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THE LOCAL MEAN SEA LEVEL: A MAJOR RESEARCH CHALLENGE

XI Hotine Marussi Symposium – 7th-11th September 2026

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THE SEA SURFACE

The sea surface can be seen as the interface between the oceans and the atmosphere.

At rest, it is theoretically coincident with an equipotential surface.

It is crucial to have such a point of view, since the major difficulties in looking for such surface at rest arise from the interaction of the oceans with the atmospheric phenomena (plus the steric effect)

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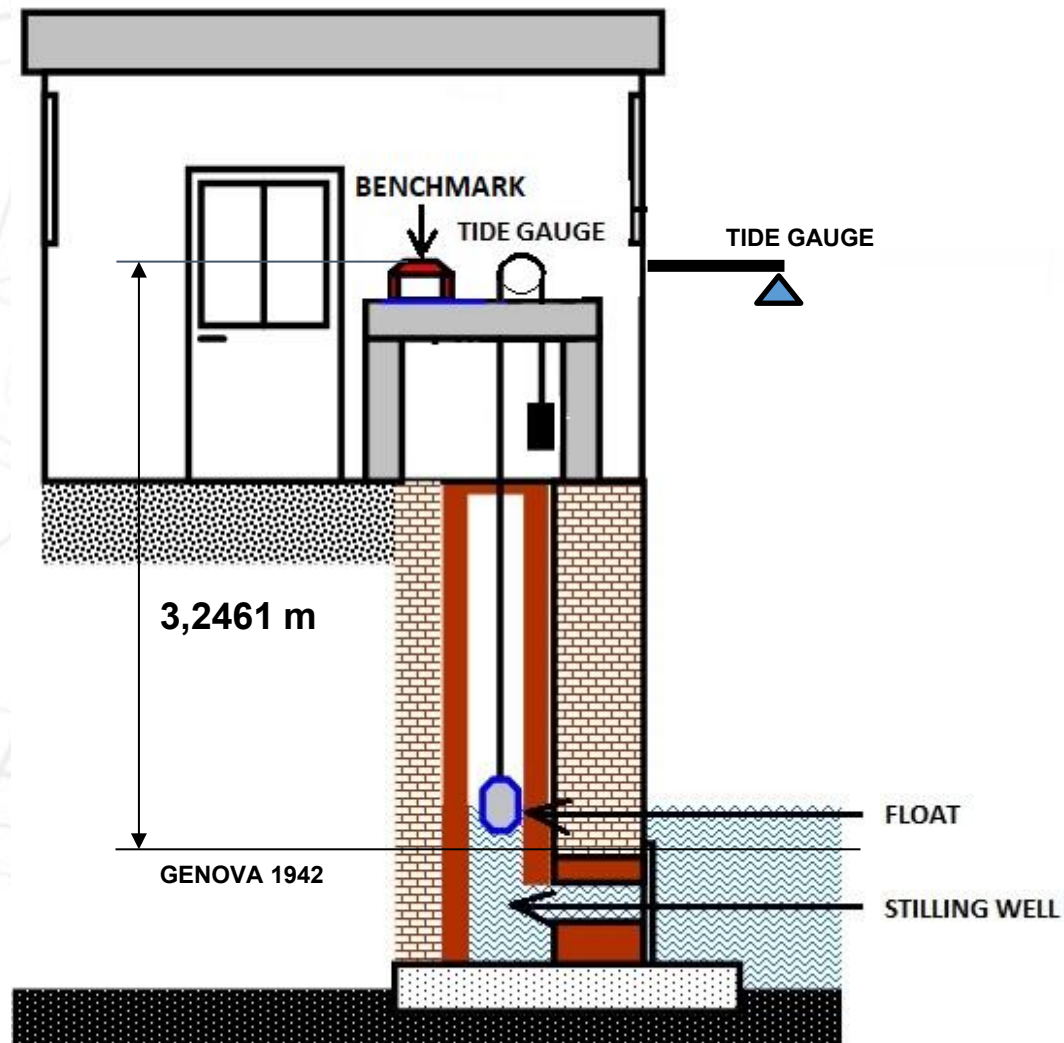
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THE SEA LEVEL

- The sea level is the distance of a given point on the sea surface from a reference level (benchmark).
- Measured with: tide gauges and satellite.
- Reference: Genova 1942.



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THE IHI TIDE GAUGES NETWORKS

The Italian Hydrographic Institute holds a network of five tide gauges:

- Genova
- Brindisi
- La Maddalena
- Gioia Tauro
- Augusta



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GENOVA TIDE GAUGE

Tide gauges

- Float (digital): since 2001
- Radar (digital): since March 2010
- Tide gauge Thomson (paper strip), stopped in 2011, but still «in situ»

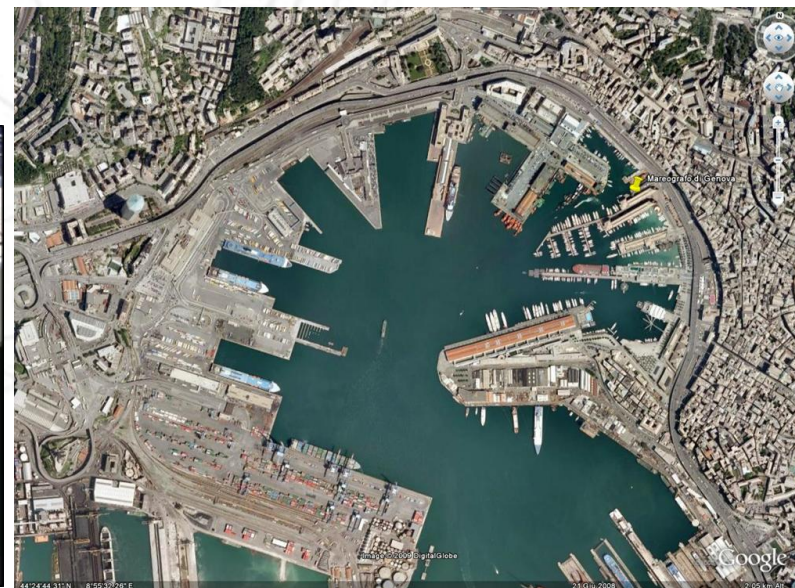
Current sampling interval

- Level: 1'
- Pressure: 5'

