UNDERSTANDING OF SEA FOG OVER THE CHINA SEAS

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China Meteorological Press

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Brief Introduction

This book is a collection of our recently-published 12 papers in international journals. It presents the remarkable achievements made during the latest decade of the 21st century in improving our understanding and ability to monitor and simulate the sea fog over the China Seas. The authors of this book have pioneered some of the achievements in sea fog study. The main purposes of this book are to summarize the current work on sea fog research, to outline perspectives for future sea fog research, as well as to enhance our understanding of sea fog over the China Seas.

The book is composed of two parts, Part I: Case study, and Part II: Comprehensive study. We hope that it may provide a useful overview on the current research of sea fog study in China, and it may work as a reference book for researchers and graduate students in the fields of atmospheric sciences and physical oceanographic sciences who have interests to investigate sea fog systematically.

图书在版编目(CIP)数据

中国海雾研究/傅刚等著. —北京:气象出版社, 2011.12
ISBN 978-7-5029-5399-7

Ⅰ.①中… Ⅱ.①傅… Ⅲ.①海雾-研究-中国
Ⅳ.①P732.2

中国版本图书馆 CIP 数据核字(2011)第 256719 号

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Publisher: China Meteorological Press
(46 Zhongguancun Nandajie, Haidian District, Beijing 100081, China)

(http://www.cmp.cma.gov.cn E-mail:qxcbs@cma.gov.cn)

First published in January 2012
First printed in January 2012
定价:60.00 元

Sea Fog

By FU Gang

No brilliance of rainbow
No magnificence of pink clouds
No cold of snow
No violence of storm
The blue sea fog
You are the gentle daughter of the vast oceans
Wearing a graceful veil
comes from the far horizon
appeared as magical image
exhibited to be a colorful light
Frost is your sister
Cloud is your brother
You look like silk velvet curtains erected for the lover
You sing songs to praise the dreams with wet sweet voice
Morning breeze blows accompanying with your gentle
Sunset goes down with your comfort and relax
This is the blue sea fog
I'd like to devote my whole life to reveal your mysteries

PREFACE

Sea fog is one kind of weather phenomenon occurring widely over oceans and coastal regions wherein tiny water droplets sustain in the atmospheric boundary layer and cause the atmospheric visibility to be less than 1 kilometer. As the low atmospheric visibility associated with heavy sea fog may cause traffic accidents and has significant effect upon the activities over seas, sea fog has long been widely concerned in the coastal nations. Gultepe *et al*. (2007) indicated that "the financial and human losses related to fog and low visibility became comparable to the losses from other weather events, e. g. , tornadoes or, in some situations, even hurricanes". Thus, to enhance our understanding to sea fog is of great importance for maritime and coastal safety.

Previous studies have indicated that the Bohai and Yellow Seas, as well as the East China Sea near Chinese coast are the regions where sea fog occurred frequently. Prof. WANG Binhua in Ocean University of China (previously named as Shandong College of Oceanography before 1988, and Ocean University of Qingdao before 2002, respectively) made outstanding contributions to the sea fog research. He has been regarded as the first scholar to investigate sea fog systematically. In 1983, he published his book "sea fog" in Chinese language by China Ocean Press. Then in 1985, the English version of this book was published by the Springer-Verlag company. To our best knowledge, it has been the first and unique professional book to study sea fog so far.

How to continue the sea fog research, the cause inherited from the older-generation of Chinese meteorologist, is one of significant problems for Chinese young researchers to think about seriously. We are very lucky to be the third-generation to study sea fog in China following Prof. ZHOU Faxiu, the second-generation successor in this field. In 2002, we published our first paper on numerical simulation of sea fog over the Yellow Sea in Chinese language. In recent years, under the financial supports of the China Meteorological Administration (CMA), the National Natural Science Foundation of China (NSFC), and the Ministry of Science and Technology of China (MOST), a sea fog research group in Department of Marine Meteorology, Ocean University of China, led by Profs. FU Gang, ZHANG Suping and GAO Shanhong, has published tens of papers on sea fog study collaborated with our colleagues and students (Ph. D students: GUO Jingtian and LI Pengyuan; Master students: WANG Jingqian, SONG Yajuan, WANG Guanlan, REN Zhaopeng, ZHANG Jiwei, ZHANG Shoubao, XU Jie, LI Ran, QI Yiling, LIU Jingwu, BAI Hui, WANG Yongming, DING Zuowei, YI Li, MENG Xiangui and LI Man; Undergraduate students: LI Xiaolan, ZHANG Shuqin and WANG

Shuai).

