莫拉克颱風造成南台灣大淹水，為台灣帶來空前考驗。/ 劉學聖攝
The downpour brought by the typhoon Morakot brought serius trail to South Taiwan./by Xue-sheng Liu

Lessons Learned from the Record-breaking Flood

百年洪帶來的啓示與覺醒

探討氣象變異與土石流防範

Reflecting on Weather Abnormalities and Debris Flow Prevention

採訪撰文 Interview & Text ／邱和珍 Jane Chiu　特別感謝 Special thanks to ／台灣大學大氣科學系周仲島教授 Professor Ben Jong-Dao Jou of the Department of Atmospheric Science of NTU，台灣大學地理環境資源系林俊全教授 Professor Jiun-Chuan Lin of the Department of Geology, NTU
翻譯 Translator ／黃詠蘭 Teresa Huang

恆春半島上的墾丁國家公園萬里桐海岸，退潮後，星羅棋布的珊瑚礁，是異鄉旅人記錄遊蹤心情的寫照。這座位於國家公園內的萬里桐海堤，也是〈海角七號〉裡男主角，看海散心的地方。

莫拉克颱風　心碎父親節

然而，今年8月8日，中度颱風莫拉克重創中、南部山區及沿海低窪地區，造成758人死亡及失蹤，農林漁牧損失金額超過164億，疏散撤離人數逾24,500人，這些令人怵目驚心，如同電影〈明天過後〉的災難，再一次提醒人們大自然災害的威力。同樣位於莫拉克颱風外圍環流影響的墾丁國家公園，在此次風災中未曾傳出重大災情，主要得力於落實自然保育，讓園區內獨特、珍貴及脆弱的特殊地景及生態，重現新生命的契機。

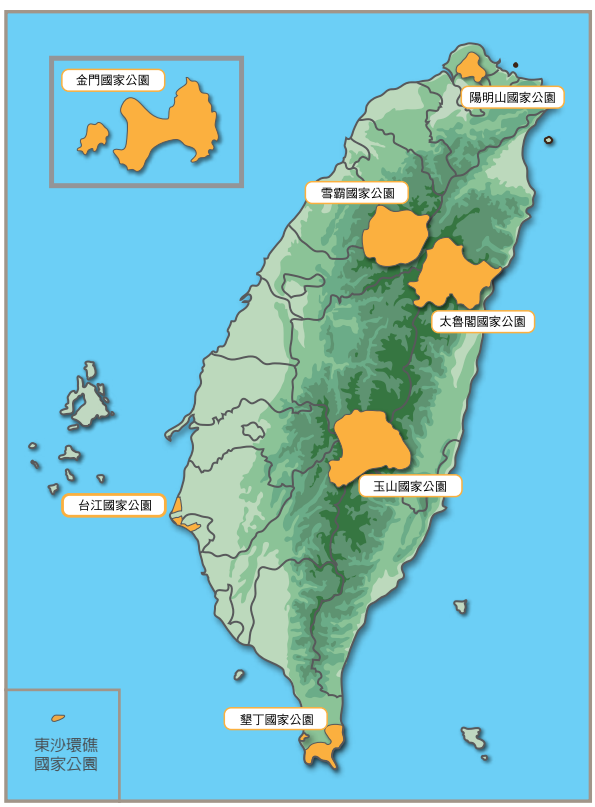
台灣是亞熱帶地區的一個海島，每年從5月開始至10月，經常遭受颱風的侵襲，對國人生命財產造成嚴重的損害及威脅。對此，台灣大學大氣科學系周仲島教授認為，影響颱風路徑的因素，複雜且詭譎多變。儘管如此，周教授說，國人如能多瞭解各種颱風百

