Sixteen-year phytoplankton biomass trends in the northwest Pacific Ocean observed by the SeaWiFS and MODIS ocean color sensors

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Background and Objectives
Phytoplankton biomass, indexed by chlorophyll-a (Chl), in the northwestern Pacific Ocean (NWPO) shows meridional differences in the seasonality as a result of seasonal changes in environmental variables such as mixed layer, light, temperature, and nutrients (e.g., Siswanto et al., 2015). Meridional differences in Chl variability emerge not only at seasonal time scales but also at interannual/decadal time scales in response to low-frequency climate variability (e.g., Goez et al., 2003; Chiba et al., 2008; Siswanto et al., submitted). For instance, the fact that phytoplankton in the subarctic and subtropical areas are respectively limited by light/temperature and nutrients, are being the reason for phytoplankton to show different meridional responses to the strengthened westerly winds associated with intensified Aleutian Low pressure system during the El Nino and/or positive phase of the Pacific Decadal Oscillation (e.g., Siswanto et al., submitted).

Considering that the NWPO phytoplankton respond differently to the same forcing factor(s) in different latitudes, it is thus likely that whether any geophysical variables (e.g., temperature, wind fields, vertical mixing, etc.) that underpins long-term trends, perhaps due to global warming, lead to Chl increase and decrease depends on the latitude. In this study, we used a sixteen-year (September 1997–June 2013) multisensor satellite data to discern recent trend of phytoplankton biomass in the NWPO, as well as the probable responsible geophysical factors.

Methods
The in situ and satellite data of merged SeaWiFS/MODIS Chl, photosynthetically available radiation (PAR), merged AVHRR/MODIS sea surface temperature (SST), merged CMAP/Windst wind speed (WS), and MSU atmospheric temperature (AT) were used. Merging one variable measured by two different sensors/platforms, which are conducted by applying linear regression-based data transformation, is to ensure the compatibility of data measured by two sensors/platforms.

Prior to trend analysis, data filling on the gappy pixels of satellite images was conducted applying EOF-based data interpolation (DINEOF, Alvera-Azcárate et al., 2007). Seasonal means of all variables were then removed by subtracting monthly climatological means from the data time series. The trend analysis was therefore based on variable anomalies. Rather than a least-squares regression, we applied a robust regressions on biophysical variables anomalies against time (monthly basis), because robust regression is less sensitive (than least-squares regression) to outliers. This implies that the observed trends are less influenced by extreme anomalies associated with climate changes on both interannual and decadal time scales. We used the slope of robust regression to approximate the trend within the recent sixteen years. A trend was defined to be meaningful (significant) when the robust regression slope was significant within 95% confidence level (p < 0.05).

Results and Discussion

Summary
In general, the NWPO high latitudes exhibit increasing trends in Chl, whereas low latitudes exhibit decreasing trends.

- Depending on the seasons, the areas showing increasing and decreasing trends in Chl undergo meridional shifting.
- In terms of annual mean, the region north and south of 45°N exhibit respectively, increasing and decreasing trends in Chl.
- The observed increasing trend in Chl (a measure of phytoplankton standing stock) at high latitudes, likely reflects a long-term changes in environmental conditions which allow positive net growth of phytoplankton. Among the environmental changes is increasing trend of SST. Although increasing SST likely also increases grazing rate, temperature-dependent phytoplankton growth rate may be higher.
- Increasing SST at mid-latitudes is however accompanied by decreasing trends in Chl, perhaps indicating a long-term reduction in nutrient supply from deep layer due to strengthened stratification.

Depending on the seasons, the trends in mixed layer are likely important in determining the trends in Chl in the NWPO low latitudes.

Climate change associated with the weakening of the Aleutian Low pressure since late 2007 is likely superimposed on the observed sixteen-year satellite-based Chl trend, especially at high latitudes.

Figure 1. Spatial variations of sixteen-year significant trends (p<0.05) for Chl, PAR, SST, MLD, WS, and AT in the NWPO. The areas with insignificant trends are masked out (white areas).

Figure 2. Spatial patterns of significant (p<0.05) correlations between Chl and MLD, Chl and PAR, and Chl and SST for different seasons in the NWPO. The areas with insignificant trends are masked out (white areas).

Figure 3. Left panel: time series of mean Chl anomaly (red bar) derived from the subarctic region (160°-170°E and 47°-52°N) and the PDO index (black bar). The solid red and black lines are regression lines for Chl and PDO index, respectively. The dashed red and black lines are same as solid lines, except that the regression lines were derived from November 1997 to September 2007 (marked by vertical dashed blue line). Right panel: same as left panel except that the mean Chl anomaly was derived from the subtropical region (130°-140°E and 24°-30°N).