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Advanced School on Understanding and Prediction of Earthquakes and other Extreme Events in Complex Systems

26 September - 8 October, 2011

Comparison between Nuclear and other Physico Chemical Candidates as Earthquake Precursors Part 1 - Part 2

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Comparison between Nuclear and other Physico-Chemical Candidates as Earthquake Precursors

Part 1 - Part 2

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Outline

- EM Precursors

- Hydrogeochemical Precursors

- Radon

...to be continued

SEISMOELECTROMAGNETIC RESEARCH

LITHOSPHERE

- DC Electric Field variations
- ULF,VLF emissions
- ULF polarization

IONOSPHERE

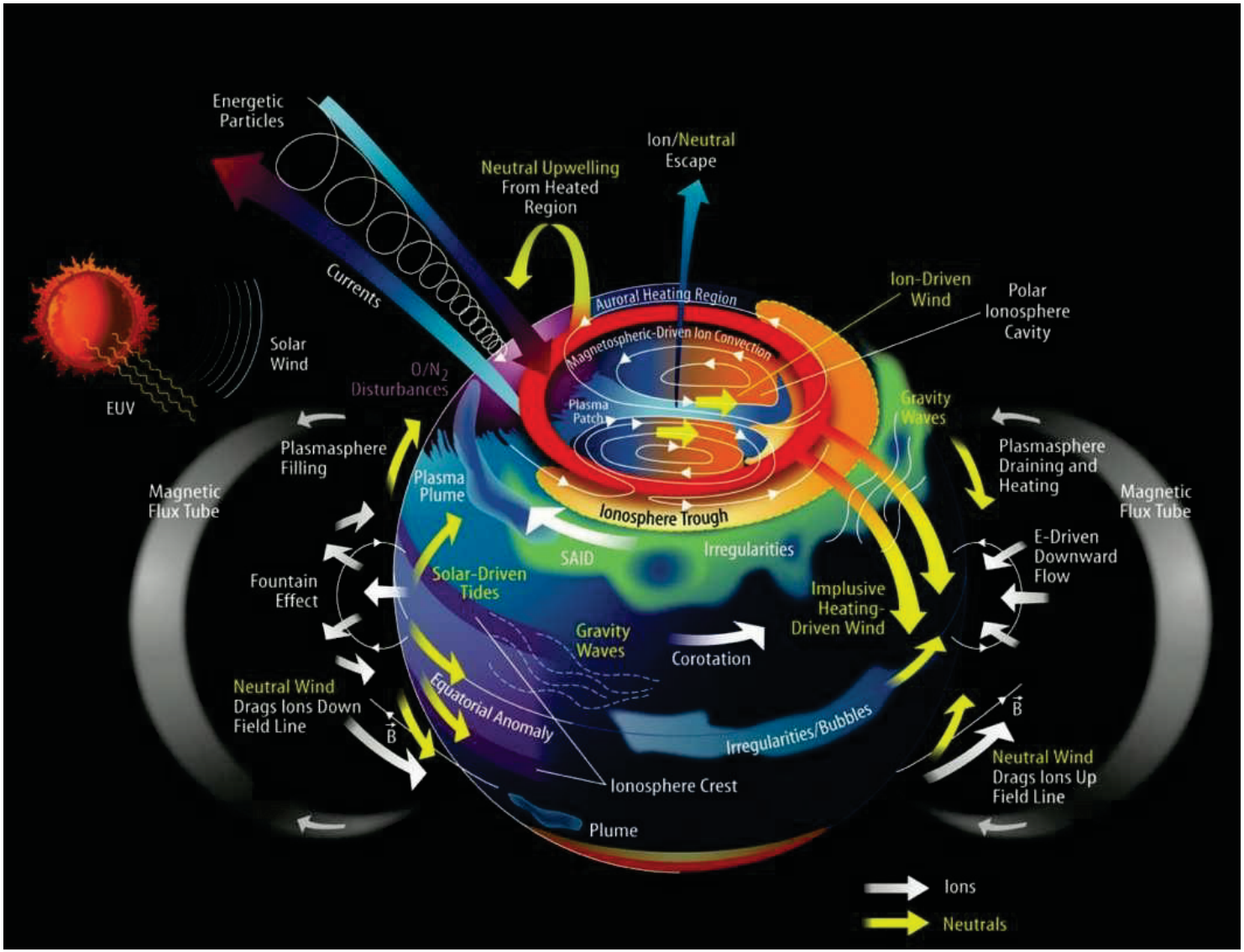
- VLF reflecting signal variations
- VLF Terminator times changes
- VLF activity increase
- Plasma variations

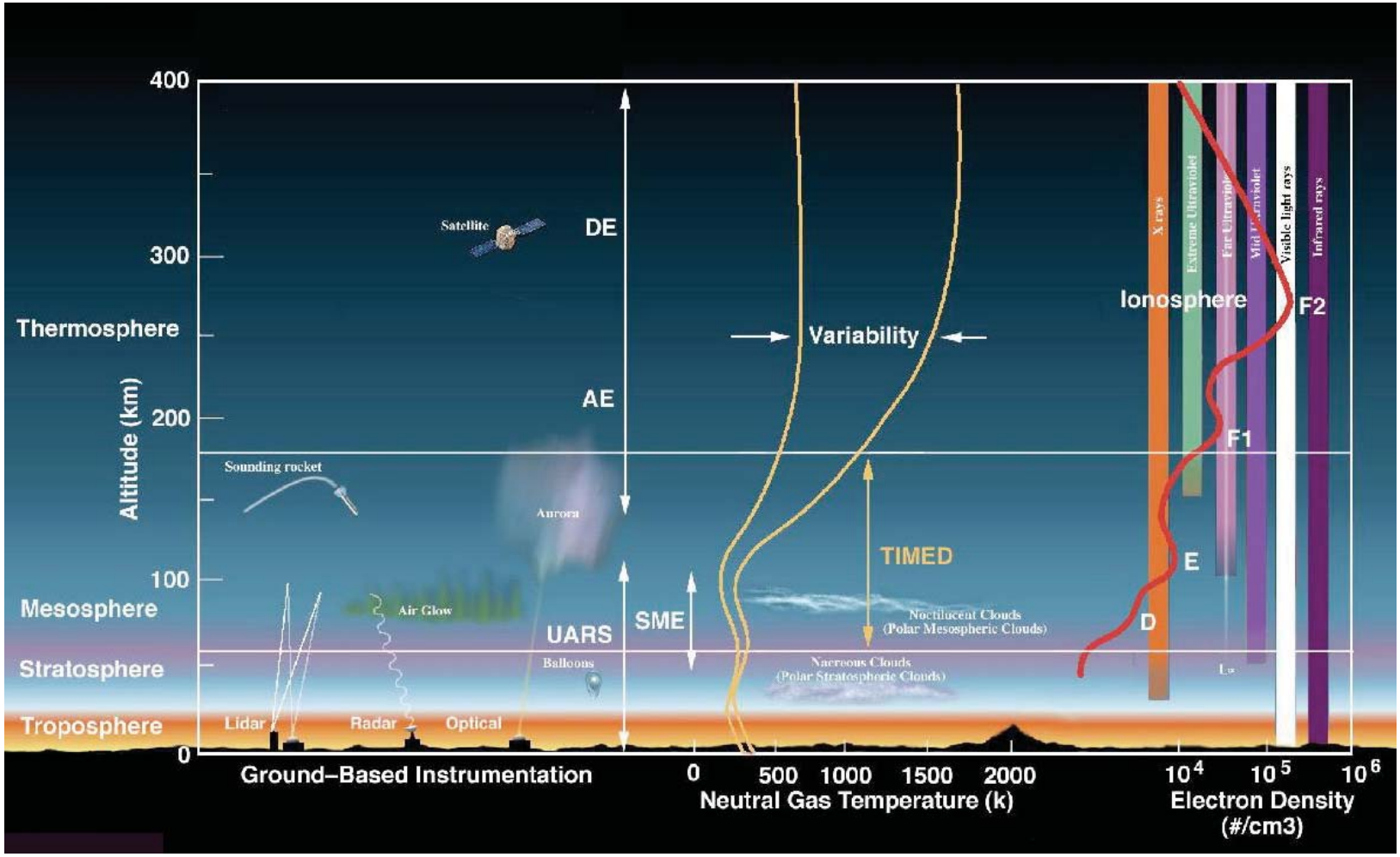
MAGNETOSPHERE

- Radiation belts electron precipitation

.....

...to be continued


Energetic Particles
Ion/Neutral Escape
Neutral Upwelling From Heated Region
Currents
Auroral Heating Region
Ion-Driven Wind
Polar Ionosphere Cavity
Magnetospheric-Driven Ion Convection
Solar Wind
EUV
O/N2 Disturbances
Plasma Patch
Gravity Waves
Plasmasphere Filling
Plasmasphere Draining and Heating
Magnetic Flux Tube
Plasma Plume
Ionosphere Trough
Magnetic Flux Tube
SAID
Irregularities
E-Driven Downward Flow
Fountain Effect
Solar-Driven Tides
Implusive Heating-Driven Wind
Gravity Waves
Corotation
Neutral Wind Drags Ions Down Field Line
Equatorial Anomaly
Irregularities/Bubbles
Neutral Wind Drags Ions Up Field Line
Ionosphere Crest
Plume
Ions
Neutrals


400
300
200
100
0
Altitude (km)
Thermosphere
Mesosphere
Stratosphere
Troposphere
Satellite
DE
AE
Variability
Sounding rocket
Aurora
TIMED
Air Glow
UARS
SME
Balloons
Noctilucent Clouds
(Polar Mesospheric Clouds)
Nacreous Clouds
(Polar Stratospheric Clouds)
Lidar
Radar
Optical
Ionosphere
F2
F1
E
D
X rays
Extreme Ultraviolet
Far Ultraviolet
Visible light rays
Infrared rays
Ground–Based Instrumentation
0
500
1000
1500
2000
Neutral Gas Temperature (k)
10 4
10 5
10 6
Electron Density
(#/cm3)

Why monitoring of EM fields may provide insight into earthquake phenomena?

i. **Dilatancy Model**: relates changes in apparent resistivity to changes in porosity as per Archie's Law [Nur, 1972], or Magnetic anomalies due to increased permeability [Merzer and Klemperer, 1997]

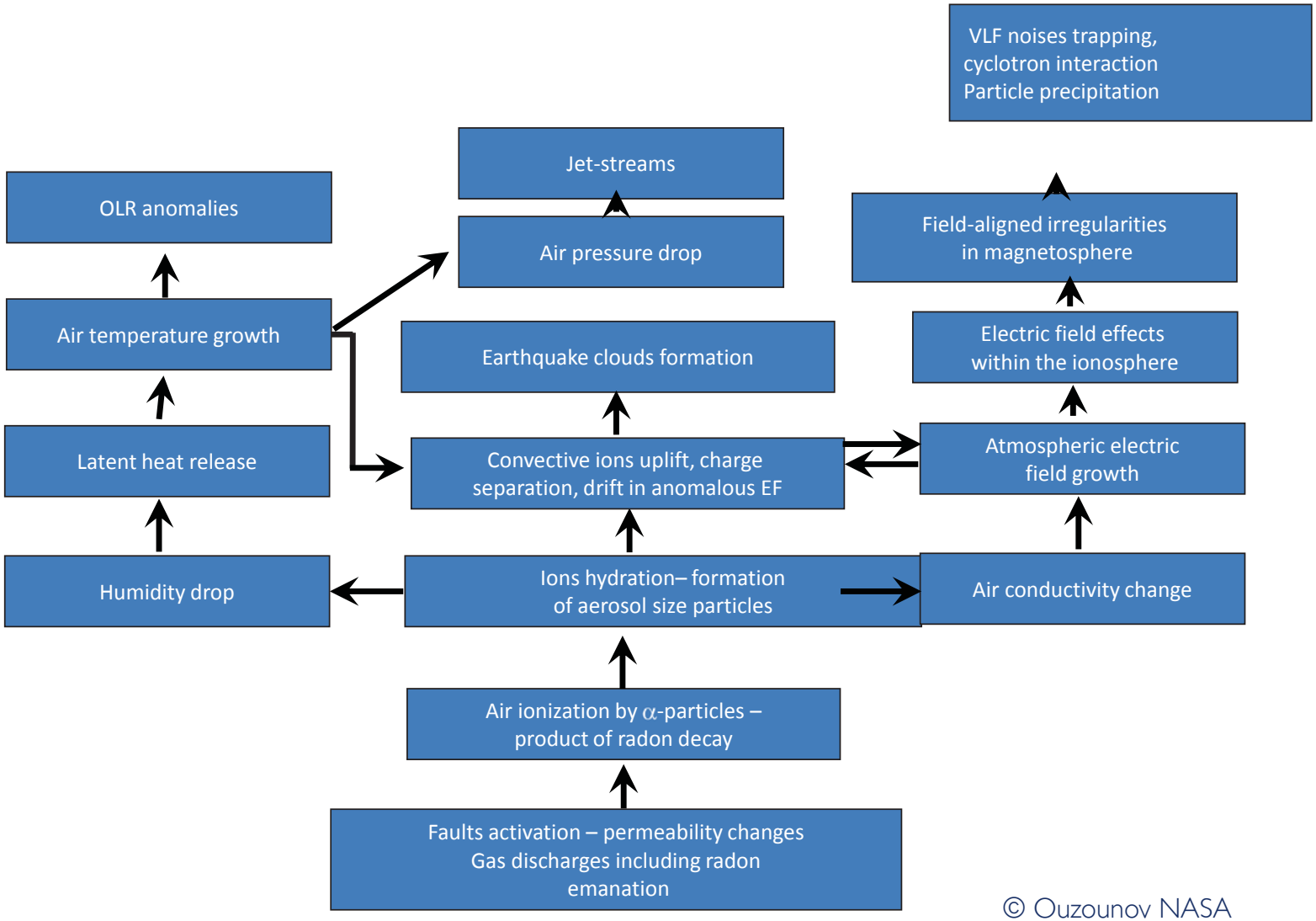
ii. **Irreversible Thermodynamic Models**: Gradients of pressure, temperature or chemical potential result in a 'coupled gradient of electrical potential' as per Onsager's relations [Nourbehecht, 1963, Pride, 1994]

iii. **Gravity wave** initiated disturbances propagating in the ionosphere [Molchanov 1998]

iv. **Fractoemissions**: Rapid increase in surface charge density of a face occurring when crystal lattices are broken. Breakdown voltages can occur before charge redistribution lowers potentials. [Karamanos, 2005].