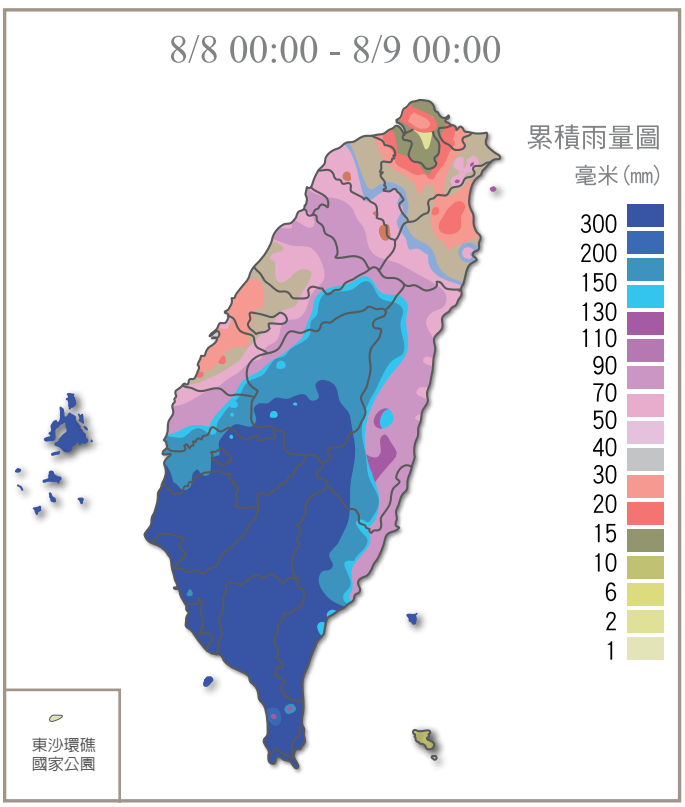
On the coast of Wan-li-tong, the ebb reveals the coral reef that spreads all over the place. The reef best describes the feelings of travelers journeying in a foreign land. Wan-li-tong, which situates within Kenting National Park (KNP), is where a lead character in the movie Cape No.7,went for sea-viewing.

A Heartbreaking Father's Day

On August 8th, 2009, Typhoon Morakot wreaked catastrophic damage in central and southern Taiwan, leaving 758 people dead and missing, resulting in NT$16.4 billion in damages, and forcing over 24,500 people to evacuate. The catastrophe reminiscent of the scene in the movie The Day After Tomorrow shows the destructive power of natural disasters. However, also within the influence of the outer band of the typhoon, KNP didn't suffer from major damages. Thanks to efforts on natural landscape conservation there, the unique, precious and fragile landscape and ecosystem were restored.

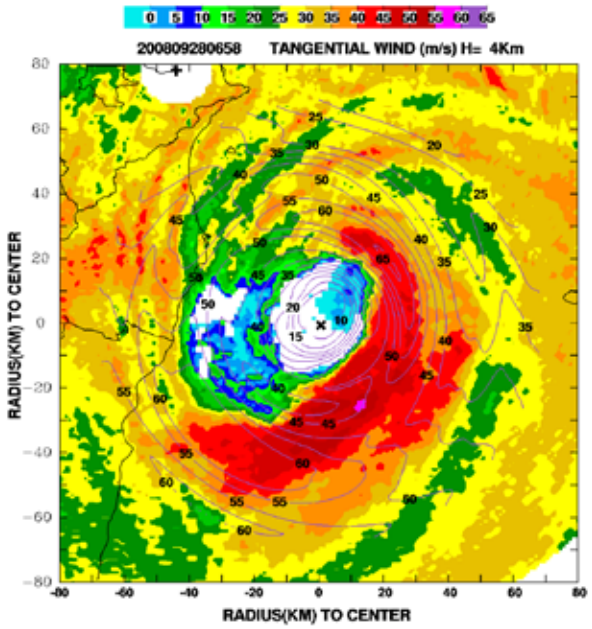
A subtropical island, Taiwan is frequented by typhoons from May through Oct., which cause great loss of life and properties. Professor Ben Jong-Dao Jou of the Department of Atmospheric Science of NTU, said that factors influencing the path of a typhoon are complex and difficult to predict. However, understanding various aspects of typhoons and





右圖為莫拉克颱風在98年8月8日至8月9日之降雨圖表，可見全台幾乎籠罩在暴雨中。左圖為國家公園分布範圍，同樣在暴雨侵襲下，水土保持良好區域的較無傳出嚴重災情 / 朱立雯繪圖，雨量參考資料來自中央氣象局

The figure on the right shows the total rainfall from Aug. 8 to Aug. 9, 2009. It shows that the whole island was shrouded in rain. The figure on the left is the distribution of national parks in Taiwan. Facing the same raging rain, areas with good water and soil conservation suffered from relatively minor damages. / Drawn by Li-wen Zhu. Data Source: Central Weather Bureau.



