Transition from balanced to unbalanced dynamics in the eastern tropical Pacific from in situ, numerical simulation and altimetry data

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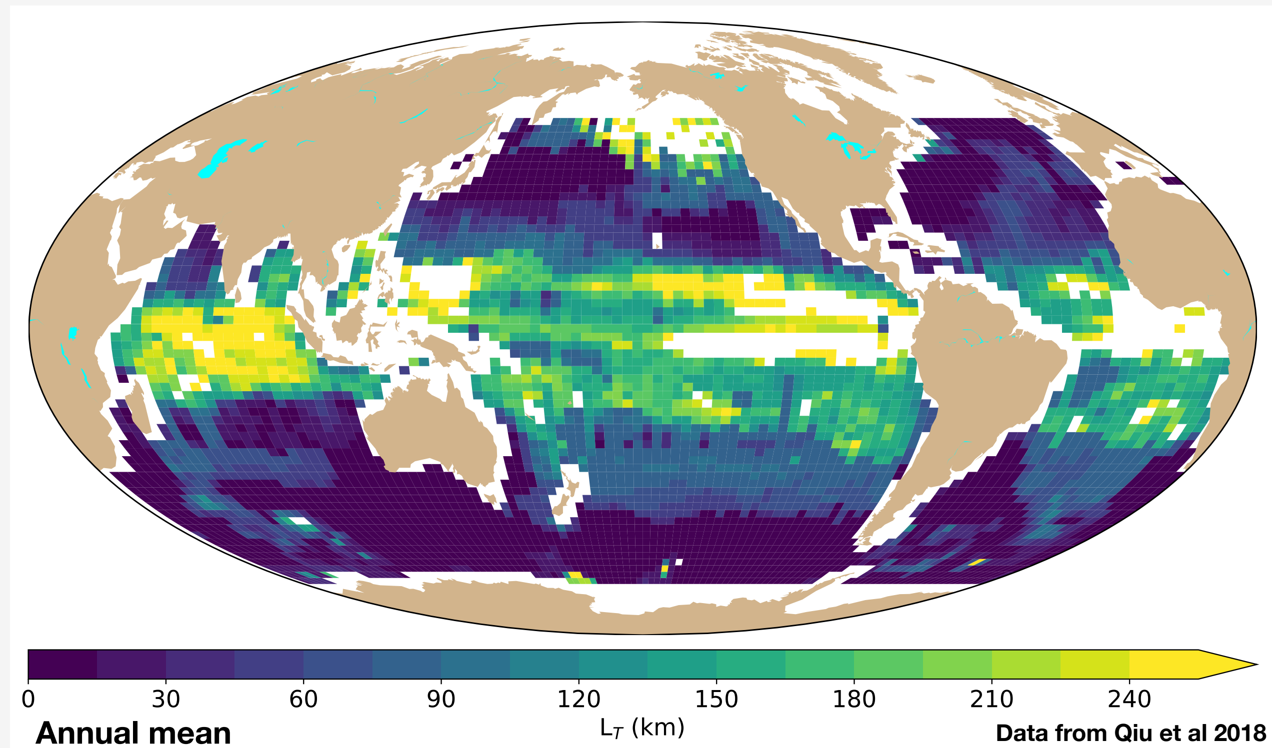
The transition from geostrophically balanced to unbalanced motion is relevant for ocean surface topography studies because it sets the smallest scale at which the altimeter derived geostrophic currents explain most of the flow variability, and hence where altimeters are most useful. Pinning the transition is also relevant to understand the relative role of the various processes that contribute to sea surface height (SSH) variability at higher resolutions. A better understanding of these processes and their signature in SSH will in turn allow extracting more useful oceanographic information at these scales from the new generation of satellite borne altimeters.