v. **Ionospheric thickening** leading to VLF radio anomalies, possibly due to increased ionizing potential from radon gas emissions [Pulinets 2004, Molchanov, 1998]

vi. **Piezoelectricity and Piezomagnetism** are changes in electric ad magnetic fields due to stress changes in rocks [Johnston 1997]



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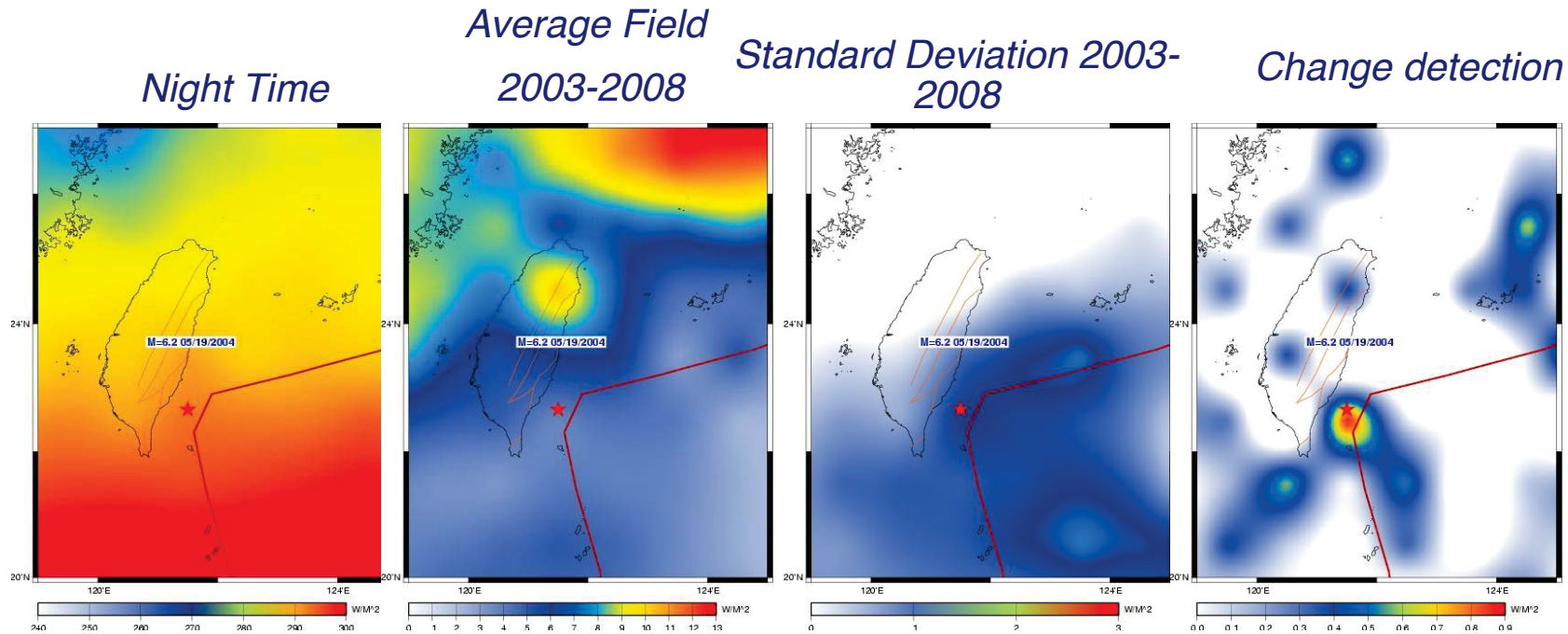

Filtering noise from transient thermal infrared anomaly, Taiwan Aug 16, 2006

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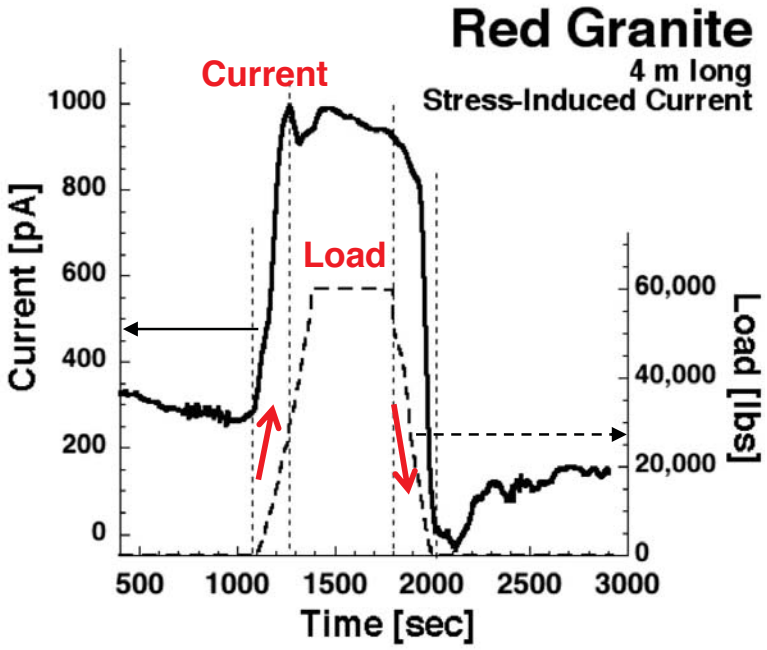
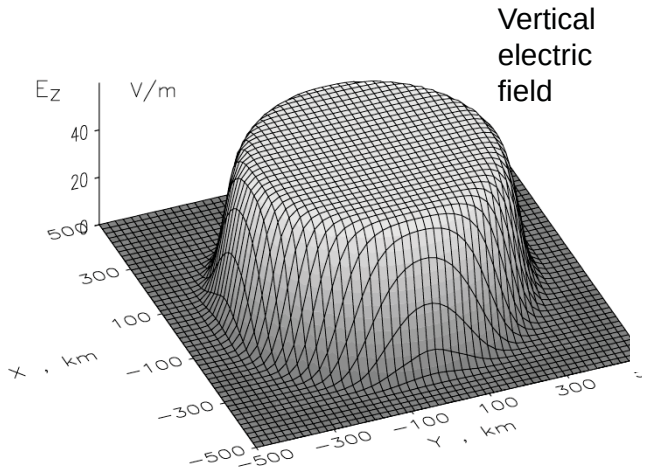
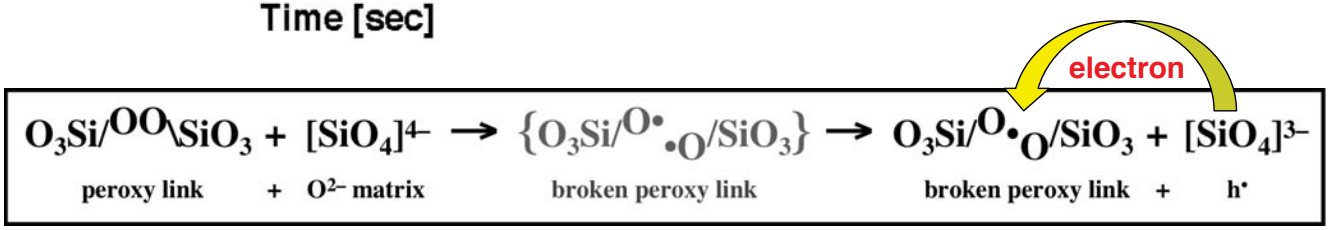




(Courtesy Valery Sorokin, 2008)



Peroxy defect, where two O's are forming a tight O-O bond

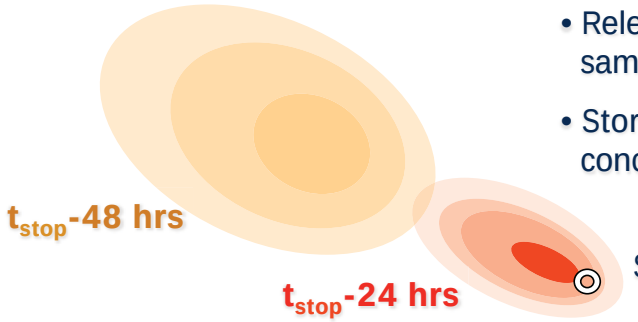
Dislocations move through like a windshield wiper and break the peroxy links.

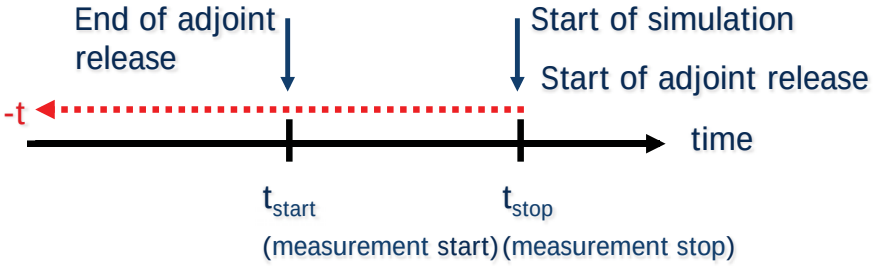
Electron

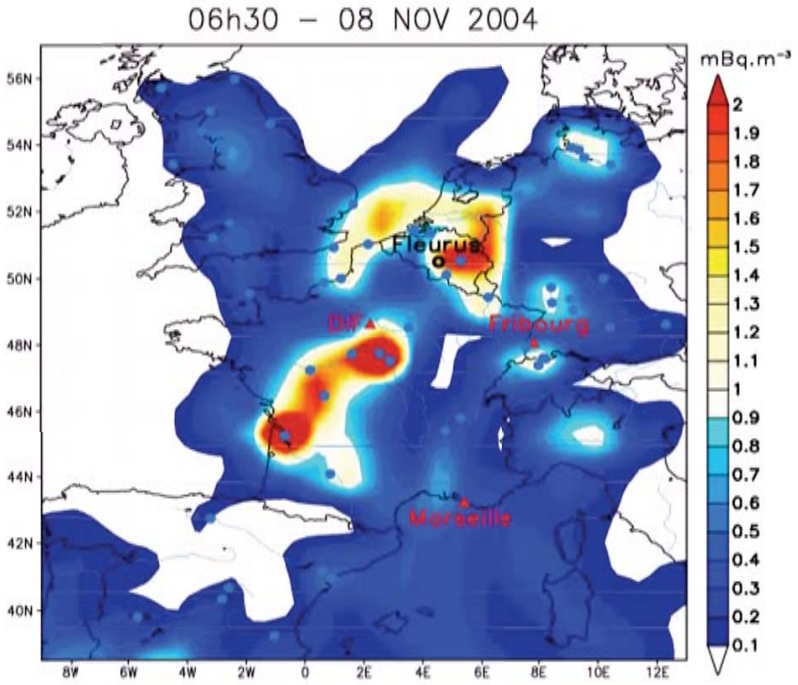
Hole

© Freund NASA

- Backward in time integration
- Release of n particles/h across 24h-sampling period
- Store surface level „retro-plume“ concentration (=SRS) every 3 hours







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Atmospheric Transport Modeling Based Estimation of Radioactive Release from the Fukushima Dai-ichi Nuclear Power Plant Accident

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***Abstract* - As a consequence of the accident at the Fukushima Dai-ichi nuclear power plant on March 2011, it is important to characterize radioactivity release into the environment. Several isotopes, amongst others caesium-137 and iodine-131, are monitored at multiple stations throughout the world by the International Monitoring System of the Comprehensive Nuclear Test Ban Treaty Organization. In this paper it is demonstrated how a worst case estimation of the radioactive release would contribute to the IMS signal. The sensitivity between source and receptor was determined using the Atmospheric Transport Modeling (ATM), running on the GRID computing facility of the Italian National Institute of Nuclear Physics (INFN) - Roma Tre. The simulations were compared with actual measurements.**

Keywords-atmospheric transport modeling; caesium; iodine; nuclear power plant.

I. Introduction

The 2011 Tōhoku earthquake and tsunami caused severe damage to Japanese infrastructure. Especially the Fukushima Dai-ichi nuclear power plant (NPP) has been presented in the media as a threat not only to its local environment, but also as an impact to the global ecosystem. Therefore, more information on the radioactive emissions has to be gathered, but it is a difficult task to determine the actual release of radioactive material. The isotopes caesium-137 and iodine-131 play a significant role here, since both are solely anthropogenic and usually only produced during nuclear weapon tests and nuclear accidents.

