# 海平面上的氣候密碼

## 專訪台大海洋研究所范光龍教授

# Decoding the Secret of Climate Change

## An Interview with Prof. Kuang-lung Fan of the Institute of Oceanography, National Taiwan University

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海洋
可以給予人們豐富的資源
也可以告訴人們氣候的秘密
誠如國家公園守護海洋資源
也有一群科學家
試圖從海洋給的訊息中
找出氣候變遷的關鍵……

The ocean
Provides humanity with rich resources
And reveals secrets of the climate.
Aside from the national parks,
There is another group of guardians over marine
Resources—a group of scientists.
They try to decode the messages from the ocean,
And unlock the mysteries of climate change.

一旦海洋環境改變，人類也將面臨不可預測的變化。地平線上的藍綠之爭才是人類該好好正視思考的問題 /Kristian 攝
Once the marine environments changes, human beings will face unpredictable adversities. "The battle between the green and the blue," the land's defense against the invading oceans, is the issue that humans should take seriously. /by Kristian

熱—全球暖化堪稱是近年來最熱門的環境議題。從西方拍攝的紀錄片〈不願面對的真相〉開始，到今年國人自製的〈±2℃〉，在在凸顯了我們的焦慮。雖然，引用的數據或推論，各方還有不同見解，但能掀起廣大迴響，有一個任誰都無法迴避的事實：天氣真的越來越熱了，極端氣候帶來的巨大環境衝擊，屢見不鮮。

## 正視海平面上升的問題

破紀錄的旱災、雪災、風災、水災，陸續在全球不同地點引爆。但對於超過7成面積為海洋覆蓋的地球來說，有一種大自然災害是不分地域的，那就是因氣候暖化而導致的海平面上升。換言之，綠色大地的面積會逐漸縮小。對陸上生物而言，這是一場地平線上的海水與陸地的領域之爭，對台灣這個島嶼型國家，更是如此。

台灣大學海洋研究所范光龍教授，從1991年開始在基隆、宜蘭、台東、高雄等沿海地區監測潮位，顯示10年間，台灣海平面平均一年升高0.32公分。數字看似微小，但已高於全球均值。按這個速度下去，百年後，台灣海平面將比現在高出至少30公分。

Global warming is by far the hottest environmental issue in recent years. From the U.S. documentary *An Inconvenient Truth* to the locally produced *±2 ℃*, the world's growing anxiety over it is unmistakable. While there are still debates over the science behind these films, no one can deny that the weather is indeed getting hotter. The enormous impacts caused by extreme climates are seen and felt everywhere.

## The Challenge of Rising Sea Levels

Record-breaking droughts, floods, snow storms and hurricanes have recently occurred on different parts of the planet. Yet an even greater disaster is still looming—global warming-induced sea level rise. Land, less than 30% of the Earth's surface, may be further diminished by the oceans' expansion. Simply put, it is the Land versus the Ocean, the land's defense against the invading oceans. It is a battle Taiwan cannot afford to lose.

Since 1991, Prof. Kuang-lung Fan of NTU's Institute of Oceanography has been monitoring tidal levels in coastal cities like Keelung, Yilan, Taitung and Kaohsiung. He found that, for the decade, Taiwan's sea level has risen at an annual rate of 0.32 cm, exceeding the global average. At this speed, it will rise by at least 0.3 m in just a century's time.

氣候暖化，造成冰川、冰山大量融化，流入海中。此外，熱漲冷縮的原理也告訴我們，溫度上升會讓海水體積增加。兩者效應相加，造成海平面上升、海岸線往內陸退縮，沿岸的生態首當其衝。

## 海洋與氣候的交互作用

在全球氣候的調節和穩定上，海洋扮演非常關鍵的角色，也唯有在穩定的氣候下，才能提供萬物永續生存的環境。而海洋與氣候的變化，是相互影響的。自然界中極為重要的水循環和能量交換，就在大氣與海洋中進行。另一方面，洋流則把低緯度海域溫暖的海水往高緯度海域帶，平衡地球的能量。

