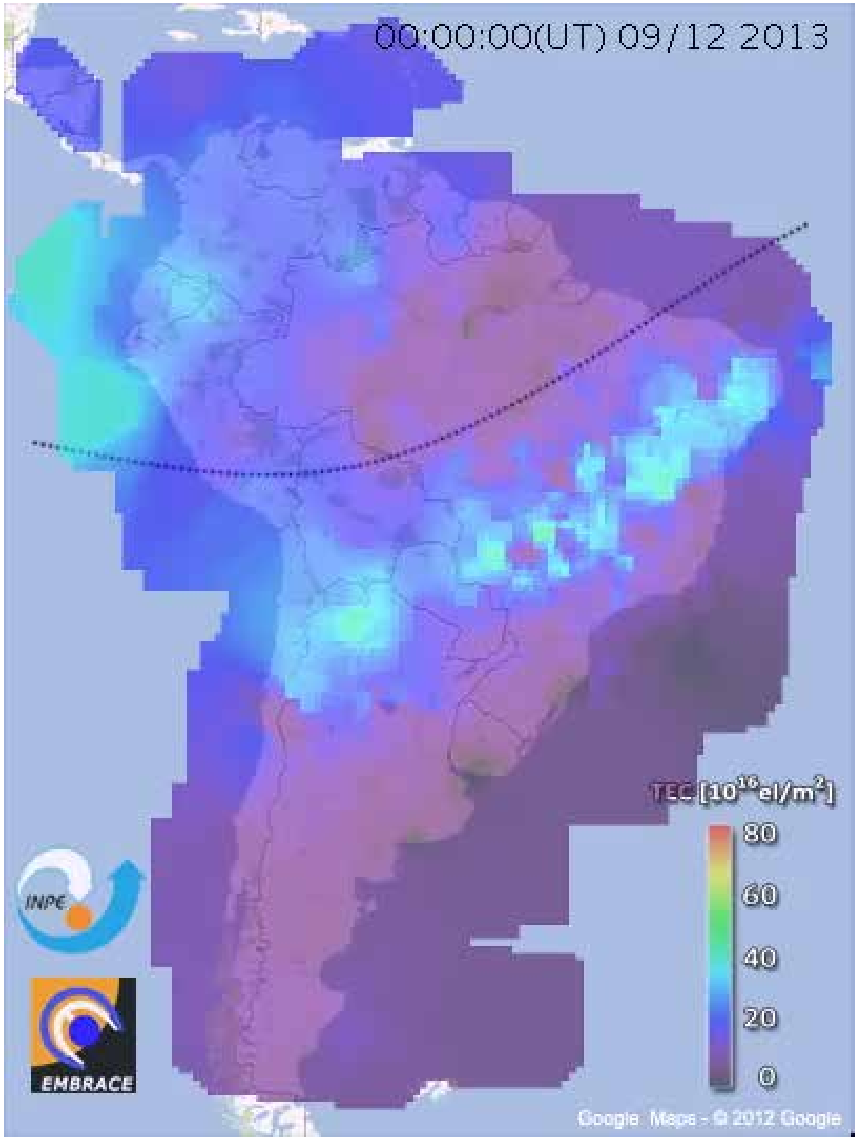
MINISTÉRIO DA CIÊNCIA E TECNOLOGIA
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

