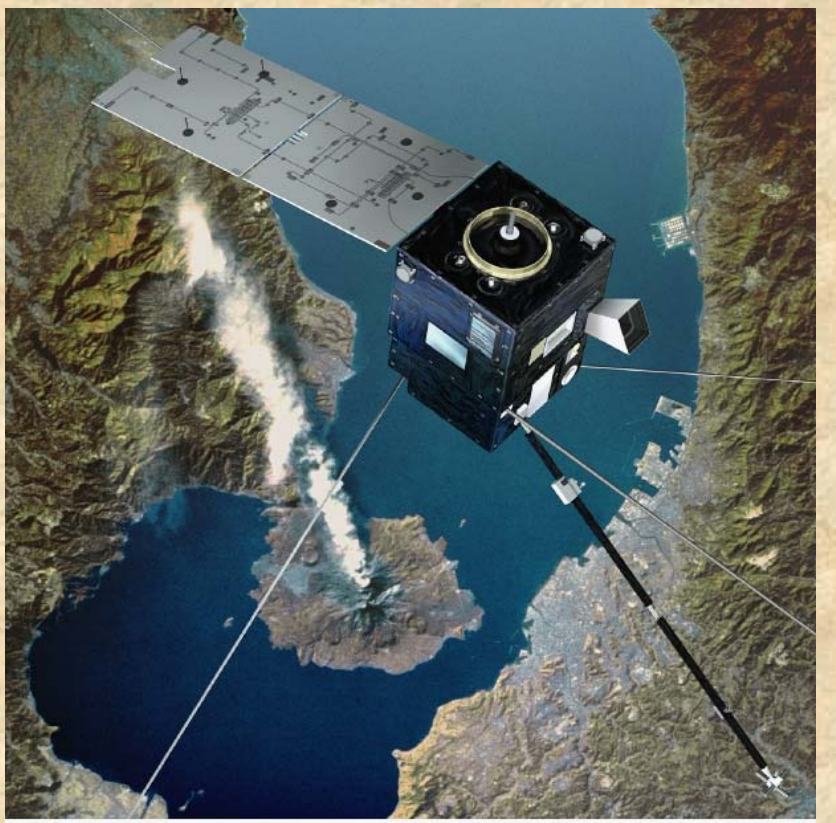
Detection of electromagnetic anomalies before volcanic eruptions by DEMETER micro-satellite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State of researches on Volcanoes

- On the ground, numbers of magnetic, electric and electromagnetic (EM) signals are observed before and during volcanic crises
- Since 2004, Demeter satellite records several parameters (electronic density and temperature (ISL), ionic density and temperature (IAP) , along with the magnetic (ISMC) and electric (ICE) fields
- But, most of the studies are devoted to EM signals related to earthquakes
- Few researches are dedicated to satellite observations above volcanoes in the EM field.
- Question: Do we observed some EM anomalies related to volcanic activity?

Database

- ► Information on volcanic activity is given by http://www.volcano.si.edu/
  - VEI (volcanic explosivity index) ≥ 1 (scale of 5)
  - Explosive eruptions
  - Period: Sept. 2004 to Dec. 2006
  - Latitudes: -55°S to +55°N

48 volcanic eruptions have been analyzed

- ► We consider orbits whose distance between the footprint of the satellite position and the eruptive center is :
  - < 900 km for the events with VEI ≥ 3
  - < 500 km for VEI < 3

- ► In this first study, data within [-30 to +15] days around the eruption are studied

In total, more than 4000 orbits have been processed

Volcanoes under study: Sept.2004-Dec. 2006

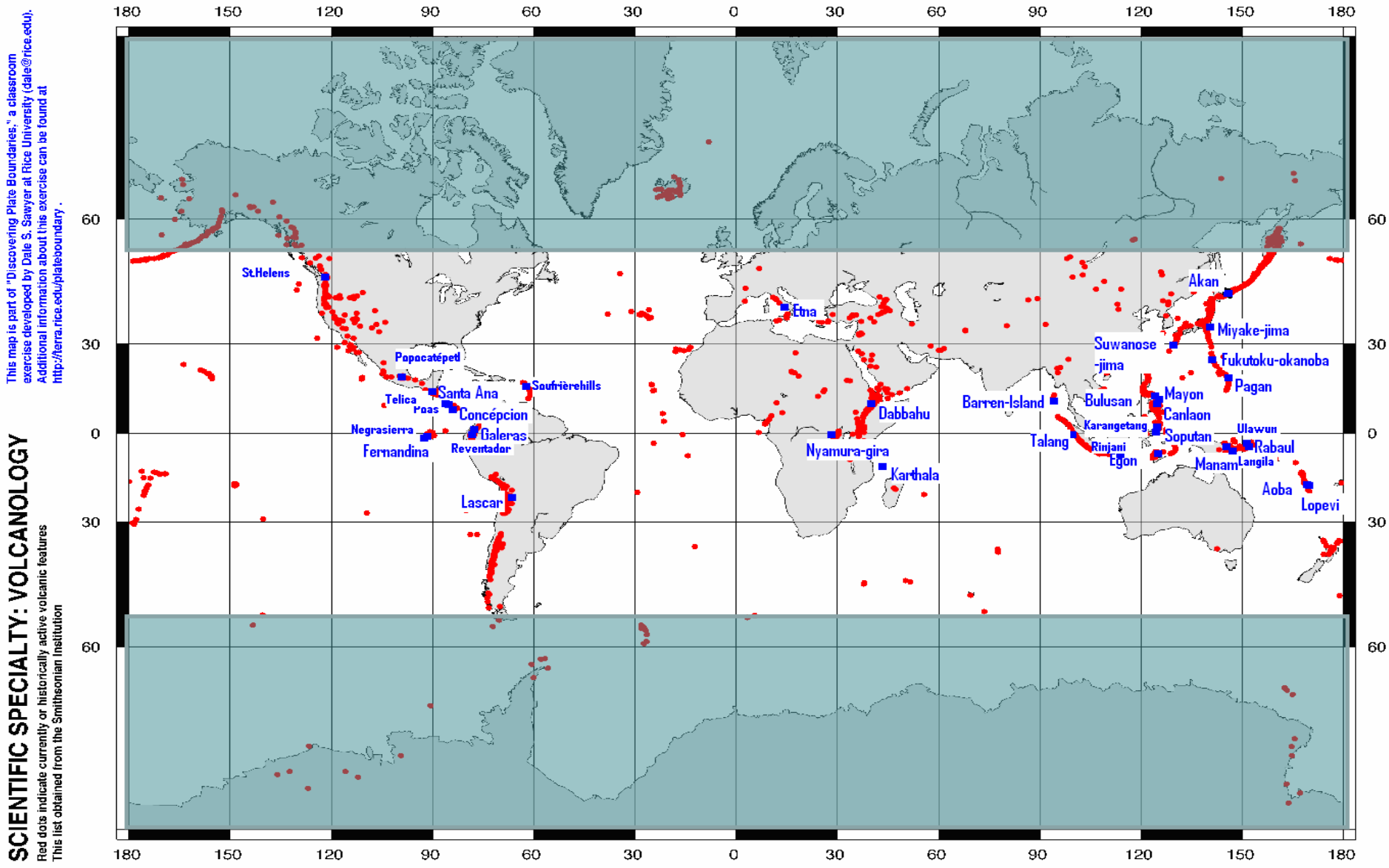


Table of volcanic events

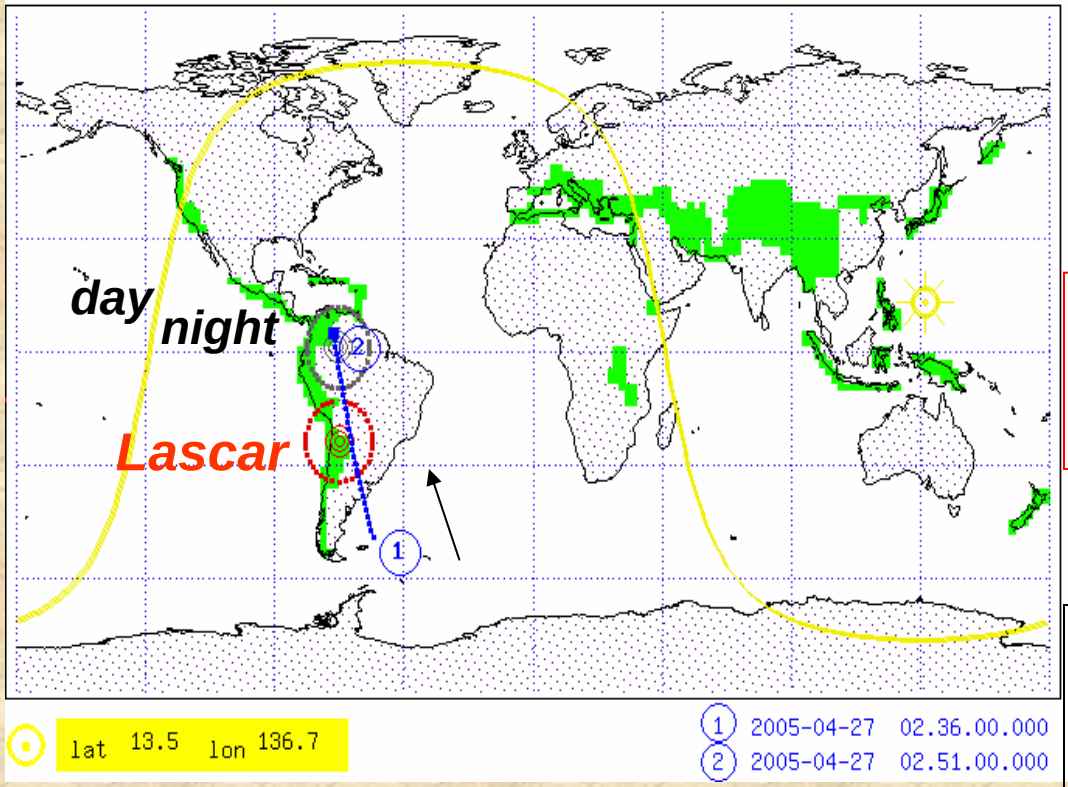
Volcano	Lat.	Long.	Volcano Type	Summit elevation (m)	Start Date (dd/mm/yy)	Stop Date (dd/mm/yy)	Eruptive – Characteristics	VEI
Akan	43.384	144.013	Caldera	1499	21/03/2006	21/03/2006	Central vent eruption Explosive eruption , Phreatic explosion(s)	1
Aoba	-15.4	167.83	Shield volcano	1496	27/11/2005	21/02/2006 (in or after)	Central vent eruption Crater lake eruption, Explosive eruption , Pyroclastic flow(s) , Phreatic explosion(s), Evacuation	2
Lascar	-23.37	92.27	Strato-volcano	5592	04/05/2005	04/05/2005	Central vent eruption, Explosive eruption	3

▪ ▪ ▪

→ *3 types of anomalies have been recognized*

Lascar volcano: Type 1

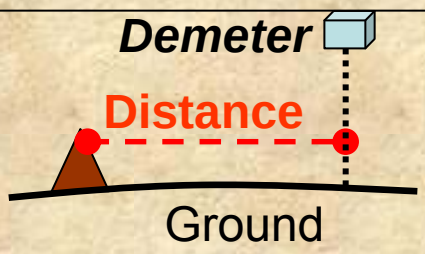
- [Ex1]-1: Lascar (23.37S , 67.73W) ; April/27/2005, VEI=3



