# InSAR and GNSS observations coupled with high resolution tropospheric modelling in the western Gulf of Corinth – A synergic approach

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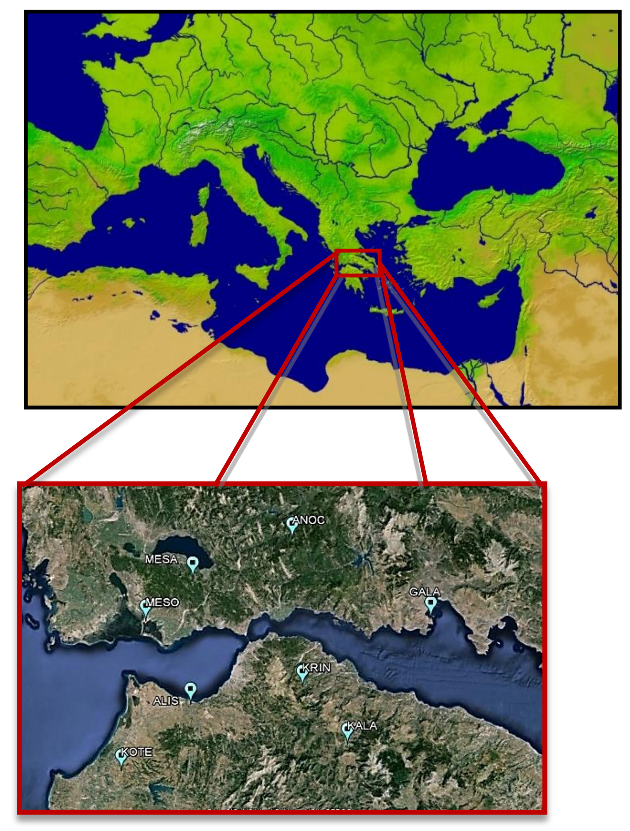
## Abstract

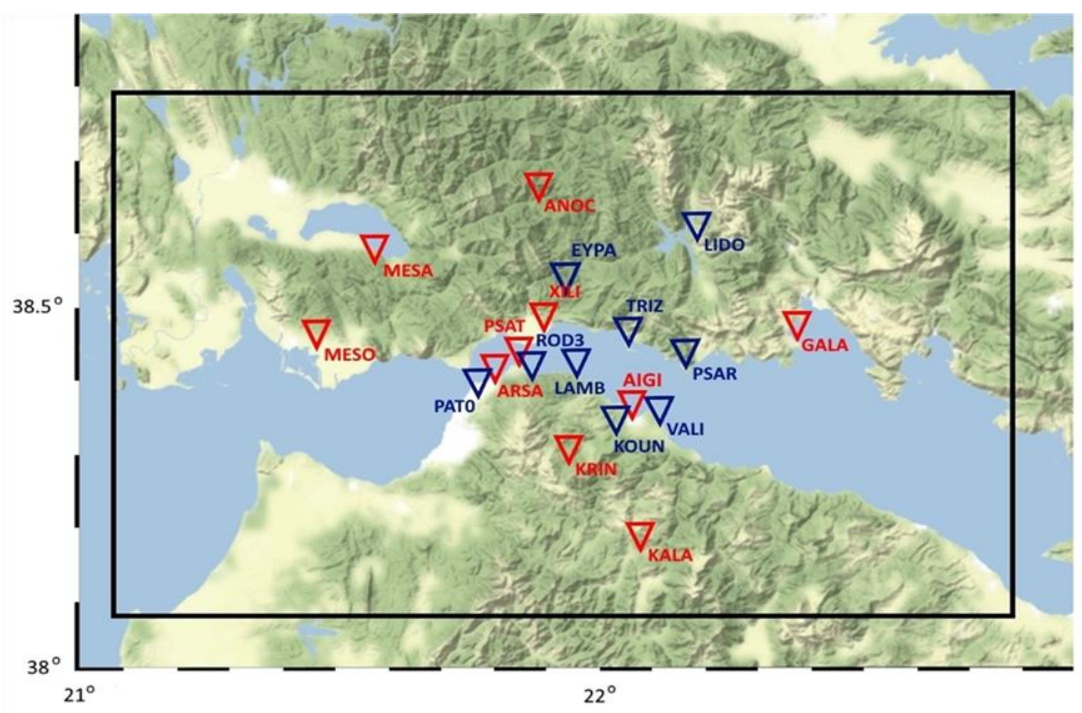
Remote sensing techniques, such as GNSS and SAR observations, together with high-resolution modelling of the atmosphere with NWP models can provide a synergic framework for a number of earth observation applications. The combination of GNSS observations with active satellite observations (InSAR), processed with advanced differential interferometry methodologies (i.e. PSI and SBAS) is capable of greatly enhancing the knowledge of local crustal deformations with multiple benefits for monitoring co-seismic, post-seismic, as well as aseismic discontinuities. Meteorology is an integral part of this monitoring technique, as high-resolution NWP models have the potential to accurately simulate the tropospheric state and remove the delay due to the atmospheric refraction of the signal. On the other hand, the same synergic approach can provide very useful information of meteorological and climatological interest. GNSS and SAR observations are already used to monitor the high temporal and spatial variability of water vapour in the troposphere. It is highly possible that in the near future, InSAR near real-time water vapour products will be assimilated in weather forecasting models for improving the localization and timing of heavy precipitation events, in the same way that GNSS data are currently being used.

