Remote Sensing and Earthquakes. A Review

A. A. Tronin

Scientific Research Centre for Ecological Safety, RAS, 197110, St-Petersburg, Korpusnaya st.,18 – tronin@at1895.spb.edu

Abstract – The current situation in earthquake space research indicates a few phenomena, related with earthquake: Earth's deformation, surface temperature, gas and aerosol content, electromagnetic disturbances in ionosphere. Both horizontal and vertical deformations scaled about tens centimetres and meters after the shock. Such deformations are recorded by InSAR technique with confidence. Pre-earthquake deformation are rather small - centimetres. A few cases of deformation mapping after the shock using satellite data are known at present time. Future development lays in precision SAR systems with medium spatial resolution and combination with GPS technique. There are numerous observations of surface and near surface temperature growth on 3-5 C prior to Earth’s crust earthquakes. Modern IR satellite systems simply record such thermal anomalies. Methods of earthquake predictions are developing using thermal IR survey. Well-known cases of gas and aerosol content change before the earthquake. Satellite methods allow to restore the concentrations of gases in atmosphere: O_3, CH_4, CO_2, CO, H_2S, SO_2, HCl and aerosol. However the spatial resolution and sensitivity of modern systems are still low. First promising results were obtained only for ozone. Electromagnetic researches of ionosphere in relation with earthquake are widely spread now. Stable statistical estimations of ionosphere-lithosphere relation were obtained. A few new ionospheric satellites are prepared for launch.

Keywords: – earthquake, remote sensing.

1. INTRODUCTION

Remote sensing has been used for earthquake research very early, with the first appearance of satellite images. First of all it was structural geological and geomorphological researches. Active faults and structures were mapped on the base of satellite images [Trifonov, 1984]. This method has significant limitation in time series analysis. There is no possibility to measure short term processes before and after the shock. Further development of satellite methods was related to geophysical methods.

Satellite electromagnetic methods also have a long history [Gokhberg et al, 1982., Molchanov, Hayakawa, Miyaki, 2001]. Numerous observations indicate the change of ionosphere related to seismic activity. These researches are out of our scope, we will concentrate on remote sensing methods.

The current situation of remote sensing application for earthquake research indicates a few phenomena, related with earthquake: Earth's deformation, surface temperature and humidity, air humidity, gas and aerosol content. Both horizontal and vertical deformations scaled about tens centimetres and meters after the shock. Such deformations are recorded by interferometric SAR (InSAR) technique with confidence. Pre-earthquake deformations are rather small - centimetres. A few cases of deformation mapping after the shock using satellite data are known at present time. Future development lays in precision SAR systems with medium spatial resolution and combination with GPS technique. There are numerous observations of surface and near surface temperature growth on 3-5 C prior to Earth’s crust earthquakes. Modern IR satellite systems simply record such thermal anomalies. Methods of earthquake predictions are developing using thermal IR survey. Well-known cases of gas and aerosol content change before the earthquake. Satellite methods allow to restore the concentrations of gases in atmosphere: O3, CH4, CO2, CO, H2S, SO2, HCl and aerosol. However the spatial resolution and sensitivity of modern systems are still low. First promising results were obtained only for ozone, aerosol and air humidity.

2. InSAR

From mapping the areal coverage and magnitude of ground motions following cataclysmic earthquakes, to measuring discrete subsidence displacements over several years, satellite InSAR or difSAR - differential Interferometry has a wide variety of uses in ground movement surveying applications. Satellite interferometry is based on multitemporal radar observations. The interferogram clearly indicates surface deformation after the shock. For that objective SAR interferometry, associated diagrams and accurate GPS measurements are the space techniques that have been used with good results even at very small displacements magnitudes. This “displacement” approach to the seismic phenomena is more related to the post-event phase of evaluation than to the prevention or hazard zone definition.
First application of satellite interferometry for earthquake research was announced in 90th [Massonnet, et al., 1993]. For example, the well-known "butterfly" image of the Landers earthquake (M=7.3, 28 June 1992) was compiled on the base of pre-seismic image of April 24, 1992 and post-seismic scenes: August 7, 1992; 3 July, 1992 and June 18, 1993. About the same pictures were obtained for Kobe Earthquake, Japan, 16.01.1995, M=6.8, Hector Mine Earthquake, USA, M=7.1, 16.10.99, Izmit Earthquake, Turkey, 17.08.1999, M=7.8 and others. All these cases demonstrate co-seismic and post-seismic deformations. There were no applications shown the pre-seismic deformation. Only recent research in Japan (fig.1) indicates probable pre-seismic deformation in Tokai region [Kuzuoka and Mizuno, 2004]. The vertical deformation recorded on the base of InSAR data coincides with ground GPS observation. This area is promising for future earthquake. Recorded Earth’s surface deformations are considered as a pre-seismic deformation.

