The Impact of Medicane Surge on the Vertical Land Motion of South Sicily Coast, Italy

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ABSTRACT

Vertical land movement is a dynamic phenomenon along the Mediterranean coast, influenced by natural and anthropogenic factors. One natural factor affecting coastal stability is storm-induced wave inundation. Annual storms are common in the Mediterranean, particularly in autumn, and include the Medicane storms, characterized by significant wave heights and occurring nearly once a year. Sicily, Italy, is frequently impacted by both annual and Medicane storms. This study investigates the impact of Medicane storms on vertical land movement along Sicily's southern coast. Using Sentinel-1 images (2015–2021) and interferometric TOPSAR analysis with SNAP 8.0, this research compares medium-term vertical land movement (2015–2020), annual vertical motion (2020–2021), and vertical displacement before and after Medicane Zorbas (September 2018) and Medicane Apollo (October 2021). Results show that medium-term and annual vertical motion and post-Medicane Zorbas dynamics predominantly indicate uplift. However, after Medicane Apollo, significant subsidence (0.005 m to 0.058 m) was observed along the southern Sicilian coast. The findings highlight that storm-induced flooding from Medicane events influences coastal subsidence. Differences in vertical land motion dynamics between Medicane Zorbas and Medicane Apollo are attributed to their distinct storm paths. Medicane Apollo crossed Sicily, moving from North Africa to Europe, causing direct impact, while Medicane Zorbas turned towards the Ionian Sea, sparing Sicily from direct effects. This study highlights the critical role of storm paths in shaping coastal land dynamics and informs coastal management strategies in Mediterranean regions.

1. Introduction

1.1 Background

Numerous studies have been conducted to understand the impact of cyclones on tidal floods in coastal environments such as in the Bay of Bengal during Cyclone Bhola in 1970 (Hafsa et al., 2021), South Korea during Typhoon MAEMI in 2003 (Kim et al., 2020), the Gulf of Mexico during Hurricane Katrina in 2005 (Kalourazi et al., 2020), the United States during Hurricane Sandy in 2012 (Sweet et al., 2013), the Philippines after Typhoon Haiyan in 2013 (Lagmay et al., 2015), East Nusa Tenggara during Tropical Cyclone Frances in 2017 (Astiduari et al., 2018), and southeast Sicily during Mediterranean Hurricane (Medicane) Zorbas in 2018 (Scicchitano et al., 2020). Most recently, Scicchitano et al. (2021) compared the impact of Medicane Zorbas with common storms, especially along the southeastern Sicilian coast, emphasizing the extent of inundation, height, and duration of tidal waves flooding the coast. Another study conducted by Tsimplis et al. (2009) estimated the return period of extreme sea levels in the Aegean and Ionian Seas based on the analysis of tide-gauge data. The combination of tidal height and storm surge causes an increase in the water column, exacerbating storm surge inundation along the coast. Storm surges are influenced by meteorological variations, in contrast to tidal oscillations, which are deterministic. However, neither study examined the correlation between storm surges and vertical land movement, leaving a critical research gap that warrants further investigation.

Over the past century, global climate change has significantly amplified the intensity of coastal flooding in the Mediterranean region, primarily due to the increasing frequency and severity of tropical-like cyclones known as Medicanes (Satta et al., 2017). These cyclones are characterized by a circular convective cloud formation surrounding a clear storm eye, with the associated cloud cluster typically measuring about 30 km in diameter (Ragone et al., 2018). While the frequency of Medicanes has decreased in the last two decades, their intensity has notably increased (Cavicchia et al., 2014). Key Medicane events include Zeo (2005), Qendresa (2014), the series of storms between 2015 and 2017, Zorbas (2018), Trudy (2019), Ianos (2020), and Apollo (2021) (Borzì et al., 2024). In addition to these intense events, the Mediterranean is also regularly impacted by annual storm surges, which, although of lower intensity, occur more frequently—typically three to four times per year (Scicchitano et al., 2021). Low-lying coastal areas, such as those in southern Sicily, are particularly vulnerable to these phenomena, which have both direct and indirect negative consequences. Direct impacts include coastal erosion, tidal flooding, and infrastructure damage, while indirect effects encompass seawater intrusion, land subsidence, and damage to vegetation. The tidal surge that occurred during Medicane Zorbas in September 2018 reached maximum values between 0.8 m and 1.2 m above sea level along the southeast coast of Sicily (Borzì et al., 2024). The propagation of Medicane tidal waves is more extensive than that of annual extreme tidal storm surges (Menna et al., 2023). However, no studies have yet revealed the impact of extreme tidal storms on land stability.