圖為2008年薔蜜颱風之都卜勒雷達觀測。白藍色區域表示弱回波為颱風中心，深紅紫色區域表示強回波為發生強降雨區域。薔蜜颱風降雨分布的不對稱特徵明顯，黑色等值線為切線風強度表示颱風旋轉度之強弱。/ 周仲島教授提供

The Doppler radar observations of Typhoon Jangmi in 2008. The white and blue area represents the eye of the typhoon and the dark magenta area represents areas with torrential rain. The distribution of rainfall brought by Typhoon Jangmi is highly asymmetric. The black lines represent the swirling intensity of the typhoon. / Photo provided by Professor Jong-dao Jou.

態，精確運用氣象單位提供的預報數據，應該可以有效降低颱風帶來的損失。

颱風路徑　詭譎難測

周教授指出，颱風移動的路徑會受到「駛流場」、大氣環境、海水溫度、藤原效應以及地球自轉等因素影響。

周教授說，大氣中的颱風運動受到駛流場的變化最大，在急速的氣流牽引下，颱風移動速度就很快；在緩滯氣流中之移動速度則較為緩慢。颱風移動的路徑類似河中的渦旋隨著水流般流動，是隨著導引的駛流場而移動，但卻較為複雜而多變。經常看到氣象局發布的颱風路徑都是由菲律賓東方海面，往西北或西北西移動，而鮮少由東北或東北東進行，為何如此？周教授說，颱風的北邊是一個廣大範圍之太平洋高壓，由於高壓環流為順時鐘方向，高壓南側為東向西之氣流，颱風受其導引，當然是往西移動。

颱風的誕生，除了要有廣闊的熱帶洋面，該地區的海水表面溫度也要高於攝氏26.5度。周教授解釋，北太平洋西部也就是菲律賓東部海面，終年海水溫度超過26.5度。若是有大氣中的擾動形成氣旋式旋轉低壓系統，大量海水蒸發變成水氣升空，而周圍的空氣流入補充，然後再上升。如此循環，終必使整個氣流不斷旋轉，且逐漸擴大而形成了颱風。

由於地球由西向東高速自轉，會使得周圍的空氣和地球表面產生摩擦，越接近赤道因偏向力接近零，摩擦力越強，就會引導這股旋轉氣流呈逆時針方向在北半球旋轉；如果是順時針方向旋轉，那麼氣流便會在南半球生成。由此可見，颱風發生的地點，大都距離赤道五個緯度以上的洋面上。

making accurate use of weather forecasts may minimize possible damages.

Unpredictable Tracks of Typhoons

The track of a typhoon is influenced by the atmospheric environment, the steering flow, , the sea surface temperature, Earth rotation, and other typhoons nearby (the Fujiwhara effect). The steering flow is a major influence over the typhoon, which moves rapidly (or slowly) when dragged by a rapid (or slow) air flow. Just like a vortex moves with water currents, the passage of a typhoon is determined by the steering flow, but it's more complex and unpredictable than the case of a vortex.

Typhoons often move from the east of the Philippines towards the northwest or west-northwest but rarely southeastwards or southwestwards because to the north of the typhoon is a vast Pacific anticyclone that rotates clockwise. Influenced by it, typhoons move westwards accordingly.

A typhoon takes shape in tropical sea surface where water temperature reaches over 26.5 ℃ , a condition that the east of the Philippines meets year-round. When atmospheric disturbances cause low atmospheric pressure, large body of sea water'll vaporize and rise up to form a tropical depression, and the air nearby flows in and then rises up again. The cycle sends the air flow into a constant rotation and extension and a typhoon might developed as a result.

