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摘要

臺灣位屬歐亞板塊與菲律賓海板塊交界的板塊碰撞帶，是世界上最活躍的地震帶之一。為了解地震發生過程中的應變移轉變化情形，中央地質調查所從 2003 年 10 月正式開始啟動利用 GTSM 井下應變儀觀測地震活動度的計畫，計劃補充連續 GPS 觀測在頻寬與精度上的不足，以提供更多的斷層觀測資訊。

在進行應變儀資料處理作業時，除去潮汐與氣壓相關效應後，我們發現一些與降雨相關的異常資訊存在，其與地下水的反應相當地相似，但是兩者的相位卻是相反的，這與我們觀測到兩者長期間變化一致的關係是不同的，在某些情形下也會影響到資料的判讀。我們利用地調所設置 5 站井下應變儀資料，透過 1-3 年以上的連續觀測，探討降雨對於埋設地下深處的應變儀觀測資料的影響，並將相關結果發表於 2014 歐洲地質科學學會(EGU)大會。

歐洲地質科學學會(EGU)係歐洲地區地球科學學門的最大國際學術組織。每年吸引全球地球科學領域超過萬名專家學者與會，觀摩與發表研究成果，為地球科學界發表研究成果及心得交流討論的重要會議。本次參加 2014 歐洲地質科學大會主要發表本所前述計畫研究之成果，同時藉由參與會議的機會，獲取新知及技術交流。會後攜回相關領域於展場所展示的相關成果資訊，作為增益本所相關業務計畫執行之參考，並吸取國外相關領域之研發經驗，提升臺灣的研發能量，進而獲取最佳的研究與分析成果。

壹、前言

歐洲地質科學學會（EGU，European Geosciences Union）係歐洲地區地球科學學門的最大國際學術組織。每年大致於春末夏初時期舉行年度大會，除了歐洲各國地球科學專家學者參加外，同時也會吸引全球各地地球科學領域的專家一同與會，每年吸引超過萬名的地球科學家前往觀摩與發表研究成果，為地球科學界發表研究成果及心得交流討論的重要會議。本年度自 4/27-5/2 在奧地利維也納 ACV 舉行，來自全球106個國家超過萬名的科學家以口頭或壁報方式發表約1萬4千餘篇科學論文，包含多數主要地球科學研究領域（大氣科學 Atmospheric Sciences、生物地質學 Biogeosciences、氣候變遷 Climate: Past, Present, Future、冰凍圈科學 Cryospheric Sciences、能源,資源與環境 Energy, Resources & the Environment、空間科學資訊 Earth & Space Science Informatics、大地測量 Geodesy、地球動力學 Geodynamics、地質科學儀器分析及資料系統 Geosciences Instrumentation & Data Systems、地形 Geomorphology、地球化學,礦物學,岩石和火山 Geochemistry, Mineralogy, Petrology & Volcanology、水文科學 Hydrological Sciences、同位素儀器在地質科學上的分析及應用 Isotopes in Geosciences: Instrumentation and Applications、磁學,古地磁,岩石物理與岩土 Magnetism, Palaeomagnetism, Rock Physics & Geomaterials、自然災害 Natural Hazards、地球物理非線性研究 Nonlinear Processes in Geophysics、海洋科學 Ocean Sciences、行星與太陽系科學 Planetary & Solar System Sciences、地震學 Seismology、地層學,沉積學及古生物學 Stratigraphy, Sedimentology & Palaeontology、土壤系統科學 Soil System Sciences、太陽地球科學 Solar-Terrestrial Sciences、大地構造與構造地質學 Tectonics & Structural Geology），其中再細分成近600個精采的科學議題、大師級的主題演講及簡短課程等，加上各種科學獎章的頒獎典禮及問題辯證，讓整個大會精采豐富，目不暇給。

本次所發表論文在本次大會構造地質（Tectonics & Structural Geology, TS），有關「Fault Zones（TS5.3）」子題，『斷層帶沿線之物

理非均質性與其暫態演化過程』（Mechanical heterogeneity and their transient evolution along fault zones (co-organized)，TS5.3』的次議題中發表，提出發表之論文題目為「Different kernel functions due to rainfall response from borehole strainmeter in Taiwan」(「從臺灣的應變觀測討論降雨對井下應變儀的影響」)。

貳、目的

臺灣位屬歐亞板塊與菲律賓海板塊交界的板塊碰撞帶，是世界上最活躍的地震帶之一。為了解地震發生過程中的應變移轉變化情形，中央地質調查所從 2003 年 10 月正式開始啟動利用 GTSM 井下應變儀觀測地震活動度的計畫，計劃補充連續 GPS 觀測在頻寬與精度上的不足，以提供更多的斷層觀測資訊。從 2003 年起在臺灣西部即陸續設置，目前運作中之應變儀觀測站共 11 站(圖 1)，每個觀測站除設置一 GTSM 井下應變儀外，更共站設置了氣壓計、水位計、雨量計與 GPS 時間校正，對臺灣西部人口較密集之地區提供初步的斷層活動性觀測。應變儀埋設在地下約 200 公尺深，提供四個不同方向的線性應變變化觀測，11 個觀測站可分為 3 個叢區(臺北，新竹與嘉南 3 區)針對地殼受板塊活動、天體運行或地震所引發的暫態應變變化進行長時且連續的觀測。

非震性應變在地震孕育期時期頻率可從數個 HZ 到數十年，地震儀、GPS 與 INSAR 等觀測皆已使用來觀測地殼的變形行為(Pearson, Beavan et al. 1995, Savage and Lisowski 1995, Loevenbruck, Cattin et al. 2001, Angelier, Lee et al. 2003, Chang, Chang et al. 2003, Huang, Hu et al. 2006, Hu, Hou et al. 2007)，應變儀具有高精度高頻寬的特性，放置於地下深處直接感受地層的變形並有效降低地表人為雜訊的干擾(Johnston, Linde et al. 1982, Gladwin and Hart 1985)，在進行資料處理作業時，除去潮汐與氣壓相關效應後，我們發現一些與降雨相關的異常資訊存在(圖 2)，其與地下水的反應相當地相似，但是兩者的相位卻是相反的，這與我們觀測到兩者長期間變化一致的關係是不同的，在某些情形下也會影響到資料的判讀。引起我們進一步的研究。

在獲得到原始觀測數據後，將計數結果轉換成應變資料後(Gladwin and Hart 1985)，可得到面應變的變化資料。在移除氣壓與潮汐的影響後，可以看到降雨對於觀測應變的影響，在去除氣壓升降所造成的應變變化，留下較為乾淨的資料，可發現另一些突兀的變化，且與降雨高度地相關。圖 2 為新樂(CINT)觀測站 2011 年的觀測資料，除去氣壓與潮汐影響後，可發現明顯的降雨影響(圖上箭頭處)。在降

