

学校编码: 10384

密级

学号: 22620091151228

廈門大學

硕士学位论文

黑潮水入侵对南海北部溶解有机碳分布的影响

The impact of Kuroshio intrusion on the distribution of dissolved organic carbon in the northern South China Sea

吴凯

指导教师姓名: 戴民汉 教授

专业名称: 环境科学

论文提交日期: 2013年4月

论文答辩时间: 2013年5月

厦门大学学位论文原创性声明

本人呈交的学位论文是本人在导师指导下,独立完成的研究成果。本人在论文写作中参考其他个人或集体已经发表的研究成果,均在文中以适当方式明确标明,并符合法律规范和《厦门大学研究生学术活动规范(试行)》。

另外,该学位论文为(厦门大学海洋碳循环)课题(组)的研究成果,获得(厦门大学海洋碳循环)课题(组)经费或实验室的资助,在(厦门大学海洋碳循环)实验室完成。(请在以上括号内填写课题或课题组负责人或实验室名称,未有此项声明内容的,可以不作特别声明。)

本人声明该学位论文不存在剽窃、抄袭等学术不端行为,并愿意承担因学术不端行为所带来的一切后果和法律责任。

声明人 (签名):

指导教师 (签名):

年 月 日

厦门大学学位论文著作权使用声明

本人同意厦门大学根据《中华人民共和国学位条例暂行实施办法》等规定保留和使用此学位论文，并向主管部门或其指定机构送交学位论文（包括纸质版和电子版），允许学位论文进入厦门大学图书馆及其数据库被查阅、借阅。本人同意厦门大学将学位论文加入全国博士、硕士学位论文共建单位数据库进行检索，将学位论文的标题和摘要汇编出版，采用影印、缩印或者其它方式合理复制学位论文。

本学位论文属于：

1. 经厦门大学保密委员会审查核定的保密学位论文，
于 年 月 日解密，解密后适用上述授权。

2. 不保密，适用上述授权。

（请在以上相应括号内打“√”或填上相应内容。保密学位论文应是已经厦门大学保密委员会审定过的学位论文，未经厦门大学保密委员会审定的学位论文均为公开学位论文。此声明栏不填写的，默认为公开学位论文，均适用上述授权。）

声明人（签名）：

年 月 日

目 录

摘 要.....	V
Abstract.....	VII
图表目录.....	X
List of Figures and Tables	XII
第一章 绪论	1
1.1 海洋 DOC 研究概况.....	2
1.1.1 海洋 DOC 的分布特征	2
1.1.2 DOC 的生物地球化学过程	5
1.1.2.1 DOC 的来源和去除	5
1.1.2.2 DOC 的运输	7
1.1.3 边缘海与开阔大洋的 DOC 交换	8
1.2 南海 DOC 研究概况	9
1.3 研究内容和目标.....	9
1.4 论文框架.....	10
第二章 研究区域和方法	11
2.1 研究区域概况.....	11
2.1.1 南海北部气候、水文及环流特征.....	11
2.1.2 南海北部水团.....	13
2.2 样品采集与分析方法.....	13
2.2.1 航次及站位描述.....	13
2.2.2 采样及基本参数数据来源.....	16
2.2.2.1 DOC 的采样	16
2.2.2.2 其它参数来源.....	16
2.2.2.3 DOC 的测定及数据质控	16

2.2.3 等密度混合模型.....	18
第三章 南海北部及吕宋海峡溶解有机碳的分布特征.....	20
3.1 航次期间水文特征.....	20
3.1.1 T-S 图.....	20
3.1.2 温盐水平分布特征.....	21
3.2 南海北部 DOC 的时空分布特征.....	24
3.2.1 南海北部 DOC 的水平分布特征.....	24
3.2.2 南海北部 DOC 断面分布特征.....	28
3.3 南海与西菲律宾海 DOC 的比较.....	34
3.4 南海北部 DOC 与盐度、Chla 的关系.....	38
3.4.1 DOC 与盐度的关系.....	38
3.4.2 DOC 和 Chla 的关系.....	39
3.5 南海北部上层 100 m DOC 储量.....	41
第四章 黑潮水入侵对南海北部陆坡和海盆区 DOC 分布的影响.....	43
4.1 等密度面混合模型.....	43
4.2 模型结果.....	46
4.2.1 模型值与实测值的比较.....	46
4.2.2 敏感性分析.....	49
4.3 讨论.....	50
4.4 南海 DOC 的收支.....	55
第五章 总结和展望.....	60
5.1 论文总结.....	60
5.2 展望和不足.....	61
参考文献.....	62
附录.....	72
致谢.....	73

