*XVIIIèmes Journées Nationales Génie Côtier – Génie Civil*
*Anglet, 2024*
*DOI:10.5150/jngcgc.2024.047* *© Editions Paralia CFL*
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# Regional assessment using public webcams of the role of post-storm recovery in the seasonal variability of beach width

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**Abstract:**
Understanding the mechanisms and times required for beaches to recover after extreme storms, as well as the effect of these episodic setbacks on long-term coastal erosion trends, is crucial for anticipating changes and implementing effective management strategies. A storm can have significant impacts on the coastline, resulting in retreats of several meters within hours. The natural recovery of the beach in the hours/days following a storm varies greatly between sites, ranging from a few days in some areas to several months in others. In this study, we examine the regional variability in coastal response during winter storms and post-storm recovery, using a beach width indicator obtained through the analysis of public webcam images on event, seasonal, and multi-year time scales. Video-derived estimates of shoreline position were used to calculate weekly average beach widths at 11 sites along the 200 km coastline of Occitanie.
The analysis demonstrated that storm responses and seasonal trends exhibit significant variability despite similarities in morphologies, sediments, and exposure to the primary direction of storm waves. Although post-storm recovery following the major events of 2021 and 2022 was nearly complete and very rapid (within a few days) for most sites, some beaches experienced prolonged recovery periods, requiring several months to return to their initial position. In these cases, the typical seasonal trend of advancement in summer and retreat in winter was no longer evident. While the results indicated that storm events were sufficiently spaced to allow these beaches to recover, and that response variability is mainly due to a site's pre-storm morphology, a series of events in autumn 2023 raises questions about this recovery capacity and underscores the potential major impact of singular events on medium- and long-term coastal evolution trends.

**Key-words:**
Storm shoreline retreat ; Post-storm recovery, Webcam, Regional assessment.

## 1. Introduction

Since the pioneering studies of HOLMAN and GUZA in the 80’s (HOLMAN & GUZA, 1984), video imagery has transformed the coastal monitoring practices (DUSEK *et al.*, 2019). It provides a continuous monitoring of physical factors (waves, water levels, run-up, …) as well as morphological evolution (shoreline and sand bars position, topography, bathymetry) (see review in HOLMAN & STANLEY, 2007). The pioneer Argus monitoring program was the first program to install ashore-based video monitoring system (HOLMAN & STANLEY, 2007), after that several commercial video systems (e.g., CoastalComs) and specialized image-processing tools (VM4GIS, RIHOUEY *et al.*, 2009, COSMOS of TABORDA & SILVA, 2012; BeachKeeper Plus of BRIGNONE *et al.*, 2012, Waves'n see) have been developed for scientific purposes. Although the use of these systems has expanded with the miniaturization and cost-effectiveness of cameras, there are challenges preventing widespread installation. These challenges include difficulties in finding suitable site infrastructures; expertise needed for installation and data processing; and costs associated with system installation, operation and maintenance (DUSEK *et al*., 2019).

Surfcams (or webcams) have emerged as a potential alternative or complement to coastal imagery systems established for scientific use. They are relatively inexpensive camera systems, which may have either remote or onsite data acquisition, processing, and analysis, and they have been widely implemented for tourism, surfing, weather conditions, … along all the world coastlines. Previous works in Australia (SPLINTER *et al*., 2011, MOLE *et al*., 2013, BRACS *et al*., 2016), in Portugal (ANDRIOLO *et al*., 2019), in the U.S. (CONLIN *et al*., 2020) have demonstrated the acceptable performance for coastal monitoring purposes. Recent works (VALENTINI *et al.*, 2020, VALENTINI & BALOUIN, 2020) have shown that resolution and quality improvement now allow quantitative studies of coastal morphologies, coastal hydrodynamics and real-time assessment of coastal responses during storm events.

In this study, available surfcam systems along the Occitanie coast are used to examine the regional variability in coastal response during winter storms and post-storm recovery, using a beach width indicator obtained through the analysis of public webcam images on events, seasonal, and multi-year time scales.