As the Earth rotates rapidly from the west to the east, it produces the Coriolis force, a deflection of the moving air. This force is zero at the equator, and becomes greater at higher latitude. This variation makes typhoons hardly originate near the equator and causes them to tend to move northwards when they travel westwards.

大多數人都有玩過打水漂兒的經驗。經驗上，石頭要夠圓，水面的漣漪才會一圈一圈的。所謂藤原效應，理論上，是兩個相距約1,000公里至1,500公里的颱風，宛如兩個在水面起了漣漪的旋渦，彼此互受影響，呈氣旋式螺旋軌跡接近，而稱之為藤原效應，或俗稱雙颱效應。周教授提到，藤原效應多數出現在西北太平洋，主要是由於這裡常生成颱風，同一時間可能有兩個颱風活躍於本區，因而容易發生藤原效應。

台灣現行的熱帶氣旋強度分級，是根據聯合國世界氣象組織的風力標準。周教授說，颱風強度除了北太平洋西部以外，其它六個海域形成的颱風規模都較小。他提醒，造成這次中度莫拉克颱風重創中、南部及南台東地區，並非強大的風力，而是五天內引進強烈的西南氣流，因連續豪大雨才釀成的重大災害。將來颱風的分級是否可以改為以雨量多寡來分級，這是可以進一步討論的。

整合資訊系統　強化降雨預報功能

如何有效預測颱風帶來的雨量，以降低災害的衝擊？周教授認為，由於台灣地理環境極為複雜，局部

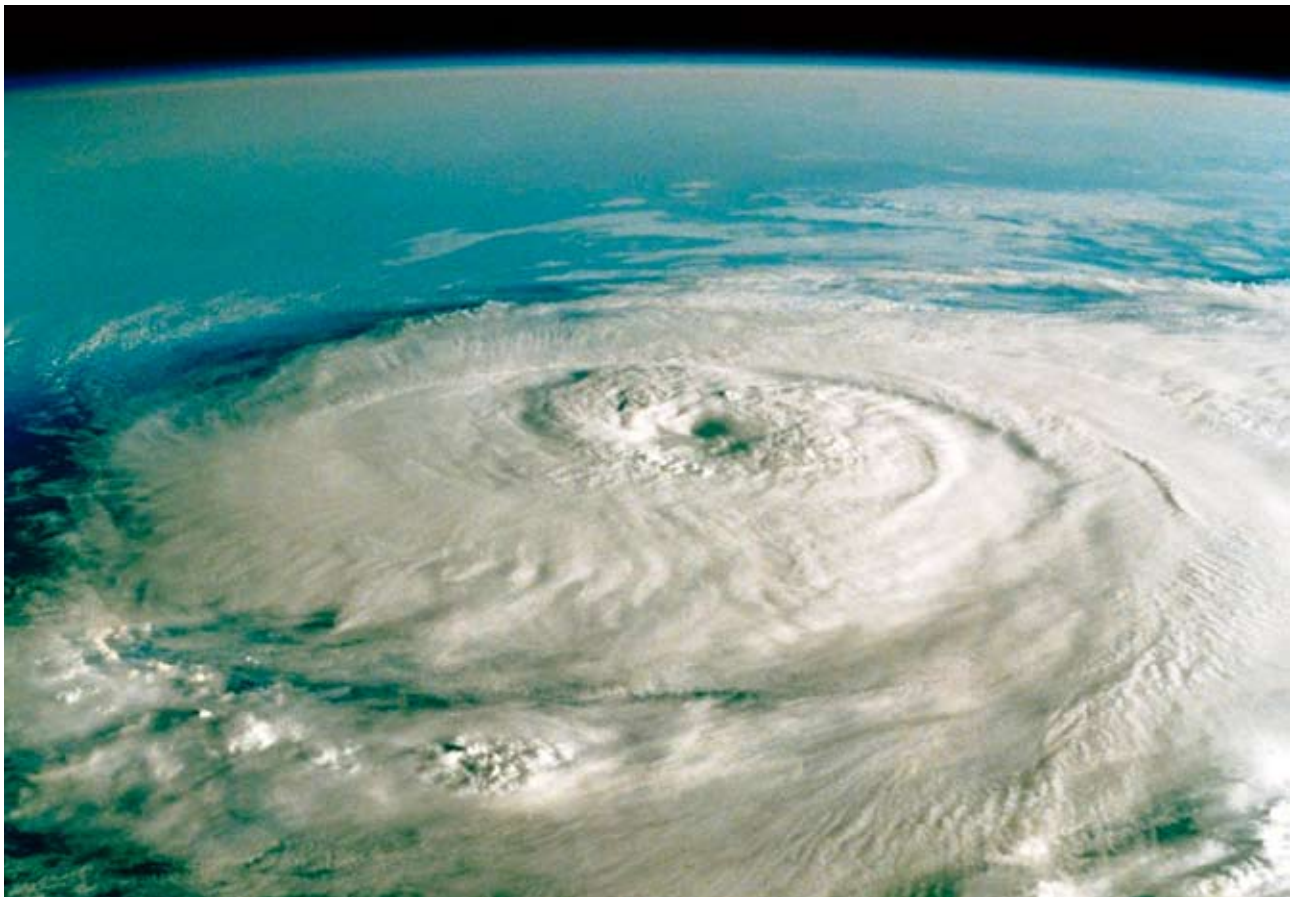
When two typhoons 1000-1500 kms away from each other draw closer, the two vortices will be attracted to each other. This phenomenon is known as the Fujiwhara effect. Jou noted that such effect usually takes place in Northwest Pacific because there tends to be two or more typhoons active concurrently in this broad sea area, thus increasing the likelihood of the Fujiwhara effect.