The transition scale L_T from balanced (mostly geostrophic) to unbalanced (mostly inertia gravity waves IGWs) motions in model (MITgcm LLC4320) surface

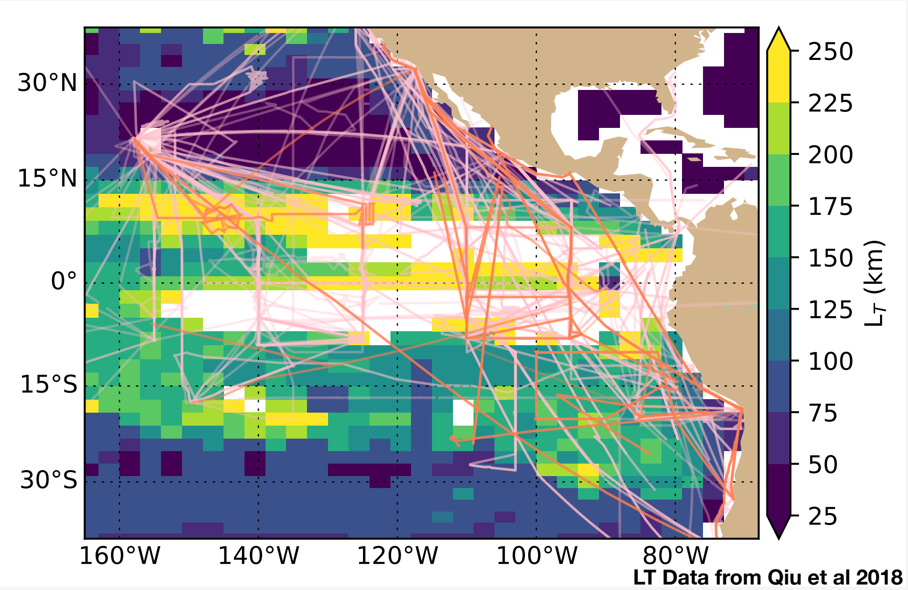


Long L_T -> energetic IGWs in the eastern Pacific tropics

A recent analysis of a global, realistic, high resolution (~2 km) simulation, suggests that the scale at which surface motions transition from being dominantly in geostrophic balance to being dominated by unbalanced inertia gravity wave like motions is longer than 200 km in the tropics. In this simulation, this transition scale L_T varies considerably regionally (as indicated by the annual mean values mapped above) and seasonally. In the region east of Hawaii (~15—25 N, 155—100W), the L_T is quite short (< 40 km), where it exhibits a large seasonal cycle, with L_T lengthening to ~100 km and longer in summer to early fall months. In contrast, the L_T is quite long (longer than 200 km) in the deep tropics and in the southeast tropical Pacific (~200 km or longer). In these two regions, the simulation shows weak seasonality in L_T.