The Comprehensive Nuclear Test Ban Treaty Organization (CTBTO) has built up an International Monitoring System (IMS), including 80 stations to measure the atmospheric radioactivity. From these daily sampling activities the radioactive concentration (Bq/m^3) of caesium-137 and iodine-131 at the monitoring stations can be determined. Compared with other stations in the IMS network the station JPP38 in the city of Gunma, Japan, has continuously measured the highest concentration of both isotopes. As a second station for comparison USP79 on Hawaii, USA, has been selected.

Then Atmospheric Transport Modeling (ATM) can be used to estimate the radioactive source term at the Fukushima Dai-ichi NPP (37.42 N, 141.03 E) that is supposed to be mainly responsible for the signal received at the stations JPP38 in Gunma (36.31 N, 139.00 E) and USP79 (21.52 N, 157.99 W). The station JPP38 is in the southwest of Fukushima and with a distance of about 250 km it is also the closest IMS station to the assumed source, and therefore the majority of the atmospheric transport can be assumed to be over land. The second station, USP79, on the other hand, has a distance of 6,200 km to the assumed source, while the transport is mainly over the sea.

II. Background

A. Atmospheric Transport Modeling

The relation between a source, which emits particles into the atmosphere, and the concentration at a receptor can be explained with a source-receptor sensitivity matrix. The concentration c (Bq/m^3) at any given receptor can be expressed as the product of a spatio-temporal source field S (Bq) and a corresponding source-receptor sensitivity field M (m^{-3}) at discrete locations (i,j) and time intervals n:

$$c = M_{ijn} S_{ijn} \,. \qquad (1)$$

The field S is a multidimensional array of sources, which is transformed by the multidimensional array of multiplicators M into the concentration c that is measured at the receptor [1]. Here M presents the sensitivity between source and receptor and has the dimension of m^{-3}, whereas the inverse element of M can be depicted as a dilution volume. Atmospheric Transport Modeling has been proven to be a valid tool for determining Source-Receptor Sensitivity (SRS) matrices. However, while the underlying

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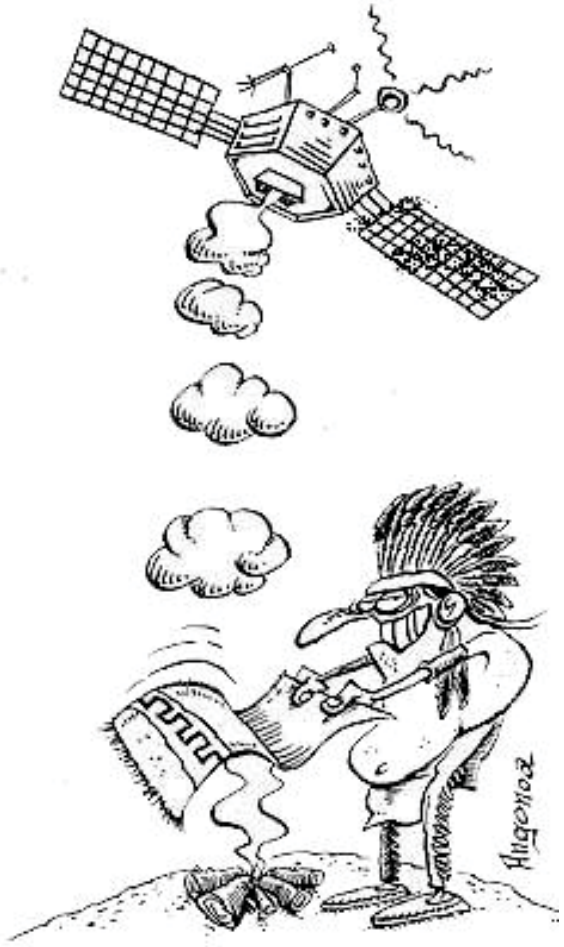

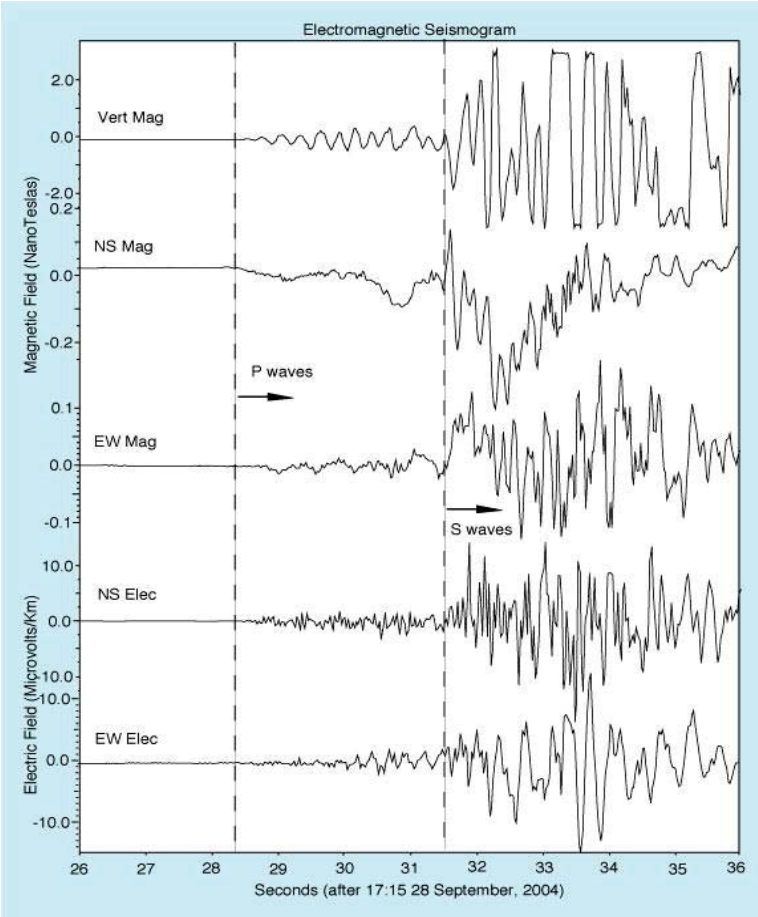

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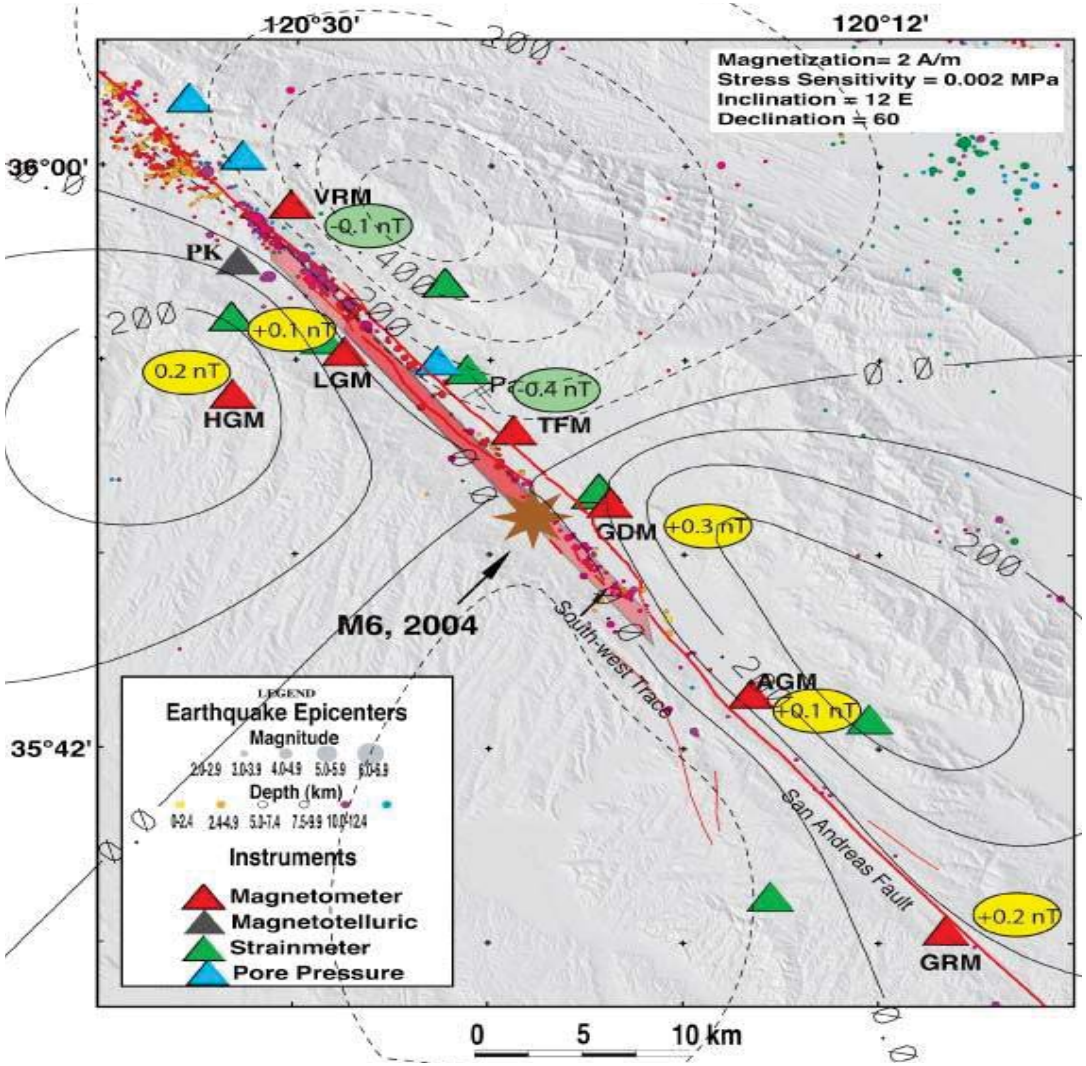
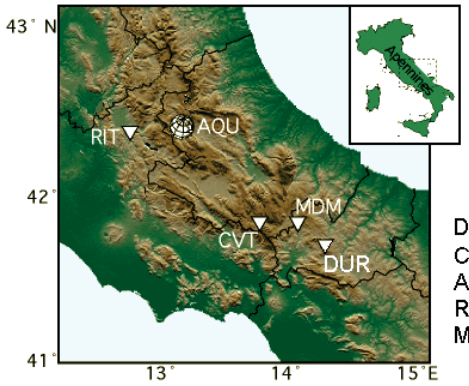


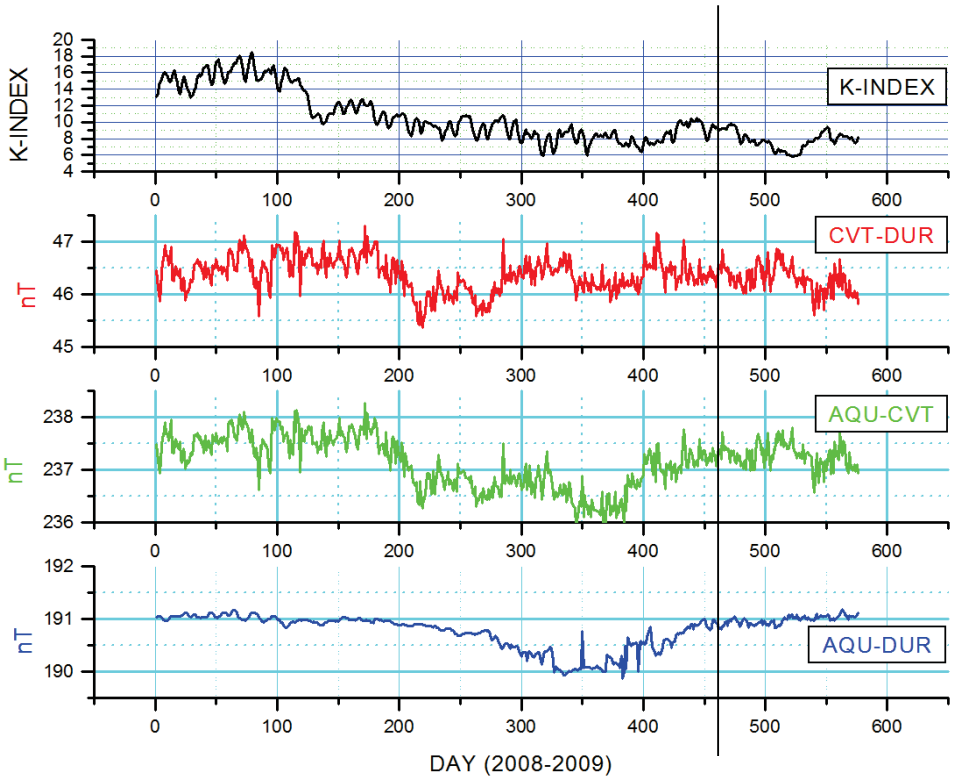
BSSA, V96, S206-220, 2006



▽ Magnetic station

National Geomagnetic Observatory (L'Aquila)

	Station Coordinates	
DUR (Duronia)	41.65°N	14.45°E
CVT (Civitella)	41.76°N	13.86°E
AQU (Aquila)	42.38°N	13.32°E
RIT (Rieti)	42.33°N	12.91°E
MDM (Monte di Mezzo)	41.75°N	14.20°E



