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RESEARCH PROGRESS ON REMOTE SENSING ANALYSIS OF SEA BREEZE FRONTS

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Abstract: This article reviews the recent 40 aResearch on remote sensing analysis of sea breeze fronts, summarizes the satellite identification and remote sensing analysis of sea breeze fronts Application of methods and techniques in the three-dimensional structure and evolution of sea breeze fronts. The results show that remote sensing research on sea breeze fronts has been carried out in many places. carried out in the region and achieved some important results; the remote sensing analysis methods of sea breeze fronts mainly include visible light image cloud line detection and thermal infrared radiation detection. Scatter meter wind field detection 3 types; detecting sea breeze fronts based on the appearance of clouds in visible light images and the propagation speed of clouds is still the current method The main means of remote sensing research on sea breeze fronts. Furthermore, based on existing research, some issues are raised that deserve further attention.
Keywords: Sea breeze front; Satellite; Remote sensing

1. INTRODUCTION

Sea and land breeze circulation is a mesoscale mesoscale phenomenon caused by thermal differences between sea and land. Circulation, including daytime sea breeze circulation and nighttime land breeze circulation. Daytime comparison The cold sea breeze encounters a layer of hotter air as it advances toward the land. A front that resembles a shallow cold front is called a sea breeze front [1]. Hai Fengfeng was also It is called the sea breeze convergence line, which is a typical boundary layer convergence line. Horizontal scale can reach 100 km, vertical scale and atmospheric boundary layer phase when. Sea breeze fronts are affected by weather conditions and large-scale background winds. When encountering other weather systems, unstable energy releases will be triggered, causing Strong convective weather such as short-term heavy precipitation, squall lines, thunderstorms and strong winds will have a great impact on the local weather, climate and environment [2-3]. sea breeze front The interaction between horizontal convective volumes is the current research topic on severe convective weather. Scientific issues that focus on the research field. The sea breeze front is pushing inland If you encounter updrafts and downdrafts when entering, they will be different from the level formed. Convection volumes interact with each other to produce convection; due to horizontal convection volumes The direct and indirect effects will be in front of the sea breeze front advancing inland. Forming a " roller cloud" Cloud), thus affecting the movement of sea breeze front moving speed and the clouds above it [4]. IWAI et al. [5] used dual Doppler stimulation Lidar and helicopter-borne sensors observed and studied the three-dimensional structure of horizontal convective volumes in the sea breeze layer, and found that the upper convective volume in the high-altitude jet stream.

already 20 century In the 1920s, sea breeze research attracted the interest and attention of European and American scientists. Relevant research results published from the 1920s to the 1950s included the structural characteristics and meteorological conditions of sea breeze. JEFFREYS [6] Theoretically revealed the formation of sea and land breezes; WEXLER [7] statistically analyzed the occurrence times and physical characteristics of sea and land breezes in different areas. The analysis further improved the theoretical framework of sea and land breezes and had a profound impact on subsequent sea breeze research. In the 1960s, meteorologists discovered that there is a special area in the front of the sea breeze where meteorological elements change strongly. area and defined it as the sea breeze front. In the following decades, meteorologists successively conducted relevant theoretical research on the sea breeze front.. For example : MILLER et al. [8] studied the forcing mechanism, structure, life cycle and That right null gas quality quantity of film ring Enter OK Got it Complete noodle discuss Argument ; CROSMAN et al. [9] conducted a systematic review of numerical studies on sea breezes (fronts), and discussed the effects of sea breeze front characteristics on surface sensible heat flux, environmental geostrophic winds, atmospheric stability, and humidity.