UT	== geographic == lat	lon	tloc	dist	dist
02.36.00	-48.76	304.26	22.9	3017	5704
02.36.30	-46.99	303.56	22.9	2816	5500
02.37.00	-45.21	302.89	22.8	2615	5295
02.37.30	-43.43	302.26	22.8	2414	5091
02.38.00	-41.65	301.65	22.7	2214	4886
02.38.30	-39.86	301.07	22.7	2014	4681
02.39.00	-38.08	300.52	22.7	1816	4477
02.39.30	-36.29	299.98	22.7	1618	4272
02.40.00	-34.50	299.47	22.6	1423	4068
02.40.30	-32.71	298.97	22.6	1230	3863
02.41.00	-30.92	298.48	22.6	1041	3659
02.41.30	-29.12	298.01	22.6	859	3453
02.42.00	-27.33	297.55	22.5	690	3249
02.42.30	-25.53	297.10	22.5	545	3044
02.43.00	-23.74	296.66	22.5	450	2840
02.43.30	-21.94	296.23	22.5	437	2634
02.44.00	-20.14	295.80	22.4	512	2429
02.44.30	-18.35	295.39	22.4	646	2226
02.45.00	-16.55	294.98	22.4	810	2021
02.45.30	-14.75	294.57	22.4	990	1816
02.46.00	-12.95	294.17	22.4	1177	1611
02.46.30	-11.15	293.77	22.4	1370	1407
02.47.00	-9.35	293.38	22.3	1565	1202
02.47.30	-7.55	292.99	22.3	1763	998
02.48.00	-5.75	292.60	22.3	1962	795
02.48.30	-3.95	292.21	22.3	2162	592
02.49.00	-2.14	291.82	22.3	2364	391
02.49.30	-0.34	291.44	22.3	2565	200
02.50.00	1.46	291.05	22.2	2767	107
02.50.30	3.26	290.67	22.2	2970	258
02.51.00	5.06	290.28	22.2	3172	454

Distance threshold

Conjugate magnetic point



Geographical position between the orbit 4344-1 and the eruptive center

7 days before

ICE

<~300 Hz
~200 km

IMSC

ISL density

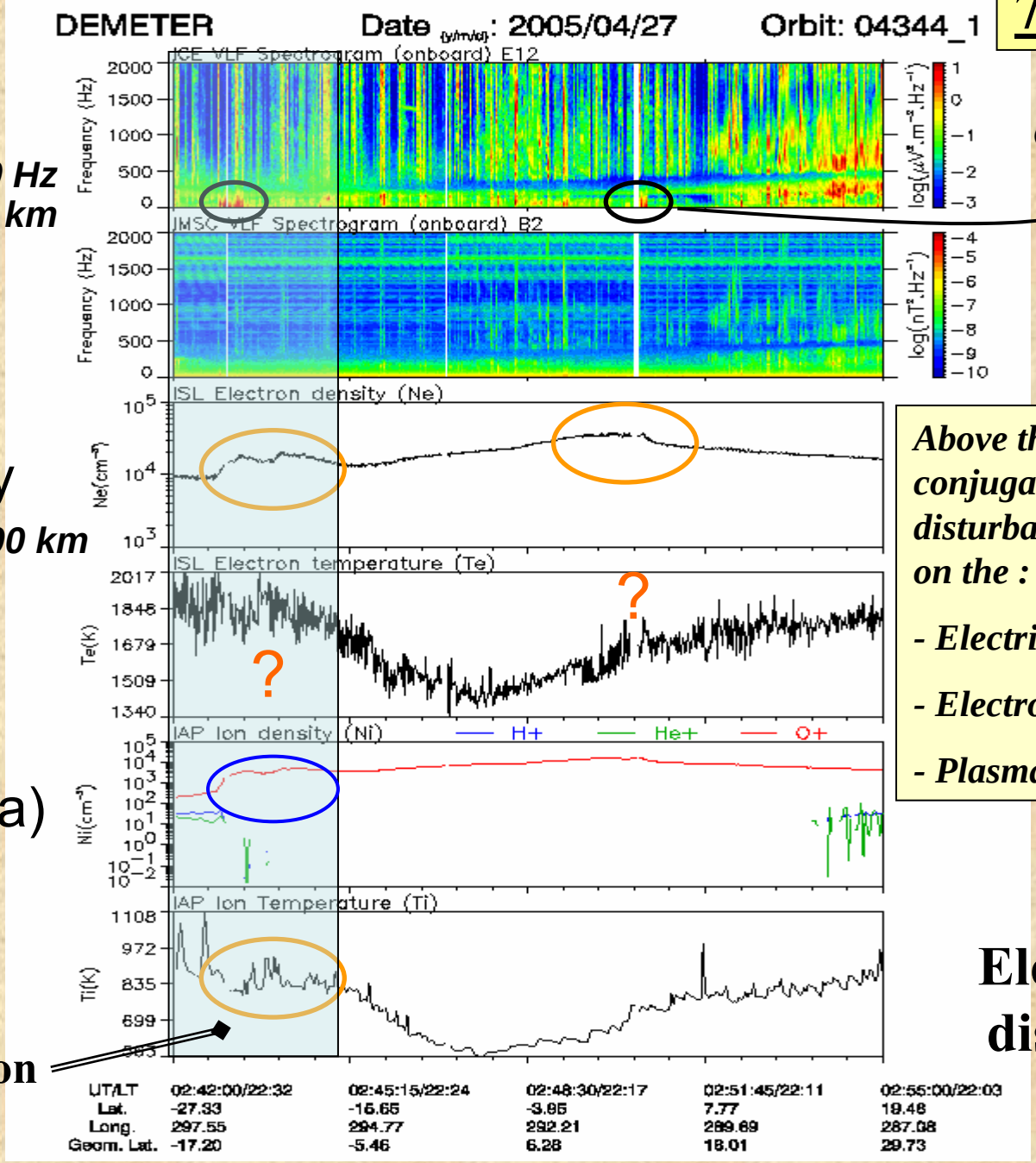
~800 km

ISL-Te

IAP(plasma)
Ionic density

Tions

Lascar location



Conjugate point

Above the volcano and the conjugate point, disturbances are observed on the :

- Electric field

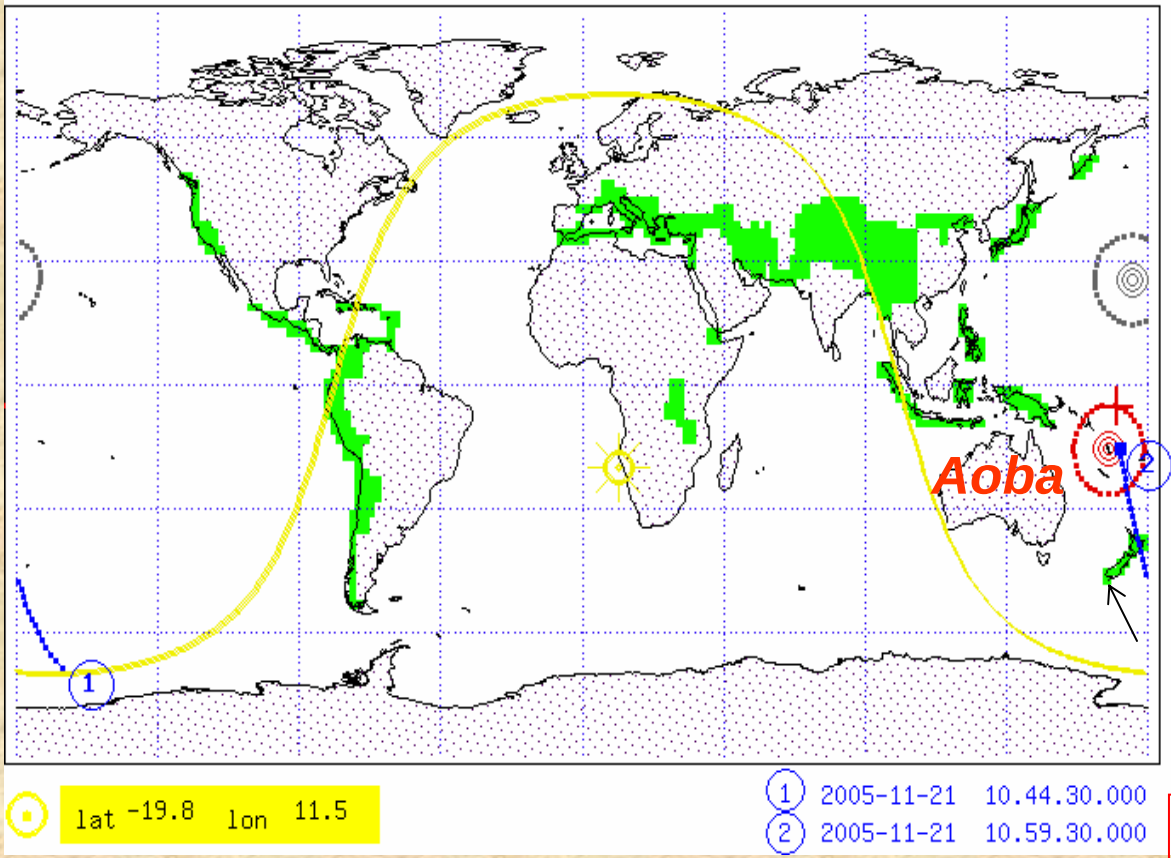
- Electronic density

- Plasma

Electrostatic disturbance

Aoba volcano: Type 1

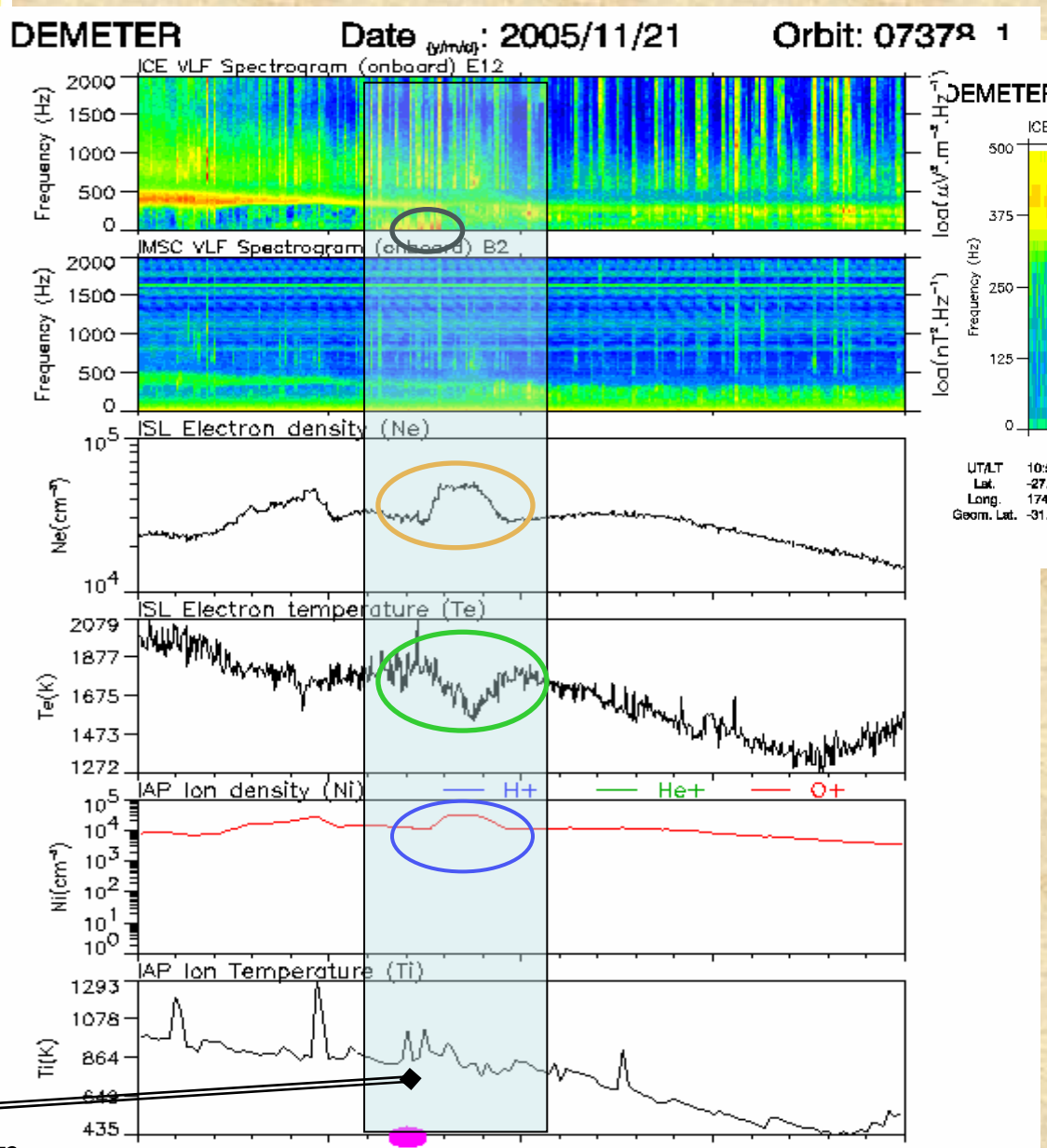
- [Ex1]-2: Aoba (15.4S , 167.83E) ; Nov./27/2005, VEI=2

