Dear Dr. Pelegrí,

Thank you very much for your careful reading and helpful comments on our manuscript. We learned so much from your comments.

This manuscript uses a comprehensive data set to assess the spatial and temporal variability of water and nutrient transports by the Kuroshio Current, from the East China Sea to south of Japan. The authors have done a commendable effort to put together and systematically analyze a very extensive data set. It consists of five sections with nutrient and hydrographic measurements taken during at least the last decade. The manuscript is a natural extension of Guo et al. (2012) where only the East China Sea sections (PN and TK) were analyzed; from the authors' references I see this is the first time this extensive data set has been examined not only for nutrient but also for water mass transports. This reason alone would deserve, in my opinion, publication of the manuscript. The authors show the Kuroshio Current transports O (1000 kmol s^{-1}*) of nitrate, which is comparable to the Gulf Stream transport (Pelegrí and Csanady, 1991; Pelegrí et al., 1996, 2006; Williams et al., 2006, 2011), although about two-thirds are associated to relatively narrow recirculations. The manuscript also analyzes the nutrient-transport errors caused by gaps in nutrient data and discusses the contributions of the Kuroshio Current through the East China Sea, the Ryukyu Current and the recirculation of a substantial part of the Kuroshio Current south of Japan.*

Since this dataset is being opened to the community, we believed that many researchers have used at least a part of it for their own purposes. To our knowledge, the calculations of horizontal nutrient flux and transport have not been reported for this area and our analysis should be the first one.

After receiving your comments, we carefully checked the nitrate data in our calculation and removed some bugs in our programs. In addition, we noted that the Kuroshio large meander significantly changes the nitrate concentration at section 137E. During the period of Kuroshio large meander, the area between the Kuroshio and the coast became large and the nitrate concentration there was high. A simple average without considering the Kuroshio path may induce a pseudo higher nitrate concentration at section 137E than at section ASUKA. Therefore, we removed the data at section 137E collected during the period of Kuroshio large meander (August 1975 to March 1980; November 1981 to May 1984; December 1986 to July 1988; December 1989 to December 1990;

July 2004 to August 2005). At the same time, we tried the method you suggested, i.e., using regression relation of water temperature and nitrate concentration to obtain unknown nitrate concentration for some cruises. All these new calculations changed the numbers reported in our previous manuscript but still confirmed the presence of nitrate transports by the Kuroshio Current with an order of 1000 kmol s^{-1}.

I would like to congratulate the authors for their interesting study. Overall, I find the manuscript is close to meeting the high standards for publication in Biogeosciences. However, I believe it would greatly benefit from a careful revision including (1) the temporal variability of the water and nutrient transports and (2) a thorough discussion of the water and nutrient transports and balances. Additionally, there are several issues that need to be addressed and clarified. My concerns and suggestions are described next, categorized as major issues, additional considerations and minor points. I encourage the authors to take these comments and suggestions into account for their revised manuscript.

Our purpose for this paper is to focus on spatial variations of mean state. We are planning to put all the temporal variations (seasonal and interannual ones for different Kuroshio paths, i.e., large meander state and no large meander state) in another paper.

It is not difficult to show the temporal variations of nitrate transports at 5 sections. However, as shown in Fig. R1, the data numbers at each observation station are a little different in past decade. This is caused by the inconsistence of observation stations among all the cruises in these years. Consequently, a simple integration of nitrate flux at these stations may cause a pseudo temporal variation due to different section area occupied by the available data. We need to consider a way to avoid this problem in the future. As you suggested, using the relation between water temperature and nitrate concentration is a potential way to obtain the time series of nitrate transport through the entire section.

In addition to careful treatment of data for time series, the interpretation on the temporal variations is actually not easy. We need to check the climate variation indexes such as PDO and ENSO to find the possible causes for the change in current fields. In fact, the understanding on the seasonal and interannual variations of Kuroshio volume transport is not insufficient. Furthermore, we need also to pay more attention on the temporal change of nitrate concentration caused by the biogeochemical processes. Therefore, we need time to produce a reliable time series of nitrate transport and need more time to find a reasonable explanation on it.

As given in the title of our manuscript, our focus is on spatial variations of mean state. Inclusion of temporal variations in this paper may cause an unnecessary confusion to the readers who like to know the spatial variations in mean state of nitrate transport. For all of these reasons, we will not include the temporal variations in our revised manuscript.

On the other hand, we completely accept your second suggestion, "*a thorough discussion of the water and nutrient transports and balances*", because this discussion really deepens our understanding on the processes responsible for the downstream increase of the nitrate transport along the Kuroshio Current. As shown in final part of this response note, we carried out a budget calculation in two boxes and separated the contributions of Kuroshio recirculation and the change in nitrate concentration between two sections due to diapycnal mixing or biogeochemical processes to the downstream increase of nitrate transport. For the entire water column, the Kuroshio recirculation contributes ~90% and the change in nitrate concentration between two sections contributes ~10% to the downstream increase of nitrate transport. However, for the isopycnal layers in the upper ocean, the contribution of change in nitrate concentration between two sections greatly increases and is even larger than that of Kuroshio recirculation. Therefore, not only the advection due to the Kuroshio recirculation, but also the change in nitrate concentration due to the physical and biogeochemical processes, should be responsible for the downstream increase of nitrate transport. Please refer to final part of this response note for the details of this calculation.

Major issues

1) Data set and time series
Figure 1 shows the data distribution, separated as Conductivity-Temperature-Depth (CTD) and nitrate data. The nitrate data goes further back in time than the CTD data, to the late 1960's in section 137E. The authors do not explain why they restrain the CTD data only to the first decade of the 21st century. Is it because there are no earlier data? However, there are CTD data for sections PN and TK from the late 1980's (Guo et al., 2012). Or do the authors avoid earlier times when a large meander in the Kuroshio Current south of Japan was observed (Kawabe, 1995)? Or is it simply because they

prefer to have one single decade with data available from all sections? There is no problem to restrict the analysis to this last decade but the authors should explain why they do so and clarify what is the real extension of the available data. Further, the authors should be careful when referring to hydrographic data: Bottle data is indeed hydrographic data, with temperature and salinity values, although with much reduced vertical resolution than CTD data (perhaps this is what the authors meant to say but I'm surprised there are many instances of sections with nitrate data but without hydrographic data).

Actually, we used only CTD data and did not use bottle data in this analysis. The CTD data are available from 1987 at sections PN and TK, from 1997 at sections ASUKA and 137E in the dataset we obtained from JMA website.

Figure 2 (not Fig.1) in our manuscript shows the data we actually used in this study, not all the available data in the JMA dataset. Since this way easily cause misunderstanding on dataset, we revised Fig. 2 by including all the available data. In addition, we will change 'hydrographic data' to 'CTD data' in our revised manuscript.

The reason that we limited our analysis to last 10 years is because we want to use a consistent average time for all the sections. As shown in Fig. 2, the data at sections ASUKA and OK concentrate in last decade.

The data set is so unique that I regret not seeing a time series of transports through each section. In my opinion, this would be a significant additional contribution in their future Biogeosciences paper. I would encourage the authors to include one figure where they show the time series of water and nitrate transports for the last decade through all five sections, it should be sufficient if they show the positive and net volume/nitrate transports.

We completely agree with your suggestion on a future paper. Actually, we have prepared some figures for the temporal variations you required. However, a full interpretation on these figures is still difficult. We do not like only present one figure without a sufficient explanation on it. Therefore, please allow us to put all the contents on the temporal variations of nitrate transport into another paper.

Further, I would incite the authors to put together these 10 years of data to calculate *monthly-mean values for these four variables, such a plot would be very nice to see; if there are no enough data to have monthly values then I would recommend them to use a two or three months averaging box.*

Since the observations by the JMA at these sections were carried out around a fixed month with a time interval of 3 months or half year, it is impossible to make a monthly-mean for the four variables. As shown in Guo et al. (2012JGR), the seasonal variations in velocity and nitrate flux at section PN are very small. The situation does not change so much for the other sections. Therefore, we still like to focus on the spatial variations of the mean state in this paper.

2) In Section 4.2 the authors discuss the water and nitrate contributions from the Kuroshio and Ryukyu Currents and the open-ocean recirculations. They emphasize the contributions from the different branches at different density layers as well as the importance of the recirculation in the open ocean south of Japan (OK, ASUKA and 137E). This is fine but, in my opinion, their discussion falls somewhat short. In Table 1 the authors provide information which is never discussed. I don't mean to go into the details but they should make an effort to extract general behaviors. For example, why showing the (layer and total) area-averaged and transport-averaged nitrate concentrations if you don't analyze them? What do we learn from these numbers, from their along-stream variation, from the differences between the positive and negative values?

The points addressed in Section 4.2 are probably the most important ones in the manuscript and the authors should make an exhaustive and convincing discussion, including plots and additional figures if necessary. For example, it would be very helpful to show some schematic diagrams, based on their results, illustrating the main streamlines (with numbers for water and nitrate transports across the sections) in layers 1, 3 and 5. This should help identify the contribution of each branch to the net downstream flux and the contributions of the open-ocean recirculations to the positive transports. The authors should also try to extract some relevant conclusions from the nitrate transport unbalances and from the differences between the area-averaged and transport-averaged nitrate concentrations, for example regarding nitrate remineralization during the offshore recirculation south of Japan.

