OSM 2014 - Session: 012: Oceanic submesoscale processes: #1501

Observations of near-inertial surface currents off Oregon: Decorrelation time and length scales

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Abstract

High-resolution (km in space and hourly in time) surface currents observed by an array of high-frequency radars off Oregon are analyzed to quantify the decorrelation time and length scales of their near-inertial motions. The near-inertial surface currents are dominantly clockwise with amplitudes of 9 to 12 $\mathrm{cm\,s^{-1}}$. However, they appear asymmetric and elliptical as a result of counter-clockwise inertial motions with magnitudes in a range of 2 to 5 $\mathrm{cm\,s^{-1}}$. The decorrelation time and length scales are computed from the decay slope of the near-inertial peak and the spatial coherence in the near-inertial frequency band, respectively. Decorrelation time scales of clockwise near-inertial motions increase from 2 days nearshore (within 30 km from the coast) to 6 days offshore, and their length scales increase from 30 km to 90 km seaward possibly due to coastal inhibition. The local spatial coherence has an exponentially decaying structure for both clockwise and counter-clockwise rotations, and their phases propagate northwestward (offshore) for clockwise and northeastward (onshore) for counter-clockwise rotations.

Observations

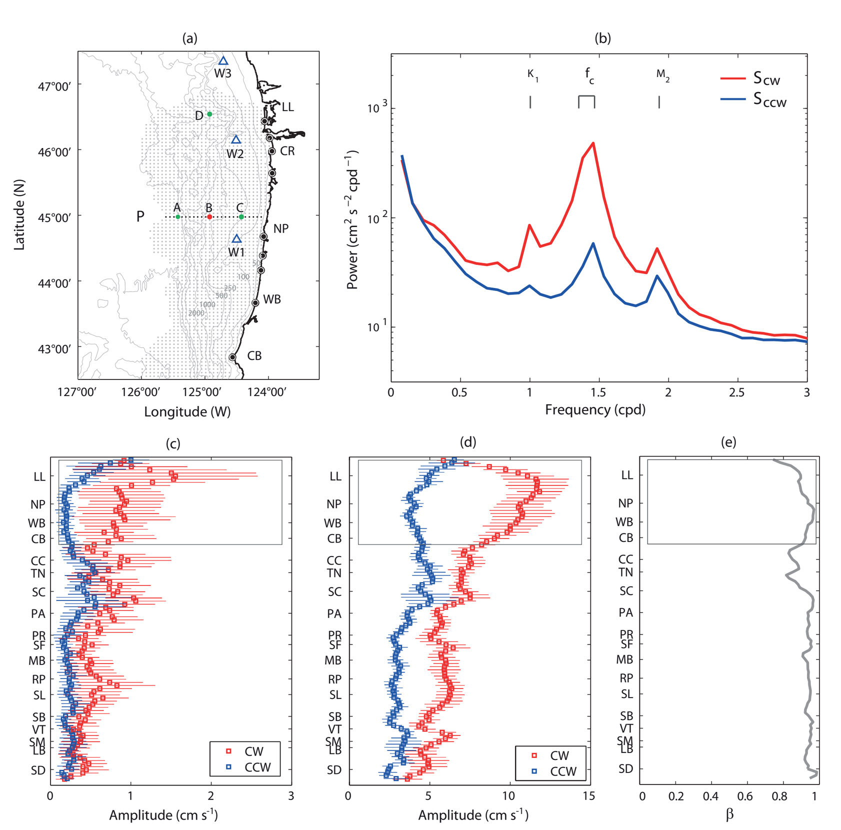

Figure 1: (a) Study area for near-inertial surface currents off Oregon and southern Washington. A gray dotted area denotes the effective spatial coverage at least 90% data availability. Blue triangles (W1, W2, and W3) and dots indicate the NDBC wind buoys (46050, 46029, and 46041) and HFRs, respectively. The estimates of decorrelation time and length scales are presented with examples on grid points A, B, and C along a cross-shore line P and the grid point D. The bottom bathymetry is contoured with 50 m, 100 m, 250 m, 500 m, 1000 m, and 2000 m. (b) Regionally averaged rotary power spectra of detided surface currents off Oregon and southern Washington. The range of local inertial frequencies and K_1 and M_2 frequencies are indicated. Alongshore distribution of the amplitudes of surface currents over the large-scale US West Coast. (c) at the local inertial frequency (d) in the near-inertial frequency band is presented as the mean (square) and standard deviation (error bar). (e) The fractional data availability (β) of only participating surface currents over two years in the computation, adapted from [1].

