Characterizing the Transition from Balanced to Unbalanced Motions in the Southern California Current System

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Observations

Currents from CalCOFI ADCP:
• sampled 4x/year along 6 lines
• horizontal resolution: 5 km
• depth range: 20 m to 300 m
• time interval: 1993-2004

SSH from altimetry:
• Jason-1/2 w/ALES, the Adaptive Leading Edge Subwaveform processing (Jan 2002 - Aug 2016)
• AltiKa Ka-band (Oct 2013 - May 2016)
• Sentinel 3 w/delayed Doppler processing (Jan 2017 - May 2018)
Numerical model simulation

LLC 4320 MITgcm numerical simulations:

• global
• forced with tides & ECMWF
• 90 vertical levels
• 1/48° resolution; 1 year simulation
Inferring dynamics from horizontal wavenumber spectra:

What do we expect for kinetic energy spectra?

Isotropic Quasi-Geostrophy:
- **interior QG predicts** $k^{-3}$ (Charney, 1970)
- **surface QG predicts** $k^{-5/3}$ (Blumen, 1978)

Ageostrophic motions can project onto similar scales, e.g., inertia-gravity waves $k^{-2}$ can flatten QG spectral slopes (Garrett & Munk, 1975)
Inferring dynamics from horizontal wavenumber spectra:

What has been observed for kinetic energy spectra?

Real ocean spectra from strong baroclinic jets (Gulf Stream, ACC, Kuroshio) are consistent with
- interior QG ($k^{-3}$) at meso- to submeso- scales
- $k^{-2}$ at submesoscales (e.g., Callies & Ferrari, 2013; Rocha et al., 2016; Qiu et al., 2017)

Is this ubiquitous? (Qiu et al., 2018)

Using observations and model to look at a weak mean flow region, southern CCS
In situ observations and model data: KE spectra

**Line 90 across/along-track KE spectra:**

- **ADCP & model-hourly KE at 20 m & HFR KE at 0 m** have similar shape, slope and energy levels.
- **Slope varies with wavenumber; about -2 for submesoscales.**
- **Model-daily KE at 20 m** has steeper slope due to less energy at wavelengths $L < 200$ km.

(HFR courtesy Song-Yong Kim; Kim et al. 2011)
Inferring dynamics from horizontal wavenumber spectra:

Some properties of isotropic spectra:
• The 1-D (alongtrack) spectra will follow the same power law as 2-D ($k^{-n}$)
• Ratio of across/along track KE components is useful diagnostic

Across-track $K_u$ and along-track $K_v$ are related through the exponent $n$:
  $K_u = n \ K_v$ purely rotational (nondivergent)
  $K_v = n \ K_u$ purely divergent (irrotational)

• Helmholtz decomposition of 1-D spectra separates rotational and divergent components (Buhler et al., 2014)

(e.g., Callies & Ferrari, 2013; Buhler et al., 2014; Rocha et al., 2016)
Helmholtz decomposition

ADCP

- Slope is close to -2
- $300 > L > 70$ km: cross-track KE and rotational KE are dominant and ratio $R \sim 1.8$
- $L < 70$ km: rotational and divergent about equal $R \sim 1$
Helmholtz decomposition

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**MODEL**
- Slope is close to -2
- $300 > L > 125$ km: cross-track KE and rotational KE are dominant
- $125 < L < 70$ km: cross- and along-track KE about equal, $R \sim 1$
- $L < 70$ km: alongtrack KE and divergent are dominant
Seasonality

Model seasonal extremes are March and September.
Model: seasonality

- No significant seasonality in model hourly KE spectra, except at L>200 km
Model: seasonality

- No significant seasonality in model hourly KE spectra, except at L>200 km
- Significant seasonality in model daily KE spectra:
  - Higher KE in spring
  - Extends to about 100 m
RMS vorticity (\(\zeta/f\)) and divergence (\(\delta/f\))

- Second order velocity statistics estimated over subdomain from hourly (solid curves) and daily (dashed) averages highlight seasonality at submesoscales.
- Hourly (solid): seasonal cycle of vorticity (\(\zeta/f\)) peaks in spring, out of phase with divergence (\(\delta/f\)) that peaks in fall.
- Daily (dashed): seasonal cycles are in phase, with only weak divergence.
ADCP seasonality: Helmholtz and wave-vortex decomposition

6-line wave-vortex decomposition:
weak seasonality in vortex component; highest in winter
• Altimeter SSH spectra are red, with slope near -4 for 250km>L>70km.
• Altimeter SSH spectra flatten for 70km>L>20 km.
• AltiKa and Jason SSH spectra have a spectral “bump” for 20km>L>2km.
• Altimeter SSH spectra are white for L<2km.

See also Gille et al., “Assessing high-wavenumber spectral slopes (and effective resolution) in new altimeter products”, Thurs. 17:00-17:15, Teatro Auditorium.
Relating SSH and KE spectra in the balanced regime

- Altimeter SSH spectra follow -4 slope for 250km > L > 70km, consistent with ADCP KE -2 slope and transition.
- Model and altimeter SSH spectra are consistent for L > 125km.
- Model daily spectra flatten relative to hourly for L < 125km.

See also Gille et al., “Assessing high-wavenumber spectral slopes (and effective resolution) in new altimeter products”, Thurs. 17:00-17:15, Teatro Auditorium
Conclusions

• At scales between 10 and 200 km, upper-ocean KE spectra in the southern CCS follow an approximately -2 power law.

• Observed transition from predominantly rotational to divergent motions occurs at L~70 km with no change in spectral slope. Model transition occurs at longer wavelength, ~125 km.

• Observed and model-hourly KE spectra have weak seasonality. Phase cancellation may reduce KE seasonality.

• ADCP and model are consistent with 3 different altimeter data sets in the “balanced regime”, L > 70 km.

• CCS results differ from strong jet/high EKE regions: flatter spectral slope, longer transition scale from balanced to unbalanced flow dominance. Similar to other low EKE regions.

• Geostrophic velocities can be diagnosed from SSH on scales larger than about 70 km in the southern CCS in all seasons.