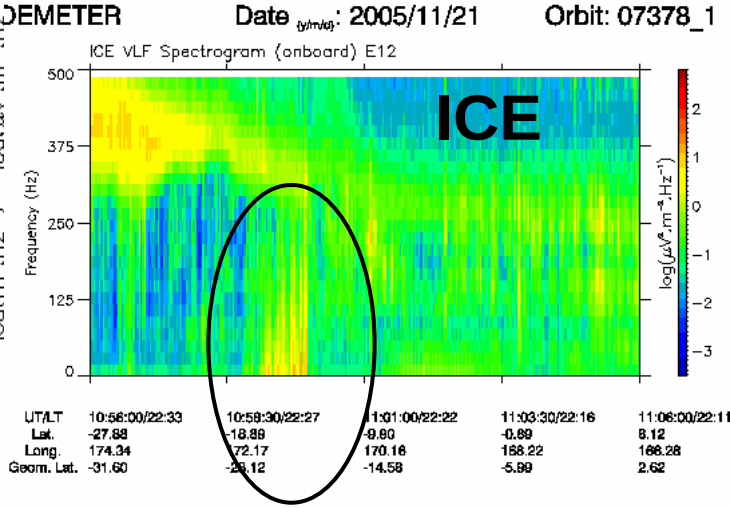


UT	== geographic == lat	lon	tloc	dist	dist
10.44.30	-68.43	194.26	23.7	6194	10596
10.45.00	-66.75	192.34	23.6	5992	10393
10.45.30	-65.05	190.66	23.5	5789	10191
10.46.00	-63.33	189.16	23.4	5586	9988
10.46.30	-61.60	187.82	23.3	5383	9785
10.47.00	-59.87	186.61	23.2	5181	9584
10.47.30	-58.12	185.51	23.2	4978	9381
10.48.00	-56.37	184.50	23.1	4775	9179
10.48.30	-54.61	183.56	23.1	4572	8977
10.49.00	-52.85	182.70	23.0	4369	8776
10.49.30	-51.08	181.89	22.9	4166	8574
10.50.00	-49.31	181.13	22.9	3963	8372
10.50.30	-47.54	180.41	22.9	3761	8171
10.51.00	-45.76	179.74	22.8	3558	7969
10.51.30	-43.98	179.10	22.8	3356	7768
10.52.00	-42.20	178.48	22.8	3153	7567
10.52.30	-40.41	177.90	22.7	2950	7366
10.53.00	-38.63	177.34	22.7	2749	7166
10.53.30	-36.84	176.80	22.7	2546	6965
10.54.00	-35.05	176.27	22.6	2344	6765
10.54.30	-33.26	175.77	22.6	2143	6565
10.55.00	-31.47	175.28	22.6	1942	6366
10.55.30	-29.67	174.81	22.6	1742	6166
10.56.00	-27.88	174.34	22.6	1543	5967
10.56.30	-26.08	173.89	22.5	1345	5768
10.57.00	-24.29	173.45	22.5	1151	5570
10.57.30	-22.49	173.01	22.5	959	5372
10.58.00	-20.69	172.59	22.5	775	5174
10.58.30	-18.89	172.17	22.4	603	4977
10.59.00	-17.10	171.76	22.4	461	4781
10.59.30	-15.30	171.35	22.4	378	4585

Geographical position between the orbit 7378-1 and the eruptive center

6 days before





Above the volcano, disturbances are observed on the :

- Electric field

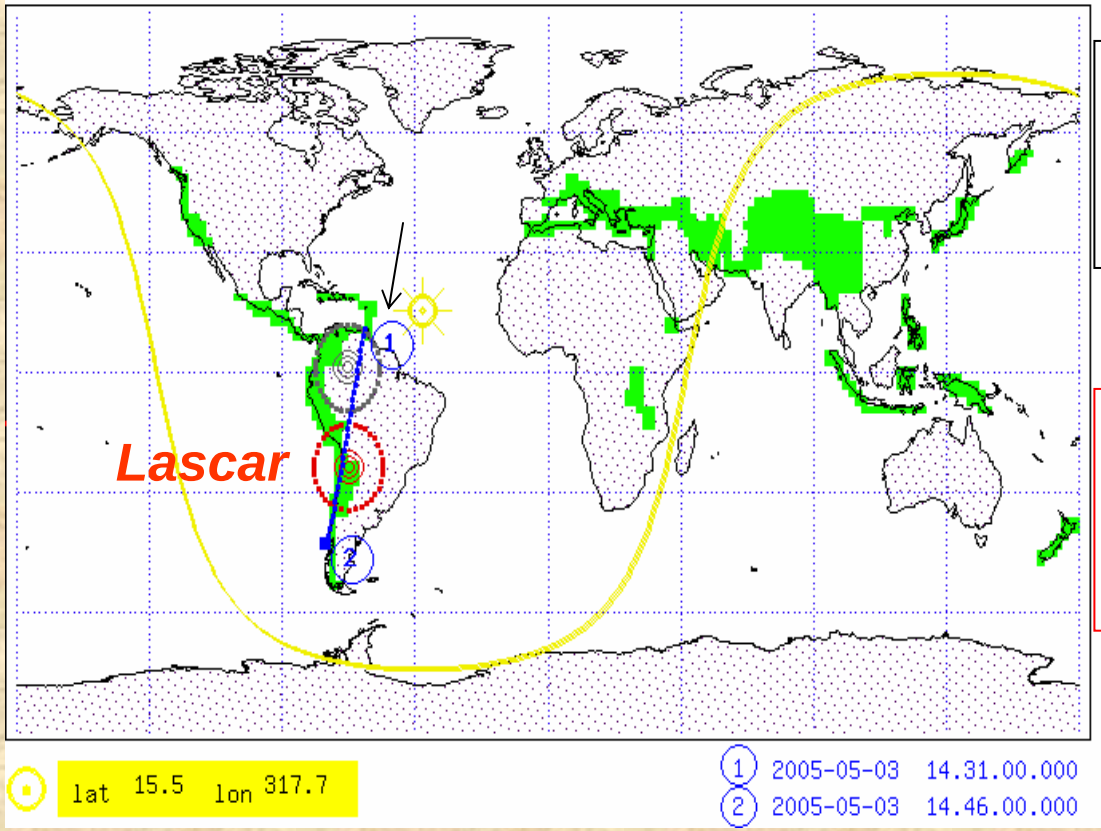
- Electronic density

- Plasma

Aoba location

Lascar volcano: Type 2

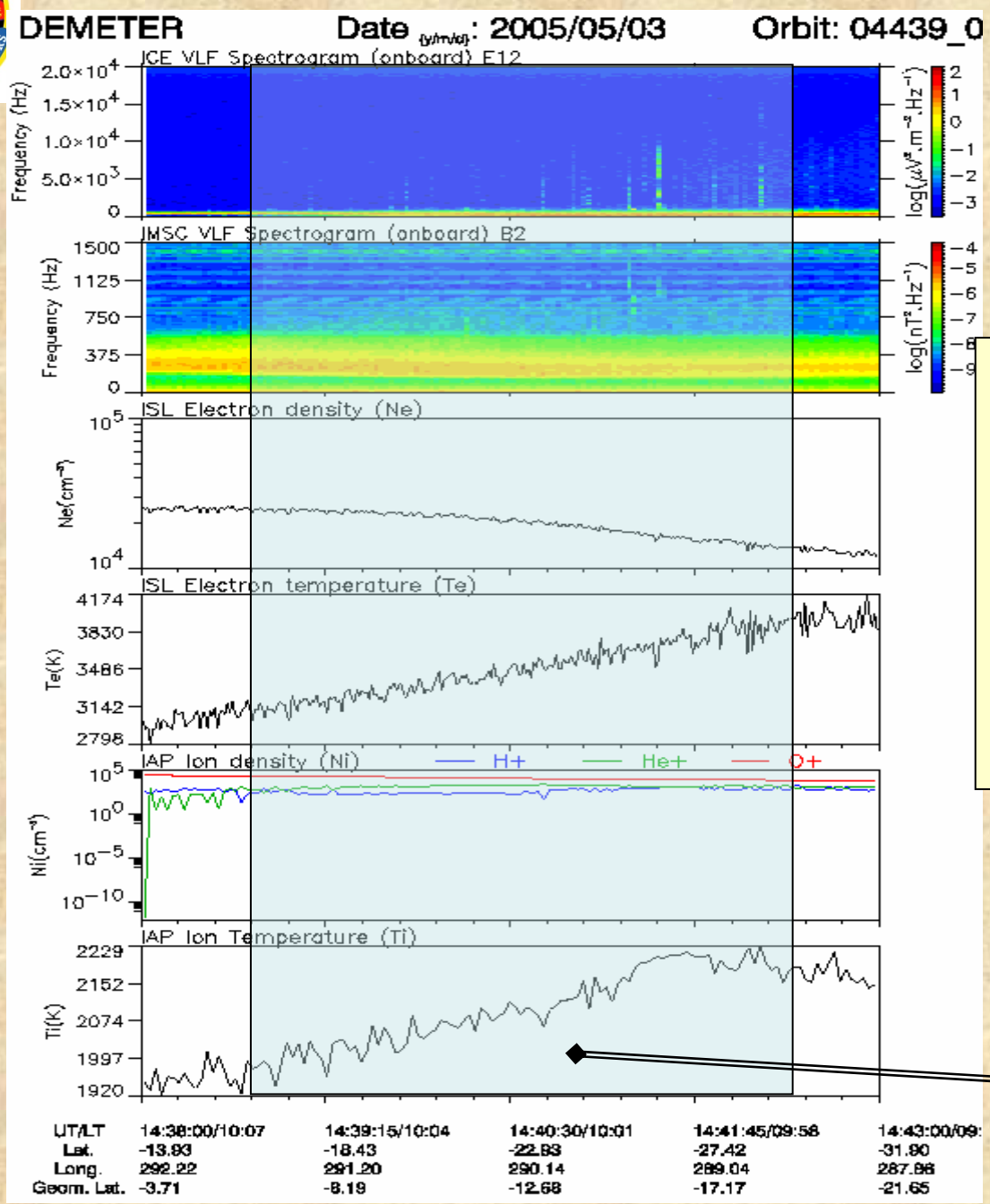
- [EX2]-1 : Lascar (23.37S , 67.73W) ; May/03/2005, VEI=3



UT	== geographic == lat	lon	tloc	dist	dist
14.31.00	11.29	297.68	10.4	3903	1270
14.31.30	9.49	297.29	10.3	3699	1077
14.32.00	7.68	296.89	10.3	3493	887
14.32.30	5.88	296.50	10.3	3288	708
14.33.00	4.08	296.12	10.3	3084	548
14.33.30	2.28	295.73	10.3	2880	426
14.34.00	0.47	295.34	10.3	2675	384
14.34.30	-1.33	294.96	10.2	2471	445
14.35.00	-3.13	294.57	10.2	2267	576
14.35.30	-4.93	294.19	10.2	2063	741
14.36.00	-6.73	293.80	10.2	1860	923
14.36.30	-8.53	293.41	10.2	1656	1112
14.37.00	-10.33	293.01	10.2	1454	1307
14.37.30	-12.13	292.62	10.1	1252	1504
14.38.00	-13.93	292.22	10.1	1051	1703
14.38.30	-15.73	291.82	10.1	852	1903
14.39.00	-17.53	291.41	10.1	656	2104
14.39.30	-19.33	290.99	10.1	469	2306
14.40.00	-21.13	290.57	10.0	305	2509
14.40.30	-22.93	290.14	10.0	223	2712
14.41.00	-24.72	289.71	10.0	301	2914
14.41.30	-26.52	289.26	10.0	464	3118
14.42.00	-28.31	288.81	9.9	650	3321
14.42.30	-30.11	288.34	9.9	846	3525
14.43.00	-31.90	287.86	9.9	1044	3729
14.43.30	-33.69	287.37	9.9	1244	3932
14.44.00	-35.48	286.86	9.9	1446	4136
14.44.30	-37.27	286.33	9.8	1648	4341
14.45.00	-39.06	285.79	9.8	1851	4545
14.45.30	-40.84	285.22	9.8	2053	4748
14.46.00	-42.63	284.63	9.7	2257	4953

Geographical position between the orbit 4439-0 and the eruptive center

1 day before



Above the volcano, sferics may appear.