Surface currents

Hourly surface currents collected by an array of 11 shore-based HFRs operated by Oregon Sate University, from Loomis Lake, WA (46.43°N) to Crescent City, CA (41.78°N) for two years (2007 to 2008) are analyzed (Figure 1a). The surface currents off the Oregon coast are characterized by variance at low frequency ($|\sigma| \le 0.4$ cpd), two tidal bands at diurnal (primarily K_1) and semi-diurnal frequencies (primarily M_2 and S_2), diurnal wind and its harmonics, as well as inertial frequency (f_c = 1.35 to 1.47 cpd for 42.5°N to 47.1°N) [e.g., [1]]. The hourly surface current time series are detided by least-squares fitting the major tidal variance at K_1, O_1, P_1, S_2, and M_2 frequencies, but not S_1 frequency, because the amplitude of S_1 tidal currents is much weaker than that of currents driven by diurnal land/sea breezes. There are still peaks around K_1 and M_2 frequencies because the cuspate variance due to modulation of barotropic tides with low frequency energy exist (Figure 1b).

Coastal winds

The hourly wind observations are available at three NDBC buoy 46050 (W1; Stonewall bank), 46029 (W2; Columbia River mouth), and 46041 (W3; Cape Elizabeth) (Figure 1a). The variability of coastal winds measured from NDBC buoys off the USWC is dominated by subinertial alongshore winds and diurnal variability.

