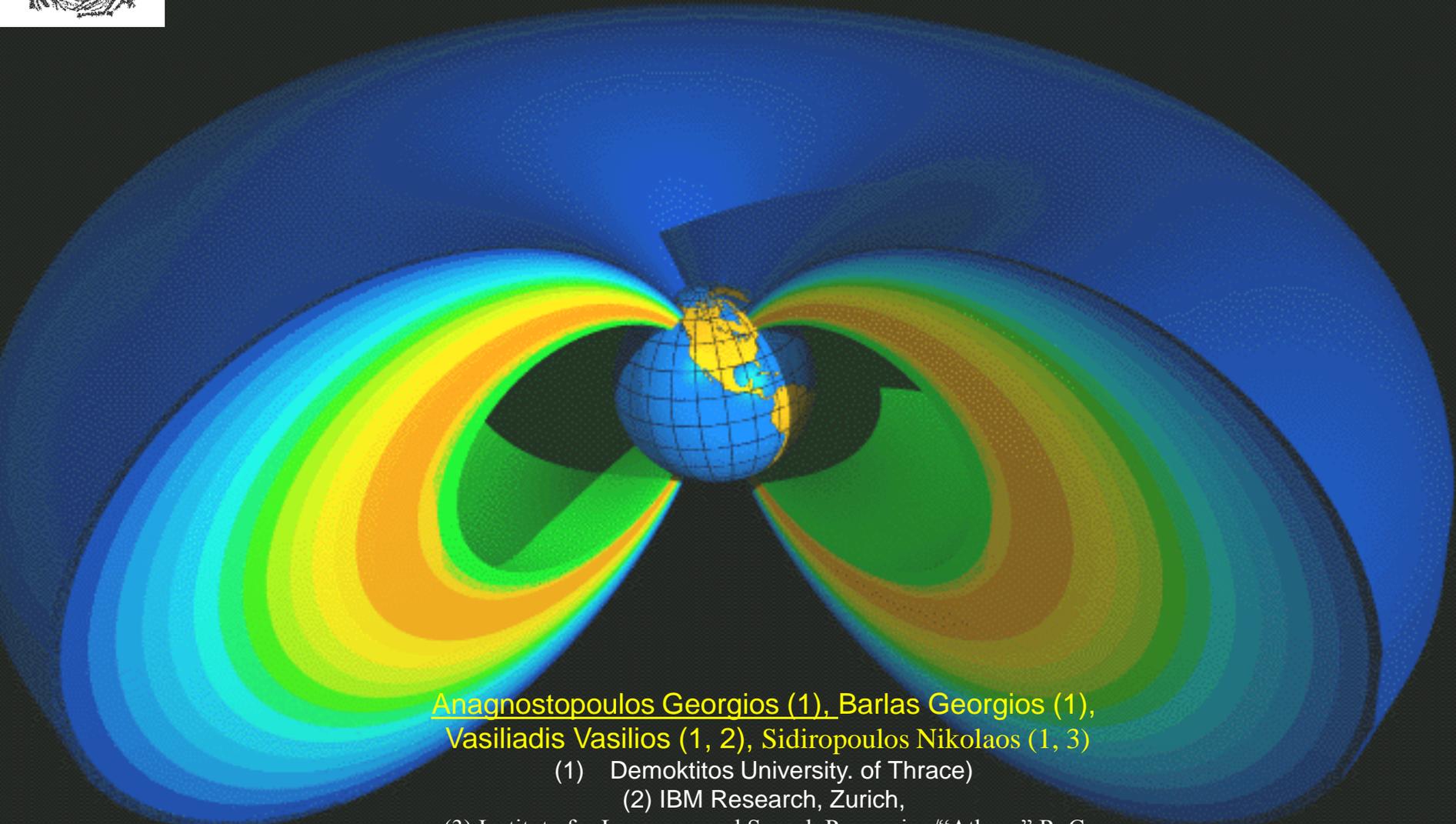
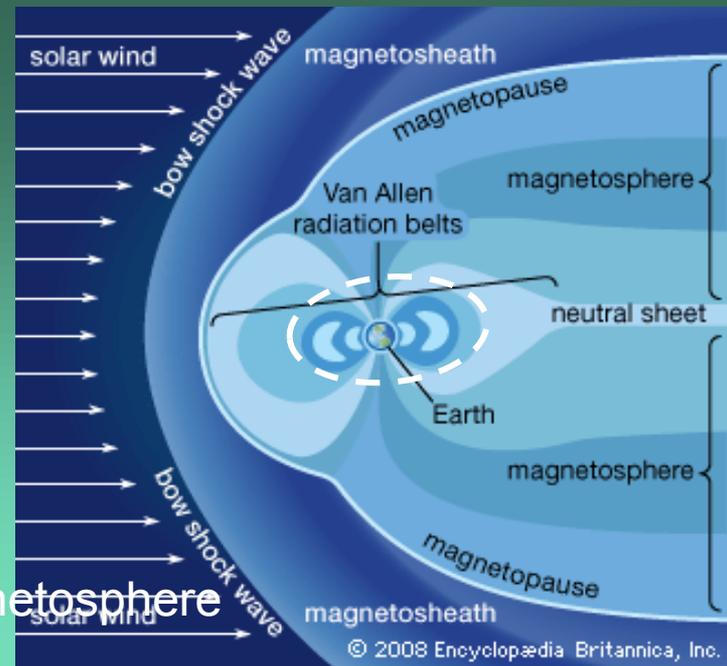
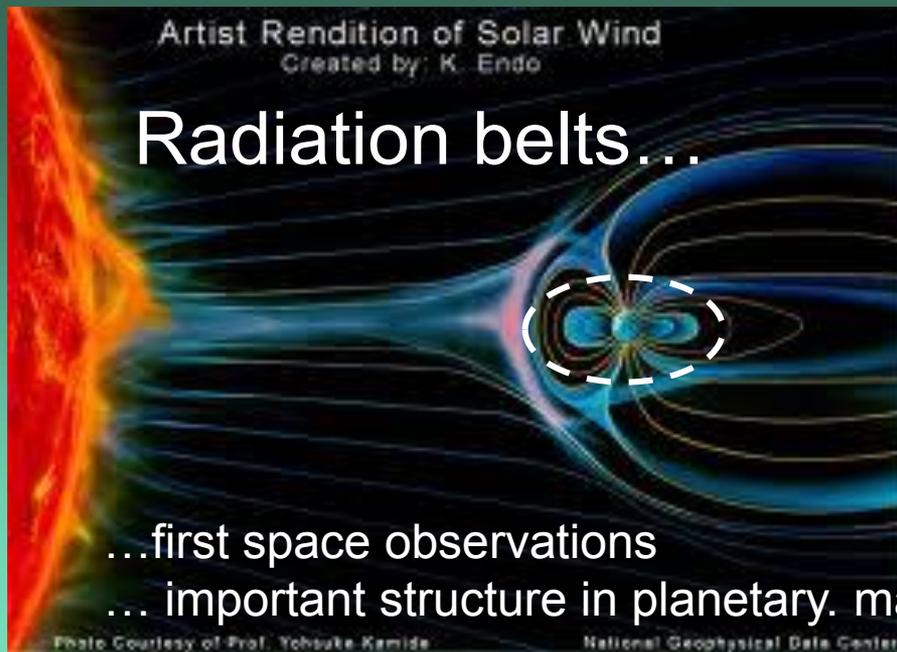




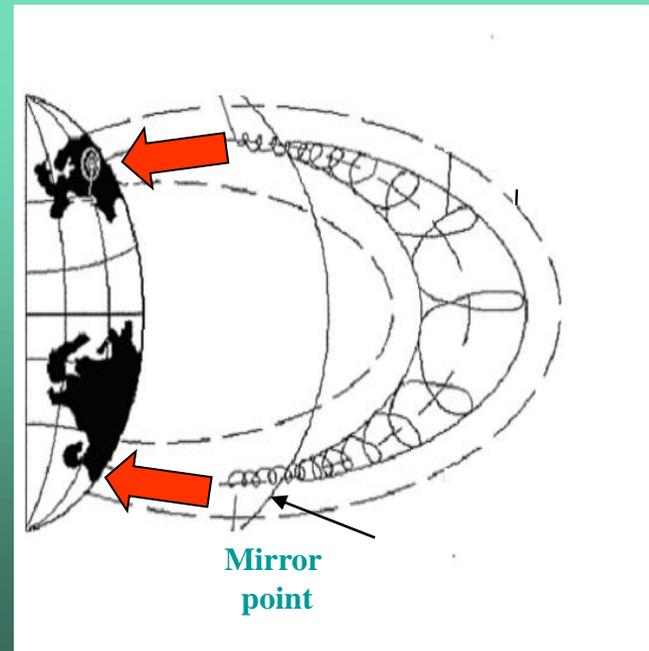
# Radiation Belt Electron Loss Mechanisms: New results



Anagnostopoulos Georgios (1), Barlas Georgios (1),  
Vasiliadis Vasilios (1, 2), Sidiropoulos Nikolaos (1, 3)  
(1) Demokritos University. of Thrace)  
(2) IBM Research, Zurich,  
(3) Institute for Language and Speech Processing/“Athena” R. C.



>>> We will compare various agents triggering radiation belt electron precipitation (RBEP) as a loss mechanism at middle latitudes

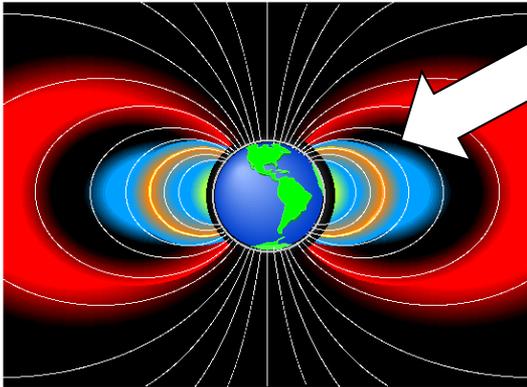


# A. Why study the radiation belt electron precipitation (RBEP)?

1. Because it's physically interesting!
2. Relativistic electrons have been associated with spacecraft 'anomalies'.



3 That paper, together with the present results, indicate that the entire slot region may be an artifact of man's activities. If satellites replace VLF transmitters for both communication and navigation, we may have a chance to observe the slot region remain filled. If that happens, we may see the inner zone become a slot region, perhaps more enhanced even during the next Starfish period. We might also have a chance to radiate VLF waves at high altitudes in order to protect low altitude



■ Outer Van Allen Belt     ■ Inner Van Allen Belt  
■ Trapped ACR (Interstellar matter)     ■ Energetic Secondary Ions

Vampola, GRL, 1983, Aerospace Corporation

4. A plan has been suggested for using VLF radio waves (over either one or several days) in order to **clean** the radiation belts and protect the spacecraft (**radiation belt remediation project**).



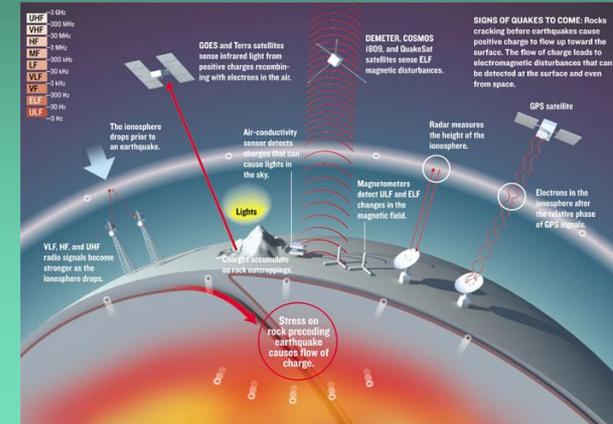
4. Rodger et al. (Ann. Geoph., 2006) noted that the radiation belt remediation program:

.**airplane** pilots and ships would lose radio contact

•unusually intense **HF blackouts** around most of the world

•**GPS** would likely also suffer large-scale disruptions,

•**the ionosphere**: Increase of VLF physical waves.



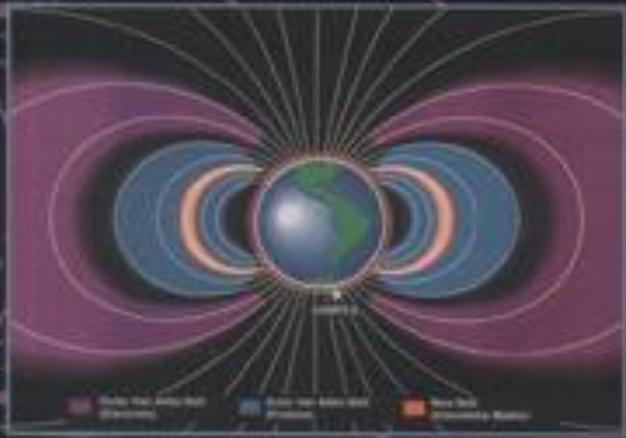
5. Possible Earthquake Q prediction tool

6. Changes the atmospheric radiation balance through the production of ozone destroying species (**NO**...)

7. Modify **climate** forcing [Haigh et al., 2005; Elias and de Artigas, 2003; Rozanov et al., 2005; Langematz et al., 2005].

