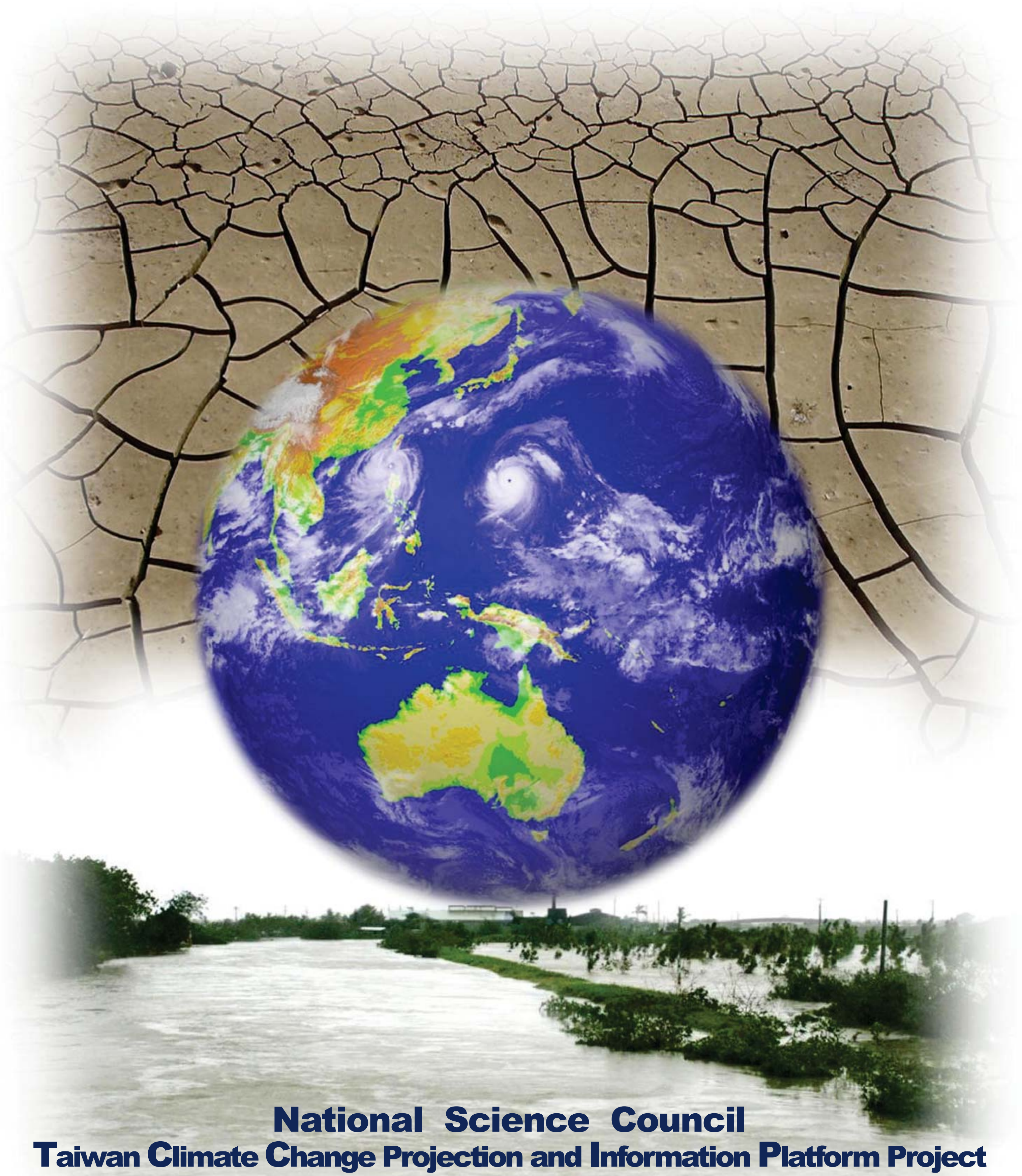
Climate Change in Taiwan : Scientific Report 2011

(Summary)



National Science Council

Taiwan Climate Change Projection and Information Platform Project

November 2011

Climate Change in Taiwan: Scientific Report 2011

(Summary)

This Summary should be cited as:

Hsu, Huang-Hsiung, Chia Chou, Yi-chao Wu, Mong-Ming Lu, Cheng-Ta Chen, Yung-Ming Chen, 2011: *Climate Change in Taiwan: Scientific Report 2011 (Summary)*. National Science Council, Taipei, Taiwan, ROC, 67pp.

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INTRODUCTION

Introduction

The Intergovernmental Panel on Climate Change (IPCC) published its fourth Assessment Report (IPCC AR4) in 2007, which discussed climate change in the last 100 years and the possible impact of continuous warming over the next 100 years. The report indicated that, in the last 100 years, global mean surface temperatures have risen by 0.74°C, the rate of warming is accelerating, the sea level has risen, and the frequency and intensity of extreme events such as heat waves, droughts, and heavy rains have increased (IPCC, 2007). The United Nations (UN) has repeatedly called on governments worldwide to reduce greenhouse gas emissions to slow down global warming, to acknowledge the impact of climate change, and to implement adaptation measures. Taiwan is in an area that is at high-risk for natural disasters. The impact of climate change is a major concern to the government and the public. Climate change and homeland security have become critical issues that cannot be ignored.

Three core issues related to global warming (Figure 1) are **science**, **mitigation,** and **impact and adaptation**. Science emphasizes the importance of climate change observation, scientific question clarification, and future climate change projections. Mitigation focuses on controlling or reducing greenhouse gas emissions through policymaking, industrial transformation, and advances in scientific techniques. Impact and adaptation assesses the extent of climate change effects and evaluates how people should prepare for and implement adaptive mechanisms to reduce these effects even global warming can be reduced, we will still experience the impact due to the long-lived greenhouse gases. The current status of the development of these three issues and the background to this report are described in the following sections.

Regarding **mitigation**, average CO_2 emissions per person in Taiwan are much higher than the global average and also higher than the average in neighboring countries. Although Taiwan is neither a member of the UN Framework Convention on Climate Change nor a signatory to the Kyoto Protocol, the government consistently acts to reduce global warming. The government has set national emission reduction targets, promulgated the Sustainable Energy Policy Convention, and drafted the Greenhouse Gas Reduction Act. It is expected to consider economic development and environmental sustainability while achieving energy conservation and carbon reduction goals.

To **adapt** to climate change, the UN Development Programme-Global Environment Facility proposed the Adaptation Policy Framework for Climate Change as a reference for every country to plan its own adaptive strategies. It also assists governments in considering climate change adaptation when establishing national development policies. After the 2010 implementation plan for the National Adaptation Policy Framework and Adaptation Programmes of Action for Climate Change, Taiwan’s Council for Economic Planning and Development developed a national adaptation strategy framework and implemented a substantial action plan that accounts for aspects of climate change such as natural disasters, water resources, coasts, agricultural production and biodiversity, health, infrastructure, energy supply and industrial economics, and land-use planning and management.

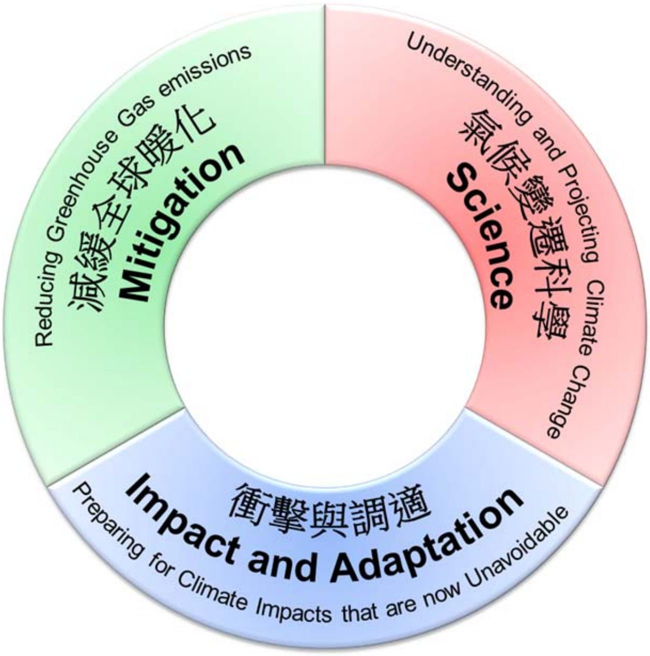


Figure 1: Three core global warming issues from the IPCC Climate Change Report.

Regarding **science**, Taiwan’s National Science Council (NSC) has accumulated research from long-term local climate change projections and impact research. Because the effects of climate change on Taiwan are likely to increase, the country requires more scientific data and research results to inform climate change adaptation policies. The conclusion of the session “Linking Technological Capabilities, Promoting Sustainable Development” at the Eighth National Science and Technology Conference in 2009 emphasized the importance of three activities: advancing climate change simulation and prediction skills and capabilities, publishing a scientific climate change report, and assessing the risks of climate change effects. Therefore, at the end of 2009, the Sustainable Development Research Committee of Taiwan’s NSC launched the Taiwan Climate Change Projection and Information Platform Project (TCCIP, 2010 to 2012). The project promotes climate change research and integrates climate change impact applications. It aims to enhance climate change research in Taiwan, to consolidate the capacity for climate change research and projection, and to implement climate change information applications and services. This scientific report, coauthored by the scholars and experts participating in the project, reviews and integrates current and past research results and scientific advances to provide the most up-to-date information on global and Taiwanese climate change. This report is valuable for academic research and government climate change policy making.

The 3-year TCCIP was planned and implemented by the National Science and Technology Center for Disaster Reduction (NCDR). It is a collaboration among institutions such as the Central Weather Bureau (CWB), Research Center for Environmental Changes in Academia Sinica, National Taiwan University, and National Taiwan Normal University. The project integrates Taiwanese research resources to project future climate change and assess the impact of disasters in Taiwan. Figure 2 shows the TCCIP framework and organizations.

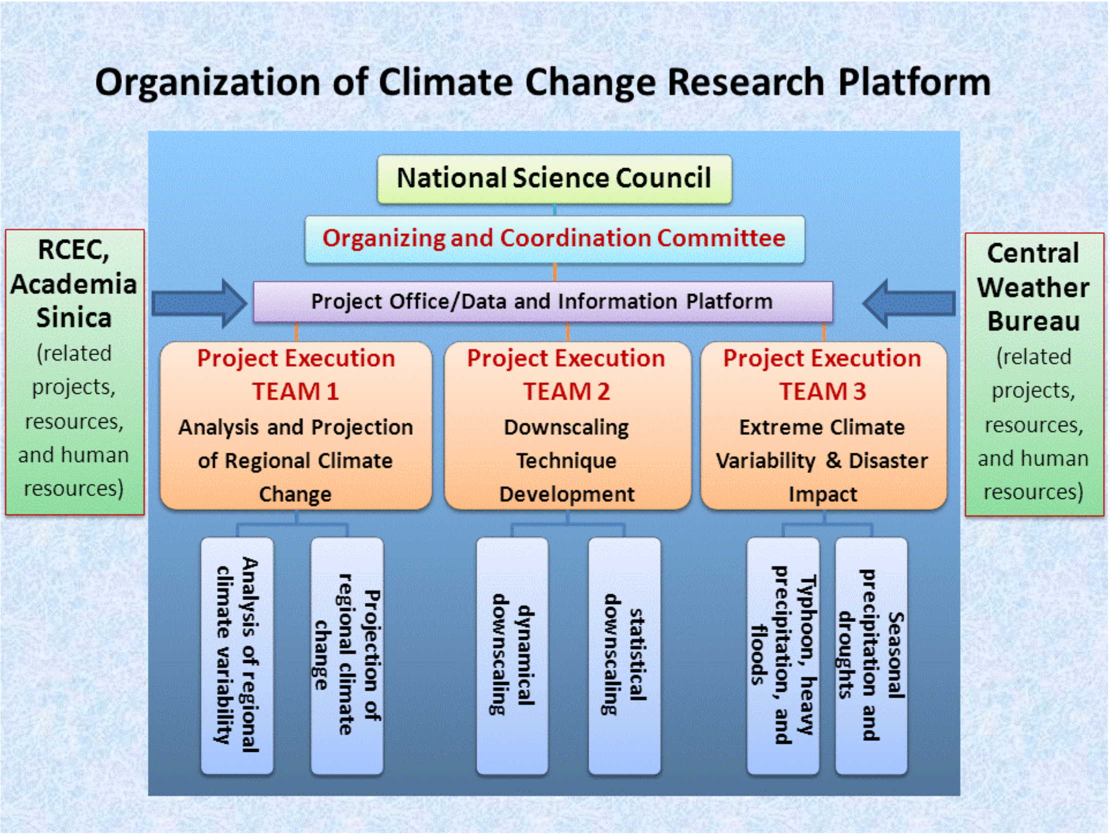


Figure 2: TCCIP framework and organizations.

The overall objectives of the TCCIP include establishing an integrated interdisciplinary climate change research and application platform, applying research and development results to inter-ministerial adaptation policies, projecting future climate change in Taiwan, and strengthening climate research in Taiwan. To achieve these goals, the project analyzes and projects regional climate change, develops downscaling techniques, and assesses extreme climate and disaster impact.

The TCCIP also analyzes the results from the IPCC AR4 and applies statistical downscaling to 24 Global Climate Models (GCMs) from the IPCC AR4to obtain regionally downscaled results for Taiwan. The TCCIP also applies dynamical downscaling approaches to high-resolution (20 km) GCM simulations from Japan's KAKUSHIN Program to project extreme climate and weather events during future climate conditions in Taiwan.

The results in this scientific report are mainly based on research results from the first year of the TCCIP. Because the TCCIP is ongoing and continues to conduct climate change research, an updated report on the most current scientific advances and the latest project progress will be published after the project ends.

This full scientific report covers a wide range of topics and consists of six chapters. The first chapter reviews and summarizes the most current global climate change research, focusing on the IPCC AR4 results and subsequent research. Because climate change in Taiwan is affected mainly by East Asian and western North Pacific climate systems, Chapter 2 reviews and summarizes the climate change research in these regions to understand regional climate change and its effects on Taiwan. When interpreting scientific data related to climate change, it is necessary to distinguish between natural climate variability (e.g. ENSO and interdecadal variability) and anthropogenic climate change. Chapter 3 clarifies this difference and discusses the current research results. Based on research results and the latest analyses, Chapter 4 describes and analyzes past trends and variations in Taiwan's climate. Chapter 5 discusses future climate change projections, including the latest climate change projections for the world, East Asia, and Taiwan. The uncertainty of climate change projection is also explained. Chapter 6 illustrates the effects of climate change (especially increases in extreme events) and environmental change (e.g. anthropogenic environmental change and population and economic growth) on the impact of disasters. It concludes that these two are essential factors leading to increases in disaster losses and changes in disaster characteristics both globally and locally.

This abridged version of the scientific report is divided into two parts. To help readers understand the main topics, the first part summarizes the most important points from the full report. The second part addresses five critical issues related to climate change in Taiwan. The original report consists of six chapters and is 362 pages long. Readers who wish to read the full report may download it at http://satis.ncdr.nat.gov.tw/ccsr/index.files/introduce.htm.

TECHNICAL SUMMARY

Global Climate Change

East Asian and Western North Pacific Climate Change

Interdecadal Climate Variation

Climate Change in Taiwan

Projection of Future Climate Change

Climate Change and Disasters

Technical Summary

Global Climate Change

1. Global surface temperature has increased by approximately 0.74°C in the past century (1906 to 2005) (Figure 3, IPCC 2007).

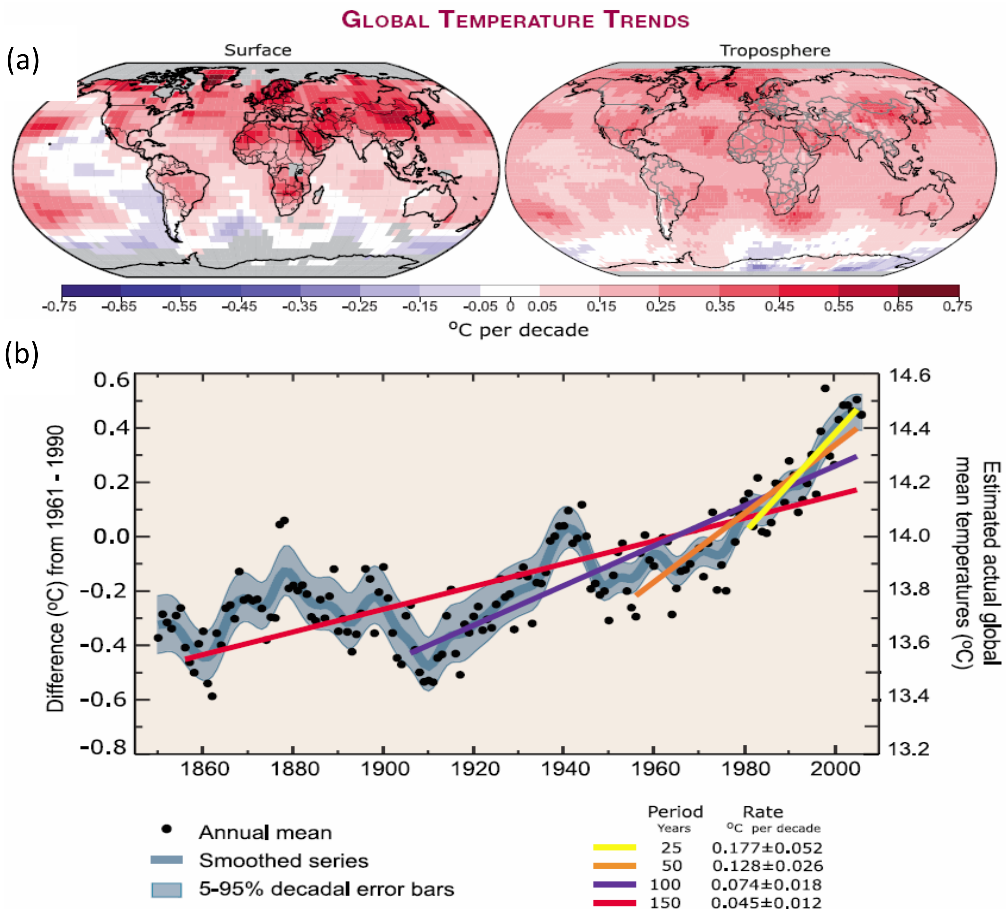


Figure 3: (a) Linear global temperature trends from 1979 to 2005 estimated at the surface (left) and the troposphere using satellite records (right). Gray indicates areas with incomplete data. (b) Annual global mean temperatures (black dots) and estimated linear trends. The left axis shows temperature anomalies relative to the 1961 to 1990 average, and the right axis shows estimated actual temperatures. Linear trends are shown for the last 25 (yellow), 50 (orange), 100 (purple), and 150years (red). The smooth blue curve shows decadal variations (see Appendix 3A), with the decadal 90% error range shown as a pale blue band surrounding the curve. Source: IPCC AR4, Figure TS.6 (IPCC 2007).

2. Other changes, such as sea level rise and sea ice melting, were also observed. Global-mean sea level rose approximately 77 mm from 1961 to 2003, with an average rate of 1.7 mm yr^{-1}. However, the rate increased to 3.1±0.7 mm between 1993 and 2003, showing that the rate of sea level rise is accelerating **(Figure 4)**.

3. Changes in mean and extreme precipitation are highly uncertain. No consistent conclusion has been drawn.

4. After the IPCC AR4 was published in 2007, many global hydrological cycle studies were published. Generally, global precipitation is increasing, but the amount is uncertain. The intensity and frequency of heavy precipitation have also increased. A general feature but with spatial variations is identified: Wet areas are becoming wetter, and dry areas are becoming drier.

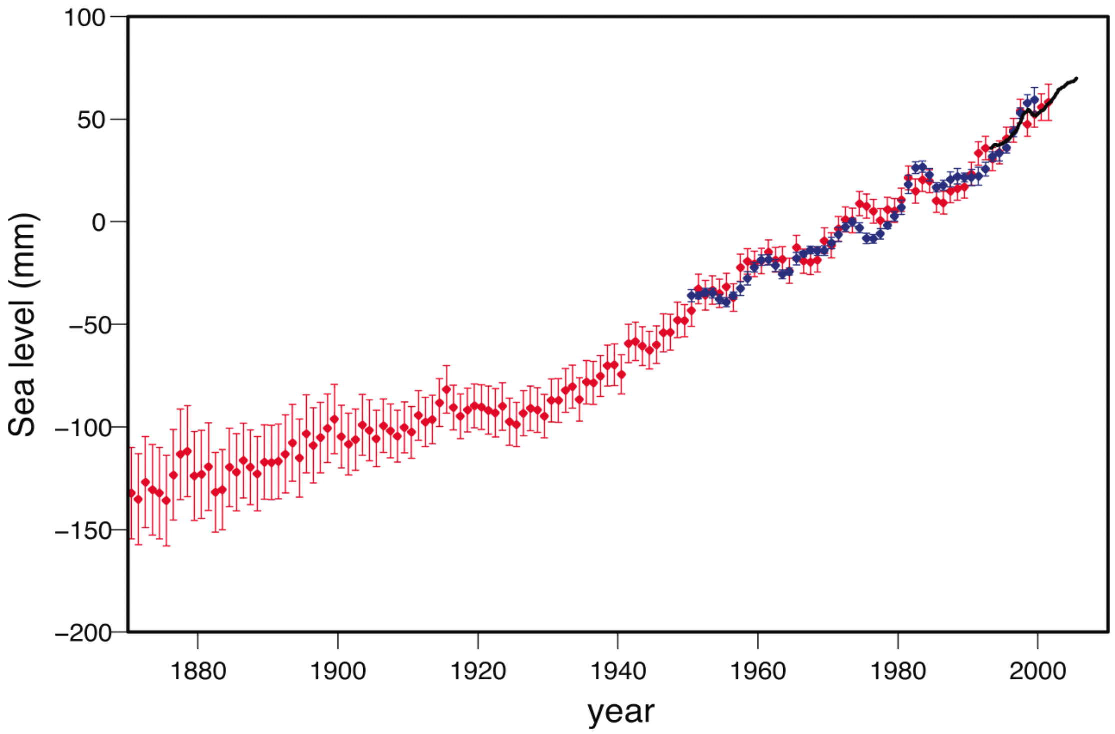


Figure 4: Annual global mean sea level based on reconstructed sea level data since 1870 (red), tide gauge measurements since 1950 (blue), and satellite altimetry since 1992 (black). Units are in mm relative to the average for 1961 to 1990. Error bars indicate 90% confidence intervals. Source: IPCC AR4, Figure 5.13 (IPCC 2007).

