

A Model of the Spatial-Temporal Variation of the Gravity Field in Italy based on the Integration of Historical and Present Gravimetric Data

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Motivation

- **No complete, publicly accessible** modern gravimetric database for Italy
- Extensive historical surveys (1825–1958) **never systematically digitized**

Aim of the work

- Integration of the historical data with **new gravimetric data** to create a **unified database**.
- To develop a **comprehensive model of the temporal variations** of the gravity field across the Italian territory.
- The combined datasets will be processed and analyzed to assess **geophysical phenomena** across the Italian peninsula.

First step: The Digitization Process

- Examination of the volumes to locate the relevant datasets.
- High-resolution scanning of documents.
- Identify effective methodologies for numerical extraction: **AI-based OCR** recognizes degraded text and table structures, reconstructing data in editable **XLSX** format.

STAZIONE N.	VALORI OSSERVATI					ANOMALIE A DENSITÀ COSTANTE 2.4 g/cm ³					ANOM. A DENS. VARIABILE			
	Latitudine Nord		Longitudine Est Greenwich		Profondità	F a e	Bouguer d = 2.4 g/cm ³	Corr. Topo. d = 2.4 g/cm ³	Gravità normale 999 000 +	Anomalia d = 2.4 g/cm ³	Anomale d (g/cm ³)	Correzioni alle anomalie (10)	Anomalia d variabile	
	°	'	°	'	(m)									(m Gal)
1	2	3	4	5	6	7	8	9	10	11	12	13		
1 L	45 26 59	12 19 49	—	7.0	651.55	— 2.16	+	1.01	—	669.98	—19.58	2.0	—0.12	—19.70
2 L	27.03	21.26	4.8	651.26	1.48	0.69	—	—	670.08	—19.61	2.0	—0.08	—19.69	
3 L	25.46	21.17	7.5	652.25	2.31	1.08	—	—	668.15	—17.13	2.0	—0.13	—17.26	
4 L	20.04	18.27	17.4	653.35	5.37	2.50	—	—	659.60	—9.12	2.0	—0.29	—9.41	
5 L	14.42	17.40	7.9	649.21	2.44	1.13	—	—	651.55	—3.65	2.0	—0.13	—3.78	
6 L	17.18	18.11	4.0	649.58	1.23	0.57	—	—	655.45	—6.53	2.0	—0.06	—6.59	
7 L	18.43	18.39	4.3	650.28	1.33	0.62	—	—	657.58	—8.01	2.0	—0.07	—8.08	
8 L	21.27	19.45	10.7	652.73	3.30	1.54	—	—	661.68	—10.71	2.0	—0.18	—10.89	
9 L	22.57	20.03	7.8	651.49	2.41	1.12	—	—	663.93	—13.73	2.0	—0.13	—13.86	
10 L	29.10	25.20	4.7	652.29	1.45	0.67	—	—	673.25	—21.74	2.0	—0.07	—21.81	
11 L	45 31 31	12 25 41	—	4.0	652.29	— 1.23	+	0.57	—	676.80	—25.17	2.0	—0.05	—25.23
12 L	28.43	28.16	5.6	654.54	1.73	0.80	—	—	672.58	—18.97	2.0	—0.09	—19.06	
13 L	31.00	28.35	4.5	654.30	1.39	0.65	—	—	676.02	—22.46	2.0	—0.08	—22.54	
14 L	30.08	31.85	7.5	656.51	2.31	1.08	—	—	674.70	—19.42	2.0	—0.13	—19.55	
15 L	26.15	24.30	6.0	651.98	1.85	0.86	—	—	668.88	—17.89	2.0	—0.10	—17.99	
1	45 38 40	13 42 21	—	23.1	672.58	— 7.13	+	3.32	—	687.60	—18.83	2.3	—0.10	—18.93
2	39.35	38.26	24.8	674.13	7.65	3.56	—	—	688.98	—18.94	2.2	—0.21	—19.15	
