Frontier Interdisciplinary Strategy

The frontier and interdisciplinary research of monitoring and prediction of pathogenic microorganisms in the atmosphere

The frontier and interdisciplinary research of monitoring and prediction of pathogenic microorganisms in the atmosphere Research Team

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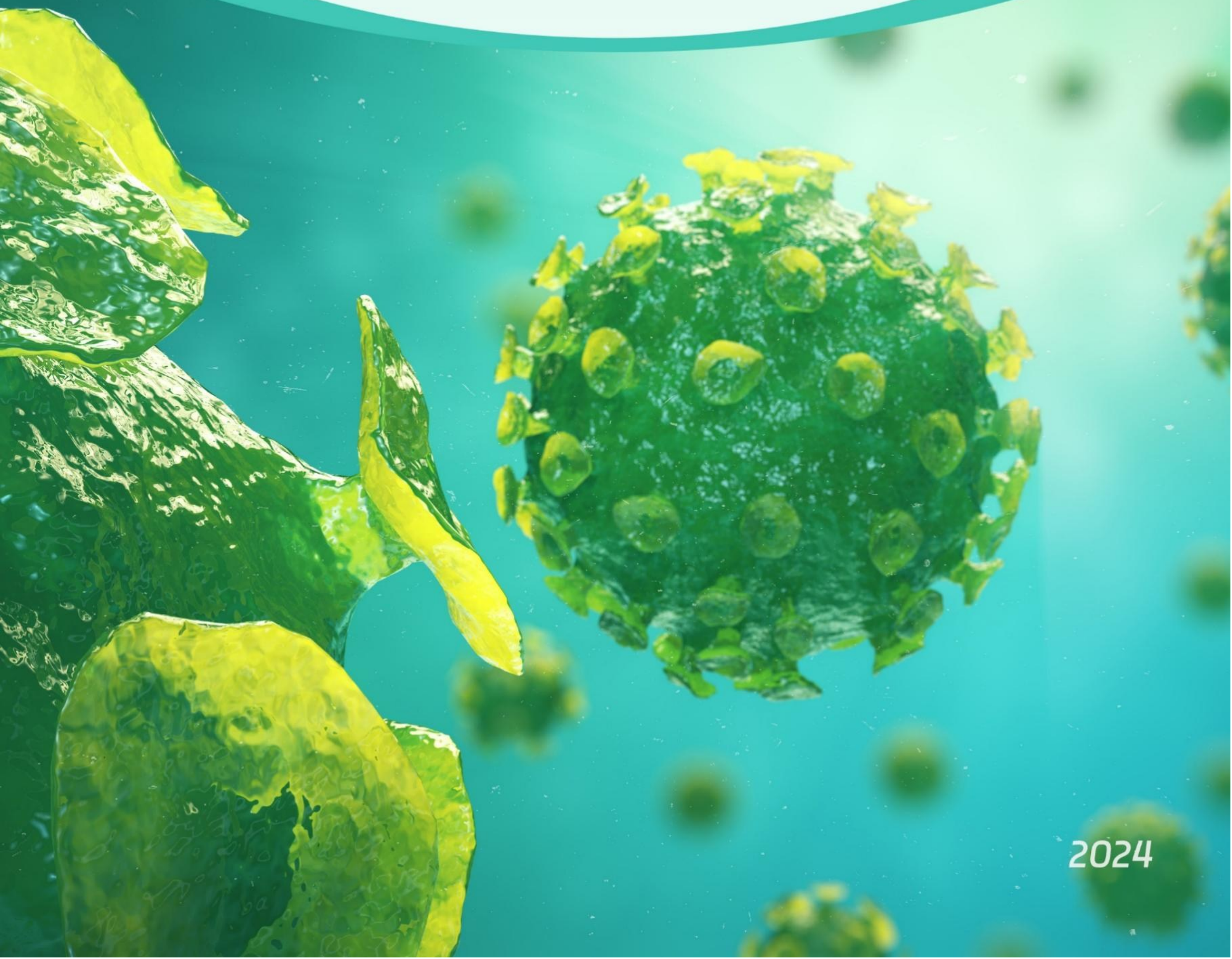

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Abstract

This report mainly focuses on the following four aspects: (1) The scientific significance and strategic value of monitoring and prediction of atmospheric pathogenic microorganisms and infectious diseases, including the disciplinary system, research paradigm and strategic position of monitoring and prediction; (2) Key scientific issues in the field of pathogenic microorganisms and infectious disease monitoring and prediction; (3) Domestic and foreign research basis and conditions in the field of pathogenic microorganisms and infectious diseases monitoring and prediction, including the impact of climate change on pathogenic microorganisms in the atmosphere, monitoring of pathogenic microorganisms in the atmosphere, prediction models and systems of infectious diseases, and national actions and countermeasures for climate governance and biosecurity; (4) The development ideas and policy recommendations in the field of pathogenic microorganisms and infectious diseases monitoring and prediction in our country. In addition to the major relevant research, the references of each chapter mainly include the latest domestic and foreign literatures in the past 5 years, so that scientific and technological personnel and graduate students involved in the teaching, research and production of atmospheric pathogenic microorganisms and infectious diseases monitoring and prediction can stay informed of and understand the domestic and foreign academic trends.

Content

Chapter 1 Scientific significance and strategic value

Section 1 Necessity and foresight of monitoring and prediction

Since the outbreak of COVID-19, public health issues have received unprecedented global attention. In the important speech at the scientist symposium on September 11, 2020, General Secretary Xi Jinping clearly proposed to "adhere to the world's scientific and technological frontier, the demands of the economic mainstay, the major needs of the country, and the life and health of the people", meaning that the scientific and technological response to the epidemic has become a top priority. In 2020, the 12th Special Meeting of the National Science Reform Leading Group and the Second meeting of the Second Qinghai-Tibet Scientific Research Leading Group pointed out that it is necessary to strengthen research on the relationship between environmental change and the occurrence of epidemics, study whether there is a link between global change and the occurrence of extreme natural disasters and human epidemic diseases, and hope to establish a comprehensive scientific research system. On the basis of future climate prediction and anticipation, we will achieve accurate prediction and anticipation of major epidemics and disasters. The monitoring and prediction of pathogenic microorganisms and infectious diseases in the atmosphere is of great significance for protecting national health and promoting economic development, and is an important subject in line with the national strategy.

Climate change is creating challenges for public health that cannot be ignored. With global climate change, increasing urbanization and human activity, pathogenic microorganisms in the atmosphere are having a significant impact on human health and ecosystems [1-6]. In recent years, studies have shown that the microbial community in the atmosphere is complex and closely related to environmental factors, which makes the monitoring and prediction of pathogenic microorganisms in the atmosphere become particularly important[7-9]. Global climate change increases the risk of the spread of pathogenic microorganisms[10-12]. Environmental changes resulting from urbanization are also affecting the distribution and spread of pathogenic microorganisms. Urban areas with high population density become hotbeds for various pathogenic microorganisms, and the decline of air quality and frequent human activities increase the risk of airborne transmission of pathogenic microorganisms [13]. Close monitoring of pathogenic microorganisms in the air and timely detection of pathogen variation, increased pathogenicity and possible transmission routes are the key to effective response to infectious disease outbreaks [14].

Section 2 Scientific significance and strategic value of discipline systems

The monitoring of pathogenic microorganisms in the atmosphere involves many disciplines such as public health, environmental science, atmospheric sciences and biology. At the strategic level, the realization of atmospheric pathogenic microorganism monitoring not only depends on the development of science and technology, but also needs interdisciplinary cooperation and policy support. Governments and international organizations need to establish cross-border monitoring networks for pathogenic microorganisms in order to respond more effectively to global health threats. A single country's monitoring system often faces the bottleneck of resource and data sharing, and cross-border cooperation can improve monitoring efficiency. By sharing data, countries can get the latest information on the spread of pathogenic microorganisms in a timely manner, allowing for rapid and collaborative responses. Multidisciplinary data integration and model construction are essential to predict the epidemic trend [15-17]. The combination of atmospheric aerosol monitoring and infectious disease prediction model can effectively improve the sensitivity judgment of epidemic situation and provide scientific support for rapid response.