Most conventional observing stations are located in densely populated areas; On the sea or in sparsely populated areas, there are very few, resulting in the loss of observation station data. The spatiotemporal coverage is low. Sea breeze fronts are complex mesoscale systems affected by Weather and topography have a great influence on the spatiotemporal characteristics of sea breeze fronts in different regions. There are obvious differences, and it is impossible to accurately observe using automatic weather station data. The occurrence and development characteristics of sea breeze fronts. In the 1980s and 1990s, Meteosat series of geostationary meteorological satellites and the successful launch of the third-generation polar-orbiting weather satellite of the United States. With the research on remote sensing observations of sea breeze fronts, meteorologists began to combine satellite The data are used to study the identification

and structural evolution of sea breeze fronts [10]. compared to Automatic station data and satellite data cover a wider area and have spatial and temporal resolution. The rate is greater, and it can be used to control the sea breeze front from the overall weather pattern. The occurrence and development are analyzed.

twenty one Over the past century, satellite remote sensing technologies in various countries have continued to improve, and the spatial and temporal resolution of satellite data has become higher and higher, which has greatly improved people's understanding of sea breeze front processes, but there are still some limitations in actual identification. To overcome the limitation that sea breeze fronts cannot be directly and clearly observed from satellite images, researchers have attempted to identify sea breeze fronts by observing related phenomena. Due to the convergence of winds near the sea breeze front, Rising air condenses to form clouds, so the presence of a sea breeze front can be inferred from lines of cumulus clouds that run parallel to the coastline and push inland. Related studies have also demonstrated the important role of cumulus lines in sea breeze front detection, such as GOLER et al [11], BIRCH Wait [12-13] The characteristics of cloud lines in different coastal areas around the world were classified and summarized, and it was found that the sea breeze circulation of different types of cloud lines is different. In addition, scatterometer wind data and ceilometer data can also be used to detect sea breeze fronts [14-18].

This article focuses on the identification of sea breeze fronts and their structural and evolutionary characteristics. In terms of aspects, it comprehensively introduces the research progress and development frontiers of remote sensing applications of sea breeze fronts at home and abroad, aiming to provide reference for related research in China.

2. IDENTIFICATION OF SEA BREEZE FRONTS

from Since the first successful launch of a meteorological satellite in 1960, space remote Sensing technology has continued to develop and mature. Satellite data in the sky Weather analysis and forecasting, numerical weather forecasting and climate prediction, especially Especially in mesoscale severe convective weather, it plays a very important role. Use [19]. In the 1960s and 1970s, the main meteorological systems operating in the world The satellites are the first and second generation operational meteorological satellites of the United States and the third A generation of operational geostationary meteorological satellites, but relying on the lower resolution of the time Radiometer data do not allow for fine observations of sea breeze fronts.

20th Century In the 1980s, the United States and Europe launched the third-generation polar-orbiting weather satellites and the Meteosat series of geostationary weather satellites respectively. The third generation of polar-orbiting weather satellites has added high-resolution infrared detectors (High - resolution Infra Red Sounder, HIRS) and multi-channel advanced even high point distinguish Rate sweep trace spoke shoot Calculation (Advanced Very High Resolution Radiometer, AVHRR), compared with the previous generation of polar-orbiting weather satellites, it has the ability to acquire multi-channel images simultaneously. The infrared visible light imager mounted on the Meteosat series of geostationary weather satellites obtained water vapor images for the first time, significantly improving the spatial and temporal resolution of the image. These high-precision satellite equipment were put into observation tests and a large amount of satellite data with wider coverage and greater spatiotemporal density were obtained. Meteorologists have also begun to use these satellite data to identify sea breeze fronts. FETT et al. [10] observed the visible light images of meteorological satellites and clearly saw that there is a light and dark linear pattern parallel to the coastline near the coastline. After analysis, they concluded that this pattern is a windless area (i.e., sea breeze front) that tends to be parallel to the coastline. This Remote sensing identification and observation of sea breeze fronts have been launched.