The further enhancement of difSAR technology will allow us to record very fine difference in surface displacement. The planned COSMO/SkyMed mission aims to provide daily observations by 2007, overcoming limited observational frequency by using a constellation of four satellites. Existing satellite INSAR instruments are C-band (a wavelength of 5.66cm), offering high resolution, but they only give reliable interferograms for coherent, non-vegetated surfaces. Data from the JERS-1 satellite demonstrated during its lifetime that L-band satellites offer reduced resolution but provide

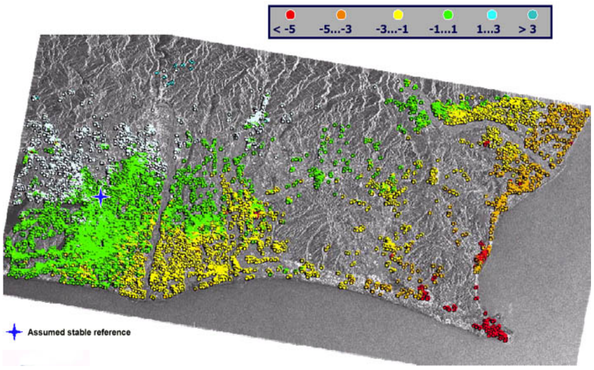

Figure 1. Average displacement rate – 1992-2000 years, mm/year. Tokai area, Japan [Kuzuoka and Mizuno, 2004].

interferograms over a far greater range of surface cover types. The next planned L-band SAR is the Japanese PALSAR on the ALOS satellite, to be launched in spring of 2004. Unfortunately, this instrument is designed to test applications other than interferometry, so it will provide only limited support for deformation analysis.

3. THERMAL DATA

The modern operational space-borne sensors in the infra-red (IR) spectrum allows monitoring of the Earth's thermal field with a spatial resolution of 0.5 - 5 km and with a temperature resolution of 0.12 - 0.5 C. Surveys are repeated every 12 hours for the polar orbit satellites, and 30 minutes for geostationary satellites. The operational system of polar orbit satellites (2-4 satellites on orbit) provides whole globe survey at least every 6 hours or more frequently. Such sensors may closely monitor seismic prone regions and provide information about the changes in surface temperature associated with an impending earthquake.

Natural phenomena and data availability stimulated the analysis of the long time series of thermal images in relation to earthquake hazard. Historically, first application of thermal images in earthquake seismology was carried out in 80th for Middle Asia [Tronin, 1996]. Later the similar researches were carried out in China [Qiang and Du, 2001], Japan [Tronin, Hayakawa, Molchanov, 2002], India [Singh and Ouzounov, 2003], Italy [Tramutoli et al., 2001], Spain and Turkey [Regular …, 2000], USA [Ouzounov, and Freund, 2003] and other countries. Thermal observations from satellites indicate the significant change of the Earth's surface temperature and near-surface atmosphere layers. A lot of thermal anomalies prior to earthquakes related to high seismic areas has been reported in Middle Asia, Iran, China, Turkey, Japan, Kamchatka, India, Turkey, Italy, Greece and Spain. Large volume of statistics was collected. Middle Asia database include seven years of observations and more then 100 earthquakes. Statistically significant correlation between thermal anomalies and seismic activity was proofed [Tronin, 1996, 1999, 2000, 2004]. Chinese scientists started operational earthquake forecast with thermal satellite data [Qiang and Du, 2001]. Just one examples of thermal anomalies in Kamchatka peninsula related with earthquakes are described in details below.

Five days before the shock on 17 Jun 1996 an anomaly was located on the east shore of the peninsula and in the basin of the Kamchatka river (fig. 2). Immediately after the shock on 22 Jun 1996 a large scale anomaly was detected in the basin of the Kamchatka river (fig. 3) at the centre of the peninsula. The result of image interpretation and analysis of the well observations are shown on fig 4. Water temperature starts to rise on 8 Jun 1996, and the clearest increase was recorded from 17 Jun 1996. Water debit showed slight growth from 12 to 18 Jun 1996. Simultaneously with the shock (21 Jun 1996) the water debit increased drastically.