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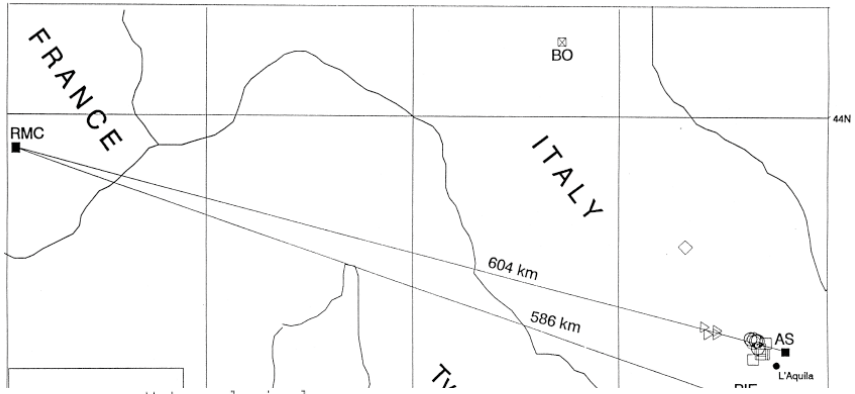
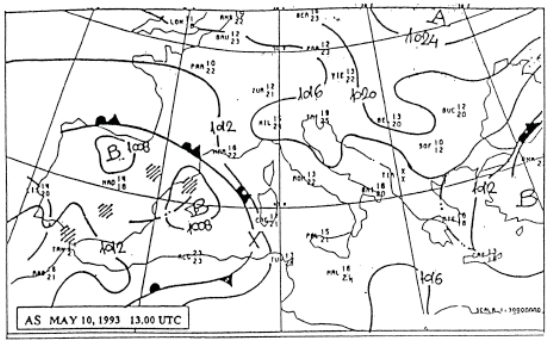
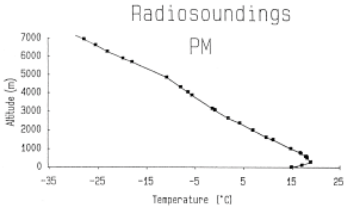
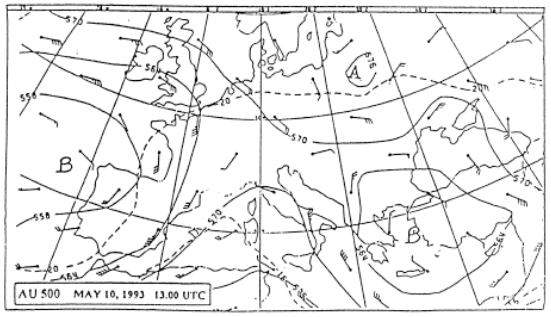
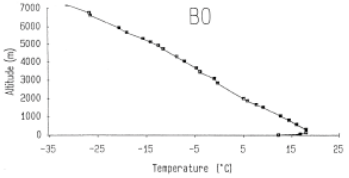


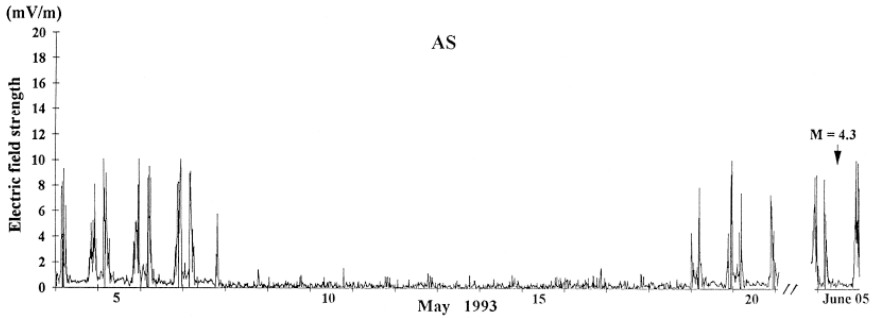
Meteorological maps

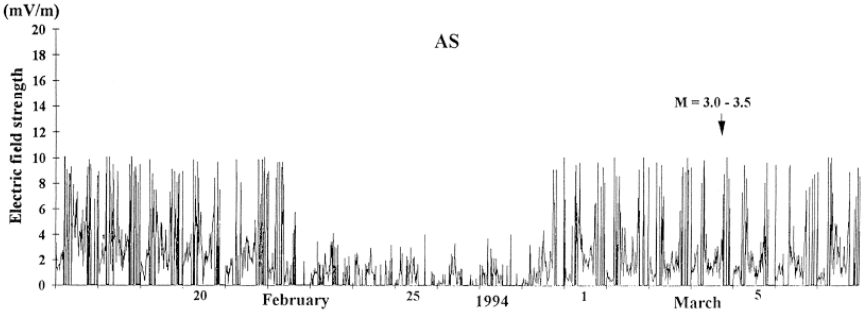












Physics of the Earth and Planetary Interiors 105 1998. 279–286

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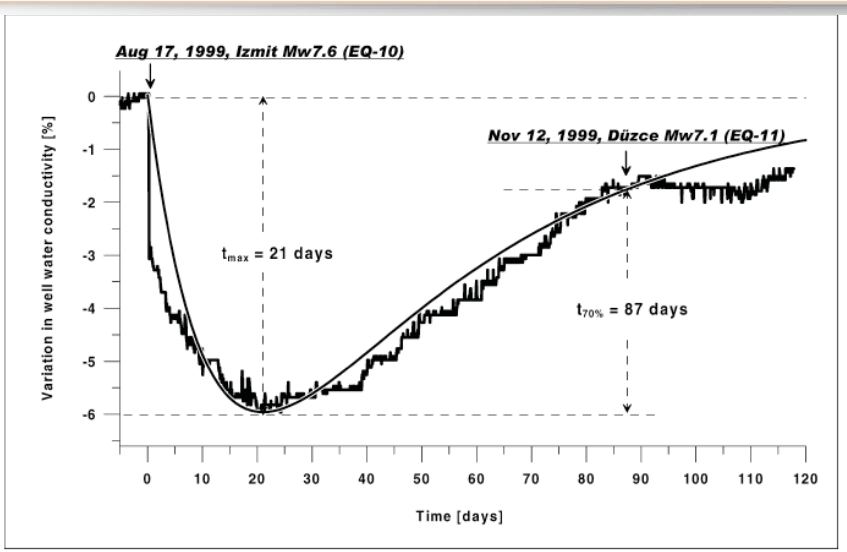
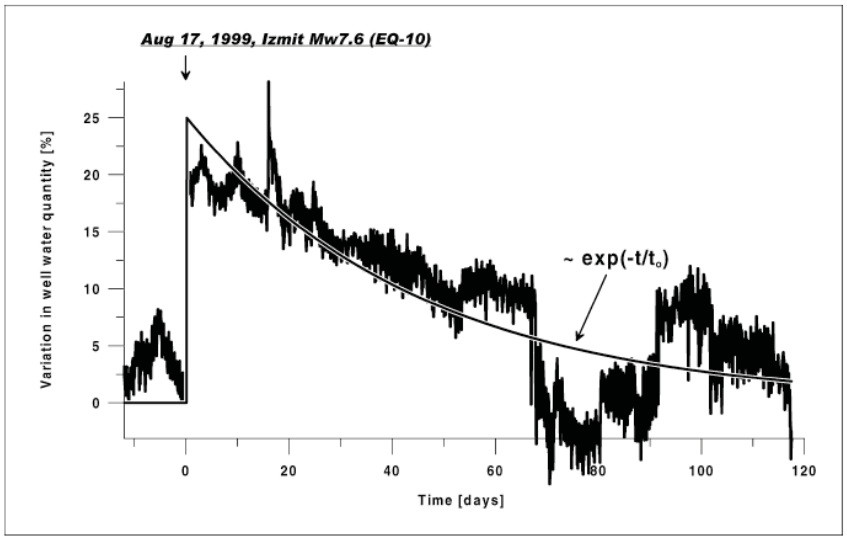
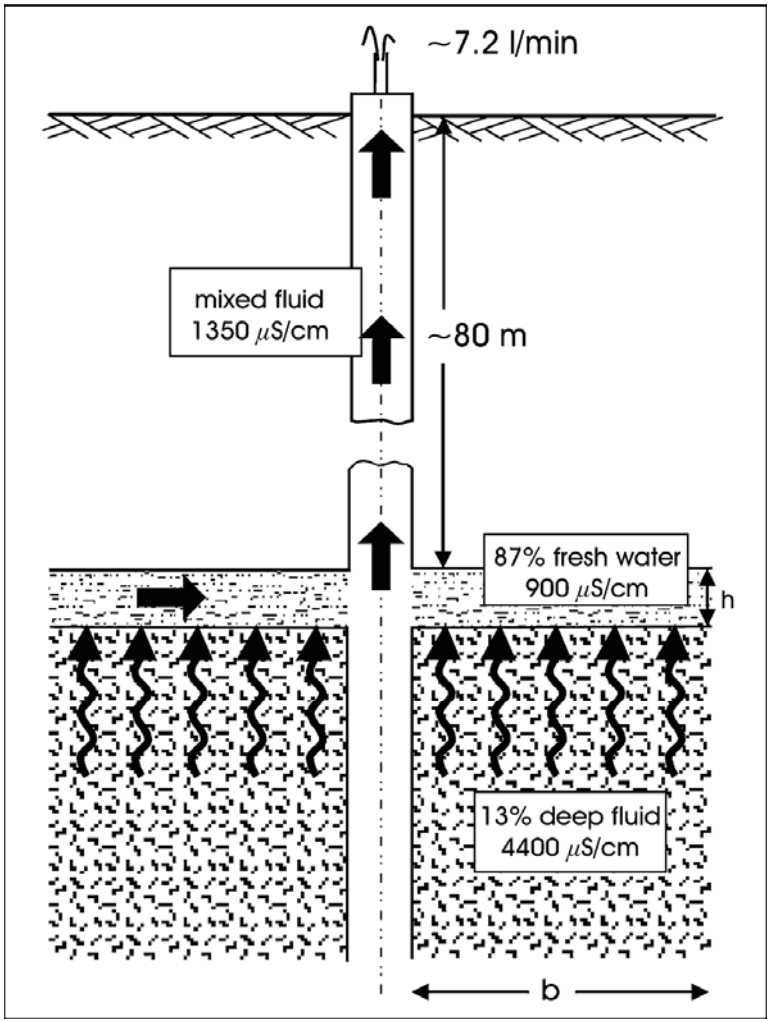
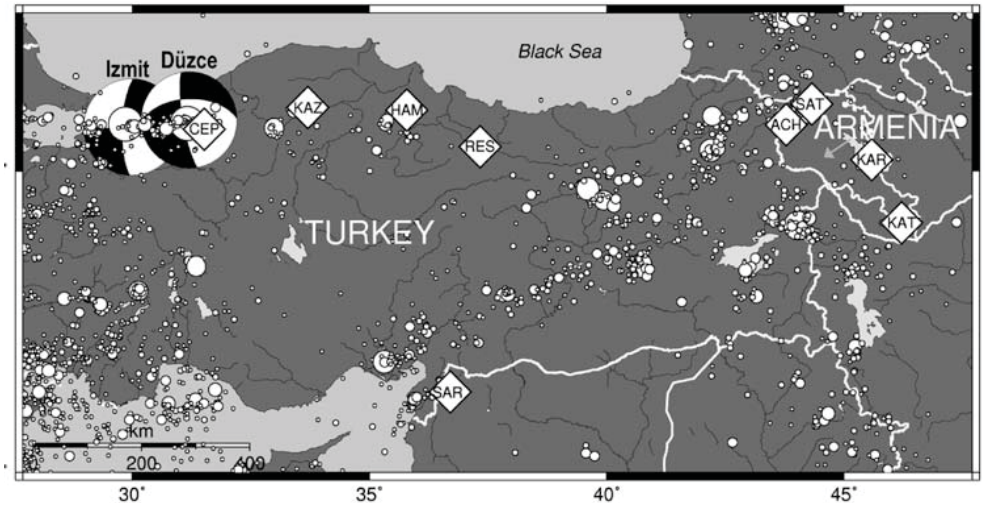
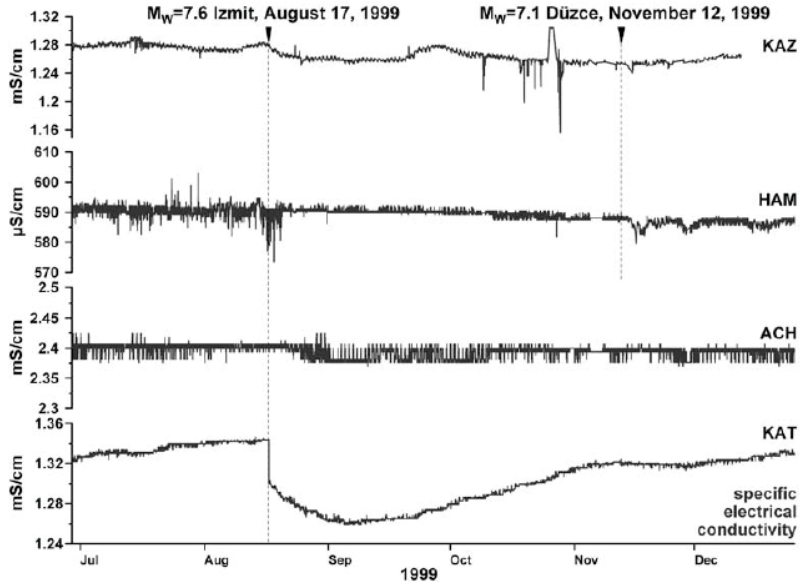