Geophysical Monograph 97

# Radiation Belts Models and Standards



J. F. Lemaire, D. Heynderickx, and D. N. Baker, Editors

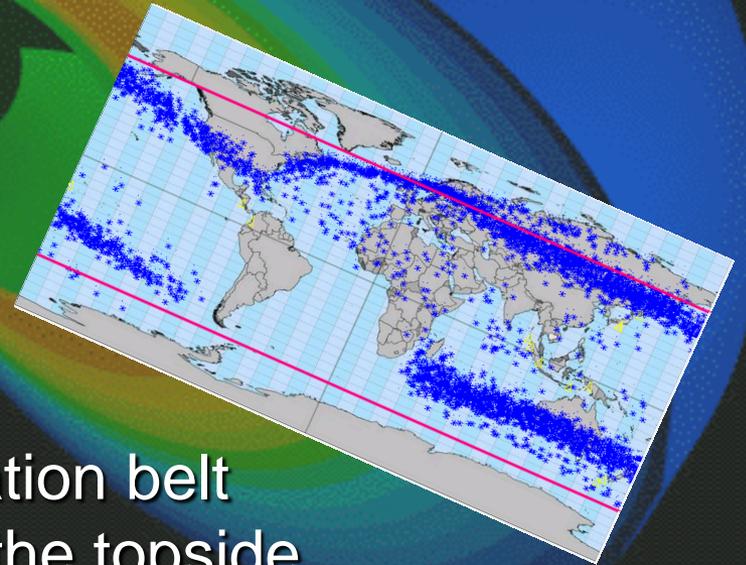
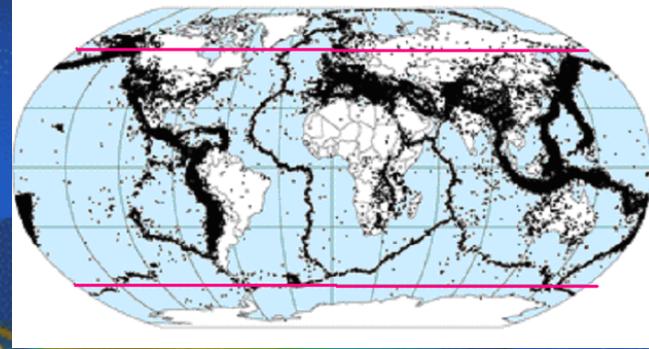
**“Shortly after the discovery of the radiation belts the search for the particle source and loss mechanisms began...(since then) the “principal sources and losses” have been discovered many times, and the search still continues...”**

M. Walt, *Source and Loss Process for Radiation Belt Particles*

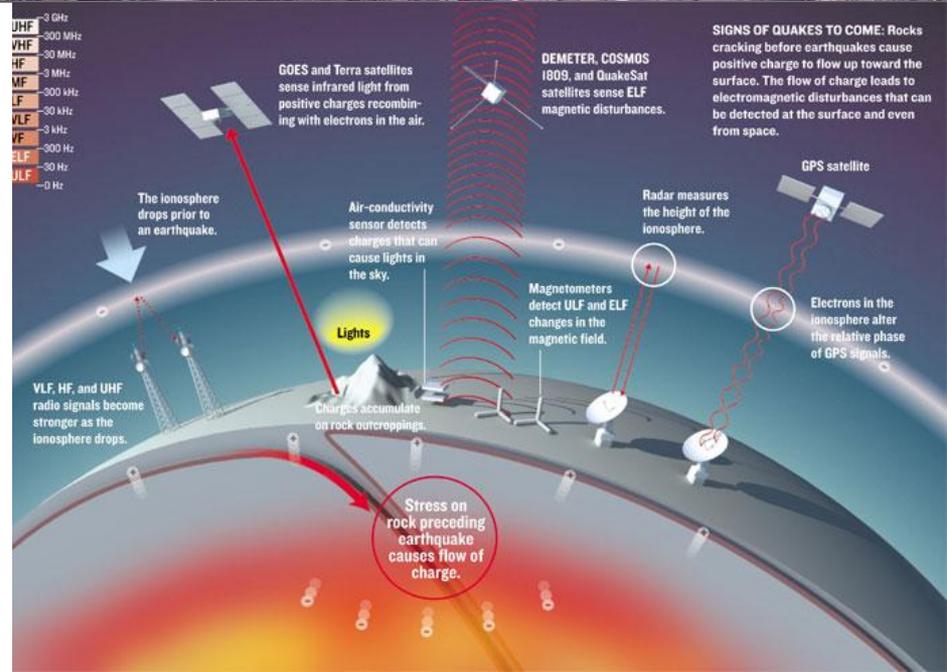
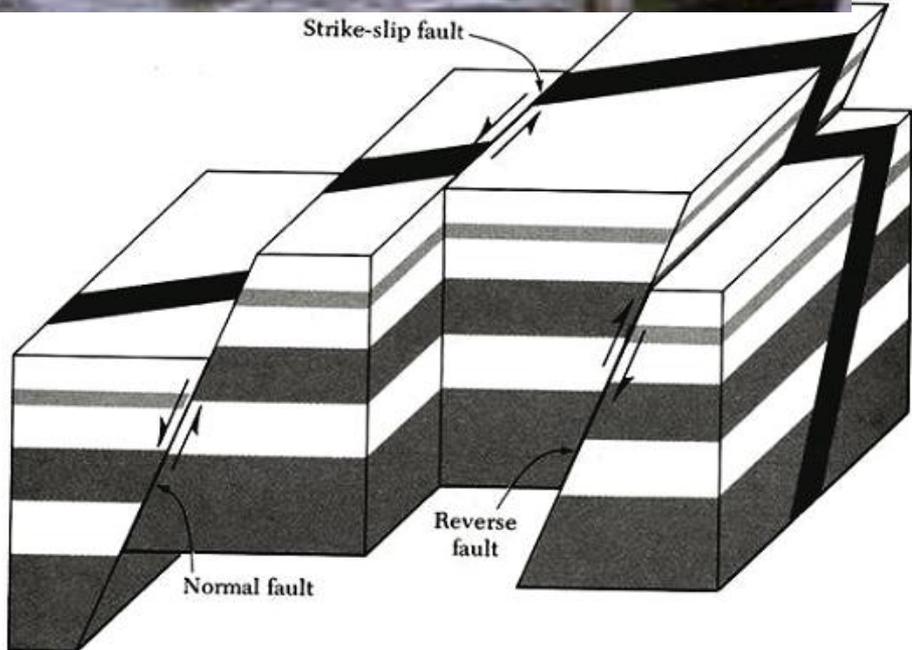


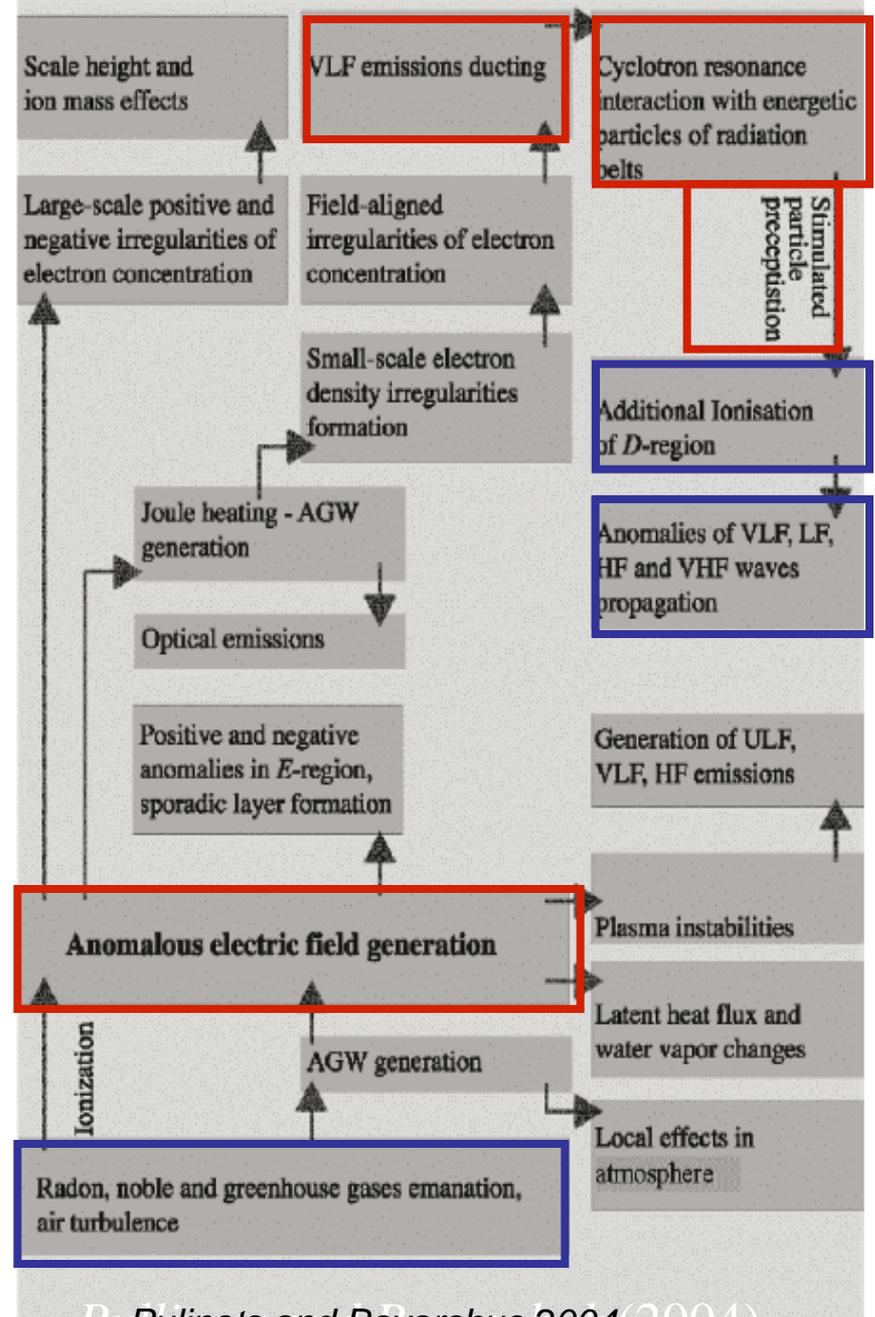
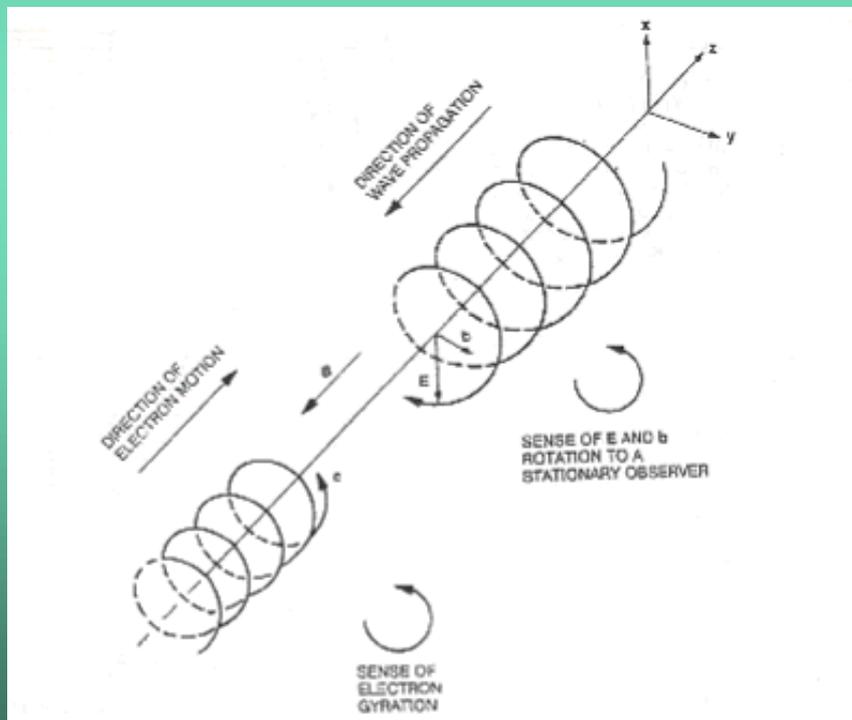
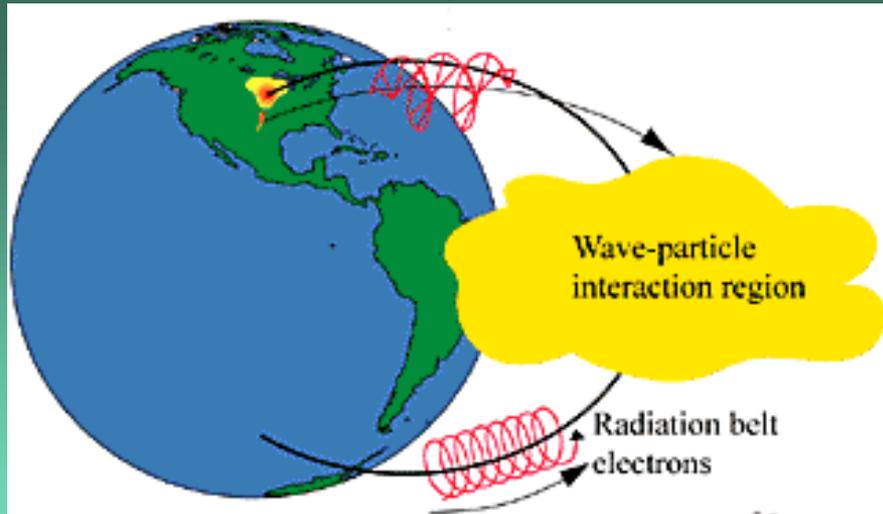
# Radiation Belt Electron Loss Mechanisms: New results

We will provide evidence that earthquakes is a major factor...

