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Economic Loss Assessment of Tropical Cyclones Based on Bibliometric Data Analysis

Ling Tan[1], Weizhi Yao[2], Fei Chen[3] and Lianshui Li[1]

Abstract

Tropical cyclone (hereafter as TC) is one of the serious environmental disasters. In order to promote theoretical research into prevention and control of TCs, the current developments and trends in research on economic loss assessment of TCs around the world need to be understood. In this paper, bibliometric visualization analysis is used to analyze research progress based on literature collected from the Web of Science Core Collection database. The evolution trend of years and countries, cooperation networks, major scholars, knowledge bases, key topics, hotspots and challenges were presented quantitatively through keyword co-occurrence analysis, burst strength analysis, cluster analysis and keyword strategy matrix. The results indicate that the USA currently has the most influential studies. The top four topics in this research field are the influence of TCs on forest ecosystem, human health, social and economic system, along with the research on the influence of TCs under climate change. In addition, more studies considering the vulnerability, variability and risk assessment of TCs need to be further investigated in the future. Through quantitative literature analysis and review, this paper can help interested scholars develop a deeper understanding of the current situation and future trends in research on economic loss assessment of TCs.

Keywords

economic loss, tropical cyclone, bibliometric, data analysis, disaster

The rapid climate warming and the frequent occurrence of tropical cyclones (TCs) have posed a serious challenge to the sustainable development of the world (Intergovernmental Panel on Climate Change [IPCC], 2013; Kalantari et al., 2019). According to EMDAT-CRED, the average annual economic losses caused by TCs were 69.9 billion U.S. dollars from 2008 to 2017. Thus, TCs have become the most destructive and serious disaster economically. By those means, such as destroying physical capital including transportation grids, communication facilities and storage, damaging human capital including causing casualties, spreading diseases and damaging human physical and mental health, TCs and the storms generated by TCs have become one of the deadliest and most destructive natural disasters in the world (Needham et al., 2015).

The economic impact caused by TCs can be classified into direct economic losses and indirect economic losses in terms of monetary price (Bosello et al., 2012; Carrera et al., 2015). Direct economic losses are represented by damage at the moment of the event, including market losses, such as losses of assets, buildings, goods and services, and non-market losses, such as losses of lives, number of people affected or impact on the environment (Meyer et al., 2013; Natho & Thieken, 2018). Indirect economic losses refer to the losses caused by the

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interruption of the flow of goods, services and business revenues caused by TCs, as well as the negative impact on the performance of the overall economy (Baghersad & Zobel, 2015; Hallegatte & Przyluski, 2010).

The enormous scale of TCs often cause substantial effects on economic development, biology conservation, natural resource management, and environmental protection (Geiger et al., 2016). And these damaged areas often require a prolonged period to recover to their prior state and function (Chen & Rose, 2018). Unless effective measures like protection and restoration are undertaken to lessen hazardous impacts, economic, social, and ecological protection remain under the threat of TCs. However, prior to planning actions for protection, it is essential to examine the post-disaster effect of TCs and screen out high-sensitivity areas. The relationship between TCs and socio-economic impact has long been the subject of active research by scholars.

To help scholars develop a deeper understanding of the current situation and future trends in research on economic loss assessment of TCs, it is necessary to make a systematic analysis of the current research results. Especially to explore new research topics and fields from the perspective of time series, identify key literature, and summarize the evolution trend of related research to form a panoramic knowledge network structure. This paper attempted to sort out the research progress, hotspots, challenges and research trends of TCs economic loss assessment through objective bibliometric analysis. The main contribution is to analyze the existing literature about economic loss assessment of TCs, evaluate and discuss key topics, point out the limitations of current research, and then provide a useful reference for future research according to bibliometric analysis.

Methods

Literature Source

The literature search of this paper is limited to international peer-reviewed studies for two reasons. First, the format of non-academic studies (unpublished papers and reports) is not standard enough to be analyzed by bibliometric analysis software. In addition, non-academic studies are more prone to possible distortion, while results published in peer-reviewed studies have been carefully examined, which makes the loss estimations more credible. Data used in this study comes from the Web of Science (WoS) core collection database of Clarivate Analytics. The database contains more than 10,000 multi-disciplinary, high impact, international, authoritative and comprehensive academic journals, and is the most academically authoritative source of citation information in the world. In order to ensure the authenticity and integrity of the research results, it is very important to set the retrieval style in the process of data collection. TCs are classified according to their place of occurrence and intensity. The broadly defined TCs include hurricanes, typhoons and cyclonic storms (Ghosh & Chakravarty, 2018), so they were all set as search terms in this paper. Through repeated discussion of the search terms and comparison of the retrieval style many times, the theme retrieval and title retrieval were both adopted for literature collection.

The identified literature has expanded to a broad range of subjects which were beyond the scope of this review. Therefore, articles on irrelevant subjects needed to be excluded. Irrelevant subject areas are those that do not fall within the scope of atmospheric science and disaster science. The irrelevant subjects were determined by the agreement of at least two research team members. Then, the selected articles went through the process of removing duplicates. Finally, the title, keywords and abstract of searched articles have been checked to determine whether they are related to the research topic. The purpose of this paper is to explore the economic loss assessment of TCs. Hence, research such as factors of increased TC intensity and frequency were excluded from further exploration. 355 articles remained after the total process. The process flows of paper identification and selection are shown in Table 1.

Research Methods

Knowledge Mapping Analysis. The knowledge map is a graphic that can show the relationship between the development process and the structure of scientific knowledge. Certain methods can be used to map abstract data into 2 D or 3 D graphics, and reveal the development of a research field and discipline from macro, meso, and micro levels. The overview enables people to comprehensively review the structure of a discipline and research hotspots from all angles.

Co-Word Analysis. Co-word analysis is a content analysis method, mainly by analyzing the phenomenon in which a terminology that can express a research topic or research direction of a certain field appears in literature together. It can judge the relationship and show the research structure of the research field. On the basis of word frequency analysis, co-word analysis is divided into two steps. The first step is to extract keywords or subject words from the relevant literature database, which are usually high-frequency words whose occurrence frequency exceeds a certain threshold and can represent the research topic or research direction. The second step is to count the simultaneous occurrences of these high-frequency words in the same article in pairs to form a co-occurrence matrix.

Table 1. The Process of Paper Identification and Selection.

The process flows		Results
(1) The process of theme search		
a. The process of literature identification		2,039
Article source	Web of science Core Collection	
Search format	TS= ((tropical cyclone OR typhoon OR hurricane OR storm OR cyclone) AND (impact OR damage OR loss OR influence OR cost))	
Language	English	
Type	Article	
Year	1960—2019	
b. The process of irrelevant subject exclusion		1,148
(2) The process of title search		
a. The process of literature identification		1,066
Article source	Web of science Core Collection	
Search format	TI= ((tropical cyclone OR typhoon OR hurricane OR storm OR cyclone) AND (economic impact OR economic damage OR economic loss OR economic influence OR economic cost))	
Language	English	
Type	Article	
Year	1960—2019	
b. The process of irrelevant subject exclusion		769
(3) The process of removing duplicates		1,127
(4) The process of title, keywords and abstract selection		355

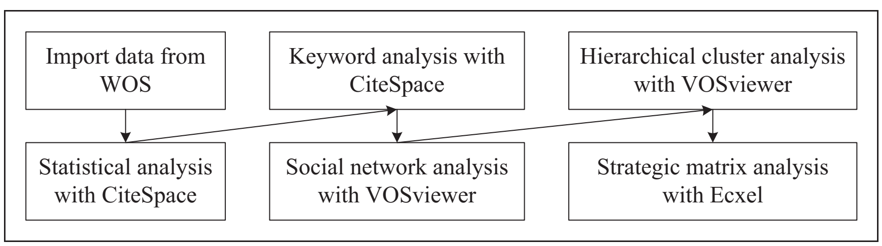

Figure 1. Research Tools and Processes of Bibliometric Data Analysis.