We completely agree with your comments that our discussions on Table 1 are too short.

We revised Table 1 (also shown in this response note) by arranging all the variables with a style along the Kuroshio. From it, it becomes easy to consider the along-stream variations in the volume and nitrate transports and in the nitrate concentrations. We also compared the area-weighted and transport-weighted mean nitrate concentrations to see how the vertical shear of current modifies the nitrate concentrations and how the transport-weighted mean nitrate concentration helps us to understand the cause for along-stream variations in the nitrate transport. In addition, we made a budget calculation for two boxes whose basic ideas are given in Fig. R6 and results in Table R1&R2. We also revised Fig.1 and Fig.5 by adding numbers of volume transport and nitrate transport across the sections. All of these new contents (Fig. R6, Table R1&R2) and revised previous figures will be included in our revision.

Additional considerations

3) The authors choose to place the reference level for their geostrophic calculations at 2000 m (or the sea floor if shallower) and use an inverse technique to calculate the velocities at this reference level. This does not mean they have obtained a unique true geostrophic solution, as there will be a different solution for each choice of reference level. For example, if the authors had chosen the reference level as 1000 m (or the sea floor when shallower) the solution would have probably been substantially different. I suspect this may be a reason for the relatively large calculated transports; the results of Ichikawa et al. (2004) and Howe et al. (2009) suggest that a shallower reference level, about 1000 m, could perhaps be more representative for the Kuroshio Current.

The optimum reference level for the inverse method to calculate the absolute geostrophic velocity in the region southeast of Ryukyu Islands was 2000 dbar (Yuan et al., 1998 & Zhu et al., 2008). This is because the norm residual volume transport decreases monotonically to about 2000 dbar and thereafter it becomes almost constant (see Figure5 in Zhu et al., 2008). Kaneko et al., (2001) suggested a reference level of 2000 dbar for the Kuroshio region south of Japan (please see Sections P24 and P9 in Fig.1 and lines 14 from bottom of right column on page 400 in their paper).

Ichikawa et al. (2004) did not suggest a shallower reference level of about 1000 m for the Ryukyu Current; they used a very shallower reference level (a shipboard ADCP velocity) to calculate the surface absolute geostrophic velocity. The research area of Howe et al. (2009) is the Kuroshio Extension region, which is a little far from our region. Therefore, the optimum reference level is probably different.

There are methodologies to select the reference level. Machín and Pelegrí (2006) applied the inverse method with a varying reference level and selected the one that minimized the mass transport unbalances. This approach provides a robust justification for choosing the reference level, but certainly implies substantial additional work. Maybe the authors would like to try this or perhaps leave it for future works; if the authors do not attempt this then they would need to provide an explanation, perhaps a relevant reference, on why the 2000 m level is a sensible selection. One possibility may be Jayne et al. (2009). Are there other references that would sustain this selection?

In principle, the way we determined a reference level of 2000 m (Zhu et al., 2008) is the same as that in Machín and Pelegrí (2006). Follows are the references supporting a reference level of 2000 m.

Kaneko, I, Y. Takatsuki and H. Kamiya (2001), Circulation of intermediate and deep waters in the Philippine Sea, J. Oceanogr., 57, 397–420.

Nagano A., H. Ichikawa, T. Miura, et al. Current system east of the Ryukyu Islands, J. Geophys. Res., 2007, 112, doi:10.1029/2006JC0003917.

Nagano A., H. Ichikawa, T. Miura, et al. Reply to comment by Xiao-Hua Zhu et al. on "Current system east of the Ryukyu Islands", J. Geophys. Res., 2008, 113, doi:10.1029/2007JC0004561.

Yuan, Y. C., A. Kaneko, J. Su, X.-H. Zhu, Y. Liu, N. Gohda and H. Chen (1998), The Kuroshio east of Taiwan and in the East China Sea and the currents east of Ryukyu Islands during early summer of 1996, J. Oceanogr., 54, 217–226.

Zhu, X.-H., J.-H. Park, M. Wimbush, et al. Comment on "Current system east of the Ryukyu Islands" by Nagano et al., J. Geophys. Res. 2008, 113, doi:10.1029/2007JC004458.

The research area of Jayne et al. (2009) is the Kuroshio Extension region, which is a little far from our region.

Finally, it would be nice if the authors show the velocities at the reference level. I would expect these to be very small if the reference level has been properly chosen.

We set depth of 2000 m as the reference level for sections OK, ASUKA, and 137E, and depth of 700 m as the reference level for sections PN and TK. If the water depth is shallower than the depth of 2000m or 700 m, we set sea bottom as the reference level. The depth of 700 m has been used by the JMA as a reference level for sections PN and TK for many years. Wei et al. (2013) also used the depth of 700 m as a reference level for sections PN and TK in their study on interannual variations in the Kuroshio transport.

As shown in Fig. R2, the temporally averaged velocity at the reference level of sections OK, ASUKA, and 137E is generally less than 0.05 ms^{-1} in deep region but increases in shallow coastal regions to an order of 0.1 ms^{-1}. The velocity at the reference level is also generally larger at sections PN and TK than at other sections. Apparently, water depth of reference level is a key factor for the velocity at reference level. We think that the relatively large reference velocity exists only at shallow depth is acceptable.

Wei, Y.Z., Huang, D.J., and Zhu, X. H. (2013): Interannual to decadal variability of the Kuroshio Current in the East China Sea from 1955 to 2010 as indicated by in-situ hydrographic data. J. Oceanogr., DOI 10.1007/s10872-013-0193-5 (published online first).

4) In pages 6741 and 6742 the authors mention that there are several instances where there are no nitrate data simultaneous with CTD data. They explain that, in such cases, they replace the simultaneous nitrate data by the corresponding temporally-averaged nitrate values (a function of spatial position). The authors explain what is the transport term neglected in this approximation (page 6742) and estimate the size of this error (page 6749). It turns out that the error is one order of magnitude smaller than the actual value. However, there is still another situation where there is no nutrient and velocity data available for the same time period (page 6749). The authors follow the same procedure but now computing the average nitrate concentrations from a totally different time period. In this case the error is substantially larger, possibly a factor 1/3 the actual value.

We revisited this error estimation by removing the data at section 137E in the period of

Kuroshio large meander. This treatment largely reduced the error shown in Fig. 6d. Another change is the average period for the mean nitrate concentration in Fig. 6d. In our previous version, we used the entire period (1965-2009) for the average of nitrate concentration. However, we noted that there is no nitrate data at section TK after 2000. Therefore, it is fair to use the period before 2000 for the average of nitrate concentration used in Fig. 6d.

The new calculation shows an error to an order of ~10% in both Fig. 6b and Fig. 6d, which are presented in this response note.

I would like to suggest the authors to examine a relatively simple alternative, as described in Pelegrí et al. (2006). Use all available data in order to obtain a temperature-nitrate relationship for each section. This relationship will probably be quite tight (low dispersion around a single curve) and, for those cases when there is only hydrographic data available, it will allow you to infer nitrate concentrations from temperature data. In this way for each CTD cast you will have an empirical simultaneous nitrate cast, and you may then use this cast to calculate the nitrate transports. You may check on the validity of this approximation in a way similar as you have done in the manuscript; I trust that it will lead to a reduction of the nitrate transport errors, as compared with your procedure, for those cases when no simultaneous nutrient data is available.

Following your suggestion, we carried out a regression analysis between water temperature and nitrate concentration for each section (Fig. R3). As you expect, the relation is tight at all the sections. The root mean square error (RMSE) for entire water temperature range is approximately 1.0 mmol m^{-3}. For some water temperature range at sections TK and PN, the RMSE is larger than 2.0 mmol m^{-3}. The bias between measured nitrate concentration and regressed nitrate concentration is generally smaller than 1.0 mmol m^{-3} (Fig. R3).

The temporally averaged nitrate concentrations based on water temperature show a small difference from temporally averaged nitrate concentration based on field measurements (Fig. R4). The difference is usually less than 1 mmol m^{-3}. The difference of nitrate flux between those shown in Fig. 4 and those calculated from the nitrate concentration regressed from water temperature is also smaller than the flux itself by one order. Therefore, it is concluded that the method you suggested can be used in the

Kuroshio region.

For the purpose of this manuscript, we think that our present analysis based on measured nitrate concentration is easily understood and sufficient. However, for a future study on temporal variations of nitrate transport, the method you suggested will be necessary, especially for the case that the measured nitrate concentration cannot cover the entire section. Therefore, we will definitely use the regression relation (Fig. R3) in a near future.

Minor points
5) The authors need to have their manuscript carefully revised by a native English speaker. There are numerous orthographic errors that need to be corrected and many sentences that could be simplified in order to facilitate reading. Further, in many places there are words that are not properly chosen and may lead to misunderstandings. For example, in the Abstract (page 6738, line 6), the authors say "4 sections along the Kuroshio path" when they probably mean "four sections across the Kuroshio path."