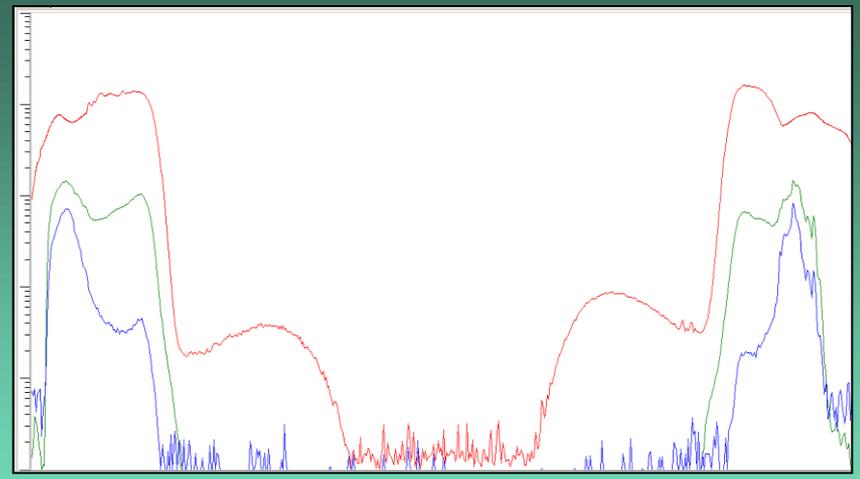
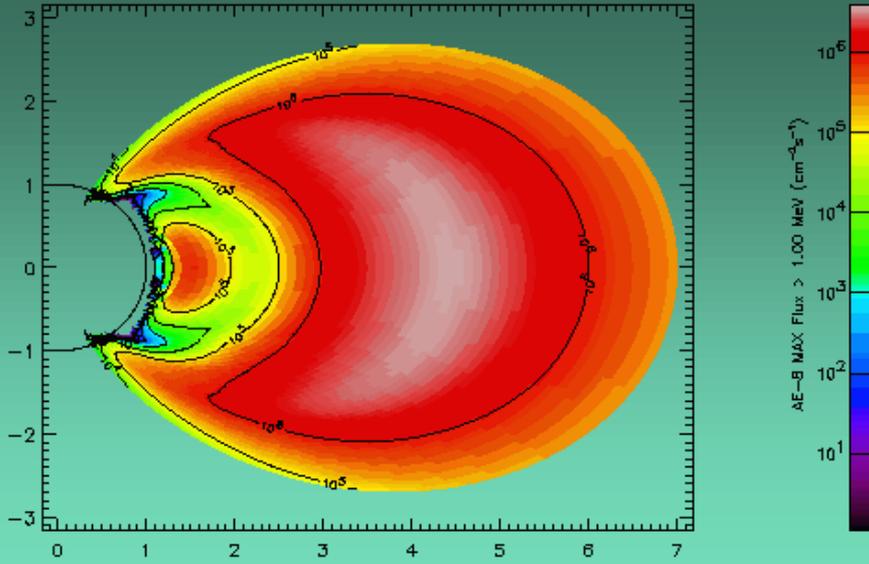


... producing radiation belt  
electron bursts in the topside  
ionosphere



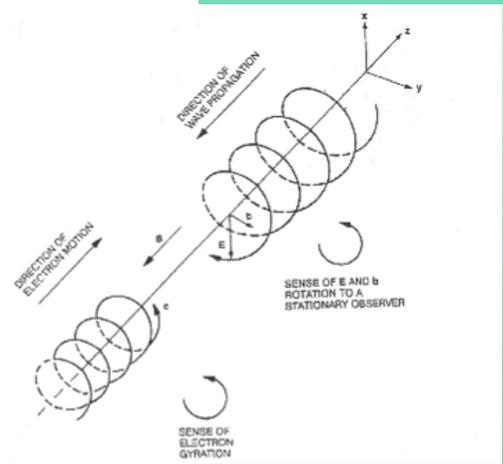
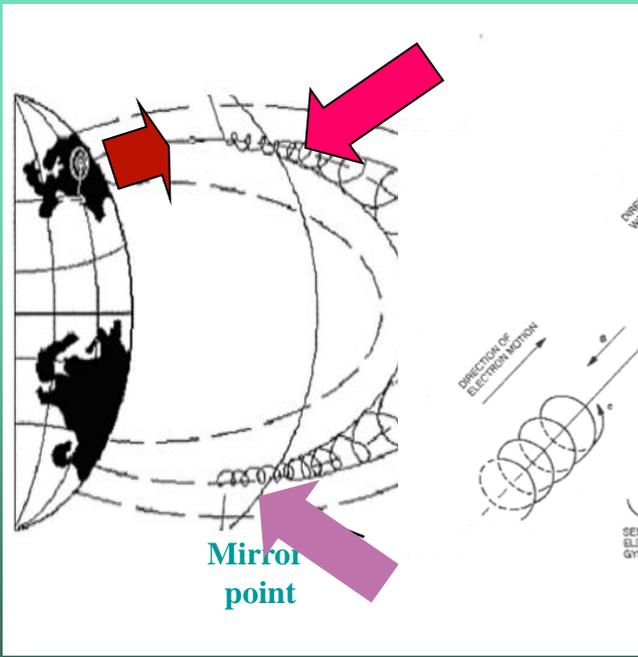


...constitutes of trapped charged particles..

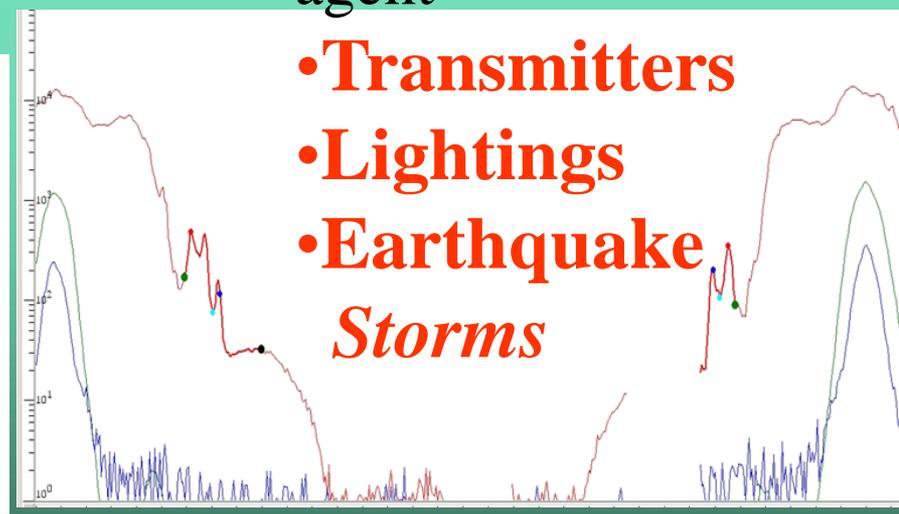


VLF whistlers interact with particles

Triggering agent

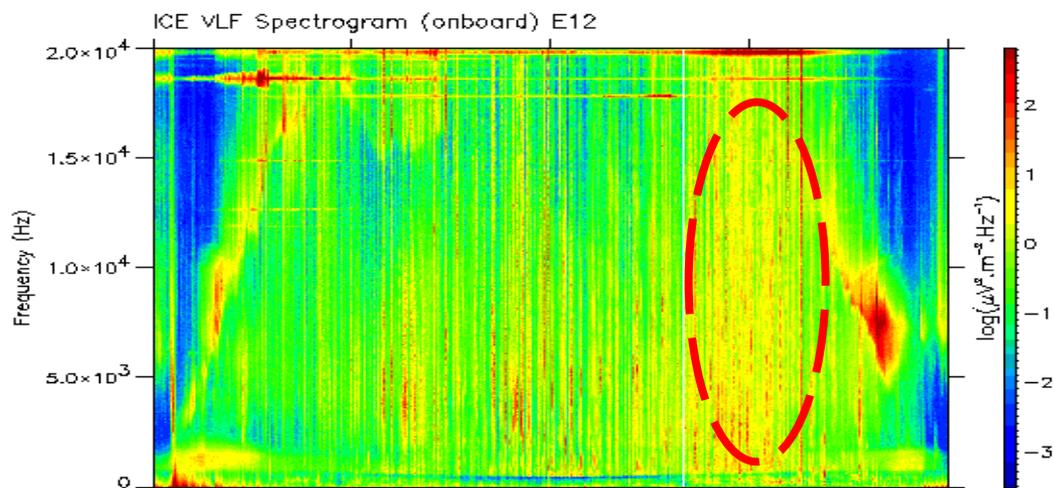
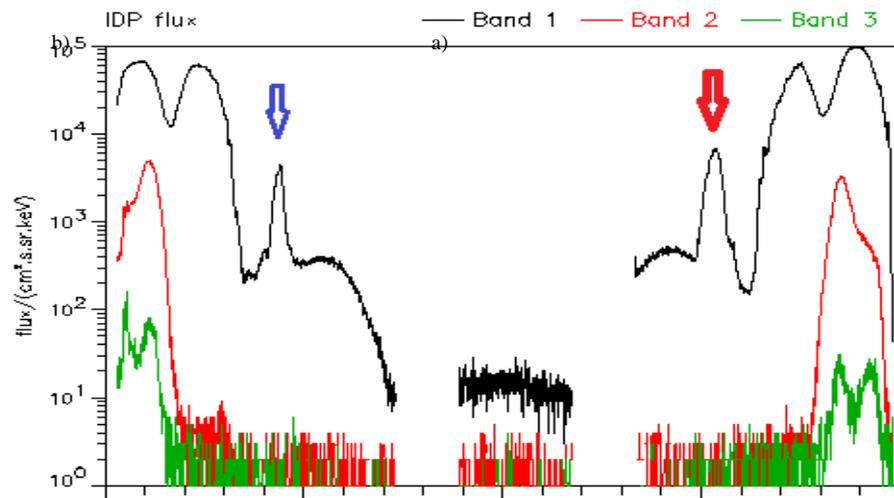