Research Tools and Processes

In order to clarify the current developments and trends of TCs economic loss assessment, scientific visualization methods were used to plot knowledge domain maps. CiteSpace was used for keyword frequency statistics and high frequency keyword screening and analysis. VOSviewer was adopted for social network analysis and hierarchical clustering to quantitatively and dynamically demonstrate the evolution of TCs economic loss assessment. Moreover, future research direction was also predicted and explored according to the keyword strategy matrix. Research tools and processes are shown in Figure 1.

Quantitative Analysis of the Literature

Quantitative Analysis of Years and Countries

The development status, knowledge accumulation and maturity of a research field can be measured by its literature publications, which is of great significance to evaluate the development trend and dynamic evolution. First, this paper described the publications and the changing trend in the past 60 years (Figure 2). In general, the volume has generally shown an upward trend, and the issue of TCs economic loss assessment has clearly been noted by scholars.

Second, to identify the main countries involved in TCs economic loss assessment and the cooperation among them, CiteSpace was used to draw maps of country distributions, which are shown in Figures 3 and 4. From the time of publications, the USA, Mexico, the UK, Netherlands, Australia are the countries that carried out the economic loss studies of TCs earlier. From the perspective of degree centrality, the USA occupies the first place, indicating that the USA has the greatest academic influence in the field of TCs economic loss assessment, while China is behind.

In terms of the number of publications, the total number of literatures in the top 8 countries is 312,

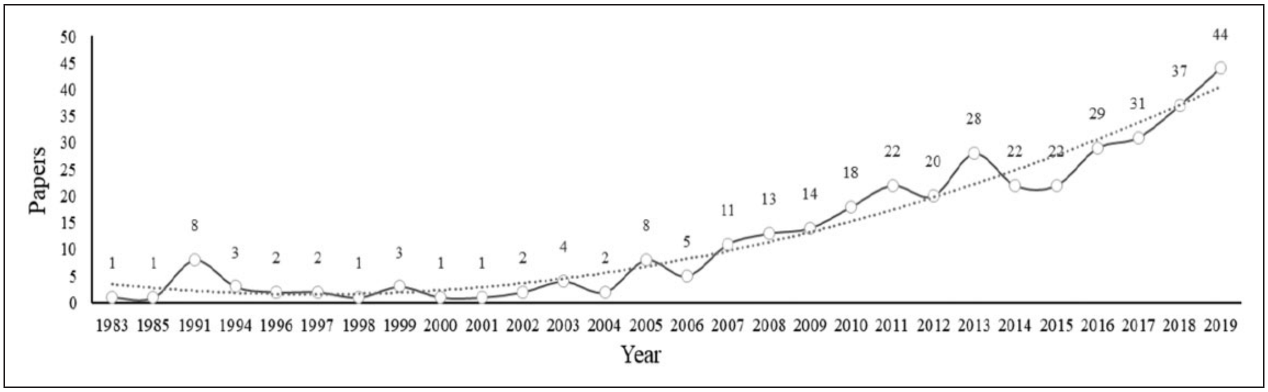

Figure 2. Annual Publication Related to Economic Loss Assessment of TCs.

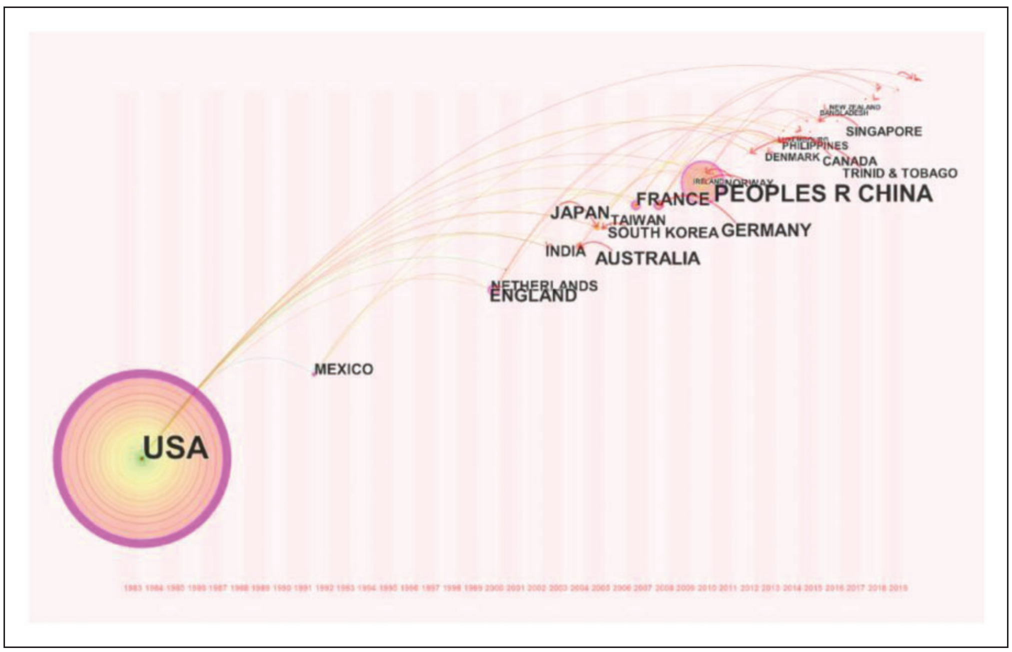

Figure 3. Countries/Regions Time Zone View Related to Economic Loss Assessment of TCs. Each dot represents a node (i.e., a country/region studying TCs economic loss assessment), and its node size is directly proportional to the number of publications. The purple ring on the outermost layer of the node represents its degree centrality.

accounting for 87.89% of the total number of literatures. The USA is the most active scholar in this field, with a dominant position in output (183 articles), accounting for about 51.55% of total publications. China ranks second with 47 papers, accounting for 13.24%. Australia ranks third with 16 publications, accounting for 4.51%. Other countries accounting for about 4% of the total literature are Germany, France, Japan and the UK. These countries are economically developed or in a period of rapid economic development, and attach great importance to this research field.

Quantitative Analysis of Institutions

Third, information on the most productive institutions that specialize in a certain theme can be identified via cooperation analysis of institutions, the academic cooperative connections among institutions are shown in Figures 5 and 6 respectively. The top 20 most productive institutions for total publications are shown on Table 2. The major academic contributions, which were concluded in terms of total publications, primarily originated from the MIT (8 articles), Texas A&M Univ (8 articles), Nanjing Univ Informat Sci & Technol (8 articles),

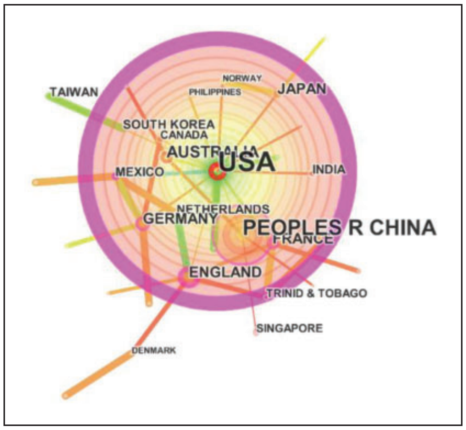

Figure 4. Countries/Regions Centrality Analysis Related to Economic Loss Assessment of TCs. The sizes of circles and fonts represent different degree centrality.

Columbia Univ (7 articles), NOAA (7 articles), and Michigan Technol Univ (7 articles). It is followed by Florida State Univ (6 articles), Florida Int Univ (6 articles), Chinese Acad Sci (6 articles), Vrije Univ Amsterdam (6 articles), Beijing Normal Univ (6 articles), Ecole Polytech (6 articles) and Univ Newcastle (6 articles), all of which are important institutions for economic loss assessment of TCs.

From the perspective of cooperative connections among institutions, this paper applied CiteSpace to generate the institution co-citation map, and found that colleges are important frontiers of TCs economic loss assessment research. Currently, three institution networks have mainly been formed. The largest cooperation network is the cooperation network centered on MIT. The cooperation institutions are Columbia Univ, Ecole Polytech, Princeton Univ, Yale Univ, and Purdue Univ.

