TAIWAN AREA MESOSCALE EXPERIMENT (TAMEX): POLITICAL TENSION AND DISASTER MITIGATION

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Abstract

Every May and June, Taiwan undergoes a period of potentially disastrous heavy rain called *mei-yu.* The rain system induced by *mei-yu* on May 28, 1981 caused significant damages to Taiwan, prompting government officials to initiate the Taiwan Area Mesoscale Experiment (TAMEX). TAMEX was carried out by Taiwanese and American meteorologists from 1983 to 1992. They collaborated and took measurements of the atmosphere over and near Taiwan. Japanese meteorologists also participated by providing data. The meteorologists aimed to improve heavy rain forecast accuracy by gaining a better understanding of the structure, formation, duration, and evolution of *mei-yu*. The project, however, faced political obstacles owing to Taiwan's unofficial diplomatic relations with Japan and the United States. This thesis investigates how political relations and scientific research influenced each other in the context of disaster mitigation. Even though Cold War politics prevented meteorologists from collaborating with each other formally, they constructed unofficial channels of exchanges. These exchanges were mostly justified scientifically and academically. In face of political obstacles, the pragmatic justification of disaster mitigation was also mobilized. This thesis thus argues that the need for disaster mitigation helps overcome political tension. Meteorologists collaborated informally to mitigate natural hazards during TAMEX. In the process, international networks were built and expanded. These resulted in further collaborations between the meteorologists, such as in the Constellation Observing System for Meteorology, Ionosphere, and Climate Program. The international contact established during TAMEX also was seized as opportunities for opening up

communication channels that developed into the normalization of relations between the Mainland Chinese and Taiwanese meteorologists.

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Introduction

Every year, Taiwan faces heavy rainfall from May to June. Such heavy rain results in disasters like flashfloods and landslides, leading to deaths and property loss.[1] This rain has a special term, *mei-yu* (梅雨), which literally translates from Chinese as "plum-rain" and brings "persistent heavy convective rainfall" to East Asia.[2] The heavy rainstorm on May 28, 1981 was especially damaging. On that day, a *mei-yu* front crossed Taiwan from the north and poured heavy rain on the Taoyuan, Hsinchu, and Miaoli counties with such intensity that it caused ten billion Taiwan dollars of damages, the equivalent of US$278 million.[3] Moreover, the Central Weather Bureau could not forecast *mei-yu*. It only received satellite images of rain clouds every three hours. These three hours were sufficient for a *mei-yu* front to form, cause damages, and dissipate.[4] The scope of damages caused by *mei-yu* underscored the importance and urgency for further meteorological research on the mechanisms of heavy precipitation in Taiwan.

In addition to the May 28th, or as the Taiwanese call it, the "528" disaster, other *mei-yu* induced rain systems had also caused significant damages in Taiwan. For example, in May 1983, another front resulted in flash floods in the Nantou

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[1] Koung-ying Liu and Mu-cun Lu, "Kongjun yu Taiwandiqu zhongchidu shixianjihua ji huigu" 空軍與臺灣地區中尺度實驗計畫之回顧 [A Review of the Air Force and the Taiwan Area Mesoscale Experiment], *Journal of the Meteorological Society of the Republic of China (MSROC)* vol. 49 (2008): 22.

[2] "Mei-yu front - AMS Glossary", American Meteorological Society, last modified April 25, 2012, accessed November 23, 2016, http://glossary.ametsoc.org/wiki/Mei-yu_front.

[3] Tai-jen Chen, "Women yiqi zuole yijian gezuo de shi: TAMEX zhi huigu yu zhanwang" 我們一起做了一件該做的事: TAMEX 之回顧與展望 [Together We Did Something We Should: TAMEX's Review and Outlook], *Journal of the MSROC* vol. 49 (2008): 9; "Taiwanese Dollar _ 1979-2017 _ Data _ Chart _ Calendar _ Forecast _ News", Trading Economics, last modified 2017, accessed March 23, 2017, http://www.tradingeconomics.com/taiwan/currency.

[4] George Tai-jen Chen, interview with Phoebe Tang, online personal interview, January 13, 2017.

county. On 3 June 1984, a similar *mei-yu* front and the subsequent flooding took thirty-two lives. What made the *mei-yu* fronts dangerous were their severity and unpredictability. Each front could bring three hundred millimeters (almost one foot) of rain per day.[5] Importantly, the existing weather forecast system was not able to predict *mei-yu,* nor record its formation and evolution. For example, during the "528" rainstorm the Central Weather Bureau did not release any warnings of heavy rain prior to the *mei-yu*'s arrival.[6]

To improve heavy rain forecast capability, the Taiwanese meteorologists thus decided to conduct a large scale weather measurement project called the Taiwan Area Mesoscale Experiment (TAMEX). TAMEX was a meteorological field experiment from 1983 to 1992. It was conducted by Taiwanese and American meteorologists, while Japanese meteorologists also participated by providing data. The scientific objectives of TAMEX were to understand the generation, structure, and dynamics of mesoscale convective systems (MCS) along the *mei-yu* front.[7] Mesoscale refers to the weather events spanning "a few to several thousand kilometers." Some of these phenomena include "thunder storms, squall lines, fronts, precipitation bands," cyclones, sea breeze, land breeze, and mountain waves, in this

[5] Central Daily News, "Meiyu zhaocheng zaihai lilizaimu neng zhangwu dungxiang jiuneng bupa ta" 梅雨造成災害歷歷在目 能掌握動向就能不怕它[The Memory of the Damages from Mei-Yu is Still Vivid, We Wouldn't be Afraid of it When We Understand it's Movements], November 10, 1986, in Tai-jen Chen, *Scientific Management of Taiwan Area Mesoscale Experiment*, National Science Council Science and Technology of Disaster Prevention Program Technical Report 76-26 (National Science Council: 1987), 22.

[6] Chen, interview.

[7] ROC-America Cooperation Planning Group, *TAMEX: Taiwan Area Mesoscale Experiment Operations Plan* (Taipei: National Science Council, 1987), 5.

case how the Central Mountain Range of Taiwan affected atmospheric air flow.[8] In the early 1980s, meteorologists already knew that mesoscale convective systems appeared at the *mei-yu* front, and that their interaction with the mountains of Taiwan resulted in heavy precipitation. Low-level jets, i.e. strong winds near the earth's surface, were also observed near the front. While meteorologists understood the correlations between the presence of these weather systems and heavy rain, they did not know much about their structure, formation, duration, and evolution. Accordingly, TAMEX aimed to measure such weather systems, including the *mei-yu* front, low-level jets, mesoscale convective systems, and low pressure areas and fronts induced by topography. Through the data collected, meteorologists hoped to find out how these systems developed and interacted with each other, especially how the *mei-yu* front was created, intensified, and sustained.[9]

Cold War Context

TAMEX was carried out in the background of Cold War tensions that began after the Second World War. After the Japanese were defeated in China in 1945, China's Communist Party and Nationalist Party fought a four-year civil war. The Nationalist Party lost and fled to Taiwan, while the Communist Party became the ruling power of Mainland China. At the time, both the United States and the Soviet

[8] "Mesoscale - AMS Glossary", American Meteorological Society, last modified April 25, 2012, accessed January 11, 2017, http://glossary.ametsoc.org/wiki/Mesoscale.

[9] "NOAA's National Weather Service - Glossary", National Weather Service, National Oceanic and Atmospheric Administration, accessed March 20, 2017. http://forecast.weather.gov/glossary.php?word=low%20level%20jet; Ying-hwa Kuo and Tai-jen Chen, "The Taiwan Area Mesoscale Experiment (TAMEX): An Overview", *Bulletin American Meteorological Society* vol. 71, no. 4 (April 1990): 488-491, 497-500; Tai-jen Chen, *Scientific Management of Taiwan Area Mesoscale Experiment*, National Science Council Science and Technology of Disaster Prevention Program Technical Report 76-26 (National Science Council: 1987), 1, 3, 6, 16.

Union wanted to expand their influence, and divided the world into two blocs. Since Communist China belonged to the Soviet bloc, the United States did not recognize it as the ruling power of China, but instead recognized the Nationalist Party that was ruling Taiwan. Japan, being part of the Western bloc, followed American policies. However, in the 1960s, the Americans began to look for alternative ways to break up the Communist bloc. One strategy was to befriend Communist countries, including the mainland People's Republic of China (PRC). In 1971 and 1972, United States and the PRC exchanged visits and established official relations, which contributed to the PRC's entry into the United Nations. Normalization of relations with the PRC, however, entailed cutting off official relations with Taiwan.[10] After the US established diplomatic relations with the PRC, Japan followed suit, establishing formal diplomatic relations with the People's Republic of China, and breaking formal ties with Taiwan in 1972. Exchanges between Japan and Taiwan became non-governmental.[11] Moreover, Taiwan was no longer represented in most international organizations, including the United Nations and the World Meteorological Organization.[12] At the founding of the World Meteorological Organization in 1950, the Americans had wanted to confine membership to sovereign states recognized by the United Nations. The People's Republic of China, colonies, and many Soviet satellite states therefore were not able to join formally. They could become

[10] "Milestones_ 1969–1976 - Office of the Historian", Office of the Historian, Bureau of Public Affairs, United States Department of State, accessed April 1, 2017. https://history.state.gov/milestones/1969-1976/rapprochement-china

[11] "Taiwan kiso deita ｜ gaimushou" 台湾基礎データ ｜ 外務省 [Basic Data of Taiwan, Ministry of Foreign Affairs], Ministry of Foreign Affairs of Japan, accessed March 3, 2017, http://www.mofa.go.jp/mofaj/area/taiwan/data.html

[12] Vincent Wei-cheng Wang, "Taiwan's participation in international organizations", in Edward Friedman ed., *China's rise, Taiwan's dilemmas and international peace* (London; New York: Routledge, 2006), 167.

observers but they held secondary status.[13] In this context, Taiwan was rejected from the World Meteorological Organization when it lost its United Nations membership. In the 1980s, Taiwan's international relations were still affected by its unofficial status and the Cold War politics.

This thesis investigates how political relations and scientific research influenced each other in the context of disaster mitigation. Using TAMEX as the example, it explores what concrete difficulties were met when scientific collaborations were carried out during times of political tensions and between nations without formal political ties, and discusses how these difficulties were solved. This thesis argues that when Cold War politics prevented meteorologists from collaborating with each other, they constructed unofficial channels of exchanges. At times, these exchanges were supported with scientific and academic justifications, but in face of political obstacles, practical justifications, namely disaster mitigation, were mobilized. The thesis therefore also argues that the need for disaster mitigation helped overcome political tension. While TAMEX might be born out of the desire to mitigate disasters, it also resulted in the building and expansion of international networks. Disaster mitigation was first a pretext for scientific exchanges, then opened up opportunities for consolidation and normalization of relations.

The thesis touches on three themes: history of meteorology, disasters studies, and international scientific collaboration. Most current studies on

[13] Paul Edwards, "Meteorology as Infrastructural Globalism" in John Krige and Kai-Henrik Barth ed. *Global Power Knowledge*, *Osiris* vol. 21 (Chicago, Ill.: University of Chicago Press, 2006), 236-7.

meteorological history focuses on the origin of meteorology in the West.[14] There are numerous publications about Taiwanese meteorological history. They discussed the research, education, and infrastructure set up by the Japanese in the first half of the twentieth century, as well as subsequent development when the Nationalist government took over the institutions.[15] This thesis will continue the timeline, with a focus on TAMEX, the major meteorological project in Taiwan in the 1980s.

The disasters studies literature has approached disaster management from various perspectives. In *Disaster Experts,* Scott Knowles took the historical perspective and discussed the roles and actions of disaster experts in the United States. He argued that risk management and the attempt to reduce vulnerability often ended up in tension, as the policies crossed jurisdictional boundaries. The book mostly discussed the forming and implementation of disaster management policies, while calling for policymakers to pay more attention to local knowledge

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[14] For examples see: James Fleming, *Meteorology in America, 1800-1870* (Baltimore: Johns Hopkins University Press, 1990)*;* James Fleming, *Inventing atmospheric science: Bjerknes, Rossby, Wexler, and the Foundations of Modern Meteorology* (Cambridge, Massachusetts : The MIT Press, 2016) *;* Robert Friedman, *Appropriating the Weather: Vilhelm Bjerknes and the Construction of a Modern Meteorology* (Ithaca, N.Y.: Cornell University Press, 1989); and Paul N. Edwards*, A Vast Machine: Computer Models, Climate Data, and the Politics Of Global Warming* (Cambridge, Mass.: MIT Press, 2010).

[15] Ming-de Zhou, "Taiwan Qixiang Shiye zhi zhaoshi" 臺灣氣象事業之肇始 [The Origin of Taiwan Meteorological Work], *Folkways,* 41.2 (1991): 17-32; Zhou-min Liu, *Zhonghua qixiangxue shi* 中華氣象學史 *[The History of Chinese Meteorology]* (Taiwan: Commercial Press Taiwan, 2011); Shih-Yeoung Tang, "Zhanhouchuqi taiwansheng qixiangju de sheli yue chongzu" 戰後初期台灣省氣象局的設立與重組 [The Founding and Restructuring of Taiwan Weather Bureau during the Early Post-War Period], *Folkways,* 43.4 (1993): 13-34; Masumi Zaiki and Togo Tsukahara. "Meteorology on the Southern Frontier of Japan's Empire: Ogasawara Kazuo at Taihoku Imperial University", *East Asian Science, Technology and Society* (2007) 1: 183-203; Chih-wen Hung, *Taiwan qixiang zhuanqi* 台灣氣象傳奇 [*The History of Meteorological Observatories in Taiwan*] (Taiwan: Tipi Press, 2007); Chih-wen Hung, "Taiwan qixiang xueshumailuo de jiangou duanlie yue chongsheng: cong zhanqian taibeidida qixiangxue jiangzuo dao zhanhou daixue qixiangkexi de dansheng" 台灣氣象學術脈絡的建構、斷裂與重生：從戰前台北帝大氣象學講座到戰後大學氣象科系的誕生 [The Building, Breaking, and Rebirth of Taiwan Meteorology's Academic Network: From Pre-War Taihoku Imperial University's Meteorology Lecture to the birth of the University's Department of Atmospheric Sciences], *Journal of the MSROC,* vol. 54 (2013): 2-24.

and concerns.[16] Another type of disaster studies literature is more theoretical. For example, in *Mapping Vulnerability*, the concept of vulnerability and its relationship with disaster management was approached analytically, and supported by case studies.[17] Another example is *Measuring Vulnerability to Natural Hazards*, which similarly targeted policymakers and suggested strategies for large scale policies for assessing and reducing vulnerability and risk.[18] Some literature takes a slightly different approach by being more specific. *Environmental Hazards* first discussed the hazard, risk, and disaster management theoretically, then explained in detail the hazards and vulnerability reduction strategies for a list of nine hazards, including earthquakes, volcanoes, and floods.[19] This thesis does not focus on policies, but instead contributes by taking TAMEX as a case study to illustrate how experts conducted disasters research even when they lacked formal institutions to support their work.