雨量明顯的時間段，面應變受到降雨荷重的影響而產生壓縮，壓縮量的大小則與降雨所帶來的累積雨量有關，降雨帶來的多餘荷重，除部分滲入地下影響地下水位面外，部分降水都會化作逕流流入地表河流中，然而地表逕流流動時在地表造成的多餘荷重，也會對於岩層造成壓縮的變形影響。從觀測應變中來看，降雨與氣壓變化相反，當降雨量增加時對面應變造成的是負的變化(壓縮)，其對應的變化量與降雨的累積多少有關，與岩層彈性係數相關，當地表逕流失去後，面應變的變化則回復原有的趨勢上。在應變研究中，若要單純觀察岩層受構造活動影響造成的應變異常現象，由於其量值可能很小，若不進行其他環境效應的濾除，則將不易查覺，因此應變資料的處理，旨在於能夠獲得相對乾淨的資料(clean data)。因此藉由國際會議的參與，與國際相關研究之學者分享研究之進度與遭遇之問題，獲取新知及技術產品交流，作為本所「斷層活動性觀測研究」計畫執行與規劃之參據。

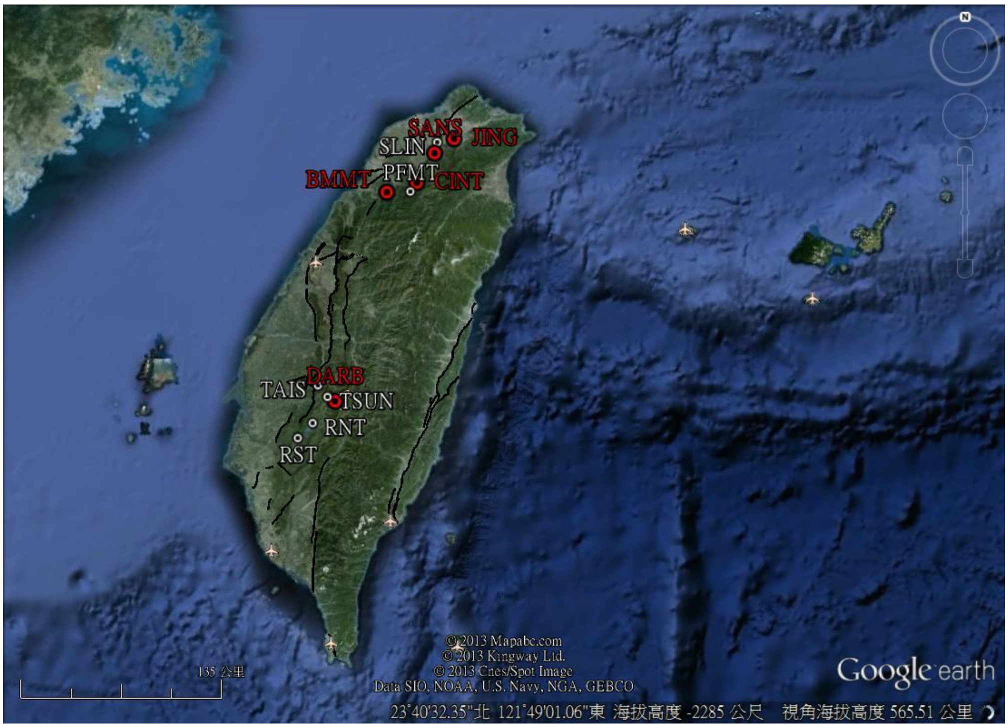

圖 1、井下應變儀設置位置與臺灣活動斷層分布(黑線)

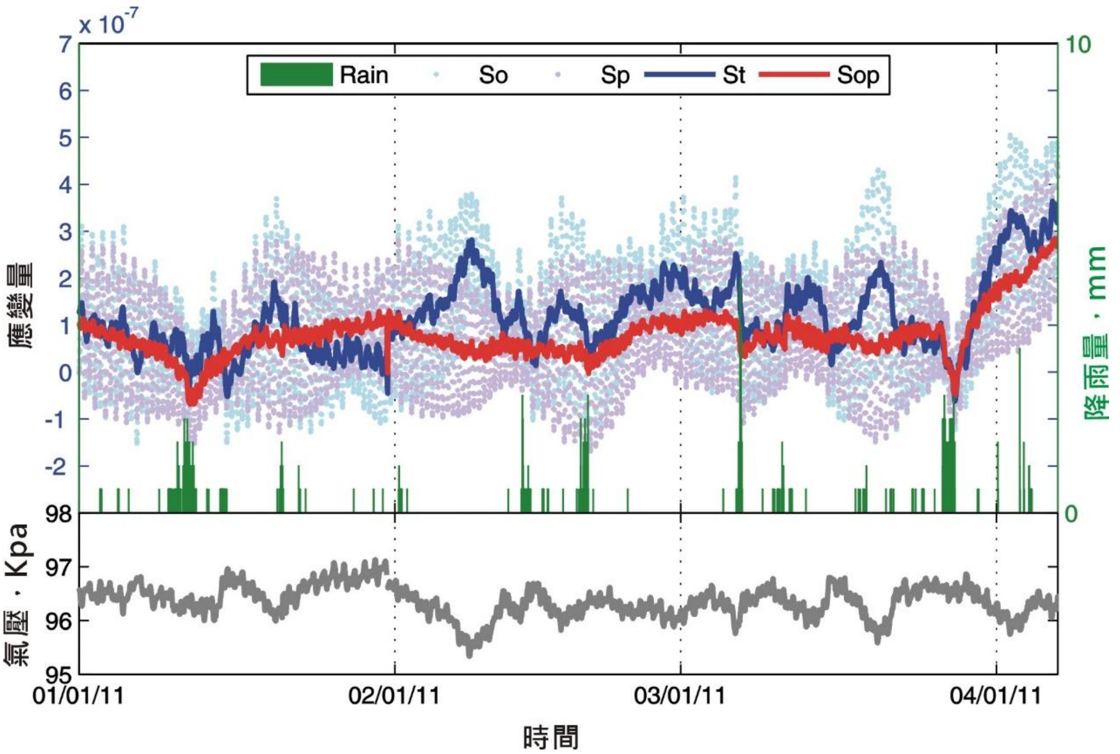

圖 2、氣壓對應變資料的影響，兩者間呈現負相關(Roeloffs 2010)，圖為新樂(CINT)CH3 之觀測應變，圖上 So 表式原始位處理資料，Sp 表示除去氣壓響應之應變，藍線為應變除去潮汐後結果，而紅色線條表示除去氣壓與潮汐之綜合結果，在除去氣壓與潮汐響應後，可明顯發現觀測應變值受到降雨的影響(圖上箭頭)。

參、過程

一、出國行程

本次出國計畫之工作會議行程如表 3-1 所示， 行程自 103 年 4 月 26 日起至 5 月 5 日止， 為期 10 天。

表 1、參加 2014 歐洲地質科學年會(EGU)出國行程表

日期	星期	往返地點	住宿地點	活動內容
103/4/26	六	台北-奧地利維也納	飛機上	啟程赴奧地利維也納
103/4/27	日	台北-奧地利維也納	維也納	註冊、報到參加歐洲地質科學年會
103/4/28	一	維也納	維也納	參加歐洲地質科學年會
103/4/29	二	維也納	維也納	參加歐洲地質科學年會
103/4/30	三	維也納	維也納	參加歐洲地質科學年會
103/5/1	四	維也納	維也納	參加歐洲地質科學年會
103/5/2	五	維也納	維也納	參加歐洲地質科學年會
103/5/3	六	維也納	維也納	待機
103/5/4	日	維也納-台北	飛機上	會議結束返回臺灣
103/5/5	一	維也納-台北		會議結束返回臺灣