Location: Ponte Morosini - Marina Porto Antico

First tide gauge installed: 1883

Orthometric elevation: benchmark of the IGM State Altimetric Network through High-precision Geometric Leveling



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PHENOMENA AFFECTING THE SEA LEVEL:

PERIODIC

- **Astronomical tide:** from the Sun and the Moon.
- **Meteotsunamis**
- **Harbour and basin seiches**

HOW TO GET RID OF

Mean, filters, quadratic fitting

NON-PERIODIC

- **Atmospheric phenomena (wind, pressure):**
 - Inverse Barometer effect
 - Storm surges
- **Steric effect:** changing in volume of the sea water -> density $\sigma_{\text{seawater}}(T, S, P)$

HOW TO GET RID OF ?

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ATMOSPHERIC PHENOMENA

Inverse Barometer effect

The Inverse Barometer (IB) effect refers to the rise and fall of the sea surface in response to variations in atmospheric pressure.

$$h = - \frac{(P_{ref} - P)}{\rho g}$$

ρ : density of sea water, g : gravitational acceleration

The sea level raises if the pressure is below P_{ref} and falls if it is higher, so the ratio should be:

1 hPa : 1 cm

P_{ref} should be 1013.25 hPa (ISA)

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ATMOSPHERIC PHENOMENA

Inverse Barometer effect

To fulfill the conservation of mass of sea water:

BASIN SHAPE	RATIO	P_{ref}	FLOW OF SEA WATER
OPEN OCEAN	1:1	1013.25 (ISA)	FREE TO FLOW
CLOSED	N.A.	N.A.	NO WAY TO GO
SEMI-ENCLOSED	Variable	MEAN OF P	FLOW CONDITIONED

Since the Mediterranean is a semi-enclosed sea, mass conservation requires P_{ref} to be defined as the mean atmospheric pressure averaged over both the specific area and the time period considered and the hPa/cm ratio varies depending on the flow velocity, primarily through the Straits of Sicily and Gibraltar

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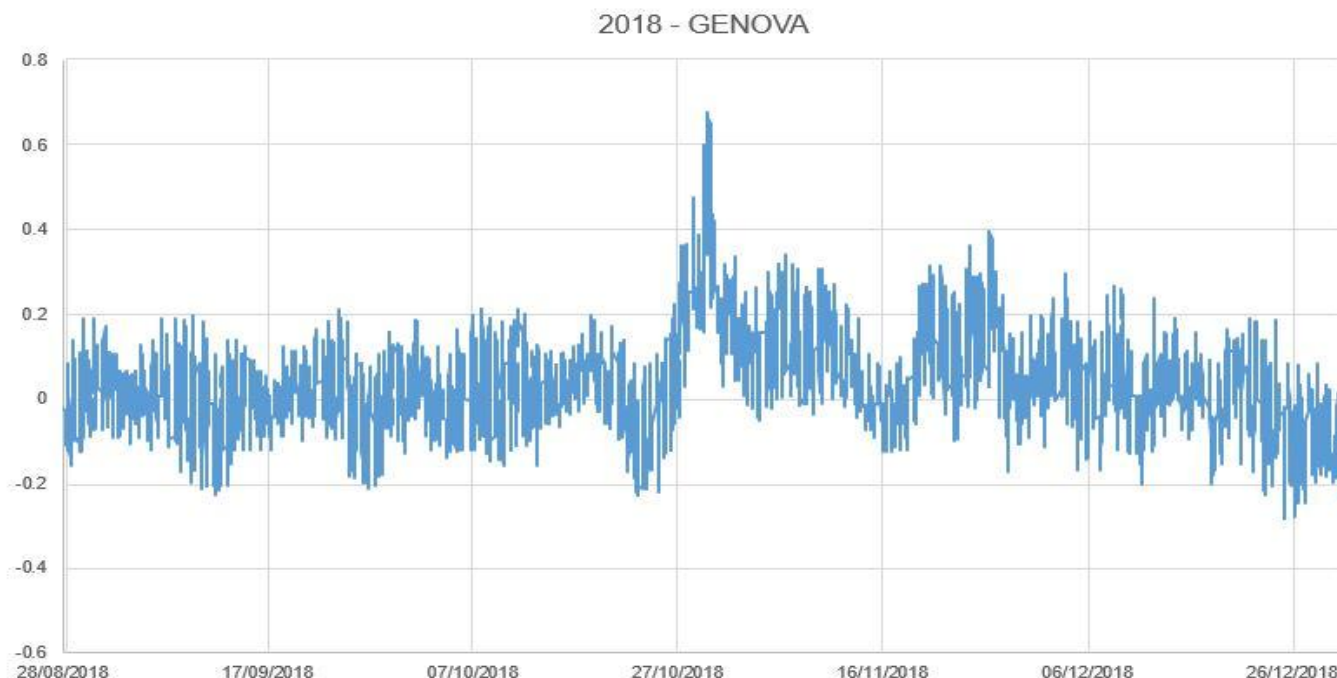


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ATMOSPHERIC PHENOMENA

Storm surge

- a rise in sea level driven by low atmospheric pressure and strong onshore winds.
- an average of fewer than 10 events per year between 10 and 20 cm.



