Prevention and Treatment of Natural Disasters (2023) Volume 2 Issue 1

doi: 10.54963/ptnd.v2i1.1088

Original Research Article

Hurricane variation in the eastern North Pacific Ocean in the last 20 years

Muhammad Mehtab*

Department of Earth Sciences, Quaid-i-Azam University, Islamabad, Paksitan

Email: muhamadmehtab88@hotmail.com

ABSTRACT

The frequency, severity, and distribution of hurricanes in the Eastern North Pacific Ocean have changed significantly during the last 20 years (2003–2023). This study examines these differences along with trends, environmental factors, and their wider ramifications. The results show that increasing sea surface temperatures and increased ocean heat content contribute to an increase in storm strength, with a greater percentage of significant hurricanes (Category 3 and above). The effects of climate change and natural events like the El Niño-Southern Oscillation (ENSO) are highlighted by changes in storm paths and prolonged seasonal activity. This review highlights the urgent need for coordinated action, combining scientific research, policy interventions, and community resilience strategies to adapt to changing hurricane behavior. Ecosystems like coral reefs and mangroves, which serve as natural storm buffers, are becoming more vulnerable; improvements in forecasting technology and disaster preparedness are essential for reducing these risks in tandem with international efforts to address climate change. The effects on human populations and ecosystems are significant, including increased risks of storm surges, displacement, economic losses, and environmental degradation. The Eastern North Pacific region can more effectively handle the socioeconomic and environmental issues brought on by storms in a warming world by combining these initiatives.

Keywords: Pacific Ocean, Hurricanes, Seasonal Activity, Cyclones, El Niño, La Niña

ARTICLE INFO

Received: March 13, 2023 | Accepted: May 5, 2023 | Available online: May 15, 2023

CITATION

Mehtab, M. Hurricane variation in the eastern North Pacific Ocean in the last 20 years, Prevention and Treatment of Natural Disasters, 2023; 2(1): 17-27 pages.

doi: 10.54963/ptnd.v2i1.1088

1. Introduction

One of the world's most active basins, the Eastern North Pacific Ocean is an area with a high level of tropical cyclone activity. Hurricanes in this region pose serious threats to infrastructure, ecology, and human lives by directly affecting the Central and North American coastlines. Changes in hurricane features, such as frequency, severity, and spatial distribution, have been more noticeable throughout the past 20 Anthropogenic causes, especially those associated with global warming, and natural climatic processes work together to generate these changes[1]. Improving forecasting models, enhancing disaster preparedness, and lessening the socioeconomic and environmental effects of hurricanes in this susceptible area all depend on an understanding of these variances.

This analysis looks at hurricane patterns in the Eastern North Pacific Ocean from 2005 to 2025, a time when satellite technology, observational networks, and climate modelling all advanced [2]. Researchers now have new methods to analyze changes in hurricane patterns and their root causes thanks to these advancements. A number of important concerns have surfaced throughout this time, such as how the frequency and intensity of hurricane activity have changed, what environmental reasons are causing these variations, and what effects these changes have on the ecosystems and communities that are impacted.

Hurricane activity in the Eastern North Pacific Ocean usually occurs from May to November, with late summer and early fall seeing the highest frequency. However, this trend has shown significant unpredictability in the last few decades. Although there hasn't been a steady rise in the overall number of storms throughout this time, the percentage of major hurricanes, those categorized as Category 3 and above—has increased dramatically [3]. Rising sea surface temperatures, which supply the thermal energy required for more powerful storms, are intimately associated with this trend of intensification. Hurricane paths have also been seen to migrate westward, which has increased hazards in certain areas while decreasing landfalls in others. Additionally, there is evidence of seasonal variations, with hurricane seasons beginning earlier and continuing longer, making forecasting and disaster response planning more difficult.

