# Relationship between 18.6-year period lunar tidal cycle and ENSO

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Bi-decadal variability is known to be a major component in the inter-decadal ocean and climate variability over the Pacific. Variations in vertical mixing induced by 18.6-year period nodal tidal cycle (18.6-yr cycle) are suggested as one of the causes of this bi-decadal variation. Previous studies showed that the north Pacific mid-high latitude SSTs and air temperature, surface and intermediate water masses in the subarctic North Pacific, the Aleutian Low Pressure, PDO (Pacific Decadal Oscillation) index etc. are synchronized with the 18.6-yr cycle (Yasuda et al., 2006; Osafune and Yasuda, 2006; 2010; Yasuda, 2009). Numerical climate model experiments with vertical mixing modulated with the period of 18.6 year near the Kuril Islands also suggested that the 18.6-yr cycle affects low-latitude Pacific and climate as PDO (Tanaka et al., 2012) and El Niño Southern Oscillation (ENSO) (Hasumi, et al. 2008). Although climate impacts from tropical variability as ENSO is large, there has been only one observational study that suggested relationship between intense El Niño and the 18.6-yr cycle; however the result (Cerveny and Shaffer, 2001) is not reliable because the analysis method used was inadequate. In the present study, long-term time series of ENSO indices (Southern Oscillation Index (SOI), NINO3-index, Cold Tongue Index (CTI) etc.) reconstructed from tree rings, etc. are analyzed to clarify the relationship between tropical climate and the 18.6-yr cycle. Furthermore, on the basis of ocean and atmosphere datasets, spatial structures of the 18.6-yr variability are examined to discuss mechanisms how the 18.6-yr cycle affects the tropical ocean and climate. Variations synchronized with the 18.6-yr cycle are detected by using “calendar composite analysis” in which the mean and its confidence interval are evaluated at each tidal year from the maximum diurnal tide in the 18.6-yr cycle. We here found 3.72 (=18.6/5)-year period variability based on a proxy record of December-February Southern Oscillation Index (SOI) reconstructed from tree-rings (Stahle et al., 1997), and showed that El-Nino (La-Nina) tends to occur in the 1st, 10th, 13th and 17th (3rd, 7th and 16th) year after the maximum diurnal tide in the 18.6-year cycle.

In the low-passed (5-year running mean) long-term time-series of ENSO indices during 1700s-1970s, statistically significant +SOI and –NINO3 is found to occur at the 4-5th tidal year from the maximum diurnal tide suggesting La Niña, and –SOI and +NINO3 at the 11-12th tidal year suggesting El Niño. These are consistent with the PDO-18.6yr cycle relationship (Yasuda, 2009). In the 10-30yr period band-passed SST/SLP during 1910-1997, low (high) SST in the tropical Pacific, high (low) SST in the mid-latitude central North Pacific, almost simultaneously weak (strong) Aleutian Low Pressure, high (low) SLP in the western tropics, and low (high) SLP in the eastern Pacific occurs at the 3-4th (12-13th) tidal year after the maximum diurnal tide in the 18.6-yr cycle.

Keywords: 18.6-year period lunar nodal cycle, ENSO, interdecadal ocean climate variability

 

# Intensive mixing along the Kuril island chain controls upward micro-, and macro-nutrient supply in the western subarctic North Pacific