They can be observed on the magnetic and electric fields

No noticeable changes of the other parameters emerge.

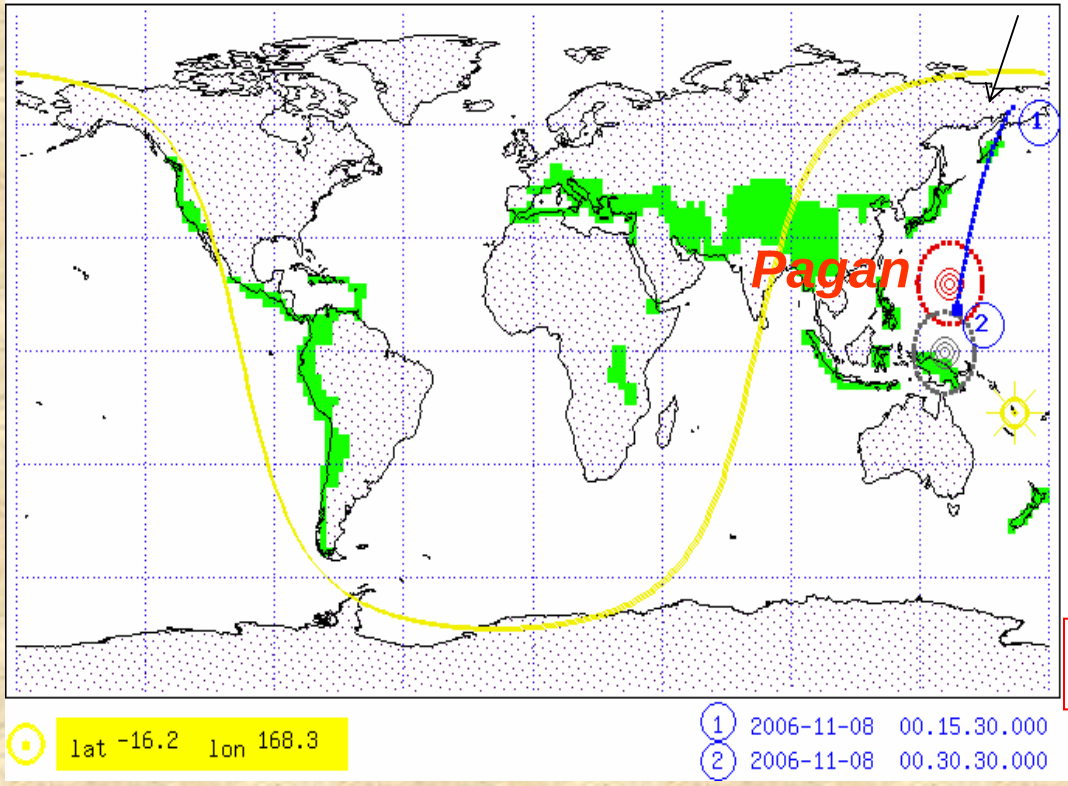
⇩

Electrostatic discharges

Lascar location

Pagan volcano: Type 2

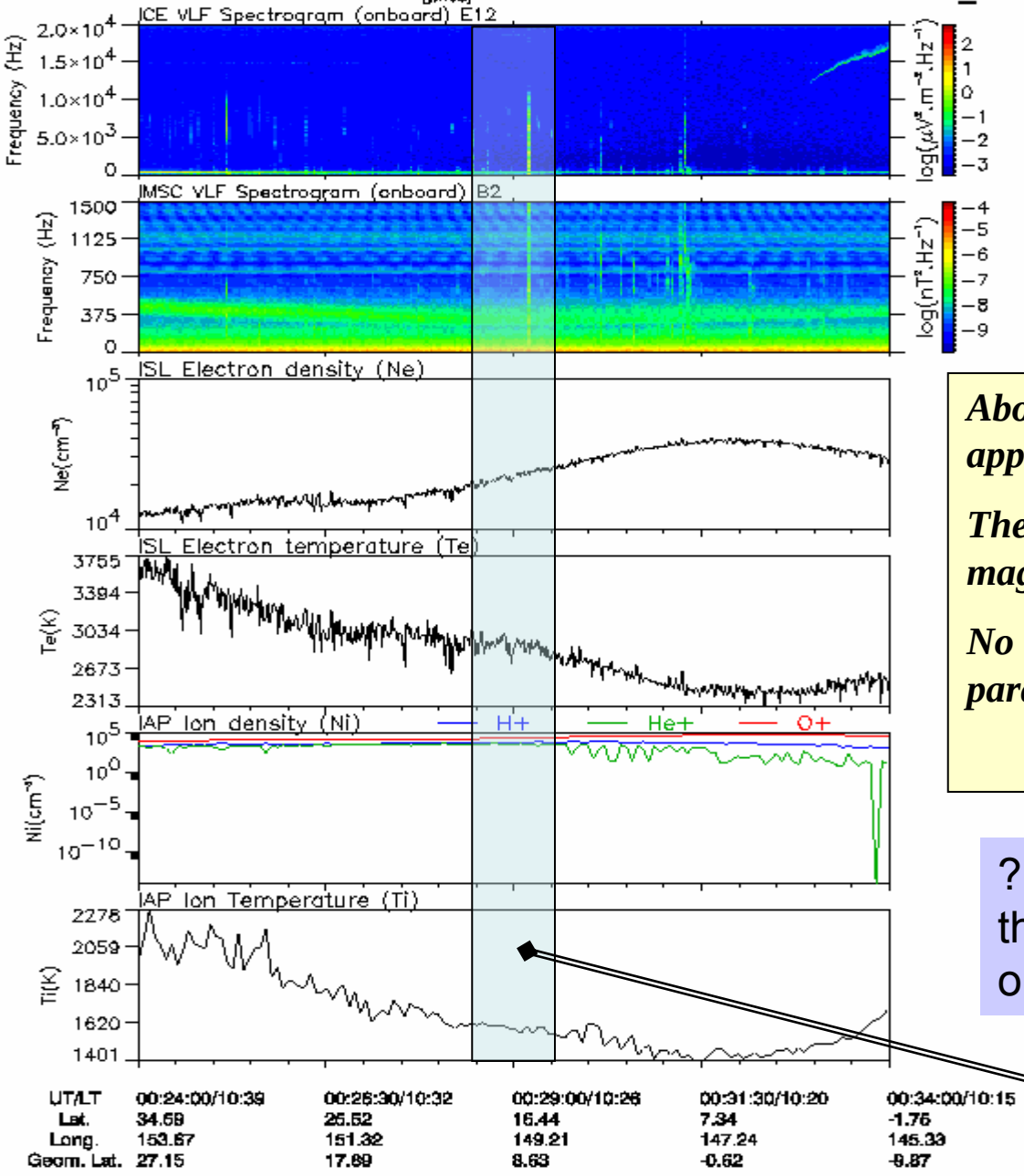
- **[EX2]-2 : Pagan (18.13N , 145.8E) ; Dec./04/2006, VEI=1**



UT	== geographic == lat	lon	tloc	dist	dist
00.15.30	65.00	167.84	11.4	5469	7510
00.16.00	63.26	166.36	11.4	5265	7304
00.16.30	61.51	165.04	11.3	5060	7098
00.17.00	59.74	163.84	11.2	4854	6891
00.17.30	57.97	162.75	11.1	4649	6685
00.18.00	56.20	161.76	11.1	4444	6480
00.18.30	54.41	160.84	11.0	4239	6273
00.19.00	52.63	159.98	11.0	4034	6068
00.19.30	50.83	159.19	10.9	3828	5861
00.20.00	49.04	158.44	10.9	3624	5655
00.20.30	47.24	157.74	10.9	3419	5449
00.21.00	45.44	157.07	10.8	3214	5242
00.21.30	43.64	156.44	10.8	3010	5036
00.22.00	41.83	155.84	10.8	2805	4830
00.22.30	40.02	155.26	10.7	2601	4623
00.23.00	38.21	154.71	10.7	2397	4416
00.23.30	36.40	154.18	10.7	2194	4210
00.24.00	34.59	153.67	10.6	1991	4004
00.24.30	32.78	153.17	10.6	1790	3798
00.25.00	30.97	152.69	10.6	1589	3592
00.25.30	29.15	152.22	10.6	1390	3385
00.26.00	27.34	151.76	10.6	1193	3179
00.26.30	25.52	151.32	10.5	1001	2972
00.27.00	23.70	150.88	10.5	814	2766
00.27.30	21.89	150.45	10.5	642	2560
00.28.00	20.07	150.03	10.5	495	2354
00.28.30	18.25	149.62	10.4	404	2148
00.29.00	16.44	149.21	10.4	408	1943
00.29.30	14.62	148.81	10.4	506	1737
00.30.00	12.80	148.41	10.4	656	1532
00.30.30	10.98	148.02	10.4	831	1327

Geographical position between the orbit 12583-0 and the eruptive center

26 days before



Above the volcano, sferics may appear.

They can be observed on the magnetic and electric fields

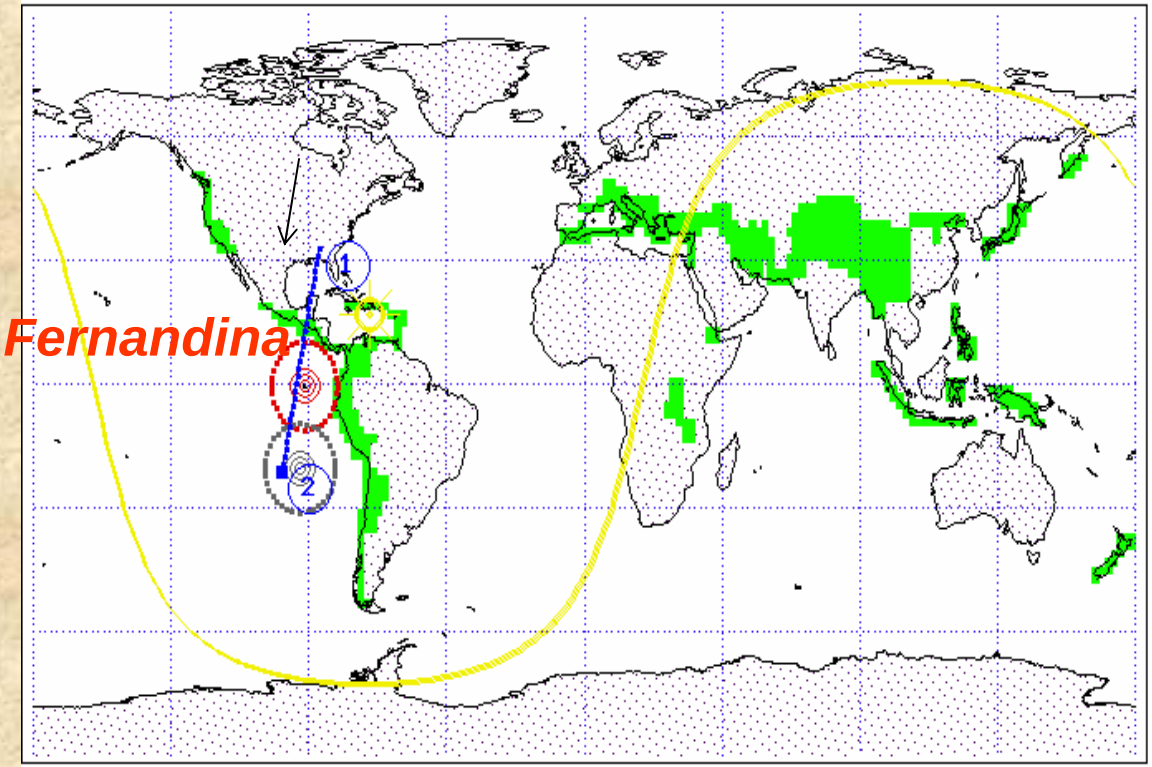
No noticeable changes of the other parameters emerge.

