

## Response document to reviews on egusphere-2026-1852 RC2

Reviewer comments are presented first in *blue italics*, then followed by the author's response in normal font. Line numbers are referring to the original manuscript and are denoted as L145 for Line 145. For changes to text, we include the original in *red* and the changed version or new additions in italic *green*.

*The authors have done a nice job of developing a high resolution simulation of the SEqld region, which indeed represents an important region and a gap between the well studied GBR region and the EAC eddy field off NSW. As such this model development/experiment description paper represents an important contribution to the field and I recommend publication after some major revisions.*

*The model validation section is lacking description of the observations used (their resolution and limitations etc) and explanation of how the model is sampled for comparison with the observations. For example, the authors state they compare against satellite derived SSH and SST but have not described the products used.*

*Further, the authors state that the benefit of SEqld ROMS is its submesoscale resolving capability; however, no submesoscale resolving observations were drawn on to validate the SEqld model. The EAC mooring array and the SE Qld moorings both measure temperature and velocities at submesoscale-type time scales. SWOT observations now provide submesoscale resolving SSH fields.*

### **Line comments:**

*Line 40: "In addition, submesoscale dynamics are further indicated by relative vorticity (spatial variation of velocity) that is comparable to the planetary vorticity ( $\zeta/f \sim O(1)$ );" This is the definition of the Rossby number – relative vorticity over planetary vorticity. Hence repetition from the sentence before.*

We agree that the original wording could imply that  $\zeta/f \sim O(1)$  represents an additional definition of the Rossby number, rather than an equivalent kinematic expression of the same scaling. We have revised the text to clarify that Rossby number can be interpreted both dynamically (as the ratio of advective to Coriolis accelerations) and kinematically (through the ratio of relative to planetary vorticity). We have also removed the implication that these represent separate criteria for identifying submesoscale dynamics. We have modified this section from:

*Submesoscale flows are fundamentally defined by Rossby numbers of order unity ( $Ro \sim O(1)$ ), indicating that the advective acceleration is as important as the Coriolis acceleration, and therefore the flow is not close to geostrophic balance. In addition, submesoscale dynamics are further indicated by relative vorticity (spatial variation of velocity) that is comparable to the planetary vorticity ( $\zeta/f \sim O(1)$ );*

To:

*Submesoscale flows are fundamentally defined by Rossby numbers of order unity ( $Ro \sim O(1)$ ), indicating that the advective acceleration is as important as the Coriolis acceleration, and therefore the flow is not close to geostrophic balance. Equivalently, this scaling implies relative vorticity (spatial variation of velocity) that is comparable to the planetary vorticity ( $\zeta/f \sim O(1)$ ). Submesoscale flows are also characterised by*

*Line 71: “ Moreover, it has been suggested that increasing model resolution to capture the submesoscale can reduce the ability of the data assimilation system to achieve skilful prediction of the mesoscale evolution (Sandery and Sakov, 2017). “ This is in contrast to findings by Kerry et al 2026 who showed that better representation of submesoscale energy resulted in improved mesoscale predictions, potentially through improved representation of the inverse energy cascade.*

We have modified this section to include the new Kerry et al., (2026) publication, and expanded on the differences and implications of these studies, from:

*Moreover, it has been suggested that increasing model resolution to capture the submesoscale can reduce the ability of the data assimilation system to achieve skilful prediction of the mesoscale evolution \citep{Sandery2017Ocean}.*

To:

*Previous work has suggested that increasing model resolution to capture the submesoscale can reduce mesoscale forecast skill in data assimilation systems (Sandery et al., 2017), potentially because lower-resolution observations are unable to constrain the submesoscale features and variability resolved by higher-resolution models. More recent work has shown that assimilating higher-resolution observations, such as SWOT wide-swath altimetry can substantially improve both mesoscale and submesoscale prediction (Kerry et al., 2026).*

*102: Explain  $rx_0$  or at least give a reference*

Changed to:

*Bathymetry is smoothed to achieve a maximum terrain roughness parameter ( $rx_0$ ) of 0.33, ensuring model stability while maintaining bedrock realism (Beckman et al., 1993).*

*108: What does ‘top out’ mean?*

Changed to: *Several guyots (eroded and subsided volcanic seamounts), which rise to depths of ~450 m,*

*114: Not sure BRAN is dynamically – consistent (are you using the EnKF version, or the EnOI version?). State version number.*

We have changed the phrasing as it was unnecessary. We now have:

*BRAN2020 was chosen as the lateral boundary forcing product as it provides a data-assimilative, mesoscale eddy-permitting estimate of the Australian-region ocean state, ensuring realistic large-scale circulation and water mass properties at the model boundaries.*

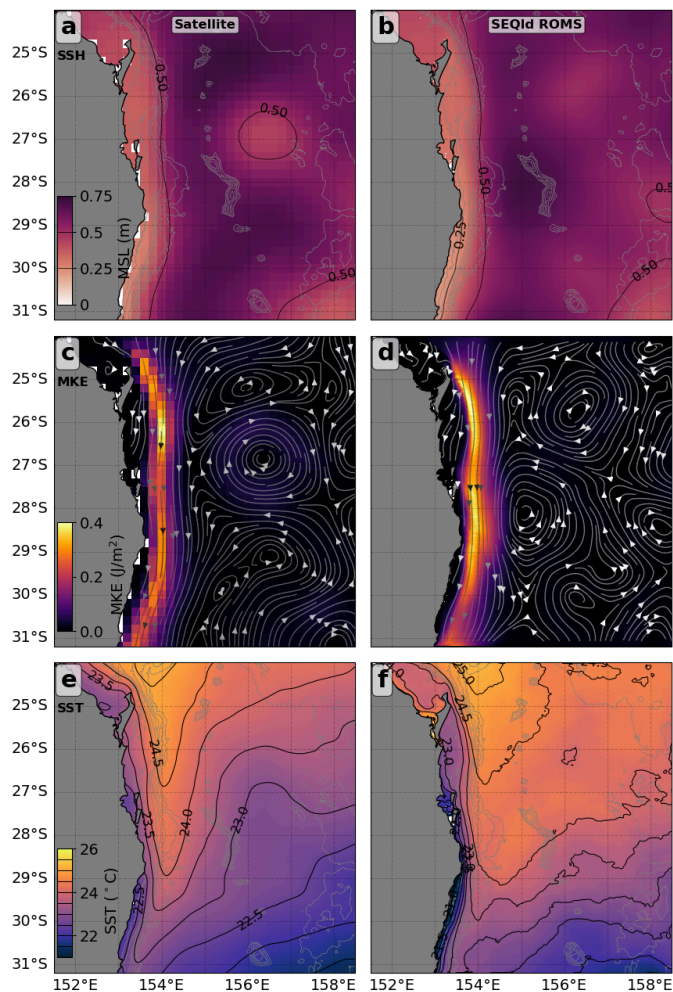
*Lines 129-145 and Figure 2 caption, please specify which satellite observations (or products) exactly you are referring to. If they are merged products please describe them and their resolution.*

A new section has been added to the methods section “2.2 Observational datasets”, which describes all observational products.

*Figure 2 e,f: What is the SST product? It seems a coarse product has been used that does not capture the cool shelf waters. This is surprising as SST products are very high resolution and should capture this. Also there is a lot of structure in the SST modelled mean (wiggly contours). This seems odd to me. Is this an average over the full year simulation output as an average file from ROMS, or have the authors averaged discrete output times to give the not-so-smooth result I wonder?*

Figure 2 has been updated. Panels have been updated to use the daily model output, rather than the 5-day snapshots. This has increased model MKE through the EAC jet, as well as modifying the model SST pattern. The model SST is now somewhat smoother (removing the ‘wiggles’ as identified by the reviewer), and the cool ‘blob’ in the middle of the domain is less evident. Switching to using the daily model output generally improves comparison to the observations. The description of the SSH and MKE has been adjusted accordingly.

The SST product originally used was RAMSSA L4 Satellite data product from AODN (e.g. <https://portal-beta.aodn.org.au/details/a4170ca8-0942-4d13-bdb8-ad4718ce14bb>). We have switched out for OSTIA as recommended. Figure 2 has been updated accordingly, as has the description of this plot.



148: Still unclear what the observations are, also is the model sampled at the observation times and locations, if so state this, if not describe how it is done.

The new methods section “2.2 Observational datasets” describes all observational products.

156: Need details of the satellite product used and what its resolution is

The new methods section “2.2 Observational datasets” describes all observational products.

159: You mean 3i? Satellite observations are typically unreliable for coastal regions (depths <100m). Again I don’t know what observations are being used. Alongtrack SSH can be trusted up to the coast but merged products not so much.

Changed to: *Differences between the model and observations on the continental shelf (e.g. Figure 3a) may also reflect limitations in the gridded observation product in the vicinity of coastlines and coastal geography.*

Details of products used have been added.

160: Not sure what this means.

Changed to: *Overall, these results demonstrate that SEQId ROMS captures both the observed temporal evolution (Figure 3) and the large-scale spatial structure (Figure 2).*

163 remove ,

Changed to: *Argo profiling float observations (IMOS, 2025a; Wong et al., 2020) throughout the model domain display a typical subtropical ocean  $\theta$ -S relationship (Figure 4a).*

*Figure 4b – Can the authors explain the tongue of cooler saltier water in the model? Was the model sampled at Argo float times and locations (I hope so)? Or is the tongue shelf waters not sampled by Argo? Can the authors explain the broader TS diagram of the model compared to the obs? Line 169 – suggests model is not sampled at Argo times and locations.*

The model was not sampled at Argo float times and observations. Only a limited number of Argo times and locations overlap with the model output (330 profiles), and so we took the Argo record from 2012 to 2026 (4075 profiles), to provide as much comparison as possible. This has been explicitly mentioned in the methods section.

The tongue of cooler, saltier water exists in the abyssal ocean of the model - this water is not sampled by Argo floats, which descend to a maximum of 2200m. The broader model T-S distribution reflects the larger range of spatial and temporal variability represented by the model, including fine-scale structure and shelf waters that are sparsely sampled by Argo. We have revised the relevant sentence to clarify the sources of this difference: *This water mass distribution is well represented in the model (Figure 4b), though it displays larger variation at depth and at the surface. Differences between the observation and model are likely due to the maximum profiling depth of Argo floats (~2200 m), limited profiling observations on the continental shelf, and the finer scale and temporal resolution captured by the model compared to the Argo observations.*

*166-167: Are these water masses all evident in the TS plot? If so, describe, if not, suggest deleting.*

These water masses are evident in the T-S plot and are already described in lines 166-167. However, we have modified to make clearer, changing from:

These water masses comprise warm, saline surface waters that transition to a salinity minimum at depth, before retroflecting to a higher salinity, temperature minimum at the bottom. This represents the warm and saline subtropical surface waters advected southwards by the EAC, overlying Sub-Antarctic Mode Water, Antarctic Intermediate Water at the salinity minimum (Bostock et al., 2013), and Lower Circumpolar Deep Water at the bottom (Sokolov et al., 2000).

To: *These water masses comprise warm, saline subtropical surface waters advected southwards by the EAC that transition with depth through Sub-Antarctic Mode Water to a salinity minimum associated with Antarctic Intermediate Water (Bostock et al., 2013), before reaching colder, more saline Lower Circumpolar Deep Water at depth (Sokolov et al., 2000).*

*Fig 4c: Surprising that the model is so off compared to the mooring array at 27S south where the EAC is most coherent. Is this an issue with getting the bifurcation of the westward currents correct? Have the authors looked at the spatial fields to understand the discrepancies. For example Jul-Sep the mooring array measures a strong southward current, but the model has weak southward and sometimes net northward flow.*

*Again were the modelled and observed sections the same? Was the method to compute transport and velocity the same from the observations and the model? Please add more detail around the methodology.*

The model and observations were sampled over the same spatial extent of the EAC mooring array. For the model, we identified the model eta-coordinate closest to the mooring-array latitude and extracted the v-velocity along this model section, restricting the extraction to the along-section extent of the mooring array. Thus, the model transport and observed transport are calculated over the same section length.

We have also examined the spatial velocity fields to investigate why the model has a strong northward transport over the array in August. During late July-September, the main EAC jet in the model shifts offshore of the continental slope while retaining strong southward velocities. At the same time, an inshore recirculation develops to the west of the jet, producing northward transport across the mooring-array section. Consequently, the net transport across the section is substantially reduced and can become northward despite the strong southward EAC jet offshore. This spatial structure explains the apparent discrepancy in Figure~\ref{fig}c and has now been described in the manuscript.

We have changed:

The total transport through ~27S, as captured by the EAC mooring array (Figure 4c), varies between 5 Sv northward to 40 Sv southward with periods of stronger and weaker transport. The model similarly shows variability between 5 Sv northward to 35 Sv southward. The model EAC transport has a similar seasonal cycle, but appears to be slightly delayed, with the observed period of northward flow in May, being delayed in the model until September.

To:

*The total transport through ~27S, as captured by the EAC mooring array (Figure 4c), varies between 5 Sv northward to 35 Sv southward with periods of stronger and weaker transport. The model similarly shows variability between 5 Sv northward to 40 Sv southward. Model velocities were sampled at the model y-coordinate closest to the EAC mooring array latitude and over the along-section extent of the array, such that the model and observations represent the same section length. The model EAC transport has a similar seasonal cycle, but appears to be slightly delayed, with the observed period of northward flow in May being delayed in the model until September. Examination of the spatial velocity fields indicates that this discrepancy is associated with an offshore displacement of the EAC jet in mid winter, while an inshore recirculation develops to the west of the jet. Although the offshore EAC maintains strong southward flow, the inshore recirculation produces net northward transport across the mooring-array section.*

*Figure 2d shows a clear weakening of the EAC MKE at 27S – which exists but is not as pronounced in the satellite derived MKE (2c)*

*This relates to 4d,e where the modelled EAC is too weak*

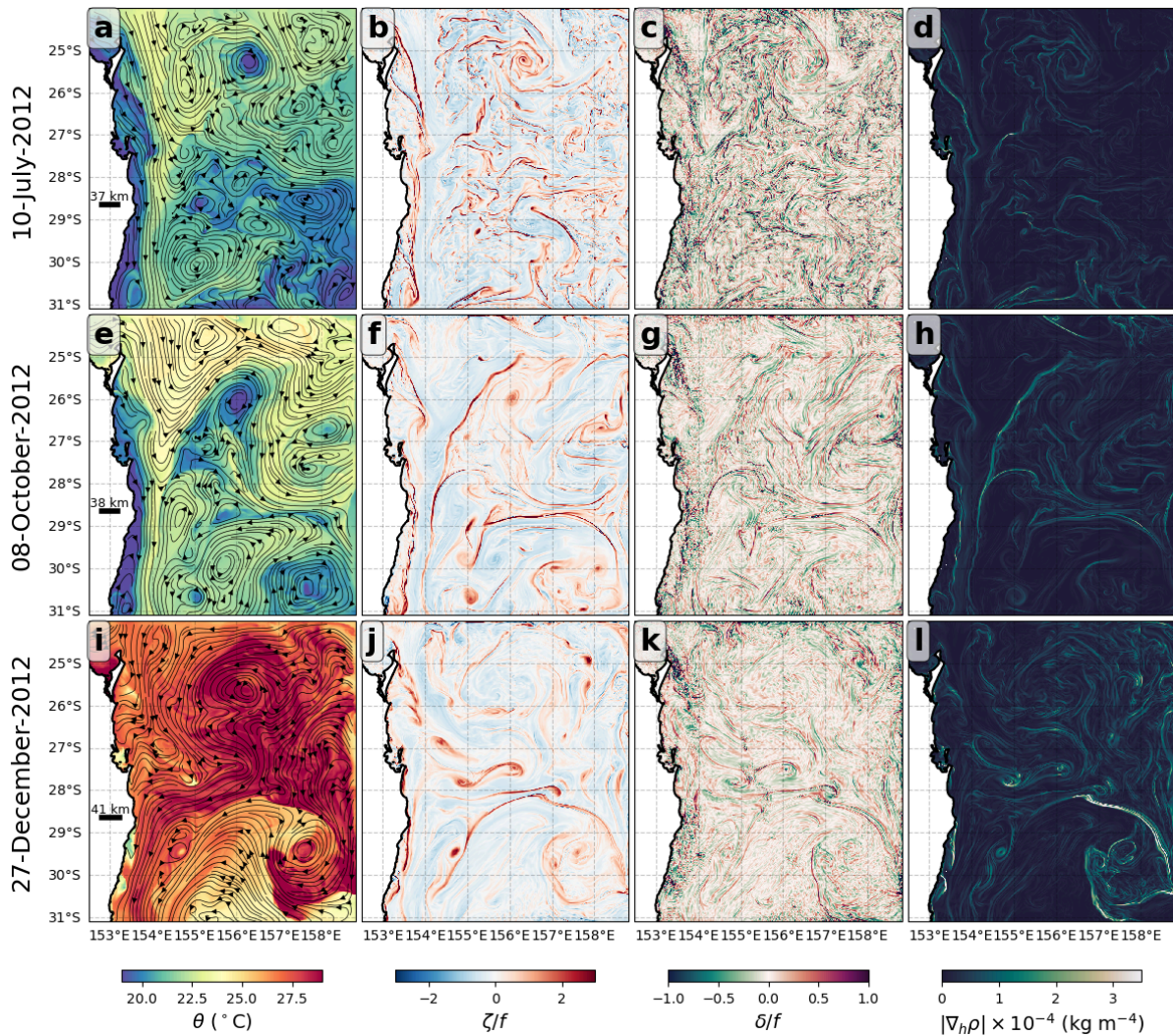
Changing the analysis to consider the daily model output (rather than the 5-day snapshots) has corrected this and increased MKE present in the jet south of 27S.

*Figure 4 caption: “In (b), only wintertime and summertime snapshots are combined to reduce data density.” Does this mean the model is not sampled at observation times and locations? Or does this mean something else? Please clarify.*

This means that T-S properties are plotted for two snapshots (02-Jan-2012 and 30-Jun-2012), as including all data for the year is computationally intensive. The model is not sampled at the same times as the Argo data, as we wanted to use the spatial coverage of the model to show all of the T-S properties in the region - rather than just at the Argo locations. Changed to: *“In (b), combined snapshots of wintertime (30-Jun-2012) and summertime (02-Jan-2012)  $\theta$ -S properties throughout the whole model domain are shown.”*

*Fig 5: “In (a), a length scale marker indicates the approximate boundary between mesoscale and submesoscale motions at this latitude.” This should vary with stratification and thus be different across summer versus winter*

The length of the representative scale marker has been updated to be more accurate, using a calculation of the deformation radius based on latitude and stratification over the EAC:



208 and Fig 6: Can you give the model a name (SEQld ROMS) rather than our model or this model?

We now refer to ‘our’ model as SEQld ROMS throughout.

It is customary to put the version rather than just BRAN i.e. BRAN2020?

A label has been added for “BRAN2023” (and throughout).

Lines 209-212 As BRAN .... To ....metrics, Thgis whole statement seems out of place and uncessary. Delete and start with: We compare annual means...

Changed to:

We compare the SEQld ROMS (Figure 5a-c) and BRAN2023 (Figure 5d-f) annual-mean fields of Rossby number ( $\zeta/f$ ), magnitude of the total strain, normalised by the Coriolis parameter ( $|S|/f$ ) and the variance in the vertical velocity ( $\{w^2\}$ ), averaged over the top 100 m.