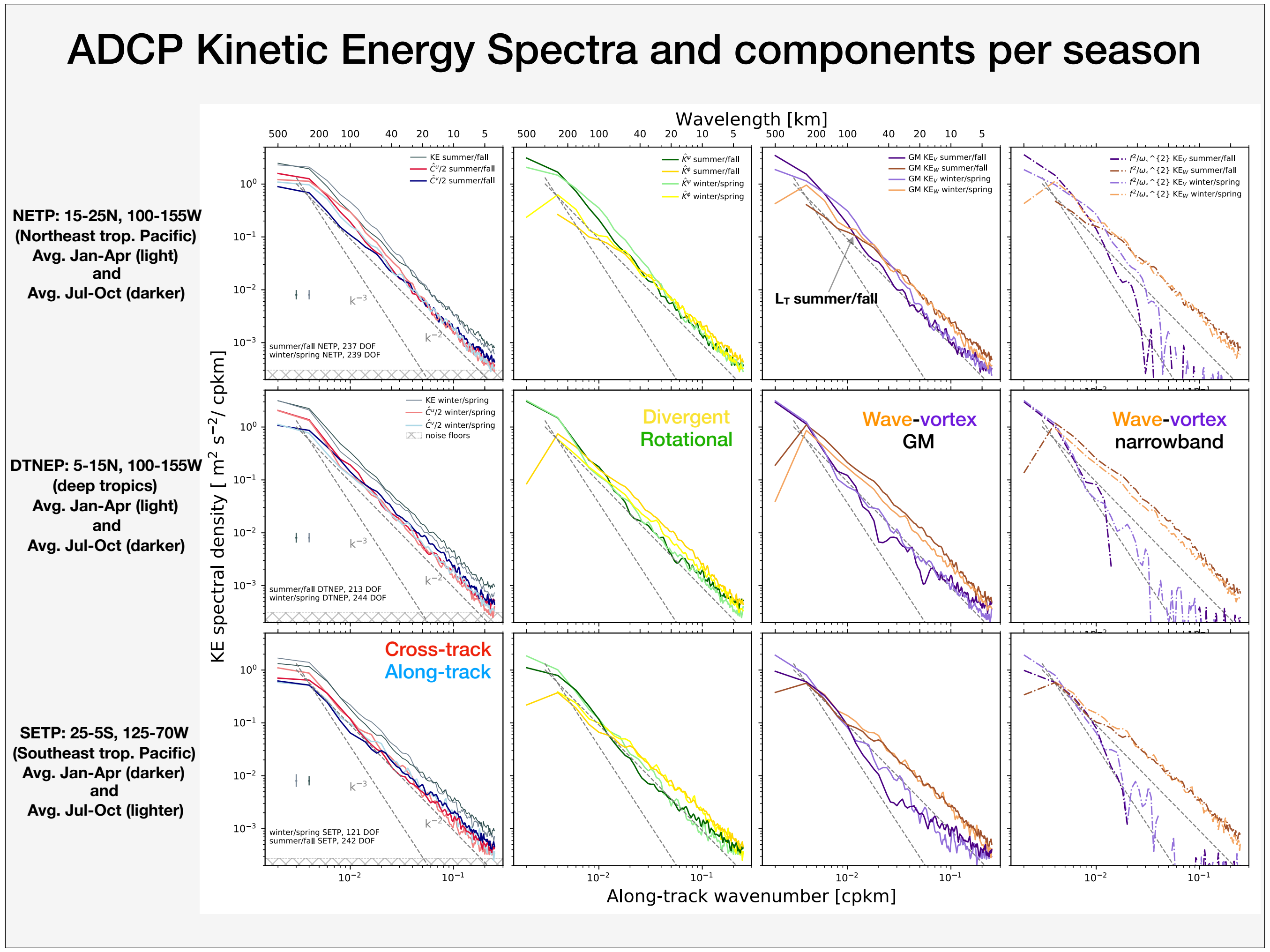
We will investigate the transition scale using Acoustic Doppler Current Profiler (ADCP) data from historical ship surveys in the eastern tropical Pacific. These data are aggregated for the relevant regions and then analyzed using the Buhler et al (2014) method for Helmholtz and wave-vortex decomposition. Our results will be compared with similarly analyzed output from the LLC4320 simulation, and when available, nadir altimeter data.

Historical ADCP data in the eastern tropical Pacific



- Along-track data from nearly 80 unique cruises
- Uninterrupted transect data
- Choose sonars and transects with minimal near-surface noise
- Analyze 500-km segments with 50% overlap

This figure shows the in situ data collected from shipboard surveys used here.
ADCP cruise data are obtained from the JASADCP repository (contains processed data, shown by light pink tracks) and the UH Currents Group repository (largely unprocessed data, coral colored tracks). We work with CODAS databases and data that are ping-averaged to 5 min or 2 min for WH300 sonars, which yield horizontal resolutions around 1—2 km. Uninterrupted transects means that no stops longer than an hour are admitted.
Appropriate sonars for near-surface are high frequency / low range such as WH300, OS150 (broadband or narrowband modes), NB150. OS75 broadband and occasionally OS75 narrowband are also appropriate, depending on weather/sailing conditions.



Shown here are the ADCP KE spectra and their Helmholtz and wave-vortex decompositions for summer/fall (Jan-Apr in NH) and winter/spring (Jul-Oct in NH).

