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TAKING THE PULSE OF OUR PLANET FROM SPACE

EUMETSAT ECMWF EUSPA

ON THE APS FILTERING OF DINSAR MEASUREMENTS IN VOLCANIC AREAS: A COMPARATIVE ANALYSIS BETWEEN METHODOLOGIES BASED ON INTERFEROMETRIC TIME SERIES AND EXTERNAL DATA BASED APPROACHES

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Outline

1. ***PROBLEM***

   Presence of Atmospheric Phase Screen (APS) in the DInSAR products

2. ***Filtering APS from DInSAR products, considered approaches***

   - APS estimation through the ECMWF ERA-5 data
   - APS estimation procedure by exploiting P-SBAS time-series approach

3. ***OBJECTIVE***

   - Comprehensive analysis of the ERA-5 APS corrections performances on large DInSAR datasets
   - Comparison with the P-SBAS-based APS filtering results

4. ***CASE STUDIES***

   - The Etna (Sicily) volcano area
   - The Canary Island of La Palma (Spain)

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Problem

DInSAR Limitations: Atmospheric Phase Screen (APS)

- Atmospheric properties such temperature, pressure and humidity can vary in space and time, thus producing variations in the refractivity index of the atmosphere (through which the transmitted microwave pulses and the backscattered signals propagate).

- Due to these variations between the acquisition times of the two SAR images, the corresponding interferogram could present an APS component, which accounts for atmospheric artifacts contaminating the DInSAR measurements.

- Distinguishing the APS from the real deformation is complicated. This is particularly true in areas characterized by the presence of significant topography (since the atmospheric phase component is correlated with topography) and significant deformation as well, as in the case of volcanic areas.

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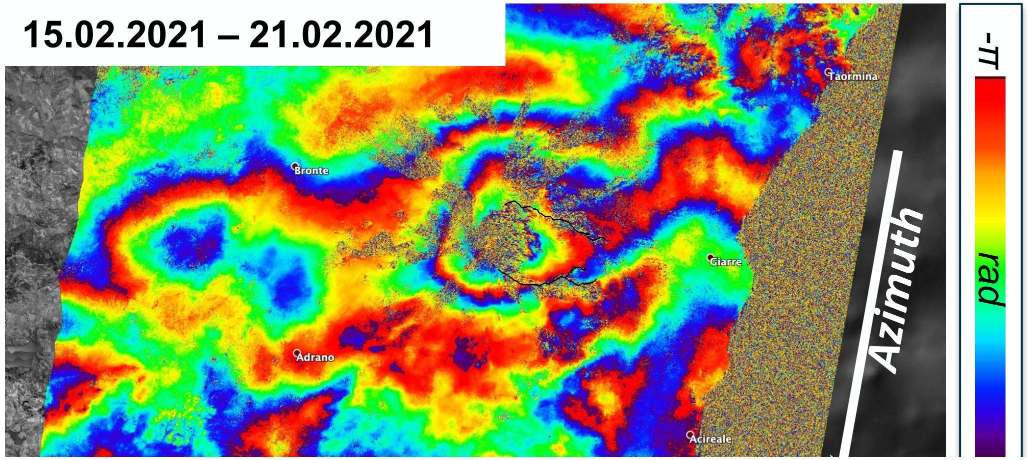
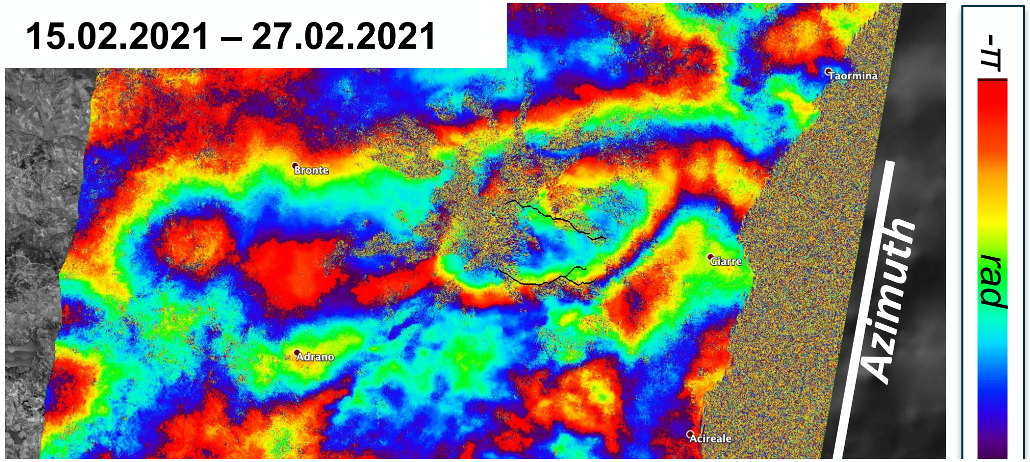
DInSAR Limitations: Atmospheric Phase Screen (APS)