二、會議議程

2014 年歐洲地質科學年會（EGU General Assembly 2014）是在奧地利維也納 Austria Center Vienna (ACV)舉行（圖 3），會議議程包括報到（圖 4、圖 5、圖 6）、論文發表（口頭或壁報）；報到時本次會議所領取之相關資料，包含議程手冊、論文摘要（以隨身碟形式）、會議收據及會議名牌。論文口頭發表共有 44 個場地，遍佈整個會議中心各樓層，有容納百人的大型會議室，也有約 30 人左右之小型會議室，壁報發表主要為會議中心地下室及會議中心 3 樓（圖 7、圖 8），另有 PICO 互動式論文發表（圖 9、圖 10）。

圖 3、2014 歐洲地質科學年會(EGU)舉辦會場-奧地利維也納中心(ACV)

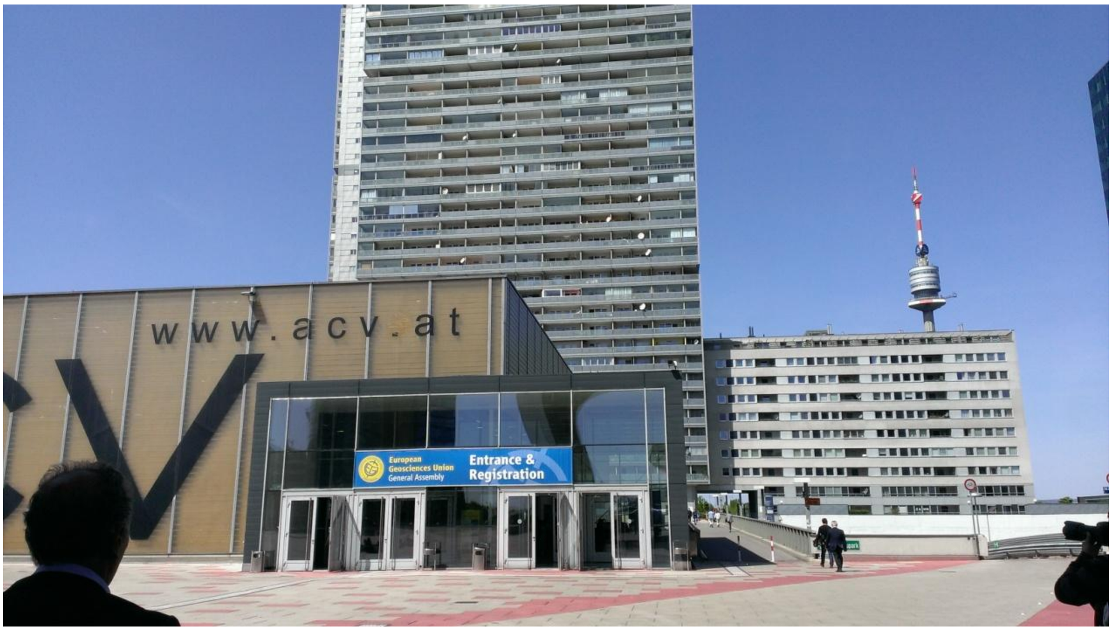

圖 4、EGU 會議會場報到處

圖 5、EGU 會議報到櫃台，參與會議人員由工作人員引導至相對應櫃檯報到並領取會議相關資料。

圖 6、EGU 年會報到登記處與歡迎櫃檯

圖 7、會議發表文章海報展示處情形

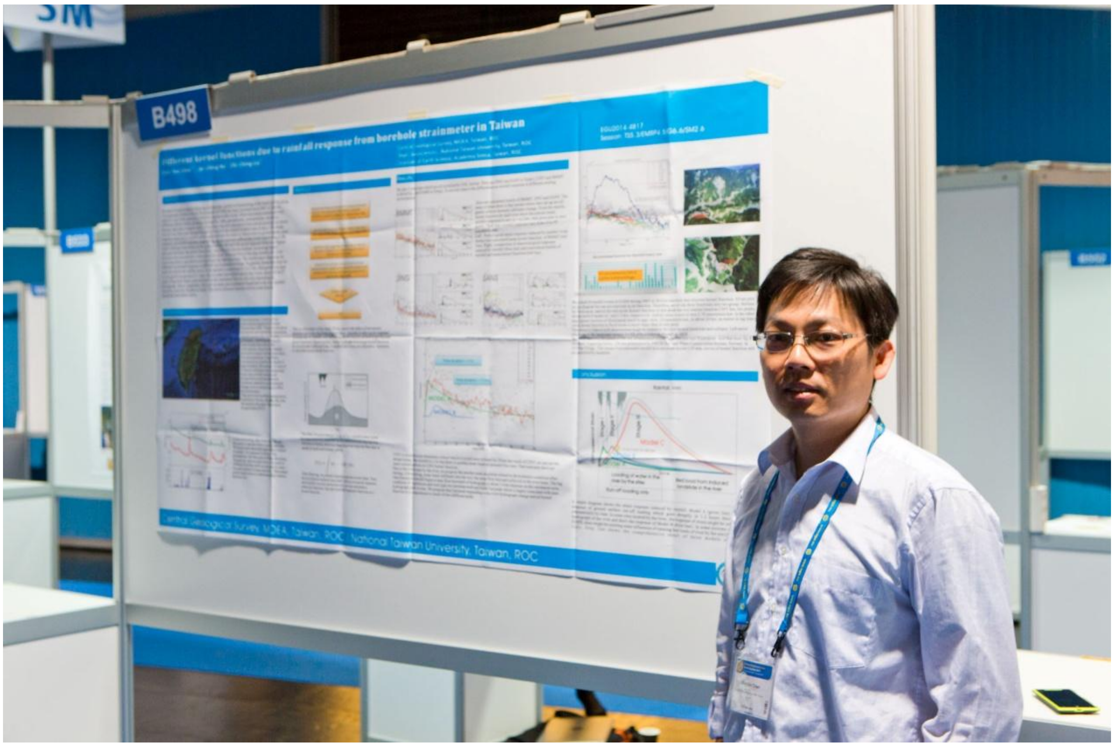

圖 8、論文發表海報展示情形。

圖 9、PICO 互動式論文發表，可與演講者密切互動之新型態報告模式。

圖 10、國內學者進行 PICO 簡報的情形

三、論文發表

本次所發表論文在本次大會構造地質（Tectonics & Structural Geology, TS），有關「Fault Zones（TS5.3）」子題，『斷層帶沿線之物理非均質性與其暫態演化過程』（Mechanical heterogeneity and their transient evolution along fault zones (co-organized)，TS5.3』的次議題中發表，議程如附錄 1，以壁報型式發表，提出發表之論文題目為「Different kernel functions due to rainfall response from borehole strainmeter in Taiwan」(「從臺灣的應變觀測討論降雨對井下應變儀的影響」)。