- Transmitters
- Lightings
- Earthquake
- Storms*

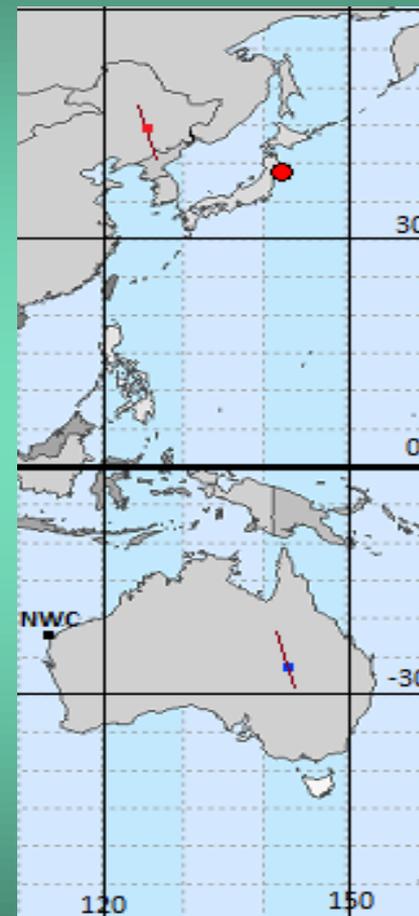


# Example of VLF emissions & RBEP

DEMETER Date (y/m/d): 2005/08/13 Orbit: 05923\_1

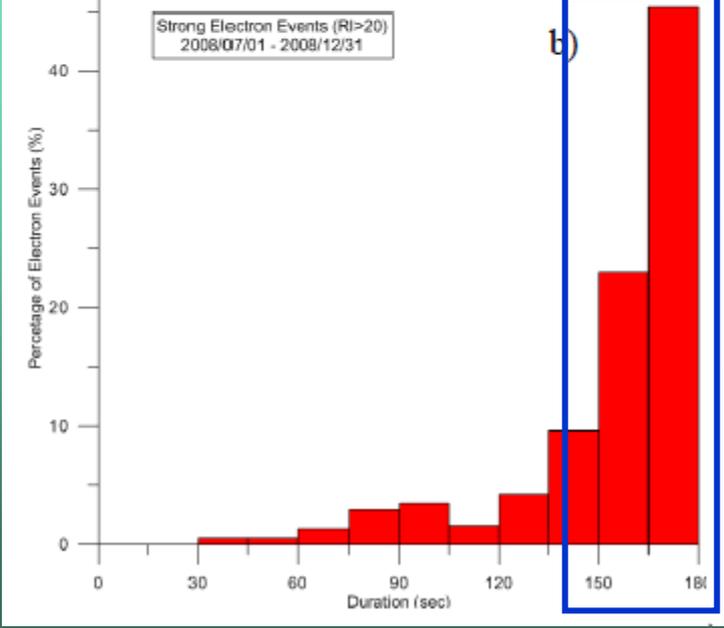
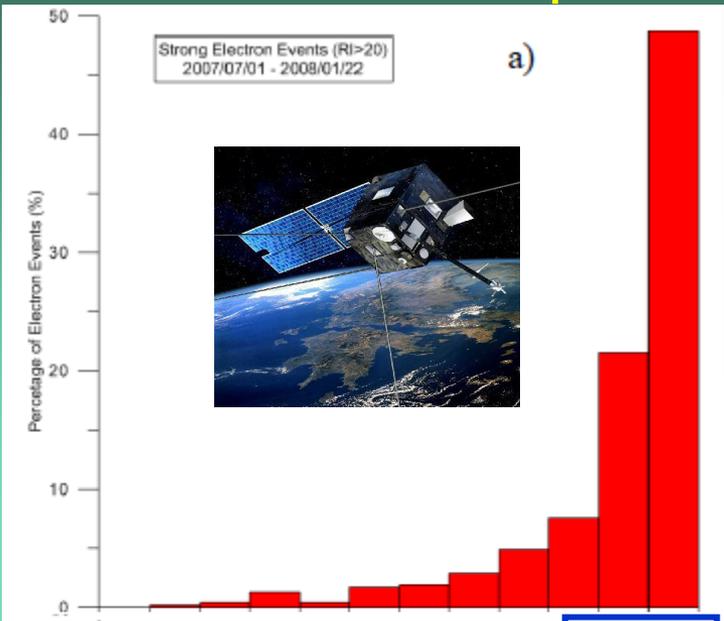
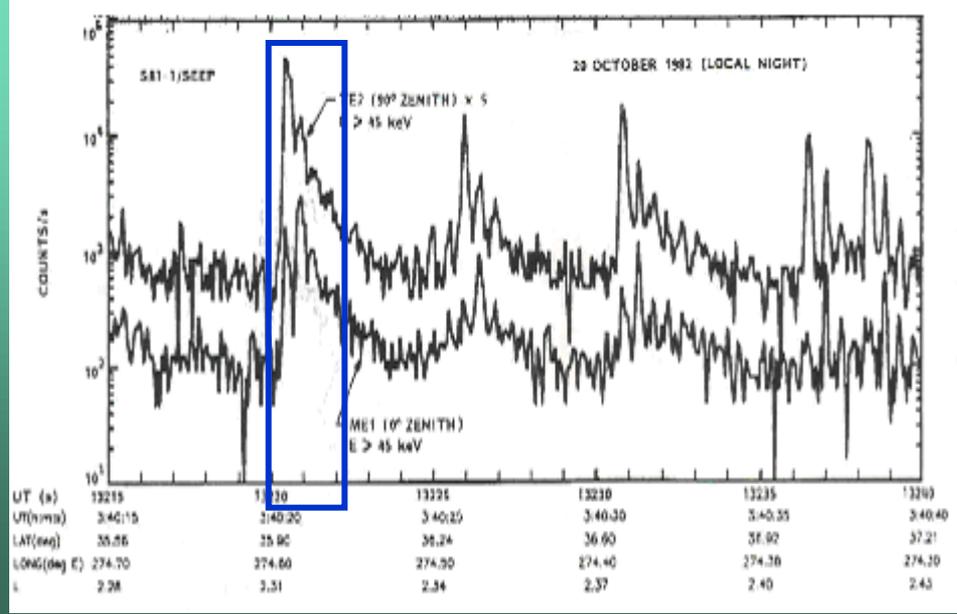
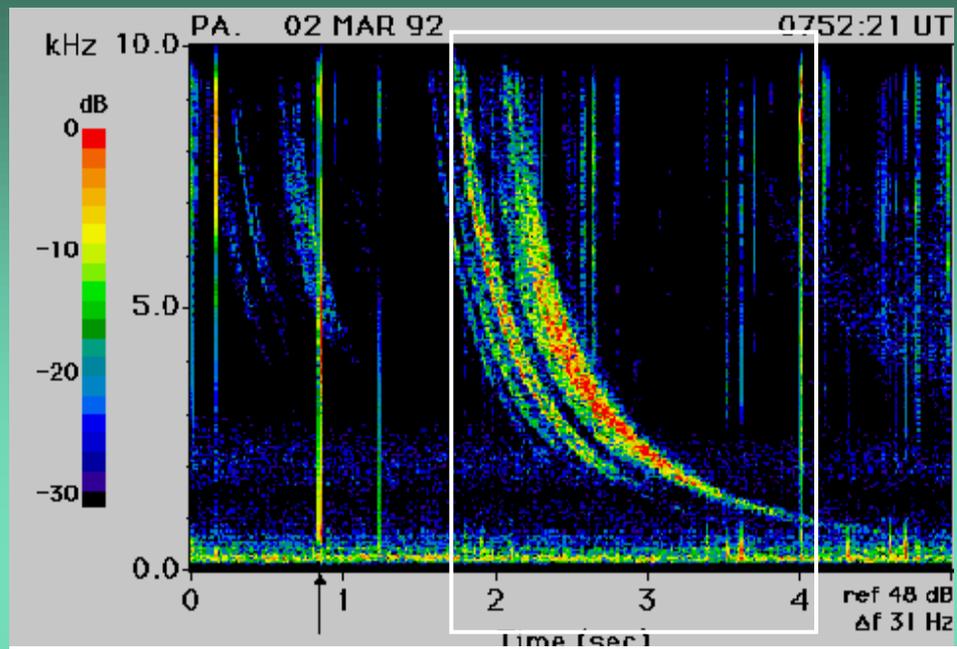


UT	12:53:00	13:02:00	13:11:00	13:20:00	13:29:00
Lat.	-55.13	-23.02	9.39	41.78	73.04
Long.	152.65	141.95	134.81	126.52	109.39
L	6.66	1.52	1.05	1.56	6.75



**~1-2 sec** Lightning-induced events

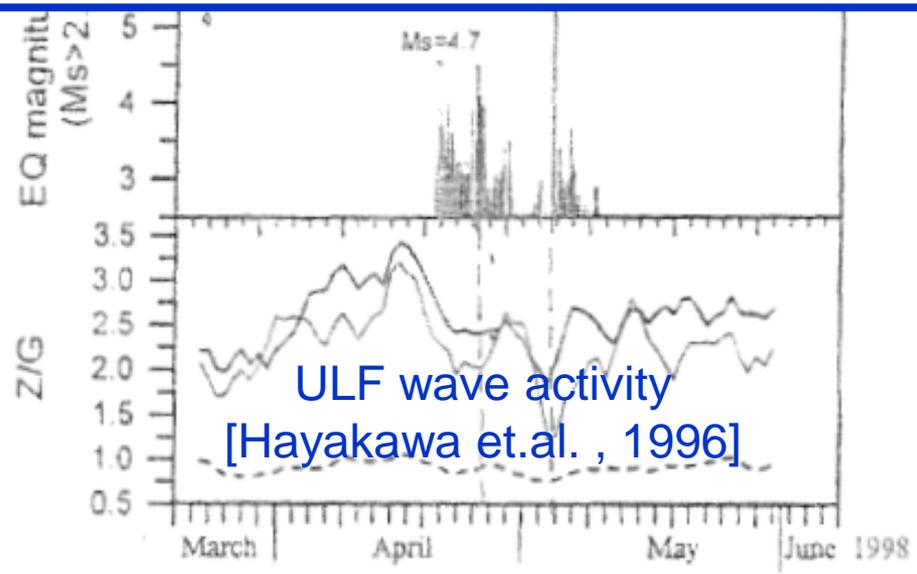
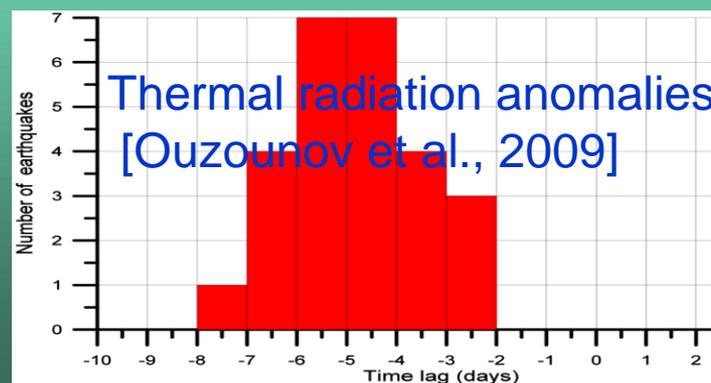
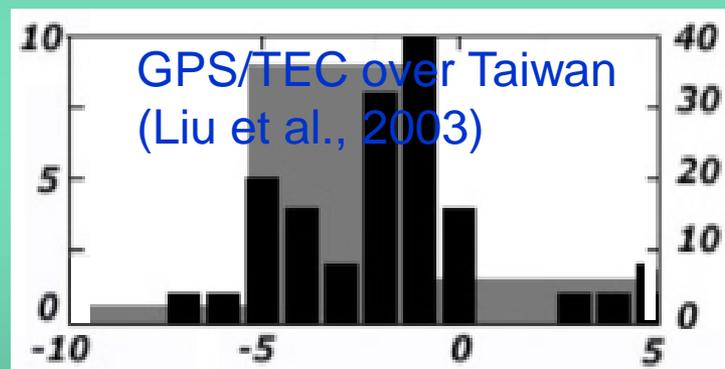
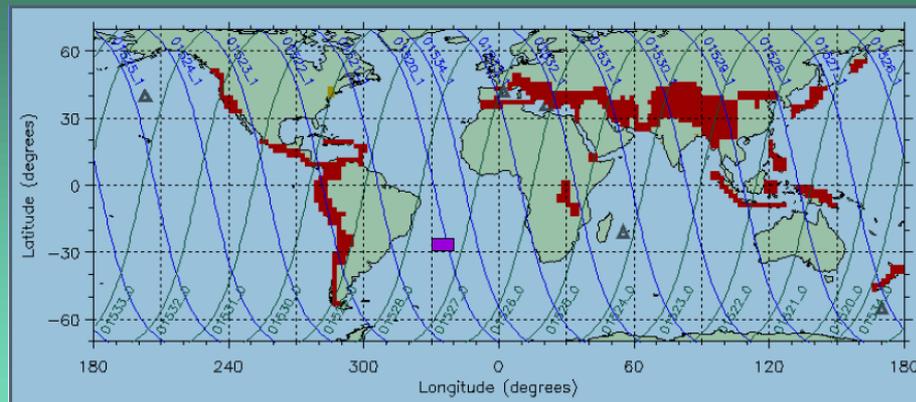
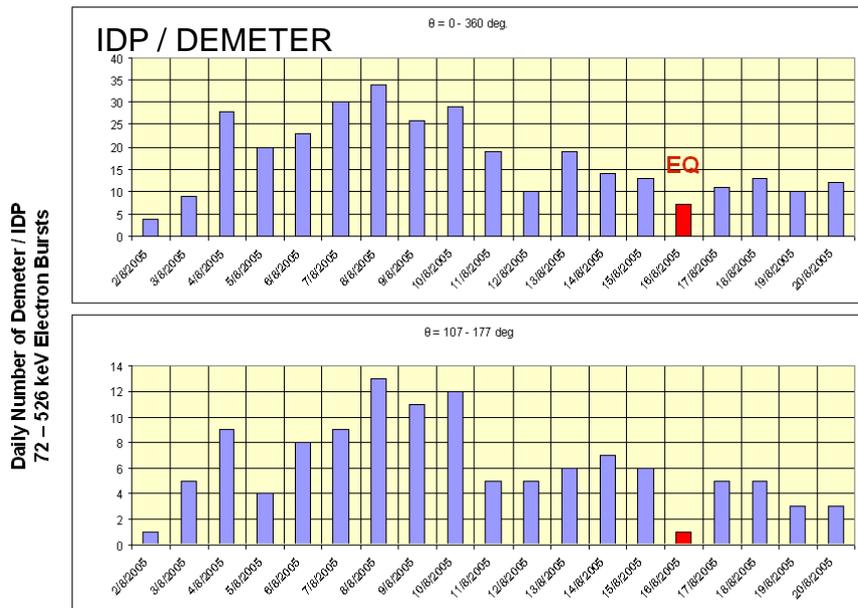
**~2-3 min** DEMETER events  
of our sample