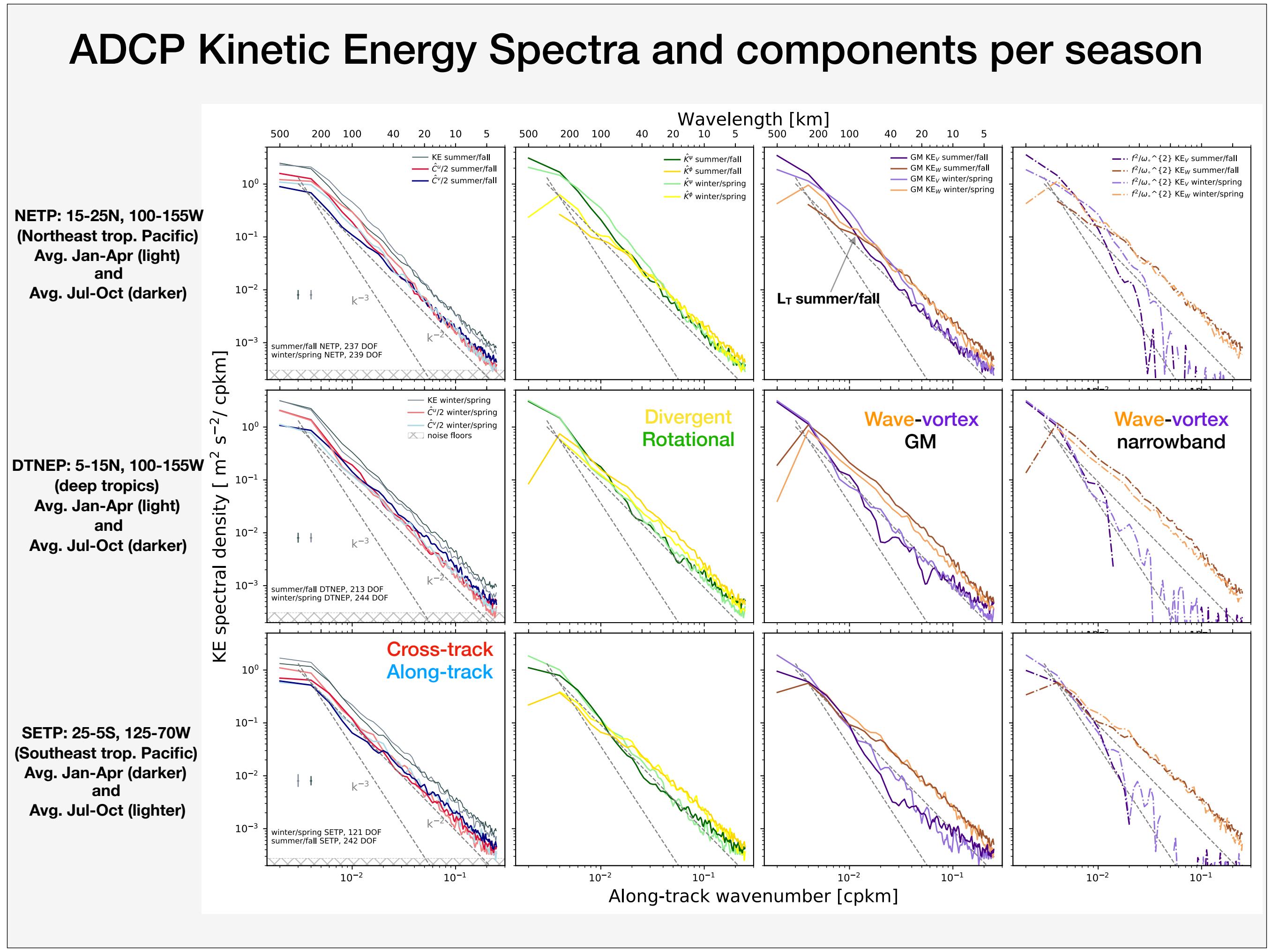
Col. 1: ADCP spectra - cross and along-track velocity spectra and their sum.
Col. 2: Helmholtz decomposition into rotational and divergent components.
Col. 3: Wave-vortex decomposition assuming Garret Munk (GM) IGW spectrum.
Col. 4: Wave-vortex decomposition assuming a dominant (nearer-inertial) IGW frequency. This frequency parameter was estimated from the Helmholtz decomposition step.

A key assumption wave-vortex decomposition is that all the divergence is due to the IGWs. The key results to highlight here are:

Generally, there is weak and formally statistically unreliable seasonality in the KE spectra in all three regions. Additional tests we performed, however, indicate that there is a significant albeit relatively weak (compared to mid latitudes) seasonal cycle in the KE in the NE trop. Pacific. This was not the case in the other regions, although the deep tropics shows signs of having enhanced KE at all scales during summer.