Mt. Etna – Sentinel-1 Descending Orbit

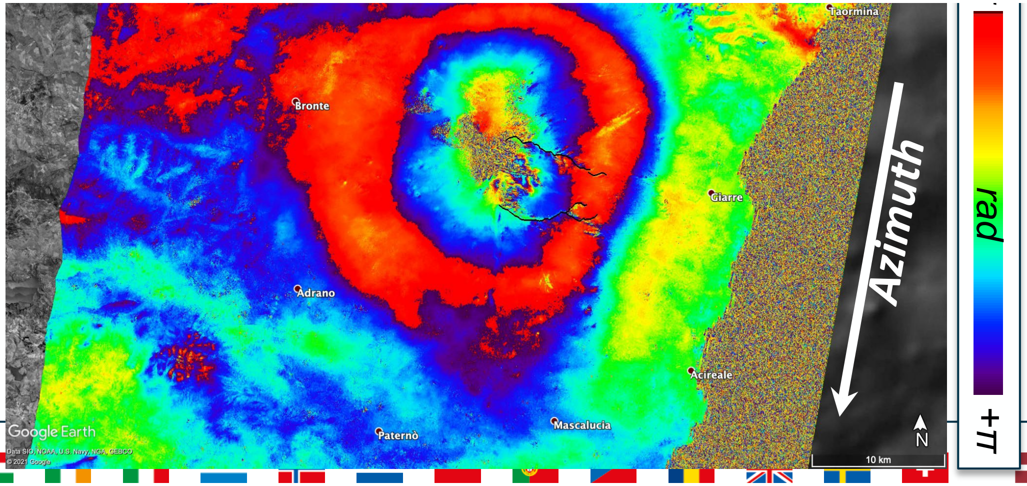
15.02.2021 – 21.02.2021



15.02.2021 – 27.02.2021



While deformation signals are persistent in time, atmospheric artifacts are typically poorly correlated in time!



Baseline Perp. ≈ 98 m

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Objectives

- Exploiting ECMWF ERA-5 data to estimate APS and evaluate their effectiveness through an extensive analysis based on statistical metrics applied to large P-SBAS interferometric datasets.

  Drawback: coarse spatial resolution of ERA-5 data

- Comparing with the P-SBAS-time-series based APS filtering

  Drawback: need of temporal sequence of SAR images

- CASE STUDIES:
  - The Etna (Sicily) volcano area: 350 S1 slices, ascending orbit, **981 Interferograms**
  - The Canary island of La Palma (Spain): both ascending (269 S1 slices, **761 interferograms**) and descending (272 S1 slices, **773 interferograms**)

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ECMWF ERA-5 atmospheric corrections

- ECMWF datasets provides meteorological parameters, including pressure, temperature, and humidity as a grid in geographic coordinates.

- The ERA-5 data grids are sampled with 137 pressure levels in altitude (from the surface up to about 80 km) and 31 km in the horizontal plane. The temporal sampling is 1 hour.

- ERA-5 APS corrections are calculated by exploiting the PyAPS* software and then applied to the P-SBAS interferograms

** Jolivet, R., R. Grandin, C. Lasserre, M.-P. Doin and G. Peltzer (2011), Systematic InSAR tropospheric phase delay corrections from global meteorological reanalysis data, Geophys. Res. Lett., 38, L17311, doi:10.1029/2011GL048757*

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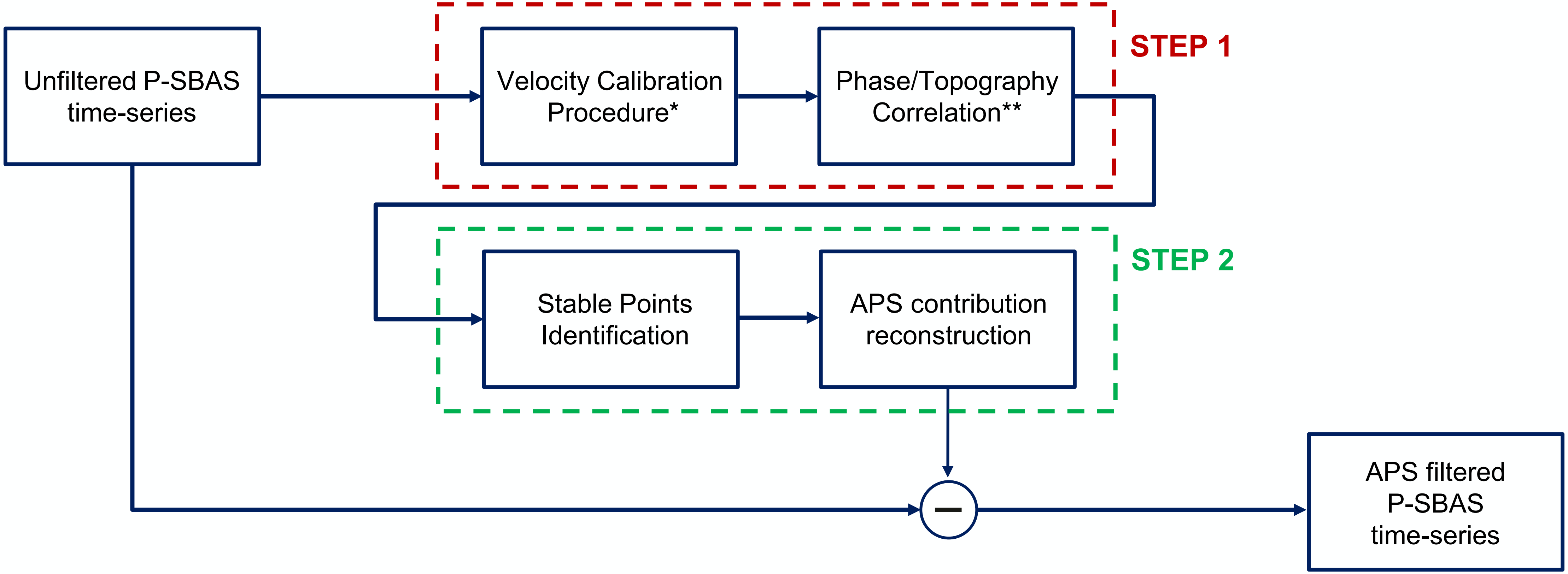
P-SBAS time-series-based APS estimation procedure



*Lanari, R., et al. "Automatic generation of sentinel-1 continental scale DInSAR deformation time series through an extended P-SBAS processing pipeline in a cloud computing environment." *Remote Sensing* 12.18 (2020): 2961.