# Earthquake induced - RBEP pattern

## 1. Increase a few days before EQs

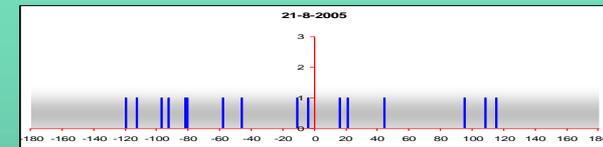
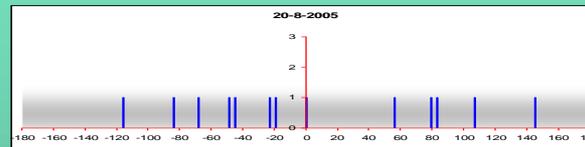
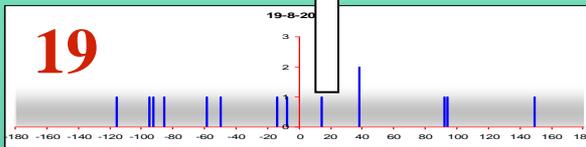
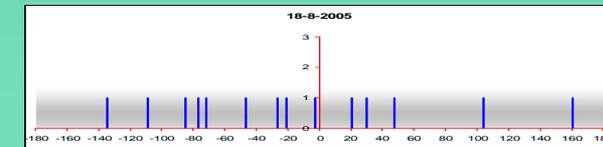
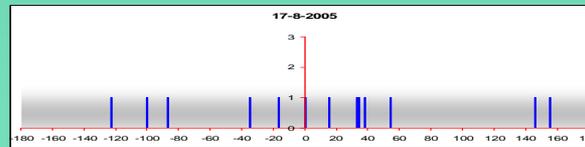
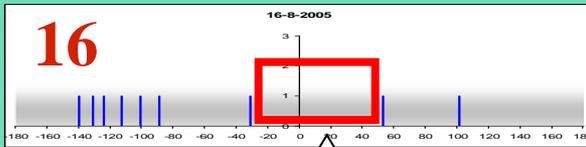
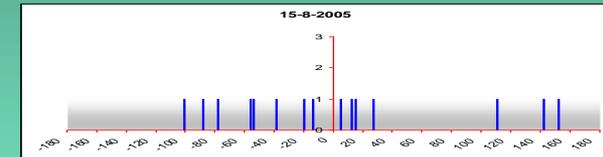
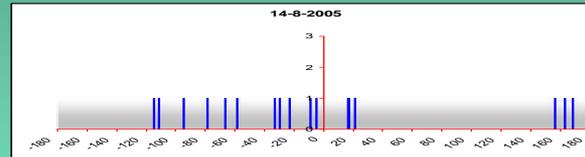
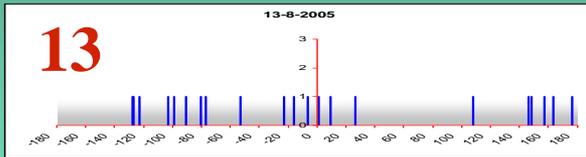
JAPAN 38.3N, 142.0E, 2005/08/16, M 7.2



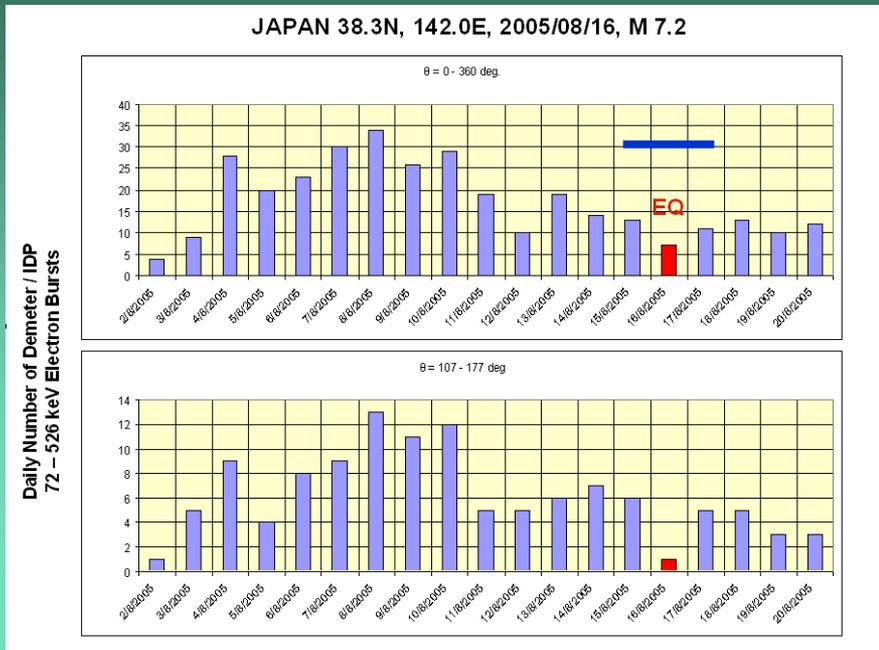
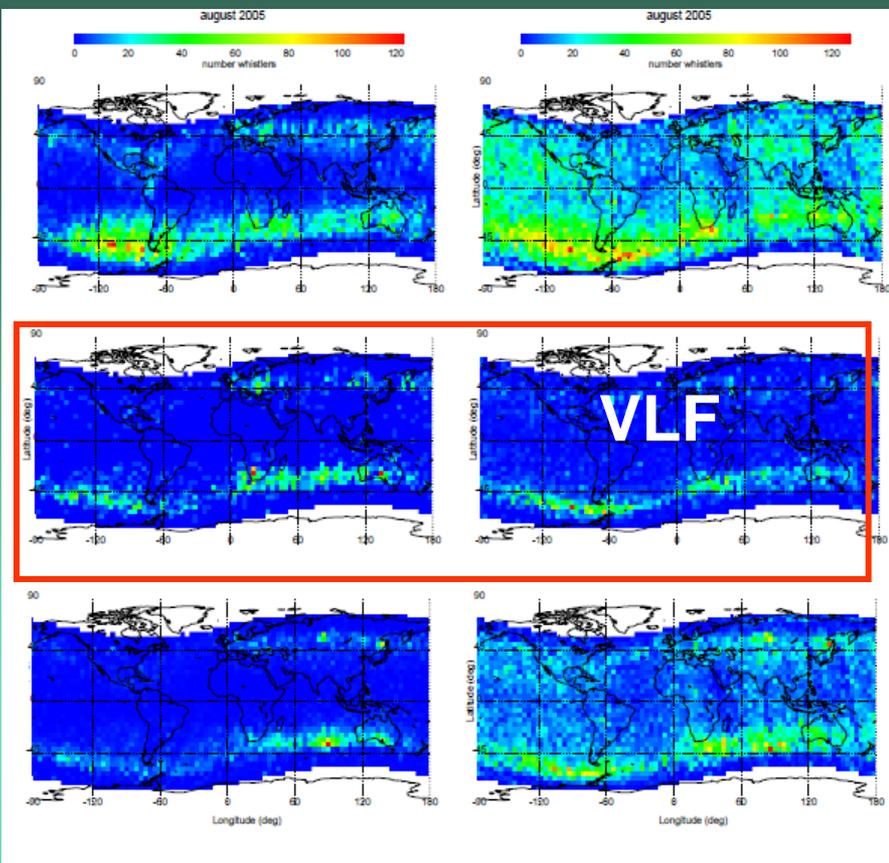
# Earthquake induced - RBEP pattern

## 2. Silence a few hours before EQs

Day of EQ: 16-08-2005



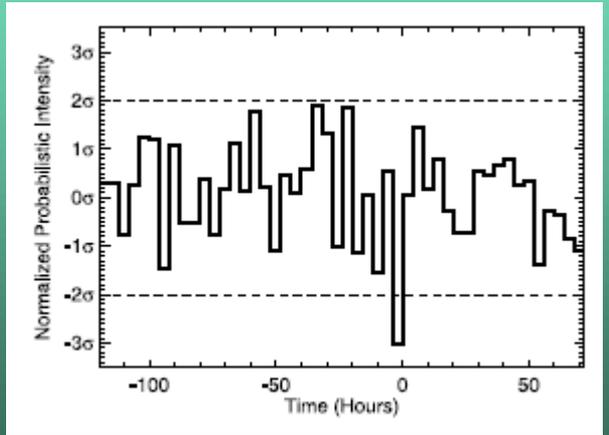
IDP / DEMETER



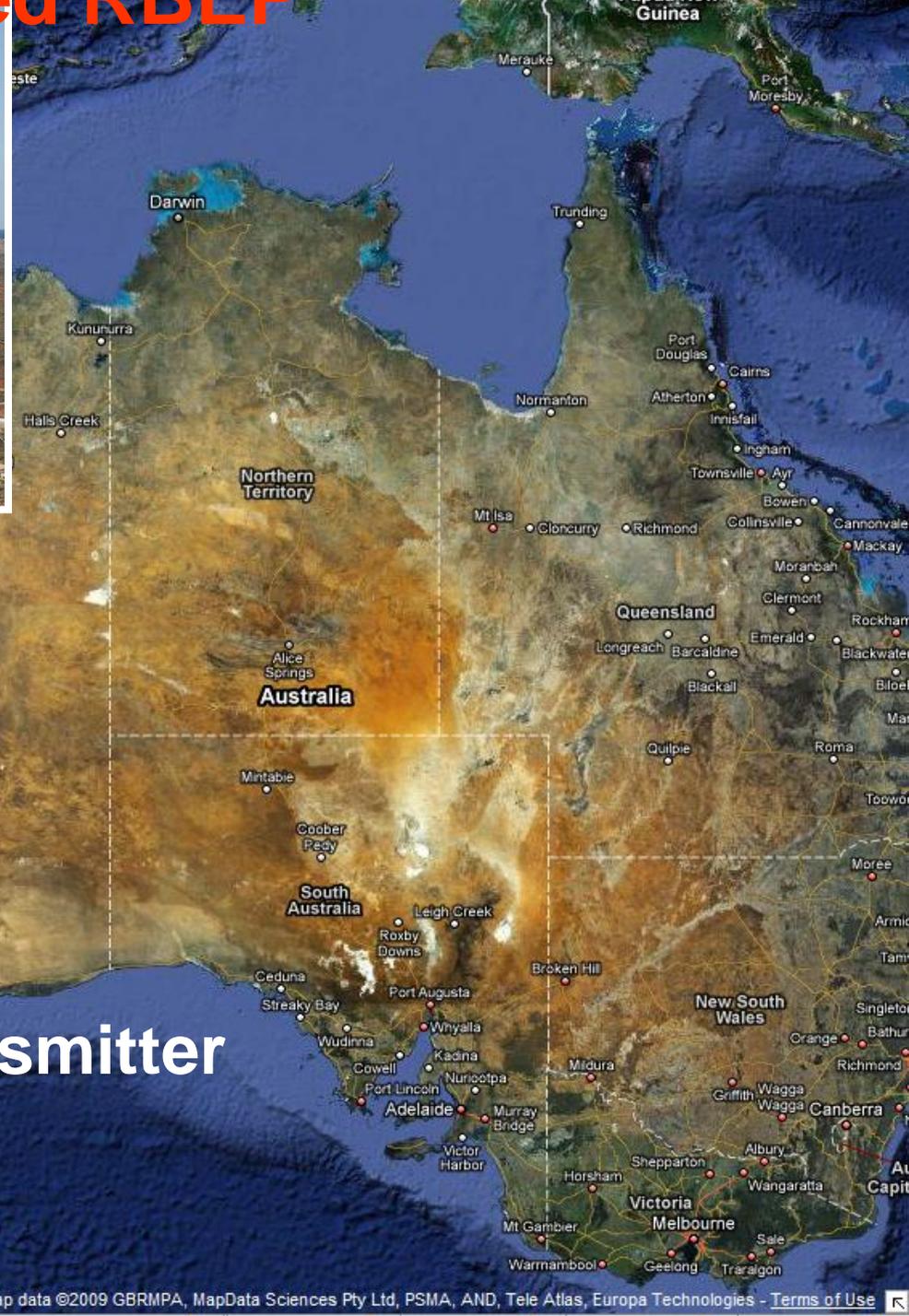
**Decrease of intensity of ELF/VLF waves observed in the upper ionosphere close to earthquakes: A statistical study**