In terms of international cooperation, much has been written with a focus on the West and little had been written on meteorology in the Cold War context in East Asia. There exists research on the establishment of formal meteorological organizations that coordinate scientists from around the world. For example, the *Osiris* volume *Global Power Knowledge* featured chapters that discussed scientific

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[16] Scott Gabriel Knowles, *The Disaster Experts: Mastering Risk in Modern America* (Philadelphia: University of Pennsylvania Press, Inc., 2012).

[17] Greg Bankoff, Georg Frerks, and Dorothea Hilhorst eds., *Mapping Vulnerability: Disasters, Development and People* (London; Sterling, VA: Earthscan Publications: 2004).

[18] Jörn Birkmann ed., *Measuring Vulnerability to Natural Hazards: Towards Disaster Resilient Societies* (New York: United Nations University, 2006); see also Rasmus Dahlberg, Oliver Rubin, and Morten Thanning Vendelø eds., *Disaster Research: Multidisciplinary and International Perspectives* (Abingdon, Oxon: Routledge, 2016).

[19] Keith Smith, *Environmental Hazards: Assessing Risk and Reducing Disaster* (London; New York: Routledge, 2001).

cooperation in various fields, such as nuclear physics and glacier motion. In the volume, Paul Edwards discussed how the need for international measurement standards led to the establishment of intergovernmental meteorological organizations.[20] This thesis contributes to the scientific international cooperation literature by exploring the topic in the Cold War in the East Asian context.

The first chapter sets the scientific and political background for TAMEX. It discusses the relevant meteorological work done by the Japanese, American, and Taiwanese meteorologists during the twentieth century before TAMEX. On the one hand, the meteorological research was carried out to satisfy scientific curiosities. On the other hand, the results of this research also were answers to pragmatic problems. Chapter two explains the course of TAMEX and argues that the pragmatic justifications for TAMEX became paramount to overcoming political obstacles that threatened to derail the whole project. Scientists collaborated to mitigate natural hazards and in the process, international connections were also established. The third chapter describes the direct and possible implications of TAMEX. The experiment resulted in better understanding of the *mei-yu* front and sped up the computerization of weather forecasts. Concurrently, it also increased Taiwan's international exposure, created more opportunities for collaboration, and possibly triggered communications that led to the normalization of relations between Taiwanese and mainland Chinese meteorologists.

[20] Paul Edwards, "Meteorology as Infrastructural Globalism": 229-250; John Krige and Kai-Henrik Barth eds. *Global Power Knowledge*, *Osiris* vol. 21 (Chicago, Ill.: University of Chicago Press, 2006).

Chapter 1: Efforts to understand heavy rain before TAMEX

Heavy rain has always been a concern for citizens, meteorologists, and government officials alike. Before the Second World War, Japanese meteorologists had already been researching the trends and effects of heavy rain in Taiwan. After the war, the Taiwanese meteorologists continued to work on understanding this natural phenomenon capable of bringing large scale death and damage. In the United States, meteorologists had been studying the formation and structure of heavy rain. This chapter provides the background of research relevant to the Taiwan Area Mesoscale Experiment (TAMEX) by discussing the work done by Japanese, Taiwanese, and American meteorologists on heavy rain in the twentieth century. It argues that even before TAMEX, research on understanding precipitation patterns was already a significant aspect of meteorological work, and at times was motivated by pragmatic justifications.

Japanese research on *mei-yu/tsuyu*

From 1894 to 1895, China and Japan fought the First Sino-Japanese War over influence in Korea. Korea was then a tribute state of China. While China's military was poorly disciplined and managed, the Japanese army and navy were recently modernized according to German and British advice. Japan quickly won the war, occupied Korea and parts of China, and was advancing towards the Chinese capital

Peking.[21] The Qing imperial government of China thus negotiated with the Japanese government and signed the Treaty of Shimonoseki. Among other demands, the Treaty dictated that China had to pay an indemnity, recognize Korea as an independent state, and cede Taiwan to Japan.[22] In 1895, Taiwan thus became a Japanese colony and part of the Japanese empire.

Japan occupied Taiwan from 1895 until the end of the Second World War in 1945. When Japan took over Taiwan, despite not having fought nor lost any wars against the western powers, it was suffering from the unequal treaties forced upon it. In the 1850s, before the Meiji restoration, the Tokugawa government was in power and signed treaties with Britain, the Netherlands, Russia, France, and the United States. With the exception of indemnity and land ceding, the treaties' demands were similar with the ones in the Treaty of Shimonoseki. Japan had to provide low customs rates, and allow foreigners to freely trade and establish settlements at designated ports. In addition, the extraterritoriality clause also dictated that foreigners did not have to follow Japanese laws.[23] This entailed that Japan did not have full jurisdiction on its own soil. After the Meiji Restoration in 1868 when the emperor was restored and given actual power, the Japanese government attempted to revise the treaties terms, but made little progress.[24] At the turn of the century, Japan desired to build up a colonial empire to improve its international standing.

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[21] William G. Beasley, *The Rise of Modern Japan*, 3rd ed. (New York, N.Y.: St. Martin's Press, 2000), 146.

[22] The Treaty of Shimonoseki. China-Japan, April 17, 1895. http://usmgtcgov.tw/forum/topics/6473745:Topic:10403

[23] Beasley, *The Rise of Modern Japan*, 28-34.

[24] *Ibid.,* 142-143.

In this colonial context, meteorological work in Japanese Taiwan was geared towards the aim of consolidating and expanding the Japanese empire. Much of this work was done at the Taihoku Imperial University, which was founded in 1928 and renamed the National Taiwan University after the Second World War.[25] Historians Masumi Zaiki and Togo Tsukahara have discussed the meteorological work conducted at the Taihoku Imperial University during the Japanese rule. They argue that the Japanese meteorologists studied the climate of Taiwan with an imperial agenda and their work was pragmatic. Japan aimed to catch up with the work of western nations by focusing on research relevant to colonial development.[26] For example, in 1929, Katsuyoshi Shiratori and Motoichi Morinaga published about the relationship between climate and rice production in Taiwan. The study focused on the rice crop yield in Taihoku, Taichu, and Tainan, the "three main localities" of Taiwan. The yield data collected was compared with the air pressure, temperature, and precipitation levels measured by the meteorological observatories at these three places. Shiratori and Morinaga then compared these results with other climates around the world to look for further correlations between climate and rice yield.[27] In 1940, Kazuo Ogasahara attempted to study the "necessary conditions" for heavy precipitation in Taiwan, so as to improve forecast capability. The study successfully summarized Taiwan's precipitation data from 1930 to 1939. However, before Ogasahara could determine the conditions for heavy rain, he needed high

[25] E. Patricia Tsurumi, "Colonial Education in Korean and Taiwan," in *The Japanese Colonial Empire*, *1895-1945,* Ramon H. Myers, and Mark R. Peattie eds. (Princeton, N.J.: Princeton University Press: 1984), 290-292.

[26] Masumi Zaiki and Togo Tsukahara, "Meteorology on the Southern Frontier of Japan's Empire": 183-203.

[27] Katsuyoshi Shiratori and Motoichi Morinaga, "Formosa rice crops and weather conditions", *Journal of the Society of Tropical Agriculture* vol. 1, no. 1 (1929): 65-78.

altitude weather data, which he did not possess. He therefore called for further studies in the future when such data became available.[28] Japanese meteorological work in Taiwan ended after the Second World War when Japan was defeated and had to give up its Taiwan colony. Most Japanese living in Taiwan, including meteorologists, were sent back to Japan. The observations stations they built and the instruments inside that remained in Taiwan were taken over by the Chinese Nationalist government.[29]

Half a century later in the 1980s, the Japanese meteorologists who originally worked in Taiwan were no longer active, yet Japan's meteorological work remained relevant to Taiwan. During the two decades after the Second World War, Japan accumulated experience in conducting large scale meteorological field programs, from which Taiwanese meteorologists could learn. As early as 1968 to 1972, Japan had already organized a large scale study on heavy rain involving seven hundred participants. In 1974 to 1975, Japan again carried out a large scale project called the Air-Mass Transformation Experiment (AMTEX).[30] AMTEX was part of the international Global Atmospheric Research Program (GARP), organized by the International Meteorological Organization and the International Council of Scientific

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[28] Kazuo Ogasahara, "Outlines of Formosan Frontology I.: On the Mechanism of Formation of Summer Squall in the Southwest Plain Region of Formosa. - Some Important Necessary Conditions of the Formation of Heavy Rainfall", *Journal of the Society of Tropical Agriculture* vol. 12, no. 1 (1940): 57-70.

[29] Su-ying Ou, *Chuangcheng yu Chuangxin: Zhanhouchuqi Taiwandaxue de zaichufa (1945-1950)* 傳承與創新: 戰後初期臺灣大學的再出發 (1945-1950) [Inheritance and Innovation: National Taiwan University's Re-Beginning during the Early Post-war Period] (Taipei: Wu-Nan Culture Enterprise, 2006), 43-96; Chih-wen Hung, *The History of Meteorological Observatories in Taiwan*, 32-35.

[30] Tai-jen Chen, Tsung-yao Wu, Long-nan Chang and Ko-kung Chu, "'juliequyusheng haoyuguance yu fenxieshixianjihua'" guihwaxiaozu meiri kaochafangwen baogao"「劇烈區域性豪雨觀測與分析實驗計劃」規劃小組美日考察訪問報告 [Report on visit to the United States and Japan for Planning of "Severe Regional Heavy Rainfall Observation and Forecast Experiment"], *Science Development*, vol. 13, no. 5 (May 1985): 553-554.

Unions. Using data collected by sub-projects from around the world, such as AMTEX, GARP aimed to improve weather models and to design an "observing system for routine numerical weather prediction."[31] Working with American and Australian meteorologists, the Japanese conducted a field program over the ocean southwest of Japan. The objectives of AMTEX were to understand the movement of heat and water vapor near the earth's surface, and to learn how the heat from the ocean interacted with the atmosphere. Using instruments like weather satellites, ships, tethered weather balloons, and airplanes, the meteorologists measured such parameters as temperature, humidity, crystallization, precipitation, salinity of the ocean, and electrical charge of the clouds.[32]

In addition to having experience in conducting large-scale meteorological programs, Japan had also been studying *mei-yu* (or *tsuyu* in Japanese) since the late 19th century. *Mei-yu* not only affected Taiwan, but also extended towards the East Asia region, including China and Japan. In 1894, there was already mention of *tsuyu* in Japanese meteorological publications. Baba Nobumichi theorized that when the easterly movement of a low pressure area was hindered, a long *tsuyu* period would occur. During the early twentieth century, Japanese meteorologists used existing data to theorize the characteristics and contributing factors of *tsuyu*. Thus, even

[31] "Global Atmospheric Research Program/First Garp Global Experiment (GARP/FGGE)", Global Change Master Directory, NASA, accessed July 20, 2017, https://gcmd.nasa.gov/KeywordSearch/Supplementals.do?Portal=NASA&KeywordPath=Projects%7CG+-+I&NumericId=6291&MetadataType=0&lbnode=mdlb2

[32] Japan National Committee for GARP, "Nansei shotou kaiiki ni okeru kidan henshitsu ni kansuru tokubetsu kansoku keikaku: AMTEX" 南西諸島海域における気団変質に関する特別観測計画: AMTEX [The Programme of Air-mass Transformation Experiment (AMTEX) in the Area of the Nansei Islands: AMTEX], *Tenki* vol. 18, no. 2 (February 1971): 75-80; D. H. Lenschow and E. M. Agee, "1974: The Air Mass Transformation Experiment (AMTEX): Preliminary Results from 1974 and Plans for 1975", *Bulletin of American Meteorological Society* vol. 55, no. 36 (October 1974): 1228-1230.

when large-scale studies had not yet been done, Japanese meteorologists were already familiar with the idea of *tsuyu.*[33] After the Second World War, the Japanese meteorologists' interest in this weather phenomenon persisted. For example, in 1965 Masatoshi Yoshino studied the position and precipitation distributions of the *tsuyu* front.[34] The Japanese government too was involved in the study of *tsuyu*. From 1951, the Japan Meteorological Agency started publishing their prediction on when *tsuyu* would begin and end.[35]

From the late nineteenth century, Japan had a vested interest in Taiwan's meteorological research. Japanese meteorologists had studied the causes and mechanism of Taiwan's heavy rain. Since *mei-yu* was also a significant weather phenomenon in Japan, the Japanese meteorologists would both benefit from, and were capable of aiding *mei-yu* research in Taiwan. These research efforts laid the groundwork for the scientific collaboration during TAMEX. The next chapter will show that even though the Japanese researchers were eager to help with TAMEX, they could not participate directly because of political obstacles.

American work on mesoscale measurements

Americans too were experienced in the research methodology that would be useful for achieving the Taiwanese meteorologists' goal for TAMEX —

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[33] Kozo Ninomiya, "1900-1930 nendai no tsuyu no chousa kenkyuushi" 1900-1930 年代の梅雨の調査研究史 [The History of tsuyu research from 1900 to 1930s], *Tenki* vol. 62, no. 4 (April 2015): 307-311.

[34] Masatoshi M. Yoshino, "Frontal Zones and Precipitation Distribution in the Rainy Season over East Asia", *Geographical Review of Japan* vol. 38, no. 1 (1965): 14-28.

