Anisotropic filtering to improve the geodetic determination of the Surface Geostrophic Currents: Edge Enhancing Diffusion

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ABSTRACT

The Surface Geostrophic Currents (SGC) can be determined from the gradient of the Mean Dynamic Topography (MDT) which is defined as the mean sea surface height referenced on the Earth's geoid. Due to the noise in the MDT, particularly for short space wave lengths, some filtering is required before the SGC computation. Since the SGC have a strong directional behaviour (emphasized when the current is stronger) anisotropic filtering would be preferred for the case. Here we deal with the capabilities of the Edge Enhancing Diffusion (EED) filters for filtering the MDT in order to improve the computation of the SGC. It is proved how this method conserves all the advantages that the non-linear isotropic filters have over the standard linear isotropic Gaussian filters. Moreover, the EED is shown to be more stable and almost independent of the local errors. This fact makes this filtering strategy more appropriated when filtering noisy surfaces.

MOTIVATION

MDT calls for filtering previous the SGC can be derived because of

(i) the omission error caused by d/o do not represented in the geoid,

(ii) the signal-to-noise rate decreases for the higher degrees (shorter wavelengths).

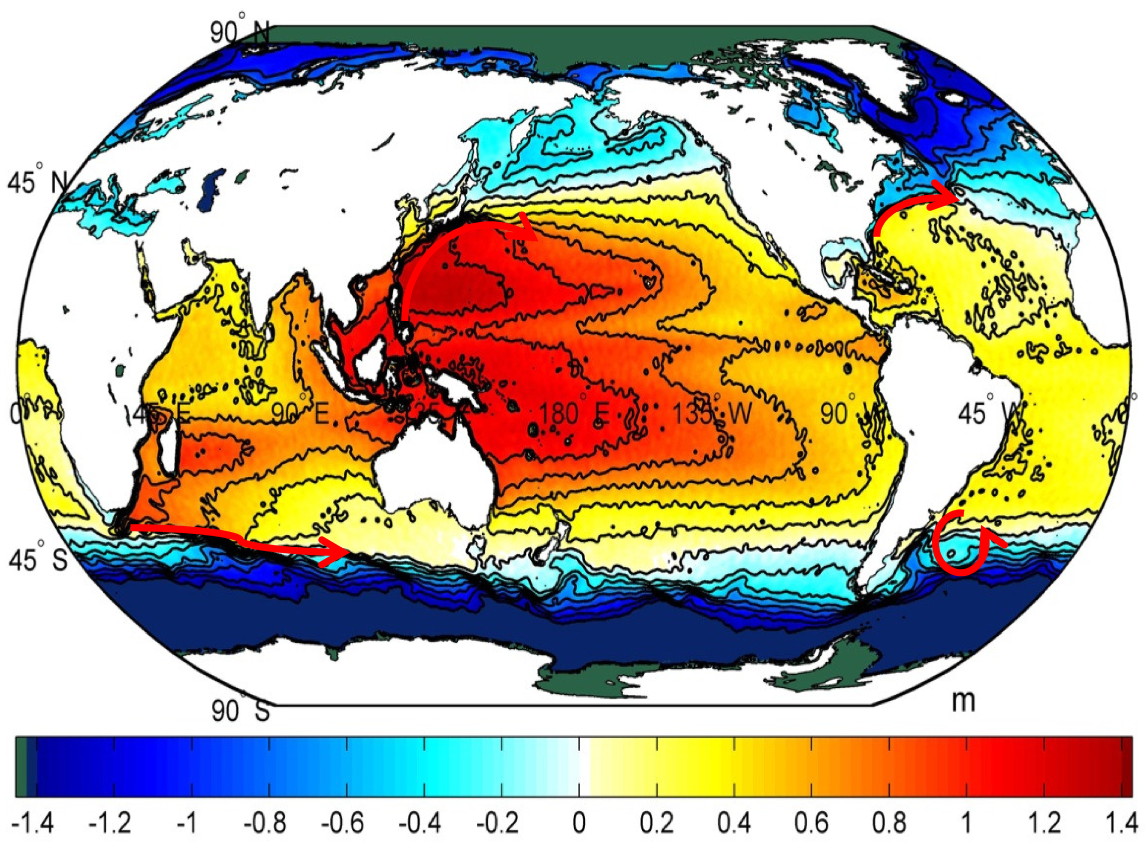


Fig. 1 MDT derived from an altimetric MSS and a GOCE geoid (filtered with a GF of 83 *km*)

$u = -\frac{g}{f} MDT_y$ level lines in the sea surface topography are streamlines of the geostrophic flow

$v = \frac{g}{f} MDT_x$ SGC are aligned along the gradients of the MDT

Anisotropic rather than isotropic filtering would be preferred!

