Earthquakes and the Upper Atmosphere

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CHAPTER 1

INTRODUCTION

Earthquakes (EQ) are the largest and long-known nature disasters. Many works of art and popular books are dedicated to them. They describe the observed patterns of destructions and their consequences. However, this book is devoted to another – the description of the physical causes of these phenomena, their mathematical modeling and EQ forecasting capabilities on a scientific basis.

Correspondingly, the author intends to describe all necessary for these goals things, namely, the structure and physics of the Earth and its shell, the observational results, basic physical principles and laws, main equations and their terms, initial and boundary conditions, coordinate systems, numerical solutions methods, numerical results and their comparison with observations, interpretation of such comparisons and discussion on the possibilities of the EQ forecasting on the modern physical and mathematical basis.

In part of the upper atmosphere physics this book is tightly connected with the monograph B. E. Brunelli and A. A. Namgaladze "Physics of the Ionosphere" (in Russian) published in 1988 by the Moscow "Nauka". Publishing and widely used later by many geophysicists in Russia and abroad. The most of the described there is a classic now, nevertheless the new observational and theoretical results are obtained continuously, and the author tried taking them into account.

The professor Boris Evgenievich Brunelli (1913–1999) having been worked at the Leningrad State University and the Polar Geophysical Institute (Apatity, Murmansk). He was the author’s supervisor and real teacher. His famous disciples V. B. Lyatsky, Yu. P. Maltsev and V. M. Chmyrev were the author’s colleagues and friends and their remarks were important in many cases.

Especially I should note my Kaliningrad and Apatity – Murmansk colleagues on modeling and ionosphere geophysics, which scientific influence was very significant. The reference list shows their names as my coauthors. Some are no longer with us, such as L. P. Zakharov, N. S. Natsvalian, K. S. Latishev, O. V. Evstafiev, Yu. N. Korenkov,

V. M. Smertin, R. Yu. Yurik and S. B. Leble. Others continue to work productively. Among them I. E. Zakharenkova, A. F. Lagovsky and I. I. Shagimuratov were the first scientists attracted me to the problem of the ionosphere precursors of earthquakes in 2007. V. V. Klimenko and M. V. Klimenko were my first coauthors on the numerical 3D modeling of the ionosphere EQ effects, whereas I. V. Karpov, F. S. Bessarab, N. M. Naumova, T. A. Glushchenko, M. Foerster, O. V. Martynenko, A. N. Namgaladze, V. N. Volkov, E. A. Doronina, Yu. A. Shapovalova, V. A. Medvedeva, I. V. Artamonov, B. E. Prokhorov, O. V. Zolotov, M. A. Knyazeva, Yu. V. Romanovskaya, M. I. Karpov, S. A. Parfenov and M. V. Rybakov are my important helpers in obtaining the results presented in this book.

The influence of all Soviet, Russian and foreign space geophysicists collaborating and discussing with me in different years on different conferences was very significant as well, of course. To all of them I devote this book.

CHAPTER 2

EARTH AND ITS NEAR–EARTH ENVIRONMENT

The Earth is a planet of the solar system, in the centre of which is the Sun. The Earth moves around the Sun according to Kepler's laws in an elliptical orbit with a minimum distance to the Sun (147 095 000 km, perihelion) around January 2, and the maximum (152 100 000 km, aphelion) around July 4 (Wikipedia, 2020). The plane of the ecliptic is the plane of rotation of the Earth around the Sun.

The Earth has the approximate shape of a ball with an average radius of 6371 km, rotating around its axis, called the geographic axis. Imaginary points of the geographical axis intersection with the Earth' surface are the geographical poles. The North Pole points out to the Polar Star.

The geographical axis tilts 22 degrees relative to the plane of the ecliptic. This angle is called the solar inclination. The Earth's joint rotations around the Sun and around the geographical axis form seasonal, diurnal and latitudinal variations in the parameters of the near-Earth environment associated with the amount of radiation incident on the Earth from the Sun.

Most of the Earth's surface is in the liquid phase, the rest – in the solid, called continental, with the first one laying on the second. The boundary between the liquid and solid phases is the coastline, which is changing over time.

The cold hard shell of the Earth is the crust, below which is the mantle with temperature and pressure increasing towards the centre of the Earth. Due to the high temperature many particles of the mantle are ionized. In the centre of the Earth, there is its core, inaccessible for direct research.

