Identifying and tracking surface-attached vortices in free-surface turbulence from above: a simple computer vision method

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§ I Summary

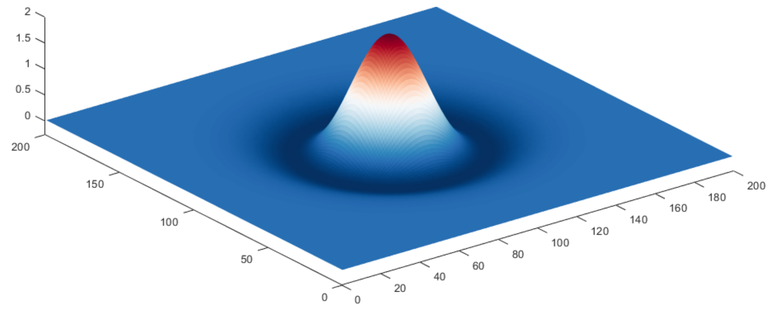
- Automated detection of attached surface vortices in DNS using surface elevation only, with wavelet-based computer vision.
- Vortices successfully distinguished from other structures.
- Validated by comparing with the vorticity field underneath.
- Tracked the attached vortices in time.

§ II Applications

- Surface-attached vortices are closely related to upwelling events which are key to gas transfer.
- Remote sensing from video, e.g. by drones.
- Assimilation into gas transfer models.

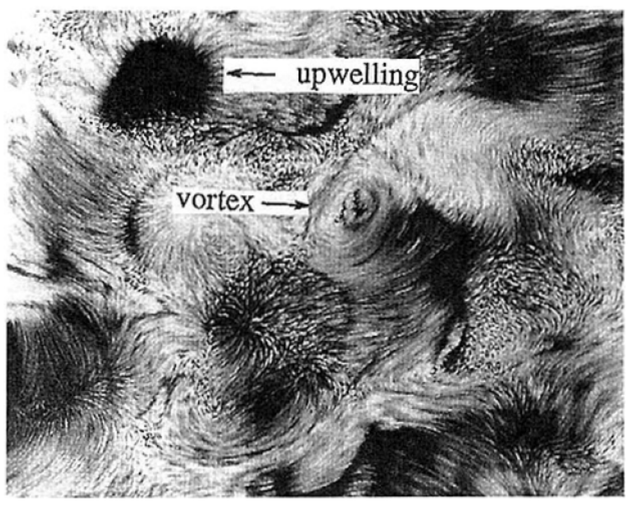
§ III The wavelet transform

- Choose Mexican hat, appropriate for detecting circular shapes.
- Apply wavelet transformation to free surface elevation $\eta(x, y, t)$
- Strong feedback when the surface has a *similar shape to the wavelet*.



