



教育部海洋科学类专业教学指导委员会规划教材  
高等学校海洋科学类本科专业基础课程规划教材

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# 海洋气象学

Marine Meteorology

傅刚 © 编著



中国海洋大学出版社  
CHINA OCEAN UNIVERSITY PRESS

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# 总前言

海洋是生命的摇篮、资源的宝库、风雨的故乡，贸易与交往的通道，是人类发展的战略空间。海洋孕育着人类经济的繁荣，见证着社会的进步，承载着文明的延续。随着科技的进步和资源开发的强烈需求，海洋成为世界各国经济与科技竞争的焦点之一，成为世界各国激烈争夺的重要战略空间。

我国是一个海洋大国，东部和南部大陆海岸线1.8万多千米，内海和边海的水域面积为470多万平方千米。这片广袤海域蕴藏着丰富的海洋资源，是我国经济社会持续发展的物质基础，也是国家安全的重要屏障。我国是世界上利用海洋最早的国家，古人很早就从海洋获得“舟楫之便，渔盐之利”。早在2 000多年前，我们的祖先就开启了“海上丝绸之路”，拓展了与世界其他国家的交往通道。郑和下西洋的航海壮举，展示了我国古代发达的航海与造船技术，比欧洲大航海时代的开启还早七八十年。然而，到了明清时期，由于实行闭关锁国的政策，错失了与世界交流的机会和技术革命的关键发展期，我国经济和技术发展逐渐落后于西方。

新中国建立以后，我国加强了海洋科技的研究和海洋军事力量的发展。改革开放以后，海洋科技得到了迅速发展，在海洋各个组成学科以及海洋资源开发利用技术等诸多方面取得了大量成果，为开发利用海洋资源，振兴海洋经济，做出了巨大贡献。但是，我国毕竟在海洋方面错失了几百年的发展时间，加之多年来对海洋科技投入的严重不足，海洋科技水平远远落后于其他海洋强国，在海洋科技领域仍处于跟进模仿的不利局面，不能最大限度地支撑我国海洋经济社会的持续快速发展。

当前，我国已开始了实现中华民族伟大复兴中国梦的征程，党的十八大提出了“提高海

洋资源开发能力,发展海洋经济,保护海洋生态环境,坚决维护国家海洋权益,建设海洋强国”的战略任务。推动实施“一带一路”“21世纪海上丝绸之路”建设宏大工程。这些战略举措进一步表明了海洋开发利用对中华民族伟大复兴的极端重要性。

实施海洋强国战略,海洋教育是基础,海洋科技是脊梁。培养追求至真至善的创新型海洋人才,推动海洋技术发展,是涉海高校肩负的历史使命!在全国涉海高校和学科快速发展的形势下,为了提高我国涉海高校海洋科学类专业的教育质量,教育部高等学校海洋科学类专业教学指导委员会根据教育部的工作部署,制定并由教育部发布了《海洋科学类专业本科教学质量国家标准》,并依据该标准组织全国涉海高校和科研机构的相关教师与科技人员编写了“高等学校海洋科学类本科专业基础课程规划教材”。本教材体系共分为三个层次:第一层次为涉海类本科专业通识课教材:《普通海洋学》;第二层次为海洋科学专业导论性质通识课教材:《海洋科学概论》《海洋技术概论》和《海洋工程概论》;第三层次为海洋科学类专业核心课程教材:《物理海洋学》《海洋气象学》《海洋声学》《海洋光学》《海洋遥感及卫星海洋学》《海洋地质学》《化学海洋学》《海洋生物学》《海洋生态学》《海洋资源导论》《生物海洋学》《海洋调查方法》等,将由中国海洋大学出版社陆续出版发行。

本套教材覆盖海洋科学、海洋技术、海洋资源与环境 and 军事海洋学等四个海洋科学类专业的通识与核心课程,知识体系相对完整,难易程度适中,作者队伍权威性强,是一套适宜涉海本科院校使用的优秀教材,建议在涉海高校海洋科学类专业推广使用。

当然,由于海洋学科是一个综合性学科,涉及面广,且限于编写团队知识结构的局限性,其中的谬误和不当之处在所难免,希望各位读者积极指出,我们会在教材修订时认真修正。

最后,衷心感谢全体参编教师的辛勤努力,感谢中国海洋大学出版社为本套教材的编写和出版所付出的劳动。希望本套教材的推广使用能为我国高校海洋科学类专业的教学质量提高发挥积极作用!