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In the subarctic North Pacific, physical processes that transport macro- and micro-nutrients from the meso-pelagic layer to the surface have not been clearly identified. *Sarmiento et al.* [2004] used the combined distributions of silicic acid and nitrate to trace the main nutrient return path from deep water to above the thermocline (approximately 26.8 $\sigma_\theta$in the subarctic Pacific) and pointed out the existence of a return process in the northwest corner of the Pacific where there is enhanced vertical mixing, perhaps driven by tidal mixing at the Kuril Islands chain (KIC). Therefore, detailed investigation of material fluxes in water flowing through the KIC is important for understanding macro- and micro-nutrient supply to the surface.
In 2006, 2007, 2010, we conducted direct observation around the KIC during R/V *Professor Khromov* cruise, and chemical measurements were carried out for clarifying vertical distribution of micro-(dissolved-Fe (Fe)), and macro-(nitrate + nitrite (N)) nutrients. From the results, we estimate the vertical fluxes of dissolved Fe and N from the subsurface to the surface at Bussol’ Strait (the deepest strait along the KIC) using the equations,
Dissolved-Fe Flux = - $K_\rho$ x(dFe/dz), Nitrate + nitrite Flux = - $K_\rho$ x(dN/dz),
where $K_\rho$ is vertical diffusivity and dFe/dz and dN/dz are the vertical gradients of dissolved-Fe and N concentrations, respectively. Our measured vertical profiles of dissolved-Fe and N in Bussol’ Strait display the influence of strong mixing in their disrupted gradients. Therefore, these gradients are not suitable for estimating material flux from intermediate to surface waters. Instead, we used the vertical profile obtained at station in the Kuril Basin to approximate the state of the water before the mixing process. The vertical gradients of dissolved-Fe (dFe/dz) and N (dN/dz) at station in the Kuril Basin are 0.0052 μmol $m^{-4}$ and 0.073 mmol $m^{-4}$, respectively. Combining these gradients with 1-day average vertical diffusivity for depths of 100–500 m in Bussol’ Strait reported by *Yagi and Yasuda* [2012] ($K_\rho$ = 1 $\times 10^{-3}$ $m^2$ $s^{-1}$), the estimated fluxes are 0.45 μmol $m^{-2}$ $day^{-1}$ for dissolved-Fe and 6.3 mmol $m^{-2}$ $day^{-1}$ for N. These fluxes are two orders of magnitude greater than that estimated in the open ocean in the western subarctic Pacific, indicating strong upward vertical transport around the Bussol’ Straits.
Our results provide observational evidence that strong vertical tidal mixing in the KIC at the margin of the Pacific Ocean plays a pivotal role in transporting Fe and nutrients from deep water to the surface.
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Keywords: Kuril Strait, iron/nutrients, tidal mixing, biogeochemical cycle

 

# Evaluation of the biogeochemical impact of iron-rich shelf water to the Green Belt in the southeastern Bering Sea

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The Green Belt (GB) in the southeastern Bering Sea lying along the continental slope is a biological hotspot where summertime high primary production is sustained by continuous input of nutrients and iron. To understand the mechanisms to sustain the GB, we need to know how dissolved iron (D-Fe), which regulates the GB production, is drawn from the abundant source in the adjacent shelf should be clarified, but no quantification has ever done yet. In the present paper, using hydrographic and D-Fe data taken by a cruise and hydrographic database, we estimate horizontal D-Fe flux from the outer-shelf along 25.4 $\sigma_\theta$and 26.2 $\sigma_\theta$density surfaces, which are proposed as possible pathways by previous studies. The hydrographic data shows that the cold outer-shelf water is distributed in the slope region, and we estimate that 10 % (65 %) of the water-mass in the slope is originated from the outer-shelf at 25.4 (26.2) $\sigma_\theta$. Assuming that this portion of the along-slope geostrophic transport is derived from the shelf through horizontal isopycnal mixing, and using the observed D-Fe concentration, we estimate the D-Fe flux of $O(10^3)$ molFe/day at 25.4 $\sigma_\theta$and $O(10^4)$ molFe/day at 26.2 $\sigma_\theta$. The large flux at 26.2 $\sigma_\theta$is consistent with the vertical maximum of D-Fe concentration previously observed off the shelf break at this density range, and the flux provides sufficient iron into the euphotic zone via the subsequent enhanced vertical mixing off the shelf break, which is estimated to be $O(10^3)$ molFe/day based on our prior studies. Since our estimated D-Fe flux through horizontal mixing at 25.4 $\sigma_\theta$and the vertical mixing off the shelf break altogether are comparable to the minimum D-Fe requirement by phytoplankton in the GB, which is estimated as $O(10^3 - 10^4)$ molFe/day, we suggest that both processes could play important roles in providing D-Fe to the euphotic zone in the GB.

Keywords: Bering Sea, Green Belt, Mixing, Dissolved iron flux

 