? Is it linked to:
the unrest of the volcano
or to natural lightnings?

Pagan location

Fernandina volcano: Type 3

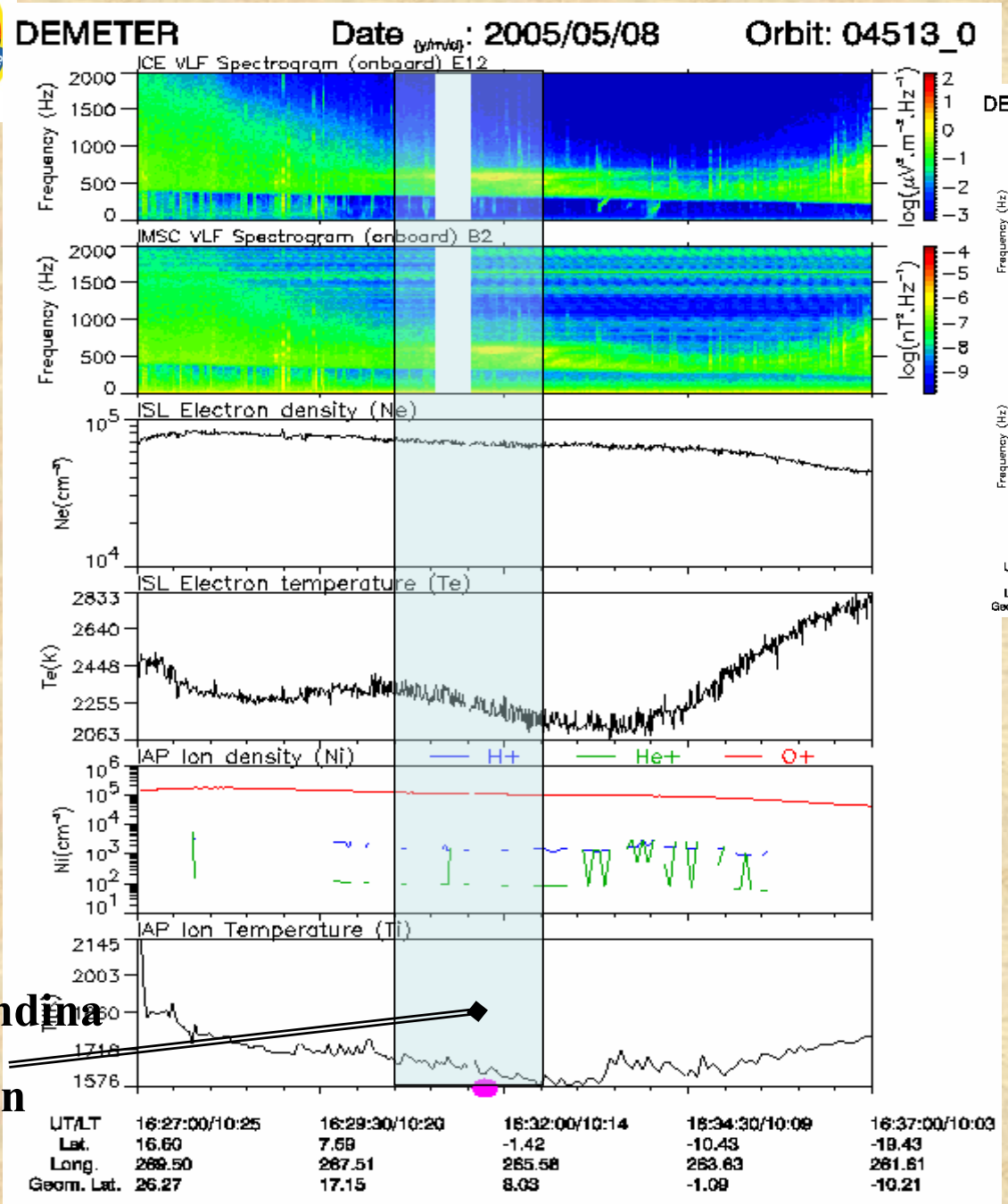
- **[EX3]-1 : Fernandina (-0.37 , 268.45) ; May/13/2005, VEI=2**

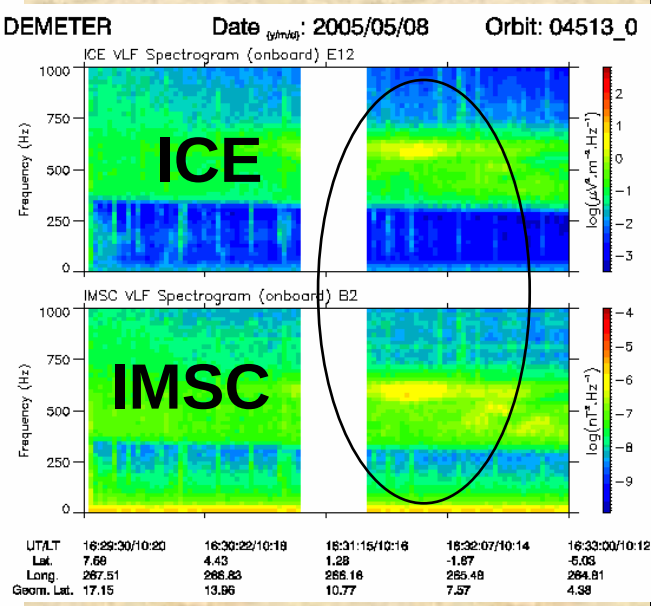


UT	== geographic == lat	lon	tloc	dist	dist
16.22.30	32.79	273.50	10.6	3729	5938
16.23.00	31.00	273.02	10.6	3525	5734
16.23.30	29.20	272.54	10.6	3320	5530
16.24.00	27.40	272.08	10.5	3116	5325
16.24.30	25.60	271.63	10.5	2911	5121
16.25.00	23.80	271.19	10.5	2707	4917
16.25.30	22.00	270.76	10.5	2503	4714
16.26.00	20.20	270.33	10.5	2299	4510
16.26.30	18.40	269.92	10.4	2096	4307
16.27.00	16.60	269.50	10.4	1893	4104
16.27.30	14.80	269.10	10.4	1690	3901
16.28.00	12.99	268.70	10.4	1487	3698
16.28.30	11.19	268.30	10.4	1287	3496
16.29.00	9.39	267.90	10.3	1088	3294
16.29.30	7.59	267.51	10.3	892	3093
16.30.00	5.79	267.12	10.3	701	2892
16.30.30	3.98	266.74	10.3	520	2691
16.31.00	2.18	266.35	10.3	368	2491
16.31.30	0.38	265.96	10.3	289	2293
16.32.00	-1.42	265.58	10.2	340	2095
16.32.30	-3.22	265.19	10.2	482	1899
16.33.00	-5.03	264.81	10.2	658	1704
16.33.30	-6.83	264.42	10.2	847	1513
16.34.00	-8.63	264.03	10.2	1042	1327
16.34.30	-10.43	263.63	10.2	1240	1146
16.35.00	-12.23	263.24	10.1	1440	974
16.35.30	-14.03	262.84	10.1	1641	818
16.36.00	-15.83	262.44	10.1	1843	687
16.36.30	-17.63	262.03	10.1	2046	599
16.37.00	-19.43	261.61	10.1	2249	574
16.37.30	-21.22	261.19	10.0	2451	619

Geographical position between the orbit 4513-0 and the eruptive center

5 days before





Unknown phenomenon has been recognized:

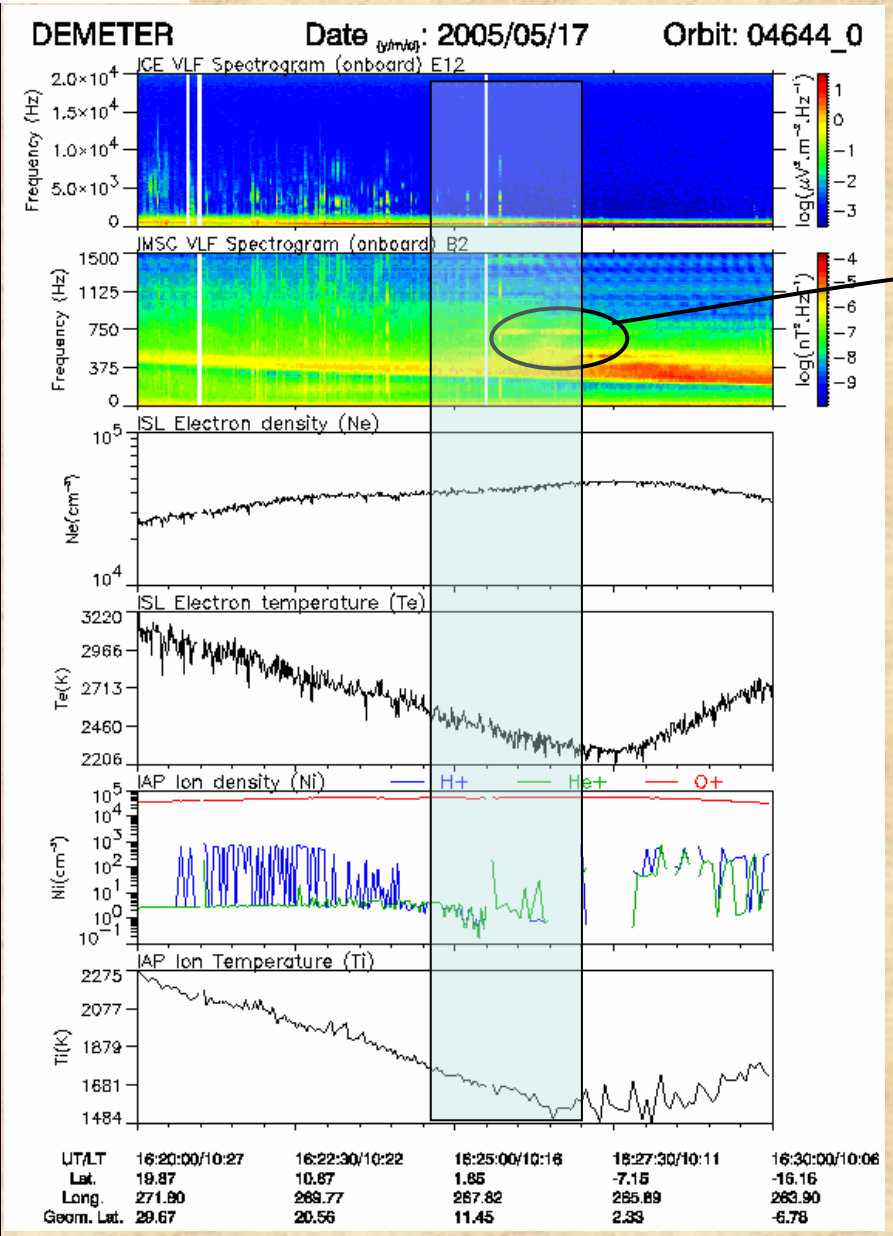
It can appear on ICE or on ICE and IMSC

No change of other parameters has been recognized yet

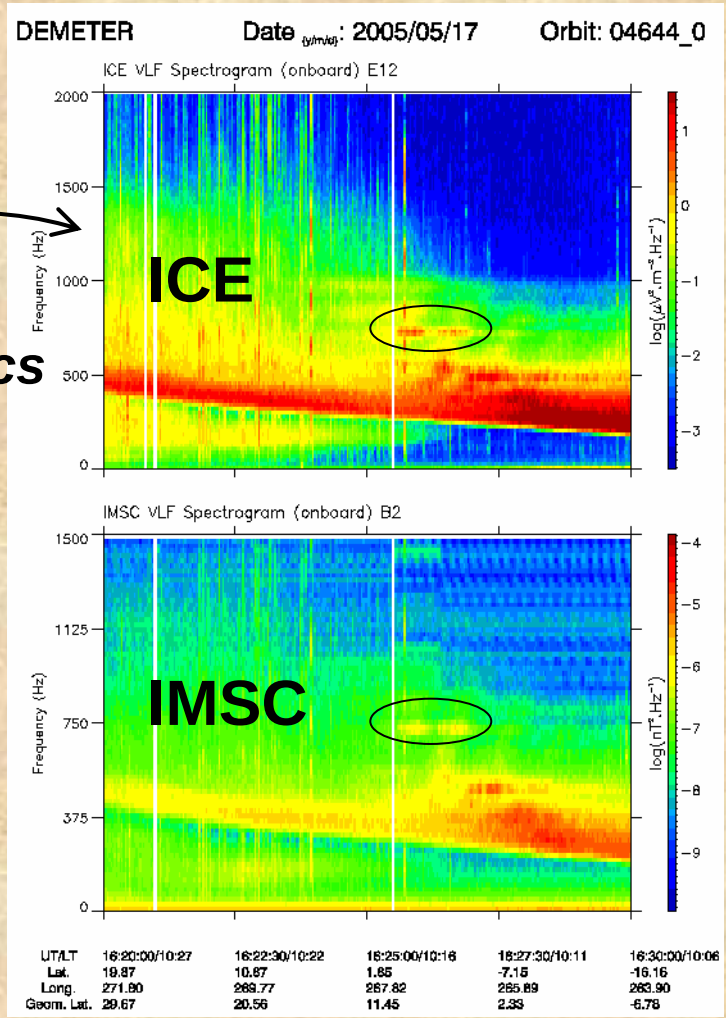
Fernandina location

Fernandina volcano: Type 3

4 days After

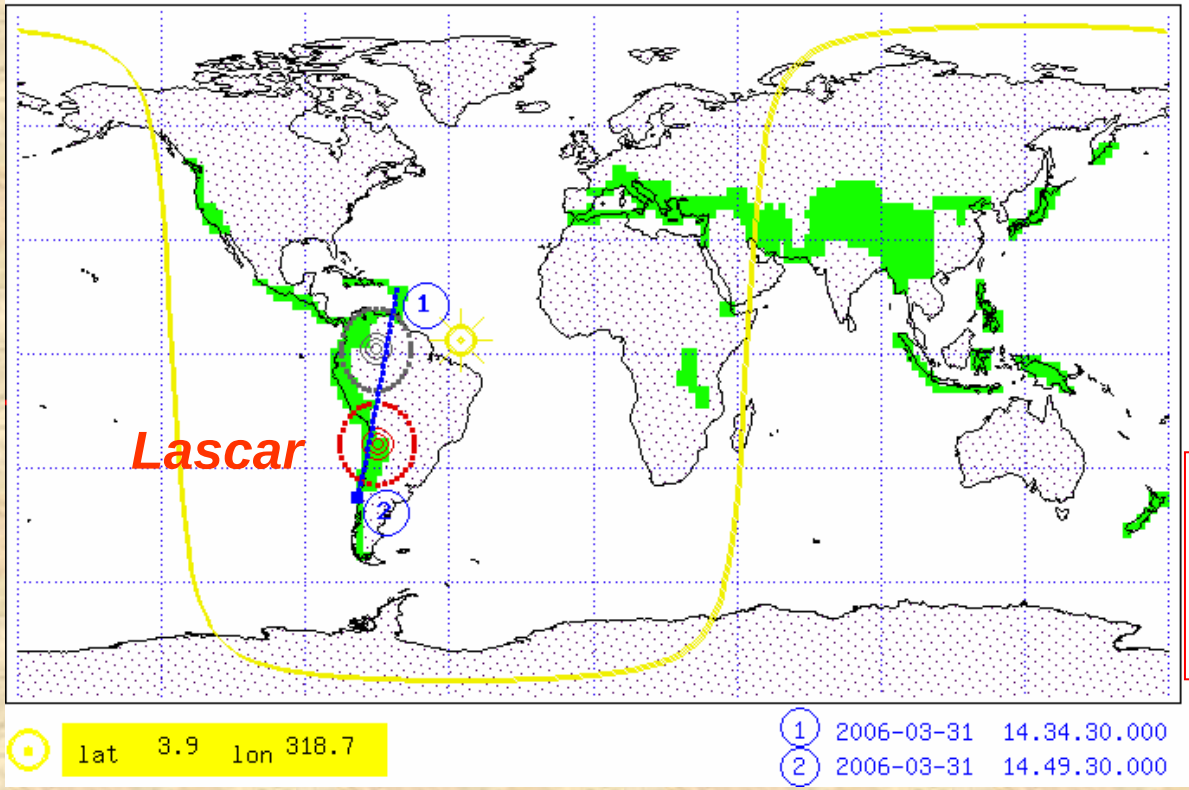


Harmonics



Lascar volcano: Type 3

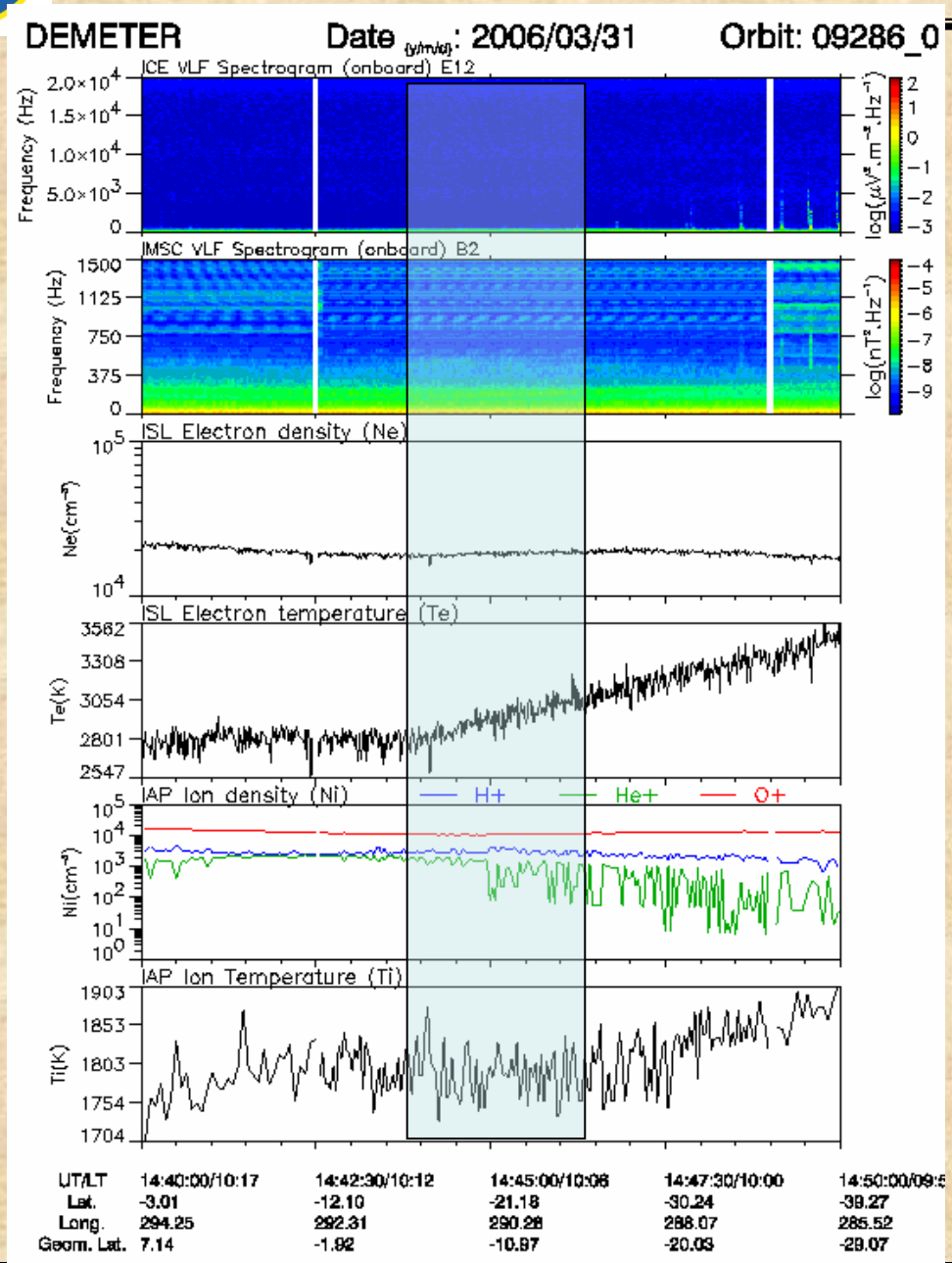
- [EX3]-3 : Lascar (23.37S , 67.73W) ; Mar./31/2006, VEI=3