This book is a collection of our recently-published 12 papers in international journals. It is composed of two parts, Part I: Case Study, and Part II: Comprehensive Study. The book aims to enhance our understanding to sea fog over the China Seas. We hope that it may provide a useful overview on the current research of sea fog study in China. However, due to our limited knowledge on sea fog, the mistakes of this book are inevitable. We highly appreciate kind comments and suggestions from readers.

We would like to express our hearty thanks to Profs. KIMURA Ryuji, and NIINO Hiroshi from Ocean Research Institute of University of Tokyo, Japan for their initial and useful discussions on the topic of sea fog during FU Gang's studying in University of Tokyo from 1995 to 1999. We also want to thank Profs. XIE Shangping from University of Hawaii, KUO Yinghwa (Bill) from NCAR, Dr. LU Chungu from Natural Sciences Foundation, Dr. SUN Shan from NOAA, USA; Dr. GULTEPE Ismail from Environment Canada; Prof. EUGSTER Werner from Swiss Federal Institute of Technology; Profs. WANG Huijun, ZHANG Meigen, ZHANG Renjian from the Institute of Atmospheric Physics of the Chinese Academy of Sciences; Profs. CHEN Lianshou, QIN Zenghao, DUAN Yihong, ZHANG Renhe from China Meteorological Administration; Profs. ZHANG Qinghong, TAN Benkui, HU Yongyun from Peking University; Profs. WU Rongsheng, TAN Zhemin, WANG Yuan from Nanjing University; Profs. SUN Zhaobo, NIU Shengjie, GUAN Zhaoyong, LI Zihua, YANG Jun from Nanjing University of Information Science and Technology; Prof. ZHAI Guoqing from Zhejiang University; Profs. GUO Shichang and CAO Jie from Yunnan University; Profs. ZHOU Dingwen and LI Guoping from the Chengdu University of Information Technology for useful sharing sea fog knowledge with each other.

We are also very grateful for the administrative helps from Drs. LUO Yunfeng, ZHANG Yaotang, Ms. YANG Lei from CMA, Dr. ZHANG Chaolin from NSFC; observational helps from Prof. WANG Jianguo from Henan Meteorological Bureau, Prof. YANG Yuqiang from Hangzhou Meteorological Bureau, Mr. XUE Deqiang, CHEN Youkuan from Shandong Meteorological Bureau, Mr. XU Xiaoliang, XUE Yunchuan, WANG Xingong from Qingdao Meteorological Bureau.

Special thanks go to Profs. WANG Binhua and ZHOU Faxiu for their fundamental work on sea fog study. Thus, we have later opportunity to stand over the shoulder of giant to explore the mystery of sea fog. The authors want to thank all staff and students in the Department of Marine Meteorology at Ocean University of China, Profs. LIU Qinyu, WU Zengmao, WANG Qi, SUN Jilin, SHENG Lifang, HU Ruijin, HUANG Fei, Drs. LI Ziliang, QU Wenjun for their kind encouragements and helpful discussions during the sea fog study.

This book is partly supported by CMA under the grant number GYHY (QX) 200706031, by NSFC under the grant numbers of 40675006, 40706004, 40975003 and 41175006, by MOST under the 863 Project grant numbers of 2006AA09Z151 and 2006AA09Z149. This work is also supported by the open project of Laboratory of Physical Oceanography, Ocean University of China. Finally, this book would not have been published without strong supports of our families and many helps from the editor, Mr. LI Taiyu from China Meteorological Press.

Profs. /Drs. FU Gang, ZHANG Suping, GAO Shanhong,
Dr. LI Pengyuan, Qingdao, China
18 September 2011

CONTENTS

PART I

CASE STUDY

CHAPTER 1

ANALYSIS AND HIGH-RESOLUTION MODELING OF A DENSE SEA FOG EVENT OVER THE YELLOW SEA

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Abstract

A ubiquitous feature of the Yellow Sea (YS) is the frequent occurrence of the sea fog in spring and summer seasons. An extremely dense sea fog episode was observed around the Shandong Peninsula in the morning of 11 April 2004. This fog patch, with a spatial scale of several hundreds kilometers, reduced the horizontal visibility to be less than 20 meters in some locations, and caused a series of traffic collisions and 12 injuries on a coastal stretch of major highway. In this paper, almost all available observational data including Geostationary Operational Environmental Satellite (GOES)-9 visible satellite imagery, objectively reanalyzed data of final run analysis (FNL) issued by National Center for Environmental Prediction (NCEP) and sounding data of Qingdao and Dalian, as well as the latest 4. 4 version of Regional Atmospheric Modeling System (RAMS) model were employed to investigate this sea fog case. Its evolutionary process and the environmental conditions that led to the fog formation were examined by using GOES-9 visible satellite imagery and sounding observations. In order to better understand the fog formation mechanism, a high-resolution modeling of 4 km×4 km using RAMS model was designed. The modeling was initialized and validated by using FNL data. A 30-h model simulation that started from 18 UTC 10 April 2004 reproduced the main characteristics of this fog episode. The simulated lower horizontal visibility area agrees reasonably well with the sea fog region identified from the satellite imagery. It is shown that advection cooling effect played a significant role in the fog formation.