# Missing source of nutrients -Mechanism of nutrients’ supply in the oligotrophic region –

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It is well known that the northwestern Pacific subtropical region is oligotrophic: its nutrient in upper sun-lit layer of this region is very low or deficient all the year around. However it is recently reported that its primary productivity is comparable to or larger than that in the northwestern Pacific subarctic eutrophic region. In order to verify the mechanism of nutrients supply to the oligotrophic upper layer, time-series sediment trap was deployed at 5000 m near National Ocean and Atmospheric Administration (NOAA) time-series station KEO, where meteorological and physical oceanographic observation has been conducted with surface buoy (NOAA-KEO buoy), and temporal variability in settling particles deeply associate with surface primary productivity was observed between July 2014 and July 2015. Total mass flux clearly increased three times: (1) first half of October 2014, (2) first half of January 2015, (3) last half of April 2015. In September 2014, two typhoons passed near station KEO. Based on analysis of satellite data, it was verified that SST decreased and chlorophyll-a increased after typhoons along typhoons’ tracks. This was supported by temporal variability in vertical profile of water temperature upper 500 m observed by NOAA-KEO buoy: during typhoon passage, a few days’ scale upwelling of subsurface cold water occurred. On the other hand, time-series observation of vertical profile of water temperature revealed that a month’s scale upwelling also occurred in July and November 2014. It is suspected that these upwelling were attributed to pass of meso-scale eddy near station KEO. In addition, winter upwelling (winter cooling mixing) was also observed, centering February and March 2015. Taking into account for the time lag, temporal variability in upwelling and total mass flux was generally synchronized. Thus upwelling caused by meteorological disturbance and meso-scale eddy likely supplied nutrients to upper sun-lit layer resulting increase of primary productivity and sequentially increase in settling particles. In future, by simultaneous time-series observation of meteorology, physical oceanography and biogeochemistry, mechanism of nutrients’ supply to oligotrophic region (not only upwelling, but also eolian input) will be quantified.

Keywords: Oligotrophic region, primary productivity, nutrients, meso-scale eddy, meteorological disturbance, Time-series observation

 

# Seasonal variations in the nitrogen isotopic composition of settling particles at station K2 in the western subarctic North Pacific

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Intensive observations using hydrographical cruises and moored sediment trap deployments during 2010 and 2012 at station K2 in the North Pacific western subarctic gyre (WSG) revealed seasonal changes in $\delta^{15}N$ of both suspended and settling particles. Suspended particles (SUS) were collected from depths between the surface and 200 m; settling particles by drifting sediment traps (DST; 100-200 m) and moored traps (MST; 200 and 500 m). All particles showed higher $\delta^{15}N$ values in winter and lower in summer, contrary to the expected by isotopic fractionation during phytoplankton nitrate consumption. We suggest that these observed isotopic patterns are due to ammonium consumption via light-controlled nitrification, which could induce variations in $\delta^{15}N$(SUS) of 0.4-3.1 ‰in the euphotic zone (EZ). The $\delta^{15}N$(SUS) signature was reflected by $\delta^{15}N$(DST) despite modifications during biogenic transformation from suspended particles in the EZ. $\delta^{15}N$ enrichment (average: 3.6 ‰) and the increase in C:N ratio (by 1.6) in settling particles suggests year-round contributions of metabolites from herbivorous zooplankton as well as TEPs produced by diatoms. Accordingly, seasonal $\delta^{15}N$(DST) variations of 2.4-7.0 ‰showed a significant correlation with primary productivity (PP) at K2. By applying the observed $\delta^{15}N$(DST) vs. PP regression to $\delta^{15}N$(MST) of 1.9-8.0 ‰, we constructed the first annual time-series of PP changes in the WSG. Moreover, the monthly export ratio at 500 m was calculated using both estimated PP and measured organic carbon fluxes. Results suggest a 1.6 to 1.8 times more efficient transport of photosynthetically-fixed carbon to the intermediate layers occurs in summer/autumn rather than winter/spring.

Keywords: nitrogen isotopes, suspended and settling particles, nitrogen recycling, biological pump

 

# Eddy transport in upper 1000 m observed by Argo floats

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Mesoscale eddies which account for most of oceanic kinetic energy plays important roles in turbulent mixing in the ocean. One of the crucial roles is horizontal transport. Because quantitative observation of eddy transport requires velocity and hydrographic measurements, at a eddy-resolving resolution, in the middle of water column, they have been estimated only from results of numerical simulations. With recent increase in number of Argo floats, fuelled by vibrant efforts of the community, it is now possible to estimate the eddy statistics using the Argo data. Here, I report horizontal eddy transport estimated using the drift and hydrographic data from the Argo floats based on the formulation by McDougall and McIntosh (2001). Eddy transport is large in the western boundary current regions in the Northern Hemisphere, the mid-latitude Indian Ocean and along the Antarctic Circumpolar Current in the Southern Hemisphere. Locally, upgradient (in thickness) transports are found, which cannot be explained by baroclinic instability per se and thus showing negative thickness diffusivity.

Keywords: eddy, parameterisation

 