Vortex imprints on a free surface as proxy for surface divergence

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§ I Summary

- Detection algorithm for surface-attached vortices in DNS using only surface elevation data.
- The detections are validated by comparing them with the bulk velocity field.
- Number of detections closely correlated with the surface divergence.
- Possibility for remote sensing of gas transfer.

§ II Applications

- Surface attached vortices are generated by upwellings which are key to gas transfer.
- The Number of detection can be used as a proxy for the surface divergence.
- Remote sensing.
- Assimilation in gas transfer models.

§ VI Visualisation of detection and performance evaluation

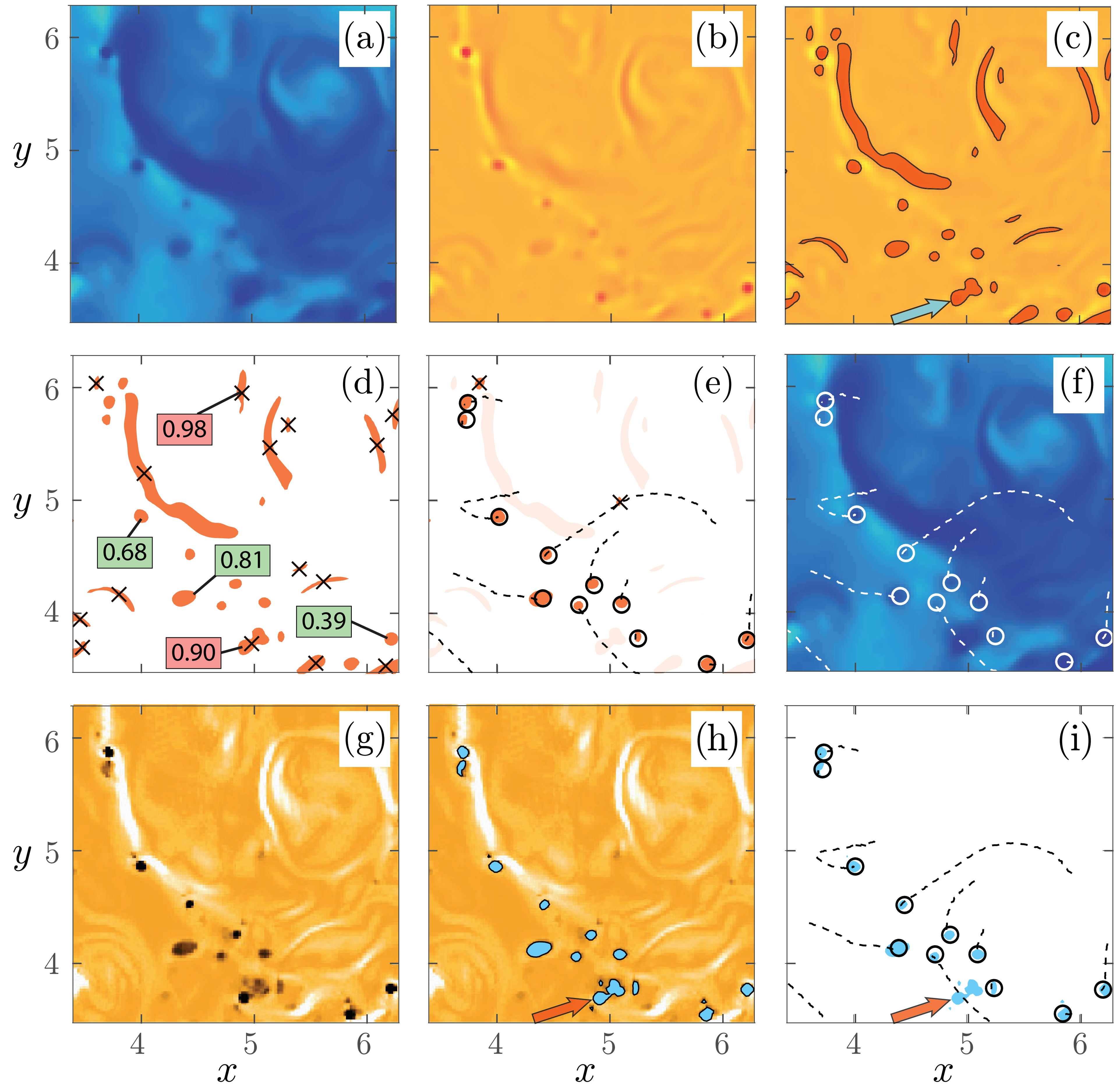

Figure 1: Illustration of the detection process, slightly simplified. a) Input surface elevation η, (b) wavelet-transform $W(x,y)$ of η; (c) regions where $W > W_{th}$; (d) calculated eccentricity of each structure (five examples given), high eccentricity structures discarded (marked with a cross); (e) time-tracking showing trajectories of area centres from birth to present time, short-lived structures discarded (crosses); (f) output: surface elevation and tracked vortices; (g-i) show steps in performance evaluation; (g) the value of λ_2 at the surface; (h) areas with $\lambda_2 < \lambda_{2,thr}$ (potential 'true' vortices); (i) detections (circles/trajectories) and actual real vortex cores (blue). Note in (c, h, i) the structure marked with an arrow, discarded due to high eccentricity (panel d) is in fact a cluster of vortex cores; a few timesteps later it splits in two whereupon both halves are detected.

