Chapter 09. Atmospheric Signals Associated with Major Earthquakes. A Multi-Sensor Approach.

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Abstract

We are studying the possibility of a connection between atmospheric observation recorded by several ground and satellites as earthquakes precursors. Our main goal is to search for the existence and cause of physical phenomenon related to prior earthquake activity and to gain a better understanding of the physics of earthquake and earthquake cycles. The recent catastrophic earthquake in Japan in March 2011 has provided a

renewed interest in the important question of the existence of precursory signals preceding strong earthquakes. We will demonstrate our approach based on integration and analysis of several atmospheric and environmental parameters that were found associated with earthquakes. These observations include: thermal infrared radiation, radon/ ion activities; air temperature and humidity and a concentration of electrons in the ionosphere. We describe a possible physical link between atmospheric observations with earthquake precursors using the latest Lithosphere-Atmosphere-Ionosphere Coupling model, one of several paradigms used to explain our observations. Initial results for the period of 2003-2009 are presented from our systematic hind-cast validation studies. We present our findings of multi-sensor atmospheric precursory signals for two major earthquakes in Japan, M6.7 Niigata-ken Chuetsu-oki of July16, 2007 and the latest M9.0 great Tohoku earthquakes of March 11, 2011

1. Introduction

We are investigating a possible link between atmospheric observation and earthquakes, which would have an impact on our further understanding of the physics of earthquakes and the phenomena that precedes their energy release. Our main activity is to search for the existence and cause of physical phenomenon related to earthquakes and to gain a better understanding of the physics of earthquake and earthquake cycles by recording satellite and ground measurements. The recent catastrophic earthquakes in Japan (March 2011), Italy (April 2009), Haiti (January 2010) and Chile (February 2010) have provided a renewed interest in the important question of the possibility of the existence of precursory signals preceding strong earthquakes. There were several papers presented at the recent Workshop on Validation of Earthquake precursor by Space and Terrestrial Observations (VESTO) at Chiba University in Japan March 2009, which described precursory atmospheric signals observed on the ground and in space associated with several recent earthquakes (JAES, 2011, 41, 4-5). The major question, still widely debated within the scientific community, is whether such signals systematically precede some major earthquakes. Our methodology is based on an integration analysis of several atmospheric and environmental parameters that were found associated with earthquakes. These observations include: thermal infrared radiation; radon/ ion activities; air

temperature and humidity, and concentration of electrons in the ionosphere We describe the link and integration between atmospheric observations using the latest development in the Lithosphere-Atmosphere-Ionosphere Coupling (LAIC, Pulinets and Boyarchuk, 2004 and Pulinets and Ouzounov, 2010) model one of several models used to explain our observations. Initial results for the period of 2003-2009 are presented from our systematic hind-cast validation studies. We demonstrate our findings of multi-sensor atmospheric precursory signals for two major earthquakes in Japan, M6.7 Niigata-ken Chuetsu-oki of July16, 2007 and the latest M9.0 great Tohoku earthquakes of March 11, 2011

2. Observation of earthquake atmospheric signals. Case studies

The latest catastrophic Tohoku-Sendai earthquake in Japan has confirmed that (1) earthquakes are an extremely difficult phenomenon to understand and forecast with a high degree of certainty with exiting science methodology and (2) The complex and dynamic nature of the earthquake phenomena requires spatial, spectral, and temporal coverage that is far beyond any single satellite mission. Recent scientific research has shown already that certain precursor signals, such as atmospheric thermal, ionospheric electric and in- situ gas anomalies have been correlated with the future occurrence of significant earthquakes (Hayakawa M, (Ed), 1999, Hayakawa M. and O.A.Molchanov, 2004; Pulinets and Boyarchuk, 2004).

The science quest for understanding the atmospheric signals related to earthquakes processes has more then 2000 years of history. According to ancient geek philosopher Aristotle, “pneuma” (wind) are involves before earthquakes producing strange atmospheric effects (MacArthur, 1980). The fundamental meaning of “pneuma" is air in motion or electricity in the airs. Fogs and clouds were recognized as observational evidence for precursory activities prior to major seismic shocks since the days of Aristotle and Pliny (Roman Empire) and many researchers in ancient China (Tributsch, 1978). John Milne - an English seismologist and geologist who invented the first modern seismograph has published the first quantitative analysis of atmospheric signals associated with seismicity in 1913. In his book “Earthquake and other movements” author found that for 387 earthquakes observed in Northern Japan, the sinuses of the curves of means monthly temperature were generally a little in advance to the crest of the waves indicating the earthquake arrival (Milne, 1913). The recent advances in remote

sensing observation, space technology and sensors have helped to advance the scientific understanding of atmospheric earthquake signals. Many new results have been reported for the last decade about the possible connection of atmospheric parameters with earthquake processes: Radon/gas/ions (), thermal infra-red (), latent heat (Dey and Singh, 2003; Cervone and all, 2005); earthquake clouds (Morosova, 2005,Doda et al, 2011), earthquake lights (Stothers, 2004, St-Laurent et al, 2006), jet stream (Wu, 2004,2007), air temperature and humidity (Milkis, 1986, Dunajecka and Pulinets, 2005), VHF signals (H. Fujiwara et al, 2004,Kushida and Kushida, 2006), GPS/TEC (Liu et al, 2004, Pulinets et al, 2006, Zakharenkova et 2006).

In our analysis we present only several continuously measurable atmospheric parameters associated with major earthquake activities (M>5.5). Data used in this study is publicly available. We studied four different physical parameters characterizing the state of the atmosphere/ionosphere during the periods before and after the major earthquake events: 1. Outgoing Long wave Radiation, OLR (infra-red 10-13 μm) measured at the top of the atmosphere; 2.Atmospheric temperature and humidity; 3.Radon/ion concentration, and 4. GPS/TEC (Total Electron Content) ionospheric variability (See Table 1). This approach provides a complex view about the scale and physics of changes in the atmospheric processes related to tectonic activity.

Table 1: Overview of EQ atmospherics signals presented in the chapter.