3	41.05	37.00	20.1	673.84	6.20	2.89	—	—	691.23	—20.70	2.1	—0.26	—20.96	
4	32.55	09.20	17.9	670.60	5.52	2.57	—	—	678.87	—11.22	2.0	—0.30	—11.52	
5	29.16	02.34	22.9	667.32	7.07	3.29	—	—	673.40	—9.86	2.0	—0.39	—10.25	
6	21.10	08.36	32.1	665.34	9.90	4.61	—	—	661.25	—1.20	2.2	—0.27	—1.47	
7	39.44	35.34	23.1	676.41	7.13	3.32	—	—	689.20	—16.60	2.1	—0.29	—16.89	
8	38.52	35.55	24.2	676.96	7.47	3.47	—	—	687.90	—14.94	2.1	—0.30	—15.24	
9	37.58	38.48	24.5	676.85	7.56	3.52	—	—	686.55	—13.74	2.2	—0.21	—13.95	
10	37.13	40.34	22.8	674.44	7.03	3.27	—	—	685.48	—14.80	2.2	—0.19	—14.99	
11	45 38 40	13 33 26	—	21.6	677.91	— 6.66	+	3.10	—	687.60	—13.25	2.0	—0.36	—13.61
12	39.23	32.14	17.8	677.21	5.49	2.56	—	—	688.68	—14.40	2.0	—0.30	—14.70	
13	40.18	28.48	8.3	675.36	2.56	1.19	—	—	689.05	—14.86	2.0	—0.14	—15.00	
14	39.20	27.12	9.0	677.80	2.78	1.29	—	—	688.60	—12.29	2.0	—0.15	—12.44	
15	39.06	29.34	10.9	677.05	3.36	1.57	—	—	688.25	—12.99	2.0	—0.19	—13.18	
16	38.00	30.58	17.7	679.04	5.46	2.54	—	—	686.60	—10.48	2.0	—0.30	—10.78	
17	37.44	27.14	18.5	689.60	5.71	2.66	—	—	686.20	—8.65	2.0	—0.31	—8.96	
18	36.22	25.18	21.0	681.50	5.48	3.02	—	—	684.15	—6.11	2.0	—0.36	—6.47	
19	38.40	24.03	14.0	679.08	4.32	2.01	—	—	687.60	—10.83	2.0	—0.23	—11.06	
20	33.50	21.18	20.9	683.64	6.45	3.00	—	—	680.31	—0.12	2.0	—0.35	—0.47	
21	45 30 48	13 17 20	—	22.3	674.16	— 6.88	+	3.20	—	675.70	—5.22	2.1	—0.28	—5.50
22	36.05	18.08	14.9	679.59	4.60	2.14	—	—	683.73	—6.60	2.0	—0.23	—6.85	
23	40.25	18.28	7.6	677.57	2.34	1.09	—	—	690.23	—13.91	2.0	—0.13	—14.04	
24	39.30	13.12	14.9	678.14	4.60	2.14	—	—	688.85	—13.17	2.0	—0.25	—13.42	
25	36.00	13.20	12.5	672.32	3.86	1.80	—	—	683.60	—13.34	2.0	—0.21	—13.55	
26	33.33	14.00	17.0	672.99	5.25	2.44	—	—	679.89	—9.71	2.0	—0.28	—9.99	
27	29.12	14.11	23.4	673.15	7.22	3.36	—	—	673.30	—4.01	2.1	—0.29	—4.30	
28	24.50	14.13	24.9	668.78	7.68	3.58	—	—	666.75	—2.07	2.2	—0.21	—2.28	
29	22.10	14.12	23.3	666.79	9.35	4.35	—	—	662.75	—0.96	2.2	—0.25	—1.21	
30	15.52	14.43	32.8	673.20	10.12	4.71	—	—	653.30	—14.49	2.3	—0.14	—14.65	
31	45 18 03	13 07 26	—	33.3	661.49	—10.27	+	4.78	—	656.58	—0.58	2.2	—0.28	—0.86
32	20.20	08.27	29.7	663.88	9.16	4.26	—	—	660.00	—1.02	2.2	—0.24	—1.26	
33	25.48	07.10	23.9	668.37	7.37	3.43	—	—	668.20	—3.77	2.1	—0.30	—4.07	
34	29.45	07.28	23.0	669.94	7.10	3.30	—	—	674.13	—7.99	2.0	—0.38	—8.37	
35	81.98	05.28	20.8	668.86	6.42	2.99	—	—	676.90	—11.47	2.0	—0.35	—11.82	
36	35.55	07.08	17.7	672.01	5.46	2.54	—	—	683.43	—14.34	2.0	—0.30	—14.64	
37	38.38	08.43	12.5	672.33	3.86	1.79	—	—	687.55	—17.29	2.0	—0.20	—17.49	
38	35.10	02.28	16.2	669.41	5.00	2.33	—	—	682.35	—15.61	2.0	—0.28	—15.89	
39	32.50	01.54	16.1	668.71	4.97	2.31	—	—	678.79	—12.74	2.0	—0.27	—13.01	
40	29.43	03.02	22.9	668.02	7.07	3.29	—	—	674.08	—9.84	2.0	—0.39	—10.23	

