THE SEARCH FOR EARTHQUAKE PRECURSORY LAND-COVER DEFORMATION IN TAIWAN IN COORDINATION WITH THE 'INTEGRATED SEARCH FOR TAIWANESE EARTHQUAKE PRECURSORS iSTEP'

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1. Introduction

Taiwan is an island located in the *'Circum-Pacific Seismic Belt'* subjected to the ongoing collision of the Philippine-Sea and the Eurasian Plates, and it experienced disastrous earthquakes in the past. The electromagnetically associated Chi-Chi (990921: M = 7.6) - Chia-Yi (991023: M = 6.8) earthquakes,
which caused the total loss of more than 2500 lives, the collapse of more than 100,000 household dwelling-units, several bridges and major highways plus hydro-electric dams and electric power-line distribution systems along the affected Chelungpu-fault; were one of the latest severe catastrophes. The incessant plate collision implies that Taiwan will inevitably face earthquake hazards in the future and for a very long time to come; yet unfortunately earthquakes cannot be forecast today for various reasons, and one being the past lack of integrated wide-area ground-based, air- and space-borne sensing and imaging. Although some skeptics believe that we will never be able to predict and forecast earthquakes, with the recent advent of these integrated sensor technologies matters have changed most drastically, and a renewed entirely novel set of approaches is warranted and justifiable.

2. Background

Worldwide, medium- to short-term earthquake prediction is becoming ever more essential for safeguarding man due to an un-abating population increase, but hitherto there have been no verifiable methods of reliable earthquake prediction developed - except for a few isolated examples of such in China and in Greece. This dilemma is a result of previous and still current approaches to earthquake prediction which are squarely based on the measurement of crustal movements, observable only after a tectonic stress-change discharge (earthquake) has occurred. The prediction models were derived from past histories of measurements, mainly carried out during the past 30 – 40 years, although initiated soon after the San Francisco Earthquake of 1906. During the past decade it was proved and shown that it is not possible to derive reliable models for earthquake predictions from crustal movement measurements alone - as valuable and as indispensable those indeed are - and that an entirely new approach must be taken and rigorously pursued over years and decades to come, and most likely throughout this twenty-first century.

In support of this conclusion, there have been reported throughout the history of man anecdotal historical up to scientifically verifiable earthquake precursor or *"seismo-genic"* signatures of various kind – first biological, geological, geo-chemical and then a rather large plethora of diverse electromagnetic ones - on ground, in air and space, denoted as *"seismo-electromagnetic"* signatures. The existence of all of these signatures can no longer be denied even by the fiercest seismological

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expert opponents; and it is absolutely high noon that those past signatures be more rigorously assessed in order to develop a strategy for designing and carrying out controlled long-lasting *"seismo-genic"* and *"seismo-electromagnetic"* studies on how **to set up world-wide a network of measurement sites for conducting a holistic set of measurements** in order for providing an improved understanding on why and how such precursor signatures are generated, and how and where those may best be observed subject to the rather poor signal-to-noise ratio (SNR), requiring much improved digital instrumentation.

A number of pilot studies had been initiated in this direction during the past two decades, had been supported for a few years, and then aborted because of the high operating costs involved, the poor SNR making signal detection being most tedious if not impossible with the prevailing state of the art in instrumentation, and because earthquakes just don't appear upon demand requiring many years and decades until "they" suddenly happen. One need to keep at all times in focus the ever persistent opposition of the scientific establishment against us "radio-alchemists" and "whoodoo-quake scientists". Several major studies were initiated such as the USGS/NSF NEHER Program of the early 1990's after the Loma Prieta M 7.1 earthquake of October 19,1989; in Japan the ERSFP after the Hyogo-Ken Nanbu M 7.2 Earthquake near Hanshin, Awaki Island of January 17, 1995; in Greece due to continuously reoccurring earthquakes of M 4.5 – 6.0 the ongoing electro-potential methods of Varatsov; in China already before the devastating Hanshin M 8.1 Earthquake; and now also as a result of the Ji-Ji M 7.4 Earthquke on 1999 September 21 in Central-South Taiwan. Currently, and after the USSR Conversion Process of the 1990-ies, in various regions as well as in some independent states of the former Soviet Union a great many rather un-coordinated group efforts have also developed – all of which WMB had visited during the ten years following the collapse of the USSR. Next to the research being carried out within the Russian Federation and the Independent States like Georgia, Armenia, Kazakhstan, Mongolia, and so on; there also exist several competing teams in China and Japan, whereas the teams in Taiwan are collaborating more harmoniously. Outranking among all previous multi-year assessment studies was the very productive internationally oriented one in Japan after the Hanshin Awaji Earthquake of 1995 January 15, coordinated by Professor Masashi Hayakawa, and the resulting four books may be considered the best collection of scientifically evaluated precursor records, to be taken most seriously.