**Fernández, J., et al. "Gravity-driven deformation of Tenerife measured by InSAR time series analysis." *Geophysical Research Letters* 36.4 (2009).

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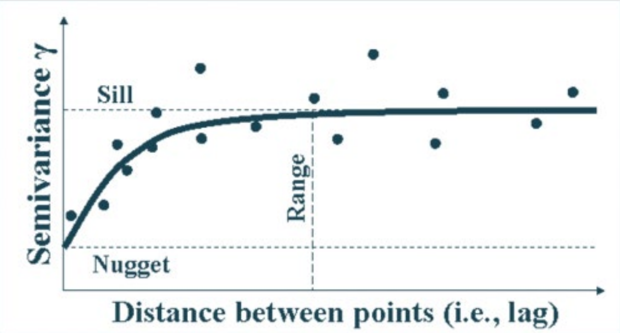
Performance evaluation of ERA-5 corrections

Statistical analysis based on the following metrics:

- Interferometric Phase Standard Deviation before and after the ERA-5 APS correction
- Correlation between unwrapped interferometric phase and elevation:
  a linear fit was considered in order to measure the correlation degree between the elevation and the phase.
- Variogram analysis:
  The experimental variograms are fitted with a parametric exponential model from which two parameters *sill* and *range*, *s* and *r*, respectively, are retrieved and compared.

$$f(h) = \begin{cases} 0 & if\ h = 0 \\ s * \left(1 - exp\left(\frac{-d}{r}\right)\right) & if\ h \neq 0 \end{cases}$$



The statistics have been calculated both with respect to the original and the ERA-5 corrected interferograms, based on their comparison the percentages of successfully corrected interferograms have been retrieved.

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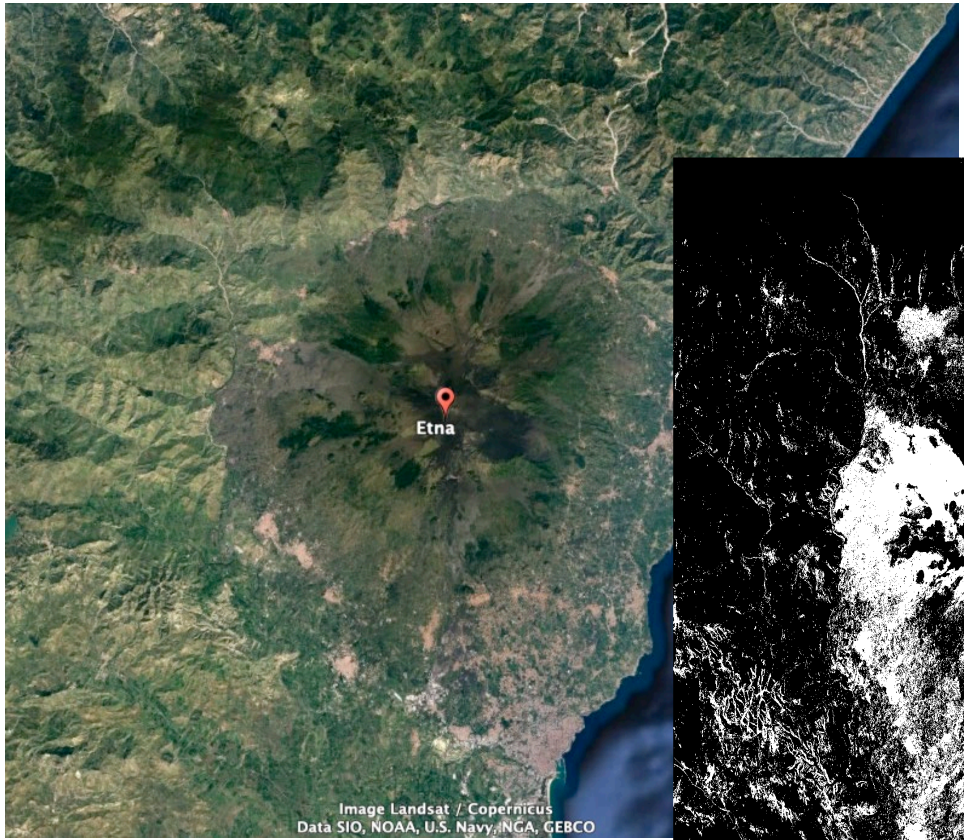
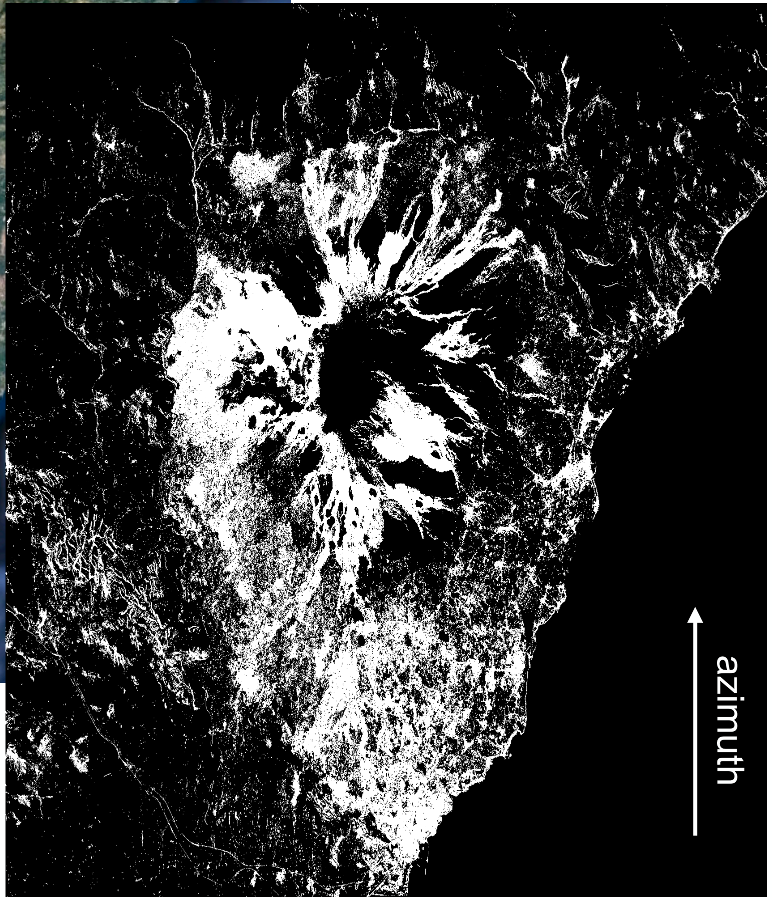
Case Study 1: the Etna volcano