Parameter	Time in advance	Anomaly Range	Sensors	Data source	References
Radon/Ion flux	Months-two weeks	Increase 2-10 fold	Ground based α and γ counters, complex radon stations, Ion counters	Radon/ion monitoring local groups participating in project	Toutain and Baubron, 1999; Omori et al, 2004; Inan et al, 2005;Ondoh, 2009
OLR	Two weeks	2 – 80 W/m^2	Aqua/AIRS NOAA/AVHRR	AIRS spectrometer, AQUA satellite, AVHRR spectrometer, NOAA satellites	Ouzounov et al, 2007; Pulinets and Ouzounov 2011
Air temperature	One week	Temperature increase (usually absolute monthly maximum)	NCEP and Ground based meteorological stations, satellite data	USAF database Local meteorological data of the project participants, NCEP	Pulinets et al, 2066a,b
Air relative humidity	One week	Humidity drop 20%-100%	NCEP and Ground based meteorological stations, satellite data	USAF database Local meteorological data of the project participants, NCEP	Pulinets et al, 2066a,b
Ionospheric variations	5-1 days before the shock	Local irregularities 15%-100%	DMSP DMETER GPS/TEC	ftp://cddisa.gsfc.nasa.gov/gps/products/ionex/ http://gage152.upc.es/~ionex3/igs_iono/igs_iono.	Zakharenkova et al,2006; Pulinets et al,

To demonstrate of our approach for each of those parameters we use two of the most dangerous earthquakes in Japan for last decade: 2007 M 6.8 Niigata-ken Chuetsu-oki and 2011 M 9.0 Great Tohoku earthquakes, which also created and additional environmental disasters (Cyranoski, 2007)

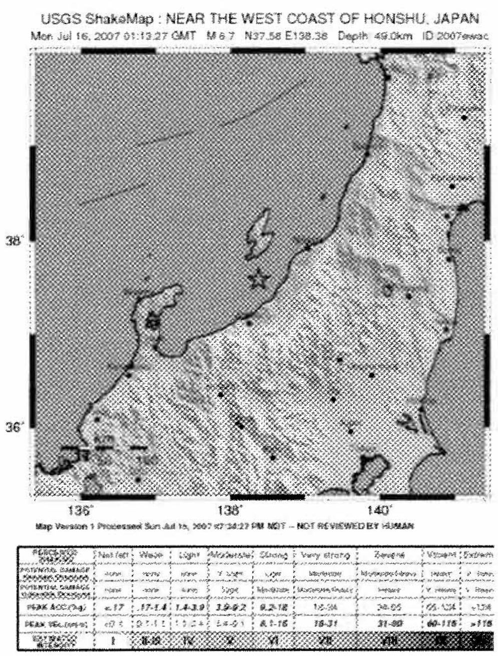
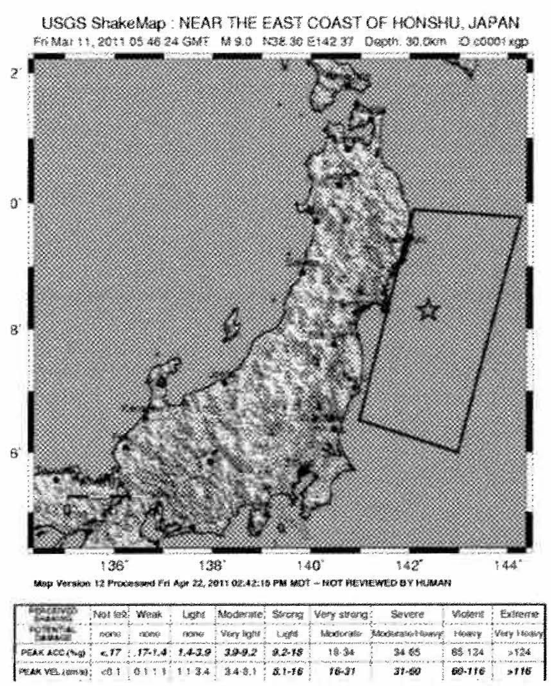


Fig 1. M6.7.0 USGS Shake map, 07.16.2007 (USGS)

2.1 M 6.8 Niigata-ken Chuetsu-oki, Japan

The 6.8M Niigata Chuetsu-oki earthquakes occurred on July 16, 2007. The epicenter was located at 37.56°N and 138.61°E at a depth of 17 km. The source was a reverse fault. (Fig.1) The largest aftershock occurred at 06:37 UT on the same day with a magnitude and depth of 6.6 and 23 km, respectively. Eleven deaths and at least 1000 injuries have been reported, and 342 buildings were completely destroyed. The quake caused the shutdown of the world's largest nuclear plant at Kashiwazaki-Kariwa.



2.2 M 9.0 Great Tohoku earthquakes, Japan

The March 11th earthquake triggered extremely destructive tsunami waves of up to 38.9 meters that struck Japan, in some cases traveling up to 10 km inland (Fig. 2) With more then 15,0 deaths, 5,282 injured, and 9,121 people missing across eighteen prefectures, as well as over 125,000 buildings damaged or destroyed, making it the most expensive natural disaster on

record with overall cost could exceed $300 billion (May, 2011,Wikipedia).

Fig 2. M9.0 USGS Shake map, 03.11.2011 (USGS)

In addition to loss of life and destruction of infrastructure, the tsunami caused a nuclear accident in Fukushima Nuclear Power Plant.

3. Atmospheric signals associated with earthquake processes.

3.1 Observations of thermal data from satellites

Satellite thermal imaging (8-11 microns) data have revealed transient features prior to major earthquakes (Tronin et al., 2004a,b; Tramutoli et al., 2005). These short-lived anomalies: (1) typically appear 2–14 days before an earthquake; (2) affect regions of large extend (up to several to hundred square km); (3) display a positive deviation of 2–4 _C or more; and (4) very quickly dissipate immediately after the event. The rapidity with which these satellite-altitude temperature excursions occur suggests that are associated with the earthquake process and less likely to be result of: (i) heat flow from the Earth's interior; (ii) because of their rapid build- up they are not the result of convective transport from friction associated with active faulting or; (iii) because of the long persistence over the same region they are not of meteorological origin.