Content

Abstract.....	VII
List of Figures and Tables	XII
Chapter 1 Introduction.....	1
1.1 DOC in the ocean	2
1.1.1 Distribution of DOC in the ocean	2
1.1.2 Biogeochemical processes of DOC in the ocean	5
1.1.2.1 Source and sink	5
1.1.2.2 Transport	7
1.1.3 The exchange of DOC between the marginal seas and the open ocean.....	8
1.2 Overview of studies on DOC in the South China Sea	9
1.3 Objectives of this study.....	9
1.4 Research framework	10
Chapter 2 Study area and Methodology	11
2.1 Study area	11
2.1.1 Meteorological system of the South China Sea	11
2.1.2 Water masses in the South China Sea	13
2.2 Sampling and analysis	13
2.2.1 Cruises.....	13
2.2.2 Sampling and determination	16
2.2.2.1 DOC sampling	16
2.2.2.2 Other parameters	16
2.2.2.3 DOC data quality control	16
2.2.3 Isopycnal mixing model.....	18
Chapter 3 DOC in the northern South China Sea and the Luzon strait.....	20

3.1 Hydrography	20
3.1.1 T-S diagrams	20
3.1.2 Horizontal distributions of temperature and salinity	21
3.2 Temporal and spatial distributions of DOC in the NSCS	24
3.2.1 Horizontal distributions of DOC in the NSCS.....	24
3.2.2 Vertical distributions of DOC in the NSCS	28
3.3 Comparison of DOC between the South China Sea and the West Philippine Sea	34
3.4 Correlation of salinity and Chla with DOC	38
3.4.1 Correlation of salinity with DOC.....	38
3.4.2 Correlation of Chla with DOC.....	39
3.5 Distribution of DOC stock in the upper 100 m of the NSCS slope and basin	41
Chapter 4 The impact of Kuroshio intrusion on the distribution of DOC in the slope and basin areas of the NSCS	43
4.1 Isopycnal mixing model.....	43
4.2 Model results	46
4.2.1 Comparison between the model results with the field measurements	46
4.2.2 The sensitive analysis of the endmembers	49
4.3 Discussion.....	50
4.4 DOC mass balance in the SCS	55
Chapter 5 Summary	60
5.1 Conclusion	60
5.2 Outlook.....	61
References	62
Appendix	72
Acknowledgements	73

摘 要

海洋中溶解有机碳(Dissolved Organic Carbon, DOC)的储量巨大,与大气中 CO_2 的储量相当,因此,认识海洋中 DOC 的分布、迁移和转化对海洋碳循环具有重要意义。本论文以南海北部陆架、海盆以及吕宋海峡为研究区域,进行了春(2011年5月)、秋(2010年10月)、冬(2010年1月)三个季节的采样分析,旨在了解南海北部及吕宋海峡 DOC 的时空分布特征,探讨影响南海北部 DOC 分布的主要因素,以及通过吕宋海峡与西北太平洋海水 DOC 的交换。