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STERIC EFFECT

It depends on seawater density and is driven by ocean warming, evaporation, and increased salinity. While other coastal phenomena act as temporary perturbations lasting only hours or days, the steric effect has also seasonal components.

Those components represent a long-term contribution, accounting for roughly 55% of sea level rise, by affecting the entire bulk of the water column.

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RESIDUALS

The core strategy is to isolate and remove periodic components from the sea-level time series to extract the so-called "residuals"—time series that capture only the sea-level variations driven by non-periodic phenomena.

The step-by-step methodology applied to each annual dataset was as follows:

High-Frequency Filtering: Seiches and meteotsunamis were filtered out using a moving least-squares quadratic fit with a six-hour window.

Tidal Harmonic Analysis: A set of harmonic constants was derived from the filtered time series to model and reconstruct the astronomical tide for that specific year.

Residual Extraction: The reconstructed astronomical tide time series was subtracted from the filtered time series to isolate the residuals. To ensure data reliability, only the residual values corresponding to the times of high and low tides were extracted, as these discrete extreme events are distinctly identifiable



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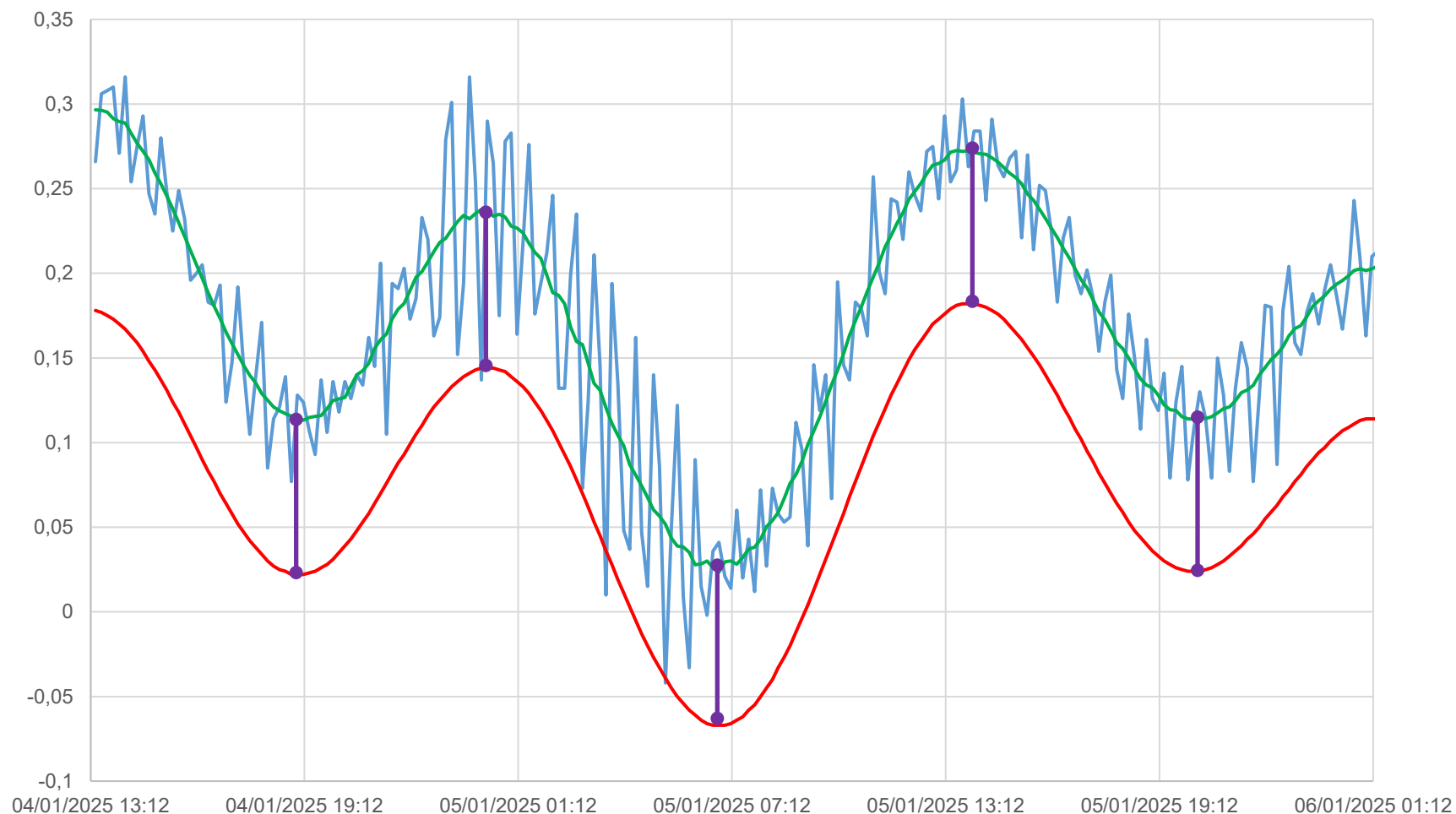


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RESIDUALS



Blue (measured) – Green (filtered) – Red (calculated tide)
Purple (residuals at low and high tides)

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RESIDUALS

As an example the next two slides contain:

- residuals and pressure levels (converted in metres with ratio 1:1 and $P_{\text{ref}} = 1016 \text{ hPa}$) of 2025 data in Genova, on a time series graph.
- The same two data series with pressure in metres on x axis and residuals on the y axis

