Implementation of differential repeat-pass SAR interferometry for the search for earthquake precursory land-cover deformation in Taiwan

#Kun-Shan Chen and Wolfgang-Martin Boerner
NCU-CSRSR Microwave Wave Scattering and Remote Sensing Laboratory
300 Chong-da Road, R-3, Jhong-Li Taoyuan, Taiwan 320-54, dkschen@csrsr.ncu.edu.tw

Abstract

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 earthquake prediction 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, and that an entirely new approach must be taken and rigorously pursued over years and decades to come. 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 – biological, geological, geo-chemical and especially 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 expert opponents; and it is absolutely high noon that those signatures be more rigorously assessed in order to develop a strategy for designing and carrying out controlled "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 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 as time goes on due to the ever increasing man-made electromagnetic noise generation. A number of pilot studies had been initiated, had been supported for a few years, and then aborted because of the high operating costs involved, the poor SNR making signal detection tedious if not impossible with the current state of the art in instrumentation, and because earthquakes don't appear upon demand. For example such major studies as the USGS/NSF NEHER Program of the early 1990's after the Loma Prieta M 7 earthquake of 1987; in Japan the ERSFP after the Kobe Earthquake of 1995; in Greece the ongoing electro-potential methods of Varatsov; in China, and in various regions as well as independent states of the former Soviet Union. There exists a rather large number of fiercely competing groups in Russia coming up with their own diversified yet highly incomplete modelling approaches seeking support from the West for unfortunately all too low-cost scientific mercenary services. No clear picture has evolved and should not be expected; and a much wider internationally coordinated investigation is required, which may well last for several decades before a unified approach and with it a solution to this vital problem may be found – if ever. In this overview a systematic analysis of main historical records, a summary of pertinent "seimo-genic" as well as observed "seismo-electromagnetic" effects and modern ground-based to air- and space-borne metrological signature investigations are presented. Specifically, remote sensing techniques not yet conceived but in urgent need - such as the remote sensing of the groundwater table - for advancing our understanding of this highly interdisciplinary complicated geophysical problem are being identified, and input is sought from participants for possible active future involvement.

1. INTRODUCTION

In fact, we need to discover the true intrinsic forces including electrodynamic stress that cause the tectonic plates to move and to undergo continuous gradual as well as abrupt seismic changes, and which are active long to close before the tectonic stress-changes occur. Implementation of novel high-altitude drone (UAV) and space borne satellite RP-Diff-POL-In-SAR will add most essential tools for advancement as will be demonstrated. 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 kinds – 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 expert opponents – residing especially deep within the hinterland of USA like *"bush"* among trees! Indeed, 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 *"seismo-genic"* and *"seismo-electromagnetic"* studies on how to set up world-wide a network of measurement sites for collecting a holistic set of measurables. This is necessary in order to provide an improved understanding on why and how such precursor signatures are generated, and how and where those may best be observed - either in the ground or on the surface through the atmosphere into the ionosphere - subject to the rather poor signal-to-noise ratio (SNR) - requiring much improved digital instrumentation. Again, the addition of implementing novel high-altitude drone (UAV) and space borne satellite RP-Diff-POL-In-SAR imaging technology will become most essential.

2. PREVIOUS AND ONGOING PILOT STUDIES

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 for several reasons. Those are the high operating costs involved, the poor SNR that makes signal detection very tedious if not impossible with the existing state of the art in instrumentation, and the fact that earthquakes just don't appear upon demand, requiring many years and decades until *"they"* happen. One needs to keep at all times in focus the ever persistent opposition of the scientific establishment against us "*radio-seismo-genic-alchemists*". Several major studies were initiated: the USGS/NSF NEHER Program of the early 1990's after the Loma Prieta M 7.1 Earthquake of 1989 October 19; in Japan, the ERSFP after the 1995 January 17 Hyogo-Ken Nanbu M 7.2 Earthquake near Hanshin, Awaki Island; in Greece, due to continuously reoccurring earthquakes of M 4.5 – 6.0, the ongoing electro-potential methods of Varatsov et al; in China, already before the devastating Yanshin M 8.1 Earthquake [1]; and now also in Taiwan as a result of the Chi-Chi M 7.4 & Chia-yi M 6.8 Earthquakes on 1999 September 21 & October 22/23 in Central-Southwest Taiwan [2]. From the USSR conversion process of the 1990s to present time, many rather un-coordinated group efforts have developed in various regions as well as in some independent states of the former Soviet Union. These efforts have been initiated due to the Spitak M 8.0 Earthquake of March/April 1989 which has been incorrectly considered as the first time that ground-based "*seismo-electromagnetic*" precursors had been observed. This honor goes to Professor Takeo Yoshino of UEC in Chofu-Shi, Tokyo, Japan who observed such "*seismo-electromagnetic*" precursors since the very late 1970-ies at ground and in space. Unpleasant reasons for these misplaced statements are manifold, and will be highlighted in a major forthcoming paper. It is noteworthy and must be reported here that there exists indeed a rather large number of fiercely competing groups within the former USSR. Each group is developing their own diversified, yet highly incomplete modeling approaches while seeking support from the West for *"unfortunately all too low-cost scientific mercenary services"*, which in the current globalization craze result in cutting resources elsewhere. In addition to the research being carried out within the Russian Federation and neighboring independent states like Georgia, Armenia, Kazakhstan, Mongolia, and so on, there also exist several competing teams in China and Japan, and teams in Taiwan and Sumatra which are collaborating more harmoniously. Outranking among all previous multi-year assessment studies was the very productive international outreach oriented one in Japan after the Hanshin Awaji Earthquake of 1995 January 15. This study coordinated by Professor Masashi Hayakawa resulted in four books [1] that may be considered the best collection of scientifically evaluated precursor records; this work should be taken more seriously worldwide. Yet, no clear picture has evolved and should also not be expected to because existing measurement studies are still too sparse, and a much wider internationally harmonious coordinated investigation is required. It may take several decades before a unified approach and solution to this vital problem may be found – if ever.