南海北部陆架区($<200\text{ m}$)表层 DOC 的浓度在 $65\sim 102\ \mu\text{mol/L}$ 之间,春季平均浓度为 $73.7\pm 7.3\ \mu\text{mol/L}$,秋季平均浓度为 $76.7\pm 9.8\ \mu\text{mol/L}$,冬季平均浓度为 $73.6\pm 9.2\ \mu\text{mol/L}$ 。水平方向上,近岸受珠江冲淡水影响区域 DOC 浓度较高,外海较低;垂直方向上,春季水体层化明显,DOC 浓度由表层向深层逐渐降低;秋、冬季,水体垂直混合强烈,DOC 浓度垂直方向差异不大。大体上,秋、冬季 DOC 浓度较高,春季较低,这可能与秋、冬季具有更高的初级生产力有关。春季,DOC 与叶绿素无相关关系,说明浮游植物对 DOC 的贡献较小;而秋、冬季 DOC 和叶绿素呈现正相关关系,说明浮游植物生产的 DOC 可能是陆架区 DOC 的重要来源之一。

陆坡和海盆区($>200\text{ m}$)表层 DOC 的浓度范围在 $64\sim 75\ \mu\text{mol/L}$ 之间,春季平均浓度为 $69.5\pm 2.5\ \mu\text{mol/L}$,秋季为 $70.9\pm 3.0\ \mu\text{mol/L}$,冬季为 $68.6\pm 3.6\ \mu\text{mol/L}$ 。春、冬季,表层 DOC 浓度与盐度存在显著的正相关关系,推测黑潮水的入侵可能是影响 DOC 分布的原因之一。通过比较南海海盆与黑潮水的 DOC 垂直剖面分布发现:在表层 $100\text{ m}(\sigma_t < 23.5)$,南海 DOC 浓度($67.2\pm 1.8\ \mu\text{mol/kg}$)低于黑潮水($73.8\pm 1.9\ \mu\text{mol/kg}$);在中层水 $1000\text{ m}\sim 1500\text{ m}(27.2 < \sigma_t < 27.6)$,南海 DOC 浓度($42.7\pm 0.9\ \mu\text{mol/kg}$)高于西北太平洋的 $40.4\pm 0.2\ \mu\text{mol/kg}(P < 0.001)$;在深层水($>1500\text{ m}$),南海水 DOC 浓度和西菲律宾海水一致。从而暗示了黑潮水的入侵将会增加南海北部陆坡和海盆区表层 100 m 以浅 DOC 的浓度,同时也证实了南海中层水向西北太平洋 DOC 的输运(Dai et al., 2009)。

南海北部陆坡和海盆区上层 100 m DOC 储量的范围在 $5.9\sim 7.5\ \text{mol/m}^2$ 之间,

春季 DOC 储量范围为 5.9~7.5 mol/m², 平均值为 6.7 mol/m²; 秋季 DOC 储量范围为 6.6~7.4 mol/m², 平均值为 6.8 mol/m²; 冬季 DOC 储量范围为 6.4~7.3 mol/m², 平均值为 6.7 mol/m²。DOC 储量的水平分布特征与表层 DOC 浓度相似, 受黑潮水影响区域 DOC 储量较高。

我们采用了等密度面混合模型 (Du et al., 2013), 用于定量分析黑潮水入侵对陆坡和海盆区上层 100 m DOC 浓度和储量产生的影响。通过此模型, 我们可以获得等密度面上南海水与黑潮水分别所占的比列, 进而可以获得由南海水和黑潮水保守混合所得的 DOC 浓度。通过比较发现, 模型计算的 DOC 浓度与实测值基本相吻合。同时, 100 m 以浅模型计算 DOC 储量与实测储量也基本相吻合。

南海北部陆坡和海盆区上层 100 m DOC 储量与黑潮水所占的比例呈现显著正相关关系。将黑潮水所占比例外推至 0, 可以获得典型南海水 (即不受黑潮水影响) 的储量: 春季为 6.3±0.1 mol/m², 秋季为 6.7±0.1 mol/m², 冬季为 6.5±0.1 mol/m²。通过与典型南海水上层 DOC 储量的比较, 我们可以得到: 由于黑潮水的入侵, 春季南海北部上层 100 m DOC 储量增加了 4%±3%, 秋季增加了 0%±3%, 冬季增加了 2%±4% (不确定度反应的是空间变异性)。春、冬季 DOC 储量的增加量较高, 秋季最低, 这与黑潮水入侵的强弱相关。如果扣除上层 100 m 水体中惰性 DOC 的储量, 那么黑潮水的入侵将分别增加春季上层 100 m 水体中活性 DOC 的储量 10%±11%, 秋季 1%±8%, 冬季 11%±10%。