## 2. Field site and methods

The French coastline of the Occitanie (Figure 1) is a low-lying coastal plain composed of a succession of lagoons, salted marshes, inlet beaches and dunes. Urbanization was strongly developed along this coastline in the 60's, resulting, among other causes, in an increase of coastal vulnerability to extreme storms. Many storm impacts have been observed over recent decades: overwash and breaching of natural sand barriers, beach and dune erosion, as well as damage to coastal infrastructure and facilities. The maximum spring tide is limited to a 0.4 m range and wave energy is moderate with a mean significant wave height of 0.7 m. Storm waves have significant wave heights over 3 m and can reach 7 m (in 30 m water depth). The Hs annual return period is around 4.3 m. The wave climate is dominated by SE swell. Waves associated with storms do not exceed 3.5% of occurrences and arrive mainly from ESE (77%), while storms from the S are less frequent

(16%). Major storm events are often associated with coastal marine winds, which generate important storm surges that can exceed +0.85 m (ULLMANN, 2007).

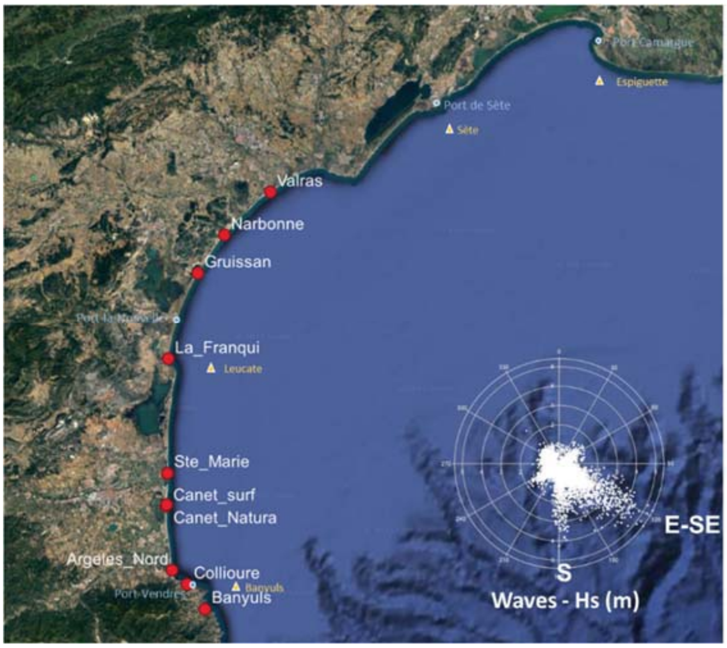


*Figure 1. Study area with the location of used webcam systems as well as hydrodynamic measurements (Candhis wave and Data-Shom water level monitoring networks).*

Along this coastline, several webcams have been installed in recent years, some of which offer high resolution and optimal positioning/views for beach monitoring purposes. In this study, we utilized images from 10 cameras (Figure 1) owned by the local collectivities, tourism offices, and operated by Viewsurf or Skaping companies, acquired during the period 2021-2023. This video data is processed using ®Matlab: Images are initially averaged and then georeferenced using ground control points, obtained through GPS surveys conducted on the beaches. They are then projected onto the Lambert 93 system. Subsequently, the shoreline is identified using an algorithmic method that detects pixel intensity and delineates the sand/water boundary. Video-derived estimations of shoreline position were used to compute weekly average beach widths (BW) for the mid-term analysis and daily BW for storm event analyses. The Shoreline detection strategy is based on individual pixel values to differentiate wet form dry pixels using the red and blue channels difference in a predefined Region of Interest (ROI). Validation of the shoreline position was carried out by confronting video-derived shorelines to GPS surveys on the beach, resulting in a mean RMS error under 2 m in the vicinity of the webcam system where beach width was analyzed. Morphology of the different sites was extracted from the available Lidar data (Figure 2): Litto3D data for the Northern sites (Valras, Narbonne, Gruissan and La Franqui), and the OBSCAT 2023 Lidar survey for the southern sites.

