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Marine Meteorology Research Progress of China from 2003 to 2006

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ABSTRACT

The progress in marine meteorology research achieved by scientists in China during the four-year period from 2003 to 2006 is summarized under four categories: marine disaster study, typhoon over the ocean, ocean-atmosphere monitoring technology, and ocean-atmosphere forecasting technology. Compared to the previous four years, many more first-hand datasets have been obtained and more scientific issues have been addressed. In particular, many contributions have been made by young scientists. A brief statement on the research strategy of marine meteorology in China for the coming years is given at the end.

Key words: marine meteorology, marine disaster, remote sensing, monitoring and forecasting technology

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1. Introduction

Marine meteorology concerns the physical principles of the atmosphere over the ocean and the interaction between the atmosphere and the ocean. It involves both the atmospheric sciences and the ocean sciences. Monitoring marine weather and understanding the mechanisms at work are necessary for providing operational services in marine meteorology, marine activities, and ocean security. It also plays an important role in forecasting and preventing disasters, and could provide important knowledge in the decision-making related to various meteorological services.

During the four years from 2003–2006, China's marine meteorological research made great progress in terms of simulating natural marine disasters and understanding the mechanisms causing these disasters, and also in terms of marine meteorological monitoring and forecasting technology. Several new techniques were developed with good results, such as the capability to observe key indicators related to the growth of sea ice, the short-term cross-correlation method in predicting marine cloud movement, the conjugated inverse technology used to establish a shallow water model, and multi-parameter marine measuring instruments. Based on previous work, a series of field experiments in marine meteorology were carried out successfully under the leadership of scientists in China; for example, the Second Arctic Scientific Expedition and the air-sea flux observation during the northern South China Sea open voyage. These field experiments further enriched our database for marine meteorology research, which lead to a number of research achievements. Built on these foundations, numerical simulations of key indicators in marine meteorology were improved greatly. The development and improvement of traditional air-sea monitoring and forecasting technology plays an important role in studying the change of marine meteorology and in predicting and preventing natural marine disasters.

The paper is organized in the following manner. Section 2 presents studies on ocean disasters, mainly including the latest studies on the influences and numerical simulations of typhoons, tsunamis, sea ice, sea fog, and waves. Section 3 introduces the marine meteorological monitoring technology, including remote sensing of the sea surface temperature (SST), precipitation, sea fog, sea ice, waves, tsunamis, and red tides, as well as remote sensing technology and seismic retrieval technology. Section 4 focuses on the marine

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weather forecast, including long-term change of SST, influences from other environmental factors, the development of SST and wave prediction technology, and research on the marine environment multi-factors measurement technology; Section 5 points out some deficiencies in the studies of marine meteorology and future prospects in China.

2. Research on marine disasters

China is vulnerable to marine disasters due to its long coastlines. Take a typhoon for instance. More than 30 typhoons are generated in the Northwest Pacific Ocean annually, more than about 1/3 of the world's tropical cyclones. China is one of the countries that is most affected by typhoons, averaging close to 20 times every year. Other disasters, such as storm tide and billow also frequently affect the coastland of China. These disasters not only threaten people's lives, property, and safety of the coastal areas, but also bring adverse factors to the nation's economy. We need to study various marine disasters in order to effectively prevent these negative impacts.

2.1 *Typhoon*

Using the global SSTs from 1951 to 2000, Zhang et al. (2003) found good correlation between the SSTs in the Pacific and the frequency of tropical cyclones in the Northwest Pacific Ocean. For these highly correlated areas, the SST data at some representative points have been selected to form an aggregative forecasting index. Using the index, two models were built: a simple linear model and a one-variable polynomial nonlinear model. It has long been recognized that the evolution of the western Pacific typhoons may be strongly affected by large-scale circulations, the asymmetric structure of the typhoon itself, and the terrain, etc. However, the role of flux-transfer processes at the air-sea interface remains unclear. The high winds of typhoons can generate a large amount of spray. Through the evaporation of spray droplets, the air-sea fluxes may be significantly modified, which can in turn affect the evolution process of a typhoon. A 2002 western Pacific typhoon, Typhoon Sinlaku, is simulated by Li et al. (2004a) using a coupled atmosphere-sea spray modeling system. It is found that sea spray can cause a significant latent-heat flux increase, up to 50% of the interfacial flux in Typhoon Sinlaku. Taking into account the effects of sea spray, the intensity of a modeled typhoon can increase significantly, by 30% in 10-m wind speed, which may greatly improve the estimate of the maximum storm intensity in the atmospheric model.

Thirteen tropical cyclones moving westward into the South China Sea were analyzed by Huang and Lin (2004). It was showed that the major characteristics of the westerlies are that the area from central Asia to East Asia was under a ridge or zonal circulation while the high latitudes were under a westerly trough. They also showed that a constantly intense zonal spreading of a subtropical high dominated the western North Pacific to Central and Southern China, or a continually strengthening subtropical ridge that extended westward, gradually built up the gradient between the ridge and tropical cyclone, and strengthened the easterly steering flow. Moreover, the easterly environmental flow, prevailing on both the southern and northern sides of the tropical cyclone, would make it travel more quickly. Li et al. (2003) analyzed the features of surface wind distribution related to Typhoon Vongfong's landfall process based on the Quick Scatterometer (QuikSCAT) data. The variance in the spectral configuration of the surface wind field was also studied using Discrete Cosine Transform (DCT). They found that the surface wind field was highly asymmetric, and that the variance components of the asymmetric surface wind field depended mainly on the window airflow direction of wave numbers 1 and 2.

A series of studies on typhoon simulation were carried out in China and abroad in the last ten years (Li et al., 2004b). For Typhoon Vongfong, a numerical experiment was conducted using the Mesoscale Modeling System (MM5) model (Li et al., 2004c). As verified against various observations, the model captured reasonably well the evolution of the track, intensity change, the maximum surface wind, detailed mesoscale precipitation distributions, and the cloud and spire rain-band associated with Typhoon Vongfong. The sensitivity experiments showed that Four Dimension Data Assimilation (FDDA) could improve the results of the simulation. Based on a regional climate model (RegCM2) that was one-way nested to a global coupled atmosphere-ocean model, the impacts of the greenhouse effect (doubled concentration of CO_2) on typhoons affecting China, as simulated by a regional climate model, were investigated (Gao et al., 2003). The results indicated that the simulation by RegCM2 at a high resolution was much better than that by the global model due to its improved horizontal resolution. Under the condition of a doubled concentration of CO_2, an increase of 26% in terms of the number of typhoons that could affect China was estimated. The greenhouse effect could also cause route changes in typhoons.

Many studies were carried out on typhoon-related rainstorm processes. The GRAPES (Global and Regional Assimilation and Prediction Enhanced System) 3D-VAR assimilation system has been released by the Chinese Academy of Meteorological Sciences (Ding et al., 2005). The extension of the Kuo cumulus parameter scheme is used as the observation operator to assimilate the TRMM (Tropical Rainfall Measuring Mission) rain rate in the GRAPES 3D-VAR system. A single observation test showed that this algorithm could adjust the vertical background structure of the moisture convergence depending on the difference between the observation operator calculation and the TRMM rain rate. After the assimilation, the observation operator can obtain a more accurate rain rate using the analysis field. In the experiment of forecasting Typhoon Dujuan, the assimilation algorithm adjusted the dynamic and thermodynamic structure of the background field and obtained more realistic wind and precipitation structures. Compared with the control test, assimilating the TRMM rain rate can improve Typhoon Dujuan's track and precipitation forecast. The impact of the TRMM's Microwave Imager (TMI) surface rainfall rate in 4D-VAR on the numerical simulation of Tropical Cyclone (TC) Danas (2001) was studied by Ma et al. (2005). On the basis of adjusting the initial fields, the direct assimilation of the rainfall rate improved the description of the TC structure and the prediction of rainfal1. Meng et al. (2005) carried out a sensitive numerical simulation study to investigate the effects of the condensation heating and surface fluxes on the development of a South China mesoscale convective system (MCS) that occurred on 23–24 May 1998. Due to surface heating, the pressure declined over the heavy rainfall and the MCS affected regions, which resulted in the intensification of southerly flows from the ocean along the South China coastline areas, and lead to the enhancement of horizontal convergence and the increase in vapor in the lower layer. All of these made the atmosphere more unstable and more favorable for the convection.