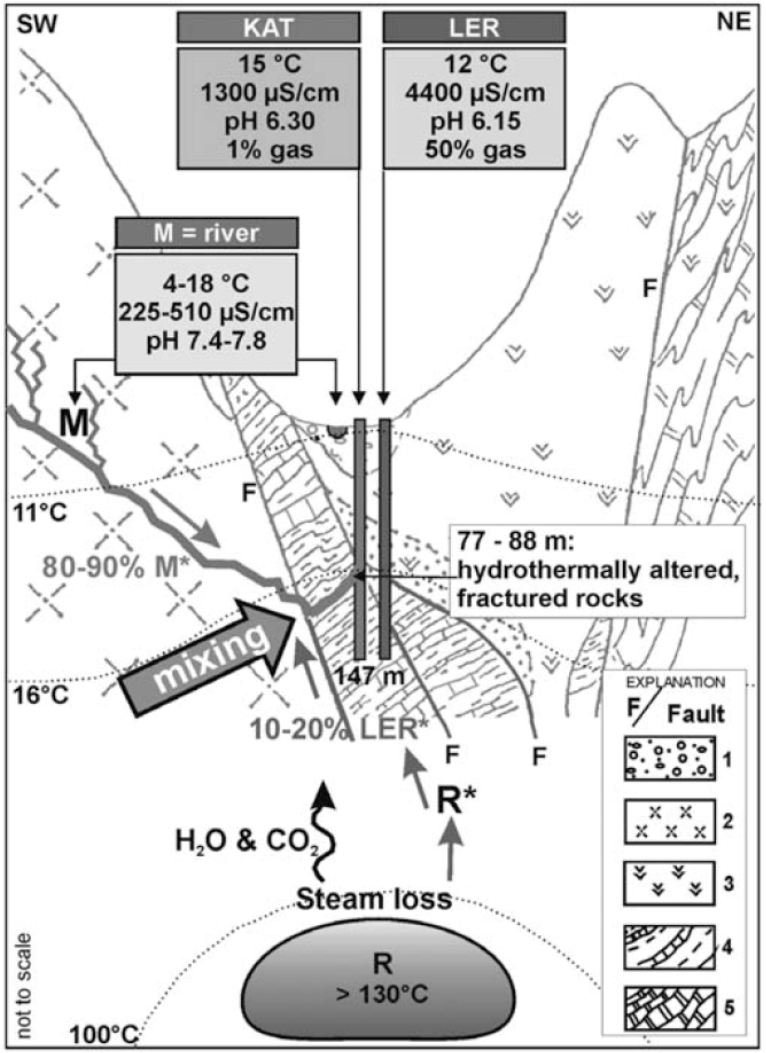




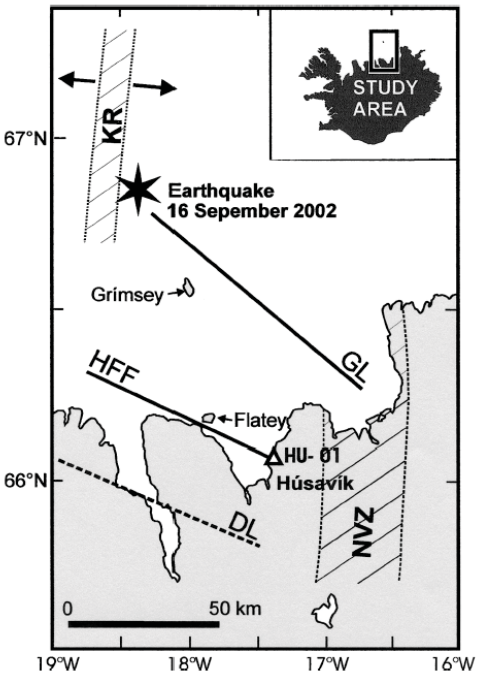
Geophys. J. Int. (2004) 157, 717–726







Hydrogeology Journal. (2003) 11, 113–121



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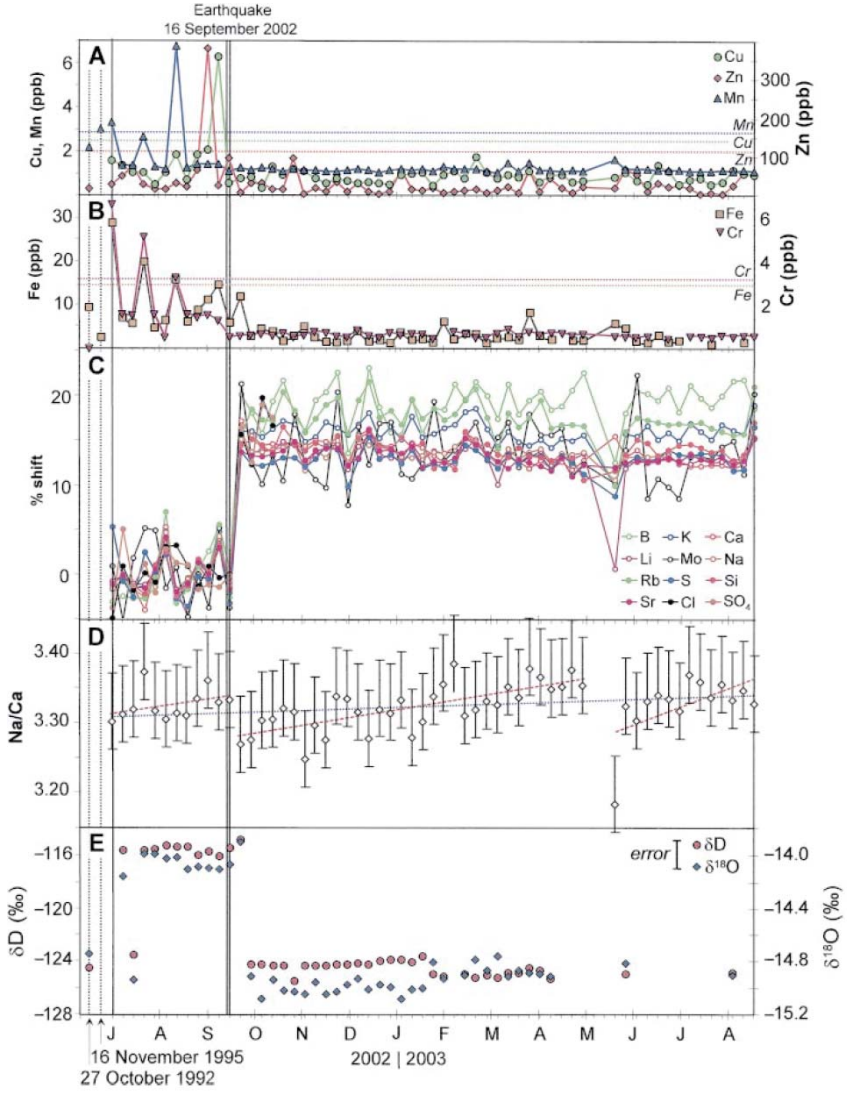

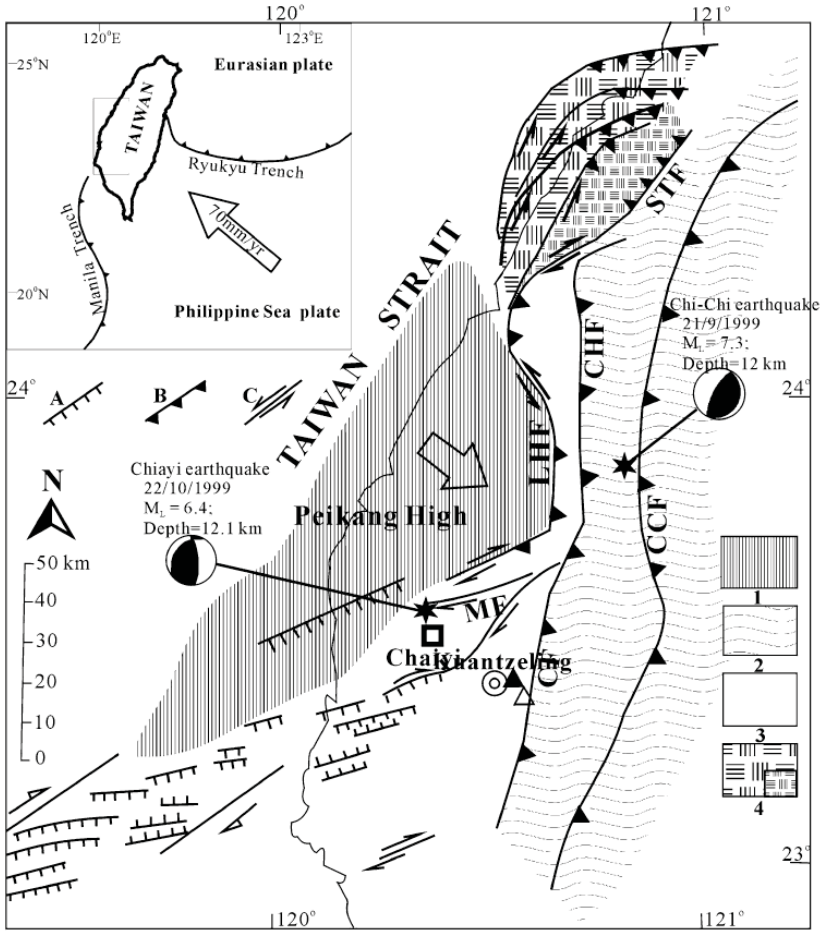

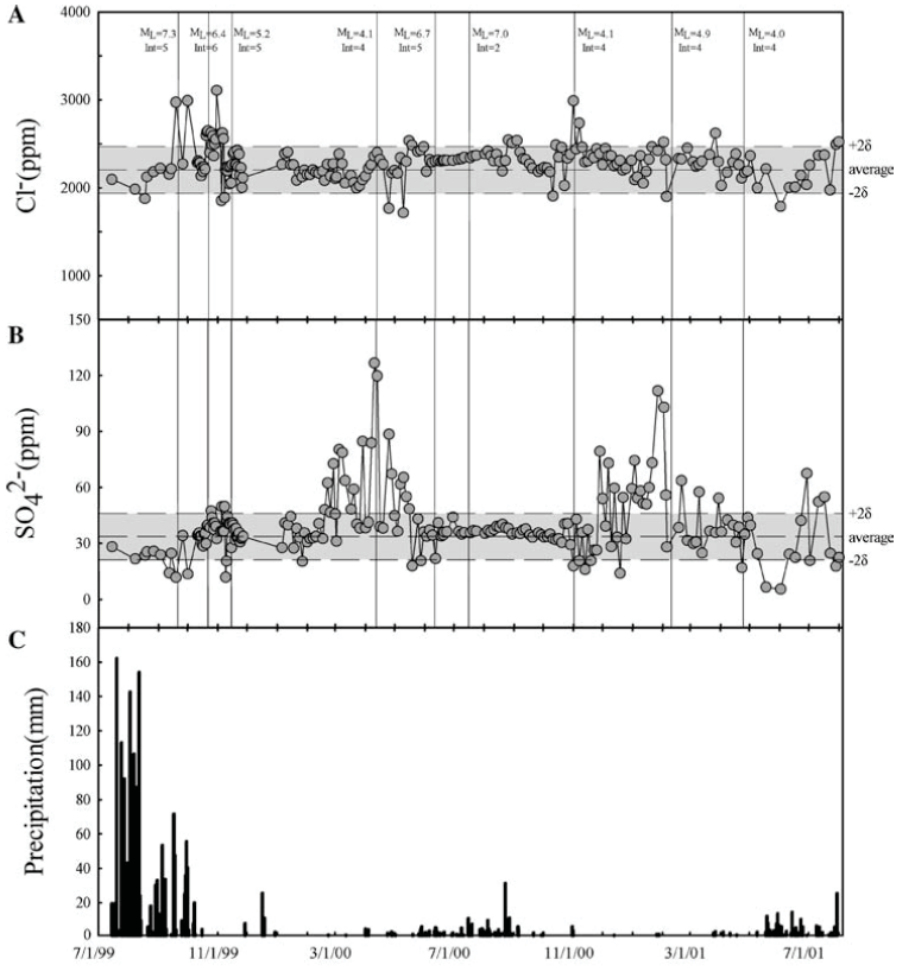

Pure Appl. Geophys. 163 (2006) 675–691

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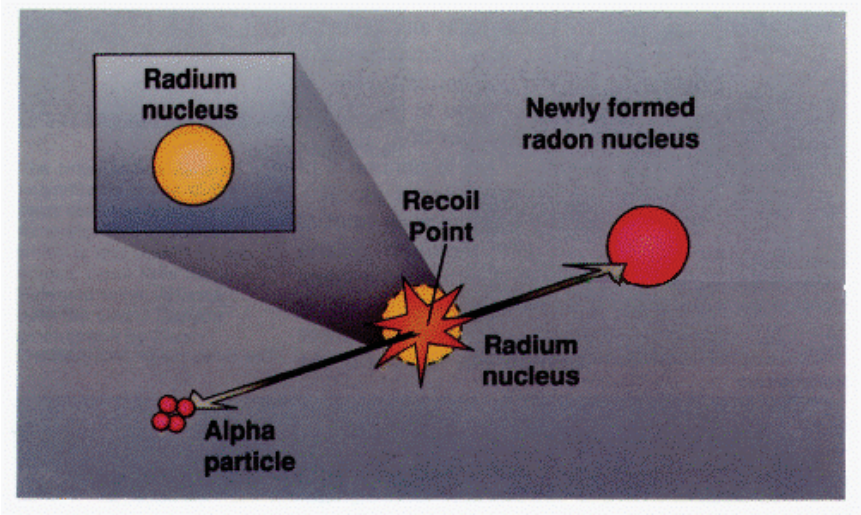
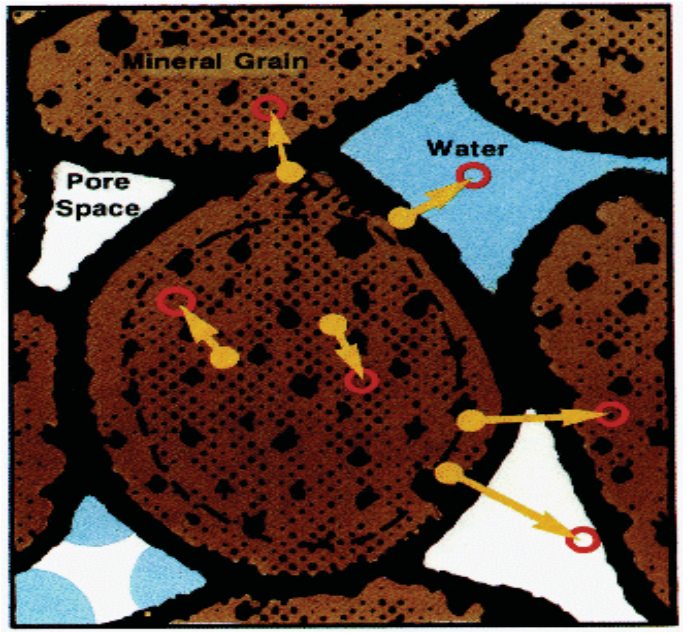