NON-LINEAR DIFFUSION FILTER

An anisotropic diffusion filter forces the MDT by

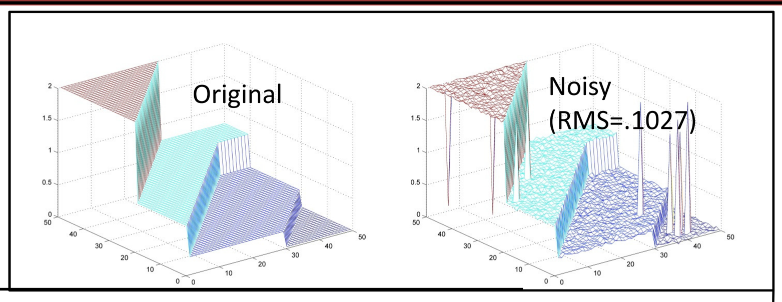
$$MDT_n = div(D \cdot \nabla MDT)$$

MDT_n: derivative of MDT relative to an iterative process through n

div: divergence ($\partial/\partial x + \partial/\partial y$)

∇MDT: gradient of MDT

D: diffusion tensor



If $D = \begin{pmatrix} d & 0 \\ 0 & d \end{pmatrix}$ → GF with standard deviation $\sqrt{2nd}$

linear isotropic→ attenuates edges of the MDT

If $D = g(|MDT|^2)$ → PMF (Perona and Malik 1990)

Adapted by Bingham (2010)

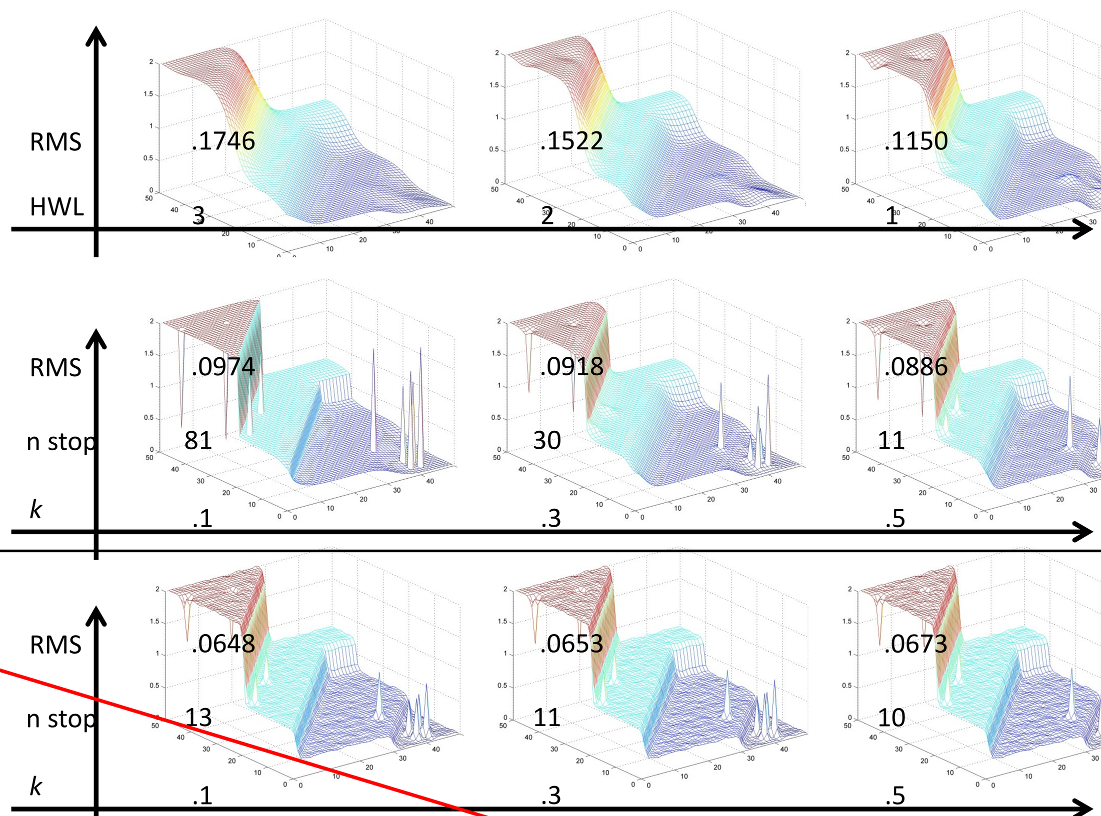
non-linear isotropic→ strongly depending on *k*