論文發表內容主要為探討降雨對於井下應變觀測之影響，經過多年的觀察研究，發現降雨是影響地下水與應變觀測的一個重要因素，對於地下水與岩層應變都會有明顯的影響，一次的降雨事件的影響，可區分為快速與緩慢兩個不同的反應。快速降雨反應可能是因為降雨造成的地表荷重所造的孔隙水壓增加的情形，在移除荷重後便會消失。本研究中以遞迴數位濾波（recursive digital filter）的方式分離面應變資料中的快速與緩慢效應，並利用反摺積(deconvolution)求取該站的快速降雨響應函式。本研究中取了五站經濟部中央地質調查所設置之井下應變儀觀測站，包含了臺灣北部的錦和國小(JING),明德(SANS)，

新竹地區的新樂國小(CINT)，大坪國小(BMMT)與嘉義的達邦觀測站(DARB)為案例進行降雨影響的探討，結果顯示錦和、明德與大坪的降雨響應函數在降雨一發生後約一小時後就會達到最大反應值，其量值在 14.2 - 65.7 nstrain/mm，隨即迅速向下衰減，大約 40- 60 小時後影響減至最小。從新樂的結果來看，河道水文的流量變化也會影響到應變儀的觀測變化。達邦站的結果就更為複雜，其反映出該站並非單純模式可以解釋，可能因強烈降雨所造成的土石崩落影響可區分為兩種不同模式，分別為受到降雨影響的降雨模式，以及因為崩坍造成河道內荷載增加的洪水模式。統計達邦累計降雨與兩種不同降雨響應函數的數值可以看到大致可以歸納出大致上有一個 200mm 左右的門檻，作為兩種不同模式的分水嶺，其量值與水保局公布阿里山鄉土石流警戒值 250mm 相當接近。降雨對井下應變觀測的影響可分為三個階段，第一階段為一般地表逕流或初期滲入地層的降雨荷重影響。若觀測站設置在河道邊，就會受到河道流量的影響，產生兩種模式的複合型式，累積雨量更大在某些土石流敏感地區將會造成更大的影響，當累積降雨超過特定門檻後，整個區域易發生崩坍，應變反應曲線就可能會受到山崩地滑事件控制而產生明顯的異常。我們也比較了氣壓與降雨響應的量值，由於兩者都是受到外在壓力影響所產生的響應值，其比值也顯得相當的一致(圖 11)。

論文壁報內容如附錄 2 所示。本所壁報展示參與之主題，大會安排發表日期為 4 月 30 日，討論及回答問題的時間為當日下午 3 點 30 至 5 點。發表當日閱覽者踴躍，除討論回答問題外，亦同時閱覽相鄰近之壁報，並與作者討論(圖 12)。