We also add: *“Furthermore, annual averaging is used because these diagnostics exhibit substantial short-term variability, making instantaneous comparisons between independent simulations less informative.”*

216 better resolved Changed.

228, 246 and throughout: Call it SEQld ROMS

We now refer to ‘our’ model as SEQld ROMS throughout.

246 across scales

Sentence has been re-written: *“SEQld ROMS has a shallower spectral gradient compared to BRAN2023 and the multi-mission geostrophic currents, close to  $k^{-2}$ , indicating significant submesoscale activity.”*

247 Please explain the resolution of the satellite derived geostrophic velocities to explain why they are less than BRAN. I would expect BRAN KE to match the satellite derived KE (see previous BRAN comparison papers)

The gridded multi-mission altimetry-derived geostrophic velocities have a nominal resolution of 20 km, while BRAN2023 has a resolution of approximately 10 km. Further, the satellite product is a multi-mission combined product, where the gridding potentially also produces some spectral filtering - so it's not surprising that the gridded satellite product has a steeper spectral slope than BRAN.

We have added the satellite product resolutions to the methods section. The added information about resolutions, plus our comment at ln250 *“likely damping and observational smoothing”*, explain the relative slopes of spectra.

250 again what product, what smoothing? KE spectra is best computed alongtrack to preserve satellite resolution

We have updated Figure 7 with improved analysis (spectral density), tweaked figure layout and new products. The revised analysis now includes the SWOT L3 unsmoothed, filtered data as well as a multi-mission altimetry product (OceanCurrent DM03), as described in the new observational data section. Along-track SSH data would preserve the native resolution of the altimetry. However, we want to calculate the 2-D KE spectra and compare its spatial distribution with ROMS and BRAN model fields, and the nadir-looking along-track analysis would provide a one-dimensional wavenumber spectrum.

251: This sentence is unclear

Changed to:

*Furthermore, the SEQld ROMS kinetic energy spectrum maintains substantial energy into the submesoscale (beyond the 38 km boundary), whereas the BRAN2023 and gridded satellite altimetry observation spectra either rapidly lose energy at the transition or exhibit a rapid decay at nearby wavenumbers. The decay in the SEQld ROMS spectrum at a*

wavenumber of  $4 - 7 \times 10^{-1} \text{ km}^{-1}$  is expected as the effective model resolution is approached -- indeed, like with BRAN2023, the spectrum persists beyond the nominal model resolution of  $4dx$ .

252: 'roll off' seems colloquial - normally the spectra would be cropped for wavenumber smaller than what is effectively resolved

See above.

252-254: I don't feel the authors have justified this conclusion in the text and the figure does not tell me this. Please revise the conclusions of this analysis.

Changed to:

*At large scales (wavenumbers smaller than  $4 \times 10^{-3} \text{ km}^{-1}$  or  $\sim 250 \text{ km}$ ), the spectral energy distribution is comparable across all systems. At scales below  $\sim 100 \text{ km}$  however, SEQld ROMS retains considerably more kinetic energy, reflecting the enhanced representation of submesoscale processes afforded by its higher spatial resolution. Although SEQld ROMS does not fully resolve the submesoscale, as indicated by the slope of the SWOT spectrum and its extension to smaller scales, the higher spatial resolution of SEQld ROMS enables a greater portion of the submesoscale energy-containing range to be resolved.*

264 "dying out" colloquial

Changed to:

*before weakening*

280-285: Speculation? Or include justification in more detail. Seems SEQld gets too much separation north of 27S -- hence the current too weak compared to the EAC array observations (Figs 2 and 3). Is this related to this statement?

Changing to daily outputs has improved the representation of MKE, which suggests that SEQld ROMS is not getting too much northern separation. We agree that the interpretation of the submesoscale activity as contributing to upstream adjustment and accelerating the EAC is speculative. We have therefore revised this section from:

The persistent submesoscale activity north and east of K'gari likely contributes to the upstream adjustment region of the EAC jet-dominated zone. In particular, the elevated strain and vorticity resolved by the model demonstrates active frontogenesis at the shelf edge. Frontal sharpening converts available potential energy into kinetic energy, accelerating the flow, while the accompanying divergence indicates lateral contraction of the jet, which further enhances acceleration.

Changed to:

*The persistent submesoscale activity north and east of K'gari is associated with the upstream adjustment region of the EAC jet-dominated zone. In particular, the elevated vorticity, divergence, strain and density gradients resolved by the model are spatially linked:*

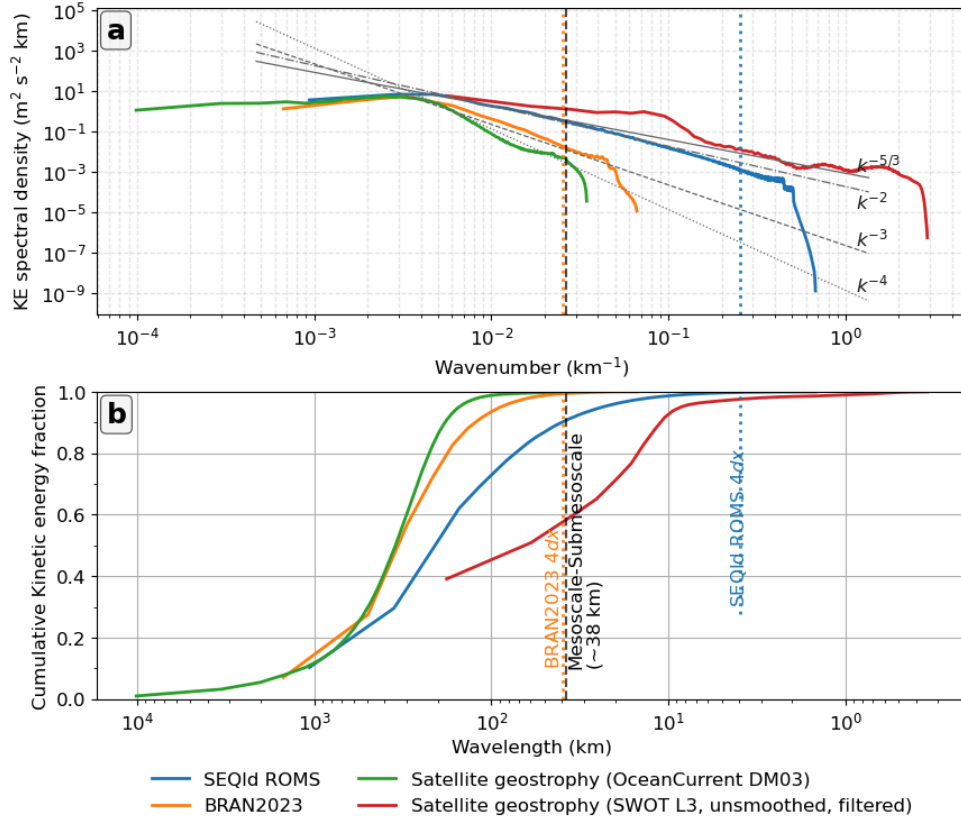
*as the jet impinges on the shelf, strong flow deformation develops downstream of the impingement region, with enhanced vorticity and divergent flow. The associated deformation sharpens density gradients downstream, promoting active frontogenesis at the shelf edge.*

*291 - be more general, all global circulation models, not just BRAN. Reanalyses will be time-accurate. “Additionally, larger-scale models which represent this study area, such as BRAN, provide time-accurate representations of the mesoscale circulation,” could be replaced with “Additionally, near-global reanalyses, such as BRAN, provide time-accurate representations of the mesoscale circulation, ....”*

*Changed to: “Additionally, near-global reanalyses, such as BRAN, provide time-accurate representations of the mesoscale circulation, making them well suited to studies of mesoscale variability and boundary current dynamics, but necessarily under-represent submesoscale processes due to their coarser resolution.”*

