Two-Decade Decrease of Particulate Phosphorus Inventory Revealed by Hawaii Ocean Time-series

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Since the Hawaii Ocean Time-series (HOT) program was initialized in 1988, repeated observations of a series of physical, chemical, and biological parameters have been made on a monthly basis at a deep-ocean station (4,700 m) located in the North Pacific subtropical gyre [1]. The two-decade data have revealed interannual variations in many parameters. Most of these interannual variations were not sustained toward one direction in the two decades. The surface particulate phosphorus (P) inventory, however, was one of the few exceptions whose annual averages changed monotonically in this period. The annual average particulate P inventory in the surface 100 m has significantly decreased (Spearman rank correlation to year: $p = -0.95, p < 0.001$) from 21 nM in 1990 to 8.6 nM in 2010, a 60% drop! Meanwhile, the particulate carbon (C) and nitrogen (N) did not show sustained decrease. This decrease may indicate a profound change at the ecosystem level, considering P as an essential nutrient utilized by all living organisms for genetic materials (DNA and RNA), membranes and energy storage (ATP and ADP).

This phenomenon was noticed by the scientists in the first decade of the HOT program [2,3]. In around 2000, it was hypothesized that the development of dinitrogen (N$_2$) fixation had increased the N to P stoichiometry in this region and had shifted the ecosystem from N-limiting to P-limiting [4,5]. A consequence of the shift was that the smaller prokaryotes with better P assimilation efficiency, such as Prochlorococcus, whose cellular C:P and N:P were also higher, would be selected against eukaryotic phytoplankton cells [3]. Thus the particulate P decreased even the particulate C and N was basically unchanged.

However, this hypothesis is not supported by the up-to-date HOT data. With one more decade of HOT data, the decrease of particulate P continued. But the abundance of Prochlorococcus did not show an increase and the abundance of eukaryotes even slightly increased. The hypothesis could still be valid if the average size of Prochlorococcus became larger so that the total Prochlorococcus biomass increased and the average size of eukaryotes became smaller so that their biomass decreased. Unfortunately, the cell size was not measured by the HOT program.

So what is the real cause for the decadal decrease of the particulate P? The only other parameter measured by the HOT program that showed a sustained change over the last two decades was the dissolved inorganic C, which increased with the atmospheric CO$_2$ (and therefore the pH decreased). We do not have any evidence that can possibly relate the high CO$_2$ and the ocean acidification to the cellular elemental compositions of marine microorganisms. Also note that the particulate P is only a small portion of the total P pool at the HOT station. It is less than 10% of the total dissolve P in the surface 100 m. In 1990-2000 when both particulate P and total dissolved P were measured by the HOT program, it was interesting that the total P pool (particulate plus total dissolved P) did not decrease and even slightly increased (not significant though, $p = 0.3$). Does that indicate that the utilization of dissolved organic P were changing so that less dissolved organic P was recycled to support phytoplankton growth and less particulate P was synthesized? However, the HOT low-level phosphorus analysis, a precise measurement for dissolve inorganic P, did not show a sustained decrease in the surface 100 m over the past two decades, which does not support that the cycling from organic P to inorganic P was slowed down. The whole mystery appears that the P continued to be redistributed from the particulate pool to the dissolved organic pool and we do not know the underlying mechanism.

Long-term observatories are very valuable, but sometimes are also challenges to oceanographers the marine sciences. As shown by this example, the HOT data have revealed an important dynamics which is hard to be explained with current available measurements. In order to solve the problem of the continuous decrease of particulate P, the diversity of microorganisms, their cell size distribution and their elemental compositions have to be tracked in a long term, which will not be a trivial work and may be limited by financial, technological and human resources. Even those measurements can be conducted in a near future, it could still have been too late. The particulate P cannot drop infinitely. We may have already missed an opportunity.

It is still exciting to track the particulate P at the HOT station to see at what condition the trend would stop or turn around.

References

1. Karl DM, Dore JE, Lukas R, Michaels AF, Bates NR, et al. (2001) Building the development of dinitrogen (N$_2$) fixation had increased the N to P stoichiometry in this region and had shifted the ecosystem from N-limiting to P-limiting [4,5]. A consequence of the shift was that the smaller prokaryotes with better P assimilation efficiency, such as Prochlorococcus, whose cellular C:P and N:P were also higher, would be selected against eukaryotic phytoplankton cells [3]. Thus the particulate P decreased even the particulate C and N was basically unchanged.


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Received April 24, 2012; Accepted April 25, 2012; Published April 27, 2012


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