East Asian and Western North Pacific Climate Change

1. Since the 1950s, the East Asian summer monsoon (EASM) has been weakening (Guo et al. 2003). Some studies have argued that the EASM has not actually weakened, but the southward shift of the summer rain belt makes it seem as if the EASM is weakening (Zhai et al. 2004, Li et al. 2010). Other studies have argued that the EASM has changed concurrently with the 1976/1977 climate regime shift (Wang 2001) and that it is closely related to ENSO variations of that period (Huang et al. 2003, Qian et al. 2003).

2. When examining the last 100 years (1873 to 1995) (Gong and Wang 1999) or the last 50 years (Chen et al. 2000, Shi 1996, Kang et al. 2006, Cui and Sun 1999), a weakening trend in the East Asian winter monsoon emerges.

3. Since 1948, the land surface in East Asia (especially Northern and Eastern China) and the entire subtropical Western North Pacific have warmed significantly **(Figure 5)**.

4. In East Asia, precipitation trends to exhibit notable regional differences. However, these trends are insignificant in most regions.

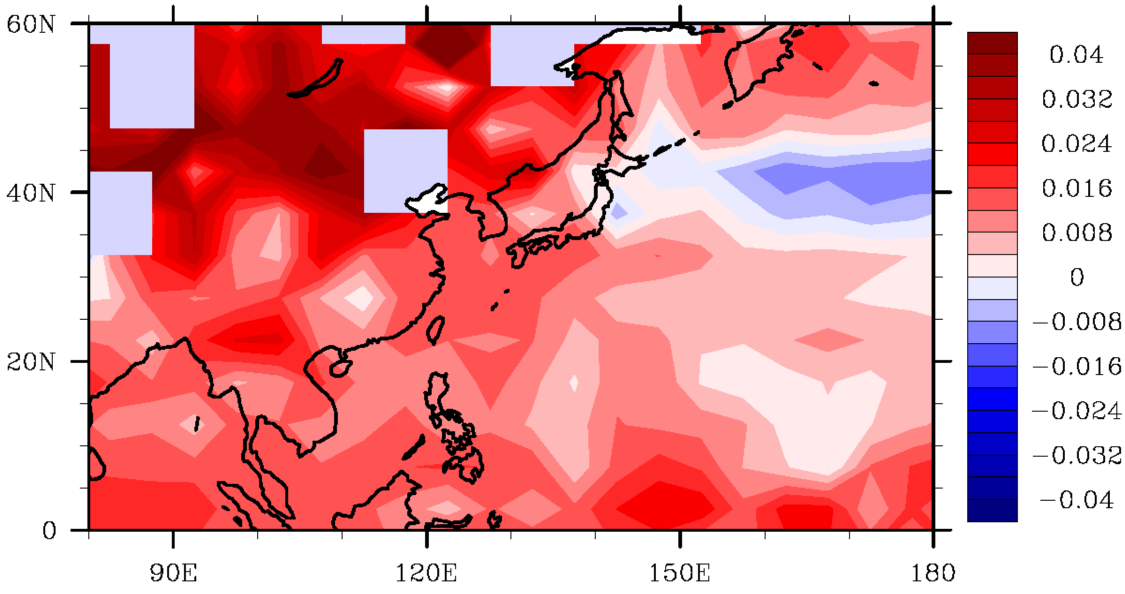


Figure 5: Long-term annual meansurface temperature and sea surface temperature trends ($^{\circ}C\ yr^{-1}$) in East Asiafrom 1948 to 2009. Trends were calculated using HadCRUT 3 (Brohan et al. 2006). Source: TCCIP project

5. Regarding the formation, intensity, track, and associated precipitation and

landfall activity of tropical cyclones (typhoons) in the Western North Pacific, the World Meteorological Organization's Expert Team on Climate Change Impacts on Tropical Cyclones concluded that the limited availability and quality of global historical observations on tropical cyclones make it uncertain whether changes in tropical cyclone activity have exceeded naturally expected variations. Identifying anthropogenic influences on tropical cyclone activity is currently difficult (Knutson et al. 2010).

- ☉ The annual number of tropical cyclones has varied considerably in decadal time scale since 1951 (**Figure 6**) (Yumoto and Matsuura 2001) and a significant decreasing trend emerges from 1961. However, no significant linear trend exists if a shorter period (e.g. from 1970) is considered (Webster et al. 2005).
- ☉ Some observational studies (Webster et al. 2005; Emanuel 2005) have reported that the intensity and number of intense tropical cyclones have increased from anthropogenic influences. These findings have been contested by other studies, mainly because of data consistency concerns (Wu et al. 2006, Kamahori et al. 2006, Kossin et al. 2007, Song et al. 2010) and the short data analysis period relative to periods of interdecadal variability (**Figure 7**) (Chan and Liu 2004, Chan 2006, 2008). Based on these disagreements, it is uncertain whether anthropogenic influences caused these changes in tropical cyclone intensity (Knutson et al. 2010).
- ☉ Since the 1960s, tropical cyclone tracks have experienced two abrupt shifts. Both shifts occurred approximately 2 years after the Pacific climate regime shifts in 1976/1977 and 1998 (Ho et al. 2004, Wu et al. 2005, Liu and Chan 2008, Tu et al. 2009). It is unclear whether a significant linear trend in tropical cyclone tracks exists.
- ☉ The number of tropical cyclones that made landfall in the Philippines from 1902 to 2005 (Kubota and Chan 2009) and in the coastal regions of East Asia from 1945 to 2004 (Chan and Xu 2009) shows no significant linear trends.

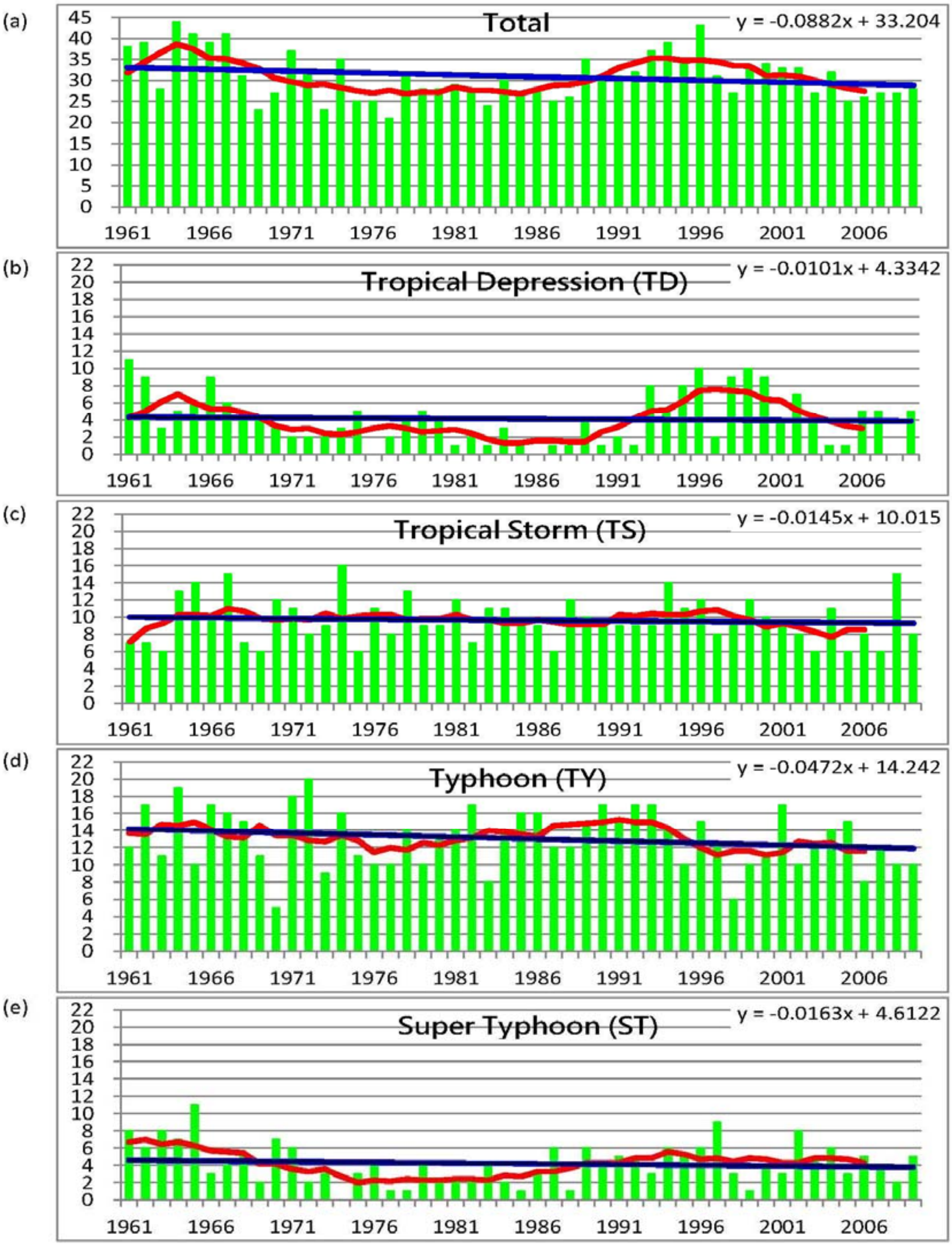


Figure 6: Interannual variation in tropical cyclone formation in the Western North Pacific from 1961 to 2009. (a) Number of tropical cyclones. Number of tropical cyclones with maximal intensity of (b) tropical depressions, (c) tropical storms, (d) typhoons, and (e) super typhoons. The intensity classification is based on the Joint Typhoon Warning Center (JTWC) definition. Blue lines show linear trends in the last 49 years, and red lines show 7-year running averages. Linear trends in (a) and (d) pass the 10% significance test. Source: TCCIP project

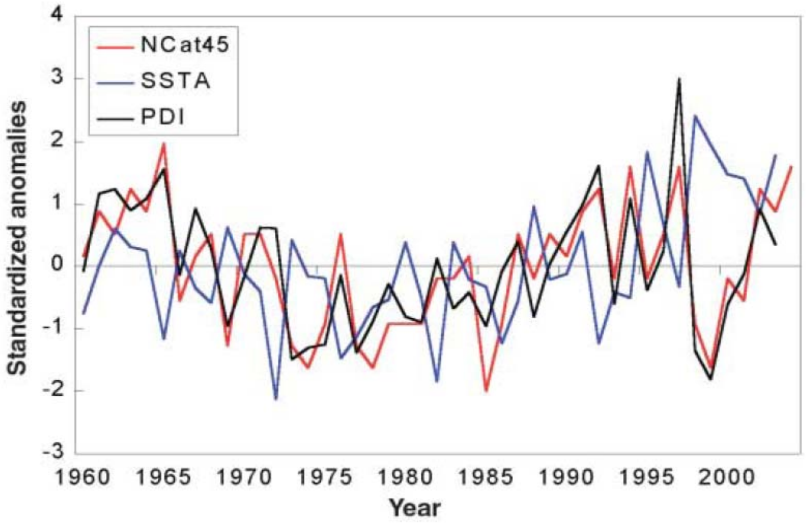


Figure 7: Long-term variation in the Potential Destruction Index (PDI), number of Category 4 and5 tropical cyclones (according to the Saffir-Simpson scale) in the western North Pacific (NCat45), and sea surface temperature anomalies averaged between May and November in the area 5°N to 30°N, 120°E to 180°E. All variables are normalized with respect to their standard deviations. Source: Chan (2006)

Interdecadal Climate Variation

1. In addition to the centennial warming trend in the last 100 years, the global-mean surface temperature has fluctuated in multidecadal time scales; for example, it warmed from the beginning of the twentieth century to the 1940s, cooled between the 1950s and 1970s, and warmed after 1980s **(Figure 8)** (Wu et al. 2007). Rainfall has also varied between decades, but with significant regional differences **(Figure 9)**.

2. The conclusion of the IPCC AR4 (2007) on accelerating warming in the last few decades does not account for the possible contribution of multidecadal oscillation. **Figure 10** shows that in the last 30 years Atlantic Multidecadal Oscillation was in the developing stage of a positive phase (i.e. a warming tendency). Its imposition on the centennial warming trend has probably led to the impression of an accelerating warming trend. It is important to account for the effects of multidecadal oscillation when examining past climate change and projecting future climate change. Multidecadal oscillation contributes to relatively short periods of climate variation, but anthropogenic greenhouse effects lead to long-term climate variation. Multidecadal fluctuation, which can contribute to more accurate climate projections, should not be ignored. Multidecadal fluctuation and decadal prediction research are important issues

and will be addressed by the IPCC Fifth Assessment Report.

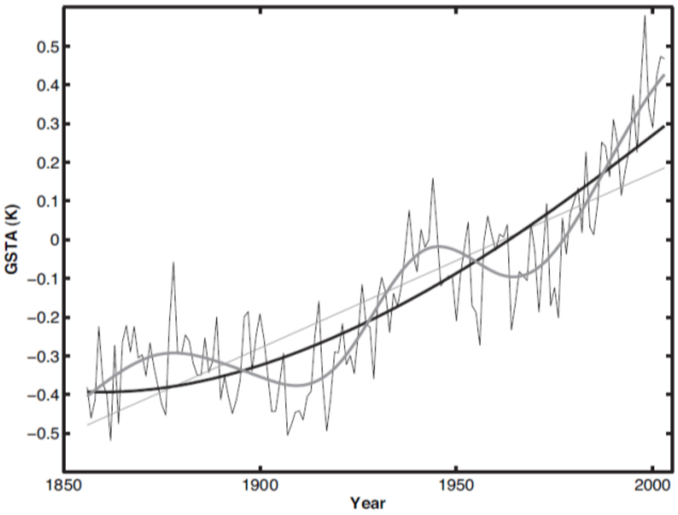


Figure 8: Variations in global mean surface temperature anomalies (with respect to the 1960 to 1999 base period). Lines and curves shown include interannual variation (thin black line), linear regression (gray straight line), the overall adaptive trend calculated using Empirical Mode Decomposition (black curve), and the overall adaptive trend added by multidecadal oscillation (thick gray curve). Source: Wu et al. (2007)

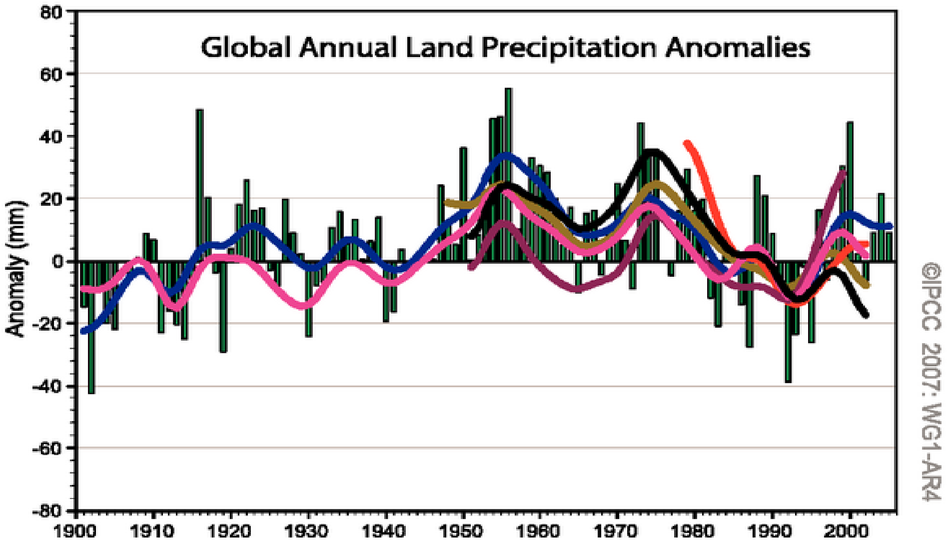


Figure 9: Annual global land precipitation anomalies with respect to the1961 to 1990 base period for 1900 to 2005. The smooth curves show decadal variation from different datasets. Source: IPCC AR4, Figure TS.9 (2007)

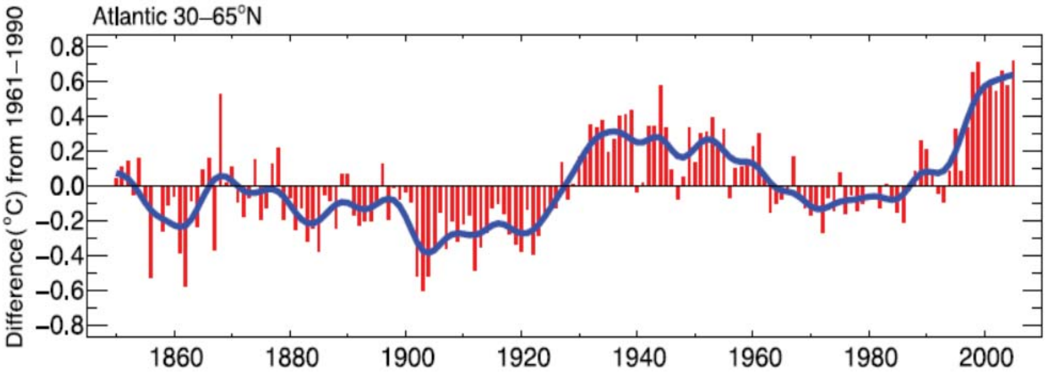


Figure 10: Interannual variations in average North Atlantic sea surface temperatures from 30°N to 65°N. Source: Trenberth et al. (2007)

3. Multidecadal fluctuations and the centennial warming trend are not contradictory. Whereas multidecadal oscillation has been most significant in the extra tropical Northern Hemisphere (Ting et al. 2009), mean surface temperatures in the Southern Hemisphere and global mean sea level have exhibited a long-term upward trend with weak multidecadal fluctuation in the last 100 years **(Figure 11c)**. Theoretically, anthropogenic warming signals are retained better in the ocean than land because of the larger heat capacity of sea water and its longer climate memory. It is likely that the increasing trends in the Southern Hemisphere mean sea surface temperature and the global mean sea level reflect better the anthropogenic warming effect (Carton et al. 2005).

4. The anthropogenic greenhouse effect has been a major contributor to warming in the last few decades. Recent observation shows that anthropogenic greenhouse gas emission has not decreased since the Kyoto Protocol; instead, it has been increasing more rapidly since then. Warming from the anthropogenic greenhouse effect is evident, and most climate models indicate that its impact is larger than that caused by observed natural factors. It is fair to conclude that global warming in the last 100 years has been partially caused by the anthropogenic greenhouse effect.

5. IPCC AR4 (2007) reported that projected future warming, based on different emission scenarios, will be between 1.1°C and 6.4°C, which is much larger than the effects of multidecadal fluctuation and the short-term cooling effects of volcanic eruption. Even if an event equivalent to the Little Ice Age from the Maunder Minimum occurs, it may cause cooling of approximately 0.3°C, which is less than the projected anthropogenic warming (Feulner and Rahmstorf 2010).