§ III Structures on the surface

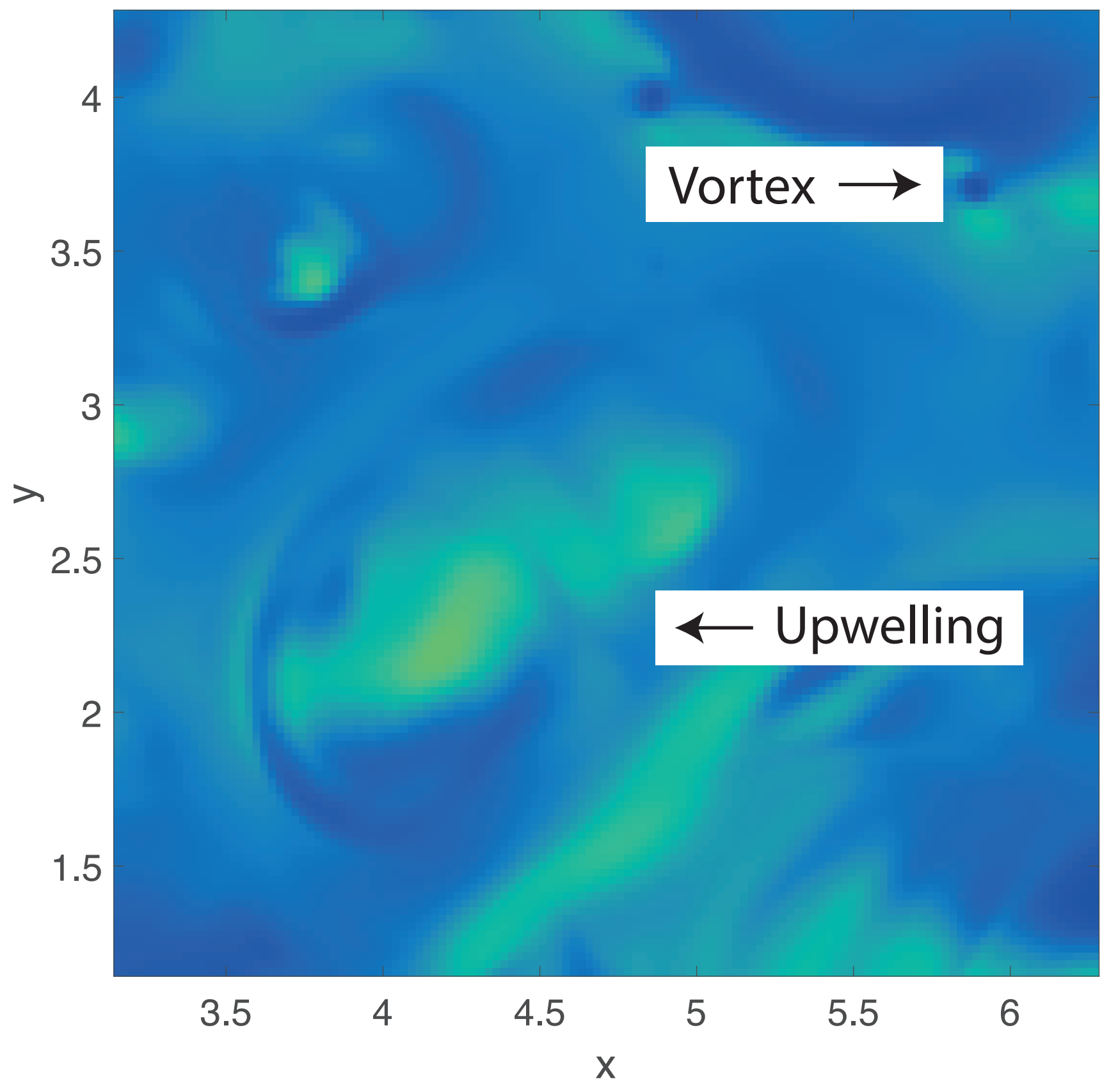

Figure 2: Free surface showing an upwelling and a vortex

- 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" which are readily detectable.

§ IV Detection Procedure

- Choose the Mexican hat wavelet, appropriate for detecting circular shapes.
- Evaluate the wavelet transform, $W(x,y)$, of the surface elevation $\eta(x,y,t)$ Figure 1 (b).
- Keep connected regions in the transform above a certain threshold, W_{th}, Figure 1 (c).
- Track regions in time and only keep regions with low eccentricity (high circularity) and high lifetime, Figure 1 (d,e).