local errors could be detected as edges

If $D = (v_1 \quad v_2)\begin{pmatrix} \mu_1 & 0 \\ 0 & \mu_2 \end{pmatrix}(v_1 \quad v_2)^T$ → EED (Weickert, 1998)

anisotropic→ similar results for a wide range of *k*

conserve edges while attenuates local errors



If we define the structure tensor,

$$J_\sigma = K_\sigma * (\nabla MDT \otimes \nabla MDT^T)$$

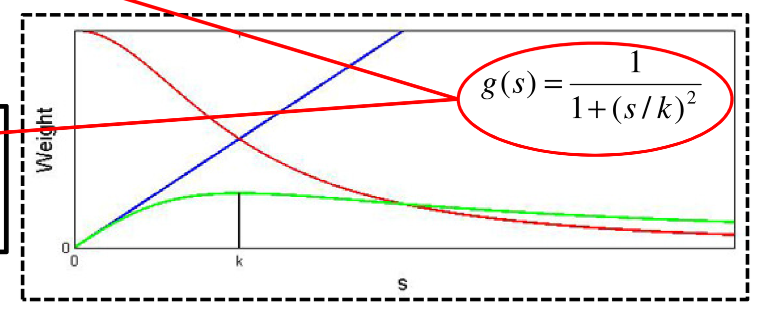
decomposed as

$$J_\sigma = (v_1 \quad v_2)\begin{pmatrix} \lambda_1 & 0 \\ 0 & \lambda_2 \end{pmatrix}(v_1 \quad v_2)^T$$

where λ_1, λ_2 are eigenvalues of J_σ associated to eigenvectors v_1, v_2

$\mu_1 = g(\lambda_1)$, and

μ_2 is normalized to be $\mu_2 = 1$



if $\lambda_1 \geq \lambda_2$,

λ_1 "magnitude" & v_1 direction across the flow

λ_2 "magnitude" & v_2 is across the flow

DATA

MDT=MSS-N

✓ MSS: CLS01 updated to 18 years (1992/10-2010/12) by using SLA (AVISO, quarter degree, 29 Mar 2011).

✓ N: REL01-DIR GOCE geoid model.

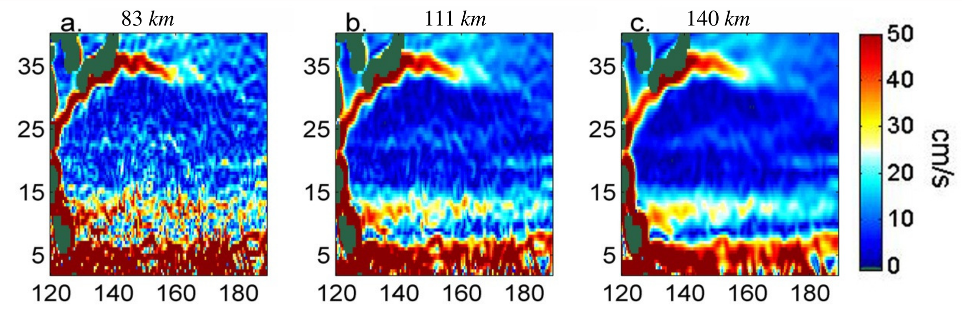


Fig. 3 SGC derived from a Gaussian filtered MDT

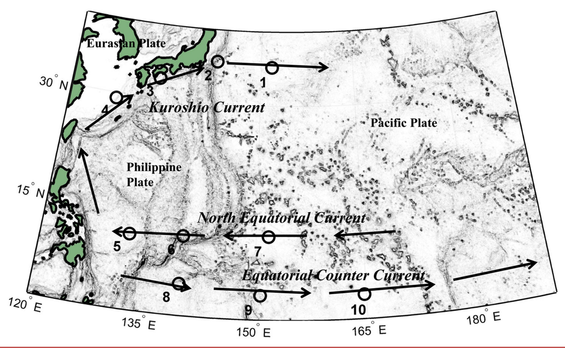


Fig. 2 Area of study: Central Western Pacific Ocean. Three major currents are displayed by arrows with the ten points used for a detailed comparison in Tables. Bathymetric features are shaded in black.