1. Public health and prevention and control of infectious diseases

Responding to public health emergencies, especially infectious diseases, has become a major challenge and strategic need for the country. The deep cross-integration of multiple disciplines such as epidemiology, atmospheric sciences and environmental science has led to the transformation of industrial models and promoted the comprehensive innovation of technologies. The rise of cutting-edge information technologies such as big data, cloud computing and artificial intelligence has provided new technologies for the effective prevention and control of infectious diseases. It is necessary to develop and optimize the monitoring, detection and analysis technology of pathogenic microorganisms, establish a multi-scale nested global microbial-climate-ecosystem coupling prediction system, promote the prevention and control technology of infectious diseases to gradually move towards the goal of "automation, intelligence, information and precision", and promote the implementation of real-time, rapid, accurate and efficient active defense measures, thus completely reversing the passive situation of human beings in response to emerging and sudden-onset infectious diseases.

2. Environmental monitoring and emerging infectious diseases

In the context of global climate change, the ecological environment has undergone significant changes, so it is particularly important to monitor and warn pathogenic microorganisms in the atmosphere. Human activities such as land use change lead to habitat fragmentation of pathogenic microorganisms and their host animals, forcing their community structure to change, forming a local "coevolutionary effect", accelerating the evolution process of pathogen microbial diversity, and thus increasing the probability of cross-species transmission of infectious diseases. Climate change will also lead to changes in animal habitats, forcing animals to migrate and resulting in an increased chance of spillover and transmission of pathogens between animals to humans. Therefore, it is urgent to monitor pathogenic microorganisms in the environment and formulate scientific and efficient early warning programs and preventive measures as soon as possible.

3. Health effects and adaptation of climate change

Climate change has a wide range of complex and far-reaching impacts on human health, which are often delayed and indirect, making it easy to overlook the risk of harm. About two-thirds of the pathogenic microorganisms that cause infectious diseases are climate sensitive. Climate change-driven changes in the Earth's environment disrupt the balance of ecosystems, affecting the survival, reproduction, spread and distribution of pathogens and their intermediate hosts, thereby increasing the risk of emerging infectious diseases. The combined effects of multiple adverse meteorological conditions may increase the risk of infectious diseases [18, 19]. Therefore, accurate monitoring and prediction of the spread of pathogenic microorganisms in the atmosphere is the core scientific research content of comprehensively building the safety line of epidemic prevention and control and improving national biosafety management capacity.

4. Ecological security construction and environmental health

Ecological security plays a vital role in safeguarding human health and safeguarding national security. Ecological security is an important guarantee for maintaining biosecurity and environmental security. During the COVID-19 pandemic, China has incorporated biosecurity into its national security system from the perspective of protecting people's health, safeguarding national security, and maintaining long-term peace and stability. The risk of new infectious disease outbreaks in the context of climate change further emphasizes the important role of ecological security construction in preventing infectious disease pandemics and ensuring human life safety. Healthy ecological security provides irreplaceable barrier protection for the maintenance of biodiversity, the protection of species habitat, and the prevention of pathogen spillover, which is conducive to alleviating the biosecurity threats caused by the expansion of human activities. Therefore, strengthening the construction of ecological security system is an important project and strategic measure to protect environmental health, human health and biosafety.

Section 3 Technological innovation and development

Infectious disease monitoring and prediction is an indispensable part of the public health field, its core goal is to achieve early prevention and effective control of diseases through efficient collection and in-depth analysis of relevant data, so as to block the path of disease transmission [20-22]. In recent years, with the rapid development of technology, especially in the fields of big data, artificial intelligence and genomics, the innovation and development of infectious disease monitoring and prediction technology has shown a significant trend of progress, which provides an important basis for public health institutions to formulate prevention and control measures [23, 24]. The innovation and development of infectious disease monitoring and prediction technology are evolving rapidly. From big data and artificial intelligence to genomics, the combination of emerging technologies not only improves the real-time and accuracy of monitoring, but also provides a new perspective for epidemic prediction and response. Through policy support and industry collaboration, it will promote the practical application of technology and provide a more solid guarantee for global public health security [16, 25-28].

1. Pathogen and infectious disease monitoring

With the rapid development of molecular biology, bioinformatics and medical detection technology, significant breakthroughs have been made in the collection, sensing and analysis stages of pathogen monitoring. Such as automated sampling and micro-sampling technology, photoelectric chemical biosensors, high-throughput nucleic acid detection, single cell antibody screening, cryo-electron microscopy tomography, polymerase chain reaction technology (PCR) and deoxyribonucleic acid (DNA) sequencing/labeling technology are widely used in the rapid diagnosis and identification of pathogens, greatly improving the efficiency and accuracy of monitoring [29, 30]. However, due to the low concentration and complex composition of pathogens in the air, it is difficult to enrich and quickly distinguish, and the monitoring and prediction of pathogenic microorganisms in the atmosphere is still a major technical problem at home and abroad, which needs to be further explored [31, 32]. Aerosols are an important route of pathogen transmission, especially playing a key role in the prevention and control of airborne diseases. Bioaerosol monitoring technology is mainly divided into offline detection and online monitoring. Offline methods usually use samplers for sampling, and then carry out qualitative and quantitative analysis through culture method, microscope analysis (such as fluorescence microscopy, scanning electron microscopy), molecular biological detection (such as polymerase chain reaction, DNA markers), immunological detection, etc. But there are some prominent problems such as high cost, low efficiency and poor timeliness [33, 34, 35]. The on-line detection technology based on photoelectric and chip technology has become one of the important choices for bioaerosol monitoring due to its advantages of real-time, high sensitivity and high resolution. Among them, laser induced fluorescence technology is the most widely used [36]. Similarly, based on the characteristic peak of Raman spectrum, bioaerosols such as pollen and bacteria can also be effectively identified [37]. The combination of biological adenosine triphosphate (ATP) self-fluorescence detection and microfluidic chip is also a hot spot in the detection of active microorganisms [38].

2. Pathogen and infectious disease prediction

Accurate prediction of the spread of viruses and microorganisms in the atmosphere is the core scientific research content of comprehensively building a safe defense line for epidemic prevention and control, improving biosafety management capacity, and providing important support for the government to formulate control measures and allocate medical resources [39-42]. In the field of infectious disease prediction, data-driven models have become a research hotspot. Through real-time analysis of large-scale social behavior data, the accuracy of epidemic prediction can be significantly improved [29, 43, 44]. The spread of pathogenic microbial aerosols in the environment and their effects on human health can be simulated by fully applying artificial intelligence (AI) to early warning systems, hotspot detection, epidemiological tracking and prediction, and resource allocation [45], through collaborative coupling of epidemiological models, atmospheric chemistry models, atmospheric diffusion models, climate models, population models, traffic models, and computational fluid dynamics (CFD) models [46-49]. In terms of technological innovation, the combination of genome sequencing technology and the Internet of Things provides a new means for pathogen tracking and prediction. Real-time monitoring of genomic variation in pathogens can help quickly identify and respond to outbreaks.

3. Platform construction

Infectious diseases pose a serious threat to human health and public safety, and it is urgent to establish a biosafety prevention and control platform with the monitoring and prediction of the spread of pathogenic microorganisms as the core. The World Health Organization (WHO), in collaboration with interested parties, created DengueNet for global epidemiological and virological surveillance of dengue fever [50]. Some countries have established surveillance and early warning platforms for infectious diseases, such as the Southern Hemisphere Influenza Vaccine Effectiveness Research and Surveillance Network (SHIVERS), Influenza Hospitalization Surveillance Network (FluSurv-NET), New Vaccine Surveillance Network (NVSN), and the International Network for Strategic Initiatives in Global HIV Trials (INSIGHT) [51-53]. However, the special monitoring platform for pathogenic microorganisms in the atmosphere is still relatively insufficient. In response to new epidemics in the future, it is urgent to give full play to the advantages of mathematics and information science, actively apply information technology, provide timely prediction and early warning information, reduce economic and social losses, and promote the development of mathematics and information science. It is urgent to take advantage of public health management integration, improve the level of infectious disease prevention, and promote the scientific and systematic level of public health management.

Section 4 Strategic positioning of monitoring and prediction

1. Satisfying the national major strategic needs

Xi Jinping's Thought of Ecological Civilization points out that "the environment is the people's livelihood". In recent years, the Chinese government has issued several strategic planning documents that address the impact of environmental change on health risks. For example, the *National Climate Change Adaptation Strategy 2035* points out that "by 2035, China will conduct health impact studies on climate change and extreme weather and climate events such as heat waves, clarify the main health risks of extreme weather and climate events, the characteristics of vulnerable areas and vulnerable populations, and establish adaptation strategies, technologies and measures." The *Healthy China 2030 Planning Outline* proposes to "strengthen the prevention and control of major infectious diseases, and improve the disease surveillance and early warning mechanisms." Therefore, strengthening the prevention and control of major infectious diseases is of great significance for safeguarding national security, social stability and people's health.