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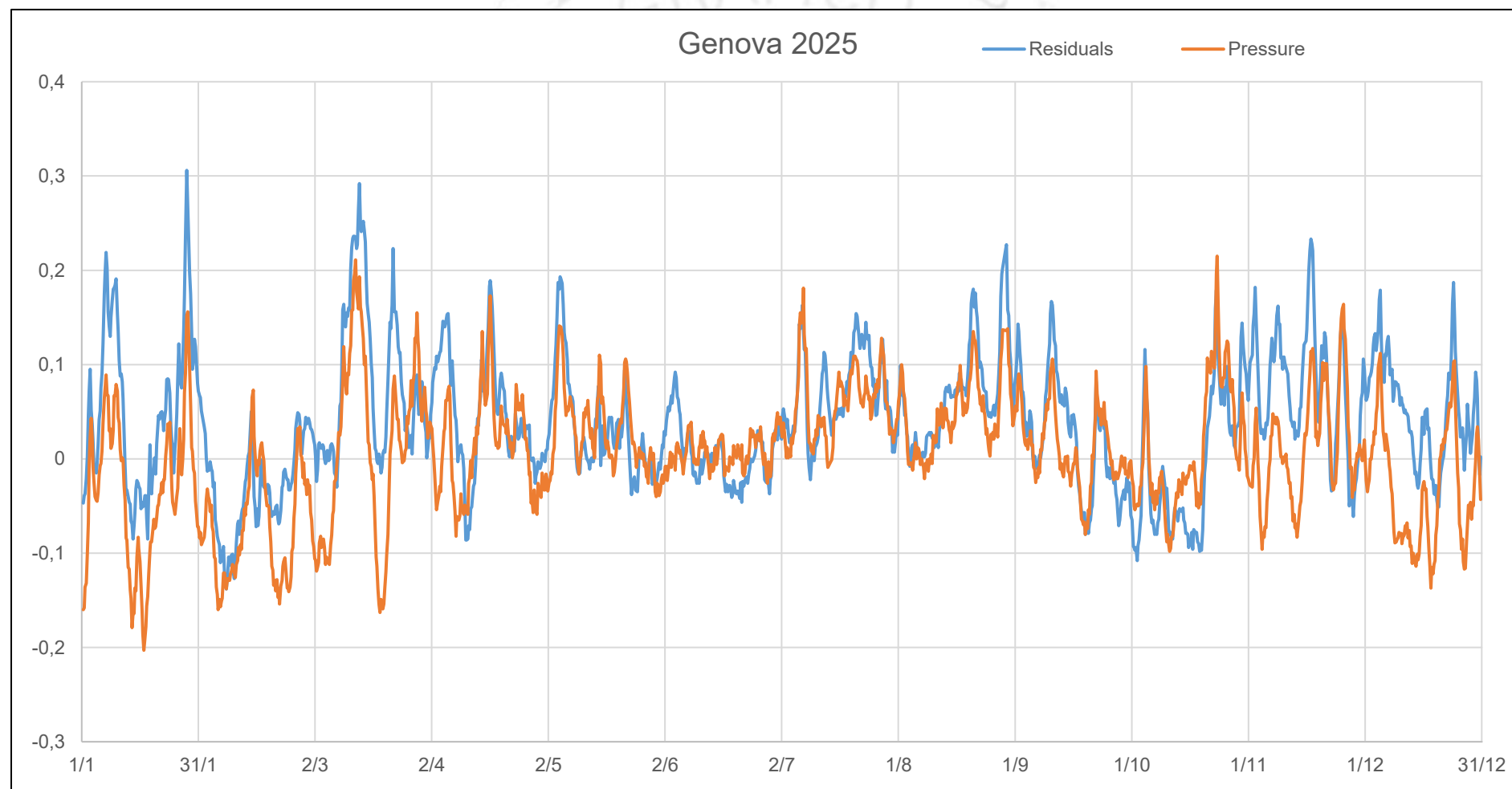


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RESIDUALS AND IB



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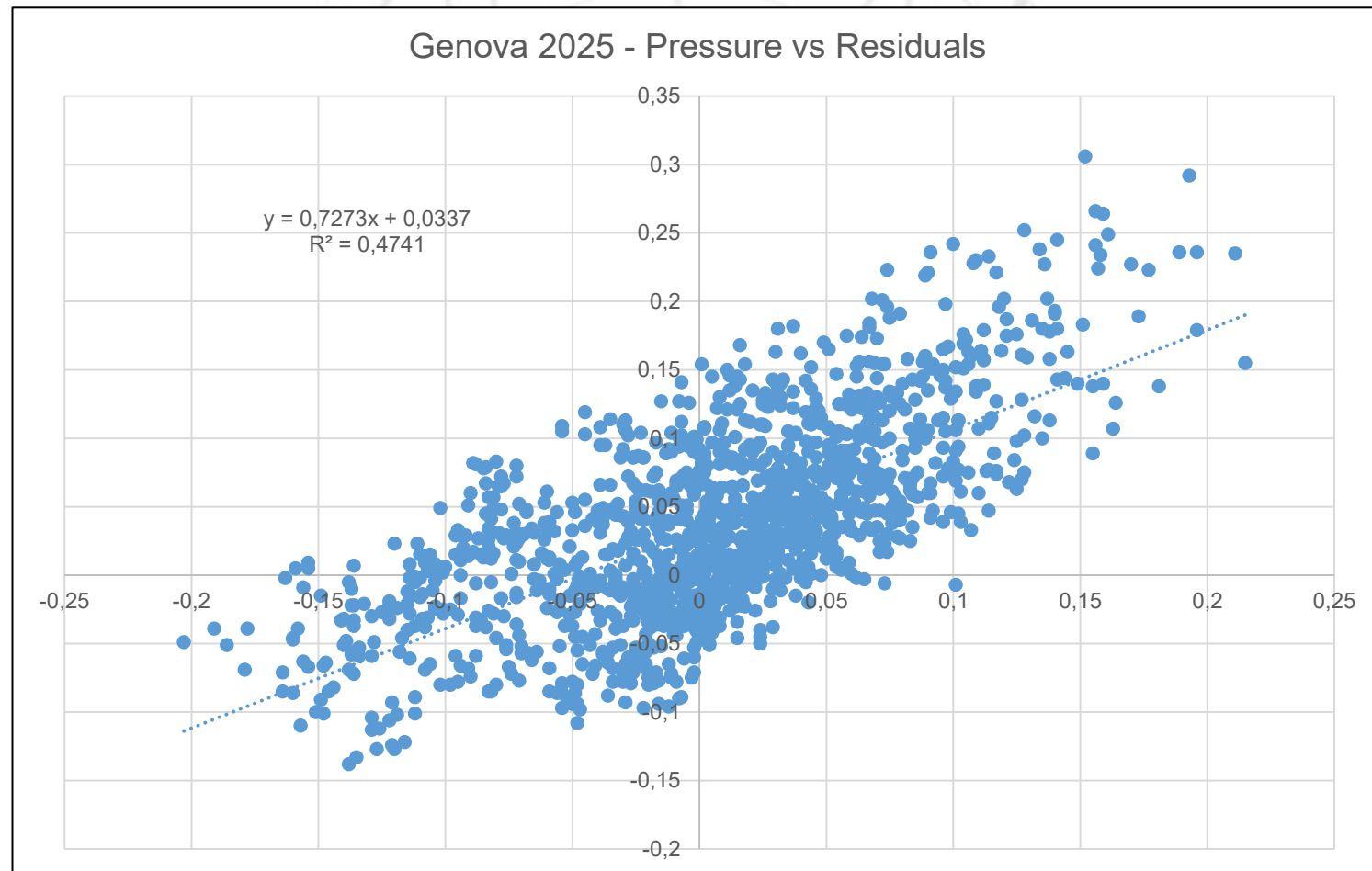