Two criteria to stop the filter:

- COM: common degree of filtering as a GF of 111 km of HWL in [20°N 30°N]x[170°E 190°E] that is a "free-of-currents area" (isotropic flow) and therefore all three filters should provide surfaces reflecting the same signals. Allows us to compare objectively the filters in their own nature.
- OPT: optimum approximation to the Kuroshio Current as measured by drifter buoys in [30ºN 40ºN]x[125ºE 155ºE]. Allows us to investigate the capabilities of each filter to approximate a solution for the SGC, since the inner characteristic of a single filter could differ with each other and therefore the requirements to find the optimal filtering could also differ.

RESULTS

Easy case:

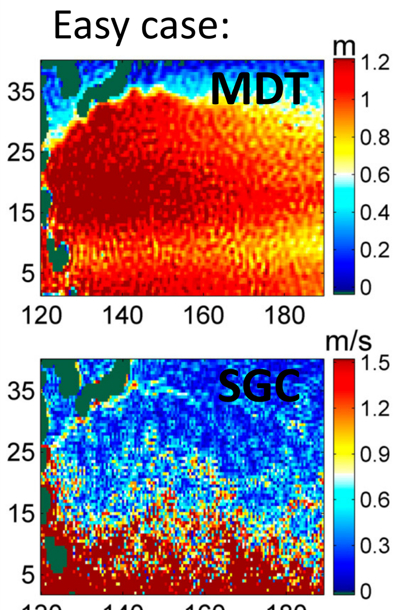


Fig. 4.1 Unfiltered MDT and derived SGC: Spectral-wise (SW) method.

		Kuroshio				North Equatorial			Equatorial Counter			
	LOC	1	2	3	4	5	6	7	8	9	10	
	DRIF	39,2	72	80,6	78,7	33,3	29,1	24	27	18,4	18,6	RMS
	UNF	49,9	129,9	506,4	134,6	358,5	432,1	248,6	1155	1871	771,7	760
EED	COM	33,7	43,7	45,5	38,4	47,3	37,6	26,1	51,9	42,9	28,5	23
EED	OPT	40,6	58,8	64,9	49	54,9	36,2	27,9	61	51,2	35	20,8
PMF	COM	32,4	43,5	45	36,4	46,3	39,6	27	47,9	45,5	25,9	23,3
PMF	OPT	39,7	61,1	70,6	47,6	53,4	44,6	28,7	60,3	59,5	32,5	22

Table 2.1 Estimated velocities (cm/s) for locations in the three major currents in the area of study (Fig. 2): Easy case.

