Responses to Reviewer #1

Note: The reviewers' comments are in black, and our responses are in blue. The changes made in the revised manuscript are highlighted in green. Figures in the manuscript are labeled using Arabic numerals (e.g., Fig. 1, Figure 1), and those in our responses to the reviewers are labeled using Arabic numerals with the prefix "R" (e.g., Fig. R1, Figure R1).

Reviewer #1:

The study investigates the regional differences (q) in the local dissipation efficiency of internal tides between the Luzon Strait and the Nansha Islands based on the LLC4320 simulation outputs. A physically-based empirical formulation and an XGBoost model are subsequently developed to parameterize q. This study contributes much to improving the understanding and parameterization of internal tide dissipation in the SCS. However, the manuscript still has some shortcomings, and the following points should be addressed further by the authors before publication.

Responses: We sincerely thank the reviewer for the valuable suggestions on our manuscript. We have carefully considered and fully incorporated all suggestions into the revised manuscript. We hope that these improvements will render the manuscript more refined and satisfy the reviewer.

1) Fig. 1: Since q is calculated from area-integrated conversion and dissipation, its magnitude may be sensitive to the choice of regional boundaries. Could the authors clarify the criteria used to determine the boundaries of the Luzon Strait and the Nansha Islands?

Responses: We are sorry for this information gap. The regional boundaries were determined according to the major topographic features and existing studies on internal tidal energetics. Specifically, the Luzon Strait domain is defined to encompass the Hengchun Ridge, the Lanyu Ridge, and the trough between them, which collectively constitute the well-known double-ridge where intense internal tides are generated (Buijsman et al., 2014; Tian et al., 2025; Wang et al., 2016). The Nansha Islands domain is selected to encompass the dominant topographic features (islands and reefs), which are located in the propagation paths of internal tides coming from the Luzon Strait (Tian et al., 2025; Xu et al., 2016). The interaction of the incoming internal tides with the rough islands and reefs promotes energy transfer to higher modes and hence enhances local dissipation (Vic et al., 2019). As a result, these two domains are chosen to represent a typical internal tide source region and a sink region, respectively. In the revised manuscript, we added a concise description about the choosing of these two domains.

References:

Buijsman, M. C., Klymak, J. M., Legg, S., Alford, M. H., Farmer, D., MacKinnon, J. A., Nash, J. D., Park, J.-H., Pickering, A., and Simmons, H.: Three-dimensional double-ridge internal tide resonance in Luzon Strait, J. Phys. Oceanogr., 44, 850–869, https://doi.org/10.1175/JPO-D-13-024.1, 2014.

Tian, Y., Bai, X., Wang, C., and Liu, Z.: Tidal energetics in the eddying South China Sea from a high-resolution numerical simulation, Prog. Oceanogr., 231, 103418, https://doi.org/10.1016/j.pocean.2025.103418, 2025.

Vic, C., Naveira Garabato, A. C., Green, J. A. M., Waterhouse, A. F., Zhao, Z., Melet, A., de Lavergne, C., Buijsman, M. C., and Stephenson, G. R.: Deep-ocean mixing driven by small-scale internal tides, Nat. Commun., 10, 2099, https://doi.org/10.1038/s41467-019-10149-5, 2019.

Wang, X., Peng, S., Liu, Z., Huang, R. X., Qian, Y.-K., and Li, Y.: Tidal mixing in the South China Sea: an estimate based on the internal tide energetics, J. Phys. Oceanogr., 46, 107–124, https://doi.org/10.1175/JPO-D-15-0082.1, 2016.
Xu, Z., Liu, K., Yin, B., Zhao, Z., Wang, Y., and Li, Q.: Long-range propagation and associated variability of internal tides in the South China Sea, J. Geophys. Res. Oceans, 121, 8268–8286, https://doi.org/10.1002/2016JC012105, 2016.

(Changes are as follows:

"The Luzon Strait domain is defined to encompass the Hengchun Ridge, the Lanyu Ridge, and the inter-ridge trough, which collectively constitute the double-ridge where intense internal tides are generated (Buijsman et al., 2014; Tian et al., 2025; Wang et al., 2016). The Nansha Islands domain is selected to encompass the dominant topographic features (islands and reefs), which are located in the propagation paths of internal tides coming from the LS (Tian et al., 2025; Xu et al., 2016). The interaction of the incoming internal tides with the rough islands and reefs promotes energy transfer to higher modes and hence enhances local dissipation (Vic et al., 2019)."

This modification can be found in Lines 91–98 of the revised manuscript.)

2) Lines 100–108: The manuscript only retains the first five baroclinic modes in the modal decomposition. Please state why five modes are sufficient for the analysis presented in this study. Given that high-mode internal tides are significant and important over steep and rough topography, it would be helpful to either provide the proportion of total baroclinic kinetic energy captured by modes 1–5, or discuss the potential influence of unresolved higher modes on the diagnosed local dissipation.

Responses: We thank the reviewer for pointing out this information gap. As the reviewer suggested, we calculate the proportion of total depth-integrated baroclinic kinetic energy captured by the first five modes (modes 1–5) for the winter and summer months analyzed in this study. For each tidal band in each region, this proportion is calculated as the ratio of the area-integrated value of depth-integrated kinetic energy from modes 1–5 to the area-integrated value of total depth-integrated baroclinic kinetic energy. The numerator is calculated from the modal decomposition result (i.e., kinetic energy of modes 1–5), whereas the denominator is calculated directly from the full baroclinic velocity field before modal decomposition. The results show that in the Luzon Strait region and the Nansha Islands, modes 1–5 account for 85% and 89% of the total baroclinic kinetic energy, 87% and 99% of the diurnal baroclinic kinetic energy, and more than 98% of the semidiurnal baroclinic kinetic energy. These results indicate that the first five modes almost make up entire baroclinic kinetic energy during the chosen periods. We have incorporated these results into the *Methods* section of the revised manuscript. The potential impact of unresolved higher modes is also given in the revised manuscript. Modes 1–5 capture the dominant part of total baroclinic kinetic energy, although unresolved higher modes may still contribute less to local dissipation of internal tides over rough topography (Vic et al., 2019).

(Changes are as follows:

"In the LS and the Nansha Islands, modes 1–5 account for 85% and 89% of the total baroclinic kinetic energy, 87% and 99% of the diurnal baroclinic kinetic energy, and more than 98% of the semidiurnal baroclinic kinetic energy. Modes 1–5 capture the dominant part of total baroclinic kinetic energy, although unresolved higher modes may still contribute less to local dissipation of internal tides over rough topography (Vic et al., 2019)."

This modification can be found in Lines 114–118 of the revised manuscript.)

3) Lines 40–44 and 122–125: q is defined as the fraction of locally dissipated internal tidal energy relative to locally generated internal tidal energy, which would conventionally be expected to fall between 0 and 1. However, subsequent results presented in the manuscript report $q > 1$ in the Nansha Islands and negative q values for some individual modes in the Luzon Strait. Please provide the definition and sign convention of q, and explicitly explain the physical meanings of $q > 1$ and $q < 0$ in the present energy-budget framework.

Responses: We are sorry for this confusion. In this study, q is defined as the ratio of the area-integrated local dissipation to the area-integrated barotropic-to-baroclinic energy conversion, i.e., $q = \int_s ds\langle DIS_{bc}\rangle / \int_s ds\langle Conv\rangle$. Here, $\langle DIS_{bc}\rangle$ is inferred as $\langle DIS_{bc}\rangle = \langle Conv\rangle - \langle \nabla_h \cdot \boldsymbol{F}\rangle$, where $\langle\cdot\rangle$ denotes the tidal-period mean, $Conv$ is the barotropic-to-baroclinic energy conversion, and $\nabla_h \cdot \boldsymbol{F}$ is the horizontal divergence of the depth-integrated baroclinic energy flux. In this way, $q > 1$ occurs in the Nansha Islands when the area-integrated divergence of the baroclinic energy flux is negative, indicating a convergence of remotely generated internal tidal energy entering here. In this case, the diagnosed local dissipation exceeds the barotropic-to-baroclinic energy conversion. It can be seen that $q > 1$ does not imply that more than 100% of the locally generated internal tidal energy must be dissipated locally; instead, it means that the local dissipation is furnished by both the local barotropic-to-baroclinic energy conversion and the convergence of incoming internal tidal energy from far-field. For individual vertical modes, $q < 0$ occurs when the area-integrated divergence of the baroclinic energy flux of this mode exceeds its local barotropic-to-baroclinic energy conversion, yielding a negative diagnosed dissipation. The divergence of the baroclinic energy flux is furnished by both the local conversion and the net energy transfer from other vertical modes, allowing the divergence of the baroclinic energy flux to exceed the local barotropic-to-baroclinic energy conversion.

(Changes are as follows:

"$\boldsymbol{F}$ is the depth-integrated internal tidal energy flux, and $\nabla_h \cdot \boldsymbol{F}$ is the horizontal divergence of the depth-integrated baroclinic energy flux. A positive divergence of $\boldsymbol{F}$ indicates that the internal tidal energy is propagating out of the local area, while a negative value indicates that internal tidal energy is propagating in from the far field."

This modification can be found in Lines 128–130 of the revised manuscript;

"In this way, q is not necessarily bounded between 0 and 1. $q > 1$ occurs when the area-integrated divergence of the baroclinic energy flux is negative, indicating a convergence of remotely generated internal tidal energy entering here. In this case, the diagnosed local dissipation exceeds the barotropic-to-baroclinic energy conversion. It can be seen that $q > 1$ means that the local dissipation is furnished by both the local barotropic-to-baroclinic energy conversion and the convergence of incoming internal tidal energy from far-field. For individual vertical modes, $q < 0$ occurs when the area-integrated divergence of the baroclinic energy flux of this mode exceeds its local barotropic-to-baroclinic energy conversion, yielding a negative diagnosed dissipation. The divergence of the baroclinic energy flux is furnished by both the local conversion and the net energy transfer from other vertical modes, allowing the divergence of the baroclinic energy flux to exceed the local barotropic-to-baroclinic energy conversion."

This modification can be found in Lines 136–144 of the revised manuscript.)

4) Lines 90–92 and 125–127: The LLC4320 simulation outputs used in this study only span

approximately 14 months, from September 2011 to November 2012. In the analysis, January and August are used to represent winter and summer, respectively. As a result, the summer-winter differences reported in this manuscript are based on a single annual cycle rather than a multiyear climatology. Could the authors point out this limitation explicitly and avoid interpreting these differences as climatological seasonal variations?

Responses: We thank the reviewer for this insightful comment. As the reviewer suggested, in the revised manuscript, January and August 2012 are now referred to as winter and summer months in the specifically simulated year, and the differences between them are interpreted as those between two individual months rather than as climatological seasonal variations.

(Changes are as follows:

"January and August 2012 are selected as winter and summer months in the simulated year, respectively."

This modification can be found in Line 147 of the revised manuscript;

"By contrast, although the semidiurnal energy budget is also dominated by modes 1–2, the proportion of mode-1 energy flux divergence is relatively smaller, and its difference between January and August 2012 is weaker than that of the diurnal tide (Fig. 3j–k)."

This modification can be found in Lines 182–184 of the revised manuscript;

"Diurnal tides dominate in the Nansha Islands, with all energy budget terms exceeding those of the semidiurnal tide and showing pronounced differences between January and August 2012 (Fig. 5j–k)."

This modification can be found in Lines 232–233 of the revised manuscript.)

5) Figs. 2–5: Since the first and final months of the dataset are incomplete, could the authors specify how the monthly mean values of q for these two months were treated in the time-series plots? If these mean values were calculated from incomplete monthly records, this should be stated clearly; alternatively, the corresponding data points can be removed or marked separately.

Response: We are sorry for this information gap. In the original manuscript, the monthly mean values of q for September 2011 and November 2012 were calculated using available days within these two months. Now the information about these two months has been removed from the time-series plots in Figs. 2–5 of the revised manuscript. The *Methods* section has also been revised accordingly to clarify that incomplete months are excluded when computing the monthly mean values of q. The revised Figs. 2–4 are provided below as Figs. R1–R3. The revised Fig. 5, which also addresses Comment 6, is presented as Fig. R4 below the response to Comment 6.

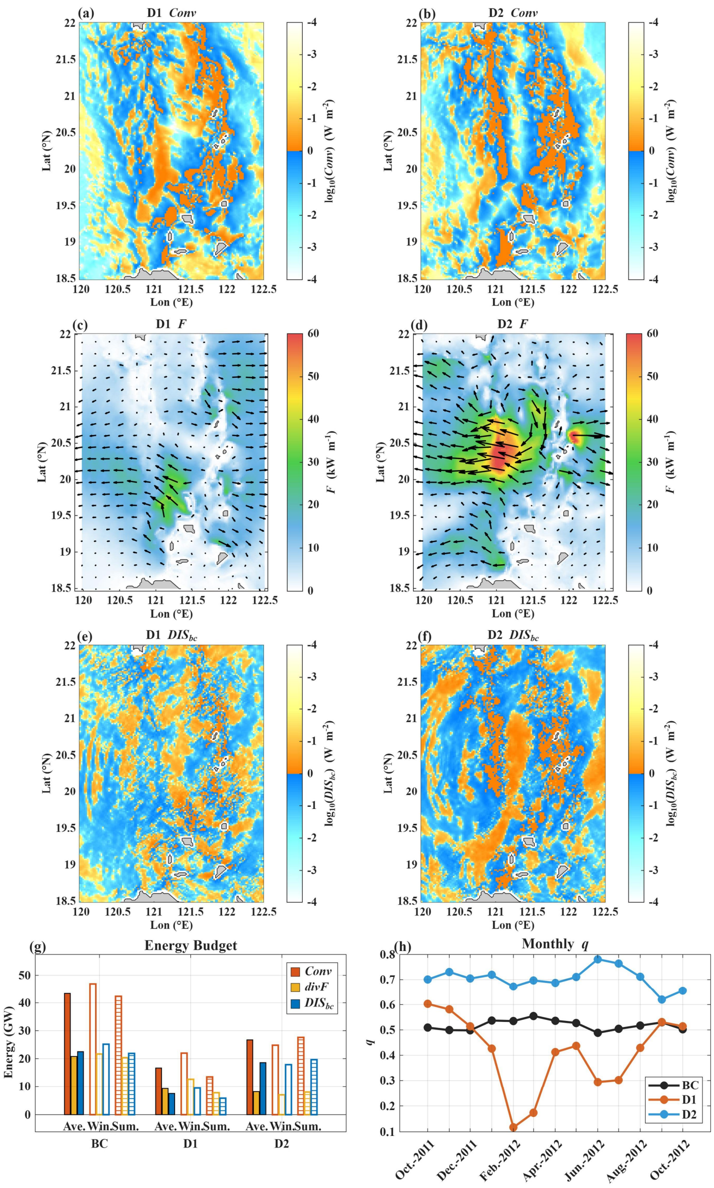

Figure R1. (a–f) Spatial distributions of the diurnal and semidiurnal internal tidal energy budget terms in the LS during summer. $\langle Conv \rangle$ is the tidal-period mean depth-integrated barotropic-to-baroclinic energy conversion, $\langle \boldsymbol{F} \rangle$ is the tidal-period mean depth-integrated internal tidal energy flux, and $\langle DIS_{bc} \rangle$ is the tidal-period mean depth-integrated local internal tidal dissipation. (g) Bar chart of the budget terms. $\langle div\boldsymbol{F} \rangle$ is the tidal-period mean divergence of the depth-integrated internal tidal energy flux. "Ave.", "Win.", and "Sum." stand for the annual-, winter-, and summer-mean values, respectively. BC, D1, and D2 represent the total internal tide, diurnal tide, and semidiurnal tide, respectively. (h) Time series of the monthly-mean local internal tidal dissipation efficiency, q. In (a–b) and (e–f), the units for $Conv$ and DIS_{bc} are W m^{-2}, with orange (blue) representing positive (negative) values. In (c–d), the unit for $\boldsymbol{F}$ is kW m^{-1}, with colors representing magnitude and arrows indicating direction. In (g), the units for $Conv$, $div\boldsymbol{F}$, and DIS_{bc} are GW.