2.2 *Tsunami*

Tsunamis are an extremely fierce marine disaster created when a body of water, such as an ocean, is rapidly displaced. A tsunami can kill 10000 people and destroy villages in a very short time. For years, marine scientists have studied the causes of tsunamis and disaster prevention methods and have had some preliminary success in reducing and preventing the ruin of tsunamis.

We studied the remote sensing imagery of tsunami-hit regions by means of spatial resolution quantitative evaluation. The spatial resolution is a key index of the image and is also an important parameter for the object. Up to now, however, there are no effective approaches to quantitatively evaluate the image resolution. The methods of forming an image can be divided in two ways: a scanning manner and a non-scanning manner (e.g., framing). Normally, forming an image by the non-scanning manner has the same spatial resolution in the vertical and horizontal directions, while an image formed by the scanning manner has different spatial resolutions in the two directions. The factors that influence the spatial resolution of the image include the contrast, shape, number of the scene that was observed, the lens, focus and instantaneous field of view (IFOV) of the imaging system, the wavelength of radiation, aperture of imaging, model of the image, and the design of the imaging system, and so on. The main effective factors are the distinguishing limit decided by the diffraction of the light, the Modulate Transfer Function (MTF) of the imaging system, the Noise Signal Ratio (NSR), and the design of the imaging system. Based on the entropy theory and the property of image information, Ji and Zhao (2005) brought forward the principle theory of varied information entropy, provided the conception, definition, method and character analysis. The experiment for bar images and remote sensing images of tsunami areas proved that the method is qualified to measure the spatial resolution in the horizontal and vertical directions for the varied information equably, and to provide a new method for qualified measuring of the spatial resolution of the image.

2.3 *Sea ice*

Sea ice forms in polar regions and high latitudes. Floating icebergs and the sudden freezing of the sea can bring great harm to ships and marine activities. The change in sea ice temperature and thickness is investigated during the Second Chinese National Arctic Research Expedition (CHINARE-2003). Temperature profiles of the sea-ice layer, the water temperature profile below the sea-ice layer, and the change of sea-ice thickness are all this investigation's key indices. High precision and accurate observations are acquired for the validation and modification of the sea-ice thermodynamic simulation model. In order to acquire accurate *in situ* observations, the test technologies and corresponding methods were designed; the manual freeze equipment, the under-ice water temperature measure in-phase equipment, and the ice layer thickness auto-monitoring equipment are all made with new technologies. Li et al. (2004d) described the first results and problems of these new technologies used in the *in-situ* survey; they also discussed ways to improve these technologies.

The ice conditions along a route or an area are consisted of point ice investigation results. The data is necessary for comparison study of large-scale remote sensing. Although the ice conditions are different at different times and locations, the ice conditions on a large scale are known statistically. Data along the route of CHINARE-2003 by ship and air surveys and ice floe stations investigations, including sea-ice concentrations, sea-ice thickness profiles, and sea-ice thickness along this route, are given in figures and tables by Li et al. (2005). The spatial distributions of ice concentrations and thicknesses are also included.

Variations of the Arctic sea ice in four sectors (I: 40°W–0°–50°E, II: 50°–140°E, III: 140°E–180°–130°W, IV: 130°–40°W) and relations with autumn temperatures in China were studied using the monthly $1^\circ \times 1^\circ$ sea-ice concentration data of January 1953 to February 2003 from the Hadley Center and the monthly temperature data at 160 stations in China (Dong and Sun, 2006). The results showed that the sea-ice concentration of various seasons all exhibited a distinctive linear descending trend in the four sectors in the last 50 years, and the decrease in sea-ice concentration was the fastest in the European sector in spring and summer. The beginning time of the abrupt change in sea-ice concentration for various seasons was different; it was the 1970s for spring and summer concentrations and the 1980s for fall and winter concentrations. The sea-ice concentration of the various sectors displayed an interdecadal variation as well as distinctive seasonal and regional differences. The distinctive correlation areas between the sea ice in Sector I and the autumn temperatures in China are the Hetao area, the mid-reach of the Yangtze River, and part of the Xinjiang Uygur Autonomous Region. The sea ice in Sectors I and II were significantly correlated with the autumn temperatures 2-year and 1-year later in China, respectively.

On the basis of dynamic analyses of the sea-ice motion, sea-ice velocity was extracted from Moderate-resolution Imaging Spectroradiometer (MODIS) images by the Maximum Cross Correlation (MCC) method for the Bohai Sea (Wu et al., 2005). The dependence of ice velocity on the wind and current was estimated using regression analysis. From the sea ice motion data, extracted from MODIS and The National Oceanic and Atmospheric Administration/Advanced Very High Resolution Radiometer (NOAA/AVHRR), it was found that the sea-ice motion in the Bohai Sea was affected not only by the prevailing winds but also by topographic steering, ocean currents, and internal ice stresses. The extracted sea-ice drifts were similar to observed ice drifts, which clearly showed the sea-ice drift in the Marginal Ice Zone. This remote-sensing data can compensate for the limited local or single station observations.

Both thermal and dynamic factors are equally important in influencing sea ice; however, the thermal part in most existing thermodynamic-dynamic sea-ice models was rather simple. The Winton's enthalpy conservation three-layer thermodynamic model was used by Song and Sun (2005) to replace the zero-layer one in the Hibler thermodynamic-dynamic sea ice model, and the 1983 Arctic sea ice was simulated using the Hibler and the improved Hibler model. Simulations suggest that the simulated sea-ice thickness is larger, the seasonal variation of the sea-ice thickness is smaller, and the simulated sea-ice compactness is in better accordance with the observations using the improved Hibler model.

Thermodynamic coupling plays an important role in the simulation of sea ice and general oceanic circulations. It is also an important factor to represent the ice-ocean interaction. It is therefore necessary to represent such a process with a detailed turbulence model; however, this treatment is limited by computational cost, especially for the climate model. The temperature of the upper oceanic mixed layer in the ice zone was assumed at the freezing point of seawater, which is often set to a constant in most ice models and coupled ice-ocean models. Such an assumption is good enough for the inner ice zone. There exist exceptions, however, when ice floe advects to warmer water in the marginal ice zone or when the freezing point varies with the salinity of seawater below the ice bottom for salt rejection while freezing or for freshening while melting. A new thermodynamic coupling scheme was presented according to the energy balance in the coupled ice-ocean system (Liu et al., 2004). The scheme neither keeps the temperature of the mixed layer at the freezing point of seawater nor considers the detailed turbulent processes at the ice-ocean interface. The analysis and experiments on the scheme showed that the coupling scheme produced more reasonable temperatures in the upper-ocean mixed layer. The temperature of the mixed layer was close to the freezing point of seawater in the ice zone and was obviously above the freezing point of seawater in the marginal ice zone under the atmospheric forcing. The simulated sea-ice extent and seasonal variations in the Arctic and the Antarctic in a global coupled ice-ocean model based on this coupling scheme were close to observations.

Based on earlier international studies on coupled ice-ocean models and hydrology, meteorology, and ice features in the Bohai Sea, a coupled ice-ocean model was developed by Su et al. (2005) using the National Marine Environment Forecast Center's (NMEFC) numerical forecasting ice model of the Bohai Sea and the Princeton ocean model (POM). In the coupled model, the transfer of momentum and heat between the ocean and ice is two-way, and the change of the ice thickness and concentration depends on the heat budget not only at the surface and bottom of the ice, but also at the surface of the open water between the pieces of ice.