The Helmholtz decomposition indicates divergent motions dominate small scales; rotational motions the largest scales. In the deep tropics and the southeast, divergence is significant at scales above 100 km, while in the NE, depending on the season, divergence is significant at 70—30 km scales and below. These results are relatively insensitive to the details of the area averaging.

To better isolate the role of eddies, we examine the results of the wave-vortex decomposition.
The wave-vortex decomposition suggests IGWs to account for most of KE at the submesoscales in the tropics.



IGW KE is also at least comparable to vortex KE at large scales in the SE and deep tropics as well. In the deep tropics region and in the SE trop. Pacific, the wave KE does not undergo a seasonal cycle, but in the NE we find significant seasonality in the balanced component, which accounts for what we see in the total KE.

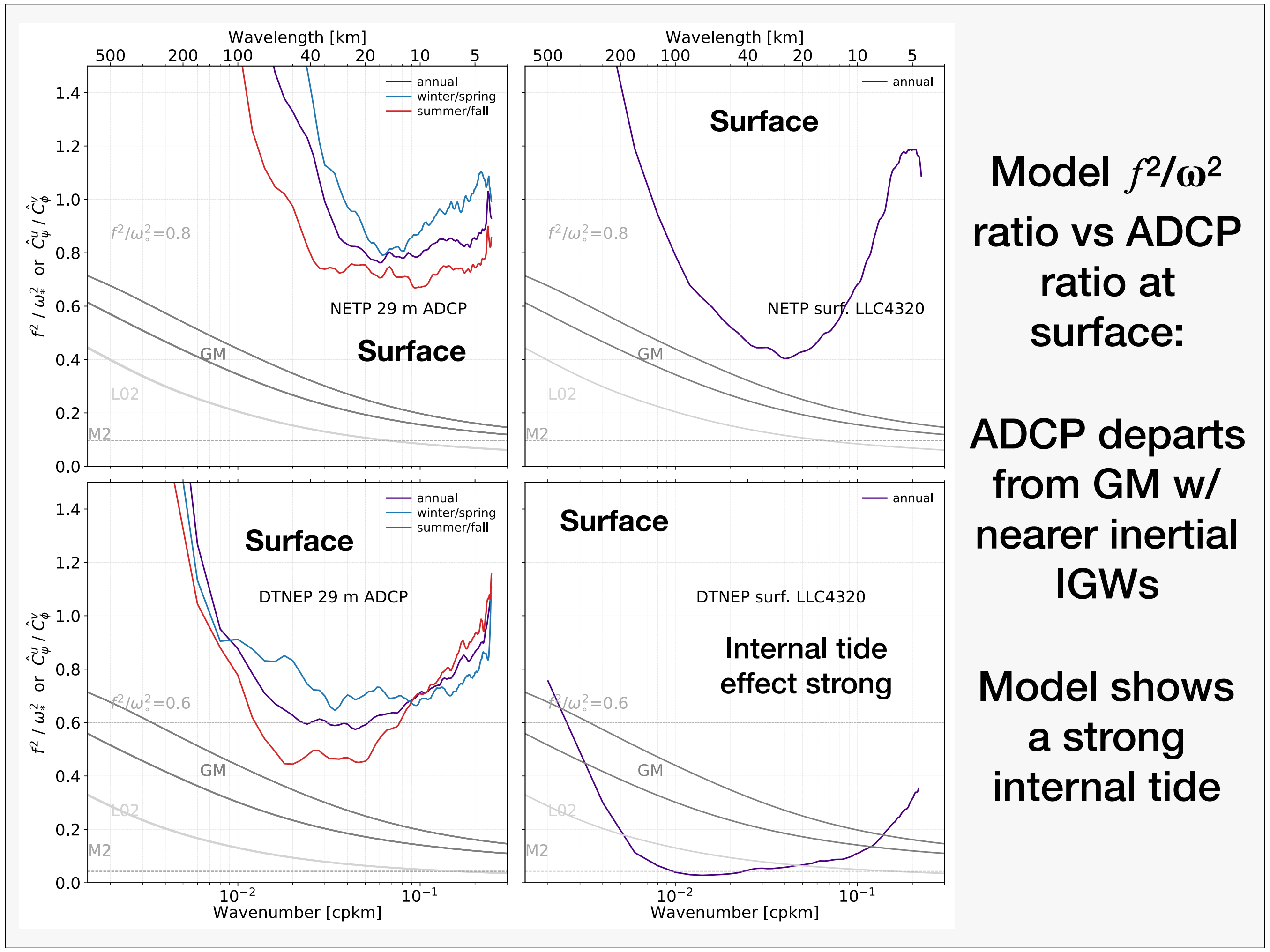
The transition scale is defined here as the wavelength at which vortex KE equals wave KE (see example annotated in the plot above). The transition scale in the observations is around 200 km in the SE and deep tropics year round. In the NE tropics, the L_T is ~90—100 km in summer/fall and ~60–70 km in winter/spring.