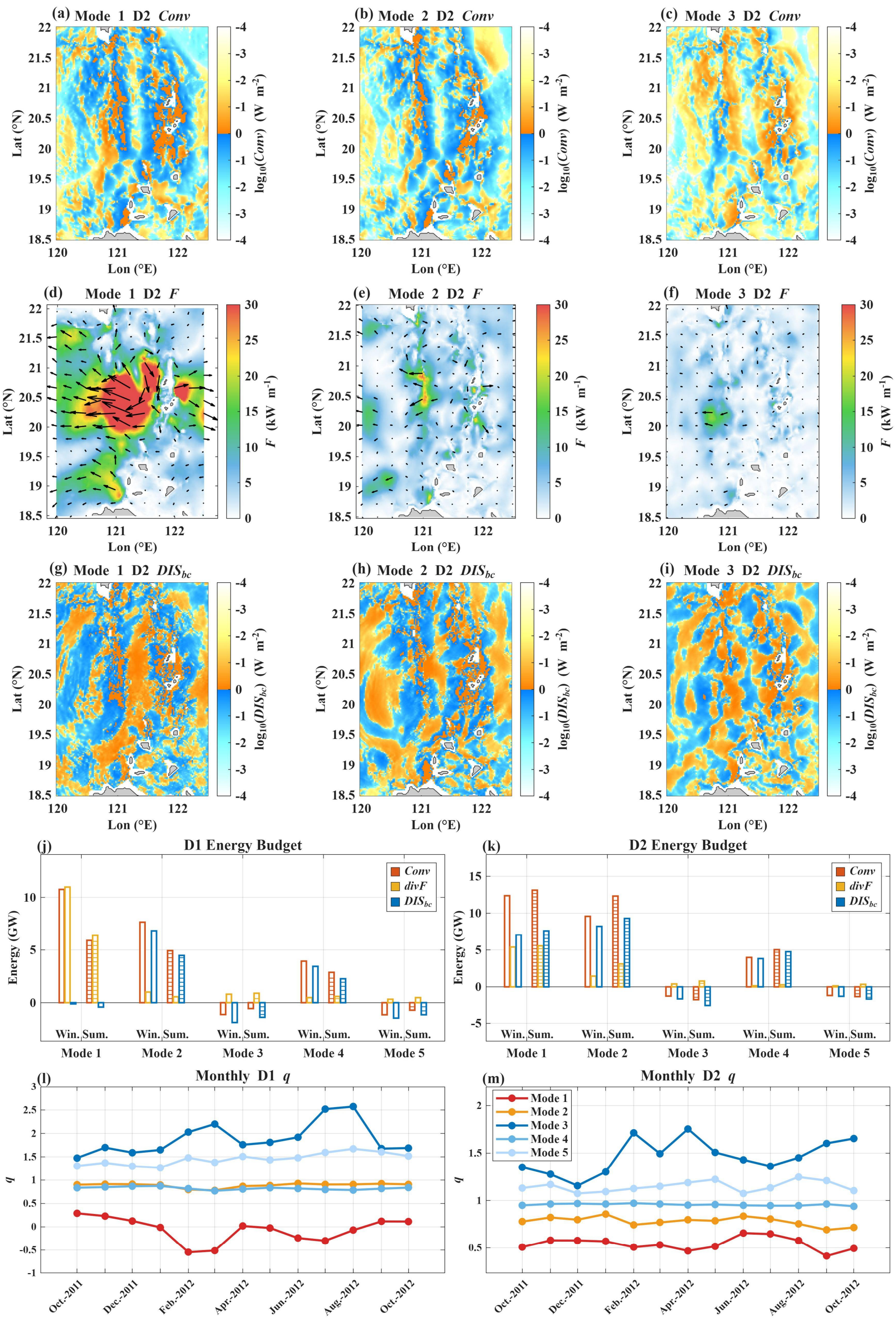

Figure R2. (a–i) Spatial distributions of the semidiurnal internal tidal energy budget terms for modes 1–3 in the LS during summer. (j–k) Bar charts of the energy budget terms for modes 1–5, and (*l*–m) time series of monthly-mean *q* for modes 1–5 for diurnal (D1) and semidiurnal (D2) tides, respectively. "Win." and "Sum." stand for winter and summer, respectively. In (a–c) and (g–i), the units for *Conv* and DIS_{bc} are W m^{-2}, with orange (blue) indicating positive (negative) values. In (d–f), the unit for ***F*** is kW m^{-1}, with colors indicating magnitude and arrows indicating direction. In (j–k), the units for *Conv*, *div**F***, and DIS_{bc} are GW.

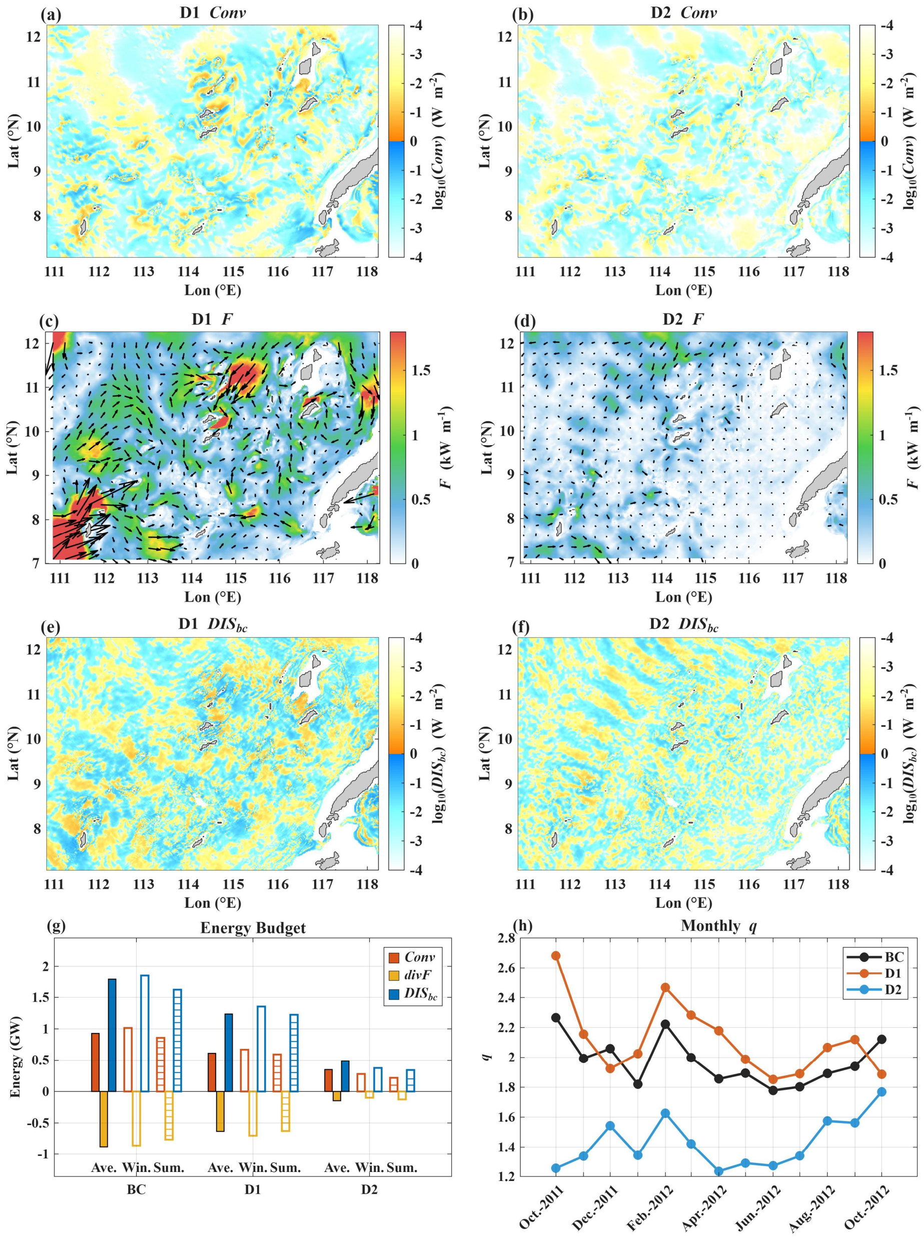

Figure R3. Same as Fig. R1, but for the Nansha Islands.

(Changes are as follows:

"Incomplete months (September 2011 and November 2012) are excluded when computing the monthly mean values of *q*."

This modification can be found in Lines 144–145 of the revised manuscript.)

6) Regarding Fig. 5j–m: These panels appear identical to Fig. 3j–m. Additionally, they are seemingly inconsistent with the results described in Lines 205–213, such as the reduced magnitude of energy-budget terms and the relatively large mode-1 *q*. Could the authors examine whether the proper data for the Nansha Islands have been plotted?

Responses: We sincerely apologize for this error. The corrected figure (Fig. 5 in the revised manuscript), presented as Fig. R4 below, shows that compared with the Luzon Strait, the Nansha Islands are characterized by smaller energy-budget terms, convergence of low-mode energy, and larger mode-1 q values that can exceed 4. In addition, we would like to clarify that when the area-integrated modal conversion is close to zero, several high-mode monthly q values can be extremely large. For the clarity of the figure, q values falling outside the displayed y-axis ranges in Fig. R4*l*–m are not shown, as noted in the revised figure caption.

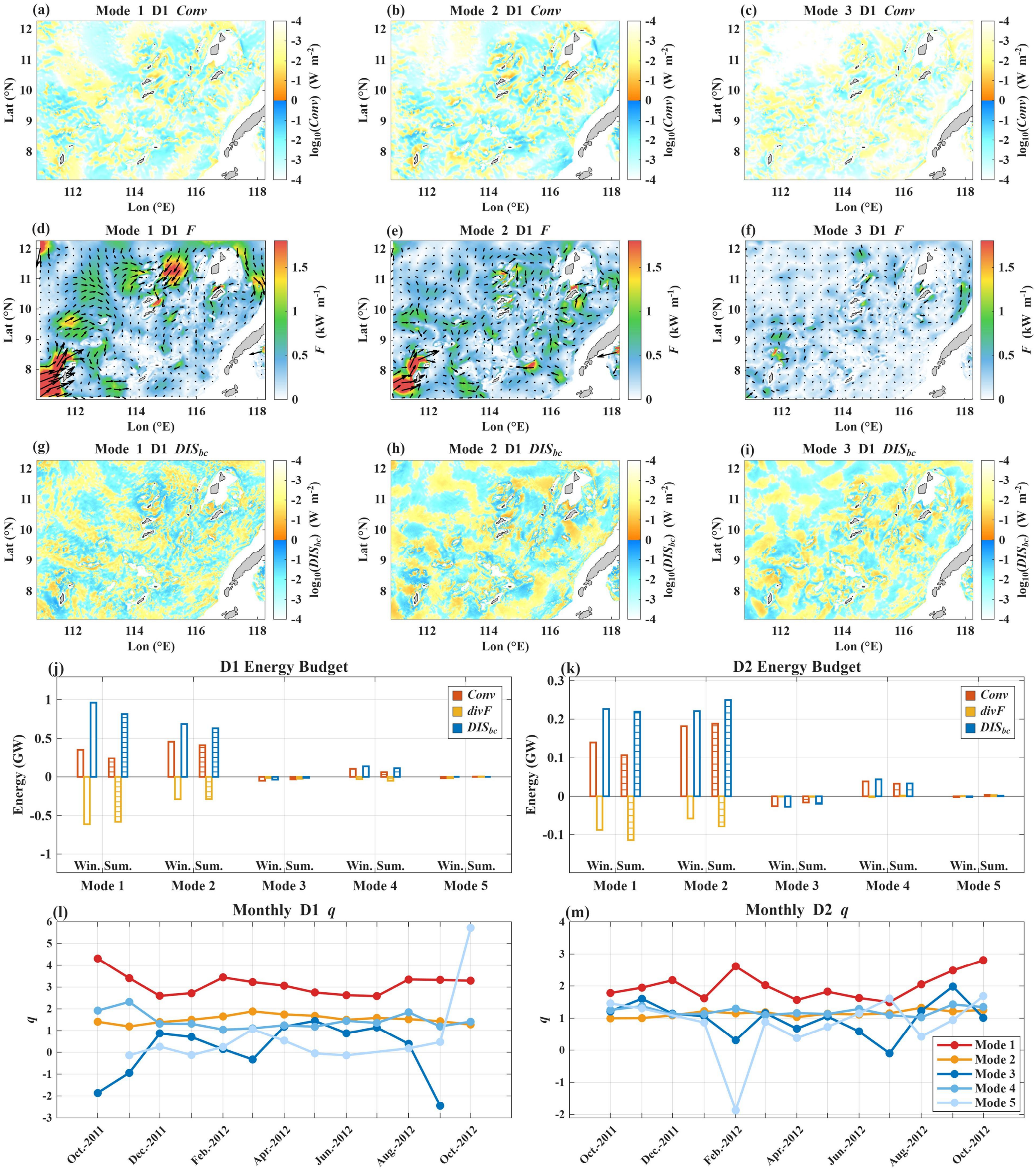

Figure R4. Same as Fig. R2, but for the Nansha Islands and (a–i) for diurnal internal tide. In (*l*–m), monthly mean values of q outside the displayed y-axis ranges are not shown for clarity.

(Changes are as follows:

"In terms of vertical modes, the internal tidal energy budget terms in the Nansha Islands are significantly smaller in magnitude than those in the LS, with strong low-mode energy convergence and high values of q. The energy budget in the Nansha Islands is dominated by modes 1 and 2 (Fig. 5j–k). Unlike in the LS, here the local generation of mode 1 is weaker than that of mode 2 (Fig. 5j–k). This energy budget, dominated by far-field input of mode-1 energy flux, directly results in the q values of mode 1 ($q > 2$) exceeding those of mode 2 ($q < 2$), as shown in Fig. 5*l*–m. The energy budget terms for modes 3–5 are all near zero with highly variable q (Fig. 5j–m), indicating that locally generated high modes are not the primary contributors to dissipation. Diurnal tides dominate in the Nansha Islands, with all energy budget terms exceeding those of the semidiurnal tide and showing pronounced differences between January and August 2012 (Fig. 5j–k). The q values of the mode-1 diurnal tide can exceed 4 (Fig. 5*l*)."

This modification can be found in Lines 226–234 of the revised manuscript.)