Exploring Recent Research on Definitions of the Myanmar Southwest Monsoon: A Comprehensive Bibliographic Overview

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Abstract: Accurately pinpointing the onset and withdrawal dates of the monsoon bears significant implications for diverse sectors. However, this task is fraught with challenges due to the intricate interannual and spatial variabilities. The Myanmar Southwest Monsoon (MSwM) index emerges as a widely adopted tool for delineating the initiation and cessation of the southwest monsoon across its respective domains. The confluence of advancements in satellite remote sensing, climate modeling, and data assimilation techniques presents opportunities for refining monsoon intensity indices. Additionally, a nuanced comprehension of the intricate interactions between the monsoon and climate teleconnections stands to enhance the assessment of monsoon intensity. Distinguished as a distinct entity from the major South Asian monsoon system, the MSwM follows a seasonal cycle intricately linked to mainland Indochina. The thermal influence of the Tibetan Plateau amplifies both meridional and zonal land-sea thermal contrasts, underscoring the importance of monitoring and anticipating monsoons. The MSwM, a product of complex interactions involving the earth, ocean, atmosphere, hydrosphere, biosphere, and cryosphere, exerts a profound impact on regional facets such as agriculture, ecology, chemistry, economics, and society. As technological strides continue, especially in satellite observations and climate models, avenues open up for refining our understanding of monsoon dynamics. The limitations inherent in the current coupled model of the land-sea-atmosphere system underscore the anticipation for advancements in modeling studies. Research in this domain not only contributes to the regulation of human activities but also fosters a harmonious coexistence between humanity and nature, safeguarding the human habitat.

Keywords: *Atmospheric Science, Bibliography, Monsoon, MSwM, Myanmar*

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1. Introduction

The monsoon system determines the seasonal climate patterns over most parts of Asia, mainly the Indian sub-continent, and over Southeast Asia and large parts of East Asia. Directly, it influences the lives of nearly one-third of the world population and indirectly the lives of nearly three-quarters of the world population. Myanmar is situated between latitudes 9° and 28°N and longitudes 92° and 101°E in, the eastern Bay of Bengal region. It is north-south elongated and located between two different major monsoon systems, Indian Monsoon and East Asian Monsoon (B. Wang & Ho, 2002). Its economy heavily relies on agriculture, with a significant portion of its population engaged in farming. The monsoon season, which typically occurs from June to October, brings much-needed rainfall to the country. This 70% of annual rainfall is essential for the cultivation of rice, which is a staple food in Myanmar and a major crop for both subsistence and export. The monsoon rains replenish rivers, lakes, and reservoirs, which are crucial for irrigation, drinking water, and industrial use throughout the year. Adequate water resources are essential for sustaining agriculture, industry, and the daily needs of the population. Furthermore, Myanmar has considerable hydropower potential, and the monsoon season contributes significantly to the filling of reservoirs that are used for hydropower generation. This renewable energy source plays a vital role in Myanmar's energy mix and helps meet the country's electricity demands. However, while the monsoon is essential for Myanmar's agriculture and water resources, it also brings challenges such as flooding and landslides, which can be devastating in some areas. Proper management of water resources, disaster preparedness, and infrastructure development is crucial for harnessing the benefits of the monsoon season while mitigating its potential hazards. The research on monsoons has always been highlighted by Asian meteorologists, especially Indian researchers. However, there is little research on the Monsoon system in Myanmar. Among them, the research on the Myanmar monsoon has a history of more than a hundred years since the 1890s. The meteorologists Blanford, (1889) and K. R. Ramanathan (1939) are the pioneer researchers of the Indian and Myanmar monsoon otherwise; the South Asian monsoon system and they explained the arrival of summer monsoon over India and Myanmar. In addition, among the very few local researchers, Tun Yin (1949) was a pioneer and he studied a synoptic-aerologic onset of the summer monsoon wind over Myanmar. Even though there are few local research papers in the Department of Meteorology and Hydrology (DMH), there is no both local and international, researchers did not publish their studies about the Myanmar region until to 2000s. However, some researchers worked on the synoptic scale Asian monsoon system including the Myanmar region. Popular scholars such as C.S Ramage and N. Sen Roy from India, Bin Wang from China, and Jun Matsumoto from Japan were made the method development to study Myanmar monsoon (Ramage, 1952; Sen Roy & Kaur, 2000; Takio Murakami, 2002; B. Wang & Ho, 2002; Zhang et al., 2002). Although there will be local research works about the Myanmar monsoon system published only locally these never came out at the international published references level. After the 2000s, the local scholar Tun Lwin, Z. M. M. Sein, Ohnmar Htway, and K. T. Oo introduced and published new methods to study the Myanmar monsoon system (Htway & Matsumoto, 2011; Lwin, 2002; Oo, 2023; Sein & Zhi, 2016). Myanmar meteorologists have recently achieved significant advancements in their studies of the Myanmar monsoon's formation mechanisms, onset features, and multiscale variability.

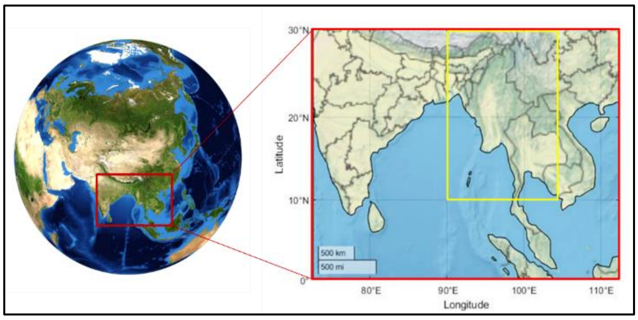


Figure 1: Geographical Location of South Asian Monsoon regions (red rectangle box) and Myanmar Southwest Monsoon regions (yellow eagle).

2. Materials and methods

The Scopus database covers a wide range of topics and is a major repository of peer-reviewed publications. The data is available from 1996 to 2022. To find the resolution of the analysis, the important keywords, which reflected the study objective, were systematically searched from the database, such as “Atmospheric Science”, “Myanmar”, and “Monsoon”. These keywords were searched by adding Advanced Search by including “AND” and “OR” conditions in the Scopus database. Because, the author follows logical filtering like “What, Where, How” that filters for a wide range to a narrow scope. There were 948 results for the said “Myanmar” keywords in the Earth and Planetary Science field. The search was further refined by adding the word “monsoon” and the number of publications then found was 281. These were used for carrying out bibliometric analysis.

The frequency analysis and linear trend analysis are mainly used for this study. The percentage is computed by dividing the category's frequency by the total number of participants and multiplying by 100 percent (Carlson & Winquist, 2014) (Eq.1). Moreover, the SC Imago Graphics tool is used for further visualization.

Eq (1)

Frequency Percentage = $elemental * 100$

2.1. Bibliometric Review of Monsoon Research

Bibliometric analysis was undertaken to explore the research trends in monsoon rainfall study with the use of a systematic manner. This analysis made it simpler to comprehend the author's contributions from various countries, organizations, journals, publications, etc. Initial keyword research concentrated on trends in searches, publishing types, and publications. Additionally, network analysis, geographic region statistical analysis, and analysis of subject areas were done. To search, it was necessary to use the keywords "Atmospheric Science" with the sub keywords "South Asian," "Rainfall," "Myanmar," "Climatology," and "Monsoon." These terms were looked for in the reliable Scopus database using the advanced search. Table 1 lists a few crucial keywords needed for the investigation because there are many reference keywords connected to atmospheric science topics.

Table 1: Collection of important keywords

Keywords	Number of Publications
South Asian	18925
Rainfall	1598
Myanmar	2658
JJAS	1181
Climatology	358
Forecasting	502
Monsoon	281

The keyword "Myanmar" was included in the search to include research articles from journals since 66.8% of publications in the field of Earth and Planetary Science are written in English. Researchers have published 9.5% of papers in journals, as review papers, 11.7% of papers in conferences, and 4.5% are available as books Fig. 2. As is evident, important papers are presented as journal articles. Table 2 shows the percentage breakdown of the publications by source type.

Table 2: Type of Publication by keywords "Myanmar" for Earth and Planetary Science field

Publication Type	Number of Publications	% of Total
Research articles	685	66.8
Review articles	97	9.5
Conference	120	11.7
Book chapters	46	4.5

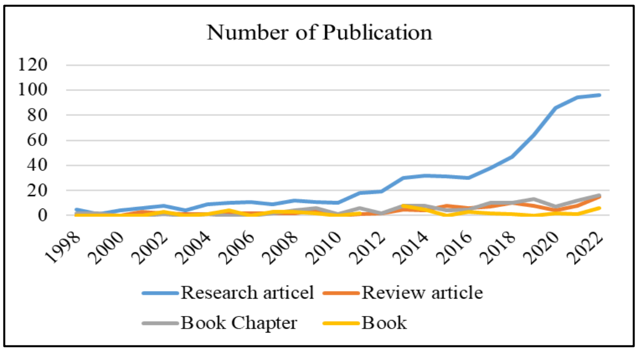


Figure 2: Number of publications by publication type.

The Scopus database's refined keyword search turned up 948 papers during the years 1998 to 2022. Trends in the number of publications are further investigated in the results. All magazine seminars, book series, and book publications were considered. Fig. 3 displays the graph illustrating the trend in the number of publications. Fig. 3 of the graph shows an up-trend year by year in the number of publications (7 in 1998 to 133 in 2022) for the study of atmospheric science with a significant level (R2=0.8).

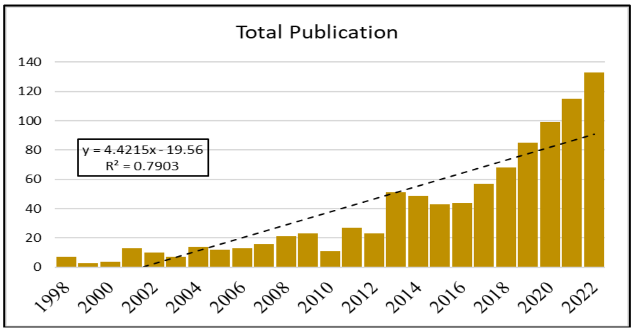


Figure 3: Time series histogram trend analysis of the total publication

2.2. Geographical Region-Based Analysis

We analyzed the nations with the highest rates of scientific publication and nearby nations to Myanmar to analyze the regional contributions to the study of "atmospheric science" by country. Fig. 4 shows the various nations' contributions to atmospheric science study.

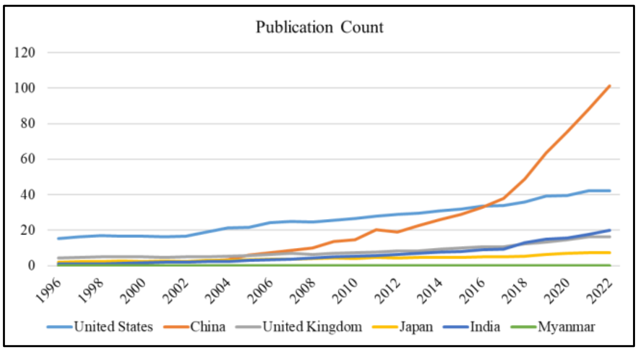


Figure 4: Publication count in (thousand) by the country during 1996-2022.

From 1996 to 2022, only 39 papers related to atmospheric science were out from Myanmar, among the 219 countries that contributed to this research. Based on the high level of support of research facilities, institutions, and funders, there were 102700 papers are out from the United States (US) researchers, and 50421 papers from China were counted. These are the major facts for publication volume differences among each country (Auranen & Nieminen, 2010; X. Wang et al., 2012). Since atmospheric science research is a phenomenon that is typically seen in each nation, it makes sense that 38% of contributions come from the US, 34% from China, and 10% or so each from the United Kingdom, India, and Japan as by orders. In contrast, Myanmar has only contributed less than 1%, leaving the remainder as an undefined local contribution. Fig. 5 displays the average percentage of articles contributed by each of the six countries.

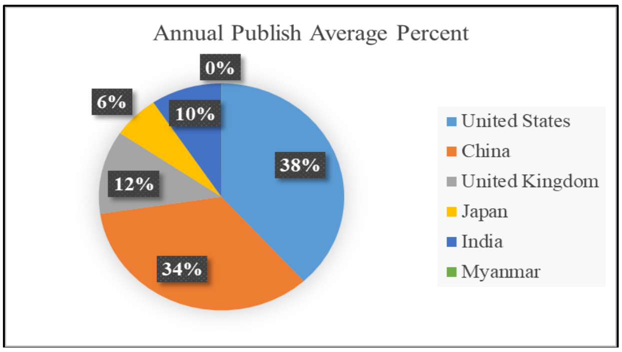


Figure 5: Annual publish average percent pie chart for 6 countries during 1996-2022.

As deep into the search as the word "monsoon" was added, 281 results were found. Years were restricted for the thorough search, and results were only provided for the years 2000 to 2020. A few local scholars (only 20 papers) were conducted over 20 years and global scholars were published 261 times for the Monsoon study (Fig. 6).

However, global scholars' papers are not mainly focused on Myanmar only.

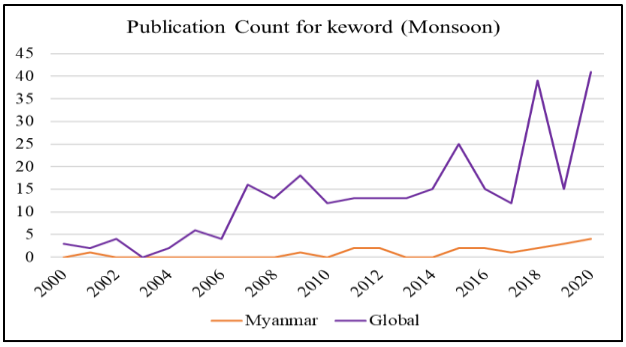


Figure 6: Comparison of paper count by keywords "Monsoon" for Global and Myanmar.

2.3. Analysis of the subject area

Environmental science, engineering, earth and planetary sciences, and computer science are just a few of the 406 subjects that made up Myanmar's science paper. In 2022, these science fields are expected to provide the biggest contributions to research, in that order. Fig. 7a represents the subject-wise research contribution through a pie chart. The subject "Atmospheric Science" in Fig. 7 includes 7 papers published in Myanmar in 2022.

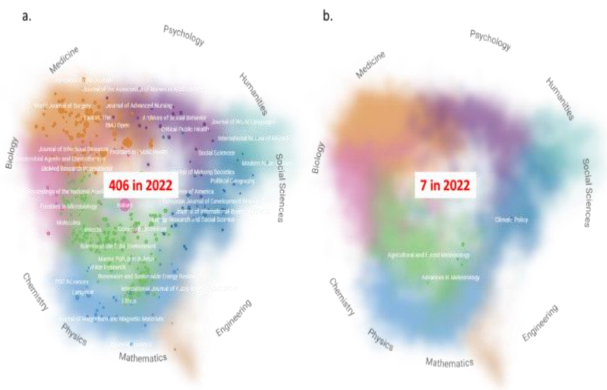


Figure 7: The published papers (a) multi-discipline and (b) atmospheric science by keywords "Myanmar" in 2022

3. Results and discussion

3.1. Description of monsoon and monsoon indices

The monsoon circulation is a seasonal climate phenomenon characterized by pronounced changes in wind patterns and associated rainfall. The beginning and end of the monsoon are separate occurrences that represent the establishment and dispersal of the monsoon system. Determining the precise dates of these events is crucial for numerous sectors, including agriculture, water resource management, and disaster preparedness.

Previous studies on Myanmar monsoon by specific objective

Monsoons are large-scale climate systems characterized by seasonal wind reversals that result in distinct dry and wet seasons. This section provides an overview of monsoons and their global significance, setting the stage for the discussion of mechanisms involved in their formation.

Land-Sea Temperature Gradients:

Land-sea temperature gradients play a fundamental role in driving monsoon circulation. Differential heating between land and ocean surfaces creates a pressure gradient, leading to the development of onshore winds during the monsoon season. This section explores the thermodynamic processes and associated atmospheric dynamics associated with land-sea temperature gradients (Chhin et al., 2020; Ren et al., 2017; Satyanarayana et al., 2020).

Large-scale patterns of atmospheric circulation:

Large-scale atmospheric circulation patterns like the Hadley Cell, Walker Circulation, and Rossby waves have an impact on the monsoons. These circulation systems interact with monsoonal flows, modulating the strength and spatial extent of monsoon precipitation. The review examines the role of these circulation patterns and their impact on monsoon formation (Giddings et al., 2020; Oo, 2021; S. Y. Wang et al., 2013; Yan et al., 2021).

Ocean-Atmosphere Interactions:

Monsoon systems are interconnected with global climate patterns through teleconnections. Oceanic processes, that is sea surface temperatures (SST), play a significant role in monsoon development. The coupling between the ocean and the atmosphere, including phenomena like El Niño-Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD), influences monsoon intensity and spatial distribution of rainfall. This section discusses the influence of ocean-atmosphere interactions on monsoon dynamics (Oo, 2022; Sein & Zhi, 2016; Zaw et al., 2020).

Topographic Influences:

Regional topography, including mountains and coastlines, can significantly influence monsoon systems. Mountain ranges act as barriers, enhancing orographic lift and modifying precipitation patterns. Coastlines contribute to the development of sea and land breezes, impacting local monsoon circulations. This section explores the role of topography in shaping monsoon behavior (D'Arrigo et al., 2011; United Nations, 2020; Zin et al., 2017).

Advances in Modelling and Predictability:

Advancements in modeling techniques, including numerical weather prediction and climate models have improved our understanding of monsoon mechanisms and enhanced prediction capabilities. This section highlights the progress in modeling and the challenges associated with monsoon predictability (Oo, 2021; Pattnayak et al., 2017; Satyanarayana et al., 2020; Sein et al., 2022)

Implications for Society and the Environment:

Monsoons have significant socio-economic and environmental implications, impacting agriculture, water resources, ecosystems, and human livelihoods. Understanding the mechanisms driving monsoon formation is crucial for managing these impacts and developing effective adaptation strategies (Khaing et al., 2019; Slagle, 2014; Taft & Evers, 2016; Zaw et al., 2020, 2021).

3.2. Index of Monsoon Onset and Withdrawal

The monsoon onset index is a key metric used to identify the initiation of the monsoon season. Various criteria and parameters have been employed to define the onset, such as rainfall thresholds, wind patterns, and changes in atmospheric conditions. A monsoon trough that was located in the eastern regions of India in winter had moved westward by summer, according to Yin's (1949) analysis of the average 8-kilometer summer and winter flow patterns over Myanmar. His analysis of the summer monsoon's arrival in 1946 reveals that it moves quite quickly and coincides with India's monsoon season's "burst." The Himalayan mountain complex's influence on the long-wave pattern, together with seasonal variations in the circumpolar jet stream's latitude in the northern hemisphere, is attributed to the migration of the trough (Fig. 8). The arrival of the southwest monsoon current over Myanmar coincides with the onset time of the ISM over the Indian subcontinent.

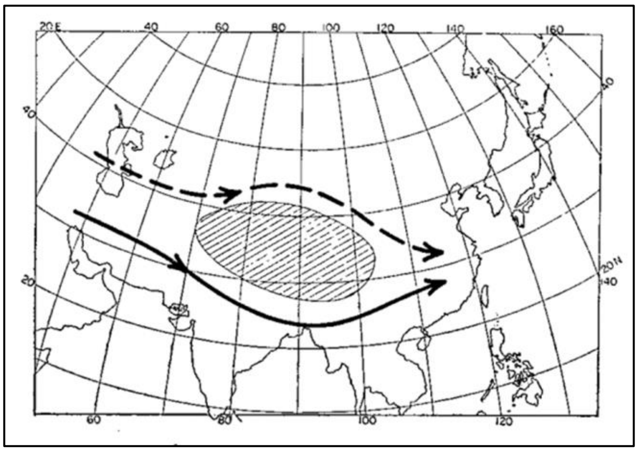


Figure 8: Schematic of the change in flow pattern resulting from the slight displacement of the jet north or south of the Himalayan mountain complex. (Yin, 1949)

Feng et al., (2020) developed a very new onset index called the "Daily Monsoon Trough Index" (DMTI) that considers the zonal wind component and the location of the monsoon trough to determine the onset date. Zhang et al., (2002) use only the rainfall index to define the monsoon onset and display the 5-day running mean climatology of the rainfall index for 46 years due to the reason that the wind patterns over Indochina are very complicated. Over Indochina, the dry season starts from November to late April, and the wet season from early May to mid-October. A dramatic increase in daily rainfall from 2 to 6 mm day 21 between late April and mid-May marks the change from a dry to a rainy season. The research suggests that the arrival of the monsoon across the Indochina Peninsula is fundamentally influenced by tropical influences.

The Department of Meteorology and Hydrology (DMH), Myanmar, currently defines the onset dates of the summer monsoon as the day of the very first three consecutive rainfall days with 2.5 mm per day amounts or greater in various locations throughout Myanmar (Aung & Thoung, 1985). Based on this definition, Lwin, (2002), utilizes the use of the frequency distribution of long-term onset dates. Lwin (2002) suggests a pre-southwest monsoon between mid-April and mid-May, a southwest monsoon between mid-May and mid-October, a post-southwest monsoon between mid-October and mid-November, a cool and dry northeast monsoon season between November and March, and a hot summer season between March and April (Fig. 9). Moreover, the summer monsoon advances in four different regions of Myanmar according to the climatological onset dates: on May 5 in southern Myanmar, which is located between latitudes 9 and 15 °N; on May 15 in the deltaic region, which is located between 15 and 17 °N; on May 20 in the eastern hills, central plane, and western coasts of Myanmar, which are located between 17 and 23.5 °N; and on June 1 in northern Myanmar, which is located between 23.5 and 28 °N (Lwin, 2002).

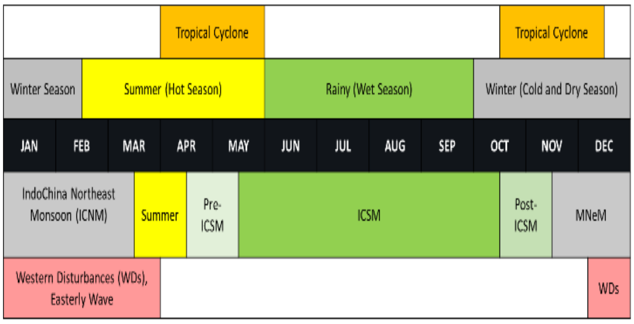
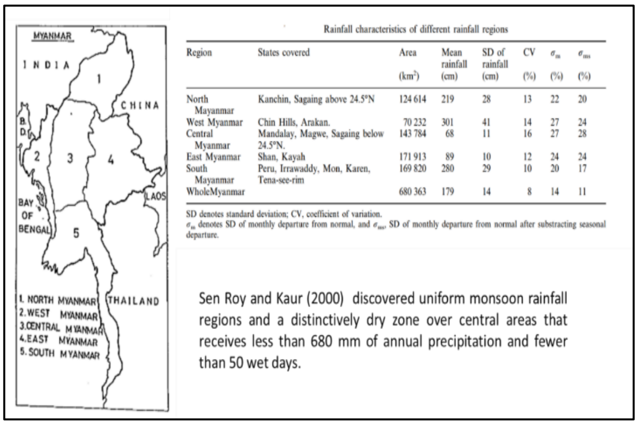


Figure 9: Schematic representation of seasonal climate variation by (Lwin, 2002)

The weakness of this definition is that it relies on the daily rainfall totals recorded at each station, which means it must disregard any precipitation that occurred before April 25 because it is not monsoon rain. Due to insolation before the monsoon, some areas of Myanmar may see rain from thunderstorm formation by South China Sea typhoons or western disturbances from India some stations may have rainfall quantities above 2.54 mm on occasion even if the rainfall duration is short. According to Sen Roy & Kaur, (2000)'s study, there are different monsoon rain zones and a centrally located, noticeably dry zone that receives less than rainfall 680 mm per year and shorter than 50 wet days (Fig. 10).



Rainfall characteristics of different rainfall regions

Region	States covered	Area (km²)	Mean rainfall (cm)	SD of rainfall (cm)	CV (%)	σ_m (%)	σ_{ms} (%)
North Mayanmar	Kanchin, Sagaing above 24.5°N	124 614	219	28	13	22	20
West Myanmar	Chin Hills, Arakan.	70 232	301	41	14	27	24
Central Myanmar	Mandalay, Magwe, Sagaing below 24.5°N.	143 784	68	11	16	27	28
East Myanmar	Shan, Kayah	171 913	89	10	12	24	24
South Mayanmar	Peru, Irrawaddy, Mon, Karen, Tena-see-rim	169 820	280	29	10	20	17
WholeMyanmar		680 363	179	14	8	14	11

SD denotes standard deviation; CV, coefficient of variation.
σ_m denotes SD of monthly departure from normal, and σ_{ms}, SD of monthly departure from normal after substracting seasonal departure.

Sen Roy and Kaur (2000) discovered uniform monsoon rainfall regions and a distinctively dry zone over central areas that receives less than 680 mm of annual precipitation and fewer than 50 wet days.

Figure 10: Summary Schematic of Sen Roy & Kaur, (2000) results.

Using the onset date isochrones map from 1967 adapted for India and Myanmar, DMH has historically identified four distinct zones of Myanmar. (Moe, 2002). There weren't many rain gauge stations in Myanmar in 1967, so those four regions should also be given another look in light of the current rainfall stations.

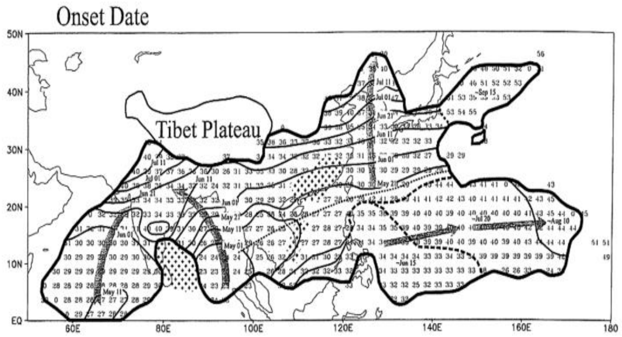


Figure 11: Mean Asian summer monsoon onset date, taken from (B. Wang & Ho, 2002). The number represents the Julian onset pentad. Discontinuities are indicated by the thick dashed lines (a merger of three or more contours). The rain-belt propagation directions are indicated by the arrows. Oceanic and subtropical monsoon zones are separated by a narrow dashed line. The contour at 3000 m delineates the Tibetan Plateau. (Zhang et al., 2002)

Thus, the commencement of the climatological monsoon over Myanmar was determined by Zhang et al., (2002) and Htway & Matsumoto, (2011) using mean or average pentad rainfall data. The onset date is determined using this method, which takes into account the cumulative rainfall and its temporal dispersion (Fig. 12). However, this time the author took topography into account and demonstrated the onset time of the southwest summer monsoon in Myanmar by two parts. The onset date of the monsoon season in southern and central regions of Myanmar on May 18 and in northern Myanmar on May 28 was proposed by Htway & Matsumoto, (2011).

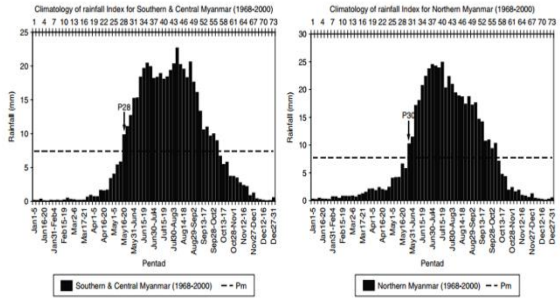


Figure 12: The climatological onset dates of summer monsoon in Myanmar based on the precipitation data. The dashed line is the level of annual mean pentad rainfall defined in the paper (Htway & Matsumoto, 2011)

Thus Oo, (2023) suggested combining wind and rainfall with other characteristics to create the MSwM change point index, a non-threshold-based index was first proposed (Fig. 13). To confirm the climatological monsoon beginning dates and regions for Myanmar, the climatological structure of several parameters from late April to early June will also be shown and examined. This should include both the observed data and the re-analysis data.

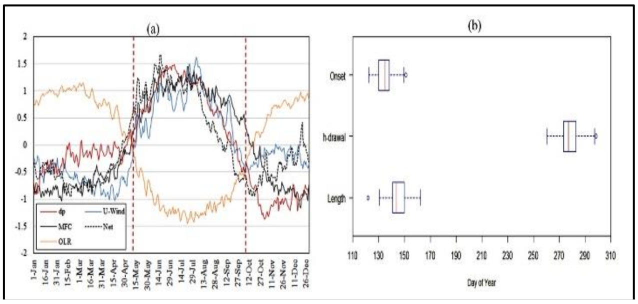


Figure 13: (a) Climatology time series of ERA-5 daily atmospheric mean sea level pressure differential averaged of northern and southern parts of mainland Indochina region (solid red) over 10-30◦N, 90-100◦E during (Jan 1, 1991 - Dec 31, 2020), the mean U-850 wind differential averaged as above regions (solid blue), MFC (solid black), Net precipitation amount (dotted black), and CMFC (red) averaged over same region. Vertical dashed red lines indicate the onset and withdrawal days in the year. (b) The seasonal onset, withdrawal, and season lengths are plotted using the MSwM box-and-whisker method. With a red median line and whiskers indicating the total range, the blue boxes show the range between the 25th and 75th percentiles. (Oo, 2023)

From the modeling insight, Mie Sein et al., (2015) study characterizes the inception, northern limit, and progression of southwest monsoon in Myanmar using synoptic maps generated through a 10-year simulation by using the model Fig. 14. This was the first work to examine the model analysis of the Myanmar monsoon and its goal was to describe the onset dates of the southwest summer monsoon over Myanmar. The Regional Climate Model (RegCM3) was run for ten years to reproduce the meteorological fields focused on the season from April to July (2000-2009).

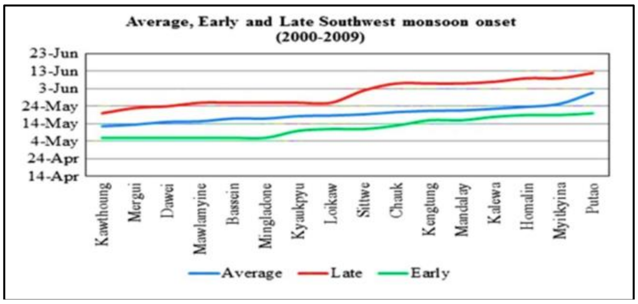


Figure 14: Based on the model, average, early, and late southwest summer monsoon onset dates are given. (Mie Sein et al., 2015).

3.3. Applications and Challenges

Accurate determination of onset and withdrawal dates has significant implications for various sectors. In agriculture, knowledge of the monsoon onset date helps in planning sowing operations and crop selection, while the withdrawal date is crucial for harvesting decisions. Water resource management relies on the monsoon cycle, and accurate predictions of these dates assist in reservoir management and water allocation.

However, determining precise onset and withdrawal dates poses several challenges. The monsoon system exhibits considerable interannual and spatial variability that makes it difficult to generalize onset and withdrawal patterns. Additionally, the selection of appropriate indices and thresholds varies across different regions, leading to variations in the determination of these events. The monsoon index is a critical parameter in quantitatively describing and studying monsoons. Researchers proposed many monsoon indexes to capture the spirit of the monsoon. To define the Myanmar southwest monsoon (MSwM) index, some factors, for example, differential heating between land and sea, rainfall intensity, meridional wind, and zonal horizontal wind shear regionally averaged over mainland Indochina were considered in previous research (Htway & Matsumoto, 2011; Oo, 2023; Sen Roy & Kaur, 2000; B. Wang & Ho, 2002). It is well known that the meridional crosswind is a crucial aspect of the MSwM. However, the zonal wind also plays an important role, as strong zonal winds over mid and high latitudes can obstruct in shifting and strength of monsoon intensity. The pentad rainfall intensity is the most popular tool to determine the onset and withdrawal dates of southwest monsoons over its regions (Tun & Division, 2017). Considering two-dimensional wind vectors, two separate modes of the MSwM have been identified (Lwin, 2000), resulting in a complete understanding of the MSwM.

Advancements in satellite remote sensing, climate modeling, and data assimilation techniques provide opportunities for refining monsoon intensity indices. Incorporating additional variables, such as humidity, cloud cover, and moisture convergence, may enhance the accuracy and reliability of these indices. Additionally, efforts to better understand the interactions between the monsoon and climate teleconnections can contribute to improved monsoon intensity assessment.

4. Conclusion

(1) The fundamental scientific challenge in the study of monsoons continues to be how to statistically define the variation of onset and withdrawal dates of the MSwM and its interannual variability. We expect to use a simple and effective index to represent the intensity and variability of monsoons. The Indian Ocean Dipole and El Nino Southern Oscillation index is the best instance employing one parameter to describe a complex phenomenon.

(2) An appropriate monsoon index helps establish associations between monsoon variability and the inner and outer forcing factors, in the search for correlations between monsoon variability, other circulation systems, and climate variability, and in the objective assessment of the ability of numerical models to replicate monsoon variability. Although many monsoon indexes have had some influence thus far, they are hardly all-inclusive. The MSwM regions' position between the West Northern Pacific Summer Monsoon (WNPSM) and Indian Monsoon (ISM) is the primary issue. It spans a latitude range of 10 to 30 and is greatly impacted by tropical and mid-latitude regions. As a result, selecting the summer monsoon index for Myanmar is substantially more challenging than selecting ISM or WNPSM. Since the circulation intensity and rainfall totals in this monsoon region are "distributed" rather than "uniform," indices created using various sub-areas and criteria lack "comparability" and can even produce contradictory results. We contend that for academics to communicate using a "single language," a "common area" and "common parameter" should be used to describe Myanmar's southwest summer monsoon index, which can reflect both wind and rain.

(3) A scientific issue that receives little attention is the fundamental nature of MSwM and how it interacts with the tropical monsoon. As was previously stated, both the ISM and WNPSM have a high influence on the MSwM region and interact with one another to directly affect large-scale flooding and drought in Myanmar. A tropical monsoon, however, exactly what is it? Alternatively, what characterizes the tropical monsoon? There are typically two misconceptions: one is based on geography, in that the monsoon that occurs in South Asia's subtropical regions is known as the "South Asian monsoon (SAM)". ; The other classifies South Asia's tropical monsoon's south-to-northward expansion as SAM. While the MSwM monsoon may operate as an independent driving component, we contend that the meridional land-sea heat contrast in mainland Indochina is the primary driving force that the heat disparity between the Asian mainland

continent, including the plateau, the western Pacific, and the north Indian Ocean, is regarded to be the primary cause of the seasonal circulation. If there was no land-sea contrast between the Asian continent and oceans, the subtropical high belt would not break, and the Monsoon trough belt would not extend and shift. We may imagine that the south-to-northward progression of these belts is the outcome of coordination and interaction between the ISM and the WNPSM monsoon. Therefore, the substance of both monsoons must be carefully examined, and their interaction with MSwM variation will improve the prediction of floods and drought in Myanmar.

(4) What components make up the MSwM if it is a separate system from the major South Asian monsoon system? What about the cycle of the seasons? When was the MSwM started and when did it end? It is a scientific issue that merits investigation because it is intimately connected to the seasonal cycle in mainland Indochina. The Tibetan Plateau's thermal influence accentuates the meridional land-sea thermal contrast (between the Indian Ocean and the Asian mainland continent) as well as the zonal land-sea thermal contrast (Asian continent and the Pacific). The plateau increases the sensitivity and forward motion of the seasonal shift of thermal contrast, particularly as an elevated heat source (or cold source). To monitor and anticipate monsoons, the plateau is crucial and sensitive. Therefore, research on the plateau is crucial.

(5) The tropical summer monsoon rain belt is situated on its forward side, thus as it advances north, the summer monsoon does as well. The summer monsoon's controlling region receives significantly less rainfall; as a result, the shifting of the rain belt is directly correlated with the activity of the summer monsoon's forward side. Hereby the research on monsoon trough otherwise Inter Tropical Convergence Zone (ITCZ), is also a meaningful problem.

(6) The MSwM region is also the outcome of interactions between the earth, ocean, atmosphere, hydrosphere, biosphere, and cryosphere. The monsoon's changing pattern and variability have a significant impact on the region's plantation, bio-earth, chemistry, economics, and society. Therefore, it is important to include monsoons in the coupled land-sea-atmosphere system and understand their characteristics and dynamics by looking at how various spheres, levels, systems, and sizes interact.

(7) The national economic and social development depends heavily on the seasonal prediction of monsoon activities, however, the current coupled model of the land-sea-atmosphere has numerous limitations in this regard. To improve the ability to anticipate the MSwM, the Tibetan plateau must be accurately described in the model, the land-atmosphere interaction must be properly introduced, and physical processes must be reasonably parameterized. Therefore, advancement in the study of models is highly anticipated. The future of the Asian monsoon might be significantly impacted by changes in land cover and atmospheric components brought on by human activity on both a regional and global scale. Research on this topic aids in regulating human activity, recognizing the harmony between people and nature, and safeguarding the human habitat. In conclusion, the key objectives in the study of monsoon in the future continue to be the processes of fluctuation of MSwM, the mechanisms of MSwM impacting weather and climate in Myanmar, particularly flood and drought, and the theories and methods of predicting MSwM.

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References

Aung, H., & Thoung, M. (1985). *A Study of the Onset of Rainy Season in Myanmar.* A Paper Submitted in The.

Auranen, O., & Nieminen, M. (2010). University research funding and publication performance international comparison. *Research Policy*, 39(6), 822–834. https://doi.org/10.1016/j.respol.2010.03.003

Blanford, H. F. (1889). *A Practical Guide to the Climates and Weather of India, Ceylon and Burmah and the Storms of Indian Seas: Based Chiefly on the Publications of the Indian Meteorological Department.* Macmillan. https://books.google.se/books?id=PNgKAAAAIAAJ

Carlson, K., & Winquist, J. (2014). Introduction to statistics and frequency distribution. *Introduction to Statistics: An Active Learning Approach*, 1–32.

Chhin, R., Shwe, M. M., & Yoden, S. (2020). Time-lagged correlations associated with interannual variations of pre-monsoon and post-monsoon precipitation in Myanmar and the Indochina Peninsula. *International Journal of Climatology*, 40(8), 3792–3812. https://doi.org/10.1002/JOC.6428

D'Arrigo, R., Palmer, J., Ummenhofer, C. C., Kyaw, N. N., & Krusic, P. (2011). Three centuries of Myanmar monsoon climate variability inferred from teak tree rings. *Geophysical Research Letters*, 38(24). https://doi.org/10.1029/2011GL049927

Feng, T., Yang, X.Q., Sun, X., Yang, D., & Chu, C. (2020). Reexamination of the Climatology and Variability of the Northwest Pacific Monsoon Trough Using a Daily Index. *Journal of Climate*, 33(14), 5919–5938. https://doi.org/10.1175/JCLI-D-19-0459.1

Giddings, J., Matthews, A.J., Klingaman, N.P., Heywood, K. J., Joshi, M., & Webber, B. G. M. (2020). The effect of seasonally and spatially varying chlorophyll on Bay of Bengal surface ocean properties and the South Asian monsoon. *Weather and Climate Dynamics*, 1(2), 635–655. https://doi.org/10.5194/wcd-1-635-2020

Htway, O., & Matsumoto, J. (2011). Climatological onset dates of summer monsoon over Myanmar. *International Journal of Climatology*, 31(3), 382–393. https://doi.org/10.1002/JOC.2076

K. R. Ramanathan, K. P. R. (1939). *The general circulation of the atmosphere over India and its neighborhood.* Mem. Ind. Met. Dep., 26, 10–10.

Khaing, Z. M., Zhang, K., Sawano, H., Shrestha, B. B., Sayama, T., & Nakamura, K. (2019). Flood hazard mapping and assessment in data-scarce Nyaungdon area, Myanmar. *PLoS ONE*, 14(11), 1–18. https://doi.org/10.1371/journal.pone.0224558

Lwin, T. (2000). *The Prevailing Synoptic Situations in Myanmar.*

Lwin, T. (2002). The climate changes in Myanmar during the last decades. *Water Resources Journal*.

Mie Sein, Z. M., Islam, A. R. M. T., Maw, K. W., & Moya, T. B. (2015). Characterization of southwest monsoon onset over Myanmar. *Meteorology and Atmospheric Physics*, 127(5), 587–603. https://doi.org/10.1007/S00703-015-0386-0

Oo, K. T. (2021). How El-Nino / La-Nina & India Ocean Dipole (IDO) Influence on Myanmar Rainfall Distribution (Statistical Analysis Report) (1990-2019). J Environ Sci. 2021, 17(1), 178. https://doi.org/10.37532/environmental-science.2021.17.178

Oo, K. T. (2022). Interannual Variability of Winter Rainfall in Upper Myanmar. Journal of Sustainability and Environmental Management, 1(3), 344–358. https://doi.org/10.3126/josem.v1i3.48001

Oo, K. T. (2023). Climatology Definition of the Myanmar Southwest Monsoon (MSwM): Change Point Index (CPI). Advances in Meteorology, 2023, 2346975. https://doi.org/10.1155/2023/2346975

Pattnayak, K. C., Kar, S. C., Dalal, M., & Pattnayak, R. K. (2017). Projections of annual rainfall and surface temperature from CMIP5 models over the BIMSTEC countries. Global and Planetary Change, 152(April), 152–166. https://doi.org/10.1016/j.gloplacha.2017.03.005

Ramage, C. S. (1952). Relationship of General Circulation to Normal Weather Over Southern Asia and the Western Pacific During the Cool Season. *Journal of Atmospheric Sciences*, 9(6), 403–408. https://doi.org/https://doi.org/10.1175/1520-0469(1952)009<0403:ROGCTN>2.0.CO;2

Ren, Y.Y., Ren, G.Y., Sun, X.B., Shrestha, A.B., You, Q. L., Zhan, Y.J., Rajbhandari, R., Zhang, P.F., & Wen, K.M. (2017). Observed changes in surface air temperature and precipitation in the Hindu Kush Himalayan region over the last 100-plus years. *Advances in Climate Change Research*, 8(3), 148–156. https://doi.org/10.1016/J.ACCRE.2017.08.001

Satyanarayana, G.C., Dodla, V.B.R., & Srinivas, D. (2020). Decreasing southwest monsoon rainfall over Myanmar in the prevailing global warming era. *Meteorological Applications*, 27(1), 1–13. https://doi.org/10.1002/met.1816

Sein, Z. M. M., & Zhi, X. (2016). Interannual variability of summer monsoon rainfall over Myanmar. *Arabian Journal of Geosciences*, 9(6). https://doi.org/10.1007/S12517-016-2502-Y

Sein, Z. M. M., Zhi, X., Ullah, I., Azam, K., Ngoma, H., Saleem, F., Xing, Y., Iyakaremye, V., Syed, S., Hina, S., & Nkunzimana, A. (2022). Recent variability of sub-seasonal monsoon precipitation and its potential drivers in Myanmar using in-situ observation during 1981–2020. *International Journal of Climatology*, 42(6), 3341–3359. https://doi.org/10.1002/JOC.7419

Sen Roy, N., & Kaur, S. (2000). Climatology of monsoon rains of Myanmar (Burma). *International Journal of Climatology*, 20(8), 913–928. https://doi.org/10.1002/1097-0088(20000630)20:8<913::AID-JOC485>3.0.CO;2-U

Slagle, J. T. (2014). *Climate change in Myanmar : impacts and adaptation* NAVAL POSTGRADUATE. Naval Postgraduate School. http://hdl.handle.net/10945/44672

Taft, L., & Evers, M. (2016). A review of current and possible future human-water dynamics in Myanmar's river basins. *Hydrology and Earth System Sciences*, 20(12), 4913–4928. https://doi.org/10.5194/HESS-20-4913-2016

Takio Murakami, J. M. (2002). Summer Monsoon over the Asian Continent and Western North Pacific. *Chemical Pharmaceutical Bulletin*, 43, 2091.

Tun, H., & Division, M. (2017). *Current Status of Weather Forecasting and Warning System in DMH.*

United Nations. (2020). Country Information. https://myanmarmissionnewyork.org/index.php/country-information/country-information

Wang, B., & Ho, L. (2002). The rainy season of the Asian-Pacific summer monsoon. *Journal of Climate*, 15(4), 386–398. https://doi.org/10.1175/1520-0442(2002)015<0386:RSOTAP>2.0.CO;2

Wang, S. Y., Buckley, B. M., Yoon, J. H., & Fosu, B. (2013). Intensification of premonsoon tropical cyclones in the Bay of Bengal and its impacts on

Myanmar. *Journal of Geophysical Research Atmospheres*, 118(10), 4373–4384. https://doi.org/10.1002/JGRD.50396

Wang, X., Liu, D., Ding, K., & Wang, X. (2012). Science funding and research output: A study on 10 countries. *Scientometrics*, 91(2), 591–599. https://doi.org/10.1007/s11192-011-0576-6

Yan, X., Yao, Y., Yang, Y., Zhang, L., & Zhang, B. (2021). Recent trends in precipitation over the Myanmar Coast during onset and withdrawal phases of monsoon season. *Theoretical and Applied Climatology*, 145(1–2), 363–376. https://doi.org/10.1007/s00704-021-03613-0

Yin, M. T. (1949). Synoptic-aerologic Study of the Onset of the Summer Monsson over India and Burma. *Journal of Meteorology*, 6(6), 393–400. https://doi.org/10.1175/1520-0469(1949)006<0393:SASOTO>2.0.CO;2

Zaw, Z., Fan, Z. X., Bräuning, A., Liu, W., Gaire, N. P., Than, K. Z., & Panthi, S. (2021). Monsoon precipitation variations in Myanmar since AD 1770: linkage to tropical ocean - atmospheric circulations. *Climate Dynamics*, 56(9 - 10), 3337 - 3352. https://doi.org/10.1007/s00382-021-05645-8

Zaw, Z., Fan, Z. X., Bräuning, A., Xu, C. X., Liu, W. J., Gaire, N. P., Panthi, S., & Than, K. Z. (2020). Drought Reconstruction Over the Past Two Centuries in Southern Myanmar Using Teak Tree-Rings: Linkages to the Pacific and Indian Oceans. *Geophysical Research Letters*, 47(10). https://doi.org/10.1029/2020GL087627

Zhang, Y., Li, T., Wang, B., & Wu, G. (2002). Onset of the Summer Monsoon over the Indochina Peninsula: Climatology and Interannual Variations. *Journal of Climate*, 15(22), 3206–3221. https://doi.org/https://doi.org/10.1175/1520-0442(2002)015<3206:OOTSMO>2.0.CO;2

Zin, E. E., Aung, L. L., Zin, E. E., Theingi, P., Elvera, N., Aung, P. P., Han, T. T., Oo, Y., & Skaland, R. G. (2017). *Myanmar Climate Report*. Norwgian Meterological Institute, 9, 105. http://files/679/MyanmarClimateReportFINAL11Oct2017.pdf.