1.1 Introduction

Fog is a weather phenomenon in which tiny water droplets suspend in the vicinity of the earth's surface atmosphere and cause the horizontal visibility to be less than 1 kilometer. The significant difference between fog and cloud is only that the base of fog is at the earth's surface while cloud is above the surface. The term sea fog is usually given to the fog that occurred over oceans and coastal regions (Wang, 1985). Sea fog is often a

deadly impediment to visibility and ocean navigation. According to Trémant (1987), over 80 percent of calamities at sea were related to sea fog. Thus, to understand, predict and forecast sea fog is extremely important for maritime and coastal safety.

The study of fog can be traced back to about 200 years ago (e. g., Wells, 1814; Taylor, 1917; Willet, 1928; Duynkerke, 1991; Guedalia and Bergot, 1994; Fu *et al.*, 2004; Pagowski *et al.*, 2004). Wang (1983) investigated sea fog systematically and indicated that weak wind speed, large stability of air were necessary conditions for fog formation. He generally categorized the fog into four types: advection fog, radiation fog, frontal fog and ice or snow fog. Actually, most fogs resulted from a combination of the above physical processes.

Among some areas where sea fog occurred frequently, the Yellow Sea (hereafter YS, see its location in Figure 1.1) is most notably. There have been several studies on sea fog over the YS (Wang, 1983; Cho *et al.*, 2000; Fu *et al.*, 2004). Zhou and Liu (1986) found that 80 percent of sea fog over the YS was advection fog. Cho *et al.* (2000) documented historical data of sea fog and investigated the relationship between the environmental factors around the Korea Peninsula (including the YS) and sea fog occurrence. Fu *et al.* (2004) provided a comprehensive view of the nature of sea fog over the YS by describing and analyzing the climactic characteristics such as the duration, the

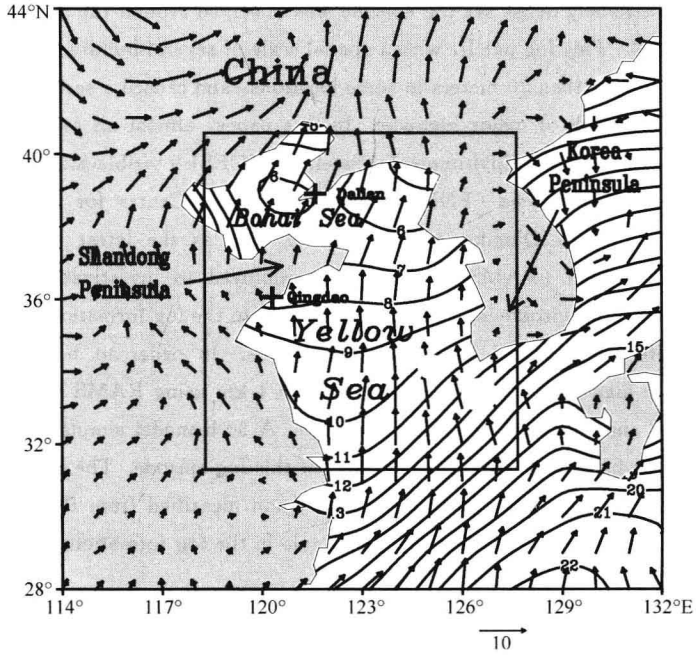

Figure 1.1 Geographic map of the Yellow Sea and its neighboring regions. The large square shows the calculation domain used for RAMS simulation later. The horizontal distributions of SST and sea surface wind field at 18 UTC 10 April 2004 is presented as contour (in ℃) and vectors, respectively. Two observational stations, Qingdao and Dalian, are indicated with "+" symbol on the map.

dissipation, the seasonal and daily variation of sea fog. In addition, the oceanic features and synoptic conditions occurring during sea fog were documented including wind field, oceanic surface currents, air temperature and humidity and the stability of lower atmosphere.