1.2 Research Objectives

The presence of critical infrastructure in the southern coastal zone of Sicily, including commercial and cargo ports, oil and gas refineries, fishing harbors, renewable energy production facilities (such as solar panels and wind power plants), tourist destinations, conservation areas, and cultural heritage sites, highlights the need to study the impacts of extreme tidal storms on vertical land movement in the region. Therefore, this study aims to assess the effects of Medicanes on vertical land movement in southern Sicily using Sentinel-1 image analysis. The research not only contributes to monitoring land stability in the region but also offers a model for evaluating land stability in other coastal areas, particularly those vulnerable to extreme storm surges. This information is essential for stakeholders in developing sustainable coastal management policies.

2. Material and Methods

2.1 Study Area

The study area is located along the southern coast of Sicily, Italy, spanning approximately 150 km from Agrigento on the western edge to Santa Maria del Focallo in the easternmost section (Figure 1). The research site lies in the transitional zone between the Gela Nappe and the Hyblean Foreland, which form part of the thrust and fold belt in the Central Mediterranean region, known as the Sicilian orogenic system (Argnani, 1989). The Sicilian orogenic system developed in response to the collision between the African plate's frontal margin and the deeper units of the European province, which occurred during the Neogene to Pleistocene. The frontal segment of this orogenic belt is represented by the Gela Nappe, which is widely exposed along the Catania-Gela route and in the offshore sector (Butler et al., 1992; Ghisetti et al., 2009). Parts of the Gela Nappe are overlain by substantial volumes of sediments filling the Gela Foredeep, a Plio-Pleistocene foredeep extending from the Hyblean Foreland onshore to the southern and southwestern offshore areas of Sicily. The subsiding areas within the Gela Foredeep are weakly deformed, while the gently northwest-dipping (NW) foreland experiences both compressional and extensional deformation (Grasso et al., 1995).

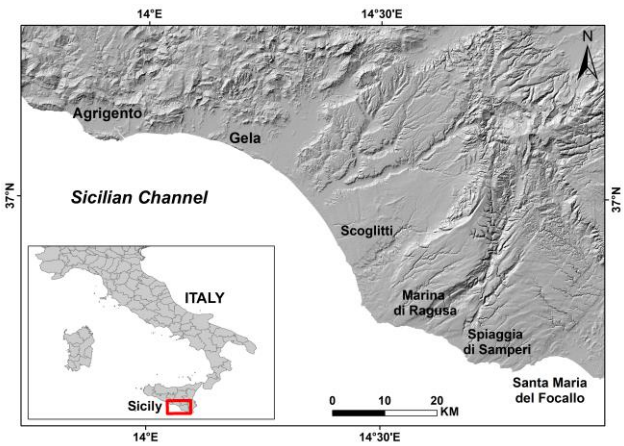

Figure 1. The study site is situated on the southern coast of Sicily, Italy, extending approximately 150 km from Agrigento in the westernmost to Santa Maria del Focallo in the easternmost.

The Hyblean Foreland, a component of the Pelagian Block, is exposed onshore in southeastern Sicily and extends offshore toward the Sicilian Channel. The Pelagian-Hyblean foreland-basement wedge originated in the Permian period. During the Plio-Pleistocene, this crust underwent a slight counterclockwise rotation. Along its eastern margin, the Hyblean Foreland is bounded by the Ionian crust, which is interpreted as a remnant of a Jurassic or older passive continental margin (Foti et al., 2023). The Pelagian Block represents a segment of the African continental margin, trending east-west (E-W), and flexing northward beneath the orogenic belt. The Hyblean-Maltese Escarpment is a prominent north-south (N-S) trending fault zone that separates the Pelagian Block to the west from the Ionian Basin to the east (Figure 2A) (Tondi et al., 2006). This system of normal faults was active during the Pliocene and Quaternary periods, playing a critical role in the seismotectonic evolution of the region. The main foreland flexure is located to the north of the orogenic system, where a broad axial depression, referred to as the Caltanissetta Basin, is identified within the chain units (Maniscalco et al., 2010).