Yes, we know this problem. We will make a comprehensive English correction by sending our revised manuscript to a professional company that provides service for English proofing by native editor before submitting it.

6) The authors state that mass conservation is assumed within each of eight isopycnal layers (Section 2, page 6740) but this is not really true. The inverse model cannot satisfy mass conservation for each layer, it simply looks for the best possible solution that approximately meets this requirement, as becomes clear from the numbers in Table 1.

Yes, it is impossible for an exact mass conservation for each layer. As we show in Table 1, there is no exact conservation for each layer. We will modify those sentences in the revised manuscript.

7) Along the text there are references to geographic locations that are not identified in Figure 1. The authors should identify Ryukyu Current, Tokara Strait, Okinawa Island and any other geographic feature mentioned in the text.

We added these terms in revised Figs. 1a and 1b, which are presented in this response note.

8) Page 6747, line 21: I trust that "unit width" again refers to 25 km, please clarify.

Yes, it is 25 km. We will add this information in revised manuscript. In fact, we revise type of lines in Fig. 1 and Fig. 5 to clearly present the idea of unit width used in these figures. For your reference, we put these figures in this response note.

9) Page 6749 (lines 18-22) and Table 1: The authors need to define the positive and negative directions.

We actually defined the positive and negative direction at the end of Section 2 (top of Page 6744).

10) Page 6752: it is true that Williams et al. (2011) reported a very significant increase in the Gulf Stream nutrient transport within a relatively short distance (35.5 to 36.5 N), therefore attributable to enhanced local recirculation, but many other characteristics (such as the along-stream changes in nutrient concentration and nutrient transport within different isopycnal layers) were earlier discussed by Pelegrí and Csanady (1991), Pelegrí et al. (1996, 2006) and Williams et al. (2006).

Yes, we did not pay sufficient attention on the role of diapycnal mixing in our early analysis. After reading your comments, we examined the along-stream change of nutrient concentration within eight isopycnal layers and found an along-stream increase of nitrate concentration in the upper layers (1-3 layers) inside the Kuroshio and from the Kuroshio recirculation to the Kuroshio main stream and an along-stream decrease of nitrate concentration in the middle and bottom layers (4-7 layers). Therefore, the diapycnal mixing and biogeochemical processes can cause the change in nitrate concentration along the stream. We will address this issue by inclusion of budget calculation in the revision.

11) Figures 1 and 5: please clarify where the origin for the water and nitrate transports is located. I understand it is between each pair of stations but it needs to be specified. I assume the scale for water and nitrate transport represents the distance between the stations (dots) and the water and nitrate transport lines (red and black lines); if so, it needs to be stated. Further, the line drawn for nitrate concentration (blue line) is confusing, I would recommend removing it.

We modified them by removing nitrate concentration (blue line in old figure); by changing line type; by adding line between stations (dots) to show reference for the water and nitrate transports; by adding number for positive and negative transport of water and nitrate over the entire sections. Please refer to Figs. 1&5 shown in this response note.

12) Figures 3 and 4: Sections OK, ASUKA and 137E are incomplete, the offshore end has been removed. This is fine but you need to say it. Similarly, explain section 137E is incomplete in Figure 6.

For a zooming up on the Kuroshio region, we did not show the entire section. In this revision, we changed the figures to cover an entire section. Please find them (Figs. 3&4) in the response note.

13) Figures 3 and 4: panels labeled (a) through (e) should be properly identified, either in each panel or in the figure's caption.

Yes, we will modify figure caption to identify (a) through (e).

14) Caption for Figure 6: It says "Fig. 3e" twice but in both instances I believe it should say "Fig. 4e".

Yes, this is our typo. We corrected them in caption for Fig. 6 shown in this response note.

A budget calculation for water and nutrient transports within each isopycnal layer in 2 boxes enclosed by four sections

The Kuroshio recirculation is an apparent cause for the downstream increase of nitrate transport (Table 1). However, the along-stream change of nitrate concentration (Table 1), which is caused by the diapycnal mixing and biological processes, must also play a role in downstream increase of nitrate transport. To quantitate the contributions of Kuroshio recirculation and downstream change in nitrate concentration, we consider a budget calculation for the water and nitrate transport in a box enclosed by two or three sections in our study.

1) A budget calculation for a box enclosed by section 137E-N and section ASUKA-N

For this calculation (Fig. R6a), section 137E is divided into two parts, separated at about 31.5N (9th station from the most north station in Fig.1) where the eastward Kuroshio almost disappears. Its north part (section 137E-N) is for the eastward Kuroshio and its south part (section 137E-S) is for the westward Kuroshio recirculation. We further divided section 137E-N into two parts: a small north one (section 137E-N-N) corresponding to a westward coastal current and a large south one (section 137E-N-S) corresponding to the Kuroshio. Similarly, section ASUKA is also divided into two parts: a north one (section ASUKA-N) and a south one (section ASUKA-S), as separated at about 31N (11th station from the most north station in Fig.1).

We denote the water volume transport within an isopycnal layer as V_1, V_2, and V_C at sections ASUKA-N, 137E-N-S, 137E-N-N (Fig. R6a), respectively; the nitrate transports within the same isopycnal layer as NT_1, NT_2, and NT_C at sections ASUKA-N, 137E-N-S, and 137E-N-N, respectively. The ratio of NT_1 to V_1, i.e., transport-weighted mean nitrate concentration, is denoted as C_1, that of NT_2 to V_2 as C_2, and that of NT_C to V_C as C_C.

We assume that the difference of the volume transports through sections ASUKA-N and 137E-N is supplied by the Kuroshio recirculation from the south region between sections 137E-S and ASUKA-S. The volume transport of Kuroshio recirculation (V_R) is therefore V_2-V_1-V_C and its nitrate transport is given by the production of V_R and the nitrate concentration (C_R) of water carried by the Kuroshio recirculation. Although we do not know the exact value of C_R, it is reasonable to assume that it equals to the transport-weighted mean nitrate concentration of westward water in the same isopycnal layer of section 137E-S that is origin of Kuroshio recirculation water into the area between sections ASUKA-N and 137E-N. Then, we obtained an equation, NT_2-NT_1-NT_C =V_RC_R+$V_1(C_2$-$C_1)$+$V_R(C_2$-$C_R)$ +$V_C(C_2$-$C_C)$, in which the first term of r.h.s, V_RC_R, is the nitrate transport by the Kuroshio recirculation, the other terms arise from the difference of nitrate concentration between each pair of sections and can be attributed to the diapycnal mixing and biological processes occurring over the area between two sections. The values of these terms within each isopycnal layer and for the entire water column are given in Table R1.

According to Table R1, the nitrate transport by the Kuroshio recirculation explains more than 95% of the downstream increase of nitrate transport for the entire water column. This result, however, does not mean that we can neglect the role of nitrate concentration change between two sections. For example, the terms arising from nitrate concentration change are more important than the Kuroshio recirculation in the upper two isopycnal layers. In the third isopycnal layer, the Kuroshio recirculation becomes dominant but the terms arising from nitrate concentration change still have positive contribution. In the deep layers (layers 4-8), the downstream increase of nitrate transport is only from the Kuroshio recirculation and the terms arising from nitrate concentration change have negative or negligible contribution.

The transport-weighted mean nitrate concentration (Table R1) shows a reduction of nitrate concentration along the Kuroshio from section ASUKA-N (C_1) to section 137E-N-S (C_2) in the first layer. This change is easily related to the consumption by biogeochemical processes occurring over the area between two sections. The nitrate concentrations in the Kuroshio recirculation (C_R) and in the westward coastal current (C_C) are also much different from those (C_1 and C_2) in the Kuroshio but their contribution to the change in nitrate transport is very small because of their little volume transport in this layer.

The transport-weighted mean nitrate concentration (Table R1) shows an increase of nitrate concentration from section ASUKA-N (C_1) to section 137E-N-S (C_2) and from the Kuroshio recirculation (C_R) to section 137E-N-S (C_2) in the second and third layers. This increase may be related to the diapycnal mixing occurring over the area between section ASUKA-N and section 137E-N-S because the downstream reduction of nitrate concentration in the 4th and fifth layers. It must be noted that the nitrate concentration is higher in the Kuroshio recirculation (C_R) than in the two sections inside Kuroshio (C_1 and C_2) from 4th layer to 7th layer, indicating an important role of remineralization occurring in the Kuroshio recirculation.

2) A budget calculation for a box enclosed by sections ASUKA-N, TK and OK-W

With a similar way, we divided section OK into two parts at about 129E (5th station from the most west station in Fig.1). The current in its western part (section OK-W) is Ryukyu Current and the current in its eastern part (section OK-E) is considered as Kuroshio recirculation.

We consider the budget in a box surrounded by sections TK, OK-W and ASUKA-N (Fig. R6b). The residual part of volume transport through three sections is supplied by the Kuroshio recirculation from the area between sections OK-E and ASUKA-S.