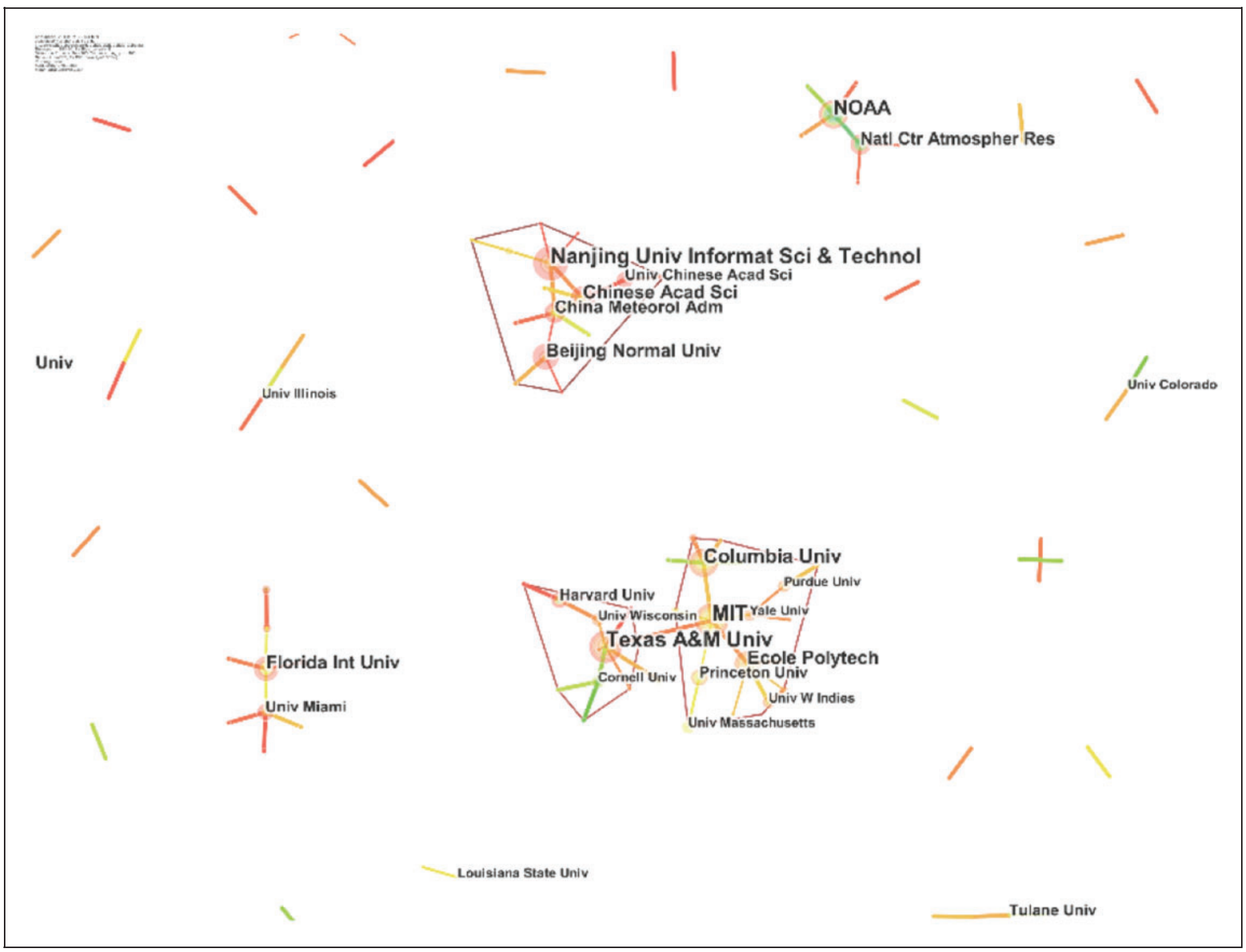

Figure 5. Institution Co-Citation Map Related to Economic Loss Assessment of TCs. The academic cooperative connections among institutions can be displayed by clustering.

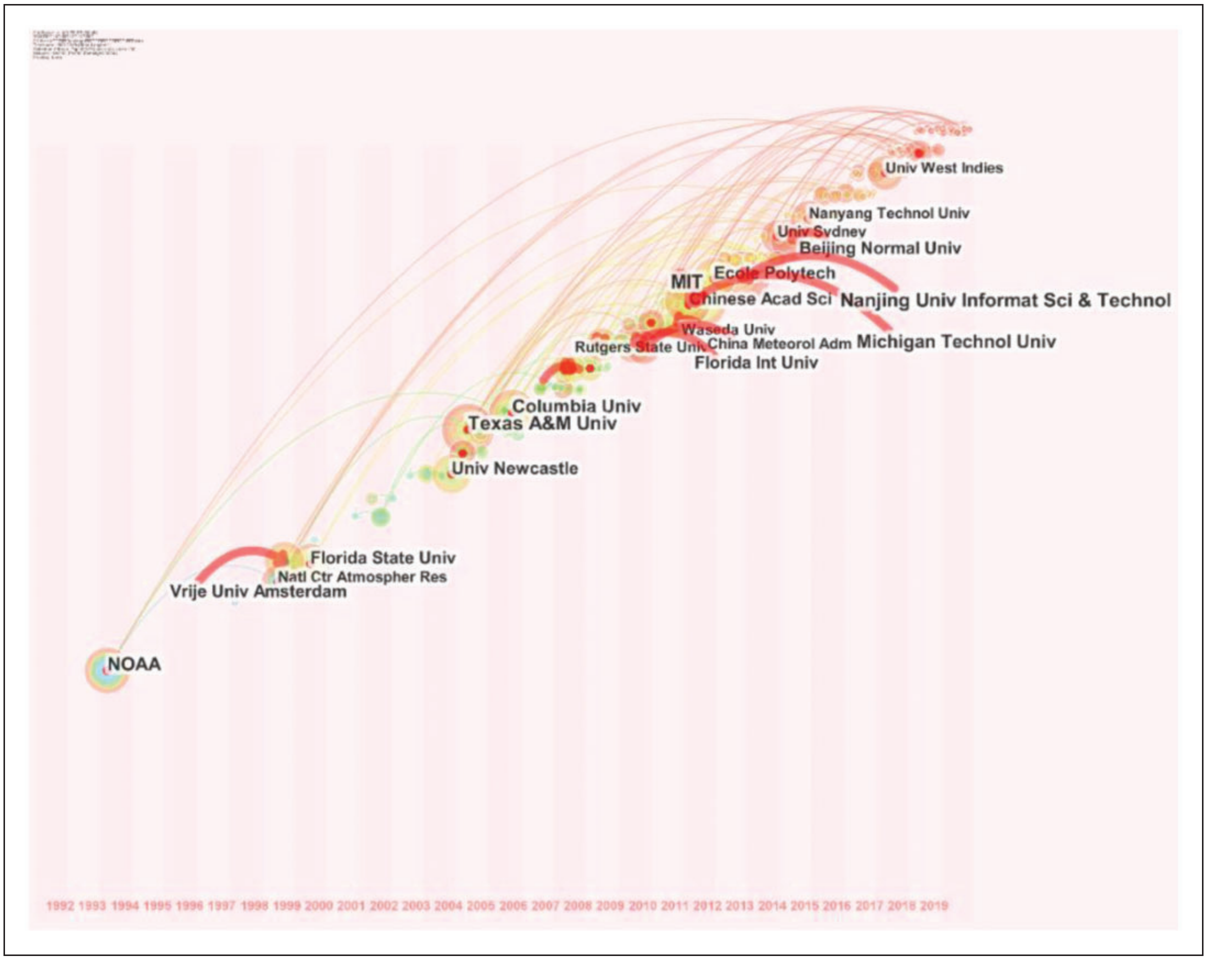

Figure 6. Institution Time Zone View Related to Economic Loss Assessment of TCs. The timeline of institutions' research can be reflected in the map.

Table 2. Top 20 Institutions With the Most Publications Related to Economic Loss Assessment of TCs.