Movements of the charged particles inside of the Earth create electric currents which in turn induce the geomagnetic field **B**. In the first approximation, this field is the dipole one. Such field corresponds to the magnetic field of the homogeny magnetized ball. The magnetic moment of the dipole geomagnetic field is equal to 7.96 × 1025 CGS. Outside of the Earth, there are other currents complicating the geomagnetic field structure.

Motions of the Earth's crust due to an imbalance of elastic stresses, carried out along the cracks, are called tectonic faults. These tectonic movements are earthquakes (EQs). Volcanic eruptions through thin places in the crust and giant waves in the liquid phase often accompany EQs. They concentrate especially at coasts of the Pacific Ocean – in Kamchatka, Japan, the Philippines, California, etc.

Earthquakes go through the preparation stage, when the energy needed to break through the crust is accumulated, and the stage of the main blow, when the stored energy is suddenly released. After that, the vibrations of the crust caused by this impact continue for several days subsiding over time.

Signs of an approaching impact in the behavior of physical parameters of the Earth's environment are precursors of earthquakes. Knowledge of these signs and the causes of their occurrence allows, in principle, to predict earthquakes and to reduce the degree of their harmful impact. However, this important task remains unsolved yet.

EQs act naturally on the Earth's gaseous shell laying over the surface called atmosphere. It consists of many different sorts of neutral and charged particles. The main force acting them is the gravitational one due to the existence of the massive Earth's body. Collisions between moving particles lead to the pressure and its gradient force, which together with the gravitational one product the well-known Boltzmann's barometric law for the gas density, which decreases exponentially with height.

For charged particles, situation is more complicated due to the geomagnetic and electric fields presence. The geomagnetic field influence depends on the collisions frequency, which decreases with height, and therefore the geomagnetic field role increases with height. The number of charged particles becomes significant above approximately 50–70 km over the Earth's surface, and this upper part of the atmosphere is usually called as the ionosphere.

The electric fields originated as the geomagnetic ones from the inner and outer (relative on the Earth's surface) sources due to the core movements and solar wind action, correspondingly. Relations between the electric fields and currents create the complex anisotropic character of the conductivity strongly depended on height.

In the lower atmosphere at heights of about 50–90 km (the ionosphere *D*-region) the electrical conductivity weakly depends on the geomagnetic field B. Then it becomes anisotropic one and important for the horizontal ionosphere currents in the *E*-region (dynamo-region) at heights 90–120 km.

At heights of about 150–200 km the geomagnetic field influence dominates over the collisions, and ionosphere becomes highly conducting along the geomagnetic field lines. The O^+ ions dominate between 200 and 1000 km. This is the *F*2-region where the main charged particle density maximum (*F*2 peak) locates at heights of about 250–500 km ($h_m F2$).

At heights of about 1000 km light ions H^+ and He^+ begin to dominate, and this area is called usually as the plasmasphere. It includes the closed dipole-like geomagnetic field tubes, acting as the plasma night-time reservoir for the *F*2-region.

Out of the magnetosphere, the solar plasma flows from the Sun. This solar wind transports the solar magnetic field (IMF – interplanetary magnetic field) from the solar spots forming the magnetosphere – the cavern where the IMF can not penetrate. The boundary of this cavern is the magnetopause. Its dimensions are of about several R_E (Earth's radius): 7–15 in the direction to the Sun as well as in the perpendicular directions. In the antisolar direction the magnetosphere stretches very far forming so-called tail with the antiparallel geomagnetic field lines open into the vacuum.

The charged particles' motions produce the electric currents, which create the magnetic fields in addition to the original geomagnetic field and form by these means the geomagnetic activity. The last correlates with the solar activity.

The structure of the magnetosphere is such that the most direct and intensive interaction between the solar wind and near-Earth plasma takes place in the polar caps located around the magnetic poles (auroral zones, where the precipitating energetic particles the polar lights (auroras)) with the boundaries at the distance of about 15 latitudinal degrees from the geomagnetic axes. From there the plasma disturbances propagate globally via the electromagnetic plasma drifts and neutral winds. These disturbances (space weather) influence very much on the electromagnetic wave propagation used for the communication, navigation and radiolocation in different devices. However, locally their influence is much less intensive than the EQs ones. Nevertheless, both kinds of disturbances of the near-Earth environment from the inner and outer sources that are very coupled to each other and should be considered and described together correspondingly to the title of this book.