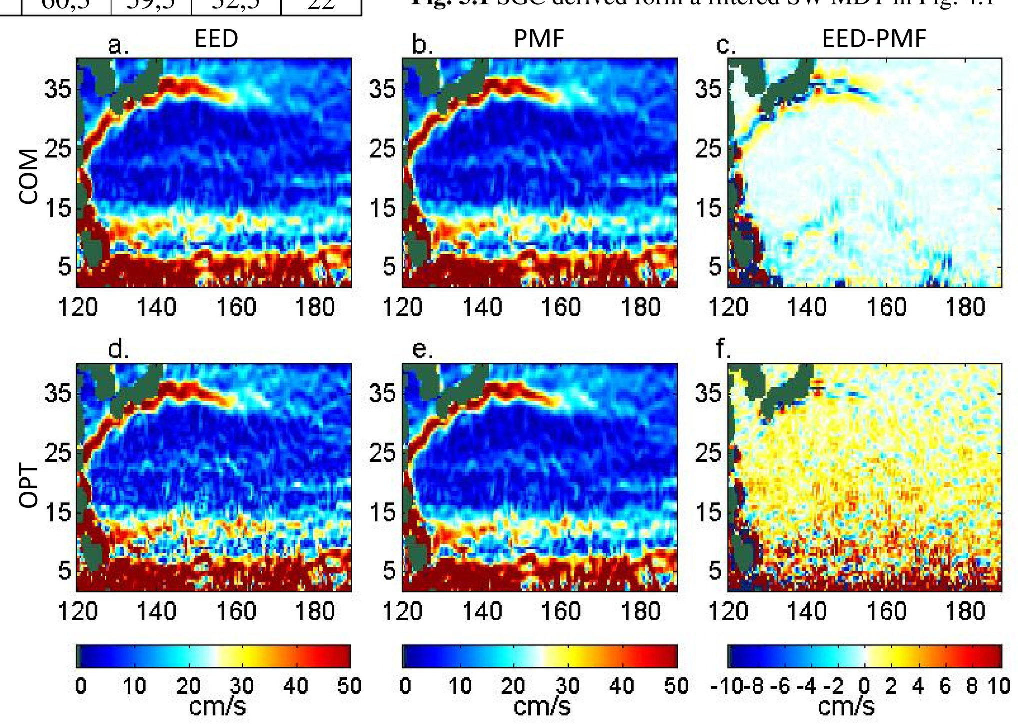
COM:

- differences arise on the stream flow along the KC
- the PMF provide higher values than the EED on the crest of the current
- the stream flow becomes wider by the EED
- results provided by the EED, 19.3 cm/s, are better than those by a PMF, 21.1 cm/s

OPT:

- only minor differences arise at the eastern coast of Japan due to a severe enhancing of the central ridge by the PMF
- most of the differences are positive corresponding to higher velocities for the EED than PMF.
- the PMF, 22.3 cm/s, is a slightly better than the EED, 22.5 cm/s

Fig. 5.1 SGC derived form a filtered SW MDT in Fig. 4.1



Hard case:

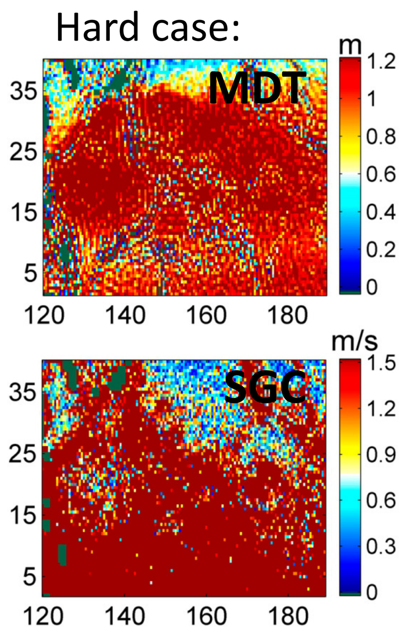


Fig. 4.2 Unfiltered MDT and derived SGC: Point-wise (PW) method.

COM:

- results by the EED, 23 cm/s, are better than the PMF, 23.3 cm/s.
- similar results with some differences along the intersection between the Pacific and Philippine plates (see figure 2)

OPT:

- results by the EED, 20.8 cm/s, are better than the PMF, 22 cm/s.
- the grid provided by the PMF is full of spots (figure 5.2e) which would make necessary to apply a higher degree of filtering for the case. This higher degree of filtering will also remove true signal in the stronger gradient areas leading to an attenuated estimation of the currents.