F. Němec,<sup>1,2,3</sup> O. Santolík,<sup>3,2</sup> and M. Parrot<sup>1</sup>

Using a larger set of data (more than 3.5 years of measurements) and a newly developed data processing method, we confirm the existence of a very small but statistically significant decrease of wave intensity 0-4 hours before the time of the main shock at frequencies of about 1.7 kHz. It is shown that the decrease does not occur directly above the



# VLF transmitter-induced RBLP



North West Cape  
(NWC)

The strongest VLF transmitter  
1 MW, 19.8 kHz

# TEST

- We compared the number of PBEP events observed during the period

2007/07/01 – 2008/01/2, **when the NWC was off,**

with the number of PBEP events in the same intervals on other years with the previous one:

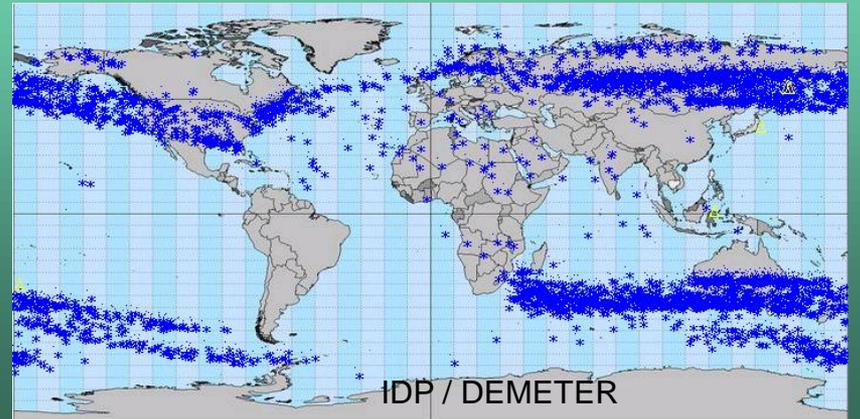
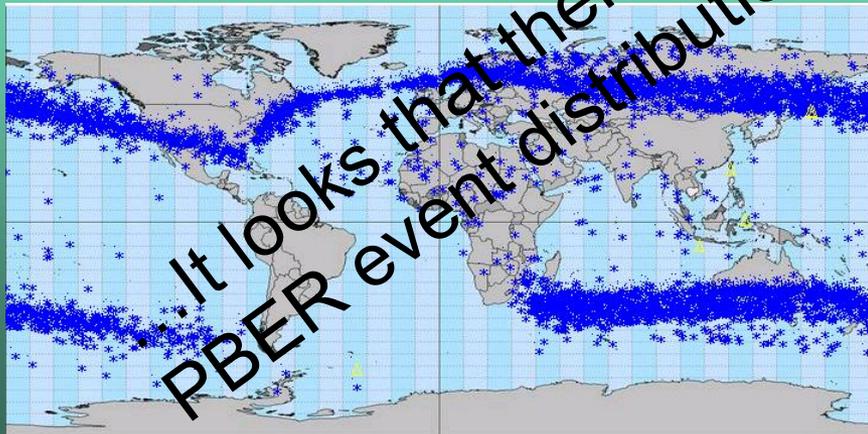
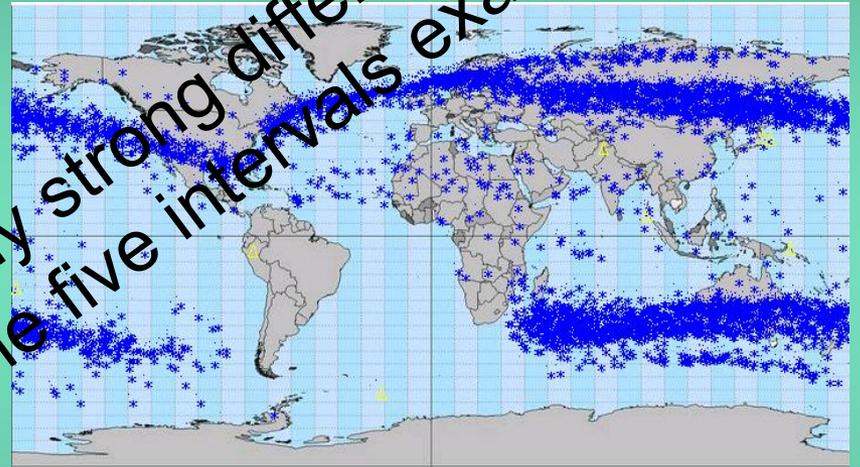
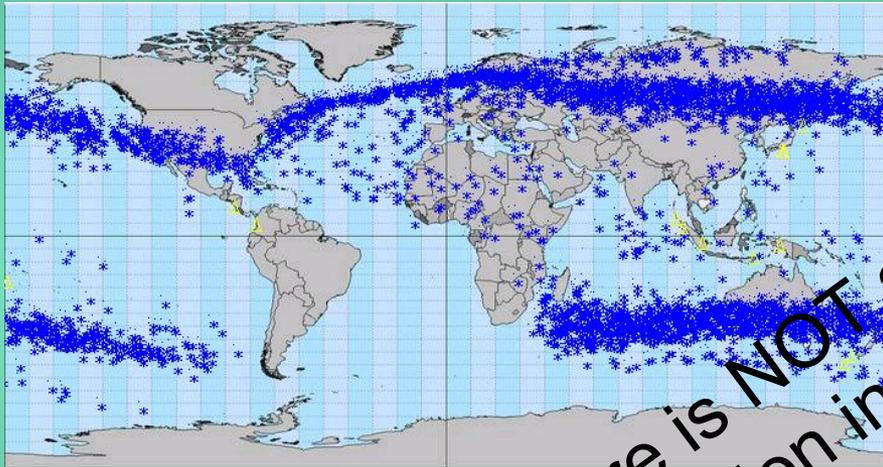
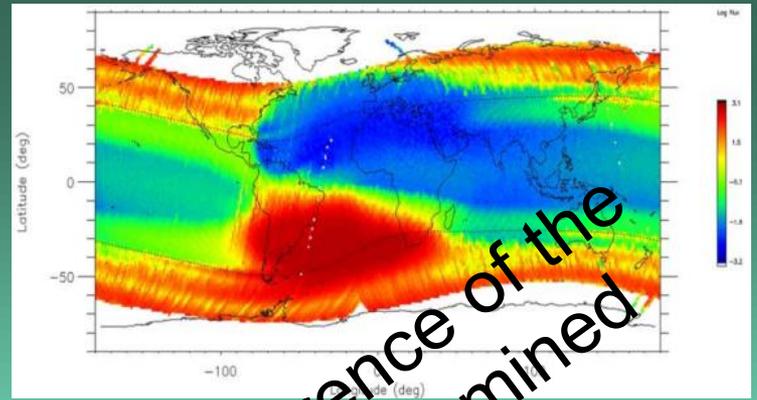
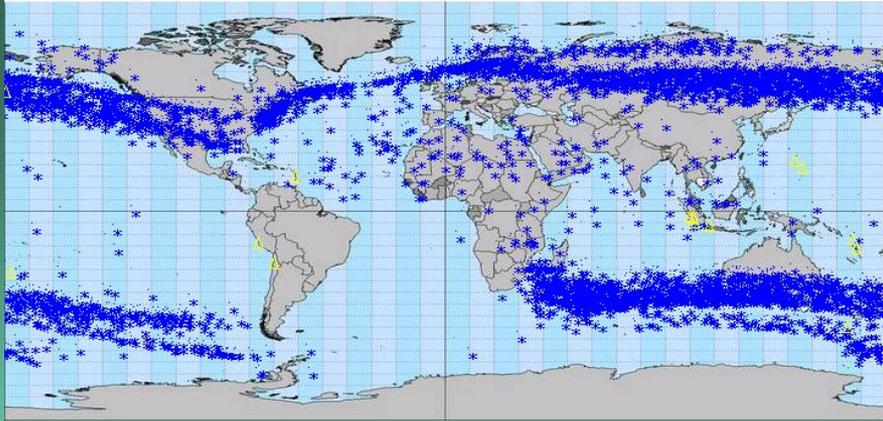
P1:2004-2005,

P2: 2005-2006,

P3:2006-2007) and the next years

P4: 2008-2009).

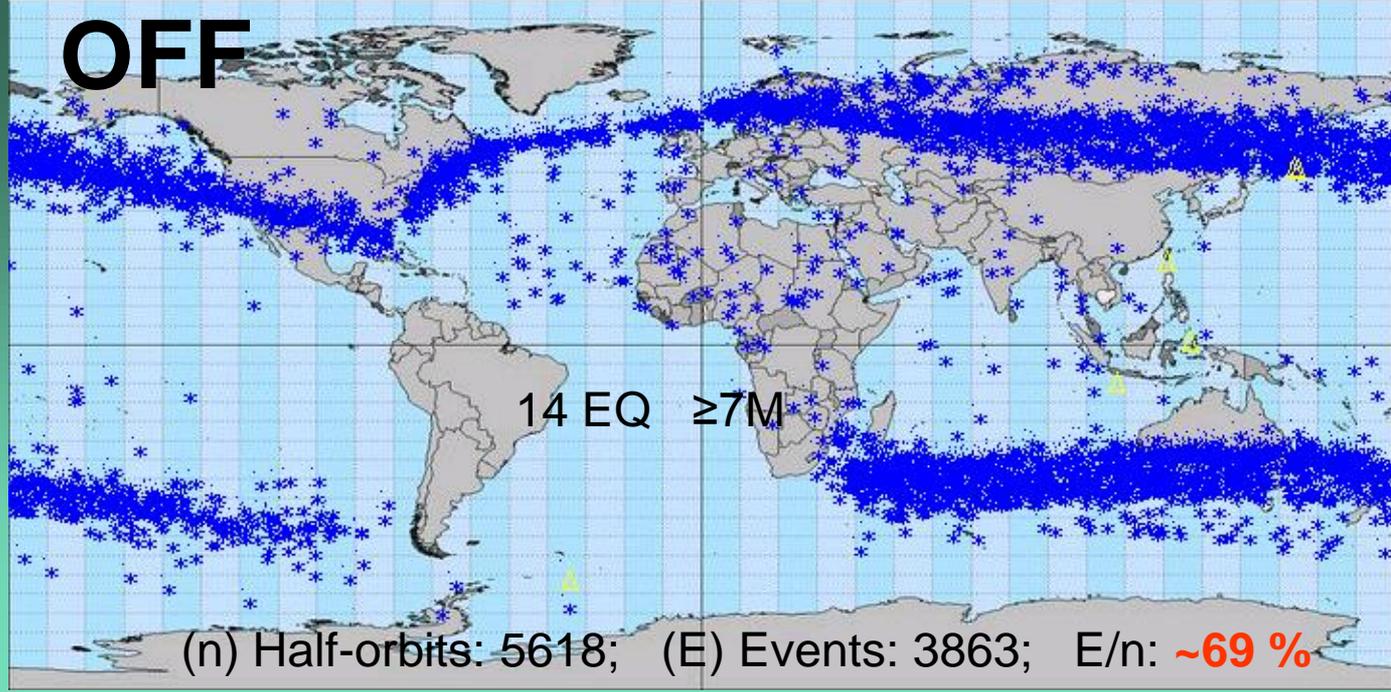
- **The crucial question is:** Does the operation of the most powerful VLF transmitter changes significantly the number of PBEP events **observed by DEMETER?**