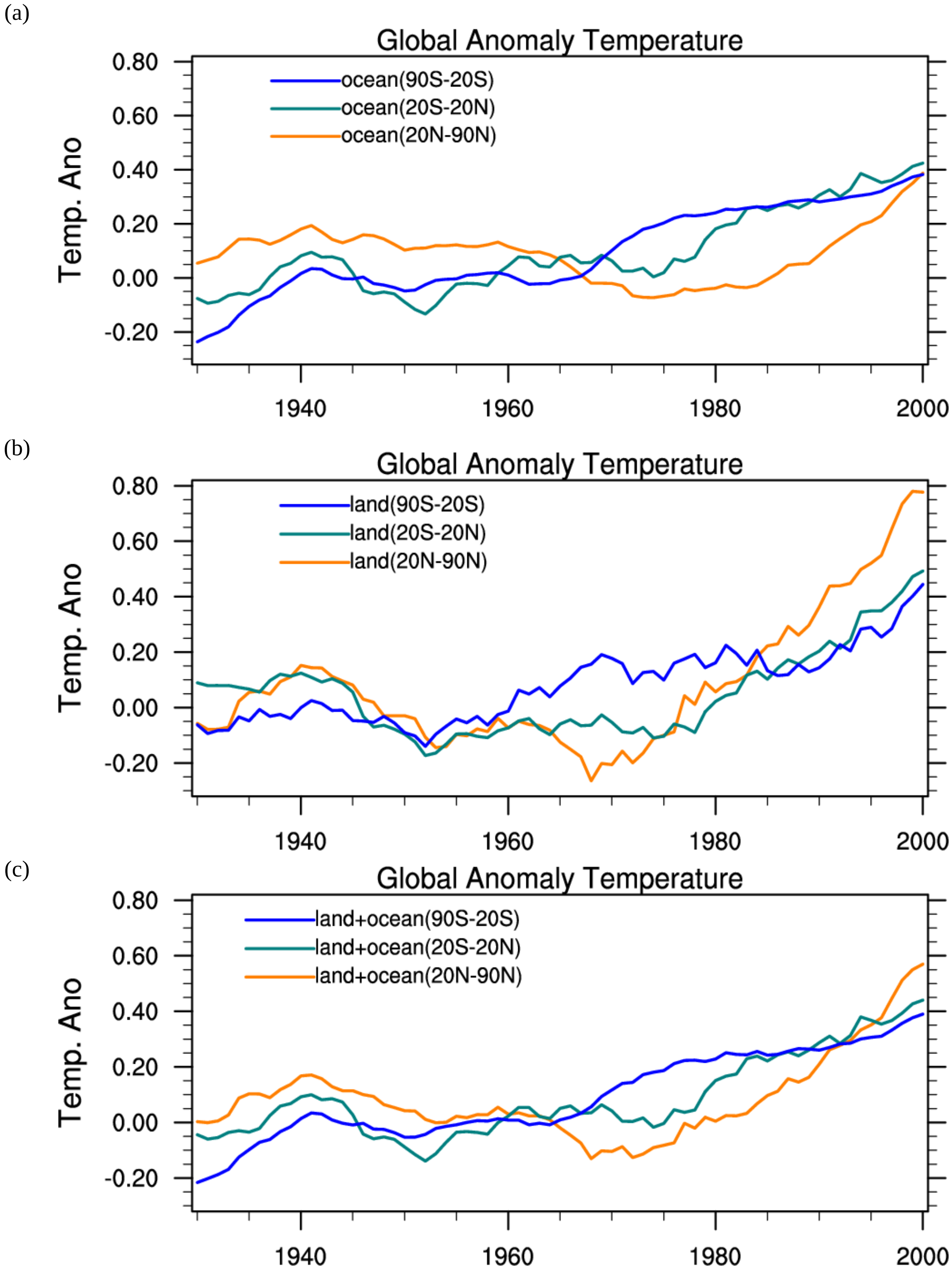


Figure 11: Long-term variation in mean surface temperatures over the (a) ocean, (b) land, and (c) ocean and land in the Southern Hemisphere (20°S to 90°S), tropics (20°S to 20°N) and Northern Hemisphere (20°N to 90°N). Source: TCCIP Project

6. In summary, anthropogenic global warming will be larger than the natural variation observed in the last 100 years if anthropogenic greenhouse gas emissions cannot be suppressed. If a catastrophic event similar to an Ice Age occurs in the future, it may suppress the projected warming trend. However, such an event cannot be predicted and is undesirable. Suppressing anthropogenic greenhouse emissions must be achieved to minimize the impact of future global warming on the earth's ecological environment. Suppressing anthropogenic greenhouse gas emission to decelerate the increasing rate of greenhouse gas concentration in the atmosphere is mankind's most important issue and greatest challenge.

Climate Change in Taiwan

1. Continuous instrumental measurement of climate parameters in Taiwan began in 1896. This century-long record, with almost no missing data, is available from six meteorological stations (Taipei, Taichung, Tainan, Hengchun, Taitung, and Hualien) (**Figure 12**) maintained by the Central Weather Bureau. Climate variations shown by data from these six stations are valuable for understanding climate change in Taiwan and the boundary region of the western rim of the Western North Pacific. Unlike temperature and precipitation data, available wind data are much shorter. Wind data are also sensitive to urban development. Therefore, in addition to the six inland stations, data from four off-shore stations (Penghu, Dongjidao, Lanyu, and Pengjiayu) (**Figure 12**) were used to study the long-term variation of surface winds. JTWC tropical cyclone best track data were used to study tropical cyclone activity near Taiwan. Statistically significant linear trends in various meteorological variables over the last 100 years (1911 to 2009), 50 years (1960 to 2009), and 30 years (1980 to 2009) are presented here to describe the climate change in Taiwan.

2. Temperature: Taiwan shows a significant warming trend. The rise in annual mean temperatures over the last 30, 50, and 100 years all reflects this tendency **(Figure 13)**. Of the six weather stations over the three periods, Taipei shows the most warming and Hengchun the least. In the last 30 years, stations along the west coast show faster warming than those along the east coast. Over the last century, warming has been most prominent in autumn. However, winter has warmed fastest in the last 30 years.

3. Precipitation: **Figure 14** shows that over the last 100, 50, and 30 years, average annual rain days in Taiwan have decreased significantly. Numbers of rain day have decreased by 4 days per decade in the last 100 years and 6 days per decade

in the last 30 years. The years 2002, 2003, and 2004 (during the latest drought) had the fewest rain days in the last 100 years.

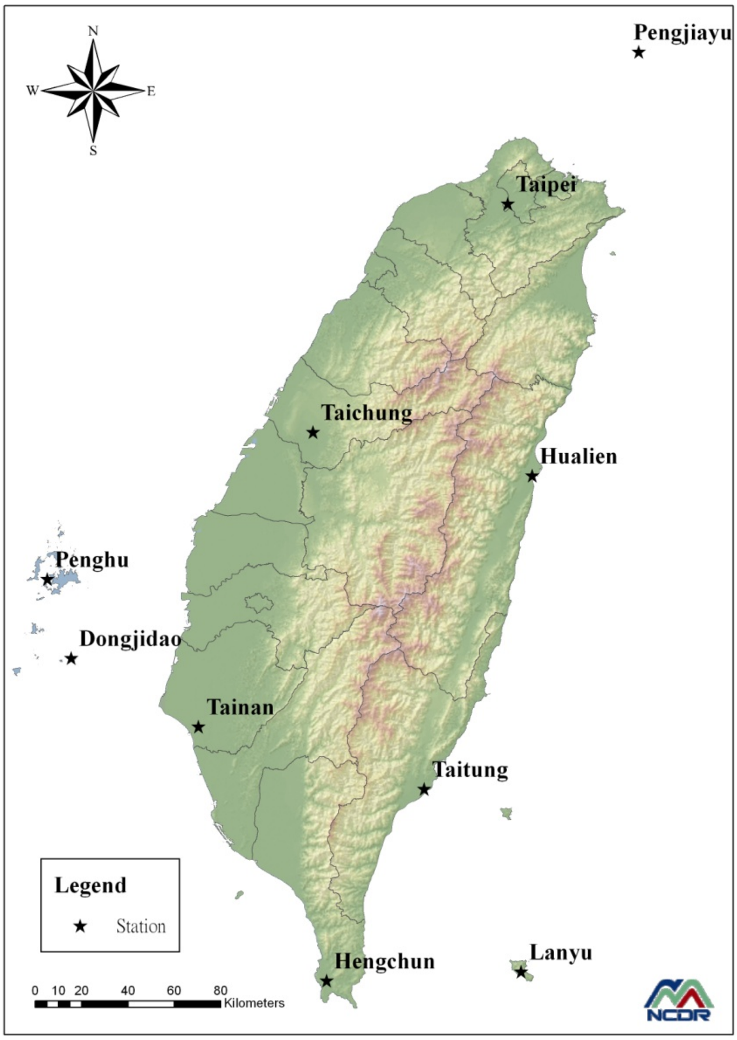


Figure 12: A map of Central Weather Bureau meteorological stations, including six inland stations (Taipei, Taichung, Tainan, Hengchun, Taitung, and Hualien) and four off-shore island stations (Penghu, Dongjidao, Lanyu, and Pengjiayu). The black lines represent boundaries of cities and counties. Source: NCDR.

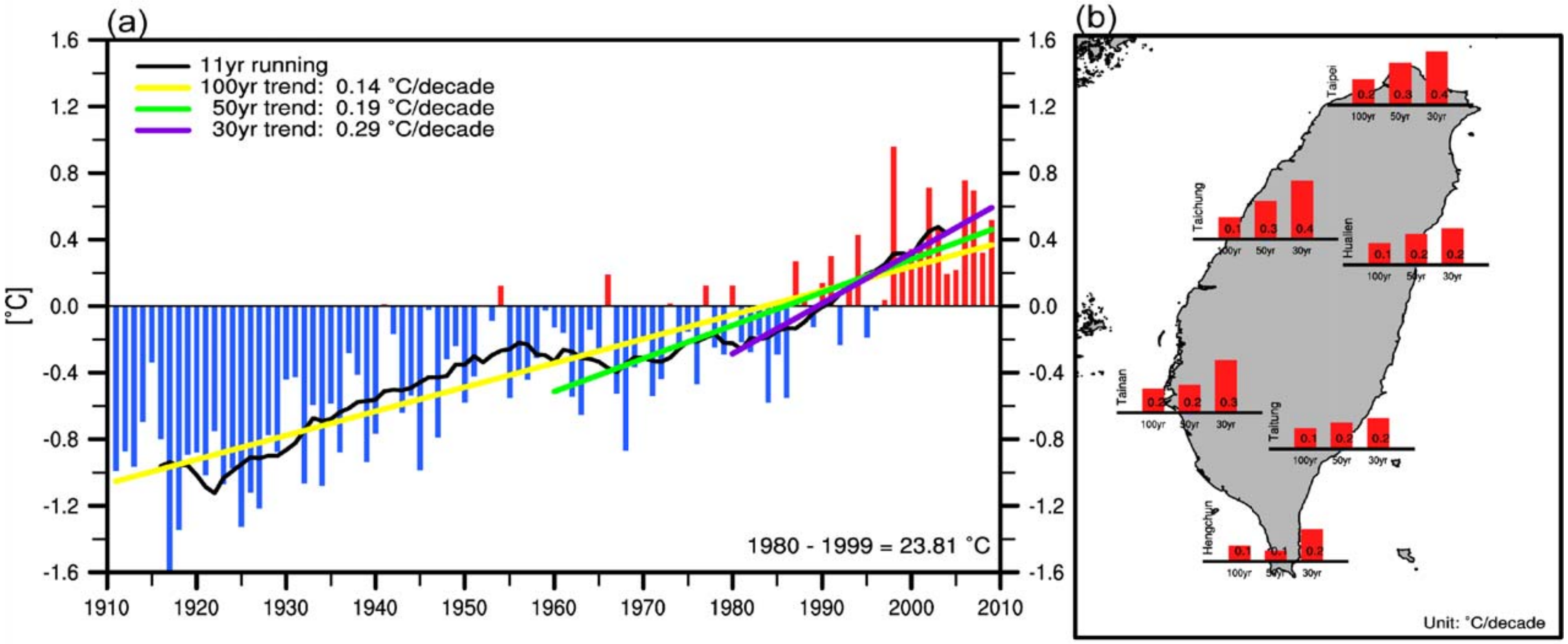


Figure 13: Time series and annual mean temperature trends in Taiwan. (a) Annual mean temperature in Taiwan from 1911 to 2009, averaged using data from six meteorological stations in Taipei, Taichung, Tainan, Hengchun, Hualien, and Taitung. The black line is the 11-year running mean. Linear regression lines are shown for the last 100 (yellow), 50 (green), and 30 (purple) years. Solid lines indicate that linear trends pass the 5% significance test and dotted lines do not. Trends calculated from regression slopes are shown in the top left corner. The mean temperature of the climatological base period from 1980 to 1999 is shown in the bottom right. (b) From left to right, the bars show the magnitude in change over the last 100, 50, and 30 years, respectively. Filled bars indicate that the linear trends pass the 5% significance test and unfilled bars

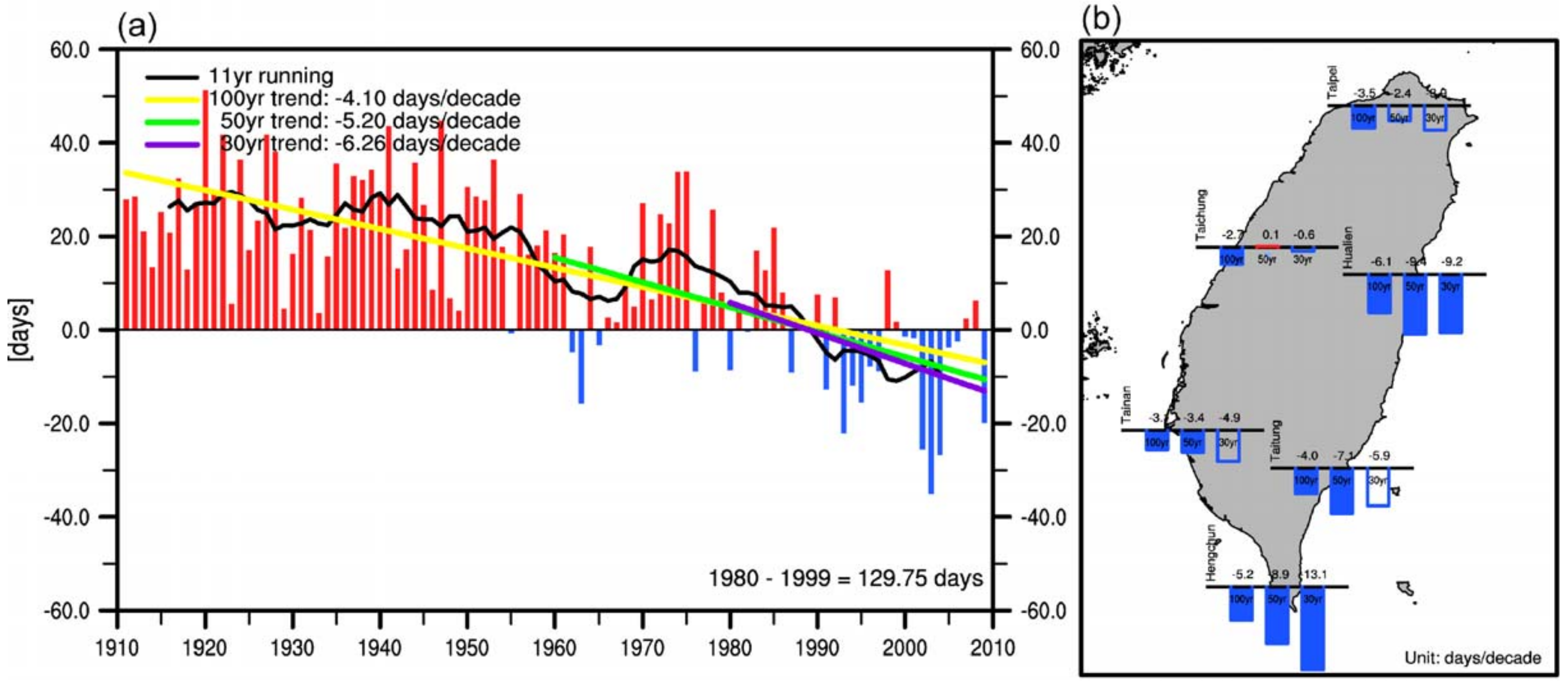


Figure 14: Time series and annual total rain day (daily rainfall ≧ 0.1 mm) trends in Taiwan. The black line is the 11-year running mean. Linear regression lines are shown for the last 100 (yellow), 50 (green), and 30 (purple) years. Solid lines indicate that linear trends pass the 5% significance test and dotted lines do not. Trends calculated from the regression slopes are shown in the top left corner. The annual total rain day mean of the climatological base period from 1980 to 1999 is shown in the bottom right. (b) From left to right, the bars show the magnitudes of change in the last 100, 50, and 30 years, respectively. Filled bars indicate that the linear trends pass the 5% significance test and unfilled bars do not.

4. High-temperature days: The annual number of extremely hot days has increased at all six stations in the last 100 years. Of the six stations, Taipei shows the fastest increasing trend (1.4 days per decade in the last 100 years, 2 days per decade in the last 50 years, and 4 days per decade in the last 30 years). Extremely hot days between 2000 and 2009 increased by more than 10 days when compared to the period from 1911 to 1920 **(Figure 15)**.

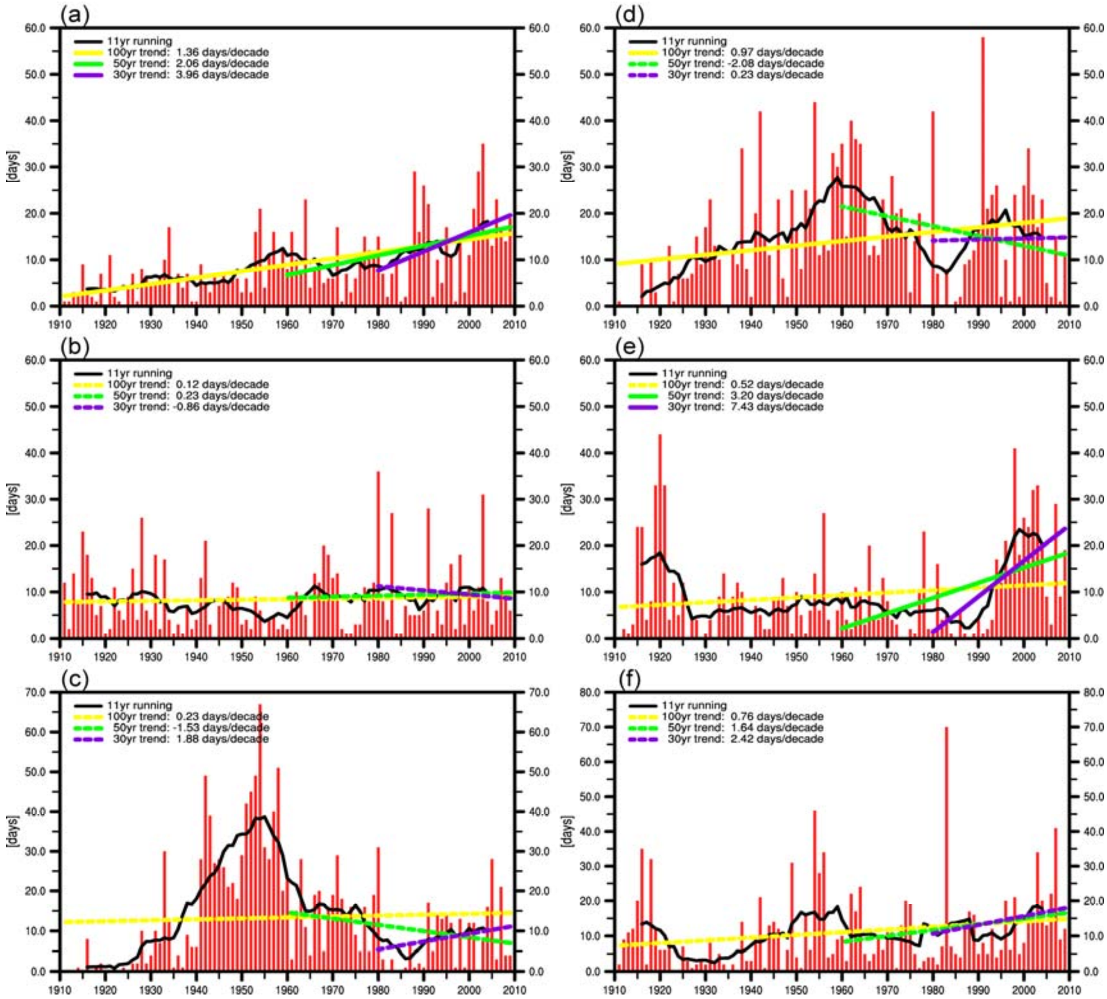


Figure15: Time series and trends for the annual number of extremely hot days from 1911 to 2009 in (a) Taipei, (b) Taichung, (c) Tainan, (d) Hengchun, (e) Hualien, and (f) Taitung. The extremely hot day threshold is defined as the 90th percentile of probability distribution of the 100-year daily temperature during the summer season (June to August) at each station. The black line is the 11-year running mean. Linear regression lines are shown for the last 100 (yellow), 50 (green), and 30 (purple) years. Solid lines indicate that linear trends pass the 5% significance test and dotted lines do not. Trends calculated from regression slopes are shown in the top left corner.

5. Low-temperature days: The number of annual cold surge events at all six stations shows a decreasing trend in the last 100 years. Taichung, Hengchun, and Hualien show the fastest decrease in the last 30 years. The rates for the last 50 years were slower, and those for the last 100 years were the slowest. By contrast, Taipei and Tainan show faster decreasing rates over the last 50 years than the last 30 years. Cold surge events occurred more frequently in Taipei and Taichung during the periods 1915-1925 and 1960-1970 and less frequently around 1950. Cold surge events at all six stations decreased consistently after 1985, which never occurred before 1985 **(Figure 16)**.