Flatfield Image + TEC Map on Nov. 24-25, 2011 - Start: 18:00 to 07:50 UT



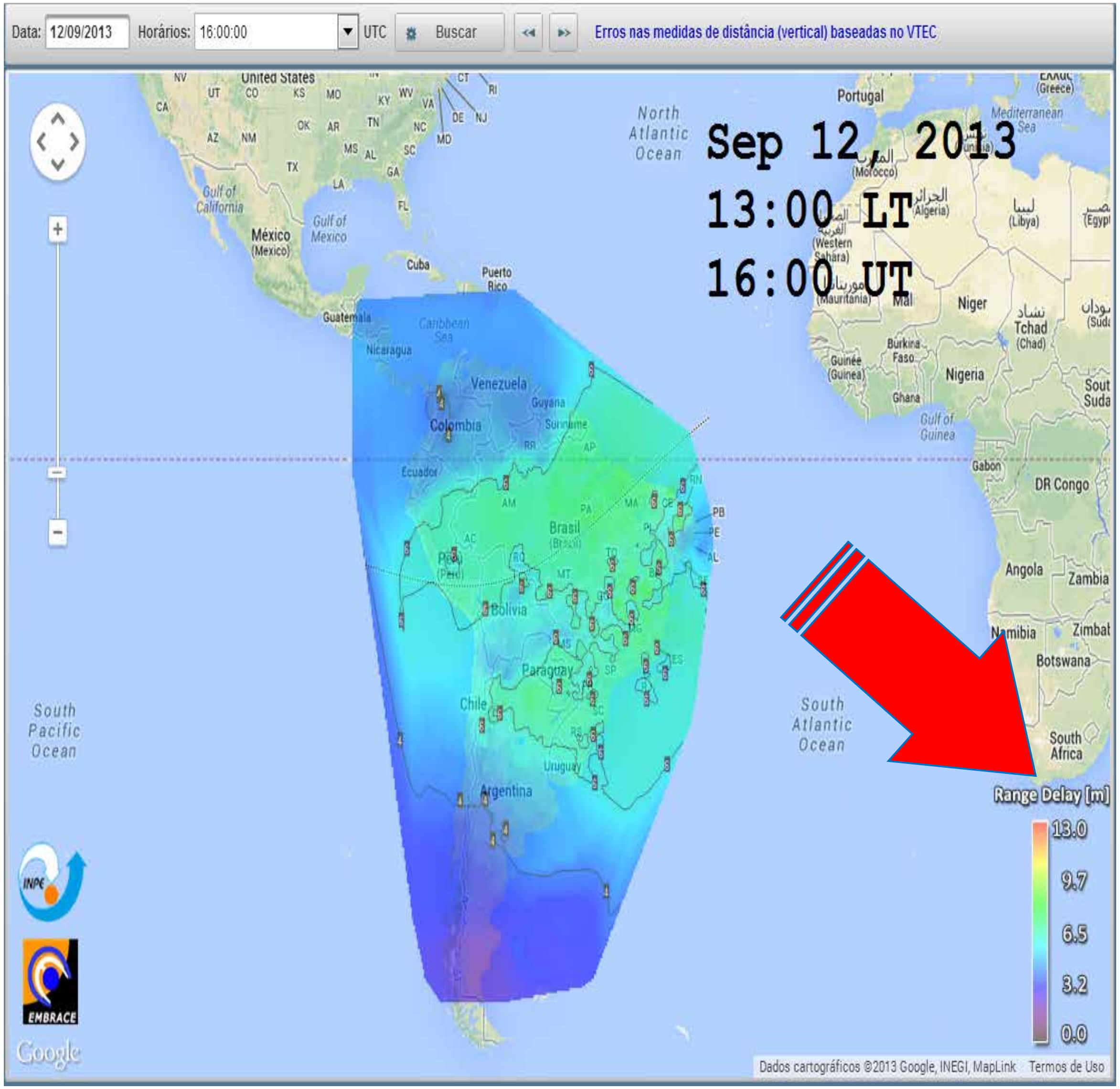
Courtesy:
Dr. Hisao Takahashi