An extremely dense sea fog episode was observed over the YS in the morning of 11 April 2004. The fog patch spread a far distance into the Shandong Peninsula and reduced the atmospheric horizontal visibility to be several tens meters on a coastal stretch of a major highway. The fog went on about one day and led to series of traffic collisions. Totally, 12 persons were injured and the traffic jam lasted about 9 hours in the highway. In the present study, almost all available observational data collected during the fog episode including Geostationary Operational Environmental Satellite (GOES)-9 visible satellite imagery, objectively reanalyzed data of the Final run analysis (FNL) issued by National Centers for Environmental Prediction (NCEP), sounding data at Qingdao and Dalian, as well as the high-resolution modeling results using the latest 4.4 version of Regional Atmospheric Modeling System (RAMS) model were employed to investigate the fog formation and development mechanism. We begin by analyzing the evolutionary process of this sea fog event and the environmental conditions that led to its formation. The modeling approach is then described. The paper concludes with a discussion and summary finally.

1.2 Data

The following data are utilized in the present study. (1) FNL data from 18 UTC 10 to 00 UTC 12 April 2004 issued by NCEP at the website of http://dss.ucar.edu/datasets/ds083.2/data/fnl-200404/. It covers the global region, and is available at 00, 06, 12, 18 UTC every day with the horizontal resolution of $1^\circ \times 1^\circ$ and 26 vertical pressure levels. (2) Visible satellite imagery of GOES-9 during the same period supplied by Kochi University of Japan at the website of http://weather.is.kochi-u.ac.jp. (3) Sounding data at 00 UTC 11 April 2004 at Qingdao (station no. 54857) and Dalian (station no. 54662).

1.3 Analysis and Modeling

The horizontal distributions of Sea Surface Temperature (SST) and the sea level wind field at 18 UTC 10 April 2004, prior to the fog formation, are shown in Figure 1.1. Some geographic area, such as the YS, its neighboring regions and two observational stations Qingdao and Dalian which will be mentioned in the following part are indicated on the map.

For the analysis of the physics of sea fog, satellite imagery may provide valuable information of fog or low clouds and complement the surface observations (Pagowski *et al.*,

2004). Figure 1.2 presents a sequence of visible satellite imagery of GOES-9 during the daytime①. It is seen that a patch of cloud with much stronger brightness occupied a part of the Bohai Sea (BS) and the northern part of the YS from 00 to 09 UTC 11 April 2004②. From 00 to 04 UTC (Figure 1.2 a,b,c), a part of cloudy area extending far into the middle part of the Shandong Peninsula corresponded with the ground-level fog as reported by Qingdao station. The dark regions represented clear or nearly clear regions. The cloud dissipated entirely over the land by 06 UTC. The patchness of the fog, as well as its stratocumulus nature, was evident in these imagery. This widespread cloud patch with uniformed cover is the dense sea fog region that will be studied in this paper. In this case, at least three evidences were found to support our identification that this cloud system was real fog patch. First, the cloud had no apparent structure, its cover was relatively uniformed and the color was not so bright, suggesting that this kind cloud was not cumulus but stratus; Second the cloud edges were distinct, hugging the shoreline around the Shandong Peninsula, suggesting that the clouds were lower even in touch with the sea surface; Third the movement of the cloud was not remarkable during the day, suggesting these cloud patches were lower because it is impossible for high-clouds without moving within a day.

FNL analyses showed that the weather of YS at 18 UTC 10 April 2004 prior to the fog formation was dominated by a stationary high-pressure system around 135°E, 30°N (not shown). At the sea surface, SST showed a "warm tongue" distribution towards the south direction. Also, a weak southerly with a speed of about 4 $m \cdot s^{-1}$ was found (see Figure 1.1). During that time neither precipitation nor passage of atmospheric front was observed over the interesting area. FNL surface observations at 00 UTC 11 April 2004 indicated that the air temperature over the YS was about 2 ℃ warmer than the SST (not shown). This is a favorable condition for the fog formation in this region (Cho *et al.*, 2000). Around 03 UTC, Qingdao station reported that very dense fog with about 20 m horizontal visibility appeared near the city of Qingdao. It caused a series of traffic accidents in the coastal stretch of a highway and 12 persons were injured.

Figures 1.3a, b show the T-ln$P$ diagrams of Qingdao and Dalian stations at 00 UTC 11 April 2004. Four distinct features associated with the sea fog formation were found in these two figures. (1) The values of Convective Available Potential Energy (CAPE) at two stations were zero, suggesting no convective activity in the lower atmosphere. (2) Below 925 hPa, there existed an air temperature inversion layer, suggesting that the lower-atmosphere was stable, and it supplied a favorable condition for the fog formation.