[35] The Tokyo Marine Research Institute, "Tsuyu nitsuite" 梅雨について [About tsuyu], *TMRI Express* vol. 3, no. 2 (July 8, 2013), http://www.tmresearch.co.jp/express/wp-content/uploads/sites/2/2014/05/20130709_TMRIE3-2.pdf.

measurements of mesoscale weather events. Americans had been working on mesoscale measurements since the mid-1970s. From 1979 to 1981, the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), and the National Science Foundation led the Severe Environmental Storms and Mesoscale Experiment (SESAME). The objective of SESAME was to combine radar images, surface measurements, and satellite images to obtain a more complete picture of how severe thunderstorms formed. The National Weather Service and the National Environmental Satellite Service joined by providing data support. Institutions that later participated in TAMEX were also involved in SESAME. For example, the Atmospheric Technology Division of National Center for Atmospheric Research (NCAR) was responsible for the radar network of SESAME. It operated the aircraft, radar, and surface weather stations. Moreover, meteorologists from universities that were part of the University Corporation for Atmospheric Research received funding from the National Science Foundation to carry out research on the SESAME data.[36] One of the findings of SESAME was that the Loran-C and Doppler Radar systems were most appropriate for mesoscale weather measurements.[37] Such knowledge became useful for TAMEX, which extensive used Doppler Radar for weather measurements. The experience these

[36] "AVE/SESAME: Atmospheric Variability Experiment/Severe Environmental Storms and Mesoscale Experiment," The Schwerdtfeger Library, Space Science & Engineering Center, University of Wisconsin-Madison, last modified July 1, 2010, accessed July 20, 2017, http://library.ssec.wisc.edu/instrumentation/AVESESAME.html; National Oceanic and Atmospheric Administration, Environmental Research Laboratories, *Project Severe Environmental Storm and Mesoscale Experiment* (Boulder, Colorado: 1976), p. 32, http://library.ssec.wisc.edu/instrumentation/Documents/AVESESAME/AVESESAMEdevelopment_.pdf.

[37] Darryl Randerson, "Conference Summary: First Conference on Regional and Mesoscale Modeling, Analysis, and Prediction," *Bulletin American Meteorological Society*, vol. 56, no. 10 (October 1975): 1094.

institutions and meteorologists accumulated contributed to TAMEX when they joined it.

The United States had also already carried out international mesoscale measurements in the 1970s. In 1974, American meteorologists organized the Global Atlantic Tropical Experiment (GATE). Like AMTEX, it was part of the Global Atmospheric Research Program. GATE aimed to increase weather forecasts to over two weeks by improving meteorologists' understanding of the atmosphere.[38] It was carried out from 15 June to 23 September in 1974 over the tropical area of the Atlantic Ocean. The Experiment utilized almost a thousand land stations, thirty-nine ships, weather balloons, conventional radars, thirteen aircrafts, and a geostationery satellite. They measured air temperature, humidity, wind speed, air pressure, precipitation, and radiation as well as the temperature, salinity, and currents of the ocean. There were altogether three rounds of measurements, each involving a twenty-day Observation Phase, followed by a ten-day adjustment period during which meteorologists made adjustments to the measurement practices.[39]

GATE consisted of five sub-programs, including the Convection Subprogram, which studied the area in the mesoscale. One objective of this subprogram was to understand the formation, evolution, and dissipation of cloud clusters, as well as

[38] "History of the GARP Atlantic Tropical Experiment," American Meteorological Society, last modified 1998, accessed July 20, 2017, http://www.ametsoc.org/sloan/gate/; "Who's Who in GATE," American Meteorological Society, last modified 1998, accessed July 20, 2017, http://www.ametsoc.org/sloan/gate/shererfiles/before.html; "Gate Timeline," American Meteorological Society, last modified 1998, accessed July 20, 2017, http://www.ametsoc.org/sloan/gate/gatetimeline.html.

[39] "Gate - Earth Observing Laboratory," Earth Observing Laboratory, University Corporation for Atmospheric Research, last modified 2017, accessed July 20, 2017, https://www.eol.ucar.edu/field_projects/gate; R.J. Polavarapu and G.L. Austin, "A Review of the GARP Atlantic Tropical Experiment (GATE)", *Atmosphere-Ocean* vol. 17, no. 1 (1979): 4-5.

mesoscale convection (how heat is transferred). The experiment was an international collaboration. Fourteen meteorological and atmospheric science university departments as well as official meteorological agencies from Canada, France, Mexico, West Germany, the United Kingdom, and the Soviet Union were among the participants. The United States, however, took up the largest share. Twenty-two universities, NCAR, NOAA, and NASA's Goddard Space Flight Center were involved in the program. In terms of individuals, Edward Zipser, who later participated in TAMEX, was one of the key GATE participants. Specifically, he used the GATE data to study cloud clusters' internal structure.[40] With such experience in large-scale international collaboration for the study of mesoscale weather systems, America demonstrated its capability in organizing and leading mesoscale meteorological studies. This capability became useful for when Taiwan asked America for assistance in TAMEX.

Moreover, in the 1980s, American meteorologists were planning for a program similar to TAMEX — STORM: Stormscale Operational and Research Meteorology. It studied the formation and development of the mesoscale convective system and aimed at improving heavy rainfall forecasts. From May to June 1985, America carried out the Preliminary Regional Experiment for STORM (Pre-STORM), a trial run that aimed to test the instruments and techniques that would be used in the major experiment. Specifically, it utilized and tested the networks of radars, wind profilers, upper-air measurement, surface measurement, a Lightning Location System, and an Aircraft Program that consisted of the P-3 airplane later used in

[40] David R. Rodenhuis, "The Convention Subprogram", *Bulletin American Meteorological Society* vol. 55, no. 7, (July 1974): 724, 729, 730.

TAMEX. Pre-STORM also evaluated the measurement strategies to ensure that the procedures in STORM were well coordinated.[41]

The rationales behind these experiments were explained in a 1975 meeting. The American Meteorological Society organized a conference on "regional and mesoscale modeling, analysis, and prediction," the first one focusing on mesoscale measurements. Meteorologists reported about the mesoscale experiments they had been conducting, including Japan's AMTEX. On the one hand, meteorologists laid out scientific justifications. Dr. William H. Klein, Director of the Systems Development Office of the National Weather Service of the National Oceanic and Atmospheric Administration (NOAA), argued that mesoscale meteorology should no longer be neglected because the mesoscale influenced the larger synoptic scale and smaller micro-scale weather events. In addition, many weather phenomena, such as severe weather and thunderstorms, could not be forecast using information from only synoptic and micro-scales. On the other hand, the experiments were conducted to satisfy socioeconomic needs. The participants agreed that more work had to be done for satisfying "national needs" that required higher forecasting accuracy, such as in the areas of agriculture, forestry, and marine operations.[42]

Taiwan's meteorological research prior to TAMEX

In the first half of the twentieth century, Japanese colonial government built

[41] University Corporation for Atmospheric Research, "PRESTORM | Earth Observing Laboratory", last modified 2016, accessed December 20, 2016. https://www.eol.ucar.edu/field_projects/prestorm; John Cunning, "The Oklahoma-Kansas Preliminary Regional Experiment for STORM-Central", *Bulletin of the American Meteorological Society* vol. 67, no. 12 (December 1986): 1478.

[42] Darryl Randerson, "Conference summary: First Conference on Regional and Mesoscale Modeling, Analysis, and Prediction", 1094-1103.

weather stations and carried out meteorological research in Taiwan. However, after the Second World War, Taiwan's meteorological field was not well supported as politics got in the way of scientific research. After the Japanese were defeated in 1945, a civil war broke out between the Nationalist Party and the Communist Party in China. In 1949, when the Communists defeated the Nationalist Party, they fled to Taiwan.[43] Many meteorologists, however, did not follow the Nationalists and chose to stay in Communist Mainland China. One of them was Chu Co-ching, the Director of the Chinese Meteorological Research Institute from 1927 to 1936, and also the director of the Meteorological Society.[44]

Without most of the experienced meteorologists and even the leading figure, for two decades Taiwan's meteorological teaching, operation, and development revolved around two meteorologists: Liu Yen-huai and Chiang Ping-jan.[45] Liu obtained a doctoral degree in Germany in 1934 in Atmospheric and Earth Sciences.[46] He then returned to China and taught aviation meteorology at the Central Aviation School, where many air force cadets attended. After several renamings and mergers, the school became part of the air force. When the Nationalist government went to Taiwan, Liu followed. The air force was thus one of the hubs in Taiwan for learning meteorology.[47] Outside of the air force, Chiang Ping-

[43] Nancy Bernkopf Tucker, *Strait Talk: United States-Taiwan Relations and the Crisis with China* (Cambridge Mass.; London, England: Harvard University Press, 2009), 13-17.

[44] Chih-wen Hung, "The Building, Breaking, and Rebirth of Taiwan Meteorology's Academic Network", *Journal of the MSROC* vol. 54 (2013): 9-10.

[45] *Ibid.,* 10-16.

[46] Yen-huai Liu, "Wo fuying qixiangxue wushiwu nian (1927-1982)" 我服膺氣象學五十五年 (1927-1982) [My Devotion to Meteorology in the Past Fifty-Five Years (1927-1982)], *Atmospheric Science,* vol. 10, no. 1 (1983): 3-4.

[47] Hung, "The Building, Breaking, and Rebirth of Taiwan Meteorology's Academic Network", 14-16; Ying-hwa Kuo, interview with Phoebe Tang, online personal interview, December 29, 2016.

jan was a major figure in early Nationalist Taiwan's meteorological development. Chiang received a doctoral degree in Agricultural Meteorology in Belgium in 1912. When he returned to China, he headed the Qingdao Observatory until the Second World War, during which he taught at the Peking University. While he did not work with the Chinese Communists, for staying in Japanese-occupied territory he was labeled as "Attached to the [Japanese] Enemies." After the War was over, he was not popular in China and was not able to retain his teaching position. Chiang therefore went to Taiwan and joined the National Taiwan University.[48]

From the 1950s to the 1970s, university meteorological education was carried out but not in an independent department. Meteorologist Hung Chih-wen argued that the meteorology departments did not become independent until two decades after the Second World War because most meteorologists stayed in Mainland China, but also because of politics. The Nationalists saw Chu Co-ching's decision and that of others to remain in China as a betrayal, thus labeling them as "Attached to the [Communist] Bandits." With few exceptions, the Nationalist government became suspicious of the whole meteorology community, even those who moved to Taiwan. Meteorology departments therefore had to "disguise" themselves as geography.[49] The National Taiwan University possessed the meteorological equipment and facilities left over by the Japanese. It, however, did not continue to develop until the 1970s. When Chiang Ping-jan took over National Taiwan University's meteorological teaching from the Japanese in 1946, the

[48] Hung, "The Building, Breaking, and Rebirth of Taiwan Meteorology's Academic Network", 10-16; Kuo, interview.

[49] Hung, "The Building, Breaking, and Rebirth of Taiwan Meteorology's Academic Network", 9-10, 16-19.

department was a "Meteorological Research Center" under the Department of Agronomy of the College of Agriculture.[50] In 1955, Chang Chi-yun, the Minister of Education proposed that a Department of Geography and Meteorology be founded at the National Taiwan University. The Research Center was thus incorporated into the Meteorology Section. In 1962, Chang founded the College of Chinese Culture. Like the National Taiwan University, it also contained a meteorology section under the Department of Geography. Meteorology was also taught at the National Taiwan Normal University where it was founded in 1946 and part of geography under the Department of History and Geography. These departments were staffed by graduates of the Central Aviation School.[51]

It was not until 1970 that the College of Chinese Culture's meteorology section became its own department, and in 1972 that National Taiwan University's Department of Atmospheric Sciences was founded. When it was still a meteorology *section*, the courses covered a narrower scope. They focused on meteorological observation, climatology, and their impact on geology. After 1972, the syllabus was updated to include hurricanes, numerical weather prediction, and mesoscale weather systems.[52] Why then, were meteorology departments allowed to form in the 1970s? Hung attributed this change to the decreasing influence of Chu's generation of meteorologists. He also hypothesized that this change was to answer

[50] Hung, "The Building, Breaking, and Rebirth of Taiwan Meteorology's Academic Network", 17; "Taida Daqixi - History" 台大大氣系 - History - [NTU Department of Atmospheric Sciences - History-], National Taiwan University Department of Atmospheric Sciences, accessed July 19, 2017, http://www.as.ntu.edu.tw/index.php/aboutus-6/history.html.

[51] Hung, "The Building, Breaking, and Rebirth of Taiwan Meteorology's Academic Network", 16-19; Kuo, interview.

[52] Kuo interview.

the need for meteorological research.[53] Another explanation might be the classified nature of weather data. In the 1960s, the Taiwan government was afraid of air raids from China. It felt that it had to protect physically the weather data from getting destroyed. Data storage was thus spread out over Taiwan. Moreover, perhaps because the weather data was crucial for the air force's operation, weather data was classified. If meteorologists wanted to access weather data, they had to obtain approval. Without weather data access, it would be difficult for meteorologists to conduct research.[54] In addition, since the government already associated meteorologists with the Chinese Communists, it might not have been politically viable either to request classified weather data.

In addition to academic departments, the Taiwanese meteorologists also re-established their professional society. The Meteorological Society of China was founded in Mainland China in 1924, but it did not move to Taiwan with the Nationalists in 1949 because most members remained in China. In 1958, Cheng Tsz-cheng, director of Taiwan government's meteorological agency (now the Central Weather Bureau) led the Society's reestablishment. Initially, the Society had 192 members, who elected Chiang Ping-jan as the first director. The year after, the Society's journal resumed publishing and in 1978 also added a journal in English. Aside from publishing and holding meetings, in 1966 the Society also began issuing prizes. The prizes were for both researchers and those who spent at least thirty years of their career on meteorological work. In 1972, the Society was renamed the

[53] Hung, "The Building, Breaking, and Rebirth of Taiwan Meteorology's Academic Network", 9-10, 16-19.

[54] Jhan-geng Siao and Tai-chong Yan, "Taiwan qixiangshiye fazhandiandi" 台灣氣象事業發展點滴 [Anecdotes of Taiwan's Meteorological Development], *Journal of the MSROC* vol. 49 (2008): 31.