Along the northern and central Tyrrhenian coast (southern Tuscany, northern and southern Latium, Campania, Sardinia), tectonic movements since the Last Interglacial appear to be minimal, and the region is assumed to be largely unaffected by vertical tectonic displacement (Figure 2B) (Lambeck et al., 2004). In southern Italy, the MIS 5.5 highstand reaches some of the highest elevations in the Mediterranean: 175 m in Sicily and 162 m in Calabria. In contrast, along the Adriatic coast, particularly in the central and northern regions, significant tectonic subsidence has occurred, as coastal features associated with the MIS 5.5 stage are found only in cores at depths of approximately 100 m to 120 m below present sea level. The estimate of vertical tectonic movement and its associated uncertainty is based on a nominal age of 12,475 ka, with an elevation of 773 m above present sea level in the absence of tectonic influence. This elevation is higher than global estimates for this level, as the sites in Italy are located relatively close to the former ice margins. The present MIS 5 shorelines in the Mediterranean may lie several meters higher compared to locations farther from the former ice margins. Sardinia has remained tectonically stable during recent glacial cycles, with the MIS 5.5 shoreline typically found at elevations of 7–10.5 m in the east, approximately 4 m in the northwest, and around 5 m in the south (Cala Mosca) (Antonioli et al., 2017).

Gela Gulf is characterized by a microtidal regime, with an average water level fluctuation of 0.04 m recorded between 2010 and 2019. Extreme storm surges predominantly originate from the west-southwest direction, with a significant wave height (H_s) of 8 m and a wave period (T) of 11 s, while smaller storm events primarily come from the southeast, with H_s = 5.5 m and T =10.5 s (Scicchitano et al., 2021). The Atlantic Ionian Stream (AIS) drives surface circulation in the Sicilian Channel. Modified Atlantic Water (MAW) flows through the Gibraltar Strait into the Sicilian Channel. Within the Sicilian Channel, the AIS forms a large cyclonic meander that encircles the Adventure Bank before approaching the southern coast of Sicily (Robinson et al., 1999). The AIS then detaches from the coast over the Maltese continental shelf, generating two cyclonic eddies off Cape Passero. Gela Gulf is influenced by the AIS and the presence of both cyclonic and anticyclonic structures, as baroclinic waves become trapped by the seabed morphology. Residual currents are stronger over the two continental shelves but weaken off Gela Bay, with speeds of approximately 0.3 m/s (Menna et al., 2023). The coastal strip between the mouth of the Acte-Dirillo River and Cape Punta Braccetto is primarily influenced by waves and storms from the west. Additionally, a littoral current flows southeastward, further affecting the coastal dynamics (Dobricic et al., 2010).

The Mediterranean climate is shaped by the interplay between air masses and orographic features. This interaction results in dry summers characterized by southerly regional winds, followed by winter rainfall events and cold, strong northerly regional winds (Deitch et al., 2017). The combination of atmospheric pressure gradients and wind forces generates baroclinic instabilities, which govern the frequent occurrence of seasonal storms. These storms are marked by temporary sea level rises due to the inverse barometric effect and wind-driven horizontal displacement of the water column, often leading to associated coastal flooding (Amarouche et al., 2022). Occasionally, seasonal storms can reach extreme values in terms of storm surges and wave heights, causing widespread coastal inundation, as exemplified by the storm event of 28 October 2018 in the northern Adriatic Sea. During this event, significant wave heights reached 6 m along the Venetian Coast, while areas near Rovinj on the Istrian coastline in Croatia recorded wave heights of up to 4.7 m (Borzì et al., 2024).