Initially the analyses of TIR observations relate to large earthquakes have been recently developed as simple approach of comparing pre *versus* post earthquake satellite TIR imagery (Gorny et al., 1988; Singh et al., 2002; Tronin et al., 2002, 2004a). With utilizing both polar orbiting and geosynchronous satellite observations new techniques have been proposed to use sub pixel level co-registration and geo-referenced imagery data from GOES, Meteosat, AVHRR and Landsat (Bryant et al., 2003; Di Bello et al., 2004). One of the main problems in detecting TIR anomalous signals was how to define and distinguish them from normal TIR fluctuations. To address this problem a robust TIR technique has been proposed, (initially as RAT-Robust AVHRR technique, then RST-Robust Satellite data analysis Technique) based on pixel temperature variance from long-term scene threshold temperatures used to identify ''hot'' (Tramutoli et al., 2001, 2005) areas. The RST technique has been successfully applied to major natural and

environmental hazards (Tramutoli et al., 2001, Di Bello et al., 2004, Filizzola et al., 2004, and Corrado et al., 2005) and improved the statistically well-founded definition for TIR anomaly for monitoring of TIR signals over seismically active regions. After the launch of the EOS satellites (1999-Terra and 2002-Aqua) a new approach to study TIR signals became available. Multi-spectral IR component analysis of these polar orbit satellites Terra/MODIS and Aqua/MODIS was done by using split window Land surface temperature (LST) for the 11-micron data (Ouzounov and Freund, 2004). TIR anomalies could also be “negative” [current temp value is lower then the background temperature]. Based on an analysis of the ocean surface temperature from MODIS, some major earthquakes in costal regions were seen with anomalous “negative” sea surface temperature (SST) (Ouzounov et al, 2006).

Outgoing Longwave Radiation

One of the main parameters we used to characterize the earth’s radiation environment is the outgoing long-wave-earth radiation (OLR, 8 to12 μm). OLR occur at the top of the atmosphere integrating and are integrated emissions from the ground, lower atmosphere and clouds (Ohring, G. and Gruber, 1982) and primary been used to study Earth radiative budget and climate (Gruber, A. and Krueger, 1984; Mehta, A., and J. Susskind, 1999). The National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center (http://www.cdc.noaa.gov/) provides daily and monthly OLR data. The algorithm for analyzing the Advanced Very High Resolution Radiometer (AVHRR) OLR data is not directly measured, but is calculated from the raw data using a separate algorithm (Gruber and Krueger, 1984). These data are mainly sensitive to near surface and cloud temperatures. A daily mean data footprints covering a significant area (90° N- 90° S, 0° E to 357.5° E) and with a spatial resolution of 2.5 ° by 2.5 ° was used to study the OLR variability in the zone of earthquake activity (Liu, 2000; Ouzounov et all, 2007, Xiong at al, 2010). An increase in radiation and a transient change in OLR were recorded at the top of the atmosphere over seismically active regions and were proposed to be related to thermodynamic processes in the earth’s surface and. An anomalous eddy was defined (Ouzounov et al, 2007) as an E_index. This index is similar to the definition of an anomalous thermal field proposed by Tramutoli et al. (1999). The E_index represents the

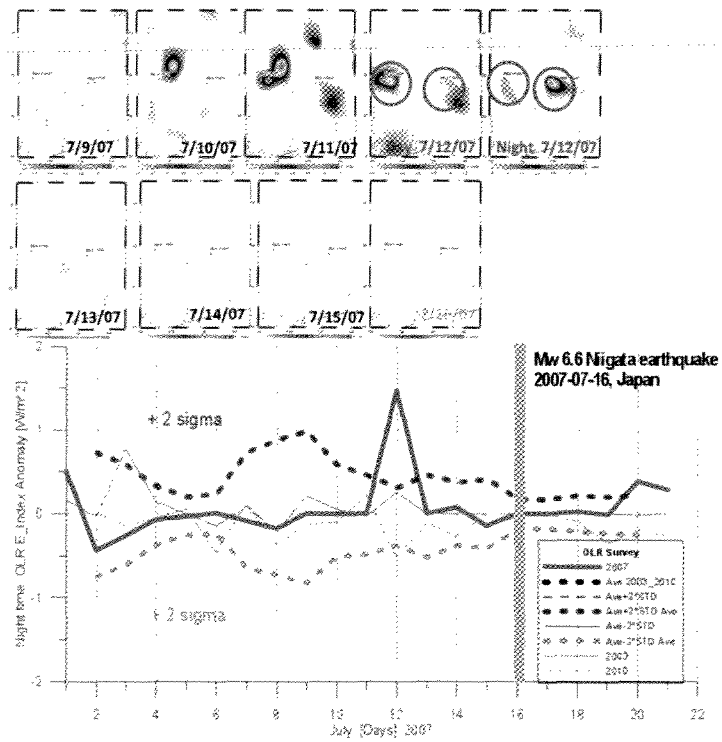


Fig 3. Evolution of daily satellite thermal anomalies around 2007-07-16 01:13 Mw 6.7 Niigata-ken Chuetsu-oki earthquake. (Top) OLR Time series of daytime anomalous OLR observed from NOAA/AVHRR (06.30LT) July 9-16, 2007 over Niigata. Tectonic plate boundaries are indicated with red lines and major faults by brown ones and earthquake location by black stars. Red circle show the spatial location of abnormal OLR anomalies near vicinities of M6.7 and M6.6 aftershock.(Bottom) Day-time anomalous OLR from July 1- July 31, 2007 observed from NOAA/ AVHRR (06.30LT)

statically defined maximum change in the rate of OLR for a specific spatial location with predefined times:

$$\Delta E\_Index(t) = (S^*(x_{i,j}, y_{i,j}, t) - \bar{S}^*(x_{i,j}, y_{i,j}, t)) / \tau_{i.j} \qquad (1)$$

Where: t=1, K – time in days, $S^*(x_{i,j}, y_{i,j}, t)$ the current OLR value and $\bar{S}^*(x_{i,j}, y_{i,j}, t)$ the computed mean of the field, defined by multiple years of observations over the same location, local time and normalized by the standard deviation $\tau_{i.j}$.

In this chapter we analyzed NOAA/AVHRR data between 2004 and 2011.

Daily mean (by 2.5°x2.5°) of OLR data been used to study the variability of transient radiation in the zone of earthquake activity. The OLR reference field was computed for July 1-31 using all available data (2004-2011) and using a ±2 sigma confidence level (Fig.3). The first indication of the formation of a transient atmospheric anomaly in July was detected on July 12th (for both day and nigh time data, Fig. 3A) in 4 days before the main shock with level of approximately 2 sigma above the monthly mean baseline (Fig 3.B). The maximum was co-located with epicenter and the reference field was computed

for the entire period of data observation.