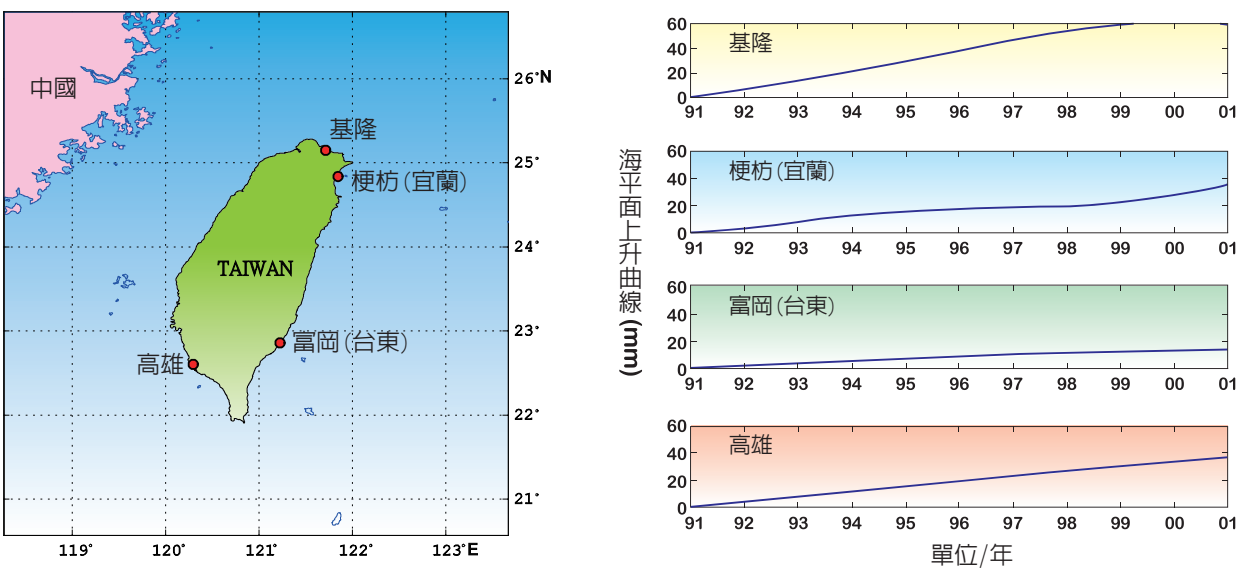
颱風逆時針向上旋轉時，會把海底的養分拉到表層，影響魚群的分佈。海浪因風而起，相對的，海洋孕育颱風，並滋養它茁壯。以2008重創緬甸的超強熱帶風暴納爾吉斯為例，在行經印度洋北部時，因為該區的暖水層比平常厚、溫度也較高，使得颶風獲得了源源不絕的能量，威力暴增。這份研究，是台大大氣科學系林依依教授與美國太空總署的共同觀查結果。海洋異常增溫的現象，可由衛星探測得知，此項技術將有助於未來災害的預報。

Two factors contribute to current sea level rise, and both are caused by global warming. The melting of continental ice sheets adds water to the oceans, and thermal expansion increases the volume of seawater. The combined effects of these factors threaten the coastal ecosystems first.

## Ocean-Climate Interactions

The ocean plays a vital role in regulating and stabilizing global climates, making a sustainable environment possible for all living beings. Crucial natural processes like water circulation and the exchange of energies take place in the ocean and the atmosphere. And ocean currents help maintain energy balance for the planet by bringing warm seawater from the vicinity of the Equator to high-latitude areas.

When typhoons swirl up counterclock- wise, they bring the nutrients of sea floors to the surface, affecting the distribution of fish species. Tropical cyclones are formed over and strengthened by the ocean. In the case of Cyclone Nargis, which ravaged Burma in 2008, the storm's sudden intensification came from the unusually heated and thickened layer of Indian Ocean's warm water, according to a study by NASA scientists and NTU Prof. I-i Lin. Since the abnormal heating of the ocean can be detected by satellites, Lin's discovery helps to improve the ability to forecast disastrous events in the future.