entering the 21st century, remote sensing instrument development technology and digital signal processing technology have continued to advance, and meteorological satellites with high spatial and temporal resolution and continuous spatial coverage have gradually become effective tools for sea breeze front observations. DAMATO et al. [20] and PLANCHON et al. [21] projected the visible light image according to the longitude and latitude reference system, used the average filter to smooth and homogenize the image, and defined and drew the sea breeze front on the image. The purpose is to detect the sea breeze from the cloud image. Fronts, and estimate the occurrence of sea breeze fronts based on weather conditions. This method of marking sea breeze fronts through remote sensing can detect sea breeze fronts more accurately, but it will be limited by interference from irrelevant cloud bands and cloud-free weather. GILLE et al. [14] analyzed the fast scatterometer (Quick Morning and evening wind measured by Scaterometer, QuikSCA T) Differences are used to determine the existence of sea breeze fronts. It is observed that significant diurnal changes in winds often occur at northern latitudes. On the coastline north of 50° and in the easterly trade wind area, the average wind and its diurnal variation tend to be parallel to the coast; however, due to QuikSCAT The scatterometer provides only two samples per day, so it is not possible to study the propagation of sea breeze fronts as gravity currents over land (this situation improved after the launch of the Japanese ADEOS - II satellite, which The QuikSCAT scatterometer provides two scatterometer wind measurements in addition to the wind measurement time). GOLER et al. [11] divided the cloud system formed in the dry season of the Bay of Carpentaria in northern Australia into 3 basic types, and summarized the relationship between different types of cloud lines and precipitation; this study found that the generation of cumulus lines is related to the previous The emergence of coastal sea breeze fronts on 1 d is closely related, and the sea breeze circulation corresponding to different types of cumulus lines is different. This result confirms the feasibility of using cumulus lines to detect sea breeze fronts. IWAI et al.[5] Using helicopter-borne sensors

combined with dual Doppler LiDAR was used to observe and study the three-dimensional structure of the sea breeze front.

In the past ten years, with the upgrading of meteorological satellites and their loading equipment, satellite data have become more and more abundant, and the spatial and temporal resolution has gradually improved. After continuous improvement and application, satellite identification methods have now become one of the main means for meteorologists to study sea breeze fronts.. CORPETTI [24] noticed that the complexity of specific cloud texture patterns generated by sea breeze fronts in satellite visible light images cannot be judged using traditional visual detection methods, so they proposed an active contour method for extracting fronts from images. This method is based on the Snake active contour method, Some specific textures and transparency characteristics in the image are processed through wavelet decomposition, which can calculate whether the front exists. This technique has been verified on instance images, and the proposed theoretical framework can be used not only for sea breeze front detection, but also for any other texture pattern analysis. The difference in reflectance between low-altitude clouds and surface features in visible light images can be used to identify cloud lines. Cloud types are classified according to color in visible light images. Gray / white shades represent different thicknesses and densities of clouds. When they appear with The presence of a sea breeze front can be inferred when the coastline is shaped like a curve that advances inland. This method can accurately identify sea breeze fronts, but has limitations in cloud-free conditions. To solve this problem, LENSKY etc [23] This paper proposes a method for detecting sea breeze fronts under clear sky conditions, which uses infrared and visible light images from the European second- generation geostationary meteorological satellites to identify and analyze sea breeze fronts under clear sky conditions in summer. This method does not rely on the presence of clouds, but uses thermal infrared radiation reflected from the ground under clear sky conditions to detect sea breeze fronts. However, due to the influence of regional conditions, the detection accuracy needs to be improved. BIRCH Wait [12-13] Using satellite cloud image data, the cloud line characteristics over northwest Australia and the Arabian Sea were classified and summarized. This study divided the cloud lines in northwest Australia into Category 3, observations show that all wavy cloud lines propagate offshore, and these wavy cloud lines are related to sea breeze convergence lines. Research also points out that the wavy cloud lines over the Arabian Sea are very similar to the wavy cloud lines in the northwest waters of Australia. ANJOS etc [24] right GOES -13 channels Visible light image of 1 (wavelength is 0.55 ~ 0.75 μm) and remote sensing data provided by the Brazilian Center for Weather Forecasting and Climate Research (CPTEC), through sequential analysis of visible light images and application of sea breeze front statistics to environmental geographical information System (Geographic Information System, GIS), add geographic information as reference, Processes such as calculating linear density and defining hourly sea breeze fronts are used to identify sea breeze fronts. FERDIANSYAH [24] proposed using the stationary earth