During February 21-24 and 8-11 March, strong transient OLR anomalous field were observed near the epicentral area of the March 11, 2001 Tohoku earthquake and over the major regional faults, with a confident level greater than +2 sigma (Fig. 4).

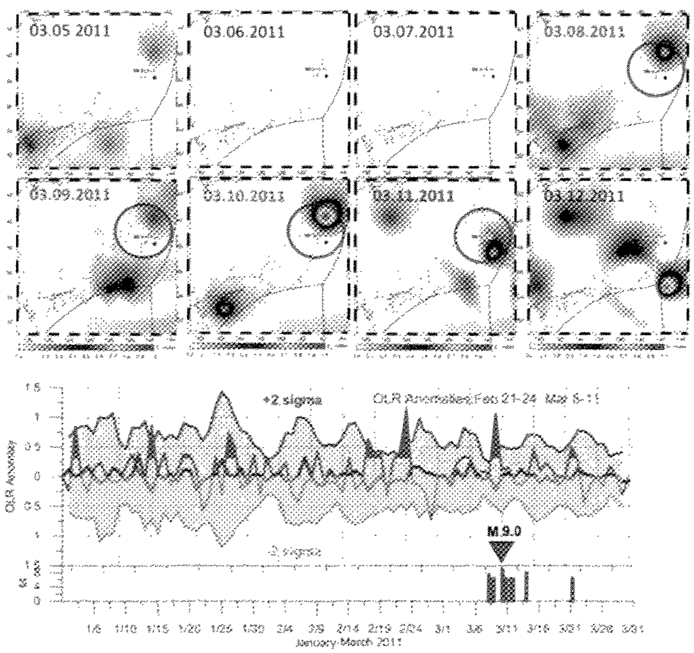


Fig .4 (Top) Time series of daytime anomalous OLR observed from NOAA/AVHRR (06.30LT) March 1-March 12, 2011. Tectonic plate boundaries with red line, major faults with brown color and earthquake location - with black star. With red circle – the spatial location of abnormal OLR anomalies within to the M9.0.(Bottom) A./ Day-time anomalous OLR , Jan 1- Mar 31, 2011 observed from NOAA/ AVHRR. B./Seismicity (M>6.0) within 200km radius of the M 9.0 epicenter.

The first indication of the formation of a transient atmospheric anomaly was detected on March 8th three days before this earthquake with a confidence level of 2 sigma above the historical mean value. The location of the OLR maximum value occurred on March 11 at 6: 30 a.m. local time and was collocated exactly with the epicenter. This rapid enhancement of radiation could be explained by an anomalous flux of the latent heat over the area of increasing tectonic activity. Similar observations were observed within a few days prior to the most recent major earthquakes China (M7.9, 2008), Italy (M6.3, 2009), Samoa (M7, 2009), Haiti (M7.0, 2010) and Chile (M8.8, 2010) and are discussed elsewhere (Pulinets and Ouzounov, 2011, Ouzounov et al, 2011a,b).

3.2 Radon/ion observations

Among the different short-term earthquake precursors radon is probably most controversial and is a source for considerable academic discussions (Toutain and Baubron, 1998 and references therein). Despite the long record of observational evidence about the connection of radon emanation with the earthquake preparation process, some networks of radon monitoring do not give a definite answer to the question of the ability of radon to be a reliable precursor (İnan et al., 2008), this may be a function of the local geology. An established connection between radon variations and earthquake thermal anomalies was provided by new these recent satellite altitude observations together with monitoring ground radon emissions in active seismic regions (Pulinets and Ouzounov 2011).

Tributsch (1978) pointed out the possibility of anomalous ion changes in the atmosphere preceding large earthquakes. Large and sudden changes in atmospheric ion concentrations have been observed at Kobe 8 days before the 1995 Kobe Earthquake (M7.3) in Japan (Satsutani, 1996). The ion data we used in our study and given in this chapter were obtained from the public materials produced by E-PISCO (http://www.e-pisco.jp/npo/pr.html). Since 2004, continuous monitoring of radon concentrations have been made rate been made in Japan by a Gerdien designed instruments. The air ion concentration measurements by three stations during the 2007 Niigata earthquake is shown on Fig.5 .

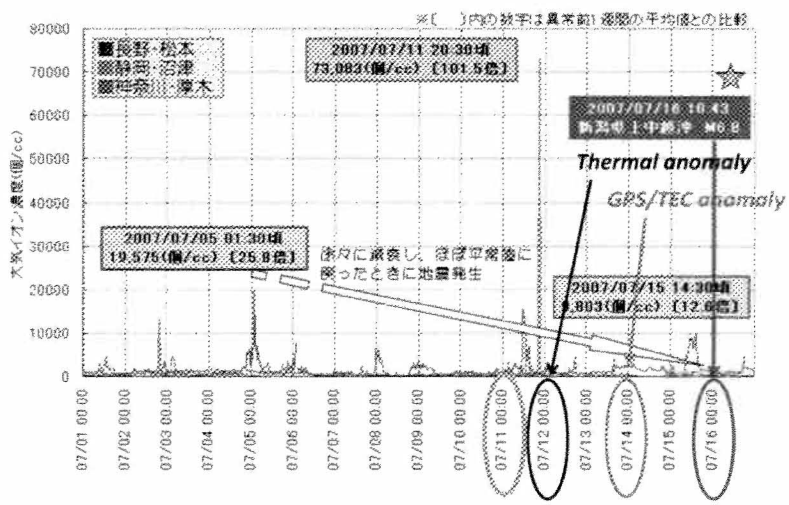


Fig .5 Ion concentration during Niigata-ken Chuetsu-oki earthquake 2007-07-16 01, Mw 6.7 Near west coast of Honshu, Japan measured by E-PISCO (http://www.e-pisco.jp/npo/pr.html).

All three stations show abnormal level few days prior to July 16th M6.7 earthquake. The largest change in air ion concentration occurs on July 11th (5 days prior to the M6.8) with gain of 110 times bigger than the normal value for the same day (Fig. 4 purple line). On the

same time scale (Fig.4) the occurrence of thermal satellite precursors detection on July 12th and GPS/TEC anomaly on July 15th are included. The time sequence for different precursors occurrence is in full support of our current understanding of the processes of their physical interconnection with the earthquake preparation processes presented in the next paragraph. Despite the facts the location of epicenters for both earthquakes (M6.7 and M6.6 aftershock) are in the Japanese Sea, the atmospheric anomalous signals were detected near to the epicentral area (over the water), which demonstrates again usefulness of the spatial detection features of the thermal satellite imagining (see Fig.3 A). The monthly time series graph of ion concentration for M9.0 Tohoku earthquake (Fig. 6) revealed a large abnormal signals start on March 7th 2011.