Liu et al. (2006a) simulated the dynamic processes of ice thickness variation using a particle-in-cell (PIC) ice model. Based on dynamic and thermodynamic research of sea ice and the ice conditions in the Bohai Sea, a PIC sea-ice model was applied to the Bohai Sea in China. The PIC method was added to the sea-ice model to efficiently reduce the numeric diffusion inherent in conventional models. The ice thickness distribution function was introduced in the model as well, and the multi-category ice thickness distribution was used, instead of the three-level ice thickness distribution of level ice, rubble ice, and the open water in the Bohai Sea ice model. Numerical experiments of the ideal ice fields were carried out simulating the dynamical processes of ice thickness variation. Comparison experiments of the forecasts for different cases of the real ice conditions in the Bohai Sea were made using the PIC model with the operational ice model. It was found that the PIC model had some advantages in improving the ice edge forecast accuracy.

Furthermore, Li and Zhang (2004) brought forward future Arctic ice research tactics. Based on the focus of sea-ice modeling in the simulation of climate, this paper overviews the status and tendency of international sea-ice models and the scientific problems of the physical processes of sea-ice in the present ice modeling, which need further field investigations and experimental research above all. It also briefly introduced the Chinese Second National Arctic Expedition in 2003. Based on China's national observations and research ability, the international focus of sea-ice science, the available sea-ice data in the world, and the actual phenomena of polar sea ice were discussed. These viewpoints may guide the future field and laboratory studies of Arctic sea ice in terms of polar sea ice theories and simulations.

2.4 *Sea fog*

Sea fog is a weather phenomenon wherein tiny water droplets suspend in the vicinity of the surface atmosphere. It occurs frequently in China's coastal areas. Sea fog occurs mainly in areas where the warm and cold water merge with each other, and where inshore cold streams and offshore warm streams join.

Hou and Wang (2004) investigated the causes and the temporal and spatial distributions of sea fog off the Zhejiang coast. The coastal is influenced by the atmospheric circulation and the water temperature. The fog happens mostly from March to June and is distributed mostly between Shengsi and Kanmen. Guo (2004) found that the probability increases for the appearance of sea advection fog at dusk or the next day. The relationship between evaporation duct and advection fog provides a new way to forecast sea advection fog from evaporation duct. Using hourly diurnal visibilities, the relative humidity, and wind at the Xiamen airport from 2000 to 2002, Wang et al. (2005a) found that there are very distinct daily, seasonal, intraseasonal, and quasi-two-week variations of visibility. In the observed time, from 0800 UTC to 2000 UTC, daily data shows that visibility is the lowest in the morning and evening but reaches its maximum in the afternoon. In seasonal variations, visibility is the lowest from March to May, a foggy season in Xiamen. That is to say, the visibility of Xiamen is greatly related with the local fog.

By analyzing the climatic background of sea fog of the Yellow Sea in spring (April), Zhou et al. (2004) showed that the vapor required is afforded by a tropical atmosphere. Compared with the circulation, vapor and its transport condition, SST is not important. The sea fog of the Yellow Sea has distinct monsoon characteristics and is involved with the production of the monsoon circulation. Wang et al. (2006a) studied the characteristics of sea-fog formation of the Yellow Sea in the summer. The results showed that the summer monsoon determines the foggy days, and vapor formatted fog is not afforded by the local atmosphere but by the lower tropospheric jet from the tropics. Cooperated with the circulation, the SST is very important for the formation of sea fog.

Representative conventional observations were used with the National Centers for Environmental Prediction/ National Center for Atmospheric Research (NCEP/NCAR) data to analyze the interannual change of sea fog over the Yellow Sea in the spring (Zhang et al., 2005a). The interannual change of it is related to the variability of atmospheric circulations. Abnormal circulations are accompanied by abnormal foggy years. Weak winter circulations are favorable for the northward transport of warm and wet air currents from the lower latitudes producing more foggy days, and vise versa. In the years of more foggy days, air stratification is stable and the middle and lower levels are moister. The pattern of the east high and west low surface level pressure is favorable for the moist air transportation from the lower latitudes and coagulation of the fog in the Yellow Sea.

2.5 *Wind wave*

Based on the data of sea surface wind and wave derived from the TOPEX/Poseidon altimeter, the relationship and characteristics of the wind and wave fields over the South China Sea are analyzed by Qi et al. (2003a). It is shown that the leading five modes can capture the spatial temporal features to the extent of about 86.28% for wind and 91.37% for wave, meanwhile the first modes for wind and wave match well with each other. By employing the numerical simulation results of typhoon wave and storm surge from 1949 to 2002 from the Wulei station at the Beibu Gulf, their extreme-values of the time series of 54 years were obtained (Li et al., 2006a). It was found that the distribution of the joint probability between the extreme-values of typhoon wave and storm surge is an exponential distribution.

Yang et al. (2005a) put the Simulating Wave Nearshore wave model (SWAN) into use to examine its applicability in the Bohai Sea. By means of the experiment of a wind-induced ocean wave, it was found that the proportionality coefficient α in a linear growth term of a wind growth source function played an important role in the process of wave development and changes along with the friction velocity (in default SWAN model, it is a constant). Based on these experiments, a new formula of α was introduced into the linear growth term of the wind growth source function in the SWAN model. These three processes of wind (two cold waves and a southerly wind) were examined to validate the improvement in the linear growth term. It was concluded that the results from the improved SWAN wave model agreed much better with the measurements than those from the previous SWAN model. The improved SWAN wave model made a solid foundation for setting up a proper model of wave numerical forecasting in the Bohai Sea.

In order to evaluate the wave-induced mixing in the upper ocean and the impact of surface waves on ocean-atmosphere fluxes, a global wave numerical model in spherical coordinates was developed based on the previous LAGFD-WAM regional model (Yang et al., 2005b). The wave energy spectrum balance equation and its complicated characteristic equations were derived in spherical coordinates. In these control equations, the modulation of background current to wave evolution and the refraction of waves propagating along great circles were included. The characteristic inlaid method was applied to integrate the wave energy spectrum balance equation. Primary calibration indicated that the global wave model can describe the dynamical processes of ocean surface gravity waves.

Using the latest version 3 of MM5, Li et al. (2006b) assimilated wind data from a scatterometer and built a model to assimilate the wind field over eastern China seas and adjacent waters, and applied the wave model WAVEWATCH-III to test the sea area with assimilated wind and blended wind of QuikSCAT and NCEP as driving forces. High precision and resolution numerical wave results were obtained. Analysis indicated that if replacing the modeled wind result with the blended wind, better sea surface wind results and wave results could be obtained.

A method was presented to extrapolate a time series of wave data to extreme wave heights (You and Yin, 2006). The l5-year time series of deepwater wave data collected for 34 minutes every hour from 1988 to 2002 in the South Pacific Ocean near Australia was analyzed to generate a set of storm peak wave heights by using the Peaks-Over-Threshold method. The probability distribution is calculated by grouping the observed storm peak wave heights into a number of wave height classes and assigning a probability to each wave height class. The observed probability distribution was then fitted to eight different probability distribution functions and found to be fitted best by the Weibull distribution (α=1.17), nearly best by the FT-I, quite well by the exponential, and poorly by the lognormal function based on the criterion of the sum of the squares of the errors. The effect of the threshold wave height on the estimated extreme wave height was also studied and was found insignificant in the study. The 95% prediction intervals of the best-fit FT-I, exponential and Weibull functions were also derived.

Chen et al. (2006) analyzed the directional spectrum character of sea waves in China. By comparing two different directional distributions, it was shown that the directional distribution recommended in the nowadays specifications in China is characteristic of wind wave and swell with a short propagation distance and in good agreement with the Mitsuyasu direction distribution. It was considered that the natural sea wave will be reflected well, when directional distribution is analyzed combining the frequency spectrum. By analyzing the characters of the directional spectrum in several offshore areas in China, it showed that the directional concentration is slightly less than that recommended in the specifications.