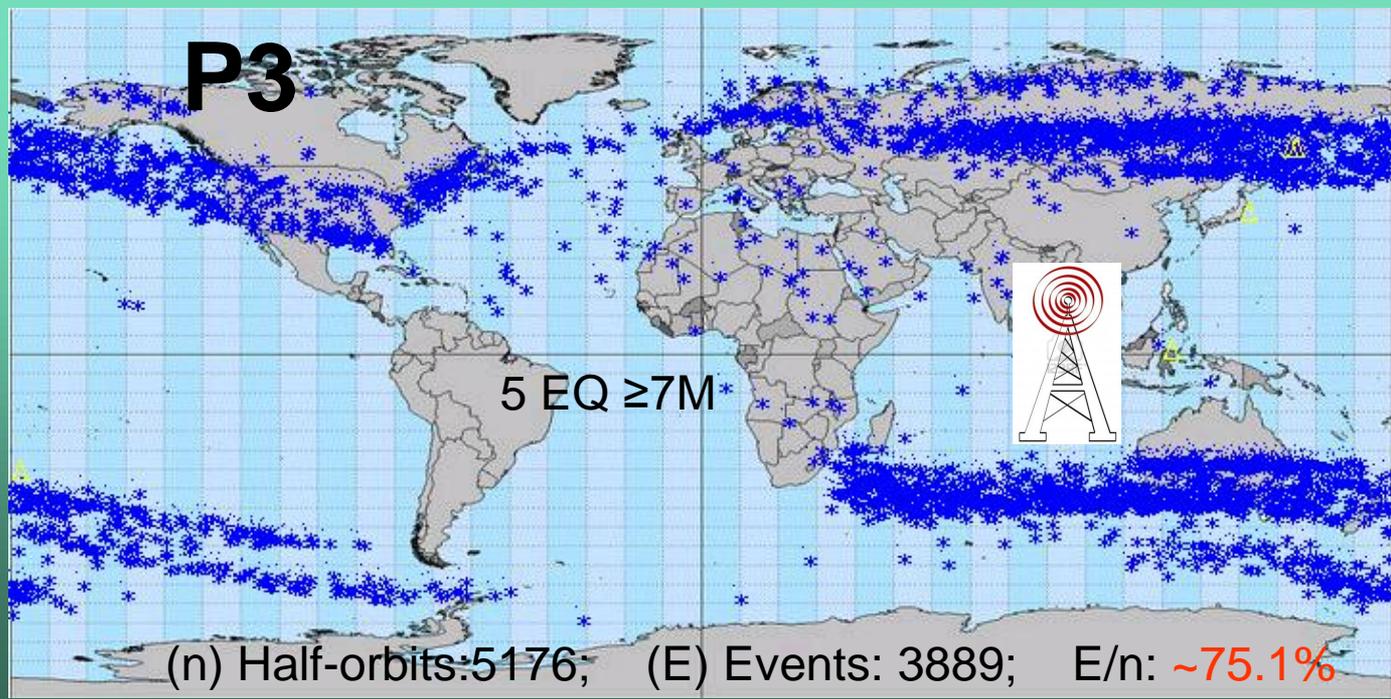
It looks that there is NOT any strong difference of the PBER event distribution in the five intervals examined

IDP / DEMETER

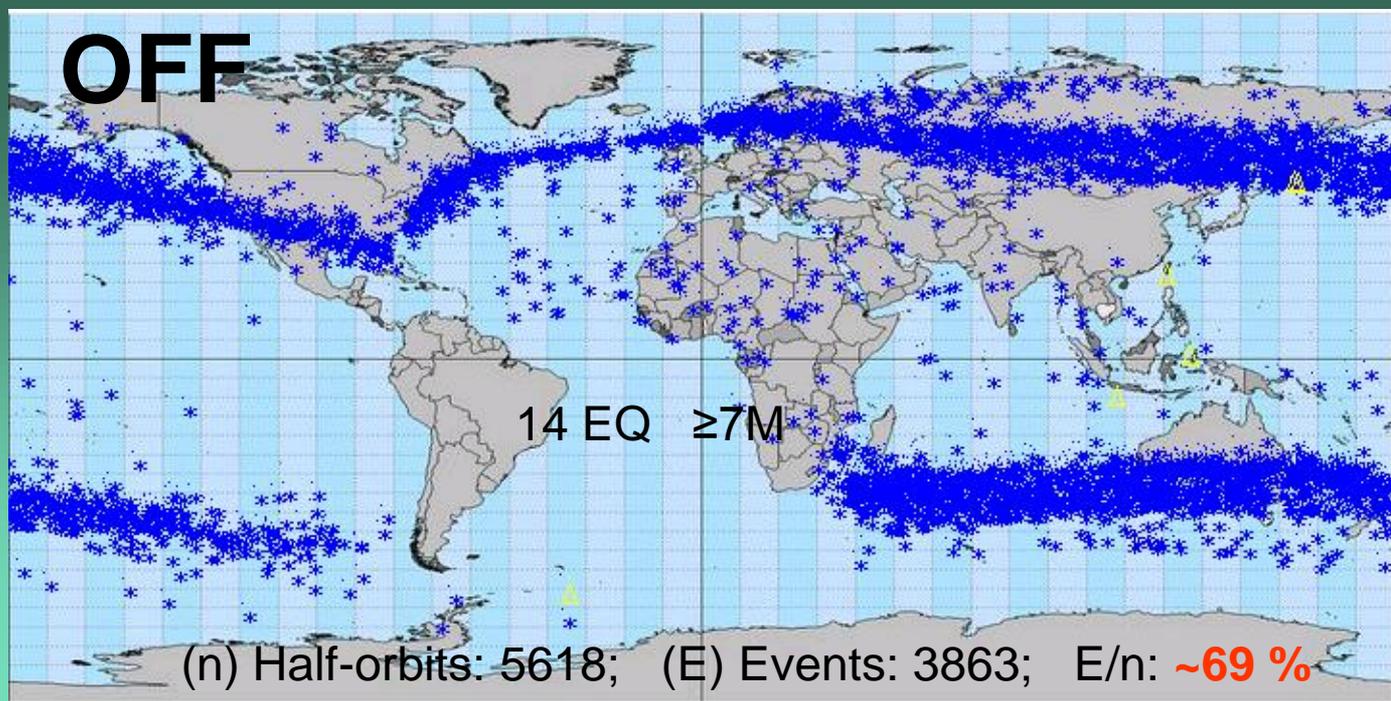
# OFF



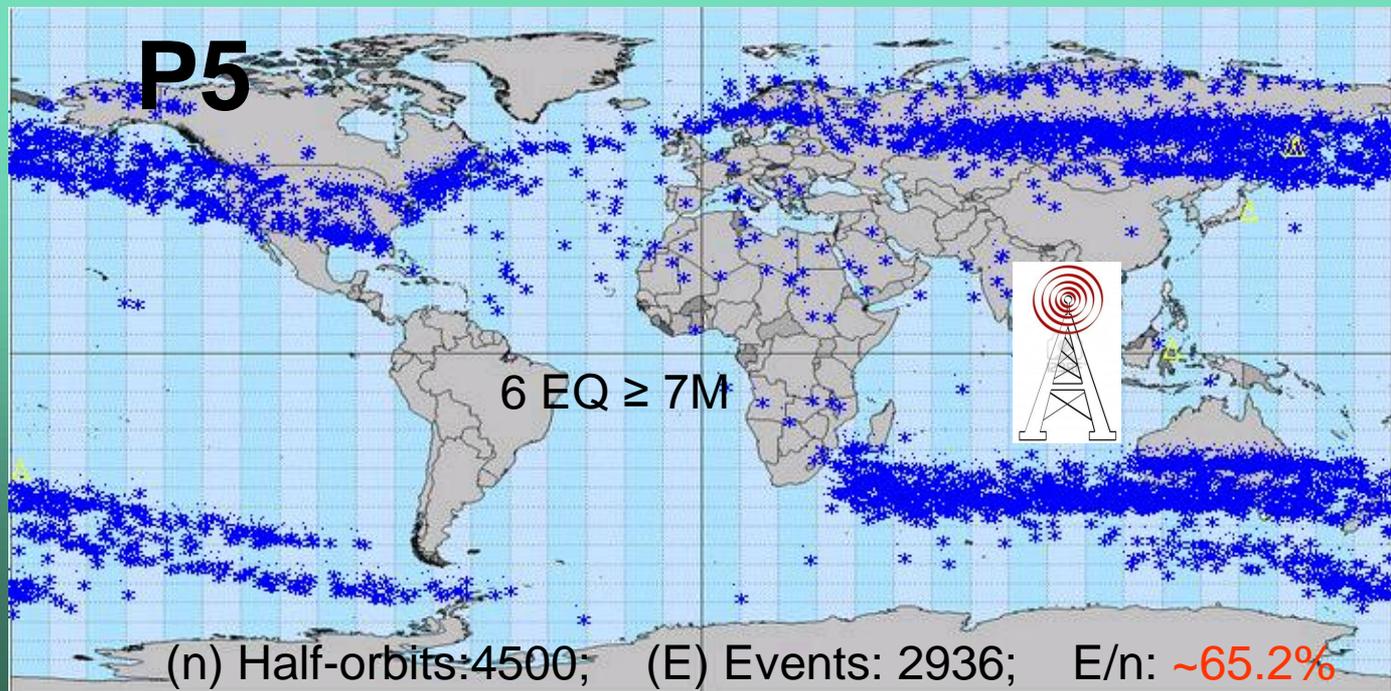
# P3



More events  
in the period  
When the  
transmitter  
was NOT  
operating

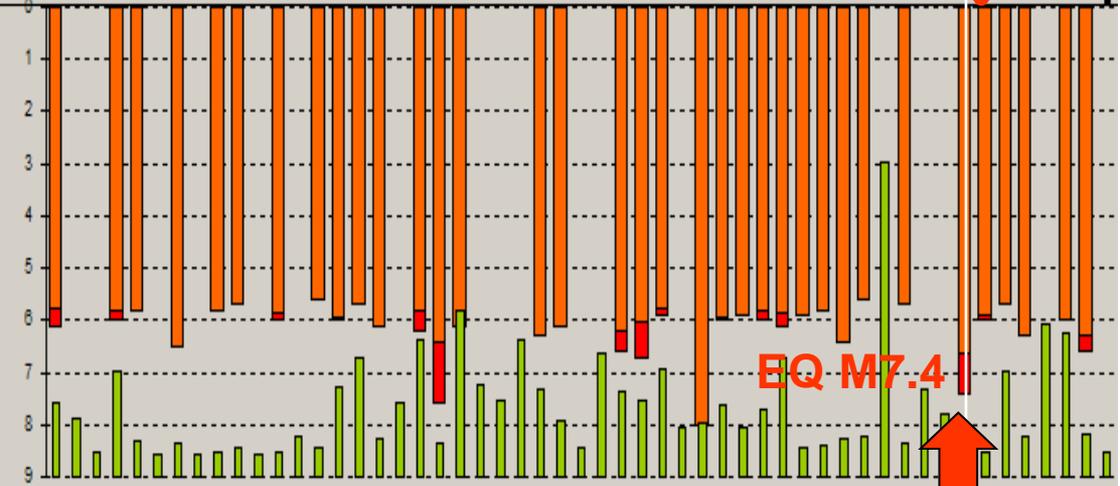
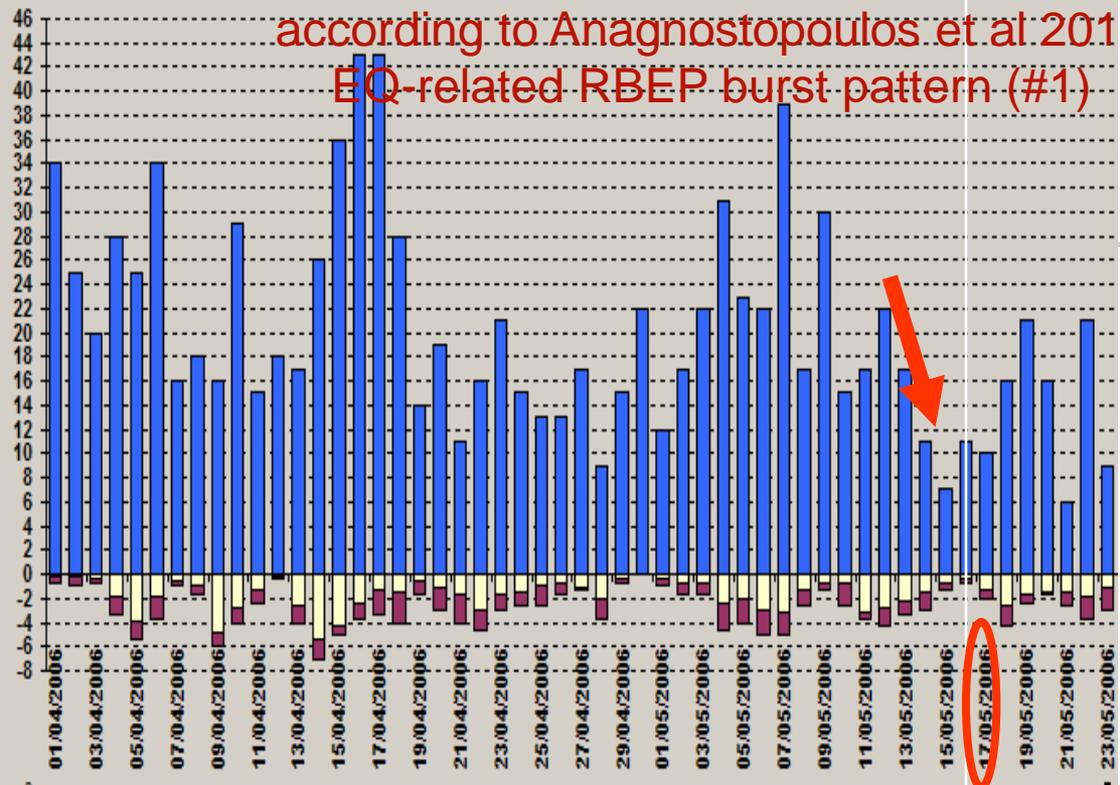