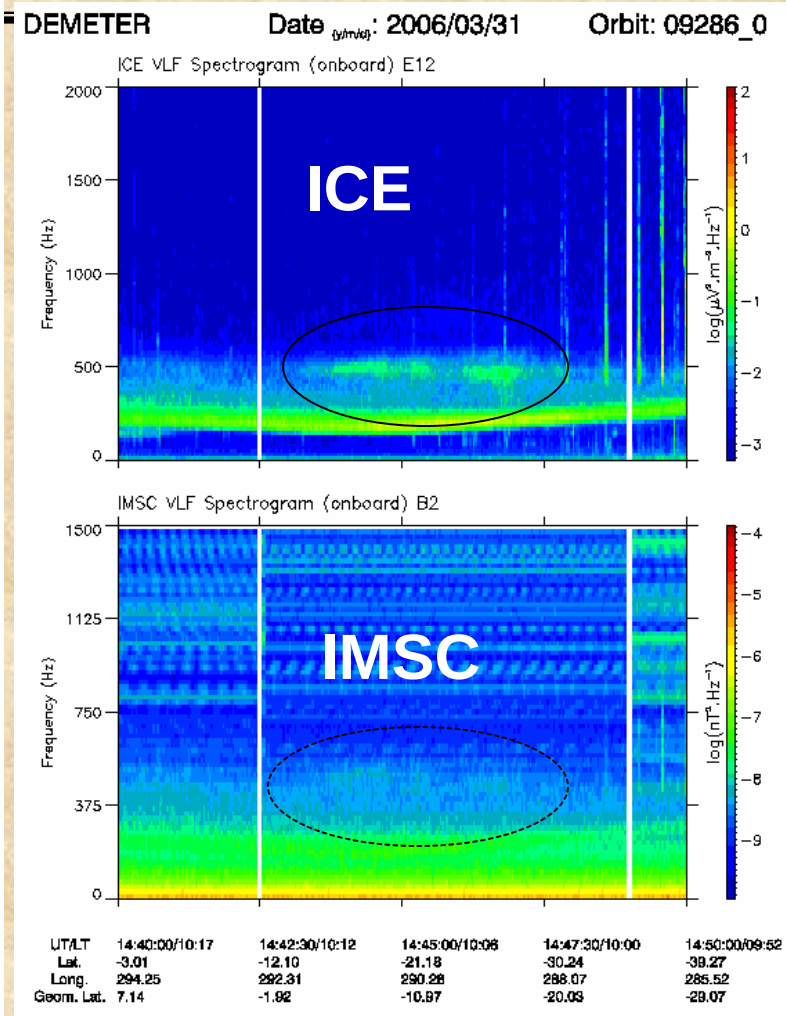


UT	== geographic == lat	lon	tloc	dist	dist
14.34.30	16.99	298.54	10.5	4544	1881
14.35.00	15.17	298.14	10.5	4338	1678
14.35.30	13.35	297.74	10.4	4131	1476
14.36.00	11.53	297.34	10.4	3924	1276
14.36.30	9.71	296.95	10.4	3718	1078
14.37.00	7.90	296.56	10.4	3512	885
14.37.30	6.08	296.17	10.4	3306	699
14.38.00	4.26	295.79	10.3	3099	530
14.38.30	2.44	295.40	10.3	2893	396
14.39.00	0.62	295.02	10.3	2687	345
14.39.30	-1.20	294.64	10.3	2481	409
14.40.00	-3.01	294.25	10.3	2276	547
14.40.30	-4.83	293.87	10.3	2071	720
14.41.00	-6.65	293.48	10.3	1866	907
14.41.30	-8.47	293.10	10.2	1661	1101
14.42.00	-10.28	292.71	10.2	1458	1299
14.42.30	-12.10	292.31	10.2	1255	1499
14.43.00	-13.92	291.92	10.2	1053	1701
14.43.30	-15.73	291.52	10.2	854	1904
14.44.00	-17.55	291.11	10.1	659	2108
14.44.30	-19.36	290.70	10.1	475	2311
14.45.00	-21.18	290.28	10.1	319	2517
14.45.30	-22.99	289.86	10.1	250	2721
14.46.00	-24.80	289.42	10.1	330	2926
14.46.30	-26.62	288.98	10.0	491	3132
14.47.00	-28.43	288.53	10.0	676	3337
14.47.30	-30.24	288.07	10.0	871	3543
14.48.00	-32.05	287.59	10.0	1070	3749
14.48.30	-33.85	287.10	9.9	1271	3954
14.49.00	-35.66	286.59	9.9	1474	4160
14.49.30	-37.47	286.07	9.9	1678	4366

Geographical position between the orbit 9286_0 and the eruptive center

The day of eruption

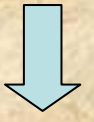




Summary of anomalies of type 1

volcano	Latitude (degree)	Longitude (degree)	Orbit	Before/ after (Day)	Hz	Eruption	ISL (Yes/No)		IAP (Yes/No)	
							D	T	D	T
Aoba (1496 m)	-15.4	167.83	7320-1 11/17/2005	-10	DC-150	11/27/2005 vei=2	Y	Y	Y	Y
			7378-1 11/21/2005	- 6	DC-200		Y	N	Y	N
Akan (1499m)	43.384	144.013	9137-1 03/21/2006	0	DC-250	03/21/2006 Vei=1	Y	Y	N	Y
			9175-0 03/24/2006	+2	DC-150		N	N	N	N
Bulusan (1565m)	12.77	124.05	12061-1 10/06/2006	-4	DC-150	10/10/2006 Vei=2	Y	Y	N	Y
			8727-1 02/21/2006	-29	DC-150	03/21/2006 Vei=2	Y	Y	Y	Y
Canlaon (2435m)	10.412	123.132	10137-1 05/28/2006	-8	DC-700	06/03/2006 Vei=2	N	N	N	N
Fukutoku-Okanoba (-14m)	24.28	141.485	4874-1 06/02/2005	-30	DC-100	07/02/2005 Vei=1	Y	N	N	N
Lascar (5592 m)	-23.37	292.27	4344-1 04/27/2005	- 7	DC-200	05/04/2005 vei=3	Y	N	Y	N
			9102-1 03/19/2006	-29	DC-250	04/18/2006 vei=3	Y	Y	Y	Y
			9220-1 03/27/2006	-21	DC-120		N	N	N	N
			9734-1 05/01/2006	+ 13	DC-250		Y	Y	Y	N
Lopevi (1413 m)	-16.507	168.346	3083-1 01/30/2005	0	DC-150	01/30/2005 vei=2	Y	N	N	N
Miyake -jima (815m)	34.079	139.529	11120-1 08/03/2006	-20	DC-100	08/23/2006 Vei=1	N	N	N	N
			11135-1 08/04/2006	-19	DC-200		N	Y	Y	N
Rabaul (688 m)	-4.271	152.203	2967-1 01/22/2005	- 3	DC-350	01/25/2005 vei=2	N	N	N	N
			11399-1 08/22/2006	+11	DC-180	08/11/2006 Vei=4	Y	Y	N	Y
Manam (1807m)	-4.08	145.037	1251-1 09/26/2004	-28	DC-500	10/24/2004 vei=4	Y	Y	Y	Y
Nyamura -gira (3058m)	-1.408	29.2	12726-1 11/20/2006	-7	DC-200	11/27/2006 Vei=2	Y	Y	N	N
Santa Ana (2381m)	13.853	270.37	4665-1 05/19/2005	-28	DC-180	06/16/2005 Vei=1	Y	Y	Y	Y
Soputan (1784 m)	1.108	124.73	1325-1 10/01/2004	-17	DC-150	10/18/2004 vei=3	Y	Y	N	Y
			3812-1 03/21/2005	-29	DC-500	04/19/2005 vei=2	Y	Y	N	Y

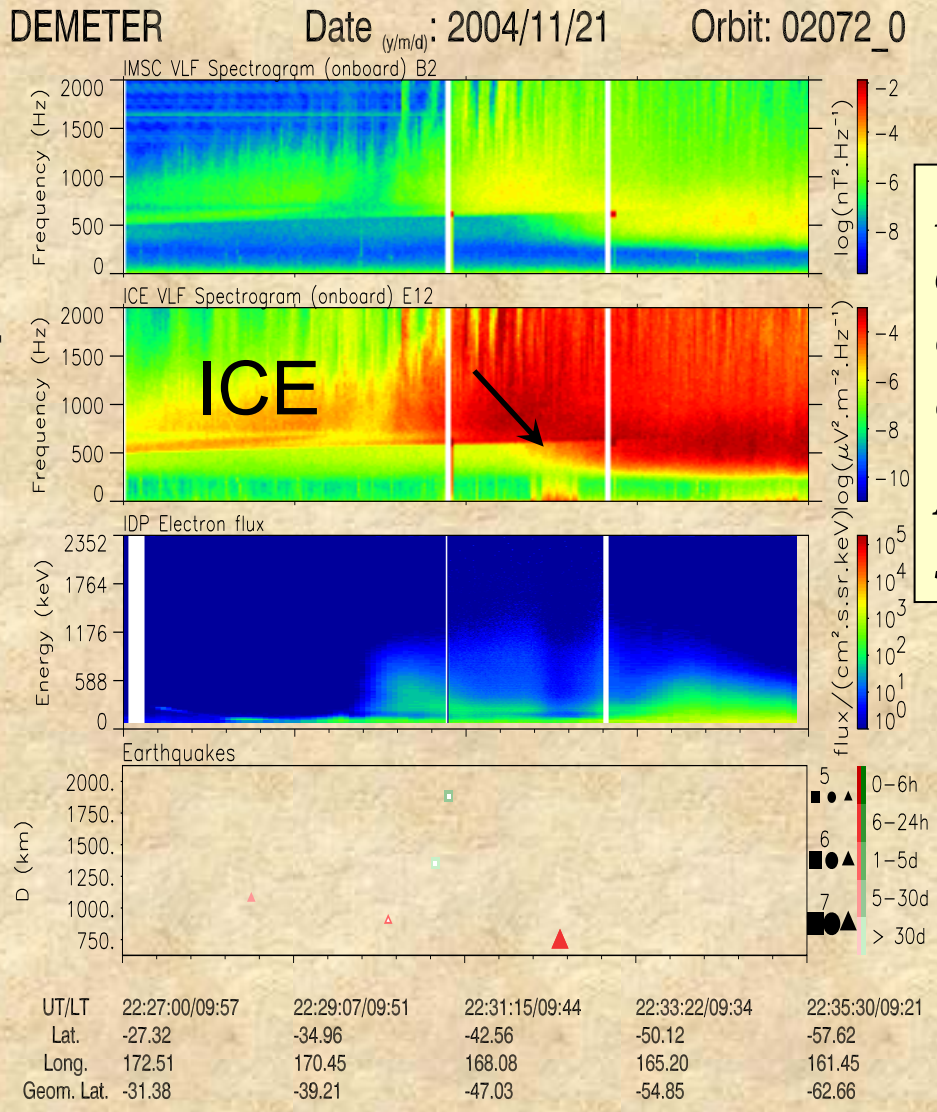
- These anomalies may appear before and after eruptions
- They seem not to be related to the VEI index ?
- They come out on the electric field (ICE), not on the magnetic one
- The frequency domain is generally below 250 Hz
- ISL and IAP should be observed simultaneously



Electrostatic turbulences

Similar event related to Earthquake

Characteristics:
Date: 22 Nov. 2004
Time: 20:26:25 UT
Position:-46.57°S
164.83°E
M = 7.3



Electrostatic turbulence appears for both earthquakes and volcanic eruptions.

And the same mechanism should be involved

After Parrot et al.,

Mechanism for type-1 phenomenon: Electrostatic turbulence

Possible mechanisms generating the volcanic related signals

(similar to seismic ones) :

►Propagation of EM waves from the ground

►Propagation of acoustic - gravity waves generated by the volcanic activity

►Piezoelectric effects related to stress variations during microfracturing of rocks in the ground

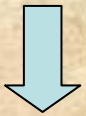
►Emission of radioactive gases (radon) during the preparatory stage of the eruption

→ Need to complete with land observations

Summary of anomalies of type 2

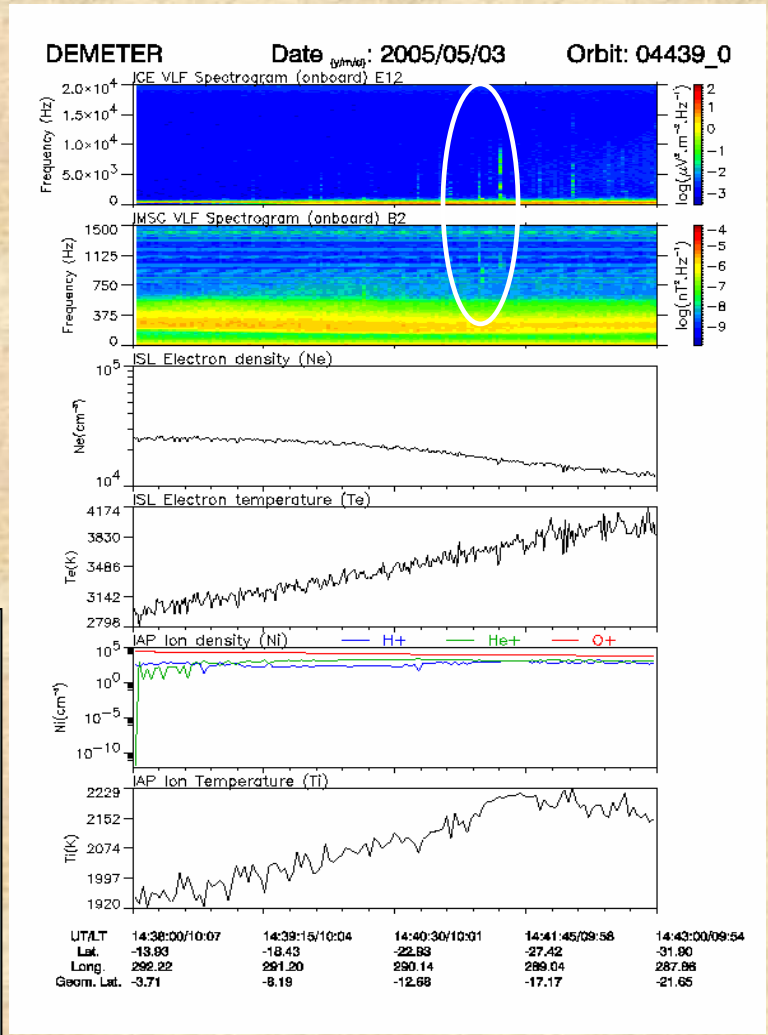
volcano	Latitude (degree)	Longitude (degree)	Orbit	Before/ after (Day)	Hz	Eruption
Egon (1703m)	-8.67	122.45	3383-0 02/20/2005	+14	DC-15000	02/06/2005 Vei=1
Fernandina 1476(m)	-0.37	268.45	4571-0 05/12/2005	- 1	DC-6000	05/13/2005 vei=2
Lascar 5592(m)	-23.37	292.27	4439-0 05/03/2005	- 1	DC-10000	05/04/2005 vei=3
Lopevi 1413(m)	-16.507	168.346	9293-1 04/01/2006	-17	DC-20000	04/18/2006 vei=3
			2654-0 12/31/2004	-30	DC-15000 DC-20000 DC-7500	01/30/2005 vei=2
			2785-0 01/09/2005	-21	DC-20000	
Mayon (2462m)	13.257	123.685	10380-0 06/14/2006	-29	DC-10000	07/13/2006 Vei=1
			8544-0 02/09/2006	-12	DC-17000	02/21/2006 Vei=1
Pagan (570m)	18.13	145.8	12538-0 11/08/2006	-26	DC-12000	12/04/2006 Vei=1
Rabaul 688(m)	-4.271	152.203	2902-0 01/17/2005	- 8	DC-20000	01/25/2005 vei=2
Soputan (1784 m)	1.108	124.73	1769-0 11/01/2004	+12	DC-13000	10/18/2004 vei=3