教育部高等学校海洋科学类专业教学指导委员会

主任委员 吴德星

2016年3月22日



# 序

海洋气象学是海洋学和气象学之间的一门交叉学科,是近三四十年来迅速发展起来的新兴学科,这门学科的关键问题是海洋大气相互作用。长期以来,海洋界和气象界都充分认识到这个问题的重要性。要解决气象科学中的一些重要问题,如热带气旋、极地低压、爆发性气旋、海洋天气/气候现象与灾害等离不开海洋学;同样,要解决海洋学中的一些重要问题,如厄尔尼诺-南方涛动(ENSO)事件、海冰融化、冰盖消融、海洋环流、海浪、海表温度变化等也离不开气象学。另外,海洋航运与海洋经济开发、军事安全与防灾减灾等也迫切需要海洋学与气象学的密切结合,所以海洋气象学是在科学和实际应用日益增长的需求下迅速发展的。现代的海洋气象学,无论从内容与研究方法,以及应用服务范围和需求与早期阶段都不可同日而语,尤其是气候模式与地球系统模式的发展和应用,海-气-冰耦合是其关键的部分。因而海洋气象学在未来将会有更为广阔和深入的发展。

傅刚教授编著的《海洋气象学》,是他多年教学成果和经验的结晶。本书的特点是对海洋气象学基础知识有深入浅出的阐述,很适合相关专业的大学生和研究生阅读;同时傅刚教授在本书正式出版前增加了不少海洋气象学发展的新内容,包括海洋大气相互作用、ENSO事件及其与台风的关系、复合海洋与气象灾害、大型海陆风与区域季风等。这对于读者了解海洋气象学的新发展十分有益。本书填补了目前海洋气象学领域中的空白,对海洋与气象领域的师生、研究人员等,都是一本重要的参考书。

本书还介绍了对海洋与气象学领域有重大贡献的前辈、中外科学家,这对初

涉这两个领域的年轻学生和学者十分有益,从中可以汲取教益和治学精神。

傅刚教授在海洋气象学教学和研究上辛勤耕耘多年,对海洋气象学有深入的了解和认识。他编著的本书对气象界和海洋界都是重要的贡献。

中国工程院院士

丁-汇

2017年11月27日 北京





# PREFACE

Marine meteorology is an interdisciplinary subject crossing both oceanography and meteorology. It is a new discipline which has been developing rapidly in recent 30~40 years. One of the key issues in marine meteorology is ocean-atmosphere interaction. For a long time, both the oceanographic and meteorological communities have fully recognized the importance of this interaction. To solve some important problems in meteorological science, such as tropical cyclone, polar low, explosive cyclone, marine weather/climate phenomenon and disasters, it is indispensable to have a full insight of oceanography. Similarly, to solve some important problems in oceanography, such as ENSO (El Niño-Southern Oscillation) event, sea ice, ice melting, oceanic circulation, oceanic wave, sea surface temperature etc., nor is it possible to get a solid grip without a full understanding of meteorology at play. In addition, marine navigation and marine economic development, military safety and disaster prevention and reduction are also in dire need of mutual and coupled understanding of oceanography and meteorology. Therefore, marine meteorology is developed responsively under the growing demands of both science and practical applications. Modern marine meteorology is quite different from its early stage, not only in term of its content, but also in term of research methods, requirements, as well as applications. In juxtaposition of all these problems and applications, sea-air-ice coupling serves as the core understanding for the development of climate models and earth system

models. Building on top of these research and development, marine meteorology will undoubtedly have a faster, wider and deeper development in future.

The book *Marine Meteorology* authored by Professor Gang FU is the fruition of his teaching and researching over decades. This book introduces the basic knowledge of marine meteorology step by step, and is suitable for undergraduate and graduate students in the relevant fields. Before the formal publication, Professor Gang FU added many new contents, including ocean-atmosphere interaction, the relationship between ENSO event and tropical cyclone, compound marine meteorological disasters, large-scale sea/land breeze and regional monsoon etc. The book can be extremely valuable for readers to understand the new development in marine meteorology, as well as a useful reference for teachers, students and researchers. The book has filled many gaps in the field of marine meteorology.