Area of Interest	Etna volcano
Sensor	Sentinel-1 A/B
Orbit	Ascending
Extent of the analyzed Area	68km x 80km
N. of S1 images	350
Time Span (mm/dd/yyyy)	06/04/2015 – 28/02/2022
Acquisition Time	4:56 p.m.
N° P-SBAS interferograms	981
Pixel size	40m x 40m
Number of coherent points	626730
Maximum Elevation	3357 m

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Case Study 1: the Etna volcano

ERA-5 corrections performance evaluation: statistical analysis results

1. **Phase Standard Deviation** (evaluated over the entire scene):

   75% of the interferograms show a reduced phase standard deviation after the ERA-5 corrections

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Case Study 1: the Etna volcano

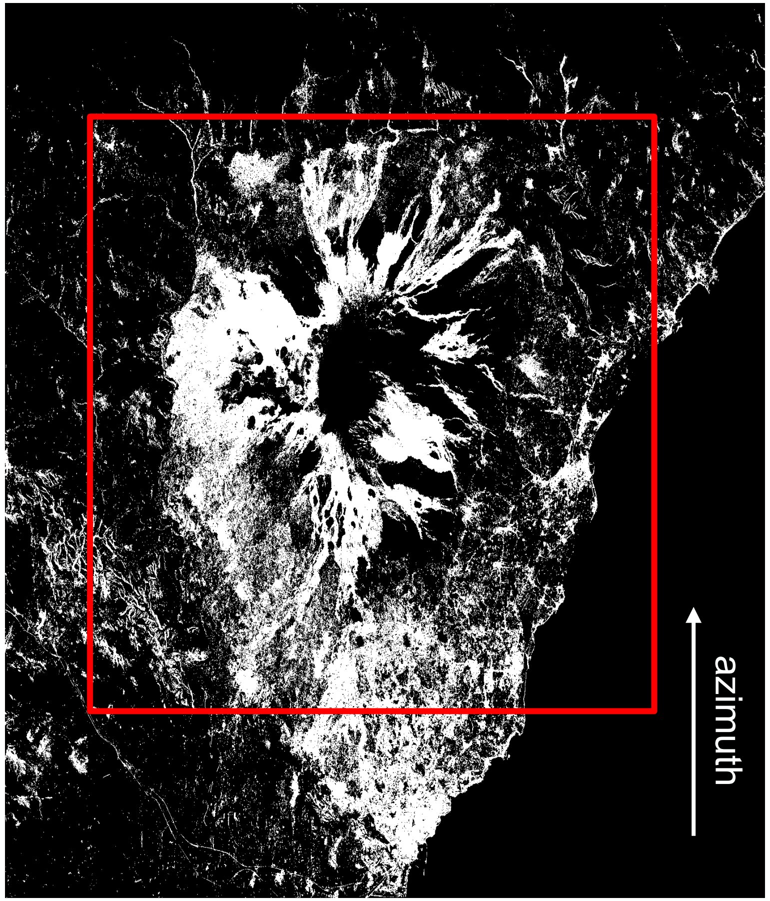
ERA-5 corrections performance evaluation: statistical analysis results

2. Correlation between uwrapped interferometric phase and topography (linear fit)

analyzed area	n. of coherent pixels	maximum DEM elevation
red crop	330484	2842 m

72 % of the interferograms show a decreased correlation with topography after the ERA-5 APS correction

73 % of the interferograms show a decreased slope after the ERA-5 APS correction



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Case Study 1: the Etna volcano