2D Mexican hat wavelet

§ IV Structures on the surface

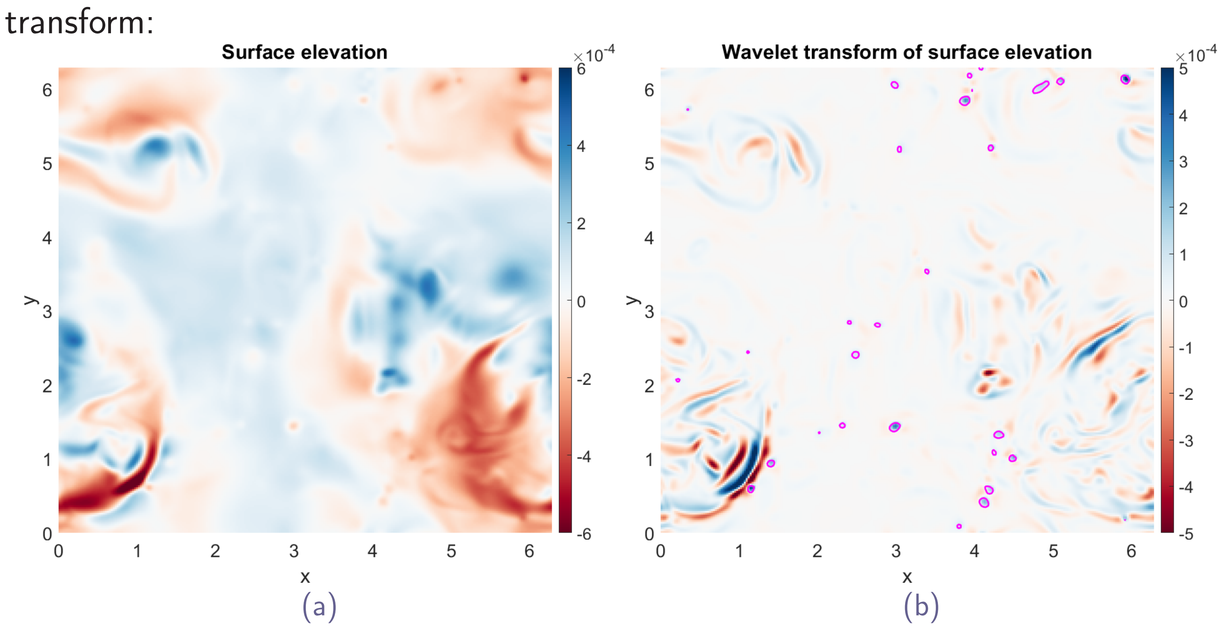


Free surface with micro balloons showing and upwelling and a vortex (Banerjee, 1994)

- Areas of turbulent upwelling and downdraughts make "hills" and "valleys" on the surface.
- Near-surface turbulent vortices break up and attach to the surface.
- These create near-circular surface depressions or "dimples".

§ V Transforms of the free surface

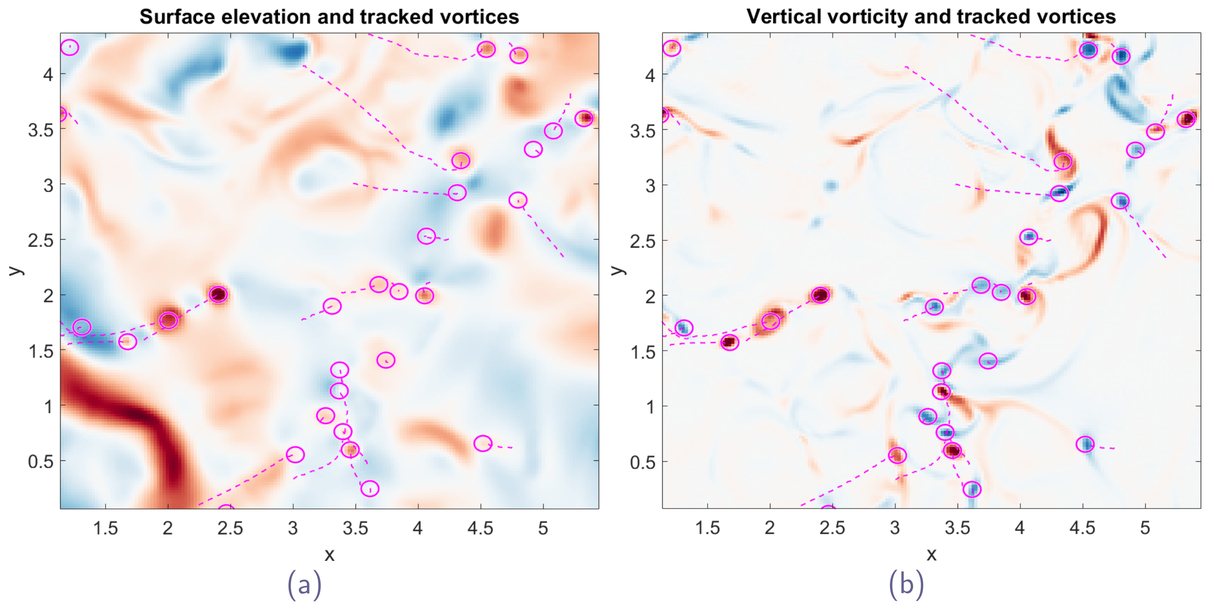
The free surface from DNS (see Gou & Shen 2010 for details), and its wavelet transform:



a) Free surface elevation from DNS data. b) Wavelet transform of the surface elevation with magenta outlines of the attached vortices found using the Joeng-Hussain (1995) criterion.