This book also introduces ten famous scientists from China and foreign countries who have made great contributions to the progress of oceanology and meteorology, which will be very useful for young students and researchers to increase their understanding to the spirit of teaching and learning.

Professor Gang FU has worked in the field of marine meteorology for many decades, and had a deep understanding of marine meteorology. The book *Marine Meteorology* which he wrote is an important contribution to both meteorology and oceanography.

Academician of the Chinese Academy of Engineering

Yihui Ding

Beijing China

27 November 2017



# 前 言

对于长期在太平洋沿岸生活的人们, 往往都有感受台风、海雾、海陆风、风暴潮、海上大风等“海洋气象”现象的经历。但如何从理论上来系统地说明什么是海洋气象学, 并不是一件十分容易的事, 这不仅是因为不同地区的人们对海洋气象学的理解有差异, 而且还与海洋气象学相关的教科书太少有关。

我从1980年~1984年在原山东海洋学院海洋气象专业学习, 1984年~1987年也在海洋气象专业攻读硕士学位, 一直受“海洋气象学”氛围的浸染。1987年硕士毕业留校工作以来, 在教学和学术活动过程中, 一直从事关于日本海极地低压、海雾、爆发性气旋等方面的研究, 并始终在思考什么是海洋气象学? 十分幸运, 我先后搜集到了三本关于海洋气象学的教科书: 德国学者H. U. Roll在1965年著的*Physics of the Marine Atmosphere* (Academic Press), 日本学者小倉義光和浅井富雄在1975年合著的《海洋气象》(东京大学出版会), 北京大学周静亚先生和杨大升先生在1993年合著的《海洋气象学》(气象出版社)。

1995年~1999年, 我受原国家教委公派到日本东京大学海洋研究所(现为大气海洋研究所)海洋气象研究室攻读博士学位。虽然那时该研究室的开山鼻祖小倉義光和浅井富雄先生已经退休, 我没有太多机会与两位前辈当面深入交流, 但作为学生也聆听过两位老师在海洋气象研究室作的学术报告。后来有机会系统地学习了两位老师在1975年合著的《海洋气象》一书, 受到很多启发。

在学习了先辈们的著作后, 2004年就萌发了自己写一本海洋气象学教科书的念头, 先后多次在中国海洋大学海洋气象系内与有关老师交流过学术思想, 如秦曾灏教授、周发琇教授、刘秦玉教授、王启教授、孙即霖教授、张苏平教授、黄菲教授、盛立芳教授、胡瑞金教授、高山红教授、李春教授、李子良副教授、李鹏远博士等, 还与美国夏威夷大学王斌教授、王玉清教授, 现在加州大学圣迭戈分校斯克里普斯(Scripps)

海洋研究所担任罗杰·雷维尔讲席教授的谢尚平教授(我的大学同学),美国大气科学研究中心(NCAR)的郭英华博士、李文兆博士,北卡州立大学谢立安教授,佛罗里达州立大学蔡鸣教授,美国国家自然科学基金委员会的陆春谷教授,德国海岸带研究所前所长Hans von Storch教授,德国不来梅(Bremen)大学的Annette Ladstaetter-Weissenmayer教授,克罗地亚斯普利特(Split)大学的Darko Koračin教授,日本东京大学的木村龍治教授和新野宏教授等讨论过海洋气象学概念的内涵等问题。经过十多年的反复思考、徘徊、犹豫,甚至放弃等思想上的碰撞、斗争和煎熬,2017年8月10日终于完成了“海洋气象学”手稿。利用书中各章间隙介绍了9位“气象风云人物”,目的是传承大气科学的研究历史,激发青年一代从事海洋气象学研究的热情和斗志。经过中国海洋大学出版社魏建功编审的初审,2017年11月25日完成第6次文字修改。

承蒙中国气象局气候中心丁一汇院士在百忙之中对本书拨冗指导。遵照他的建议,在第二章增加了“第五节 海洋-大气相互作用”和“第六节 ENSO及其对大气环流的影响”,专门阐述海气相互作用这一海洋气象学的核心问题;在第三章插入了“第四节 大型海陆风——季风”;第四章增加了“第六节 热带气旋与ENSO的关系”;第八章增加了“第四节 风暴潮与复合性海洋气象灾害”,在“气象风云人物”中增加了对中国海洋科学与海洋教育事业的奠基人赫崇本先生生平的介绍。作者在此对各位教授们的有益讨论和建设性意见表示衷心的感谢!

