SEISMO - IONOSPHERIC COUPLING AND EARTHQUAKE FORECAST PROBABILITY

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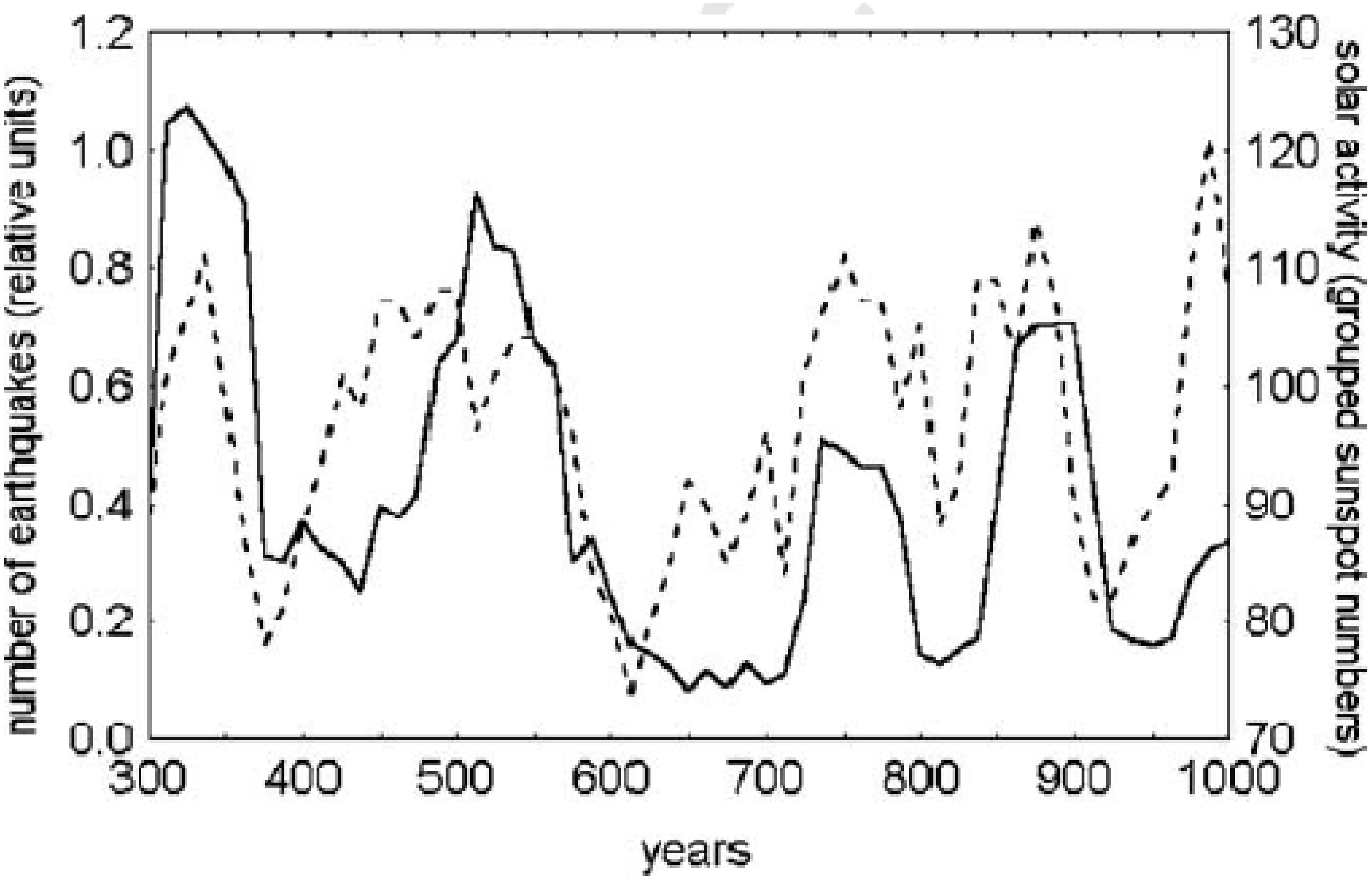
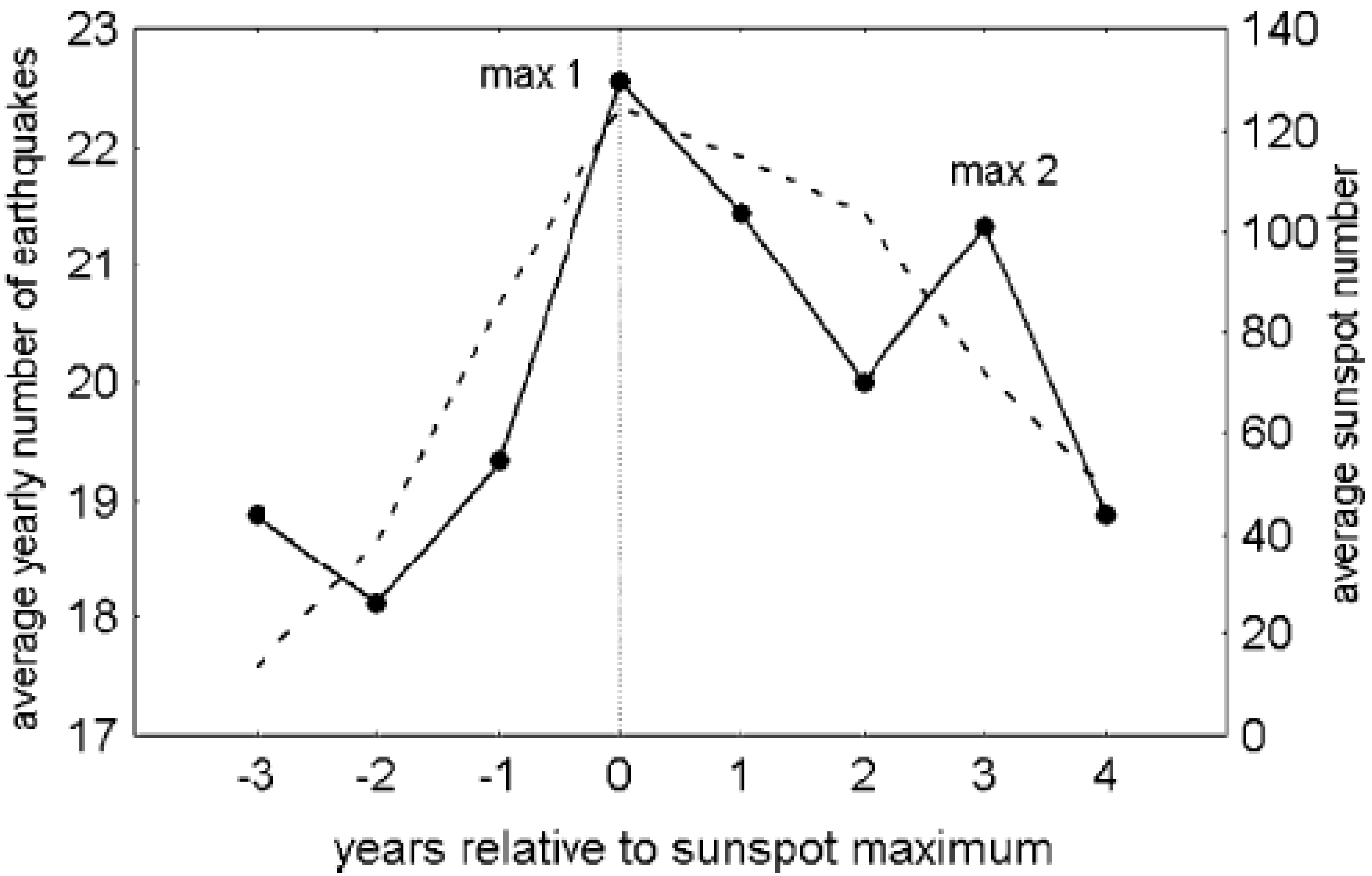
INFLUENCE FROM
“ABOVE”

Number of earthquakes in the Mediterranean area summed over the 11-year solar cycles (solid line) and solar activity in the maxima of the solar cycles (broken line) in the period 296–1000; 3-point running means.



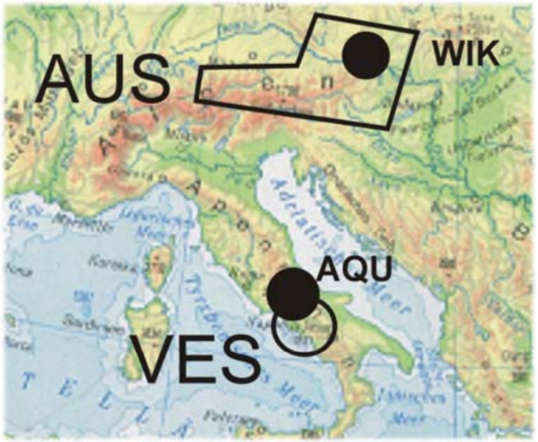
Courtesy of
Dr. Katya Georgieva

Average number of earthquakes (solid line) and solar activity (broken line) in the 11-year solar cycle for the period 1900–1999