Radium decay involves the release of the excess energy which is shared between the **α** particle which forms (98.1%), and the new radon atom



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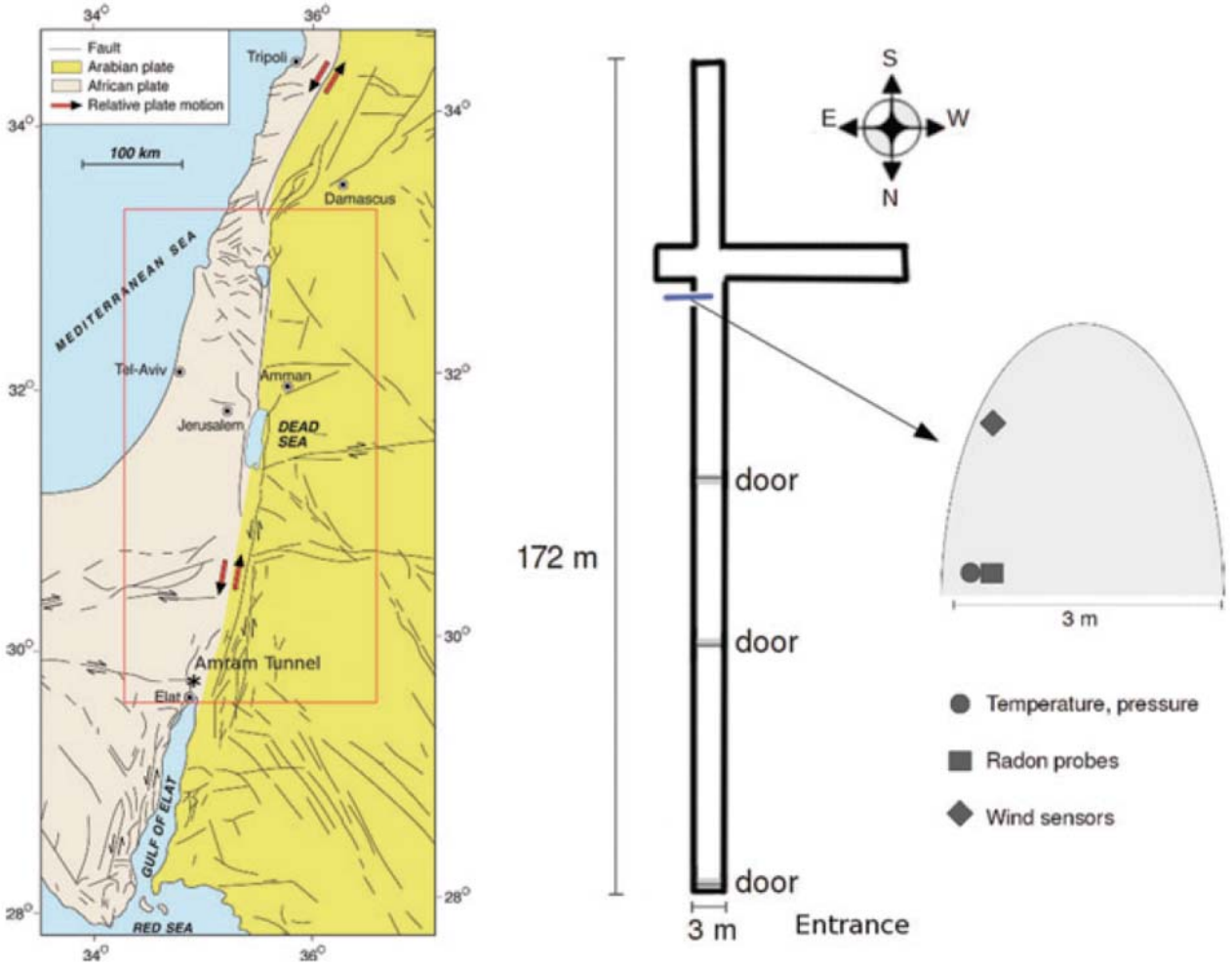
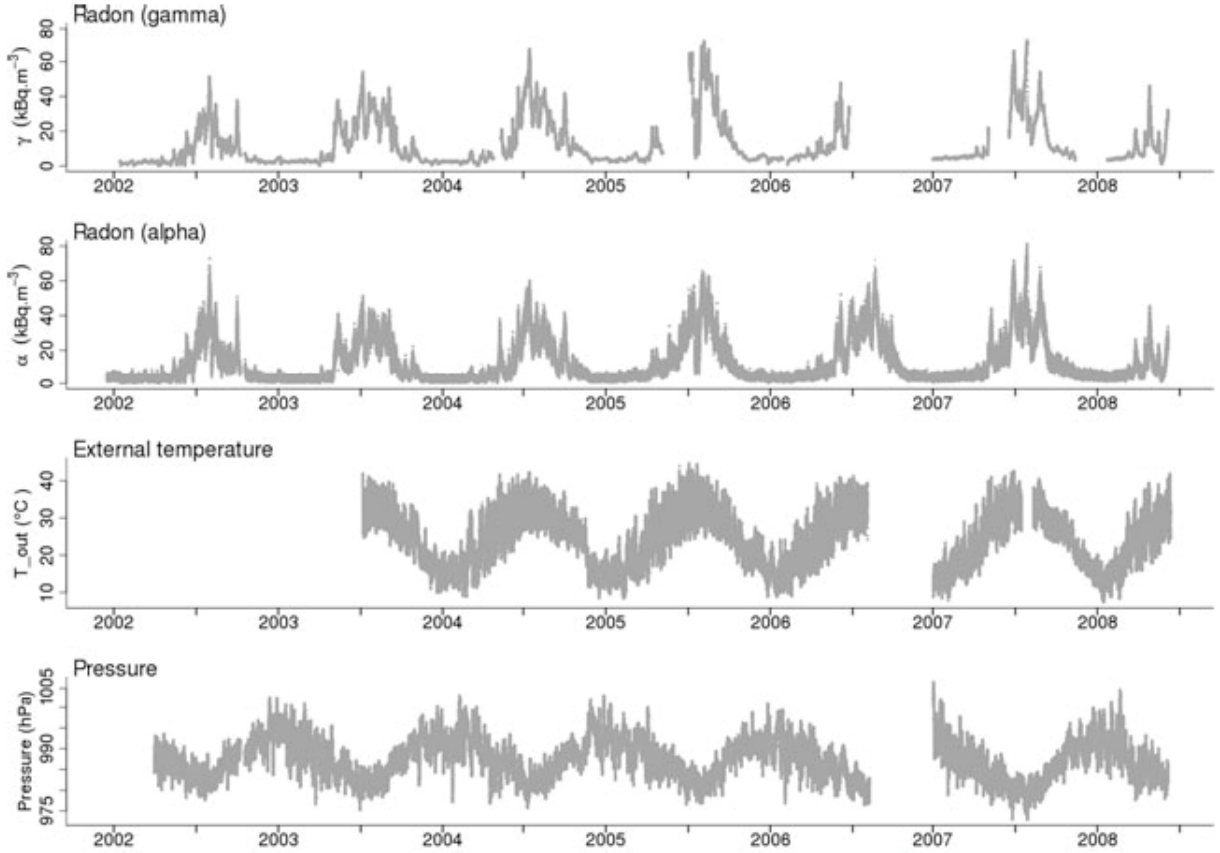
The emanating power of rocks is defined as the ratio between the amount of radon escaping from the solid matrix and that produced by radioactive decay



Geophys. J. Int. (2010) 182, 829–842



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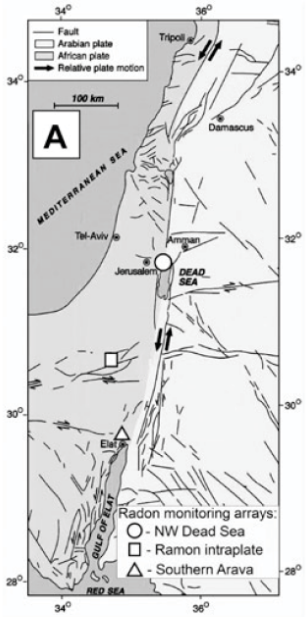

