# Report of ISPRS Scientific Initiatives project: A Forecasted Surface Velocity Database for Cities of the Mediterranean Southern Coast to Assess Coastal Displacement Contribution to Shoreline Change by 2030

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## Abstract:

This project aimed to create a surface displacement database for 27 coastal cities in North Africa, from Egypt in the east to Morocco in the west. The InSAR study covers more than ten years and forecasts the surface displacement time series for an additional five years, providing detailed measurements of surface displacement observed and predicted from 2014 to 2030. This database is a core for studying the relationship between coastal surface change and local sea level rise in North Africa. The data analysis was carried out utilizing open-source data and software. Sentinel-1 imagery was used for InSAR analysis; the Alaska Satellite Facility (ASF) Hyp3 API was for interferogram generation for each city; MINTPY was used to correct all interferograms for topographic and atmospheric effects and create surface displacement time series; and QGIS was used for visualization and clipping tasks. Copilot was used to create a time series deep learning forecasting model for surface displacement until 2030. The project team completed the analysis and forecasts for all 27 cities, and the results are freely available on the ScienceDB website, https://doi.org/10.57760/sciencedb.31439. The team is currently working with a representative from Digital Earth Africa (DE Africa) to determine the best way to distribute this database at the DE Africa Analysis Sandbox.

## Introduction

Coastal erosion, a serious problem facing many coastal countries in Africa, results in the degradation of nearshore assets and is expected to cause people to relocate away from the African coasts. This problem affects 270 million people living on African coasts and costs about 7 billion USD in annual losses. While many researchers investigated the dynamics of African shorelines, especially under the impact of climate change and sea level rise, coastal subsidence was found to be neglected in many studies on shoreline retreat in Africa. Hence, this project aimed to build a surface displacement database for the main coastal cities of North Africa and forecast subsidence trends up to 2030 to help future studies on the correlation between shoreline change and coastal subsidence. The region experiences an erosion rate of 1.58 meters annually on average. Hence, it was important to define sinking coastal areas by detecting surface displacement for future management planning efforts.

In recent years, the availability of SAR data has become a major controlling factor for the use of InSAR technology for coastal vertical velocity detection. Since 2014, the European Space Agency's Sentinel-1 mission has been imaging Earth's surface every 12 days or less. AI technologies have also developed a rule to classify results and forecast future trends for InSAR measurements. In this project, we evaluated several deep learning time series forecasting models to determine the most effective model for predicting coastal subsidence in the African cities under study until 2030.

This project aimed to initiate a database on surface displacement in 27 African cities located along the southern coast of the Mediterranean Sea, from Al-Arish in Egypt at the east to Tangier in Morocco at the west. This database can be used by researchers from all over the world to assess the contribution of coastal area subsidence to coastal erosion in Northern Africa.

The project achieved the following objectives:

- Surface displacement analysis of 27 cities in North Africa was observed mostly between October 2014 and April 2025.

-Developed a new robust forecasting model for time series analysis to apply to all cities despite their differences in many geographical and construction characteristics.

- Forecast coastal cities' time series displacement for each city mostly until April 2030.

Publish the observed and forecasted timeseries data of the displacement in the 27 cities online for free access to everyone.

## Methodology

Working on terabytes of data with different coordinate system zones on local PCs was really challenging for the team. In the initial proposal we suggested overcoming this problem by renting a cloud-based analysis website. However, we found many limitations in online connection, processor speed, and storage, which would cost hundreds of thousands of yuan to process the huge amount of data for the project cities. Therefore, we decided to use cloud-based analysis for a specific stage of the project, after which we would download the results to continue the remaining analysis on our PCs.

### Data selection and interferogram generation

We have developed a Python code to call the Alaska Satellite Facility (ASF) Hyp3 API to proceed with InSAR analysis on the cloud to produce thousands of interferograms for each city. Using this code, we define the area of interest as a rectangle based on the min. and max. of lat. and long; the orbit, ascending or descending; starting and ending dates of imagery search; the minimum and maximum temporal and perpendicular baselines; the polarization; and the beam mode. Generally, starting and ending dates were 2014-10-01 to 2025-04-30. While the minimum and maximum temporal baselines were 12 and 48, respectively. The perpendicular baseline of interferograms is between 0 and 300, the beam mode is IW, and the polarization is VV. Most of the cities were analyzed based on the ascending line of sight (LOS), but due to data availability and analysis complications, some cities were analyzed from the descending orbit. Table 1 in the results section includes all analyzed orbits of the 27 cities.

### Time series analysis

After downloading interferogram results from ASF Hyp3, the following step was to clip all results to the city area and prepare the data for the MINTPY required files. We then run MINTPY to correct interferograms for topographic effects by using a 30 m DEM and correct for atmospheric delay by downloading ERA5 atmospheric data and set up PyAPS to be run during the MINTPY time series analysis phase. The corrections allowed us to extract the correct time series displacement of each city. Unless the results are not satisfying, we keep most MINTPY default parameters as they are. The exception is for selecting PyAPS as the tropospheric delay method and changing the reference date for the time series to start from the first interferogram date. In a few cases, the selected reference point by default was inapplicable and showed biased displacement patterns. In these rare instances, we chose a different reference point than the one the software initially selected.

### Time Series Forecasting

The research advances beyond a standard forecasting pipeline by introducing a carefully engineered data foundation and a rigorously controlled evaluation setup. The dataset was not treated as a passive input but actively structured to reflect the full spectrum of deformation behavior across coastal environments. From an initial multi-million pixels archive, a class-stratified sampling strategy was applied to construct a balanced corpus of 200,000 time series, explicitly preserving slow, moderate, and rapid deformation regimes, as well as subsidence and uplift patterns. This design directly addresses the inherent imbalance in InSAR data, where stable pixels dominate and can bias models toward underestimating high-risk dynamics.

In parallel, normalization and preprocessing were strictly confined to training cities, eliminating subtle forms of spatial leakage and ensuring that the learning process reflects transferable temporal behavior rather than location-specific statistics. On the modeling side, seven forecasting architectures spanning statistical, machine learning, and deep learning paradigms were evaluated under a unified framework [cnn_lstm_attention, gru_attention, mamba, patch_tst, tcn_attention, dlinear, and transformer_encoder].

## Results

Some examples of surface displacement observation results are presented in figure 1.

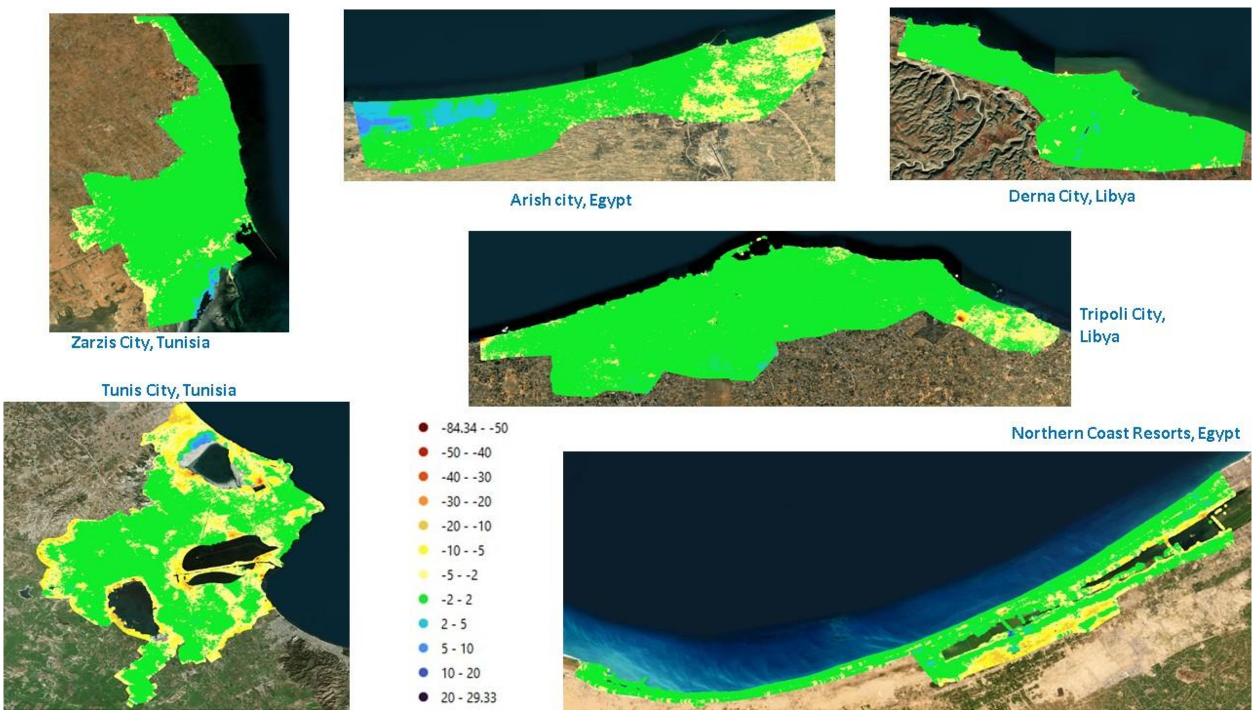


*Figure 1. InSAR analysis results of surface displacement for 6 cities in the project.*

The project team members have some field investigations trips in Egypt and Algeria to check subsidence results on the ground. Figure 2 showed some pictures captured in the field for cracks and subsidence signs in several cities.

*Figure 2. Subsidence signs as observed in field investigations for several Egyptian coastal cities.*

Forecasting results show a clear and stable performance hierarchy under geographically independent testing. The Temporal Convolutional Network (TCN)-Attention model achieved the best performance (RMSE $\approx$ 4.03 mm), closely followed by the Patch Time Series Transformer (TST) ($\approx$ 4.11 mm), with both models demonstrating high correlation ($r \approx 0.99$) and strong explanatory power ($R^2 \approx 0.98$). Importantly, all models significantly outperformed baseline approaches, with the top models exceeding them in more than 97% of pixels, confirming that the learned representations capture meaningful temporal deformation dynamics. Performance degradation from development to independent testing remained controlled ($\approx$ 12 – 15% for top models), providing direct evidence of genuine cross-regional generalization rather than overfitting. Figure 3 illustrates samples of time series forecasting from the TCN model during the training and testing phase.

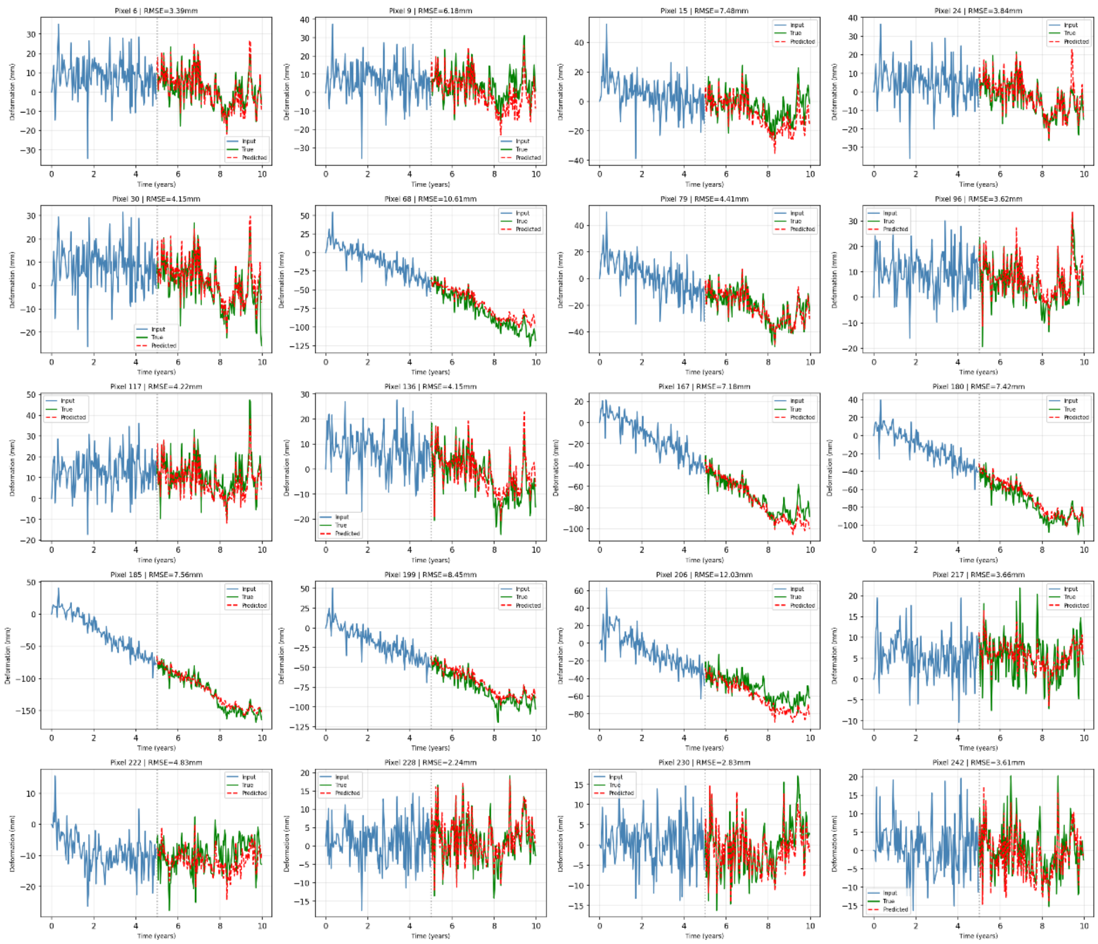


Figure 3. Samples of time series forecasting from the TCN model during the training and testing phase.

A key outcome is that model behavior is not only ranked but also interpretable: different architectures exhibit sensitivity to different deformation processes. This complementarity enabled ensemble strategies to further improve performance, with the optimal combination reducing RMSE to ~3.8 mm ($\approx$ 4.6% improvement over the best individual model). Overall, the results confirm that multi-city training, when combined with balanced sampling and strict geographic validation, allows deep learning models to learn transferable deformation patterns on a regional scale, while also highlighting the importance of evaluation design in producing realistic and operationally meaningful performance estimates. Figure 4 illustrates four forecasted surface displacement time series sample areas suffering current subsidence rates.

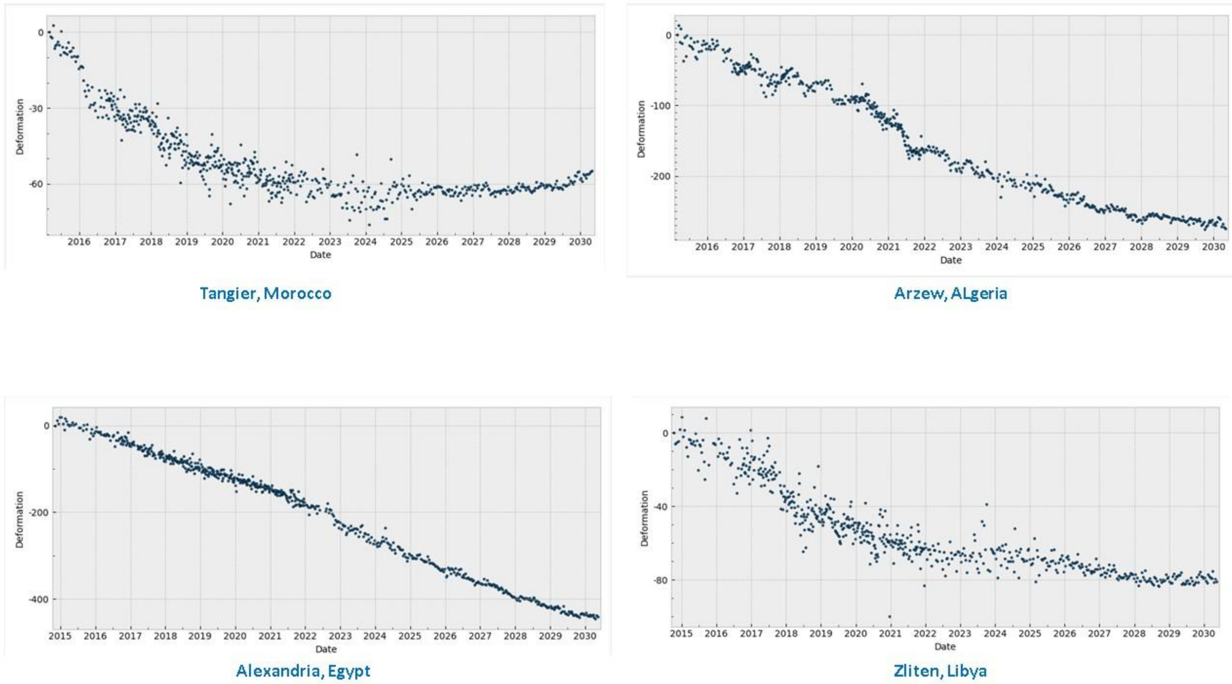


*Figure 4. Forecasted time series for four different cities in the project.*

The generated database of this project was published in ScienceDB website, https://doi.org/10.57760/sciencedb.31439. Align with the published data, there is a metadata file explains the data, the project, and the ISPRS project support. The information of the metadata file as follows:

"These data are the surface displacement of 27 South Mediterranean coastal cities over 15 years, where 10 years were observed by the InSAR Time Series technique of Small BASeline (SBAS) and 5 years were forecasted by using the Temporal Convolutional Networks (TCN) deep learning forecasting model. This work was supported by the International Society of Photogrammetry and Remote Sensing (ISPRS) Scientific Initiatives 2025 project: A forecasted surface velocity database for cities of the Mediterranean's southern coast to assess coastal displacement's contribution to shoreline change by 2030. The data collection and interferogram generation were done using the Alaska Satellite Facility (ASF)'s Hyp3, and the time-series generation for InSAR surface displacement was done using Miami InSAR time-series software in Python (MINTPY)". Cities data information in the metadata file can be summarized in Table 1.