Coordinate System Transformation

- Historical coordinates recorded in obsolete reference systems (e.g. **Roma 40**, **ED50**)
- **Converted to modern WGS84 and RDN2008 (UTM) via IGM's Verto Online service**



Sistema Rif. in Ingresso(1): Scegli un valore

Sistema Rif. in Uscita: Scegli un valore

File: Scegli file Nessun file selezionato

Esegui Trasformazione

Sistemi di riferimento

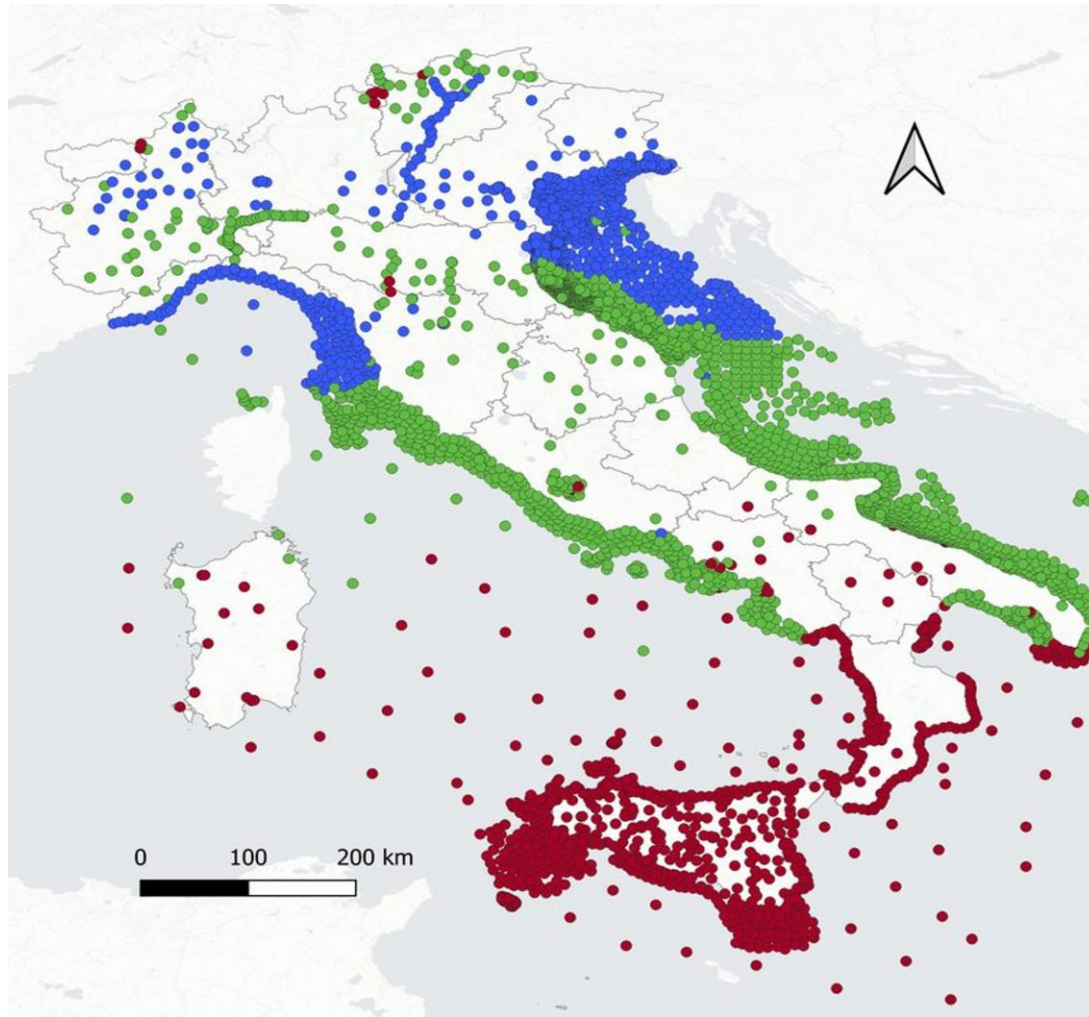
La trasformazione è possibile fra i Sistemi Geodetici più utilizzati in Italia: ROMA40, ED50, ETRF89 ed ETRF2000, sia in coordinate geografiche che nei sistemi piani ad essi normalmente associati, con riferimento ai codici EPSG (European Petroleum Survey Group). Fra i codici presenti nell'EPSG non sono accettati: 4978, 4979, 32632, 32633 e 32634, poiché riferiti al WGS84 che non è mai stato utilizzato in Italia. Una spiegazione che illustra il significato dei codici EPSG è riportata nella pubblicazione: ["Corretto utilizzo dei Sistemi Geodetici di Riferimento all'interno dei software GIS"](#) - Carroccio Marianna, Cima Virgilio, Maseroli Renzo - Atti della 18a Conferenza Nazionale ASITA, Firenze, 14-16 ottobre 2014