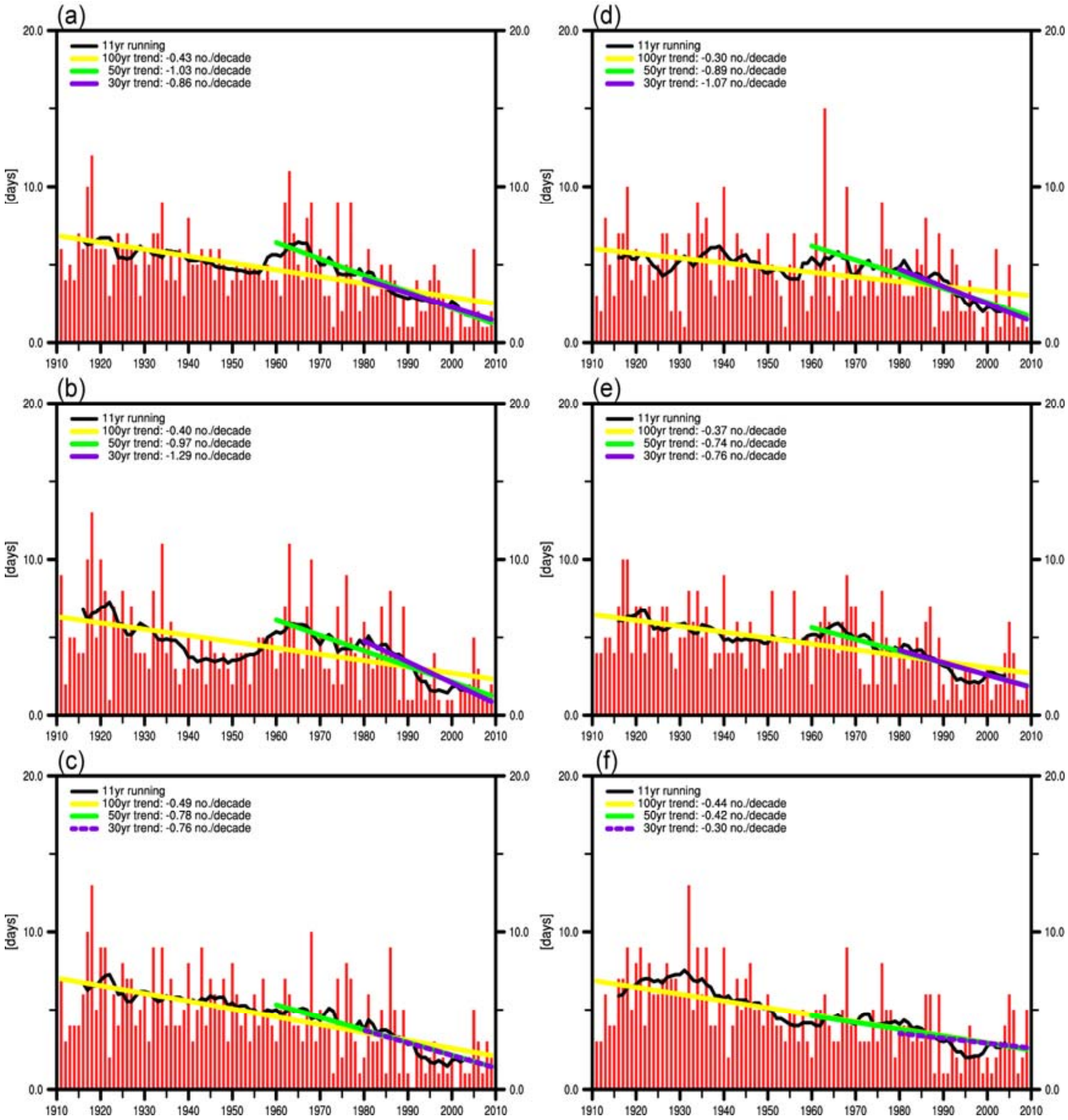


Figure 16: Same as in **Figure 15**, but for the annual frequency of cold surge events.

6. Dry spells: Extreme dry spells in Hengchun and Hualien occurred more frequently in the last 30 years than in any other period **(Figure17)**.

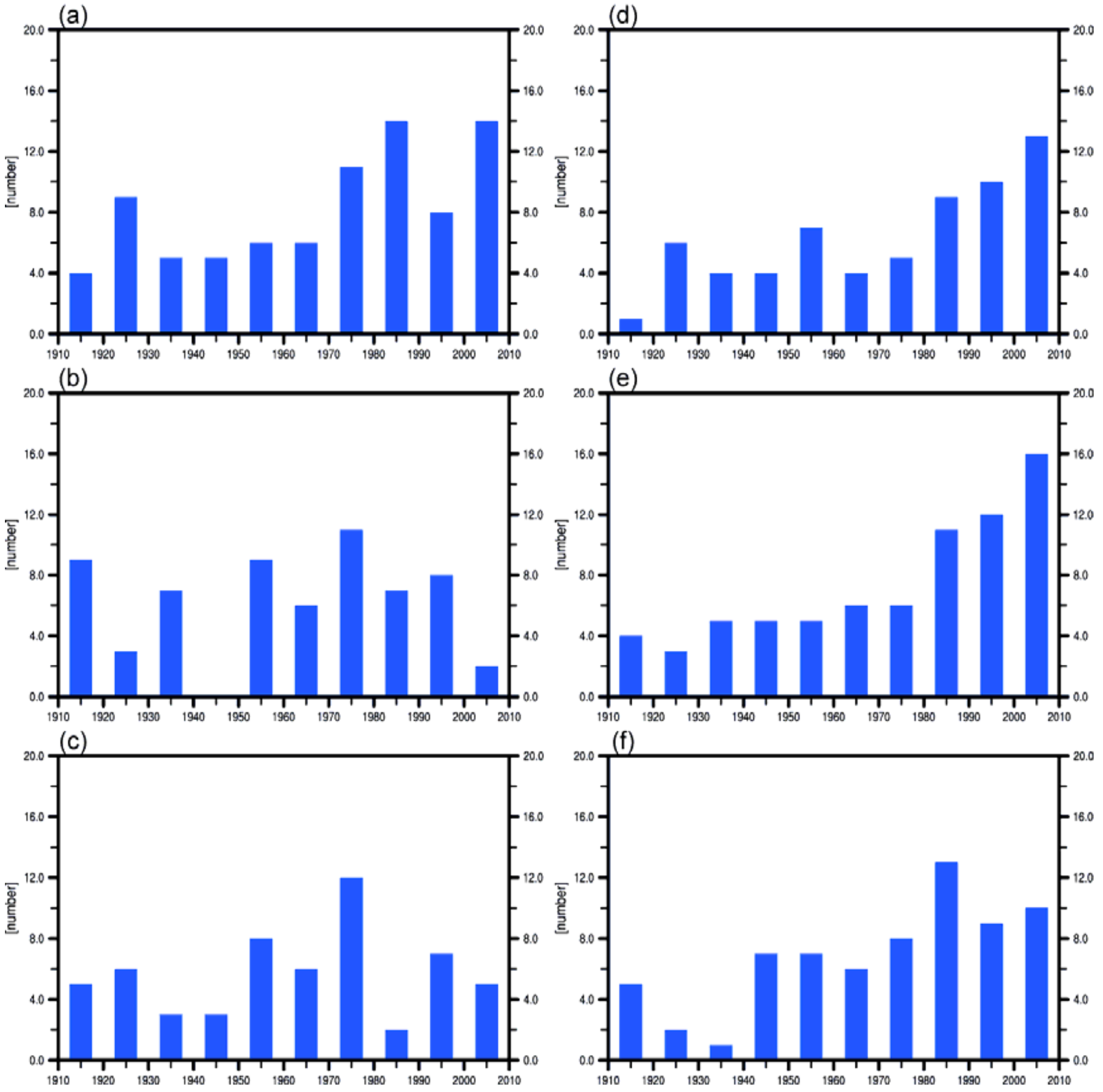


Figure 17: Frequency of dry spells for every decade. The dry spells are defined based on the two-year return period threshold in (a) Taipei, (b) Taichung, (c) Tainan, (d) Hengchun, (e) Hualien, and (f) Taitung.

7. Wind speed: Days with strong winds are divided into typhoon and non-typhoon days. For non-typhoon days since 1950, all stations except Ilan show a decreasing trend. Of the stations, Taitung has the fastest decreasing rate **(Figure 18)**. Regardless of the wind intensity threshold (stronger than a strong breeze or near gale force on the Beaufort scale), all four offshore stations show decreasing wind speed trends **(Figure 19)**. For typhoon-day winds since 1950, two stations (Ilan and Hualien) show an increasing trend, and the other four

stations on Taiwan Island show a decreasing trend. All off-shore stations, except Penghu, show an increasing trend, which may be because of the increasing intensity of typhoons.

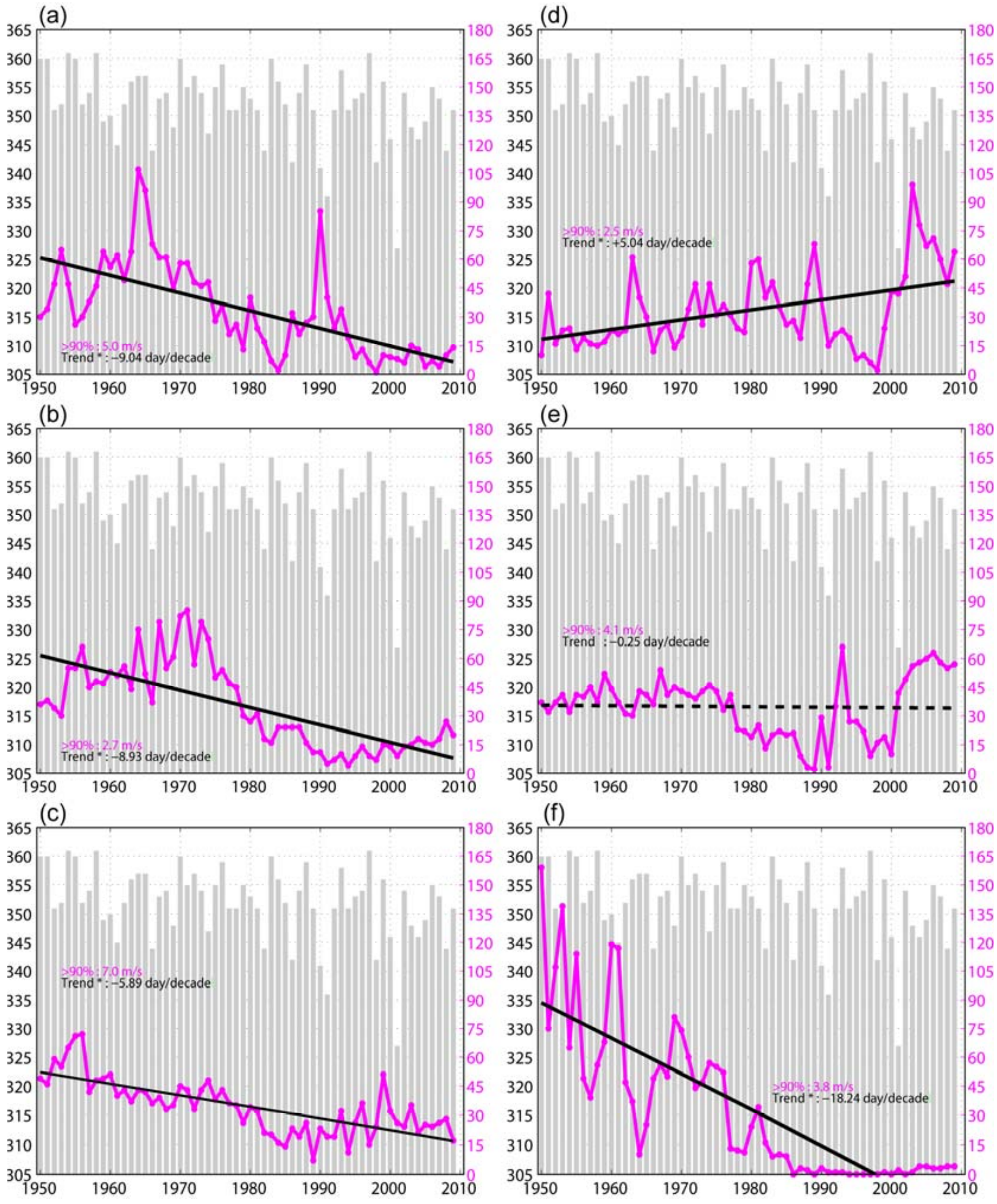


Figure 18: Number of strong wind day without typhoons' influences between 1950 and 2009 in (a) Taipei, (b) Taichung, (c) Hengchun, (d) Ilan, (e) Hualien, and (f) Taitung. The gray bars show the number of day unaffected by typhoons, and the pink lines show the number of day with strong winds. Black lines represent the 60-year linear regression. Solid lines indicate that linear trends pass the 5% significance test and dotted lines do not.

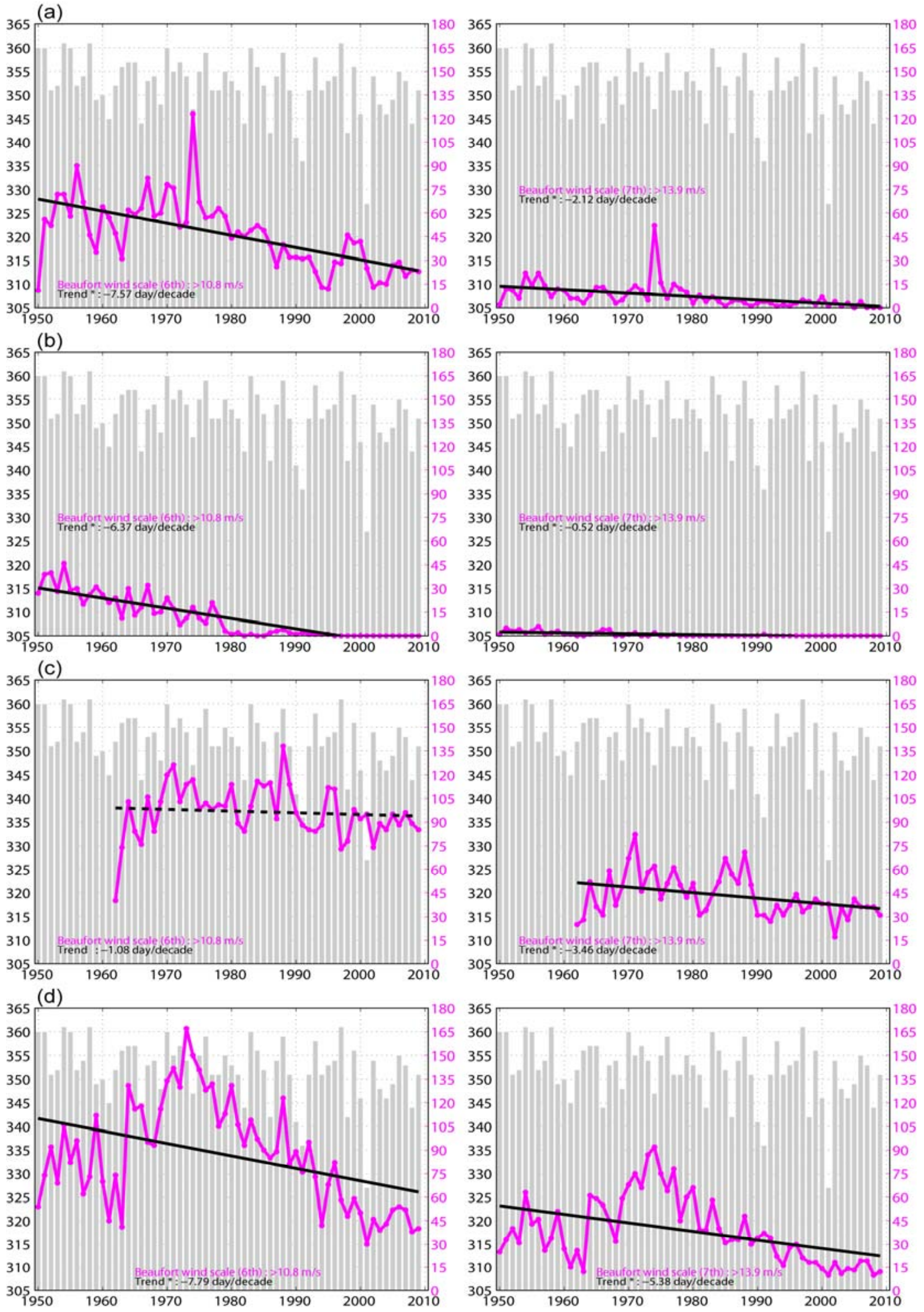


Figure 19: Similar to **Figure 18**, but shows days with winds of at least Beaufort force 6 (left) and Beaufort force 7 (right) in four off-shore stations: (a) Pengjiayu, (b) Penghu, (c) Dongjidao, and (d) Lanyu.

8. Typhoons: More typhoons affected Taiwan after 1990 than between 1961 and 1989, with a sharp increase near 2000 **(Figure 20)**.This change was probably caused by the northward shift of typhoon tracks over the Western North Pacific. The proportion of typhoons reaching the intensity of strong typhoons increased after 1980 **(Figure 21)**. These changes in typhoon intensity and tracks are closely related to interdecadal variation in the Western North Pacific sea surface temperature and tropical cyclones.

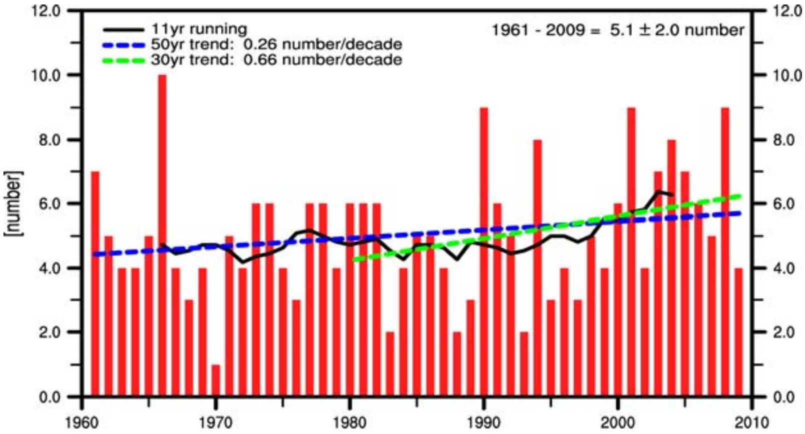


Figure 20: Annual number of typhoon affecting Taiwan from 1961 to 2009. The black line is the 11-year running mean. Linear regression lines are shown for the last 50 (blue) and 30 (green) years. Solid lines indicate that linear trends pass the 5% significance test and dotted lines do not. Trends calculated from regression slopes are shown in the top left corner.

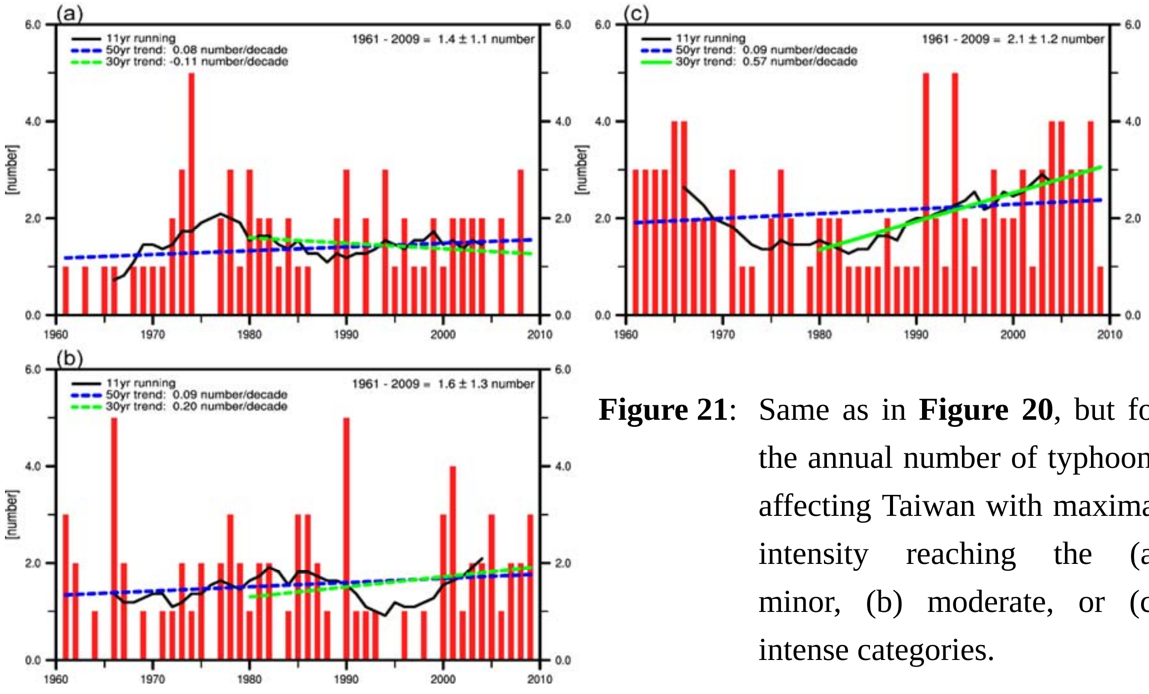


Figure 21: Same as in **Figure 20**, but for the annual number of typhoons affecting Taiwan with maximal intensity reaching the (a) minor, (b) moderate, or (c) intense categories.

9. Heavy precipitation events: Days with torrential rain (daily rainfall ≧ 200 mm) in Taiwan show a significant increasing trend in the last 50 years and 30 years. However, 50-60 year variation was also evident. It is difficult to determine whether this trend will continue in the future. Days with light rain (daily rainfall < 1 mm) have decreased substantially, with a decrease of 2 days per decade in the last 100 years and 4 days per decade in the last 30 years. Days with torrential rain show 10-20 years fluctuation. There were fewer days with torrential rain from 1920 to 1935 and from 1965 to 1985, but more from 1940 to 1960 and after 1985 **(Figure 22)**.