Rank	Organization	Publications	Country	Rank	Organization	Publications	Country
1	MIT	8	USA	11	Beijing Normal Univ	6	China
2	Texas A&M Univ	8	USA	12	Ecole Polytech	6	France
3	Nanjing Univ Informat Sci & Technol	8	China	13	Univ Newcastle	6	UK
4	Columbia Univ	7	USA	14	Waseda Univ	5	Japan
5	NOAA	7	USA	15	Rutgers State Univ	5	USA
6	Michigan Technol Univ	7	USA	16	Univ Sydney	5	Australia
7	Florida State Univ	6	USA	17	Nanyang Technol Univ	5	Singapore
8	Florida Int Univ	6	USA	18	Natl Ctr Atmospher Res	5	USA
9	Chinese Acad Sci	6	China	19	China Meteorol Adm	5	China
10	Vrije Univ Amsterdam	6	Netherlands	20	Univ West Indies	5	India

The cooperative network with Nanjing Univ Informat Sci & Technol as the center is the second, and the cooperative institutions mainly included Chinese Acad Sci, China Meteorol Adm and Beijing Normal Univ. The third cooperative network is centered on Texas A&M Univ, and the cooperative institutions mainly include Univ Wisconsin and Harvard Univ. From the perspective of the timeline, NOAA is the core institution for the earliest TCs economic loss assessment research, while Texas A&M Univ, Columbia Univ, Nanjing Univ Informat Sci & Technol and Michigan Technol Univ are frontier institutions for TCs research.

Quantitative Analysis of Authors

Forth, the academic cooperative connections among authors are shown in Figure 7. Tended to cooperate with small groups of collaborators, the authors generated several clusters. However, the research teams of high-yielding authors are scattered, and the research cooperation network has not been formed yet. A total of 678 authors (including all authors of a single article) were counted. The top 16 most productive authors for total publications are shown in Table 3. The major academic contributions, which were concluded in terms of total publications, primarily originated from professor Strobl from University of Bern (12 articles), professor Li from Case Western Reserve University (7 articles) and professor Esteban from Waseda University (6 articles). It indicates that these authors have made outstanding contributions to the research of TCs in different time periods.

Quantitative Analysis of Knowledge Bases

Finally, this paper adopted Citespace to plot a reference co-citation knowledge domain map and generated clusters that change over time, as shown in Figure 8. The concept of co-citation was proposed by Henry Small, who is an American intelligence scientist. Co-citation analysis refers to identifying whether two pieces of literature appear together in the references of a third citing piece of literature, in which the two pieces of literature have a co-citation relationship (Small,1973). The knowledge bases of TCs economic loss assessment are composed of citation collection of all literature on this topic. Through the analysis of literature co-citation, foundational knowledge can be revealed from the perspective of the citation trajectory. In the co-citation

Table 3. Top 16 Authors With the Most Publications Related to Economic Loss Assessment of TCs.

Rank	Author	Publications	Rank	Author	Publications
1	Strobl, E.	12	9	Czajkowski, J.	4
2	Li, Y.	7	10	Emanuel, K.	4
3	Esteban, M.	6	11	Hallegatte, S.	4
4	Wang, Y.J.	5	12	Lam, J.S.L.	4
5	Stewart, M.G.	5	13	Jiang, T.	4
6	Wen, S.S.	5	14	Fischer, T.	4
7	Mohan, P.	5	15	Hamid, S.	4
8	Tol, R.S.J.	4	16	Pielke Jr, R.A.	4

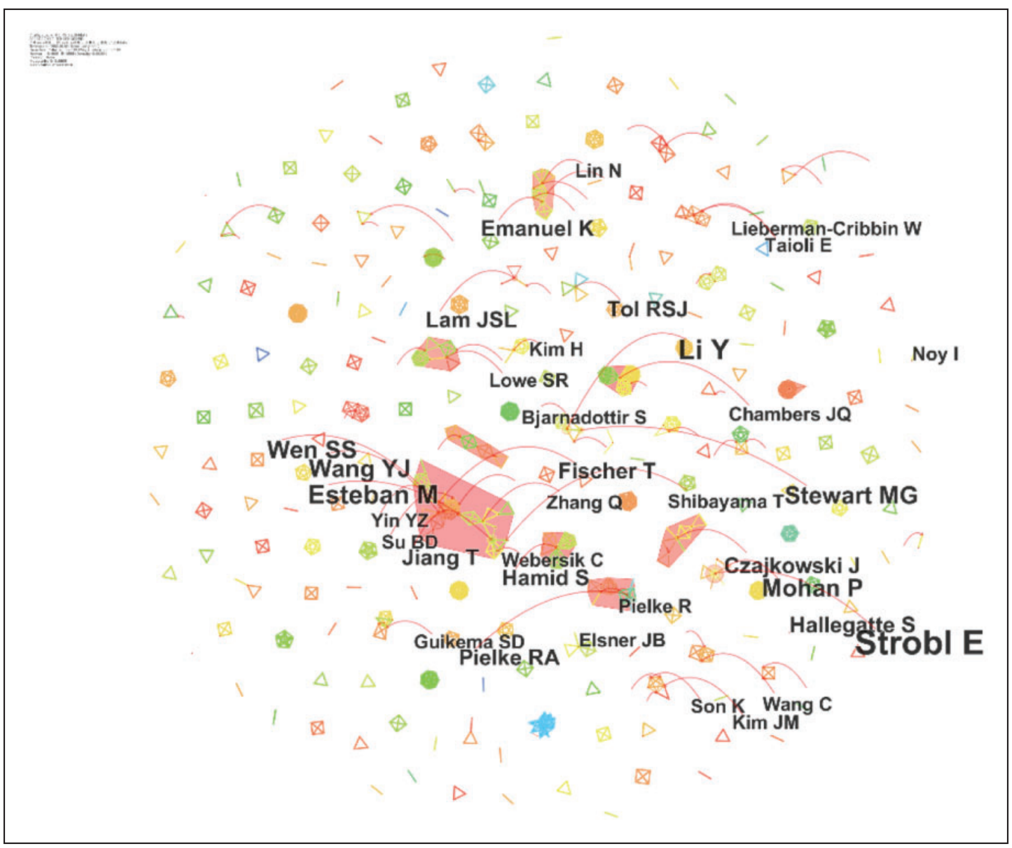

Figure 7. Author Co-Citation Map Related to Economic Loss Assessment of TCs. The academic cooperative connections among authors can be displayed by clustering.

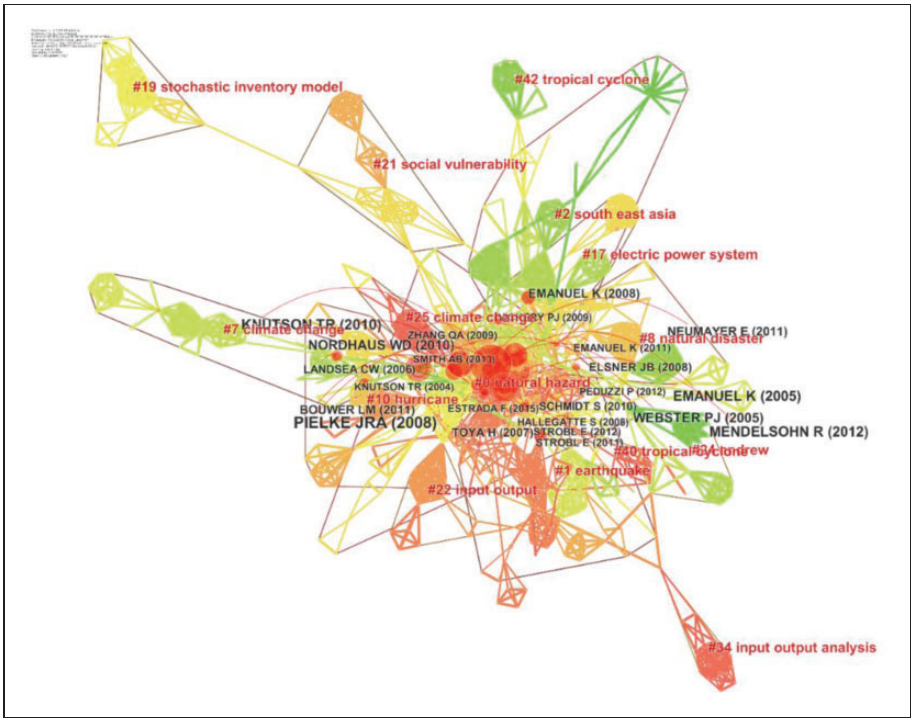

Figure 8. Clustering of the Literature Co-Citation Network Related to Economic Loss Assessment of TCs. The nodes represent different co-cited references, where bigger nodes indicate more co-citation, and each cluster is identified by a different color.

network, each cluster is identified by a different color, and the deeper the cluster fill color, the earlier the research theme formed. As shown, a total of 43 clusters are obtained related to economic loss assessment of TCs.