2. Promoting national economic and social development

The *Guiding Opinions on Establishing and Improving a Smart Multi-point Trigger-based Surveillance and Early Warning System for Infectious Diseases* pointed out that "Guided by the Xi Jinping's Thought on Socialism with Chinese Characteristics for a New Era, we should comprehensively implement the spirit of the 20th National Congress of the Communist Party of China (CPC) and the second and third plenary sessions of the 20th CPC Central Committee, practice the overall national security concept, always putting the people and their lives above all else. By leveraging the opportunities presented by advancing the Healthy China initiative and promoting high-quality development of disease control, and driven by the growth of new quality productive forces and digital-intelligent empowerment, we will establish a sound smart multi-point trigger-based surveillance and early warning system for infectious diseases, adhering to the principles of problem orientation, systemic connectivity, and priority focus. By 2030, a scientific and efficient surveillance and early warning system for infectious diseases with multiple triggers and rapid response should be established. The sensitivity and accuracy of monitoring and early warning of emerging infectious diseases, mass diseases of unknown cause and key infectious diseases should be significantly improved. The capacity for early detection of epidemics, scientific research and judgment, and timely early warning should reach the international advanced level." Accurate real-time monitoring and early warning can realize the advance of epidemic prevention, help formulate effective policies to control the further spread of large-scale infectious diseases, and is of great significance for maintaining social stability and reducing economic losses.

Chapter 2 Key scientific issues

Section 1 Key scientific issues in pathogen and infectious disease monitoring

Studies have shown that a wide range of pathogenic microorganisms are transmitted through the air and pose a serious threat to public health. At present, there is a lack of research and attention on the spread of pathogenic microorganisms caused by climate change. It is urgent to carry out systematic and integrated research on the atmospheric transmission mechanism of pathogenic microbial aerosols to comprehensively clarify the identification, monitoring and atmospheric transmission mechanism of pathogenic microbial aerosols, as well as their interaction with the host. Therefore, the specific key scientific issues to be addressed are:

(1) How to develop rapid detection technology and online sensors for pathogenic microorganisms;

(2) How to develop standardized and operational monitoring instruments for atmospheric microorganisms;

(3) How to build a national microbial monitoring network in the atmosphere and water bodies (including glaciers);

(4) How to build a national environmental monitoring database of pathogenic microorganisms in the atmosphere and water.

Section 2 Key scientific issues in prediction of infectious diseases

Effective prediction and early warning mechanism not only depends on the timely monitoring of pathogens, but also needs a deep understanding of ecological environment. The analysis of pathogen ecological adaptation mechanisms, pathogen-host interactions, and the links between scientific research and public health policies through multi-source data such as the integrated pathogen microbial monitoring network database will provide an important guarantee for effectively responding to the threat of emerging infectious diseases in the future. Accurate prediction of the epidemic is an important scientific basis for ensuring the safety of people's lives, for the government to formulate prevention and control measures, for rational allocation of medical resources and reducing economic losses. At present, the prediction system of infectious diseases faces challenging scientific issues such as insufficient data and model accuracy and low timeliness. The key scientific issues are:

(1) How to reveal the interaction among pathogenic microorganisms, climate, health and ecosystems;

(2) How to scientifically and rationally arrange the national monitoring system of pathogenic microorganisms, and build the national database of pathogenic microorganisms in the atmospheric environment;

(3) How to build a multi-scale nested global pathogenic microbe-climate-ecosystem numerical model;

(4) How to quantify the impact of global/regional spread of pathogenic microorganisms on human health risks and scientific prevention and control.

Chapter 3 National and international research status

Infectious diseases exert a profound influence on the evolution and progress of human civilization, and humanity has been constantly monitoring the occurrence and development of infectious diseases around the world [19, 11]. Pathogenic microorganisms in the atmosphere are closely related to biological transmission and public health. Comprehending and coping with the impact of climate change on pathogenic microorganisms in the atmosphere is of great significance for protecting human health [54-56]. Pathogenic microorganisms invade animals or humans through the environment (air, water) or food, thereby causing a variety of diseases, and even large-scale outbreaks, seriously threatening the lives of animals and humans. Therefore, it is of great significance to monitor pathogenic microorganisms in the atmosphere [57, 58]. Infectious disease prediction models are widely used to better understand transmission mechanisms and the factors that most influence transmission. They continue to play an important role in the prediction of epidemic development trend, scientific prevention and control guidance and evaluation, and provides important data basis and theoretical support for public health managers to make decisions and implement efficient intervention measures [44, 59].

Section 1 Effects of climate change on pathogenic microorganisms in the atmosphere

1. The relationship between pathogenic microorganisms in the atmosphere and meteorological elements

Climate change has a significant impact on the spread of pathogenic microorganisms in the atmosphere. On the one hand, those pathogens with weak resistance to the external environment may be limited to spread in a specific area because of harsh meteorological conditions. On the other hand, those infectious disease pathogens that exhibit greater environmental resilience may, under favorable transmission conditions, cause their spread to be wider and more intense. Meteorological factors such as temperature, humidity, air pressure, wind speed and precipitation are closely related to the spread of pathogenic microorganisms [60-62].

Take Mycobacterium tuberculosis as an example, which causes tuberculosis, its spread and reproduction are significantly affected by meteorological conditions. Studies have shown that the incidence of tuberculosis varies seasonally and is greatly affected by meteorological factors such as temperature, humidity, wind speed and sunshine [63-65]. The higher the humidity, the greater the water vapor pressure, and the longer the time of tuberculosis droplets staying in the air, the greater the probability of infection in the population [66]. Many diseases caused by respiratory viruses have obvious seasonality, and specific meteorological conditions and air pollution have a certain inducing effect on respiratory diseases. When the average daily temperature, air pressure and relative humidity were 12.3℃ ~ 14.4℃, 89.2kPa ~ 89.6kPa and 38.9%-44.1%, respectively, SARS was more likely to occur [67]. For SARS-CoV-2 virus, which causes the COVID-19 pandemic, low temperature environment is conducive to maintaining virus activity, and high temperature environment can inhibit virus activity. Cold and dry environment may be conducive to the survival and transmission of viral aerosols, and strong light irradiation accelerates the half-life of viral aerosols [68-71]. Studies have found that low humidity and cold conditions facilitate the spread of influenza viruses, which is why seasonal flu outbreaks often occur in winter [72].

2. Effects of extreme weather on pathogenic microorganisms in the atmosphere

Climate change has increased the frequency and breadth of extreme weather events, such as heat waves, cold waves, droughts and floods, which have an impact on pathogenic microorganisms in the atmosphere. On the one hand, extreme weather conditions can alter the physical and chemical environment of the atmosphere, thus affecting the survival and reproduction of pathogenic microorganisms. Abrupt changes in climatic conditions can affect the activity of microorganisms in the atmosphere, may lead to the expansion or disappearance of certain microbial communities, thereby altering microbial diversity. On the other hand, extreme weather events also affect the transport and diffusion of atmospheric pollutants, providing favorable conditions for the spread of pathogens [73].

During the SARS outbreak in Beijing and Hong Kong in 2003, the warm, moist and stable air of the cold front led to the retention and accumulation of the virus at low altitude, which aggravated the spread of SARS [74]. In California, the average death rate of influenza in normal weather years is three times higher than that in El Nino years, indicating that the spread of influenza virus is affected by El Nino [75]. Heavy rain increases humidity of air and the surrounding environment, breeding mildew and mites and other allergenic substances, making asthma worse[76].

In conclusion, extreme weather can change the distribution and concentration of pathogenic microorganisms in the atmosphere, expand their spread range, and enhance the virulence of infectious diseases. These impacts further fuel the spread and prevalence of disease and pose a serious challenge to global public health.