范光龍教授從1991年開始在基隆、宜蘭、台東、高雄等沿海地區監測潮位變化。10年間，台灣海平面平均升高0.32公分，其中基隆上升幅度最大 / 范光龍提供，朱立雯繪

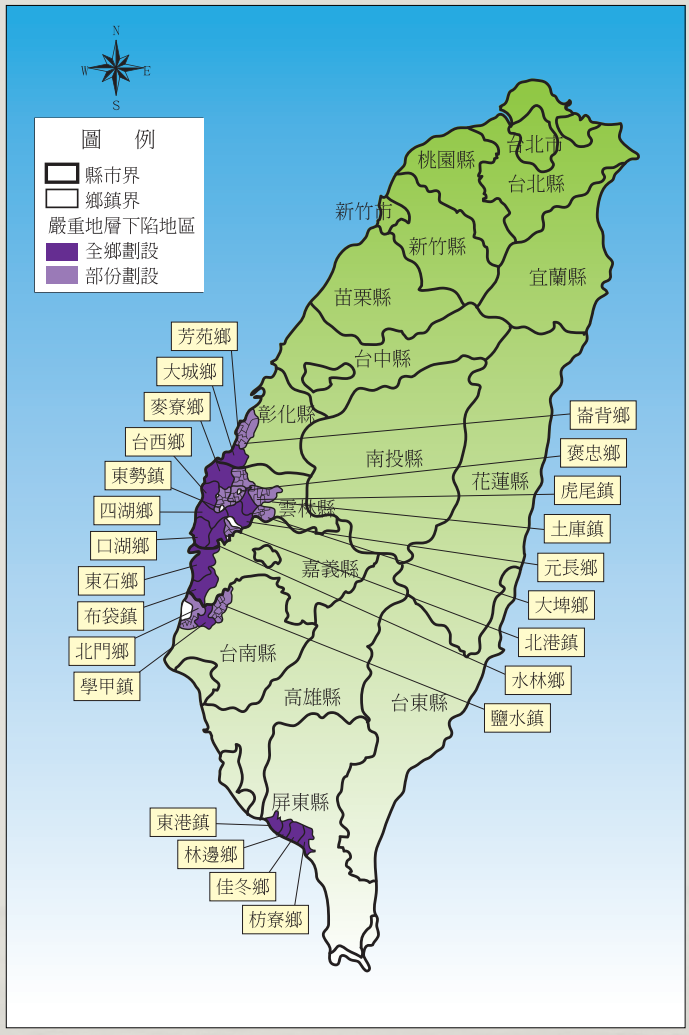
Prof. Kuang-lung Fan has been monitoring tidal levels in coastal cities like Keelung, Yilan, Taitung and Kaohsiung since 1991. For the decade, Taiwan's sea level has risen at an annual rate of 0.32 cm. The rising rate of the sea level in Keelung is the highest. /Provided by Prof. Kuang-lung Fan,(right)illustrated by Li-wen Zhu

今年3月，台灣則經歷了史上最強烈的沙塵暴侵襲。雖然有研究報導，沙塵暴所夾帶的微量元素（有機磷和有機氮），或許能提供海藻養分、加速海中生物生長。但范教授指出，對海洋的整體生態環境而言，沙塵暴仍是弊多於利。

確實，自然界的變化，好壞的影響並非絕對。范教授承認，地球暖化，讓一些長年被冰雪覆蓋的區域解凍，能源探採機會或可耕地面積因而增加，對像俄羅斯、加拿大這些高緯度國家，是有短暫的好處。然而，海平面上升，對人口主要集中在水岸的多數國家而言，衝擊將非常大。照這個趨勢下去，一些較小的島嶼，甚至面臨消失的命運。

In March, Taiwan was hit by the biggest sandstorm in history. Although sandstorms may have positive effects (the micronutrients they carry, such as organic phosphorus and organic nitrogen, can benefit the growth of marine life), overall they do more harm than good to marine ecosystems, according to Fan.

Of course nobody has the absolute standard to call certain natural changes “good” or others “bad.” Fan admitted that even global warming brings short term benefits to high-latitude nations like Russia and Canada by increasing arable land and mining opportunities. But for most countries whose coasts are densely populated, the impacts of global warming can be catastrophic. If the trend keeps going, some smaller islands may even disappear from the surface of the planet.




台灣地層下陷嚴重地區分佈圖 / 資料來源：經濟部水利署地層下陷防治資訊網，朱立雯繪

This is the map that indicates serious land subsidence areas in Taiwan.