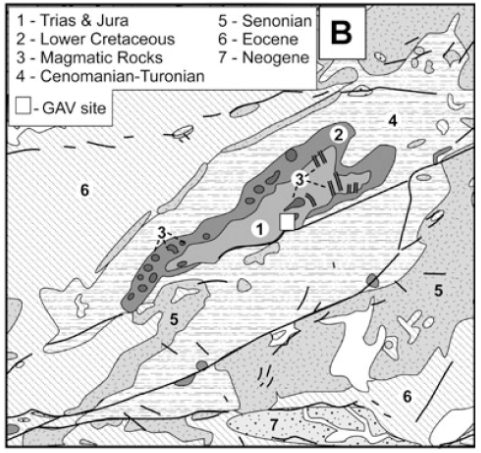

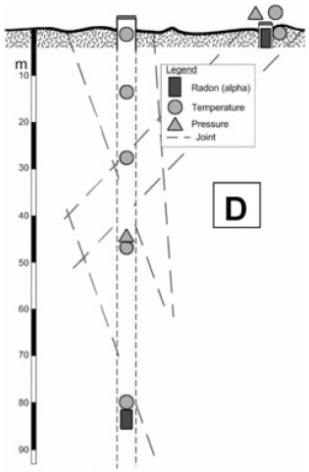

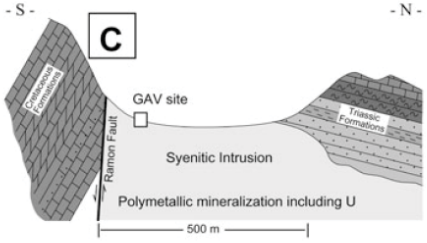

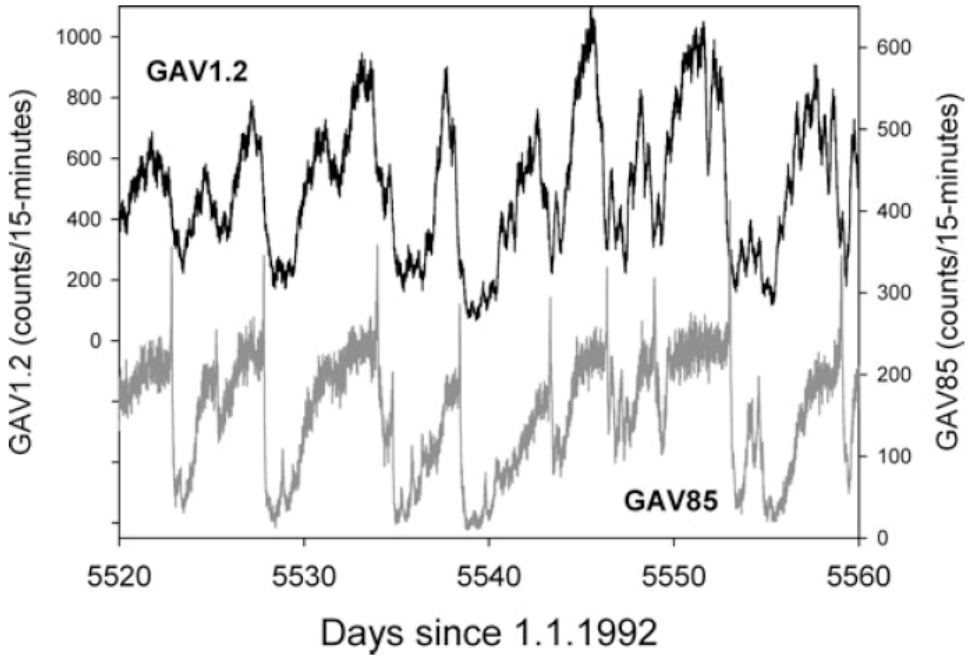

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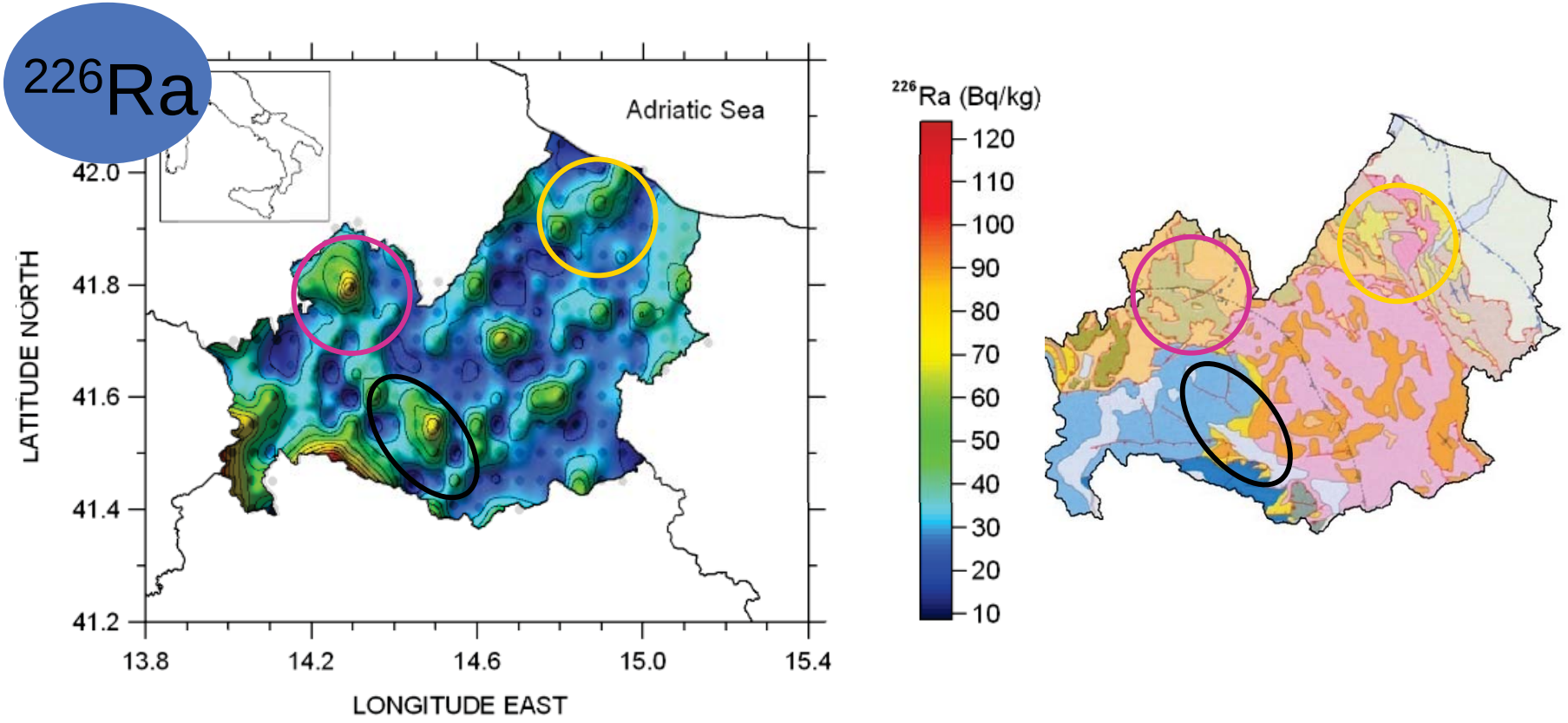
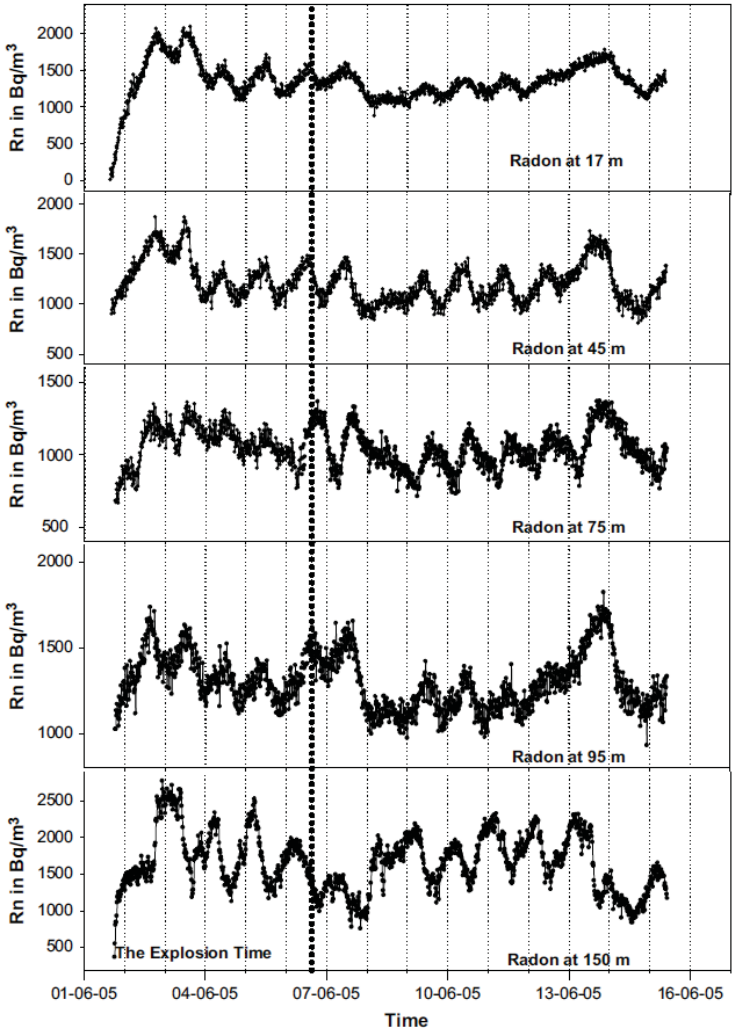
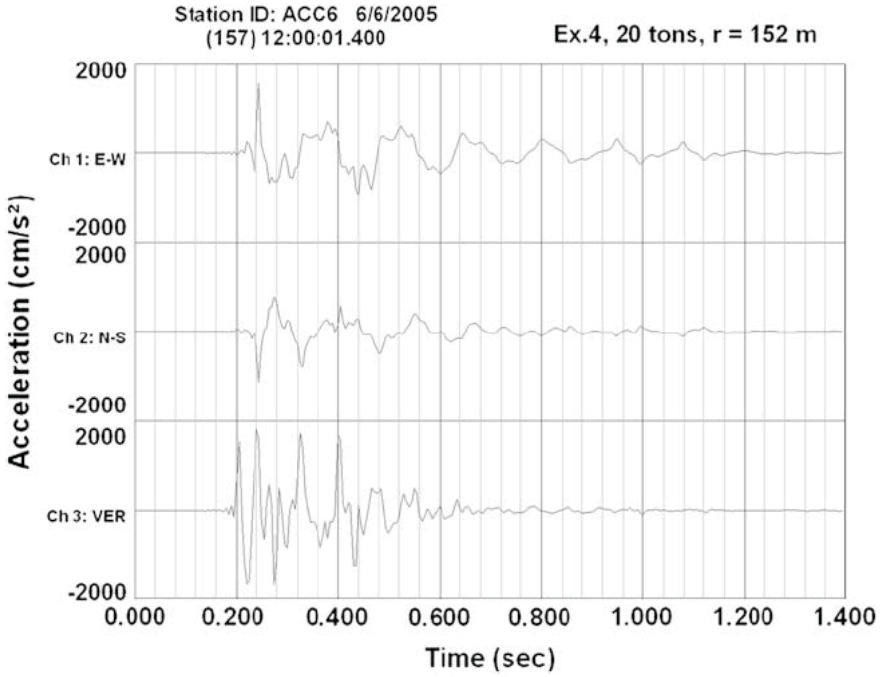

226Ra
Adriatic Sea
LATITUDE NORTH
42.0
41.8
41.6
41.4
41.2
13.8
14.2
14.6
15.0
15.4
LONGITUDE EAST
226Ra (Bq/kg)
120
110
100
90
80
70
60
50
40
30
20
10

© ERMES





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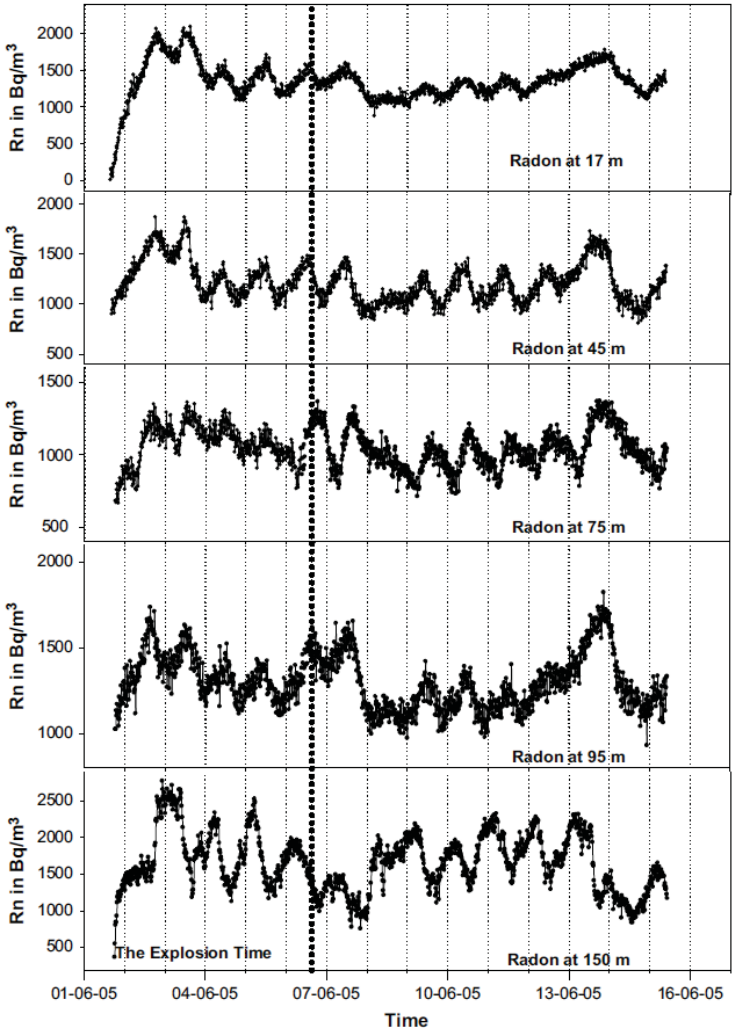
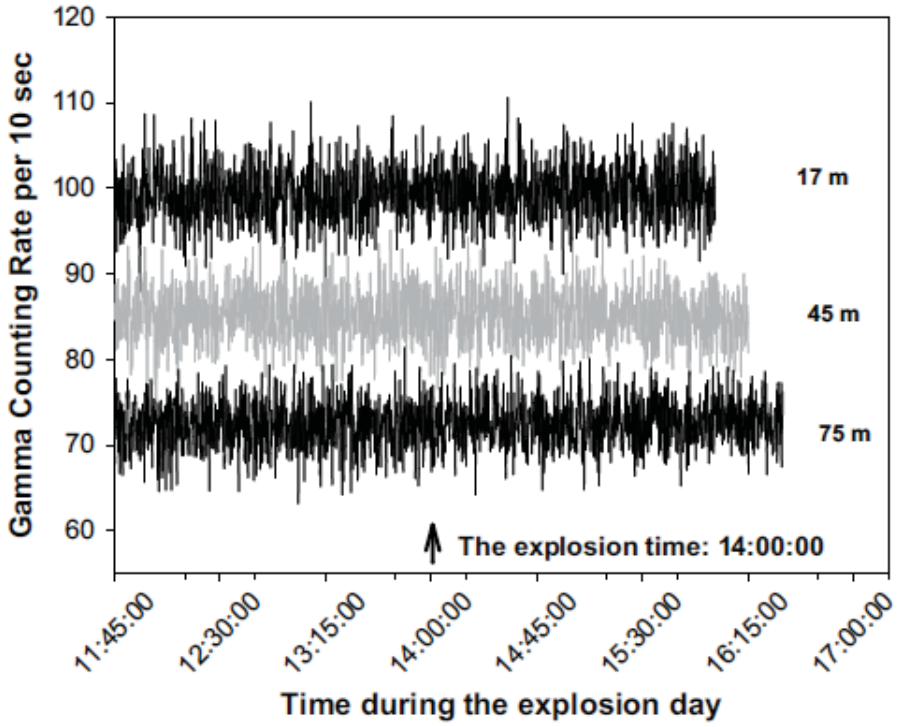
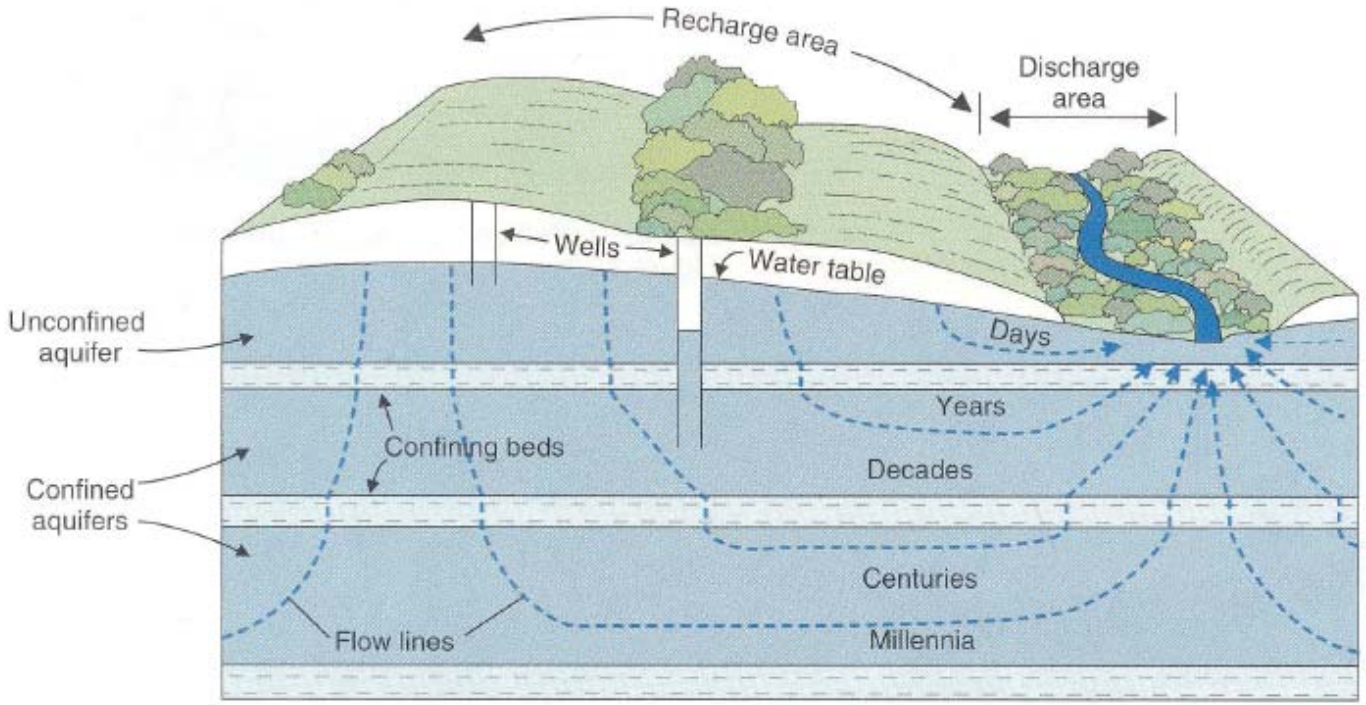