Observations of the near-Earth environment are mainly performed due to meteorological needs for the weather forecasting. The measured physical parameters are temperature, pressure, wind direction, and speed, humidity, and cloud cover. These measurements means are thermometers, barometers, weather vents, and similar simple instruments located on weather stations connected by telegraph and radio into a network.

For navigation purposes, variations of the Earth's magnetic field measured be a magnet with a mirror on a quartz thread, play role of a compass. With the discovery of the ionosphere reflecting electromagnetic waves, the measured parameters of the reflections of these waves become important. At the same time, the spatial scope of the measurement area expanded. On October 4, 1957, the first Soviet satellite flew into space, and the near-Earth space rightfully considered space. The absence of inter-state borders in space led to broad coordination and cooperation of the international scientific community, which expressed in the International Geophysical Year (1957–1958), as well as a number of subsequent similar events that put geophysics at the forefront of science.

In addition to the above-mentioned ground meteorological, magnetic and ground observations, measurements from satellites are very useful, both near them and at a distance, remote. Especially important are the so-called geostationary satellites that rotate with the Earth and hover over a certain place on the Earth's surface. Measurements of the Total Electron Content (TEC) in the column with the unit cross-section along the beam from the satellite to the ground receiver, coincide together with subsequent tomography processing these signals. That allows us to create navigation measurements and is successful means to determine the location of various vehicles.

As it will be shown later, measurements of TEC in areas of tectonic faults provide an ability to study TEC disturbances, created by seismogenic electric fields, during the preparation of earthquakes. However, a detailed review of the methods of observations and the results obtained with their help requires an explanation of the physical basis for describing the variations in the parameters of the near-Earth environment, which there is in the following chapters together with the observational methods and results.

CHAPTER 3

LITHOSPHERE AND ITS DISTURBANCES (EQS)

3.1. Tectonic plates and their movements

Lithosphere is not a continuous sphere; it is covered with cracks, (tectonic faults), formed by the movements of tectonic plates. The plates float on a molten substance, whose own vortex movements are transmitted to the plates. As a result, the plates collide and run over each other's edges. In these places, the energy of compression accumulates, the release of which can occur suddenly in the form of the formation of a new crack. The main attack at the same time is an earthquake.

3.2. Internal structure of the Earth

The Earth consists of several shells, distinguished by chemical or deformation properties. Then there is the outer core (consisting mainly of iron) with a thickness of about 2200 km. Above it lie 2.900 km of viscous mantle consisting of silicates and oxides, and even higher – a fairly thin hard crust. It also consists of silicates and oxides, but is enriched with elements that are not found in mantle rocks.

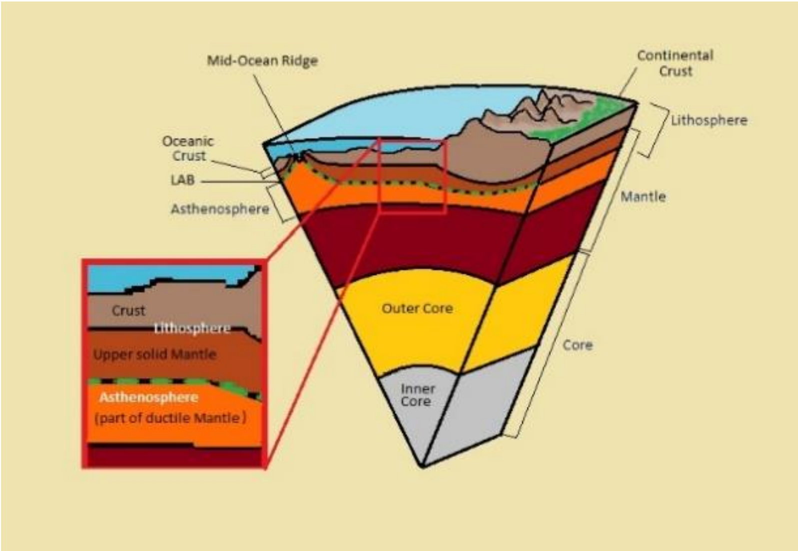

Fig. 3.1. Schematic representation of the internal structure of the Earth ("Earth - Wikipedia" 2021).