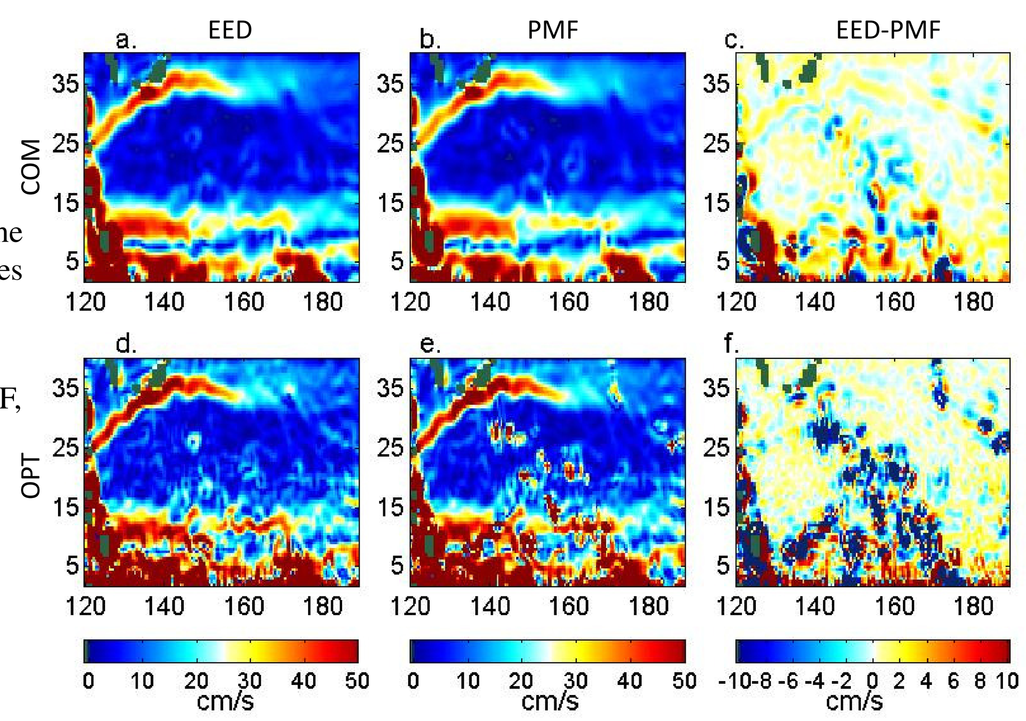


Fig. 5.2 SGC derived form a filtered PW MDT in Fig. 4.2

		Kuroshio				North Equatorial			Equatorial Counter			
	LOC	1	2	3	4	5	6	7	8	9	10	
	DRIF	39,2	72	80,6	78,7	33,3	29,1	24	27	18,4	18,6	RMS
	UNF	72,9	151,7	180,5	100	57,4	241,9	128,6	284,8	616	111,2	225
EED	COM	42,2	61,5	76,1	52,9	40,3	36,1	26,2	52,4	50,8	51,9	19,3
EED	OPT	45,7	71	92,6	58,4	45,2	41,9	25,1	60,2	60,2	54,6	22,5
PMF	COM	44,5	100,2	94,3	57,4	40,9	39,1	26,5	51,7	51,1	52,5	21,1
PMF	OPT	45,1	103,2	98,3	58,6	41,9	40,5	26,4	52,6	52,6	53,1	22,3

Table 2.2 Estimated velocities (cm/s) for locations in the three major currents in the area of study (Fig. 2): Hard case.

CONCLUSIONS

The PMF does not control the diffusion direction but only the magnitude of the diffusion flux. The EED strategy is one step further than the PMF, forcing the filtering process not just by the size of the edges but also by the direction of the flow.

The **main advantage of the EED** is the relative **low influence that the local errors** have **in the final results**. Because the PMF just uses the nearest neighbours to filter a single location, errors at such neighbours are kept through the iterations leading to errors at the final surface. In contrast, the EED filters in the direction of the flow (determined from a regularized MDT) attenuating the individual errors influence.

The PMF is strongly sensitive to variations of *k* leading to very different solutions. Because the EED works on a regularized MDT, it provides similar results for a much wider range of values of *k*. This makes the **EED more robust.**

For a surface with low noise (easy case, SW MDT) both filters work fine finding similar results. However, when in cases with a strong presence of noise (hard case, PW MDT), the EED provided acceptable results while the PMF showed some problem with local errors throughout the entire grid.

The **EED** filtering strategy **should clearly be preferred** particularly **in cases with a noisy signal**, to both the PMF and the GF. Results provided by the EED were shown to be in closer agreement between both the easy and hard cases.

Comparing geodetic estimation of the surface velocities with those provided with buoys measurements we found a more or less good agreement at the KC and the NEC areas. Nevertheless, a strong discrepancy arises for the ECC where the in-situ data provide much smaller velocities than the satellite, probably due to the poor coverage of in-situ data in this zone.

At those areas where the flow is relatively weak, the noise could be identified as signal by the EED influencing the determination of the direction by the filter and leading to fictitious results. Therefore deeper investigations are needed for the case.

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