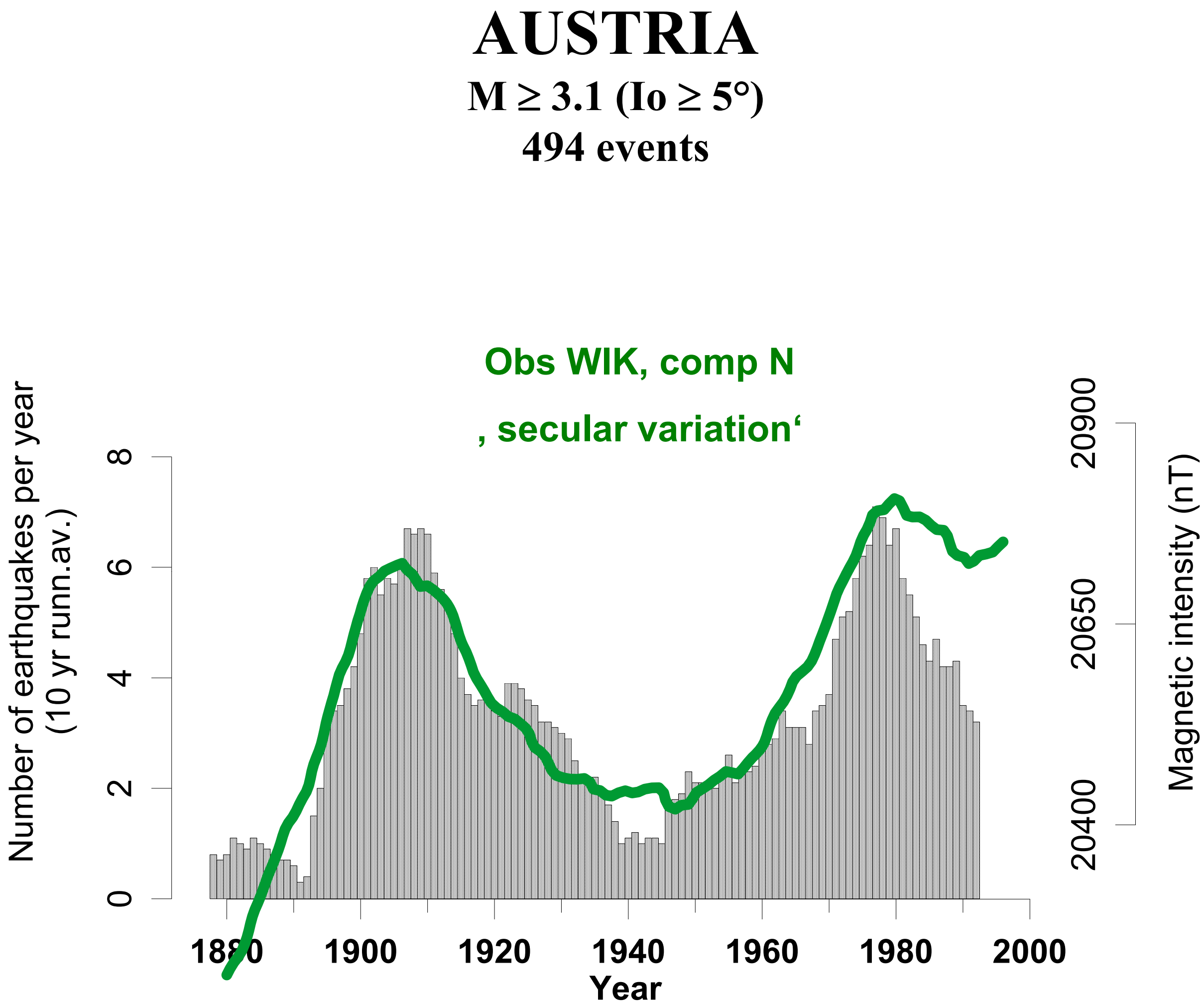


Courtesy of
Dr. Katya Georgieva

Observations (1996) – long term



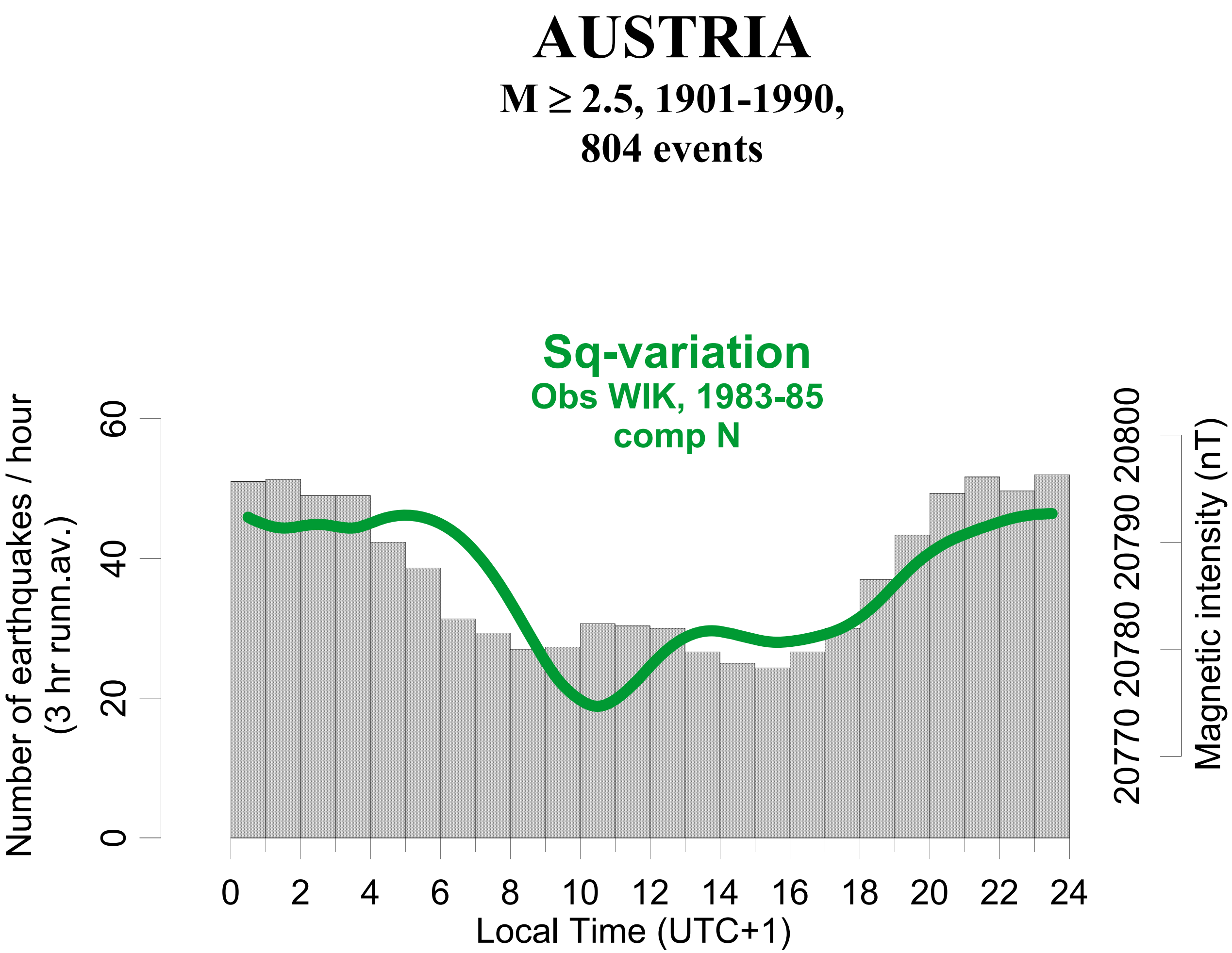
Geomagnetic Observatory



Courtesy of
Dr. Gerald Duma

Observations (1996) – daily range

● Geomagnetic Observatory



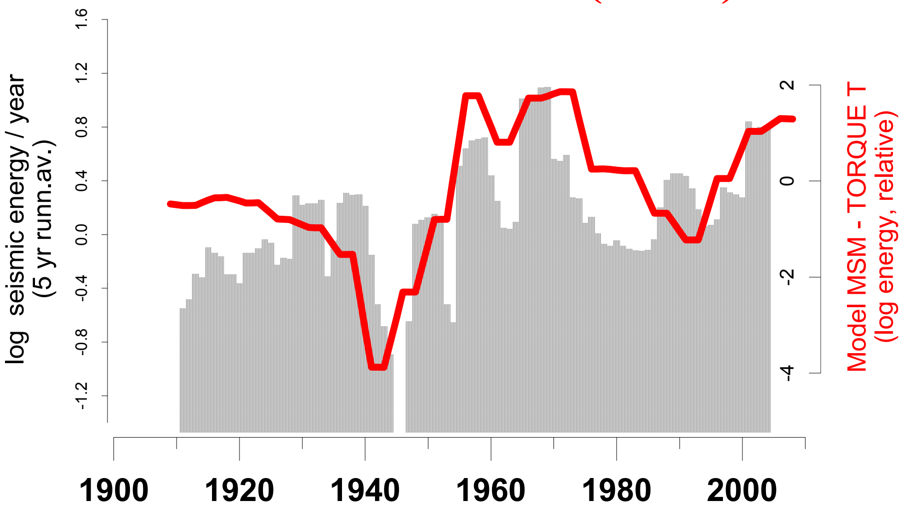
Courtesy of
Dr. Gerald Duma

Gradient ΔH calculated from IGRF 1900-2010 vs. Seismic energy release / year

BAIKAL

Earthquakes M ≥ 5

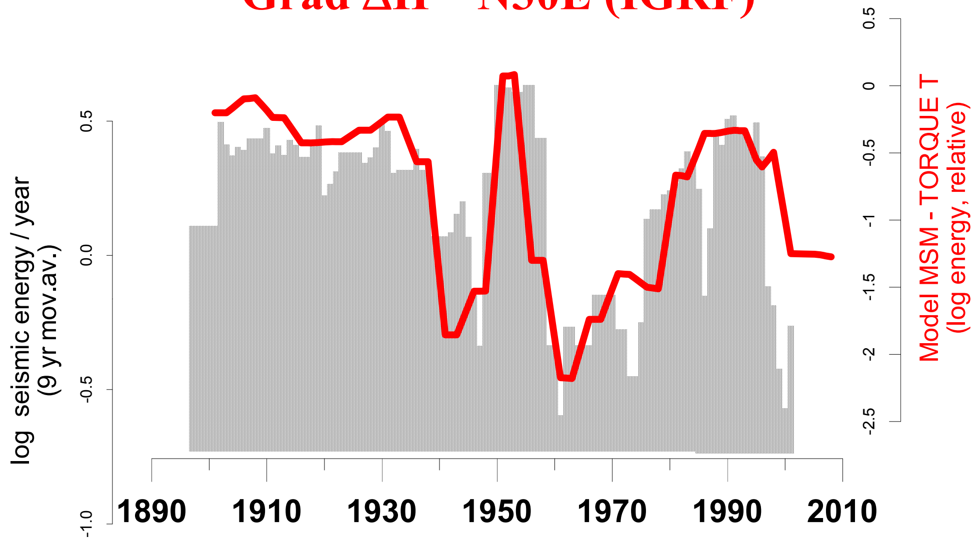
Grad ΔH – N00E (IGRF)



CALIFORNIA

Earthquakes M ≥ 6

Grad ΔH – N30E (IGRF)



Courtesy of
Dr. Gerald Duma

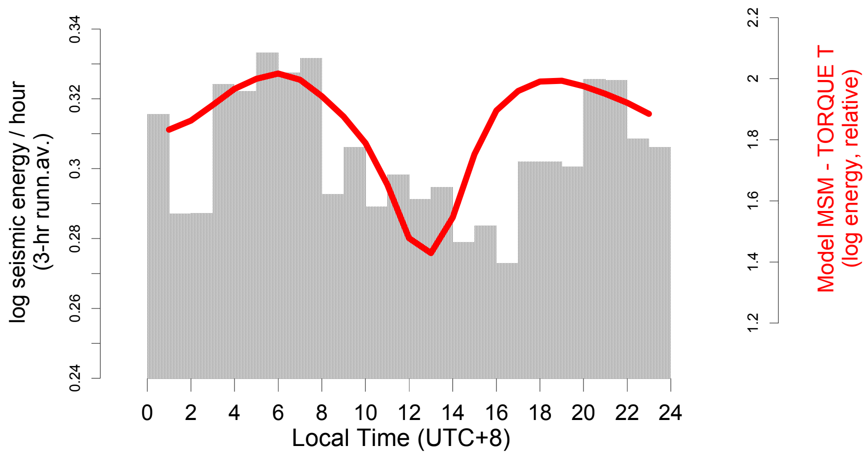
Gradient ΔH calculated from Sq-Model vs. Seismic energy release / hour LT

TAIWAN

Earthquakes M ≥ 5

Grad ΔH – N55E (Sq-Model)

1973 - 1998

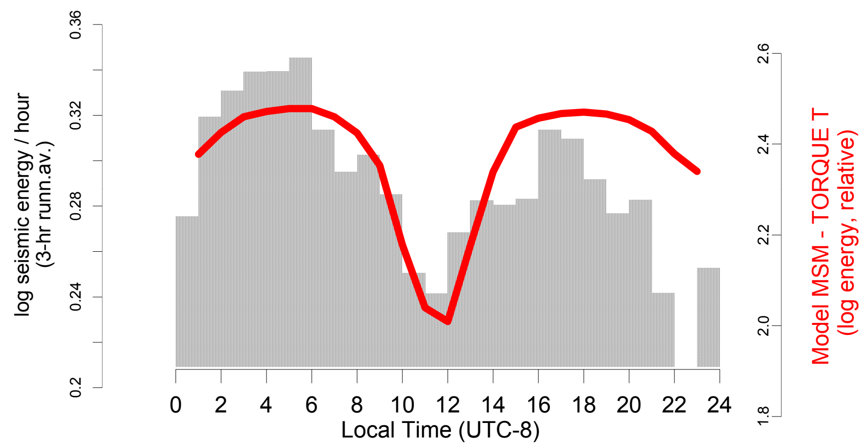


CALIFORNIA

Earthquakes M ≥ 6

Grad ΔH – N30E (Sq-Model)

1970 - 2005



Courtesy of
Dr. Gerald Duma

Triggering mechanism:

Stress due to the mechanic moment of Sq for a single loop

(Duma, Ruzhin, 2003)

Magnetic moment MM:

Diameter $D = 3000\ \text{km}$

Ring current $I = 10 * 10^3\ \text{A}$

$MM = \mu_0 * I * (D^2 * \pi / 4)$

$= 0.89 * 10^{11}\ \text{Am}^2 [= \text{Vsm}]$

Torque T:

$T = MM \times H$

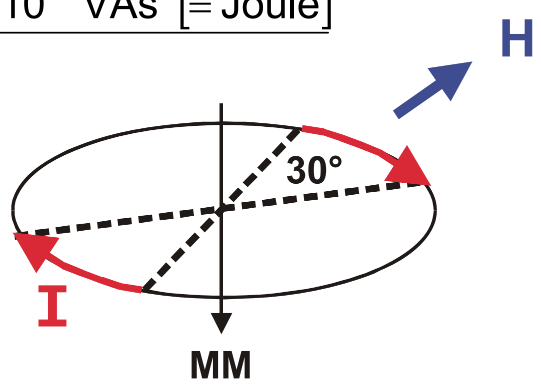
$= (0.89 * 10^{11})\ \text{Vsm} * 30\ \text{A/m}$

$= 26.6 * 10^{11}\ \text{VAs}\ [= \text{Joule}]$

Result:

Torque is equivalent to energy of an earthquake M 5.1

Energy concentrates to a 30° segment



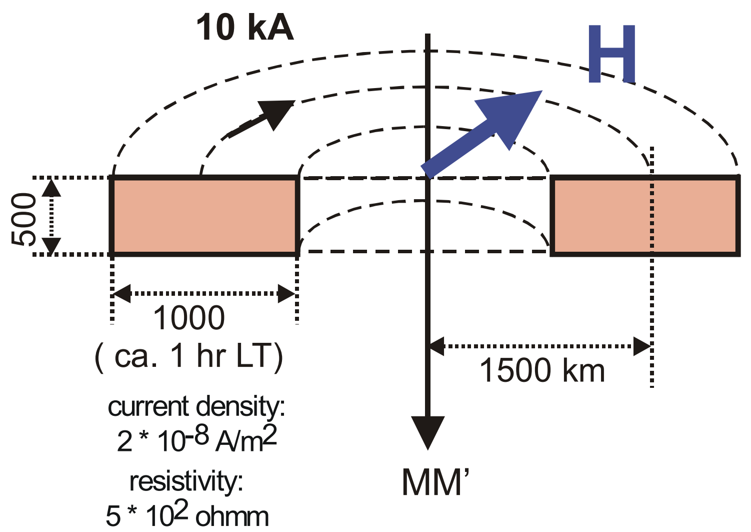


Table 1. Contribution of each current ring to the total magnetic moment of the current vortex (Fig. 12) and torques, generated by an average horizontal intensity of 30 000 nT of the Earth's magnetic field. The results reveal that even in a smaller circular area surrounding the center of the current system (which is at 32° geogr. latitude) considerable torques are generated, equivalent to the energy of a *M*4.7 or *M*5.5 earthquake (bold values)

Ring radius to vortex center (km)	Current (10^3 Amp)	Magnetic moment (10^{11} Am^2)	Torque (10^{12} Joule)	Equivalent magnitude (lgE = 4.8 + 1.5M)
3217	−15.9	6.5	19.4	5.7
2242	−36.5	7.2	21.7	5.7
1267	−53.0	3.4	10.1	**5.5**
292	−62.2	0.2	0.6	**4.7**
	total current system	17.3	51.9	5.9

The magnetic field intensity: $H = \dfrac{IR^2}{2\left(R^2 + z^2\right)^{1.5}}$ or $B(\mathrm{nT}) = \dfrac{200M\,(\mathrm{Am}^2)}{\left(R^2 + z^2\right)^{1.5}}$

z << *R* (ring radius): $B = B_{\max} \approx \dfrac{200M\,(\mathrm{Am}^2)}{R^3(\mathrm{m})} = \dfrac{200\pi I\,(\mathrm{A})}{R(\mathrm{m})}$

R=3.2<u>17</u>*10^6 m, I=1.6*10^4 A

$M = \pi R^2 I \approx 5.2*10^{17}$ A*m^2

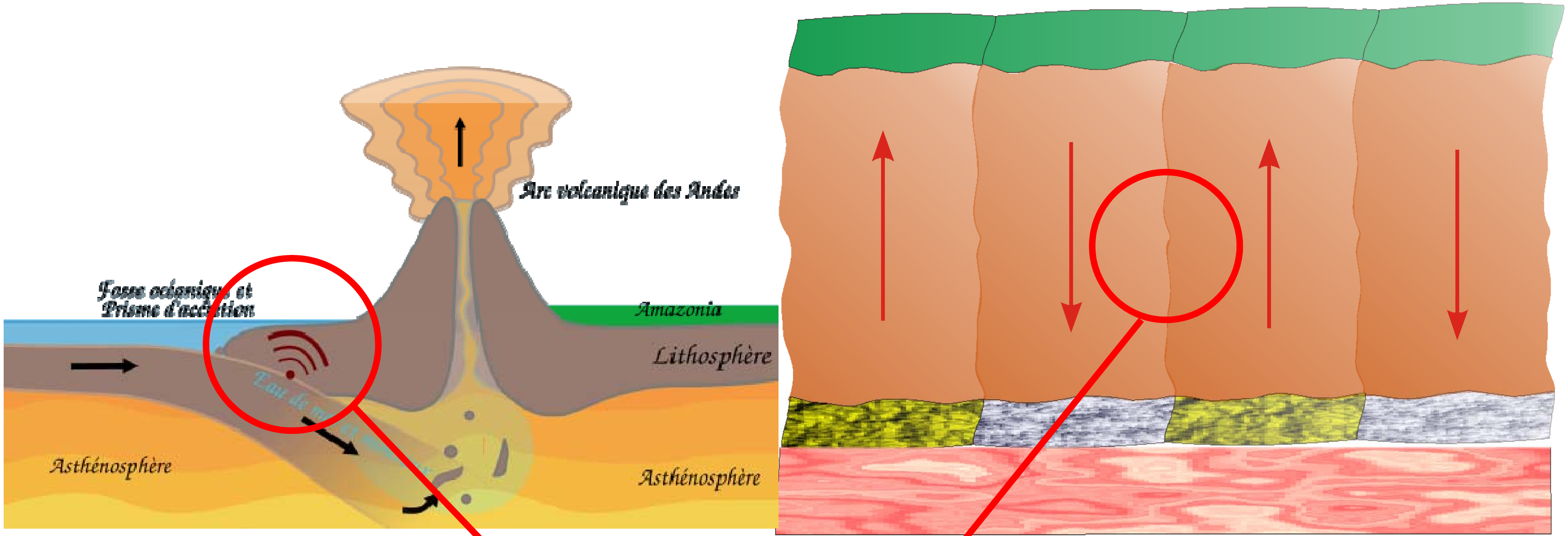
Torque: T=MB=**1.6*10^9 N*m**, [N*m]=[J],

To compare with erroneous result: T=MB=**1.94*10^{13} J!**.

No correlation between lunar tides, producing strongest stresses in Earth's crust, and earthquake activity.

Probably, no mechanical stress has to be considered as earthquake triggering mechanism.

Possible mechanism of earthquake triggering by magnetic field



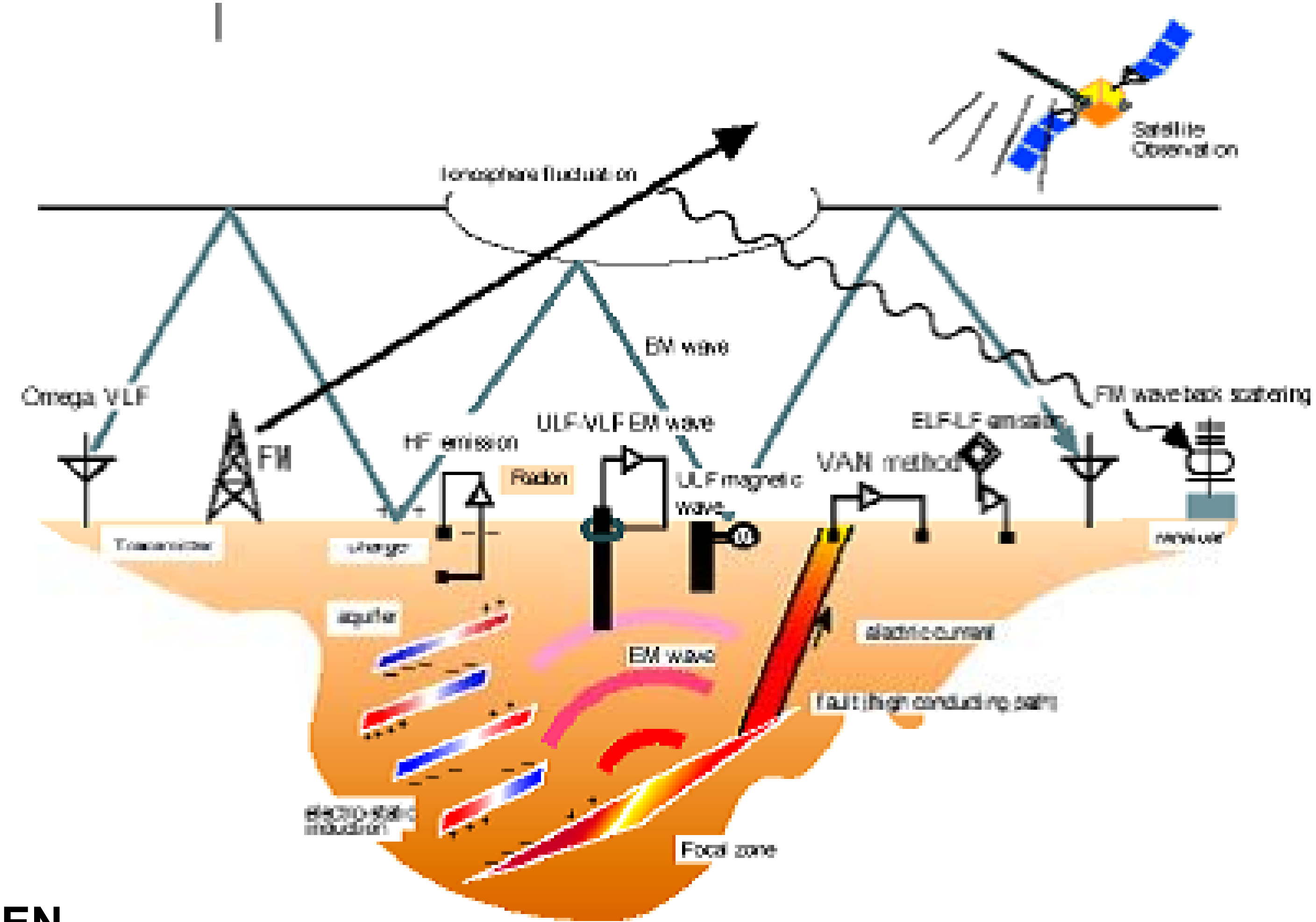
Magnetostriction ?