TEC Map over South America



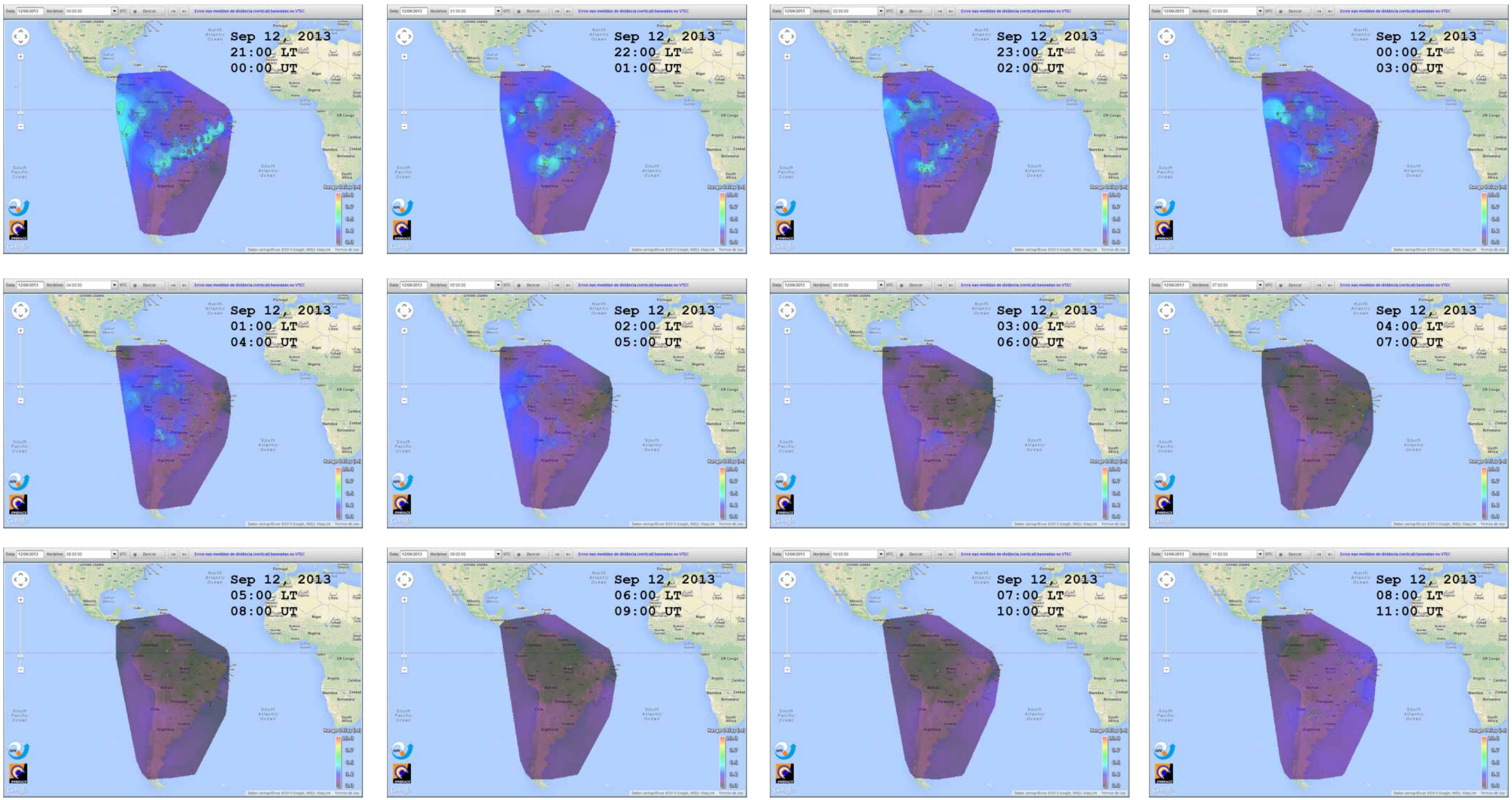
MINISTÉRIO DA CIÊNCIA E TECNOLOGIA
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