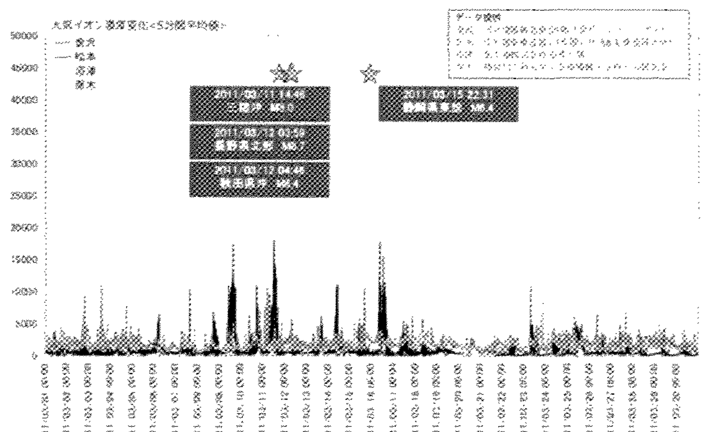


Fig. 6 Ion concentration during M9.0 Tohoku Earthquake measured by E-PISCO (http://www.e-pisco.jp/npo/pr.html). Stations name: Kanazawa (purple) Matsumoto (blue), Numazu (cyan), Atsugi (green).

The level of ion extends to March 11 where it reaches a maximum level. Surprisingly the abnormal level continues after the main the main shock on 11th, which could be explained, that ions react to the strong and long aftershock sequence. One of possible explanation of the distinct difference between the maximum level of 73,000 ions/cm^3 registered before Niigata 2007 earthquake in comparison to 17,000 ions/cm^3 before Tohoku 2011 is the network configuration - only west sided of network sensitivity towards Tohoku epicenter and the W-E direction of the jet stream, could keep away from the sensor the larger change in the ion concentration.

3.3 Atmospheric Temperature and Humidity Variations

Mil'kis (1986) demonstrated the presence long term thermal effects associated with seismic activity by studying thermal weather anomalies during the month (or season) of

strong earthquakes in the former Soviet Union. He used the data from more than 120 meteorological stations in Turkmenia, Uzbekistan and other regions of Central Asia. His results show that within interval of tens of years the mean monthly temperature for the year of earthquake practically in all cases is anomalously high and is the local maximum for the multi-year interval. Similar results been found in study short term change in air temperate and relative humidity (RH) around the time of Colima Earthquake in Mexico in 2003 and before the devastating M7.6 Kashmir earthquake on 8 of October 2005 in Pakistan (Pulinets et al, 2006, Pulinets and Ouzounov, 2011)

The processes nearest to the ground surface observed in atmosphere are the changes of air humidity and temperature. Because gas/radon is emitted from underground, the increase of the temperature is marked immediately on the ground surface. Temperature difference between faults area and far from the faults leads to horizontal air movements, air mixture and air temperature rise over all earthquake preparation area. The relative humidity drop often accompanies it: water vapor attachment to the ions decreases the content of free water vapor in air. These anomalies can be registered as seasonal or monthly extreme of meteorological parameters (Mil'kis, 1986) and short-term pre-seismic variations (Pulinets et al., 2006). We are studying the daily temperature and humidity variations (every 10 minutes) from 19 metrological stations on Honshu, Japan (Fig 7A) before and after the Tohoku earthquake.

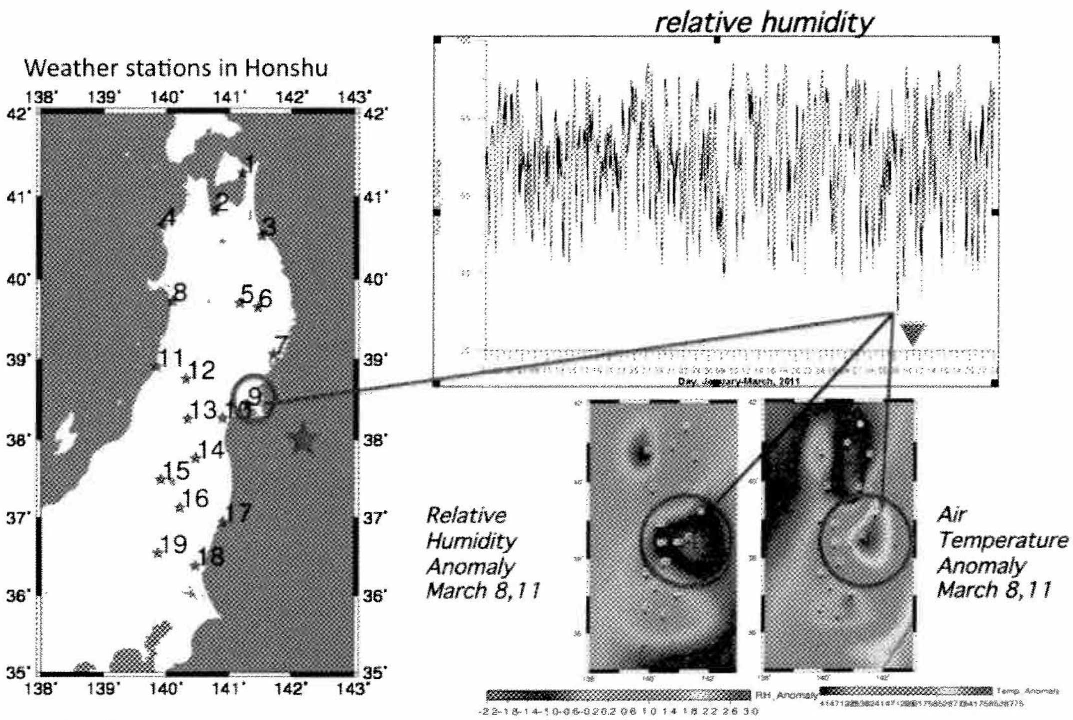


Fig .7 Air Temperature variations and Humidity around the time of M9.0 Tohoku earthquake (Lefty-right; Top-down) .A. Weather stations in Honshu .B. relative humidity (6 time per hour) January-March 2011 for station # 9. Figure shows rapid drop in the relative humidity and increase in the air temperature at 15.00 LT on March 8^{th}, 2011, 3 days before Tohoku Earthquake.