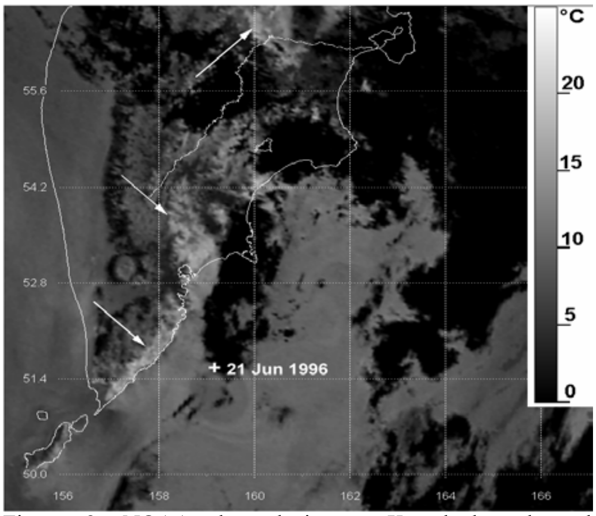

Figure 2. NOAA thermal image, Kamchatka, thermal anomaly, 17.06.1996, 16:11:12 GMT. Arrows show thermal anomaly, cross – earthquake epicentre 21.06. 96.

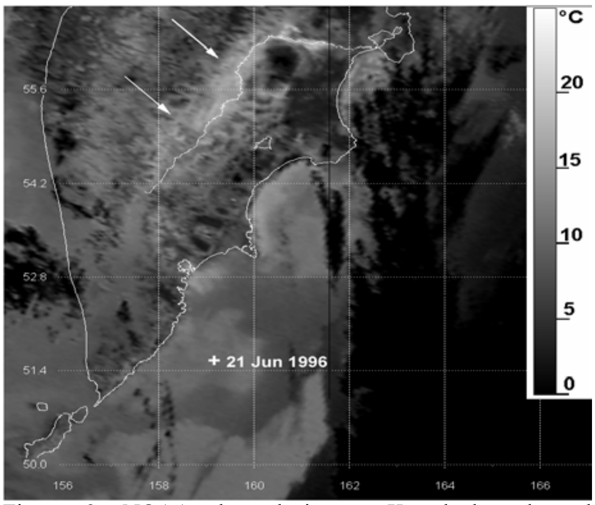

Figure 3. NOAA thermal image, Kamchatka, thermal anomaly, 22.06.1996, 16:57:28 GMT. Arrows show thermal anomaly, cross – earthquake epicentre 21.06.96.

The problem of thermal anomalies nature belongs to fundamental problem of litho-atmospheric coupling. The causes of the thermal anomalies lie in the lithosphere and are related to the earthquake preparation. The geological structures (faults, cracks, fractures etc.) act as preferred conduits because the convective flow of fluids and gas in the

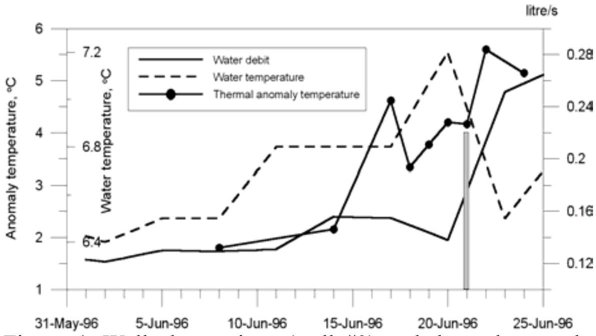

Figure 4. Well observations (well #3) and thermal anomaly temperature response on earthquake 21 Jun 96 in Kamchatka. Column shows the earthquake 21 Jun 96.

upper levels of the lithosphere, and thereby the transport of heat, is orders of magnitude higher than the diffusive flow. The thermal anomalies are typically observed above large faults and their intersections. Depending on the geological and tectonic setting, near the surface, at depths of a few kilometres, the fluid is divided into water and gas. The water causes change of debit and chemical composition in wells and springs. Gas (H2, He, CH4, CO2, O3, H2S, Rn) moves to the atmosphere. Depth and magnitude of the shock and geological conditions determine the mosaic character of phenomena on the Earth's surface.

The heat, water vapour and gas reach the Earth's surface. As a result the litho-atmospheric coupling starts. A few mechanisms of interaction are considered. First, convective heat flux (hot water and gas) changes the temperature of the Earth's surface. Second, change of the water level with usual temperature leads to change in soil moisture, and consequently the physical properties of the soil. The difference in physical properties determines the different temperatures on the surface. Third, greenhouse effect, when the optically active gases are escaped on the surface.