The Earth's geological layers are located at the following depths below the surface: 1) lithosphere (5–200 km), 2) crust (5–70 km), 3) upper mantle (35–60 km), 4) mantle (35–2890 km), 5) asthenosphere (100–200 km), 6) upper mantle (35–660 km), 7) lower mantle (660–2890 km), 8) external core (2890–5150 km), 9) inner core (5150–6371 km).

The Earth's layers were determined by measuring the propagation time of refracted and reflected seismic waves created by earthquakes. The core does not pass transverse waves, and the speed of wave propagation differs in different layers. Changes in the speed of seismic waves between different layers cause their refraction due to Snell's law.

3.2.2. Earth core

The average Earth density is 5515 kg/m^3. Since the average density of the surface matter is only about 3000 kg/m^3, it should be concluded that dense substances exist in the Earth's core. Another proof of the high core density is based on the seismological data. The compaction of the substance by pressure should also be taken into account. There are data from laboratory studies with the conclusion that the density of substances changes by the denser packing of atoms, for example, iron is already compacted by about 30% at 1 million atmospheres. The density of the upper mantle, starting from a value of 3.2 g/cm^3 on the surface, gradually increases with depth due to the compression of its substance in the lower mantle. Significant rearrangements in the crystal structure of matter no longer occur, since all oxides in this geosphere are already in a state of extremely dense packing of atoms and the compression of mantle matter occurs only due to the compression of the atoms themselves.

Seismic measurements show that the core is divided into two parts – a solid inner core with a radius of ~1200 km and a liquid outer core with a radius of ~3400 km.

3.2.3. Mantle of the Earth

The Earth's mantle extends to a depth of 2.890 km, making it the Earth's thickest layer. The pressure in the lower mantle is about 140 GPA ($1.4 \cdot 10^6$ ATM). The mantle consists of silicate rocks rich in iron and magnesium relative to the overlying crust. High temperatures in the mantle make the silicate material plastic enough that there can be convection of matter in the mantle coming to the surface through faults in tectonic plates. The melting and viscosity of a substance depend on pressure and chemical changes in the mantle. The mantle viscosity varies from 10^{21} to 10^{24} PA·s depending on the depth. For comparison, the viscosity of water is about 10^{-3} PA·s, and sand – 10^7 PA·s.

The crust and mantle are separated by the mohorovichich boundary, where the seismic wave velocities sharply increase.

3.2.4. Crust

The Earth has two fundamentally different types of crust: continental (older) and oceanic (no older than 200 million years). The Earth's crust is characterized by constant movements: horizontal and oscillatory. Some lithospheric plates are composed exclusively of oceanic crust (for example, the largest Pacific plate), while others consist of a block of continental crust soldered into the oceanic crust. The Earth's crust under the continents consists of sedimentary, granite and basalt layers with a total thickness of up to 80 km.

The Earth's crust under the oceans has undergone many stages of partial melting as a result of the formation of oceanic crust, it is highly depleted of low-melting rare elements, mainly consists of dunites and harzburgites, its thickness is 5–10 km, and the granite layer is completely absent.

Most of the crust consists of basalts. The mass of the Earth's crust is estimated at $2.8 \cdot 10^{19}$ tons (of which 21% is oceanic and 79% is continental). The crust is only 0.473% of the Earth's total mass.

The continental crust has a three-layer structure. The upper layer is represented by an intermittent cover of sedimentary rocks, which is widely developed, but rarely has a large thickness. Most of the crust is folded under the upper crust, a layer consisting mainly of granites and gneisses with a low density and ancient history. Research shows that most of these rocks were formed very long ago, about 3 billion years ago. Below is the lower crust consisting of metamorphic rocks such as granulites, and the like.

The structure of the lithosphere is characterized by mobile areas (folded belts) and relatively stable platforms. Blocks of the lithosphere – lithospheric plates – move along a relatively plastic asthenosphere. A lithospheric plate is a large stable section of the Earth's crust. The lithosphere is divided into blocks by narrow and active zones, latitudinal faults.

Lithospheric plates are limited by zones of seismic, volcanic, and tectonic activity – plate boundaries. There are three types of plate boundaries: divergent, convergent, and transform.