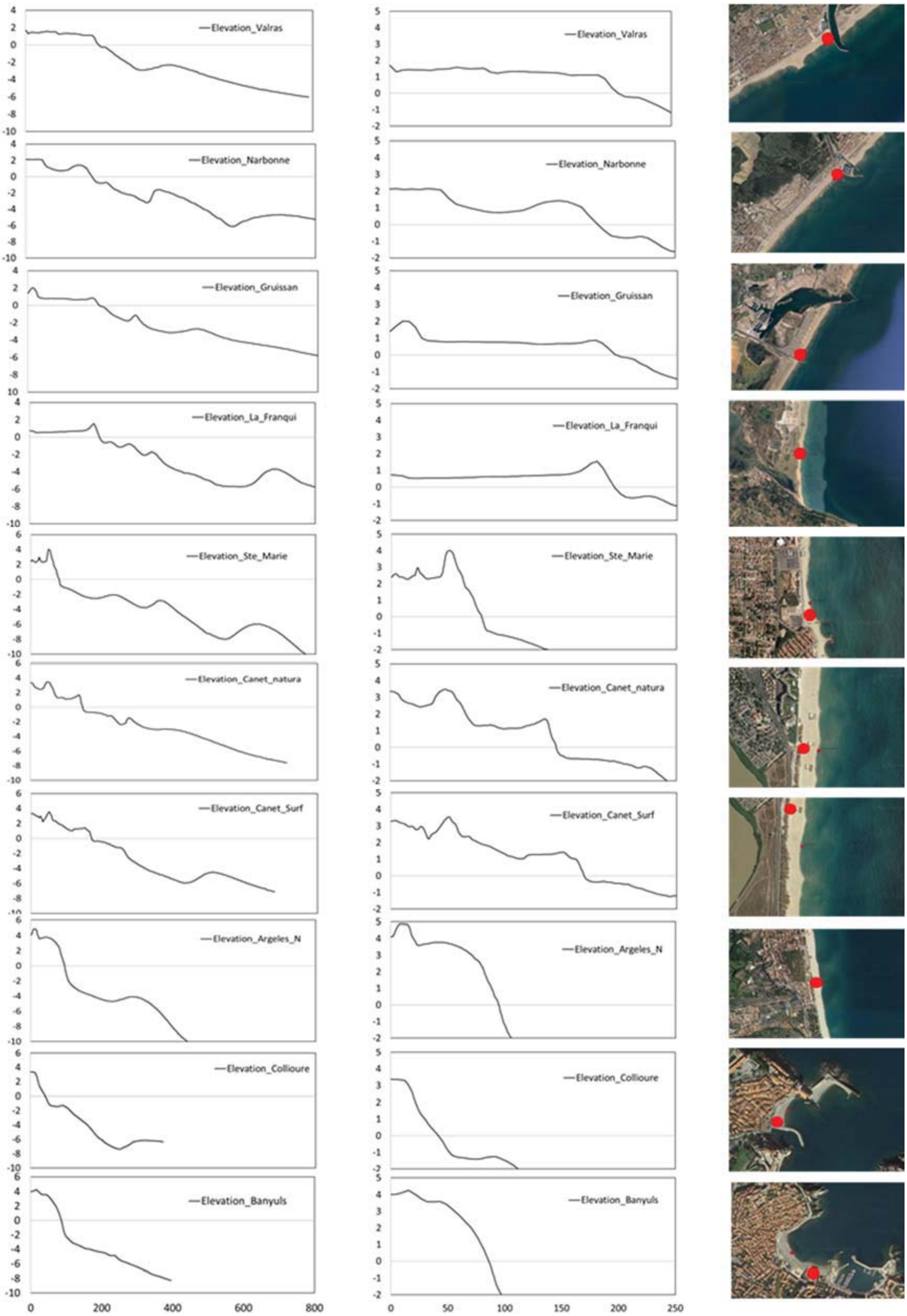


*Figure 2. Beach profiles of the studied sites (elevation NGF): entire profile (left), zoom on the aerial beach (middle) and 2023 Sentinel imagery (right).*

**3. Results**

3.1 Hydrodynamic condition during the studied period
Hydrodynamic conditions during the studied period (2021-2023) were relatively calm (see Figure 3). Significant wave height at Leucate Buoy remained very low (under 2 m) during the entire period, except during two storm events: Celia storm in March 2022 and a second event in February 2023. Both events were ESE oriented with Hs exceeding 5 m.