3. Effects of climate change on characteristics of pathogenic microorganisms

Climate warming speeds up the development and reproduction of pathogenic microorganisms, causing their distribution range to expand to higher latitudes and altitudes [77]. In a relatively high temperature environment, the proliferation and reproduction rate of pathogenic microorganisms increase, and the transmission season is prolonged, resulting in an increase in the range and speed of disease transmission [78]. At the same time, climate change is altering the adaptability, range and life cycle of disease vectors. Rising temperatures make it easier for mosquitoes to breed and shorten their life cycle[79], and change their living habits and migration patterns, resulting in the geographical spread of diseases such as dengue fever [80]. Increasing geographic movement and the exposure of human and animal hosts to pathogens (especially viruses) will break through their parasitic, infecting distribution areas and form pathogens for emerging infectious diseases [81-83]. For viruses that have the ability to spread across species and could cause pandemics, climate change is expected to create new opportunities for the emergence and spread of these viruses [22, 84, 85].

Section 2 Monitoring of pathogenic microorganisms in the atmosphere

1. Types and detection methods of pathogenic microorganisms in the atmosphere

Pathogenic microorganisms in the atmosphere are mainly bacterial, fungal and viral. Bacteria are the most common type, accounting for the vast majority of the total microbial population in the atmosphere, with more than 1,200 species of bacteria and actinomycetes known to exist in the atmosphere [86]. Airborne fungi are even more abundant, with more than 40,000 species. Viral pathogenic microorganisms such as coronaviruses and influenza viruses are very complicated in their transmission and survival in the atmosphere due to their instability, irregular movement, renewability and various infection routes [87, 88]. In addition, because different types of pathogenic microorganisms in the atmosphere have different structures and characteristics, their detection methods are not the same.

Based on traditional sampling methods, such as microbial sampling using filters, impactors, or condensers, it is possible to count and observe the morphology of microorganisms by culture and using an electron microscope. However, these methods have certain limitations in terms of ease of operation, speed of detection, species of detectable microorganisms and sensitivity [89]. Biochemical methods detect pathogenic microorganisms by measuring microbially specific enzymes or small molecules of metabolites. However, the search for specific enzymes or metabolites is often time-consuming and laborious, and relies on complex instruments, increasing the cost and technical threshold of detection [90]. Immunological methods such as enzyme-linked immunosorbent assay (ELISA) and immunofluorescence techniques use specific antigen-antibody responses to detect. Qualitative, locational or quantitative studies are carried out under the microscope through the introduction of markers (e.g. fluorescence, enzymes). This method has strong specificity and high sensitivity, and is widely used in the detection of pathogenic microorganisms, but for very low content of target proteins or antibodies, its detection sensitivity may be insufficient [91, 92].

Common molecular biological detection methods include: Polymerase chain reaction (PCR) can quickly detect specific pathogenic microorganisms by extracting microbial DNA or RNA from air samples and using specific primers for amplification, which has the advantages of high sensitivity, speed and specificity [93]; Real-time fluorescence quantitative PCR (RT-qPCR), microdrop digital PCR (ddPCR) and high-throughput gene sequencing technology can further quantify the content of pathogenic microorganisms, improving the sensitivity and accuracy of detection. However, the high false positive rate in low epidemic environment limits its reliability as an independent diagnostic basis [94, 95, 96]. In contrast, serological testing plays an irreplaceable role in vaccine development, antibody prevalence monitoring, and community infection confirmation. However, the method also presents certain challenges, including a complex operational procedure and a lengthy processing time. In the context of the COVID-19 pandemic, novel detection methods based on CRISPR/Cas systems, such as CRISPR/Cas12a-NER, have shown great potential. The method does not require special instruments, is highly consistent with qPCR detection, and can detect at least 10 copies of the virus gene within 45 minutes [97].

2. Bioaerosol monitoring

Bioaerosol is an important component of atmospheric aerosol, accounting for 30%-80% of atmospheric particulate matter, and is an important carrier of pathogenic microorganisms. Airborne pathogenic bioaerosols, such as COVID-19, influenza and tuberculosis, pose a serious threat to human health [98, 99, 39]. Traditional bioaerosol detection methods mainly rely on sampling techniques such as filtration, impinging and electrostatic precipitation. However, these methods have low rate, poor accuracy and high resource consumption when capturing small bioaerosols (< 0.1μm).

With the rapid development of photoelectric technology in recent years, LIF instruments based on fluorescence scattering effect are constantly upgraded and updated. Fluorescent Lidar, WIBS multi-band bioaerosol sensor, Rapid-E real-time particle detector are widely used in the field of bioaerosol detection. However, due to the lack of excitation light source and fluorescence spectrum library, and the interference of environmental noise, LIF instrument still has shortcomings in the identification of aerosol types and detection accuracy [100-103]. Similarly, new detection instruments based on Raman scattering effect, such as micro-confocal Raman spectrometer and multi-wavelength anti-fluorescence Raman spectrometer, provide new ideas for detecting single virus particles [104, 105]. By combining the microfluidic chip with bioATP autofluorescence technology, the content of bioaerosol active cells can be quantified by the fluorescence intensity emitted by the luciferin - luciferase reaction[106]. Mass spectrometry and laser-induced breakdown spectroscopy also provide important technical support for bioaerosol detection [107, 108]. However, in the face of complex and diverse bioaerosol types, these technologies still face multiple challenges in sensitivity, accuracy, real-time, throughput and operational complexity in practical applications.

The impact of the COVID-19 pandemic has forced the emergence of bioaerosol monitoring instruments with higher throughput, faster detection and greater sensitivity [45]. The application of innovative technologies such as integrated bioaerosol to hydrosol air sampling, microfluidic chips, light scattering, real-time PCR (qPCR), and field-effect silicon nanowire sensors has made it possible to monitor airborne viruses in real time. In addition, exhaled breath detection has great potential for early diagnosis of disease. A variety of biomarkers, such as volatile organic compounds (VOCs) and particulates, can reflect human health or disease status. In order to break through the bottleneck of exhaled gas enrichment technology such as low concentration level of markers and background noise interference, the use of nano-adsorption materials or condensation technology, new mass spectrometry equipment, artificial intelligence technology, etc., is expected to improve the capture rate and detection accuracy of biomarkers, which shows great potential in the diagnosis of respiratory infection [109, 110].

3. Monitoring status of pathogenic microorganisms in the atmosphere

Microbial status in the atmosphere is the concentrated embodiment of the comprehensive factors of atmospheric environment, and is one of the important indicators to evaluate the regional ambient air quality [14, 111]. Nevertheless, significant challenges remain in distinguishing between biological and non-biological components, as well as marginal and non-marginal microorganisms. Additionally, the study of pathogenic mechanisms of bacteria, fungi and viruses under different climatic conditions, and the investigation of the influence mechanism of different virus-host-climate environments, still present considerable obstacles [112]. How to promote the research of these four levels is an important guide for the monitoring and prediction of pathogenic microorganisms and infectious diseases. However, at present, the focus of atmospheric monitoring is still the pollution of physical and chemical properties, such as soot, dust, fine particles, SO_2, NO_x, photochemical smog, etc., and less attention is paid to atmospheric microorganisms. The pandemic of emerging and re-emerging infectious diseases makes the comprehensive and in-depth monitoring of atmospheric microorganisms more important.

At present, domestic research institutes have conducted research monitoring of atmospheric microorganisms, which has laid a certain theoretical foundation for atmospheric microbial monitoring. The health and medical care department’s microbiological research is limited to patients and hospital indoor environments. The medical and food department is also limited to the detection of microbial content in food and medicines. For atmospheric environment monitoring outside medical institutions, it mainly relies on environmental protection departments to carry out. However, national environmental protection authorities pay relatively less attention to microbiological monitoring. They only proposed the detection methods and standards for the total number of bacteria in the indoor ambient air, and did not involve the monitoring of microorganisms in the atmospheric environment [113].

Section 3 Prediction model and system for infectious diseases

1. Dynamics model of infectious diseases

Infectious disease dynamics modelling employs a quantitative approach to elucidate the fundamental attributes of infectious diseases. This is achieved by postulating parameters and variables, along with the interconnections between them. The methodology relies on data obtained from the early stages of an outbreak, incorporating future uncertainties. This enables the identification of the mechanisms underlying infectious disease transmission and the scientific prediction of epidemic trends. The infectious model Susceptible-Infective-Recovered (SIR), created in 1927, is still being developed and widely used today. On the basis of SIR Model, an incubation period population is added to form a Susceptible-Exposed-Infective-Recovered (SEIR) model to reflect the asymptomatic but infectious characteristics of some infectious diseases at the initial stage of infection.