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RESIDUALS AND IB



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RESIDUAL ANALISYS

Statistical Analysis

Objective: due to the complex nature of non-periodic phenomena, histograms were used to evaluate the statistical distribution of the residuals.

Dataset: annual histograms of residual frequencies during high and low tides were constructed for all five tide gauge stations from 2020 to 2025.

Binning & Normalization: the occurrences were normalized, referred to their mean and categorized into 15 classes (0.05 m bin width, ranging from -0.35 m to 0.35 m).

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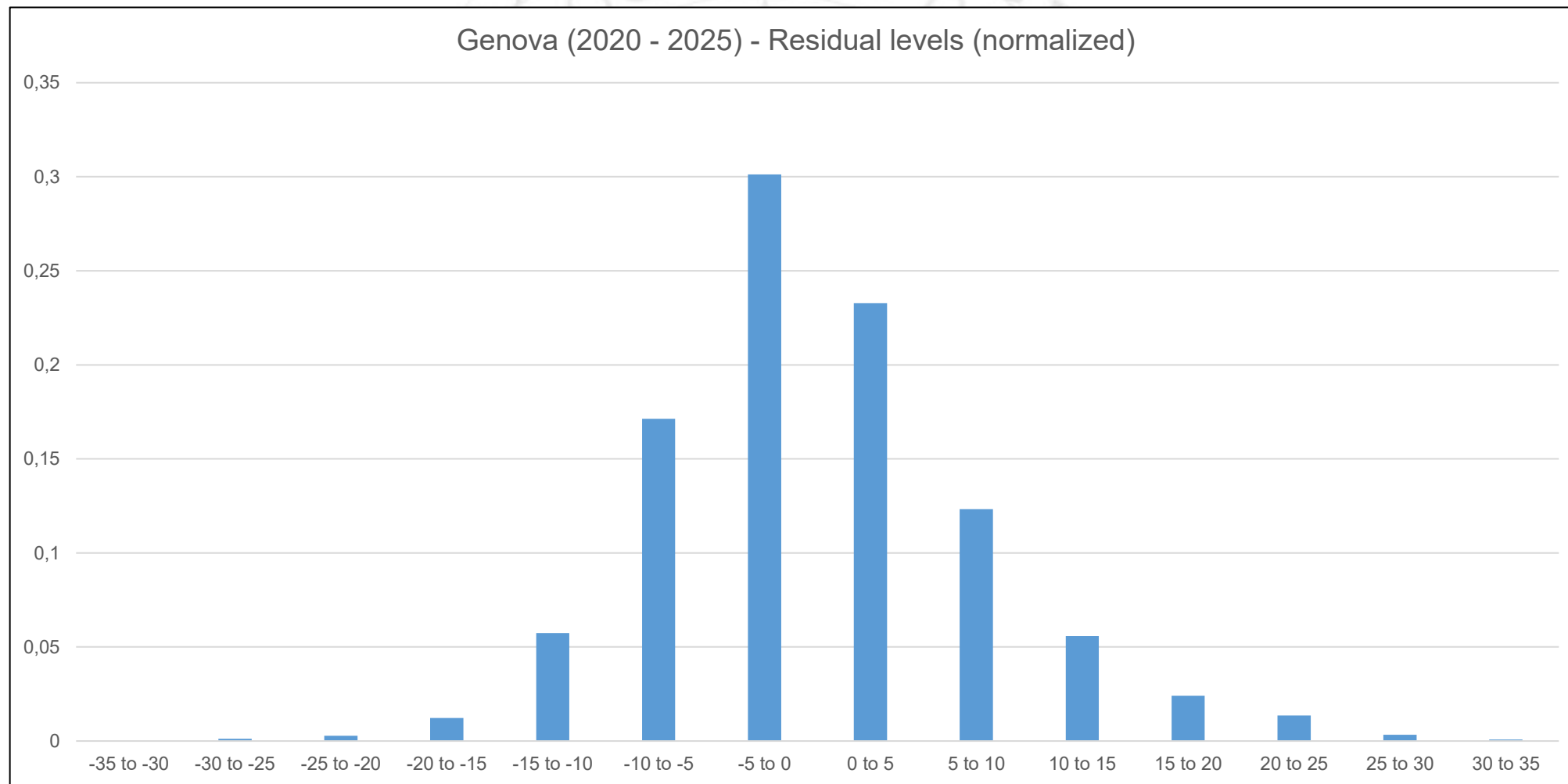
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RESIDUAL ANALISYS