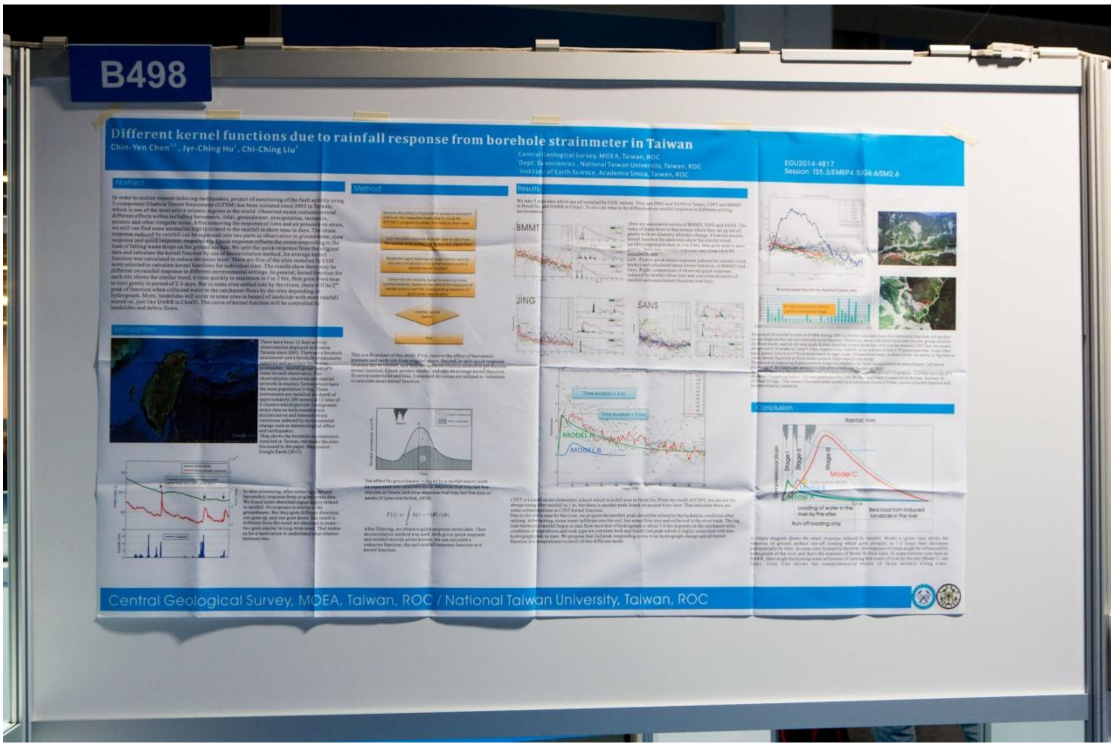

圖 11、本次發表之論文海報

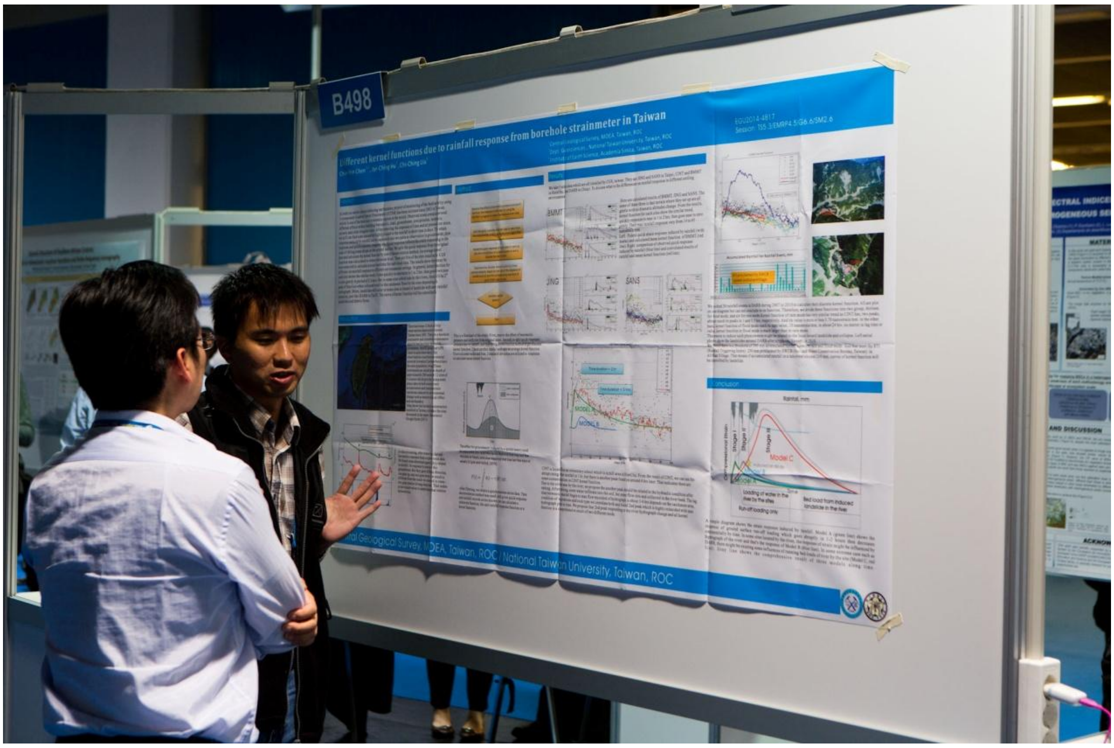

圖 12、論文討論時間，與相關研究學者討論與意見分享

肆、心得

本次職參加歐洲地質科學學會 EGU(European Geosciences Union)，與多位國際相關研究學者交流研究心得，包含中美日多位在地球物理與地震水文觀測研究領域上有多年豐富經驗之研究員，獲益匪淺。對於目前世界各地的井下應變儀觀測、分析技術、短期暫態慢地震與地震前兆的研究也有更新的體驗與認識。對於參加會議的心得如下:

1. 與美國地質調查所人員交流相關井下應變儀觀測經驗有助於雙方交換各自在井下應變儀上之研究經驗，台灣地區地殼變形量大，觀測資料上也呈現相當大的變化，從觀測資料中可發現多處饒富趣味的地方，對於應變觀測研究將可有相當大的幫助。現階段各國井下應變儀觀測研究資料分析與觀察經驗尚在小步測試階段，實務操作上的經驗交流相當寶貴。
2. 井下應變儀可觀測的頻寬可包含每秒至數年以上的變形，但由於井下型應變儀屬於短基線的設計原理，需利用與其他資料校正方式轉換成現地實際應變情形，且短基線應變儀的設計理念，會造成局部地層變化情形的擴大現象，是在資料處理前必須要有的了解。此外，從觀測結果來看，觀測資料常受到一些自然雜訊的影響，如氣壓、降雨與地下水文的影響，想要獲得乾淨的地殼應變訊號，必須先將相關效應引發的應變響應去除。利用觀測與理論地潮分量的比較，可校正儀器的校正因子，與檢驗儀器的運作可信度。
3. 氣壓與地下水文的變化常會在觀測訊號上造成不正常或是非預期的雜訊，而由於各觀測站地質與地形環境的不同，在氣壓地下水文的變化也會有所不同，因此針對各站進行氣壓與水文的修正時必須非常地謹慎。而在進行上述兩種效應修正前，將會有幾個問題必須先行解決，首先是氣壓變化與降雨的關係；其次是降雨與地下水位面的關係，這個問題較為複雜，因為降雨與地下水位的升降常非一線性的關係，其間牽涉到該地區的水文特性與水力係數，這些因素都讓這個問題更顯複雜；第三、氣候的變化在地潮

的全日、半日或更長的週期變化的影響，都是可能會影響到應變儀觀測資料的品質。

4. 從美日的研究案例中顯示，利用井下應變儀對於板塊邊界所產生的長微震(tremor)進行觀測，發現在地震發生時區域性的應變場發生變化，不僅在量度上有所變化，在應變主軸的方向也有明顯轉向的情形發生，此種現象可供台灣進行相關研究的重要參考方向。

伍、建議

地震發生之機制至今仍未能釐清，可靠的地震前兆因子亦尚未獲學界肯定。但是地震預測若能成功，則對地震防災減災之社會效益貢獻極大，故美、日等先進國家至今仍戮力以赴。美國自 1999 年開始規劃並從 2004 年開始推動執行的「北美西部板塊邊界觀測（PBO）計畫」即是以慎密佈置大量高精度的儀器分別觀測涵蓋不同頻率之各種變形，期能解開地震形成之謎，並篩選可靠之地震前兆。利用本所設置之井下應變儀觀測站儀器以三分量井下應變儀為主，並搭配井下微震儀、水位計、井下寬頻地震儀與 GPS 連續觀測站，藉由長期連續的觀測，可對斷層活動潛勢有更深入的了解。

井下應變儀因其埋入地下深處，可有效降低干擾雜訊，又可緊密接觸地下厚實且未經風化之堅硬岩盤，不僅在精度上可量測到小至 10^{-8} 的地潮訊號(可感測 10^{-9}~10^{-12} 之微細應變)，且其週期變化可觀測到短中長期甚至數十年以上的構造變化。恰可填補地震儀與 GPS 觀測不到的頻率範圍。因此，井下應變儀若能結合連續 GPS 觀測，對於數個月至數十個 Hz 的範圍內的微細地殼應變研究，提供另一有力的工具，有助於臺灣活動斷層的活動度及其地震潛勢之評估。

研判活動斷層是否再活動是一個相當具研究性質的工作，對於社會經濟的影響也是相當地重大，然而至目前為止，世界上還沒有任何國家可以對斷層再活動的時間進行預測。本所就防災的觀點提供資訊，進行斷層活動性觀測研究計畫，除井下應變儀觀測外，也參考美日各國的經驗擬定全面性的觀測計畫，從時間與空間上觀測斷層的活動性，研判可能的斷層再活動潛勢與地震前兆現象，相關研究成果與技術成果斐然，應多與國內外學術機關交流合作，不僅提升國際能見度，也能不落於國際研究趨勢。

歐洲地質科學學會 EGU（European Geosciences Union）係歐洲地區地球科學學門的最大國際學術組織。除了歐洲各國地球科學專家學者參加外，同時也會吸引全球各地地球科學領域的專家一同與會，每年吸引超過萬名的地球科學家前往觀摩與發表研究成果，為地球科學

界發表研究成果及心得交流討論的重要會議，而來自全球近百國家超過萬名的科學家以口頭或壁報方式發表超過1萬篇以上的科學論文，包含地球科學各個領域和學門，其中細分近600個精采的科學議題、大師級的主題演講及簡短課程，加上各種科學獎章的頒獎典禮及問題辯證，因此參加此會議可以儘速吸取國外相關領域之研發經驗，提升臺灣研發能量，可獲取最佳的研究與分析成果，故值得政府機關派員參加此會議，瞭解地球科學界最新研發趨勢與動態。建議本所未來也能派員參加此大會。