Radiation Measurements 44 (2009) 193-198



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Diffusion in porous layers with memory

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SUMMARY

The process of diffusion of fluid in porous media and biological membranes has usually been modelled with Darcy's constitutive equation, which states that the flux is proportional to the pressure gradient. However, when the permeability of the matrix changes during the process, solution of the equations governing the diffusion presents severe analytical difficulties because the variation of permeability is not known *a priori*.

A diverse formulation of the constitutive law of diffusion is therefore needed and many authors have studied this problem using various methods and solutions. In this paper Darcy's constitutive equation is modified with the introduction of a memory formalism. We have also modified the second constitutive equation of diffusion which relates the density variations in the fluid to the pressure, introducing rheology in the fluid represented by memory formalisms operating on pressure variations as well as on density variations. The memory formalisms are then specified as derivatives of fractional order, solving the problem in the case of a porous layer when constant pressures are applied to its sides.

For technical reasons many studies of diffusion are devoted to the flux rather than to the pressure; in this work we shall devote our attention to studying the pressure and compute the Green's function of the pressure in the layer when a constant pressure is applied to the boundary (Case A) for which we have found closed-form formulae. The described problem has already been considered for a half space (Caputo 2000); however, the results for a half space are mostly qualitative since in most practical problems the diffusion occurs in layers.

The solution is also readily extended to the case when a periodic pressure is applied to one of the boundary planes while on the other the pressure is constant (Case B) which mimics the effect of the tides on sea coasts. In this case we have found a skin effect for the flux which limits the flux to a surface layer whose thickness decreases with increasing frequency. Regarding the effect of pressure due to tidal waters on the coast, it has been observed that when the medium is sand and the fluid is water, for a sinusoidal pressure of 2×10^4 Pa and a period of 24 hr at one of the boundaries and zero pressure at the other boundary, the flux is sinusoidal with the same period and amplitude decaying exponentially with distance to become negligible at a distance of a few hundred metres.

A brief discussion is given concerning the mode of determination of the parameters of memory formalisms governing the diffusion using the observed pressure at several frequencies. We shall also see that, as in the classic case of pure Darcy's law behaviour, the equation governing the flux resulting in the diffusion through porous media with memory is the same as that governing the pressure.

Key words: Darcy, diffusion, filtering, flux, memory, porous media.

Ground-Water Radon Anomaly Before the Kobe Earthquake in Japan

G. Igarashi, S. Saeki, N. Takahata, K. Sumikawa, S. Tasaka, Y. Sasaki, M. Takahashi, Y. Sano

Radon concentration in ground water increased for several months before the 1995 southern Hyogo Prefecture (Kobe) earthquake on 17 January 1995. From late October 1994, the beginning of the observation, to the end of December 1994, radon concentration increased about fourfold. On 8 January, 9 days before the earthquake, the radon concentration reached a peak of more than 10 times that at the beginning of the observation, before starting to decrease. These radon changes are likely to be precursory phenomena of the disastrous earthquake.

Motivated by the report of precursory changes in ground-water radon associated with the 1966 Tashkent earthquake (*1*) and some radon observations in China (*2*), a group of scientists developed an automated continuous monitoring system for ground-water radon in Japan (*3*). For some 20 years, an extensive network of ground-water radon monitoring has been operated mainly

and roughly inversely proportional to, the effective grain size of rocks in an aquifer (*5*). Formation of microcracks will reduce the effective grain size of rocks and thereby enhance radon concentration in the ground water.

To accumulate data on ground-water radon concentration, we began studying the southern part of Nishinomiya city, Hyogo

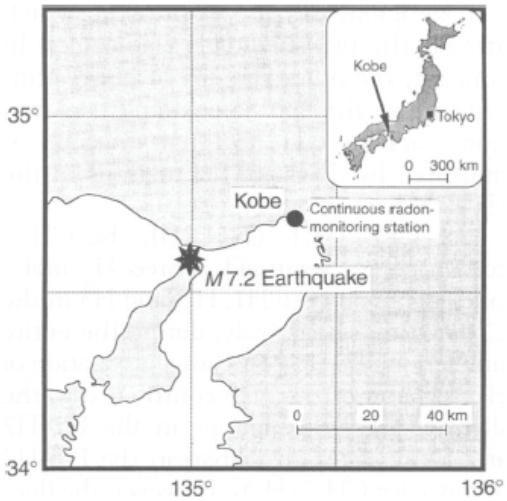
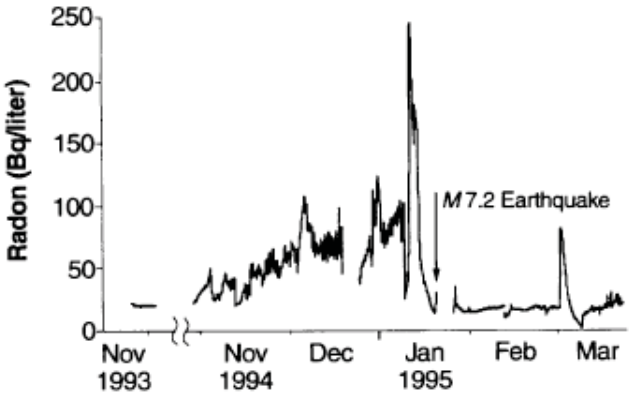


Fig. 1. Map of the continuous radon monitoring station and the epicenter of the Kobe earthquake (from Japan Meteorological Agency).



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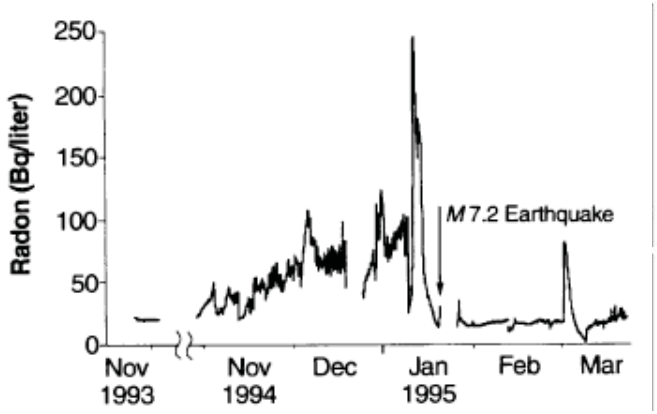

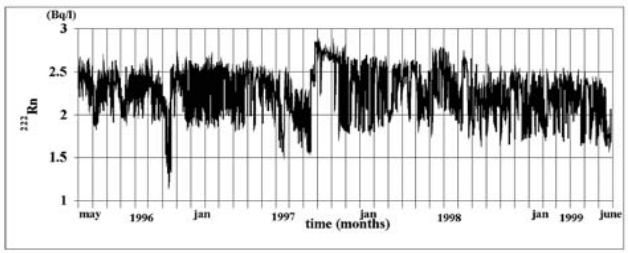

Earth science

Radon and rock deformation

Evelyn Roeloffs

What happens when stress is applied to rocks in the Earth's crust so that the crust deforms? This is a question tackled by Trique *et al.* on page 137 of this issue[1]. They have used a natural laboratory in the French Alps — the Roselend reservoir — to monitor the geophysical signals that result from the greater or lesser pressure on the underlying crust exerted by the weight of water in the reservoir. This area is not itself prone to earthquakes. But the broader interest of this work is in what it may tell us about the events, induced by crustal deformation, that precede earthquakes.

The ability to predict earthquakes is of course highly desirable. But progress in this difficult and highly contentious science will depend on detecting and interpreting physical changes stemming from the processes of earthquake generation. Many possible precursors have been reported, but seismologists are sceptical of those that are not clearly linked to crustal deformation. This 'unproven' category includes the well-documented precursory decrease and increase of radon concentration before the 1978 Izu–Oshima earthquake in Japan[2] (Fig. 1), as well as the controversial assertion that

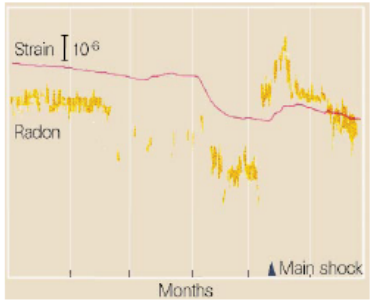

Figure 1 **The radon and strain data for the magnitude-7 Izu–Oshima earthquake[2,9] of 14 January 1978 show changes preceding the earthquake. But they do not match the model shown in Fig. 2; in particular, neither change is monotonic, and in both cases the pre-earthquake change exceeds that produced by the earthquake itself.**

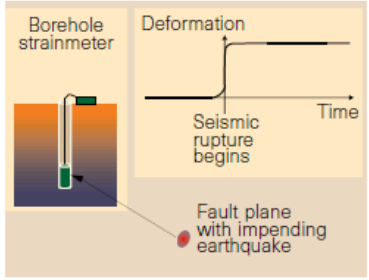

Figure 2 **Rock friction, which depends on slip rate and sliding-induced changes on a fault surface, implies that seismic slip should be preceded by accelerating aseismic slip near the hypocentre of an impending earthquake. Sufficient aseismic slip would produce near-surface deformation detectable by a borehole strainmeter. Compared with the strain step recorded at the time of the earthquake, the precursory strain signal would be in the same direction but of much smaller amplitude. A magnitude-5 earthquake, 10 km deep, produces maximum near-surface strain of about 10^{-7} at a site 5 km from its fault plane; strain increases 30-fold for each unit increase of magnitude, but falls off as the third power of distance from the source. Estimates of pre-seismic slip duration and amplitude range widely because frictional parameters of natural faults are poorly known.**

Seismologists expect earthquake precursors to take the form of transient crustal-strain signals from 'aseismic' fault slip near the earthquake's nucleation point (that is, fault slip that is too slow to radiate seismic waves) (Fig. 2). Numerical simulations show, however, that such signals would be exceedingly small[4]. Even the best existing instruments — borehole strainmeters with resolution exceeding a part per billion — would need to be within a few kilometres of the impending earthquake's epicentre to detect this aseismic strain. Although strain changes preceding two California earthquakes have been identified[5,6], they don't resemble the expected signals.

Proponents of earthquake prediction maintain that changes in radon emission, or in electrical or magnetic fields, represent a natural amplification of pre-earthquake deformation under special geological conditions. For example, the conductance by rock fractures of water or gas is proportional to the third power of the fracture's aperture[7]. Fluid flow past ions adsorbed on rock surfaces produces an electric field, termed a 'streaming potential', that varies with pressure gradient and permeability[8]. Fluid, gas or electromagnetic measurements might thus detect deformation indirectly, albeit at localized sites and with amplitudes related nonlinearly to strain.

Silver and Wakita[9] list many potential examples of such pre-earthquake 'strain indicators'. Unfortunately, these indicators are irreproducible: they can be detected only in certain locations, but in any one location earthquakes recur infrequently. What is needed is evidence that transient strain leads consistently, if not linearly or uniformly, to observable phenomena. The radon, electrical and ground-tilt measurements from Roselend lake constitute this kind of reproducible evidence.

The shallow crust's reaction to large changes in lake level may also illuminate the

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