We denote the volume transport through sections OK-W, TK and ASUKA-N by V_0, V_1, and V_2, respectively. The volume transport of Kuroshio recirculation (V_R) is obtained by $V_R=V_2-V_0-V_1$. The nitrate transport through sections OK-W, TK and ASUKA-N is denoted by NT_0, NT_1 and NT_2, respectively and the corresponding transport-weighted mean nitrate concentration is C_0, C_1, and C_2. The nitrate concentration of Kuroshio recirculation into the box (C_R) is assumed to be equal to the transport-weighted mean nitrate concentration in the westward water through section ASUKA-S and that in the eastward water through section OK-E. Again, we obtained $NT_2-NT_1-NT_0=V_RC_R+V_0(C_2-C_0)+V_1(C_2-C_1)+V_R(C_2-C_R)$.

According to Table R2, the Kuroshio recirculation is more important than the terms arising from nitrate concentration difference between a pair of sections. The contribution of Kuroshio recirculation to the downstream increase of nitrate transport within entire 8 layers is approximately 90%. Like the situation in the box between sections ASUKA-N and 137E-N-S, this does not mean the negligible role of terms related to the nitrate concentration difference between a pair of sections. For example, the terms depending on the nitrate concentration difference between a pair of sections are more important than the Kuroshio recirculation in the first layer (Table R2). In the second and third layers, the terms depending on the nitrate concentration difference between a pair of sections are still important. It is only below the 4th layer, the Kuroshio recirculation become the only contribution to the downstream increase of nitrate transport.

The downstream increase of nitrate concentration inside the Kuroshio (from section TK to section ASUKA-N) and from the Kuroshio recirculation to the Kuroshio (section ASUKA-N) in the upper three layers as well as the downstream reduction of nitrate concentration from the Kuroshio recirculation to the Kuroshio are found again in this box. This is likely a consistent feature in the Kuroshio and Kuroshio recirculation.

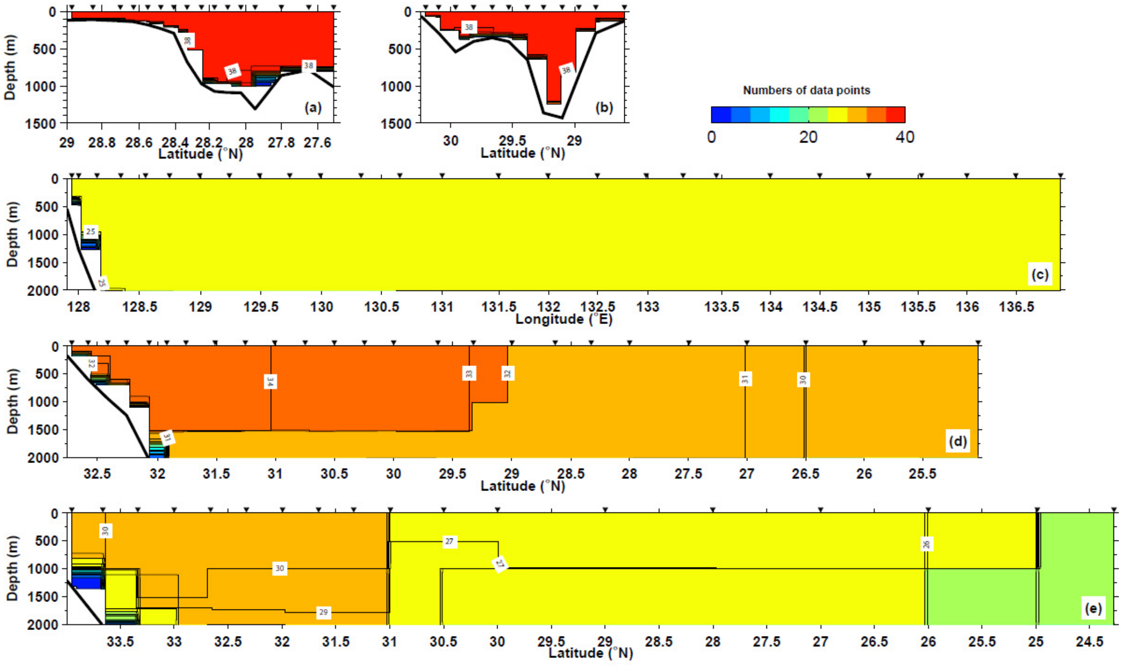

Figure R1. Nitrate data number at (a) section PN, (b) section TK, (c) section OK, (d) section ASUKA, and (e) section 137E for the average to obtain the mean state shown in Fig. 3 and 4.

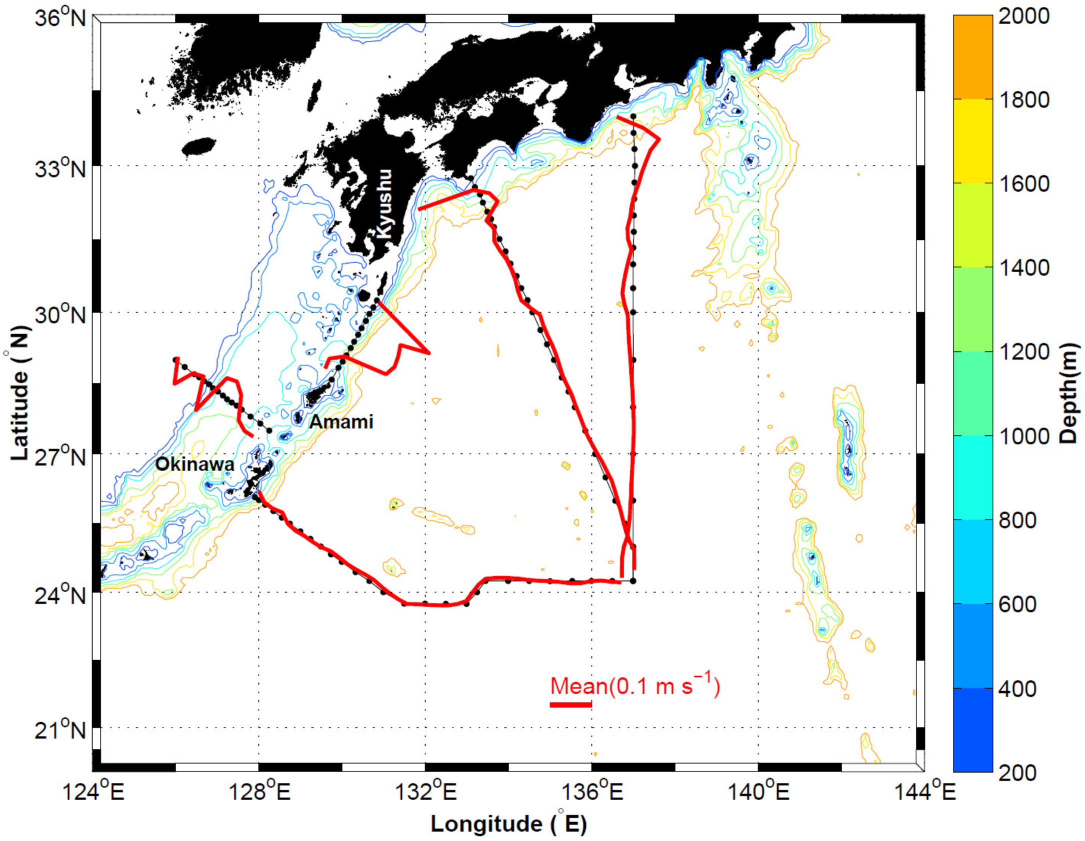

Figure R2. Mean velocities (red line) at reference level that are defined as depth of 2000 m for section OK, ASUKA, and 137E, respectively, as depth of 700 m for sections PN and TK, respectively, and as sea bottom if it is shallower than the depth of 2000m or 700 m. The lines between stations (black dots) are reference line for the velocity. The thin color lines are contours for water depth.