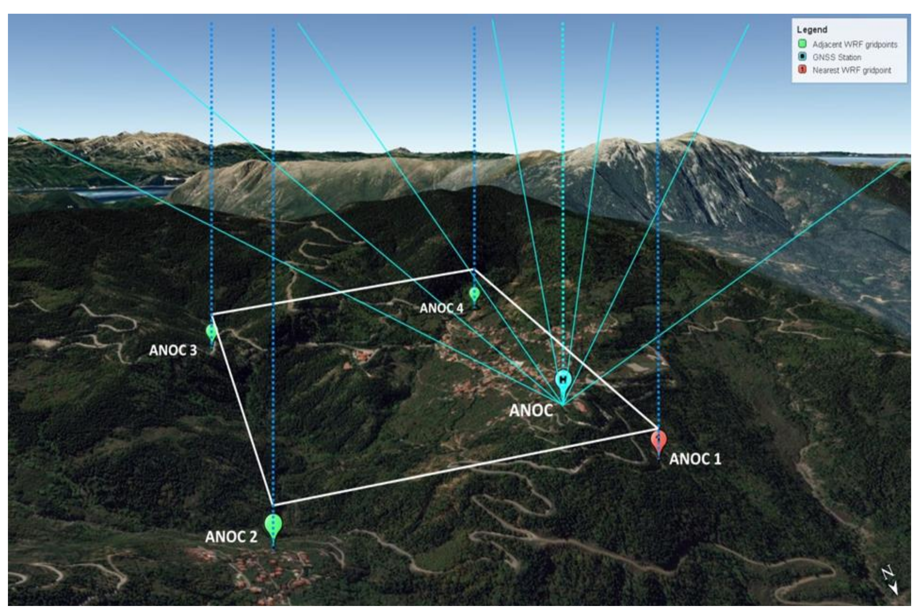
Our work focuses on the interaction of the three aforementioned techniques in the area of the western Gulf of Corinth in Greece and aims to optimise their synergic output by identifying strengths, weaknesses and uncertainties with respect to the measurement of zenithal tropospheric delays. We investigate the extent to which a high-resolution WRF 1-km re-analysis can produce detailed tropospheric delay maps of the required accuracy, by coupling its output (in terms of Zenith Total Delay or ZTD) with the vertical delay component in GNSS measurements. The model is operated with varying parameterization in order to demonstrate the best possible configuration, with GNSS measurements providing a benchmark of real atmospheric conditions. The two datasets (predicted and observed) are compared and statistically evaluated for a period of one year, in order to investigate the extent to which meteorological parameters that affect ZTD, can be simulated accurately by the model. Finally, we compare twenty Sentinel-1A interferograms with differential delay maps at the LOS produced by WRF re-analysis. We find that WRF-derived differential meteograms correlate in various degrees with the real interferograms, with results suggesting a potential of the model to re-produce both the long-wavelength stratified atmospheric signal and the short-wave turbulent atmospheric component which is evident in the interferograms.



## The PaTrop Experiment

An annual campaign designed and implemented for providing the data needed for this study. Tropospheric delays from GNSS measurements (ZTDs) are coupled with the output from a high-resolution meteorological model (WRF), in order to investigate the model's capability to reproduce the tropospheric conditions that contribute to the noise signal, especially the highly variable water vapour distribution.