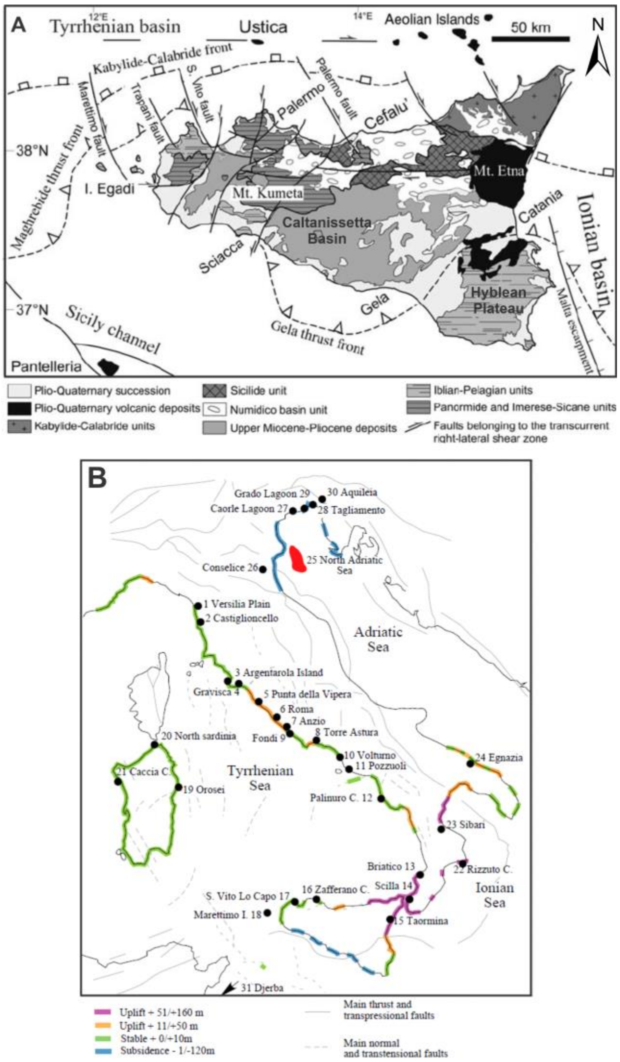

Figure 2. A. Tectonic setting and geological structure map of Sicily (Tondi et al., 2006). B. The distribution of changes in land surface elevation relative to mean sea level in Italy throughout the Holocene (Lambeck et al., 2004).

Medicanes are generated through convection and air-sea interactions, rather than the baroclinic instabilities that drive seasonal storms, and exhibit characteristics similar to tropical cyclones. Although these events form significant wave heights comparable to seasonal storms, Medicanes induce more extensive coastal flooding (Emanuel, 2005). In southeastern Sicily, Medicane Zorbas, which occurred in September 2018, caused significant coastal inundation and transported boulders across rocky platforms (Scicchitano et al., 2020). Furthermore, recorded sea level and wave height data near Catania reveal that Medicanes display hydrodynamic features comparable to typical storms, despite field evidence often indicating more severe flooding associated with these phenomena (Scicchitano et al., 2021).

2.2 Data Collection and Processing

The eight Sentinel-1 images from 8 December 2015, 23 September 2018, 29 September 2018, 4 January 2020, 29 December 2020, 22 January 2021, 19 October 2021, and 31 October 2021, were downloaded from the ESA Copernicus (European Space Agency, 2024a). These images are of the Ground Range Detected (GRD) product type, with Interferometric Wide Swath (IW) sensor mode and Vertical Transmit, Vertical Receive (VV) and Vertical Transmit, Horizontal Receive (VH) polarization. The selection of the Sentinel-1 image dates is based on the occurrence of Medicanes that have affected the Mediterranean region, including Sicily, such as Medicane Zorbas, Ianos, and Apollo. It aims to compare them with short- to medium-term vertical ground displacement patterns. Each of these Sentinel-1 images was imported into the Sentinel Application Platform (SNAP) software developed by the European Space Agency (ESA) (European Space Agency, 2024b).

The research area was initially delineated using the rectangle drawing tool during the subset step to extract a portion of the image data from the larger overall area. Following this, the coregistration process, including Apply Orbit File, Back-geocoding, and Enhanced Spectral Diversity, was performed before interferogram formation. The next step was Deburst, which aims to merge bursts and eliminate discontinuities, followed by Topographic Phase Removal, Multilooking to reduce speckle noise, and Phase Unwrapping after exporting the data by selecting Deformation (DEFO) as the input statistical cost mode and Minimum Cost Flow as the input initial method. This was followed by Snaphu import, Phase to Displacement Conversion, and Geocoding, which included creating a stack and applying range-doppler terrain correction, Land-Sea Mask, and Masking-Band Maths. The process was completed by analyzing data and exporting the results to ArcGIS 10.8.2 (Figure 3).