// Reference:The website of Land Subsidence Prevention and Reclamation Data Network, Water Resource Agency, Ministry of Economic Affairs, illustrated by Li-wen Zhu

台灣的地形陡峭、地質鬆軟，河川含沙量高，水庫容易淤積，需要極大的維護成本，水庫壽命不長 / 范光龍提供

Existing reservoirs in Taiwan tend to suffer from sediment deposition due to steep landforms and soft soils. It is costly to maintain Taiwan's reservoirs and their life are short. /Photo provided by Prof. Kuang-lung Fan

整體而言，暖化對地球生態是個災難，層出不窮的極端氣候現象，和它脫離不了關係。許多水中生物對溫度變化非常敏感，只要升高攝氏1、2度就會受不了。魚類也許可往別處移動，但植物或其他固著生物卻跑不了。珊瑚的大量死亡就是最明顯的例子。而生物間是彼此依賴的，逃命的魚蝦若找不到相對應的棲地庇護，一樣難以生存。雖然，從長期演化的觀點來看，萬物慢慢會找到適應的方式，但若環境變異速度過快，很多物種在還來不及反應時，就已走上滅絕。

## 人類的反省

「所有生物環環相扣，一旦海洋環境改變，人類也將面臨不可預測的變化」，范光龍教授嚴肅的表示。然而，越來越多證據顯示，海洋與氣候平衡狀態的破壞者，就是人類自己。

雖然人類出現的歷史很短，造成的傷害卻很深。

Global warming, in general, is a disaster to Earth's ecosystems. It is responsible for the extreme climatic phenomena that keep emerging. Many marine species are highly sensitive to temperatures; an increase of one or two Celsius degrees may be more than they can tolerate. While fish can still relocate, immobile creatures have much fewer alternatives, as evidenced in the massive death of corals. But the escaping fish or crustaceans may still perish if they lose suitable habitats. Although life will ultimately find its way, a huge number of species may face extinction when the environments change too fast.

## The Lesson for Mankind

"All living creatures are interrelated. Once the marine environment changes, mankind will face unpredictable changes too," Fan warned. Ironically, mounting evidences show that the disturber of the balance between the climate and the ocean is mankind itself.

The history of mankind is short, but the damages it has caused are monstrous.

許多水中生物對溫度變化非常敏感，魚類也許還可往別處移動，然固定住的美麗珊瑚卻可能因面臨威脅而白化死亡 / 洪登富攝
Many marine species are highly sensitive to temperatures; fish can still relocate, but immobile corals may face the threats of bleaching or death. / by Deng-fu Hong

台灣沿海地區地層下陷、海水倒灌情形 / 范光龍提供
The picture shows the situation of land subsidence and seawater intrusion in Taiwan's coastal areas. /Photo provided by Prof. Kuang-lung Fan

氣候暖化主要成因於溫室效應趨強，即停留在大氣層內的二氧化碳太多，熱能無法散去，讓地球成為一個過熱的大溫室。人類大量使用石化燃料，則直接導致了二氧化碳的激增。此外，人類還任意砍伐森林，削減了樹木吸收二氧化碳的功能，讓問題雪上加霜。另有學者指出，過多的二氧化碳溶於水中，造成海水酸化，也會引發新的環境問題。

除了造成氣候暖化，對於海洋本身，人類也不夠珍惜愛護。漁民濫捕加上使用流刺網，造成漁群數量大幅下降。過度發展海運和海岸開發，也為海洋環境帶來深遠的衝擊。循環下來，人類終究會嚐到惡果。還先不論油污、垃圾造成的影響，范教授舉例，船隻為了防鏽、防生物附著，通常會使用含重金屬的化學塗料，這些物質溶入海水，累積在魚類體內。最後，我們可能無魚可吃，或是吃下去的魚，也是有毒的。

當然，從氣候與海洋的層面來檢討，還不夠，那只是當今地球環保問題的一部份。畢竟地球是一個相互鏈結的生態系統，要讓整個系統和諧的運行下去，人類要做出更全面、更深刻的反省。

## 共同打一場長期全面抗戰

如陸地上的水資源，就是另一個迫切的課題。對保水不易的台灣而言，更是個大挑戰。台灣由於地形陡峭、地質鬆軟，河川含沙量高，水庫因容易淤積而導致使用壽命不長；但繼續興建水庫又會破壞環境生態。而山坡地違法濫墾、砍樹造路，更讓大自然的水土保持功能受損。平地方面，則有超抽地下水的問題，導致地層下陷，讓彰化、雲林、嘉義等沿海低窪地區，面對海平面上升的威脅時，更加捉襟見肘。另一方面，為了追求經濟發展，西海岸面臨了大規模開發的壓力。范教授認為，在我們還沒有能力判斷、掌握個別的衝擊，並擬定因應對策時，這些海岸就著手進行開發，造成的傷害，很難彌補。

When too much carbon dioxide accumulates in the atmosphere, trapping more and more heat from the sun, Earth becomes an overheated greenhouse. Large consumption of fossil fuel results in enormous CO2 emission, and deforestation weakens Earth's ability to self-regulate. Scholars also point out that the acidification of the ocean, caused by excessive amounts of carbon dioxide dissolving in water, will bring new environmental problems.