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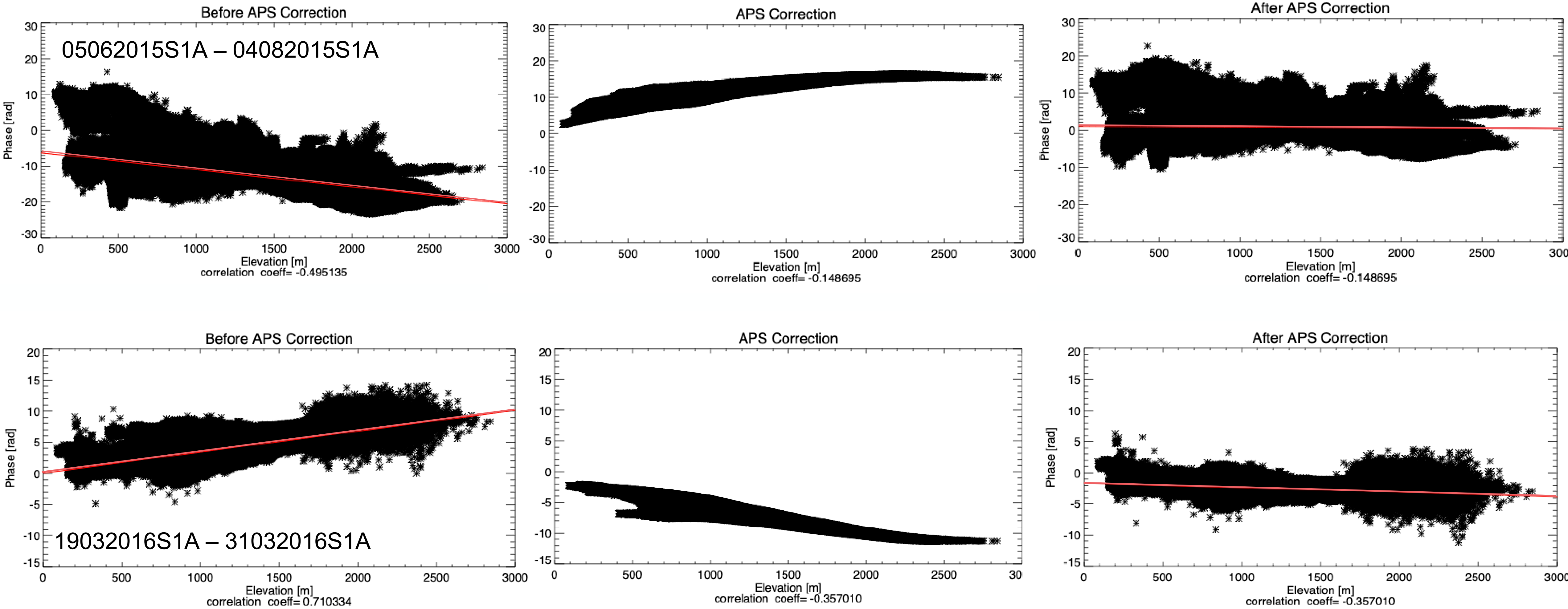
Scatterplots Phase/Elevation before and after ERA-5 APS correction



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Case Study 1: the Etna volcano

ERA-5 corrections performance evaluation: statistical analysis results

1. **Phase Standard Deviation**:

   75% of the interferograms show a reduced phase standard deviation after the ERA-5 corrections

2. **Correlation between uwrapped interferometric phase and topography** (linear fit):

   72 % of the interferograms show a decreased correlation with topography after the ERA-5 correction;

   73 % of the interferograms show a decreased slope after the ERA-5 APS correction

3. **Variogram Analysis**

   in the **71 %** of the interferograms, variogram shows a decreased sill after the ERA-5 APS correction

   in the **74 %** of the interferograms, variogram shows an improved range value after the correction

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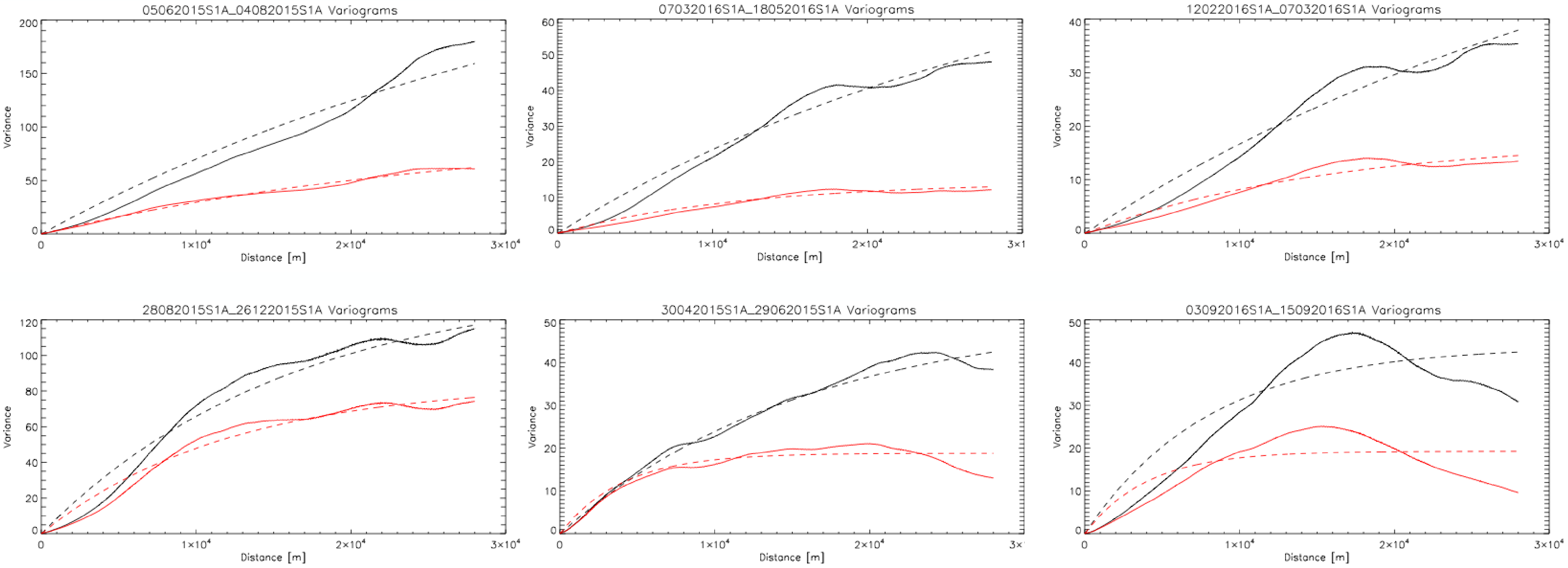
Case Study 1: the Etna volcano