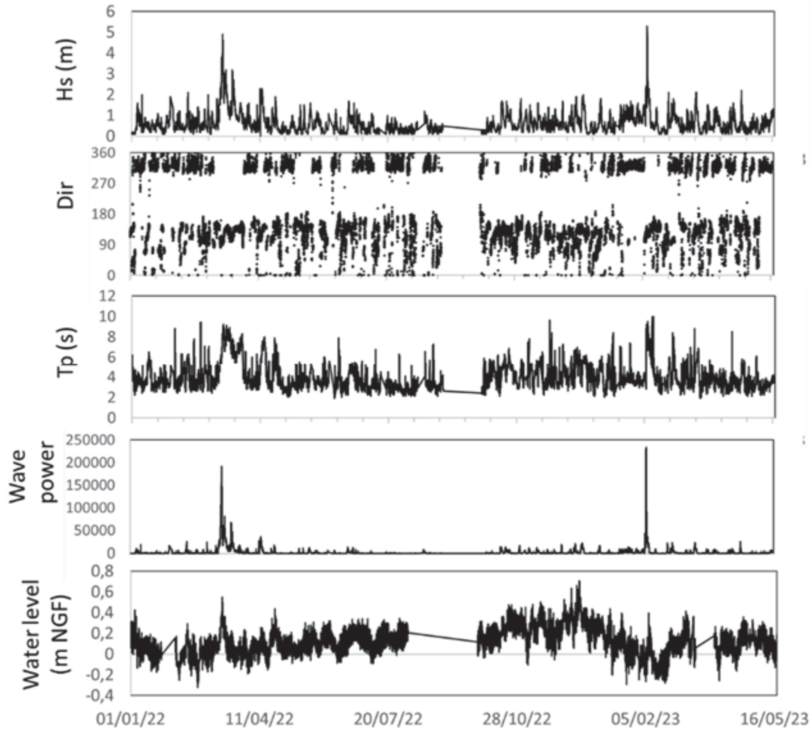


*Figure 3. Hydrodynamic conditions during the studied period. Waves at Leucate buoy (©CANDHIS) and water level at Port-La-Nouvelle (Data-Shom).*

3.2 Beach width seasonal evolution
Video derived shorelines allow to compute beach width at all sites from January 2022 to May 2023 (Figure 4). This dataset evidences different morphological behavior of the sites that have not been evidenced before:

- Very stable sites: Collioure, Banyuls, Argeles, Sainte-Marie where no seasonal variation is observed, and where BW is only decreasing during storms when the water level is increased;
- Sites where an increase in BW is observed during summer and a decrease during winter: Narbonne, La Franqui, Valras, Canet;
- A site with saw-like evolution: Gruissan where evolution seems to be mainly driven by storm events that generate strong shoreline retreat followed by a very long recovery period lasting to the successive event.