$K_m \approx 10^{-3}$ ppm/nT

(K. Yamazaki, S33B1307 Report, AGU Fall Meeting, 2007)


INFLUENCE FROM
“BELOW”

Earthquake precursors detection methods

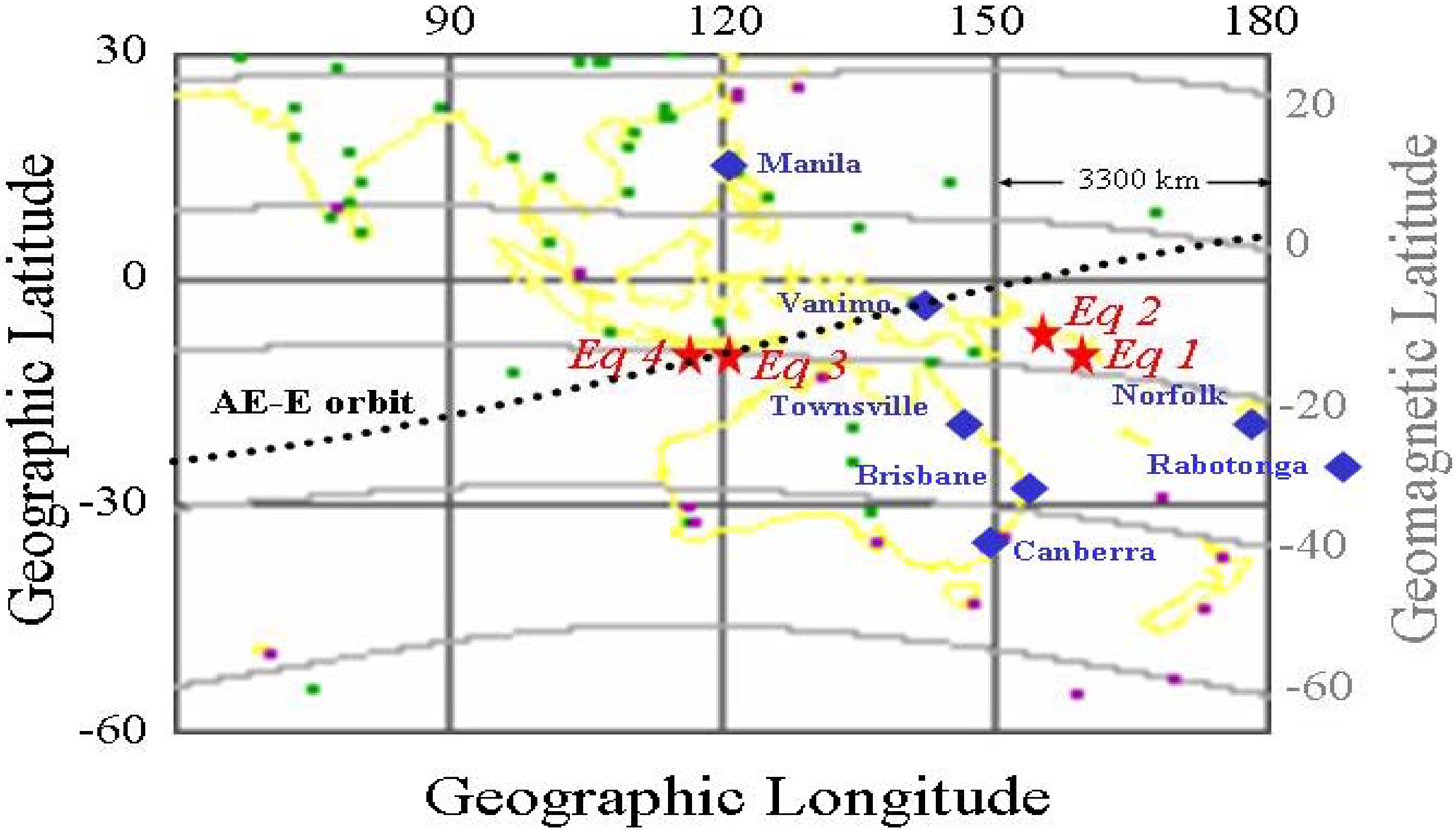


From RIKEN report

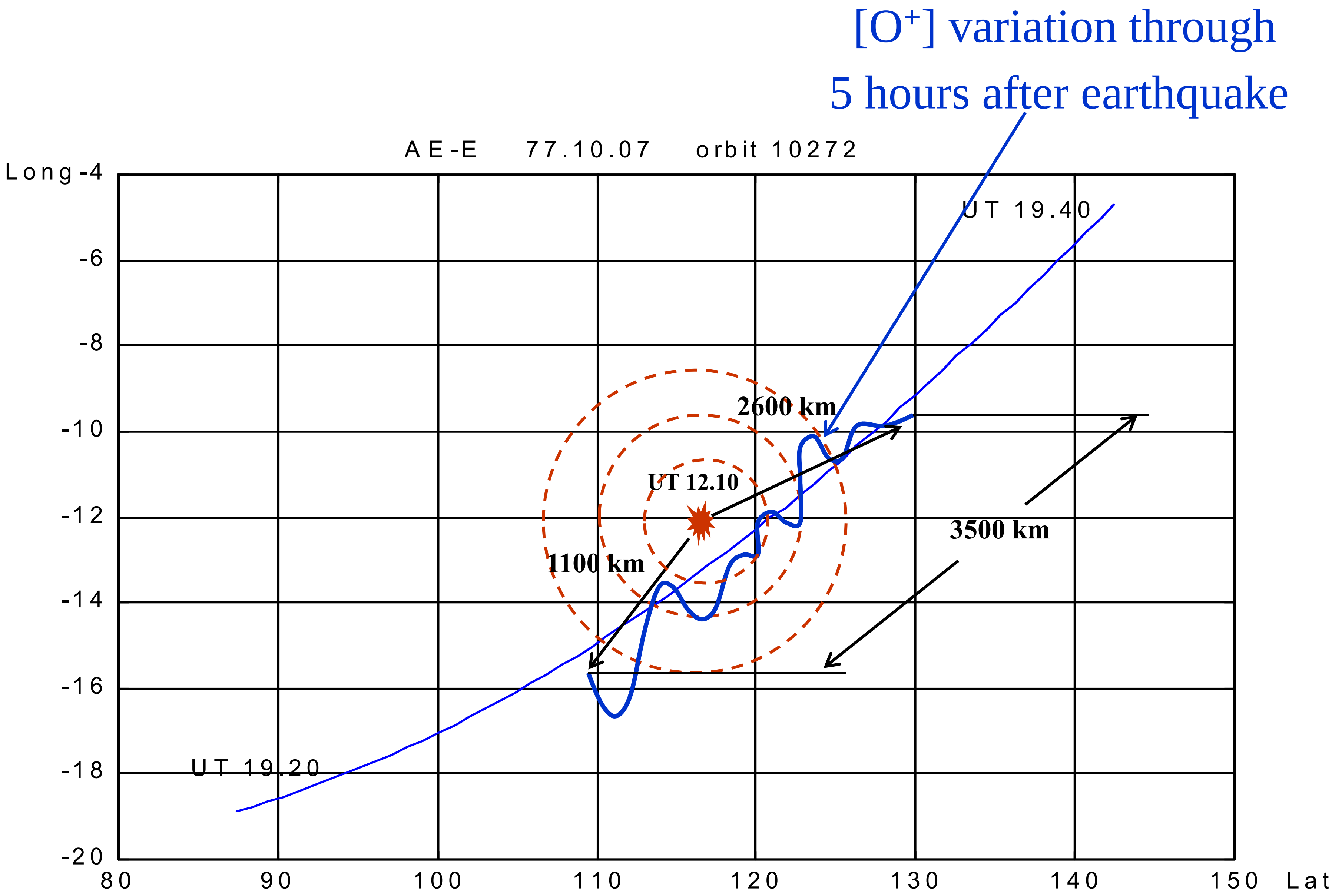
CO- AND POST-SEISMIC IONOSPHERIC PHENOMENA

Direct AGW/TID registration with "AE-E" satellite

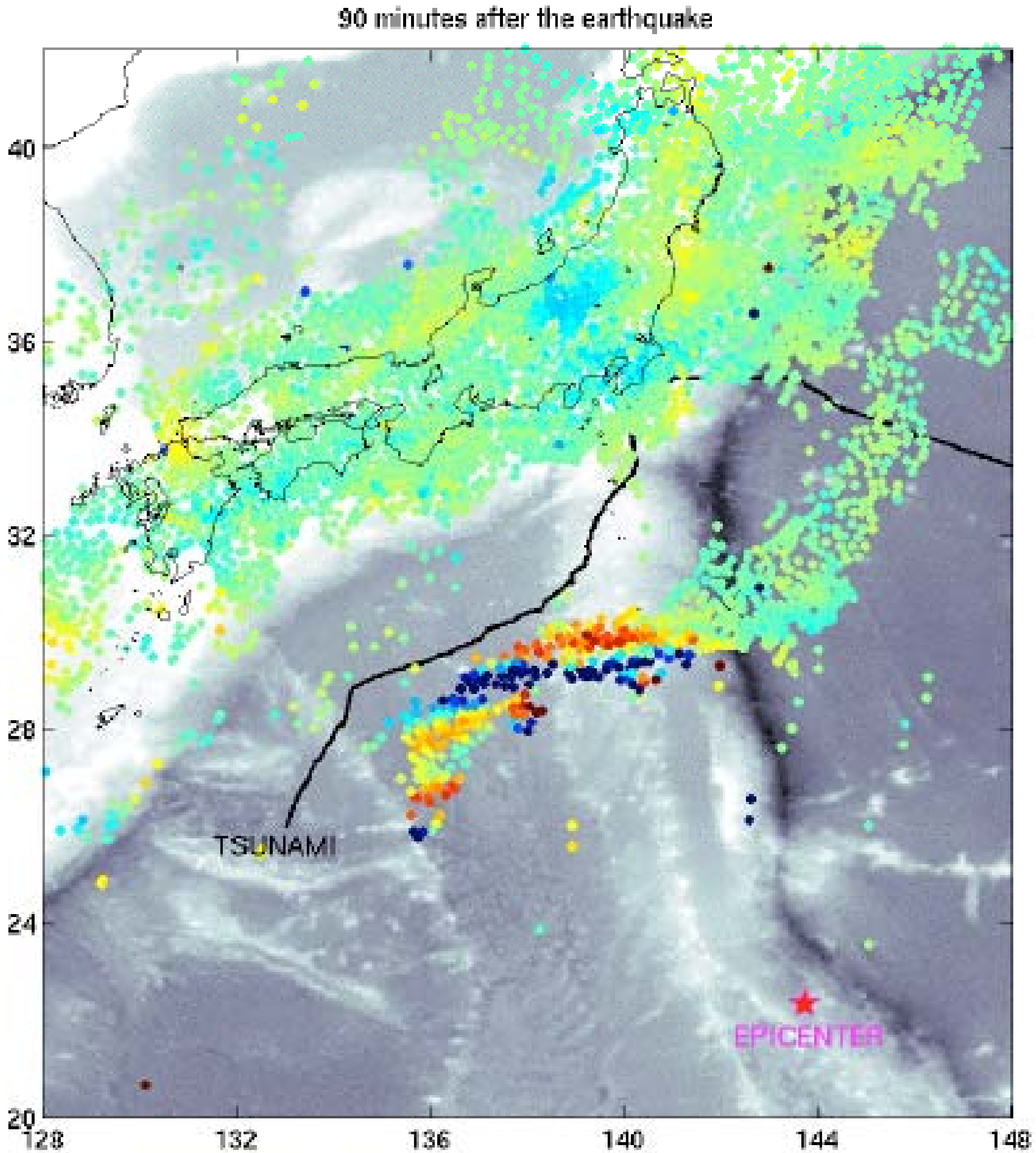
"Atmosphere Explorer - E"/ Mission of the beginning of 70-th.
Orbit: inclination 19 Degree, altitude 250-300 km.
Sensors for neutral and ionized atmosphere components.



Direct AGW / TID registration with “AE-E” satellite



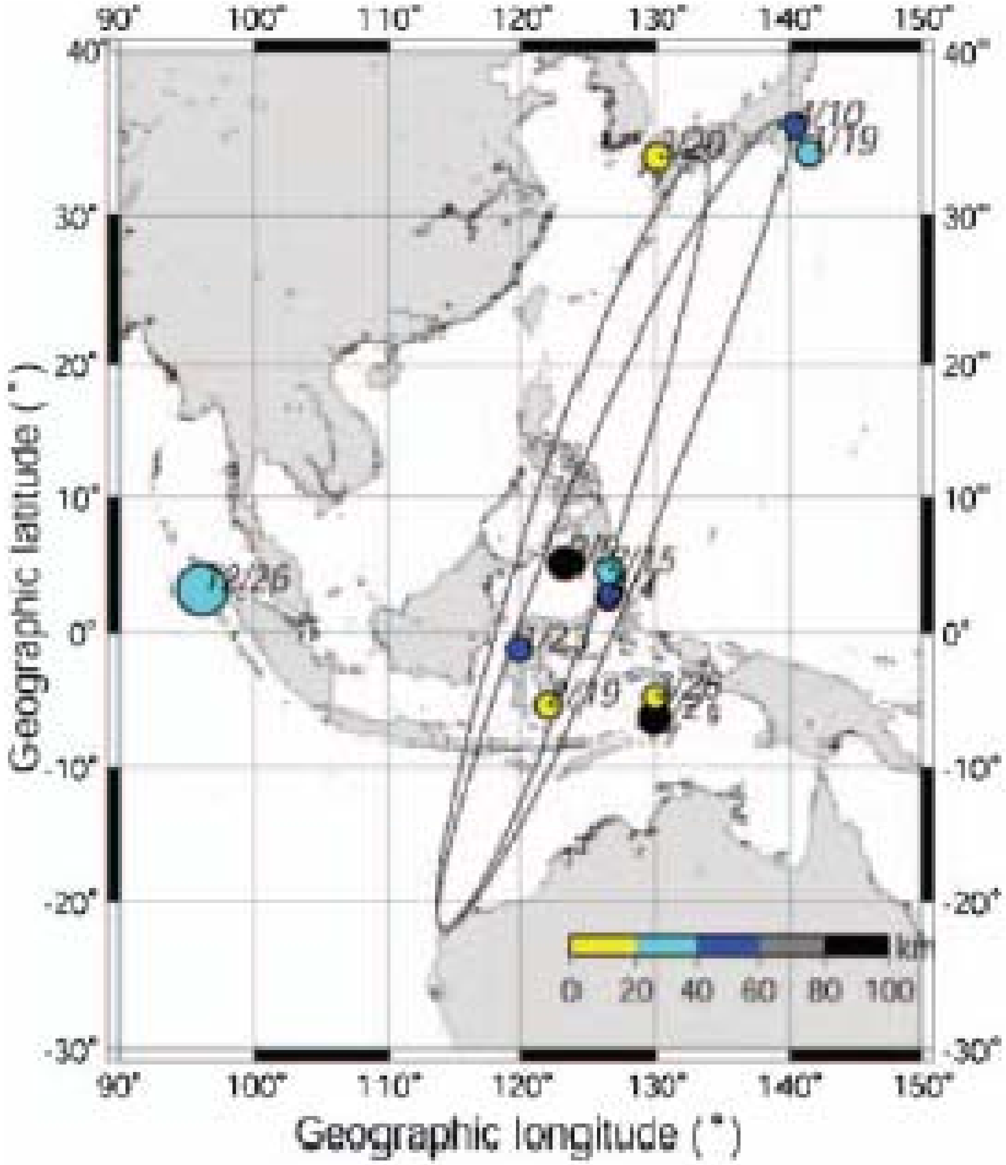
Post-seismic TEC variations



From J. Artru et al, Tsunami in the open ocean detected and imaged by GPS ionospheric monitoring