- **These anomalies may appear before and after eruptions**
  Some of them should occur the day the eruptive event
- **They seem not to be related to the VEI index ?**
- **They come out on the electric and the magnetic fields; they are sferics**
- **The frequency domain goes up to 15 kHz and more**
- **No other parameter is disturbed**



Electrostatic discharges

Mechanism for type-2 phenomenon: Sferics produced by electrostatic discharges



Many explosive volcanic eruptions are accompanied by lighting and atmospheric electrical phenomena. Maybe some of them can occur before eruptions?

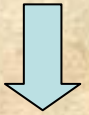
During eruptions, plumes generate large perturbations at the surface and in the air. Atmospheric electric potential gradient and high charge densities are generated by ash particles.
This eruptive electrostatic discharge can change the atmospheric conductivity and be monitored by Demeter.

→ ***Database: Mc Nutt works***

Summary of anomalies of type 3

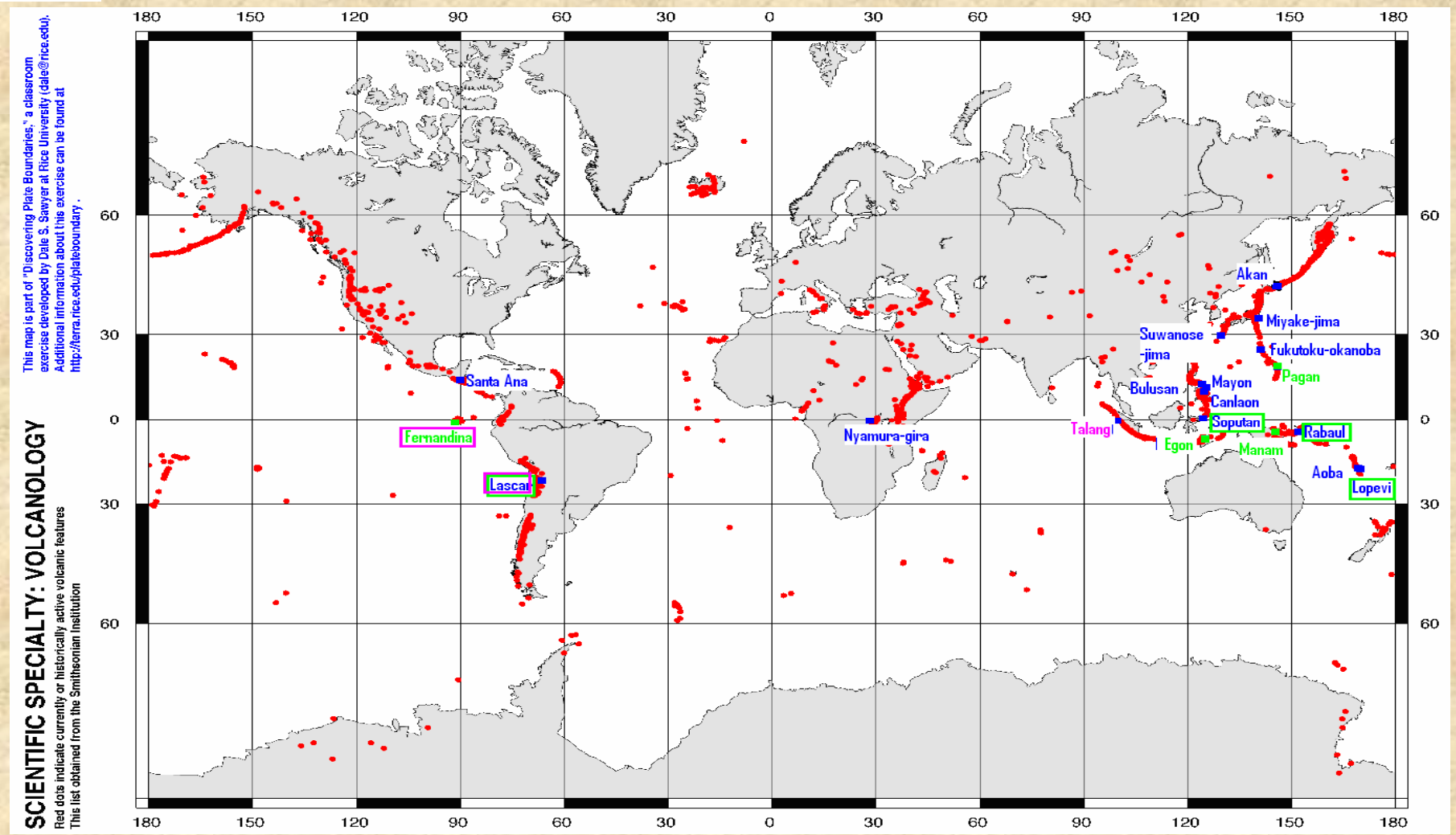
volcano	Latitude (degree)	Longitude (degree)	Orbit	Before/ after (Day)	Hz	Eruption	ISL (Yes/ No)		IAP (Yes/No)	
							D	T	D	T
Fernandina 1476(m)	-0.37	268.45	4513-0 05/08/2005	- 5	600	05/13/2005 vei=2	N	N	N	N
Lascar 5592(m)	-23.37	292.27	4644-0 05/17/2005	+ 4	750		N	N	N	N
			9286-0 03/31/2006	-18	500	04/18/2006 vei=3	N	N	N	N
Suwanose-Jima (799m)	29.635	129.716	1237-1 09/25/2004	-28	250	10/23/2004 Vei=2	N	N	N	N
Talang (2597m)	-0.978	100.679	11225-1 08/23/2006	-18	100	09/10/2006 Vei=1	N	N	N	N

- These anomalies may appear before and after eruptions
- They seem not to be related to the VEI index ?
- They come out on the electric field and/or the magnetic field. They appear as unknown phenomena
- The frequency domain goes from ~100 to 700 Hz
- No change is observed on the other parameters



?

Map of volcanoes showing an anomaly

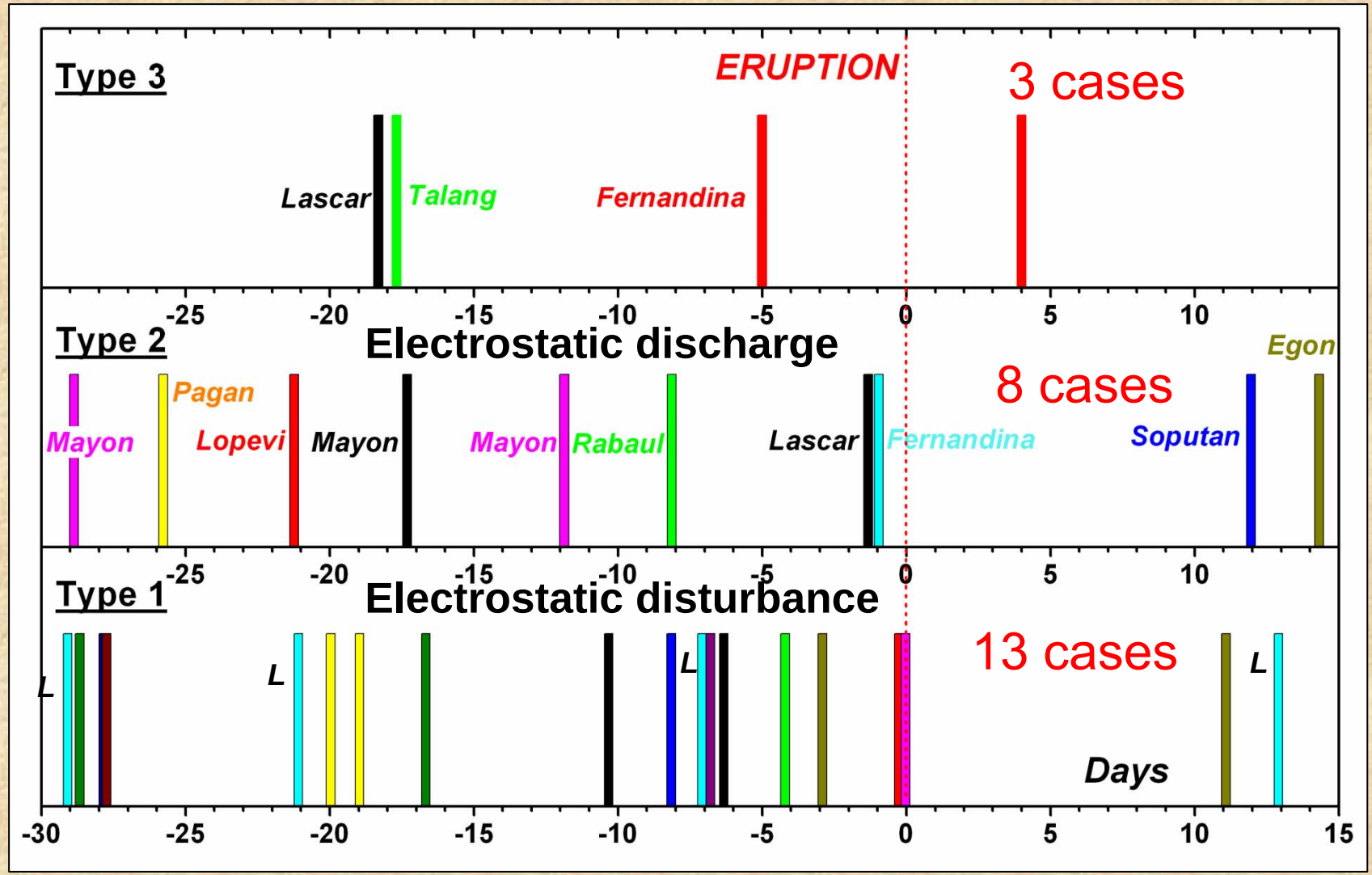


On the 48 volcanic eruptions that have occurred during the period Sept. 2004 – Dec. 2006,

19 were accompanied by one or several types of EM disturbances

Occurrence of the 3 types of anomalies

Preliminary results



Concluding remarks

- ► Electric and Magnetic signals exist before and after volcanic eruptions; they are not systematic

- ► 3 anomaly types are recognized in the considered database; These phenomena seem randomly distributed but we should notice that Demeter time series are irregularly recorded over a particular volcano

- ► The characteristics of the signals can be classified in three types which could be related to different mechanisms

- ► No strict relationship between electromagnetic phenomena and parameters as ISL, IAP exist, except in the ULF range

- ► More than 4000 orbits were considered corresponding to specific criteria. Further studies are still needed to make a proper analysis in association with land observations