Satellite images derive a framework for the two-dimensional distribution of sea breeze fronts, which incorporates the Morphological Serpentine Algorithm. Snake Algorithm) Applied to visible light images to automatically detect cumulus cloud lines related to sea breeze fronts; in order to ensure that the cloud lines on selected sea breeze days are related to sea breeze fronts, sea breezes with a change in wind direction from land breeze to sea breeze and a sea breeze pattern that lasts for at least 2 hours were selected Japan; combined with ground observations, it was proved that sea breeze fronts can be judged based on changes in factors such as increased humidity, reduced temperature rise rates, and increased wind speeds.

The above research shows that there are obvious differences between different sea breeze front identification methods. The difference. Morning and evening wind differences measured using spaceborne scatterometers can determine However, due to the limitation of measurement time, it is impossible to confirm the existence of sea breeze front. Determine the location and start time of the sea breeze front. Visible light image inspection The measurement method is more conducive to determining the position of the sea breeze front, although its early visual The computational cost of the visual detection method is lower and the time consumption is shorter, but it cannot be adapted to Complex texture analysis of related cloud lines leads to large recognition errors; The subsequent detection methods have been developed and updated, and combined with algorithms can achieve Extracting fronts from images solves the problem of large recognition errors to a certain extent, but there are still many limitations.

3. SEA BREEZE FRONT STRUCTURE AND EVOLUTION CHARACTERISTICS

1960s and 1970s, with the gradual development of theoretical research on sea breeze fronts, With the further improvement and rapid progress of observation technology, scientists have accumulated a wealth of rich sea breeze front observation examples, and proposed a more mature sea breeze front model type. 20th Century In the 1980s, with the continuous advancement of satellite technology and the accumulation of observation data, the understanding of the structure and evolution of sea breeze fronts was also continuously improved. In particular, high spatial resolution meteorological satellite loaders were put into observation tests and a large amount of data was obtained. It is used in the study of the detailed structure and evolution characteristics of sea breeze fronts. RAMIS etc [26] in analysis During a sea breeze front on the Spanish island of Majorca, a line corresponding to the convergence line of sea breeze amplitudes was discovered through meteorological satellite cloud images. The cumulus cloud line advances into the interior of the island, confirming the detection of sea breeze fronts by the cloud line indication function. CAUTENET [27] used

visible light images to follow traced the gulf of guinea in west africa 1979 _ Sea breeze front penetrates inland in January Through the diurnal changes, it was found that the area around the Gulf of Guinea is affected by sea breeze circulation. Surfaces have unique commonalities and local characteristics; research also uses numerical modeling The changes in the effective potential energy of convection at this location were analyzed, and the results showed that the convection The instability is greatest on its sides, and the location of enhanced convection is determined by It is determined by the wind shear at the 500-2000 m level. 20th Century the 90s, WAKIMOTO et al. [28] used single Doppler observations, satellite images, convection and precipitation / electrification (Convection and Precipitation / Electrification, CaPE) images collected from experiments, on August 1991_6 days (land) and August _ A comparative analysis of the sea breeze events on the 12th (at sea) was conducted. The results showed that the characteristics of the sea breeze fronts on the cloud maps on the two days were very different. The horizontal convection volume on August 6 was closely parallel to the sea breeze front, and the propagation speed of the front was faster. Uniform ; August On the 12th, the horizontal convection volume was almost vertical to the direction of the front, and the sea breeze front was wide and easy to identify. BRUMMER et al. [29] in in 1989 A cloud line corresponding to a weather-scale cold front was observed on the visible light image on May 9, moving from the North Sea to northern Germany. After the cold front reached the coast, it interacted with the sea breeze front, pushing the sea breeze front to move inland.