模型值与实测值的差值反应了 DOC 的生产和消耗情况, 结果显示: 春季存在 DOC 的净消耗过程, 而秋、冬季存在 DOC 的净生产过程。我们计算了秋、冬季 DOC 的净生产速率分别为 0.02 g C/m²/d 和 0.012 g C/m²/d, 其中冬季 DOC 的净生产量约占到净群落生产力的 10%, 占到实测新生产力的 6%。

最后, 我们初步构建了南海 DOC 的质量平衡。结果显示, 通过各海峡输入南海的 DOC 通量要多于输出通量, 净通量为 25±28 Tg C/y。假设南海 DOC 收支处于平衡状态, 则说明南海 DOC 的净消耗量为 25±28 Tg C/y。

关键词: 南海北部; 黑潮水入侵; DOC; 生物地球化学过程

Abstract

Dissolved organic carbon(DOC) is the largest pool of organic carbon in the ocean, and is equivalent to the CO₂ stock in the atmosphere. A better understanding of DOC distribution, transport and transformation is thus vitally important to studying global oceanic carbon cycle. In this study, we examined the seasonal distribution of DOC in the northern South China Sea (NSCS), and attempt to elucidate physical-biogeochemical processes that control DOC distribution, including the exchange between the SCS and the North Western Pacific through the Luzon strait.

In the northern shelf of the SCS, surface DOC concentrations varied from 65 μmol/L to 105 μmol/L. Surface DOC concentrations were high in the coastal water influenced by the riverine input. Vertically, DOC concentration decreased from surface to deep during spring, while it was almost well mixed during fall and winter. Overall, DOC concentrations during fall and winter were higher than in spring, due likely to the higher primary production in the latter seasons, which was evidenced by the significant positive correlations between DOC and Chla.

In the slope and basin areas of the NSCS, surface DOC concentrations varied from 64 μmol/L to 75 μmol/L. The significant correlation between surface DOC concentration and salinity during spring and winter indicated that Kuroshio was one of the factors for the DOC distribution. Comparison of the DOC profiles in the NSCS basin with the West Philippine Sea showed that DOC in the NSCS was lower in the upper 100 m layer, higher in the intermediate layer (1000 m-1500 m). This difference in concentration disappeared in the deep layer (>1500 m). Our results implied that the Kuroshio intrusion would increase the DOC concentration and stock in the upper 100 m layer of the NSCS. Our results also confirmed the previously discovered by Dai et al.(2009) excess DOC in the intermediate layer of the NSCS.

The stock of DOC in the upper 100 m water column in the slope and basin areas of the NSCS varied from 5.9 to 7.5 mol/m² during spring, from 6.6 to 7.4 mol/m²

during fall, and from 6.4 to 7.3 mol/m² during winter. And the horizontal distributions of DOC stock were as similar as the surface DOC concentrations.

Using an isopycnal mixing model (Du et al., 2013), we derived the water proportional contributions from the SCS water and Kuroshio water along the isopycnal surface. Then we derived the conservative portion of the DOC concentration solely determined by the mixing between the SCS water and Kuroshio water. The overall agreement between the model prediction and the field measurements proved that the Kuroshio intrusion was the dominant factor for DOC distribution in the upper layer of the NSCS. There was significant positive correlation between DOC stock and the Kuroshio water proportion in the upper 100 m. Thus, the intercept of the regression line, when Kuroshio water proportion was 0, would infer the DOC stock of the typical SCS water without the Kuroshio influence. We could then derive the DOC stock of the typical SCS water, 6.3±0.1 mol/m² in spring, 6.7±0.1 mol/m² in fall and 6.5±0.1 mol/m² in winter, respectively. DOC stock in fall and winter was a little higher than spring, inferring that the net DOC production occurred in fall and winter. Moreover, based on the DOC stock of the pure SCS water during the different cruises, we could estimate that due to the Kuroshio intrusion, DOC stock in the upper 100 m of the NSCS increased by 4%±3% in spring, 0%±3% in fall and 2%±4% in winter, respectively. And the increase percent of DOC stock during spring and winter was higher than in fall, which correlated with the strength of the Kuroshio intrusion. If we removed the refractory DOC stock from the bulk DOC stock, the non-refractory DOC stock would increase by 10%±11% in spring, 1%±8% in fall and 11%±10% in winter, respectively.