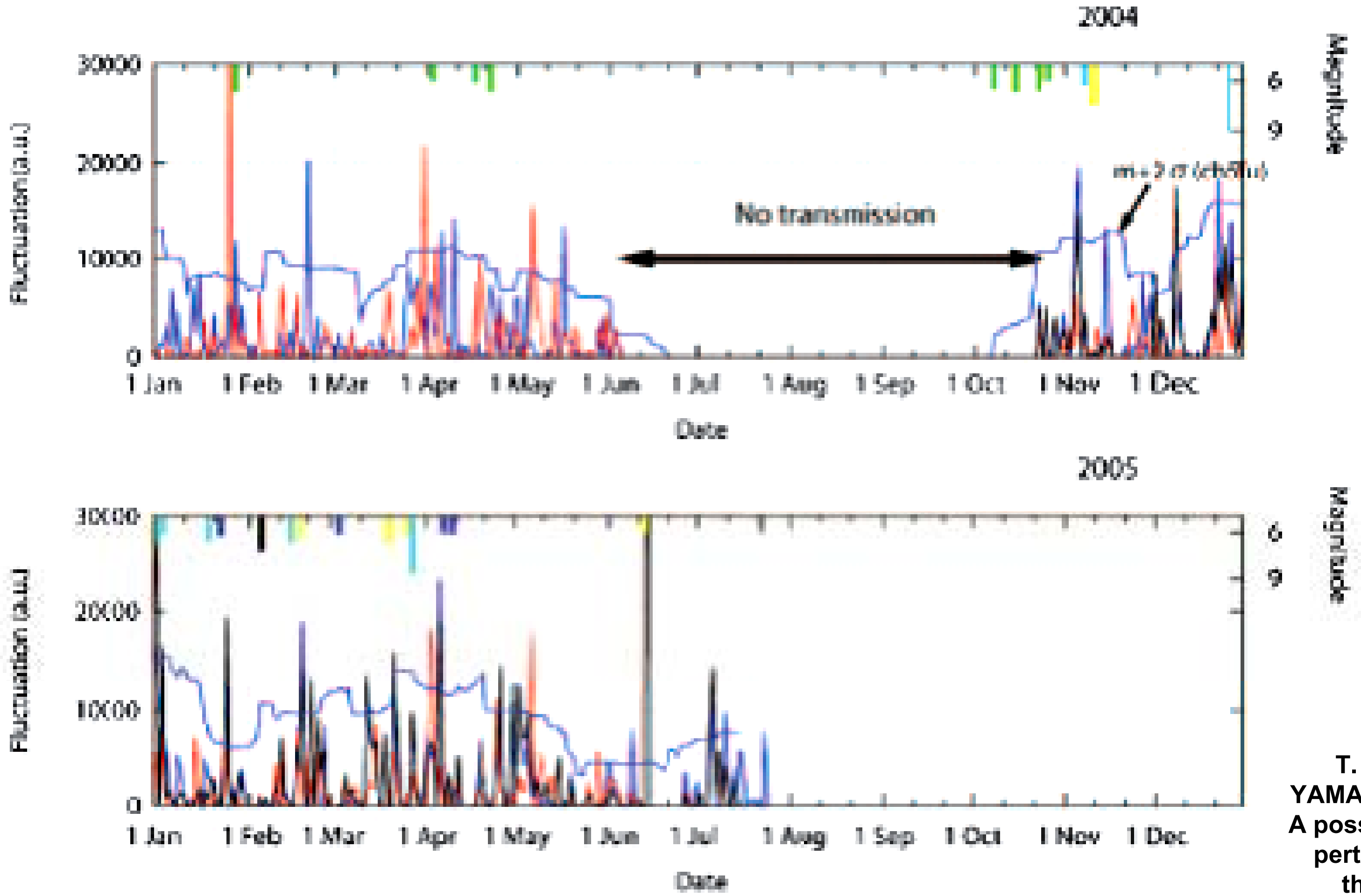
POSSIBLE SEISMIC EVENTS IONOSPHERIC PRECURSORS

Propagation paths from the transmitter, NWC (in Australia) to the two receiving sites (Kochi and Chofu)



T. HORIE*, S. MAEKAWA, T. YAMAUCHI and M. HAYAKAWA
A possible effect of ionospheric perturbations associated with the Sumatra earthquake, as revealed from subionospheric very-low-frequency (VLF) propagation (NWC-Japan)

Temporal evolution of the VLF amplitude night-time fluctuation (dA2) at the three observing stations, Chofu (Blue), Chiba (Black), and Kochi (Red)



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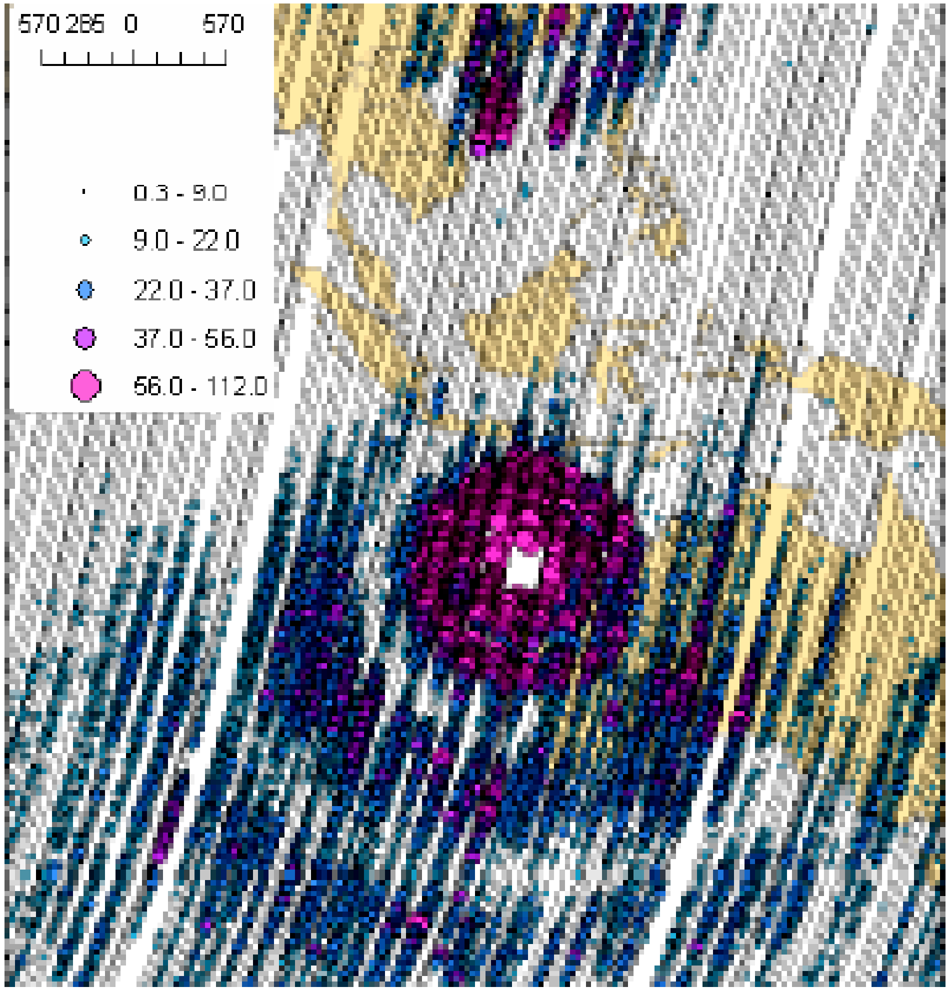
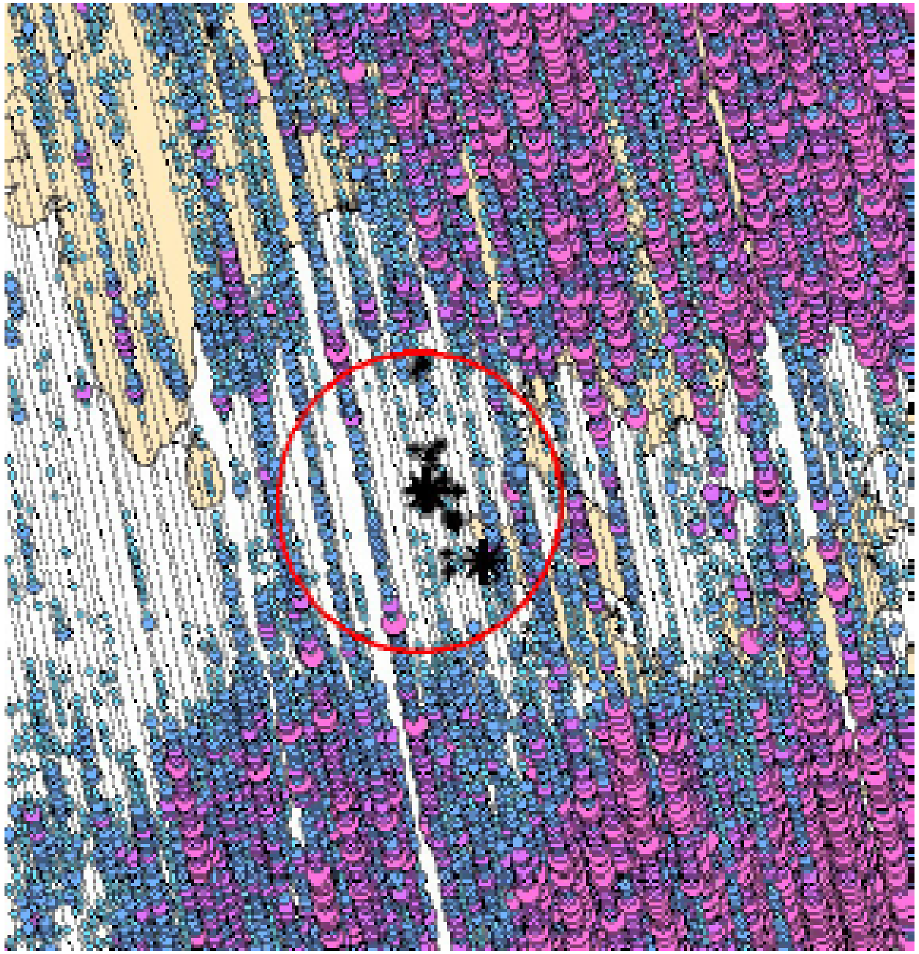
A possible effect of ionospheric perturbations associated with the Sumatra earthquake, as revealed from subionospheric very-low-frequency (VLF) propagation (NWC-Japan)

SNR distribution during two months of observation for NWC transmitter in Australia (F= 19.8 kHz) day-time orbits, LT~10.

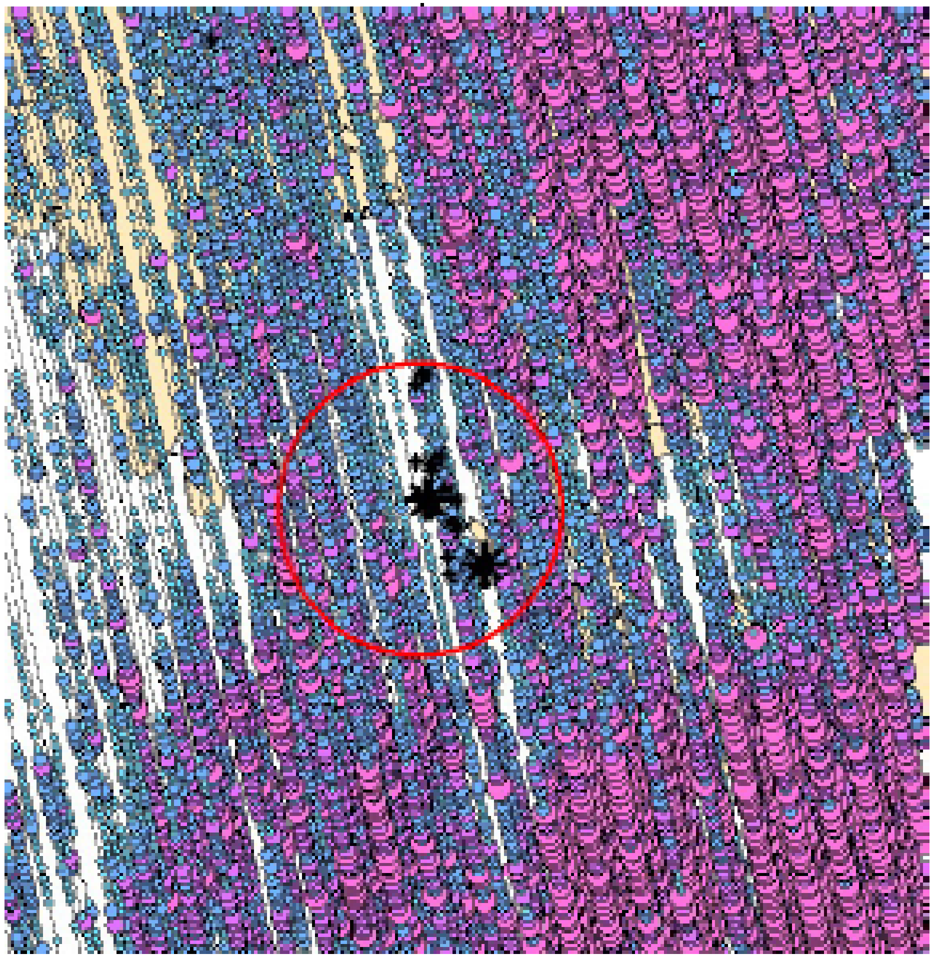


Courtesy of prof.
Oleg Molchanov

SNR values for NWC VLF transmitter (19.8 kHz) from November 1 to December 25, 2004 before Sumatra earthquake

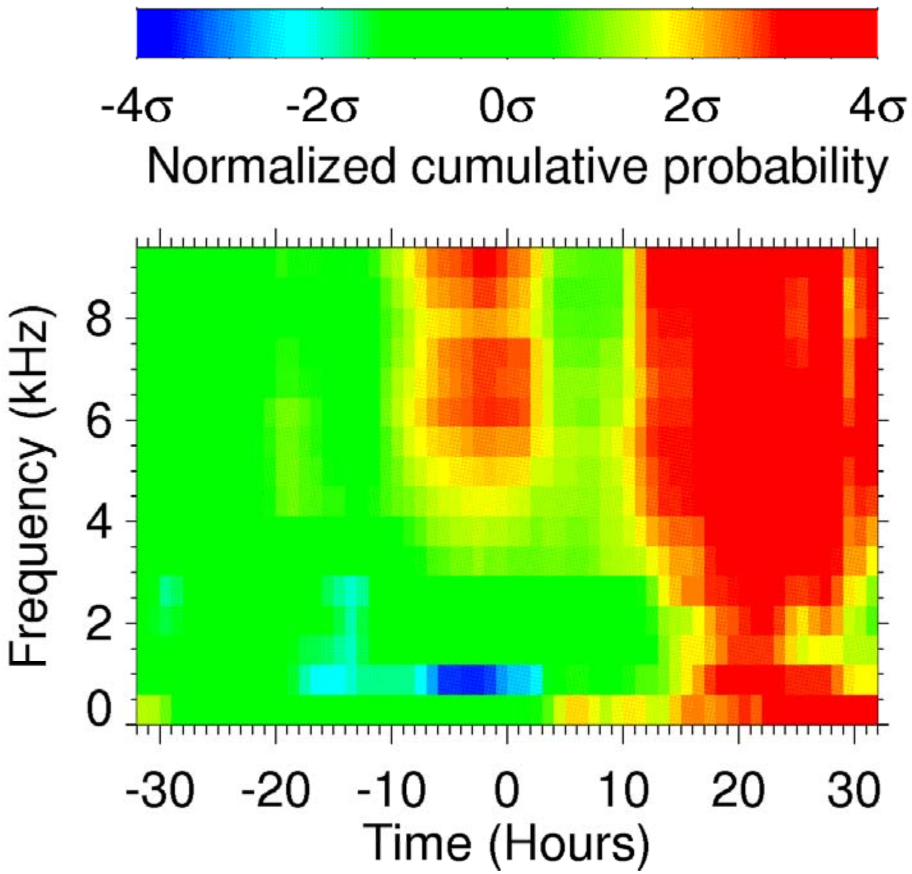


SNR values for NWC VLF transmitter (19.8 kHz) from January 6 to February 15, 2005 after Sumatra earthquake