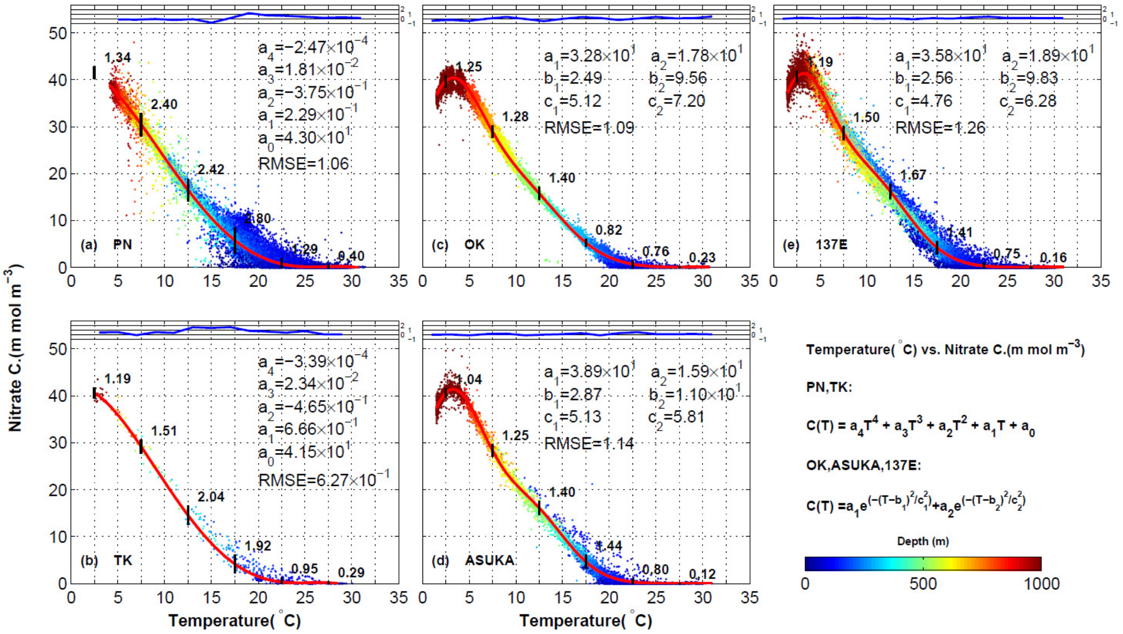

Figure R3. Regression relation for nitrate concentration versus water temperature. A polynomial function $C(T) = a_4T^4 + a_3T^3 + a_2T^2 + a_1T + a_0$ was used at sections PN and TK, while a combination of two exponential functions $C(T) = a_1e^{-(T-b_1)^2/c_1^2} + a_2e^{-(T-b_2)^2/c_2^2}$ were used at sections OK, ASUKA, 137E. In the formula, T is water temperature in degree and C is nitrate concentration in mmol m^{-3}. Root mean square error (RMSE) for entire range of water temperature is given inside each panel. The red line shows regression function, dots represent a pair of water temperature and nitrate concentration, the color of dot shows water depth, the number along with black bar over the red line denotes RMSE for every 5 degree. The blue line at top of each panel shows the bias of nitrate concentration from the regression function.

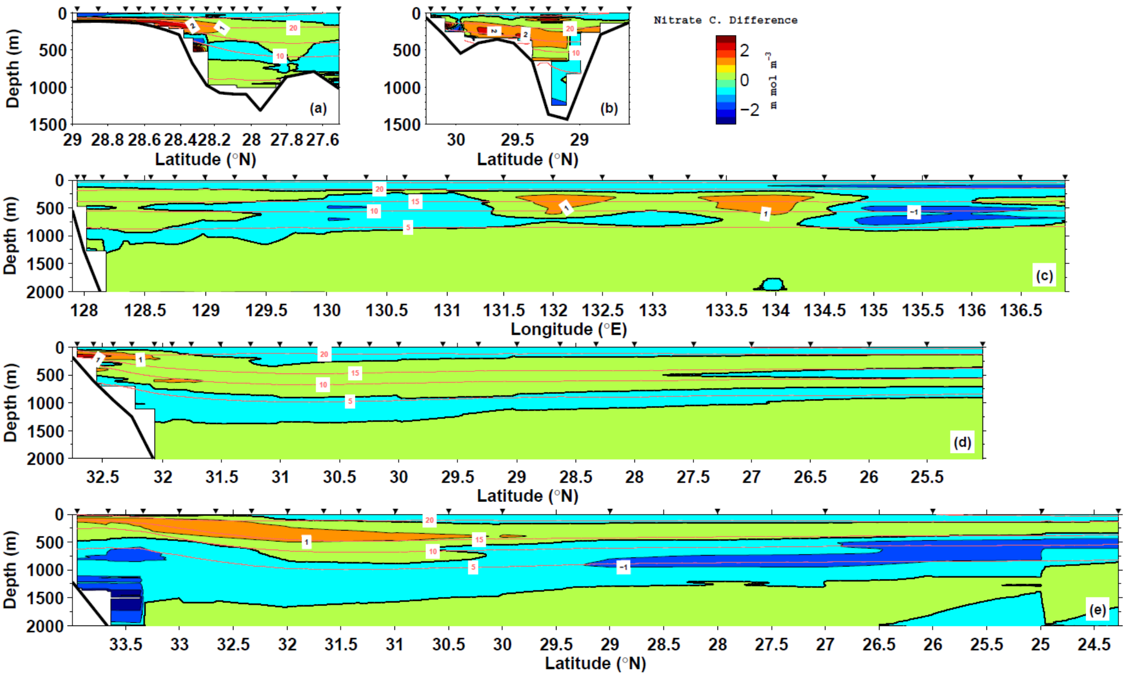

Figure R4. Difference between temporally averaged nitrate concentration from field measurement and temporally averaged nitrate concentration from water temperature regression (measurement - regression).

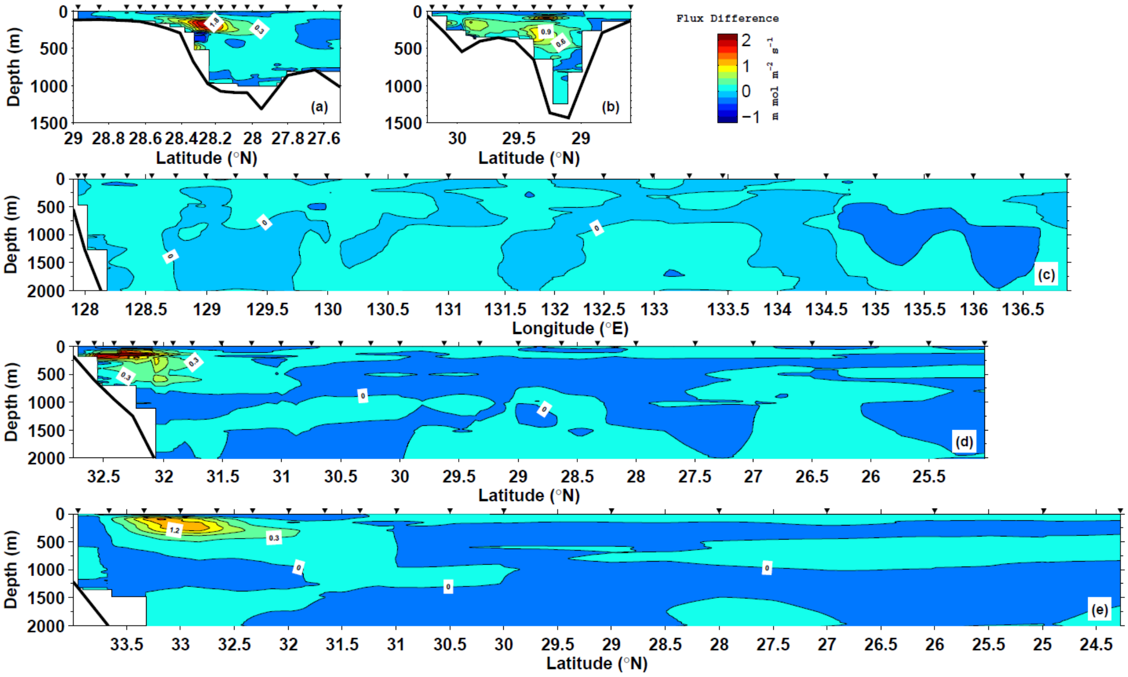

Figure R5. Difference between temporally averaged nitrate flux calculated from field measured nitrate concentration (Fig. 4) and temporally averaged nitrate flux calculated from water temperature regressed nitrate concentration (measurement - regression).

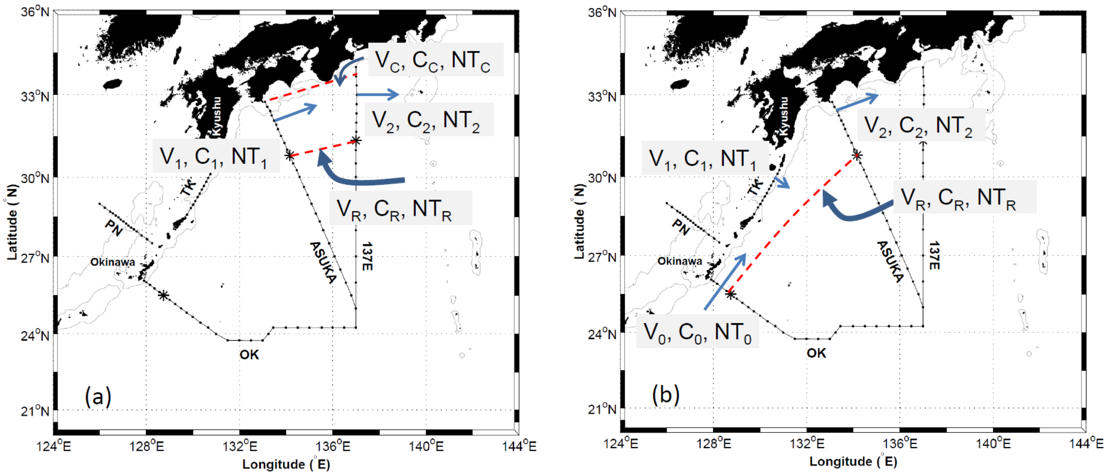

Figure R6. Schematic for (a) a box model between sections ASUKA-N and 137E-N-S, (b) a box model between sections ASUKA-N, TK and OK-W. V is volume transport; NT is nitrate transport; C is ratio of NT to V. (a) subscript ‘1’ denotes section ASUKA-N; subscript ‘2’ denotes section 137E-N-S; subscript ‘C’ denotes section 137E-N-N where a westward coast current flows into the box, and subscript ‘R’ denotes a section (red dash line) where the Kuroshio recirculation flows into the box. (b) subscript ‘1’ denotes section TK; subscript ‘2’ denotes section ASUKA-N; subscript ‘0’ denotes section OK-W, and subscript ‘R’ denotes a section (red dash line) where the Kuroshio recirculation flows into the box.