The difference between the model prediction and the field measurements could reflect the net DOC production or consumption processes in the NSCS. We discovered that net DOC consumption existed in spring, while net DOC production existed during fall and winter. The net DOC production rate in winter was 0.012 g C/m²/d, which represented about 10% of the net community production and about 6% of the new production.

As a first order approximation, DOC mass balance was established for the SCS.

Our result showed that there was a net input of 25 ± 28 Tg C/y. This would suggest that there existed net DOC consumption processes in the SCS if DOC was at steady state.

Keywords: Northern South China Sea; Kuroshio intrusion; DOC; Biogeochemistry processes

厦门大学博硕士学位论文摘要库

图表目录

图 1-1 碳的全球生物地球化学循环图	2
图 1-2 海洋有机物的生产和消耗过程	5
图 1-3 海洋中惰性、半活性和活性 DOC 的垂直分布	6
图 2-1 南海环流模式示意图	12
图 2-2 南海北部 DOC 采样站位图	15
图 2-3 TOC 测定工作曲线	17
图 3-1 航次调查期间的 T-S 图	21
图 3-2 南海北部上层 100 m 温度、盐度水平分布	23
图 3-3 南海北部上层 100 m DOC 浓度水平分布	25
图 3-4 南海北部上层 100 m Chla 水平分布	26
图 3-5 E6 断面温度、盐度、叶绿素和 DOC 分布	31
图 3-6 A 断面温度、盐度、叶绿素和 DOC 分布	32
图 3-7 S5 断面温度、盐度、叶绿素和 DOC 分布	33
图 3-8 吕宋海峡附近 E4、Lu5、Lu6 断面 T-S 分布	35
图 3-9 E4、Lu5、Lu6 断面温度、盐度和 DOC 分布	36
图 3-10 南海与西菲律宾海 DOC 垂直分布比较	37
图 3-11 南海北部陆架区表层 DOC 和盐度的关系	38
图 3-12 南海北部陆坡和海盆区表层 DOC 与盐度的关系	39
图 3-13 南海北部陆架区 DOC 和叶绿素的关系	40
图 3-14 南海北部陆坡和海盆区 DOC 和叶绿素的关系	41
图 3-15 南海北部陆坡和海盆区上层 100 m 总 DOC 储量和活性 DOC 储量	42
图 4-1 等密度模型计算混合水中南海水所占的比列	44
图 4-2 南海与黑潮 T-S 及 DOC 浓度图	45
图 4-3 模型结果与实测值的比较	47
图 4-4 南海北部与吕宋海峡上层 100 m 黑潮水(左)与黑潮水 DOC (右)所占的比例	48
图 4-5 不同南海端元与黑潮水端元值的 T-S 图	49

图 4-6 不同端元值计算结果的比较	50
图 4-7 模型结果与实测值的差值随深度和位密变化	52
图 4-8 南海北部陆坡和海盆区上层 100 m DOC 储量与黑潮水所占比例的关系	54
图 4-9 南海与外海水交换示意图	56
表 1-1 世界大洋 DOC 浓度分布	4
表 2-1 2009 年至 2011 年南海北部航次信息一览表	14
表 2-2 DOC 测定过程中标准海水的浓度	18
表 3-1 南海北部 DOC 浓度范围和均值	28
表 4-1 南海北部陆坡和海盆区上层 100 m DOC 储量的变化	55
表 4-2 南海北部陆坡和海盆区上层 100 m 活性 DOC 储量的变化	55
表 4-3 南海 DOC 收支	58