Courtesy of prof. Oleg Molchanov

Méthode des époques superposées

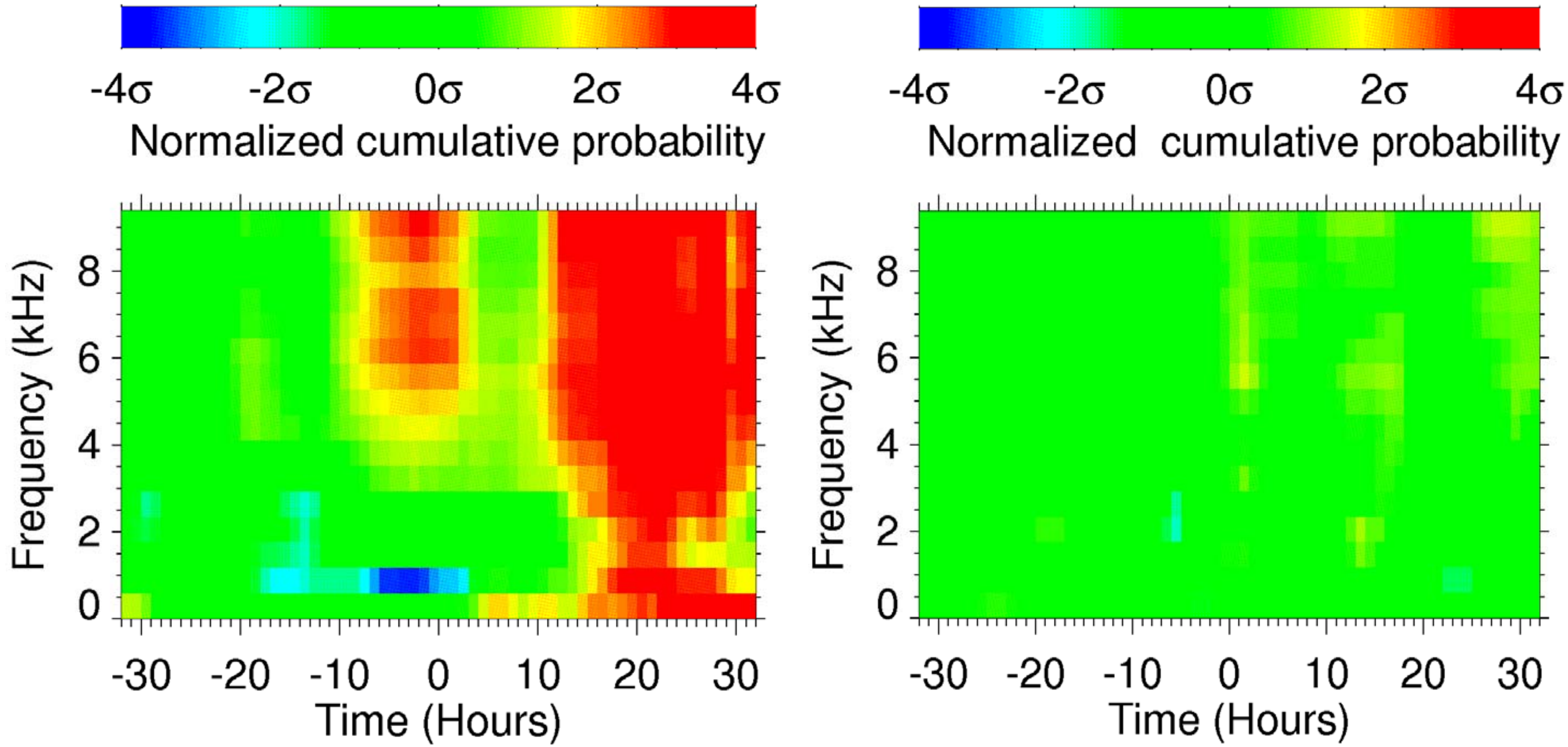


Distance
entre
l'épicentre et la
trace de l'orbite
< 700 km

Courtesy of
Dr. Michel Parrot

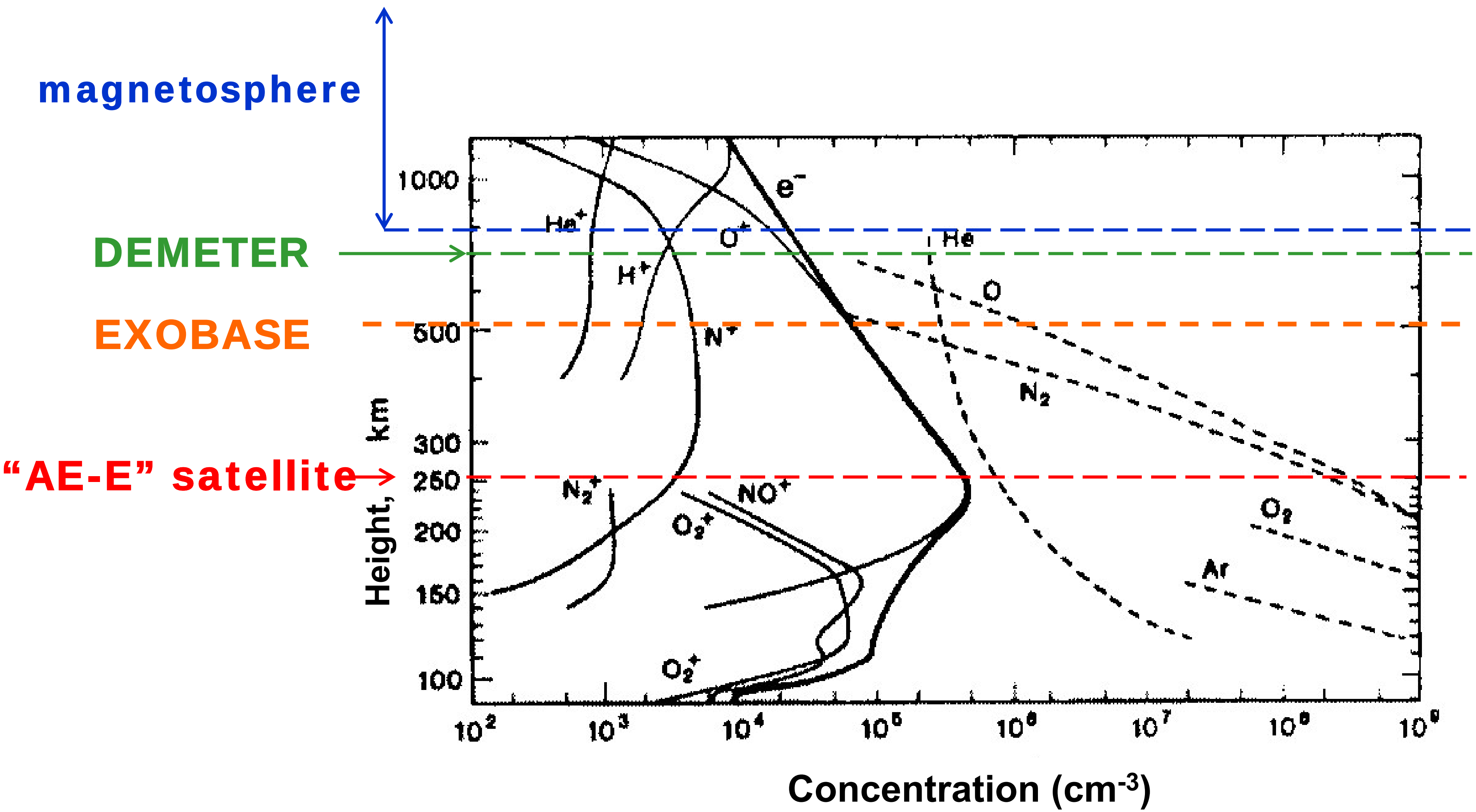
2628 séismes avec M > 4.8 et d < 40 km

2628 cas avec des temps et des positions
pris au hasard



Courtesy of
Dr. Michel Parrot

TIME DELAY EXPLANATION

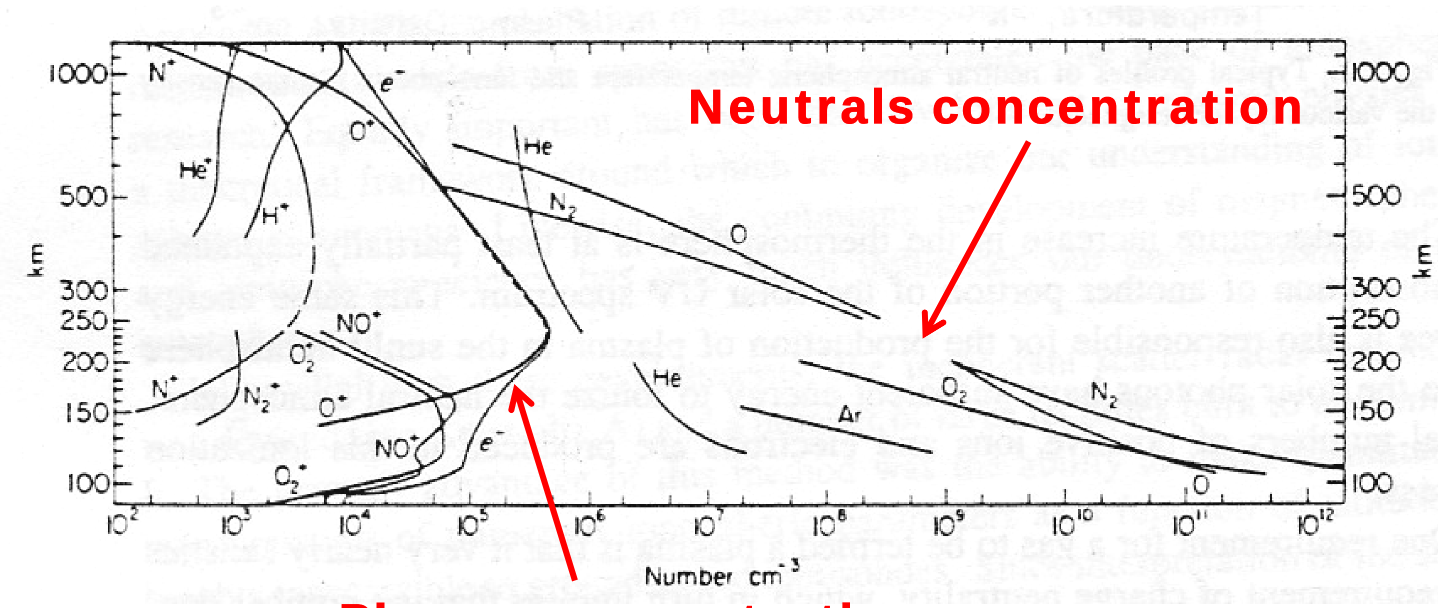


Possible mechanisms of energy transfer from lithosphere to ionosphere

- **Fair weather currents** → **affecting ionized ionosphere component**

- **Atmospheric gravity waves** → **affecting neutral ionosphere component**

Ionosphere composition



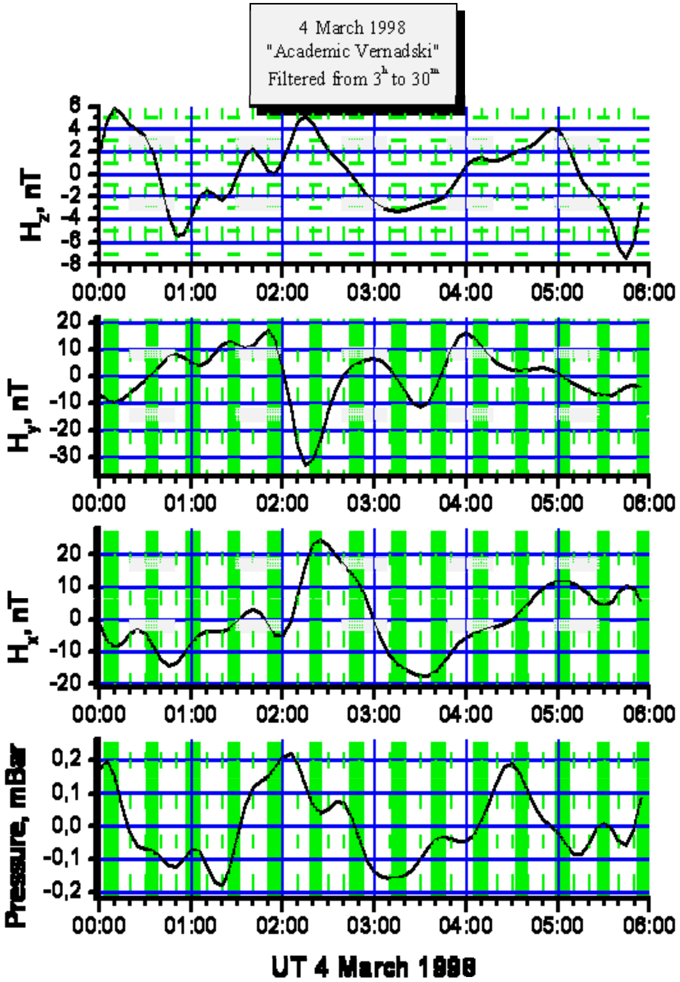
• Ionosphere is a small chemical additive to the neutral atmosphere.

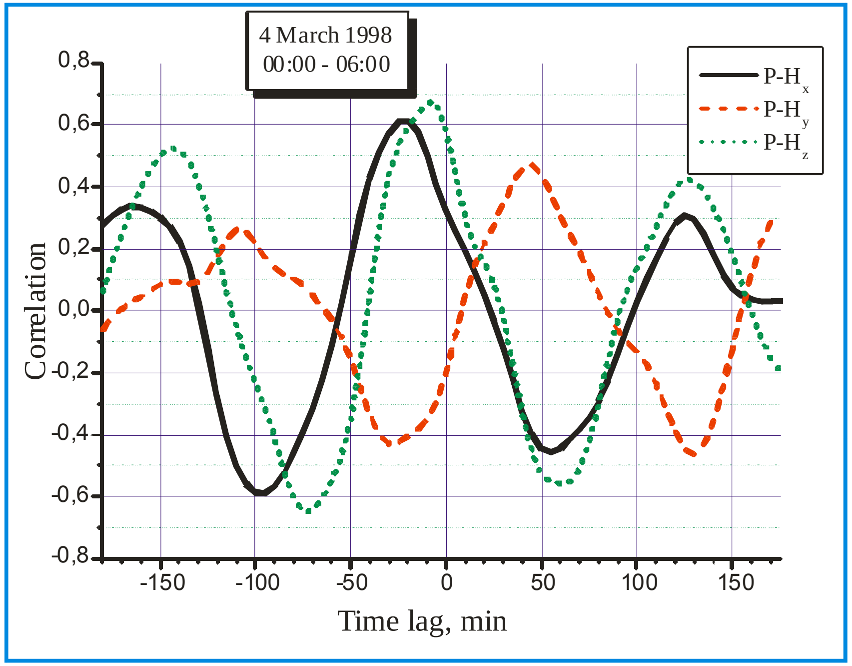
• That is why any even minor movements of neutral gas at ionospheric heights are strongly influencing ionospheric dynamics.