The RH from January 1 to March 31. The absolute minimum value of 30% was recorded on March 15.00 LT at Ishinomaki, Station number 9 (Fig .7B). The spatial distribution of the RH absolute minimum for January through March is given in Figure 6C. At this same station on March 8 at 3:00 p.m., local time there was a high in the daily average air temperature indicating an anomalous increase of +0.6C over Sendai – Ishinomaki region. The anomaly was defined as a residual between daily value and monthly average for the entire Honshu region (Fig.7D). The continuous negative humidity trend on March 8^{th}, along with spatially located temperature anomalies around Sendai region on same day, indicating a process of rapid increase in the ground temperature and this is similar with other atmospheric changes registered on the same day.

3.4 GPS/TEC ionospheric variations

Ionospheric variations associated with earthquake preparation have been described elsewhere (Hayakawa 1999,2004; Pulinets and Boyarchuk, 2004 and references therein). Here we discuss only the GPS/TEC ionospheric observations that are related to the atmosphere prior to large earthquakes. There are two chapters s in this book dedicated to detail description of seismo ionospheric process (see Parrot, Liu).

Recently the global ionosphere maps (GIM) containing grid data of the vertical TEC are used to study ionospheric phenomena (Mendillo et al., 2005; Afraimovich et al., 2008; Hocke, 2008). GIM is also considered as a useful source of data to analyze earthquake-related TEC variations (Nishihashi et al., 2009; Zakharenkova et al., 2006, 2008; Afraimovich and Astafyeva, 2008; Zhao et al., 2008; Liu et al., 2009; Yu et al., 2009, Kon et al, 2011). GIM data derived by the Center for Orbit Determination in Europe (CODE; ftp://ftp.unibe.ch/aiub/CODE/) is selected for the Niigata 2007 earthquake. The spatial resolution is 2.5-degree in latitude, and 5-degree in longitude and the temporal resolution is 2 hours. We derived the normalized GIM-TEC* proposed in Kon et all, 2011.

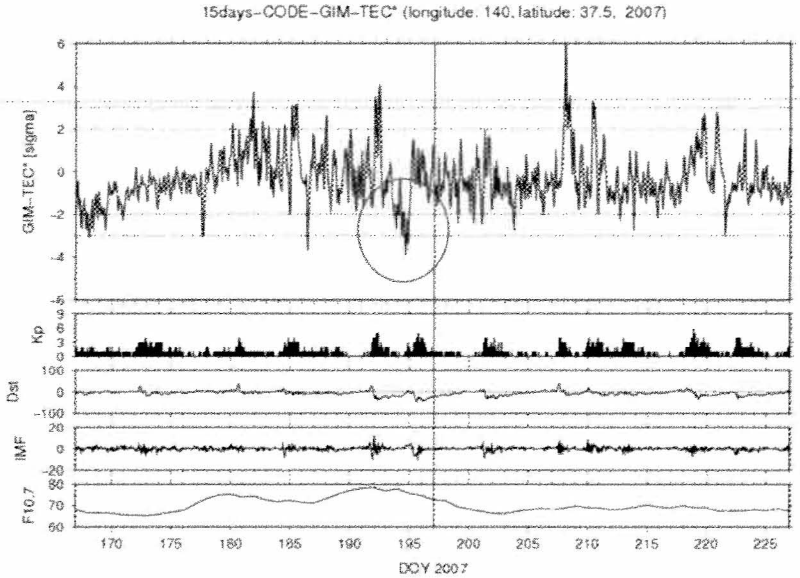
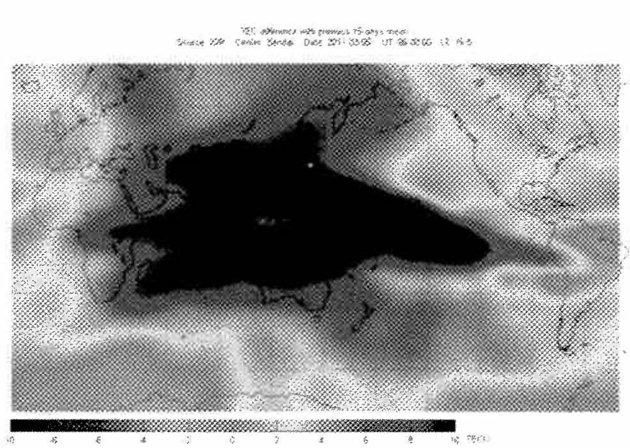


Fig. 8 Evolution of GIM GPS/TEC anomalies around the time of Mw 6.7 Niigata-ken Chuetsu-oki earthquake (Top to Bottom.) A. GIM-TEC.B/Kp Index; C/IMF index, D/F10.7 index

Figure 8 shows the variation of GIM-TEC* associated with the 2007 Niigata earthquake. It is found that the strongest positive GIM-TEC* anomaly is on July 11th - 5 days before the earthquake. Their total duration exceeding +2 sigma is about 10 hours. The major reductions in GPS/TEC appear 2 days before the earthquakes. Their duration exceeding -2 s is over 18 hours in a geomagnetically quiet condition. During the time of the M9.0 Tohoku earthquake it was very environmentally noisy period since two small and moderate geomagnetic storms took place on the first and eleventh of March respectively (Fig 9B, C). For TEC analysis we applied IONEX GIM data provided by NASA Crustal Dynamics Data Information System (http://cddis.gsfc.nasa.gov/).