Aside from triggering global warming, mankind is also guilty of ill treatment of the sea. Overfishing, coupled with the use of illegitimate fishing tools, has dramatically reduced fish populations. And serious pollutions are caused by overdevelopment of coastal areas and eco-threatening practices of marine transportation. Fan said that heavy-metal-laden chemicals are usually applied to cargo ships to fend off rust. And the toxic materials may eventually find their way to people's stomachs through the seafood they consume.

Yet it is not enough to discuss the issue merely from the viewpoint of climatic or marine impacts. They are, after all, just one part of Earth's current environmental woes. To keep the intricate ecosystems of this planet operating in a sustainable way, a more comprehensive approach is needed.

## A Long Battle Requiring Concerted Efforts

Conservation of water resources on land is particularly important and challenging for Taiwan. Existing reservoirs in the island tend to suffer from sediment deposition due to steep landforms and soft soils, but to build new ones are not environmentally viable.

Illegal logging and cultivation on the mountain sides only made the situation worse. Besides, land subsidence induced by groundwater extraction in plain areas has put coastal lowlands like Changhua, Yunlin and Chiayi vulnerable to the threats of sea level rise. Moreover, Taiwan's west coast is facing tremendous pressure for massive development out of economic concerns. Fan worries large-scale projects have jump started without a careful review of environmental impacts. And the consequent damages are hard to compensate for.

從政策的引導與教育，到每個人生活習慣的改變，都需要政府與民間共同投入 / 後壁湖警察小隊提供
Marine conservation requires changes in all aspects from governmental policies to each individual's daily habits. / Photo provided by Houbihu Police Squad

以上這些，不但和國家的水資源政策有關，也和長遠的國土規劃、國土保育有關，是因應氣候變遷的一環。為了台灣的永續生存與發展，「政府要拿出魄力來」，范教授語重心長的說。

歸根究柢，人的慾望與觀念首先需要調整。范教授表示，地球會變成這樣，主要就是人太多了。而當人類大肆開發、需求無度時，就會影響氣候與環境的平衡。因此，我們對資源的使用方式、都市生活與消費行為，都要節制，才能減輕地球的負擔。

氣候暖化，海平面上升。背後，是一場攸關地球萬物長居久安的生存之役。從政策的引導與教育，到每個人生活習慣的改變，都需要政府與民間共同投入。因為，這勢必是場全面而持續的抗戰。

The above discussion not only concerns Taiwan's policies on water resources, but involves the long term conservation outlook as well. For a sustainable future of this island, "the government must tackle these problems with determination," Fan emphasized.

The root of all the mess may still be the desires and misconceptions of mankind. Fan believes Earth's current problems starts with overpopulation, and when people overindulge their own cravings and ambitions, the balance between the climate and the environment suffers. Therefore, everyone must use the resources responsibly to lighten the burden on the planet.

Behind the warnings of global warming and sea level rise is a battle on which the survival and security of most existing species depend. It requires changes in all aspects from governmental policies to each individual's daily habits. No one can afford to stay out of it.

## 簡介 *Profile*


### 范光龍 Kuang-lung Fan

師範大學物理系畢業，台灣大學海洋研究所碩士，美國北卡羅來那州立大學地球科學系博士。專長為海洋環境、物理海洋學、海洋污染。曾任台灣大學海洋研究所所長、物理組教授，以及環保署環評委員。現為台灣大學海洋研究所兼任教授。

Professor Fan owns a Ph.D. in Earth Sciences from the University of North Carolina. He earned his M.S. from NTU's Institute of Oceanography (IO) and his B.A. from NTNU's Department of Physics. His research areas include marine environment, marine physics and marine pollution. A former member of EPA's Environmental Impact Assessment Committee, Fan is currently a part-time professor at IO, NTU, where he used to serve as director and full-time professor.