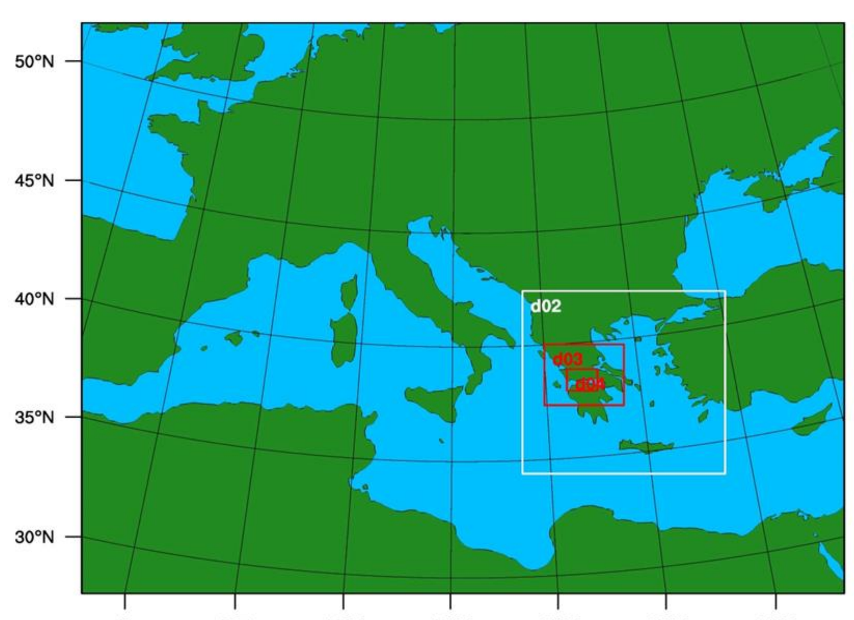



The PaTrop test site covers an area of approximately 150 × 90 km in the region of the Western Gulf of Corinth (GoC). A network of 19 permanent GNSS receivers provides the tropospheric measurement database. Stations are installed at elevations between 0-1020 m ASL thus capturing different types of terrain characteristics (i.e. coastal, inland, or mountainous terrain).

## WRF 1x1 km Parameterization

For the high-resolution dynamical downscaling simulation performed with WRF v 3.7.1 over the PaTrop area, four nested domains are used (d01-d04), with horizontal resolution of 27, 9, 3 and 1 km. The vertical layer distribution consists of 45 sigma levels up to a height of about 20 km. Boundary conditions are taken from ERA-Interim and a high resolution terrestrial dataset (ASTER 1s global GDEM v2) is introduced. Model output is recorded every 30 minutes, from which Zenith Hydrostatic Delays (ZHDs) and Zenith Wet Delays (ZWDs) are calculated.