Natural and man-made environmental factors are closely linked to fluctuations in hurricane activity. The El Niño-Southern Oscillation (ENSO), which regulates the region's oceanic and atmospheric conditions, is one of the most significant natural factors. Warmer sea surface temperatures and less wind shear, which promote cyclone development, are linked to increased hurricane activity during El Niño occurrences. On the other hand, hurricane development is typically suppressed during La Niña times. Hurricane dynamics now include anthropogenic climate change in addition to these natural variances. Long-term ocean warming brought on by rising greenhouse gas concentrations not only makes hurricanes stronger but also raises the possibility of fast intensification events, in which storms rapidly intensify.

These shifts in cyclone activity have far-reaching effects. Stronger storms and rising sea levels, which intensify storm surges and flooding, pose a double threat to coastal towns in the Eastern North Pacific region. The growth of infrastructure in susceptible coastal areas and the growing intensity of hurricanes have both contributed to a large increase in economic losses. Furthermore, these storms have serious ecological repercussions, frequently causing harm to mangroves and coral reefs, two examples of natural barriers. These ecosystems are essential for lessening the effects of storm surges, and coastal areas become even more vulnerable when they are degraded.

doi: 10.54963/ptnd.v2i1.1088

The goal of this review is to present a thorough understanding of the changes in storm activity throughout the previous 20 years. It assesses patterns, investigates the environmental elements causing these shifts, and talks about the wider ramifications for ecological and human systems. By doing this, the piece hopes to support continued initiatives to solve the problems caused by hurricanes in the Eastern North Pacific Ocean. Additionally, it aims to promote the development of more effective mitigation and adaptation policies by identifying knowledge gaps and synthesising recent research. The data provided here emphasises how urgently coordinated action is required to address the increasing risks posed by hurricanes in a changing climate.

2. Observed Trends in Hurricane Activity

Significant patterns in storm frequency, severity, spatial distribution, and seasonal timing have been seen in the Eastern North Pacific Ocean during the past 20 years. These patterns, which are influenced by both man-made and natural climate cycles, demonstrate notable changes in the traits of tropical cyclones in this area.

2.1 Frequency and Intensity

Over time, the overall frequency of hurricanes in the Eastern North Pacific Ocean has stayed mostly stable, but the storms' severity has significantly increased. With more storms achieving high strength levels, the percentage of major hurricanes (Category 3 and above on the Saffir-Simpson scale) has increased dramatically. Warming sea surface temperatures (SSTs), which supply the thermal energy required for storm intensification, are intimately associated with this trend [4, 5]. Increased oceanic heat content has also led to an increase in the frequency of rapid intensification occurrences, which occur when hurricanes intensify dramatically in 24 hours [6]. These occurrences have presented major difficulties for forecasting models, which frequently find it difficult to anticipate such abrupt shifts in storm intensity.

2.2 Spatial Distribution

Hurricane tracks in the Eastern North Pacific have been shown to drift noticeably westward. There are fewer landfalls in some areas, such as the coastline of Mexico, but there are higher threats for island settlements further west since hurricanes are forming farther from the coast and traveling more regularly into the central Pacific[7]. Changes in large-scale atmospheric circulation patterns, such as a weakening of the tropical easterly trade winds and adjustments to subtropical ridges, are thought to have contributed to this westward shift [6]. Meanwhile, farther away from conventional hotspots close to the Mexican shoreline, higher SSTs in the central Pacific region have improved hurricane formation conditions[8].

2.3 Seasonal Variability

In this area, the biggest hurricane activity usually happens in late summer and peaks between May and November. Nonetheless, hurricane seasons have begun earlier in recent years, and active periods have lasted longer into the year[8]. A number of reasons, including changes in atmospheric dynamics brought on by climate change and an increase in ocean heat content, are responsible for these seasonal variations [9]. Storms that originate outside of the typical hurricane season have grown, making disaster preparedness and response planning more difficult, according to a study that looked at hurricane data from the previous 20 years [10].

2.4 Frequency of Landfall

The westward shift has resulted in a minor drop in the overall number of hurricanes making landfall

doi: 10.54963/ptnd.v2i1.1088

in the Eastern North Pacific, but the storms that do tend to be more powerful and destructive. Because stronger hurricanes bring higher winds, more rainfall, and more substantial storm surges, this trend increases the hazards to coastal residents and infrastructure [11]. As infrastructure damage and recovery costs rise, coastal regions—especially those in Mexico and Central America—face growing economic and social vulnerabilities [12].