Applying the wave model WAVEWATCH-III to the East China Sea, Li and Hou (2005) simulated the wind wave field with the QuikSCAT and NCEP blended wind. The comparison between the model results and the observations from buoys indicates the simulative wave result was obtained with high precision and resolution. Xu et al. (2005) used the WAVEWATCH-III wave model in the East China Sea to set up a proper numerical wave model. We implemented wind fields from NCEP (National Centers for Environmental Prediction), and combined NCEP and QSCAT wind field data in a computational domain to simulate the wind wave field for two time ranges in the East China Sea. The observation spots were distributed in the Bohai Sea and the East China Sea and the model gave out corresponding outputs between the two points. A full-spectral third-generation ocean wind-wave model WAVEWATCH-III was used to simulate the wind wave during 1996 in the South China Sea Qi et al. (2003b). The significant wave heights from the model and the TOPEX/Poseidon (T/P) altimetry data were compared over the crossover points.

3. Marine meteorological monitoring technologies

From the 1960s, the marine meteorological monitoring technology in China has made great progress: having developed large-scale ocean and atmosphere field experiments and having carried out various marine observations. However, the observations only covered a limited part of the ocean. Such traditional marine observations prevent comprehensive investigations on the entire ocean at the same time. Remote sensing ocean and atmosphere observations showed great advantage, thanks to the launch of various marine and atmosphere satellites. Large-scale observations at different heights from space at real time, direct and indirect observations of air temperature, humidity, surface wind speed, cloud, mist, SST, sea surface wind, wave, sea level height, and sea ice, etc. can be acquired routinely. Particularly, satellites can monitor disastrous weather, such as typhoons, tropical storms, subtropical cyclones, and flooding, providing a great deal of precious data of global climate change for research.

3.1 *Sea surface temperature remote sensing*

The sea surface temperature distribution and variability are basic contents of physical oceanography. Observations based on ships and stations alone cannot provide simultaneous sea surface data for a large area. Thermal infrared remote sensing observations provide easy access to the global SSTs at real time and low cost.

Many scientists have studied the SSTs from infrared remote sensing. Zheng et al. (2006) introduced the characteristics of MODIS and the algorithm for the retrieval of SSTs from MODIS data. The retrieval of SSTs in 2003 and 2004 was obtained with SeaDAS software. The results showed that the mean error is 0.23°C, the standard error is 0.29°C, and the maximum error is 0.5°C between the retrieved SSTs and *in-situ* data. The variation of SSTs at 124°E and 29°30′N over four months was analyzed along with monthly SST changes in 2004. They also showed that the retrieved monthly SST changes and distributions were consistent with real changes.

3.2 *Cloud remote sensing*

In the weather forecasting report, satellitic nephogram information plays a more and more important part as the key information resource. Recently, speedy development of computer auto-analyzing technology greatly accelerated the theoretical study and technology application of atmospheric remote sensing. Auto-distill and the quantitative distinguish of weather information from the nephogram and the realization by computers are the main task of today's atmospheric remote sensing. Wu et al. (2004a) used the fuzzy clustering method (FCM) to classify clouds and then developed nephogram cloud classification to a certain extent.

Based on two-dimensional (infrared and visible) gray space projections of cloud classification samples, the FCM is used to adjust and optimize the characteristic area of cloud classification samples in order to reduce the sampling errors (Wang et al., 2005b). In view of the limitation of conventional FCM in tackling the above problems, an improved FCM is used to characterize the mean of the cloud samples instead of the random initial clustering center that was proposed. The improved FCM avoids the defect that was sensitive to the initial clustering center in the conventional FCM and rectifies the distortion of the characteristic structure of the cloud samples by the clustering results. As a result, the improved FCM clustering results can reduce the sampling errors and retain the main attributes of the cloud classification samples. The classification results can be used to correctly identify land, water, low clouds, middle clouds, cirrus, convective clouds and cumulonimbus, along with delivering segmentation and discrimination results that are consistent with the objective facts.

Meso-scale disastrous weather, such as rainstorms, thunderstorms, gales, and so on, are usually ruinous, occur abruptly, and move fast. The forecast of these systems is a difficult issue that has yet to be solved and requires an exigent demand of monitoring. Stable satellites could provide large-scale, round-the-clock nephogram information. The monitoring and forecasting of clouds help to forecast disastrous weather in real time and objectively, which is a practical and complicated subject in the remote sensing study and is of great importance.

In order to predict the movement and change of clouds using a nephogram, Liu et al. (2006b) described a cloud forecast technique using cross-correlation from two time sequential Geostationary Meteorological Satellite-5 (GMS-5) images. Cloud movement vectors were retrieved at a 32×32 subset of points through the application of a cross-correlation analysis. An area in the first of the two sequential frames of the satellite data was correlated with the surrounding areas in the second frame to find the one surrounding area best correlated. The location difference of the areas defined the displacement vector. After the objective analysis of the displacements, a forecast was then produced with a backward trajectory technique using these displacements. The results showed that short-time forecasts of cloud motion with slow change achieved better results by the quantificational and fast scheme.

3.3 *Precipitation remote sensing*

Precipitation data derived from the TRMM Precipitation Radar (PR) are used by Fu et al. (2003) to study precipitation characteristics in 1998 over East Asia (10°–38°N, 100°–145°E), especially over the midlatitude (continental) land and ocean and its comparison with precipitation in the tropics. Yearly statistics show dominant stratiform rain events over East Asia, contributing to 50% of the total precipitation with a 83.7% area fraction. Deep convective rains contribute 48% to the total precipitation with a 13.7% area fraction. The statistics also show the unimportance of warm convective rain in East Asia, contributing only 1.5% to the total precipitation with a 2.7% area fraction. On a seasonal scale, the results indicated that the rainfall ratio of stratiform rain to deep convective rain is proportional to their rainfall pixel ratio. Seasonal precipitation patterns compare well with the Global Precipitation Climatology Project (GPCP) rainfall and the TRMM PR measurements except in the summer. The study indicated a clear opposite shift in rainfall amounts and events between deep convective and stratiform rain in the meridional direction in East Asia, which corresponds to the alternative activities of the summer monsoon and the winter monsoon in this region. The vertical structure of precipitation also exhibited strong seasonal variability in the Contoured Rain-rate by Altitude Diagrams (CRADs) and mean profiles in the mid-latitudes of East Asia. However, the precipitation structure in the South China Sea is of the tropical type except in the winter. The analysis of CRADs revealed a wide range of surface rainfall rates for most deep convective rains, especially over the land, and light rain rates for most stratiform rains in East Asia, regardless over land or ocean.

In Li and Fu (2005), monthly mean tropical precipitations estimated using the latest GPCP version 2 and the TRMM PR data sets were compared in terms of temporal and spatial scales in order to obtain comprehensive tropical rainfall climatology. Reasons for the rainfall differences between the two datasets were discussed. It was found that the GPCP and the TRMM PR datasets present similar distribution patterns over the tropics but with some differences in terms of the amplitude and location. Generally, the average difference over the ocean was about 0.5 mm d^{-1} larger than that of about 0.1 mm d^{-1} over land. Results also showed that the GPCP tends to underestimate the monthly precipitation over the land with sparse rain gauges in contrast to the regions with more rain gauge stations. A probability distribution function (PDF) analysis indicated that the GPCP rain rate at its maximum PDF is generally consistent with the TRMM PR rain rate when the latter is less than 8 mm d^{-1}. When the TRMM PR rain rate is greater than 8 mm d^{-1}, the GPCP rain rate at its maximum PDF is at least 1 mm d^{-1} less compared to the TRMM PR estimate. Results also showed an absolute bias of less than 1 mm d^{-1} between the two datasets when the rain rate is less than 10 mm d^{-1}. A large relative bias of the two datasets occurs at both weak and heavy rain rates.

3.4 *Fog and visibility remote sensing*

Fog can also cause severe weather because it can reduce the visibility, worsen the air quality, and thereby influence navigation, military affairs, and people's health, therefore, making the monitoring of fog very important. Using a remote sensing method to identify and forecast fog has been studied and developed for many years in other countries. Fog studies focus on its identification during the day, and mainly use the threshold method and experiences to identify fog from the fog's structure and distribution in the satellite images. In December 1999, MODIS was launched successfully and its high resolution and multi-channel character became the hotspot of remote sensing. Using a statistical analysis method, Zhang et al. (2003) monitored fog during the day using the data from MODIS channels 1, 3, and 7, and monitored the fog at night with the data from MODIS channels 21 and 31. Based on meteorological observation data，NOAA-17 and EOS/MODIS satellite remote sensing image data, 37 sea fog examples were analyzed (Sun et al., 2006). The statistical characteristics of sea fog, atmospheric and oceanic background conditions were helpful for sea fog formation on the Dandong coast, were revealed. A synoptic forecasting method was developed.