Result of thermal satellite data application for different areas looks similar: 1) thermal anomalies appeared about 6 – 24 days before and continued about a week after earthquake; 2) the anomalies are sensitive to crustal earthquakes with a magnitude more than 4.5; 3) the size of anomaly is n*100 km in length and n*10 km in width; 4) thermal anomaly has a mosaic internal structure with average element size about 40x130 km; 5) the amplitude of the anomaly is about 3 - 6 C; 6) thermal anomalies are attracted to large faults; 7) the nature of thermal anomalies is not clear now; 8) the response of water in wells and surface temperature in thermal anomaly on earthquake look similar; 9) increase of air and surface temperature as a consequence of the hot water eruption in a few days before strong earthquakes could lead to atmospheric perturbations (atmospheric gravity waves) and could be helpful to explain an origin of some preseismic electromagnetic effects (in the ULF, VLF, LF frequency range).

4. OTHER METHODS

Case studies of various remote sensing methods applications for earthquake were reported recently. Pinty and others [2003] have found significant surface moisture growth after the Gudjarat earthquake, 26 Jan 2001, using of MISR radiometer onboard of Terra satellite. Dey and Singh [2003] inform about evaporation change related with the same earthquake. Surface latent heat flux was measured on the base of ground meteo and satellite IR data. Dey, Sarkar and Singh [2004] mention about air water content change after Gujarat earthquake (fig. 5). Water content was retrieved by SSM/I microwave radiometer on Tropical rainfall Measuring Mission (TRMM) satellite. Okada, Mukai, and Singh [2004] report about changes in atmospheric aerosol parameters after Gujarat earthquake. Aerosol above sea surface was recorded by SeaWiFS satellite. Singh, Bhoi, and Sahoo [2002] mention about water colour and surface changes related with Gujarat earthquake of January 26 using IRS satellite data. A few examples of ozone concentrations changes measured by TOMS related with earthquakes (fig. 6) reports by Tronin [2002]. Such data was proved by ground ozone observations [Akselevich, Tertyshnikov, 1995]. Night ionosphere fluorescence was discovered by ground observations in the end of 80th [Fishkova, Gokhberg, Pilipenko, 1985]. The fluorescence was associated with E layer (85-110 km). A few hours before the shock the intensity of oxygen lines 5577 A and 6300 A fluorescence increased. Also we can mention about numerous attempts to use cloud detection for earthquake research [Morozova, 1996].

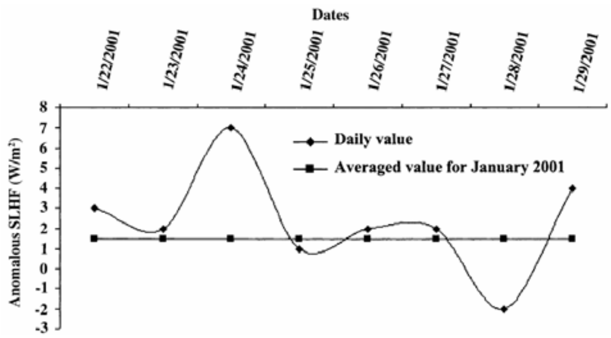

Figure 5. Surface latent heat flux at the epicentre region of Gujarat earthquake 26.01.01, India [Dey, Sarkar, Singh, 2004]

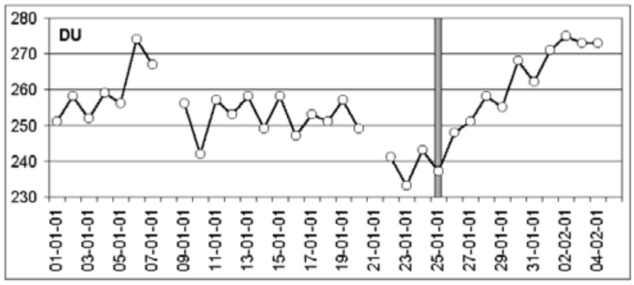

Figure 6. Stratosphere ozone distribution above epicentre of Gujarat earthquake 26.01.01, India.

5. REFERENCES

Akselevich V.I., Tertyshnikov A.V., 1995. Methodology of ecological monitoring data application to seismic forecasting. Atmospheric and Oceanic Optics. Vol. 8, No.07, 567.

Dey S., Sarkar S. and Singh R.P., 2004. Anomalous changes in column water vapor after Gujarat earthquake. Advances in Space Research, v. 33, no. 3, 274-278.