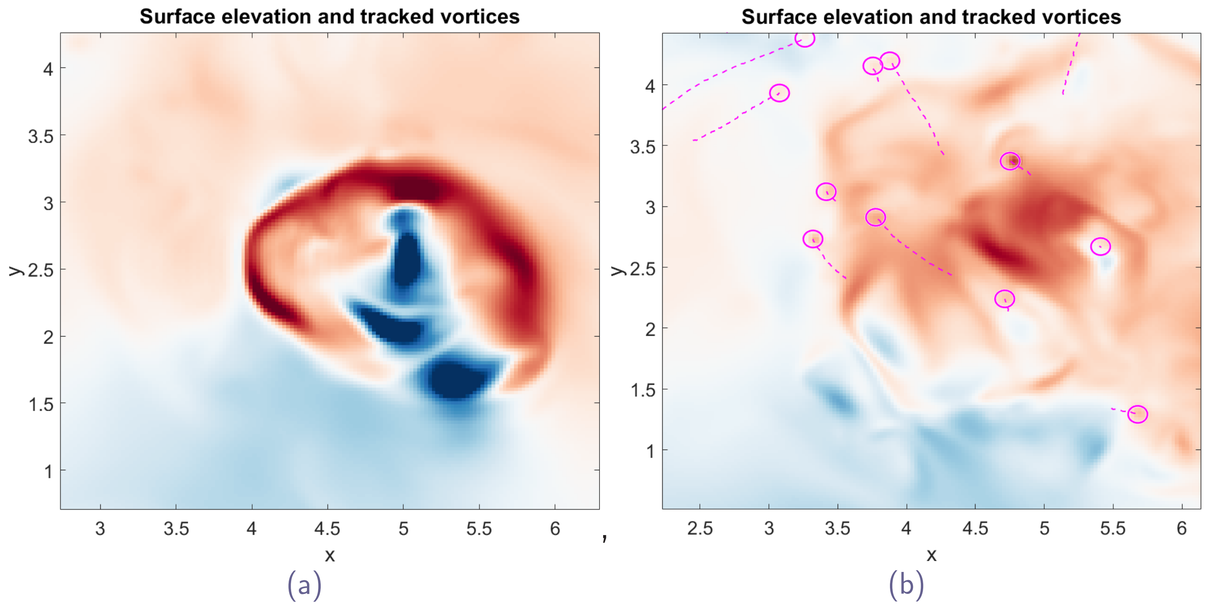
- Attached vortices give small circular peaks in the wavelet spectrum, but other features also give strong signals.

§ VI Filtering and Tracking



Surface elevation (a) and vertical vorticity (b) with the tracked attached vortices on top.

- Candidate vortices distinguished from other features by their circularity (low eccentricity).
- True/significant vortices identified by long lifetime.
- Identified vortices successfully tracked in time.



Surface elevation at the start (a) and at the end (b) of an upwelling. Number of vortices has increased substantially.

- Time delay between upwellings and appearance of vortices.
- Vortices are observed to occur at the edge of strong upwelling events (e.g. Kumar et al., 1998).
- Compare with surface divergence as indication of upwelling.

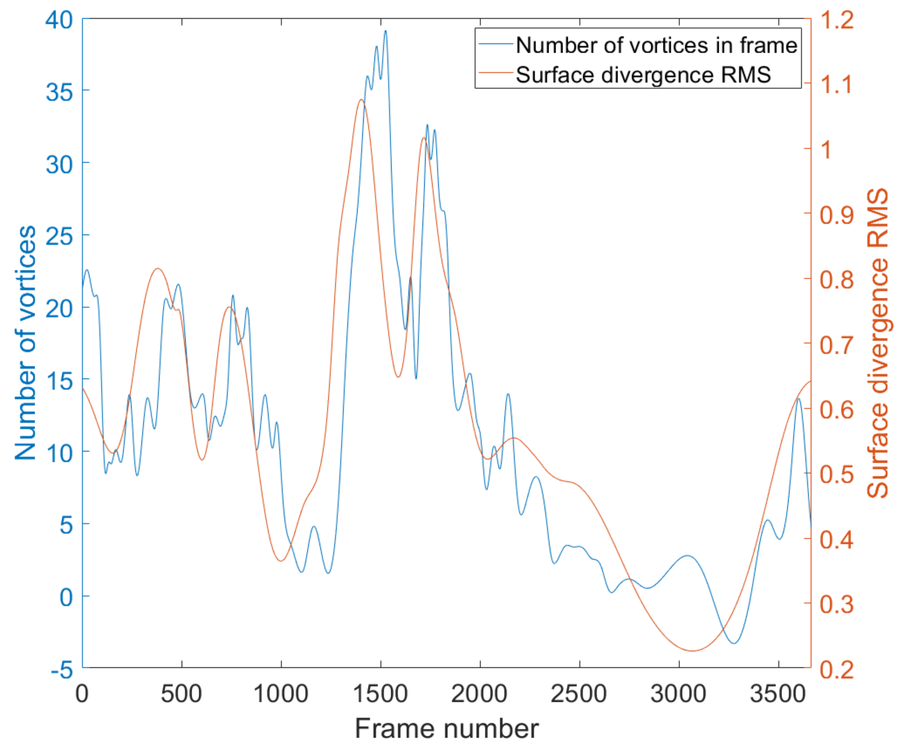


Figure: Time series of the surface divergence RMS and the number of vortices at each frame. Used the Empirical Mode Decomposition method take out the fastest oscillations, which is why there are apparent, unphysical negative values.

References

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