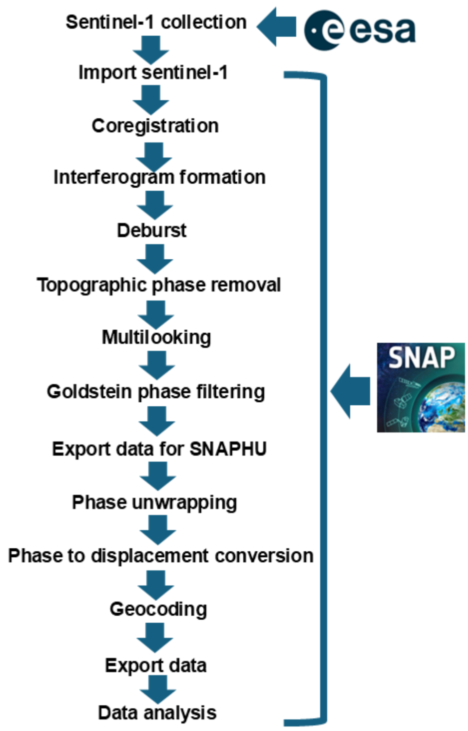

Figure 3. Flowchart of vertical land displacement analysis on Sentinel-1 images using SNAP software developed by ESA.

3. Results and Discussion

3.1 Vertical Land Motion Pre- and Post-Medicane Apollo

The map of vertical land motion distribution is categorized into two value classifications. Positive values represent uplift, while negative values indicate subsidence. Based on the analysis of Sentinel-1 images acquired before and after Medicane Apollo on 19 October 2021, and 31 October 2021, at five primary observation sites, Gela, Scoglitti, Marina di Ragusa, Spiaggia di Samperi, and Santa Maria del Focallo, the coastal region exhibits a general pattern of vertical land motion showing subsidence ranging from 0.005 m to 0.04 m (Figure 4). In the Gela coastal area, the land surface experienced a decrease of approximately 0.03 to 0.04 m, whereas in Agrigento, the subsidence was even more significant, reaching approximately 0.06 m. At Marina di Ragusa, Spiaggia di Samperi, and Santa Maria del Focallo, land subsidence between 0.005 m and 0.03 m was detected. The subsidence pattern exhibits an increasing trend from east to west.

The analysis of vertical land motion suggests that prior to and after Medicane Apollo, subsidence occurred with a westward increasing pattern. The storm pathway of Medicane Apollo originated from Tunisia and moved northward toward Sicily through the Sicilian Channel and Malta between 26 and 29 October 2021. By 30 October 2021, the storm continued its movement toward the Ionian Sea, and by 31 October 2021, it approached the northern coast of Egypt. According to Borzì et al. (2022), the impact of Medicane Apollo resulted in extreme storm surges, flooding Sicily's southern and eastern coasts. The highest recorded wind speed reached 104 km/hour on 29 October 2021, with rainfall exceeding 200 mm in Syracuse. A total of ten fatalities occurred due to the storm, affecting regions across Algeria, Tunisia, Sicily, Malta, and Egypt.

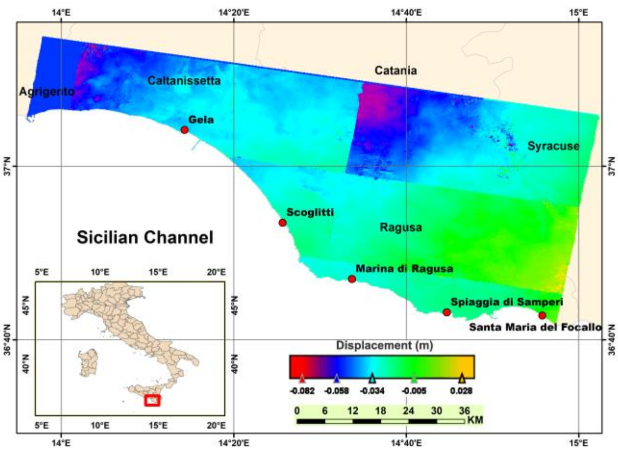

Figure 4. The map of vertical land motion distribution along the southern coast of Sicily shows a phenomenon of subsidence between the periods before and after Medicane Apollo in 2021.