Attenzione! A partire dal giorno 21/11/2024 i codici per indicare la realizzazione ETRF89 sono: IGM95 3D (4983), IGM95 2D (4670) e i relativi SR proiettati. Questi sostituiscono i codici precedentemente utilizzati: ETRS89 3D (4937), ETRS89 2D (4258) e i relativi SR proiettati (vedi la pubblicazione sopra citata)

Formati accettati

IGM Official Conversion Tool

Distribution of Historical Gravimetric Observations in Italy



- **Low** (< 980.253 Gal)
- **Medium** (980.253 – 980.510 Gal)
- **High** (> 980.510 Gal)

Current dataset

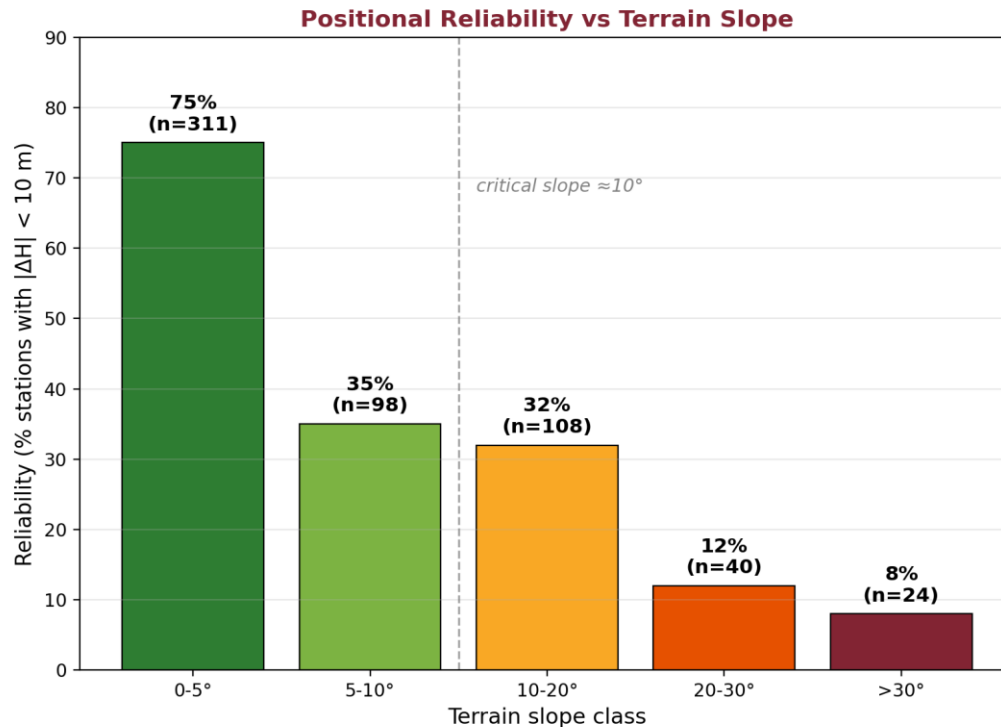
- Around **3,500 digitized stations** from the Commissione Geodetica Italiana archives
- 605 terrestrial stations, 2,958 marine stations.
- We split stations into three epochs: **before 1900** (189 stations), from **1901 to 1932** (359), from **1933 to 1958** (3015)