§ V Performance evaluation

- Calculate the Jeong & Hussain (1995) λ_2 value at the surface, Figure 1 (g).
- Areas with $\lambda_2 < \lambda_{2,thr}$ are considered "true" voritces, Figure 1 (h).
- Check overlap between detected regions and "true" vortices, Figure 1 (i).
- Around 90% of "true" vortices detected with around 5% false detections (detected regions that were not "true" vortices).

References

Jeong, J., & Hussain, F. (1995). On the identification of a vortex. Journal of fluid mechanics, 285, 69-94.

§ VII Correlation with surface divergence

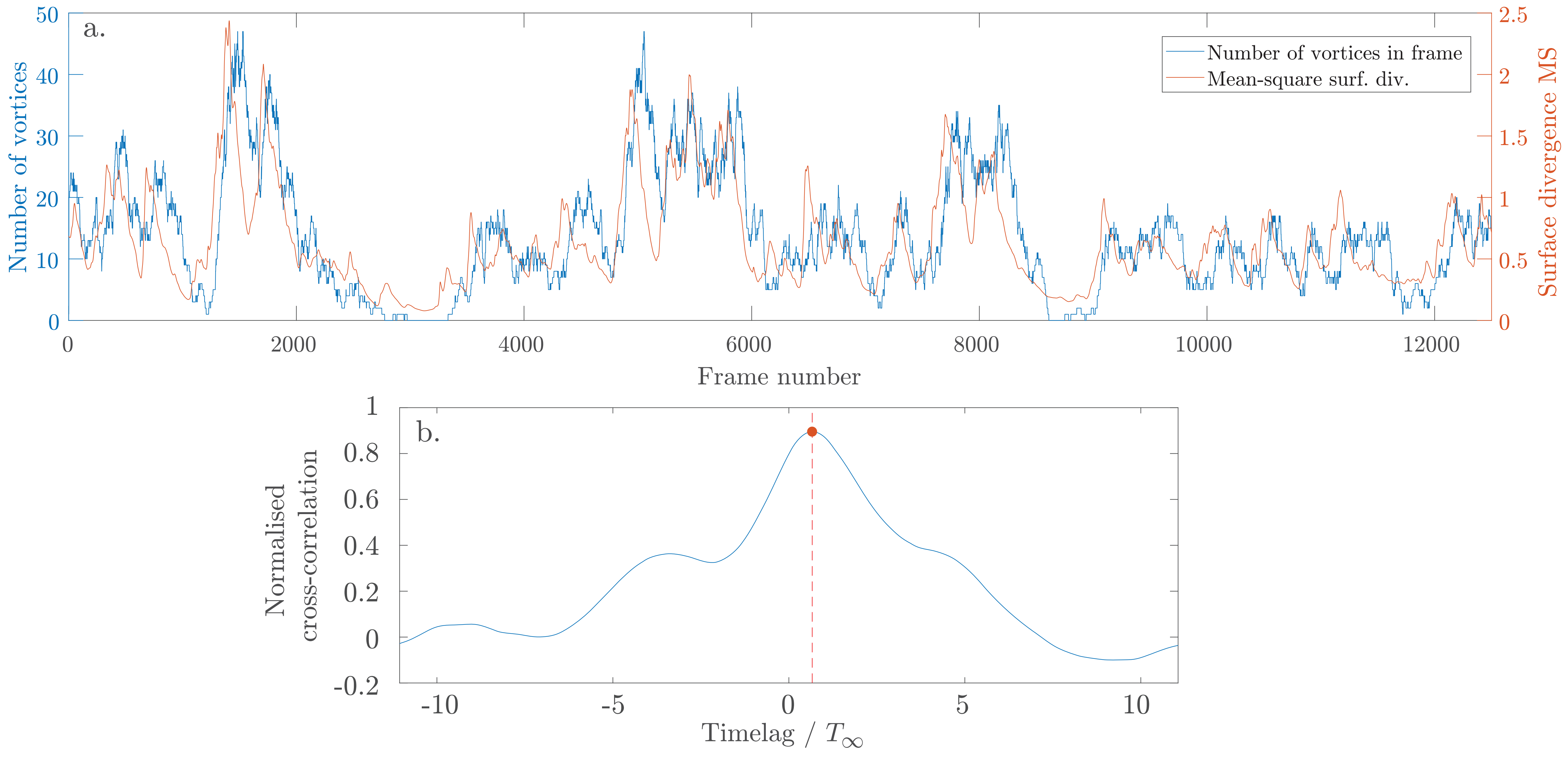

Figure 3: (a) Plot of the mean-square surface divergence against the detected vortices. (b) The normalised cross-correlation between the two (average values subtracted) as a function of lag, peaking at 0.90 with lag 0.74 T_∞.

- A high correlation (peak at around 0.9) was found between the number of detection and the mean square surface divergence at each timestep, Figure 3 (a.).
- There is a time lag between the two graphs of around 0.74 of the integral timescale defined using L_{inf}/u_{rms}. This lag is owing to the fact that the vortices appear at the edges of upwelling events (strong surface divergence), when upwelling is dying out, Figure 3 (b.).

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