• Because of this AGW propagation are accompanied by corresponding periodic variations of plasma parameters.

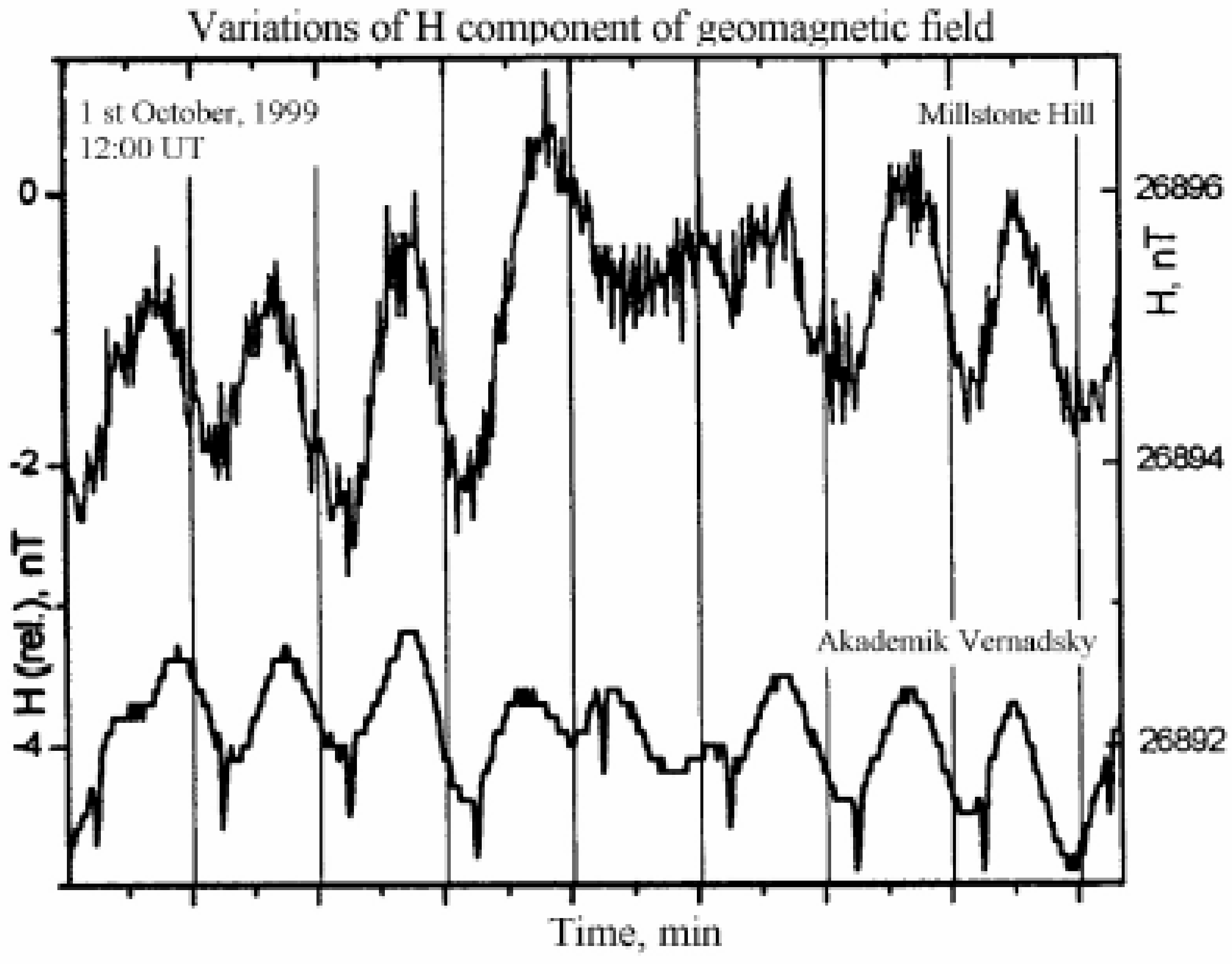
AGW EXPERIMENTAL STUDY

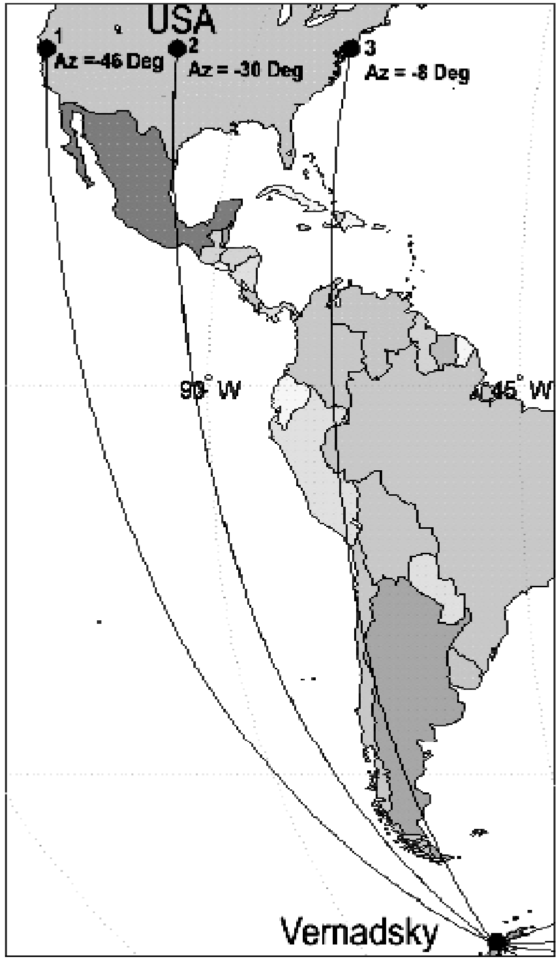
CORRELATION BETWEEN ATMOSPHERIC PRESSURE AND GEOMAGNETIC FIELD VARIATIONS





Variation of geomagnetic field at conjugated point





Neutral atmosphere - ionosphere coupling

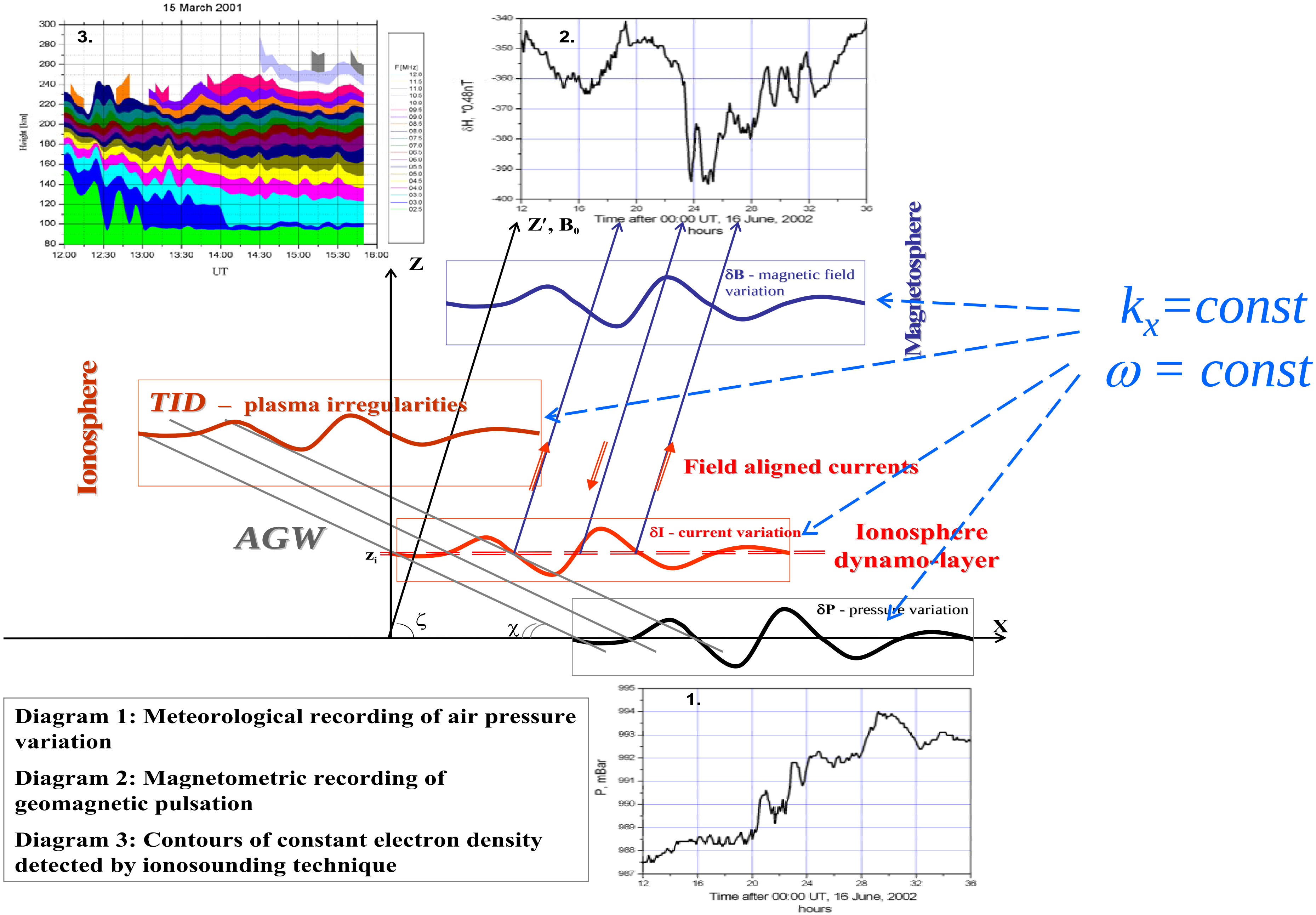


Diagram 1: Meteorological recording of air pressure variation

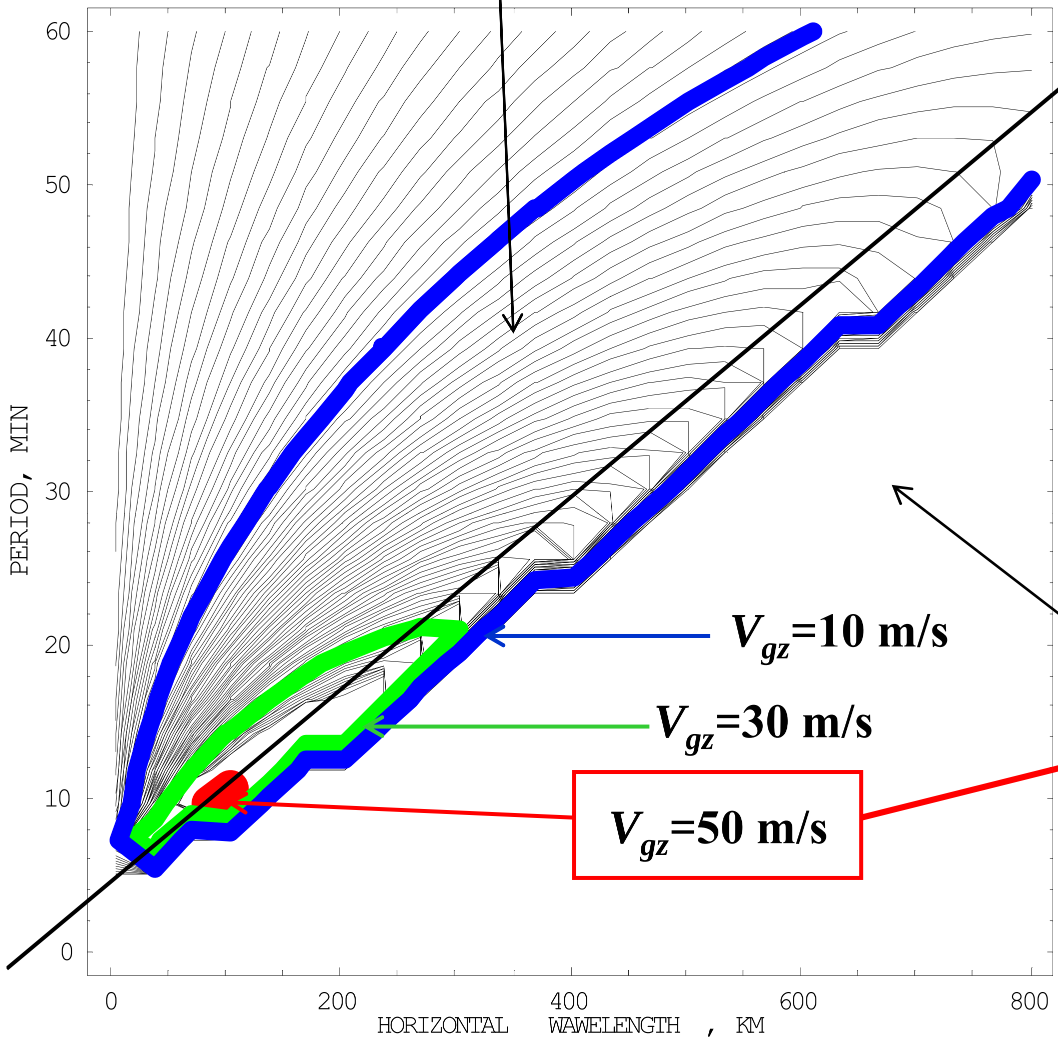
Diagram 2: Magnetometric recording of geomagnetic pulsation

Diagram 3: Contours of constant electron density detected by ionosounding technique

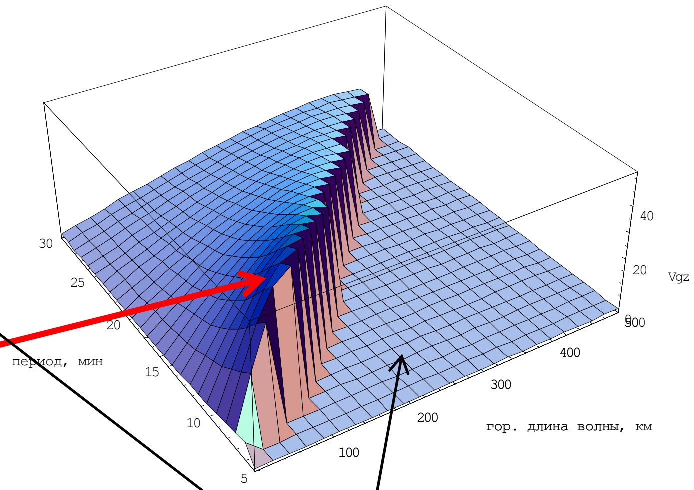
Theory. Atmosphere as a filter of AGW

AGW vertical group velocity

$$V_{gz} = \partial\omega / \partial k_z$$



Quick AGW.
Their horizontal
phase velocity is
$V_x = \lambda_x / T \sim 200$ m/s



Spectral region
forbidden for AGW

Theory. AGW magnetic signature

Let us consider ambient electric current in the ionosphere:

$$\vec{j} = \sum_{\alpha} e_{\alpha} n_{p} \vec{V}_{\alpha} = \hat{\sigma} \cdot \vec{E}_0$$

Then its change by AGW:

$$\delta\vec{j} = \sum_{\alpha} e_{\alpha} n_{p} \cdot \delta\vec{V}_{\alpha} + \delta\hat{\sigma} \cdot \vec{E}_0 + \hat{\sigma} \cdot \delta\vec{E}_0$$

Dynamo-current: ions are dragged by neutrals

Modification of **electric field distribution** in global electric circuit

Ambient **current variation** due to conductivity modulation

Theory. AGW magnetic signature

$$\delta B_Y = -\delta B_X = \frac{2\pi}{c} A_* I_g$$

where

$$A_* = A(z_i) = \left.\frac{\delta N}{N}\right|_{z=z_i} = \left.\frac{\delta N}{N}\right|_{z=0} \cdot \exp\left\{\int_0^{z_i} \frac{dz}{2H(z)}\right\}$$