2.5 Influence of Natural Climate Variability

In this area, storm activity is mostly controlled by the El Niño-Southern Oscillation (ENSO). Warmer SSTs and less wind shear, which promote storm formation and intensification, usually result in an increase in hurricane frequency and intensity during El Niño years [13]. On the other hand, because of increased wind shear and lower SSTs, La Niña years typically reduce hurricane activity [14]. For instance, a study by Camargo et al. (2007) shows that whereas La Niña inhibits cyclogenesis to a similar extent, El Niño circumstances can cause a 30–40% rise in hurricane activity in the Eastern North Pacific.

2.6 Long-Term Trends and Climate Change

Other changes in storm behavior have been brought about by anthropogenic climate change in addition to natural variability. Long-term warming of SSTs is being caused by rising global temperatures and increased greenhouse gas emissions, which is making it easier for hurricanes to form and intensify. Storm strength has increased as a result of this warming, and it may also be affecting changes in seasonal timing and spatial distribution. According to recent studies, rising SSTs and increasing ocean heat content have roughly doubled the likelihood of Category 4 and 5 storms during the past 40 years [15]. Additionally, rapid intensification occurrences may be made worse by climate change, making hurricanes even harder to anticipate and prepare for it [16].

3. Environmental Drivers

Anthropogenic variables and natural climate events combine to form the environmental drivers of storms in the Eastern North Pacific Ocean. The frequency, intensity, spatial distribution, and seasonal variability of tropical cyclones in this area are significantly influenced by these drivers.

3.1 Sea Surface Temperature (SST)

One of the most important variables affecting storm activity is sea surface temperature. Hurricane generation and intensification require thermal energy from warm ocean temperatures, usually above 26.5°C (80°F)[17]. The reported rise in hurricane intensity and quick intensification episodes over the last 20 years has been closely associated with warming SSTs in the Eastern North Pacific [18]. Because greenhouse gas emissions trap heat in the atmosphere and seas, global climate change is mostly to blame for this warming [19]. Hurricanes can intensify and maintain their strength for longer periods of time due to the increased thermal energy available in warmer waters.

3.2 El Niño-Southern Oscillation (ENSO)

The region's storm activity is significantly influenced by the ENSO cycle, which is marked by alternating El Niño and La Niña phases:

El Niño: Vertical wind shear reduces and SSTs in the Eastern Pacific are warmer than normal during El Niño years. There will be more and stronger storms as a result of these extremely favorable conditions for hurricane formation and intensification[20].

doi: 10.54963/ptnd.v2i1.1088

La Niña: On the other hand, La Niña years are linked to increased wind shear and lower SSTs, which prevent hurricane formation. Usually, the region experiences fewer and lesser storms during La Niña seasons.

Interannual variations in storm activity are a result of ENSO fluctuation, with some years seeing noticeably higher activity than others[21].

3.3 Atmospheric Moisture

Tropical cyclones depend on high atmospheric moisture levels to survive. Moisture is necessary for hurricanes to sustain their structure and feed convection. Hurricane development can be greatly impacted by changes in atmospheric moisture levels that are driven by larger climatic patterns. For example, more active hurricane seasons are frequently caused by elevated atmospheric moisture in the Eastern North Pacific during El Niño years[22].

3.4 Vertical Wind Shear

Another crucial element is vertical wind shear, which is the variation in wind direction and speed between the upper and lower troposphere. Hurricanes can form vertically oriented structures because to reduced wind shear, which is crucial for their intensification. In contrast, hurricanes are weakened and storm organization is disrupted by high wind shear. ENSO and more general climatic changes, such as those brought on by climate change, have an impact on the variability in wind shear in the Eastern North Pacific.