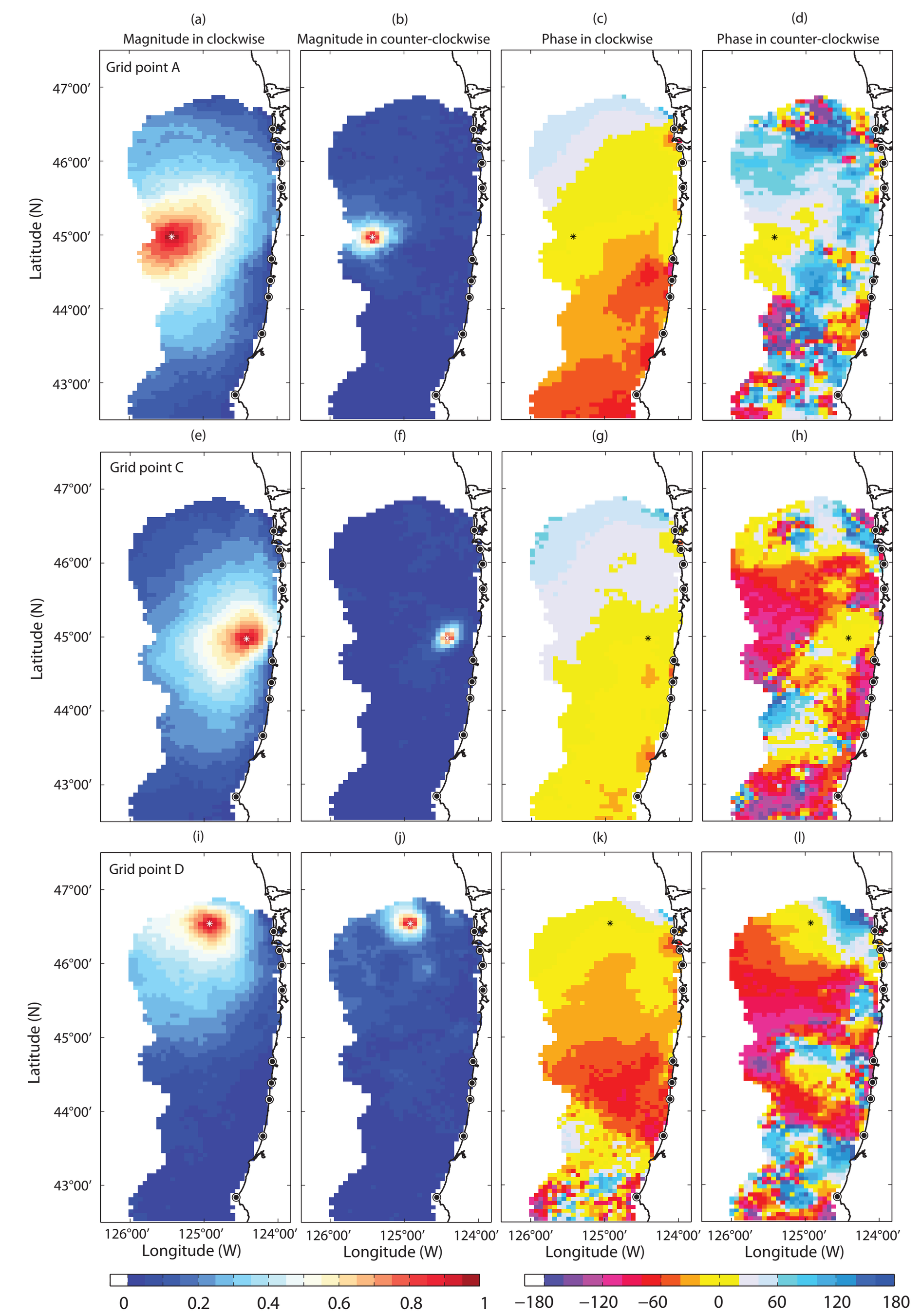

Figure 2: Magnitude and phase (degrees) of coherence of near-inertial surface currents relative to a reference location (A, C, and D in Figure 1a presented with white or black stars). (first column) Clockwise magnitude. (second column) Counter-clockwise magnitude. (third column) Clockwise phase. (fourth column) Counter-clockwise phase. The magnitude is averaged over the near-inertial frequency band, and the phase is computed from a single frequency bin nearby two near-inertial peak. (a) to (d): Grid point A. (e) to (h): Grid point C. (i) to (l): Grid point D.

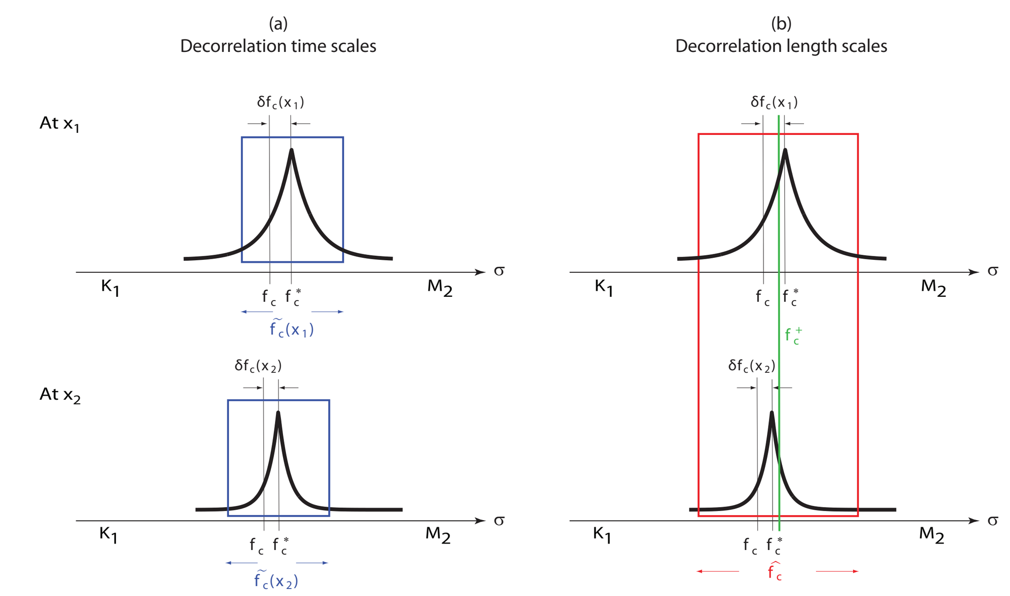

Figure 3: A schematic presentation of two near-inertial frequency bands [$\tilde{f}_c$ as blue boxes in (a); $\hat{f}_c$ as a red box in (b)] using power spectra of near-inertial surface currents at two locations (x_1 and x_2). The peak inertial frequency (f_c^*) is a sum of the local inertial frequency (f_c) and a deviation (δf_c). For the estimate of decorrelation time scales, a frequency band ($\tilde{f}_c$), centered by f_c^* as a function of space (x), is considered. On the other hand, decorrelation length scales are computed from coherence in a frequency band ($\hat{f}_c$), which covers near-inertial variance in two locations. Its center frequency ($\hat{f}_c^*$; a green line in (b)) is an average of two local Coriolis frequencies [$f_c(\mathrm{x}_1)$ and $f_c(\mathrm{x}_2)$].

