ENSOと18.6年周期潮汐変動との関係
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.

キーワード：潮汐18.6年振動、エルニーニョ・南方振動、長周期気候海洋変動
Keywords: 18.6-year period lunar nodal cycle, ENSO, interdecadal ocean climate variability

クリル海峡における混合過程が西部北太平洋亜寒帯域の物質循環に与える影響
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_ρ x(dFe/dz), Nitrate + nitrite Flux = - K_ρ x(dN/dz),
where K_ρ 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_ρ = 1 x10^{-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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キーワード：クリル海峡、鉄・栄養塩、潮汐混合、生物地球化学的循環

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) σ_θ. 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 σ_θ. 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

栄養塩のミッシングソース -貧栄養海域における栄養塩の供給メカニズム-

Missing source of nutrients -Mechanism of nutrients' supply in the oligotrophic region -

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北西部北太平洋亜熱帯海域表層は１年を通して栄養塩濃度が極めて低いか枯渇している。それにもかかわらず基礎生産力は１年を通して栄養塩が豊富な亜寒帯域のものに匹敵することが近年報告されてきた。この基礎生産力を維持するための栄養塩の供給メカニズムを解明するために、米国海洋大気庁（NOAA）が表層ブイ（NOAA-KEO buoy）を用いて海洋気象海洋・物理を観測している西部北太平洋亜熱帯海域観測定点KEO付近の水深5000mに時系列式セジメントトラップを設置し、2014年7月から約1年間、基礎生産力の変動と連動した沈降粒子の季節変動を観測した。全粒子フラックスは観測期間中3回の顕著な増加をしていた：(1) 2014年10月前半、(2) 2015年1月前半、(3) 2015年4月後半。2014年9月にKEO付近を2個の台風が通過しており、衛星データの解析の結果、台風通過後に表層水温が低下しクロロフィルaが増加していたことが明らかになっている。NOAA-KEO buoyの500m以浅の水温データの解析の結果、台風通過後に突発的に亜表層水の湧昇が発生していたことがわかった。一方、台風が通過していない2014年7月、11月には約１ヶ月間にわたる亜表層水の湧昇が確認された。これは同海域を通過した中規模渦によるものと推察された。また2015年2月～3月を中心に冬季冷却混合が活発であったことが窺えた。これらの湧昇と沈降粒子の増加は、タイムラグを考慮すると概して同調していた。従って観測された全ての鉛直混合が亜表層の栄養塩を、栄養が枯渇した表層へ供給し基礎生産力を増加させ引いては沈降粒子の増加につながったと推察された。今後は生物地球化学的・気象学的・海洋物理学的時系列観測を継続しながら、台風等の気象擾乱、中規模渦、さらには大気からの栄養塩供給等も考慮して、同海域の栄養塩供給メカニズムを定量化していく予定である。

キーワード：貧栄養海域、基礎生産力、栄養塩、中規模渦、気象擾乱、時系列観測
Keywords: Oligotrophic region, primary productivity, nutrients, meso-scale eddy, meteorological disturbance, Time-series observation

西部北太平洋亜寒帯循環域における沈降粒子の窒素安定同位体比の季節変化

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

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2010-2012年に亜寒帯循環域定点K2（47°N,160°E）において５回の航海観測および係留式セジメントトラップ実験を実施し、懸濁粒子および沈降粒子の窒素安定同位体比（δ^{15}N）の季節変化について検討した。懸濁粒子は浅層海水（水深0-200 m）から採取し、沈降粒子は漂流式トラップ(100-200 m：DST粒子)と係留式トラップ（200, 500 m：MST粒子）によって捕集した。どの粒子のδ^{15}N値も冬季に高く夏季に低い傾向を示し、植物プランクトンによる季節的な硝酸消費に伴う分別効果では説明できなかった。この変化は、光依存性を持つ硝化反応（アンモニア酸化）に起因したアンモニアδ^{15}N値の季節変化を反映していたと考えられる。このことは、浅層で生産され下層へ沈降する粒子δ^{15}Nが、季節的に大きく異なる混合層内の平均光環境を指標していることを示唆する。これは、DST粒子のδ^{15}N値と基礎生産力の間に見られた高い負相関（r^2 = 0.94）からも支持された。この関係を水深500 mで捕集したMST粒子の時系列δ^{15}Nデータに当てはめることで、基礎生産力の月別変化を検討した。推定した基礎生産力は65-550 mg m^{-2} d^{-1}の範囲で変化し、2月に最小値、7月に最大値をとった。更に水深500 mにおける有機炭素フラックスの月別データを用いて輸出生産率（*e*-ratio）を算出した。11-5月に比べて7-10月はe-ratio が1.6-1.8倍大きく、成層期に効率的な有機炭素輸送が生じていることが明らかになった。

キーワード：窒素同位体比、懸濁・沈降粒子、表層窒素循環、生物ポンプ
Keywords: nitrogen isotopes, suspended and settling particles, nitrogen recycling, biological pump

アルゴフロートで観測された海洋上層 1000 m の渦輸送
Eddy transport in upper 1000 m observed by Argo floats

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海洋の運動エネルギーの大半を説明するメソスケール渦は乱流混合に重要な役割を果たしている。ひとつの大きな役割は渦による水平輸送である。定量的な渦輸送の観測のためには海洋中層における速度場と成層データの高密度な観測が必要であり、これまではもっぱら数値シミュレーションにより推定されていた。コミュニティの不断の努力により近年密度を増加させてきたアルゴフロートのデータを用いて、海洋上層の渦輸送を直接観測した結果を報告する。McDougall and McIntosh（2001）による定式化を用いた。渦輸送は北半球では西岸境界、南半球では中緯度インド洋と南極環海流に沿って活発である。局所的には傾圧不安定では説明出来ない密度勾配と同方向の輸送が見られここでは厚さ拡散係数が負である、などの渦活動の全球海洋の分布が分かる。

キーワード：渦、パラメタリゼーション
Keywords: eddy, parameterisation