Example of Variograms before and after ERA-5 APS correction



black: before APS correction
solid lines: experimental variogram

red: after APS correction
dashed lines: exponential fitted behavior

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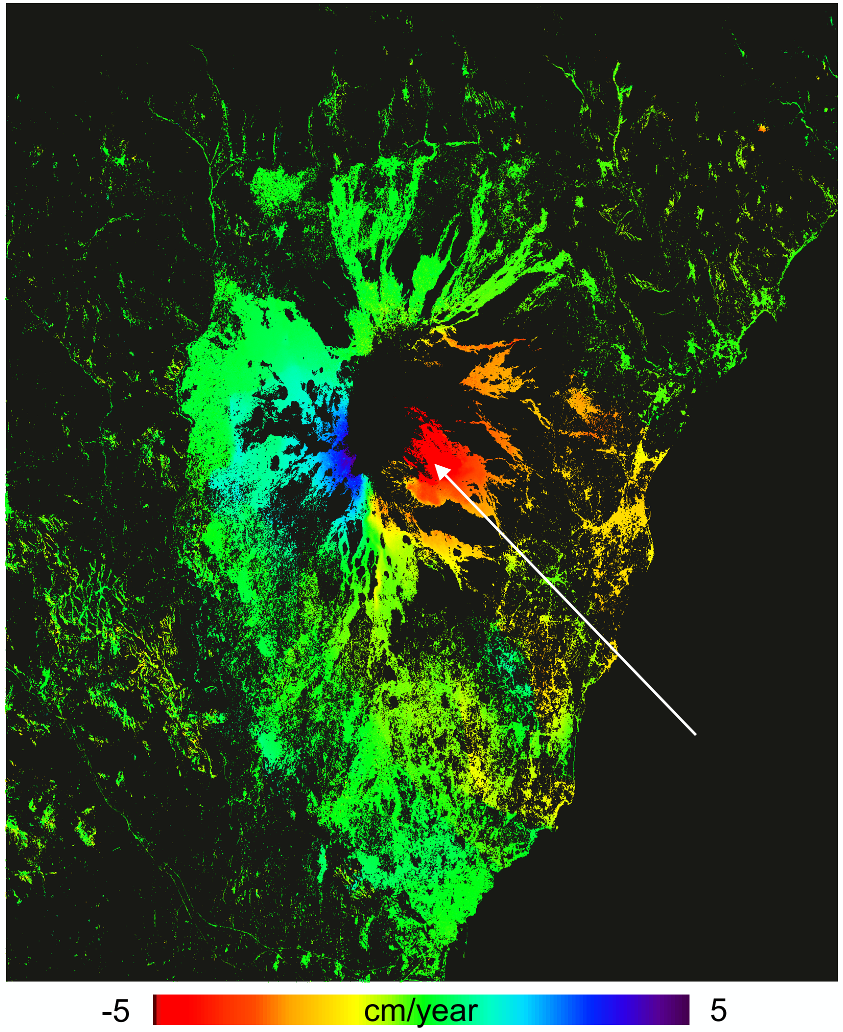
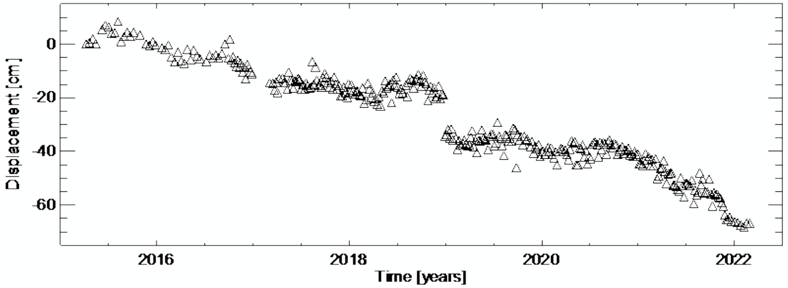
Case Study 1: the Etna volcano

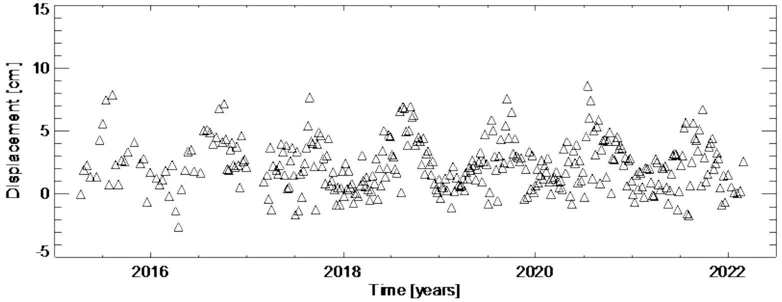
Mean deformation velocity map



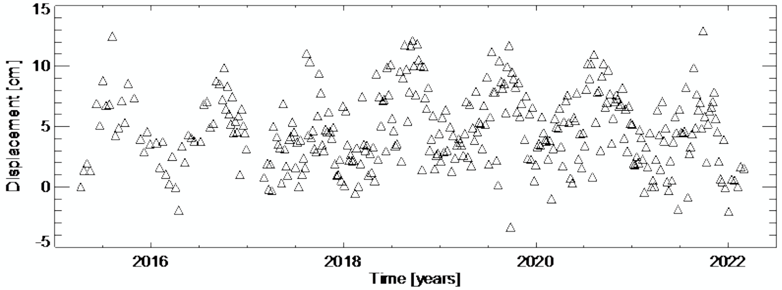
P-SBAS non filtered deformation time-series