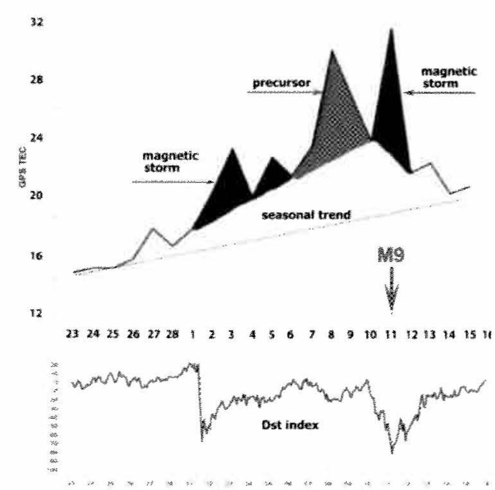


Fig .9. GIM GPS/TEC analysis. (Left-right, top-bottom); A./Differential TEC Map of March 8, 2011 at 15.5 LT; B./ time series of GPS/TEC variability observed from Feb 23 to March 16, 2011 for the grid point closest to epicenter for the 15.5 LT; and C./ The Dst index for the same period . The Dst data were provided by World Data Center (WDC), Geomagnetism, Kyoto, Japan

There was a short period of quiet geomagnetic activity between March fifth and tenth. Nevertheless an extremely strong increase in the electron concentration of the ionosphere was registered on March 8th, which we attribute to a seismogenic origin. To estimate variability from GIM the current average map was calculated for the previous 15 days and then the differential distribution of TEC was calculated by subtraction from current GIM the previous 15-day current average (Fig 9. A). This value was selected at 0600 UT corresponding to 15.5 LT, when the equatorial anomaly is close to a maximum (one might expect the strongest variations at this local time). The most remarkable property of differential maps was the sharp TEC increase during period of recovery phase of March 5 through 8 (Fig9. B). A strong and very unusual increase of TEC was registered on March 8 (marked in the figure by red). The positive effects of magnetic storms are marked in blue in the figures. One can observe the gradual trend of background TEC values; it is connected with the general electron density increase at equinox transition period (passing from winter to summer electron concentration distribution).

4 Mechanisms of generating earthquake atmospheric signals

4. 1 Lithosphere- Atmosphere-Ionosphere Coupling concepts.

The history of the LAIC model goes back for more than 15 years. The first ideas appeared as early as in 1994 (Pulinets et al., 1994) and since then many scientists have contributed in the development and validation (Hayakawa and Molchanov, 2002, Pulinets and Boyarchuk, 2004). More details could be found in Pulinets and Ouzounov (2011).

The main concept of this hypothesis is that the effects of stress build up in the atmosphere and ionosphere is transmitted through three channels, each of which is characterized by prevailing physical laws and corresponding physical equations (Fig.10). Here is a brief description of the concept:

A thermo-hydrodynamic and plasma-chemical processes in the atmosphere involving ionization of the near-ground layer from α-particles emitted by radon (Rn^{222}) during

decay (radon is emitted from active tectonic faults, see, Toutain and Baubron, 1998; Inan, 2008; Omori et al., 2007 and; Ondoh, 2009), formation of large ion clusters due to newly formed water vapor molecules attachment to ions (ion hydration). Formation of nano-embrios *ions* could be followed by the burst-like ion-induced nucleation (IIN) process (Pulintets and Ouzounov, 2011) with formation of particles of a few microns in size. Due to the release of latent heat resulting from water condensation on ions the hydrostatic equilibrium of the boundary layer is violated. The convective flows of air increases and there is a rise of a large ion clusters to the upper layers of atmosphere over the active tectonic faults that leads to formation of linear cloud structures, called Earthquake clouds (Morosova, 2005; Pulinets and Ouzounov 2011). These so called meteorological precursors of earthquakes (Milkis, 1986, Dunajecka and Pulinets, 2005) are conditioned by thermodynamic processes in the boundary layer and are subsequently released in the form of an increase in the ground air temperature and a drop in the relative humidity over the earthquake preparation area. They are also accompanied by a large-scale change in the atmospheric pressure and jet streams morphology (Wu 2004,2007).

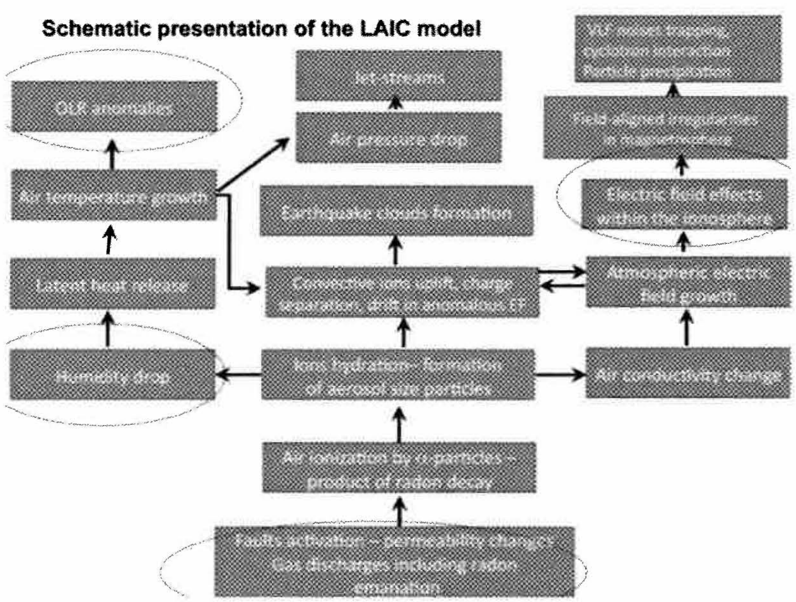


Fig. 10 Schematic presentation of the LAIC concept (Pulinets and Ouzounov, 2011)

B. Changes in the radiative balance of the atmosphere. As a result of water vapor condensation on ions the large amount of latent heat is released. These anomalous fluxes of Surface Latent Heat are registered regularly over the areas of earthquake preparation

observed by satellite remote sensing data (Dey and Singh, 2003; Cervone and all, 2005). Infrared satellite radiometry that we call Outgoing Longwavelength Radiation (OLR), 8-12 μ, is measured (up to several tens of W/m^2) at top of the tropopause (or Top of Atmosphere, TOA, Ouzounov at al, 2007). Further details on this process can be found in Pulinets and Ouzounov, 2011).

C. Electrodynamic processes. Due to their low mobility (several orders of magnitude lower than the light ions mobility) the conductivity of boundary layer of the atmosphere drops. The Global Electric Circuit (GEC) is providing the vertical electric current between the ionosphere and ground. The ionosphere potential in relation to the ground increases over the earthquake preparation area. The ionosphere is a highly conductive equipotential layer and this leads to the formation of large-scale anomalies of electron and ions. These ions are disturbed over an area on the top of the atmosphere and are recorded by ground based and satellites techniques. Further details on this process can be found in Pulinets and Ouzounov, 2011.