Projection of Future Climate Change

Global

1. The main scientific method for projecting long-term climate change due to possible human effects on future climate is the use of GCM simulations. GCMs use the greenhouse gas and aerosol concentrations estimated from the greenhouse gas emissions under different population, economic, societal and environmental development scenarios. Both the changing greenhouse gas and aerosol concentrations contribute to the perturbation to the radiative balance of climate system. Because of differences in model structures and parameters and the difficulty of accurately estimating climate system natural variation and feedback, scientists cannot precisely project global mean surface temperature response to the radiative forcing for the next century. Although the extent of warming is uncertain, all research indicates that the anthropogenic effect will cause continually rising global temperatures. GCMs running with different future scenarios show that global mean surface temperatures are projected to rise by an average of 2.8^{o}C, ranging between 1.8^{o}C and 4^{o}C by the end of 21st century (IPCC, 2007) **(Figure 23)**.

2. Regarding the spatial distribution of near-surface temperature warming (IPCC, 2007) **(Figure 24)**, GCMs project significant temperature increases over land and the Arctic by the end of the century. Temperatures in the Arctic will increase more in winter than in summer. Increased greenhouse gases will cause the troposphere to warm and the stratosphere to cool. Because of tropical convection, warming in the upper troposphere will be slightly more than at the surface in tropical regions.

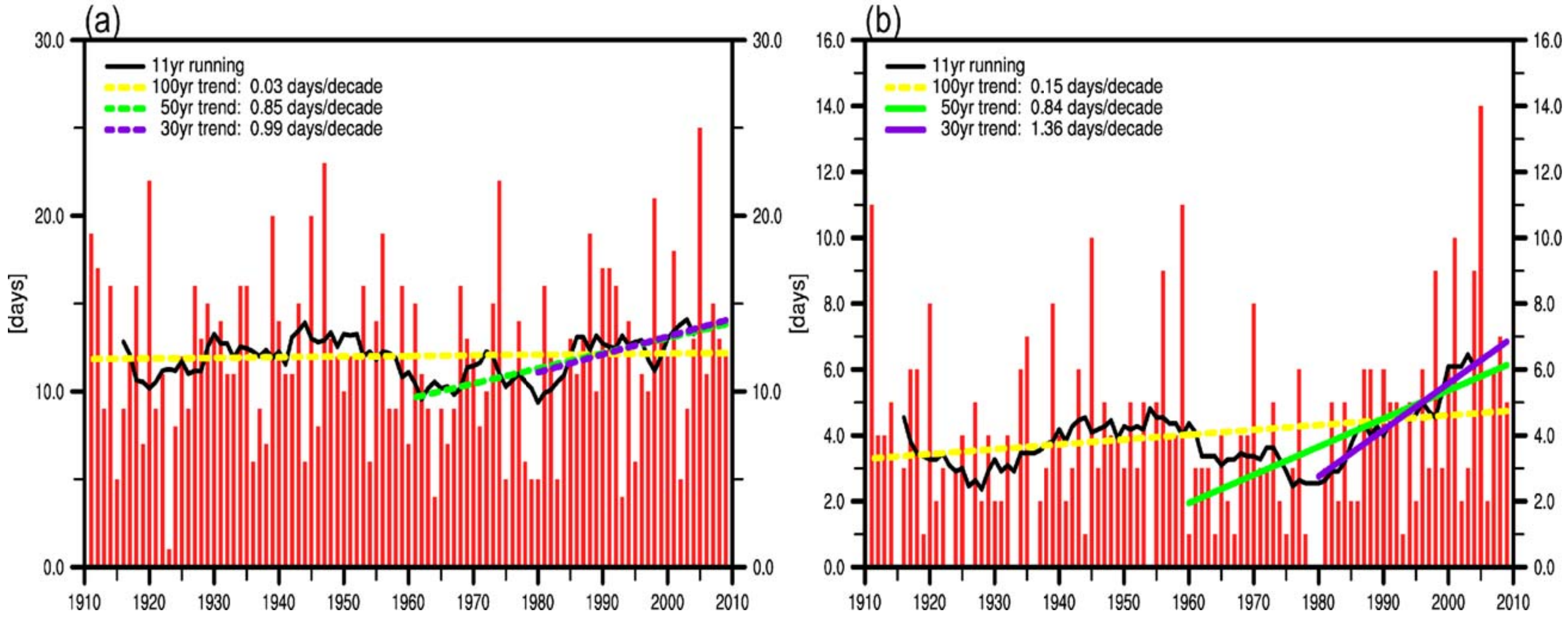


Figure 22: Time series and trends for the annual number of days with (a) extremely heavy rain (daily rainfall ≧ 130 mm) and (b) torrential rain (daily rainfall ≧ 200 mm) in Taiwan from 1911 to 2009. The black line shows the 11-year running mean. Linear regressions lines are shown for the last 100 (yellow), 50 (green), and 30 (purple) years. Solid lines indicate that linear trends pass the 95% significance test and dotted lines do not. Trends calculated from regression slopes are shown in the top left corner.

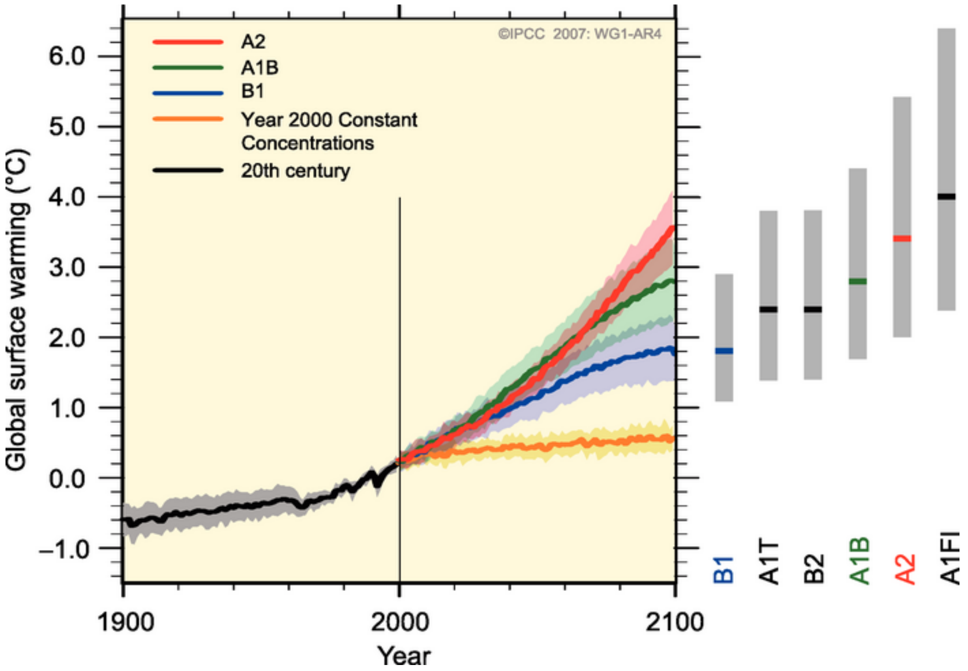


Figure 23: Solid lines represent multi-model global surface warming averages (relative to 1980 to 1999) for Scenarios A2, A1B, and B1, shown as continuations of the 20th century simulations. The orange line shows the model that maintains concentrations at year 2000 values. The gray bars on the right indicate the best estimate (solid line within each bar) and the likely range for the six SRES marker scenarios. The best estimates and likely ranges in the gray bars include the AOGCMs simulations on the left of the figure and results from several independent models, observational constraints, and expert judgements. Source: IPCC AR4, Figure SPM.5 (2007)

3. By considering different future development scenarios, the IPCC projected that from 2090 to 2099, global mean sea levels will rise 18cm to 59cm, with the most probable increase between 30cm and 40cm (IPCC 2007). Thermal expansion accompanying warming seawater will be the main cause, and melting sea ice, land glaciers, and ice caps will contribute less. Ice and snow accumulation on Antarctica may even decrease sea levels. Because previous estimates have not considered ice sheet dynamics and understanding of ice sheet variation is limited, several experts believe it is likely that current sea level projections underestimate actual future sea levels. Recent studies have found that global sea levels have been rising at a rate approaching the upper limit of the IPCC estimate. Sea ice in the Arctic Ocean is also melting at a faster rate than the IPCC AR4 predicted.

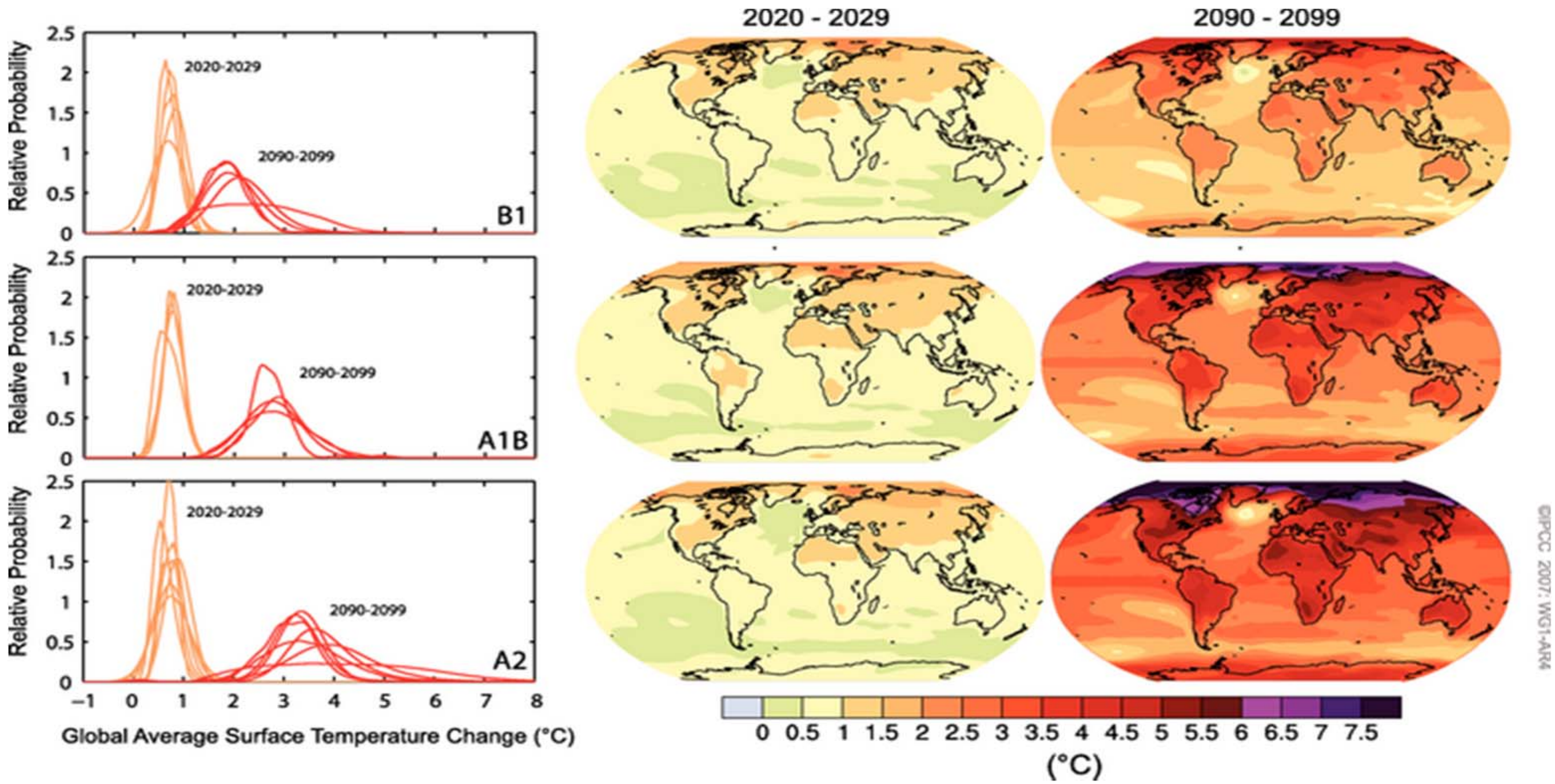


Figure 24: Projected surface temperature changes during the early and late 21st century relative to the period from 1980 to 1999. The middle and right panels show AOGCM multi-model average projections for B1 (top), A1B (middle), and A2 (bottom) SRES scenarios from 2020 to 2029 (middle) and 2090 to 2099 (right). The left panel shows corresponding uncertainty as a relative probability of estimated global average warming from several different intermediately complex AOGCM and Earth System Model studies for the same periods. Some studies only presented results for a subset of SRES scenarios or for various model versions. Therefore, the difference in the number of curves in the left panels is caused by differences in the availability of results.

The Copenhagen Diagnosis (2009) reviewed research published after 2007. It indicated that the increase in sea levels will be twice the IPCC AR4 estimate by the end of the twenty-first Century. Some research has even stated that the likely upper limit is 2 m. The rapid progress of relevant research means that observations and projections are continually updated. This updated research should not be ignored. In the long term, melting of the massive Greenland ice sheet could lead to sea level increases of up to 7 m. However, the possibility of such large-scale melting occurring at the end of the century is small based on projected global climate change. Thermal expansion related to warming seawater is the main cause of sea levels rising. Because the deep ocean responds slowly to climate change, sea levels will continue to rise slowly for hundreds of years, even if atmospheric greenhouse gas concentrations stabilize.

4. Global average precipitation in the 21st century will increase with time, resulting in a strengthening global hydrological cycle. With 1°C of warming, precipitation will increase by 1% to 2%, which is less than the 6% to 7% increase in atmospheric water vapor. This phenomenon indicates that changes in atmospheric circulation, especially the Hadley and Walker circulations that dominate tropical precipitation, must be considered. Current climate models significantly underestimate the intensity of extreme precipitation; therefore, the reliability of these estimates must be investigated. This is one of the most critical issues in climate change projection research.

5. Regarding the spatial distribution of precipitation changes, precipitation in high latitudes will likely increase because of more water vapor transported toward the polar regions, and that precipitation will increase slightly more in winter than in summer **(Figure 25)**. Precipitation is likely to decrease over subtropical areas. The multi-model ensemble mean shows an increasing trend near the tropics, although individual models show diverse results. On average, mid-latitude storm tracks will move poleward, and the subsidence area of the Hadley Circulation will expand poleward. This will cause desertification in certain regions. Precipitation in East Asia is mainly influenced by the monsoon circulation and the amount of moisture transport. Climate model simulations show that large-scale circulation in the tropics and the Asian monsoon circulation will weaken with warming. In winter, although precipitation is likely to increase in the high latitudes of Asia, most climate model simulations project that precipitation will decrease from the Western Pacific, Taiwan, South China Sea, Indochina Peninsula, Bay of Bengal, to the Arabian Peninsula.

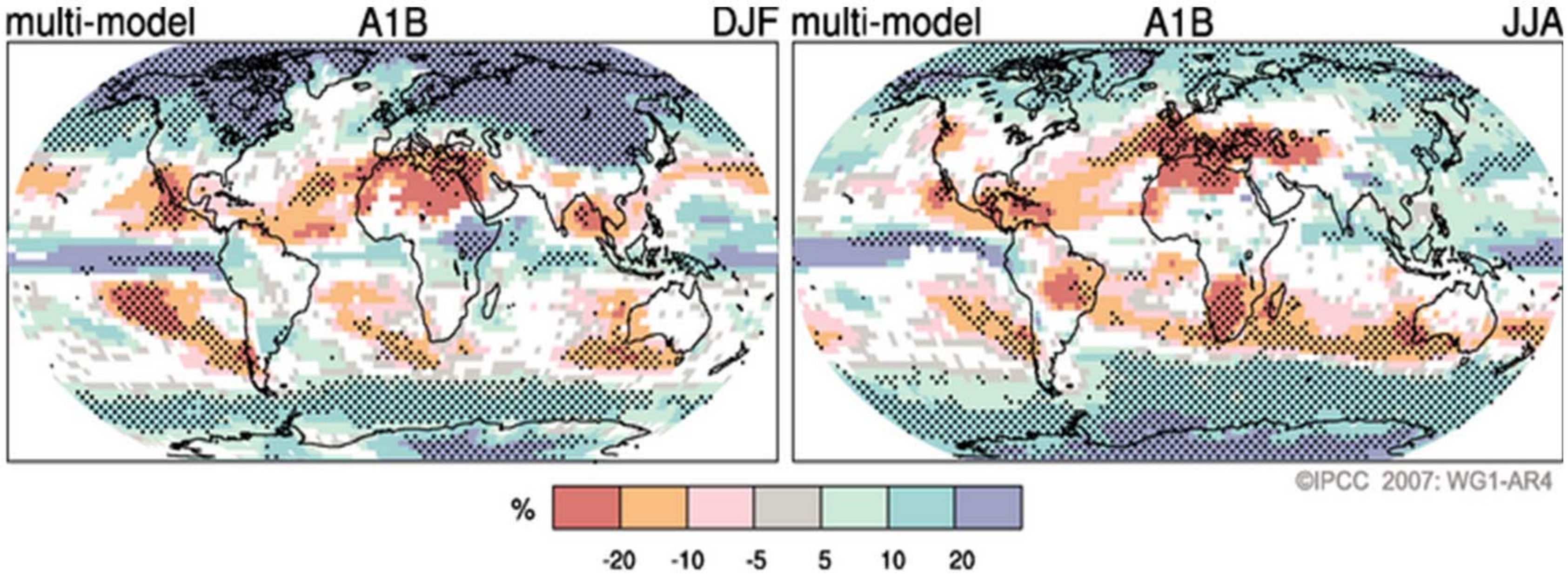


Figure 25: Changes in precipitation (in percentages) from 2090 to 2099 relative to changes from 1980 to 1999. Values are multi-model averages based on the SRES A1B scenario for December to February (left) and June to August (right). White represents areas where fewer than 66% of the models agree on the direction of change and stippled areas represent areas where more than 90% of the models agree on the direction of change. Source: IPCC AR4, Fig. SPM.7 (2007)

6. Climate and Weather extremes affect society more significantly. Models project that, in a warming environment, heat waves and heavy precipitation events are very likely to be more intense and occur more frequently. The average length of consecutive dry days may increase, resulting in more temporal precipitation variation. More aggressive water resource management may be required in many areas. Except in dry subtropical regions, by the end of the century, daily precipitation extremes will increase in most areas, with a 10% to 20% increase on average in the mid and high latitudes and over 30% in regions near the tropics. Most simulations show that the global total number of tropical cyclones may decrease because the tropical atmosphere may become more stable due to larger warming in the upper troposphere. However, minimal pressure and maximal wind speeds near typhoon centers will strengthen, and precipitation near the center may also increase significantly. Current climate models with relatively low resolutions have difficulty in simulating extreme weather, such as typhoons. The impact of climate change on future typhoon activities and characteristics needs further exploration.

Taiwan

7. For climate change impact assessment and adaptation, the most important information is temperature and precipitation changes in each local area, and not global mean temperature changes. Based on regional results of GCM, this report applied statistical downscaling technique to analyze the probability distribution range of Taiwan's future climate change. Results are similar to the regional characteristics of the GCM simulation, but they are more detailed. Using Scenario A1B as an example, the principal findings of Taiwan's climate change projections are as follows:

   - ⊙ The median of the near-surface temperature change projected by all climate models is between 2.1^{o}C and 2.4^{o}C (**Table 1**). This temperature increase is slightly higher in Northern Taiwan than in Southern Taiwan, and it is lower in autumn than in other seasons. Approximately half of the models predict regional mean seasonal temperature changes between 2^{o}C and 3^{o}C, and more than 90% of the models predict changes higher than 1.3^{o}C and lower than 3.2^{o}C. This temperature increase is also higher in Northern Taiwan.

   - ⊙ Most multi-model simulations project that mean winter precipitation in Northern, Central, Southern, and Eastern Taiwan will decrease **(Table 1)**, with approximately half of the model projecting a 1% to 23% decrease. In Southern Taiwan, mean precipitation changes in spring are similar to those in winter. In summer, more than 60% of the models project an increase in seasonal mean precipitation in all regions, and approximately half of the models project an increase between 15% and 45%. For Central and Southern Taiwan, where rain is abundant in summer and scarce in winter, these projections indicate a greater rainfall contrast between the wet and dry seasons. Allocating water resources between seasons is a critical issue and requires more attention.

Table 1: Regional (Northern, Central, Southern, and Eastern Taiwan) temperature and precipitation change averages (the 2080 to 2099 average minus the 1980 to 1999 average) for Scenario A1B. The table shows the minimum, maximum, 10th, 25th, 50th, 75th, and 90th percentile values for all changes in the same season for the same region. Regions where at least 75% of all models agree on the precipitation response direction are highlighted in orange to show decreasing precipitation.