From TEC Map to Error Map



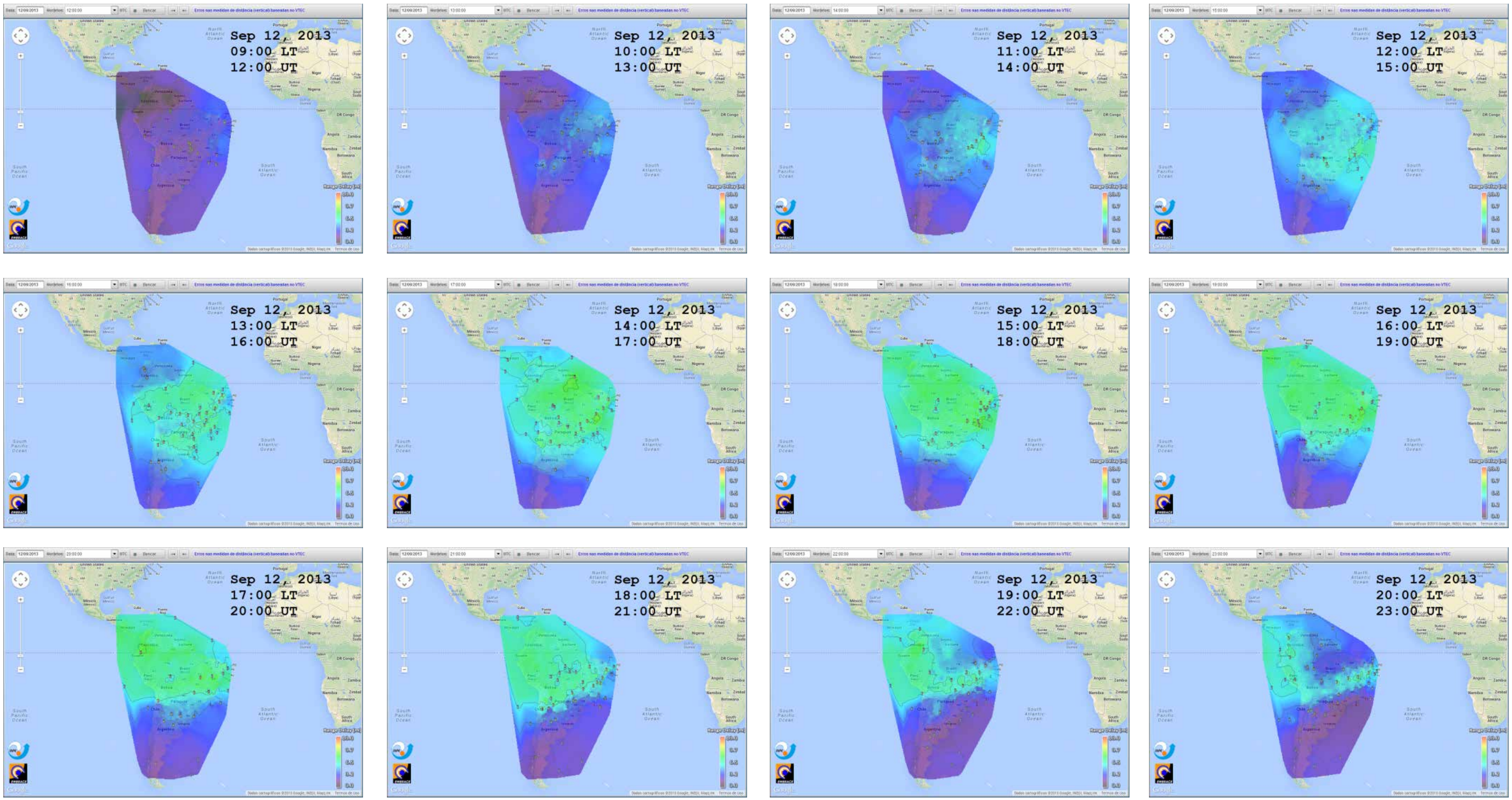
GNSS Vertical Error Maps

Vertical error map on Sep. 12, 2013 - Start: 00:00 to 11:00 UT



GNSS Vertical Error Maps

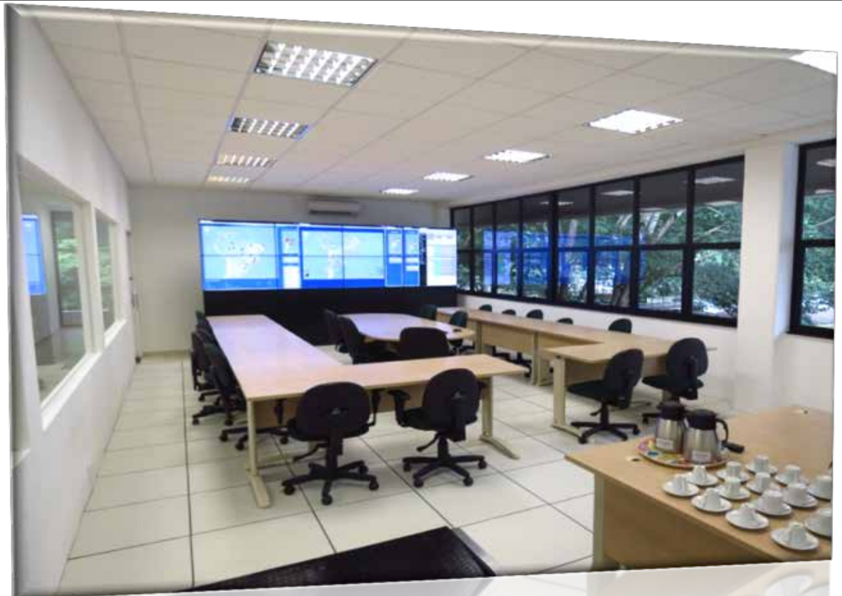
Vertical error map on Sep. 12, 2013 - Start: 12:00 to 23:00 UT



MINISTÉRIO DA CIÊNCIA E TECNOLOGIA
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

Where it is processed ?

How it is processed ?



MINISTÉRIO DA CIÊNCIA E TECNOLOGIA
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

Summary

- MAGNETIC INFORMATION
  - We have 6 magnetic stations providing quality data
  - Anther is to be installed this year and 3 others in the next semester
  - 4 other magnetic sensor ere to be bought this December
  - We already have Ksa, a Dst proxy and GIC proxy (not shown here)
  - Graphs are available online FREE and data is coming online soon
- GNSS ERROR INFORMATION
  - We collect data from 4 GNSS networks in South America
  - Access to another dedicated network is under negotiation right now
  - We are producing an TEC map covering South America every 10 min., with 10 minutes delay for Brazil and up to 12 hours for South America
  - Data are being transformed in vertical error on the fly and e GNSS Vertical Error Map over South America is also produced every 10 min.