由于作者出生在中国,学术活动也集中在环太平洋地区(中国、美国、日本和韩国),因此本书研究的所谓“海洋气象”现象也主要集中在太平洋地区和与中国邻近的海域。

在本书的写作和修改过程中,作者十分感谢中国海洋大学海洋气象系众多的毕业生和在读的研究生们的大力帮助,如郭敬天博士(国家海洋局北海预报中心)、庞华基博士(青岛市气象局)、王磊博士(美国芝加哥大学)、王帅博士(英国帝国理工学院)、张干博士(美国伊利诺伊大学)、傅聃博士(美国德州农工大学)、张树钦、徐杰、孙雅文、井苗苗、刘珊、李昱薇、陈莅佳、张雪贝提供素材、帮助绘制和修改图片。特别是王磊博士和王帅博士提供了多篇作者当时无法及时找到的原始文献。

作者感谢李子良副教授,其教学手稿“海洋气象学”对考虑组织本书的内容有很多启发和借鉴意义。作者还感谢中国海洋大学教务处给予的资金支持。最后要特别感谢中国海洋大学学报(自然版)编辑部的庞旻编审(我的夫人)对本书在文字、修辞、排版等方面提出的建设性意见。

作者衷心期盼有更多的“海洋气象学”能够出版,并希望未来10年本书能够经过补充和完善出版第2版。

谨将此书奉献给我的亲人们,特别是我将要出生的小孙女。

傅 刚

2017年11月25日 青岛



# INTRODUCTION

For people who lived near the coastal regions of the Pacific Ocean for long time, most of them may have the experiences of encountering typhoon, sea fog, sea/land breeze, storm surge and strong winds over ocean as well as other marine meteorological phenomena. However, it seems not an easy task for one to explain the concept of “marine meteorology” clearly and systematically. The is not only due to the fact that various people in different places have different understanding to marine meteorology, but also is perhaps related to the shortage of textbook of marine meteorology.

From 1980 to 1984, the present author studied his undergraduate major in marine meteorology in the former Shandong College of Oceanography (now named as Ocean University of China). From 1984 to 1987, he read for his master degree in the same major. He has been influenced heavily in the atmosphere of “marine meteorology”. After working as a teacher since 1987, he has been engaging in the researches of polar lows over the Japan Sea, sea fog, explosive cyclones during his process of teaching and researching activities. Meanwhile for a long time, he has been thinking about what is marine meteorology? Occasionally and fortunately, he collected three textbooks of marine meteorology: *Physics of the Marine Atmosphere* (1965, Academic Press) written by Prof. H. U. Roll in Germany, *Marine Meteorology* (in Japanese *Kaiyo Kishou*, 1975, Press of University of Tokyo) co-written by Japanese Profs. Tomio Asai and Yoshi Ogura, and *Marine Meteorology* (1993, China Meteorological Press) co-authored by Prof. Jing-Ya ZHOU and Prof. Da-Sheng YANG from Peking University.

From 1995 to 1999, supported by the Chinese government, the present author had

an opportunity to read for his Ph. D degree in Division of Marine Meteorology from Ocean Research Institute (renamed as Atmosphere and Ocean Research Institute) in University of Tokyo. It also supplied the present authors a chance to feel the academic influence of marine meteorology. Although Profs. Tomio Asai and Yoshi Ogura had already retired from this division at that time, the present author did not have more opportunities to make direct communication with these two great masters deeply, but being a student he also heard several academic reports of these two masters. Especially, after reading their co-authored book *Marine Meteorology* (published in 1975 in Japanese) systematically, the present author got a lot of inspiration.