The current intensity classification of typhoons adopted in Taiwan is in pursuant to the one employed to categorize wind force by the UN World Meteorological Organization (WMO). It makes sense because typhoons make impact mainly by storm surges caused by strong wind. But in the case of Morakot, Jou reminded, the devastation caused was not by the strong wind but by the southwesterly airflow which brought heavy rains. In the future, whether the classification of typhoons should take rainfall into account worths discussion.

Integrate Information System and Improve Rainfall Forecast

How may rainfall be accurately predicted so as to minimize the impact of a typhoon? Due to Taiwan's highly complex geographical environment, it's hard to forecast the precipitation of sudden torrential rains. For instance, a

極端氣候造就出的完美風暴，已成為世界各國最重視的議題 /Photos.Com (USA) 提供
Perfect storms created by extreme weather patterns have become a big concern for countries around the world. / Photo provided by Photos.com



※2004年7月1日敏督利颱風挾帶豪雨成災，尤以中部大甲溪流域的災情最為嚴重。(林俊全教授提供)
On July 1st 2004, Typhoon Mindulle brought torrential rain and caused calamities. The Tachia River basin of Central Taiwan suffered the greatest damages. / Photo provided by Professor Jiun-chuan Lin.

1. 大甲溪支流東卯溪遭受土石流侵襲。
Tungmao River, a confluent of the Tachia River, was affected by debris flows.
2. 大甲溪因河道側蝕而造成公路中斷。
Lateral erosion of the Tachia River has broken off the roads.
3. 一場百年洪患，一堂昂貴的課，許多人們引以為傲的建設，反而成了大自然的負擔 / 阿杜攝
The severest flood in a hundred years was a lesson learned the hard way. Many infrastructure people take pride in turned out to be a burden for Nature. / by Adu.

地區突發性豪雨的預測困難度相當高，以莫拉克颱風為例，要事先預報兩日總降雨量超過兩千毫米，並不容易。

周教授建議，定量降雨的預報工作，應整合相關單位的防災資訊，如經濟部水利署集水區的降雨估計和預報、農委會水土保持局的土石流預警系統、啓動國軍的氣象觀測。如能有效整合這些資訊，萬一發生災難時，才能讓救災單位迅速掌握災情，降低颱風和豪雨所帶來的災害。

為何發生在夏、秋之際的颱風，其威力和損害如此之大？周教授表示，這十年所發生的颱風，因引進旺盛西南氣流，導致連續豪大雨而釀成嚴重災害的，有賀伯、敏督利、海棠以及莫拉克颱風。周教授呼籲，七、八、九月可能引進西南氣流的颱風，無論大小，全國民眾都應提高戒備，以減少生命財產的損失。秋末冬初與東北季風共伴是另一種要特別注意的。

rainfall over 2,000 millimeters was truly difficult to estimate in advance of the landfall of Morakot.