3.2 Vertical Land Motion in 2020-2021

The analysis of Sentinel-1 images over one year between 4 January 2020 and 22 January 2021, reveals a different pattern compared to the vertical land motion before and after Medicane Apollo, although, during this period, the Ianos storm occurred from 17 to 21 September 2020 along with the annual storm surges that typically happen three to four times a year. Unlike Medicane Apollo, which passed through Sicily from Tunisia before heading toward the eastern Mediterranean, the pathway of Medicane Ianos did not pass through Sicily but rather traversed the Ionian Sea from Libya before moving toward the eastern Mediterranean along the western coast of Greece, the Aegean Sea, and finally ending near Egypt (Borzì et al., 2024). This difference in pathways also influenced variations in rainfall, wind gusts, and violent sea waves in the affected areas (Cama et al., 2015). No reports of tidal flooding caused by this storm were recorded along the eastern or southern coast of Sicily. However, Medicane Ianos caused damage to property and public facilities in Greece. This rare storm passed through Greece, with its center crossing Thessaly, impacting areas around the cities of Karditsa and Farsala. The storm also moved toward Crete, losing intensity as it headed southeast. It brought winds of up to 120 km/hour, heavy rainfall, and floods that led to three fatalities in Greece and inundated at least 5,000 homes in Karditsa (Androulidakis et al., 2023). The storm induced a seven-fold increase in surface currents and a sea-level rise of 25 cm, which increased to 30 cm near the shore. The maximum significant wave height during Medicane Ianos was 6.5 m (Varlas et al., 2023).

Based on Figure 5, the pattern of vertical land motion along the southern coast of Sicily generally shows an uplift. Uplift ranging from 0.018 m to 0.11 m occurred in Agrigento and Caltanissetta. In Gela, Scoglitti, Marina di Ragusa, Spiaggia di Samperi, and Santa Maria del Focallo, uplift was detected between 0.018 m and 0.061 m. Subsidence was only observed around the Caltanissetta Basin, which is far from the coastal area. Subsidence in the Caltanissetta Basin was also detected in the vertical land motion map during Medicane Apollo in 2021. This phenomenon is attributed to sediment filling in the basin originating from Mt. Kumeta, Panormide and Imerese-Sicane Units, and Mt. Etna (Foti et al., 2023). Although the annual storm surge caused flooding along the southern coast of Sicily, its impacts were not as severe as those of Medicane Apollo. The estimated sea-level rise from the annual storm surge was no more than one meter and mainly resulted in increased coastal erosion, though the extent of the flooding was limited (Scicchitano et al., 2021).

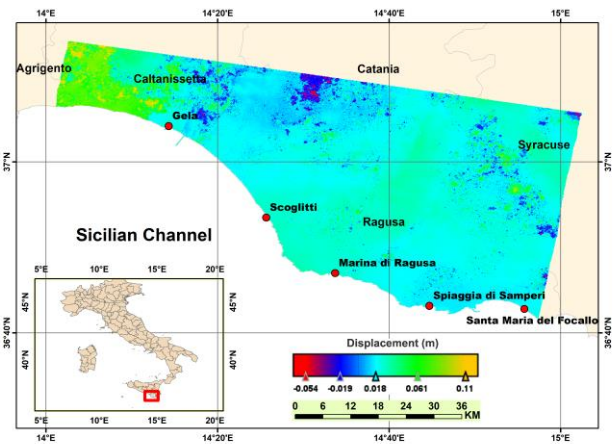

Figure 5. The map of vertical land motion in southern Sicily from 2020 to 2021 indicates a predominant pattern of uplift during this period, despite the annual storm surges that also inundated the southern coast of Sicily.