Enter After the 21st century, with the further development of remote sensing technology, the understanding of the structure and evolution of sea breeze fronts has been continuously updated and improved. In particular, a variety of high spatial and temporal resolution satellite detection systems have been put into observation experiments, and a large amount of information about sea breeze has been obtained. Refined data on front structure and evolution characteristics. DAMATO etc [20] The occurrence frequency of sea breeze fronts and their inland penetration in the warm season in Western Europe were estimated using satellite visible light images. The results show that the distribution and inland penetration of sea breeze fronts are affected by time and space, due to geographical (topography and coastal exposure) and meteorological factors. As a result, the inland penetration distance in the afternoon is 10 ~ 50km _ The frequency of sea breeze fronts observed in the English Channel region is related to the Nordic anticyclone. APARNA etc [15] A method to quantify the seaward extent of sea breezes is proposed, which has QuikSCAT The instantaneous wind vector data from satellite scatterometers are processed, and the seaward degree of the sea breeze is estimated through the degradation performance of the wind vector correlation coefficient. The advantage of this method is that it relies entirely on satellite measurements and does not require wind data over land, but this method cannot determine day-to-day changes in seaward extent. PLANCHON [21] used satellite remote sensing data to estimate the frequency of sea breeze fronts in northern Brazil and the The average distance that the sea breeze front penetrates inland at 18:00 (UTC), the study found that the sea breeze front penetrates inland during the dry season (9 — December) has the highest frequency of occurrence, in 9 - In November, it goes furthest inland, from the coast of Ceara (the coast at The maximum distance of Cear á) is 100 km. AZORIN - MOLINA etc [30] Based on satellite observations, a detailed summary is made of the influence of the convective inner boundary layer and the sea breeze convergence zone in the southeastern Iberian Peninsula on the development of various clouds. Further summary shows that the sea breeze front can increase the frequency of low clouds and convective cumulus clouds, and at the same time also Inhibits the development of high, medium and low clouds associated with cumulonimbus clouds. LI etc [31] The National Oceanic and Atmospheric Administration (National Oceanic and Atmospheric Administration) Oceanic and Atmospheric Administration, NOAA) _ _ NOAA -16 satellite of AVHRR image and visible light images from the GOES - 8 satellite for 2001 August _ Observation and analysis of the coastal cumulus cloud line on the east coast of the United States on the 17th showed that the cloud line formed at local time 16:00, extending from Florida to North carolina of Cape Hatteras Hatteras), long contract 850 km, width approx. 8.5 km, penetrating inland in the shape of the coastline Pass 20 km and the penetration speed is uneven; combined with numerical simulation results, it is proved It is confirmed that the formation of this kind of cloud line is related to sea breeze circulation. The model simulated The area of maximum vertical velocity also agrees well with the position of the cloud lines.

twenty one At the beginning of the 20th century, IWAI et al. [18] used Doppler lidar, The data obtained by the ceilometer and meteorological ground station recorded the three-dimensional structure of a sea breeze front in the Tokyo area and the vertical aerosol transport related to the sea breeze front; the ceilometer observed aerosol backscattering 2 km from the ground, and the sea breeze The denser aerosols at the front of the front escape from the head of the sea breeze front, and are then transported vertically to the mixing height by the strong updraft. Combining radar and weather station data, it is inferred that the thermal interaction between the sea breeze front and the front airflow will Affects sea breeze front structure and air quality in related areas. LENSKY etc [23] Using continuous thermal infrared images and actual measurement data from meteorological satellites, we analyzed the weather conditions in 2010 based on different weather circulation. Israel in July 10 instances were classified and counted. The characteristics of sea breeze and two different modes of sea breeze under clear sky conditions in summer are revealed. The results show that weak horizontal pressure gradient promotes the development of sea breeze, while strong horizontal pressure gradient inhibits the development of sea breeze. BROWN [16] used scatterometer wind observations to study offshore sea and land winds near Darwin, Australia. The data used were from the European Operational Polar Orbiting Meteorological Observatory. Star METOP- B two class high class scattered shoot Coastal optimization product (Advanced Scatterometer, ASCAT), optimization data It is formed by initially averaging ASCAT measurement values