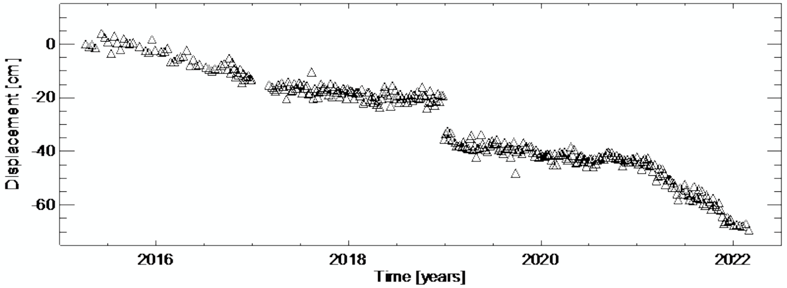
ERA-5 correction time-series



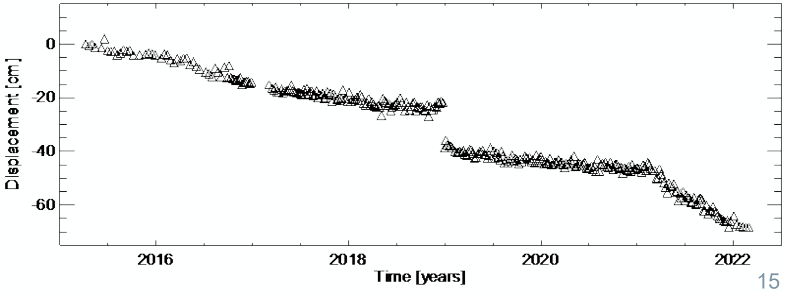
P-SBAS correction time-series



ERA-5 filtered deformation time-series



P-SBAS filtered deformation time-series



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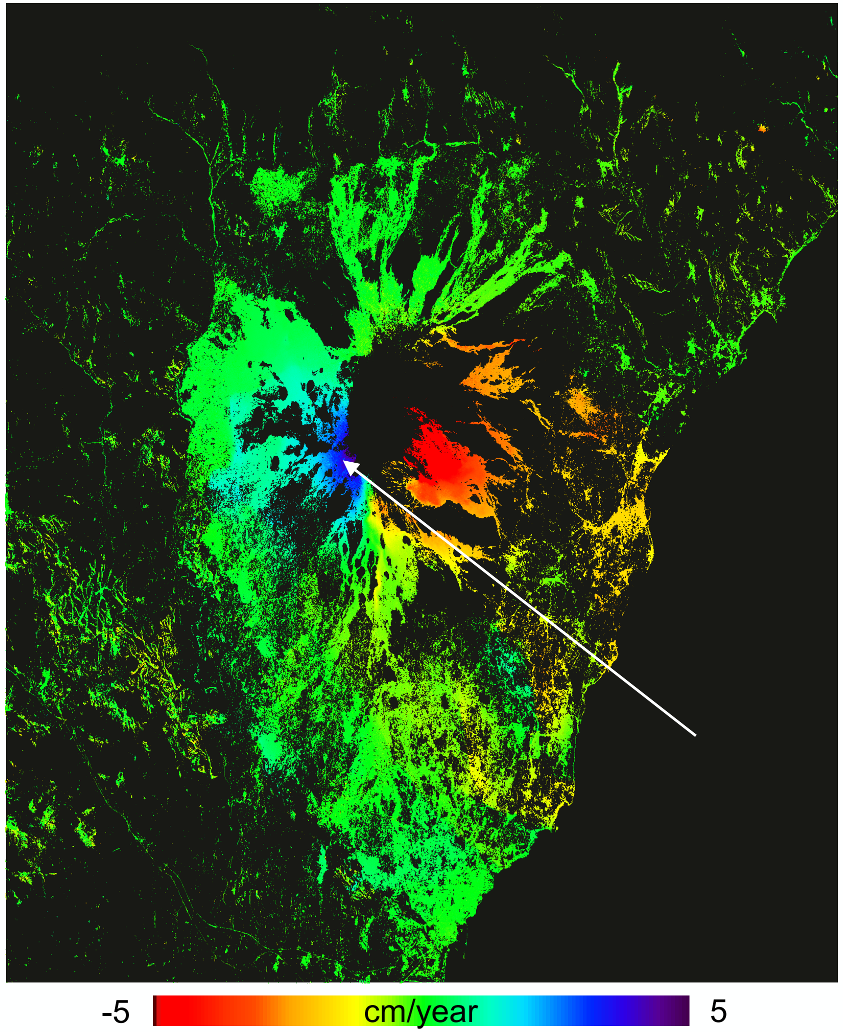
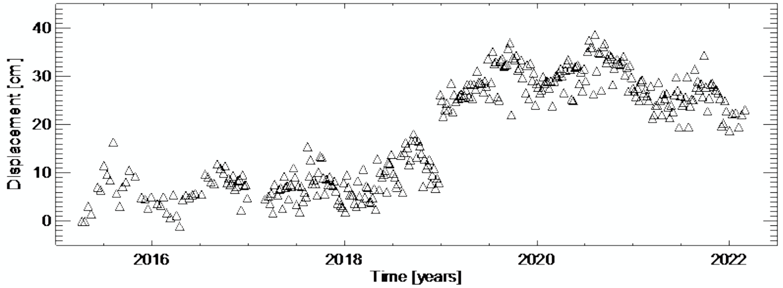
Case Study 1: the Etna volcano