The total thickness of the oceanic lithosphere varies from 2–3 km in the area of rift zones of the oceans to 80–90 km near the continental margins. The thickness of the continental lithosphere reaches 200–220 km.

Lithospheric plates constantly change their shape, they can split as a result of rifting and solder, forming a single plate as a result of collision. They can also sink into the planet's mantle, reaching the depth of the outer core.

3.3. Tectonics

Tectonics is a branch of the geology that studies the structure of the tectonosphere (lithosphere + asthenosphere) and its movements. At the same time, new oceanic crust is formed in expansion zones (mid-ocean ridges and continental rifts) as a result of spreading (spreading of the sea floor), and the old one is absorbed in subduction zones.

3.3.1. Plate movements

The idea of the movement of crustal blocks was first expressed in the theory of continental drift, proposed by Alfred Wegener in the 1920s. This theory was initially rejected. Its revival occurred in the 1960s, when data were obtained indicating the processes of expansion of the oceanic crust and subduction of some parts of the crust under others. Combining these concepts with the old theory of continental drift gave rise to the modern theory of plate tectonics.

The main provisions of plate tectonics can be formulated as follows. The upper part of the solid Earth is divided into a brittle lithosphere and a plastic asthenosphere. Convection in the asthenosphere is the main cause of plate movement. The modern lithosphere is divided into 8 large plates, dozens of medium plates and many small ones. Small plates are located in the belts between the large plates. Seismic, tectonic, and magmatic activity is concentrated at the plate boundaries. Lithospheric plates are described as solid bodies in the first approximation, and their motion obeys Euler's rotation theorem.

There are three main types of relative plate movements: divergence, expressed by rifting and spreading; convergence, expressed by subduction and collision; and shear movements along transform geological faults. Spreading in the oceans is compensated by subduction and collision along their periphery, and the radius and volume of the Earth are constant up to the thermal compression of the planet (in any case, the average temperature of the Earth's interior slowly decreases over billions of years).

The movement of lithospheric plates is caused by their entrainment by convective currents in the asthenosphere.The eight largest lithospheric plates cover more than 90% of the Earth's surface in the modern era.

3.3.2. The force that moves the plates

Horizontal movement of plates occurs due to the mantle heat and gravity flows – convection. The energy source for these flows is the difference between the temperature of the central regions of the Earth and the temperature on its surface. The rocks heated in the central zones of the Earth expand, their density decreases, and they float up, giving way to descending colder and therefore heavier masses that have already given some of the heat to the Earth's crust. This process of heat transfer is continuous, resulting in convective flows. These flows close on themselves and form the stable convective cells that are consistent in the flow directions with neighboring cells. In the upper part of the cell, the substance occurs almost in the horizontal plane, this part of the course carries the plate in a horizontal direction due to the huge viscosity of the mantle material.

The driving force of the viscous mantle material directly below the crust is the elevation of the free surface of the mantle between the area of lifting and lowering area of convection flow. This height difference is formed due to the different densities of slightly hotter and slightly colder matter, since the weight of more and less hot columns in equilibrium is the same. This same driving force determines the degree of elastic horizontal compression of the crust by the force of viscous friction of the flow on the Earth's crust. The magnitude of this compression is small in the region of the ascent of mantle flow and increases as you get closer to the place of lower flow. Above the descending flow, the compressive force in the crust is so great that from time to time the strength of the crust is exceeded, and an inelastic deformation of the crust occurs – an earthquake. At the same time, entire mountain ranges, such as the Himalayas, are squeezed out of the place of crust deformation.

During plastic deformation, the stress in the crust decreases very quickly – the compressive force in the earthquake centre and its surroundings. However, immediately after the end of inelastic deformation, the very slow increase in stress interrupted by the earthquake continues due to the very slow movement of the viscous mantle flow, starting the cycle of preparation for the next earthquake.

Thus, the movement of plates is a consequence of heat transfer from the central zones of the Earth by very viscous magma. In this case, part of the heat energy is converted into mechanical work to overcome the friction forces, and part, passing through the Earth's crust, is radiated into the surrounding space. Therefore, our planet is in a sense a heat engine.

3.4. Earthquakes

Earthquake – are tremors and vibrations of the Earth's surface. The primary cause of earthquakes is the global geological and tectonic forces, the appearance of which is caused by temperature changes in the Earth's interior. Most earthquakes occur on the margins of tectonic plates. It has been observed that over the past two centuries, strong earthquakes have occurred as a result of the opening of large faults that come to the surface.