After studying several textbooks written by old generation, the present author had his own idea of writing a textbook “Marine Meteorology” in 2004 initially. He had discussed, for many times, in the Department of Marine Meteorology of Ocean University of China with Prof. Zenghao QIN, Prof. Faxiu ZHOU, Prof. Qinyu LIU, Prof. Qi WANG, Prof. Jilin SUN, Prof. Suping ZHANG, Prof. Fei HUANG, Prof. Lifang SHENG, Prof. Ruijin HU, Prof. Shanhong GAO, Prof. Chun LI, Dr. Ziliang LI and Dr. Pengyuan LI to exchange academic thoughts. He had discussed with Prof. Bin WANG and Prof. Yuqing WANG at the University of Hawaii, Prof. Shangping XIE, the Roger Revelle Chair Professor at Scripps Institution of Oceanography in University of California, San Diego (the present author’s classmate), Dr. Ying-Hwa Bill KUO and Dr. Wen-Chau LEE from NCAR, Prof. Lian XIE from North Carolina State University, Prof. Ming CAI from Florida State University, Prof. Chungu LU from National Science Foundation of USA, Prof. Hans von Storch, the director emeritus of the Institute for Coastal Research of the Helmholtz-Zentrum in Geesthacht (previous name GKSS Research Center), Germany, Prof. Annette Ladstaetter-Weissenmayer from Institute of Environmental Physics, Institute of Remote Sensing, University of Bremen, Germany, Prof. Darko Koraćin from University of Split, Croatia, Prof. Ryuji Kimura and Prof. Hiroshi Niino from University of Tokyo, Japan, about the concept of marine meteorology. After undergoing a lot of bitter and painful consideration, struggling, hesitation and even abandoning for more than 10 years, eventually, he completed his first version of manuscript “Marine Meteorology” on 10 August 2017. By using the gap of different chapters of the book, he tried to introduce 9 great masters in the development history of atmospheric and oceanic sciences aiming to inherit the history of atmospheric and oceanic sciences and to stimulate the enthusiasm and morale of younger generation to engage in marine meteorology research. After the preliminary examination of Prof. Jiangong WEI, the chief editor from the Press of Ocean University of China, the present author had completed his sixth revision of this textbook on 25

November 2017.

The present author is very grateful to the distinguished Prof. Yihui DING, an Academician of Chinese Academy of Engineering from China Meteorological Administration to supply many constructive suggestions to this book. Following his kind advices, the present author added two sections “Section 5 Ocean-Atmosphere Interaction” and “Section 6 ENSO and Its Effects on Atmospheric Circulation” in Chapter 2, inserted one section “Section 4 Large-Scale Sea/Land Breeze——Monsoon” in Chapter 3, one section “The Relationship between Tropical Cyclone and ENSO” in Chapter 4, one section “Storm Surge and Compound Marine Meteorological Disasters” in Chapter 8. He also added an introduction to the life of Prof. Chongben HE who was one of the key founders of China oceanic sciences. Here, the present author wants to address his sincerest thanks to all professors for their constructive suggestions and helpful discussions.

As the present author was born in China, and his main academic activities were concentrated in the Pacific regions such as China, USA, Japan and South Korea, thus, the main contents of this book are mainly concentrated on the “marine meteorological phenomena” occurred in the Pacific region and the adjacent seas of China.

During the writing and editing of this tbook, the author would like to express his great thanks for many helps from the graduate students who had graduated, or still continue their studies in the Department of Marine Meteorology, Ocean University of China, such as Dr. Jingtian GUO (North Sea Forecasting Center, State Oceanic Administration, China), Dr. Huaji PANG (Qingdao Meteorological Administration, China), Dr. Lei WANG (University of Chicago, USA), Dr. Shuai WANG (Imperial College London, UK), Dr. Gan ZHANG (University of Illinois, USA), Dr. Dan FU (Texas A&M University, USA), Mr. Shuqin ZHANG, Mr. Jie XU and Mr. Lijia CHEN, Miss Yawen SUN, Miss Miaomiao JING, Miss Shan LIU, Miss Yuwei LI and Miss Xuebei ZHANG for drawing and revising some figures. Particularly, thanks to Dr. Lei WANG and Dr. Shuai WANG for their instantly providing some important and original papers which the present author couldn't get on time during his writing.

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The author sincerely expects that more and more books of “marine meteorology ”

would be published in future. He also hopes to be able to publish the second edition of this book within 10 years.

He would like to dedicate this book to all of his family members whom he loved very deeply, especially to his grand-daughter who will be born soon.

Gang FU  
Qingdao China  
25 November 2017



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