Dey S. and Singh R.P., 2003. Surface Latent Heat Flux as an Earthquake Precursor. Natural Hazards and Earth System Sciences, v. 3, no. 6, 749-755.

Fishkova, L.M., Gokhberg, M.B., and Pilipenko, V.A., 1985. Relationship between night airglow and seismic activity, Annales Geophysicae, 3, 689-694.

Gokhberg, M.B., Morgunov, V.A., Yoshino, T., and Tomizawa, I., 1982. Experimental measurement of electromagnetic emissions possibly related to earthquakes in Japan. J. Geophys. Res., 87, 7824.

Kuzuoka S. and Mizuno T., 2004. Land Deformation Monitoring Using PSInSAR Technique. International Symposium on Monitoring, Prediction and Mitigation of Disasters by Satellite Remote Sensing, MPMD-2004, January 19-21, 2004. p. 176-181.

Massonnet D., Rossi M., Carmona C., Adragna F., Peltzer G., Feigl K., and Rabaute T., 1993. The displacement field of the Landers earthquake mapped by radar interferometry. Nature, 364, 138-142.

Morozova, L.I., 1996. Features of atmo-lithmospheric relationships during periods of strong Asian earthquakes. Fizika Zemli, N5, 63-68.

Okada Y., Mukai S., Singh R.P., 2004. Changes in atmospheric aerosol parameters after Gujarat earthquake of January 26, 2001. Advances in Space Research, v. 33, no. 3, 254-258.

Ouzounov D., and Freund F., 2003. Mid-infrared emission prior to strong earthquakes analyzed by remote sensing data. Adv. Space Res.,Vol 33/3, 268-273.

Pinty B., N. Gobron M. M. Verstraete F. Mélin, J-L. Widlowski, Y. Govaerts, D. J. Diner, E. Fielding, D. L. Nelson, R. Madariaga, and M. P. Tuttle , 2003. 'Observing Earthquake-Related Dewatering Using MISR/Terra Satellite Data'. EOS Transactions of the American Geophysical Union, 84, 37-48.

Qiang Z.J. and Du L.T., 2001. Earth degassing, forest fire and seismic activities. Earth Science Frontiers, 8, 235-245.

Regular update of seismic hazard maps through thermal space observations. CORDIS RTD-PROJECTS / European Communities. Project Reference: ENV4980741, 2000.

Singh R.P. and Ouzounov D., 2003. Earth Processes in Wake of Gujarat Earthquake Reviewed from Space. EOS Trans. AGU, Vol. 84, 244.

Singh R. P., Bhoi S., and Sahoo A.K., 2002. Changes observed on land and ocean after Gujarat earthquake of January 26, 2001 using IRS data. International Journal of Remote Sensing, v. 23, no. 16, 3123-3128.

Tramutoli V., Bello G.D., Pergola N., Piscitelli, S., 2001. Robust satellite techniques for remote sensing of seismically active areas. Annali di Geofisica, 44, 295-312.

Trifonov V.G., 1984. Application of space images for neotectonic studies. In book: Remote sensing for geological mapping. Paris: IUGS Publ., vol.18, 41-56.

Tronin A.A., 1996. Satellite thermal survey - a new tool for the studies of seismoactive regions. International Journal of Remote Sensing, vol.17, No.8., 1439-1455.

Tronin A.A., 1999. Satellite thermal survey application for earthquake prediction. In book:“Atmospheric and ionospheric electromagnetic phenomena associated with earthquakes.” Edited by M. Hayakawa, TERRAPUB, Tokyo, 717-746.

Tronin A.A., 2000. Thermal IR satellite sensor data application for earthquake research in China. International Journal of Remote Sensing, Vol. 21, No. 16, 3169-3177.

Tronin A.A., 2002. Atmosphere-litosphere coupling. Thermal anomalies on the Earth surface in seismic processes. In book: Seismo Electromagnetics: Lithosphere-Atmosphere-Ionosphere Coupling. Edited by Edited by M. Hayakawa and O.A.Molchanov, TERRAPUB, Tokyo, pp.173-176.

Tronin A.A., Hayakawa M., Molchanov O.A., 2002. Thermal IR satellite data application for earthquake research in Japan and China. Journal of Geodynamics, Vol. 33, pp. 519-534.

Tronin A.A., Biagi P.F., Molchanov O.A., et al., 2004. Temperature variations related to earthquakes from simultaneous observation at the ground stations and by satellites in Kamchatka area. Physics and Chemistry of the Earth. v. 29, p. 501-506.