Area	Season	Near-surface air temperature change (°C)							Precipitation change (%)						
		Min.	10	25	50	75	90	Max.	Min.	10	25	50	75	90	Max.
Northern	Winter (DJF)	1.1	1.4	1.9	2.4	2.9	3	3.7	-39	-34	-21	-13	0	6	30
	Spring (MAM)	1.6	1.7	1.9	2.3	2.6	2.7	3.5	-24	-23	-15	-3	8	13	20
	Summer (JJA)	1.2	1.4	1.9	2.3	2.6	3	3.6	-12	-10	-3	13	26	36	43
	Autumn (SON)	1.3	1.4	2	2.2	2.7	3	3.5	-25	-23	-12	-3	11	14	38
Central	Winter (DJF)	1.1	1.3	1.8	2.3	2.7	3.1	3.4	-41	-38	-22	-15	0	6	34
	Spring (MAM)	1.6	1.6	1.9	2.3	2.6	2.8	3.5	-27	-26	-18	-3	8	11	29
	Summer (JJA)	1.2	1.4	1.9	2.2	2.6	3	3.6	-9	-8	-4	15	28	34	47
	Autumn (SON)	1.3	1.4	2	2.2	2.7	2.9	3.4	-26	-20	-11	-2	14	18	47
Southern	Winter (DJF)	1	1.4	1.8	2.2	2.5	2.9	3.2	-37	-35	-23	-16	-2	6	35
	Spring (MAM)	1.5	1.6	1.8	2.2	2.4	2.7	3.3	-31	-29	-22	-7	4	10	35
	Summer (JJA)	1.2	1.3	1.9	2.1	2.5	2.9	3.7	-16	-14	-3	19	28	34	52
	Autumn (SON)	1.2	1.4	1.9	2.1	2.6	2.8	3.4	-25	-20	-9	-1	15	22	55
Eastern	Winter (DJF)	1	1.3	1.9	2.3	2.7	2.9	3.5	-37	-34	-20	-15	-1	6	26
	Spring (MAM)	1.6	1.6	1.8	2.2	2.6	2.7	3.5	-27	-26	-19	-4	6	10	28
	Summer (JJA)	1.2	1.3	1.9	2.2	2.6	2.9	3.7	-14	-12	-3	16	28	33	43
	Autumn (SON)	1.2	1.4	2	2.2	2.7	2.9	3.5	-24	-21	-11	-3	13	18	48

8. Regarding near-surface temperature change projections for Taiwan, regional averages, values at individual grid points, and monthly, seasonal, and annual means show that temperature increases by the end of the twenty-first century are much larger than possible errors and uncertainties from models or statistical downscaling processes. This indicates that warming must be taken seriously. Projected precipitation changes in Taiwan are not necessarily statistically significant. Therefore, the projected precipitation changes are less reliable.

Climate Change and Disasters

The magnitude and frequency of disasters associated with extreme weather and climate events have increased in recent years. The relationship between climate change and disaster impact is a major concern for policymakers, scientists, and the public.

Global Trends

1. Global statistics from the International Disaster Database (EM-DAT, http://www.emdat.be/) from 1900 to 2009 show that, although the frequency, the affected population, and economic losses associated with natural disasters have increased rapidly since the 1970s, the death toll has decreased **(Table 2)**. Disasters that occur more frequently are primarily hydrometeorological disasters (floods, typhoons, slopeland disasters, and droughts). They account for as much as 78% of all natural disasters in the last 10 years **(Figure 26)**. Based on the EM-DAT statistics (1990 to 2008), climate-related disasters (such as extreme events) have caused annual economic losses of approximately US$59 million globally, which was approximately 0.1% of the global production value in 2008. Tropical cyclones (such as typhoons in Western North Pacific) and floods accounted for 44% and 33% of these losses, respectively. The increase in hydrometeorological disasters is related to the increasing frequency of extreme climate and weather events and the rapid increase in population and economic development.

2. Projection of disasters: The IPCC AR4 projection indicated that, in a warming environment, the frequency of extreme events (such as heat waves, heavy precipitation events, droughts, intense tropical cyclone activity, and sea level rise) will increase (with a likelihood ranging from 66% to 90%). With global economic development and population growth, the World Bank estimates that the frequency, affected population, and economic losses associated with disasters will increase substantially in the future (IPCC 2007).

Table 2: Global natural disaster statistics from 1900 to 2009. Source: Disaster Management White Paper (2011)

	Frequency	Death Toll (thousands)	Population Affected (thousands)	Economic losses (US$ millions)
1900-1909	72	4,497	240	1,307
1910-1919	71	3,326	5,766	600
1920-1929	96	8,724	44,342	979
1930-1939	100	4,700	13,921	3,322
1940-1949	142	3,871	2,885	3,009
1950-1959	293	2,127	19,678	6,059
1960-1969	582	1,750	199,444	17,836
1970-1979	910	987	550,781	54,040
1980-1989	1,832	794	1,252,760	190,965
1990-1999	2,975	526	2,035,562	699,589
2000-2009	4,491	839	2,326,603	890,320

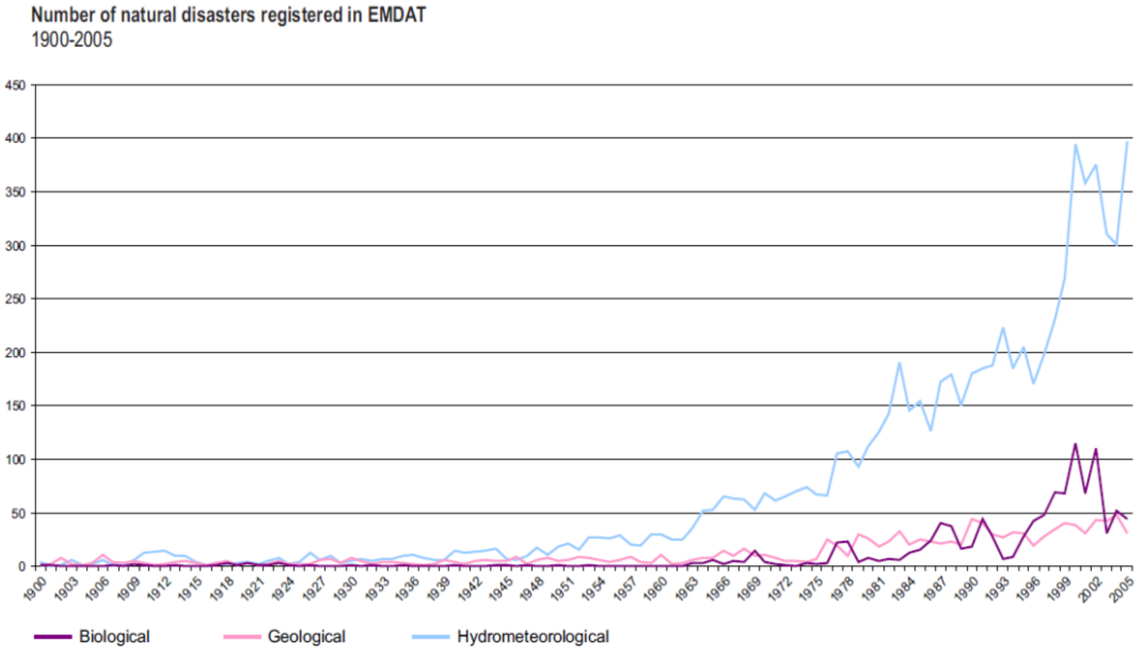


Figure 26: Frequency of natural disasters from 1900 to 2005. Blue, pink, and purple curves represent hydrometeorological, geological, and biological disasters, respectively. Source: UNISDR (2005)

Taiwan Climate Variability and Disaster Impact

1. World Bank statistics show that because there are many types of natural disasters, Taiwan is a high-risk disaster area (Dilley et al. 2005). The characteristics of disasters in Taiwan are similar to those of global ones; that is, most of them are hydrometeorological. Both the increase in weather and climate extremes and the changes in natural and social environments are closely related to more devastating disasters.

2. Statistics show that the severity of typhoon and flood disasters is related to an increase in extreme precipitation (which is not necessarily related to typhoon intensity). In the last 40 years, whether intense precipitation typhoons are defined by the intensity of their short-term (1 to 6 hrs.), long-term (more than 48 hrs.), or total (accumulated over the typhoon warning period) precipitation, their frequency have increased in the last decade (2000 to 2009). In the last 40 years, intense precipitation typhoons (the top 10% of typhoons according to their precipitation) often caused severe disasters (e.g. Typhoons Morakot, Herb, and Nari). The frequency of these typhoons has increased substantially in the last decade. Between 1970 and 1999, they occurred every 3 to 4 years. After 2000, they occurred annually on average **(Figure 27)**. The frequency of intense precipitation typhoons shows significant climate variation, including possible decadal variation and long-term climate change trends. Whether these variations will continue in the future is a complex scientific question that requires further research. Although uncertainty about the future exists, government agencies must acknowledge the possible effects of climate change. Although there has been no significant change in annual rainfall in the last 40 years, the ratio of typhoon precipitation to total precipitation has increased from 15% in the 1970s to 30% in the 2000s. Therefore, precipitation increases in the wet season and decreases in the dry season, leading to uneven seasonal precipitation. Increased precipitation in the wet season cannot be preserved and it raises flood risks, whereas decreasing precipitation in the dry season increases drought risks. This is a serious threat to water resources.

3. Floods: The history of flood disasters in Taiwan shows that the causes of disaster can be divided into natural and human factors. Some natural factors (e.g. heavy precipitation exceeding flood protection standards or reduced river cross-section areas from sand and stone storage in upstream or midstream river beds) are closely related to weather and climate extremes. However, human effects on the number of flood disasters cannot be ignored. Because rainfall intensity resulting in floods in each local area is different, the effects of rainfall

intensity changes also differ by area. Using local flood warning rainfall thresholds set by the Water Resources Agency (WRA), this report analyzes variations in rainfall intensity and calculates the change in rainfall intensity that exceeds the flood warning rainfall threshold. The average of the next 10 years (1989 to 1999) is higher than the average of the first 10 years (1999 to 2009), although the overall change is not significant (**Figure 28**). The same analysis was applied to Northern, Central, Southern, and Eastern Taiwan (**Figure 29**). This showed that flood potential (i.e., the frequency of rainfall exceeding the flood warning rainfall threshold) increases in Western Taiwan (including the northern, central, and southern regions), but decreases slightly in Eastern Taiwan. In Taiwan, rainfall that causes flood disasters is often related to disastrous weather, including typhoons, Mei-Yu, and southwesterly monsoons. Of these, typhoons cause most floods. Research shows that climate change may affect the intensity and frequency of typhoons. However, how climate change affects precipitation intensity, translation speed, and landfall location of typhoons (which affect the impact of typhoons) is complex and need to be further explored (IPCC, 2007; Knutson et al., 2010). Although the intensity of extreme precipitation appears to be increasing, it is difficult to establish whether this is related to climate change because of the relatively short 20-year disaster-related observation period. Nevertheless, the effects of both rainfall intensity variation and environmental changes on flood disasters should not be ignored.

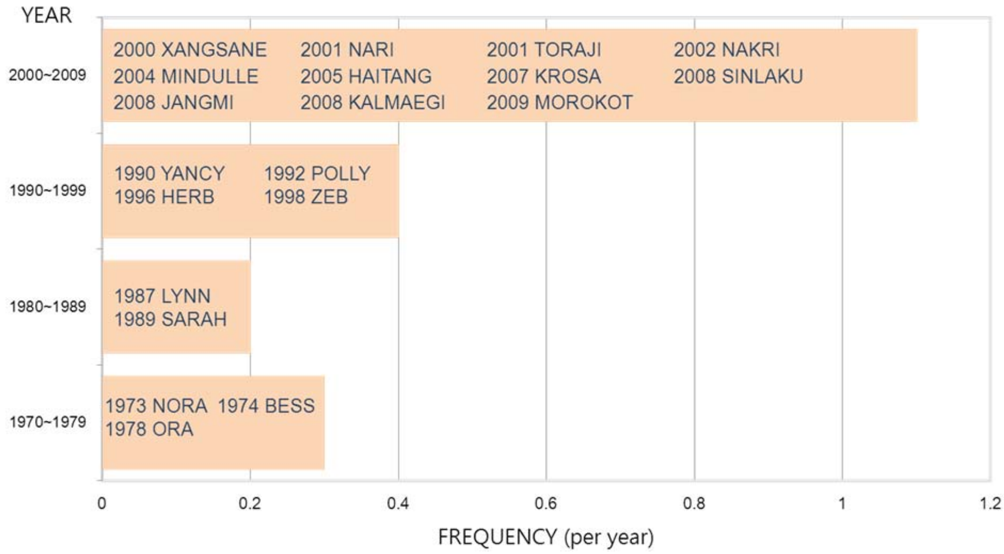
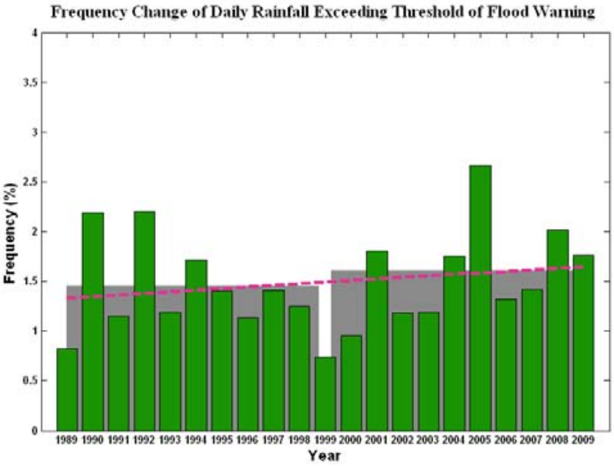
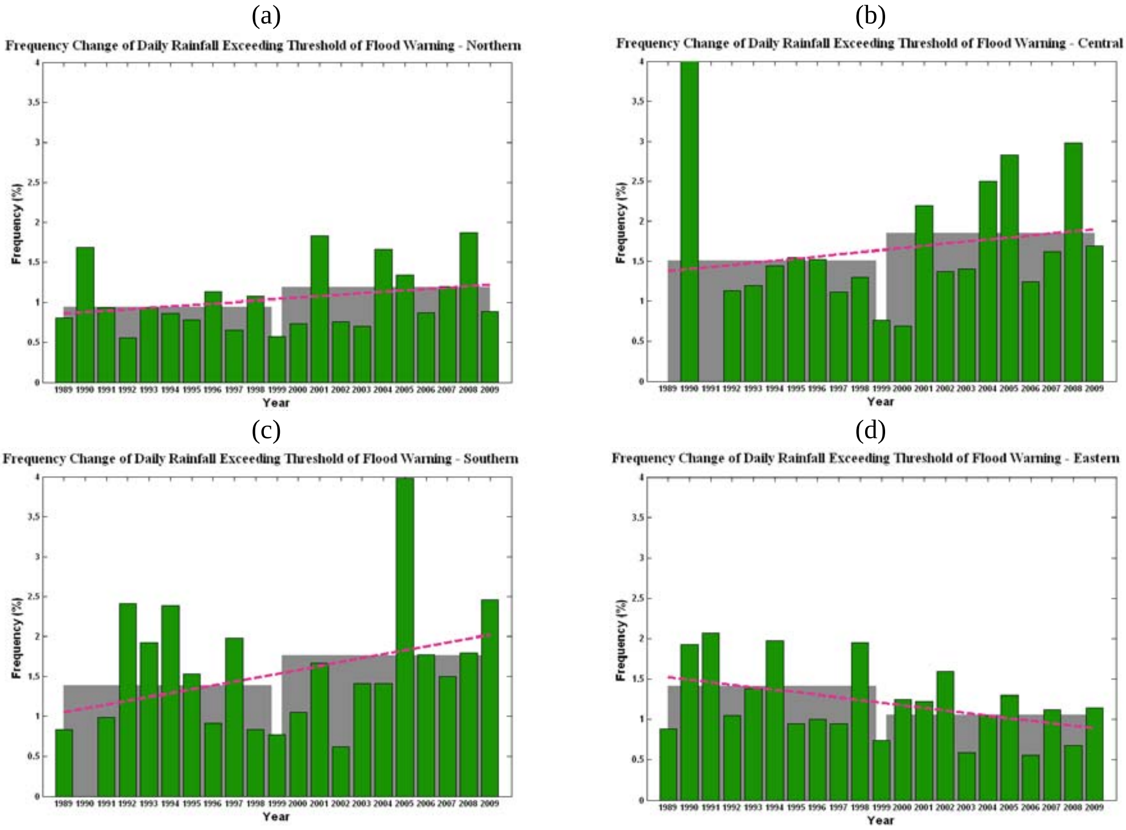


Figure 27: Variation in frequency of intense precipitation typhoons. Intense precipitation typhoons are defined as the 20 top-ranking typhoons on the integrated typhoon precipitation index. Source: NCDR



Frequency Change of Daily Rainfall Exceeding Threshold of Flood Warning

Figure 28: Change in the frequency of daily rainfall exceeding the flood warning threshold from 1989 to 2009. Green bars show annual means, and gray blocks show the averages for the first and second decades. The red dashed line is the linear regression curve.



(a)

Frequency Change of Daily Rainfall Exceeding Threshold of Flood Warning - Northern

(b)

Frequency Change of Daily Rainfall Exceeding Threshold of Flood Warning - Central

(c)

Frequency Change of Daily Rainfall Exceeding Threshold of Flood Warning - Southern

(d)

Frequency Change of Daily Rainfall Exceeding Threshold of Flood Warning - Eastern

Figure 29: Change in the frequency of daily rainfall exceeding the flood warning threshold in (a) Northern, (b) Central, (c) Southern, and (d) Eastern Taiwan from 1989 to 2009. Green bars show annual means, and gray blocks show the averages for the first and second decades. The red dashed line is the linear regression curve.

4. Slopeland disasters: More than 73.6% of Taiwan is on hill slopes or mountains. Slopeland disasters include debris flow, landslides, dip slope slides, rock falls, landslips, and creep. Several factors may cause slopeland disasters, including fragile geological conditions, steep topography, earthquakes, torrential rain, and human development. Of these, fragile geological conditions and steep topography are natural causes. Earthquakes and human development are environmental causes. Torrential rain is related to climate change and extreme rainfall. The amount of water that soil can hold differs by area because of different soil types. Soil and Water Conservation Bureau's research and NCDR's research define slopeland disaster warning rainfall thresholds in different areas based on accumulated daily rainfall. These thresholds range between 300 and 700 mm. The frequency of daily rainfall exceeding warning thresholds in the last 20 years (1989 to 2009) was analyzed, and the results show that it is increasing. The frequency was below 0.6% from 1989 to 1999 and increased to 0.8% from 2000 to 2009 **(Figure 30)**. Rainfall exceeding slopeland disaster warning thresholds in Northern, Central, Southern, and Eastern Taiwan all show increasing trends, with the most prominent increase in Southern Taiwan **(Figure 31)**. Similar to the flooding potential analysis results, the frequency of rainfall exceeding the threshold values increases more west of Central Mountains than east of Central Mountains. Because the rainfall observation period from automatic rain gauge stations is relatively short, it is difficult to prove whether the increasing frequency of intense rainfall, which affects slopeland disasters, is directly related to climate change. The results may only indicate that intense rainfall associated with slopeland disasters has increased from 1989 to 2009. To account for the recent increase in the severity of slopeland disasters, the effects of climate change on intense rainfall and other natural (e.g. earthquakes) and human causes (e.g. road development and mountain recreation industry development) should be considered.

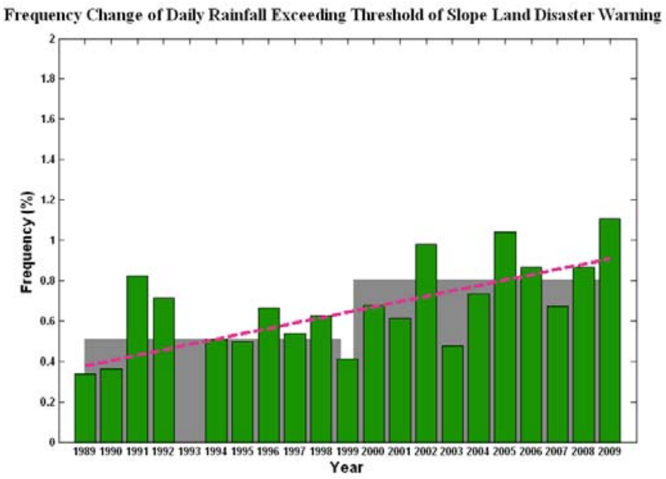


Figure 30: Change in frequency of daily rainfall exceeding the slopeland disaster warning threshold from 1989 to 2009. Green bars show annual means, and gray blocks show the averages for the first and second decades. The red dashed line is the linear regression curve.