3.3 Vertical Land Motion Pre- and Post-Medicane Zorbas

The vertical land motion before and after Medicane Zorbas was dominated by uplift, with an increasing pattern towards the east. Uplift in Agrigento and Catania was around 0.07 m, in Gela, Scoglitti, and Marina di Ragusa approximately 0.04 m, and in Spiaggia di Samperi and Santa Maria del Focallo around ±0.01 m (Figure 5). On 27 September 2018, a low-pressure system formed over the Gulf of Sidra in the central-southern Mediterranean Sea (Portmann et al., 2020). This system then moved towards the southern Ionian Sea and southern Greece on 28-29 September 2018. Just before reaching the Greek coastline on 30 September 2018, Medicane Zorbas weakened and briefly lost its cyclonic eye formation. This Medicane impacted an area with a radius of over 400 km, generating winds of over 72 km/hour, waves exceeding 5 m, and storms that caused flooding along the southwest coast of Greece (Jangir et al., 2023). The central pressure reached 990 hPa, accompanied by heavy rainfall exceeding 100 mm in several parts of Greece, causing flooding and damage to infrastructure (Portmann et al., 2020). The peak intensity of this medicane occurred 12 hours after cyclogenesis. In the ancient Greek mines, Medicane Zorbas caused the shifting of large rocks (Scicchitano et al., 2021). Although this storm caused significant damage along the Greek coastline, there were no reports of flooding in southern Sicily during Medicane Zorbas, as had been observed with Medicane Apollo in 2021. While there were no reports of storm surge flooding due to Medicane Zorbas, rainfall during the storm was significantly higher. The pattern of vertical land motion showed a difference around the Hyblean Plateau, where during the 2020-2021 period, uplift of around 0.018 m occurred, whereas pre- and post-Medicane Zorbas indicated subsidence ranging from 0.013 m to 0.036 m (Figure 5).

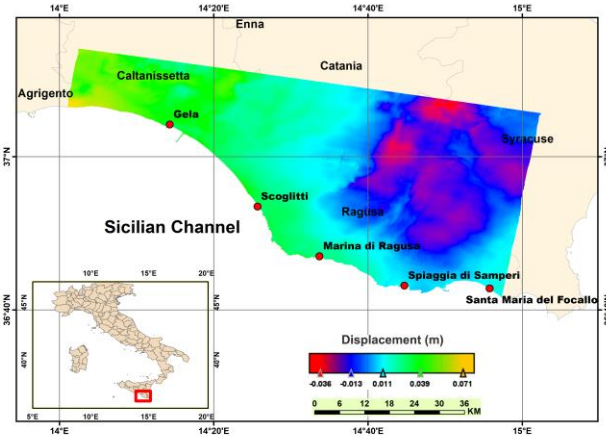

Figure 5. The map of vertical land motion distribution on the southern coast of Sicily before and after Medicane Zorbas in 2018 shows a tendency towards uplift, with values varying between 0.01 m and 0.07 m.

3.4 Vertical Land Motion in 2015 to 2020

The analysis of vertical land motion over the medium term between 2015 and 2020 shows a pattern predominantly dominated by uplift, especially around Scoglitti and Agrigento, with values ranging from approximately 0.08 m to 0.168 m. In contrast, the uplift at Caltanissetta and Gela is the lowest, around 0.01 m, while in Marina di Ragusa and Spiaggia di Samperi, it ranges between 0.08 m and 0.16 m (Figure 6). Despite several recorded Medicanes during this period, such as Medicane Trixie in 2016, Numa in 2016, Zorbas in 2018, Ianos in 2020, and Apollo in 2021, as well as annual storm surges, the vertical land motion still shows positive values or uplift, even reaching 0.168 m in Agrigento and Scoglitti. This medium-term pattern is quite similar to the post-Medicane Zorbas, and annual patterns observed during 2020-2021.

According to Scicchitano et al. (2021), in Catania, Sicily, a water column increases of 0.25 ± 0.01 m occurred during the annual storm between February 10-12, 2015, and 0.49 m ± 0.01 m in Portopalo di Capo Passero between October 28-30, 2016. Other events include 0.175 m ± 0.01 m in Catania between December 21-25, 2017, 0.65 m ± 0.01 m in Portopalo di Capo Passero between September 27-28, 2018, 0.98 m ± 0.01 m in Portopalo di Capo Passero after Medicane Trudy in 2019, and 0.46 m ± 0.01 m in Malta after Medicane Ianos. The combined effects of high tides and storms determine the increase in the water column, which amplifies storm surge intrusion across the coastal landscape (Mariotti et al., 2010). As the southern coast of Sicily is characterized by micro tidal amplitudes, storms are likely a significant component contributing to the increase in the water column (Scicchitano et al., 2021). Medicanes generate stronger effects, particularly in terms of coastal flooding, compared to regular seasonal storms. This difference is attributed to the higher rise in the water column along the coast caused by Medicanes (Honeycutt et al., 2001). Other factors, such as relative sea-level rise, sediment balance changes, coastal line movement, and anthropogenic influences around the coast, can further amplify the effects of the Medicane (Ferrarin et al., 2013).