Meteorological Society of the Republic of China, because the international community began recognizing mainland China instead of Taiwan as *the* "China."[55]

While meteorological research was difficult and not encouraged, the Taiwan government did undertake meteorological work for strategic and military purposes. The Air Force, the Civil Aviation Administration, and the Central Weather Bureau each played a part in weather forecast and equipment development. The Air Force weather service received the most resources for meteorological work. In the 1950s, because of Taiwan's proximity to China and therefore its strategic position, it received equipment from the United States that helped improve aviation safety. The equipment improved high-altitude weather analysis, and was useful for preventing aviation hazards, such as control surfaces freezing, turbulence, lightning, and crosswinds. In 1966, it was also the first government agency in Taiwan to build a weather satellite image receiver.[56] The Civil Aeronautics Administration was significant to aviation weather too. It built a weather observation station at the Taipei Songshan Airport in 1950, and began providing aviation weather information

[55] Secretariat of the Meteorological Society of the Republic of China, "Qixiang xuehui laitai fuhui yu fazhan" 氣象學會來台復會與發展 [Meteorological Society's Re-establishment and Development in Taiwan] *Journal of the MSROC*, vol. 43 (2002): 54-56; "Xuehui laitai fuhui jingguo" 學會來台復會經過 [MSROC's Re-establishment in Taiwan], MSROC, last modified 2013, retrieved July 21, 2017, http://www.msroc.org.tw/history.php?content=his05; "Zhonghuaminguo qixiangxuehui dashiji" 中華民國氣象學會大事記 [Annals of the MSROC], MSROC, last modified 2013, retrieved July 21, 2017, http://www.msroc.org.tw/history.php?content=his09; "Xuehui yuanliu" 學會源流 [The Origin and History of the MSROC], MSROC, last modified 2013, retrieved July 21, 2017, http://www.msroc.org.tw/history.php?content=his01; "Zhonghuaminguo qixiangxuehui biaoyang teshugongxian ji zhishenjiyou qixiangrenyuan banfa" 中華民國氣象學會表揚特殊貢獻及資深績優氣象人員辦法 [MSROC's Rules for Honoring People Who Contributed to, and Senior Staff Members of Meteorology in Taiwan], MSROC, retrieved July 21, 2017, http://www.msroc.org.tw/PDF/msway04.pdf

[56] Chi-hsun Chi, "Zhengfu qiantai qijin qixiangxueshu zhi fazhan" 政府遷台迄今氣象學術之發展 [Academic meteorological development since the government moved to Taiwan], *Journal of the MSROC* vol. 35, no. 1(1994): 7-8.

from 1953. It also organized conferences on aviation weather and turbulence.[57] Founded in 1941 in Mainland China, the meteorological agency was responsible for general weather forecast. Before 1972, when Taiwan was still part of the World Meteorological Organization (WMO), it participated in international meteorological meetings, and worked with the WMO to install radar stations and rain gauges in Taiwan.[58] After 1975, the agency restructured and expanded its scope of work and responsibilities, such as international communication, atmospheric physics, marine meteorology, meteorological service, and meteorological radar. In 1981, it also started receiving satellite images from the United States.[59]

With these academic departments, a professional society, and governmental facilities, Taiwanese meteorologists began researching on *mei-yu* in the 1960s. The first paper published in Taiwan on *mei-yu* was in 1964 by meteorologist Chi Chi-hsun.[60] It discussed whether Taiwan, like Mainland China and Japan, was also affected by *mei-yu*. The article also speculated the causes and of *mei-yu* by studying the weather characteristics of surrounding areas, such as the air pressure of Siberia. While the article did not explain the specific details of how heavy rain was formed, it drew correlations between heavy rain in May and June in Taiwan, and various weather phenomenon, thus setting up directions for Taiwanese meteorologists' research on *mei-yu*.[61] From 1964 to the early 1980s, Taiwanese meteorologists first determined the characteristics of *mei-yu.* Some of these included the start and end

[57] Chi, "Academic meteorological development", 8-9.
[58] *Ibid.,* 6-7.
[59] Siao and Yan, "Anecdotes of Taiwan's Meteorological Development", 29-30.
[60] Tai-jen Chen, "Taiwan meiyu yanjiu de huigu" 台灣梅雨研究的回顧 [A Review of Taiwan's *Mei-yu* Research], *Quarterly Journal of Meteorology* no. 119 (May 1989): 42.
[61] Chi-hsun Chi, "Plum Rains in Taiwan", *Meteorological Bulletin*, no. 10 (1964): 1-12.

dates, the types of precipitation involved, location and amount of rainfall, location of weather fronts' formation and the number of rainy days during the *mei-yu* period. Meteorologists also speculated about the causes of *mei-yu* by drawing correlations with other weather phenomenon, such as wind direction and temperature change in the area. The studies during these two decades also discovered that *mei-yu* was correlated with the appearance of low-level jets, mesoscale convective systems, and topographical change. Correlation aside, meteorologists did not really understand how these weather phenomena led to heavy rain, so these studies pointed out the areas that needed more in-depth studies.[62]

By the early 1980s, the Japanese, American, and Taiwanese meteorologists had accumulated considerable knowledge on heavy rain large scale research, knowledge that would come to be useful for TAMEX. Japanese meteorologists had research experience in *mei-yu* and in large scale programs. The Americans similarly had been working on international programs, and were experienced in mesoscale weather measurements. Taiwan's meteorological field received limited resources, and most of that went to the Air Force. However, the Taiwanese meteorologists still founded several academic departments and a professional society. While these efforts nominally were to solve scientific problems and gain knowledge, they also served military and socioeconomic purposes. Moreover, the skills and knowledge resulting from these efforts were put to full use when the meteorologists took measurements during TAMEX.

[62] Chen, "A Review of Taiwan's *Mei-yu* Research": 42-46, 51.

Chapter 2

Measuring the Sky

Since Taiwan did not have any experience in large-scale meteorological field measurements, Taiwanese scientists had to look outside of the country for advice.[63] To ask the United States and Japan for assistance, the Taiwanese meteorologists came up with justifications for TAMEX. These justifications were based on the intensity of natural hazards, the damage potential of heavy rain, and TAMEX's general contributions to meteorology academically. From May to June 1987, American meteorologists joined the Taiwanese to take measurements of the atmosphere over and near Taiwan. While TAMEX did run into administrative obstacles because of political tension between Taiwan and China, ultimately the issue was solved and the experiments were carried out as planned. This chapter argues that despite political challenges, the need for mitigating natural hazards through scientific cooperation overrode the political tensions. International meteorological work was first a necessity for minimizing damages, then used as an opportunity for establishing international connections.

TAMEX's early stage and justifications

Both meteorologists and the Taiwanese government hoped that further research on heavy rainfall would lead to improved forecast accuracy, which could then reduce the scope of damages. In 1979, the Taiwan Area Disastrous Weather

[63] Chen, interview.

Conference established four weather disasters specific to Taiwan that required action: typhoons, heavy rain, cold currents, and aridity.[64] Even though meteorologists were aware of the heavy rain hazard before the 1980s, the May 28th disaster, which was caused by the *mei-yu* front and inflicted serious damage highlighted the importance of more accurate forecasting. After the disaster, Taiwan's Premier Sun Yun-suan contacted the Central Weather Bureau's Director-General Wu Tsung-yao, expressing his hope that the Bureau would improve its forecast accuracy for similar heavy rainfall.[65]

Wu looked outside of the Bureau for assistance. He contacted Chen Tai-jen, professor of the Department of Atmospheric Sciences at the National Taiwan University for advice.[66] Chen graduated from the National University of Taiwan (NTU) in 1966. He majored in meteorology, which at the time was a section under the Department of Geography.[67] Since Taiwan had no Master's program until 1982 and no Doctoral program until 1987, Chen continued his studies in the United States.[68] He attended the State University of New York at Albany and obtained a Masters degree in 1971, and a Ph.D. degree in 1974 in Atmospheric Sciences. Upon graduation, Chen returned to his alma mater and taught in the Department of Atmospheric Sciences (restructured from the Meteorology Section). Aside from

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[64] Koung-ying Liu, "Qixiang xuehui bashizhounian jinian huigu yougan" 氣象學會八十週年紀念回顧有感 [Meteorological Society Eighteenth Anniversary Thoughts and Review], *Journal of the MSROC* vol. 46 (2005): 2.

[65] Chen, interview.

[66] Chen, interview.

[67] George Tai-jen Chen, "Guoli Taiwandaxue Xiaozhang houxuanren ziliaobiao" 國立臺灣大學校長候選人資料表[Information form of National Taiwan University President Candidate], 1, accessed March 10, 2017. http://host.cc.ntu.edu.tw/sec/president/陳教授泰然資料表.doc.

[68] "Taida Daqixi - History" 台大大氣系 - History - [NTU Department of Atmospheric Sciences - History-], National Taiwan University Department of Atmospheric Sciences, accessed March 10, 2017, http://www.as.ntu.edu.tw/index.php/aboutus-6/history.html; Chen, "Information form", 1.

university positions, Chen took up numerous posts in governmental and professional organizations in Taiwan. From 1975 to 1980, he was an advisor of the Central Weather Bureau; from 1984 to 1998, he was a member of the Ministry of Transportation and Communication's Office of Science and Technology Advisors. In addition, Chen had been a member of the Meteorological Society of the Republic of China since 1976, and was later its Director from 1991 to 1995.[69] His research focused on the *mei-yu* front, which he began studying in 1975. However, he studied continuous rainfall and not the heavy rainfall, which was characteristic of the "528" disaster. Nevertheless, Chen was happy to focus on heavy rainfall instead, and suggested to Wu that the country should carry out field experiments to study the mechanisms of the *mei-yu*.[70] The next year, in 1982, Chen formally proposed to the National Science Council the "Severe Mesoscale Rainstorm Experiment", which later became TAMEX.[71]

For the Taiwanese meteorologists, getting funding for TAMEX was easy albeit not straightforward. As a national project, TAMEX received dedicated support from the National Science Council (NSC), a government ministry. Chen recalled that whenever he needed extra funding, he simply had to give presentations to the National Science Council and then funding would be granted.[72] However, in 1985, even though ten years of work was expected to be carried out, there was no funding secured for the experiments scheduled after 1987. The National Science Council

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[69] George Tai-jen Chen, "George Chen", accessed March 3, 2017, http://front.as.ntu.edu.tw/t1.htm.

[70] Chen, interview.

[71] Tai-jen Chen, "Together We Did Something We Should: TAMEX: Looking Back and Forward", 9; Ying-hwa Kuo and George Tai-jen Chen, "The Taiwan Area Mesoscale Experiment (TAMEX): An Overview", *Bulletin American Meteorological Society* vol. 71, no. 4 (April 1990): 488.

[72] Chen, interview.

only suggested that they might provide financial support in subsequent years, but did not make any promises.[73] After the measurement stage of TAMEX ended in 1987, Chen along with Tsay Ching-Yen and Hong Siu-shung formally made a proposal to the NSC for more funding to carry out Post-TAMEX work.[74] TAMEX consequently carried out ten years of research, so the initial ambiguity did not affect the actual operation of the project.

While asking for TAMEX funding was not difficult, the Taiwanese meteorologists nevertheless emphasized the importance of the project by explaining the socioeconomic damage *mei-yu* could cause. In many of the TAMEX reports, casualties and loss of property were often cited as the major reasons for carrying out TAMEX. For example, in the feasibility study for TAMEX, Chen argued that the project's focus was on northern Taiwan because the area was the most densely populated. He then elaborated his point by presenting two bar charts indicating that the crops, houses, and lives lost to heavy rain were most severe in June, when *mei-yu* affected Taiwan.[75] Liu Koung-ying of the Chinese Culture University, in another article, similarly argued in support of mesoscale research of the *mei-yu* front. As Taiwan urbanized and more hilly areas were developed, the effect of *mei-yu* would

[73] George Tai-jen Chen, Tsung-yao Wu, *Pilot Study of "A Severe Regional Precipitation Observation and Analysis Experiment",* National Science Council Science and Technology of Disaster Prevention Program Technical Report 74-25 (Taipei: National Science Council, 1985), 107.

[74] Siu-shung Hong, Ching-yen Tsay, Tai-jen Chen, *TAMEX houxuyanjiu zhi guihua* TAMEX 後續研究之規畫 [*Post-TAMEX research planning*], NSC-77-0202-M002-11 (Taipei: National Science Council, 1988).

[75] Tai-jen Chen, *Feasibility Study of "A Severe Regional Precipitation Observation and Analysis Experiment"*, National Science Council Science and Technology of Disaster Prevention Program Technical Report 73-42 (Taipei: National Science Council, 1985), 16-17.

be increasingly strongly felt. The damage would thus become more costly.[76] Indeed, according to the National Statistics Database published by the Taiwanese government, during most of the 1980s, the annual Gross Domestic Product growth for the "Securities, Futures and Other Financing" sector ranged from 60% to 2.5 times.[77] Taiwan's tertiary industry's share in the economy was rapidly increasing. As wealth in the built-up areas become more concentrated, flooding to a small area would become particularly costly compared with damages done to the more spread-out rural areas. The Taiwanese government was aware of these financial ramifications of the *mei-yu*, and gave strong monetary support to TAMEX.

Having secured governmental support, the Taiwanese meteorologists began to look outside of the country for advice and support. This initial planning phase of TAMEX was called Pre-TAMEX. It was carried out from 1983 to 1986 and included both Taiwanese and American participants. One of the key events of Pre-TAMEX was a one-week trip from January to February 1985. Five of TAMEX's Principal Investigators and Co-Principal Investigators from the Central Weather Bureau and Taiwanese universities (Chen Tai-jen, Wu Tsung-yao, Chang Long-nan, Chu Ko-kung, and Yu Chia-chung) visited Japan's Meteorological Research Institute at the Japan Meteorological Agency**,** the American National Severe Storms Forecast Center, NOAA's Environmental Research Laboratory, NCAR, and Colorado State

[76] Koung-ying Liu, "A Study of the Heavy Rainfall in the Mei-Yu Seasons of Taiwan", *Quarterly Journal of Meteorology* no. 88 (August 1981): 11.

[77] "Table: Gross Domestic Product by Kind of Activity and Price Deflators-Annual", Directorate-General of Budget, Accounting and Statistics, Executive Yuan, Republic of China (Taiwan), accessed March 5, 2017, http://statdb.dgbas.gov.tw/pxweb/Dialog/varval.asp?ma=NA8103A1A&ti=Gross%20Domestic%20Product%20by%20Kind%20of%20Activity%20and%20Price%20Deflators-Annual&path=../PXfileE/NationalIncome/&lang=1&strList=L

University.[78]

Before heading to America, the team of five scientists first visited Japan for two days to learn about Japan's meteorological research and explore collaboration opportunities. At the Japan Meteorological Agency, the Taiwanese meteorologists learned about how Japan conducted its large scale field programs, including its own study on heavy rainfall in 1968-1972.[79] While the Japanese meteorologists generously showed their work to the Taiwanese, they could not cooperate formally because Japan did not have formal political ties with Taiwan. The Japan Meteorological Agency, as a governmental organization, did not receive permission from Japan's Ministry of Foreign Affairs to participate formally in TAMEX, which was a national and thus an official program. Despite such restriction, Japanese meteorologists were interested in TAMEX and wanted to contribute to it. They therefore continued to work with Taiwan unofficially and on an individual basis, and were generous with their data.[80] Japan shared its summary of and data collected from the Air Mass Transformation Experiment.[81] The Japanese meteorologists also expressed their willingness to unofficially share data collected by Japanese satellites, and would even increase observation frequency for TAMEX.[82] Indeed, during TAMEX Taiwan received satellite images taken by the GMS-3 Satellite.[83] After learning about Japan's research and the extent of collaboration possible, the

[78] Chen, interview; Kuo, interview.
[79] Chen, Wu, Chang, and Chu, "Report on visit to the United States and Japan", 553-554.
[80] Chen, interview.
[81] Lenschow and Agee, "1974: The Air Mass Transformation Experiment (AMTEX)", 1228-1229; Chen, Wu, Chang, and Chu, "Report on visit to the United States and Japan", 553-554.
[82] Chen, Wu, Chang, and Chu, "Report on visit to the United States and Japan", 553.
[83] ROC-America Cooperation Planning Group, *TAMEX: Taiwan Area Mesoscale Experiment Operations Plan*, 127-134.