Jou said that forecasts on rainfall and related disasters require the integration of disaster prevention information from relevant bodies such as rainfall forecasts from CWB, rainfall estimates and forecasts for the watersheds of the Water Resources Agency, and the Warning System of the Debris Flow by the Soil and Water Conservation Bureau. With such information at hand, disaster rescue can be carried out more smoothly and effectively.

Typhoons occurring between summer and autumn are particularly destructive because the accompanying strong southwesterly flow brings heavy rain, as in the case of Typhoon Herb (1996), Mindulle (2004), Haitang (2005) and Morakot (2009). Jou warns that people should be vigilant and stay on high alert to minimize the loss of life and property.

莫拉克颱風造成多處道路坍方，圖為救難人員冒險挺進受災嚴重的小林村景況 / 高彬原攝
The typhoon Morakot of Torrential rain collapsed the road. Photo was rescue team to get into Xiao lin village by walkng. /by Gao Binyuan

颱風　台灣的最大威脅

台灣原屬於年輕的地質結構，因地表旺盛的侵蝕及搬運力量，所造成的土石流，原是「自然現象」。然而，土石流之所以構成災害，甚至危及國人生命財產，是過度與大自然爭地，土地超限使用的結果。

台灣大學地理環境資源系教授林俊全指出，凡已列入土石流危險溪流，不論高山、丘陵或低窪地區均不適宜再繼續開發、居住；否則，長期而言並無法有效達到水土保持的目的。

遭逢台灣歷史上最大降雨，中、南部災區留下滿目瘡夷的殘破景象。林教授感嘆，遭莫拉克重創的土石流災害區，其實有許多都是名列農委會水保局的土石流警戒區，但仍然付出如此慘痛的傷亡代價。他表示，政府應儘早成立跨部會國土監測中心，整合氣象、地理、水文等資訊，如此才能立即做出正確判斷，達成救災任務。

河川生態　自我復原

如何疏導土石流會經過的河道呢？林教授說，河川本身是一個動態平衡系統，當颱風挾帶豐沛雨量，會使得河川透過水流的運沙能力，將沈積河床的淤沙搬離至出海口處，最後達到新平衡。目前堆積在河道的土石又將如何處理呢？林教授認為，砂石也是一種國土資源，應該加以利用。開採河川砂石，只要遠離橋梁約300至500公尺，的確可以避免河川掏挖切割，減少侵蝕沖刷。但

Typhoon, Most Destructive Threat to Taiwan

Taiwan has a relatively young geological structure, thus debris flows caused by the land erosion and transposition are just natural occurrences. But they become life-threatening because humans have exploited Nature and overused the land.

Professor Jiun-Chuan Lin of the Department of Gegraphy, NTU, noted that neither development nor inhabitation is appropriate in all areas listed as debris flow hazard zones, for this may impair water and soil conservation.

With the heaviest rainfall in Taiwan's recorded history, Typhoon Morakot took an enormous toll in central and southern Taiwan. Lin said that many of the affected areas are in fact the debris flow warning areas and yet the damages were still severe. He commented that the government should establish a cross-ministry land monitoring center to put together data on meteorology, geography, and hydrology so as to make informed decisions for disaster relief.