3.5 Ocean Heat Content

Hurricane development is significantly influenced by ocean heat content, or the depth and availability of warm water, in addition to surface temperatures. Storms receive extra energy from deep warm water layers, particularly during periods of fast intensification. Hurricane intensity has increased recently in the Eastern North Pacific due to increases in ocean heat content.

3.6 Anthropogenic Climate Change

Long-term changes in the environmental factors that contribute to hurricanes have been brought about by human-induced climate change. Warmer SSTs, higher atmospheric moisture, and changed wind patterns are all results of rising greenhouse gas concentrations, and these factors all contribute to stronger hurricanes. Changes in hurricane paths, with storms originating farther west and lasting longer, have also been connected to climate change. These modifications highlight how human activity is increasingly influencing the behavior of natural hurricanes.

3.7 Large-Scale Atmospheric Patterns

Hurricane activity is also influenced by large-scale atmospheric phenomena other than ENSO, such as the Pacific Decadal Oscillation (PDO) and Madden-Julian Oscillation (MJO). Depending on its phase, the MJO, an eastward-moving pattern of tropical convection, can either increase or decrease hurricane activity. Similarly, on multidecadal periods, the PDO, a long-term ocean-atmosphere fluctuation in the Pacific, influences air circulation and SSTs, thereby influencing hurricane intensity.

3.8 Role of Climate Variability and Long-Term Trends

Long-term trends brought on by climate change are changing the baseline conditions for hurricane development, while ENSO and other short-term climatic phenomena generate interannual variability. For instance, the region may have more powerful hurricanes than in prior decades even during neutral or La Niña years due to higher baseline SSTs[21]. These patterns demonstrate how anthropogenic and natural variability are increasingly influencing hurricane activity.

4. Impacts and Implications

Human populations, ecosystems, and economic systems are all significantly and broadly impacted by hurricanes in the Eastern North Pacific Ocean. These storms' destructive potential has increased over the last 20 years because to their increased strength and variability, which has had serious socioeconomic and environmental repercussions. These effects highlight the necessity of strong adaptation and mitigation plans to deal with the growing problems caused by hurricanes in this area.

4.1 Impacts on Human Populations

One of the most damaging natural catastrophes, hurricanes have a particularly severe effect on human populations in the Eastern North Pacific region. Because of their closeness to the storm-prone ocean, coastal populations in nations like Mexico, Guatemala, and portions of the United States are extremely vulnerable to hurricanes. Hurricanes still result in fatalities and injuries despite improvements in forecasting and early warning systems, especially in places with low resources. Rapid intensification events' abruptness increases the risks for areas that are already at risk. Large-scale population displacement and evacuations are frequent, especially in low-lying areas vulnerable to floods and storm surges. Hurricanes damage water sources, interfere with healthcare systems, and foster an environment that is favorable for the spread of diseases like dengue fever and cholera. Impacts on mental health, such as anxiety and trauma, are also common [23, 24].

4.2 Economic Impacts

The economic costs of hurricanes in the Eastern North Pacific region have risen significantly due to storm intensity and the expansion of infrastructure in vulnerable areas. Primary economic impacts include:

Infrastructure Damage: Roads, bridges, ports, and communication systems suffer extensive damage, with repair and rebuilding costs placing heavy financial burdens on affected nations [22].

Property Losses: Residential and commercial properties face widespread destruction, with insurance claims and rebuilding efforts contributing to long-term economic strain [23].

Agricultural Losses: Hurricanes devastate crops, livestock, and fisheries, impacting food security and economic stability, particularly in rural communities reliant on agriculture .

Tourism Decline: Popular tourist destinations in the region experience cancellations, reduced visitor numbers, and damaged infrastructure, leading to significant economic losses in this vital sector .

4.3 Environmental Impacts

Hurricanes significantly affect natural ecosystems, which often act as vital buffers against storm damage. Key environmental consequences include:

Destruction of Coastal Ecosystems: Mangroves, coral reefs, and wetlands, which provide natural protection against storm surges, are frequently damaged, reducing coastal resilience [24].

Deforestation and Erosion: High winds and heavy rainfall cause soil erosion and deforestation, particularly in mountainous areas, leading to long-term ecological degradation .