Taiwanese team then traveled to the United States.

On the American side, even though the US and Taiwan had not established formal political relations, the American meteorologists were allowed to work with their Taiwanese counterparts. This permission possibly stemmed from the notion of "scientific internationalism" described by John Krige. In 1950, a report to the State Department entitled *Science and Foreign Relations* argued that it was difficult to learn about foreign scientific progress by surveillance. Krige argued that during the Cold War, the American government promoted "scientific internationalism" by encouraging scientists to participate in international conferences, form personal contacts, and create a body of shared knowledge. These activities were expected to make international exchange "at once a window and a probe" into rival countries' scientific capabilities.[84] While Taiwan was not a political rival and TAMEX was not about atomic science, the same spirit of encouraging scientists to form international networks was at work during TAMEX. The practice of allowing scientists to work freely with their colleagues from other countries entailed that the American government did not impose restrictions on meteorologists. Unlike Japan, the nationality of scientists was not a parameter for judging whether a scientific cooperation project was feasible.

Even though there were no political obstacles for Americans to participate in TAMEX, their participation still required scientific justifications. *Mei-yu* was confined to East Asia and did not directly affect American interests. While socioeconomic justifications alone could convince the Taiwanese government of

[84] John Krige, "Atoms for Peace, Scientific Internationalism, and Scientific Intelligence" in John Krige and Kai-Henrik Barth ed. *Global Power Knowledge*, 166-172.

TAMEX's importance, justifying TAMEX to Americans required more. To ask the American meteorologists for support, Chen began by contacting Kuo Ying-hwa who was working at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado. Chen had known Kuo since the 1970s when they were both in Taiwan. Kuo majored in Atmospheric Sciences at the National University of Taiwan where Chen taught him cloud microphysics. In 1976, Kuo completed his Bachelor of Science degree.[85] After two years of compulsory military service, he went to South Dakota School of Mines and Technology for a Masters Degree in Environmental Sciences (Meteorology). Kuo then attended Pennsylvania State University's Department of Meteorology and obtained a doctorate degree there in 1983.[86] Kuo had wanted to work on hurricanes. However, his advisor, Richard Anthes had switched from studying hurricanes to studying mesoscale convective system (MCS). Kuo therefore worked on the MCS instead. Before Kuo graduated, Anthes was offered a job at NCAR.[87] Founded in 1950 by the University Corporation for Atmospheric Research and comprised of scientists from fourteen American universities, NCAR was a meteorological research and development center supported by the National Science Foundation. It aimed to conduct meteorological research, facilitate communications about the meteorological community, and apply scientific knowledge for practical use.[88] Kuo then followed Anthes to NCAR, and finished his Ph.D. thesis there in 1983. While Kuo had previously intended to return

[85] Kuo, interview.

[86] Ying-hwa Kuo, "Kuo-CV-Aug-2015", accessed March 1, 2017, https://www.ucp.ucar.edu/sites/default/files/attachments/Kuo-CV-Aug-2015.pdf

[87] Kuo, interview.

[88] "UCAR & NCAR - Our History", University Corporation for Atmospheric Research, last modified 2017, accessed April 1, 2017. https://www2.ucar.edu/about-us/history.

to Taiwan upon graduation, he stayed in the US and accepted a junior research scientist position at NCAR.[89] He first worked at the Mesoscale Research Section under Aviation Applications Program for three years, then went to the Mesoscale Prediction Section under the Mesoscale & Microscale Meteorology Laboratory. From 1994 to 2012, Kuo was head of the Mesoscale Prediction Group.[90]

To apply for financial support, the new justifications devised for American support of TAMEX described the project as capable of producing general knowledge, so that it would not only specifically benefit Taiwan, but also contribute to the understanding of American climate. Kuo stated in an interview that when he was asking for American support for TAMEX, he had to look at the project from the American perspective. Kuo and other scientists interested in TAMEX justified it by pointing out that the mesoscale convective systems in Taiwan were similar to those in the southern US. Both locations' systems did not produce tornadoes but produced heavy rain, and were different from storm systems in Texas and Tennessee, which produced very little rain and many tornadoes. Kuo thus argued that TAMEX would improve understanding of these weather systems.[91] Stephan Nelson of the Division of Atmospheric & Geospace Sciences of the National Science Foundation wrote a grant proposal to the National Science Foundation in 1992. He argued that TAMEX's data would also improve prediction of flash floods, "major meteorological disasters which occur around the globe." By using data obtained from TAMEX and with the aid of weather modeling, he would study jet streams and upper-level circulations to

[89] Kuo, interview.
[90] Kuo, "Kuo-CV-Aug-2015".
[91] Kuo, interview.

"help identify the important dynamic factors for heavy rain production."[92] In other words, the knowledge gained from the experiment was described as deserving American funding because it was general enough that it could be applied to the United States as a whole.

During the visit at NCAR, TAMEX's scientific requirements as a field program convinced American meteorologists to show the Taiwanese their own research. In an interview, Chen pointed out that in the first visit, before Americans promised to help, Edward Zipser, Director of NOAA's Convective Storm Division, candidly criticized the feasibility of TAMEX. He pointed out that Taiwan lacked the expertise, personnel, technique, and instruments. Chen admitted Taiwan's inadequacy, and followed up with Zipser about possible cooperation opportunities. He explained that TAMEX's scientific questions were relevant to America, such as the effect of mountains on weather systems. Zipser subsequently invited the Taiwanese scientists to shadow the American Pre-STORM program.[93] Leaders of TAMEX on the Taiwan side, Chen Tai-jen, Tsay Ching-yen, and Chu Ko-kung spent thirteen days in Oklahoma and Kansas, where the experiment was conducted, and in Boulder, Colorado where the NCAR headquarters is located. They visited the Operations Control Center, learned how the Doppler radar works, and joined the P-3 airplane flight through the weather systems for detailed data collection. From the trip, the Taiwanese learned about the amount of planning, manpower, organization, and

[92] Stephan P. Nelson, "NSF Award Search: Award#9206124: Conditions Favourable for the Development of Heavy Precipitation During TAMEX", National Science Foundation, May 11, 1993, accessed January 21, 2017, https://www.nsf.gov/awardsearch/showAward?AWD_ID=9206124&HistoricalAwards=false

[93] Chen, interview. I have referred to the textual record but this detail was not documented.

equipment needed for a similarly scaled program.[94] The magnitude of the scientific requirements of TAMEX and the problems it studied, while presenting difficulties to the Taiwanese at first, actually created opportunities for exposure to the most up-to-date meteorological research.

In addition to understanding weather systems, meteorologists also argued that TAMEX was capable of improving the American forecast system. In the announcement of TAMEX in the *Bulletin of the American Meteorological Society*, meteorologists from both Taiwan and the US agreed that the data collected would aid the development of mesoscale numerical weather models. This type of model would be more detailed than existing synoptic ones, utilizing measurements from TAMEX and using mathematical equations to understand the detailed mechanisms of weather phenomena, thus improving forecast capability.[95] For example, one model developed as a result of TAMEX describes how lower-level wind was blocked by the Central Mountain Range of Taiwan, while upper-level wind descended along the Range and created a vortex of warm air.[96]

After the Taiwanese meteorologists first visited Japan and America in 1985, the Taiwanese and American meteorologists held nine more meetings.[97] They

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[94] Tai-jen Chen, Ching-yen Tsay, and Ko-kung Chu, "meiguo PRE-STORM shixianjihua ji zhongmei hezuo Taiwandiqu zhongchidu tianqi shixian yanjiu TAMEX zhi chuyi" 美國「PRE-STORM 實驗計畫」及中美合作「臺灣地區中尺度天氣實驗研究 TAMEX」之芻議 [American "Pre-STORM Program" and Proposal for ROC-US Cooperation "Taiwan Area Mesoscale Experiment (TAMEX)"], *Science Development* vol. 13, no. 11 (1985): 1427-1432.

[95] Ying-hwa Kuo, Robert Serafin, and Tai-jen Chen, "Mesoscale Field Experiment To Be Held in Taiwan, R.O.C.", *Bulletin of the American Meteorological Society* vol. 66, no. 9 (1985): 1166; "How Mesoscale Models Work", Cooperative Program for Operational Meteorology, The University Corporation for Atmospheric Research, accessed March 31, 2017, http://www.meted.ucar.edu/mesoprim/models/print.htm

[96] Kuo and Chen, "The Taiwan Area Mesoscale Experiment (TAMEX): An Overview": 499.

[97] Chen, *Scientific Management of Taiwan Area Mesoscale Experiment*, 5, 16.

discussed the scientific benefits of TAMEX, America's role in the program and the support that they would provide. In the meetings, meteorologists agreed that the data collection would benefit if America lent instruments that Taiwan did not yet own, such as Doppler Radars and an aircraft for weather measurements. The progress timetable, operation plans and procedures, funding, management, data requirement, and facilities were also covered in the meetings.[98]

Taking Measurements

Aside from meetings and visits, another key part of Pre-TAMEX was a preparatory Phrase I of the 1987 experiments. It was held from May to June 1986, exactly a year before the TAMEX field program. The aims of Phase I were similar with TAMEX in that it aimed to improve understanding of the environmental factors in the formation of a mesoscale convective system. This phase, however, also aimed to test the capabilities of the Operations Center that coordinated the various observation stations. These stations included rain gauges, wind tower stations, surface stations, and high altitude wind measurement stations, which would be used in 1987. Being a preparatory experiment, it did not involve as many institutions as the main project did. In this phase, only nine institutions from Taiwan, including the Central Weather Bureau, the Civil Aviation Administration, and three universities participated.[99] Weather measurements were taken using existing sites and

[98] Tai-jen Chen, "'Taiwandiqu zhongchidu shixianjihua' (TAMEX) zhi yuanqi guihua yu shishi" 「臺灣地區中尺度實驗計畫(TAMEX)」之緣起規劃與實施 [TAMEX's Origin, Planning, and Implementation], *Quarterly Journal of Meteorology* no. 113 (November 1987): 13-25.

[99] Chen, "TAMEX's Origin, Planning and Implementation", 25-26.

equipment, but with increased observation frequencies.[100] During the two months, there were three intensive observation periods that altogether lasted seven days. They were scheduled when a *mei-yu* front was expected, during which weather measurements were carried out more frequently.[101]

From May to June 1987, TAMEX was undertaken. The 125 participants built a network of collaboration, as they were from different institutions, and had often worked at scattered locations. Professors, students, technicians, administrators, and operators from fifteen universities and government bureaus in Taiwan helped carry out the experiment. On the American side, specialists from ten universities and three research institutions, including the Colorado State University, the University of Hawaii, the National Center for Atmospheric Research, the National Oceanic and Atmospheric Administration (NOAA), and the Naval Research Laboratory joined the project.[102] For most American scientists and technicians who went to Taiwan, accompanying and operating these instruments was the sole reason for their travels. According to TAMEX's Operations Plan, of the forty-one American personnel, only twelve of them were not specifically working with the radar or the airplane. During TAMEX, the P-3 airplane was staffed by sixteen people, including pilots, meteorologists, technicians, and engineers responsible for the instruments.[103]

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[100] Tsung-yao Wu, "A Review of Taiwan Area Mesoscale Experiment (TAMEX) and Post-field Phase Activities", in *Workshop on TAMEX Scientific Results : Proceedings: 24-26 September 1990, Boulder, Colorado* (Boulder, CO.: Distributed by TAMEX U.S. Project Office, MMM Division, NCAR, 1990), 1-2.

[101] Chen, "TAMEX's Origin, Planning and Implementation", 25.

[102] Tai-jen Chen, "Together We Did Something We Should: TAMEX: Looking Back and Forward", 13; ROC-America Cooperation Planning Group, *TAMEX: Taiwan Area Mesoscale Experiment Operations Plan*, 4.

[103] ROC-America Cooperation Planning Group, *TAMEX: Taiwan Area Mesoscale Experiment Operations Plan*, 29-30, 174-178.

In this process, scientists physically traveled to and worked with each other, and fostered working relationships that later opened up more collaboration opportunities.

During these two months, the Scientific Planning meeting determined daily the measurements to be carried out. The meeting agenda included briefing on weather, observation platforms' status, and amount of resources remaining. It also discussed how well the scientific objectives had been obtained, and determined upcoming weather status of the day in order to coordinate the scope of measurements to be done. The meetings would also be the place for discussing and solving any problems encountered during the field work.[104]

Meteorologists, with the help of pilots, engineers, technicians, and Taiwanese soldiers, used a large variety of instruments to measure the weather. Existing facilities such as surface stations, rain gauges, wind tower stations, and conventional radar stations were enlisted into TAMEX. The project also used extra resources, such as three research ships, and high frequency and high-altitude wind profilers.[105] In addition to receiving regular satellite images from the NOAA-8 and NOAA-9 satellites every six hours, TAMEX used images from the Japanese Geostationary Meteorological Satellite (GMS-3).[106] The GMS-3 provided a broader observation area, and hourly observations on top of the basic three-hourly ones. It also provided

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[104] Tai-jen Chen, *Scientific Management of Taiwan Area Mesoscale Experiment*, 18-19.

[105] Tai-jen Chen, *'Taiwandiqu zhongchidu shixianjihua' (TAMEX) zhi huigu yu zhanwang*「台灣地區中尺度實驗計畫」（TAMEX）之回顧與展望 [TAMEX's Review and Outlook], *Science Development* vol. 15, issue 12 (1987): 1746; ROC-America Cooperation Planning Group, *TAMEX: Taiwan Area Mesoscale Experiment Operations Plan* (Taipei: National Science Council, 1987), 1-2.

[106] Tai-jen Chen, *Experiment Design of Taiwan Area Mesoscale Experiment (TAMEX)*, National Science Council Science and Technology of Disaster Prevention Program Technical Report 75-01 (Taipei: National Science Council, 1986), 76-77.

wind calculations to TAMEX, doubling the frequency of data observed and sent from twice to four times a day.[107]

Another key piece of equipment used throughout TAMEX was the P-3 airplane. The P-3 was originally developed for the military as a patrol and surveillance aircraft.[108] NOAA first purchased two P-3 airplanes in the mid-1970s, and equipped them with a Doppler radar, a system to record the radar data taken, and one that measured physical properties of clouds. As the P-3 flew, scientists released probes, which would "transmit pressure, temperature, humidity, wind speed and wind direction data back to the aircraft" as they fell. Depending on the available weather phenomena, the P-3 would carry out different flight patterns and use different instruments.[109] While all the scientific and technical aspects had been taken care of, politics interfered with TAMEX's plan to use the P-3.