Scholars have made many improvements on the basis of the traditional model, introducing more complex factors and mechanisms to more accurately simulate and predict the spread trend of infectious diseases, such as the integration of environmental and social factors. By introducing the compartment of nonlinear interaction between human and environment, the application range of SEIR model is extended [114]. Considering isolation and hospitalization groups, the model is more closely related to the actual development of the COVID-19 epidemic [115]. By establishing a VEFIAR transmission dynamics model, Chen Tianmu's team at Xiamen University predicted the peak and scale of infection and quantified the transmission capacity by considering multiple factors such as population flow, vaccine attenuation and contact patterns. There is a team to study the risk of epidemic transmission in small and medium-sized cities and establish an urban epidemic hazard index for prefecture-level cities in China [116-118]. The construction of infectious disease prediction system is no longer limited to a single discipline, but more and more integration of atmospheric sciences, statistics, artificial intelligence and other fields of knowledge and technology. The Global Prediction System for COVID-19 (GPCP), developed by Huang Jianping's team at Lanzhou University, combines statistics-dynamic climate prediction methods in atmospheric sciences with infectious disease models, significantly improving the accuracy of predictions [119]. In order to more accurately guide regional epidemic prevention and control and build a region-specific prediction system, the Coronavirus Disease 2019 Forecasting System developed by Zhong Nanshan's team at Guangzhou National Laboratory provides strong support for regional epidemic prevention and control based on domestic population migration data and COVID-19 epidemiological data [120, 121].

At present, there are still many shortcomings in the prediction of infectious diseases in China, such as the lack of temporal and spatial characteristics, the limitations of data acquisition and processing, and the complexity of model construction. The establishment of a sound epidemic prediction system for infectious diseases is of great significance for the government to formulate effective control policies, rationally allocate medical resources and protect people's life safety [122].

2. Statistical model of infectious diseases

Statistical models are modeled based on historical epidemic data. The time series analysis method in traditional statistical model is a common method for the prediction of infectious diseases. Autoregressive Integrated Moving Average Model (ARIMA) can accurately predict the development trend of the epidemic by capturing the autocorrelation in the time series data. Combined with Empirical Mode Decomposition (EMD) and Ensemble Empirical Mode Decomposition (EEMD), different components of epidemic data can be further extracted to improve the prediction accuracy. In addition, statistical methods such as Markov chains and Bayesian models are also favored for their ability to simulate the uncertainty of epidemic transmission, providing decision-makers with a more comprehensive risk assessment [123].

With the popularization of digital medical data such as electronic health records and health reporting systems, artificial intelligence algorithms offer new possibilities for infectious disease prediction. In the prediction of infectious diseases, machine learning algorithms such as tree-based models (such as decision trees, random forests) and support vector machines (SVM) have been widely used. The rise of deep learning algorithms, particularly recurrent neural networks (RNNS), long and short term memory networks (LSTMS), and convolutional neural networks (CNNS), has allowed researchers to better capture relationships between time series and complex data [119, 124, 125]. One of the key challenges in using machine learning for disease prediction is the availability of high-quality, large-scale data. Infectious disease surveillance systems typically collect data on a variety of factors, including the number of reported cases, the location of the outbreak, and the demographic characteristics of those infected. However, this data is often incomplete, biased, or noisy, which can affect the performance of machine learning models. In addition, the long incubation period of many infectious diseases means that data from past outbreaks may not accurately reflect the current situation. Finally, complex machine learning models sacrifice the interpretability of the models in order to achieve high accuracy predictions, which is also a major drawback of its application to infectious disease prediction.

In order to combine the advantages of various approaches or to improve the interpretability of machine learning models, researchers have developed hybrid and integrated models. Hybrid models such as ARMI-LSTM combine the advantages of time series analysis methods and deep learning to achieve accurate prediction of epidemic trends. The integrated model further improves the accuracy and stability of prediction by integrating the results of multiple prediction models. For example, Whale Optimization Convolutional Neural Networks (CNN), Long-Short Term Memory (LSTM) and Artificial Neural Network (ANN), called WOCLSA, integrates three deep learning models, ANN, CNN and LSTM, and optimizes parameters through whale optimization algorithm, significantly improving the prediction of COVID-19 [126].

3. Coupled prediction system of infectious diseases

In the face of large-scale epidemics such as COVID-19, traditional infectious disease models have been unable to meet the needs of predicting and responding to complex outbreaks. Therefore, the expansion and coupling of the model become an inevitable trend. By integrating social behavior, mobility pattern, environmental factors, socioeconomic status, medical resources, climate environment and public health policies, the coupled prediction system greatly improves the accuracy and scientificity of the prediction of infectious disease dynamics [127].

In recent years, infectious disease models have made remarkable progress in integrating different influencing factors to more accurately simulate the spread of COVID-19. The researchers have developed a variety of models, including infectious disease models that incorporate migration data, community-level simulations, and dynamic migration networks. These models, combined with data assimilation, machine learning, and geographic transmission pattern analysis, are able to more accurately simulate the impact of people movement on the spread of outbreaks. In addition, some studies are quantifying the movement of people by using mobile phone data, traffic flow statistics, etc., and incorporating these data into infectious disease models to assess the effects of travel restrictions, lockdowns, and other public health interventions. With the continuous advancement of data science and computing technology, infectious disease models are developing in a more complex and diversified direction. Models are no longer limited to a single discipline, but integrates knowledge and methods from multiple disciplines such as epidemiology, data science, social science and economics. Data-driven research methods have become mainstream, collecting and analyzing large amounts of real-time data to predict the course of outbreaks. China has shown remarkable advantages in this field, especially in data collection and processing, tracking and analysis of the spread of the epidemic [26].

Section 4 National actions and countermeasures for climate governance and biosecurity

1. Climate governance policy

China has sensitive and vulnerable areas affected by global climate change, and is one of the countries where extreme weather and climate events occur most frequently. The *China Blue Book on Climate Change (2019)* released by the Climate Change Center of the China Meteorological Administration points out that extreme weather and climate events are becoming more and more intense in China, and the level of climate risk is on the rise. China has continuously strengthened disaster risk assessment and management, and strengthened its capacity to adapt to climate change. In 2013 and 2016 respectively, the National Development and Reform Commission (NDRC) and other relevant agencies formulated and issued the *National Climate Change Adaptation Strategy* (NDRC Climate Document No. 2252 [2013]) and the *Urban Climate Change Adaptation Action Plan* (NDRC Climate Document No. 245 [2016])., respectively, to promote the capacity of China's urban areas to adapt to climate change, improve the governance level of typical cities to adapt to climate change and promote sustainable social and economic development. In 2022, the Ministry of Ecology and Environment (MEE) issued the *National Climate Change Adaptation Strategy 2035* (MEE Climate Document No. 41 [2022]) to actively respond to climate change as a national strategy, strengthen action measures to adapt to climate change, and effectively prevent adverse impacts and risks of climate change. In 2016, China acceded to the *Paris Agreement*, and during the 75th UN General Assembly announced its Dual Carbon goals: peaking carbon dioxide emissions before 2030 and achieving carbon neutrality before 2060. The Report to the 20th CPC National Congress further emphasized "advancing carbon peak and carbon neutrality with proactive yet prudent approaches" and "promoting green development to foster harmonious coexistence between humanity and nature", demonstrating China's resolute commitment and policy continuity in addressing climate change. [128].

2. Biosecurity policy and response strategy

In 2004, representatives from the World Health Organization (WHO), Food and Agriculture Organization of the United Nations (FAO), centers for disease control and prevention (CDC) of various countries, the US Geological Survey's National Wildlife Health Center, and other institutions jointly promulgated the "One World, One Health" Manhattan Principles in the United States. "One Health" is an interdisciplinary, intersectoral and interregional approach to prevent emerging infectious diseases and safeguard human, animal and environmental health. Building on the concept of "One Health", "One Biosecurity" is proposed in 2020 to use interdisciplinary biosecurity policy and research approaches to address the biosecurity risks that transcend the traditional boundaries of health, agriculture and the environment in an integrated perspective [129]. Global governance of biosecurity threats requires the implementation of three interrelated initiatives, improving risk assessment methods to look beyond national borders at the risks of invasive alien species; implementing proactive surveillance and response to global biosecurity threats through IHR-modeled international regulatory instruments; establishing a dedicated, multilateral biosafety convention to be responsible for international biosafety governance [130].