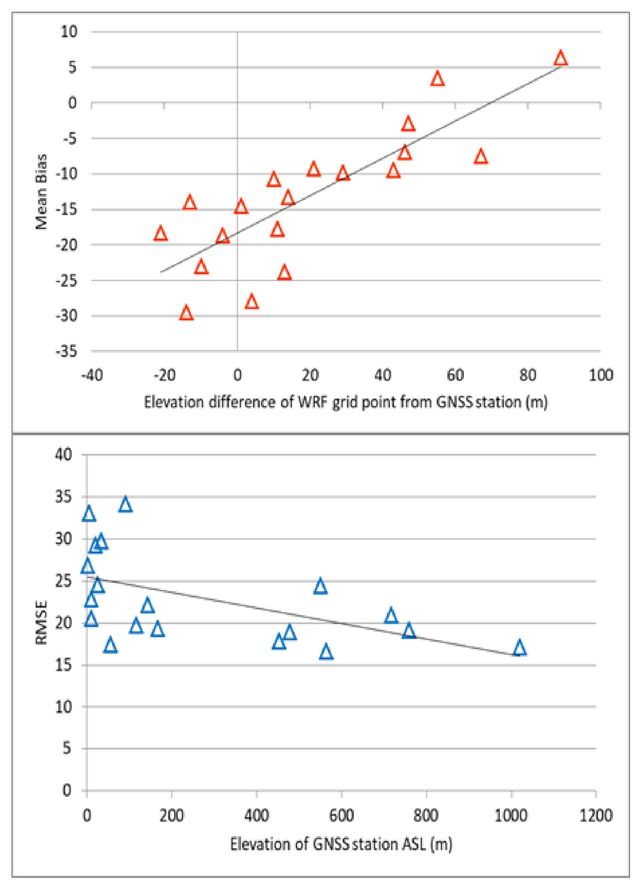


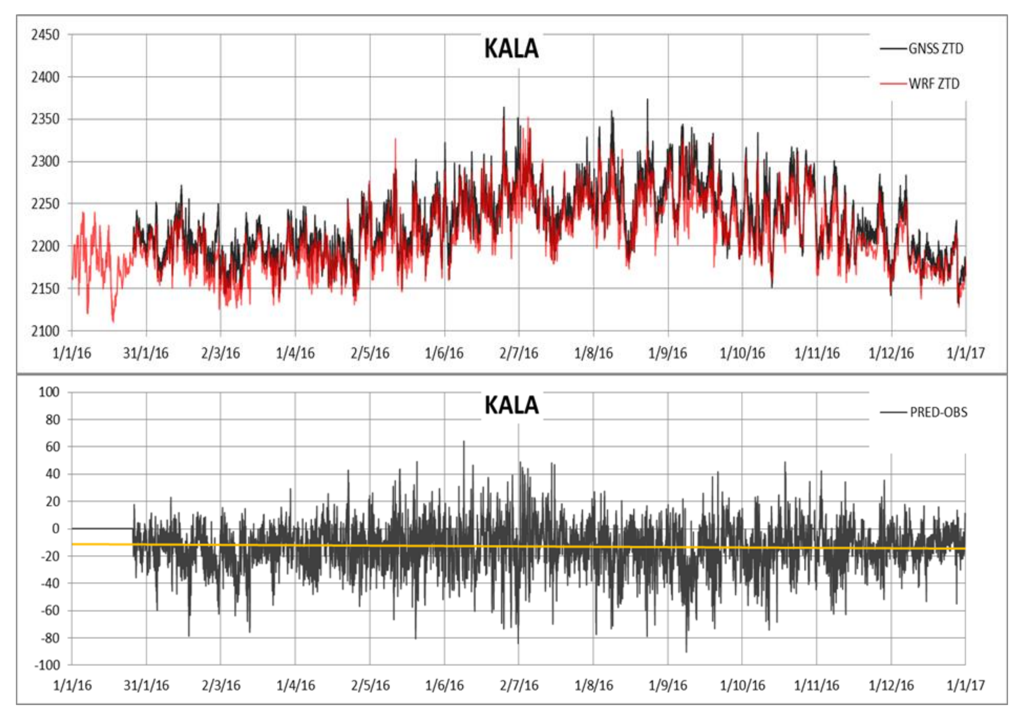

| | MOD1 | MOD2 | MOD3 | MOD4 | MOD5 |
|---|---|---|---|---|---|
| Microphysics | WSM3 | Morrison | Morrison | Morrison | SBU-YLin |
| Land surface | NOAH | NOAH | Pleim-Xiu | Pleim-Xiu | NOAH |
| Surface layer physics | Monin-Obukhov | Monin-Obukhov | Pleim-Xiu | Pleim-Xiu | MM5 similarity |
| Radiation physics (sw) | | | | | |
| Radiation physics (lw) | RRTM | RRTM | RRTM | RRTM | RRTM |
| Planetary boundary layer | MYJ | MYJ | ACM2 | ACM2 | YSU |
| Cloud physics | Kain-Fritsch at 27 km | Kain-Fritsch at 27 km | Kain-Fritsch at 27 km | Kain-Fritsch at 27/9 km | Kain-Fritsch at 27/9 km |

Five different physical parameterization schemes are tested against GNSS measurements, in order to evaluate the model's forecasting skill. The sensitivity analysis demonstrates that the optimum WRF configuration to be used for the entire period of the PaTrop experiment is MOD5.

## Validation of WRF Derived ZTDs with GNSS ZTD Measurements

The optimal WRF scheme is selected for the whole PaTrop period (Jan-Dec 2016), and model output is validated with the use of GNSS tropospheric data.

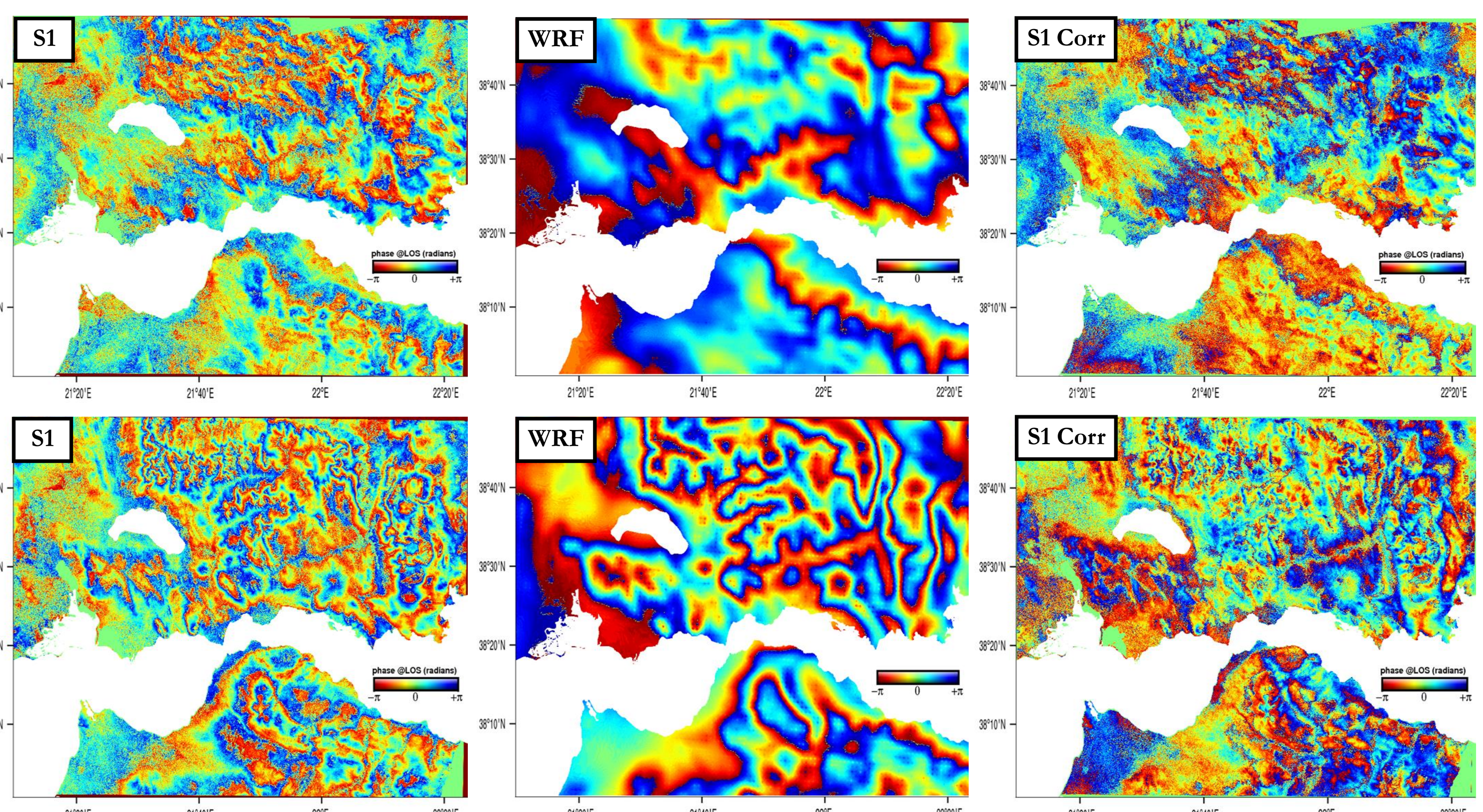



Statistical analysis reveals that correlation between WRF and GNSS ZTDs at the 19 stations is good (correlation co-efficient 0.91-0.93), with mean bias (MB) ranging from -29.50 mm (PAT0 station) to 6.41 mm (KRIN station), indicating that the model tends to slightly underestimate the tropospheric ZTD as compared to the GNSS derived values.

## InSAR Tropospheric Correction with the use of WRF Derived Delay Maps

Tropospheric corrections over a set of 20 wrapped Sentinel-1 interferograms are performed by calculating tropospheric delay (ZTD) fields over the PaTrop study area with the use of WRF. In most cases, corrections applied to the wrapped interferograms lead to a decrease of the phase gradient. The degree of tropospheric delay correction is correlated with WRF-GNSS average bias differences (Δbias) at the times of acquisitions. The proposed methodology produces encouraging results and can be applied in any geographical location, as long as the LAM is locally configured.

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