Most earthquake foci occur in the Earth's crust at a depth of 30–40 km below the Earth's surface. The most active zones for earthquakes are the Pacific belt, which runs along almost the entire coast of the Pacific Ocean (about 90% of all earthquakes on Earth) and the Alpine belt, which stretches from Indonesia to the Mediterranean Sea (5–6 % of all earthquakes).

Volcanic earthquakes are a type of earthquake in which tremors occur as a result of high stress in the interior of a volcano. The cause of such earthquakes is lava and volcanic gases. Earthquakes of this type are weak, but last for a long time, repeatedly – weeks and months. However, an earthquake of this type does not pose a danger to people. By the way, an earthquake is sometimes the most dangerous natural disaster along with a volcanic eruption.

The cause of the earthquake is the rapid displacement of a section of the lithosphere as a whole at the moment of relaxation of elastic deformation of stressed rocks in the earthquake source.

According to the scientific classification, as for the depth of occurrence, earthquakes are divided into 3 groups: "normal" – 34–70 km, "intermediate" – up to 300 km, "deep-focus" – over 300 km.

3.4.1. Seismic waves

Seismic waves generated by earthquakes propagate in all directions from the hearth like sound waves. The point at which the movement of rocks begins is called the **focus** or **hypocentre**, and the point on the Earth’s surface above the focus is called the **epicentre** of the earthquake. Shock waves propagate in all directions from the hearth, and their intensity decreases as they move away from it. The speed of seismic waves can reach 10 km/s.

Near the epicentre, the vibrations may be too strong for seismographs to register. Therefore, accelerographs are used for near-term earthquakes that start working during an earthquake and record the acceleration of ground movements.

3.4.2. Processes that occur during strong earthquakes

An earthquake starts with a push, and then it breaks and moves rocks in the depth of the Earth. Hypocentre depth is usually no more than 100 km, but sometimes it reaches up to 700 km. In some cases, the layers of Earth located on the sides of the fault are moving towards each other. In others, the ground on one side of the fault sinks, forming discharges. In places where they cross the river, there are waterfalls. The vaults of underground caves crack and collapse. It happens that after an earthquake, large areas of land are lowered and filled with water. Aftershocks displace the upper, loose soil layers from the slopes, forming landslides, and soil liquefaction can occur. During the earthquake in California in 1906, a section of 477 kilometers was observed to shift the ground at a distance of 6–8.5 m.

Underwater earthquakes (seaquakes) are the cause of tsunamis – long waves generated by a powerful impact on the entire water column in the ocean, during which there is a sharp shift (rising or falling) section of the sea floor. Tsunamis are formed during an earthquake of any strength, but those that occur due to strong earthquakes reach a large force.

Positive Freund Holes

Considering the problem of the connection of earthquakes with the upper atmosphere, it is necessary to note a possible additional source of atmosphere ionization associated with processes in the lithosphere, which was proposed in a series of experimental works (Freund et al., 2007, 2009; Freund and Sornette, 2007; Freund, 2011). When the rock is compressed, so-called positive holes are activated – defects in the crystal lattice, which are highly mobile carriers of positive charges. As the volume is compressed, positive holes accumulate near the surface, at the earth-air interface, and finally, breakdown ionization of neutral surface air molecules occurs. Laboratory experiments have shown that this creates a powerful source of the electric field, and the density of the corresponding electric current according to the measurement data was 0.5–1.25 $\mu a/m^2$.

3.4.3. Measuring the strength and impact of earthquakes

The scale of magnitudes. Richter scale

The magnitude scale distinguishes earthquakes by their magnitude, which is the relative energy characteristic of the earthquake. There are several magnitudes and, accordingly, magnitude scales: local magnitude (Ml); magnitude determined from surface waves (Ms); magnitude determined from volume waves (Mb); moment magnitude (Mw).