Since the 18th National Congress of the CPC, "traditional biosecurity problems and new biosecurity risks are superimposed on each other, overseas biological threats and internal biological risks coexist, and biosecurity risks show many new characteristics." On October 17, 2020, the *Biosecurity Law of the People's Republic of China* was adopted at the 22nd Session of the 13th National People's Congress Standing Committee, marking the establishment of a foundational legal framework for China's biosecurity governance. The Law clearly defines the definition of biosafety, that is, the nation effectively prevents and responds to the threat of dangerous biological factors and related factors, biotechnology can develop stably and healthily, people's lives and health and ecosystems are relatively safe and unthreatened, and provides a fundamental basis for biosafety governance.

The definition of “biosafety” in the Biosafety Law includes the subject, object, external conditions and prevention and control strategies of biosafety. External conditions include non-human factors such as biological hazards and environmental disasters caused by climate change [131]. Biohazards caused by climate change include changes in species distribution, increased risk of biological invasions, increased risk of biodiversity loss, and changes and degradation of ecosystems. At present, in our national action and strategy to cope with climate change, the content of biosecurity governance needs to be strengthened.

3. Recent national investment and the latest measures

The National Health Commission and National Administration of Disease Control and Prevention have set up a multi-channel surveillance and early warning system to monitor the epidemic in sentinel hospitals, fever clinics, key sites and urban sewage. We actively promoted the continued implementation of the major national science and technology projects on the Prevention and Control of Emerging Infectious Diseases, and promoted the implementation of the key national research and development plan on the research of Etiology and Epidemic Prevention Technology System. We continue to improve our surveillance and early warning capabilities, establish and improve emergency response mechanisms, increase public health input, and allocate 20.88 billion yuan for the prevention and control of major infectious diseases in 2023. National Administration of Disease Control and Prevention has organized the development of national infectious disease intelligent surveillance and early warning software to achieve the goal of automatic exchange of infectious disease related data in medical institutions, and changed “passive surveillance” to a combination of “passive surveillance” and “active surveillance”. China has established an online direct reporting system for infectious diseases and public health emergencies, covering 84,000 medical and health institutions nationwide. The average reporting time of public health emergency information has been reduced to less than four hours, and it has the ability to detect more than 300 pathogens within 72 hours. A risk assessment system for public health emergencies has been established, and 59 national health emergency response teams in four categories have been set up nationwide. For respiratory diseases such as the COVID-19, ten surveillance subsystems have been expanded and formed, including sentinel hospitals, virus mutation, urban sewage and public opinion monitoring. It has carried out a pilot program of multi-pathogen surveillance for acute respiratory diseases, set up four types of risk signals, scientifically studied and analyzed the monitoring results, and timely reported and issued early warning information.

In 2018, the National Natural Science Foundation of China (NSFC) continued to promote the systematic reform of science funds, among which the adjustment of application code is the entry point for optimizing the reform of discipline layout. With the support of strategic research projects, the working group optimized and adjusted the application code of atmospheric science disciplines and the research directions and keywords. In 2019, the discipline of atmospheric sciences was listed as one of the 17 reform pilot disciplines of the NSFC. After full research and discussion in the scientific community, D0513 (atmospheric chemistry and atmospheric environment) was adjusted to D0506 (atmospheric chemistry) and D0514 (atmospheric environment and health meteorology). Application code D0514 (atmospheric environment and health meteorology) extends the knowledge chain of atmospheric environment, aiming at the complexity and comprehensiveness of environmental issues such as air pollution and climate change, and focusing on health meteorology, it promotes the intersection of atmospheric environment and other disciplines, and obtains comprehensive understanding of atmospheric environment governance issues. It serves the coordinated sustainable development of environment, health and economy and the implementation of the national health strategy [132]. In response to the COVID-19 pandemic in 2020, the NSFC supported the special project with D0514 (atmospheric environment and health meteorology) as the application code: Evolution of viral aerosol infection activity during atmospheric transmission (Grant Number: 42041002). Forward-looking application code adjustments better advance interdisciplinary science to serve critical national needs [133]. Through the implementation of measures such as clear funding guidance, improving the review mechanism, strengthening interdisciplinary cooperation and training interdisciplinary talents, the research level and innovation ability of interdisciplinary science in China will be further improved, and strong support will be provided for the national economic and social development.

Chapter 4 Development thoughts and policy suggestions

Section 1 Development thoughts and direction

1. The priority development direction and suggestion of monitoring system

Aerosol transmission of pathogenic microorganisms is an important factor leading to the aggravation of the epidemic. By monitoring pathogenic microorganisms in the atmosphere, early warning of pathogens can be provided before they spread to the population, so as to achieve early detection and control of outbreaks. Therefore, accelerating the development of high-precision, real-time monitoring technology for airborne pathogens is essential, and sentinel monitoring of atmospheric pathogenic microorganisms in frontline positions of epidemic prevention should be carried out. A real-time monitoring network of pathogenic microorganisms in the atmosphere should be established as soon as possible to detect the source of infection at the first time, and a new pattern of regular epidemic prevention and control with active monitoring and prevention in advance should be formed. Future research can be prioritized in the following directions:

(1) Using existing real-time online monitoring instruments, pilot projects should be carried out at important ports of entry and key public spaces in big cities (such as hospitals, stations/airports) to build an accurate real-time monitoring network and effectively help the epidemic prevention gate move forward.

(2) We should develop standardized and business-oriented rapid and accurate online monitoring technologies based on advanced technologies such as laser-induced fluorescence and surface-enhanced Raman, combined with artificial intelligence algorithms, and research and develop real-time "alarms" for atmospheric pathogenic microorganisms; The unique technical advantages of laser remote sensing should be brought into play to develop a full-band fluorescent lidar with a wide detection range, high spatiotemporal resolution and strong reliability. To further strengthen epidemic

prevention measures, the monitoring scope should be expanded to key areas such as glaciers and permafrost.

(3) A world-class large-scale real-time monitoring network should be built based on the newly developed real-time monitoring instrument for pathogenic microorganisms in the atmosphere and high-resolution fluorescent lidar, combined with the advantages of offline monitoring technology. It can accurately and quickly sense the source of epidemic outbreaks, and significantly improve national capacity to prevent and control major infectious diseases and biosecurity risks. Expanding international cooperation, particularly through South-South cooperation mechanism, will support the establishment of monitoring networks in Africa and other regions, and will help developing countries enhance their capabilities in epidemic monitoring and response, strengthening global epidemic prevention and control.

(4) We should strengthen the etiological diagnosis of abnormal health events such as mass diseases of unknown cause, clusters of pneumonia of unknown cause, clinically critical cases with epidemiological links and deaths of unknown cause, and focus on monitoring of atmospheric pathogens. It is necessary to establish the detection technology of unknown pathogens, form a more sensitive and effective monitoring and early warning network, and build a multi-trigger, rapid response, scientific and efficient monitoring platform for emerging infectious diseases, mass diseases of unknown cause, and key infectious diseases.

(5) Multi-sectoral cooperation should be opened, and a national and provincial pathogenic microorganism monitoring network should be established through the joint efforts of government-enterprise-academic departments. Disease control departments, medical and health institutions, blood transfusion services, inspection and testing institutions, entry-exit inspection and quarantine institutions, animal disease prevention and control institutions, institutions of higher learning, scientific research institutes and other laboratories with biosafety and pathogen detection qualifications should be included in the atmospheric pathogen microbial monitoring network layout.

(6) Priority should be given to regional monitoring of airborne pathogens on a global

scale. Based on the infectious disease epidemic information released by the World Health Organization and other international professional institutions, key concern countries and neighboring countries, efforts should be made to promote cross-border joint monitoring of infectious diseases and atmospheric pathogenic microorganisms with neighboring countries. It is necessary to strengthen the global monitoring of atmospheric pathogenic microorganisms and actively track the cutting-edge development trends of emerging and sudden infectious diseases worldwide.

2. The priority development direction and suggestion of prediction system

The fast development of technologies such as artificial intelligence, big data and genomics enables researchers to identify the transmission patterns and variations of infectious diseases more accurately, allowing public health decision-making authorities to respond more flexibly to the changing health challenges. The priority development of infectious disease prediction and early warning should be based on multiple dimensions, focusing on strengthening data collection and sharing, applying cutting-edge technology, promoting multi-sectoral and interdisciplinary cooperation, strengthening global multi-country and multi-regional collaboration, improving early medical diagnosis capacity, and strengthening vaccine research and development and distribution. These measures will help the public health system respond more effectively to emerging, sudden and frequent infectious disease outbreaks, enhance intelligent decision-making capabilities, and achieve effective prevention and control of known and unknown infectious diseases. Future research can be prioritized in the following directions:

(1) Risk assessment tools should be developed based on technologies such as the Internet of Things, big data, cloud computing, artificial intelligence and simulation. Through multi-sectoral cooperation, government-enterprise-academic departments should jointly build large-scale databases from risk sources, recipient vulnerability, public safety and other aspects. Data fusion technology should be used to open up multi-source

heterogeneous data, and a standard system for public health data interconnection and sharing should be developed. It is necessary to combine the real-time monitoring network data of pathogenic microorganisms in the atmosphere to build a national data center that can be used by the real-time prediction and early warning system of pathogens.