Estimates of decorrelation scales

Here we estimate the decorrelation scales in time and space with spectral analysis. The decorrelation time and length scales are computed from the decay slope of the peak and the spatial coherence in the near-inertial frequency band, respectively. The decay slope of the peak can be estimated from the spectra at individual grid points. On the other hand, the spatial coherence should be taken into account in pairs of two grid points. Thus, the near-inertial frequency bands can be defined in slightly different ways ($\tilde{f}_c$ and $\hat{f}_c$) (Figure 3).

The individual power spectra within $\hat{f}_c$ are approximated with a σ^{-2} function and a decay slope (λ) (equation 1) in order to quantify the decorrelation time scale (λ) (equation 2).

$$S(\sigma) = \frac{A^2\lambda^2}{1+\lambda^2\left(\sigma+f_c^*\right)^2}, \qquad (1)$$

$$c(t) = Ae^{-if_c^* t}e^{-\frac{t}{\lambda}}, \;\; t \ge 0 \qquad (2)$$

where A is the constant amplitude in the time domain.

The decorrelation length scales of near-inertial surface currents are examined with spatial coherence, regarded as the spatial correlation within a specific frequency band:

$$\hat{c}\left(\Delta\mathbf{x}, \hat{f}_c\right) = \frac{\langle \hat{\mathbf{u}}(\mathbf{x},\hat{f}_c)\hat{\mathbf{u}}^\dagger(\mathbf{x}+\Delta\mathbf{x},\hat{f}_c)\rangle}{\sqrt{\langle|\hat{\mathbf{u}}(\mathbf{x},\hat{f}_c)|^2\rangle}\sqrt{\langle|\hat{\mathbf{u}}(\mathbf{x}+\Delta\mathbf{x},\hat{f}_c)|^2\rangle}}, \qquad (3)$$

where $\hat{\mathbf{u}}$ is the Fourier coefficients of vector current time series and $\langle\cdot\rangle$ indicates averaging over the near-inertial frequency band ($\hat{f}_c$). To estimate the spatial coherence of near-inertial surface currents at two grid points, a common near-inertial frequency band should be determined (Figure 3b). Although the same bandwidth in both rotations could be applied as was done for the time scale estimate (Figure 3a), it may not guarantee that basis functions of Fourier coefficients computed at two different locations are orthogonal. Thus, the near-inertial frequency band ($\hat{f}_c$) (Figure 3b) for coherent estimates is defined from the finite frequency axis.