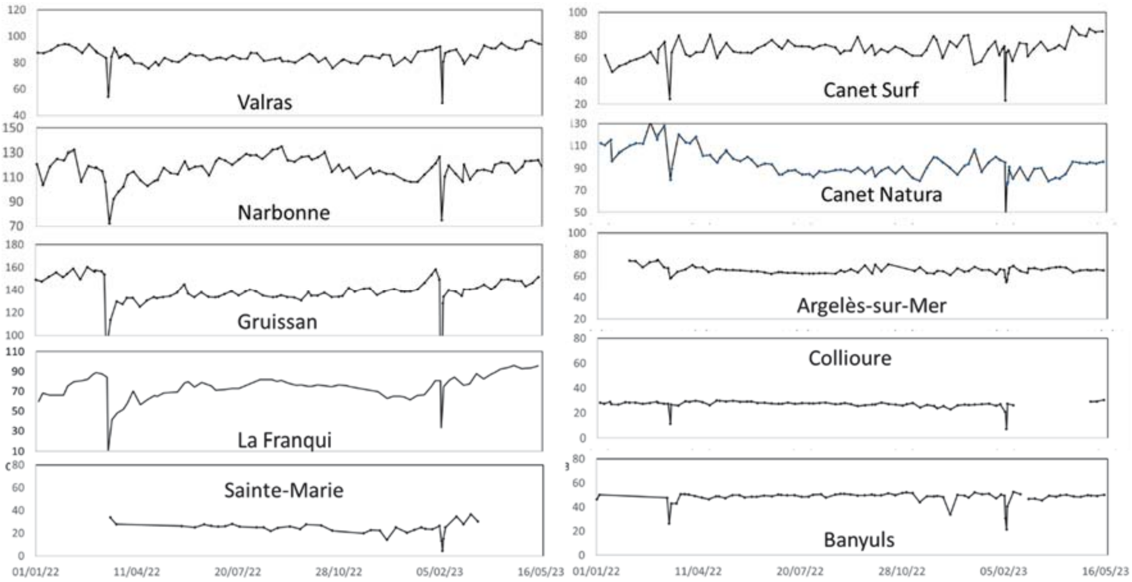


*Figure 4. Beach width seasonal evolution at the studied sites (in meter).*

3.3 Beach width variation during storm events

The video-derived shorelines during the events can provide different indicators (Figure 5): the maximum retreat is a proxy for beach inundation as the detected shoreline results mainly from the storm surge level rather than coastal erosion; the difference in BW just before/after that indicate the real shoreline retreat.

Results indicate that the behavior during the two studied events was similar in terms of global morphological responses. Pre/post-storm BW decrease was slightly stronger during Celia storm that was characterized by a higher water level (exceeding 0.6 m). The most important beach width decrease was observed at Gruissan and La Franqui sites with value of shoreline retreat exceeding 15 m, while other sites exhibited a moderate shoreline retreat (few meters). The recovery period was very rapid (from 1 to 3 days at almost all sites, excepted Gruissan and La Franqui where it took several months for the beach to recover its initial width. The recovery was much quicker for the 2023 event at Narbonne, Gruissan, La Franqui and Argelès.

At the peak of the events, the maximum beach inundation was also very different from site to site: Gruissan and La Franqui were widely inundated with a BW decrease exceeding 120 m at Gruissan and 70 m at La Franqui, corresponding to 85% of their total width. The northern sites (Valras and Narbonne) and the Roussillon sites (Sainte-Marie to Argelès) exhibited moderate beach inundation with a BW decrease around 40 m corresponding to 40 to 60% of their total width. Pocket beaches of the Cote Vermeille (Banyuls and Collioure) had a low BW decrease.