(2) Based on the multi-dimensional monitoring and early warning indicators and thresholds established by the National Administration of Disease Control and Prevention and provincial disease control and prevention departments and the trigger verification standards for abnormal signals of infectious diseases, the trigger verification standards for abnormal signals of pathogenic microorganisms in the atmosphere should be improved. It is necessary to use big data, cloud computing, artificial intelligence and other technical means to automatically capture abnormal signals of infectious diseases based on the monitoring network of pathogenic microorganisms in the atmosphere. A multi-category and multi-scenario model base composed of algorithm model and knowledge graph should be constructed to predict epidemic trend and improve intelligent decision-making ability.

(3) In view of the current situation of insufficient spatial resolution and low accuracy of prediction and early warning of major new epidemic outbreaks, the existing single-point model of infectious diseases should be expanded to two-dimensional space by adding the spatial diffusion term of population flow. The spatial diffusion coefficient parameterization scheme of population flow should be established by combining the traditional optimization inversion algorithm and artificial intelligence algorithm. Combined with the quantified parameters of key influencing factors of epidemic transmission, a spatial complex parametric grid distribution should be formed. A two-dimensional prediction and early warning model combining “statistics and dynamics” should be built to realize the two-dimensional high-precision operational daily forecast and seasonal prediction of major epidemic.

(4) The basic information list of climate-sensitive diseases should be investigated and sorted out, and the risk warning system of climate-sensitive diseases should be built. On the basis of the establishment of a sound monitoring system, the key technologies of

epidemic prediction system based on environmental meteorological data and geographical spatiotemporal distribution of pathogenic microorganisms should be studied. Early warning of vector-borne diseases such as plague, dengue fever, malaria, epidemic encephalitis B, zoonotic diseases and emerging infectious diseases should be carried out.

(5) The simulation and prediction of abnormal health events such as mass diseases of unknown cause, clusters of pneumonia of unknown cause, clinically critical cases with epidemiological links, and deaths of unknown cause should be strengthened. The effects of ecological changes, climate change and human activities on the transmission of unknown pathogens should be studied to gain an in-depth understanding of their transmission mechanisms and life cycles. Risk assessment, prediction and early warning should be carried out on the outbreak probability, active areas and origin of unknown new infectious diseases in the future.

(6) It is urgent to combine the cooperation of health, agriculture and rural areas, forestry and grass, ecological environment, customs, education, civil affairs and other departments, strengthen the interdisciplinary cooperation of epidemiology, atmospheric sciences, environmental science, applied mathematics and computer science, and realize the multi-model coupling epidemic prediction and early warning. Considering the population distribution, transportation network and medical facilities, the spatial optimization model and multi-objective decision-making method should be adopted to realize the rational allocation of resources.

Section 2 Suggestions on funding system and policy

1. Strengthening research on basic issues

At present, research teams have limited understanding of the functional potential of atmospheric microbiota, and the combined effects of various influencing factors and their respective influence weights on pathogen transmission are still unclear. Potential animal hosts or vectors have not been fully identified, and there is a lack of systematic screening of pathogenic microorganisms carried by animal hosts and vectors.

In the future, it is urgent to strengthen the basic research on the formation, source analysis, environmental evolution and transmission mechanism of atmospheric pathogenic microorganisms. Based on observation and historical data, the statistical relationship between meteorological and environmental factors and the spread of pathogenic microorganisms and aerosols should be established, and the research on the key influencing factors of climatic environment on the spread of pathogenic microorganisms should be strengthened. The influence and mechanism of weather, climate and atmospheric environment on the propagation, variation and spread of pathogenic microorganisms should be revealed, and the influence and contribution of key factors such as climate, environment, society, economy, health and human immunity should be clarified. It is also necessary to clarify the mechanism of the transmission of bioaerosols by meteorological factors and seasonal changes in different climate zones, developing and developed countries at the global scale. It is necessary to study the circulation process and propagation rule of bioaerosols at regional and global scales in depth, and clarify the response of pathogen identification, characterization, transport and transformation process in climate and environment. The mechanism of climate-driven pathogen evolution and cross-species transmission should be clarified, the distribution and determinants of pathogens in different environments, time, space and populations should be determined, the dynamic distribution and evolution characteristics of pathogens in the animal-human environment should be explored, and the transmission capacity and cross-species transmission efficiency of pathogens should be revealed. Interdisciplinary studies including mass spectrometry and spectroscopy, gene sequencing and molecular biology should be used to quantitatively study the carrier of atmospheric environment, reconstruct the time series of the occurrence and development of COVID-19 and other major epidemics, and reveal the characteristics of their spatial distribution and evolution.

2. Strengthening the development of monitoring instruments and the construction of monitoring networks

At present, the high-precision monitoring technology of atmospheric pathogenic microorganisms is not mature, and there are technical bottlenecks such as difficult capture, slow detection and poor identification of monitoring instruments, and the perfect monitoring network has not been established. Each link relies heavily on manual operation, the steps are cumbersome, time-consuming, high cost, and has not yet realized the one-stop automatic operation of environmental samples from detection preprocessing to detection analysis. It is urgent to lay out and establish a real-time monitoring network of pathogenic microorganisms in the atmosphere as soon as possible, so as to transform from passive defense to active monitoring.

It is urgent to accelerate the research and development of real-time monitoring technologies for pathogenic microorganisms in the atmosphere. By integrating air sampling, microfluidics, and highly sensitive and reproducible biosensing technologies, we can distinguish between microbial and non-biological components, pathogenic and non-pathogenic microorganisms in the atmosphere, and accurately identify bacteria, fungi and viruses in pathogenic microorganisms and their types. It should be combined with artificial intelligence algorithms to develop standardized and operational rapid monitoring technology and online monitoring instruments, improve the comprehensive monitoring capabilities of software and hardware, reduce monitoring costs, and lay a good foundation for the construction of real-time monitoring networks for pathogenic microorganisms in the atmosphere. Sentinel monitoring of pathogenic microorganisms in the atmosphere should be carried out at key places and ports in all provinces and urban areas, and an integrated monitoring system for people, objects, the environment and key places should be established. It is necessary to monitor and analyze the spread of atmospheric pathogenic microorganisms in real time, discover the source of infection in time, shorten the transmission window period, establish monitoring emergency plans at all levels from the community to the province, form a new pattern of health safety management with active monitoring and prevention in advance, and win more valuable opportunities and time to further improve the emergency management system of public health emergencies.

3. Strengthening the construction of data sharing systems

Data sharing enables the rapid transmission of information between different agencies and departments, so that epidemic information can be quickly conveyed to decision-making departments and primary health service institutions, thereby reducing response time and promoting cooperation and coordination between different departments. However, there is the data isolation among different regions and departments, and there is a lack of uniform standards for data collection and management. There is the privacy leakage risk of personal health data in data sharing, so how to realize effective data sharing while protecting personal privacy needs to be further explored.

It is urgent that the CDC departments, together with relevant health departments and the military, improve the working mechanism for collaborative information sharing on infectious diseases, formulate an information sharing list, smooth the channels for information notification, gather the forces of various parties, and establish an authoritative national data sharing system. Efforts should be accelerated to promote multi-departmental cooperation. Through the joint efforts of the government, enterprises and academic departments, data sharing among multiple departments should be accelerated with plans such as the deployment of work by the disease control department, project leadership, and talent cultivation and exchange. We should establish a comprehensive biobank for major infectious disease outbreaks, and develop a standard system for public health data interconnection and sharing. It is urgent to establish a data fusion system based on data standards and specifications, with data interface as a bridge and open data management as a basis, to provide data services for government departments, medical institutions and scientific research institutions. A comprehensive monitoring and database of infectious diseases covering environment, vector, natural host, population and clinical samples should be built based on the data management system of hierarchical classification. Pathogen data resources should be integrated and synchronized, including major infectious disease pathogen genome, transcriptome, metagenome, metatranscriptomics, proteome and other omics data and analysis results, gene and protein annotation information, basic pathogen information. Standard operating procedures (SOP) for data collection and data quality control should be established for representative data resources, and continuous automatic updating of the comprehensive data integration platform for infectious diseases should be realized. Risk assessment tools should be developed based on technologies such as the Internet of Things, big data, cloud computing, artificial intelligence and simulation, and large-scale database construction should be carried out in three aspects: risk source, recipient vulnerability, and public safety capability.