Since the United States did not formally recognize Taiwan after 1979, interactions were conducted according to the "Taiwan Relations Act" in which all governmental relations had been terminated. Nonetheless, the Act also allowed the "continuation of commercial, cultural, and other relations."[110] The severance of formal relations posed administrative difficulties for TAMEX. Without specifying instructions for scientific studies, the Taiwan Relations Act left a grey area on how

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[107] ROC-America Cooperation Planning Group, *TAMEX: Taiwan Area Mesoscale Experiment Operations Plan*, 127.

[108] "The US Navy -- Fact File_ P-3C Orion long range ASW aircraft", United States Navy, last modified May 23, 2016, accessed April 1, 2017, http://www.navy.mil/navydata/fact_display.asp?cid=1100&tid=1400&ct=1

[109] "Lockheed WP-3D Orion _ Office of Marine and Aviation Operations", Office of Marine and Aviation Operations, last modified January 30, 2017, accessed April 1, 2017, http://www.omao.noaa.gov/learn/aircraft-operations/aircraft/lockheed-wp-3d-orion; ROC-America Cooperation Planning Group, *TAMEX: Taiwan Area Mesoscale Experiment Operations Plan*, 29-51.

[110] Taiwan Relations Act, Public Law 96-8 96th Congress, January 1, 1979, accessed March 10, 2017, https://www.ait.org.tw/en/taiwan-relations-act.html

American-Taiwan meteorological cooperation could be carried out.

In November 1986, half a year before the P-3 was expected to fly, Chen Tai-jen received the notification that the American State Department would not allow the P-3 airplane to participate in TAMEX. Through the United States State Department, the PRC had learned that the P-3 airplane would fly to Taiwan to take measurements there. Citing the Taiwan Relations Act, China opposed the P-3 airplane operations on the basis that the plane belonged to NOAA, a branch of the federal government. Upon learning about the ban, Chen met with Chen Yu-an, Director of the National Science Council to discuss the matter. Chen Tai-jen proposed to Chen Yu-an that they could use personal and unofficial governmental relations with the United States and China to overturn the flight ban. Chen therefore asked to speak with Frederick Seitz, a member of Taiwan's Science Advisory Committee who had served on President John Kennedy's Science Advisory Committee from 1962 to 1969, and was later a member of President Ronald Reagan's Strategic Defense Initiative scientific advisory group. Seitz was convinced by Chen, and agreed to speak for Taiwan when he returned to the United States.[111] In addition, while Taiwan did not have formal diplomatic relations with the US, it did have an office there acting as a de-facto embassy called the Taipei Economic and Cultural Representative Office (TECRO). Chen thus asked TECRO to help with the

[111] "Dr. Frederick Seitz (saichi)(xingzhengyuan kejihuibao-guowaiguwen)" Dr. Frederick Seitz (賽馳)(行政院科技會報-國外顧問) [Dr. Frederick Seitz (Seitz) (Board of Science and Technology, Executive Yuan - International Advisor)], Board of Science and Technology, Executive Yuan, last modified April 17, 2017, accessed April 17, 2017, http://www.bost.ey.gov.tw/News_Content.aspx?n=33F7946C1005555F&sms=EA35D3EEE05D43B7&s=5026DED1E93CD1C9; Chen, interview; Patrick Sullivan, "Frederick Seitz, 96; Physicist Cast Doubt On Global Warming", March 6, 2008, accessed April 1, 2017, http://www.washingtonpost.com/wp-dyn/content/article/2008/03/05/AR2008030503524.html.

negotiations. Moreover, since the no-fly decision was made jointly by the United States and the People's Republic of China, Chen also contacted Zou Jing-meng, the Administrator of PRC's State Meteorological Administration. Zou's brother, Zou Jia-hua, was a member of the Central Committee of the Communist Party of China, and was the Vice-Minister of State Administration for Science, Technology and Industry for National Defense for three years between 1982 and 1985. Chen thought that Zou and his brother's political standing and scientific inclinations might be able to influence the Chinese government's stance.[112]

A few weeks after Chen appealed for permission to fly, he received the news that the US State Department had granted permission for the P-3 plane to carry out experiments in Taiwan. The plane would not be allowed to land, so it would be stationed at the Kadena Air Base in Okinawa, Japan.[113] Okinawa is 400 miles from Taiwan. It took over an hour for the P-3 to reach the Taiwan area. That could have affected the final measurement. The TAMEX report in 1987 claimed that even though the decision to fly was usually made hours in advance, there were instances when this one hour of flight time resulted in missed observation opportunities.[114] Chen and David Jorgensen, who was responsible for the P-3 program, claimed otherwise.[115]

Even though Chen did not know whether the efforts of the ex-President

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[112] "China Vitae _ Biography of Zou Jiahua", China Vitae, accessed March 3, 2017, http://www.chinavitae.com/biography/Zou_Jiahua/career; Chen, interview.

[113] Chen, interview.

[114] ROC-America Cooperation Planning Group, *TAMEX: Taiwan Area Mesoscale Experiment Operations Plan*, 29-33; Tsung-yao Wu and Tai-jen Chen, *Taiwan Area Mesoscale Experiment*, National Science Council Science and Technology of Disaster Prevention Program Technical Report 76-19 (Taipei: National Science Council, 1987), 130.

[115] Chen, interview; David Jorgensen, interview with Phoebe Tang, phone interview, February 28, 2017.

Science Advisor, the Taiwan representative in Washington, or the China Meteorological Administrator President contributed to the flight permission, the personal relations and posts held by these officials might shed light on the question. Seitz was a scientific advisor for Reagan's Strategic Defense Initiative. His opinion therefore might be influential at the White House and in the federal government. TECRO, as Taiwan's own representative, might not have as much influence on American policy, or else it would have settled the matter at the beginning. Importantly, even if the US government were willing to let the P-3 operate, they would still need the approval by the PRC. It is likely that Zou's negotiation with the Mainland Chinese officials contributed significantly to the lifting of the ban. Zou Jing-meng was more than just the brother of a Central Committee member. The Zou brothers were actually the adopted sons of mainland China's former Premier Zhou En-lai, whose position was only second to the President. Zou was therefore well-connected with the center of power. Indeed, from June to July 1989, even at the sensitive and tense time after the June 4th Tiananmen Massacre, Zou was able to convince the top Chinese officials to let Chinese meteorologists go to Hong Kong to attend the first cross-strait meteorological conference.[116] This being the only international meeting Chinese scientists were allowed to attend during the time, it would not be surprising nor difficult for Zou to pull strings for TAMEX.

Having solved the political troubles, the meteorologists went ahead with the weather measurements and carried them out over weather conditions from sea

[116] Chih-pei Chang, "haixialiangan qixiangjiaoliu -- shibanianqian pobing de huiyi" 海峽兩岸氣象交流 --- 十八年前破冰的回憶 [Cross-Strait Meteorological Interaction: Memories of Ice-breaking 18 years ago], *Journal of the MSROC* vol. 48 (2007): 12-18.

level to high altitudes. The equipment was grouped into three networks and two programs, namely the Upper-air network, the Surface network, the Radar network, the Aircraft program, and the Satellite program. Weather data such as temperature, humidity, wind speed, wind direction, precipitation, and dew point temperature were recorded by these networks. Depending on the weather forecast given by the TAMEX Operations Forecast Center (OFC), observations sometimes were carried out more frequently. On a calm day, routine observation was carried out at set intervals of twice to twenty-four times per day, depending on the networks involved. From 15 May to 15 June, a special observing period was carried out in which measurements were taken twice as frequently. The third type of observation, called an Intensive Observation Period (IOP), took measurements three times more frequently than during routine observations, and the P-3 airplane was deployed to the developing weather fronts and systems for more detailed on-site radar measurements.[117] During the two months of May and June 1987, there were thirteen of these occasions. Some of the IOPs spanned two to three days. Altogether, of the sixty-one days in May and June, Intensive Observation took up twenty-five days.[118]

Before making the collected data public, as part of the data management process, the TAMEX meteorologists validated all the data first. They designed a variety of measures to check and correct the collected data, and set accepted ranges for different type of data. For example, air temperature from sea level to one thousand meter altitude should be above -1°C. If the measurement was under -1°C,

[117] Kuo and Chen, "The Taiwan Area Mesoscale Experiment (TAMEX): An Overview", 492-495.

[118] Tai-jen, Chen, "TAMEX's Review and Outlook", 1747.

it would be marked as a possibly erroneous measurement. If the temperature was under -3°C, then it would be marked as incorrect. The data sets were also compared with other instruments of the same type. For example, the data of the ships were compared with data taken on land. Any deviations from normal temperature patterns would be seen as unreliable.[119] Coordination analysts working for TAMEX and at the Central Weather Bureau forecasting center reported any suspicious errors, and forwarded them to specialists of the specific measuring procedures and instruments.[120]

After all the data had been collected for TAMEX, meteorologists realized that what they received contained much more error than expected. Human error was one type of error. It included wrong station numbers, wrong times of the day, and wrong names of instruments. Moreover, sometimes the decimal point was left out, and when there was no precipitation the entry was left blank instead of with zero indicated. Even when the handwritten record was correct, typists made mistakes when they entered the data into the computer.[121] Some precipitation data was even wiped out accidentally at the Operation Center.[122] To fill in the missing or incorrect data, meteorologists used records collected through other methods, despite being less detailed. An example would be a research ship that did not always record its location, so the meteorologists used GPS records to determine the general location

[119] Feng-lun Chiao, *Taiwan Area Mesoscale Experiment (TAMEX) Data Management*, National Science Council Science and Technology of Disaster Prevention Program Technical Report 77-11 (Taipei: National Science Council, 1988), 42-43, 72-73.

[120] ROC-America Cooperation Planning Group, *TAMEX: Taiwan Area Mesoscale Experiment Operations Plan*, 136-138.

[121] Chiao, *Taiwan Area Mesoscale Experiment (TAMEX) Data Management*, 7, 34.

[122] Wu and Chen, *Taiwan Area Mesoscale Experiment,* 129.

of the vessel.[123] This data checking process was repeated six times before the information was finalized and published.[124]

The Taiwanese meteorologists highlighted the socioeconomic and scientific benefits to justify the necessity of TAMEX. This strategy applied to both the Taiwanese and the American governments. They were however not always adequate to overcome political tensions. Japan did not formally work on TAMEX, and the US P-3 airplane was not permitted to land in Taiwan. Nevertheless, the meteorologists worked around these obstacles and the TAMEX measurements were successfully carried out. In the process, the meteorologists formed a network of collaboration, which would lead them to further cooperation opportunities.

[123] Chiao, *Taiwan Area Mesoscale Experiment (TAMEX) Data Management*, 7.
[124] *Ibid.*, 34.

Chapter 3: Contributions of TAMEX

TAMEX contributed to Taiwan's meteorological development through various aspects. It improved meteorologists' understanding of how heavy rain formed during the *mei-yu* season, and sped up the construction of a new computerized system capable of utilizing data collected during TAMEX. In addition to scientific benefits, the international networks that Taiwanese meteorologists formed during TAMEX and the 1987-1992 Post-TAMEX also increased their international exposure through conferences and publications. The collaborative relations established during TAMEX moreover led to further cooperation opportunities, including the COSMIC program and TimREX, or TAMEX II. While there is no concrete evidence on the correlation between TAMEX and establishment of official relations between Mainland Chinese and Taiwanese meteorologists, it is possible that the mainland-Taiwan meteorologists' interaction during TAMEX contributed to the initiation of communication. This chapter discusses the contributions of TAMEX to Taiwan and their possible international relations implications.

Scientific contributions

The data collected contributed to TAMEX's objectives: understanding the formation of the *mei-yu* front system, the mesoscale convective system, and the effect of Taiwan's topography on precipitation. In terms of the *mei-yu* front, the data showed the location and strength of the front, and also confirmed that a mesoscale

convective system existed before the formation of the *mei-yu* front. For the MCS itself, the measurements showed its structure, location, and its source of energy. TAMEX also measured the locations of low-level jets and the convection mechanism that induced the formation of the MCS. Topographically, data from the P-3 airplane and from Doppler radars showed the process of intensified precipitation, how air flowed past mountains, and how weather systems interacted with the topography.[125]

In the long term, TAMEX brought systematic changes to Taiwan meteorological computerization, and created future cooperation opportunities. Long before TAMEX, Taiwan had already started using computers to help with processing weather data. From the mid-1970s, Taiwan's weather forecast and observation system rapidly computerized. In 1974, Taiwan started using computers to "calculate, verify, and compile monthly and annual reports for meteorological stations." Three years later, it was already developing numerical weather forecast models.[126] The numerical model was originally Vilhelm Bjerknes' idea in the early 20th century. He theorized that weather could be interpreted and predicted by calculations using the laws from mechanical physics. His Bergen school also incorporated the vertical dimension into the calculations, so that weather was studied in three-dimensions. Previous weather measurements were confined to the surface only. This method, however, required complex hand calculations and thus

[125] Tai-jen, Chen, "TAMEX's Review and Outlook", 1747-49.

[126] Jhan-geng Siao and Tai-chong Yan, "Taiwan qixiangshiye fazhandiandi" 台灣氣象事業發展點滴 [Anecdotes of Taiwan's Meteorological Development], *Journal of the MSROC* vol. 49 (2008): 31-32.

took a long time.[127] Only after the Second World War with a new generation of computers could the Bergen school's numerical method be implemented. The first successful real-time numerical forecast was performed by Bjerknes' student Carl Rossby, who used the Swedish BESK computer, at the time one of the fastest computers in the world.[128] Computing power became one of the key elements to weather forecasting.