onto a regular spatiotemporal grid ; the offshore surface sea breeze characteristics (intensity and horizontal spatial range) estimated using models and satellites are generally consistent, with intensity differences less than 2 m/s. The sea extent does not change by more than 150 km, the model can well simulate the changes in sea breeze disturbance amplitude with monsoon conditions. ANJOS etc [24] It was found that the increase in temperature in the Sergipe area on the northeastern coast of Brazil is related to the development of sea breeze fronts. Therefore, the temperature rise in northeastern Brazil in 2015 was 847 visible light images were analyzed sequentially, combined with surface meteorological data to perform statistical analysis on the daily performance of sea breeze fronts, meteorological variables on sea breeze front days and non-sea breeze front days; the results show that most sea breeze fronts start from local time Start at 12:00, stop at 19:00, continue The time is 7 h, the maximum inland penetration distance from the coast 94 km ; in addition, the sea The argument that wind fronts are associated with increases in solar radiation, temperature, and decreases in relative humidity and dew point temperature is also confirmed. This phenomenon subverts the previous understanding that sea breeze is conducive to lowering temperatures. Miao Chunsheng et al. [32] used the National Satellite Meteorological Center FY -2D The brightness temperature of the satellite (Black Body Temperature (TBB) product observed and analyzed the convective cloud activities of sea breeze fronts along the coast of Jiangsu in summer. SHORT etc. [17] Comprehensive Considered together 5 Satellite data: NOAA satellite in 4 A look at the seasons Measurement Arrived towards outside long Wave spoke (Outgoing Longwave Radiation, OLR) data, METOP-A and METOP-B two pieces ASCAT data on the satellite, carried on the OceanSat -2 satellite Rapid scatterometer Scatterometer, RSCAT) data, matching Onboard the Haiyang-2 (HY -2A) satellite star Scatterometer (HY 2 -SCAT) data and data from the International Space Station (International Fast scatterometer data carried by the Space Station (ISS), utilizing multiple instances Analyzing the connection between sea breeze fronts and the diurnal cycle of offshore precipitation The analysis found that sea breeze fronts from nearby islands have an impact on the daily precipitation cycle.

the 1920s, BERRI et al. [33] used spatial resolution The rate is 1 km × 1 km, the time resolution is Visible light image for 30 minutes Like to La Two well-developed sea breeze cases in the Plata River area were analyzed and it was found that the local coastline characteristics significantly affect the inward direction of the sea breeze front. Continental penetration, combining local observations and static boundary layer model simulations It can be found that the propagation of the sea breeze front is related to the changes in the three-dimensional circulation in the boundary layer. ation, the model better simulates the obvious cloud bands in satellite images. Inland propagation speed, but the estimated inland propagation speed of the sea breeze front The speed is significantly greater than the propagation speed of high-altitude cloud belts. FERDIANSYAH [25] used the Japanese operational geostationary meteorological satellite Himawari - 8 to detect the B03 band visible light image of the cumulus line (spatial resolution 500 m, the time resolution is 10 min) and used to invert the surface temperature of B13 thermal infrared image (spatial resolution 2 km, time resolution The rate is 10 min) Sea breeze front in Jakarta, Indonesia A detection study was conducted, and the results showed that cloud lines can reasonably represent sea breeze fronts. arrival time, but the updrafts caused by urban heat island circulation will cause The time deviation in the city center is slightly larger than that in other areas. GRAU et al [34] Using the second generation of geostationary meteorological satellites (Meteosat Second Generation, MSG) surface and sea surface temperature data gauges Calculate the temperature difference between land and sea in the Parma Basin in the western Mediterranean, and Analyze and study the sea breeze front occurring in the Palma Basin to evaluate Estimate the contribution of horizontal temperature difference in sea breeze characteristics; the study found that during the warm months, the sea-land temperature difference (about 13 ℃) is slightly larger than that of non-marine Fengfeng Day (approx. 11 ℃).

At present, sea breeze front research mainly relies on conventional weather station data and radar data, supplemented by satellite remote sensing data. satellite scattering Meteorometers and optical imagers can provide high spatial and temporal resolution meteorological information, which can be used to infer the occurrence and development characteristics of sea breeze fronts. early profit Most studies of sea breeze fronts using optical imagers describe their evolution through the movement of cloud lines. Later studies went further, It can be determined by cloud types, cloud appearance, and convective clouds. The top height and cloud propagation speed are used to quantitatively describe the sea breeze front.

Domestic meteorological satellites and oceanographic satellites have been developed in series. Subsequent development and launch of Fengyun-3 F Star, G Polar-orbiting meteorological satellites of the same magnitude will be equipped with microwave imagers and medium-resolution spectral imagers with wider fields of view and higher observation frequencies; microwave scatterometers carried by ocean dynamic and environmental satellites have already been formed HY -2B/C/D Samsung network observation capabilities, with every 6 hours worldwide Covering more than 80% of the sea area monitoring, a second marine dynamic environment satellite constellation will be built in the future. Focus on strengthening the design of satellite-ground integration to improve multi-element, high-precision and full-coverage comprehensive observation capabilities [35-37]. The analysis and application of these remote sensing data are expected to significantly improve the scientific understanding of the structure and evolution of small- and medium-scale weather systems such as sea breeze fronts.

4. SUMMARY AND OUTLOOK

In the field of sea breeze front research, it is difficult to accurately detect sea breeze fronts due to the limited spatiotemporal density of conventional meteorological observations and models. As an effective tool for sea breeze front research, satellite remote sensing observations with high spatial and temporal resolution have been carried out in many regions and have received widespread attention from meteorologists (see Table 1). From the perspective of remote sensing means, remote sensing data has changed from a single spaceborne optical imager data in the early stage to a combination of spaceborne scatterometer wind field data and spaceborne infrared imager data [14-1 7] ; from the perspective of research content, Remote sensing data are mostly used to identify sea breeze fronts, The three-dimensional structure and evolution characteristics are studied, but the applied research on the physical mechanism of sea breeze fronts is rarely involved.

Table 1 It can be seen that although the sea breeze front remote sensing analysis research has begun It started late, but with the rapid development of remote sensing detection technology, it is also gradually Continuous progress; meteorological satellites can provide high spatial and temporal resolution and high precision data, satellite scanning can reach 10 min level update, spatial resolution Achievable 500 m, the use of these data makes it possible to study the sea breeze front Fine structures and meticulous continuous evolution processes are possible. future Research may focus on the following issues:

(1) By identifying clouds associated with sea breeze fronts in visible light images The method of detecting sea breeze fronts is often used, and the effect is relatively stable. determined, but due to the presence of a large number of irrelevant cloud line interference and cloudless weather limitations, sea breeze fronts are not always associated with cloud lines; in addition, it is mathematically difficult to process visible light images due to very complex boundary conditions noise in.

(2) Detecting sea breeze fronts through thermal infrared radiation reflected from the ground can detect sea breeze fronts under clear sky conditions, but due to the influence of geographical information, the detection accuracy is low.