3. ADVANCEMENTS OF GROUND-BASED TO SPACE-BORNE SEISMO ELECTROMAGNETIC MEASUREMENTS

In order to obtain a much better insight into the worldwide appearance of *"seismo-electromagnetic precursors"*, it would seem most essential to upgrade the existing INTER-MAG magnetometer network (only records up to frequencies of 0.1 mHz are collected and stored on venerable magnetic tapes) by adding 3-axis flux-gate magnetometers (able to operate up to several Hertz) at each of the INTER-MAG stations worldwide. This was already proposed more than fifteen years ago by the late Dr. Arthur William (Bill) Green, the colleague of Dr. Wallace Campbell and former director of USGS-GRF in Golden, CO. Such an upgrade is costly but highly desirable also for various other reasons, and now feasible with the highly improved ELF/ULF digital signal recording plus centralized telemetric collection, storage, analysis and processing systems, which did not exist only fifteen years ago, when Bill Green strongly recommended such studies. With it several sub-oceanic recording INTER-MAG recording stations require also to be upgraded. In order to assess any lithospheric to mesospheric to ionospheric precursor interaction effects such vital important continuous 3-axis magneto-metric records up to several Hertz must be obtained and the frequency bands of measurement and data storage must be extended to about 20 Hz. Note that Bill Green did not observe any seismo-electromagnetic signatures below 10 mHz but above 100 mHz, which appears to apply to all earthquakes; and since very few or no measurements were conducted on a standardized continuous manner with only a very few exceptions and then only for short periods of time within this ELF/ULF frequency band of 10 mHz to about 20 Hz as is here desired, these vital *"seismo-electromagnetic precursors"* signatures were inadvertently not or only very incompletely and rarely being observed [2]. Prime emphasis must also be given to ionospheric precursor observations, which are summarized well in the various book-reports by Hayakawa et al [1]. There exist a few pertinent newly discovered types of observations, which need to be further explored such as the flare-up of ionosphere-bound lightning discharges, the *"sprites (or Spritzer – according to Schumann)"*, in addition to the observable earth-bound lightning- strokes *"Blitz"* located above highly ionized clouds generated during the early phases of final localized tectonic stress culmination close to epicenter regions. These phenomena require subtle additional studies and coordinated coincident ground to space recordings as proposed in several papers by Hayakawa, Yoshino in Japan, and others in China and Taiwan.

More so, remote sensing techniques - not yet conceived but in urgent need – are much sought for. An example is the remote sensing of the groundwater table with the tracking of sub-surface fluid flow [3]. The implementation of existing well established historical records collected by utilities worldwide is in desperate need. They are required for advancing our understanding of this highly interdisciplinary, complicated geophysical problem. Input is sought for highly expanded international collaboration and possible involvement for a major long-lasting global pilot study to be carried out simultaneously at several *"seismic hot spots."* The common saying of *"Detecting Groundwater from Satellite Platforms"* is highly misleading in that the referenced satellite SAR and/or GRACE techniques only permit the very coarse recognition of the top layers of sub-surface surface water – at most down to a meter, and not much deeper. Entirely novel techniques for identifying and tracking the fluid flow at depths down to several hundreds of meters are desired. This remains to be a very essential research task of the twenty-first century, and of paramount relevance to these kinds *of "seismo-genic and seismo-electromagnetic precursor"* investigations. Closely related to the detection of sub-surface fluid-flow is the bulging and subsidence of surfaces before, during and after tectonic stress change events which need not necessarily be catastrophic. This can now be achieved with implementation of air/high-altitude/space-borne RP-Diff-POL-In-SAR imaging. As regards the acquisition of satellite SAR measurement data sets, the space-launched ALOS PALSAR, the forthcoming RADARSAT-II and TERRASAT-1&2 fully polarimetric sensors will play an essential role, and ought to be fully integrated in all of the forthcoming studies [4].