List of Figures and Tables

Figure 1-1 The schematic box model of Global Carbon Cycle	2
Figure 1-2 Schematic representation of the DOM production and consumption processes in marine	5
Figure 1-3 Conceptual cartoon of the various pools of refractory, semilabile and labile DOC in the ocean	6
Figure 2-1 Schematic diagram of the circulation patterns in the South China Sea	12
Figure 2-2 Maps of the Northern South China Sea (NSCS) showing the sampling locations	15
Figure 2-3 Standard curve of TOC-V cph	17
Figure 3-1 Potential temperature versus salinity in the water column for the sampling stations in the northern South China Sea(NSCS).....	21
Figure 3-2 Horizontal distributions of temperature and salinity in the upper 100 m in the NSCS	23
Figure 3-3 Horizontal distributions of DOC concentration in the upper 100 m in the NSCS	25
Figure 3-4 Horizontal distributions of Chla in the upper 100 m in the NSCS	26
Figure 3-5 Contour plots of temperature, salinity, Chla and DOC along Section E6 during spring, fall and winter	31
Figure 3-6 Contour plots of temperature, salinity, Chla and DOC along Section A during spring, fall and winter	32
Figure 3-7 Contour plots of temperature, salinity, Chla and DOC along Section S5 during spring, fall and winter	33
Figure 3-8 Potential temperature (P.T.) and salinity relationship of the E4, Lu5 and Lu6 sections	35
Figure 3-9 Distributions of temperature, salinity and DOC in the upper 200m	

along E4, Lu5 and Lu6 sections	36
Figure 3-10 Comparison in the DOC vertical distribution between the South China Sea and the West Philippine Sea	37
Figure 3-11 Surface DOC vs. salinity on the shelf of the NSCS.....	38
Figure 3-12 Surface DOC vs. salinity in the slope and basin areas of the NSCS .	39
Figure 3-13 DOC vs. Chla on the shelf of the NSCS.....	40
Figure 3-14 DOC vs. Chla in the slope and basin areas of the NSCS	41
Figure 3-15 Stocks of bulk DOC and semi-labile DOC in the upper 100 m of the slope and basin of the northern South China Sea.....	42
Figure 4-1 The South China Sea water proportion in the mixed water derived from the isopycnal model	44
Figure 4-2 The T-S and DOC concentration diagram of SCS and Kuroshio	45
Figure 4-3 The the field measurement DOC concentrations versus the model prediction and the field measurement DOC stock versus the model prediction in the upper 100 m in the slope and basin areas of the NSCS	47
Figure 4-4 Distribution of the Kuroshio water ratio and the Kuroshio DOC ratio in the upper 100 m of the Northern South China Sea and Luzon strait.....	48
Figure4-5 Potential temperature and salinity plots of the different endmembers 	49
Figure 4-6 Comparisons of the results between the different endmembers	50
Figure 4-7 Modeled DOC concentration subtract the field results	52
Figure 4-8 The relationship between the field DOC stock and the Kuroshio water proportion in the northern South China Sea	54
Figure 4-9 Schematics of the water exchanges between the South China Sea and adjacent Ocean/Seas through Luzon Strait and other shallow straits	56
Table 1-1 The concentrations of DOC in the oceans.....	4
Table 2-1 Information of the cruises to the northern South China Sea from 2009 to 2011	14
Table 2-2 DOC concentrations of the reference throughout the analysis.....	18
Table 3-1 The range and average of DOC concentrations in different regions of	

Degree papers are in the "[Xiamen University Electronic Theses and Dissertations Database](#)". Full texts are available in the following ways:

1. If your library is a CALIS member libraries, please log on <http://etd.calis.edu.cn/> and submit requests online, or consult the interlibrary loan department in your library.
2. For users of non-CALIS member libraries, please mail to etd@xmu.edu.cn for delivery details.

厦门大学博硕士论文摘要库