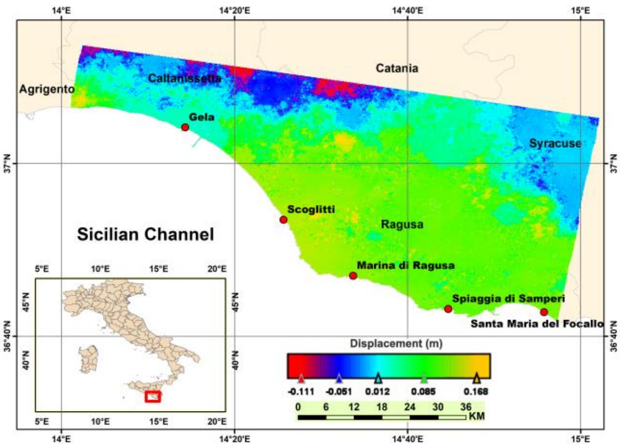

Figure 6. The distribution of vertical land motion in southern Sicily between 2015 and 2020 shows an uplift ranging from 0.01 m to 0.168 m.

Meteorological phenomena such as storms, accompanied by subsidence, can be linked because storms lead to an increase in the water column near the coast, which can result in flooding in coastal areas (Chaumillon et al., 2017). This inundation exerts additional pressure on the surrounding land, which is typically composed of unconsolidated alluvial or beach sediments, as seen in the case study of the southern coast of Sicily (Butler et al., 1992). The presence of flooding in the coastal environment also triggers an increase in soil saturation, particularly in soil layers with large pore spaces. As a result, the soil becomes waterlogged and more susceptible to compaction. This natural compaction process can be accelerated by the weight of the water during flooding (Cahoon, 2006). Strong currents caused by storm surges also contribute to soil erosion, weakening the underlying soil structure and triggering subsidence (Amores et al., 2020). Additionally, seawater intrusion during storm surges accelerates the dissolution of minerals in the soil, further contributing to soil compaction and subsidence (Wong et al., 2015).

Although during the Holocene, Lambeck et al. (2004) mentioned that the southern coast of Sicily experienced

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subsidence, analysis of vertical land motion distribution between 2015-2020 shows the opposite phenomenon, namely uplift. The southeastward rollback of the Ionian slab is the primary factor driving uplift in southern Sicily (Ferranti et al., 2021). This rollback generates a compressive tectonic regime that affects the entire region. In the foreland of the Hyblean Plateau, the uplift rate increases gradually from south to north, influenced by the activity of an active offshore normal fault dipping to the east (Bonforte et al., 2015).

The radar interferometry method from the Sentinel-1 missions for detecting vertical land displacement has proven reliable. Tretyak and Kukhtar (2023) validated the radar interferometry results by comparing vertical displacement values recorded by GNSS. The differences in vertical displacements obtained from the GNSS time series and differential interferograms did not exceed 1 cm and provided highly accurate, nearly identical results. Differences of less than 1 cm can be considered a reasonable measurement inaccuracy due to the limitations in radar acquisition and GNSS data collection. The vertical position changes of the Earth's surface measured using radar interferometry techniques can be calculated with extremely high precision, up to the millimeter level.

4. Conclusions

The storm surge caused by Medicane Apollo led to subsidence along the coast. In contrast, the impact of Medicane Zorbas on the southern coast of Sicily did not cause subsidence because the rise in the water column did not flood the coastal zone. The storm pathway of Medicane Zorbas did not directly pass through Sicily; instead, it traveled through the Ionian Sea, to the east of Sicily, before moving towards Greece, where it had a significantly affected coastal area. This contrasts with the storm pathway of Medicane Apollo, which traveled toward Sicily from Tunisia before turning eastward toward Greece and Egypt. The vertical land motion pattern on the southern coast of Sicily tends to show uplift, which is controlled by the southeastward rollback of the Ionian slab and the activity of active normal faults in the foreland of the Hyblean Plateau. The correlation between the meteorological phenomenon of storm surge and subsidence lies in the flooding, which increases the pressure on the ground along the coast, which is dominated by unconsolidated sediments. The increased soil saturation also makes the surface layer more susceptible to compaction, eventually leading to subsidence.

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