4. Strengthening the construction of monitoring and prediction platforms

Epidemic prediction and early warning have become an important means for decision-making departments to scientifically control epidemics and reduce economic and social losses during the epidemic. At present, epidemic prediction team is scattered, and there is no concentrated research force to establish an authoritative prediction platform. The self-developed local, regional and global prediction models for the spread of infectious diseases include limited natural, environmental and social factors, and are not sufficiently integrated with the actual situation of the outbreak, and no authoritative national prediction platform has been established.

In the future, it is urgent to concentrate research forces in multiple fields and build a multi-scale coupled accurate prediction system of “epidemic, environment, meteorology, climate, population, transportation, economy, society”. Based on artificial intelligence and biomedical big data operating system, real-time monitoring network data information should be integrated, a dynamic display system including database, real-time monitoring network and integrated prediction should be established, and a national collaborative intelligence decision-making platform for emerging outbreaks should be built. To meet the needs of prevention and prediction of major public health emergencies and simulate the development trend of the epidemic situation under different scenarios and different measures, the optimal response and unlockdown plan should be established. Based on the epidemic prediction and prevention digital twin model, multi-agent system, health economics evaluation model, and simulation and analysis data, we can evaluate the impact of the epidemic and rationally allocate health resources. Early warning, situation prediction and risk assessment of sudden and emerging infectious diseases will be carried out, and early warning information will be released in a timely manner to provide scientific support for the government and epidemic prevention departments to formulate relevant policies. It is urgent to strengthen the application of artificial intelligence technology in the early screening and early diagnosis of major diseases, precision treatment, and intelligent management of clinical scenarios, and carry out research on intelligent collection and management of clinical data, multi-modal data fusion and association models, and the construction and verification of special large model pre-training models. It should be combined with artificial intelligence technology to explore the rules and mechanisms of the occurrence, development and outcome of major diseases, and improve the efficiency of clinical intervention and the accuracy of full-cycle management of major diseases.

In addition, it is urgent to pay attention to the impact of climate and environmental change on emerging infectious diseases, use artificial intelligence methods and metagenomic methods to identify possible pathogens in the environment and animals, and strengthen the prediction system for future unknown infectious diseases. From the perspective of population vulnerability, the health risks of climate change should be identified, the single factors of climate and environmental change and their interactions, as well as the pathways and pathogenic mechanisms affecting human health should be clarified. Research and development of trend health risk prediction and decision support tools should be carried out to build a technology system for near-real-time characterization and short-term prediction of atmospheric environmental change, and a multi-scale nested pathogenic microbe-climate-ecosystem coupling prediction model should be established to realize dynamic characterization and prediction of epidemic control, socio-economic activities, anthropogenic emissions, and atmospheric composition changes. A business platform of prediction should be established to regularly release systematic information every year, including relevant data such as the number of deaths caused by climate and environmental factors and the number of excess death toll.

5. Promoting major research projects and transformation of scientific research achievement

The monitoring and prediction of pathogenic microorganisms in the atmosphere are interdependent and mutually reinforcing, which is crucial for the prevention and control of emerging and sudden major epidemics. Atmospheric pathogenic microorganisms affect human health from multiple aspects and multiple ways. Firstly, they harm human and animal health through exposure routes such as skin and mucous membranes, digestive tract and respiratory tract, involving multiple disciplines including environmental ecology, environmental health, infectious diseases and epidemiology. These disciplines study the link between atmospheric pathogenic microorganisms and human activities and how they affect plant, animal and human health through airborne transmission. Secondly, atmospheric pathogenic microorganisms can enter water bodies and glaciers through atmospheric sedimentation, precipitation and other ways, affecting the health of aquatic ecosystems, the melting rate of glaciers and the stability of glacier ecosystems, involving many disciplines including atmospheric sciences, geographical science, environmental science and other sciences. Therefore, the monitoring and prediction of pathogenic microorganisms in the atmosphere involves many fields and disciplines. It is suggested to set up major research programs related to the monitoring and prediction of pathogenic microorganisms in the atmosphere, establish state key laboratories or state laboratories, and coordinate the development and innovation of the monitoring technology of pathogenic microorganisms in the atmosphere, the construction of monitoring networks and the establishment of monitoring and prediction platforms. It is necessary to strengthen joint research and development, personnel training and base construction, concentrate resources, improve research efficiency, form a scientific community in this field, achieve greater progress as soon as possible, produce high-level scientific research results for epidemic monitoring and prediction services, effectively improve the early detection and early warning capacity of major epidemics, and further enhance national capacity for emergency management of public health emergencies.

In August 2024, multiple Chinese ministries and commissions jointly issued the *Guidelines on Establishing a Sound Smart Multi-Point Trigger-Based Surveillance and Early Warning System for Infectious Diseases*, which set out specific goals and requirements for improving the surveillance and early warning system and mechanism, carrying out multi-channel infectious disease surveillance, promoting the construction of surveillance and early warning information platforms, and strengthening surveillance and early warning capacity building. In order to further improve the emergency response capacity of major public health emergencies, it is proposed to integrate relevant projects, gather national disease control departments, regional public health centers, enterprises, universities and research institutions, promote major research plans at the national level, and accelerate the establishment of an intelligent multi-point trigger infectious disease surveillance and early warning system for provincial and municipal disease control departments with the assistance of scientific research institutions. We should focus on the task chain of "monitoring → prediction → early warning → prevention and control", upgrade the efficient use of research results, promote the rapid detection and early warning of new outbreaks, move the epidemic prevention and control threshold forward, effectively achieve early detection and early control of epidemics, and realize efficient coordination between regular epidemic prevention and control and economic and social development. This will significantly improve national ability to prevent and respond to biosecurity risks such as major outbreaks of infectious diseases.

6. Strengthening national multi-sectoral cooperation and international cooperation

Promoting intersectoral cooperation and international cooperation in monitoring and prediction research of pathogenic microorganisms in the atmosphere is the key to addressing climate change and protecting human health. Cross-sectoral cooperation can integrate theoretical foundations and resources in different fields, while international cooperation can learn from the successful experience of other countries to jointly address global challenges.

Experts and scholars in the field of atmospheric pathogenic microorganisms in universities and medical institutions should jointly carry out scientific research on the risk assessment of climate-sensitive diseases and the construction of a monitoring and prediction platform for major epidemics. Interdisciplinary health meteorological research teams should be set up to carry out technical research, enrich and improve the health meteorological public service product system, release disease risk prediction and early warning and life health index products, and build a health meteorological science and technology cooperation platform. Policies and action plans at the national level should be formulated and implemented to ensure the sustainable development of health meteorological services, and efforts should be made to promote the construction of national atmospheric pathogenic microorganisms monitoring and prediction platforms and the deployment of atmospheric pathogenic microorganisms monitoring and prediction work in various provinces and cities.

In addition, in the context of globalization, disease transmission takes on the character of cross-border, so international data sharing is essential, and there is an urgent need to work together to address global health threats. In the future, it is urgent to strengthen joint research, personnel training and base construction, strengthen multi-dimensional and multi-level international cooperation in data sharing, monitoring and prediction technology, personnel training and other aspects, and attract more international experts and resources. Advanced experience and technology in monitoring and prediction of pathogenic microorganisms in the atmosphere should be discussed through hosting international conferences and participating in the revision work of the international organization for standardization, so as to enhance international influence. It is urgent to establish regular international cooperation and technical support for instrument comparison, ensure the sustainability and stability of cooperation projects, use international cooperation projects to carry out key regional monitoring of pathogenic microorganisms in the atmosphere at a global scale, and promote the deployment of atmospheric pathogenic microorganisms monitoring networks. We should cooperate with neighboring countries to carry out joint monitoring of cross-border infectious diseases, actively follow the forefront development trends of emerging infectious diseases in the world, prepare for future unknown infectious diseases in advance, and promote the building of a community of human health.

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