3. Assessment of the Current State of the Art

The ERPS research is still in its infant state and we need to catch up, which is possible subject to proper support. The most negative aspect is the currently existing isolated fractal approach, which must be rapidly internationally integrated worldwide. In this very limited aspect of a much wider variety of seismo-genic signatures, a great many pertinent interrelated effects of ground-based signature observations had to be neglected, but those must not be fully disregarded, which includes very recognizable strong biological signatures in flora and fauna. Hitherto those biological and also geological seismo-genic signatures were the ones used by historical man, and we need to highly upgrade our pertinent understanding of plant physiology in context with sub-surface fluid flow, and so on.

4. Major Obstacles in the Development Earthquake Remote Precursor Sensing (ERPS)

The major obstacle for making any progress in this very complex, multidisciplinary, still highly open research discipline was the stiff opposition of the established science expert community in seismology and tectonology, rejecting the notion of the existence of seismo-genic signatures right out. This preposterous ARROGANT attitude has to change, and we need actually establish a separate major research and development agency, very distinct from the USGS, NSF in the USA for example and so, on otherwise no progress will be made because the "old-boys" will dictate in their glorious narrow-mindedness on what they believe exists and what does not.

Another very serious obstacle is the complete lack of educating research and engineering experts in the related multi-disciplinary fields; and any one familiar with the generation of experts must be wondering on what may be happening with so many trained researchers and scientists very soon transferring into retirement – especially within the USA – and who is to generate the entirely new

class of multi-disciplinary scientists, which are not forthcoming from within the \USA, and we had better awaken very rapidly or else the rapidly emerging East-Asian cross/multi/interdisciplinary approach to science and technology will be whipping us soon very harshly. Taiwan must be given the chance to lead the way because of its foresight and vision.

5. A future Integrated Multi-Purpose Remote Sensing Satellite Cluster including GPS

What eventually is required in many diverse fields of monitoring the terrestrial covers – from the height of the outer ionosphere through the vegetated covers into the lithosphere – is the design and creation of a permanent fleet of multi-purpose remote sensing satellites similar to the current GPS Cluster of satellites, which one day should be merged. In addition, along at least the major Rift Zones very elaborate Earthquake Early Warning Networks of 3-axis Electric plus Magnetic Sensors covering the 0.1 – 30 Hz spectral domain need to be implemented on a pertinent basis The initiated studies should be focused also on generating the desired input parameters for the sensors of such a space-borne plus ground-based fully integrated low-frequency "electro"-"magnetic" sensor system.

6. Earthquake electromagnetic precursor research in Taiwan

Indeed, there has been a renewed worldwide renaissance on searching for past and hitherto yet not discovered space-borne earthquake precursor signatures and especially its integral evaluation of its not necessarily overlapping appearances. Because Taiwan and its environs to the East have been for eons, currently and will so be in the nearer to far distant future experiencing seismic activity on a very wide scale from millions of small to several truly large earthquakes a year, it is ideally suited for embarking on a long-lasting major Earthquake Hazard investigation program. In comparison with other similar seismically active regions of the two major terrestrial seismic belts, Taiwan is relatively small, compact in shape, sits on top of two violently colliding plates, and in comparison still rather virgin as regards electromagnetic background noise, it was decided appropriate to initiate a National Taiwanese Program for Excellence in University Research on the subject of "Research on Seismo-Electromagnet Precursors of Earthquakes" entitled '*integrated Search for Taiwanese Earthquake Precursors – iSTEP'* at the National Central University (NCU) in Chong-Li, Tao-Yuan, Taiwan. Currently, it consists of five major interrelated sub-projects on the Study of Earthquake Precursors (SEP): SEP-I, Seismological variations; SEP-II, Variations of geomagnetic and gravitational fields; SEP-III, Radar and SAR interferometry for the detection of surface deformations; SEP-IV, Atmospheric, mesospheric and ionospheric variations; SEP-V, Statistical assessment of integrated electromagnetic, geomagnetic and geo electric plus other related signatures; to which ought to be added SEP-VI, Ocean-bottom integrated sea-quake precursor metrology with the assessment of interrelated effects with earthquake precursor signatures on Taiwan soil.