Fu et al. (2004) used almost all available observational data and the RAMS (Regional Atmospheric Modeling System, Version 4.4) model to investigate a dense sea fog event that occurred over the Yellow Sea on 11 April 2004. The evolutionary process of this fog event is described based on the GOES (Geostationary Operational Environmental Satellite)-9 and NOAA-14 visible satellite imagery. The synoptic situation prior to the sea fog formation and the temperature difference between the 2-m air and sea surface during the sea fog formation are also analyzed. The stability of the lower atmosphere when the sea fog occurred are also examined by using sounding data at the Qingdao and Cheju stations.

In the light of the differences of microphysical characteristics between fog and clouds, Deng et al. (2006) simulated the spectrum characteristics of MODIS Channels 1, 6, 20, and 31 by using the Santa Barbara DISORT Atmospheric Radiative Transfer (SBDART) model. They indicated that the measurements of these four channels all contain information of clouds and fog and can be used to detect daytime fogs. A monitoring algorithm based on the simulations was presented and demonstrated by analyzing a fog case. The analysis showed that the monitoring method could improve the capability of daytime heavy fog and low cloud monitoring through satellites. The relative humidity equation and numerical models are used to study the advection, turbulence, and radiation effects in the sea fog formation process (Hu et al., 2006). It is shown from the study's results that the main driving force of sea fog formation is the longwave radiation cooling. The turbulent cooling of the lower layer of the atmosphere occurs only at the initial stage of the advection process, and the turbulence effect on the lower layer of the atmosphere quickly turns to the heating effect with the elapse of time so as to be unfavorable to the sea fog formation.

Recently, using the photics imaging theory to get visibility data is the main method in visibility studies. The remote sensing data has been applied broadly in the monitoring of fog and visibility and the data mostly comes from Japanese Geostationary Meteorological Satellites (GMS) and NOAA satellites. The correlation between the MODIS spectral data and the atmospheric horizontal visibility (AHV) was analyzed over the South China coastal area from October 2002 through August 2003 (Qian et al., 2006). Firstly, the MODIS images were classified into four categories: clear sky (I), fog and lower-layer cloud (II), cumulonimbus (III), and the rest (IV). Then the optimal bands were selected to minimize correlated bands and maximize the correlation coefficients to AHV. Statistic analysis showed that certain relationships did exist between the visibility and the surface reflectance of MODIS. Categories I and III achieved better results (correlation coefficients above 0.6 and 0.9, exceeding 95% confidence leve1), due to relatively fixed atmospheric composition and simple extinction process. Category II was a mole complex atmospheric condition and thus resulted in a relatively low retrieval precision, with a correlation coefficient of 0.5 and a 94.2% confidence leve1. Finally, categorized regression models were built and simulated results were compared to actual observations. In summary, the classified statistical retrieval model based on atmospheric conditions is an effective method for the AHV retrieval problem.

3.5 *Sea-ice remote sensing*

Monitoring sea ice with remote sensing technology can provide long term, successive, large-scale data at real time. The study and application of this technology enhances the study of sea-ice dynamics, providing ground for the study of air-ice-ocean interaction and data for ice-ocean coupled modeling.

The high resolution and wide spatia1 coverage enable MODIS to be more useful to represent the distribution of ice concentration and thickness and in sea-ice monitoring and forecasting than other data. The contrast between retrieval results from MODIS and those from HY-1A/COCTS is revelatory for the development of HY-1 series satellites. It can help to improve mapping and quantification of sea ice from HY-1. To meet the demand of monitoring and forecasting sea ice, it is necessary to quantify sea ice from satellites using remote sensing. Sea ice in the Bohai Sea is retrieved from MODIS/1B data by Wu et al. (2006). Sea-ice images and digital data on ice concentration and thickness were provided. This data is an important source of information for monitoring sea ice in the Bohai Sea and for providing initial data for sea-ice forecasting and for verifying sea-ice forecasting.

Based on meteorological observation data, NOAA-17 and EOS/MODIS satellite remote sensing image data, 37 sea fog examples were analyzed (Sun et al., 2006). The statistical characteristics of sea fog, atmospheric and oceanic background conditions were helpful for sea fog formation in the Dandong coast, were revealed. A synoptic forecasting method was developed. Fu et al. (2004) used almost all available observational data and the RAMS (Regional Atmospheric Modeling System, Version 4.4) model to investigate a dense sea fog event that occurred over the Yellow Sea on 11 April 2004. The evolutionary process of this fog event is described based on the GOES (Geostationary Operational Environmental Satellite)-9 and NOAA-14 visible satellite imagery.

Using hourly diurnal visibilities, relative humidity, and the wind at the Xiamen airport from 2000 to 2002, Wang et al. (2005a) found that there were distinct daily, seasonal, intraseasonal, and quasi-two-week variations of visibility by the statistical method and the wavelet analysis method. In the observed time, from 0800 UTC to 2000 UTC, daily data shows that the visibility is the lowest in the morning and evening but reaches its maximum in the afternoon. In seasonal variation, visibility is the lowest from March to May, a foggy season in Xiamen. Besides the oscillations mentioned above, the visibility has two other remarkable variations: intraseasonal variability and quasi-two-week variability. The two variations have the same variability of the quasi-two-year period in both the summer and the winter, which relates to the oscillation of the monsoon in eastern Asia.

3.6 *Red tide and wave remote sensing*

In recent years, red tides appear to have increased in frequency, intensity, and geographic distribution. It has been one of the common ocean disasters in near shore areas of China. It has had serious impacts on the ecosystem, the economy, and the life of inhabitants along the coast. Wang et al. (2006b) compared the spectrum of red tides and its surrounding water and analyzed the changing characters of chlorophyll-a concentration during the period of a red tide occurrence. A method of extracting red tide information with EOS/MODIS data was developed, which considers the ratio of Channels 3 and 4 reflectance and the ratio of Channe1s 9 and 11 water leaving radiance, combined with suspended sediments. On 15 June 2002 and 31 May 2004, red tides occurred in the Bohai Sea. Results indicated that the method is useful to retrieve red tide information from the surrounding waters.

For validating the results of the retrieved mean wave period, four empirical algorithms previously established were introduced by Sun and Song (2006). Based on the data from over five years derived from the TOPEX/Poseidon satellite altimeter for the entire East China Sea, ocean wave periods were calculated and statistical comparisons among them were performed. The retrieved mean wave period (T) obtained with new distribution parameters showed better agreement with the wave period measured by buoys (T_{B}) than that calculated by the other three algorithms. The difference between the mean values of T and that of T_{B} is 0.16 and the RMSE (root mean square error) of T has the lowest value (0.48).

3.7 *Earthquake and tsunami remote sensing*

Temperature anomalies before earthquakes have been recognized for years by many researchers who have studied temperature anomalies with satellite thermal infrared data. On the other hand, gas anomalies, such as methane and carbon dioxide, before earthquakes have only been derived from limited ground measurements and are still not applicable over large areas. MODIS thermal infrared data was used to study the temperature increase before the Ms 5.0 Taiwan earthquake on 15 January 2002, and Measurements of Pollution in the Troposphere (MOPITT) data was used to study the CO total column concentration before the Ms 7.5 Taiwan earthquake on 31 March 2002 (Guo et al., 2006). There existed both high temperature areas and high CO total column areas near the Ms 7.5 earthquake epicenter and these two areas were located at the same place. It is considered that this CO increase was caused by Earth's degassing. When these gases emit into the atmosphere, they will also lead to a temperature increase under the atmosphere's electromagnetic field.