Table 1 Age and regional distribution of satellite remote sensing studies of sea breeze fronts

years	Author (year)	study area	Remote sensing data / satellite name
2020 —	GRAU et al (2021)	Mallorca, Spain	European second generation geostationary meteorological satellite (MSG) Japanese operational geostationary meteorological satellite (Hiawari -8) The fourth generation of U.S. geostationary weather satellites (GOES -13)
	FERDIANSYAH et al (2020)	Jakarta Indonesia	
	BERRI et al. (2020)	Argentina	
2010 — 2019	SHORT et al (2019)	Sumatra, New Guinea, Oceania Gulf of Papua	Europe's first generation of operational polar-orbiting meteorological satellites (METOP -A and METOP-B) Advanced Scatterometer (ASCAT), India OceanSat-2
	ANJOS et al (2018)	northeastern brazil	Rapid Satellite Scatterometer (RSCAT), China HY-2A Satellite Scatterometer (HY 2- SCAT) The Fourth Generation of American Stationary Meteorology (GOES -13)
	BROWN et al. (2017)	northern australia	
	BIRCH et al. (2014)	arabian sea	
	BIRCH et al. (2013)	northern australia	Europe's first-generation operational polar-orbiting meteorological satellite (METOP -B), a level 2 high-speed level scatterometer European Geostationary Meteorological Satellite 2 (MSG) Japan Multifunctional Transmission Satellite (MTSAT) European Geostationary Meteorological Satellite 2 (MSG) European Geostationary Meteorological Satellite 2 (MSG)
	LENSKY et al. (2012)	Israel	
	CORPETTI et al. (2011)	—	
2000 — 2009	LI et al (2009)	U.S. East Coast	The fourth generation of U.S. geostationary meteorological satellites (GOES -13), the fourth generation of U.S. polar satellites
	PLANCHON et al. (2006)	northeastern brazil	
	APARNA et al (2005)		Orbiting operational meteorological satellite (NOAA -16)
	GILLE et al. (2003)	—	
	DAMATO et al (2003)	english channel	The third generation of U.S. geostationary weather satellites (GOES -8) US Quick Scatterometer Satellite (QuikSCAT) US Quick Scatterometer Satellite (QuikSCAT) The third generation of U.S. polar-orbiting operational meteorological satellites (NOAA -14)
1990 — 1999	BRUMMER et al (1995)	Berlin, Germany	Visible light image
	WAKIMOTO et al. (1993)	Florida, USA	The third generation of U.S. polar-orbiting operational meteorological satellites (NOAA -11)

1980 — 1989	CAUTENET et al. (1989) RAMIS et al (1988) FETT et al. (1984)	Guinea, West Africa Mallorca, Spain Florida, USA	Europe's first generation geostationary meteorological satellite (Meteosat -1) Europe's first generation geostationary meteorological satellite (Meteosat -2) U.S. Defense Meteorological Satellite Program (DMSP) satellites	

(3) Sea breeze front analysis based on scatterometer wind data can eliminate In addition to the above restrictions, and can clearly show the sea breeze characteristics, but Since scatterometer data are limited by satellite strip time, they cannot be easily Good representation of diurnal changes in sea breeze fronts.

my country is still in its infancy in remote sensing research on sea breezes (fronts) stage, there is a lack of targeted research so far, and relevant research uses the Visual inspection methods are more traditional, unable to accurately detect sea breeze Front [32, 38]. From a technical perspective, using satellite images to extract sea breeze The active contour of the front, the application of "morphological serpentine algorithm" to automatically detect cumulus lines in visible light images, and other methods to detect sea breeze fronts are better than traditional vision. The detection method is more efficient and accurate; by observing the development characteristics of early cumulus clouds and changes in relative humidity, it can be monitored more directly and quantitatively. Measuring sea wind fronts. In addition, domestic meteorological satellites and oceanographic satellites are In the period of upgrading, the new generation of meteorological satellites and oceanographic satellites are changing in time and space. resolution, number of spectral channels, and instrument performance, etc. The qualitative improvement is expected to promote in-depth research on sea breeze fronts.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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