In the winter, the KE spectrum along with its rotational component show characteristics of being in geostrophic balance to leading order for scales above ~40 km. Together with the wintertime vortex energization, these suggest that mixed layer baroclinic instabilities are a viable theoretical framework to interpret these results; for stratification conditions observed in the NE during these cruises, the mixed layer injection scale is ~ 15 km wavelength.

The details of the wave and vortex partitioning of KE is dependent on the frequency model used, but not the general conclusions outlined here.

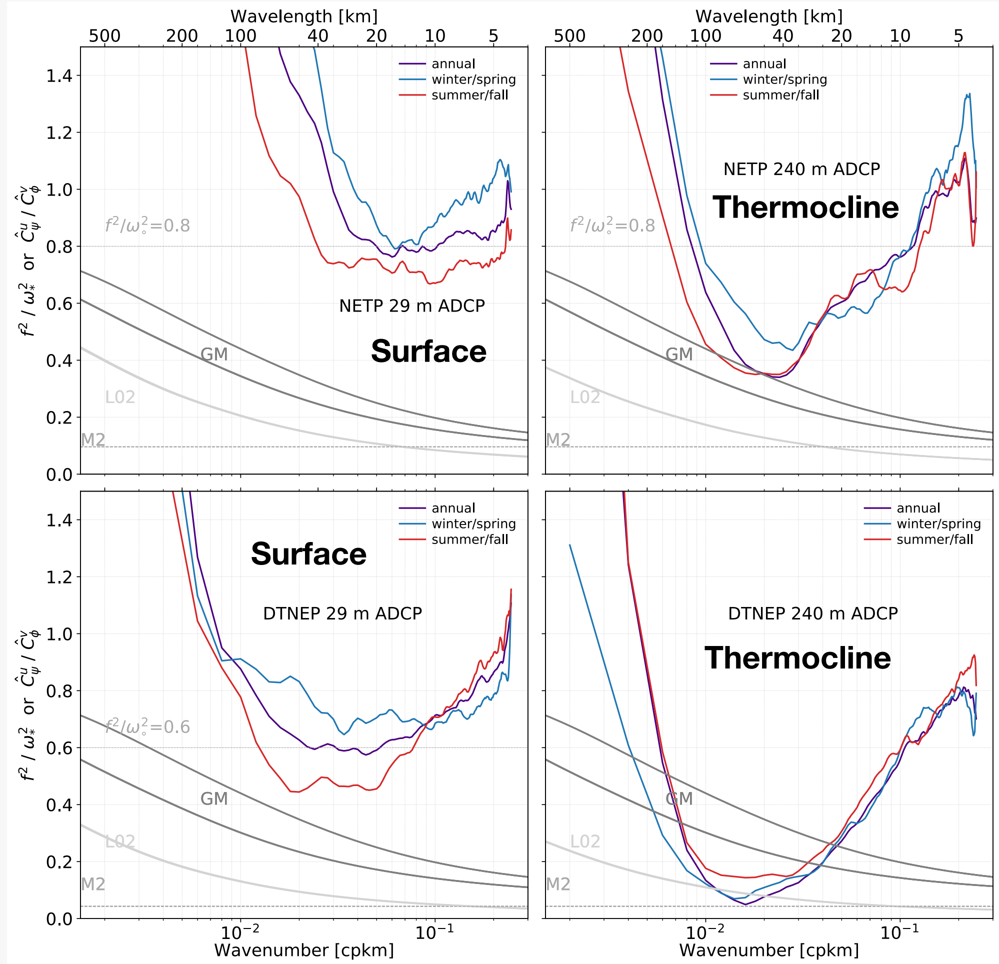
Transition scales from the ADCP are in qualitative agreement with those from the high resolution simulation, when using the same techniques applied to the model output, and also in agreement with those derived by Qiu et al 2018 analysis from the same model. The results from our analysis of the model using the one dimensional techniques is omitted here for brevity. For the deep tropics and SE Pacific, ADCP L_T tend to be slightly shorter than the model's.