4. DEVELOPMENT OF MULTI-MODAL SYNTHETIC APERTURE RADAR (SAR) IMAGING TECHNOLOGY IN AIR AND SPACE

Decisive progress was made in advancing fundamental POL-IN-SAR theory and algorithm development during the past decade, which was based on the underlying accomplishments of fully polarimetric SAR and differential SAR interferometry and its current merger. This was accomplished with the aid of airborne & shuttle platforms supporting single-to-multi-band multi-modal POL-SAR and also some POL-IN-SAR sensor systems, which will be compared and assessed with the aim of establishing the hitherto incomplete but required missions such as tomographic and holographic imaging. Because the operation of airborne test-beds is extremely expensive, aircraft platforms are not suited for routine monitoring campaigns. These are better accomplished with the use of drones (UAV). Such unmanned aerial vehicles (drones), hitherto developed mainly for defense applications, are currently lacking the sophistication for implementing advanced forefront POL-IN-SAR technology. This shortcoming will be thoroughly scrutinized resulting in the finding that we do now need to develop most rapidly also POL-IN-SAR drone-platform technology because low to medium altitude aircraft platforms cannot be deployed in severe weather conditions. Thus, drones are required in order to develop algorithms for RP-Diff-POL-IN-SAR environmental stress change monitoring. High altitude drones are necessary for a great variance of applications beginning with flood, bush/forest-fire to tectonic-stress (earth-quake to volcanic eruptions) for real-short-time hazard mitigation. For routine global monitoring purposes of the terrestrial covers neither airborne sensor implementation - aircraft and/or drones - are sufficient; and therefore multi-modal and multi-band space-borne POL-IN-SAR space-shuttle and satellite sensor technology needs to be further advanced at a much more rapid pace. The existing ENVISAT and most recently launched ALOS-PALSAR will be compared with the forthcoming RADARSAT-2 and the TERRASAT-1&2, demonstrating that at this phase of development the fully polarimetric and polarimetric-interferometric SAR modes of operation must be treated as preliminary algorithm verification support, and not to be viewed as routine modes. The same considerations apply to the near future implementation of any satellite-cluster bi/multi-static space-borne tomographic imaging modes, which must however be developed concurrently in collaboration with all major national or joint continental efforts in order to reduce spending and the proliferation of space-platforms. Prioritization of developmental stages will be assessed according to applications, and will differ for air-borne to space-borne sensors with the aim of developing a permanently orbiting fleet of equidistantly space-distributed satellites similar to the GPS configuration, and each being equipped with the identical set of multi-band POL-IN-SAR sensors [4 - 7].

5. IMPLEMENTATION OF RP-DIFF-POL-IN-SAR ENVIRONMENTAL STRESS-CHANGE MONITORING FOR THE ANALYSES OF EARTHQUAKE EPISODES IN TAIWAN WITH SUBSEQUENT LAND-COVER SUBSIDENCE AND BULGING

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 inter-related Chi-Chi (990921: M = 7.6) - Chia-Yi (991022/23: M = 6.8) earthquakes, which caused a total loss of more than 2500 lives, the collapse of more than 100,000 household dwelling-units, several bridges and major highways, hydro-electric dams and electric power-line distribution systems along the affected Chelungpu fault [1 – 3]. The incessant plate collision implies that Taiwan will inevitably face earthquake hazards in the future and for a very long time to come. Earthquakes unfortunately cannot be forecasted today for various reasons, one being the past lack of integrated wide-area ground-based, air- and space-borne sensing and imaging. Taiwan and its environs to the East have, are, and will be experiencing seismic activity on a very wide scale from millions of small to several truly large earthquakes a year, Taiwan 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. In comparison to other highly populated earthquake regions, it is still rather virgin as regards electromagnetic background noise. Therefore, 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 Chung-Li, Tao-Yuan, Taiwan [3]. In support of the well developing iSTEP ground-based magneto-metric seismo-genic signature measurements [2], the SAR Image processing and analysis group of the NCU CSRSR (Center for Space & Remote Sensing Research) have embarked on a rigorous program for producing a large set of RP-Diff-In-SAR overlay interferometric images that show the temporal stress-change history of up to six months in advance of the Chi-Chi (990921; M = 7.6), during the electromagnetically exceedingly active time-period until the two major aftershocks of the Chia-yi (991022/23; M = 6.8) earthquakes occurred, and thereafter for several months [3]. Every effort is now being made for correlating the time-sequential ground-based "seismo-electromagnetic" signatures with the corresponding set of RP-Diff-In-SAR overlay interferometric images. In addition, associated land-cover subsidence and bulging episodes plus resulting mud-avalanches will be scrutinized and interpreted. In addition, the assessment of land-cover subsidence by ground-water withdrawal and/or sea-water infusion by coastal erosion as it pertains to the Taiwan West coast will also be investigated.

6. CONCLUSION

Large figures and tables may span across both the columns. Figure captions must be placed below the figures as shown

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