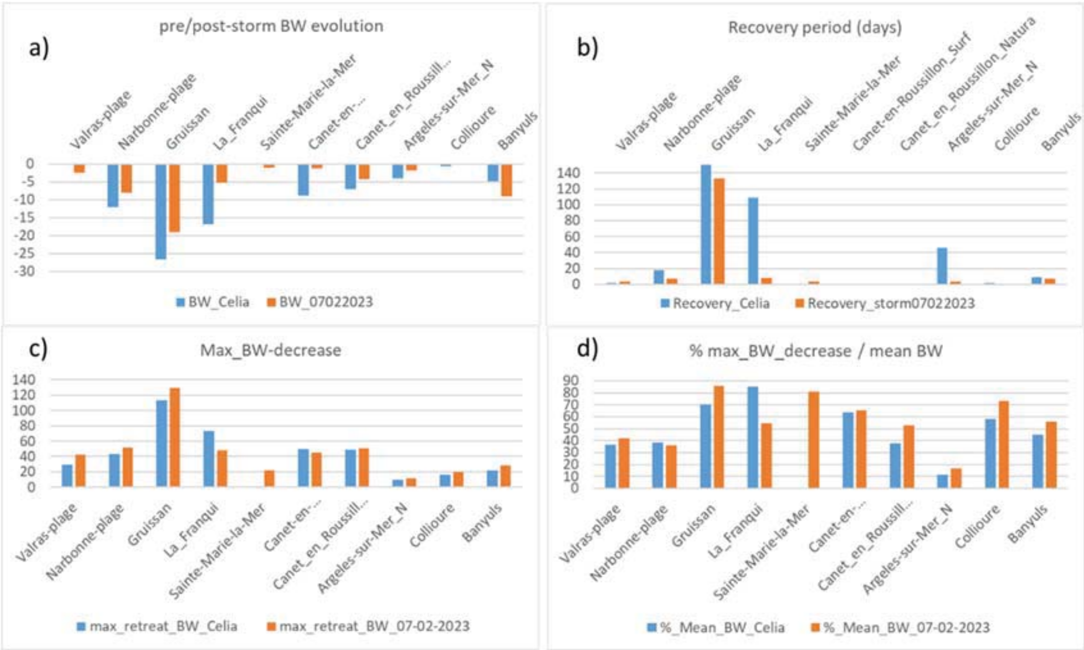


*Figure 5. BW evolution associated with the 2 storm events of March 2022 and Feb 2023. a) pre-post-storm BW variation (m); b) recovery period (days); c) max BW decrease (inundation) and d) percentage of inundated beach.*

## 4. Discussion and concluding remarks

4.1 The use of webcams for coastal monitoring

In this study, webcams with varying resolution, frequencies, acquisition processes were used to obtain shoreline positions at two different timescales: seasonal and event-based. Across all sites, the necessary indicators were obtained at a frequency of 2-3 shorelines per day during the storms and weekly for the mid-term analysis. This underscores the significant potential of such systems for coastal monitoring at timescale and resolution not achievable through other monitoring techniques (such as field survey or satellite imagery, etc.). Despite the ongoing requirement for a high level of expertise (including image extraction from the video, motion correction, and photogrammetry), these webcam systems offers a very low cost-effective solution for costal monitoring that is easier to maintain compared to dedicated systems with higher capabilities but also higher costs. The widespread deployment of coastal webcams provides access to regional monitoring networks (such as Webcat in the US, DUSEK *et al.*, 2019), complementing existing field monitoring programs of coastal observatories. Furthermore, the rapid advancement in imagery processing now enables the coastal community, managers, and civil security services to stay informed about real-time coastal erosion and inundation conditions.

4.2 Regional assessment using public webcams of the role of post-storm recovery in the seasonal variability of beach width.

Results have highlighted different behaviors among sites exposed to similar storm conditions. Coastal morphology emerges as a crucial factor in beach erosion and recovery dynamics. The most dissipative beaches, such as Narbonne, Gruissan and La Franqui experienced the most significant impacts. This is closely linked to their very large and low-lying beaches, which are prone to inundation during storm events compared to the reflective beaches in the South. Additionally, these beaches experienced notably higher frontal waves. However, exposure to storm waves and beach morphology alone cannot fully account for the longshore variability in shoreline responses to storms and their role in multi-year evolution. Longshore transport and its interaction with coastal structures play a significant role in beach recovery. For instance, although Gruissan and Narbonne share similar morphologies and exposure, Narbonne's recovery was notably quicker. Following the storm events, longshore wave energy remained elevated for several weeks, particularly after Celia, resulting in a south to north sediment transport. Narbonne, positioned at the northern end of its coastal cell, benefited from this transport, unlike Gruissan or La Franqui, located in the southern part of their respective coastal cells.

While the results suggest that storm events were adequately spaced to facilitate beach recovery and that response variability primarily stems from pre-storm morphology, a series of events in autumn 2023 raises concerns about this recovery capacity. This highlights the potential significant impact of singular events on medium- and long-term coastal evolution trends.

These preliminary observations necessitate further data collection under varying storm conditions to better understand and anticipate morphological events. Establishing a coastal monitoring network using webcams could greatly enhance our understanding and management of coastal areas.

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