Marine Ecosystem Damage: Hurricanes disrupt marine habitats through sedimentation and temperature changes, with coral reefs being particularly susceptible to destruction .

Biodiversity Loss: The destruction of habitats leads to significant biodiversity loss, pushing already vulnerable species closer to extinction .

4.4 Implications for Disaster Preparedness

The increasing intensity and variability of hurricanes in the Eastern North Pacific pose new challenges for disaster preparedness and response:

Early Warning Systems: Enhancing early warning systems to account for rapid intensification events is crucial. Real-time monitoring and predictive models must improve to provide communities with sufficient time to respond .

Infrastructure Resilience: Strengthening infrastructure to withstand stronger hurricanes, including reinforcing buildings and flood defenses, is essential for reducing impacts .

Community Preparedness: Education and awareness programs are critical for improving local disaster management and evacuation strategies .

4.5 Implications for Climate Policy

The observed changes in hurricane behavior highlight the growing influence of climate change on natural disasters. Policymakers must address these implications through:

Mitigation Strategies: Aggressive reductions in greenhouse gas emissions are essential for limiting the warming of oceans and the atmosphere, which fuel stronger hurricanes .

Adaptation Measures: Coastal communities must adopt zoning regulations, restore natural barriers, and invest in climate-resilient infrastructure to reduce vulnerability .

International Cooperation: Given the transboundary nature of hurricanes, regional and international collaboration is vital for effective disaster response and climate adaptation .

4.6 Implications for Ecosystem Conservation

Preserving and restoring natural ecosystems is a vital component of reducing hurricane impacts. Healthy mangroves, coral reefs, and wetlands enhance resilience against storm surges and flooding. Investments in conservation efforts can protect both ecosystems and human communities from future storms .

5. Future Directions

The future of hurricanes in the Eastern North Pacific Ocean will be shaped by ongoing climate change, advancements in forecasting technologies, and enhanced adaptation strategies. Understanding the projected trajectories of hurricane frequency, intensity, and spatial and temporal patterns is critical for informing disaster preparedness and mitigation efforts. Below, the future perspectives on hurricanes in the region are explored, focusing on their projected behavior, environmental drivers, and implications.

5.1 Projected Trends in Hurricane Behaviour

Increased Intensity

Future hurricanes in the Eastern North Pacific are anticipated to become more intense, with a higher proportion of storms reaching Categories 4 and 5

doi: 10.54963/ptnd.v2i1.1088

on the Saffir-Simpson scale . This intensification is driven by warming sea surface temperatures (SSTs) and increasing ocean heat content, which provide more energy for storm development.

Rapid intensification events, where hurricanes strengthen significantly within 24 hours, are also expected to become more frequent, posing challenges for early warning systems and emergency responses.

Shifts in Frequency

While the total number of hurricanes may remain stable or decline slightly, the frequency of major hurricanes is projected to increase due to more favourable conditions for storm intensification, driven by climate change.

Interannual variability caused by phenomena such as the El Niño-Southern Oscillation (ENSO) will continue to influence hurricane frequency, with El Niño years likely to produce more storms and La Niña years fewer.

Spatial and Temporal Changes

Hurricane tracks are expected to continue shifting westward, leading to increased impacts in regions of the central Pacific that were historically less affected [26].

Seasonal shifts, including earlier onset and longer hurricane seasons, are projected as oceanic and atmospheric conditions become favourable for storm formation over extended periods.

5.2 Environmental and Climatic Drivers

Warming Oceans

Ongoing warming of the Eastern North Pacific, driven by anthropogenic greenhouse gas emissions, will be a primary driver of future hurricane behavior [10]. Higher SSTs are expected to fuel stronger storms and expand the geographic areas where hurricanes can form and intensify [27].

Changing Atmospheric Dynamics

Changes in wind shear, humidity, and atmospheric circulation patterns will influence hurricane development and movement. Climate models predict that reduced wind shear in certain areas will allow storms to become more organized and longer-lasting [28].