The overall and the specific sub-projects will be briefly reviewed, placing major emphasis on sub-topic SEP-III, , Radar and SAR interferometry for the detection of surface deformations - for which WMB was invited as the '*Distinguished Chair Professor 2004 of NCU-CSRSR'* at Chong-Li, Taiwan In this context two related Repeat-Pass Interferometric SAR (RP-IN-SAR) projects are analyzed.

7. Repeat-pass InSAR derived surface deformation in Western Taiwan associated with the 1990 September 29 Chi-Chi Earthquake

The complex hydro-geological settings and yet environmentally sensitive, in Western Taiwan, posed serious concerns over recent years. Geological hazards such as surface subsidence frequently occur due in major part to human activities like groundwater withdrawal and sea water intrusion resulting from coastal erosion. The pattern of the subsidence generally is temporally dependent on rainfall which is also seasonal and at times is abundant. Satellite radar interferometry offers several advantages over traditional means of measuring due to the fine spatial resolution, wide coverage, and repeat observations. In this paper, a method for monitoring the land subsidence by integrating the GPS measurements and RP-In-SAR image data takes collected with ERS-1/2. The complementary and supplementary information gained between GPS and InSAR was analyzed and is demonstrated. Combining these two methods offers a powerful tool for operational detection of subsidence at the centimeter scale resolution. The subsidence rate over the period of InSAR data taken was calculated and analyzed with the recorded rainfall rate. Uplift was observed to correlate with heavy rainfall. In

particular, the years of 1996-1997 were focused on. After 1998, the subsidence rate tended to be flat. The driving force behind the drastic subsidence just within several months was found to be associated with intensive activity of aquaculture fish-farming development prior to measurements. We successfully demonstrated the joint use of space measurement techniques by GPS and InSAR, which provides detailed information on land subsidence and reveals insights into its physical occurrence and its originating source mechanisms, as will be shown and demonstrated for two severely affected regions in Taiwan – in the Chung-Li urban area of North Taiwan and in the Ping-Tong Plain of South Taiwan.

Similarly, the active and complex seismo-tectonic settings in Taiwan have drawn substantial attentions from various communities for many decades because of their vulnerability to produce possible geological hazards at different scales. Monitoring of their status and phenomena becomes critical for disaster preparedness, mitigation, and for improving our understanding of underlying physical mechanisms. In this study, we applied the radar interferometry technique to investigate the progress and evolution, in case observable, of surface deformations due to earthquakes. We selected the Chi-Chi Earthquake which occurred on September 21, 1999 at a magnitude of M7.6. The ERS-1/2 SAR data were acquired for the periods of pre-seismic, inter-seismic, and post-seismic tectonic stress change phases. The time span covers the years of 1996 to 2000. As many as 19 interferograms were processed and analyzed, among them, 12 for pre-seismic, 3 for inter-seismic, and 4 for post-seismic events.

8. Conclusions

Only a very skimpy summary was here presented, which will be greatly expanded once other similar studies currently being proposed worldwide, are put in place, allowing free exchange of information. The most essential point is that we are finally – worldwide - generating the guts and the will power for initiating this important research on ERPS, which is long overdue. However, it is sad to comprehend that in order to do so we require making use of *"Le Legion Etrange Scientifique"* or of low-cost scientific mercenaries in order to catch up with the progress made in other historical geophysical disciplines, receiving comparatively all too generous funding support.

9. Recommendation for Expanding and Introducing New Metrological Approaches for Taiwan and elsewhere

- Expansion and Enlargement of INTER-MAG to include 3-axis flux-gate magnetometers and improved recorders at each of the international recording stations, plus 3-axis electro-metric sensors operating from about .1 – 20 Hz.
- Selection of Promising Research Sites: A world-wide effort must be undertaken, and the National Utilities must be involved for carrying out routine recordings at least for the next several decades
- Development of Ground Based Instrumentation: It is essential to develop a prototype holistic measurement station including all of the essential electromagnetic, acoustic and also seismic sensors together with a central multi-channel terrestrial-space data-take collection system
- Implementation of the use of the OTHR HF/VHF sensor facilities for obtaining ionospheric parameters in concert with local GPS measurements
- Novel Satellite Sensors – The existing fleet of space-borne SAR sensors and imagers must be greatly advanced including additional frequency bands down to 100Mhz for which Faraday Rotation effects need to be corrected, which has become feasible.
- Development of groundwater table and fluid flow at moderate (several deci-meters) to great (several hundreds of meters and beyond) depths – by extending the GRACE gravitational anomaly measurement tandem satellite systems.