Table R1. Budget of nitrate transport for each isopycnal layer between sections 137E-N-S and ASUKA-N.

Layer	NT_2-NT_1-NT_C (kmol s^{-1})	V_RC_R (kmol s^{-1})	$V_1(C_2$-$C_1)$ (kmol s^{-1})	$V_R(C_2$-$C_R)$ (kmol s^{-1})	$V_C(C_2$-$C_C)$ (kmol s^{-1})	C_1 (mmol m^{-3})	C_R (mmol m^{-3})	C_C (mmol m^{-3})	C_2 (mmol m^{-3})
1	-8.2	0.0	-8.1	0.0	-0.1	2.5	0.7	3.0	2.1
2	24.8	10.7	10.2	4.0	-0.1	6.1	5.0	7.5	6.9
3	82.7	69.0	9.3	4.6	-0.2	16.0	15.6	17.1	16.6
4	46.8	51.6	-2.6	-2.4	0.2	29.8	30.8	28.9	29.4
5	65.3	70.2	-2.0	-3.0	0.1	38.1	39.1	37.3	37.4
6	87.0	88.2	0.0	-1.2	0.0	40.7	41.3	40.8	40.7
7	50.8	51.1	0.0	-0.3	0.0	40.8	41.1	40.8	40.8
8	29.9	30.0	0.0	0.0	0.0	40.6	40.1	39.8	40.1
All	379.2	370.9	6.6	1.7	0.0				

Table R2. Budget of nitrate transport (kmol s^{-1}) for each isopycnal layer between sections TK, OK-W, and ASUKA-N.

Layer	NT_2-NT_1-NT_0 (kmol s^{-1})	V_RC_R (kmol s^{-1})	$V_0(C_2$-$C_0)$ (kmol s^{-1})	$V_1(C_2$-$C_1)$ (kmol s^{-1})	$V_R(C_2$-$C_R)$ (kmol s^{-1})	C_0 (mmol m^{-3})	C_1 (mmol m^{-3})	C_R (mmol m^{-3})	C_2 (mmol m^{-3})
1	26.0	3.6	1.6	12.1	8.6	1.4	1.4	0.8	2.5
2	49.9	38.6	0.2	0.4	10.7	6.0	6.1	4.8	6.1
3	140.0	123.7	0.9	9.9	5.6	15.7	14.1	15.3	16.0
4	113.2	114.8	-0.9	2.5	-3.3	30.4	28.1	30.6	29.8
5	65.5	65.1	0.7	0.9	-1.1	37.5	34.8	38.8	38.1
6	60.5	60.8	0.4	-0.3	-0.4	39.6	39.1	41.0	40.7
7	19.7	19.6	0.1	0.0	0.0	40.1	0.0	40.7	40.8
8	-1.2	-1.3	0.1	0.0	0.0	39.3	0.0	39.7	40.6
All	473.7	425.0	3.2	25.4	20.1				

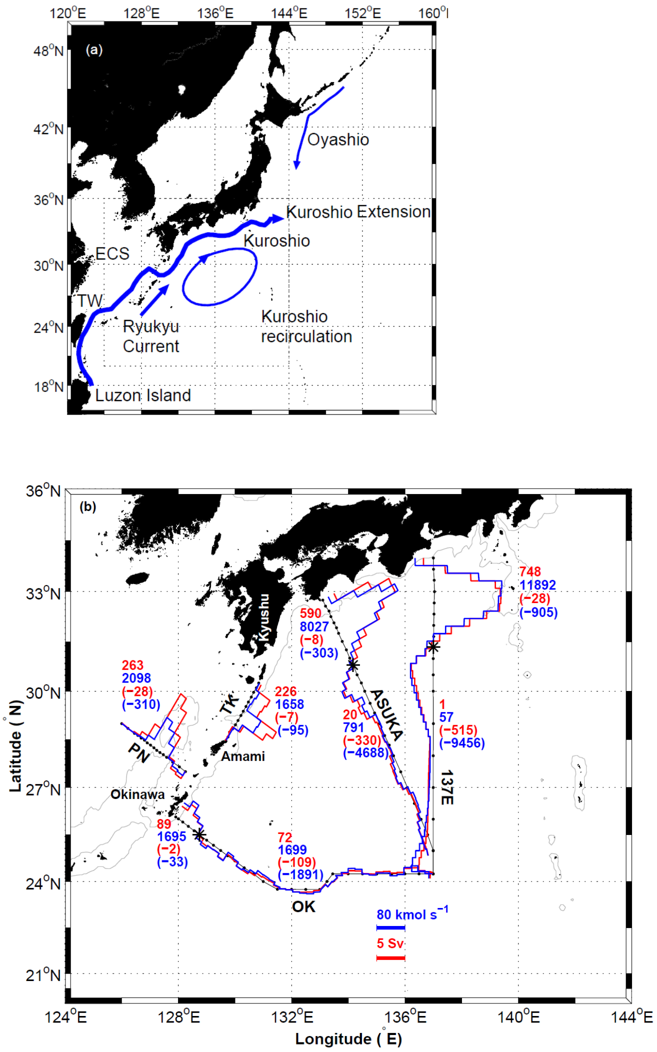

Figure 1. (a) Study area and schematic image of Kuroshio path, Kuroshio recirculation, Ryukyu Current. ‘ECS’ denotes East China Sea; ‘TW’ denotes Taiwan. (b) Position of hydrographic stations (black dots), volume transport (red line, 1 Sv=10^6 m^3s^{-1}) and nitrate transport (blue line, kmol s^{-1}) integrated from sea surface to deepest layer within 25 km width. The positive direction for two transports is defined as the same as the Kuroshio or Ryukyu Current. The thin straight lines connecting dots are served as a reference the transports. See Eqs. (4) - (6) and their description in section 2 for the calculation method of these variables. ‘PN’, ‘TK’, ‘OK’, ‘ASUKA’, and ‘137E’ are the name of sections. Tokaara Strait is at section TK. The thin curve line denotes 200 m isobath. The black star separates section OK into two parts: section OK-W at its west and section OK-E at its east; section ASUKA into two parts: section ASUKA-N at its north and section AUSKA-S at its south; section 137E into two parts: section 137E-N at its north and section 137E-S at its south. There are four numbers for each section, in which two red numbers are for positive and negative volume transports through the section in a unit of 0.1 Sv; two blue numbers are for positive and negative nitrate transports through the section in a unit of 0.1 kmol s^{-1}.

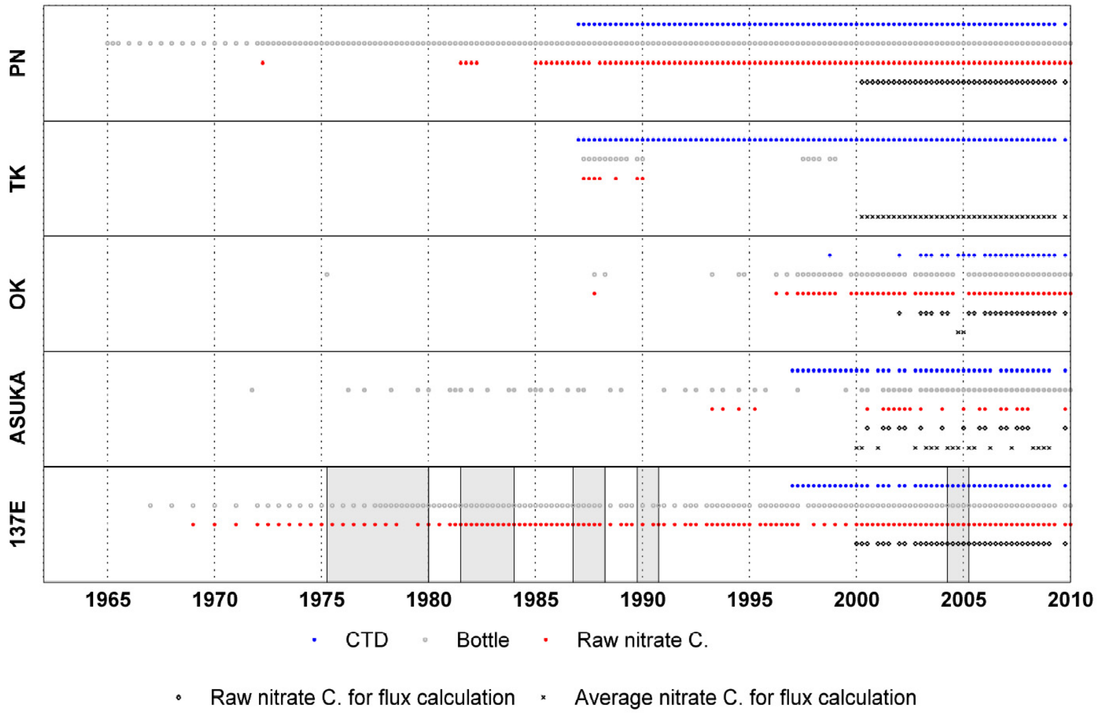

Figure 2. Data distribution at five sections. Blue dots denote CTD data for calculating velocity; grey circles denote bottle data for water temperature and salinity; red dots denote raw nitrate concentration; black circles denote raw nitrate concentration used in the calculation of nitrate flux; black crosses denote temporally averaged nitrate concentration used in the calculation of nitrate flux when the raw nitrate concentration was not available. The grey background at section 137E denotes the period of Kuroshio large meander and the data collected in this period were not used in this study.