  - There is work in progress to increase spatial resolution, by including GLONAS and GALILEO systems in the TEC Map and by increasing the ground receiver site sin the equatorial region (Amazon area)
- BOTTOM-LINE
  - All the information is free of charge and open to the whole world.
  - All that we ask is to put the proper credit in the acknowledgement of the papers and presentations

Acknowledgement

CNPq — Conselho Nacional de Desenvolvimento Científico e Tecnológico

Scholarship in Research Productivity
(Grants 305242/2011-3)

FAPESP

Research Thematic Project
(Grants 2012/08445-9)

Governo Federal
Ministério da Ciência e Tecnologia

Research and Development Action
(PLOA 2013, Action 20VB, PO 08)

UNOOSA
United Nations Office for Outer Space Affairs

Workshop Organizers
(travel support)

EMBRACE

Embrace Program (Network manager)

Universidade do Vale do Paraíba (Network partner)

Universidad Nacional de La Plata (Network partner)

Contact Information

Clezio M. De Nardin - clezio.denardin@dae.inpe.br
http://www.dae.inpe.br/~clezio.denardin/

Instituto Nacional de Pesquisas Espaciais
C. P. 515
CEP 12201-970
São José dos Campos, SP - Brazil

+55 12 3208 7180 (Secretary)
+55 12 3208 7055 (Direct)

+55 12 3208 6990

EMBRACE

PROGRAM FOR

ESTUDO E
MONITORAMENTO
BRASILEIRO DO
CLIMA
ESPACIAL

www.inpe.br/climaespacial

MINISTÉRIO DA CIÊNCIA E TECNOLOGIA
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

Remember to visit Brazil