The geographical information system (GIS) has been applied to earthquake and tsunami emergency works, and an earthquake and tsunami emergency command system (ETECS) for seaside cities has been developed that is composed of a basic database and six subsystems (Guan et al., 2006). By employing this system, the responsible municipal departments can make rapid predictions before the occurrence of an earthquake or tsunami; make commanding decisions concerning the disaster-fight during a disastrous event, and make rapid estimates of the casualties and economic losses. The government could then conduct relief work in time and plan for future disaster reductions and prevention methods.

4. Marine meteorological forecasting technologies

4.1 *Sea surface temperature forecasting*

According to the fact that the offshore sea has a smaller thermal capacity due to its shallow depth, a one-dimension model, based on the energy balance, was used by Qin and Sun (2005) to simulate the mean annual SST of the East China Sea. The simulated results were consistent with the observations, and the feature of SST variation as a function of latitude (longitude) was well reproduced. At the same time, the ability of simulating the SST interannual variability in the model was examined. The authors analyzed both advantages and disadvantages of the simple model used for the shelf sea.

Based on the spectrum analysis of the temperature field of the deep water in the Pacific and Atlantic Oceans, Qu et al. (2004) revealed that variation with a period of 22 years prevails in the global marine temperature change. Such cyclic change is much clearer in deep oceans. It is believed that this is the response of the global marine temperature field to the periodic change of the solar magnetic field. There are obvious phase differences between the water temperatures of the deep sea in different oceans. There is a phase difference of 115 degrees between the temperature changes of the southern and northern Atlantic Ocean; namely, the trends of their changes are almost contrary. The difference is 19 degrees between those of the southern and northern Pacific Ocean, with the change of the southern Pacific Ocean leading. In addition, the oscillation amplitude of the marine temperature change stimulated by the solar activities varies greatly in different waters. The amplitude of temperature change with a period of 22 years is 0.07°C in the northern Atlantic Ocean, while it is up to 0.18°C in the southern Atlantic Ocean, 2.5 times of that of the northern Atlantic Ocean. In the Pacific Ocean, the amplitude of temperature change with a period of 22 years is the largest in the northern Pacific Ocean; it is smaller in the southern Pacific Ocean and is the smallest near the equator.

By using the $1^\circ \times 1^\circ$ Hadley SST from 1901 to 2004 to study the long-term change of the SST in the offshore sea of China, Zhang et al. (2005b) found that the SST took on a warming tendency in the last 100 years and was the warmest from the l990s until now in the Bohai Sea, the Yellow Sea, the East China Sea, and the South China Sea. The change stream of annual and January averaged SSTs took on ladder types in the Bohai Sea, the Yellow Sea, and the East China Sea; SSTs were cold from the 1900s to the 1930s, warm in the 1950s, slightly cold in the 1960s, and increasing from the 1980s. The change stream of July average SSTs took on two wave types in the Bohai Sea and the Yellow Sea; it was cold in the 1900s and the 1980s, warm from the 1930s to the 1950s, and again in the 1990s. In the South China Sea, SSTs changed little from the 1900s to the 1970s. Except for the annual average SSTs in the East China Sea, annual, January and July monthly averaged SSTs of all areas had multi-periods of 2–4 years and 7 years.

Serious floods occurred in the central, southern, and southwestern Guangdong Province in May 1998. With a meso-scale model (MM5), Feng et al. (2004) simulated the climate in southern China for the month successfully and studied the effects of anomalous SST warming in the South China Sea on the weather and climate in southern China through sensitivity experiments. The results showed that the warming changed the energy exchange between the sea surface and the planetary boundary layer. It added, in effect, latent and sensible heat transmitting upward from sea surface to increase the monthly-mean air temperature in the lower troposphere over the sea and adjacent regions and the instability of air columns. These changes also resulted in an additional differential cyclonic (anti-cyclonic) circulation in the lower (upper) part of the troposphere. The changes in the atmospheric circulation structure had an important effect on the floods in the above-mentioned regions in May l998.

Lin et al. (2003) used the upper ocean data (from sea surface to 400-m depth; downloaded from the website of the Scripps Institution of Oceanography, available online from: http://jedac.ucsd.edu) to investigate the seasonal cycle of heat storage in the tropical Pacific Ocean. The different features from that of the SSTs was showed. Two low value areas occurred through the Pacific Ocean between 5°N and 10°N, and there were two rather clear patterns, one being a "boreal winter pattern (November to February)" and the other, a "boreal summer pattern (May to August)" with the other months (March, April, September, and October) being transition periods. The seasonality along 2°N and 10°N varies out of phase. On the contrary, the seasonality varies in phase along 2°N and 10°S. The variation in the eastern Pacific Ocean starts earlier than that in the central Pacific Ocean, clearly propagating from east to west.

4.2 *Wave forecast technology*

It is traditionally assumed that the relationship between wave steepness and wave age is independent of the wind wave growth state. In fact, the traditional relationship cannot describe the whole course of the wind wave growth. Wu et al. (2004b) assumed that the relationship between wave steepness and wave age changed with the variety of dimensionless fetch, and revealed a new relationship in the course of wind wave growth. Comparison with previous relationships showed that this new relationship explains the observations better than other existing relationships. In the case of small (large) fetch, the wave age value increases (decreases) more quickly than in other models. The results can clearly reflect the whole course of wind wave growth, an improvement over traditional results.

Taking the shallow water tide wave model as an example, the adjoint model of the marine shallow water model was established by Yin et al. (2003); the authors also discussed the usage of adjoint code technique and its code check in detai1. The shallow water tide wave model and its adjoint model were used to make the optimization test for the initial fields of the current velocity and water level. It was shown from the test results that the optimization of the initial field played an important role in the numerical simulation of the tidal wave system, and the adjoint code technique can be used to effectively design the adjoint model to make different assimilation tests and studies.

4.3 *Application of multi-sensor monitoring technology*

The marine environmental extreme va1ue parameters, such as wind speed, current speed, wave height, and wave period play an important role in marine engineering design. The new developments in extreme value statistics theory were used by Zhao et al. (2003) to theoretically prove that the Weibull distribution is the best among many statistical distributions and makes the long-term extreme value statistics more effective. Furthermore, a large amount of datasets were used to make a comparison between the least square estimation method and the maximum likelihood estimation method, and it was shown from the comparison that the latter was a more accurate estimation and the former was a more conservative estimation.

Multi-parameter hydrological gauge is an instrument developed by the South China Sea Institute of Oceanology, the Chinese Academy of Sciences, to measure synchronous currents, waves, tides, water temperature, and conductivity. By using the PUV method, a method to compute the wave directional spectrum with observed pressure and current vectors, the wave directional spectrum can be calculated and the dominant wave direction is then obtained. The comparison of the dominant wave directions derived from the multi-parameter hydrological gauge and the MARK II "Wave-Rider" directional buoy showed that both results coincide well with each other (Long et al., 2005).

In addition, a class of models for equatorial air-sea coupled oscillators is studied (Mo et al., 2005). Using the perturbation method, the asymptotic solution of the corresponding model was obtained.

5. Summary and discussion

Marine meteorology plays an extremely important part in marine-related industry. Without the high-quality weather service, it is impossible for various maritime activities to operate smoothly. Offshore oil drilling, bridges, coastal highways, ocean transportation departments, maritime search and rescue centers, transport docks, and civil aviation centers all depend on weather forecasts based on marine meteorology.

Coastal weather and climate are complex and multivariant, while marine production activities are complicated; therefore the exploration of the marine meteorology information is particularly important. China's marine meteorological observations have made great progress, including lots of large-scale in situ experiments. However, it is still far from meeting the need of marine production activities due to the lack of advanced overseas technology and services, which means accuracy and timeliness.

In order to advance marine meteorology, much work needs to be done. In particular, we should improve the detection system. To improve the precision in observations, we need more in situ investigations and experiments. We need to reveal undocumented phenomena in air-sea interactions using the acquired data and illustrating the intrinsic theory. Finally, we should apply research results to forecast marine weather and the sea state. On the other hand, a proper ocean-atmosphere fluid dynamics model based on the understanding of the air-sea interaction in theory should be established. With such a model we could illustrate the importance of the ocean on the evolution of atmospheric circulations and climate change, and analyze the impact of the atmosphere on the ocean circulation and wave development.