Positional Quality Assessment — Methodology

- Historic coordinates cross-checked against **TINITALY DTM** (INGV, 10 m)
- GeoNames used **to re-geocode stations** with ambiguous or place-name-only historic coordinates
- **Reliability indicator:** $\Delta H = H(\text{historic}) - H(\text{TINITALY})$

Positional Quality Assessment — Results

- Only 51.8% of land stations meet reliability criteria ($|\Delta H| < 10$ m)



- Reliability drops sharply with terrain slope: 75% (0–5°) → 8% (>30°); critical slope $\approx 10^\circ$ (reliability % = share of stations meeting $|\Delta H| < 10$ m within each slope class)
- 1901–1932 the most problematic period — median deviation 21.8 m, with a few large outliers (std=203 m)

Challenge: Spatial Heterogeneity



● Gravimetric Stations pre 1900

- **Highly uneven station density across regions and epochs**
- **Nationwide interpolation not meaningful**
- **Local kriging on spatially coherent clusters**

Target Variable: Gravity Disturbance

- Kriging is performed on the **gravity disturbance (δg)**
- $\delta g = g(\text{measured}) - \gamma(\text{normal})$
normal gravity computed via the ICGEM online service (GFZ Potsdam)
- Normal gravity from EGM2008 on the GRS80 ellipsoid, at each station's ellipsoidal height

Spatial Clustering



- **DBSCAN** clustering performed separately for each epoch
- **Epsilon calibrated objectively via k-distance graph**
- **Fixed Minimum Points across epochs for methodological consistency**

Clusters from 1933 – 1958 period

Kriging & Validation

Epoca	Cl.	Zona	N	R2	RMSE (Gal)	Range(km)
Pre-1900	Extra	Dorsale Adriatica (manuale)	28	51.5%	0.048	643.7
Pre-1900	6	Alpi/Trentino	49	43.6%	0.050	48.9
Pre-1900	2	Campania	11	36.7%	0.045	159.8
Pre-1900	5	Veneto orientale/Friuli	9	18.6%	0.024	123.9
Pre-1900	4	Piemonte/Lombardia occidentale	13	6.2%	0.044	98.2
Pre-1900	1	Sicilia orientale/Calabria	41	1.5%	0.052	17.5
Pre-1900	3	Marche	7	-36.1%	0.019	21.4
1901-1932	1	Sicilia	122	74.0%	0.029	98.0
1901-1932	3	Appennino toscano-emiliano	15	65.4%	0.044	90.3
1901-1932	4	Piemonte (Torino)	19	19.2%	0.061	110.3
1901-1932	6	Piemonte sett./Val d'Ossola	9	11.9%	0.054	48.4
1901-1932	5	Veneto (Padova)	6	-7.8%	0.010	24.2
1901-1932	2	Toscana (Firenze)	6	-12.5%	0.027	13.4
1933-1958	3	Pianura Padana (Genova-Vicenza)	67	95.9%	0.011	247.4
1933-1958	2	Roma/Castelli Romani	26	81.3%	0.010	25.7
1933-1958	1	Napoli/Campi Flegrei	9	-32.7%	0.033	11.6

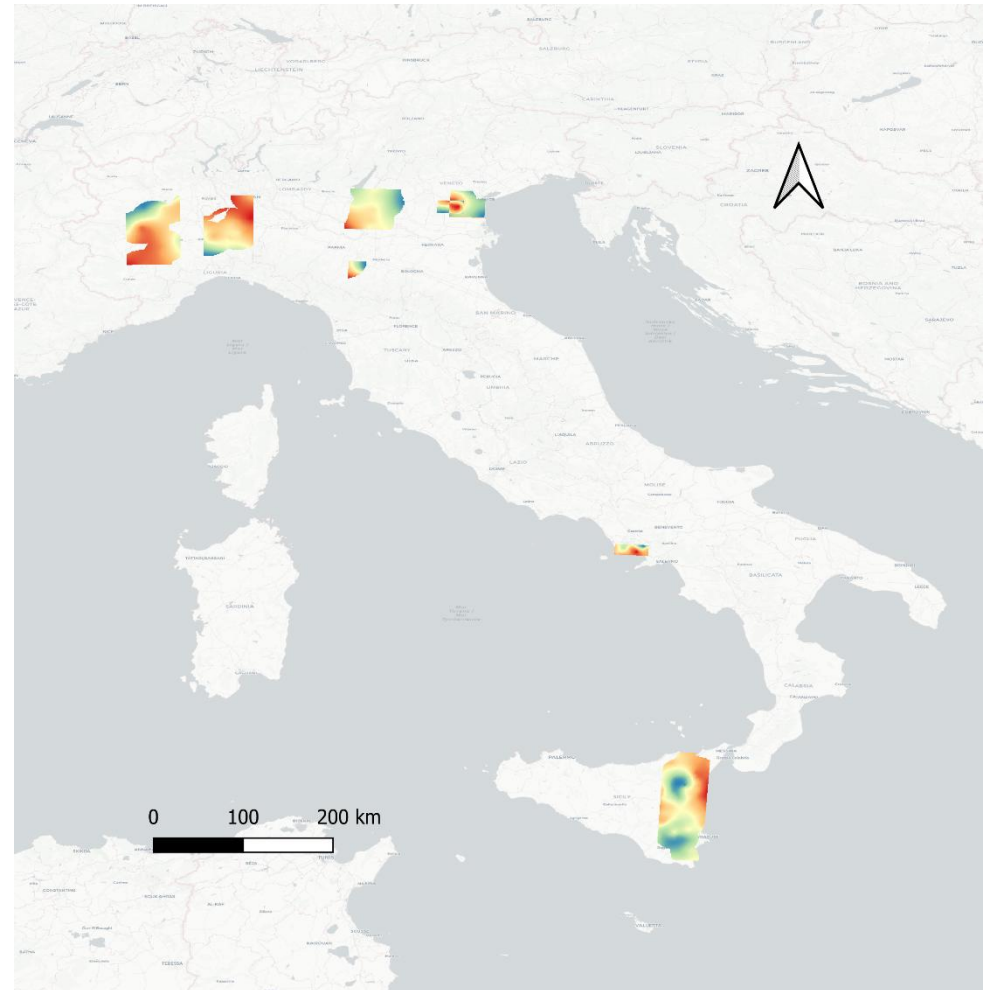
- **Ordinary kriging;**
empirical comparison of
variogram models:
spherical most stable
- **Validated via leave-one-out cross-validation** on every cluster:
R² (predictive skill vs. mean) and RMSE (average prediction error, in Gal)

Spatio-Temporal Comparison

- Cross-epoch comparison **only where geographically overlapping and reliable**
- True buffer-intersection check, not bounding-box approximation:
9 valid comparisons identified

Spatio-Temporal Comparison

Confronto	Min (Gal)	Max (Gal)
Sicilia	-0.0895	+0.0634
Piemonte (pre-1900 vs 1901-32)	+0.0127	+0.0997
Padova (pre-1900 vs 1901-32)	-0.0035	+0.0111
Padova (1933-58 vs 1901-32)	-0.0203	+0.0208
Napoli (pre-1900 vs 1933-58)	-0.0353	+0.0647
Liguria/Lombardia (pre-1900 vs 1933-58)	-0.0436	+0.0421
Appennino sett. (1901-32 vs 1933-58)	-0.0421	+0.0376
Verona (pre-1900 vs 1933-58)	-0.0492	+0.0571
Venezia (pre-1900 vs 1933-58)	-0.0317	+0.0317



Reliability & Limitations

- Kriging R^2 ranges from 96% (67 points) to –36% (7 points) — density, not geography, drives reliability
- Low-density clusters flagged and excluded from further analysis
- **Differences may reflect campaign/instrumental inconsistencies, not only geophysical change**

Conclusions & Next Steps

- **Reproducible, validated pipeline:** clustering → kriging → cross-validation → comparison
- Integration with modern and new data from PNRR airborne gravity survey
- **Extending validated cross-epoch comparisons**

Thank You for your attention!

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