4.2 Other concepts

Atmospheric signals in relation to earthquakes are part of the larger science field of atmospheric and ionospheric electromagnetic phenomena associated with earthquakes (Hayakawa and Fujinawa 1994). There are many models created during the last two decades providing connections between earthquake processes and the atmosphere and ionosphere (Hayakawa 1999; Hayakawa and Molchanov 2002, Pulinets and Boayrchuk 2004, Meister et al, 2011). Lithosphere–Atmosphere–Ionosphere coupling (LAIC) concept is one of them. We support and use this concept because of its modality, and probably one of the strongest argument in favor of the LAIC concept is that all the effects are independent on the epicenter location: subduction, intraplate or underwater earthquakes, LAIC explained by the same universal mechanism, contrary to some other proposed mechanisms. Therefore LAIC hypothesis should not be associated only with the generation of earthquake atmospheric signals concept can explain many other complex phenomenon existing in the atmosphere (Bondur et al, 2008).

One of key processes in atmosphere observed by satellite sensors and in possible connection with major lithosphere activities is the satellite thermal anomalies. Over the

time several different activities have been considered as possible contributors to the transient short-lived ''thermal anomalies'': (a) rising fluids that would lead to the emanation of warm gases (Salman et al., 1992; Gorny et al., 1988); (b) rising well water levels and CO_2 spreading laterally and causing a ''local greenhouse'' effect (Qiang et al., 1991; Tronin et al., 2002; Tramutoli et al., 2005); (c) activating positive-hole pairs during rock deformation (Freund, 2002,2011) and (d) Air ionization by radon and latent heat change due to change of air humidity (Pulinets and Ouzounov 2011). Future satellite observations and the new applications will put into test of all of these ideas on generation of thermal signals and we believe the that best idea (or all of them) probably will provide the confidence we need to understand better the whole framework of process lead to generation of atmospheric signals associated with earth preparation process.

5. Statistical analysis of atmospheric signals

We have analyzed the transient atmospheric features continuously for the period of 2003-2009, by using thermal satellite data from NOAA and NASA. In addition to the thermal data we also analyzed as complimentary (i) radon, in-situ data and (ii) ionospheric variations (from GPS/TEC data). Satellite thermal data for Outgoing long wave radiation (OLR) from NOAA/AVHRR and Cloud-free Outgoing long wave radiation (CLROLR) from NASA/AIRS have been analyzed for the period of 2003-2009 - 9 major events in Taiwan, fifteen major events in Japan shown in Fig 11 A,B. (Ouzounov et al, 2010).

The anomalous behavior for OLR/CLROLR was defined as a maximum of Eddy change in the daily average of earth outgoing radiation in comparison to the average (normal) field. The normal field was estimated as multiyear average (2003-2009) for each pixel. The thermal anomaly has been calculated as a deviation from the normal state (with threshold of minimum one sigma value) and normalized by the multiyear standard deviation for the same pixel.

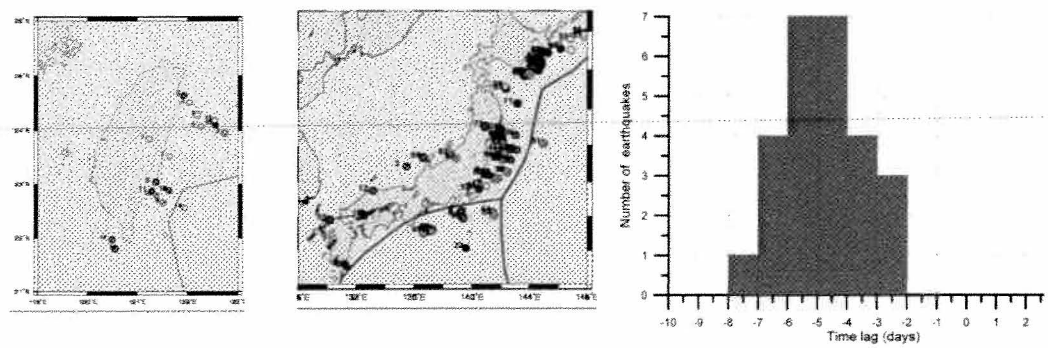


Fig 11. Statistical studies of OLR anomalies associated with major seismicity in Taiwan and Japan (left-right). Data selection. A. Location of 9 earthquakes (red+green) M>5.9 in Taiwan .B Location of 15 earthquakes (red) M>5.9 in Japan. C. Statistical distribution of lag time of appearance of OLR anomaly during the time of 24 tested earthquakes. Mean value of lag time is 4 days.

Our preliminary results show repeatable appearance of rapid elevation in the earth outgoing radiation (day or night - time) on the top of the atmosphere in advance of the main shock. We have found anomalous behavior before all of 24 hind casted events (no false negatives). Each anomaly was seen in the vicinity of the epicenter, within one 1.5 pixel radius around the epicenter (Ouzounov et al, 2010). The time lag of anomalous signals before the earthquake occurrence varies between 2 and 7 days. The mean value is about 4 days. (Fig 10, C). The time lag graph is specific for this study only and has regional character. More cases are needed to extend the statistical significance for each region.

The false alarm ratio (FAR) has been calculated for the same month of the earthquake occurrence for the entire period of analysis 2003-2009. FAR is close to 0 for 22 of hind casted events. Only for 2 events the monthly threshold of FAR exceed 0 (false positive).

6.Conclusions

Understanding the nature of earthquake precursors would have an enormous impact, both humanitarian and economic. This Chapter described the latest progress in advancing the knowledge about the connection between atmospheric/ionospheric variability's, and medium to strong earthquakes. Understanding this fundamental connection will contribute to earthquake hazard reduction. Latest results suggest a systematic appearance of atmospheric anomalies near the epicentral area, 1 to 5 days prior to the largest earthquakes, which could be explained by a coupling process between the observed

physical parameters within the area of earthquake preparation. Precursory activity has been observed for the recent catastrophic earthquakes in Japan, Haiti, Italy and China and these provide new evidence about the existence atmospheric signals related to strong earthquakes. We now have the capability to observe such signatures from space using decadal global data from NASA (USA), ESA (Europe), RSA (Russia) and JAXA (Japan). The latest satellite missions, remote sensing data together with ground observations provide a unique opportunity for comprehensive understanding and study of atmospheric precursory phenomena related to earthquake process and this knowledge would fill out the existing gap in understanding the interaction between solid Earth processes and the Atmosphere in the global concept of Earth-Space system science.

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