CMIP5 model analysis of future changes in ocean net primary production by focusing on different response among the individual oceans and models

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Due to global warming, changes in ocean environment such as stratification, acidification and deoxygenation are taking place and it is pointed out that such changes also affect primary productivity of marine phytoplankton. Previous modeling studies show that global primary production will decrease in the future because stratification caused by global warming reduces supply of nutrient from the deep ocean. Previous studies mainly emphasized the importance of only nutrient limitation in explaining the changes in primary production; however, phytoplankton growth is actually determined by temperature limitation, light limitation and nutrient limitation. Nevertheless, far less quantitative analysis has been done regarding contribution of each limitation factor. Moreover, although future changes of primary production differ depending on areas, many research discuss only global mean mechanisms and it is not well understood how the mechanisms differ depending on various areas.

The purpose of this study is to quantitatively evaluate contribution of each limitation factor for explaining the future changes in primary production in various areas by using 9 CMIP5 models. First, we calculate temperature limitation, light limitation and nutrient limitation for each model, which are not directly available from CMIP5 output data. After that, we quantitatively evaluate main drivers for changes in primary production not only for the global ocean but also for low latitudes, the North Atlantic Ocean, the North Pacific Ocean, the Arctic Ocean and the Southern Ocean, separately. In the global ocean, we confirm that primary production will decrease and its main driver is nutrient limitation, however, some models show that main driver is biomass or temperature limitation. In contrast to many prior studies that focus on role of nutrient limitation, our result shows that other two factors are also important: warming-induced enhancement of phytoplankton growth and decreasing biomass caused by enhanced grazing. In low latitudes where more than half of global primary production is produced, we show that the same mechanism as global is operating in this area. In the North Atlantic Ocean, decrease in primary production is larger than low latitudes because stratification will become enhanced more significantly in the North Atlantic Ocean, resulting in the most severe nutrient limitation. In the North Pacific Ocean, primary production will increase contrast to the North Atlantic Ocean, mainly because of warmer sea surface temperature caused by large retreating of sea ice cover there. Moreover, we show that there are different mechanisms between the Arctic Ocean and Southern Ocean. In the Arctic Ocean primary production will increase because mitigating light limitation caused by melting sea ice facilitate phytoplankton photosynthesis. This mechanism is robust for almost all of the model results, while it is not in Southern Ocean. Main driver of change in primary production in the Southern Ocean is mitigation of temperature limitation for the model-mean result, but it is not common for individual models. We suggest that the causes of such uncertainty in the Southern Ocean mainly comes from light limitation, which is largely due to uncertainty of changes in physical fields such as sea ice and radiation.

In conclusion, by quantitative evaluation on contribution of limitation factors of primary production, we show that the future changes in primary production due to global warming is controlled by not only nutrient limitation but also warming-induced enhancement of phytoplankton growth and decreasing

biomass caused by enhanced grazing. Moreover, we show that future changes in primary production and its mechanisms differ depending on individual area.

Keywords: global warming, net primary production, CMIP5