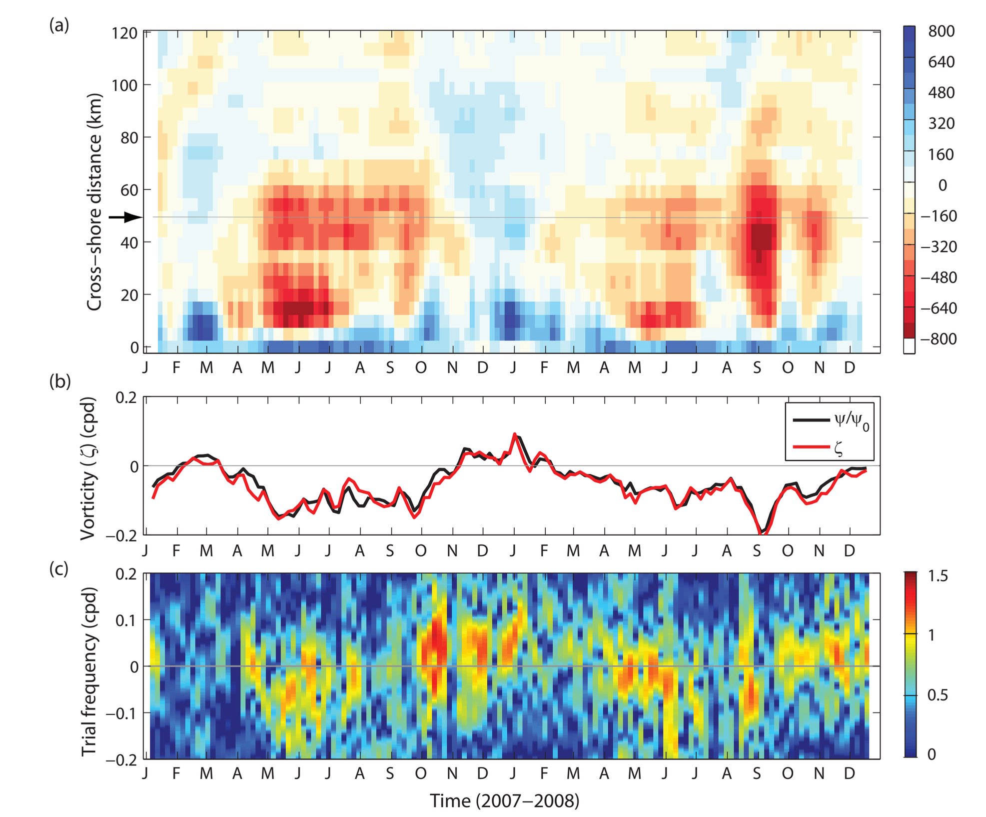

Figure 4: (a) Time evolution of stream function ($\mathrm{m^2\,s^{-1}}$) along a grid line P in Figure 1a. (b) Time evolution of vorticity (ζ, cpd) and scaled stream function (ψ/ψ_0, $\psi_0 = 4000\ \mathrm{m^2\,s^{-1}}$) at the grid point B in Figure 1a. (c) Clockwise variance ($\mathrm{cm^2\,s^{-2}}$, $\log_{10}$ scale) of surface currents at trial frequencies, centered by the local inertial frequency ($f_c = 1.4136$ cpd).

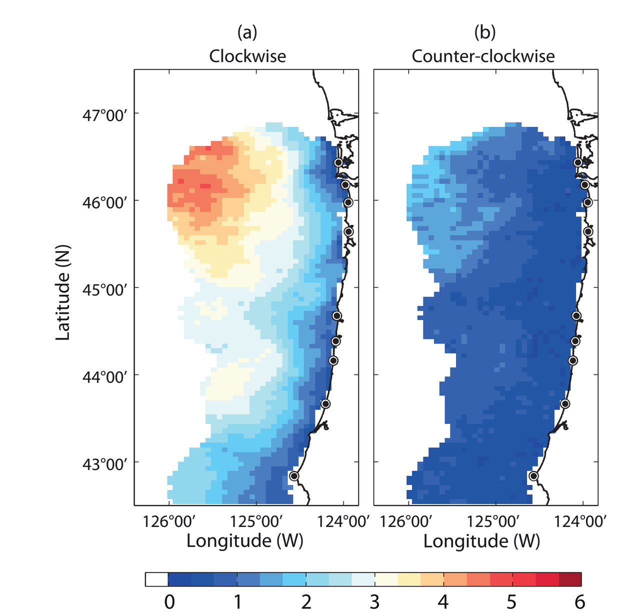

Figure 5: Decorrelation time scales (days) of (a) clockwise and (b) counter-clockwise near-inertial surface currents.