- AGW amplitude at characteristic height z = 130 km

I_g – characteristic current depending on ionosphere parameters only

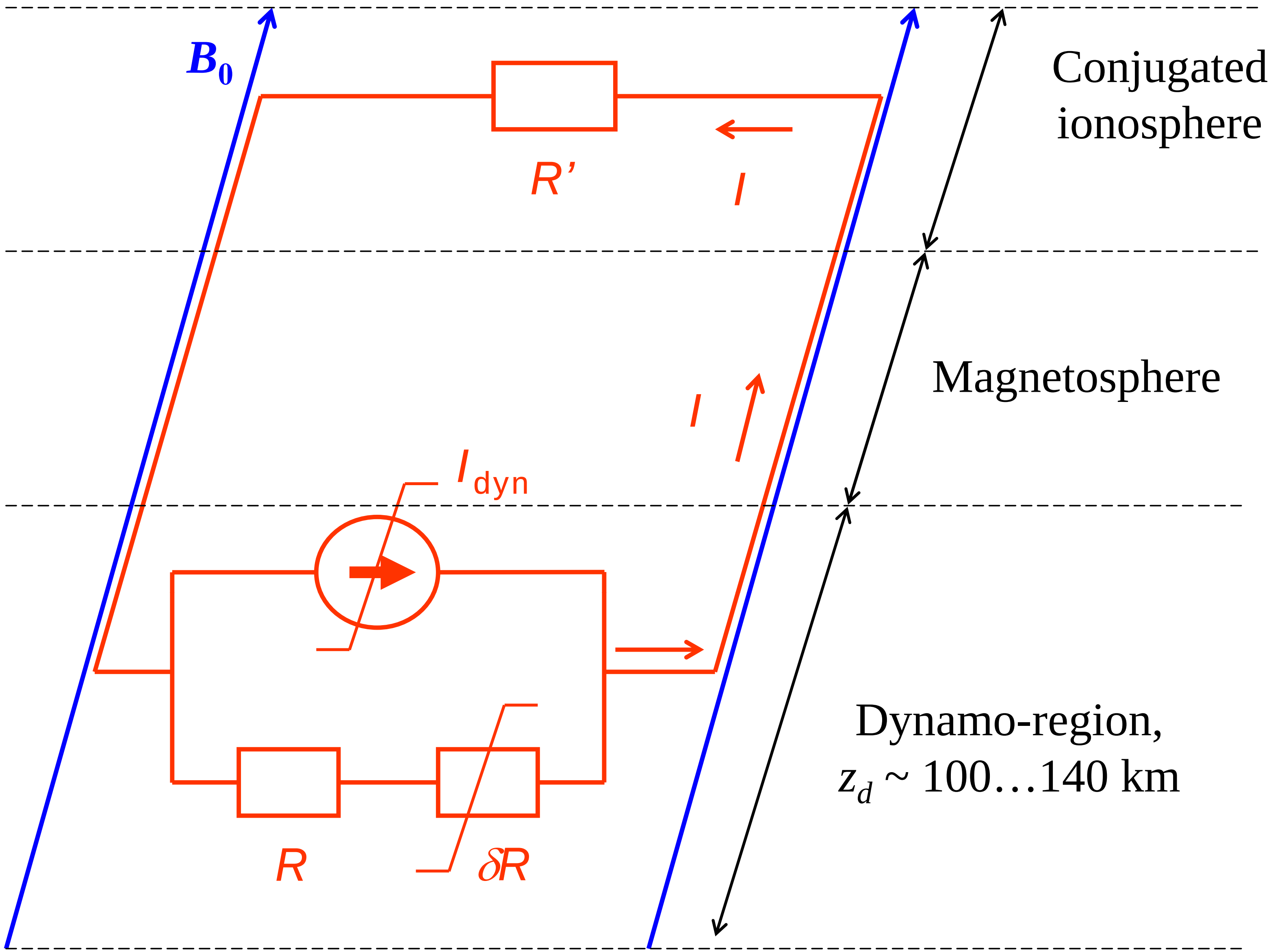
Theory. AGW magnetic signature

Numerical estimations

$n_p = 2{\cdot}10^4$ cm^{-3} (night)		$n_p = 2{\cdot}10^5$ cm^{-3} (day)	
$u_{AGW} = 10$ m/s (moderate)	$u_{AGW} = 70$ m/s (extreme)	$u_{AGW} = 10$ m/s (moderate)	$u_{AGW} = 70$ m/s (extreme)
$\delta B = 0.3$ nT	$\delta B = 2$ nT	$\delta B = 3$ nT	$\delta B = 20$ nT

Parameters are given for effective dynamo-current altitude $z = z_i \sim$ 130 km

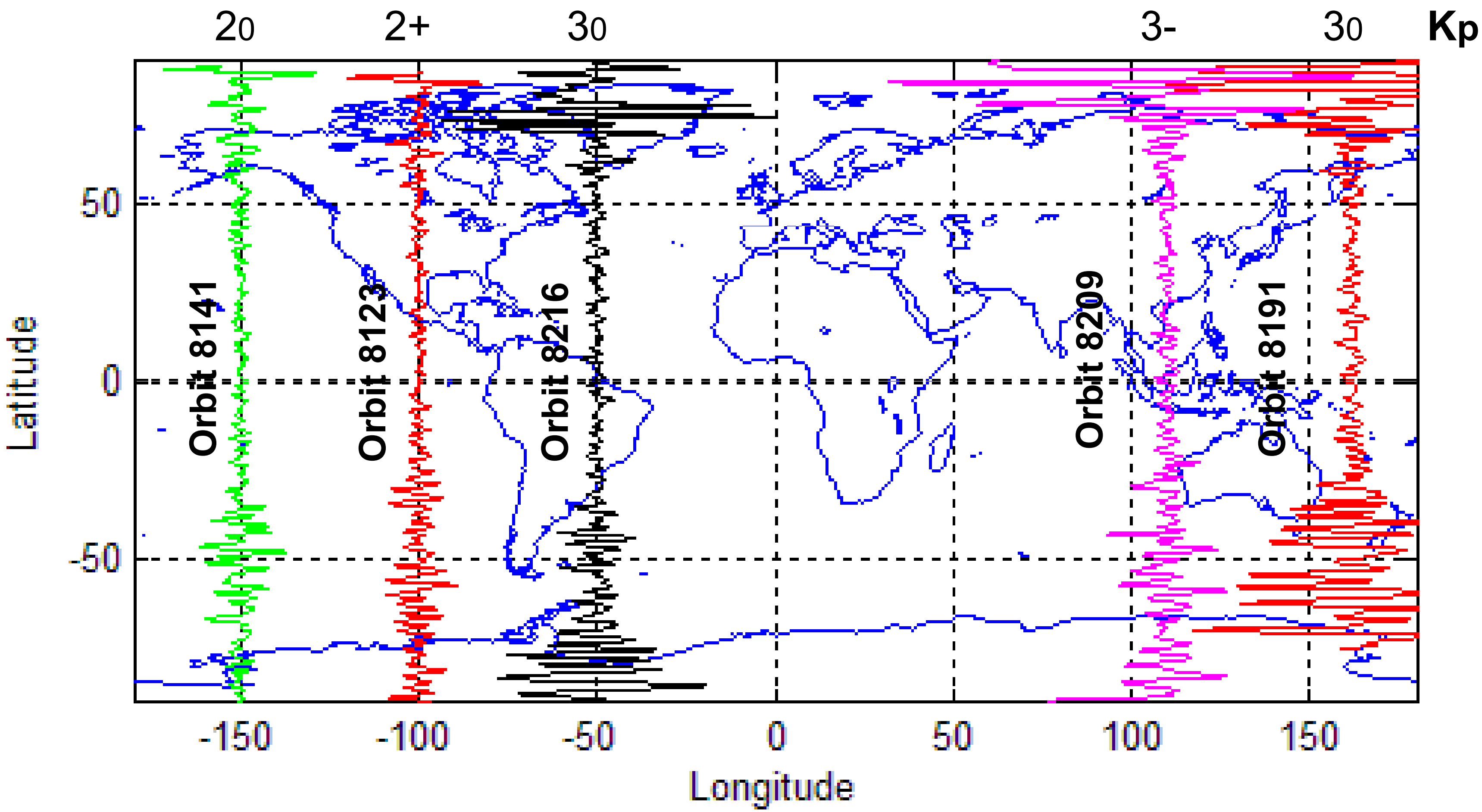
Theory. AGW magnetic signature in conjugated point



Auroral AGW propagation

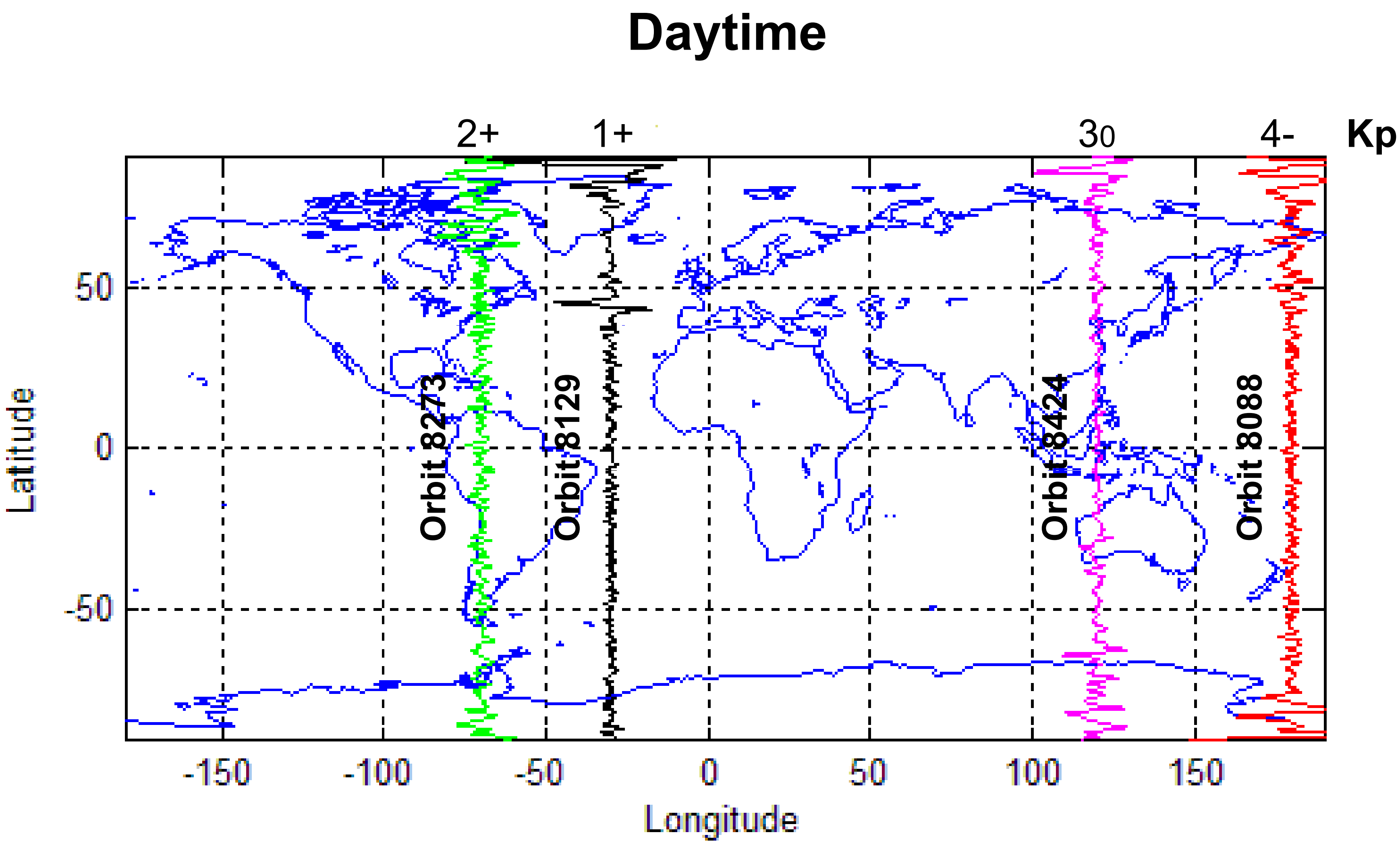
(after the data of DE-2 satellite)

Nighttime



Auroral AGW propagation

(after the data of DE-2 satellite)



Background and AGW intensity

Background		Auroral AGW-free sector		Seismogenic AGW ($M_{max} \approx 5,5$)	
Day	Night	Day	Night	Covered area	AGW amplitude
0,2-0,3%	0,4-0,5%	± 70°	up to ± 40°	$R_{max} \approx$3500 km 20% of ionosphere perturbed	< 1% night < 0,7% day

WDC for Seismology: 1983 year

4100 EQ with M > 4,5 → 3-5 times per day

1813 EQ with M > 5,0 → once per day

140 EQ with M > 6,0 → 1-2 times per month

Conclusions - 1:

The experimental results evidence that ionospheric response to seismic and meteorological processes occurs in a definite range of parameters that are characteristic for the middle-scale AGW/TID. So, we found that:

- **Atmosphere plays the role of filter that transmits upwards only sufficiently long and quick AGW;**
- **Seismic and meteorological AGW sources excite middle-scale TIDs in ionosphere.**

Conclusions -2:

- Horizontal AGW wavelength is 400…700 km, period ~ 1 hour;

- Relative AGW amplitude near the Earth surface is about 0.01%, at ionospheric heights about 1…10%;

- Relative TID amplitude reaches 20%, in variation of magnetic field component ~1…20 nT;

- At F-region altitudes the length of AGW/TID wave train is approximately 3000 km (five-six wave periods). The disturbances are shifted at a few thousand kilometers from the earthquake epicenters; they are registered through approximately 5 - 10 h after the shock.

Conclusions - 3:

- **Seismo-ionospheric coupling existence conclusively confirmed.**

- **AGW is the most probable energy carrier from lithosphere to ionosphere.**

- **Several sources of interference exist: background variations, auroral AGW propagating till mid-latitudes, especially at night time, terminator – generated AGW, etc.**

- **Still necessary to discover: statistics of background formation along seismically active and fault zones, the seismogenic AGW generation mechanism during earthquake preparation phase.**

Thermal gradient during EQ preparation phase – possible source of AGW generation

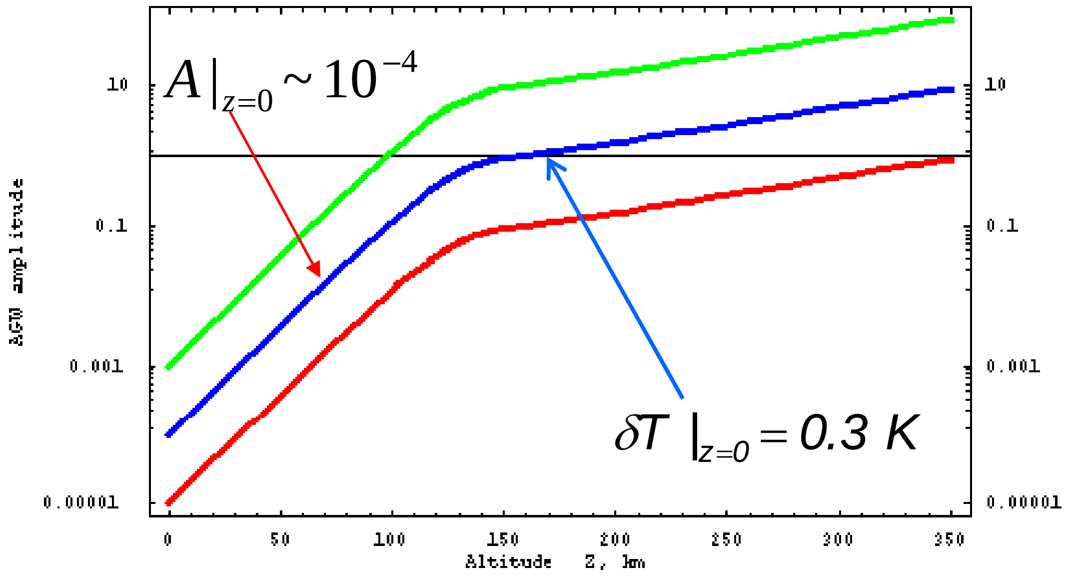
$$A_{AGW}(z) = A_0 \exp\{+z / 2H\}$$

Thermodynamics relation:

$$\frac{\delta\rho}{\rho} = \frac{1}{\gamma}\frac{\delta P}{P} = \frac{1}{\gamma - 1}\frac{\delta T}{T}$$

↓

$$A \equiv \delta\rho / \delta \sim \delta P / P \sim \delta T / T \sim \delta V$$