The salient differences to highlight are that seasonality is somewhat weaker in the NE tropical Pacific in the ADCP than in the model. And differences in the dynamics are also apparent: the model has much higher levels of divergence relative to rotation than the ADCP. The ADCP does not show strong seasonal modulation of IGW energy, except perhaps in the deep tropics. In the observations any seasonality is largely driven by the balanced component, whereas in the model both components contribute roughly proportionally.



For the wave-vortex decomposition we typically assume that the IGW field obeys the GM spectrum. This dependency is manifested though the parameter ratio f^2/ω^2, where ω is frequency and f the Coriolis parameter. The parameter, in turn, is used to determine the fraction of rotational energy that is assigned to IGWs. The grey lines show the parameter predictions using the canonical GM, the GM model adapted to the observed stratification in the sampled areas; the lighter grey lines show predictions of the parameter using the Levine (2002) IGW model. The colored lines show the parameter, or ratio, as diagnosed from the Buhler et al (2014) Helmholtz decomposition (the ratio of auxiliary spectral functions C^u_ψ and C^v_ϕ), and we highlighted the values of the parameter in the range of scales where IGWs are expected to dominate (i.e. well shorter than the transition scale) that we have used to perform the narrowband wave-vortex decomposition shown previously.

The diagnostic from Buhler et al (2014) suggests that the observed near-surface IGW field would be dominated by IGWs with frequencies much closer to the inertial period. For the model, this diagnostic suggests that M2 internal tides are very influential, which lower the ratio, at times quite strongly (as in the deep tropics example shown above). This would be a natural response to the apparently abnormally strong internal tides in this simulation arising from too-strong astronomical tide forcing (personal communication Brian Arbic).