GENOVA - (Skewness=0.05)



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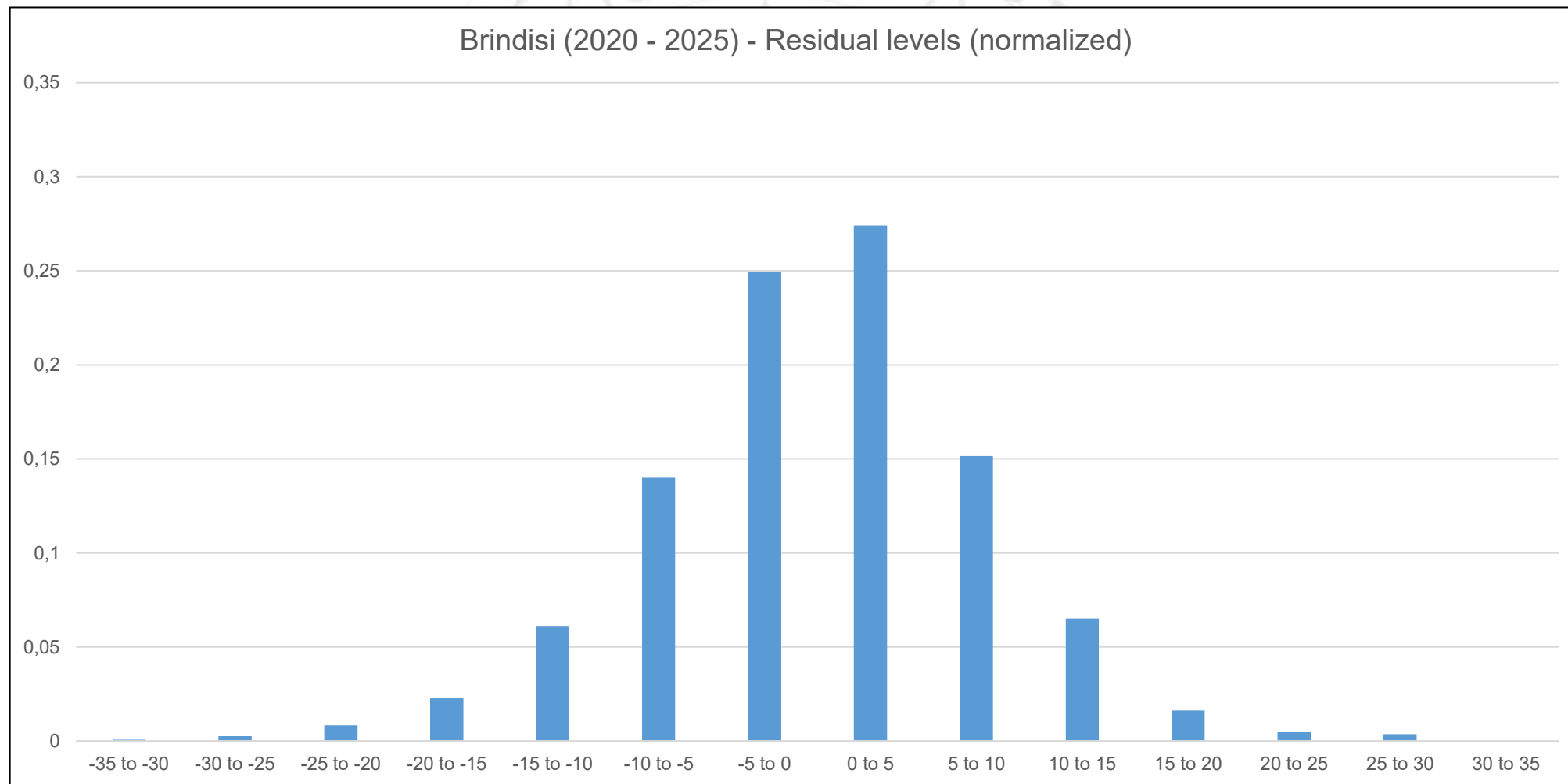