In order to gain a deeper understanding of economic loss assessment of TCs, it is necessary to determine the distribution of the most influential literature, thus this paper collected the top ten articles with the most co-citations. By analyzing literature with high co-citation frequency, this paper can draw hotspots in the field of TCs economic loss assessment. However, the citation relationship of scientific literature is also affected by factors such as the author's social relationship, journal category, and influencing factors, so the analysis only based on the citation frequency will produce bias. By analyzing literature with the highest degree centrality simultaneously, which refers to literature that has important links with many articles, as shown in Table 4, this paper can elaborate key studies more objectively. Through the analysis of these important literature, it can be found that research on TCs economic loss assessment focuses on the application of historical data to carry out the assessment, which has a strong influence.

Research Topics and Frontier Analysis

Research Trend Analysis

The research achievements in the field of TCs economic loss assessment are gradually enriched, and the research perspectives and methods are also increasingly diversified. As a highly generalized and research focus of academic topics, keywords are extracted from titles, abstracts and core research perspectives. The co-occurrence network analysis of keywords in academic articles can help to dig out the development trends of the research field more intuitively and clearly.

Using the statistical function of keyword co-occurrence in CiteSpace, this paper sorted out the top 20 high-frequency keywords in the research field of TCs economic loss assessment based on the statistics of key word frequency of the original data. They are climate change, hurricane, impact, tropical cyclone, model, natural disaster, damage, vulnerability, intensity, hurricane katrina, United States, risk, wind, resilience, China, adaptation, risk assessment, typhoon, cyclone and disturbance. According to the annual time zone of TCs economic loss assessment in Figure 9, each keyword node is represented as tree rings, the rings and links

Table 4. Reviews of Top 10 Co-Cited Literature With Most Citations and Highest Degree Centrality.

Author	Object	Method	Conclusion
Pielke Jr, R.A. (2008)	TCs of US	Normalization method with historical data	There is no remaining trend of increasing absolute damage to TCs.
Knutson, T.R. (2010)	Global TCs	Historical data analysis	Projected changes and damage have shown large differences among different modeling studies.
Mendelsohn, R. (2012)	Global TCs	Climate model and damage model with historical data	Climate change doubles economic damage, and almost all of the TCs damage from climate change tends to be concentrated in North America, East Asia and the Caribbean-Central American region.
Emanuel, K. (2005)	Global TCs	Construction of index system with historical data	Future warming may lead to an upward trend in destructive potential of TCs.
Webster, P.J. (2005)	Global TCs	Historical data analysis	A 30-year trend toward more frequent and destructive hurricanes.
Nordhaus, W.D. (2010)	TCs of US	Damage-intensity function with historical data	The average annual hurricane damage will increase by $10 billion (0.08 percent of GDP) due to global warming.
Emanuel, K. (2008)	Global TCs	Climatological analysis model with historical data	There is an increased frequency of TCs globally, but some tendency toward a reduction in Southern Hemisphere, which will lead to change in losses.
Neumayer, E. (2011)	Global TCs	Improved normalization method with historical data	There is no evidence that climate change has increased the normalized economic losses caused by TCs.
Bouwer, L.M. (2011)	Global TCs	Historical data analysis	Although economic losses from weather-related hazards have increased, anthropogenic climate change did not have a significant impact on losses.
Elsner, J.B. (2008)	Global TCs	Climate model and historical data analysis	As the seas warm, the ocean has more energy to convert to TC wind, the destructive force is stronger.
Toya, H. (2007)	Global TCs	Regression model with historical data	Countries with higher income, higher educational attainment, greater openness, more complete financial systems and smaller governments experience fewer losses.
Landsea, C.W. (2006)	Global TCs	Historical data analysis	An actual increase in global extreme TCs and their destruction due to warming sea surface temperatures should have continued.
Strobl, E. (2011)	TCs of US	Regression model with historical data	The impact of TCs is netted out in annual terms at the state level and does not affect national economic growth rates at all.
Bender, M.A. (2010)	Global TCs	Hurricane prediction model with historical data	Nearly a doubling of the frequency of category 4 and 5 storms by the end of the 21st century, the impact will be more serious.

are represented in a spectrum of colors corresponding to the years of the keywords' appearance. Combining the statistical results of keywords with the time zone view of the keyword co-occurrence map, it can be seen that keywords such as climate change, model construction, vulnerability assessment, and risk analysis have long been hot topics.

Microcosmic Research Topic Analysis

Keywords co-occurrence analysis can describe the core content and structure for certain academic domains, and reveal research frontiers from a large number of articles. This paper used VOSviewer to visualize the results, generated the co-occurrence map of keywords through

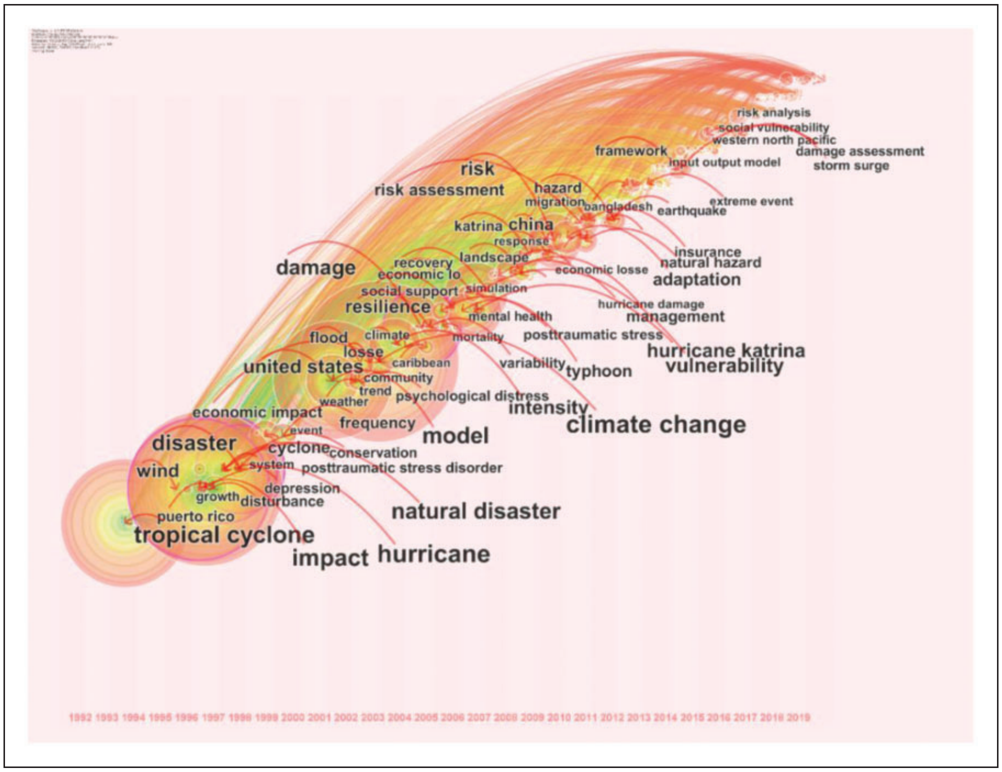

Figure 9. Time Zone View of the Keywords Co-Citation Map Related to Economic Loss Assessment of TCs. Each dot represents a keyword, and its node size is proportional to the frequency of the keyword.

clustering analysis, and made specific analysis according to the clusters, as shown in Figures 10 and 11. Nodes represent keywords and node size indicates the occurrence frequency of the keyword. Node connection thickness indicates the strength of co-occurrence between keywords. Combined with the keyword co-occurrence network and density clustering, it can be found that the economic loss assessment of TCs can be mainly divided into four main hot clusters.

Cluster 1 (green): The green cluster is mainly centered on research of TCs on forest ecosystems. TCs disturb forest ecosystems and have the potential to alter forest structure and species composition as well as ecosystem functions (Chapman et al., 2008; Negrón-Juárez et al., 2010). Quantifying these forest disturbances is necessary to evaluate the extent and severity of damage for estimating biomass loss and making management decisions. The main research methods are statistical analysis, remote sensing image analysis, etc. For example, Zeng et al. (2009) synthesized field measurements, satellite image analyses, and empirical models to evaluate forest and carbon cycle impacts for historical TCs from 1851 to 2000. Hochard et al. (2019) used nighttime luminosity to represent temporal trends in coastal economic activity and found that direct cyclone exposure typically results in permanent loss of 5.4–6.7 mo for a community with an average mangrove extent (6.3 m per meter of coastline); whereas, a community with more extensive mangroves (25.6 m per meter of coastline) experiences a loss equivalent to 2.6–5.5 mo.

Cluster 2 (blue): The blue cluster is mainly centered on research of TCs on human health. Research on the influence of TCs on human health includes both the influence on physical impact and mental state. The main methods adopted are statistical analysis, surveys and interviews, etc. For example, Galea et al. (2007) explored the prevalence, severity, and correlations of mental disorders among people exposed to Hurricane Katrina. Kessler et al. (2008) investigated patterns-correlates of recovery from Hurricane Katrina related to post-traumatic stress disorder (PTSD). They found that people were more likely to suffer from mental illness after Hurricane Katrina, such as PTSD (20.9% vs 14.9% at baseline), serious mental illness (14.0% vs 10.9%), suicidal ideation (6.4% vs 2.8%) and suicide plans (2.5% vs 1.0%). Kishore et al. (2018) surveyed 3299 randomly chosen households across Puerto Rico to produce an independent estimate of all-cause mortality after hurricane Maria.

Cluster 3 (yellow): The yellow cluster is mainly centered on research of TCs on social economic systems. The social economic impact assessment of TCs is mainly divided into direct economic losses and indirect economic losses. From the perspective of direct loss

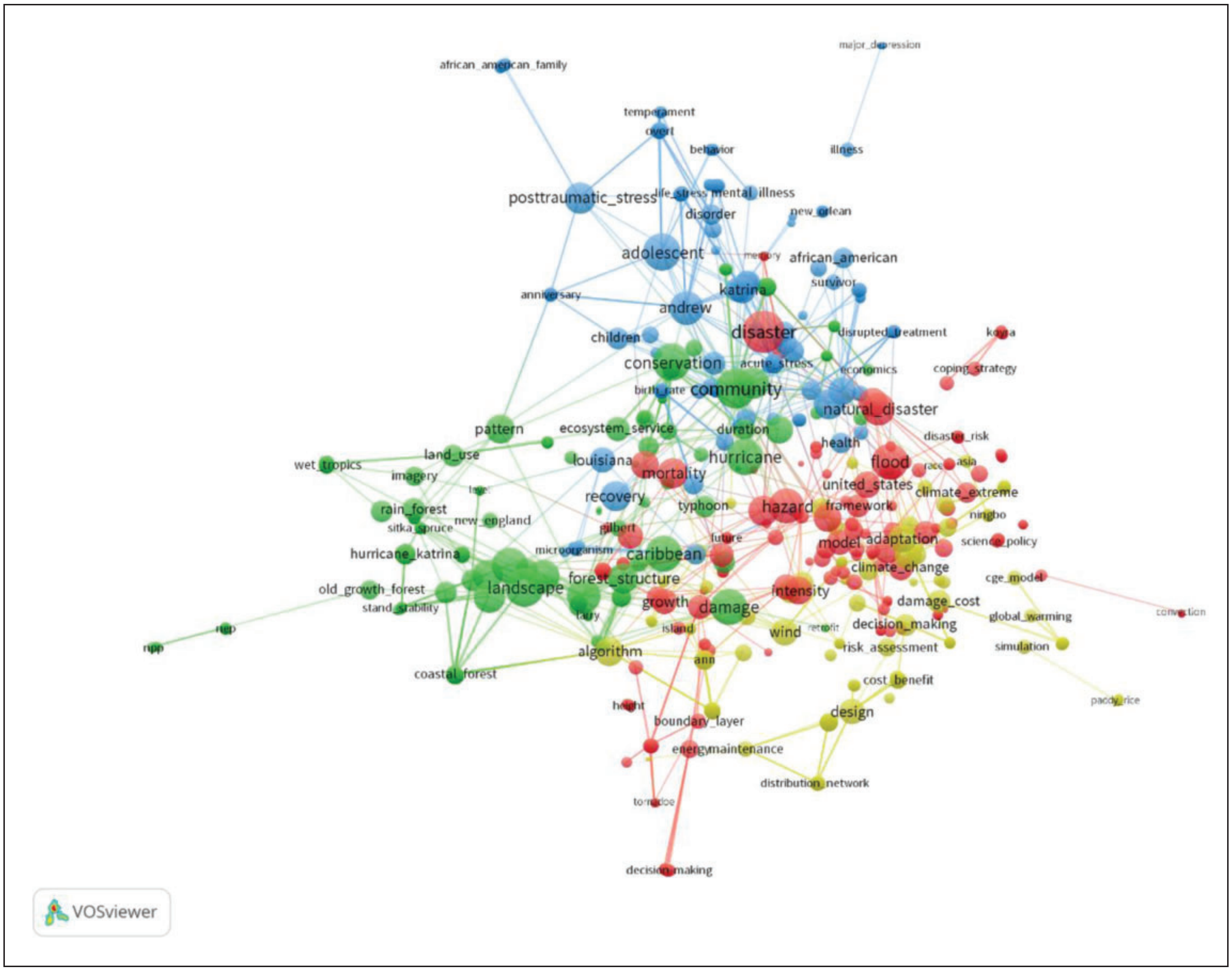

Figure 10. Knowledge Domain Map of a Keyword Co-Occurrence Network Related to Economic Loss Assessment of TCs. Each dot represents a keyword, and each cluster is identified by a different color.

research, the impact of TCs on industries and infrastructure (Mitsova et al., 2019; Philpott et al., 2008), quantity and remuneration of labor force (Belasen & Polachek, 2009; Wu et al., 2019), also with a possibility on the overall social economy (Pielke Jr et al., 2003; Wang et al., 2016) is included. The main methods adopted are vulnerability analysis methods, econometric models, along with damage models and artificial intelligence methods respectively. For example, Wen et al. (2018) constructed a damage rate curve based on multiple reference databases and socio-economic data to deduce TCs losses for major economic sectors in China. Deryugina et al. (2018) provided analyses of Hurricane Katrina's long-term economic impact on its victims by using a panel of tax return data. Hallegatte (2007) calibrated the vulnerability of each USA coastal county using data on past hurricanes and their normalized economic losses, and the annual hurricane damage increased by 54% in response to a 10% increase in potential intensity. Shan et al. (2019) collected social media texts sent during and after Typhoon Nepartak and constituted the database for rapid damage evaluations.

In addition, the methods for assessing the indirect economic influence of TCs can be mainly grouped into computable general equilibrium (CGE) models and input-output (IO) models. For example, Chen and Rose (2018) applied a multimodal CGE model to investigate the economic consequences of transportation system failures, and found that the road transportation sector had imposed the largest loss, accounting for 0.6% without resilience by Hurricane Katrina. Lenzen et al. (2019) used a multiregional IO framework to analyze the negative impacts of Hurricane Debbie. The results indicate that the disaster resulted in an additional indirect loss of 3685 jobs and 659 million AUD of value added.

Cluster 4 (red): The red cluster mainly reflects the topic of the influence of TCs under climate change. Recent research suggests that TCs may increase in intensity in the future due to the warming effect of greenhouse

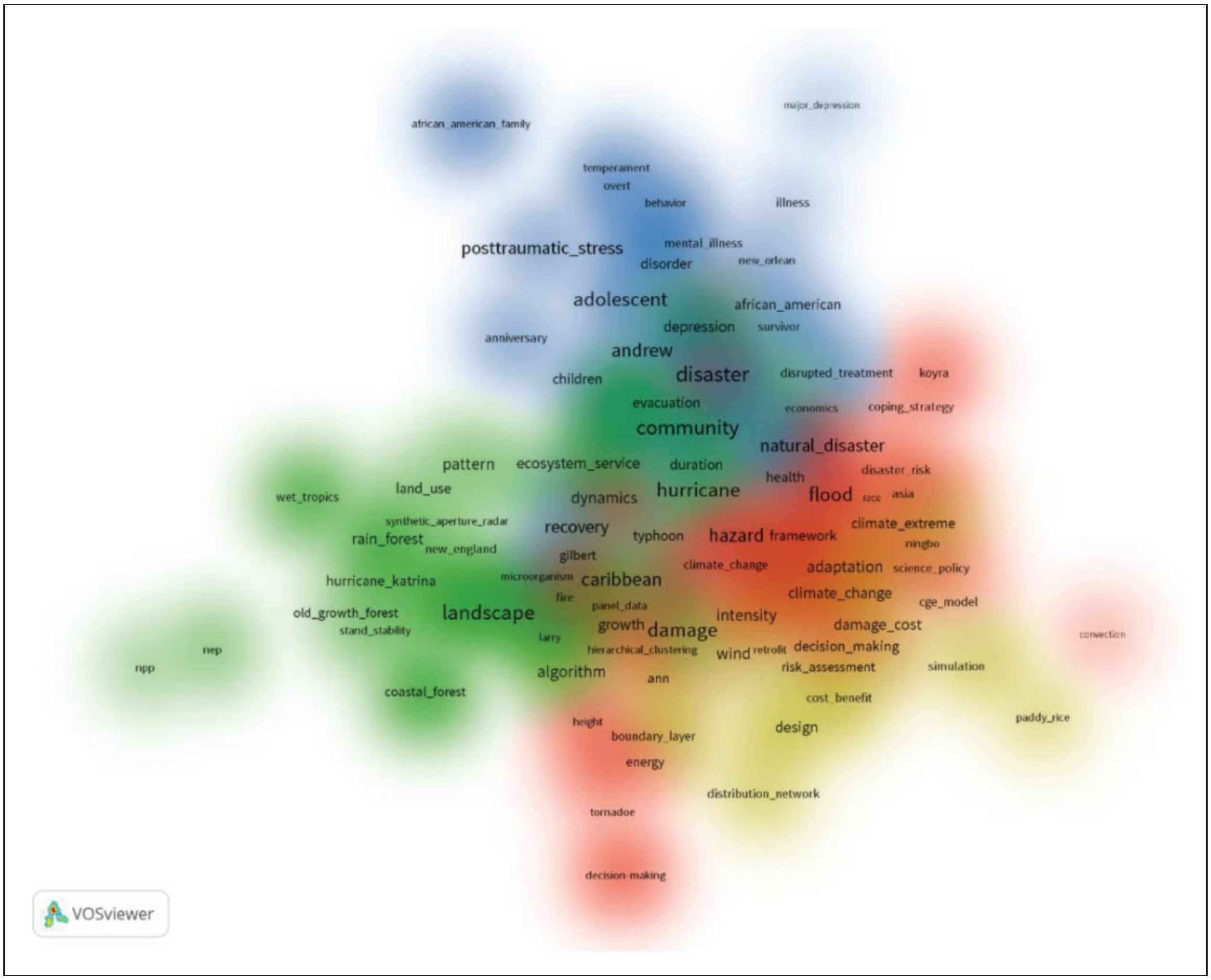

Figure 11. Knowledge Domain Map of a Keyword Co-Occurrence Network With Density-Based Clustering Related to Economic Loss Assessment of TCs. Each cluster is identified by a different color.

gases on surface sea temperature (Kalantari et al., 2019). This will probably lead to changes in the impact of TCs on the economy. Studies that project future losses may give a better indication of the potential impact of climate change on disaster losses and needs for adaptation than the analysis of historical losses (Bjarnadottir et al., 2011; Dorland et al., 1999). The research methods in this field mainly include simulating the running trajectory of TCs and constructing damage models. For example, Esteban et al. (2009) simulated future tropical cyclones by magnifying the intensity of historical tropical cyclones between the years 1978 and 2008 and then used a monte carlo simulation to obtain the expected number of hours that a certain area can expect to be affected by winds of a given strength. It shows the decrease in productivity could result in a loss of up to 0.7% of the annual Taiwanese GDP by 2085. Ye et al. (2019) reconstructed the wind and rainfall fields of historical TCs through an extensive database to extract economic exposure to TC-prone areas in mainland China.

Research Hotspots and Challenges Analysis

Keyword strategy matrix can further reflect the research focus, trend and challenges directly. In this paper, keyword frequency of TCs economic loss assessment was taken as the horizontal axis, and keyword degree centrality was taken as the vertical axis. The mean value of keyword frequency and degree centrality was taken as a dividing basis. Finally, the coordinate system of keyword strategy matrix related to economic loss assessment of TCs was made, as shown in Figure 12.

Keywords represented by "hurricane", "impact", "natural disaster" and "model" are located in the first quadrant and belong to the popular issues, with higher frequency and degree centrality. The research topics

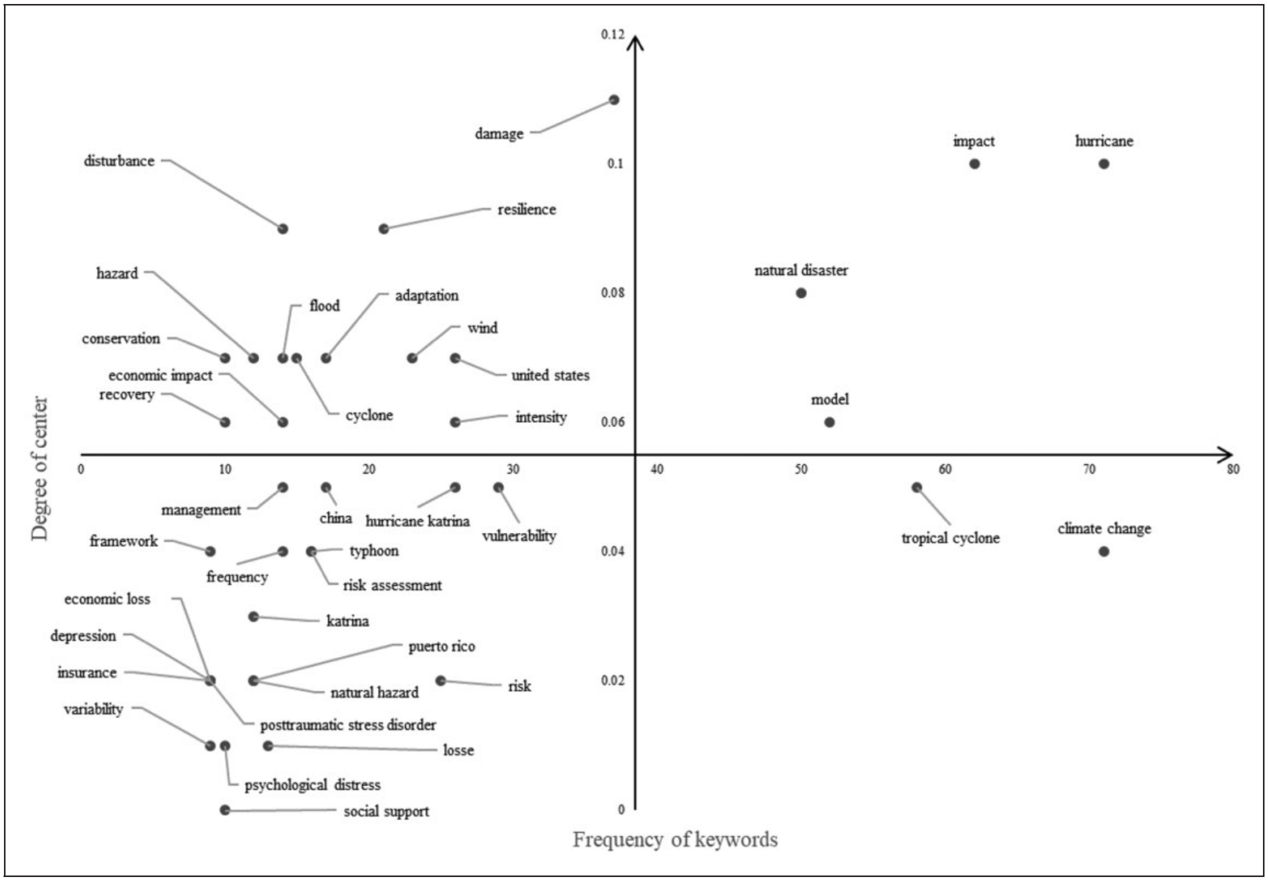

Figure 12. Keyword Strategy Keyword Strategy Matrix Related to Economic Loss Assessment of TCs. Keywords in the same quadrant have the same development trend.