The large amount of data collected during TAMEX sped up Taiwan's weather forecast computerization. In 1980, the Central Weather Bureau purchased the TI DS990/20 computer system for processing weather data. A year later, Taiwan began receiving and using satellite images from the US.[129] The preexisting computer system thus contributed to the success of TAMEX by processing the data collected during TAMEX. However, after all the measurements had been taken, Chen realized that the weather forecast system in Taiwan did not have the capacity to *utilize* the larger amount of data recorded from mesoscale measurements. At the time, weather forecasting relied heavily on human labor. For each forecast, the forecaster referred to dozens of written documents, charts, and images. Therefore, in 1988, a year after the field phase of TAMEX, Chen urged the Central Weather Bureau to build a computerized system that could carry out mesoscale forecasting.[130] While this system was, according to Kuo, already considered for development by the Central Weather Bureau before TAMEX, Chen's urging did play a part in speeding up its

[127] Robert Friedman, *Appropriating the Weather,* 51-52, 158-164; Paul N. Edwards*, A Vast Machine,* 85-88; James Fleming, *Inventing Atmospheric Science,* 9, 23.
[128] Fleming, *Inventing Atmospheric Science*, 9-10, 119, 156-157.
[129] Siao and Yan, "Anecdotes of Taiwan's Meteorological Development", 31-32.
[130] Chen, interview.

development.[131] Even though it was not in full operation until 1994, it developed quickly enough to make mesoscale predictions during the Post-TAMEX *mei-yu* forecast exercise.[132]

From 1990 to 1994, Taiwan's Central Weather Bureau worked with NOAA's Forecasting System Laboratory at Boulder to develop the Weather Integration and Nowcasting System (WINS), a computer network and a software program that summarized different types of weather data such as satellite images, precipitation measurement, lightning location, and radar. The computers responsible for individual weather data type at the Central Weather Bureau were linked into a network. Software then converted the various types of data into a single image for the forecaster. The forecaster could specify the time frame, area, color code, and the types of data shown on the computer screen, then create weather maps with the data.[133] Developing WINS furthered collaboration between Taiwan and the United States. To create this system, Taiwanese and Americans traveled back and forth between the two countries, and they worked closely to design the system according to parameters suitable for Taiwan.[134]

In 1992, with the TAMEX data and the newly developed Weather Integration and Nowcasting System, meteorologists attempted to predict the formation of *mei-yu* from May to June.[135] The data collected during TAMEX showed how the weather

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[131] Kuo, interview.

[132] Siao and Yan, "Anecdotes of Taiwan's Meteorological Development", 33.

[133] Chia-ping Cheng, "WINS - Total System Design" in *Proceedings : Conference on Weather Analysis and Forecasting* (Taipei: Central Weather Bureau, 1992), 327-333. http://photino.cwb.gov.tw/rdcweb/lib/cd/cd01conf/dissertation/1992/31.pdf; Siao and Yan, "Anecdotes of Taiwan's Meteorological Development", 33.

[134] Chen, interview.

[135] Chen, interview; Chen, "Together We Did Something We Should", 14.

systems worked, for example how they interacted with the mountains, the location and strength of the *mei-yu* front, and the structure and location of the mesoscale convective system.[136] After the scientists carried out the forecast, their performance was compared with real data. While the forecast accuracy for 1 to 3-hours was over 50%, the accuracy for heavy rain in 12 hours was only 30%.[137] Despite the low accuracy for the 12-hour forecast, the 1 to 3-hour accuracy was an improvement from the complete inability to forecast imminent heavy rain.

Post-TAMEX Publications and Conferences

Between 1987 and 1992, the meteorologists carried out the Post-TAMEX work, through which they gained international exposure and further consolidated their working relationships. They published the data in journal articles, such as the special edition of *Monthly Weather Review* in November 1991, in the *Terrestrial, Atmospheric and Oceanic Sciences* in December 1992, top-tier international journals. In 1993, a year after the TAMEX program was officially completed, the Taiwanese published six more journal articles on mesoscale meteorology. In subsequent years, this number more than tripled.[138] Such international exposure showed that Taiwanese meteorologists were steadily internationalizing their meteorological research.

In addition to publications, five annual meetings were also held to discuss the

[136] Chen, "TAMEX's Review and Outlook", 1747-49.

[137] Bian-jyun Li, *Verification and Assessment of 1992 TAMEX Forecast Exercise*, National Science Council Science and Technology of Disaster Prevention Program Technical Report 81-20 (Taipei: National Science Council, October 1992), 16.

[138] Chen, "Together We Did Something We Should", 17-18.

findings. Two of the meetings were held at NCAR, and three in Taipei. In the earlier meetings, many of the papers analyzed the structures and formation mechanisms of individual weather phenomenon observed during TAMEX. Some of the phenomena included a rain band, a subtropical squall line, and a cold front. The Intensive Observation Periods were also individually analyzed as case studies. The meetings concluded with discussions of upcoming events and experiments.[139] The content of later meetings became more general after the meteorologists finished discussing the TAMEX findings in detail, and the participants' nationalities became more diverse too. Participants included more than just those who worked on TAMEX. In the 1991 International Conference on Mesoscale Meteorology and TAMEX, which was held in Taipei, there were scientists from Australia, Canada, India, South Korea, and Sweden. Some papers were coauthored by scientists from American and Taiwanese universities, the data TAMEX produced were thus indeed useful for both the United States and Taiwan. These papers discussed the similar weather phenomena in their respective countries, such as storm fronts, how clouds merge together, and precipitation systems.[140] The meetings thus had become a platform for discussing mesoscale convective systems as a general and worldwide weather hazard. They culminated in the 1993 International Workshop on Mesoscale Research and TAMEX

[139] Tai-jen Chen, "Together We Did Something We Should", 13; Taiwan Area Mesoscale Experiment Program, National Science Council (U.S.), National Science Foundation (U.S.), National Center for Atmospheric Research (U.S.) and National Science Foundation, *Workshop on TAMEX Scientific Results: Proceedings: 24-26 September 1990, Boulder, Colorado* (Boulder, CO.: Distributed by TAMEX U.S. Project Office, MMM Division, NCAR, 1990).

[140] The Meteorological Society of the Republic of China and the American Meteorological Society, *International Conference on Mesoscale Meteorology and TAMEX, December 3-6, 1991* (Taipei: Meteorological Society of the Republic of China, 1991), vii-xvi.

Program Review in Taipei.[141]

The meetings were also an opportunity for Japanese who had wished to participate in TAMEX to contribute unofficially. Meteorologists from Japan attended and presented at the meetings that discussed TAMEX results. For example, Masanori Yoshizaki from the University of Tokyo's Ocean Research Institute presented at the Workshop on TAMEX Preliminary Scientific Results in 1989, and at the 1991 International Conference on Mesoscale Meteorology and TAMEX.[142] Nobutaka Mannouji and Kazuo Kurihara from the Japan Meteorological Agency attended the 1990 Workshop on TAMEX Results and discussed one of the Intensive Observation Periods using the Japan Meteorological Agency's own Spectral Limited Area Model.[143] This type of model was first successfully designed in 1986. Its advantage was that while its resolution was high enough to handle mesoscale measurements, it did not take up a lot of computing power and was therefore less costly to run.[144] In other words, while the Japanese meteorologists did not participate officially in TAMEX, they did use government resources and newly-developed models to study TAMEX data. Nevertheless, the degree of cooperation between the Taiwanese and Japanese meteorologists would have been more fruitful had politics not interfered

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[141] Tai-jen Chen, "Together We Did Something We Should", 13.

[142] Taiwan Area Mesoscale Experiment Program, National Science Council (U.S.), National Science Foundation (U.S.), *Workshop on TAMEX Preliminary Scientific Results: Taipei, 22-30 June 1989* (Taipei, Taiwan: 1989), vii; The Meteorological Society of the Republic of China and the American Meteorological Society, *International Conference on Mesoscale Meteorology and TAMEX, December 3-6, 1991* (Taipei: Meteorological Society of the Republic of China, 1991), xiv.

[143] Taiwan Area Mesoscale Experiment Program, National Science Council (U.S.), National Science Foundation (U.S.), *Workshop on TAMEX Scientific Results: Proceedings: 24-26 September 1990*, ix.

[144] J. M. Hoyer, "The ECMWF Spectral Limited Model", proceedings at *Workshop on Techniques for Horizontal Discretization in Numerical Weather Prediction Models, 2-4 November 1987* (Shinfield Park, Reading: European Centre for Medium-Range Weather Forecasts, 1987), 343-344. http://www.ecmwf.int/sites/default/files/elibrary/1987/10050-ecmwf-spectral-limited-area-model.pdf.

with scientific relations. Thus, the international political environment might have been detrimental to scientific knowledge creation.

Future Collaboration Projects

Another long term contribution of TAMEX was that it provided opportunities for future collaboration projects. In 1995, two years after TAMEX ended, American meteorologists from the University Corporation for Atmospheric Research (UCAR) wanted to use GPS radio signals emitted from satellites to measure the atmosphere. Even though it had already conducted a test mission and proven that the concept was viable, when UCAR scientists proposed this scheme to the National Oceanic and Atmospheric Administration (NOAA), the plan was rejected. According to Kuo Ying-hwa, director of the program, this was because NOAA scientists adhered to the "traditional infrared and microwave satellite programs," and were not interested in incorporating radio satellites.[145]

Having developed a close working relationship with Taiwan, UCAR turned to the Taiwanese meteorologists for a collaboration project.[146] In 1995 when UCAR contacted Taiwan about the COSMIC program, Taiwan had already finished designing its first satellite FORMOSAT-1 and was developing its second satellite FORMOSAT-2. FORMOSAT-1 was launched in 1999 from the Kennedy Space Center.[147] Since Taiwan had no experience in satellites nor spaceflight before and

[145] Kuo, interview.
[146] Kuo, interview.
[147] "FORMOSAT-1: Launch System", National Space Organization, last modified 2016, accessed July 20, 2017, http://www.nspo.narl.org.tw/en2016/projects/FORMOSAT-1/launch-system.html

only started its space program in 1991, the National Space Organization sent 56 staff members to the American aerospace company TRW to learn about the construction, operation, and management of satellites. Half of the staff members also worked with TRW to develop FORMOSAT-1.This satellite studied the ionosphere to understand how it affected wireless communication, tested satellite communication at different data transfer rates, and took images of ocean color for research on the environment, fisheries, and developed areas.[148] FORMOSAT-2's development began in 1999 and was launched in 2004 to the Sun-synchronous orbit (891 kilometers). The National Space Organization developed its own image processing system, worked with Taiwanese industries, and contracted French aerospace contractor EADS Astrium to design and develop the satellite. When the satellite passed the earth during daytime, it captured both black-and-white, and colored images; when it passed through the dark side of the earth, it took images of the sprites (red flashes) and lightning in the upper atmosphere.[149] With FORMOSAT-1 developed and FORMOSAT-2 in development, the National Space Organization possessed the necessary support infrastructure and experience for collaborating with the United States on a satellite program.

UCAR's project was named the Constellation Observing System for

[148] "News and Events: Historical Events", National Space Organization, last modified 2016, accessed July 20, 2017, http://www.nspo.narl.org.tw/en2016/aboutNSPO/events.html; "FORMOSAT-1: Satellite", National Space Organization, last modified 2016, accessed July 20, 2017, http://www.nspo.narl.org.tw/en2016/projects/FORMOSAT-1/satellite.html; "FORMOSAT-1: Program Description", National Space Organization, last modified 2016, accessed July 20, 2017, http://www.nspo.narl.org.tw/en2016/projects/FORMOSAT-1/program-description.html.

[149] "News and Events: Historical Events", National Space Organization, last modified 2016, accessed July 20, 2017, http://www.nspo.narl.org.tw/en2016/aboutNSPO/events.html; "FORMOSAT-2: Satellite", National Space Organization, last modified 2016, accessed July 20, 2017, http://www.nspo.narl.org.tw/en2016/projects/FORMOSAT-2/satellite.html; "FORMOSAT-2: Program Description", National Space Organization, last modified 2016, accessed July 20, 2017, http://www.nspo.narl.org.tw/en2016/projects/FORMOSAT-2/program-description.html.

Meteorology, Ionosphere, and Climate (COSMIC) Program. In Taiwan, it was called FORMOSAT-3 and was managed by Taiwan's National Space Organization. Six microsatellites were launched into low earth orbit (700 to 800 kilometers) in 2006 and they have been collecting radio data since then. These satellites provide data about the whole world, even the polar regions.[150] They operate by measuring the delay of radio signals from twenty-four American GPS satellites. The delay would reflect the amount of "electric density, temperature, pressure, and water content in the ionosphere and atmosphere." Similarly, the satellites also transmitted radio signals to ground receivers for measuring electrical density and content in the trans-ionosphere region, which was below the satellites' orbital height. In addition, FORMOSAT-3 carried instruments that measured the density of electricity in the atmosphere.[151] Aside from these core objectives, the satellites also assisted in scientific research projects, such as studying ozone depletion, volcanoes, and distribution of moisture around the world.[152]

Since 2010, Taiwan's National Space Organization and the American NOAA have been working on a FORMOSAT-7, or COSMIC-2, a follow-up program of FORMOSAT-3 consisting of thirteen satellites. Using a similar measurement mechanism as FORMOSAT-3, the satellite group is expected to provide eight thousand data points on air pressure, temperature, and humidity from around the

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[150] "FORMOSAT-3: Achievements", National Space Organization, last modified 2016, accessed January 20, 2017, http://www.nspo.narl.org.tw/en2016/projects/FORMOSAT-3/achievements.html; "COSMIC - About Us", COSMIC Program Office, University Corporation for Atmospheric Research, last modified 2016, accessed January 20, 2017, http://www.cosmic.ucar.edu/about.html.

[151] "FORMOSAT-3: Payloads", National Space Organization, last modified 2016, accessed July 20, 2017, http://www.nspo.narl.org.tw/en2016/projects/FORMOSAT-3/payloads.html

[152] "COSMIC-1: FORMOSAT-3/COSMIC (COSMIC-1) Science Mission", COSMIC Program Office, University Corporation for Atmospheric Research, last modified January 2, 2017, accessed July 20, 2017, http://www.cosmic.ucar.edu/satStatus/index.html.

world. The new satellite clusters are set to be launched in 2017 and 2020. The project aims to provide more data for meteorological research, such as on hurricanes and the weekly and monthly weather oscillations in tropical climate (Madden-Julian Oscillation).[153]

Through providing manpower and financial support, Taiwan therefore provided an opportunity for American meteorologists to develop a project that might have been aborted for the lack of institutional support. The international collaborative relationships not only benefited Taiwan's meteorological field, it also gave Americans extra options and resources for the creation of knowledge. During TAMEX America assisted Taiwan, but during FORMOSAT-3 the relationship reversed. Taiwan was giving America the opportunities it needed for exploring a new way of measuring the atmosphere.