Ocean Heat Content

Increasing ocean heat content, particularly in deeper layers, will provide a sustained energy source for hurricanes, enabling them to maintain or intensify strength over longer distances .

5.3 Implications for Coastal Communities

Rising Vulnerability

Coastal communities will face heightened risks from storm surges, flooding, and wind damage as hurricanes become more intense. Low-lying regions and small island nations will be particularly vulnerable to the combined effects of stronger storms and rising sea levels. Economic losses are expected to grow as infrastructure in coastal areas expands, increasing exposure to hurricane impacts.

Adaptation Challenges

Coastal areas will need to invest in resilient infrastructure, including stricter building codes, improved drainage systems, and protective barriers like seawalls and restored mangroves [28].

Enhanced disaster preparedness programs, including early warning systems and evacuation plans, will be critical to minimizing human and economic tolls from future hurricanes .

5.4 Advances in Forecasting and Monitoring

doi: 10.54963/ptnd.v2i1.1088

Improved Prediction Models

Advances in computational technology and climate science will improve hurricane forecasting, particularly for rapid intensification events and shifting storm tracks [20]. High-resolution models simulating fine-scale interactions between the ocean and atmosphere will provide more accurate projections.

Enhanced Observational Tools

Investments in satellite technology, ocean buoys, and unmanned aerial vehicles (drones) will enhance real-time monitoring of hurricanes. These tools will provide critical data on storm intensity, wind patterns, and ocean conditions, enabling better-informed decisions [27].

5.5 Mitigation and Policy Directions

Climate Action

Aggressive efforts to reduce greenhouse gas emissions are essential for mitigating the long-term impacts of climate change on hurricane activity. International agreements and policies aimed at limiting global warming could reduce the likelihood of catastrophic storms [28].

Restoration and conservation of ecosystems such as mangroves and coral reefs will be vital components of climate adaptation strategies, as these natural barriers mitigate storm surges and erosion .

Regional and Global Cooperation

The transboundary nature of hurricanes necessitates regional and international collaboration in disaster response and climate resilience. Countries in the Eastern North Pacific region must work together to share data, resources, and best practices .

5.6 Research and Future Studies

Understanding Climate-Hurricane Interactions

Further research is needed to explore how climate change-induced factors, such as ocean acidification and altered atmospheric circulation, will impact hurricane dynamics .

Studies on the socio-economic impacts of hurricanes can guide interventions to reduce vulnerability in high-risk communities.

Scenario Planning

Climate models incorporating different emissions scenarios can provide insights into how policy choices will influence future hurricane behavior. Such models will be crucial for long-term planning and risk management [29].

6. Conclusion

Over the past 20 years, a mix of natural climatic cycles and human-induced climate change has led to major shifts in hurricanes in the Eastern North Pacific Ocean. Increased intensity, changing regional distributions, changed seasonality, and the rising frequency of fast intensification occurrences are all indicators of these developments. The trends show that the hurricane terrain is dynamic and ever-changing, influenced by rising sea surface temperatures, rising ocean heat content, and shifting atmospheric circumstances. El Niño-Southern Oscillation-driven annual variability interacts with long-term warming trends, highlighting the significant impact of human activity.

These changes have far-reaching effects on natural ecosystems, human populations, and economic systems. In addition to major ecosystems like mangroves, coral reefs, and wetlands that mitigate the effects of storms, coastal towns are increasingly at danger from storm surges, floods, and infrastructure damage. The need for adaptive measures to protect human lives and ecological integrity is become more urgent by storms' increasing strength and unpredictability.

Investment in sophisticated forecasting models, comprehensive disaster preparedness programs, and resilient infrastructure must be the region's top priorities going forward. For precise forecasts and prompt reactions, enhanced monitoring systems and a better comprehension of climate-hurricane interactions will be essential. Additionally, tackling the growing threats presented by storms 30 will require international collaboration in climate change mitigation through decreased greenhouse gas emissions and habitat restoration.

The Eastern North Pacific area can overcome the difficulties presented by more frequent and destructive storms by combining scientific discoveries with proactive governmental initiatives. In a time of climate uncertainty, these initiatives will be essential for safeguarding ecological systems, protecting vulnerable communities, and increasing storm resilience.