陸、参考文獻

1. Angelier, J., J.-C. Lee, H.-T. Chu and J.-C. Hu (2003). "Reconstruction of fault slip of the September 21st, 1999, Taiwan earthquake in the asphalted surface of a car park, and co-seismic slip partitioning." Journal of Structural Geology **25**(3): 345-350.
2. Arnold, J., P. Allen, R. Muttiah and G. Bernhardt (1995). "Automated base flow separation and recession analysis techniques." Ground water **33**(6): 1010-1018.
3. Bardsley, W. and D. Campbell (2000). "Natural geological weighing lysimeters: calibration tools for satellite and ground surface gravity monitoring of subsurface water-mass change." Natural Resources Research **9**(2): 147-156.
4. Braja, M. (1994). "Das “Principles of Geotechnical Engineering”." PWS Engineering, Boston.
5. Chang, C.-P., T.-Y. Chang, J. Angelier, H. Kao, J.-C. Lee and S.-B. Yu (2003). "Strain and stress field in Taiwan oblique convergent system: constraints from GPS observation and tectonic data." Earth and Planetary Science Letters **214**(1): 115-127.
6. Dreiss, S. J. (1989). "Regional scale transport in a karst aquifer: 1. Component separation of spring flow hydrographs." Water Resources Research **25**(1): 117-125.
7. Gladwin, M. T. and R. Hart (1985). "Design Parameters for Borehole Strain Instrumentation." Pure and Applied Geophysics **123**(1): 59-80.
8. Hart, R. H. G., M. T. Gladwin, R. L. Gwyther, D. C. Agnew and F. K. Wyatt (1996). "Tidal calibration of borehole strain meters: Removing the effects of small-scale inhomogeneity." Journal of Geophysical Research-Solid Earth **101**(B11): 25553-25571.
9. Hodgkinson, K., J. Langbein, B. Henderson, D. Mencin and A. Borsa (2013). "Tidal calibration of plate boundary observatory borehole strainmeters." Journal of Geophysical Research: Solid Earth: n/a-n/a.
10. Hu, J.-C., C.-S. Hou, L.-C. Shen, Y.-C. Chan, R.-F. Chen, C. Huang, R.-J. Rau, K. H.-H. Chen, C.-W. Lin and M.-H. Huang (2007). "Fault activity and lateral extrusion inferred from velocity field revealed by GPS measurements in the Pingtung area of southwestern Taiwan." Journal of Asian Earth Sciences **31**(3): 287-302.
11. Huang, M. H., J. C. Hu, C. S. Hsieh, K. E. Ching, R. J. Rau, E. Pathier, B. Fruneau and B. Deffontaines (2006). "A growing structure near the deformation front in SW Taiwan as deduced from SAR interferometry and geodetic observation." Geophysical Research Letters **33**(12).

12. Jan, C.-D., T.-H. Chen and H.-M. Huang (2011). "Analysis of rainfall-induced quick groundwater-level response by using a Kernel function." Paddy and Water Environment: 1-10.
13. Johnston, M., A. Linde, I. Sacks and D. Myren (1982). "Borehole dilatometer strain array—installation and preliminary results from the Mojave desert." EOS **63**: 430.
14. Jurgenson, L. (1934). "The application of theories of elasticity and plasticity to foundation problems." Journal of the Boston Society of Civil Engineers **21**(3).
15. Loevenbruck, A., R. Cattin, X. Le Pichon, M.-L. Courty and S.-B. Yu (2001). "Seismic cycle in Taiwan derived from GPS measurements." Comptes Rendus de l'Académie des Sciences-Series IIA-Earth and Planetary Science **333**(1): 57-64.
16. Lyne, V. and M. Hollick (1979). Stochastic time-variable rainfall-runoff modelling. Institute of Engineers Australia National Conference.
17. Matsumoto, N. (1992). "Regression-Analysis for Anomalous Changes of Ground-Water Level Due to Earthquakes." Geophysical Research Letters **19**(12): 1193-1196.
18. Nathan, R. and T. McMahon (1990). "Evaluation of automated techniques for base flow and recession analyses." Water Resources Research **26**(7): 1465-1473.
19. Pearson, C., J. Beavan, D. Darby, G. Blick and R. Walcott (1995). "Strain distribution across the Australian-Pacific plate boundary in the central South Island, New Zealand, from 1992 GPS and earlier terrestrial observations." Journal of Geophysical Research: Solid Earth (1978–2012) **100**(B11): 22071-22081.
20. Rice, J. R. and M. P. Cleary (1976). "Some basic stress diffusion solutions for fluid-saturated elastic porous media with compressible constituents." Reviews of Geophysics **14**(2): 227-241.
21. Roeloffs, E. (2010). "Tidal calibration of Plate Boundary Observatory borehole strainmeters: Roles of vertical and shear coupling." Journal of Geophysical Research-Solid Earth **115**: 25.
22. Roeloffs, E. A. (1996). "Poroelastic techniques in the study of earthquake-related hydrologic phenomena." Advances in Geophysics, Vol 37 **37**: 135-195.
23. Rojstaczer, S. (1988). "Intermediate period response of water levels in wells to crustal strain: sensitivity and noise level." Journal of Geophysical Research: Solid Earth (1978–2012) **93**(B11): 13619-13634.
24. Savage, J. and M. Lisowski (1995). "Strain accumulation in Owens Valley, California, 1974 to 1988." Bulletin of the Seismological Society of America **85**(1): 151-158.

25. Tamura, Y., T. Sato, M. Ooe and M. Ishiguro (1991). "A Procedure for Tidal Analysis with a Bayesian Information Criterion." Geophysical Journal International **104**(3): 507-516.
26. Wakita, H. (1975). "Water wells as possible indicators of tectonic strain." Science 189(4202): 553-555.

附錄 1、參與之研討會議程

TS5.3/EMRP4.5/G6.6/SM2.6
Mechanical heterogeneity and their transient evolution along fault zones (co-organized)

Convener: Hiroki Sone
Co-Conveners: Marcos Moreno, Dietrich Lange, Nadaya Cubas, Mauro Palo

- Orals / **Wed, 30 Apr, 08:30–12:00** / **Room B14**
- Posters / **Attendance Wed, 30 Apr, 15:30–17:00** / **Blue Posters**

Add this Session to your Personal Programme

Geophysical studies of recent well-monitored mega-earthquakes are revealing with an increasing resolution the complex mechanical heterogeneities along faults (differential locking behavior, differential rupture behavior, rheological and structural variations, among others). Furthermore, observations of various transient events (after slips, slow slips, tectonic tremors, low frequency earthquakes) also evidence the temporal evolutional nature of fault systems. While fault heterogeneities seem to have first order controls on the pattern of strain accumulation/release and carry fundamental information about the mechanical setting of faults, we have limited physical and mechanical understanding of what causes these heterogeneities, their kinematics and transient evolution between major events, and how they ultimately influence the largest seismic events. We aim to integrate studies from various disciplines in order to compare different observations and provide insights into the physical and transient properties of fault heterogeneities and their relation to earthquakes. Contributions from geologists, seismologists, geodesists, experimentalists, and modelers are invited. Some suggested topics are:
* Roughness/asperities/geometry of faults
* Geodetic records of fault slip in different periods of the earthquake cycle
* Co-seismic slip inferred from seismic records of various frequencies
* Spatiotemporal variation of seismicity and transient events, seismic vs. aseismic slip
* Seismic and electromagnetic attributes around faults from tomography
* Relation between fault heterogeneity and rock physical/rheological properties
* Numerical modeling of fault zone kinematics

Invited Speakers: Martin Mai

Posters TS5.3/EMRP4.5/G6.6/SM2.6

Mechanical heterogeneity and their transient evolution along fault zones
Convener: Hiroki Sone
Co-Conveners: Marcos Moreno, Dietrich Lange, Nadaya Cubas, and Mauro Palo
Session Details Orals