**Conclusion:**  
Insignificant  
contribution  
of NWC  
to the RBEP  
number  
of events



IDP / DEMETER Temporal evolution Events, Kp

according to Anagnostopoulos et al 2011 EQ-related RBEP burst pattern (#1)



EQ M7.4

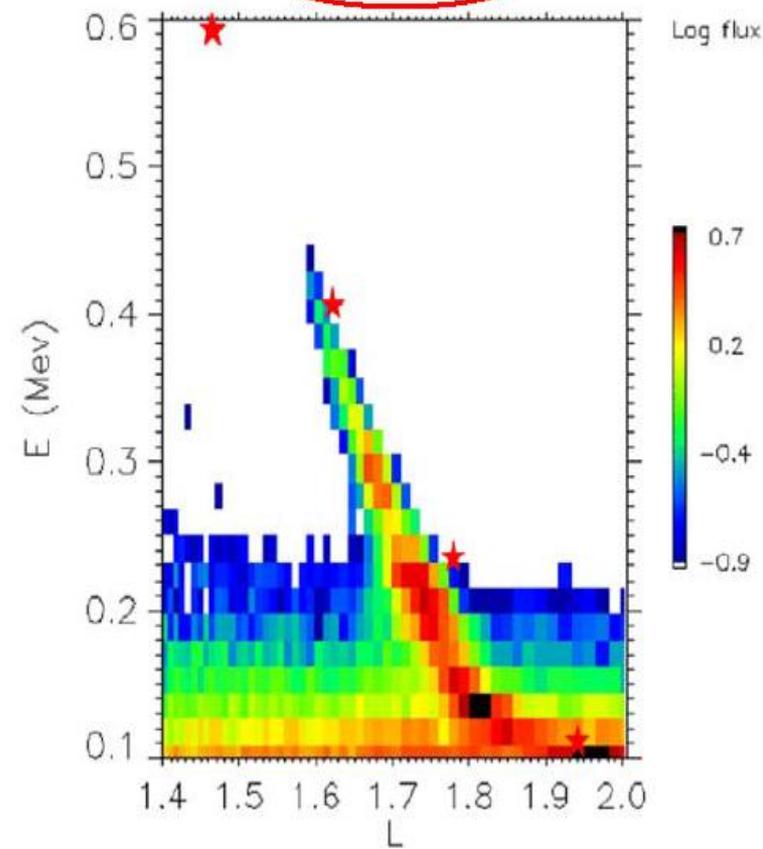
Radiation belt electron precipitation due to VLF transmitters:

Satellite observations

J.-A. Sauvaud,<sup>1</sup> R. Maggiolo,<sup>1</sup> C. Jacquey,<sup>1</sup> M. Parrot,<sup>2</sup> J.-J. Berthelier,<sup>3</sup> R. J. Gamble,<sup>4</sup> and Craig J. Rodger<sup>4</sup>

SAUVAUD ET AL.: MAN-MADE VLF ELECTRON PRECIPITATION

May 17, 2006



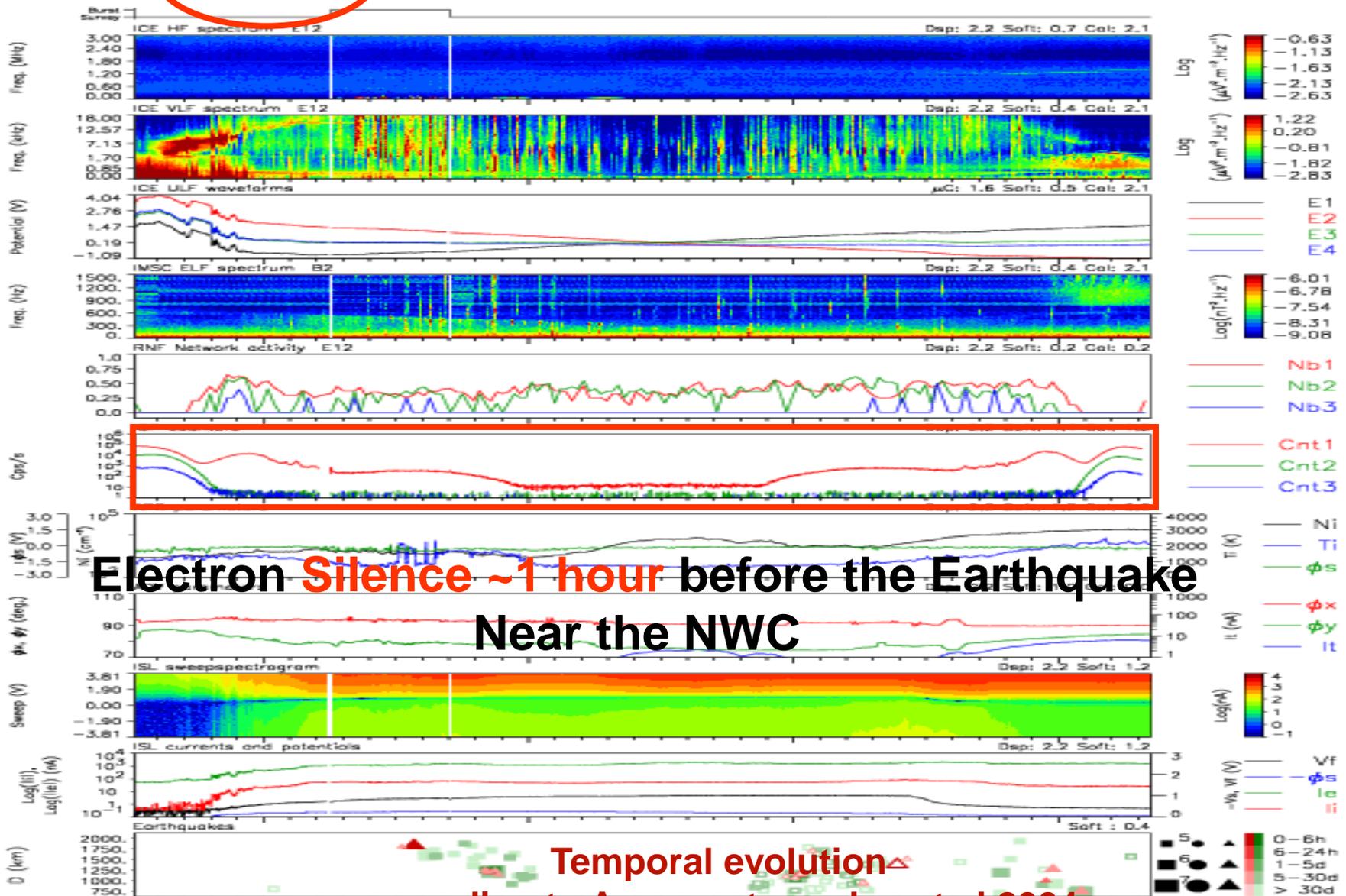
RLAT	-19.50	-24.94	-30.38	-35.80
RLONG	175.21	173.93	172.57	171.10

# DEMETER / QUICKLOOK

Date: 2006/05/16

Orbit: 09958\_1

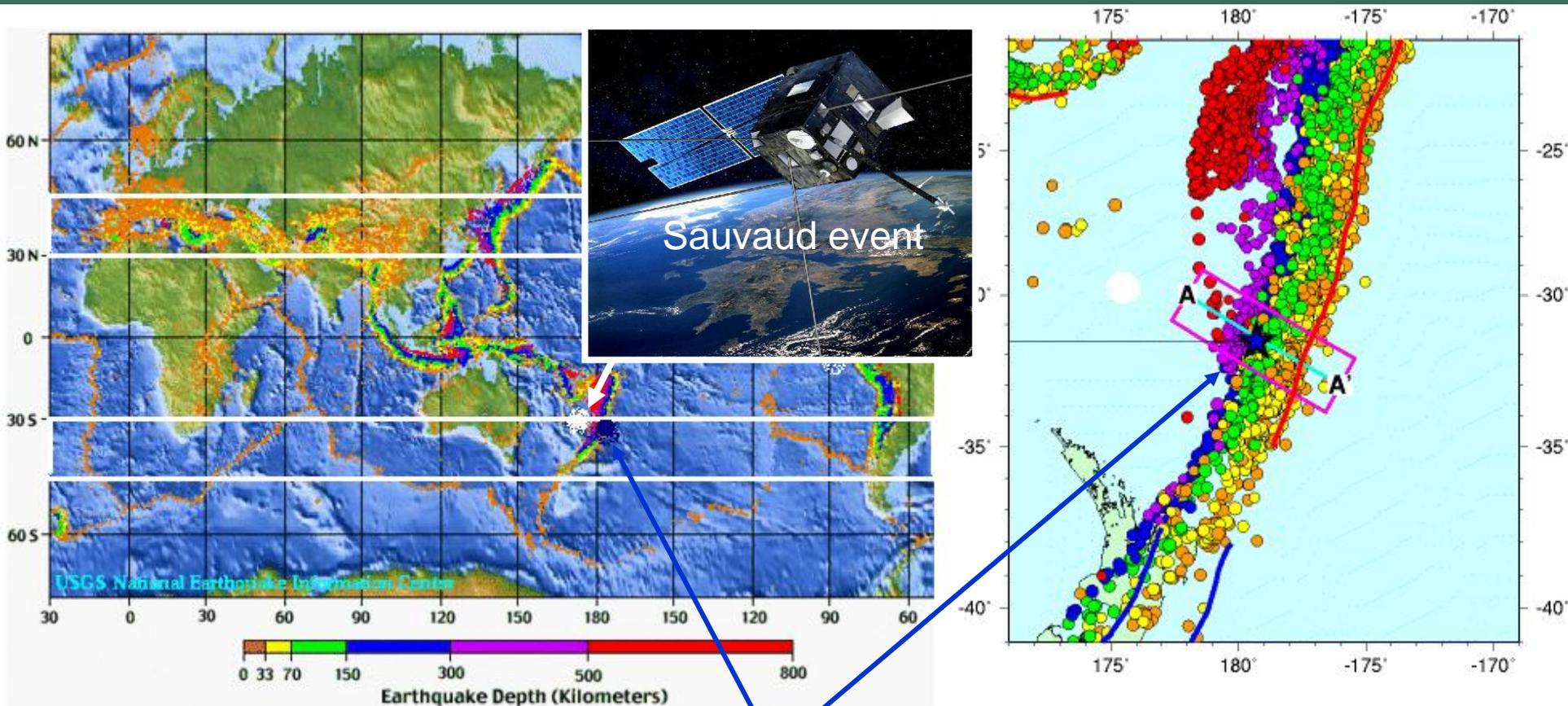
Produced by LPCE 2006/05/16 16:50:27 V3.6



**Electron Silence ~1 hour before the Earthquake**  
**Near the NWC**

Temporal evolution according to Anagnostopoulos et al 2004  
 EQ-related RBEP burst pattern (#2)

UT/LT Lat. Long. 09:19:00/20:59 -49.78 203.97 09:29:00/21:09 -13.64 183.80 09:39:00/21:09 22.71 185.93 09:49:00/21:22 58.77 173.33



**16/10/2006 M7.4 (!!!) Earthquake**  
at almost the same coordinates with Sauvaud et al event  
~1 day earlier (!)

**The characteristic temporal evolution of the RBEP events around the time of the Sauvaud et al event (17/05/2006) and**

**the spatial coincidence of the Sauvaud et al event with a giant earthquake (16/5/2006)**

**suggest that seismic activity was most probably the triggering mechanism of that RBEP event**

# CONCLUSIONS

- The radiation belt electron precipitation (RBEP) into the topside ionosphere is a phenomenon which is known for several decades. However, the inner radiation belt source and loss mechanisms have not still well understood.

- We compared EQs, lightnings and Earth based transmitters as mechanisms triggering RBEP and we found significant evidence that **seismic activity seems to be a major agent** contributing to the RBEP at middle latitudes.
- *Further research is in progress in order to further test the present results.*

ΕΑΝΘΗ



Thank you for your attention and interest