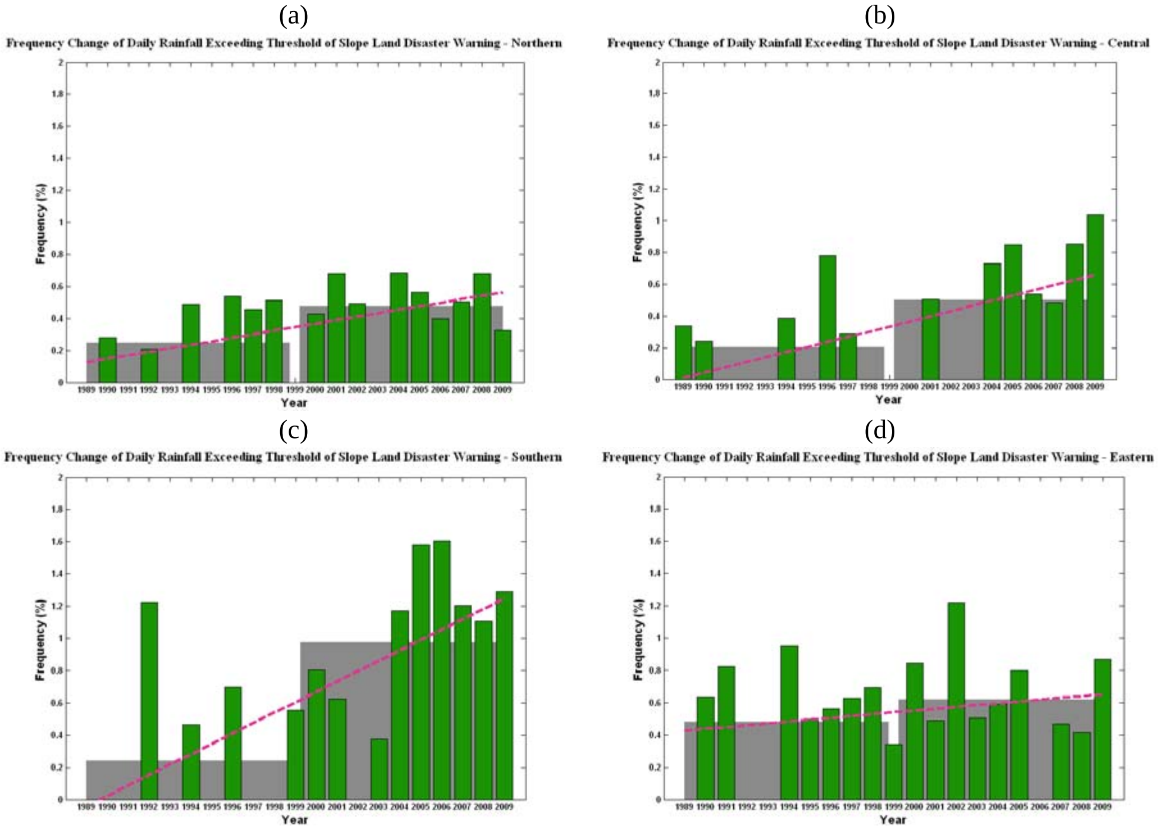


Figure 31: Change in frequency of daily rainfall exceeding the slopeland disaster warning threshold in (a) Northern, (b) Central, (c) Southern, and (d) Eastern Taiwan from 1989 to 2009. Green bars show annual means, and gray blocks show the averages for the first and second decades. The red dashed line is the linear regression curve.

5. Drought: According to WRA statistics, on average, a serious drought occurs every 10 years and a minor drought every 2 to 3 years. This report integrates and analyzes historical drought events to show their seasonal and spatial distribution characteristics. Although the reasons droughts occur and why they end (e.g. water resources management) are complex, serious droughts are directly related to rainfall. Seasonal distribution analysis shows that insufficient spring rains and high water demand in the first rice-growing period lead to a concentration of droughts in spring **(Figure 32)**. Spatial distribution analysis shows that droughts occur most frequently in Southern Taiwan. The most droughts occur in Chiai, Tainan, and Kaohsiung in Southern Taiwan and in Taoyuan and Hinchu in Northern Taiwan **(Figure 33)**. **Figure 34** shows drought frequency from 1953 to 2007 in Northern, Central, Southern, and Eastern Taiwan. In the last 10 years, droughts occurred more frequently in Northern and Southern Taiwan than in Central and Eastern Taiwan. Eastern Taiwan is least affected by drought. This is related to increased water consumption and the asymmetric distribution of seasonal rainfall in Taiwan (more rain in the wet season and less rain in the dry season).

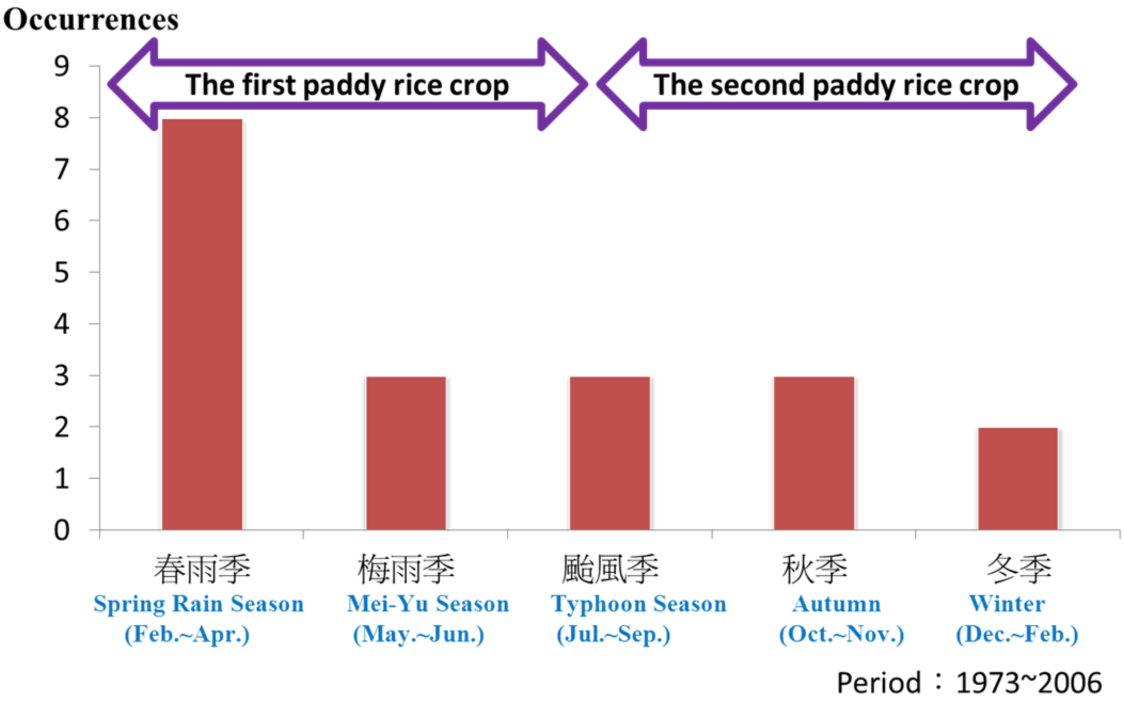


Figure 32: Seasonal distribution of droughts from 1973 to 2006 and rice-growing periods.

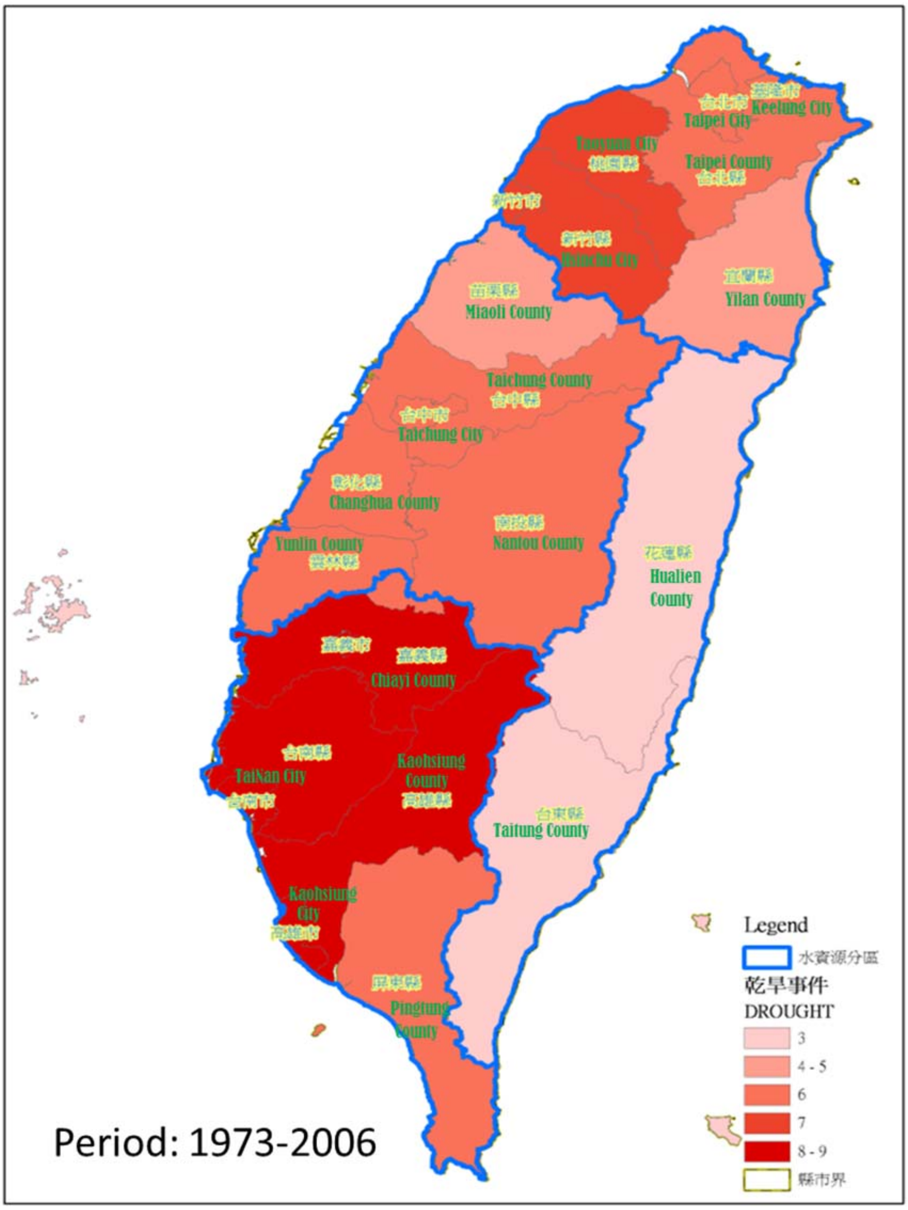


Figure 33: Spatial distribution of droughts from 1973 to 2006.

6. Taiwan is a high-risk natural disaster area. Climate and environmental changes exacerbate this problem, including water soil compound disasters caused by extreme weather and land development, water resource problems resulting from uneven rainfall and increasing water demands, coastal changes caused by land subsidence, sea level rise, and increasing storm surges **(Table 3)**. The spatial distribution of these problems indicates which areas are disaster sensitive, including river basins (water-soil-bridge-road compound disasters), urban and developed areas, mountains (highly vulnerable and environmentally sensitive), and coastal and land subsidence areas (highly vulnerable to disasters).

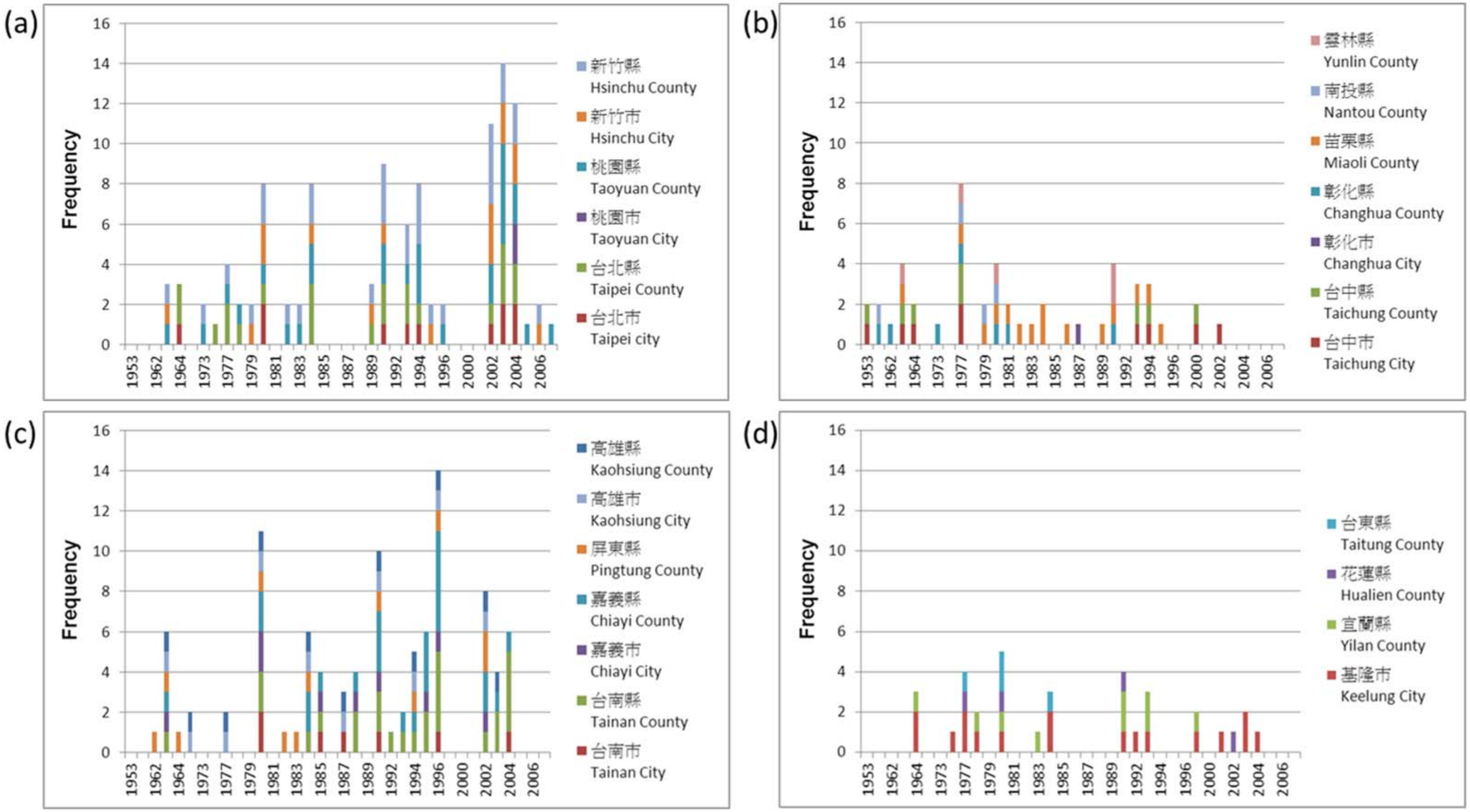


Figure 34: Frequency of droughts in counties and cities in (a) Northern, (b) Central, (c) Southern, and (d) Eastern Taiwan.

Table3: Factors of climate and environmental change and their effects on floods, slopeland disasters, and compound disasters.

Factors of climate and environmental change	Impacts on floods	Impacts on slopeland disasters	Impacts on compound disasters
Increase in extreme precipitation intensity	Intense precipitation exceeding the carrying capacity of regional drainage systems or dike protection standards will increase flood risk.	Increasing precipitation intensity will raise the risk of slope disasters, which affects the safety of mountainous routes, communities, tourism industries, and minorities without resources to manage disasters.	The effects of compound sediment and flood disasters will increase, affecting government emergency response planning and long-term disaster prevention or reduction policies. Aspects affected include the following: • Disaster prevention and emergency response capabilities in high-risk disaster areas; • Safety of infrastructure (such as reservoirs, bridges, dikes, and electricity towers); • Stability of water quality, reservoir operations, and droughts; • River channel erosion, sediment transport, riverbed deposition, and repeated disasters; and • Driftwood and landslide dam problems.
Increase in frequency of intense typhoons	Successive large-scale disasters will affect the emergency response and recovery capabilities of disaster prevention systems.	The increase in typhoons will cause more recovery and reconstruction problems for slopeland disasters than flood disasters. Successive disasters will increase the risk of repeated disasters and threaten the emergency response and recovery capabilities of disaster prevention systems.	
Uneven distribution of precipitation in wet and dry seasons	Uneven precipitation will affect reservoir storage capacity, water quality stability, reservoir operation safety, and downstream flood risks.	Uneven distribution of precipitation will affect soil water retention capacity, which threatens the sustainability and safety of the soil and water environment.	
Sea level rise and land subsidence	Sea level rise will make flood discharge more difficult when heavy precipitation events occur, increasing flood risk in low-lying coastal and land subsidence areas.		
Environmental impacts of frequent earthquakes and devastating disasters (such as Morakot)	Increased environmental vulnerability after disasters and the recovery and reconstruction of public construction will increase the probability and risk of subsequent disasters occurring.		

Conclusion

Climate change and its impact are among the biggest challenges faced by mankind in the twenty-first century. Most countries treat it as a long-term problem and conduct comprehensive research, attempting to thoroughly understand the characteristics of past climate change and its major influencing mechanisms to properly interpret the current climate. Efforts are also made to project future climate change scenarios with continuous emission of anthropogenic greenhouse gases to access impacts and formulate appropriate responses. A major difficulty of climate change research is differentiating between the effects of natural and anthropogenic factors and assessing the impact of future climate change on local climate and weather extremes. Taiwan is a small, densely populated region with complex terrain. It is located in the East Asian monsoon region and is concurrently affected by both extra tropical and tropical climates. Therefore, projecting future climate change in Taiwan is more difficult than in many other areas.

This report is based on the first-year research of the TCCIP project. It investigates past climate change by reviewing previous research and examining important mechanisms affecting climate variation in Taiwan and East Asia. The project applies dynamical and statistical downscaling on the 24 IPCC AR4 GCM simulations to project future climate change in Taiwan. It also provides an uncertainty estimate to allow risk assessments.

The report describes current understandings of past climate change and future climate projections in Taiwan. It includes new research results and several unresolved issues. Unresolved issues include an incomplete understanding of factors affecting Taiwan’s climate and the uncertainty of future climate change. Climate change projections are uncertain because of GCM simulation uncertainty and downscaling process errors. No adequate scientific technique exists to fully address these problems. Climate change research and projection is an ongoing process. The more climate change is understood, the more GCM projections will improve. Climate change research and projection in Taiwan should also be ongoing processes. The IPCC data will be regularly updated and should be used to regularly update Taiwan’s climate change projection. The IPCC schedules to publish its fifth assessment report and updated projection in 2013. This information should be used to update Taiwan’s climate change research and projections.

Climate change projections in this report indicate that Taiwan may experience the effects of increased rainfall in the wet season and less rainfall in the dry season. Future climate change may worsen this effect. As future climate extremes and environmental changes affect Taiwan’s environment, current disaster reduction systems and homeland security must adapt to different challenges; for example, extremes becoming normal, changing types of disasters, and disaster magnitude exceeding historical experience and protection capabilities. While the government should consider the existing experience of disaster response and management systems to reduce disaster risks, homeland security and sustainable development authorities must apply new thinking and actions to strengthen homeland security and develop disaster reduction adaptation strategies to respond to climate and environmental changes and efficiently mitigate the impact of climate change.

CRITICAL ISSUES

What are overall climate trends in Taiwan relative to global climate trends?

To what degree has climate change affected disastrous weather events (such as typhoons, heavy rainfall, drought, heat waves, and cold surges)?

What is the relationship between climate change and climate events such as El Niño or Arctic Oscillation (usually interpreted as abnormal climate by the public)?

How are natural disasters, which are becoming more serious, related to climate change?

How reliable are Taiwan’s future climate projections? How should the government and the public use or interpret climate change information?

Critical Issues

What are overall climate trends in Taiwan relative to global climate trends?

(1) What is the rate and magnitude of climate change in Taiwan? How do temperature, rainfall, and sea level trends in Taiwan compare to global trends?

Climate change in Taiwan is a part of global climate change. The rate and magnitude of many changes in Taiwan are similar to global averages. For example, the annual mean temperature in Taiwan has been increasing since the beginning of the last century (CWB 2009), and this increase has become more evident after the 1970s. This is similar to average global temperature changes. Although the rate and magnitude differ slightly by weather station and year, this has a minor effect on the overall warming trend.

Taiwan’s warming rate was determined using results from the Taiwan Climate Change Projection and Information Platform (TCCIP) project. Data collected for over a century from Taipei, Taichung, Tainan, Hengchun, Taitung, and Hualien meteorological stations show that **the annual mean temperature in Taiwan increased by 1.4°C between 1911 and 2009. This is equal to an increase of 0.14°C per decade, which is higher than the global warming rate of 0.07°C per decade.** Taiwan’s annual warming rate was calculated using low-altitude weather station observation. The global warming rate, however, is the average of ocean and land records. **Regional differences also exist in global warming patterns. Taiwan is not the only country with a warming rate higher than the global average.** According to the fourth assessment report (AR4) of the Intergovernmental Panel on Climate Change (IPCC), the East Asian coastal region (from Japan to Korea to the South China Sea) is one of several regions with higher warming rates. During the last century, temperatures in China, Japan, and South Korea have increased at rates of 0.081°C, 0.113°C, and 0.187°C per decade, respectively. These figures are all higher than the global average. **In the last 30 years (1980 to 2009), the warming rate in Taiwan has accelerated significantly at a rate of 0.29°C per decade. This is almost twice the rate of the last century. The recent warming rate increase is consistent with the conclusion drawn by IPCC AR4**. Whether the warming rate will continue to increase or whether it is simply a part of natural decadal variation is uncertain.

IPCC AR4 (2007) showed no conclusive evidence of the rate or magnitude of global precipitation change. This is because precipitation is affected by many complicated factors and it differs by region. **Taiwan has a complex terrain and different weather systems affect different seasons. Although overall average precipitation shows multidecadal variability, a century-long linear trend is not evident** (Hsu and Chen 2002, Lu and May 2003, Liu et al. 2008)**. The number of rain days throughout Taiwan is consistently decreasing** (Hsu and Chen 2002, Hung and Kao 2010). The average number of rain days in Taiwan (represented by the average from six stations) has decreased by 4 days per decade in the last 100 years and 6 days per decade since 1980. The 3 years with the least rain days in the last 100 years were 2002, 2003, and 2004 (when the last droughts occurred). Rain days have decreased in all four seasons, with summer showing the fastest decreasing rate.