Table 1. Detailed information for each city in the produced database

| Country | City | Orbit (LOS) | Observation dates | | Forecasted dates | | Data original size | Data compressed size |
|---|---|---|---|---|---|---|---|---|
| | | | Start | End | Start | End | | |
| Egypt | Alexandria | Asc | 2014-11-07 | 2025-05-13 | 2025-05-25 | 2030-05-11 | 897.9 MB | 307.2 MB |
| | Arish | Desc | 2014-10-12 | 2025-04-17 | 2025-04-29 | 2030-04-15 | 511.8 MB | 171.3 MB |
| | Damietta | Asc | 2014-10-21 | 2025-04-26 | 2025-05-08 | 2030-04-24 | 833.8 MB | 277.0 MB |
| | Egyptian Northern coast | Asc | 2014-11-07 | 2025-04-25 | 2025-05-07 | 2030-04-23 | 6.281 GB | 1.884 GB |
| | Marsa Matrouh | Asc | 2014-11-12 | 2025-04-24 | 2025-05-06 | 2030-04-22 | 6.180 GB | 2.063 GB |
| | Rosetta | Asc | 2014-11-07 | 2025-05-13 | 2025-05-25 | 2030-05-11 | 225.0 MB | 076.4 MB |
| Libya | Benghazi | Asc | 2014-11-15 | 2025-04-27 | 2025-05-09 | 2030-04-25 | 2.462 GB | 750.0 MB |
| | Derna | Asc | 2016-06-08 | 2025-07-27 | 2025-08-08 | 2030-07-25 | 1.580 GB | 546.9 MB |
| | Misrata | Asc | 2014-10-13 | 2025-04-18 | 2025-04-30 | 2030-04-16 | 1.615 GB | 509.7 MB |
| | Sirte | Asc | 2014-11-13 | 2025-04-25 | 2025-05-07 | 2030-04-23 | 1.320 GB | 394.2 MB |
| | Tripoli | Asc | 2014-10-18 | 2025-04-29 | 2025-05-11 | 2030-04-27 | 2.477 GB | 778.2 MB |
| | Tobruk | Asc | 2014-11-29 | 2025-04-05 | 2025-04-17 | 2030-04-03 | 453.9 MB | 135.4 MB |
| | Zliten | Asc | 2014-10-13 | 2025-05-12 | 2025-05-24 | 2030-05-10 | 691.7 MB | 239.0 MB |
| Tunisia | Bizerte | Desc | 2015-02-09 | 2025-05-11 | 2025-05-23 | 2030-05-09 | 184.5 MB | 062.2 MB |
| | Gabes | Desc | 2014-10-24 | 2025-05-23 | 2025-06-04 | 2030-05-21 | 2.970 GB | 916.7 MB |
| | Sfax | Asc | 2014-10-30 | 2025-04-23 | 2025-05-05 | 2030-04-21 | 5.458 GB | 1.789 GB |
| | Sousse | Asc | 2014-10-30 | 2025-04-29 | 2025-05-11 | 2030-04-27 | 3.760 GB | 1.245 GB |
| | Tunis | Desc | 2015-02-09 | 2025-05-11 | 2025-05-23 | 2030-05-09 | 2.223 GB | 740.6 MB |
| | Zarzis | Asc | 2014-11-04 | 2025-05-22 | 2025-06-03 | 2030-05-20 | 285.3 MB | 084.9 MB |
| Algeria | Annaba | Asc | 2016-01-03 | 2025-04-21 | 2025-05-03 | 2030-04-19 | 374.5 MB | 130.1 MB |
| | Algiers | Asc | 2015-03-08 | 2025-04-26 | 2025-05-08 | 2030-04-24 | 2.085 GB | 654.0 MB |
| | Arzew | Asc | 2015-03-05 | 2025-04-29 | 2025-05-11 | 2030-04-27 | 1.037 GB | 362.1 MB |
| | Mostaghnem | Asc | 2015-03-05 | 2025-06-04 | 2025-06-16 | 2030-06-02 | 742.9 MB | 261.4 MB |
| | Oran | Desc | 2015-03-30 | 2025-04-18 | 2025-04-30 | 2030-04-16 | 1.982 GB | 584.9 MB |
| | Skikda | Desc | 2015-03-03 | 2025-04-27 | 2025-05-09 | 2030-04-25 | 368.1 MB | 118.7 MB |
| Morocco | Nador | Desc | 2015-03-10 | 2025-04-22 | 2025-04-05 | 2030-04-20 | 1.748 GB | 617.6 MB |
| | Tangier | Asc | 2015-03-03 | 2025-04-27 | 2025-05-09 | 2030-04-25 | 597.3 MB | 190.6 MB |

Some of this project's findings were presented in the GISEIA conference in Wuhan, Nov. 8-9, 2025, to promote the project and ISPRS. Several posts were also published on LinkedIn referring to the project, and there will be a series of posts on LinkedIn about the project's results to promote the database and ISPRS and the funding organization of this project. The team is currently working with a representative from Digital Earth Africa (DE Africa) to determine the best way to distribute this database at the DE Africa Analysis Sandbox. Additionally, the team is now writing two scientific papers to submit in Q1 journals based on this project's findings.

## Conclusion

The team of this project has successfully achieved its aim and all its objectives. However, our work on the project has not concluded yet. We will work with the DE Africa team to upload the project results on their analysis sandbox to provide a direct visualization of our project results on an interacting map. We are working on two current publication ideas and considering the possibility of preparing another paper in the near future based on the project findings. Additionally, there will be a series of posts on LinkedIn showing the project findings to promote to the database and ISPRS.