Add this Session to your Personal Programme

Attendance Time: Wednesday, 30 Apr, 15:30–17:00
Blue Posters
Chairperson: Hiroki Sone, Mauro Palo

B498 EGU2014-4817
Different kernel functions due to rainfall response from borehole strainmeter in Taiwan
Chih Yen Chen, Jyr Ching Hu, and Chi Ching LIu

B499 EGU2014-11927
Measuring Transient Signals in Plate Boundary Faults Zones with Strainmeters
Kathleen Hodgkinson, *Dave Mencin*, David Phillips, Brent Henderson, Mike Gottlieb, Warren Gallaher, Wade Johnson, Chad Pyatt, Elizabeth Van Boskirk, Otina Fox, Glen Mattioli, and Chuck Meertens

B500 EGU2014-15396
GeoSEA: Geodetic Earthquake Observatory on the Seafloor
Heidrun Kopp, Dietrich Lange, Ernst R. Flueh, Florian Petersen, Jan-Hinrich Behrmann, and Colin Devey

B501 EGU2014-14847
Slip Vectors and Strain Partitioning Along the Maule 2010 Rupture Zone
Dietrich Lange, Marcos Moreno, and John Bedford

B503 EGU2014-4900
Geodetic slip solutions for the Mw=7.4 Champerico (Guatemala) subduction earthquake of November 7 2012
Andria Ellis, Charles DeMets, *Pierre Briole*, Enrique Molina, Omar Flores, Jeffrey Rivera, Cécile Lasserre, Hélène Lyon-Caen, and Neal Lord

附錄 2、發表之壁報論文內容

Geophysical Research Abstracts
Vol. 16, EGU2014-4817, 2014
EGU General Assembly 2014

Different kernel functions due to rainfall response from borehole strainmeter in Taiwan

Chih Yen Chen (1,2), Jyr Ching Hu (2), and Chi Ching LIu (3)

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In order to realize reasons inducing earthquakes, project of monitoring of the fault activity using 3-component Gladwin Tensor Strainmeter (GTSM) has been initiated since 2003 in Taiwan, which is one of the most active seismic regions in the world. Observed strain contains several different effects within including barometric, tidal, groundwater, precipitation, tectonics, seismic and other irregular noise. After removing the response of tides and air pressure on strain, we still can find some anomalies highly related to the rainfall in short time in days. The strain response induced by rainfall can be separated into two parts as observation in groundwater, slow response and quick response, respectively. Quick response reflects the strain responding to the load of falling water drops on the ground surface. A kernel function shows the continual response induced by unit precipitation water in time domain. We split the quick response from data removing tidal and barometric response, and then calculate the kernel function by use of deconvolution method. More, an average kernel function was calculated to reduce the noise level. There are five of the sites installed by CGS Taiwan were selected to calculate kernel functions for individual sites. The results show there may be different on rainfall response in different environmental settings. In the case of stations site on gentle terrain, kernel function for each site shows the similar trend, it rises quickly to maximum in 1 to 2 hrs, and then goes down near to zero gently in period of 2-3 days. But in the case of sites settled side by the rivers, there will be 2nd peak of function when collected water in the catchment flows along by the sites related to the hydrograph of creeks. More, landslides will occur in some sites in hazard of landslide with more rainfall stored on, just like DARB in ChiaYi. The curve of kernel function will be controlled by landslides and debris flows.

Different kernel functions due to rainfall response from borehole strainmeter in Taiwan

Chin-Yen Chen[1,2], Jyr-Ching Hu[2], Chi-Ching Liu[3]

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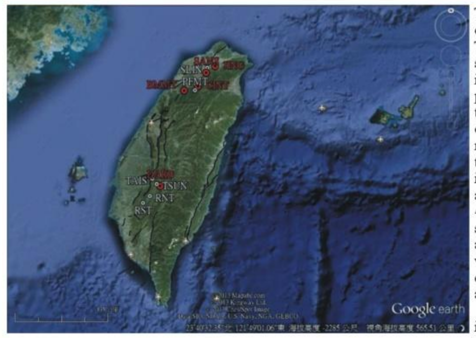
EGU2014-4817
Session: TS5.3/EMRP4.5/G6.6/SM2.6

Abstract

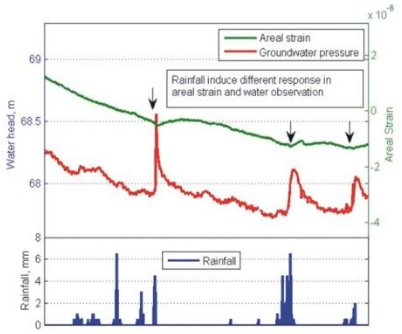
In order to realize reasons inducing earthquakes, project of monitoring of the fault activity using 3-component Gladwin Tensor Strainmeter (GTSM) has been initiated since 2003 in Taiwan, which is one of the most active seismic regions in the world. Observed strain contains several different effects within including barometric, tidal, groundwater, precipitation, tectonics, seismic and other irregular noise. After removing the response of tides and air pressure on strain, we still can find some anomalies highly related to the rainfall in short time in days. The strain response induced by rainfall can be separated into two parts as observation in groundwater, slow response and quick response, respectively. Quick response reflects the strain responding to the load of falling water drops on the ground surface. We split the quick response from the original data and calculate the kernel function by use of deconvolution method. An average kernel function was calculated to reduce the noise level. There are five of the sites installed by CGS were selected to calculate kernel functions for individual sites. The results show there may be different on rainfall response in different environmental settings. In general, kernel function for each site shows the similar trend, it rises quickly to maximum in 1 to 2 hrs, then goes down near to zero gently in period of 2-3 days. But in some sites settled side by the rivers, there will be 2[nd] peak of function when collected water in the catchment flows by the sites depending on hydrograph. More, landslides will occur in some sites in hazard of landslide with more rainfall stored on, just like DARB in ChiaYi. The curve of kernel function will be controlled by landslides and debris flows.

Introduction



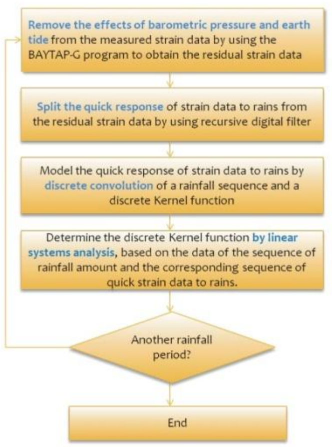
There have been 12 fault activity observatories deployed in western Taiwan since 2003. There are a borehole strainmeter and a borehole seismometer installed and auxiliary barometer, piezometer, rainfall gauge and GPS timer in each observatory. The observatories constitute an essential network in western Taiwan where have the most population living. These instruments are installed at a depth of approximately 200 meters at 12 sites of 4 clusters which provide 3 component strain data on both crustal strain accumulation and transient strain variations induced by environmental change such as meteorological effect and earthquakes.