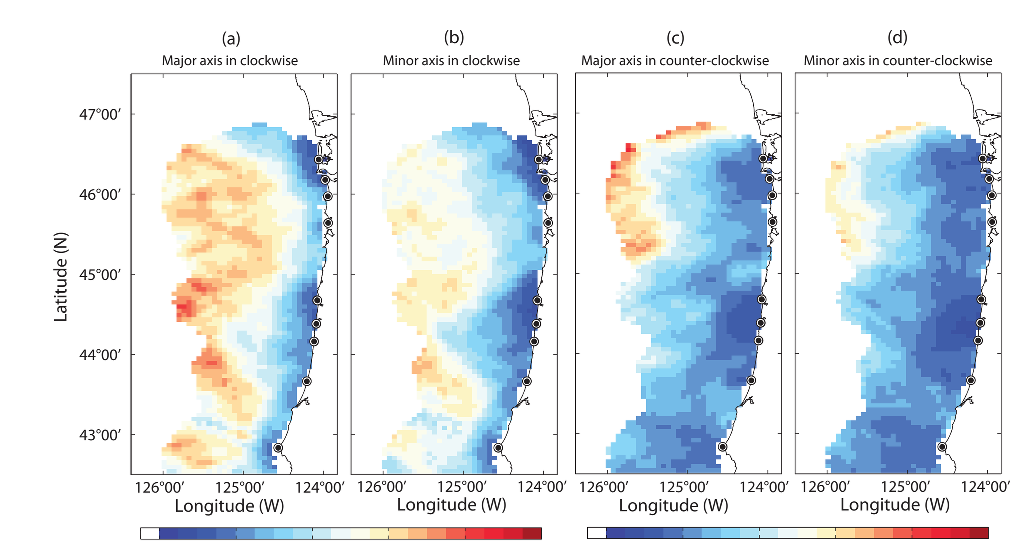

Figure 7: Decorrelation length scales (km) of near-inertial surface currents ($\hat{f}_c$), fitted into an exponential function. (a) and (b): Length scales on major and minor axes in the clockwise direction. (c) and (d): Length scales on major and minor axes in the counter-clockwise direction.

Concluding remarks

The decorrelation scales of near-inertial surface currents observed by an array of high-frequency radar off the Oregon coast have been investigated. The decorrelation time and length scales are computed from the decay slope of the near-inertial peak and the spatial coherence in the near-inertial frequency band, respectively. In order to increase degrees of freedom, a single time series of surface currents is divided into non-overlapped time series with identical record lengths, and spectral estimates are based on their ensemble average. As the inertial peak is shifted with background vorticity, the decay slopes of the peak are computed following the peak in each chunk of the time series. Decorrelation time scales of clockwise near-inertial motions increase from nearshore (within 30 km from the coast) to offshore from 2 to 6 days, and their length scales have a similar spatial tendency increasing from 30 km to 90 km seaward. The spatial coherence has an exponentially decaying structure for both rotations and their phases propagate northwestward (offshore) in clockwise and northeastward (onshore) in counter-clockwise rotations. The northeastward phase propagation in the counter-clockwise rotation is only observed at the northern domain. These partially poleward propagations may be caused by the positively shifted near-inertial currents due to positive vorticity near the coast. The beta-dispersion effect predicts that near-inertial internal waves are free to propagate equatorward (northward phase propagation), but are restricted in their poleward propagation by the planetary vorticity gradient.

The near-inertial surface currents are dominantly clockwise with amplitudes of 9 to 12 $\mathrm{cm\,s^{-1}}$ and appear as asymmetric and elliptical as a result of counter-clockwise inertial motions with magnitudes in a range of 2 to 5 $\mathrm{cm\,s^{-1}}$. Reduced clockwise variance is found in nearcoast areas, possibly as a result of coastal inhibition, which is a downward flux from the surface-coast corner (upward and offshore phase propagations). Although the inertial currents in the Northern Hemisphere dominantly rotate clockwise, the reflection of near-inertial waves from the continental slope or the coast can produce a superposition of the incident and reflected waves, which can cause the counter-clockwise components. In particular, the currents can be rectilinear near the coast, so the clockwise and counter-clockwise near-inertial variance is expected to be nearly equal [e.g., [2]], which can be speculated as a result of the coastal reflection of near-inertial waves or bottom trapped waves [e.g., [3, 4]].

Acknowledgement

Sung Yong Kim is supported by the Human Resources Development of the Korea Institute of Energy Technology Evaluation and Planning (KETEP), Ministry of Trade, Industry and Energy (No. 20114030200040). P. Michael Kosro is supported by the National Science Foundation (Grants 0434810, 0237710) and the National Oceanic Atmospheric Administration IOOS program (most recently NA11NOS0120036). Long-range radars in Oregon are due to the Northeast Pacific GLOBEC program (contribution 728). The wind data are from the National Data Buoy Center (NDBC).

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