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① During the daytime, the fog banks or lower clouds can be determined by visible satellite imagery. However, during nighttime, it is hard to distinguish fog or low clouds by using a single infrared channel because the temperature of fog or low clouds is usually close to the surrounding cloud-free areas.

② For local standard time 08 LST is 00 UTC.

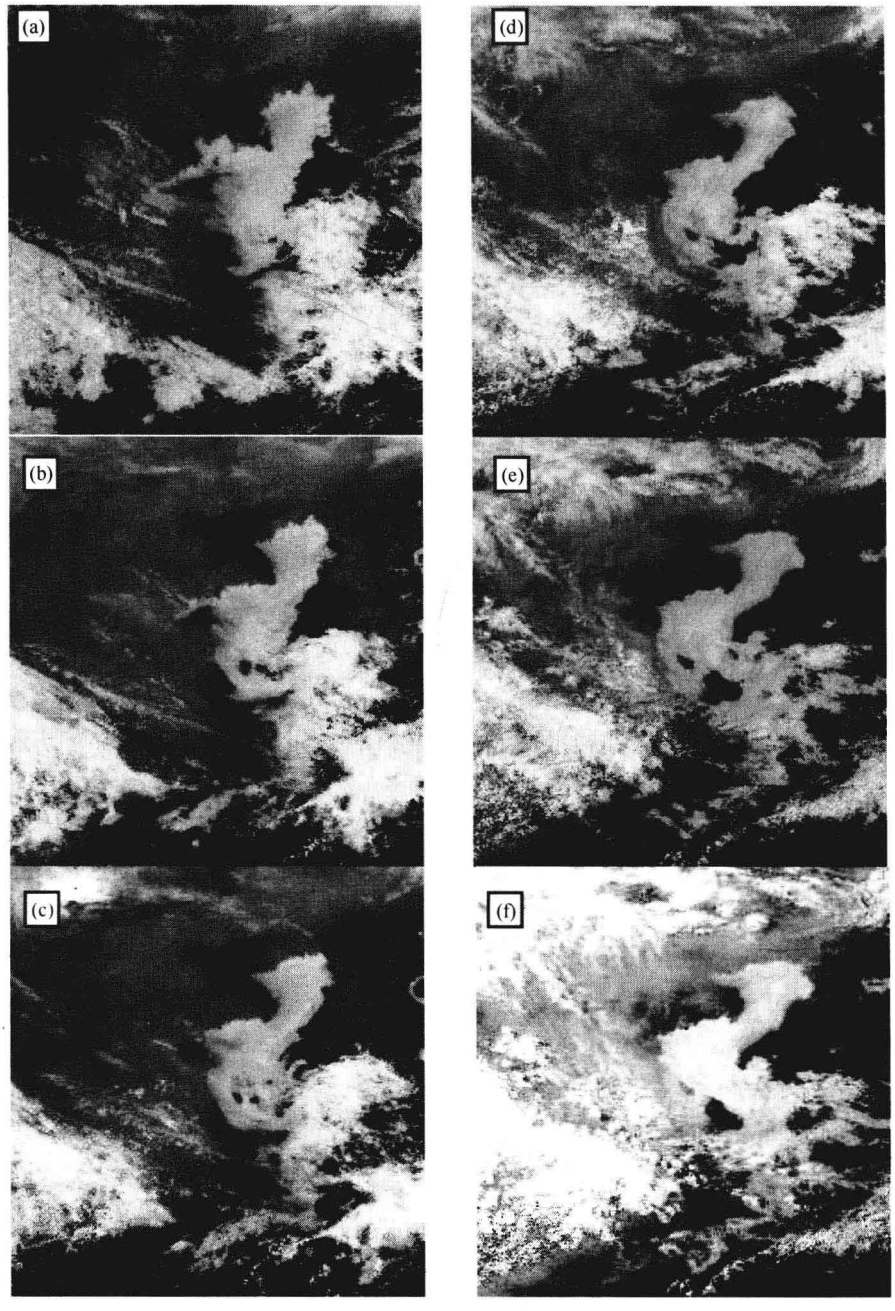

Figure 1.2 GOES-9 visible satellite imagery from 00 to 09 UTC 11 April 2004 showing the evolutionary process of sea fog event. The feather-like cloud system located in the northern part of the Yellow Sea and a part of the Bohai Sea is sea fog that will be studied in this paper. (a)00 UTC; (b) 02 UTC; (c)04 UTC; (d) 06 UTC; (e) 08 UTC; (f) 09 UTC. The minimum horizontal visibility of Qingdao at 03 UTC is less than 20 m.