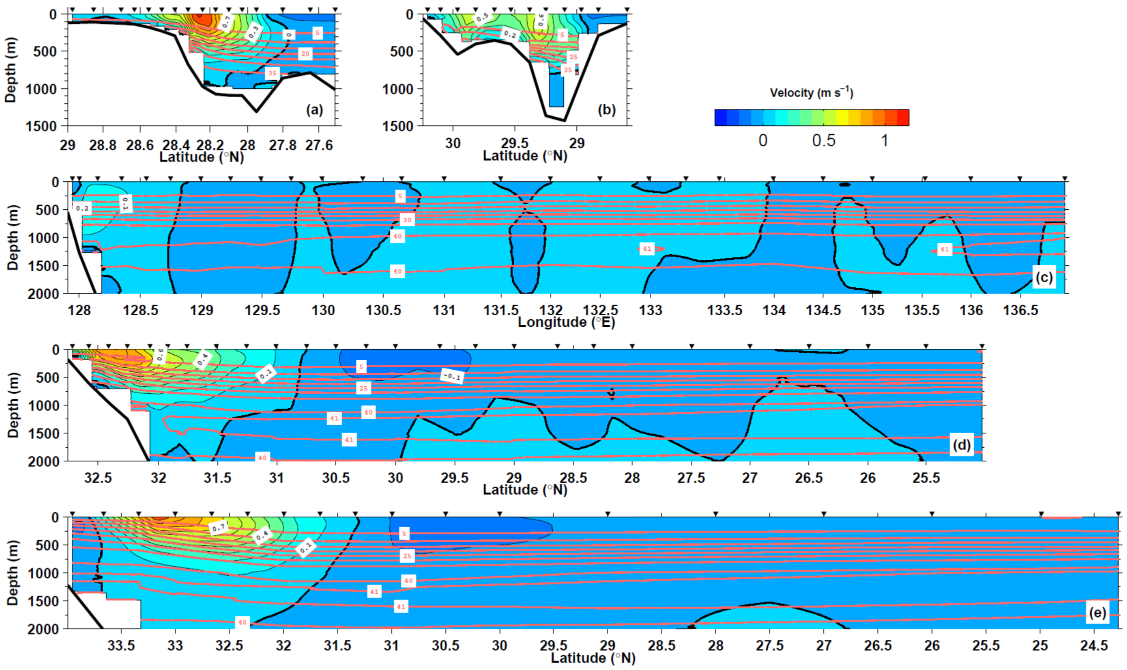

Figure 3. Temporally averaged absolute geostrophic velocity (ms^{-1}) and nitrate concentration (mmol m^{-3}) at 5 sections. Color tone and black contours show velocity with an interval of 0.1 ms^{-1}. Positive values is defined as at the same direction as the Kuroshio or Ryukyu Current. Red contours indicate nitrate concentration with an interval of 5 mmol m^{-3} except for 41 mmol m^{-3}. Thick black line shows zero speed. The inverse triangles denote hydrographic stations where water temperature, salinity, and nitrate concentration are available.

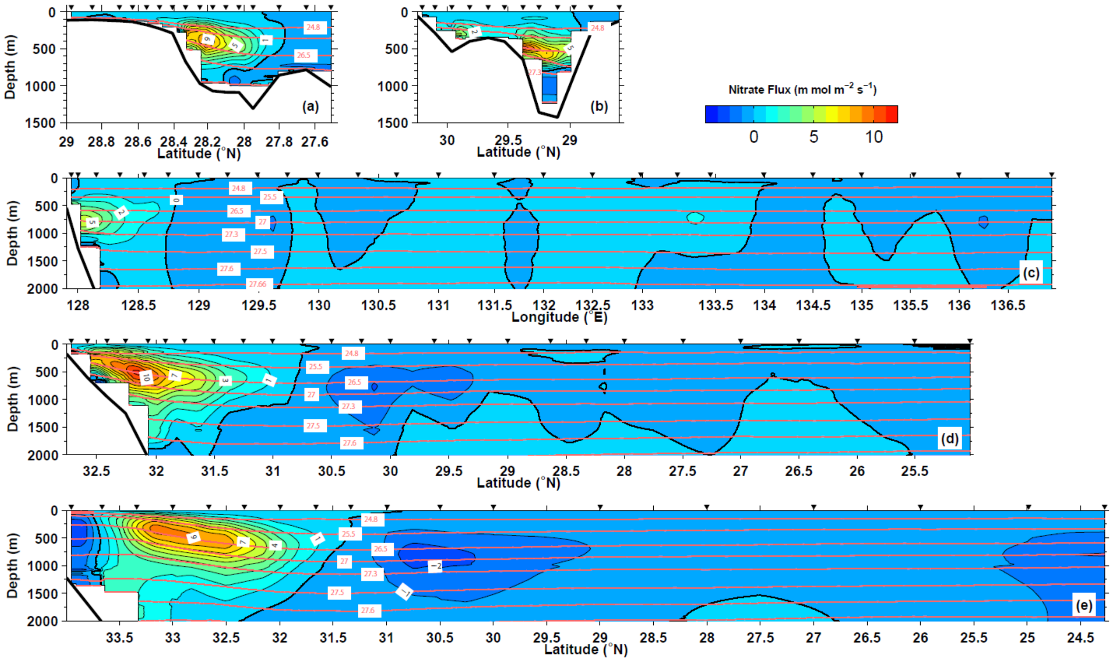

Figure 4. Temporally averaged nitrate flux (mmol m^{-2} s^{-1}) at 5 sections. Color tone and black contours show nitrate flux with an interval of 1 mmol m^{-2} s^{-1}. Definition for positive values is the same as the velocity (Fig. 3). Red contours indicate 8 isopycnal layers. Thick black line shows zero nitrate flux. The inverse triangles are the same as those in Fig.3.

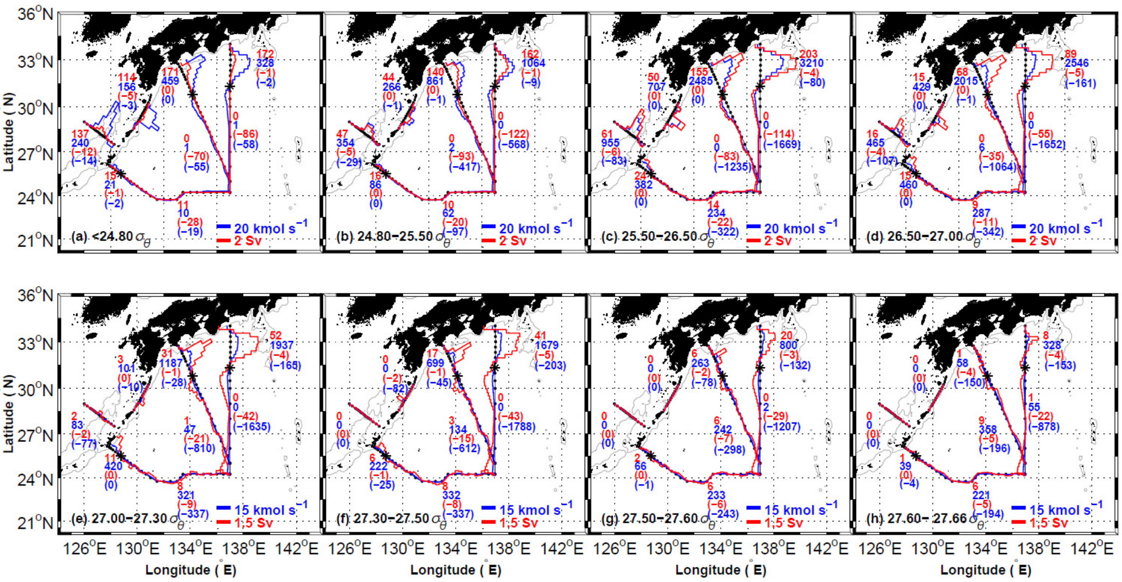

Figure 5. The same as Fig. 1b but for each of 8 isopycnal layers: (a) sea surface - 24.8σ_θ, (b) 24.8 - 25.5σ_θ, (c) 25.5 - 26.5σ_θ, (d) 26.5 - 27σ_θ, (e) 27 - 27.3σ_θ, (f) 27.3 - 27.5σ_θ, (g) 27.5-27.6σ_θ, (h) 27.6-27.66σ_θ.