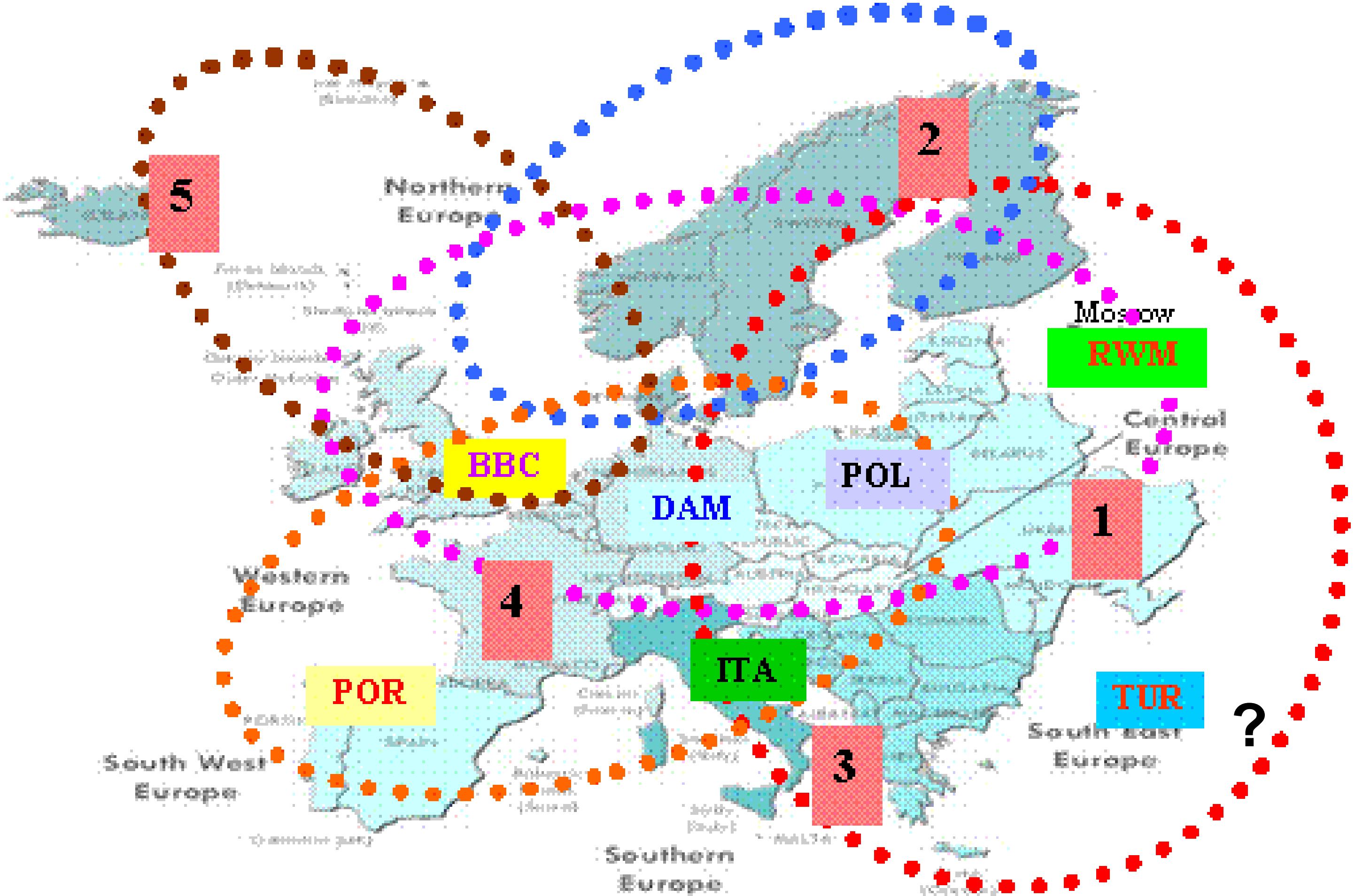
Thermal anomaly area ~ hundreds of km ~ middle-scale AGW

Future plans

- On-ground observations
- Satellite experiment

Frequency
Angular
Sounding of
Ionosphere

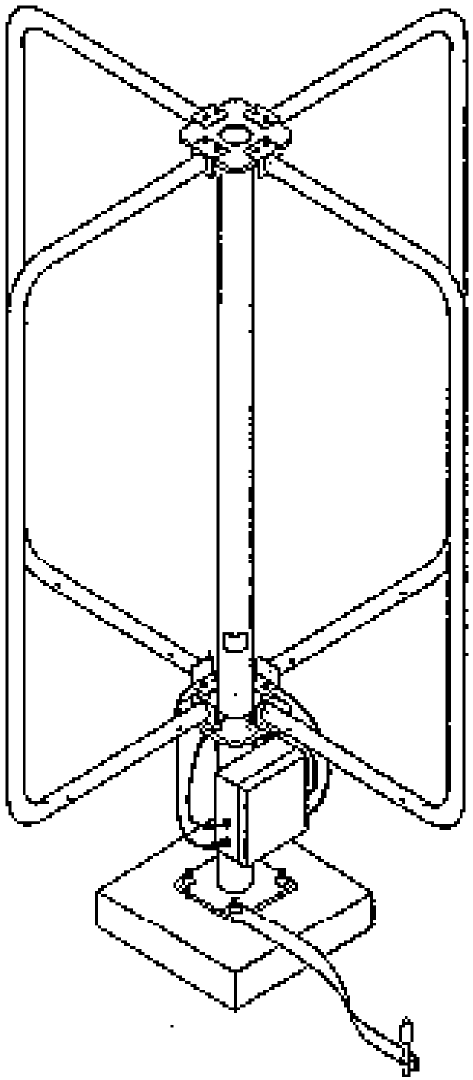
European FASI System for TID Diagnostic

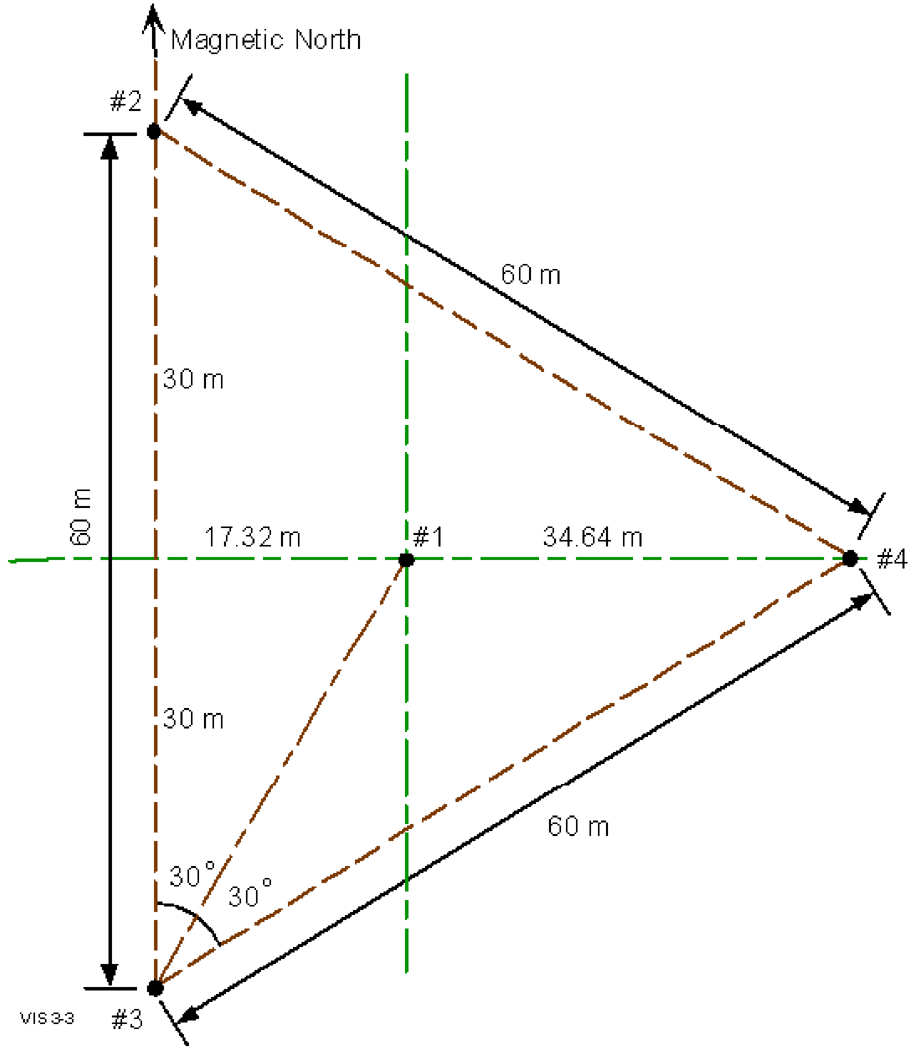


HF broadcasting stations:
BBC (UK), **RWM** (Russia), **ITA** (Italy), **POL** (Poland), **POR** (Portugal), **DAM** (Germany), **TUR** (Turkey)

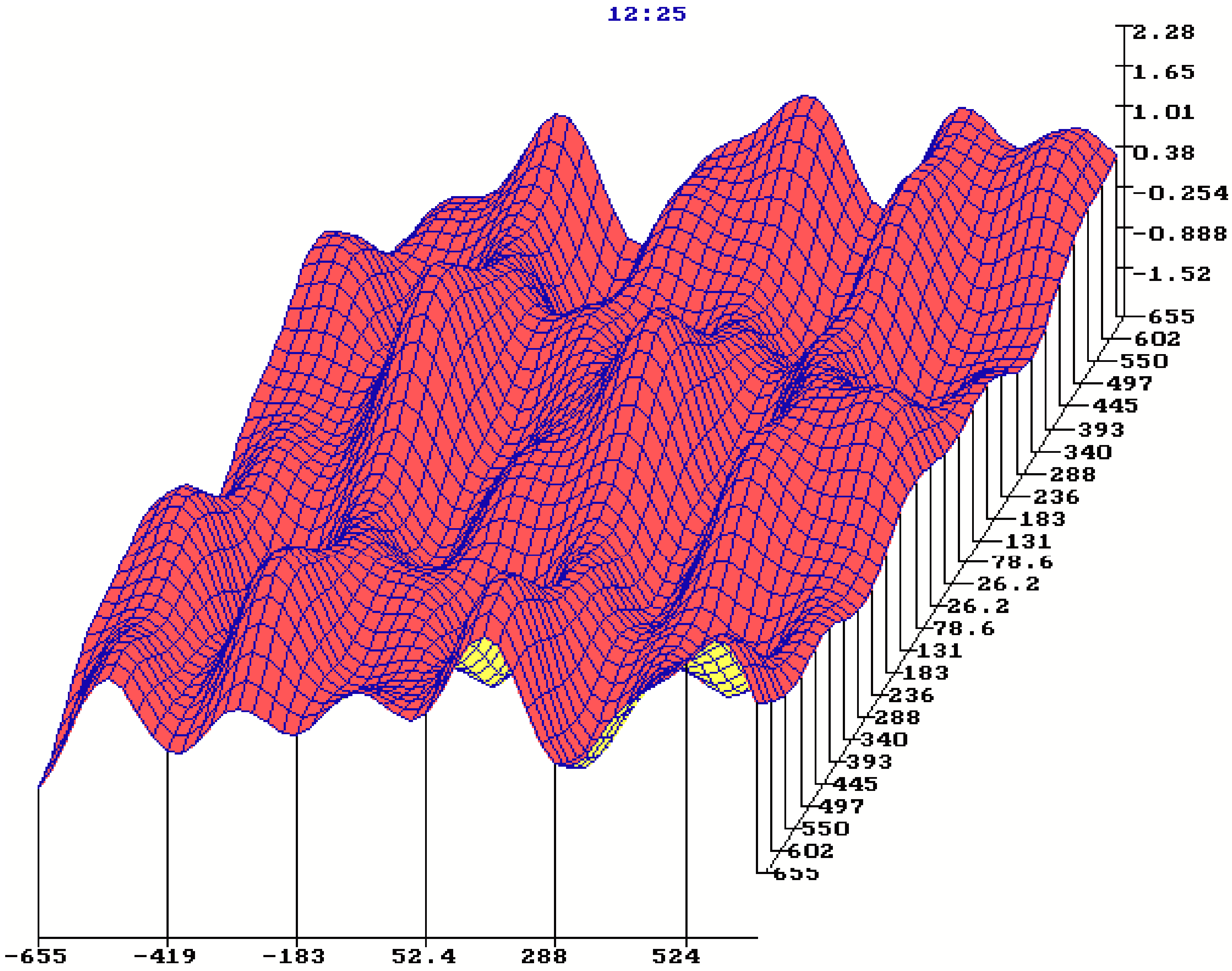
Receiving sites:
1-Ukraine, **2**-Norway (Finland), **3**-Italy (Greece), **4**-France, **5**-Iceland
? - Turkey

Separate antenna and reception antennae system configuration





A fragment of constructed “effective” reflecting surface for 12:25 UT 15.03.2001



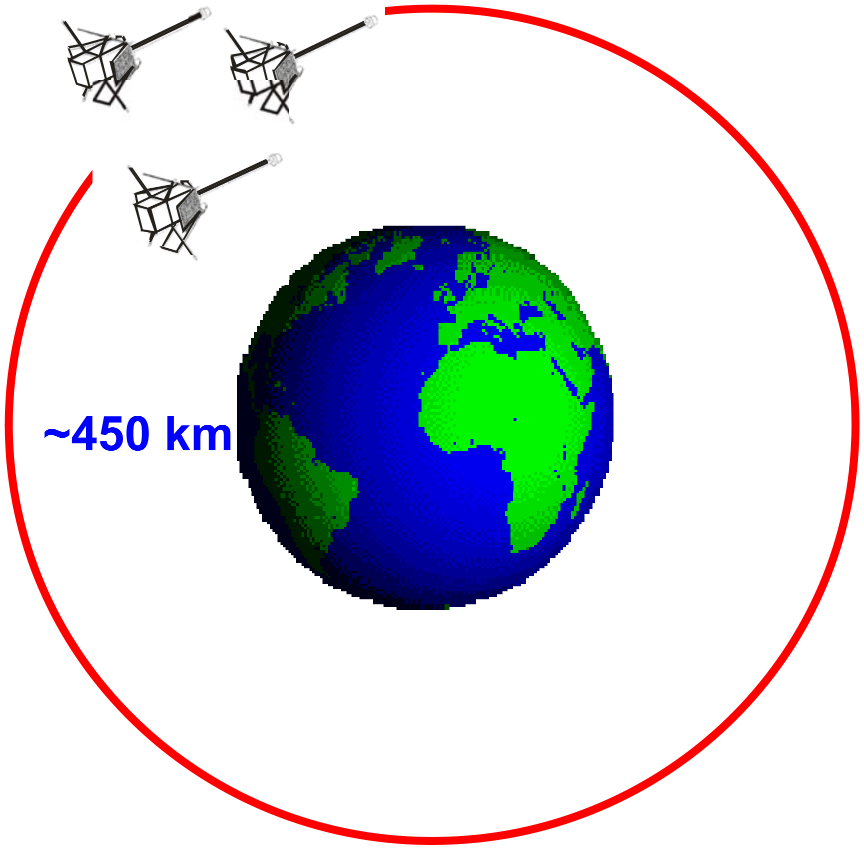
IONOSAT

National Space Agency of Ukraine satellite project proposed for First European Space Program

IONOSAT project main tasks

- **Scientific and methodological substantiation of the efficiency of the use of LEO satellites for SW monitoring, corresponding technological realization development and tests.**
- **Systematic study of the dynamic response of the ionosphere to the influences “from above” (solar and geomagnetic activity) and “from below” (meteorological, seismic and technologic processes).**
- **Spatial-temporal monitoring of ionospheric disturbances with the aim to extract the signatures of natural and technogenic catastrophic events in the lower atmosphere and at the Earth’s surface.**

IONOSAT experiment



Tentative launch date: 2012

Mean orbit altitude: ~ 450 km

Orbit inclination: ~ 83°

Distance between satellites:

50-3000 km

Optimal project realization schedule

2008	2009-2010	2011-2012
Decision-making, sending of invitations, feasibility study. (Stage A)	Development and manufacturing of the devices, autonomous tests. (Stage B)	Assembling, assembly testing and launch. (Stage C)

PARTICIPATION PROPOSALS ARE WELCOME

vakor@isr.lviv.ua

THANK YOU

FOR ATTENTION!