Placing Importance to the Ecology and the Regeneration Capacity of the Rivers

A river is a system of dynamic equilibrium: heavy rainfall will help the river carry sand that deposits in the riverbed to the estuary, thus reaching a new balance. So artificial channeling is not necessary. As for the gravels piled at the river course, Lin advocated the proper use of them. As long as the quarrying takes place 300-500 m away from

如過度開採，使得整個河床被掏空，將危及河道上的橋墩與堤防。林教授特別提醒，居住於河道中下游、低窪海埔地以及山坡地，具有潛在危險威脅的民眾，只要氣象局發布颱風警報並有預估雨量時，便應及早疏遷至政府準備好的安全避難所，災後再回到住所，應該可減少許多重大傷亡。

無人為干擾　地震是大自然衍化的結果

在地球演化過程中，地震是一種自然現象，它在地表上留下許多痕跡，如我們所處的高山、丘陵、海蝕平台等地形。然而，發生於1999年的九二一大地震，卻凸顯山崩、地滑、岩屑滑落與土壤液化的問題。林教授指出，自賀伯颱風以及九二一地震後，那些地質脆弱、地形陡峭且坡度大的地區，每逢豪雨或地震，地表物質向下邊坡移動，是造成山崩和土石流的主要原因。

在這塊兩千三百萬台灣人賴以為繫的小島上，地景隨著時空在變化，處處充滿著生機。林教授強調，為了讓國土重建工作能順利進行，國人應抱持戒慎恐懼的態度，深入瞭解這塊土地的地景特色，藉以還地於林，還道於河，趨吉避凶，讓福爾摩沙能永續發展。

the bridge, erosions can be avoided. But over-quarrying will hallow out the entire riverbed and jeopardize the bridges and dykes on the river course. Lin warned that people living at mid- and down- streams of a river, low-lying areas and hillsides must evacuate and take shelter in case of a typhoon warning, so as to avoid major casualties.

Earthquake — Simply a Natural Occurrence

During the course of the Earth's evolution, earthquakes have always been a natural phenomenon, leaving many traces on the Earth surface such as mountains and hills as we see today. The 921 Earthquake, however, brought to light problems such as landslides, slide-rocks and soil liquefaction. Lin pointed out that following Typhoon Herb and the 921 Earthquake, the downward movement of the surface materials from the geologically fragile, steep and cliffy areas caused by heavy rainfall or quakes should be held accountable for landslides and debris flows.

Taiwan's landscape changes over time and is full of life. Lin stressed that to facilitate the reconstruction of national land, people in Taiwan should remain deeply concerned and try to understand the characteristics of the land so as to give space back to it and allow Formosa to develop a sustainable environment.

林俊全教授簡介
Profile of Professor Jiun-Chuan Lin

英國倫敦大學地理學博士，研究專長為地形變遷、沖蝕研究、崩塌地形災害、地景保育等。曾參與國科會委託之「中橫公路崩山災害研究」、經建會委託之「中美基金94年度國土監測中心可行性分析案」、教育部委託之「94～95年基礎科學前瞻性人才培育計劃」等研究計劃案。

A Ph.D. in Geography at London University, U.K, Professor Lin had directed the Department of Geography, NTU, from 2000 to 2006 and he is now a full professor at the department. He specializes in changes in the landscape, erosions, landscape conservation, etc. He took part in research projects funded by the NSC, projects commissioned by the CEPD, and Human Resource Development Plan commissioned by the MOE.

周仲島教授簡介
Profile of Professor Jong-dao Jou

美國華盛頓大學大氣科學博士，現為國立台灣大學大氣科學系教授。研究專長為中尺度氣象、災變天氣動力以及都卜勒雷達分析。曾主持國科會資助之「台灣地區災變天氣整合研究」、台北市政府消防局委託之「颱洪應變與監測預警之研究」等研究計劃案。並主持97年在南台灣進行的西南氣流國際氣象觀測實驗計畫，又稱追雨計畫，共有美日韓加等國科學家參與豪雨天氣系統的密集觀測研究。

A Ph.D. in Atmospheric Science at Washington University, U.S. A, Professor Jou is currently teaching at the Department of Atmospheric Science of NTU. He specializes in Mesoscale Meteorology, weather dynamics and Doppler Radar Analysis. He had chaired various research projects, including one funded by the National Science Council, one commissioned by the Taipei City Government, and another experiment carried out with scientists elsewhere on southwesterly airflow.