The most popular scale for estimating earthquake energy has long been the **local Richter magnitude scale**. On this scale, an increase in magnitude per unit corresponds to a 32-fold increase in the released seismic energy. An earthquake with a magnitude of 2 is barely noticeable, while a magnitude of 7 corresponds to the lower limit of destructive earthquakes that cover large territories. However, since 2002, the US geological survey has used instant magnitude for strong earthquakes. If in the 1970s–1980s, the strongest earthquakes in history were considered an earthquake off the coast of Ecuador (1906) and the Sanriku earthquake (1933) with Ml = 8.9 for both, since the beginning of the 21st century, the Great Chilean earthquake with Mw = 9.5 is considered such, while its Ml = 8.4– 8.5.

General characteristics of earthquakes on the intensity scale:

1 point (invisible) – marked only with special devices;

2 points (very weak) – only felt by very sensitive pets and some people in the upper floors of buildings;

3 points (weak) – there is only inside some buildings, like the shaking of the truck;

4 points (moderate) – the earthquake is noted by many people; windows and doors may fluctuate;

5 points (quite strong) – swinging of hanging objects, creaking of floors, rattling of windows, shedding of whitewash;

6 points (strong) – light damage to buildings: thin cracks in plaster, cracks in stoves, etc.;

7 points (very strong) – significant damage to buildings; cracks in the plaster and breaking off individual pieces, thin cracks in the walls, damage to chimneys; cracks in wet soils;

8 points (destructive) – destruction in buildings: large cracks in the walls, falling eaves, chimneys. Landslides and cracks up to several centimeters wide on mountain slopes;

9 points (devastating) – collapses in some buildings, collapse of walls, partitions, roofs. Collapses, scree and landslides in the mountains. The crack propagation speed can reach 2 cm/s;

10 points (destructive) – collapses in many buildings; in the rest – serious damage. Cracks in the ground up to 1 m wide, landslides, and landslides. Lakes are formed due to the blockages of river valleys;

11 points (disaster) – numerous cracks on the Earth’s surface, large collapses in the mountains. General destruction of buildings;

12 points (severe disaster) – large-scale terrain changes. Huge landslides. General destruction of buildings and structures.

Earthquakes and solar activity

Recently (2020, July), V. Martichelli, H. Harabaglia, C. Troise and G. DeNatale published the paper “On the correlation between solar activity and large earthquakes worldwide” in Nature, (Marchitelli et al. 2020).

The authors note, that “Large earthquakes occurring worldwide have long been recognized to be non Poisson distributed, so involving some correlation mechanisms, which could be internal or external to the Earth. Until now, no statistically significant correlation of the global seismicity with one of the possible mechanisms has been demonstrated yet. In this paper, we analyze 20 years of proton density and velocity data, as recorded by the SOHO satellite and the worldwide seismicity in the corresponding period, as reported by the ISC-GEM catalogue. We found clear correlation between proton density and the occurrence of large earthquakes ($M > 5.6$), with a time shift of one day. The significance of such correlation is very high, with probability to be wrong lower than 10^{-5}. The correlation increases with the magnitude threshold of the seismic catalogue. A tentative model explaining such a correlation is also proposed, in terms of the reverse piezoelectric effect induced by the applied electric field related to the proton density. This result opens new perspectives in seismological interpretations, as well in earthquake forecast".

3.4.4. Forecasting

At the end of the 20th century, a group of well-known western seismologists held an online debate, the main question of which was "is a reliable forecast of individual earthquakes a realistic scientific goal?" All participants in the discussion, despite significant differences in particular issues, agreed that:

deterministic predictions of individual earthquakes with sufficient accuracy to allow evacuation programs to be planned are unrealistic;

at least some forms of probabilistic prediction of the current seismic hazard, based on the physics of the process and observational data, can be justified.

Even if the accuracy of measurements and a non-existent physical and mathematical model of the seismic process made it possible to determine with sufficient accuracy the place and time of the beginning of the destruction of a section of the Earth's crust, the magnitude of the future earthquake remains unknown. The fact is that all models of seismicity that reproduce the graph of earthquake recurrence contain one or another stochastic generator that creates dynamic chaos in these models, which is described only in probabilistic terms. More explicitly, the source of stochasticity can be described qualitatively as follows. Let the destruction front propagating during an earthquake approach the area of increased strength. The magnitude of the earthquake depends on whether this section will be destroyed or not. For example, if the front of destruction passes further, the earthquake will become catastrophic, and if not, it will remain small. The outcome depends on the strength of the site: if it is below a certain threshold, the destruction will go according to the first scenario, and if it is higher, according to the second. A "butterfly effect" occurs: