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Article

Review of the History of Mesoscale Convective System Forecasts on Aviation

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Abstract.

Airports are important national resources, and Aviation Weather Services are critical to the aviation industry's success. According to the National Transportation Safety Board's (NTSB) analysis of weather-related circumstances that influence near- surface aircraft operations, wind and turbulence caused 1381 accidents, visibility, ceiling height (hc), and precipitation-related accidents occurred 485 times, and aircraft icing caused 150 accidents between 2003 and 2007. Mesoscale convective systems (MCSs) arise when cumulonimbus clouds merge into a single entity that can span hundreds of miles and continue for hours, posing a higher threat to aviation due to its size and duration. The mesoscale downdraft of a squall-line MCS's stratiform area sometimes merges with the convective downdrafts in the leading line of convection, and these mergers can produce strong effects, with the gust front surging forward and triggering new convection in the form of a "bow echo," according to Doppler radar. Bow echo events are of particular concern to forecasters because they are typically associated with strong, damaging surface winds. Because MCSs are still a major socioeconomic issue, it's critical to construct climate models that incorporate them, whether through cloud-resolving modeling or parameterization. MCS characteristics are influenced by the increasingly contaminated aerosol environment in most parts of the world, and as the Earth warms, MCS patterns will certainly change.

Keywords: MCS, convective, aviation meteorology, aviation hazards.

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1. Introduction

Aviation provides the sole fast global transportation network, making it critical for international logistics and tourism. Aviation contributes significantly to the economic development and long-term growth of industrialized countries, such as P.R China; landlocked countries, countries with limited road infrastructure, such as Laos, and small island nations, such as Madagascar, rely heavily on aviation. Other economic activities like domestic trade, military operations, and tourism also benefit from the rise of the aircraft industry [1].

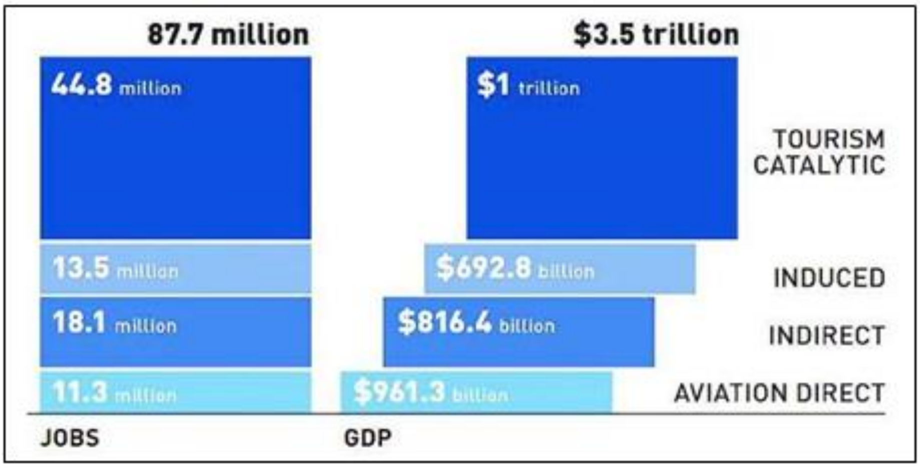

Figure 1. Aviation Global employment and GDP Impact (Beyond 2021 to 2024), [2]

According to the Air Transport Action Group, the aviation industry generated 961.3 billion USD in direct gross benefits (2021-2024) and supported 87.7 million jobs worldwide (Figure 1). Totally $3.5 trillion in aviation's global economic impact (includes direct, indirect, induced, and tourism-related catalytic effects) and 4.1% of global GDP supported by aviation [2].

Airports are vital national resources and Aviation Weather Services play an indispensable role in the functioning of the aviation industry. Weather is also important for aviation industry benefits but unfortunately, it is uncontrollable as everyone knew. Weather occurrences have a significant influence on the aviation sector, especially economic performance by causing delays and cancellations. Airlines need to consider weather particular to each airport and region if they wish to reduce the amount of delayed and canceled flights [3]. The weather has a variety of effects on aviation and is a key source of concern for the industry [4].

From the beginning of the 20th century, the impact of atmospheric processes on aviation has been acknowledged. Wind, visibility/ceiling, thunderstorms, high-density altitude, wind shear, turbulence, updrafts/downdrafts, precipitation, icing, thermal lift, extremes in temperature, and lightning are all-weather phenomena that cause or contribute to aviation accidents [5]. Convective storms are a major issue in the aviation industry, as they cause delays and reduce safety and efficiency. Thunderstorms may be a combination of the numerous types of weather that cause the majority of aviation operations' disruptions, particularly near airports [6].

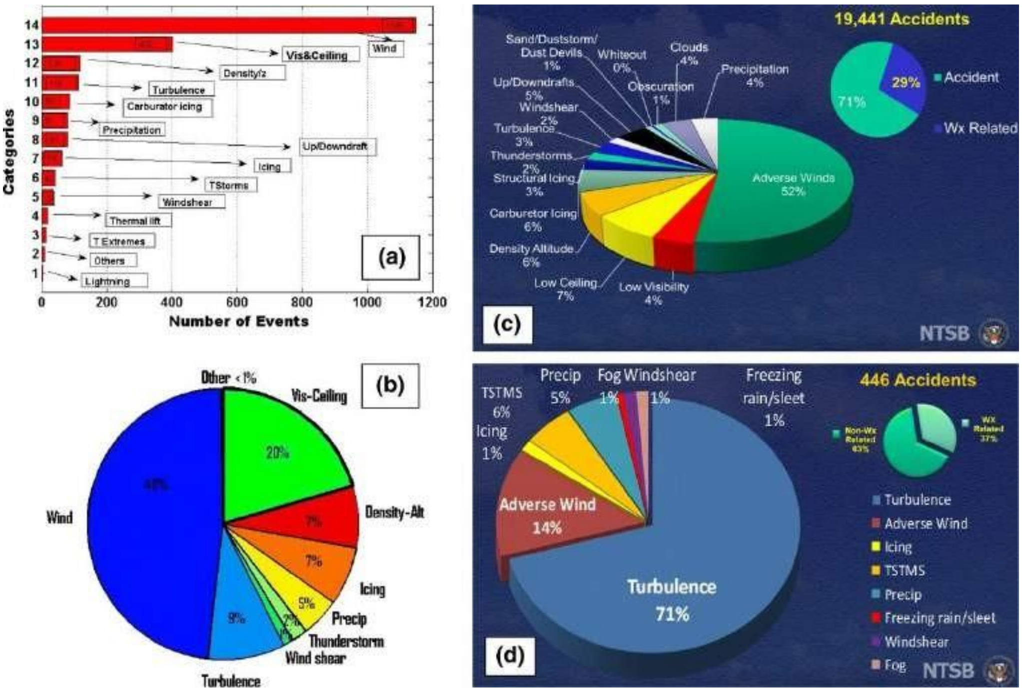

Figure 2. Statistics on aircraft-related accidents based on meteorological data were compiled during 1994-2000, (a) actual numbers of accidents, (b) probabilistic distributions in a pie chart, (c) The National Transportation Safety Board (NTSB) based statistics results, during 1994-2000 (19,441 accidents occurred and 29% were a weather-related accident and (d) Part 121-air carrier weather-related cause/factors for 2000–2011. [7]

Figure 2 shows statistics on aircraft-related accidents obtained from meteorological data between 1994 and 2011. During the period 2003-2007, Figure 2. a displayed a bar plot of statistics for weather-related circumstances that influence near-surface aircraft operations, revealing that wind and turbulence occurred 1381 times, visibility, ceiling height (hc), and the precipitation-related accident occurred 485 times, and 150 times accidents are occurred by aircraft icing. Figure 2. b displays similar parameters in percentiles for the same period (1994- 2003); wind and visibility are still the most important. From 2000 to 2011, adverse winds were the leading cause of weather-related incidents for small, non-commercial aircraft, followed by low ceilings (hc) (Figure 2. c). From 2000 to 2011, turbulence accounted for more than 70% of weather-related occurrences for commercial jet aircraft at cruising altitudes, according to Figure 2.d.[7].

Following a spate of tragic collisions, the National Transportation Safety Board (NTSB) of the United States published a safety notice in October 2006 explaining measures pilots should follow while dealing with "thunderstorm encounters" [8]. Incidents continued to occur despite these guidelines. One source of concern is that certain members of the aviation community are unfamiliar with meteorological terminology. A "mesoscale convective complex" was implicated in the Hawker 800A plane crash in Owatonna, Minnesota, in June 2008 [9]. The crash of Air France's Airbus A330 aircraft, Flight 447, in June 2009, which resulted in the deaths of 228 passengers, was suspected to be caused by a mesoscale convective storm near the equator [10]. A "Bow-shaped mesoscale convective system" was noted in a case report for the deadly crash down of a medical helicopter in Brownsville, Tennessee, in March 2010 [11].

Convection has been studied intensively in recent years to improve the warning capacities of various weather agencies, leading to several novel discoveries. Although scientific developments have improved our understanding and convection forecasts, the difficulty of getting the information to those who need it persists, made more difficult by the deluge of new language that generally accompanies scientific progress.

2. Convective Systems' impact on Aviation

Convection is the study of vertical motions in the atmosphere produced by changes in temperature or, more accurately, density differences. The adage "warm air rises" is well known. A parcel of air will rise if it is less dense than the air in the surrounding environment, according to meteorology. Warmer air has a lower density and rises. Colder air, on the other hand, sinks due to its density. Pilots, especially glider pilots, must understand clouds have to rise and sink air currents. When air rises, though, it expands and cools. Condensation occurs when the air cools to its dew point, and if there is enough moisture present, a cloud forms. The typical convective clouds are cumulus clouds. Even though all convection poses a threat to aviation, these storms are often weak.

Individual convective cells will occasionally produce severe surface winds for several kilometers, as well as the storms themselves, which are very tiny. They may typically be avoided or postponed for aviation purposes. On the surface, convection appears to be neither damaging nor necessary for life. However, when it is combined with precipitation and the correct thermal conditions, it produces lightning and turbulence that may devastate any airspace. Rerouting delays and the aftermath of a run-in with severe storms can have devastating consequences. Unplanned repairs, injuries, and delays cost airlines hundreds of millions of dollars each year due to turbulence. According to the NTSB, 18% of fatal GA incidents may occur due to turbulence [5, 7]. There are powerful opposing updrafts and downdrafts within a thunderstorm, which can cause significant turbulence. Also while many types of spatial-temporal wind variations can cause aviation safety concerns, such as clear-air turbulence [12], mountain waves [13], or simply vertical shear of horizontal winds [14], an aircraft's vulnerability to shear- induced rolling motion or changes in a lift is greatest during the landing and take-off stages of flight, because of its proximity to the ground [15]. Even flying over a growing storm can cause severe flight turbulence due to the powerful updrafts that exist above the noticeable cloud top. Even at high altitudes, turbulence can exist around any convective activity.

Thunderstorms are another complex weather phenomenon. They come in several different sizes and forms, and their lifespans range from 15 minutes to many hours. Thunderstorms were recognized as a contributory factor in 2%–4% of weather-related incidents from 1989 to 1997, depending on the type of aircraft involved, according to a National Aviation Safety Data Center (NASDAC) research. Rainfall was responsible for 6% of commercial airline mishaps, 10% of general aviation incidents, and nearly 19% of commuter and air taxi mishaps. Convective weather is responsible for 55% of turbulence events, according to American Airlines [4]. As previously stated, airplanes flying through thunderstorms face a number of risks. These dangers can interact, and their severity is determined by the type and intensity of a thunderstorm, the height at which the aircraft passes through it, the duration of exposure, the type of aircraft, and the flight phase.

Hail is another threat associated with thunderstorms. A thunderstorm's strong updrafts can hold massive hail stationary in the air while it develops, or they might fling it miles away from the storm center. Hail most often damages the radome (radar on the nose of aircraft) of an aircraft, but is also known to severely damage windshields as well. Figure 3 shows two examples where aircraft have been hit by hail when passing through a thunderstorm. In both cases, the aircraft's nose has been heavily damaged, and in one case also the windshield has been cracked. When a thunderstorm contains one or more of the following: one-inch hail, winds reaching over 50 knots (57.5 mph), or a tornado, it is regarded as "severe." And thunderstorms, whether single or multi-cell, are the mother of all of these weather occurrences. At any given time, there are approximately 2,000 thunderstorms alive, with an assessed 16 million thunderstorms occurring each year around the world (NOAA). Thunderstorms are most common over land in tropical latitudes, where the air heats up quickly and forms strong updrafts.

Figure 3. Nose and windshield damage of two aircraft hit by hail stones during the passage of thunderstorms. Left: On July 26th, 2018, Tianjin Airlines flew an Airbus A320 from Tianjin to Haikou. Right and below: On May 26th, 2019, flight No. CZ3101 was flying from Guangzhou to Beijing.

The greatest unpredictable threat for aviators is lightning, particularly for ground staff during refueling. As long as most commercial aircraft can withstand direct lightning strikes without affecting flight, impacts can cause holes in the plane, disrupt the electrical systems, and the plane may unserviceable. Airline budgets can be severely affected by unscheduled maintenance like this, both in terms of the cost of repairing the aircraft as well as the loss of income while the aircraft is not in service.

Most commercial planes can endure some icing without endangering the flight. It is more severe than ice crystal icing, which occurs as a result of glaciated convective clouds. There is a risk of this happening in areas with high ice water content (HIWC), and it can cause engine failure, flameouts, and other problems.

On the ground, the foregoing parameters, as well as IFR ceilings and visibility, still play a role. The microburst, a powerful downdraft that can impact the speed of planes attempting to land, is the most dangerous hazard associated with thunderstorms at the aerodrome. Before a low-level wind shear alert system (LLWAS) was built across the United States to help detect wind shear near the aerodrome, this condition had caused several major aviation accidents.

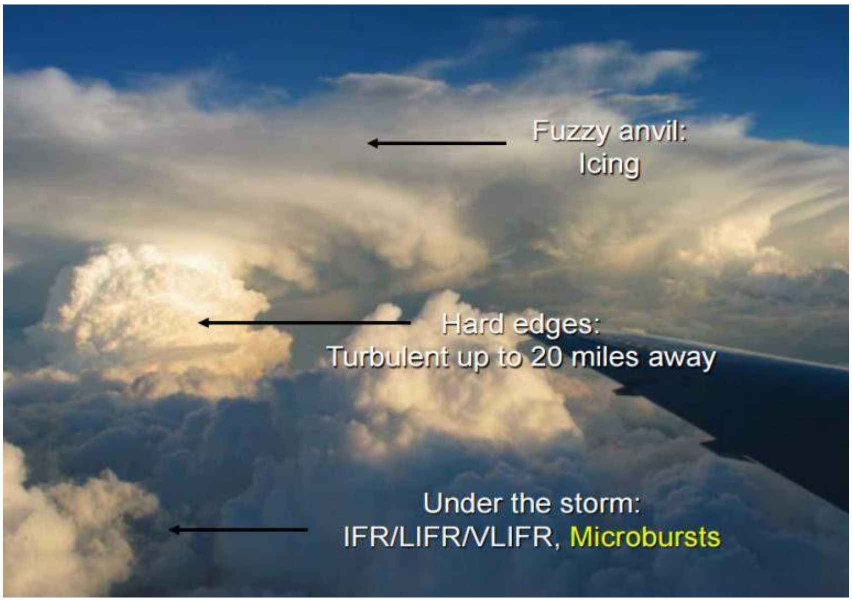

Figure 4. An inflight illustration of what a pilot would see flying in convective weather highlighting the various hazards mentioned above can be found in the graphic. [16].

Convection gets organized at other times. This is either the product of larger-scale atmospheric forces at work or the interaction of numerous convective constituents that is unaffected by external forces. Mesoscale convective systems (MCSs) are formed when cumulonimbus clouds are evolving into a single entity with precipitation spanning hundreds of kilometers horizontally [17]. MCSs can be hundreds of miles across and last for hours, making them a greater threat to aircraft because of their magnitude and length.

The squall line is the most prominent and well-known MCS configuration. A squall line is a line of thunderstorms that, at first, appears to be continuous. If conditions are good, the squall line can linger for hours and evolve into a much larger and more complicated storm. Many lines of convection may exist, with the strongest on the system's leading edge, which is normally on the east or south side in northern hemisphere mid-latitudes, and the weakest behind it.

A "bow echo" occurs when a squall line or a portion of a squall line begins to curl or bow outward. Because these systems were first discovered and are frequently still identifiable on weather radar, the term "echo" refers to a radar return. The bowing part of the line can move quite quickly, up to 50 knots at times. Bow echoes are frequently linked to strong straight-line winds and, on rare occasions, weak tornadoes. The pilot of a Brownsville-based medical helicopter decided on March 25, 2010, that he was capable to outrunning a convective line. and safely return to Brownsville. With an estimated forward speed of 60 knots, the line developed a bow that blasted ahead of the main system [11].

MCS movement is influenced by two factors: simple advection by the wind and system propagation, which is the outcome of the growth and dissipation of individual convective elements, and storms themselves. Advection by the wind is simple enough, with convective cells being driven by the mean wind that the average wind in the layer of air contains them. Single cells or storms can move at speeds of up to 60 kilometers per hour. The effects of propagation are more intricate. Within the MCS, single convective cells form and evaporate, having a considerably shorter lifespan than the MCS. This has an impact on the mesoscale system's overall movement. Convective cells and systems prefer to proliferate in the same direction that warm, moist air is "fed" into them. In the northern hemisphere, this mainly comes from the south. This appears to induce a rightward deflection. Thunderstorms classified as supercells are known to travel to the right of the mean wind. New cells grow on the south end of an MCS, such as a squall line, while older cells die out on the north end. The entire system moves or propagates to the right of the mean wind as a result of this. A squall line, for example, is likely to move directly east while individual storms inside it move quickly northeast.

MCSs aren't just found in the middle of both latitudes. There are also tropical variations (Figure 5). The Air France Flight 447 accident in the tropical Atlantic, not far north of the equator, is largely thought to have been caused by a tropical MCS. The plane was traveling at 35,000 feet with no difficulties, according to data acquired from the recently found black boxes [10]. However, just ahead was a swath of thunderstorms with tops of 50,000 feet, according to infrared satellite images. The pilots were aware of this and issued a warning to the cabin crew about the possibility of turbulence. The turbulence was never more than mild, according to the instruments. However, as the plane met heavy clouds, the pitot tubes for the airspeed sensors froze, causing a chain of events that culminated in the jet's crash.

Mesoscale convective systems are ubiquitous in many places on the planet, despite their obscure nomenclature. Individual thunderstorms provide far less of a threat to aviation than these systems. Understanding them is crucial to treating them with respect when you come across them.

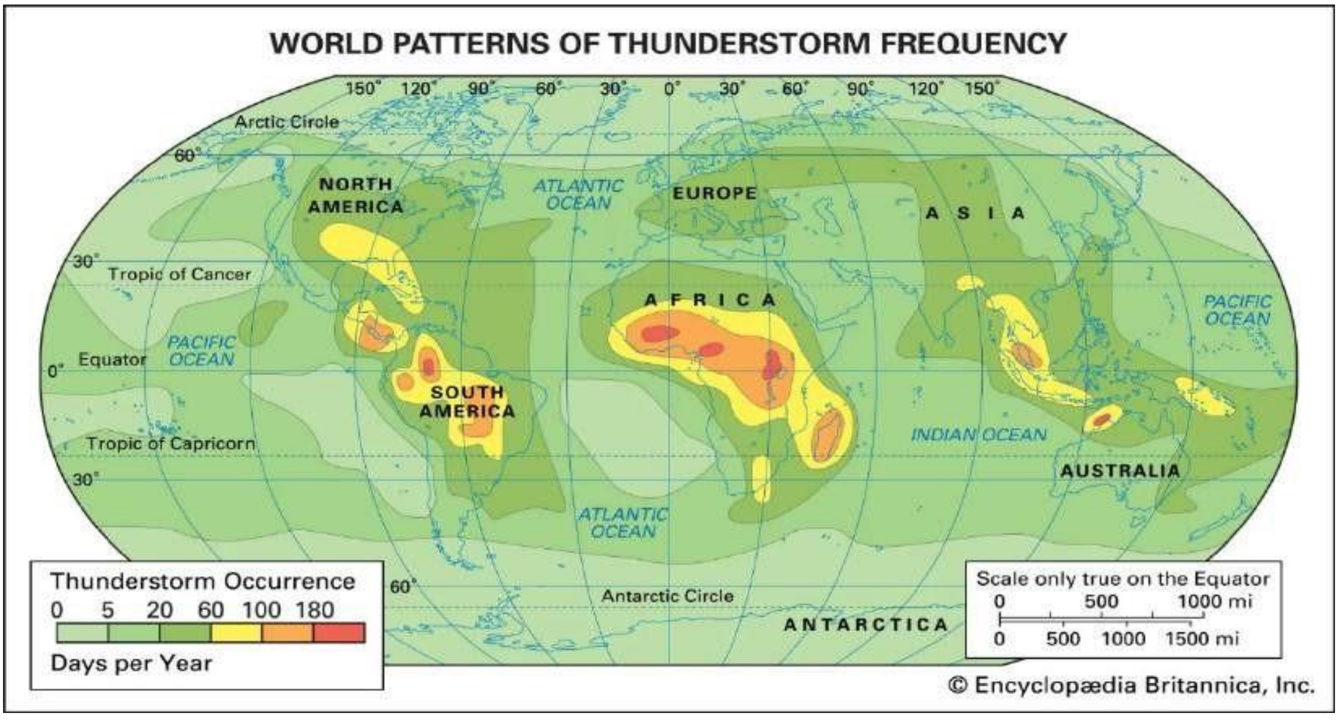

Figure 5. world patterns of thunderstorm frequency

3. Review of Previous Study

The outstanding study reported by Robert A. Houze Jr. explained understanding the details of mesoscale convective systems for aviation meteorology researchers and forecasters. Because it exhibited the development timeline of convective system dynamical methods from the very first time to the present day.

3.1. Early Days of Convective Systems

A few hints about the mesoscale organization of convection also cropped up in the scientific community in the nineteenth century. The Scottish meteorologist Abercromby. Ralph, in partnership with the Swedish meteorologist Hugo Hildebrand Hildebrandsson, identified the cloud type that is today known as cumulonimbus by studying some of the very first cloud photos [18, 19].

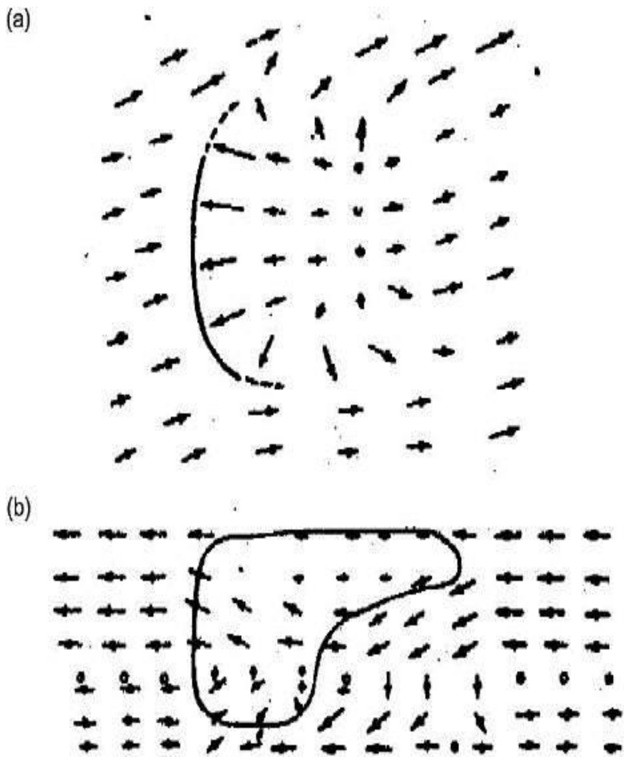

Figure 6. (a) Squall line and surface wind, and (b) In a vertical plane, a West African cloud outline and circulation "disturbance line." From [20].

During World War II, the two Royal Air Force officers assisting wartime air operations in Nigeria created an exhaustive manual on tropical western Africa meteorology [20]. Pilot reports, balloon soundings, and surface meteorological data were used to determine the mesoscale nature of convective storms defined as regionally extensive convective "disturbance lines." It was assigned that the rainfall zones were 75–150 km wide based on the observed speed and length of the episodes passing a site. Surface station reports are analyzed holistically is showed that the leading wind-shift lines were up to 1000 km in length and bowed outwardly in the direction of storm motion. The disturbance lines, in other words, the leading- edges of a mesoscale storm can be found, according to these initial observations. Convection was structured on a considerably larger spatial scale than isolated convective clouds, but much smaller than synoptic size.

Later than World War II, despite this, the enormous postwar Thunderstorm Project led by University of Chicago researchers was gaining traction in the United States, including a study on convective storms in the midlatitudes [21]. They sent aircraft, radars, and radiosonde units left over from the war to observe storms in Ohio and Florida, in what remains one of the largest and most inventive field programs in meteorology history. Convective storms are embedded with individual updrafts and downdrafts discovered by the Thunderstorm Project. The Project's mesoscale characteristics were more difficult to determine because, unlike tropical convection considered by Hamilton and Archbold, it was difficult to separate midlatitude convective processes from other factors, particularly frontal dynamics in Ohio and sea-breeze dynamics in Florida.

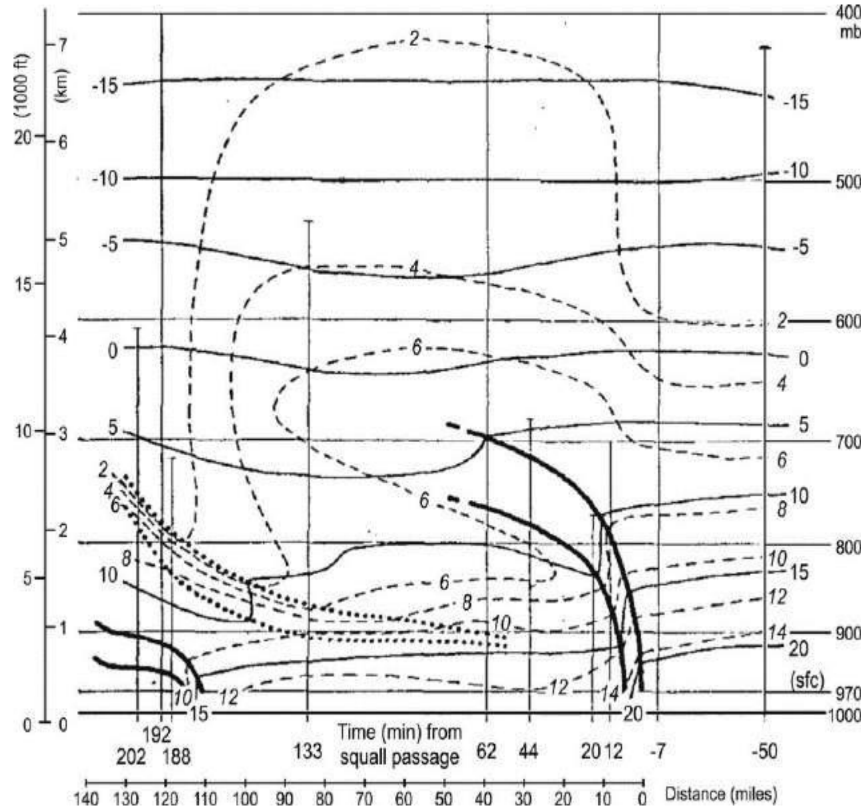

Figure 7. Time cross-section through squall line and cold front, Wilmington, OH, 0730–1135 eastern standard time (EST) 29 May 1947. Heavy lines show boundaries of squall-front and polar-front layers; heavy dotted lines show boundaries of subsidence inversion. Light solid lines show isotherms (0°C); light dashed lines show isolines of mixing ratio (g kg−1).

Below the cross-section is the time of radiosonde observation before or after squall-line passage; the distance scale is in miles. From [22].

C. W. Newton 1950 was a prominent meteorologist of the time who presented a cross-section study of Thunderstorm Project radiosonde data gathered in Ohio and drew isotherms according to typical synoptic frontal analysis procedures, with first-order discontinuities indicating frontal zone boundaries (indicated heavy lines) (Figure 7). Tetsuya (Ted) Fujita immigrated from post– World War II Japan and joined the Chicago School of Byers and Braham, which ushered in a paradigm shift in analysis approaches in a paper [5]. He popularized mesometeorology, which involved meticulously combining meteorological readings with space-time conversion to construct horizontal and vertical cross-sections that revealed meteorological processes on sub-synoptic scales. Fujita's inferred MCS conceptual model is exhibited in Figure 8. The storm's imprint on a horizontal scale, which was ;300 km, is an essential component of this conceptual model. As a result, in terms of scale and air motion characteristics, this model was equivalent to the tropical systems studied by [20].

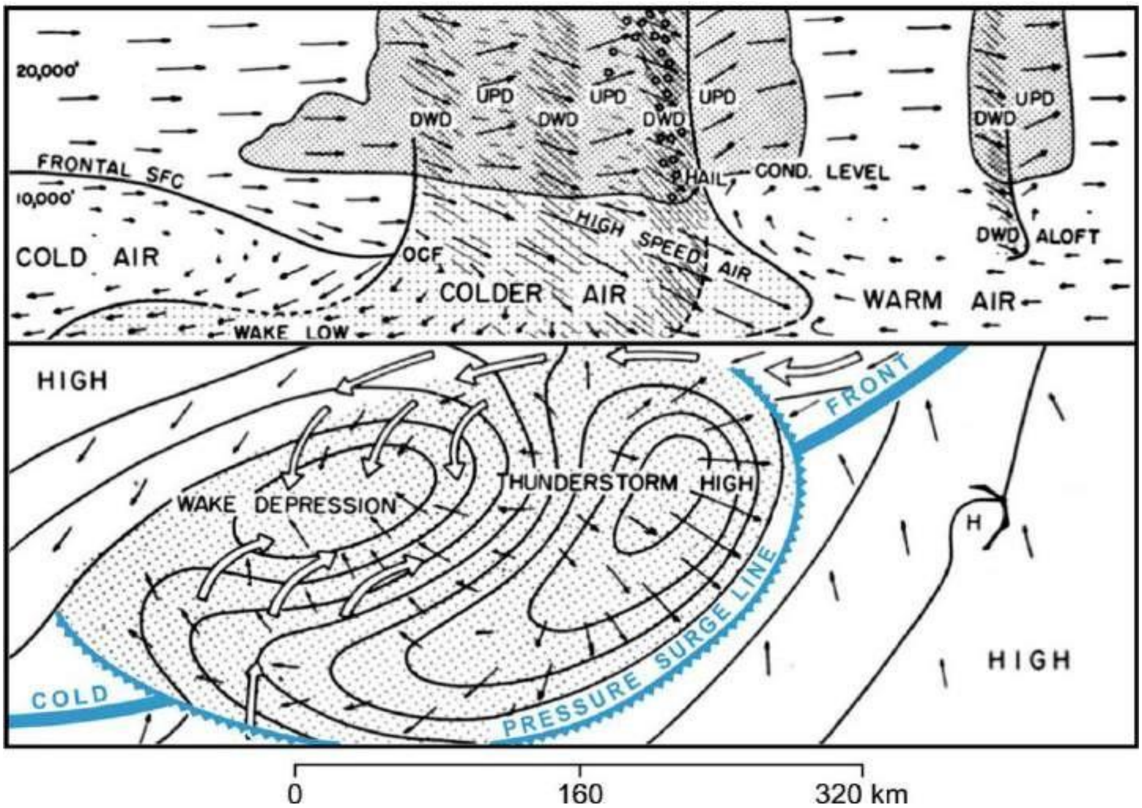

Figure 8. Schematic section through a squall line by Tetsuya Fujita. Adapted from [5].

3.2. Radar for Mesoscale

Fujita couldn't reveal anything about the internal structures of MCSs on smaller scales, even with his clever time-space conversions, because his mesometeorological methods didn't benefit from targeted aircraft measurements like those in the Thunderstorm Project, or from radar, which was still emerging from World War II development to become one of the most important meteorological instruments of the last 100 years. Herbert Ligda, who worked at the Massachusetts Institute of Technology, Texas A&M University, and Stanford University but wrote nothing in the formal literature, was one of the early pioneers of radar meteorology. During his time at Texas A&M, Ligda made a startling discovery: the internal structure of the same sorts of MCSs identified by Hamilton and Archbold as well as Fujita. Figure 9 appeared in the non-refereed proceedings of a glider pilots' meeting [23]. It showed in schematic but amazingly precise form the details of the typical radar echo pattern of an MCS of the type analyzed by Hamilton, Archbold, and Douglas (1945) and Fujita (1955). Notable features were a narrow sharp line of weak echo (A) marking the gust front immediately ahead of a convective line (B), a strong echo that was advancing with an eastward component of motion and consisted of numerous intense convective elements, each elongated northwest to southeast. A mild echo separates a lagged zone of stratiform precipitation from the line of convective cells zone (C) and (D). Radar was beginning to show that an MCS with a horizontal scale of a few hundred kilometers, as determined by Hamilton, Archbold, and Fujita, contained important substructures on a variety of smaller scales, all of which have proven to be important elements when considering the function of MCSs as weather producers and elements of larger-scale circulations.

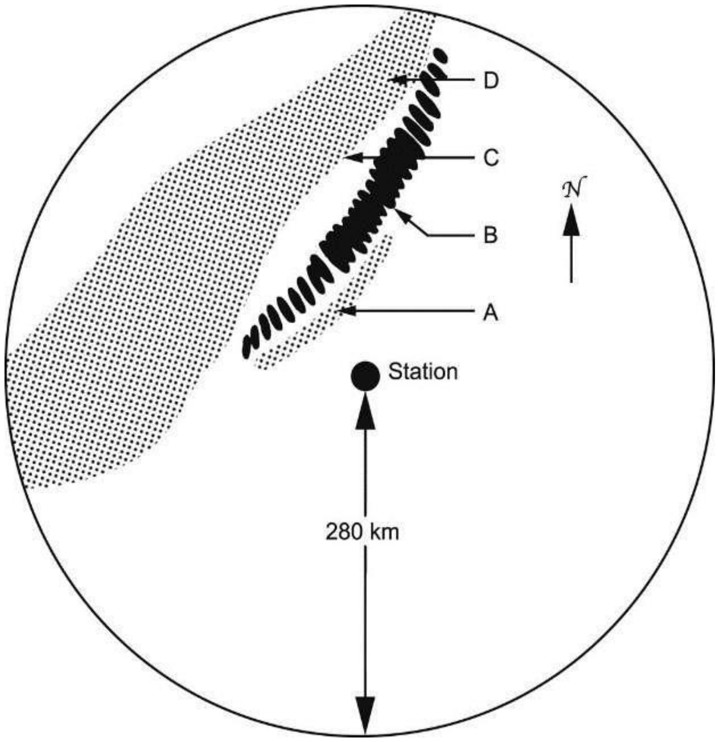

Figure 9. Schematic structure of surface precipitation features seen in early meteorological radar data. Adapted from [23].

3.3. Composite Analysis of MCS

Doppler radar has shown that the mesoscale downdraft of the stratiform area of a squall- line MCS sometimes merges with the convective downdrafts in the leading line of convection and that these mergers can produce strong effects, with the gust front surging forward and triggering new convection in the form of a "bow echo." Figure 10a from [24] and [25] shows an example of a bow echo. Doppler radar scans revealed substantial midlevel flow along the curved convective line's back edge. The back inflow is falling from the stratiform area of an MCS penetrating the convective region, where it combined with the convective-scale downdraft and pushed the gust front forward, underneath the main updraft cell, can be seen in a vertical cross-section thoroughly the bow echo portion of the line (Figure 10b). Bow echo events are a key source of concern for forecasters since they are frequently connected with powerful, damaging surface winds.

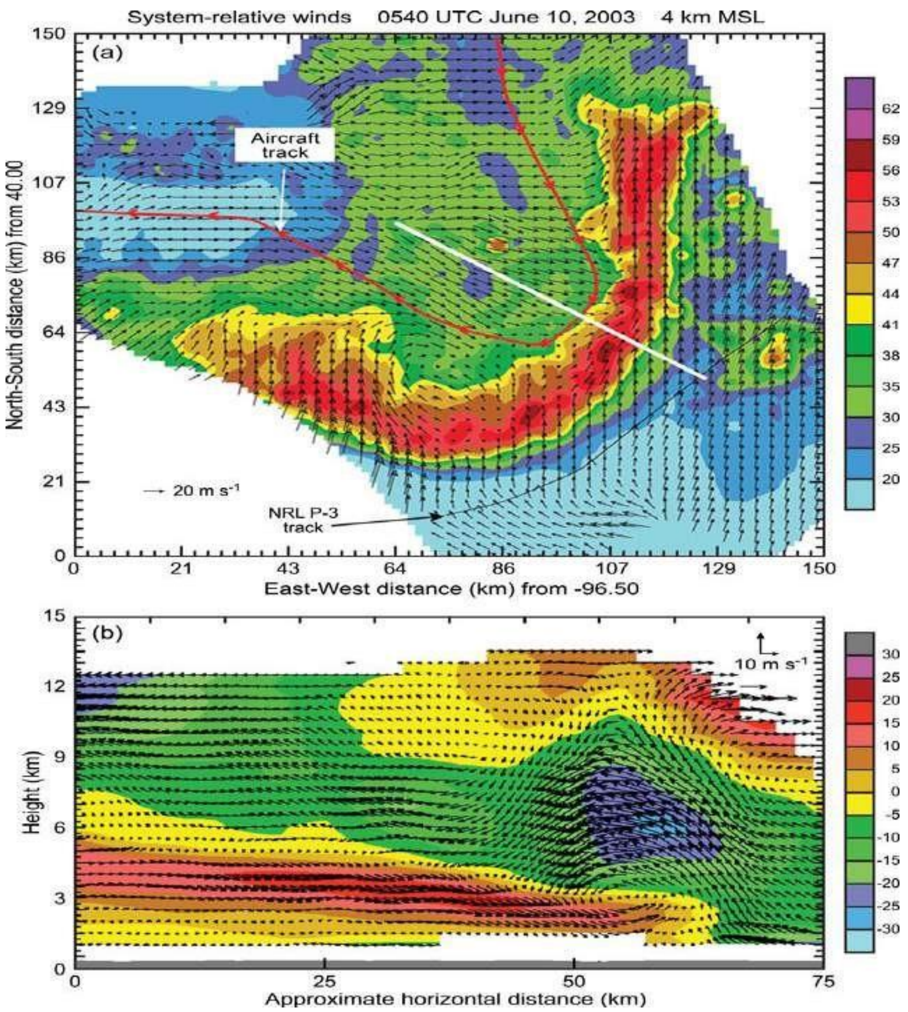

Figure 10. (a) System-relative winds at the 4-km level derived from airborne Doppler radar data within a bow echo on 10 Jun 2003. Aircraft tracks are superimposed. Reflectivity in dBZ is in color. (b) The white line in the vertical cross-section ahead (a) of the Doppler-derived storm-relative flow. Positive velocities (brown, magenta, and red hues) approach the convective line when negative velocities (blue, green, and yellow colors) recede. The vector scale (shown in the upper right of (b)) is vertically stretched to match the aspect ratio of the plot. The panels are adapted from [24] and [25], respectively, by [26].

3.4. Satellite Era

Ground-based radar researches, such as the ones mentioned above, have a regional reach by definition. The global significance of MCSs and their convective-stratiform structures has risen as a result of advances in satellite meteorology, which now allows for a global investigation of the frequency of occurrence of MCSs of various forms. With the launch of the earliest weather satellite in 1960, this possibility came [27]. [28]Martin & Suomi, 1972, was able to track "cloud clusters" that lasted 3–6 days using digitally improved visible photos. These clusters were high cloud areas with a horizontal scale of 3000–7000 km, making them practically synoptic size structures. However, early researchers noticed brilliant cores within these cloud shields that lasted 1–4 hours, traveled slower than the clusters, and occasionally took the appearance of bands. These brilliant cores were very likely active convective entities, which we now refer to as MCSs. Visible satellite imagery is only available throughout the day and is mostly nonquantitative.

The function of infrared imagers on satellites, which provide an indicator of cloud-top temperature, led to the first clear detection of MCSs in satellite data. [29]Maddox, 1980 observed what he dubbed mesoscale convective complexes using early infrared images (MCCs). Large, circular, cold cloud tops with infrared brightness temperatures less than 23.2°C over a region of 100 000 km2 (radius of 178 km) and less than 25.2°C over an embedded region of 50 000 km2 are defined as these entities. Surprising limits of 23.2°C and 25.2°C resulted from the fact that the work was done using photographic operational satellite products that employed these particular isotherm values, as shown in Maddox's classic paper's image of an MCC (Figure 11).

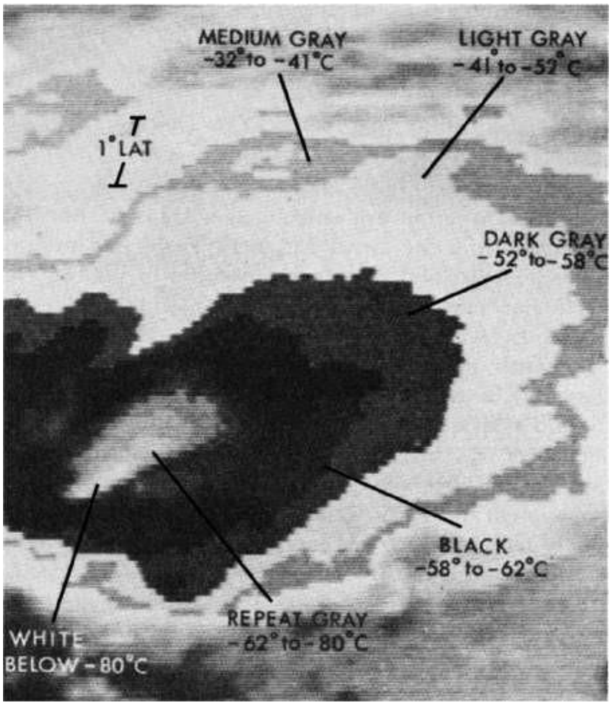

Figure 11. Infrared image showing temperature ranges corresponding to the various gray shades. From Maddox 1980 [29].

3.5. Representing MCS dynamics in global climate models

The requirement for an observational basis for parameterizing convective clouds in global atmospheric models prompted the Atlantic Tropical Experiment Project (GATE) in the early 1970s [30]. The consensus was that the size difference between boundary layer convective updraft plumes and large-scale motions allowed for such parameterization [31, 32]. GATE then showed that the scale separation did not exist and that MCS were important forms of convective clouds [33]. Computing technology has increased in recent years, and many numerical weathers forecast models can now resolve MCSs. However, climate projections for tens to hundreds of years are still impossible at the global cloud-resolving resolution, hence some method of capturing MCSs in global climate models will be required for some time.

To account for MCS properties in climate models, new techniques are being explored. One line of research is based on the [34] building-block idea, which states that a population of convective clouds is made up of three different types of clouds: congestus, deep convection, and precipitating stratiform components (Figure 12).

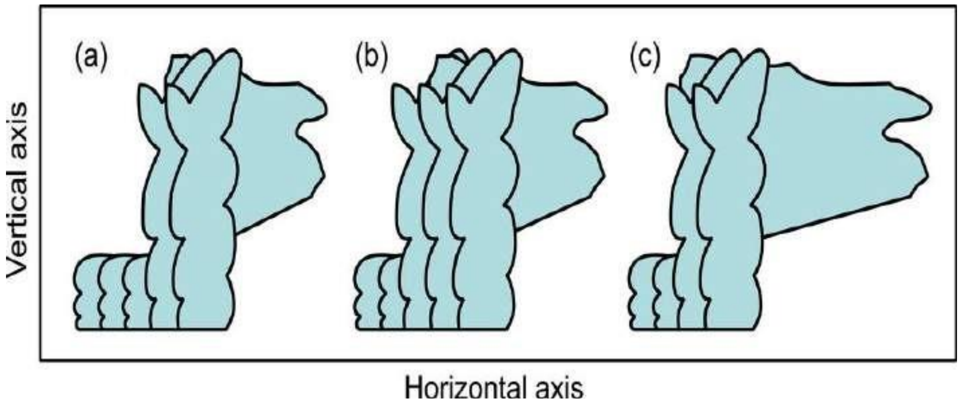

Figure 12. Depiction of three cloud populations, made up of (a) shallow convection, (b) deep convection, and (c) stratiform elements. In (a) the fraction of shallow convection is highest in the left-hand population. In (b) the fraction of deep convective elements is highest. In (c) the fraction of stratiform elements is greatest. Adapted from [34].

[35] Moncrieff et al., 2017 takes a different method, allowing a typical convective parameterization to operate while also using a parameterization that represents the layered overturning of MCSs. This extra parameterization entails adding a top-heavy heating profile to the convective heating profile, as well as a corresponding momentum transport profile that is compatible with the layered flow's momentum transfer. Tunable multiplicative coefficients regulate the profile magnitudes. This MCS parameterization is consistent with the effects of shear in influencing MCS dynamics since these coefficients have the potential to be functions of large-scale shear. This parameterization technique can be conceptualized as seen in Figure 13, where a layered overturning on a larger-than-convective scale is used when a convective population occurs in a large-scale shear environment. The overall scale of the overturning can change depending on the extent of the parameterized convection field, which is a unique aspect of this method.

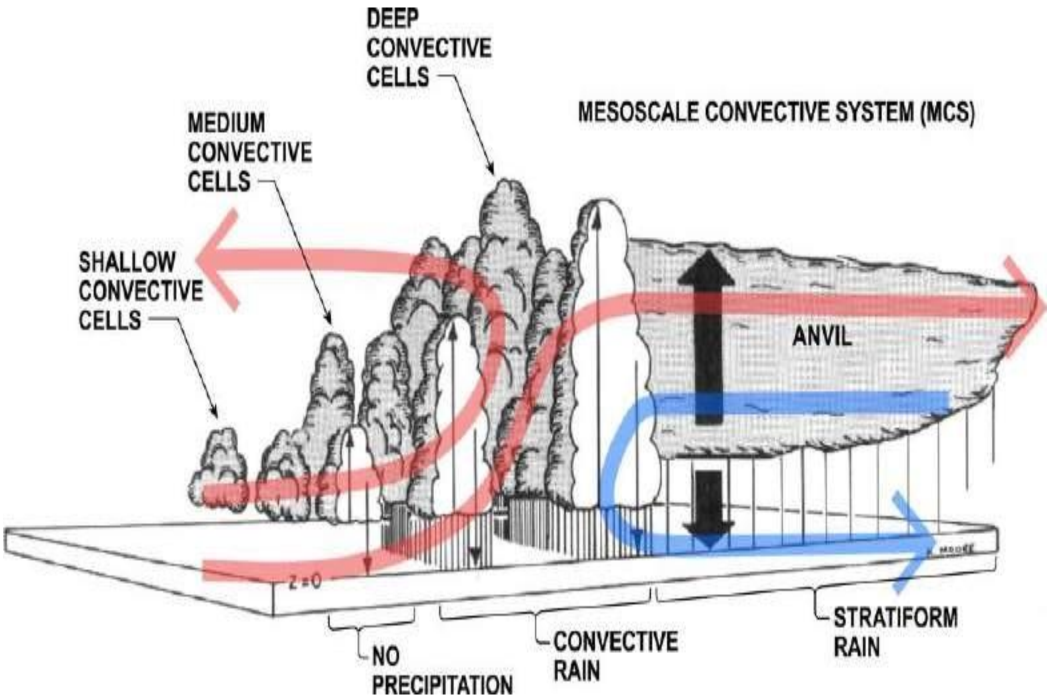

Figure 13. Overlay of a convective cloud population and superimposed layered overturning. Adapted from Houze et al. [33] and Moncrieff et al. [35].

4. Discussion of Review

Very details of MCSs have emerged in tandem with developments in observational technology and modeling since the time of Hamilton [20]. There are essential components of climate change and global circulation, as well as precipitation and flooding producers around the world. MCSs can arise in several meteorological regimes and take many contrasting forms, but they all have the same denominators: mesoscale horizontal scale and the development of stratiform parts that move latent and radiative heating feedbacks upward into the mid-upper troposphere. The understanding of these systems, as well as how to represent them in forecasting and climate models, is still a hot topic of research. The following are some current and prospective research areas focused on improving knowledge, understanding, and ability to appropriately describe MCSs.

The history of mesoscale convection research has been covered in this review. The MCS is the most massive of the convective cloud systems. And Houze [17] well explained that MCS exists along the energy-spectrum boundary between two- and three-dimensional atmospheric turbulence, with a horizontal dimension of hundreds of kilometers. When deep convective clouds collect in a region of 500–1000 km2, an MCS occurs. Congregated clouds heat the troposphere through latent and radiative processes, resulting in a bigger circulation that is mesoscale in scale and consists of the atmosphere's layers overturning: the rising layer comes from the lower troposphere, while the sinking layer comes from the mid-levels. The lower- tropospheric layer that feeds the ascending branch of the circulation can be several kilometers thick, implying that the rising air is not always rooted in the boundary layer. The full mesoscale overturning circulation can sometimes be found above a layer of stable air, disconnected from the boundary layer. This multilayer, mesoscale circulation distinguishes the MCS as a separate phenomenon with its own set of dynamics. MCSs are familiar to weather forecasters and other students of severe weather.

Nowadays, MCSs are fairly accurately captured by weather models with high resolution, and as cloud microphysical parameterizations improve, these simulations will become even more precise. Such models, which are now being performed across a little part of the world, are revealing parts of MCSs' function in climate change [36, 37]. Climate models that predict changes worldwide over extended periods, for example, must either wait for the computational capability to mature sufficiently to enable global high-resolution models operating over centuries of model time, or build proper parameterizations of MCSs. Because of the horizontal dimension of MCSs, convective parameterizations based on a scale separation between convective and synoptic scales would not suffice. In climate models, several strategies for parameterizing the heating and momentum transfer patterns of MCSs are being developed. Because MCSs remains a significant social issue, effective climate model creation that include MCSs, whether through cloud-resolving modeling or parameterization, is vital. In most regions of the world, the increasingly polluted aerosol environment affects MCS characteristics, and as the Earth warms, the patterns of MCS occurrence will likely vary, changing the areas affected by MCSs. Forecasting MCSs in real-time, as well as projecting their future occurrence in a changing climate, remains a significant challenge for meteorology and climate science.

Conflicts of Interest

I declared that there is no potential conflict of interest with any of the following statements.

1. For any component of the submitted work, the author received no cash or services from a third party (government, commercial, private foundation, etc). (Including but not limited to grants, data monitoring board, study design, manuscript preparation, statistical analysis, etc.).

2. The author is not affiliated with any entity that has a direct or indirect financial interest in the manuscript's subject matter.

3. The author was involved in the following aspects of the project: (a) idea and design, or data analysis and interpretation; (b) authoring the article or critically reviewing it for essential intellectual content, and (c) approval of the final version.

4. This work has not been submitted to and is not currently being reviewed by any other journal or publishing venue.

5. The author has no patents that are broadly relevant to the work, whether proposed, pending, or issued.

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References

1. Oo, K. and K. Oo, *Analysis of the Most Common Aviation Weather Hazard and Its Key Mechanisms over the Yangon Flight Information Region.* Advances in Meteorology, 2022. **2022**.
2. Astuti, S.I., Arso, S. P., & Wigati, P. A. , *Aviation Benefits beyond borders-Covid 19 analysis Fact sheet.* Air Transpot Action Group, 2020. **3**: p. 103-111.
3. Goodman, C.J. and J.D.S. Griswold, *Meteorological impacts on commercial aviation delays and cancellations in the continental United States.* Journal of applied meteorology and climatology, 2019. **58**(3): p. 479-494.
4. Kulesa, G. *Weather and aviation: How does weather affect the safety and operations of airports and aviation, and how does FAA work to manage weather-related effects?* in *The Potential Impacts of Climate Change on TransportationUS Department of Transportation Center for Climate Change and Environmental Forecasting; US Environmental Protection Agency; US Department of Energy; and US Global Change Research Program*. 2003.
5. Adminstration, F.A., *Weather Related Aviation Accident. Fujita, T. (1955). Results of Detailed Synoptic Studies of Squall Lines.* . 2010.
6. Charba, J.P. and F. Samplatsky. *Operational 2-h thunderstorm guidance forecasts to 24 hours on a 20-km grid.* in *Preprints, 23rd Conf. on Weather Analysis and Forecasting/19th Conf. on Numerical Weather Prediction, Omaha, NE, Amer. Meteor. Soc. B*. 2009.
7. Gultepe, I., et al., *A review of high impact weather for aviation meteorology.* Pure and applied geophysics, 2019. **176**: p. 1869-1921.
8. NTSB, *Special investigation report on – emergency medical services operations.* 2006. **78**(4): p. 124-138.
9. NTSB, *East Coast Jet Flight 81 Accident Report. Aviation Accident Report.* 2011.
10. BEA, *Airbus A330-203 Accident Report.* 2011.
11. NTSB, *Preliminary Report On Tennessee Medical Helo Crash | Aero- News Network.* . 2010.
12. Ellrod, G.P. and J.A. Knox, *Improvements to an operational clear-air turbulence diagnostic index by addition of a divergence trend term.* Weather and forecasting, 2010. **25**(2): p. 789-798.
13. Bramberger, M., et al., *Vertically propagating mountain waves—A hazard for high-flying aircraft?* Journal of applied meteorology and climatology, 2018. **57**(9): p. 1957-1975.
14. ICAO, *Manual on Low-level Wind Shear. . . Doc 9817 AN/449, 2, 213.* 2005.
15. Proctor, F.H., D.A. Hinton, and R.L. Bowles, *A windshear hazard index.* Aviation, Range and Aerospace Meteorology, 2000.
16. Krajewski, E., *Flying in Convective Weather … And Why You Shouldn't - IBM Business Operations Blog.* 2019.
17. Houze, R., *100 years of research on mesoscale convective systems, Meteorol. Monogr., 59, 17.1–17.54.* 2018.
18. Abercromby, R., *Suggestions for an international nomenclature of clouds.* Quarterly Journal of the Royal Meteorological Society, 1887. **13**(62): p. 154-166.
19. Hildebrandsson, H.H., *Remarks concerning the nomenclature of clouds for ordinary use.* Quarterly Journal of the Royal Meteorological Society, 1887. **13**(62): p. 148-154.
20. Hamilton, R., J. Archbold, and C. Douglas, *Meteorology of Nigeria and adjacent territory.* Quarterly Journal of the Royal Meteorological Society, 1945. **71**(309-310): p. 231-264.
21. Byers, H.R. and R.R. Braham, *The thunderstorm: report of the Thunderstorm Project.* 1949: US Government Printing Office.
22. Newton, C.W., *Structure and mechanism of the prefrontal squall line.* Journal of Atmospheric Sciences, 1950. **7**(3): p. 210-222.
23. Ligda, M., *The radar observation of mature prefrontal squall lines in the midwestern United States.* OSTIV Publications, 1956. **4**: p. 141-143.
24. Davis, C., et al., *The Bow Echo and MCV experiment: observations and opportunities: observations and opportunities.* Bulletin of the American Meteorological Society, 2004. **85**(8): p. 1075-1094.
25. Jorgensen, D.P., H. Murphey, and R. Wakimoto. *Rearinflow evolution in a non-severe bow echo observed by airborne Doppler radar during BAMEX.* in *Preprints, 22nd Conf. on Severe Local Storms, Hyannis, MA, Amer. Meteor. Soc.* 2004.
26. Houze Jr, R.A., et al., *The variable nature of convection in the tropics and subtropics: A legacy of 16 years of the Tropical Rainfall Measuring Mission satellite.* Reviews of Geophysics, 2015. **53**(3): p. 994-1021.
27. Anderson, G.D., *The first weather satellite picture.* Weather, 2010. **4**(65): p. 87-87.
28. Martin, D.W. and V.E. Suomi, *A satellite study of cloud clusters over the tropical North Atlantic Ocean.* Bulletin of the American Meteorological Society, 1972. **53**(2): p. 135-157.
29. Maddox, R.A., *Mesoscale convective complexes.* Bulletin of the American Meteorological Society, 1980: p. 1374-1387.
30. Kuettner, J.P. and D.E. Parker, *GATE: Report on the field phase.* sciences, 1976. **57**: p. 11-27.
31. Yanai, M., S. Esbensen, and J.-H. Chu, *Determination of bulk properties of tropical cloud clusters from large-scale heat and moisture budgets.* Journal of Atmospheric Sciences, 1973. **30**(4): p. 611-627.
32. Arakawa, A. and W.H. Schubert, *Interaction of a cumulus cloud ensemble with the large-scale environment, Part I.* Journal of the atmospheric sciences, 1974. **31**(3): p. 674-701.

33. Houze Jr, R.A. and A.K. Betts, *Convection in GATE.* Reviews of Geophysics, 1981. **19**(4): p. 541-576.
34. Mapes, B., et al., *The mesoscale convection life cycle: Building block or prototype for large-scale tropical waves?* Dynamics of atmospheres and oceans, 2006. **42**(1-4): p. 3-29.
35. Moncrieff, M.W., C. Liu, and P. Bogenschutz, *Simulation, modeling, and dynamically based parameterization of organized tropical convection for global climate models.* Journal of the Atmospheric Sciences, 2017. **74**(5): p. 1363-1380.
36. Prein, A.F., et al., *A review on regional convection-permitting climate modeling: Demonstrations, prospects, and challenges.* Reviews of geophysics, 2015. **53**(2): p. 323-361.
37. Yang, Q., et al., *Environments of long-lived mesoscale convective systems over the central United States in convection permitting climate simulations.* Journal of Geophysical Research: Atmospheres, 2017. **122**(24): p. 13,288-13,307.