Our prospects of the marine atmosphere are the remote sensing, telemetry, continuum and automation of observation systems, the colligation, broadband, high speed and numeric of the information processing system, and the personal and multimedia service systems in the future.

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REFERENCES

Chen, H. B., B. Chen, and H. Y. Liu, 2006: Analysis of directional spectrum of sea waves in China. *Journal of Waterway and Harbour*, **27**(2), 69–73. (in Chinese)

Deng, J., J. Bai, J. W. Liu, X. W. Wang, and H. Y. Shi, 2006: Detection of daytime fog using MODIS multispectral data. *Meteorological Science and Technology*, **34**(2), 188–193. (in Chinese)

Ding, W. Y., Q. L. Wan, and Y. H. Duan, 2005: 3D-Var assimilation of TRMM rain rate and its impact on the typhoon Dujuan (0313) forecast. *Chinese J. Atmos. Sci.*, **29**(4), 600–608. (in Chinese)

Dong, X. N., and Z. B. Sun, 2006: Characteristics of Arctic sea-ice and its relation with autumn air temperature in China. *Journal of Nanjing Institute of Meteorology*, **29**(2), 82–87. (in Chinese)

Feng, R. Q., Z. M. Gu, C. S. Wu, E. B. Hou, A. Y. Wang, and T. Y. Tang, 2004: A numerical study of the effects of South China Sea SST anomalies on the climate in South China. *Journal of Tropical Meteorology*, **20**(1), 32–38. (in Chinese)

Fu, G., J. Q. Wang, M. G. Zhang, J. T. Guo, M. K. Guo, and K. C. Guo, 2004: An observational and numerical study of a sea fog event over the Yellow Sea on 11 April，2004. *Periodical of Ocean University of China*, **34**(5), 720–726. (in Chinese)

Fu, Y. F., Y. H. Lin, G. S. Liu, and Q. Wang, 2003: Seasonal characteristics of precipitation in 1998 over East Asia as derived from TRMM PR. *Adv. Atmos. Sci.*, **20**(4), 511–529.

Gao, X. J., Y. H. Lin, Z. C. Zhao, and F. Giorgi, 2003: Impacts of greenhouse effect on typhoon over China as simulated by a regional climate model. *Journal of Tropical Oceanography*, **22**(4), 77–83. (in Chinese)

Guan, Y. H., Q. M. Feng, and J. Jia, 2006: A GIS-based earthquake and tsunami emergency command system for seaside cities. *Journal of Ocean University of*

China, **5**(2), 181–186.

Guo, G. M., Y. G. Cao, and J. M. Gong, 2006: Monitoring anomaly before earthquake with MODIS and MOPITT data. *Advances in Earth Science*, **21**(7), 695–698. (in Chinese)

Guo, T. B., 2004: The way to forecast sea advection fog from evaporation duct. *Marine Forecasts*, **21**(4), 40–47. (in Chinese)

Hou, W. W., and J. H. Wang, 2004: Analyze Zhejiang inshore fog's law and cause. *Donghai Marine Science*, **22**(2), 9–12. (in Chinese)

Hu, R. J., K. H. Dong, and F. X. Zhou, 2006: Numerical experiments with the advection, turbulence and radiation effects in the sea fog formation process. *Advances in Marine Science*, **24**(2), 156–165. (in Chinese)

Huang, Z., and L. X. Lin, 2004: Climatic Features of Tropical Cyclones Invaded Southwestern China. *Meteorological Monthly*, **30**(9), 14–18. (in Chinese)

Ji, T. K., and Z. M. Zhao, 2005: The theory to evaluate the image spatial resolution quantitatively. *Journal of Remote Sensing*, **9**(4), 486–493. (in Chinese)

Li, R., and Y. Fu, 2005: A comparison of the tropical monthly precipitation estimated by GPCP version 2 datasets and TRMM PR observations. *Acta Meteorologica Sinica*, **63**(2), 146–160. (in Chinese)

Li, W. B., X. C. He, and J. Tang, 2004a: Numerical simulation of typhoon "Sinlaku": roles of sea spray. *Journal of Tropical Oceanography*, **23**(3), 58–65. (in Chinese)

Li, J. N., A. Y. Wang, Z. L. Yang, G. L. Li, C. S. Wu, and E. B. Hou, 2003: Features of the surface wind distribution of typhoon Vongfong landfall progress based on QuikSCAT data. *Journal of Tropical Meteorology*, **19**(S1), 88–96. (in Chinese)

Li, J. N., Z. P. Gong, A. Y. Wang, G. L. Li, and Z. M. Gu, 2004b: Progress in the study of typhoon rainstorm in recent ten years. *Tropical Geography*, **24**(2), 113–117. (in Chinese)

Li, J. N., Z. P. Gong, A. Y. Wang, G. L. Li, and E. B. Hou, 2004c: Numerical experiments of the South China Sea typhoon Vongfong (2002). *Acta Scientiarum Naturalium Universitatis Sunyatseni*, **43**(3), 85–89. (in Chinese)

Li, M. L., and Y. J. Hou, 2005: Simulating wind-wave field of the East China Seas with QuikSCAT/NCEP blended wind and WAVEWATCH. *Marine Sciences*, **29**(6), 9–12. (in Chinese)

Li, M. K., Y. J. Hou，B. S. Yin，J. B. Song, and W. Zhao, 2006b: Numerical simulation of scatterometer assimilated wind and ocean wave in eastern China seas and adjacent waters. *Chinese Journal of Oceanology and Limnology*, **24**(1), 42–47.

Li, S. J., W. Y. Sha, and Y. Q. Qi, 2006a: Joint probability analysis of numerical simulation results of typhoon wave and storm surge of the Wulei station at the Beibu Bay. *Marine Science Bulletin*, **25**(4), 23–28. (in Chinese)

Li, Z. J., and Z. H. Zhang, 2004: Sea ice investigation in CHIARE-2003 and future arctic ice research tactic. *Chinese Journal of Polar Research*, **16**(3), 202–210. (in Chinese)

Li, Z. J., Z. H. Zhang, X. L. Dong, and P. Lu, 2004d: A new observation technology of the key index of the growth and erosion processes of arctic ice. *Progress in Natural Science*, **14**(9), 1077–1080. (in Chinese)

Li, Z. J., Z. H. Zhang, X. L. Dong, and P. Lu, 2005: The sea ice conditions along the route of CHINARE-2003. *Chinese Journal of Polar Research*, **17**(4), 291–298. (in Chinese)

Lin, Y. H., X. B. You, and Z. B. Sun, 2003: Seasonal cycle of heat storage from surface to 400 m depth in the tropical Pacific ocean. *Chinese Journal of Geophysics*, **46**(4), 590–594. (in Chinese)

Liu, Q. Z., S. Bai, J. Y. Huang, and H. D. Wu, 2004: A thermodynamic coupling scheme for ice-ocean model. *Acta Oceanologica Sinica*, **26**(6), 13–21. (in Chinese)

Liu, Y., H. D. Wu, Z. H. Zhang, Q. Z. Liu, and S. Bai, 2006a: Modeling for the dynamic process of ice thickness variation using a particle-in-cell ice model. *Acta Oceanologica Sinica*, **28**(2), 14–21. (in Chinese)

Liu, K. F., R. Zhang, and Z. B. Sun, 2006b: A cloud movement short-time forecast based on cross-correlation. *Journal of Image and Graphics*, **11**(4), 586–590. (in Chinese)

Long, X. M., K. B. Zhang, S. A. Wang, S. Q. Cai, and J. C. Chen, 2005: A method for determining dominant wave direction by using multi-parameter hydrological gauge and its application. *Journal of Tropical Oceanography*, **24**(6), 72–78. (in Chinese)

Ma, L. M., Y. H. Duan, X. D. Liang, D. L. Wang, Z. H. Qin, and Z. H. Zeng, 2005: Four-dimensional variational data assimilation of TRMM data in numerical prediction of TC Danas (2001). *Acta Oceanologica Sinica*, **27**(6), 16–25. (in Chinese)

Meng, W. G., J. N. Li, A. Y. Wang, R. Q. Feng, Z. M. Gu, and J. H. Yan, 2005: Effects of condensation heating and surface fluxes on the development of a South China mesoscale convective system (MCS). *Journal of Tropical Meteorology*, **11**(2), 144–152.