IPCC AR4 indicated that the average global sea level rose by 1.7 mm yr^{-1} from 1961 to 2003. However, the rate increased to 3.1±0.7 mm yr^{-1} between 1993 and 2003, indicating that the sea level rise is accelerating. **An analysis of tidal gauge observations of Taiwan's coastal regions shows that, from 1993 to 2003, the sea level in basins close to Taiwan rose at a rate of 5.7 mm yr^{-1}. This is twice the rate in the last 50 years** and is slightly higher than the 5.3 mm yr^{-1}calculated using satellite observations. **This rate is substantially higher than the global average of 3.1 mm yr^{-1}** (Tseng et al. 2010). Although global warming contributes to rising sea levels, increased sea levels near Taiwan may be partly attributed to regional causes, including decreasing sea levels in the Eastern Pacific Ocean in the last few decades, increasing sea levels in the Western Pacific Ocean, the effects of climate variations such as the El Nino-Southern Oscillation, and sea level changes in nearby basins (such as the South China Sea).

(2) How should readers interpret research results if differences exist between estimated climate change rates and magnitudes?

When scientists estimate the rate and magnitude of climate change, results differ because of differences in the number of stations, observation length, seasons, months, equipment calibration, and data imputation methods. For example, this report discusses the results of the TCCIP project, which used data from six low-altitude stations (Taipei, Taichung, Kaohsiung, Hengchun, Taitung, and Hualien) situated in regions lower than 400 m, to analyze warming trends in Taiwan in the last 100 years. The project indicated that the average temperature rose by 1.4°C from 1911 to 2009. The Central Weather Bureau climate change report (2009) accounted for regional characteristics and calculated trends from 25 stations in Taiwan (located on plains, mountains, urban areas, and off-shore islands) from 1909 to 2008. The trend estimated at urban stations is consistent with the TCCIP results, which showed that Taiwan has warmed at an average rate of 0.8°C in the last century (averaged from observations from several stations, some of which did not have 100 years of data).This is similar to the average global warming rate. **To avoid misunderstanding or misusing estimated results, readers should note descriptions of station features, data characteristics, and calculation methods as well as the effects of data length, density, and heterogeneity on results.** For example, the warming rate in this report does not reflect long-term temperature variation in Taiwan’s mountainous areas. Long-term climate trend analyses in Taiwan should be modified according to the number of stations used for estimation.

(3) What is Taiwan’s projected future climate change?

Using IPCC ScenarioA1B (Nakicenovic et al. 2000), that is considered the most likely future outcome by scientists, as an example, the TCCIP projects future climate change in Taiwan using spatial downscaling techniques from various global climate models (GCMs).

Regarding near-surface temperature projections, approximately half of the climate models project that temperature increases at the end of the twenty-first century (compared to 100 years ago) will range between 2°C and 3°C, which is slightly lower than the average global temperature increase. Regional and seasonal changes show that Northern Taiwan is likely to warm faster than Southern Taiwan, and autumn will be least affected by climate change.

Almost all projections project global average annual precipitation changes of less than 5%, although substantial regional differences exist. Precipitation may increase in wet regions and decrease in dry subtropical regions, causing subtropical semi-arid areas to extend toward high latitudes. Precipitation may increase in mid and high latitudes because of increased moisture transport to high latitudes. These changes are particularly prominent in winter. Because warming occurs faster over land than sea, Asian winter monsoon circulation may weaken. **Winter precipitation in Taiwan is projected to decrease,** which is consistent with the weakening of the Asian winter monsoon. Although summer monsoon circulation may not strengthen from increasing land-sea thermal contrast, increased atmospheric vapor may enhance moisture transport and cause **increasing precipitation in the Asian summer monsoon region**. The projected summer precipitation trend in Taiwan is consistent with the Asian summer monsoon trend. **Most of the multi-model simulations project that mean winter precipitation in Northern, Central, Southern, and Eastern Taiwan will decrease, with approximately half of the models projecting a decrease between 1% and 23%.** In Southern Taiwan, mean spring precipitation changes are similar to winter changes. **In summer, more than 60% of the models project an increase in seasonal mean precipitation in all regions, and approximately half of the models project an increase between 15% and 45%. For Central and Southern Taiwan, where rain is abundant in summer and scarce in winter, these projections indicate a greater difference in precipitation between wet and dry seasons. Allocating water resources between wet and dry seasons is a water resource management challenge.**

To what degree has climate change affected disastrous weather events (such as typhoons, heavy rainfall, drought, heat waves, and cold surges)?

(1) Relationship between climate change and the number, intensity, and tracks of typhoons that strike Taiwan

Every year, approximate 79 typhoons form globally, and approximate 27 of them form in the Western North Pacific. Taiwan is located in a region characterized by frequent passages of Western North Pacific typhoons, and on average approximately 13% strike Taiwan. **The number of Western North Pacific typhoons varies by decade** (Yumoto and Matsuura, 2001), **but a century-long linear trend is not evident.** The number of typhoons affecting Taiwan, as analyzed by the TCCIP project and referred to in this report, shows significant interannual variability but no significant linear long-term trend. More typhoons affected Taiwan after 1990 than between 1961 and 1989 (Chia and Lee 2008), with a sharp increase near 2000 (Tu et al. 2009). This is related to the average northward shift of typhoon tracks over the Western North Pacific. **The proportion of typhoons reaching strong typhoon intensity increased significantly after 1980. This and the northward movement of typhoon tracks are closely related to interdecadal variations in Pacific sea surface temperatures and Western North Pacific tropical cyclones**.

How will climate change affect typhoons in the future? Current climate model deficiencies mean that climate projection simulations cannot correctly simulate typhoon wind fields because of inadequate spatial resolution. Although scientists have used dynamical downscaling and enhanced regional and global climate simulation resolution, **large uncertainty remains in typhoon (tropical cyclone) change projections. Current global research shows that most GCMs are projecting that the number of tropical cyclones will remain unchanged or decrease (6% to 34%) in a warmer climate**. However, changes in the number of typhoons in individual basins are undetermined (Knutson et al. 2010). This decrease in global tropical cyclone numbers is related to future increasing stability of the vertical thermal structure of the tropical atmosphere. However, other factors affecting tropical cyclone formation (e.g. vertical wind shear and low and mid-level humidity) are usually related to variations in projected sea surface temperature and associated circulation. Thus, their effects on tropical cyclone formation may differ by basin. For example, future sea surface temperature changes in the tropical Pacific Ocean may not consistently affect the number of typhoons that form in the Western North Pacific.

These changes are likely to affect Western North Pacific typhoons by moving their average formation location southeastward and increase the probability of north-recurving typhoons. However, this will have no systematic effect on the number of typhoons that strike Taiwan.

Because of the inadequate resolution of most dynamical climate models, the structure and intensity of simulated typhoons differ substantially from observation. Therefore, these models cannot determine future intensity changes in typhoons. The accuracy of these model projections must be further examined. Nonetheless, because temperature is projected to rise and moisture is projected to increase in the tropics, a higher proportion of tropical cyclones, which once form in model simulations, may develop into intense typhoons. This conclusion is supported by most simulation experiments using high-resolution regional typhoon models to project typhoon intensity changes.

(2) Changes in precipitation intensity

IPCC AR4 (2007) indicated that climate and weather extremes may occur more frequently because of climate change. Research published after IPCC AR4 (after 2007) has shown that global precipitation has been increasing (Chou et al. 2009), but the rate of increase is uncertain. The intensity and frequency of global intense precipitation have been increasing, with wet seasons becoming wetter and the dry seasons becoming drier. However, these changes differ by region. Model projections show that average global precipitation will increase with time in the twenty-first century, which means the global hydrological cycle will enhance. A 1°C temperature increase will result in precipitation increasing by 1% to 2% relative to a 6% to7% increase in atmospheric water vapor (IPCC 2007). Because current climate models significantly underestimate the intensity of extreme precipitation, the reliability of these estimates should be examined. **Model projections indicate that, by the end of the twenty-first century, extreme daily rainfall will increase in almost all regions except in subtropical dry regions. The average increase will be 10% to 20% in the mid and high latitudes and over 30% near the equator.**

An analysis of the average number of annual rain days with different precipitation intensities showed that the number of torrential rain days (daily rainfall ≧ 200 mm) in Taiwan has increased significantly in the last 50 years and the last 30 years, respectively, with 50-60-year multidecadal variability. The number of light rain days (daily rainfall < 1 mm) in Taiwan has decreased substantially, with a decreasing trend of 2 days per decade in the last 100 years and 4 days per decade in the last 30 years. These trends are similar to the long-term variations from global weather station observation analysis, but with large regional differences.

(3) Frequency and intensity of droughts

Because precipitation patterns have changed, in many regions precipitation concentrates in particular seasons, and in other regions uneven distribution of precipitation causes droughts. IPCC AR4 (2007) indicated that droughts in the tropics and subtropics have intensified and occurred more frequently. **Analyses of global precipitation variation in wet and dry seasons show that precipitation has increased in wet seasons and decreased in dry seasons. Therefore, seasonal differences in precipitation will increase, and this difference will be larger in regions where precipitation contrast between wet and dry seasons is already prominent.**

Using observations from six stations in Taiwan, this report analyzes the number of consecutive dry days and finds that they are consistently increasing. In the last 30 years, extremely dry spells in Hengchun and Hualien occurred more frequently than in any other period. Dry spells from other stations showed no significant variation. Regarding the change in the future, the global trend of increasing precipitation differences between dry and wet seasons will continue in the twenty-first century, affecting Northern Taiwan’s water supply in the dry season (winter and spring). If there is insufficient precipitation in winter and spring, the frequency and intensity of droughts in Northern Taiwan may increase. Because Southern Taiwan relies heavily on rainy season precipitation, it is essential to reinforce reservoir operations and water resource management in the summer, Mei-Yu, and typhoon seasons.

(4) Variation in heat wave and cold surge events

Since 1950, hot days and nights in Asia have shown an increasing trend. Hot nights have increased more rapidly and occurred in broader areas than hot days. In Taiwan, daily maximal and minimal temperatures have also increased, with a higher increasing rate at night than during the day (Chu 2007). **The number of days with high temperatures has shown an increasing trend at all six stations in the last 100 years, with Taipei showing the fastest increasing trend. Compared to the 1911-1920 decade, the annual number of days with high temperatures increased by more than 10 days on average between 2000 and 2009. Extremely cold events**

at all six stations have decreased in the last 100 years (Lu and Lee 2009)**. Both the frequency and intensity of cold surges have decreased from the effects of warming.**

An analysis of future extreme temperatures using the change in the projected probability density function distribution of daily mean temperature (including the maximum and the minimum) shows that mean temperature is likely to rise, but the change in variance is not significant. When analyzed according to current definitions of extremely high and low temperatures, **the number of days with extreme high temperatures will increase significantly in a warming climate as projected by most models, and those with extremely low temperatures will decrease** (Liu et al. 2008)**. Persistent summer heat waves will occur more frequently, which will affect sectors such as energy, health and medical care, and agriculture.**

What is the relationship between climate change and climate events such as El Niño or Arctic Oscillation (usually interpreted as abnormal climate by the public)?

Many factors cause climate change; some are natural and some are anthropogenic. Rare and powerful climate events are often seen as abnormal and attributed to anthropogenic global warming. However, these phenomena would still occur, even without the anthropogenic warming effect.

Arctic Oscillation (AO) has strong influence on winter climate in northern extratropics in recent years. **It varies in a timescale shorter than a season** and results in large-scale damage caused by extremely cold weather in the mid-latitudes of the northern hemisphere during 2009/2010 and 2010/2011 winters. Similar to high- or low-pressure systems and typhoons, AO is a natural atmospheric disturbance. How it occurs and changes is poorly understood. **El Niño and La Niña**, which are more familiar to the public, **are natural interannual variations**. An El Niño event usually lasts less than a year, whereas a La Niña event tends to last longer (1 to 2 years). Compared to the effects of anthropogenic warming or interdecadal climate variation, which can last several decades, they cause short-term variation with no evident effect on long-term climate change. However, **if climate change alters how climate systems interact, this may change the characteristics of El Niño and La Niña.**

Analysis of long-term global climate change shows that climate variation exists between several decades, called interdecadal variability. IPCC AR4 indicated that the rate of global warming is increasing. However, research has shown that temperature increases have slowed in recent decades and may even decrease in the next few decades. These inconsistencies arise because **climate change has several time scale characteristics. During the last century, in addition to a long-term increasing trend, global temperatures have also shown interdecadal variation with a period approximately several decades.** These interdecadal variations may be natural climate variations caused by ocean circulation variation and may be unrelated to anthropogenic global warming; however, its origin is not understood. **Recent research has discovered that a combination of interdecadal variation and long-term warming may have increased the rate of global warming in recent decades. However, interdecadal variation alone cannot explain the century-long warming trend.** If interdecadal variation begins a descending phase and temperatures decrease, this may temporarily offset long-term warming, but will not suppress it completely.

Climate change projections from IPCC AR4 (2007) **models do not consider how volcanic eruptions or events such as the Little Ice Age in the Middle Ages could influence future climate**. Past observations show that volcanic eruption could only cause global cooling of less than 1°C, which may last 1 to 2 years. Research has indicated that an event similar to a Little Ice Age would result in cooling of approximately 0.3°C (Feulner and Rahmstor 2010). The effect of interdecadal variation on temperature would also be less than 1°C. Although it is difficult to accurately predict the effects of natural variability on future climate, **all current research has shown that the influence of natural variation on global temperature is far less than that of the projected anthropogenic effect.**

Whether the frequency and intensity of recently observed abnormal climate events will change significantly in a warming climate should be examined. This is a critical aspect of climate change research and projection where advances must be made. Techniques to quantify the differences between the effects of anthropogenic global warming and natural climate variability are still under development.

How are natural disasters, which are becoming more serious, related to climate change?

Global statistics from the International Disaster Database (EM-DAT) from 1900 to 2009 show that, although the frequency, affected population, and economic loss associated with natural disasters have increased rapidly since the 1970s, the death toll has decreased. Disasters that occur more frequently are primarily hydrometeorological disasters (floods, typhoons, slopeland disasters, and droughts), which account for as much as 78% of all natural disasters of the last 10 years. The rise in hydrometeorological disasters is related to the increase of extreme climate and weather events as well as the rapid increase in population and economic development. **Regarding the projection of future disaster tendency, IPCC AR4** (2007) **indicated that, in a warmer climate, the frequency of extreme events (such as heat waves, heavy precipitation events, droughts, intense tropical cyclone activity, and sea level) will increase with a probability of 66% to 90%. The World Bank estimated that, with global economic development and population growth, the frequency, affected population, and economic loss associated with disasters will increase substantially in the future.**

According to World Bank statistics, Taiwan is a high-risk disaster area because it is affected by multiple types of disasters (Dilley et al. 2005). **Characteristics of disasters in Taiwan are similar to those of global disasters; that is, most of them are hydrometeorological. Disaster statistics (for floods, slopeland disasters, and droughts) show that disaster frequency in Taiwan has increased, and disaster characteristics have changed (mainly water-soil compound disasters) recently. Economic losses associated with disasters have increased, and the aspects influenced by disasters have broadened, indicating that disaster magnitude has increased.** This is closely related to the increase in weather and climate extremes and to changes in the natural and social environment. Statistics show that **the severity of typhoon and flood disasters is related to an increase in extreme precipitation**. **Whether precipitation-intense typhoons are defined by their short-term (accumulated over 1 to 6 hrs.) or long-term (accumulated over 48 hrs.) precipitation, the frequency of intense precipitation typhoons has increased prominently from 2000 to 2009.** From 1970 to 2009, precipitation-intense typhoons (the top 10% of typhoons according to their precipitation) often caused severe disasters (e.g. Typhoons Morakot, Herb, and Nari). Before 2000, this type of typhoon occurred once every 3 to 4 years on average, but after 2000, they occurred on average once a year. Although it is uncertain whether the increase in extreme rainfall intensity is caused entirely by global warming, this increase and increased disaster risk are alarming.

Environmental changes are also important causes of the recent intensification of disasters in Taiwan. Environmental changes such as the 921 Chi-Chi Earthquake, land subsidence, overdevelopment and construction on mountains, urbanization, and economic development requirements all contribute to more severe disasters.

Floods in Australia from 2010 to 2011 caused tremendous damage. The United Nations International Strategy for Disaster Reduction (2010) issued a press release to emphasize the importance of planning for situations where unpredictable and extreme weather patterns would be normal to mitigate economic loss. Therefore, **the traditional view that disasters are natural should be adjusted to a new view that disasters can be anthropogenically provoked**. **This press release shows the important influence of human environmental changes on disasters. The United Nations also called on governments worldwide to plan ahead to confront this issue.**

How reliable are Taiwan's future climate projections? How should the government and the public use or interpret climate change information?

Scientific approaches used to project long-term global climate change are quite complex. Possible future global population and socioeconomic development scenarios are determined in advance. Based on these scenarios, temporal variations in atmospheric constituents such as greenhouse gases and aerosols are estimated. These estimates are then used to drive climate models to simulate future climate and long-term climate change trends are then projected. If projections cannot provide regional climate change details, dynamical or statistical models are used for further estimation. The TCCIP climate change projections referred to in this report were obtained through this process.

Because climate change projections include uncertainties, it is important for users to thoroughly understand climate change projections and their limitations before assessing climate change impacts and drafting adaptive strategies for Taiwan. Causes of uncertainty in climate change projections for Taiwan include the followings:

(1) **Model simulation uncertainty**: This uncertainty originates from an insufficient understanding of climate systems and inadequate models. Even if the same radiative forcing is used to drive climate models, projected surface temperatures and precipitation may differ because of differences in model structure and the parameterization of physical processes. Several physical, chemical, and biological processes (such as the carbon cycle and ecological system) that affect climate change have not been completely included in current climate models. This can also cause uncertainties. For example, preliminary research has shown that the carbon cycle affects the climate. Warming effects in model simulations may increase if climate models include the carbon cycle.

(2) **Natural climate variability uncertainty**: This uncertainty originates from the internal variability in the climate systems. GCMs incorporate atmosphere, ocean, and land models and the interaction of these internal systems may cause natural climate variability. Hence, in addition to variation caused by the external radiative forcing of greenhouse gases, each model's projected climate change also includes natural climate variation caused by internal dynamical processes. Because each model simulates natural climate variation differently, results differ by model. In addition, because future changes in external natural

forces (e.g. solar radiation and aerosols from volcanic eruption) are unpredictable, they may not be included in current projections.

(3) **Future scenario uncertainty**: This originates from uncertainties regarding actual future developments and their corresponding greenhouse gas emission and concentration variations. The IPCC developed scenarios describing future world development. Based on these scenarios, simulations were designed and conducted by 24 GCMs. However, actual future development may not reflect these scenarios, and it is impossible to determine whether these scenarios will occur. Because the scenarios are hypothesized, they can only show possible future outcomes. Users of climate projection data must understand these future scenarios and their relevant assumptions.

(4) **Downscaling**: This refers to an increasing spatial resolution to several kilometers or fewer. Using statistical or dynamical methods to downscale the lower resolution GCM data (the average grid distance of IPCC AR4 GCMs is approximately 300 km) and projecting regional climate change introduces additional errors and uncertainties. Generally, the uncertainties introduced by models, natural climate variation, and scenarios are greater than the uncertainty introduced by downscaling methods. Errors and noise introduced by downscaling do not significantly increase the uncertainty of regional climate change projections in Taiwan. However, uncertainty introduced by the downscaling process should always be quantified.

Because of these uncertainties and data generation limitations, a relatively reliable method of quantifying an uncertainty range is to represent the result using probability distribution after climate projections are downscaled to a certain region.

If the magnitude of climate change projections is much larger than the uncertainty range, the confidence level of projected results is high. Generally, for changes in global average near-surface temperatures at the end of twenty-first century (or even regional changes of a small area in Taiwan), scientists are highly confident in the range of probability distribution. However, for precipitation changes, the confidence level is relatively low because of the large uncertainty range. Usually, a smaller area has a lower confidence level. Hence, users must note uncertainty and confidence levels to cautiously assess data limitations and risks in applying projections to policymaking and implementation when using climate change projections from the TCCIP project.

Scientists cannot predict actual global development nor can they predict how the world will gradually respond and adapt to the impacts of climate change. How the earth's climate systems operate is still not fully understood. What we can do is to realize through what processes the future climate change projections and the range of its possible probability distribution are obtained. Research assumptions must be understood to properly analyze and assess the possible impacts of future climate change on society and the environment. This will allow us to design strategic plans to minimize the ranges affected by climate change and the size of these effects. Governments must respond positively to the effects and threats of climate change. In addition to mitigating greenhouse gases, adaptation strategies should be considered. According to the Adaptation Policy Framework for Climate Change from the United Nations Development Program, each country must assess future climate risks before drafting climate change adaptation policies. Although current scientific advances enable the assessment of climate change projection trends, globally and locally, projection uncertainties exist. This is particularly true for Taiwan. Because of the complex weather systems and small area, it is difficult to quantitatively project future climate change in Taiwan. Suggestions for managing climate change uncertainties and benefitting from research include the following:

(1) The government and the public must realize the limitations of science and the uncertainties of future projections; that is, it is important to communicate climate change projection uncertainties to the public. For example, what should be done if the frequency of climate and weather extremes is likely to increase because of climate change? Climate change magnitude and probability will affect policy strength and consensus formation. Therefore, learning how to interpret data is essential.

(2) Data generators (e.g. scholars or research institutions) must be responsible for providing scientific data to users (e.g. policymakers and the public) and ensure that scientific data are converted to usable and accessible information. Data generators should explain and communicate data limitations to users to prevent incorrect conclusions and creating panic.

(3) Governments should use current scientific assessments to evaluate sustainable development options for a country and usable resources for communicating with the public and forming a social consensus. Policy and risk assessments can then be conducted.

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