Another collaboration project resulting from relationship built during TAMEX was TAMEX II. The Taiwanese and the American meteorologists continued to work with each other on mesoscale weather measurements after TAMEX. From 15 May to 30 June 2008, the Americans and Taiwanese conducted an experiment called the Terrain-influenced Monsoon Rainfall Experiment (TimREX), but it was also named TAMEX II for the similarities. The programs were held in the same months albeit half a month shorter. They also had similar objectives. TAMEX II

[153] "FORMOSAT-7: Program Description", National Space Organization, last modified 2016, accessed April 12, 2017. http://www.nspo.narl.org.tw/en2016/projects/FORMOSAT-7/program-description.html; "News and Events: Historical Events", National Space Organization, last modified 2016, accessed July 20, 2017, http://www.nspo.narl.org.tw/en2016/info/events.html; "COSMIC-2: FORMOSAT-7/COSMIC-2 (COSMIC-2) Science Mission", COSMIC Program Office, University Corporation for Atmospheric Research, last modified August 29, 2016, accessed July 20, 2017, http://www.cosmic.ucar.edu/cosmic2/index.html; "Madden-Julian Oscillation (MJO)", Bureau of Meteorology, Australian Government, last modified 2017, accessed July 20, 2017, http://www.bom.gov.au/climate/mjo.

focused on studying how the low-level jet, mesoscale convective systems, and the *mei-yu* front interacted with each other. The experiment aimed to improve forecasting of heavy rain, so that the government and the general public could be warned about possible disasters such as flooding and landslides.[154]

Even though the objectives were similar, the scope of TAMEX II expanded compared with the first TAMEX. This time, the focus of study was southwestern Taiwan and the ocean near it, instead of northern Taiwan. While TAMEX only took mesoscale measurements, the meteorologists also wanted TAMEX II to understand the large-scale, the smaller "local-scale", and even the microphysical processes of how heavy rain formed and developed. The measurements taken were thus more detailed in TAMEX II. The length of forecast attempt was also extended from 12 hours during TAMEX, to 36 hours. Such extra details would allow meteorologists to study how the time of the day and the weather upstream of Taiwan affected the locations of heavy rain.[155]

Another difference between TAMEX and TAMEX II was the participants. This time, international relations was no longer a barrier to scientific investigations. Apart from the United States, Japan also formally joined the experiment. Even Mainland China, which twenty years earlier was trying to keep the P-3 airplane from flying to Taiwan, shared its "concurrent field experiments" data with TAMEX II. There also were concurrent programs in the area to provide detailed data from neighboring areas. During TAMEX II, Mainland China was taking measurements of

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[154] Wen-chau Lee, Jim Wilson, and Yi-leng Chen et. al., "Scientific Overview Document: TiMREX: Terrain-influenced Monsoon Rainfall Experiment", March 12, 2007, 1, 3. https://www.eol.ucar.edu/system/files/TiMREX_SCIENTIFIC_OVERVIEW_12MAR07.pdf

[155] *Ibid.,* 1, 6, 7.

the atmosphere over Tibet, and carrying out the China Heavy Rain Experiment. Japan too was carrying out two similar weather measurement projects over the Pacific Ocean near Okinawa and the Palau islands.[156] These concurrent projects allowed TAMEX forecasters not only to consider the atmospheric measurements of their own area of study, but also to consider atmospheric influences from further away.

Establishing communication with Chinese meteorologists

China's participation in TAMEX II was a result of years of effort on establishing communications between Mainland Chinese and Taiwanese meteorologists after TAMEX. Since 1979, the Taiwan government had been imposing a "three-no policy" concerning exchanges with China: no contact, no negotiation, and no compromise. When Taiwanese officials encountered Mainland Chinese at international meetings, they were expected to maintain no contact, no handshakes, but also no avoidance. Under this policy, the Taiwanese and Mainland Chinese meteorologists could not work with each other nor formally exchange weather data, despite being at the same East Asia geographical location and thus sharing weather and climate conditions.[157] Even though they had met at meetings in the Philippines and in Australia during the 1980s, there had not yet been any official

[156] *Ibid.,* 1, 10.

[157] Chih-pei Chang, "Mainland-Taiwan Meteorological Interaction: Memories of Ice-breaking 18 years ago", 12-13.

exchanges.[158]

In late 1987, Mainland Chinese meteorologists Tao Shi-yan and Ding Yi-hui from the Chinese Academy of Sciences initiated informal contact with their Taiwanese counterparts. The timing may have been coincident, but the norm-breaking during TAMEX's P-3 incident possibly set contact in motion. While visiting the Royal Observatory, Hong Kong, Tao and Ding expressed to the Hong Kong Observatory Director that they wished to begin exchanges with Taiwanese meteorologists in Hong Kong. Then a British colony, Hong Kong appeared to be a neutral and apolitical territory for conducting a first meeting.[159]

National Taiwan University's Atmospheric Sciences professor Chang Chih-pei learned about this and asked his colleagues and the Taiwan government officials for their opinion. Tsay and Wu, who participated in TAMEX, were supportive of the exchange prospects. Other meteorologists, however, were concerned that even if the meeting was held in Hong Kong, if it only involved mainland Chinese and Taiwanese meteorologists, the Taiwanese participants would be seen as communist sympathizers. Chang thus asked Richard Anthes (who also participated in TAMEX) for help.[160]

Anthes was supportive of the meeting. American participation would make the meeting international, which would keep Taiwanese meteorologists from being seen as communist-sympathizers, but it was mainland Chinese government's turn to

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[158] "Haixialiangan qixiang keji jiaoliu lishi huigu" 海峡两岸气象科技交流历史回顾 [Review of the History of Cross-Strait Meteorological Technology Exchange], Chinese Meteorological Society, accessed July 20, 2017 http://www.cms1924.org/WebPage/WebPage2_80_98_199.aspx.

[159] Chih-pei Chang, "Mainland-Taiwan Meteorological Interaction: Memories of Ice-breaking 18 years ago", 12-15.

[160] *Ibid.,* 12-13.

have reservations. They were worried that the meeting would create an impression that there were "two Chinas" or two countries: China and Taiwan. China did not recognize Taiwan as a country, nor did it want the international community to do so. To satisfy both the Taiwanese and the Chinese government, the meteorologists would all be attending the meeting as individuals and by invitation by the Hong Kong Observatory Director. Even the mailing addresses of the participants had to omit the organization's name.[161]

The meeting might have been cancelled if not for Zou's intervention mentioned in the previous chapter. On June 4th, 1989, student protests at the Tiananmen Square in Beijing were violently suppressed by the Chinese military. The Chinese government was sensitive about any form of exchanges outside the country, and announced that the Chinese meteorologists would not be traveling to the July meeting. This only changed after Zou Jing-meng's assistance. As the President of the World Meteorological Organization and the adopted son of former Premier Zhou En-lai, Zou was influential enough to convince the administration to let the mainland meteorologists travel to Hong Kong.[162]

The meeting was entitled "International Conference on East Asia and West Pacific Meteorology and Climate", and was successfully held in July 1989. This was followed by a second meeting in 1992.[163] After the second meeting, the mainland Chinese Meteorological Society invited Chen Tai-jen to visit China. Chen was the

[161] *Ibid.,* 13-14.
[162] *Ibid.,* 14-18.
[163] *Ibid.,* 17-18.

Director of the Meteorological Society of the Republic of China.[164] From 1994, exchanges between Taiwanese and mainland Chinese meteorologists bypassed Hong Kong. Meteorologists visited each other and held scientific conferences on such topics as disaster prevention technology, monsoon wind, droughts, typhoons, and heavy rain. The lack of contact between the meteorologists for four decades meant that they used different terms for the same weather phenomena. Thus, there also were five meetings held for sorting out the semantic differences.[165]

In 2015, Taiwan and China finally signed a formal agreement institutionalizing information exchange on earthquakes and weather.[166] The agreement entitled "Cross-Strait Collaboration Agreement on Meteorology" stipulated that the meteorological departments would exchange real time weather data, and set up direct communication channels during extreme weather events, such as "typhoons, torrential rains, heat waves and cold waves" in the area. In addition, the Taiwanese and mainland Chinese meteorologists would carry out joint projects on extreme weather "observation, monitoring and experiments",

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[164] "Review of the History of Meteorological Technology Exchange between mainland China and Taiwan", Chinese Meteorological Society, accessed July 20, 2017. http://www.cms1924.org/WebPage/WebPage2_80_98_199.aspx

[165] "Minguo 83-98 nian liangan qixiang xueshu jiaoliu jilu" 民國 83~98 年兩岸氣象學術交流記錄 [Record of Cross-Strait Academic Meteorological Exchange in 1994-2009], MSROC, last modified 2013, accessed July 20, 2017, http://www.msroc.org.tw/index.php?content=active2

[166] Department of Navigation and Aviation, "Haixialiangan dizhen jiancha hezuo xieyi ji haixialiangan qixiang hezuo xieyi zhiri shengxiao shishi" 「海陝兩岸地震監測合作協議」及「海峽兩岸氣象合作協議」即日生效實施 [Cross-Strait Collaboration Agreement on Earthquake Monitoring and Cross-Strait Collaboration Agreement on Meteorology are Effective from Today], June 24, 2015, accessed July 20, 2017, http://www.motc.gov.tw/ch/home.jsp?id=14&parentpath=0,2&mcustomize=news_view.jsp&dataserno=201506240004; Cross-Strait Collaboration Agreement on Meteorology, Straits Exchange Foundation Association for Relations Across the Straits, China-Taiwan, February 27, 2014, http://www.mac.gov.tw/public/Data/45716402971.pdf

meteorological service technologies research, and organize annual meetings.[167] Interestingly, the agreement did not specify which organizations were responsible or allowed to conduct these activities. The lack of restrictions implied that governmental organizations such as the Central Weather Bureau, and academic meteorological departments alike could take part in such systematic exchanges.

Much like how the United States and China normalized relations beginning with the Ping Pong diplomacy at which American and mainland Chinese table tennis delegations visited each other, exchanges between mainland China and Taiwan also started in practical areas. Meteorological exchange was one such area. The pretext for the scientific exchanges was based on practical justifications, such exchanges were in turn seized as the means to normalize relations. For instance, when Taiwanese and mainland Chinese meteorologists formally met for the first time in Hong Kong, they used the pretext that they were traveling on an individual basis as scientists attending a conference on East Asian meteorology. It was only after years of meetings that the two sides finally set up a formal channel of communication, signified by the Cross Strait Collaboration Agreement. Still, the stated objectives of the Cross-Strait Agreement perpetuated the practical rhetoric and argued that formal collaboration would improve the weather bureaus' abilities to "analyze, forecast, and mitigate against" weather disasters, so that "the wellbeing and safety of citizens from both sides of the strait."[168] Such justification could only be

[167] Cross-Strait Collaboration Agreement on Meteorology, Straits Exchange Foundation Association for Relations Across the Straits, China-Taiwan, February 27, 2014.

[168] Department of Navigation and Aviation, "Cross-Strait Collaboration Agreement on Earthquake Monitoring and Cross-Strait Collaboration Agreement on Meteorology are Effective from Today".

convincing when based on the years of unofficial collaboration. At times of official negotiation, the collaborations were concrete examples to support the establishment of communication channels. The negotiations resulted in more than just opening official communications channels. The negotiation process also was communication opportunities for the two diplomatic agencies of the strait. In this instance, the Cross-Strait Agreement was negotiated not by the meteorological agencies. The Straits Exchange Foundation of Taiwan and the Association for Relations Across the Taiwan Straits were the governmental departments responsible for organizing, negotiating, and signing this agreement. Thus, beginning with practical pretexts, scientific exchanges were transformed into diplomatic opportunities.

To conclude, practically, TAMEX brought scientific contributions in the form of better understanding of *mei-yu,* and a new computerized forecast system. Taiwan's meteorological field also gained international exposure through conferences and publications. These opened up opportunities to future collaboration projects, including the COSMIC program and TAMEX II. After TAMEX, mainland Chinese and Taiwanese meteorologists began establishing informal contacts, signified in the July 1989 conference in Hong Kong. Citing practical reasons as justifications, subsequent meetings intensified contact. The exchanges became opportunities for the normalization of relations through the setting up official communication channels.

Conclusion

The Taiwan Area Mesoscale Experiment was initiated as a response to the "528" disaster which brought destruction and casualties. The institutions and technology utilized in TAMEX grew out of decades of experience accumulated in Taiwan, Japan, and the United States. The Japanese who assisted in TAMEX were experienced in large-scale research and in the same *mei-yu* weather phenomenon; the American meteorologist and meteorological institutions that participated in TAMEX likewise were knowledgeable about international meteorological field experiments. Taiwan had not yet conducted any large-scale programs before TAMEX. However, they had already set up institutions for meteorological observations, teaching, and research. Of these, the governmental ones were given the most resources. By the 1980s, the Taiwanese meteorologists understood the basic causes and structures of *mei-yu*, and had pinpointed areas for further research. When the Taiwanese meteorologists looked for assistance in TAMEX, they mobilized multiple types of justifications. Better understanding of heavy rain was a scientific reason repeatedly used. In addition, practical justifications, such as crops damages, heavy rain's effect on GDP, and improved forecast accuracy were cited.

The major phase of TAMEX took place from May to June 1987. American and Taiwanese meteorologists collaborated in taking measurements of the atmosphere over and near Taiwan. While the meteorologists were willing to work with each other, the project faced political obstacles owing to Taiwan's unofficial diplomatic relations with Japan and the United States. In spite of this, the meteorologists worked around the constraints and explored informal channels to collaborate. The

Japanese participated by attending conferences, and the P-3 airplane flew over Taiwan but was stationed in Okinawa. In this instance, political tensions were overcome by the desire to conduct scientific research for better understanding and forecast of the *mei-yu.*

Through TAMEX, the meteorologists built a network of collaboration that carried on beyond the project. Scientifically, the weather data collected satisfied TAMEX's objectives, improved *mei-yu* forecast accuracy, and sped up Taiwan's weather forecasting system's computerization with the setting up of the Weather Integration and Nowcasting System. Importantly, TAMEX set up and consolidated Taiwanese meteorologists' international network. The publications, conferences, and personal contacts increased Taiwan meteorology's international exposure, and opened up further collaboration opportunities. From the beginning of TAMEX, the Taiwanese meteorologists were working with their American colleagues. During TAMEX and especially at conferences, the Taiwanese collaborated informally with the Japanese meteorologists. The Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) Program and TAMEX II were direct outgrowths of the experience and relationships accumulated during TAMEX. In addition, the necessary interaction between Taiwan's and mainland China's meteorologists helped open the door to the normalization of relations. In the 1990s, the Taiwanese meteorologists finally began forming collaborative relationships with their Chinese counterparts. Thus, this thesis argues that disasters management and research could help overcome political tension, build international networks, and lead to the normalization of relations.

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Curriculum Vitae

Yin Hang Phoebe Tang was born in Hong Kong on July 5, 1989. She obtained a Bachelor of Arts in History in 2011, and a Master of Philosophy in History in 2013 from the University of Hong Kong. She worked as a Teaching Demonstrator from 2013 to 2015, during which she led undergraduate class discussions, helped organize conferences, and provided technical support. She completed an MA in History of Science and Technology at the Johns Hopkins University in 2017.