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RESIDUAL ANALISYS BRINDISI



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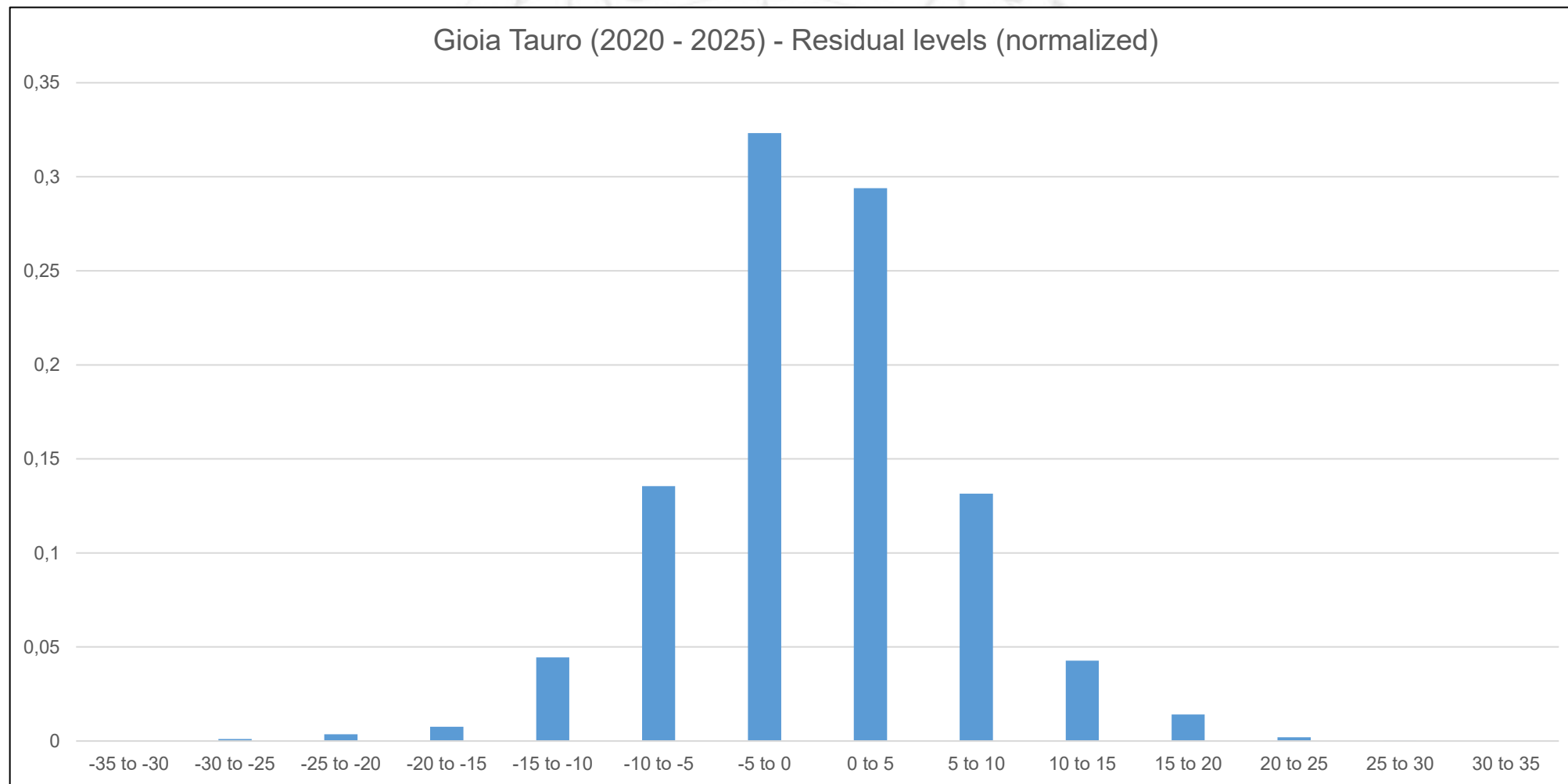


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RESIDUAL ANALISYS GIOIA TAURO



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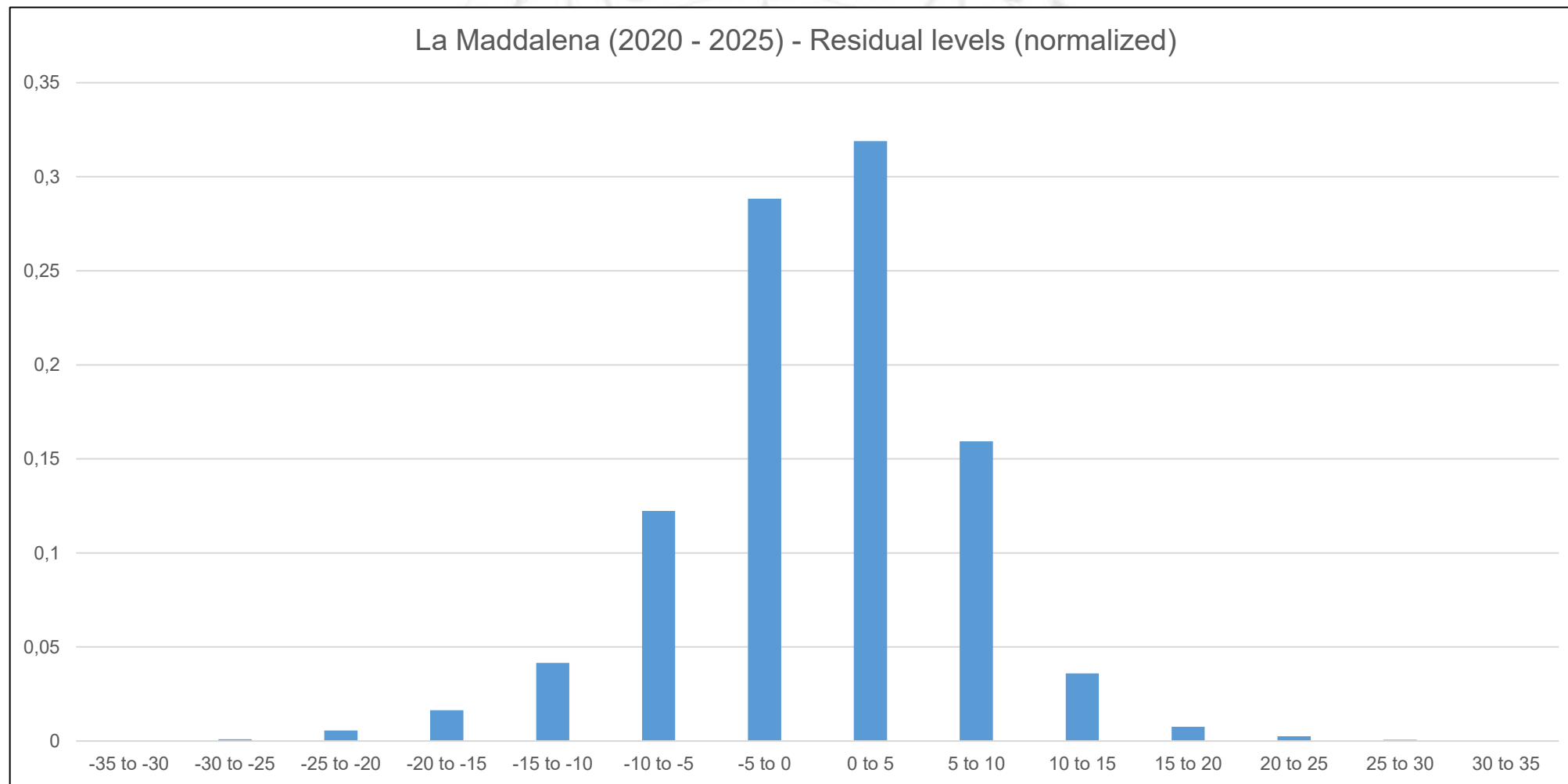