*297: I feel this model validation is really lacking the submesoscale – what about using the high frequency moorings to show frequency spectra and how the fine scale, high frequency motions are represented in SEqld ROMS compared to coarser products or models. Or better still SWOT KE spectra. Can you add a SWOT line to a and b (obviously not for 2012 but for the available period)?*

We have updated Figure 7 to include submesoscale validation. Figure 7 now includes two altimetry products: a multi-mission altimetry compilation (OceanCurrent DM03) with a spatial resolution of ~20km, and the highest resolution SWOT data currently available (SWOT L3 unsmoothed) with a spatial resolution of ~250m. The figure has been updated to show the KE spectral density, which compares the different products and models across a similar energy baseline. While this loses the display of overall increased energy baseline in the higher resolution models/products, the benefit of a more straightforward comparison of the spectra is more important.



The figure caption and description has been updated accordingly:

SEQId ROMS has a shallower spectral gradient compared to BRAN2023 and the multi-mission geostrophic currents, close to  $k^{-2}$ , indicating significant submesoscale activity. BRAN2023 closely follows the  $k^{-3}$  relationship, consistent with quasi-geostrophic dynamics, but with limited submesoscale energy, and the multi-mission satellite geostrophy has a steeper slope than  $k^{-3}$  indicating likely damping and observational smoothing (Figure 6a). Furthermore, the SEQId ROMS kinetic energy spectrum maintains energy well into the submesoscale (beyond the  $\sim 38 \text{ km}$  boundary), whereas the BRAN2023 and gridded altimetry satellite observations either rapidly lose energy at the transition or exhibit a rapid decay at nearby wavenumbers. The decay in the SEQId ROMS spectrum at a wavenumber of  $4 - 7 \times 10^{-1} \text{ km}^{-1}$  is expected as the effective model resolution is approached -- indeed, like with BRAN2023, the spectrum persists beyond the nominal model resolution of  $4dx$ . The spectrum for the high-resolution SWOT data shows the shallowest gradient, approximately  $k^{-5/3}$ , consistent with KE associated with resolved ageostrophic motions. At large scales (wavenumbers smaller than  $4 \times 10^{-3} \text{ km}^{-1}$  or  $\sim 250 \text{ km}$ ), the spectral energy distribution is comparable across all systems. At scales below  $\sim 100 \text{ km}$  however, SEQId ROMS retains considerably more kinetic energy, reflecting the enhanced representation of submesoscale processes afforded by its higher spatial resolution. Although SEQId ROMS does not fully resolve the submesoscale, as indicated by the slope of the SWOT spectrum and its extension to smaller scales, the higher spatial resolution of SEQId ROMS enables a greater portion of the submesoscale energy-containing range to be resolved.

*304-305: Yes – if you don't validate against submesoscale resolving obs directly, perhaps reference some of the values observed further south and show your model looks more like these... i.e. what  $Ro$  are observed by the Coffs radar – do they look similar to your model values...?*

We have added analysis and comparison to submesoscale resolving SWOT observations. We already reference the  $Ro$  observed at the Coffs radar, but have modified to add more details:

*Observations from HF radar and in situ measurements have identified filaments with  $O(1)$  Rossby number (Mantovanelli et al., 2017), strong vertical shear (Archer et al., 2020), and  $O(1)$  frontal strain and divergence Schaeffer et al., 2017).*

*314 comparable slope? 315-316, good*

Changed to: *The KE spectra indicate that SEQld ROMS reproduces the mesoscale spectral energy distribution of coarser-resolution models while retaining substantially more kinetic energy at smaller scales and exhibiting a shallower spectral slope, consistent with enhanced representation of ageostrophic and submesoscale motions.*

*329 BARRA is hourly, correct?* We use the daily BARRA-R2 output for forcing of this model, which we now explicitly describe in the methods:

*This product has high spatial and temporal resolution (12km and daily, respectively),*