represented by these keywords are not only mature in themselves, but also closely related to other research topics, which can be divided into research hotspots of current research. For example, Zhai and Jiang (2014) used a multi-variate least squares regression to construct a hurricane loss model for accurately predicting the impact of super-sized storms.

Keywords such as "damage", "resilience", "economic impact" and "recovery" are located in the second quadrant, belonging to the potential hotspots, which are characterized by lower frequency and higher degree centrality. Research represented by these keywords is still in the initial stage of development, but they are related to other topics closely and have the potential to become new hotspots. For example, Ouyang and Duenas-Osorio (2014) introduced a probabilistic modeling approach for quantifying the hurricane resilience of contemporary electric power systems, including a hurricane hazard model, component fragility models, a power system performance model, and a system restoration model.

"Vulnerability", "variability", "risk assessment", "management" and other keywords in the third quadrant, represented by characteristics of lower frequency and lower degree centrality. That is to say, research represented by these keywords belongs to topics that have not been developed yet and have poor connections with other topics. But that also means these topics need more attention, and more scholars are required to keep pushing for breakthroughs in the future. For example, Mitsova et al. (2018) used power outage data to investigate the relationship between the duration of power outage and socioeconomic vulnerability from hurricanes and high-wind events.

Keywords represented by "tropical cyclone" and "climate change" are located in the fourth quadrant, belonging to the marginal zone with higher frequency and lower degree centrality. It suggests that although these topics are well developed, they are less relevant to other topics and may gradually be marginalized. However, research topics represented by these keywords can also be continuously researched in combination with other popular topics or potential issues. For example, Gettelman et al. (2018) adopted a high-resolution climate model and damage model to simulate future economic damage due to TCs in the context of climate change.

Discussion

TCs damage the environment, ecosystems, and social economic systems frequently. Efficient conservation and management strategies require linking dominant effects to management actions (Tulloch et al., 2020). Therefore, a comprehensive and accurate assessment of TCs economic losses is essential to inform policy planning and support mitigation strategies. This paper applied visualization and analysis of mapping knowledge domains to analyze the economic loss assessment research of TCs from 1960 to 2019. The research results can reflect the evolutionary characteristics and research hotspots of this research field.

First, through the statistical analysis of the publication distribution of years, countries and institutions, the research heat is increasing yearly. The USA is the country that carries out research in this field first and has the largest publications. Colleges are important frontiers of TCs economic loss assessment. And, three cooperation networks among institutions have been mainly formed, the largest of which is MIT-centered cooperation network, including Columbia Univ, Ecole Polytech, Princeton Univ, Yale Univ and Purdue Univ.

Second, through statistical analysis of authors and citations, many authors are committed to investigating TCs economic losses. However, the research teams of high-yielding authors are scattered, and the research cooperation network has not been formed yet. The articles published by professor Pielke Jr from University of Colorado in 2008, professor Mendelsohn from Yale School of Forestry and Environmental Studies in 2012, and professor Emanuel from Massachusetts Institute of Technology in 2005 have strong influence, mainly focusing on the application of historical data for loss evaluation.

Third, according to the analysis of keywords co-occurrence, four clusters of TCs economic loss assessment are mainly formed, namely, the influence of TCs on forest ecosystem, the influence of TCs on human health, the influence of TCs on social and economic system and research on the influence of TCs under climate change. Among them, the influence of TCs on social and economic system can be further divided into the influence of TC on industries and infrastructure, quantity and remuneration of labor force, the direct economic influence on the overall social economy and the indirect economic loss assessment.

Fourth, combined with specific literature, from the perspective of methodology, the common methods used to measure the impact of TCs on forest ecosystems are statistical analysis and remote sensing image analysis. The common methods used to evaluate the impact of TCs on human health are statistical analysis, surveys and interviews. The common methods for assessing the TCs direct impact on industries and infrastructure, quantity and remuneration of labor force, and overall social economic systems are vulnerability analysis methods, econometric models, damage models and artificial intelligence methods respectively. CGE models and IO models are commonly used to assess the indirect economic influence of TCs.

Fifth, by analyzing the keyword strategy matrix of TCs economic loss assessment, it can be concluded that the research topics represented by "hurricane", "impact", "natural disaster", "model" and "damage", "resilience", "economic impact" and "recovery" are relatively mature and belong to current or potential research hotspots. In addition, research topics represented by keywords such as "vulnerability", "variability", "risk assessment", "management", "tropical cyclone", and "climate change" are relatively inadequate and need to be further enriched and improved in the future.

Based on the above analysis and discussion, future studies should focus on the following aspects. First, it is necessary to strengthen cooperation with different authors, universities and research institutes to promote the development of TCs economic loss assessment. Furthermore, more studies investigating the vulnerability, variability and risk assessment of TCs are needed. In addition, in order to further improve the level of estimation, models of TCs economic loss assessment need to be constantly improved. Finally, the application of current assessment models is highly limited owing to the numerous data required. Owing to the relevant disaster datasets measurement error, the available results of independent research can be used to report data and publication outlet bias, such as meta-analytic reviews.

Although this study is intended to help us better understand the research evolution and orientation in TCs economic loss assessment, there are several key issues that should be further explored in future research endeavors. For instance, the research data is based on the WoS core collection database, which may be affected by the coverage of WoS. In addition, the retrieval style and keyword structure were designed through many trials, however, there may still be some related articles that have not been captured. Future research can address these limitations by using multiple databases or focus on the development of methods to collect data more widely.

Implications for Conservation

TC is one of the most frequent and influential disasters in the world. Long-term protection of normal economic activities and ecosystems requires recognition of the impact caused by TCs. The evaluation of economic losses caused by TCs has played an important role in guiding the post-disaster reconstruction and allocation of funds (Tan et al., 2019). Besides, reflecting the impact of TCs in a comprehensive way is also more conducive to heightening the awareness of the public, so as to unite and carry out conservation strategies together (Wu et al., 2018). In this paper, how scholars can improve conservation outcomes by building scientific knowledge, informing policy formulation, and inspiring public action has been described.

The research findings provide the following important implications for conservation. First of all, reasonable planning of infrastructure, effective early warning systems, and evacuation drills based on past TC events can improve the level of protection of human life, economic activities and ecosystems in the future. For this step, ecosystem-based approaches, such as a hybrid approach between engineering and natural systems that integrate sustainable urban drainage systems, greenways and ecological networks, can reduce the impact of TCs and thus improve regional conservation capabilities. Moreover, implementation should be on a larger scale that is actually affected by the direct influence of the TCs to optimize protection. Generally, the scale of protection should be broad enough to realistically account for the economic, social, and ecological effects that are invisible. In addition, investing in the development of techniques or methods to gather, share, and analyze large quantities of data collected by different projects across large areas will further improve the precision in tracking the trajectory of TCs. It is only through data collected over time and areas that precise forecasting and assessment models can be built for better economic, social, and ecological protection.

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