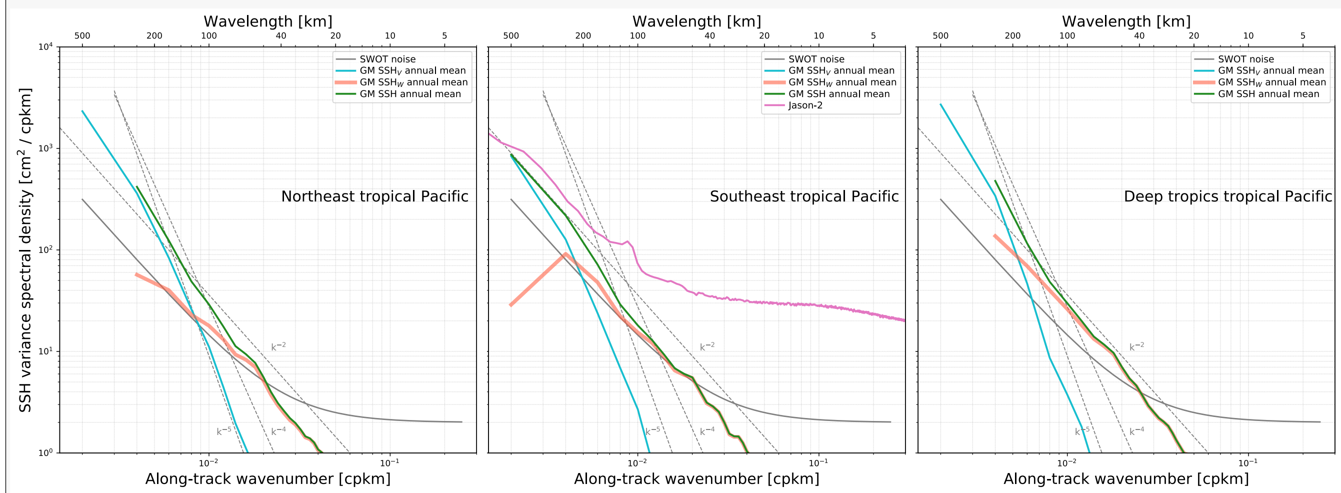


The f^2/ω^2 ratio 30m vs 240m

Near-inertial IGWs at surface vs GM in thermocline

For the ADCP, as one moves into the thermocline, the diagnostic from the Helmholtz decomposition suggests an increased contribution from higher frequency IGWs, such that the GM-like models (e.g. Levine 2002) appear more relevant for the wave-vortex decomposition at depth.

SSH from ADCP vortex and wave



- Annual means of wave-vortex decomposition in the three areas of interest using ADCP data using the GM spectrum model
- Converted to SSH also assuming a GM IGW field; represents upper bound of (non tidal) IGW signature in SSH measurements
- Compared to ALES (Passaro et al 2016) reprocessed Jason-2 data in the southeast tropical Pacific
- Resolution scale for SWOT given by the intersection of the geostrophic balanced SSH (from vortex KE) with its noise level

Next we focus on the SSH signature of geostrophic motions and wave motions inferred from the ADCP analysis.
For this calculation we will use the GM model as it provides an upper bound estimate on the role of IGWs in SSH variability that may be seen by altimeters. This is relevant for tropical regions because IGWs appear to have a larger surface energy imprint in these areas, in contrast to mid latitude and other higher energy regimes.

For the deep tropical and southeastern tropical Pacific, the ADCP suggests that balanced SSH dominate only at the largest scales (> 200 km). The resolution scale for SWOT is thus expected to be near 200 km in these two areas. Even in the northeast trop. Pacific, the resolution scale is above 100 km. This occurs regardless of the IGW model used here, and this scale undergoes little (in the NETP, ~90 km in winter/spring, not shown) to no seasonality.

If the GM is a valid framework to convert the inferred wave KE to its SSH variance, this analysis indicate that the IGW would have levels close to the noise level for SWOT, except perhaps in the deep tropics. We also note that these GM-IGW SSH variance levels would lead to a flattening of the observed SSH (indicated by the sum of vortex and wave in green above). The resulting slope is consistent with those observed by current altimeters (e.g. Jason-2) for scales above 100 km (pink line). However, since the ADCP analysis suggests that IGWs with lower frequencies dominate the surface KE, the wave SSH variances inferred here, as well as their comparison with altimetry, are to be viewed as a first exploration of this topic, and likely a gross overestimation of their true impact.

Summary

- We analyzed the KE spectra from historical ADCP data in eastern tropical Pacific and compared with results from a high resolution numerical model.
- ADCP observations indicate a relatively long O(100s km), regionally dependent, transition scale from balanced to unbalanced motions in the eastern tropical Pacific, in qualitative agreement with the simulation.
- Observed seasonality is weaker than modeled and driven solely by the balanced component. This seasonality has characteristics of mixed-layer baroclinic instabilities.
- Observed IGW surface wavenumber spectra are “nearer”-inertial rather than GM-like. In the model, there is a strong signature of internal tides. This has a significant impact on wave-vortex partitioning.
- The KE spectra was converted to SSH: the geostrophic balanced signal lies above the expect noise level of SWOT at scales > 100 km; the IGW (unbalanced) signal likely falls close to or below the noise floor.
- A strong IGW SSH wavenumber spectrum requires significant contributions from higher frequencies, specially the internal tides. This appears to be the case in the model - not so in the ADCP data.
- The ADCP SSH compares well against ALES reprocessed altimeter data.

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These are the main conclusions. Thank you for reading.

References

Bühler, O., J. Callies, and R. Ferrari (2014) Wave-vortex decomposition of one-dimensional shiptrack data. J. Fluid. Mech., 756, 10071026.

Qiu B., S. Chen, P. Klein, J. Wang, H. Torres, L.-L. Fu, and D. Menemenlis, 2018: Seasonality in transition scale from balanced to unbalanced motions in the world ocean. J. Phys. Oceanogr., 48, 591–605.