Map shows the borehole strainmenters installed in Taiwan, red marks the sites discussed in the paper. Map source: Google Earth (2013)

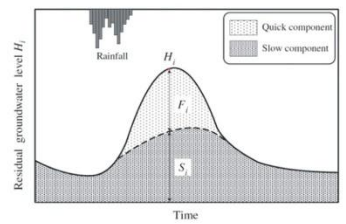


In data processing, after removing tidal and barometric response from original strain data. We found some abnormal signal highly related to rainfall. Its response is similar to the groundwater. But they goes different direction, one goes up, and one goes down. The result is different from the result we observed in years - two goes similar in long-term trend. That makes us have motivation to understand what relation between two.

Mothod



This is a flowchart of this study. First, remove the effect of barometric pressure and earth tide from original strain. Second, to split quick response of strain due to rainfall, and then using deconvolution method to get discrete kernel function. Check another rainfall and take an average kernel function. To avoid some noise and bias, 2 standard deviation are utilized to constrain to calculate mean kernel function.



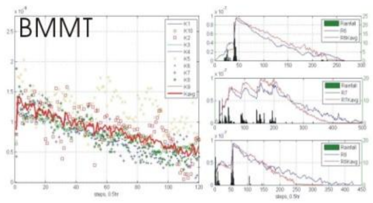
The effect for groundwater induced by a rainfall event could be separated into relatively quick response that may last few minutes or hours, and slow response that may last few days or weeks [*V Lyne and Hollick*, 1979].

$$F(t) = \int_0^t h(t-\tau)R(\tau)\mathrm{d}\tau,$$

After filtering, we obtain a quick response series data. Then deconvolution method was used. with given quick response and rainfall records series known, we can calculate a unknown function, the unit rainfall response function or a kernel function.

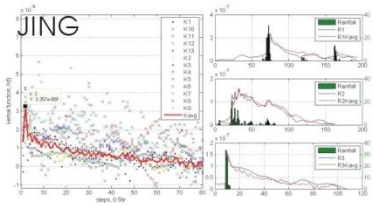
Results

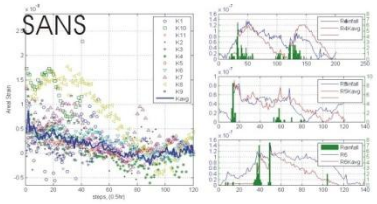
We take 5 sites data which are all installed by CGS, taiwan. They are JING and SANS in Taipei, CINT and BMMT in HsinChu, and DARB in Chiayi. To discuss what is the differences on rainfall response in different settling environment.

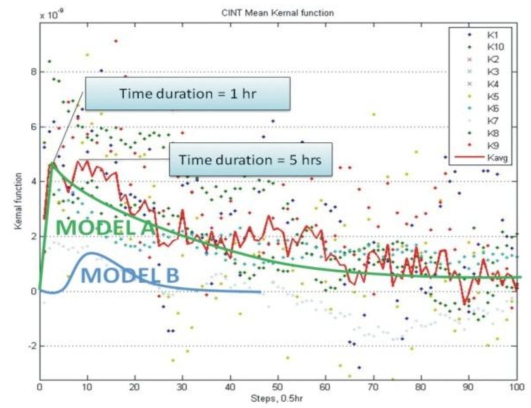


Here are calculated results of BMMT, JING and SANS. The same of these three is that terrain where they set up are all gentle with no dramatic altitudes change. From the results, kernel function for each sites show the similar trend, quickly response to max in 1 to 2 hrs, then goes near to zero gently. Their max rainfall response vary from 14 to 65 nanostrain/mm.

Left : Picked quick strain response induced by rainfall (with marks) and calculated mean kernel function of BMMT (red line). Right: comparison of observed quick response induced by rainfall (blue line) and convoluted results of rainfall and mean kernel function (red line).

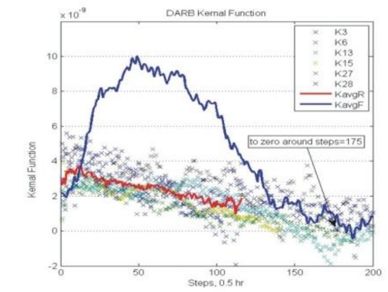


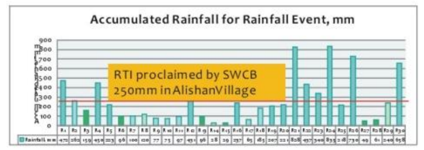




CINT is located on an elementary school which is in hill area in HsinChu. From the result of CINT, we can see the abrupt rising after rainfall in 1 hr, but there is another peak found on around 4 hrs later. That indicates there are some contaminations in CINT kernel function.

Due to the site is near by the river, we propose the another peak should be related to the hydraulic condition after raining. After raining, some water infiltrate into the soil, but some flow into and collected in the river bank. The lag time between a rainfall begin to max flow recorded of hydrograph is about 3-6 hrs depends on the catchment area, condition of vegetations and rock type.we correlate both and found 2nd peak which is highly coincided with max hydrograph peak in time. We propose that 2nd peak responding to the river hydrograph change and all kernel function is a comprehensive result of two different mode.



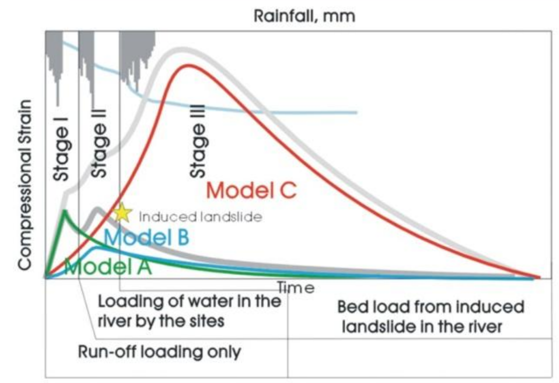


We picked 30 rainfall events in DARB during 2007 to 2010 to calculate their discrete kernel function. All are plot on one diagram but can not conclude in on function. Therefore, we divide these functions into two group, thirteen for flood mode, and six for rain mode.Kernel function of rain mode has very similar trend as CINT has, two peaks, abrupt reach its peaks in 1 and 5.5 hrs, respectively. And its value is more or less 3.70 nanostrain/mm. in the other hand, kernel function of flood mode reach its max value, 10 nanostrain/mm, in about 24 hrs. no matter in lag time or value, kernel function in flood mode is much larger than in rain mode.

The reason to induce such phenomenon might be related to the local hazard landslide and collapse. Left aerial photos show the landslides around DARB after a typhoon, Vanapi, in 2010.

We found there is a threshold of 200 mm accumulated rainfall between rain and flood mode. And that meet the RTI (Rainfall Triggering Index) 250 mm proclaimed by SWCB (Soil and Water Conservation Bureau, Taiwan) in AliShan Village. That means if accumulated rainfall in a rain event excess 250 mm, curves of kernel function will be controlled by landslide.

Conclusion



A simple diagram shows the strain response induced by rainfall. Model A (green line) shows the response of ground surface run-off loading which goes abruptly in 1-2 hours then decreases exponentially by time. In some sites located by the river, the response of strain might be influenced by hydrograph of the river and that's the response of Model B (blue line). In some extreme case such as DARB, there might be existing some influences of running bed-loads of river by the site (Model C, red line). Gray line shows the comprehensive result of three models along time.