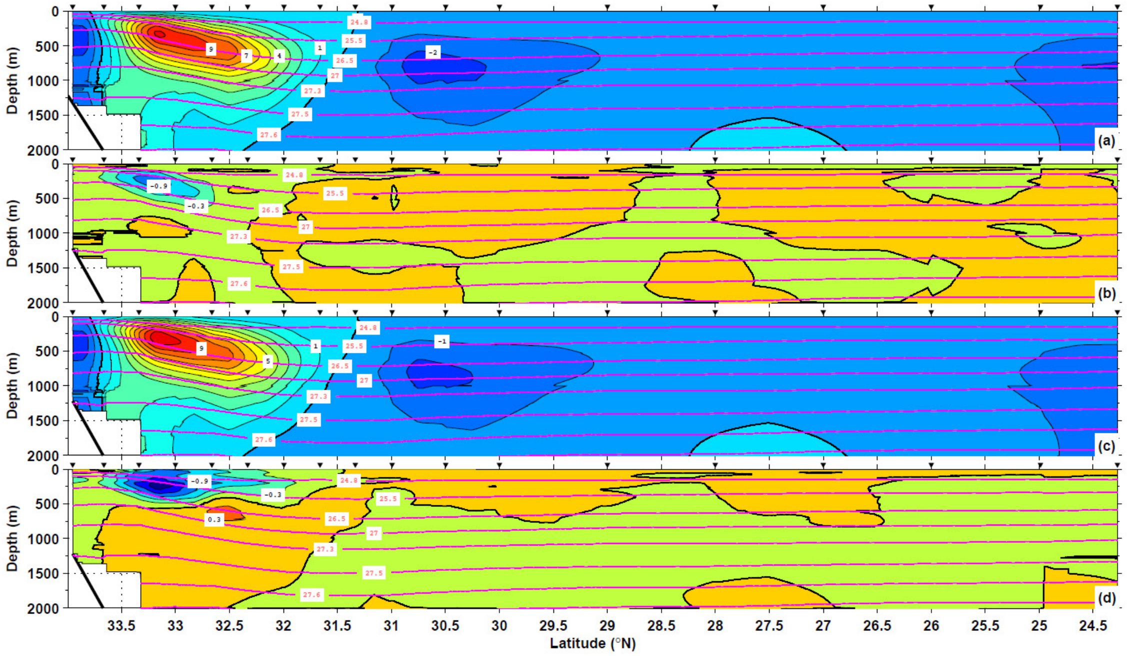

Figure 6. Nitrate flux (mol $m^{-2}s^{-1}$) at section 137E calculated by temporally averaged speed from 2000 to 2009 and, (a) temporally averaged nitrate concentration before 2000; (c) temporally averaged nitrate concentration from 2000 to 2009. (b) Difference between Fig. 4e and (a); (d) difference between Fig. 4e and (c). Color tone and black contour lines show nitrate flux with an interval of 1 mol $m^{-2}s^{-1}$ in (a) and (c), with an interval of 0.3 mol $m^{-2}s^{-1}$ in (b) and (d). Positive values indicate eastward flux. Red contour lines indicate 8 isopycnal layers. Thick black line shows zero nitrate flux. The inverse triangles denote hydrographic stations where water temperature, salinity, and nitrate concentration are available.

Table 1. Along-stream variation of VTP(Sv), VTN(Sv), NTP(kmols^{-1}), NTN(kmols^{-1}), CTP(mmolm^{-3}), CTN(mmolm^{-3}), CAP(mmolm^{-3}), CAN(mmolm^{-3}), VT(Sv), and NT(kmols^{-1}). The first column is number of layer; the second to sixth columns are one variable for sections PN, TK, OK, ASUKA, and 137E, respectively; the seventh to eleventh columns are another variable for sections PN, TK, OK, ASUKA, and 137E, respectively.

	PN	TK	OK	ASUKA	137E	PN	TK	OK	ASUKA	137E
	VTP					VTN				
1	13.7	11.4	2.5	17.1	17.2	−1.2	−0.5	−2.9	−7.0	−8.7
2	4.7	4.4	2.6	14.0	16.2	−0.5	0.0	−2.0	−9.3	−12.3
3	6.1	5.0	3.9	15.5	20.3	−0.6	0.0	−2.2	−8.4	−11.8
4	1.6	1.5	2.4	6.8	8.9	−0.4	0.0	−1.1	−3.5	−6.1
5	0.2	0.3	1.9	3.2	5.2	−0.2	0.0	−0.9	−2.2	−4.6
6	0.0	0.0	1.4	2.0	4.1	0.0	−0.2	−1.0	−1.6	−4.8
7	0.0	0.0	0.7	1.2	2.0	0.0	0.0	−0.6	−0.9	−3.3
8	0.0	0.0	0.7	1.0	1.0	0.0	0.0	−0.5	−0.9	−2.6
All	**26.3**	**22.6**	**16.1**	**61.0**	**75.0**	**−2.8**	**−0.7**	**−11.2**	**−33.8**	**−54.2**
	NTP					NTN				
1	23.6	15.6	2.9	43.3	35.3	−1.3	−0.3	−2.0	−5.2	−6.6
2	33.7	26.6	15.3	86.0	111.5	−2.9	−0.1	−10.4	−44.0	−62.1
3	93.5	70.7	61.8	249.2	338.4	−8.7	0.0	−33.3	−126.7	−185.0
4	45.8	42.9	74.5	202.2	262.5	−11.2	0.0	−34.5	−107.9	−186.3
5	8.3	10.1	73.6	123.2	194.8	−7.8	−1.0	−33.6	−84.1	−181.0
6	0.0	0.0	55.1	83.3	168.4	0.0	−8.2	−40.3	−65.9	−198.8
7	0.0	0.0	29.7	50.5	81.4	0.0	0.0	−24.3	−37.7	−133.8
8	0.0	0.0	25.8	41.6	38.2	0.0	0.0	−19.7	−34.7	−103.3
All	**204.8**	**165.8**	**338.6**	**879.3**	**1230.4**	**−31.9**	**−9.5**	**−198.1**	**−506.2**	**−1057.0**
	CTP					CTN				
1	1.7	1.4	1.1	2.5	2.1	1.1	0.5	0.7	0.7	0.8
2	7.2	6.1	5.9	6.2	6.9	6.2	4.9	5.2	4.7	5.0
3	15.4	14.1	15.9	16.0	16.6	15.6	0.0	15.2	15.2	15.7
4	28.6	28.1	30.8	29.8	29.4	29.4	0.0	30.6	30.4	30.7
5	36.0	34.9	38.2	38.1	37.4	36.2	36.3	38.7	38.6	38.9
6	0.0	0.0	40.4	40.9	40.7	0.0	39.1	40.5	41.1	41.2
7	0.0	0.0	40.3	40.9	40.8	0.0	0.0	40.2	41.0	41.1
8	0.0	0.0	39.4	40.2	40.0	0.0	0.0	39.2	40.0	40.1
All	**7.8**	**7.3**	**21.0**	**14.4**	**16.4**	**11.3**	**12.7**	**17.7**	**15.0**	**19.5**
	CAP					CAN				
1	1.9	1.4	0.9	1.8	1.7	1.5	0.8	0.8	0.6	0.7
2	7.2	6.2	5.8	5.6	6.3	6.3	4.6	5.4	4.9	5.1
3	16.3	13.6	16.6	17.1	17.2	16.6	0.0	15.9	16.0	16.2
4	29.9	28.7	31.5	31.2	30.0	29.4	0.0	31.0	30.8	31.0
5	36.4	35.3	39.0	38.8	37.8	36.3	36.4	38.9	38.9	39.2
6	0.0	0.0	40.7	41.2	40.8	0.0	39.1	40.6	41.2	41.3
7	0.0	0.0	40.2	41.0	40.8	0.0	0.0	40.2	41.1	41.1
8	0.0	0.0	39.4	40.2	40.1	0.0	0.0	39.2	40.1	40.1
All	**14.5**	**9.7**	**30.8**	**33.5**	**30.0**	**18.4**	**21.7**	**27.2**	**26.7**	**29.6**
	VT					NT				
1	12.5	10.9	−0.4	10.1	8.5	22.3	15.3	0.9	38.1	28.7
2	4.2	4.4	0.6	4.6	3.9	30.8	26.5	4.9	42.0	49.4
3	5.5	5.0	1.7	7.2	8.5	84.8	70.7	28.5	122.4	153.3
4	1.2	1.5	1.3	3.2	2.9	34.5	42.9	40.0	94.4	76.2
5	0.0	0.3	1.1	1.1	0.6	0.5	9.1	40.0	39.1	13.8
6	0.0	−0.2	0.4	0.4	−0.7	0.0	−8.2	14.7	17.4	−30.4
7	0.0	0.0	0.1	0.3	−1.3	0.0	0.0	5.4	12.8	−52.5
8	0.0	0.0	0.2	0.2	−1.6	0.0	0.0	6.0	6.9	−65.1
All	**23.5**	**21.8**	**4.9**	**27.2**	**20.7**	**172.9**	**156.3**	**140.4**	**373.0**	**173.5**