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厦门大学

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

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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 m)表层 DOC 的浓度在 65~102 μmol/L 之间，春季平均浓度为 73.7±7.3 μmol/L，秋季平均浓度为 76.7±9.8 μmol/L，冬季平均浓度为 73.6±9.2 μmol/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 m)表层 DOC 的浓度范围在 64~75 μmol/L 之间，春季平均浓度为 69.5±2.5 μmol/L，秋季为 70.9±3.0 μmol/L，冬季为 68.6±3.6 μmol/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 m(σ_t<23.5)，南海 DOC 浓度(67.2±1.8 μmol/kg)低于黑潮水(73.8±1.9 μmol/kg)；在中层水 1000 m~1500 m(27.2<σ_t<27.6)，南海 DOC 浓度(42.7±0.9 μmol/kg)高于西北太平洋的 40.4±0.2 μmol/kg(P<0.001)；在深层水(>1500 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 5.9~7.5 mol/m^2 之间，

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春季 DOC 储量范围为 5.9~7.5 mol/m^2，平均值为 6.7 mol/m^2；秋季 DOC 储量范围为 6.6~7.4 mol/m^2，平均值为 6.8 mol/m^2；冬季 DOC 储量范围为 6.4~7.3 mol/m^2，平均值为 6.7 mol/m^2。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/m^2，秋季为 6.7±0.1 mol/m^2，冬季为 6.5±0.1 mol/m^2。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/m^2/d 和 0.012 g C/m^2/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

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Abstract

Dissolved organic carbon(DOC) is the largest pool of organic carbon in the ocean, and is equivalent to the CO_2 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/m^2 during spring, from 6.6 to 7.4 mol/m^2

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during fall, and from 6.4 to 7.3 mol/m^2 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/m^2 in spring, 6.7±0.1 mol/m^2 in fall and 6.5±0.1 mol/m^2 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/m^2/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.

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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

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