Mo, J. Q., Y. H. Lin, and W. T. Lin, 2005: The perturbative solution for the tropical sea-air coupled oscillators. *Acta Physica Sinica*, **54**(9), 3971–3974. (in Chinese)

Qi, Y. Q., P. Shi, Q. W. Mao, and J. Wang, 2003a: Relationship and characteristic of the sea surface wind and wave fields over the South China Sea derived from T/P altimeter. *Journal Hydrodynamics*, **18**(5), 619–624. (in Chinese)

Qi, Y. Q., P. C. Chu, P. Shi, Q. W. Mao, and C. W. Fan, 2003b: Analysis of significant wave heights from WWATCH and TOPEX/Poseidon Altimetry. *Acta Oceanologica Sinica*, **25**(4), 1–9.

Qian, J. P., F. Huang, Z. Q. Cui, Z. H. Zheng, and Z. J. Wu, 2004: Spectral analysis and statistical retrieval of marine meteorological visibility using MODIS data. *Advances in Marine Science*, **22**(Z1), 58–64. (in Chinese)

Qian, J. P., F. Huang, G. F. Wang, W. X. Liu, Z. Q. Cui, and Z. H. Zheng, 2006: Empirical models for retrieval of atmospheric horizontal visibility over the sea based on MODIS data. *Journal of Ocean University of China*, **36**(3), 355–360. (in Chinese)

Qin, Z. K., and Z. B. Sun, 2005: Simulation of SST in the offshore sea of East China with a one-dimension Model. *Journal of Nanjing Institute of Meteorology*, **28**(4), 477–482. (in Chinese)

Qu, W. Z., S. G. Deng, F. Huang, X. Zhang, and W. Zhang, 2004: Response of change of deep sea temperature to sun activity. *Quaternary Sciences*, **24**(3), 285–292. (in Chinese)

Song, J., and Z. B. Sun, 2005: Improvement of a thermodynamic-dynamic sea ice model. *Journal of Nanjing Institute of Meteorology*, **28**(4), 433–441. (in Chinese)

Su, J., H. D. Wu, Q. Z. Liu, Y. F. Zhang, and S. Bai, 2005: A coupled ice- ocean model for the Bohai Sea I. Study on model and parameter. *Acta Oceanologica Sinica*, **27**(1), 19–26. (in Chinese)

Sun, L. Q., S. P. Liu, S. Y. Gao, S. M. Cao, W. W. Wang, and X. B. Fan, 2006: Conditions for sea fog formation in Dandong coast and its synoptic forecasting method. *Journal of Meteorology and Environment*, **22**(1), 25–28. (in Chinese)

Sun, Q., and J. B. Song, 2006: Comparison of retrieving methods of ocean wave periods from satellite altimeter with buoy measurements. *Chinese Journal of Oceanology and Limnology*, **24**(1), 6–11.

Wang, Q. M., C. F. Ma, J. W. Tang, and M. H. Guo, 2006b: A method for detecting red tide information using EOS/MODIS data. *Remote Sensing Technology and Application*, **21**(1), 6–10. (in Chinese)

Wang, X., F. Huang, F. X. Zhou, and Y. Li, 2005a: The analysis of meteorological visibility of Xiamen airport. *Journal of Tropical meteorology*, **21**(4), 420–426. (in Chinese)

Wang, X., F. Huang, and F. X. Zhou, 2006a: Climatic characteristics of sea fog formation of the Yellow Sea in summer. *Acta Oceanologica Sinica*, **28**(1), 26–34. (in Chinese)

Wang, Y. L., R. Zhang, Z. B. Sun, S. J. Niu, Q. L. Wan, and J. Y. Liang, 2005b: Modification of cloud picture sample and automatic identification of cloud type based on fuzzy clustering method. *Advances in Marine Science*, **23**(2), 219–225. (in Chinese)

Wu, L. T., H. D. Wu, W. B. Li, Q. Z. Liu, Y. F. Zhang, Y. Liu, and S. Bai, 2005: Sea ice drifts in response to winds and tide in the Bohai Sea. *Acta Oceanologica Sinica*, **27**(5), 15–21. (in Chinese)

Wu, L. T., H. D. Wu, L. T. Sun, Y. F. Zhang, Y. Liu, and X. Q. Wei, 2006: Retrieval of sea ice in the Bohai Sea from MODIS data. *Periodical of Ocean University of China*, **36**(2), 173–179. (in Chinese)

Wu, S. P., Y. J. Hou, B. S. Yin, J. B. Song, and X. X. Zhao, 2004b: Relationship between wave steepness and wave age in the course of wind wave growth. *Chinese Journal of Oceanology and Limnology*, **22**(4), 340–343.

Wu, Y. M., R. Zhang, G. R. Jiang, Z. B. Sun, and S. J. Niu, 2004a: A fuzzy clustering method for multispectral satellite images. *Journal of Tropical Meteorology*, **20**(6), 689–696. (in Chinese)

Xu, Y. Q., B. S. Yin, D. Z. Yang, and M. H. Cheng, 2005: Study of wave numerical model in East China Sea. *Marine Sciences*, **29**(6), 42–47. (in Chinese)

Yang, D. Z., B. S. Yin, Y. Q. Xu, J. Y. Wang, and R. N. Sha, 2005a: Application of the SWAN wave model to Bohai Sea: Improvement of Phillips linear growth term. *Advances in Water Science*, **16**(5), 710–714. (in Chinese)

Yang, Y. Z., F. L. Qiao, W. Zhao, Y. Teng, and Y. L. Yuan, 2005b: MASNUM ocean wave numerical model in spherical coordinates and its application. *Acta Oceanologica Sinica*, **27**(2), 1–7. (in Chinese)

Yin, X. Q., Y. Z. Yang, and F. L. Qiao, 2003: Study on variational data assimilation adjoint code technique for shallow water tide wave model. *Advances in Marine Science*, **21**(4), 413–423. (in Chinese)

You, Z. J., and B. S. Yin, 2006: Estimation of extreme coastal wave heights from time series of wave data. *China Ocean Engineering*, **20**(2), 225–241.

Zhang, H. Y., F. X. Zhou, and X. H. Zhang, 2005a: Interannual change of sea fog over the Yellow Sea in spring. *Oceanologia et Limnologia Sinica*, **36**(1), 36–42. (in Chinese)

Zhang, W. Z., M. N. Chen, and H. F. Zhao, 2003: Using SST of the Pacific to forecast the frequency of tropical cyclone on the northwest Pacific. *Marine Forecasts*, **20**(3), 18–24. (in Chinese)

Zhang, X. Z., Y. F. Qiu, and X. Y. Wu, 2005b: The long-term change for sea surface temperature in the last 100 years in the offshore sea of China. *Climatic and Environmental Research*, **10**(4), 799–907. (in Chinese)

Zhao, W., Y. Z. Yang, W. D. Yu, and F. L. Qiao, 2003: Long-term extreme value statistics theory and its application to the marine environmental parameter statistics and analysis. *Advances in Marine Science*, **21**(4), 471–476. (in Chinese)

Zheng, J. G., J. L. Li, and W. B. Yang, 2006: Retrieval of SST in the East China Sea with MODIS remote sensing data. *Marine Fisheries*, **28**(2), 141–145. (in Chinese)

Zhou, F. X., X. Wang, and X. W. Bao, 2004: Climatic characteristics of sea fog formation of the Huanghai Sea in spring. *Acta Oceanologica Sinica*, **26**(3), 28–37. (in Chinese)