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RESIDUAL ANALISYS LA MADDALENA



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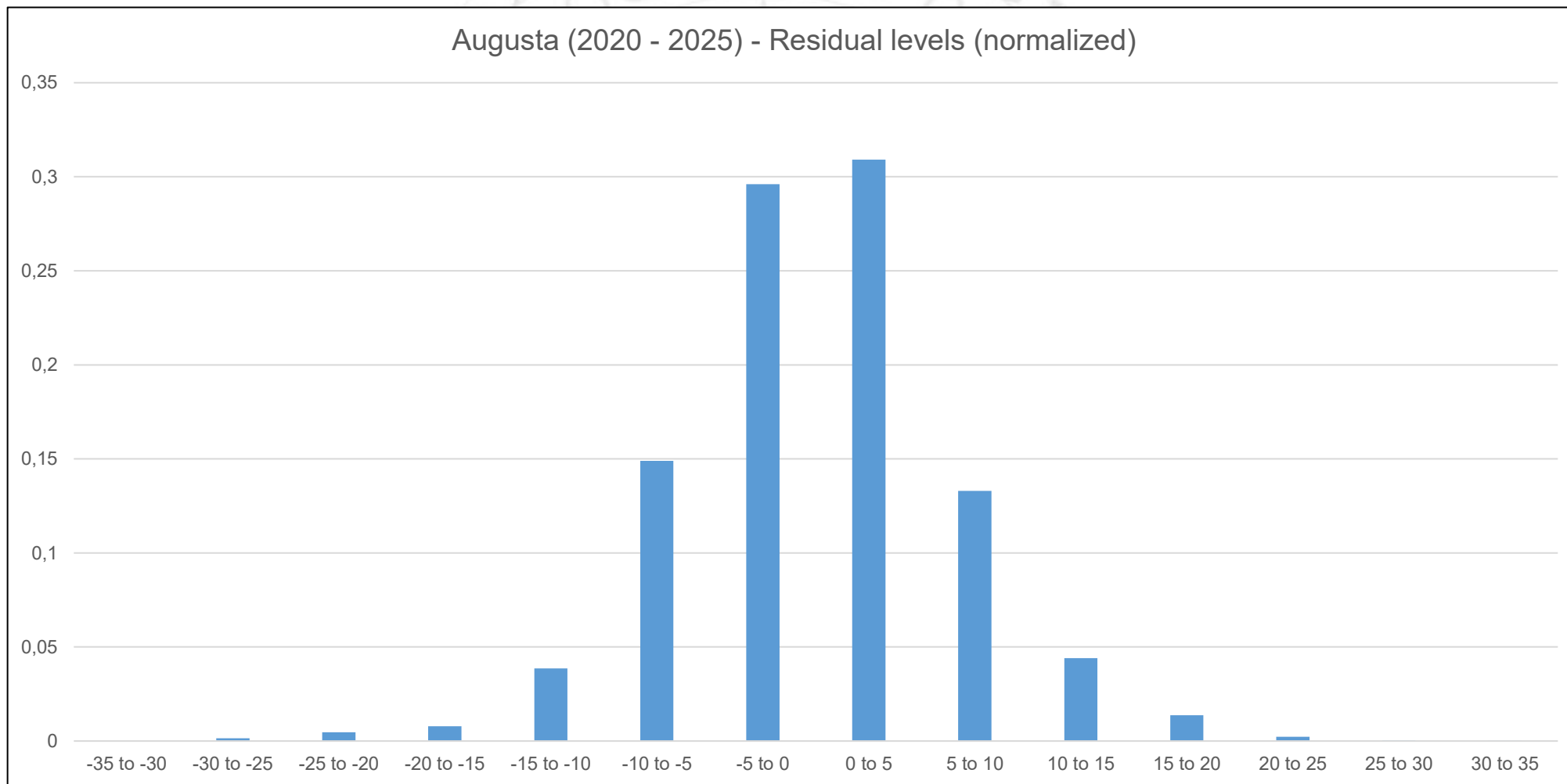


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RESIDUAL ANALISYS AUGUSTA



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RESIDUAL ANALISYS

COMMENTS AND CONCLUSIONS:

- The histograms show a well-structured pattern that approximates a normal distribution, except for Genova, which displays a slight skewness.
- This implies that despite different sources of perturbation, each contribution is randomly and evenly distributed.
- This is excellent news: even if we lack detailed knowledge of every single effect statistically we found that the mean of the residuals = MSL, and σ is its uncertainty.
- Beyond the results obtained, understanding the role of all phenomena that perturb sea levels remains a major research challenge.

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RESIDUAL ANALISYS

The results (years 2020 – 2025)
(values in metres and referred to 0 IGM)

STATION	MSL	σ	MAX	MIN
GENOVA	0.13	0.08	0.30	-0.28
BRINDISI	-0.13	0.08	0.30	-0.31
GIOIA TAURO	0.10	0.06	0.25	-0.29
LA MADDALENA	0.29	0.07	0.28	-0.28
AUGUSTA	0.13	0.07	0.32	-0.26

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THANK YOU FOR YOUR KIND ATTENTION

QUESTIONS ?

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