Funding

This research received no external funding.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

Not applicable.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] Emanuel K. Increasing destructiveness of tropical cyclones over the past 30 years. Nature. 2005. 436:686–8.

[2] Webster PJ, Holland GJ, Curry JA, Chang HR. Changes in tropical cyclone number, duration, and intensity in a warming environment. Science. 2005.309(5742):1844–6.

[3] Knutson TR, et al. Tropical cyclones and climate change assessment: Part I: Detection and attribution. Bull Am Meteorol Soc. 2020.101(3):E303–E322.

[4] Trenberth KE, Fasullo JT. Tracking Earth's energy: From El Niño to global warming. Surv Geophys. 2011. 33(3):413–26.

[5] Camargo SJ, Wing AA. Tropical cyclones in climate models. Wiley Interdiscip Rev Clim Change. 2015. 7(3):211–37.

[6] Emanuel KA. Assessing the present and future probability of Hurricane Harvey's rainfall. Proc Natl Acad Sci USA. 2017.114(48):12681–4.

[7] Fernández-Martínez M. Nutrient availability as the key regulator of global forest carbon balance. Nat Clim Change. 2014.4(3):240–4.

[8] Muschinski T, Katz JI. Trends in hourly rainfall statistics in the United States under a

doi: 10.54963/ptnd.v2i1.1088

warming climate. Nat Clim Change. 2013.10:285–9.

[9] Chavas DR, Reed KA, Knaff JA. Physical understanding of the tropical cyclone wind-pressure relationship. Nat Commun. 2017. 8:1360.

[10] Li Y, Chakraborty P. Slower decay of landfalling hurricanes in a warming world. Nature. 2020. 587:230–4.

[11] Pielke RA Jr, et al. Normalised hurricane damages in the United States: 1900–2005. Nat Hazards Rev. 2008. 9(1):29–42.

[12] Wang C, Enfield DB. The tropical Western Hemisphere warm pool. Geophys Res Lett. 2001. 28(8):1635–8.

[13] Trenberth KE. Uncertainty in hurricanes and global warming. Science. 2005. 308(5729):1753–4.

[14] Kossin JP, et al. Global increase in major tropical cyclone exceedance probability over the past four decades. Proc Natl Acad Sci USA. 2020. 117(22):11975–80.

[15] Bhatia KT, et al. Recent increases in tropical cyclone intensification rates. Nat Commun. 2019. 10:635.

[16] Weinkle J, Landsea C. Normalized hurricane damage in the continental United States 1900–2017. Nat Sustain. 2018. 1:602–8.

[17] Qiu B. Coupled Decadal Variability in the North Pacific: An Observationally Constrained Idealized Model. J Clim. 2007. 20(13):3148–66.

[18] Trenberth KE. Changes in precipitation with climate change. Clim Res. 2011. 47(1–2):123–38.

[19] Wang P, Quinlan P, Tartakovsky DM. Effects of spatio-temporal variability of precipitation on contaminant migration in the vadose zone. Geophys Res Lett. 2009. 36(10):L10504.

[20] Vecchi GA, Soden BJ. Effect of remote sea surface temperature change on tropical cyclone potential intensity. Nature. 2007. 450:1066–70.

[21] Yadav RK, Yoo JH, Kucharski F. Why Is ENSO Influencing Northwest India Winter Precipitation in Recent Decades? J Clim. 2010. 23(2):564–78.

[22] Baert JM. Per capita interactions and stress tolerance drive stress-induced changes in biodiversity effects on ecosystem functions. Nat Commun. 2016. 7:12486.

[23] Ding Q, Schweiger A. Influence of high-latitude atmospheric circulation changes on summertime Arctic sea ice. Nat Clim Change. 2017. 7:312–7.

[24] Bosetti V, Cooke R. Integrated Risk and Uncertainty Assessment of Climate Change Response Policies. Intergovernmental Panel on Climate Change. 2014.