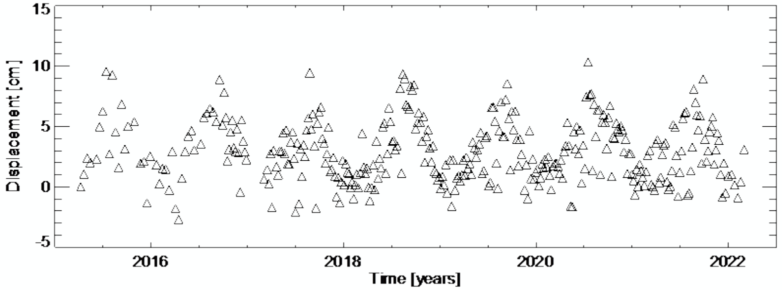
Mean deformation velocity map



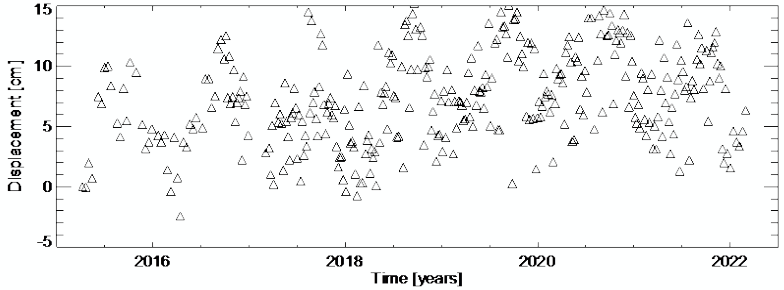
P-SBAS non filtered deformation time-series



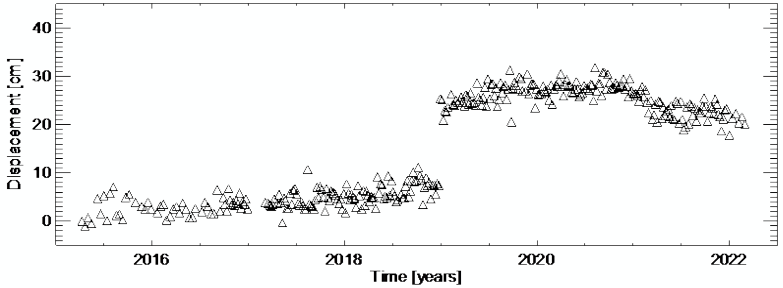
ERA-5 correction time-series



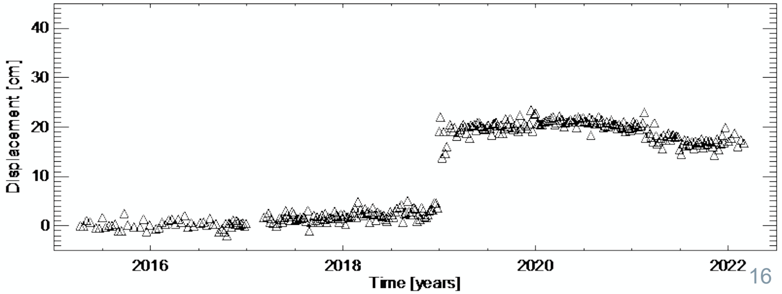
P-SBAS correction time-series



ERA-5 filtered deformation time-series



P-SBAS filtered deformation time-series



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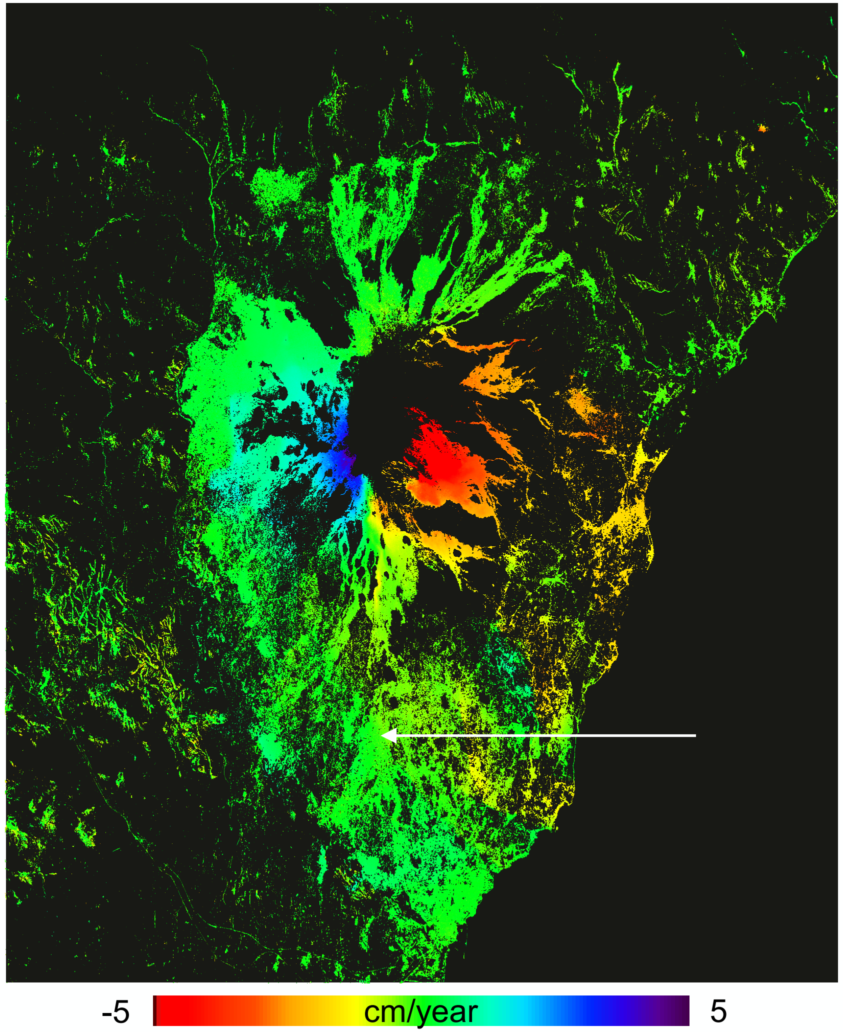
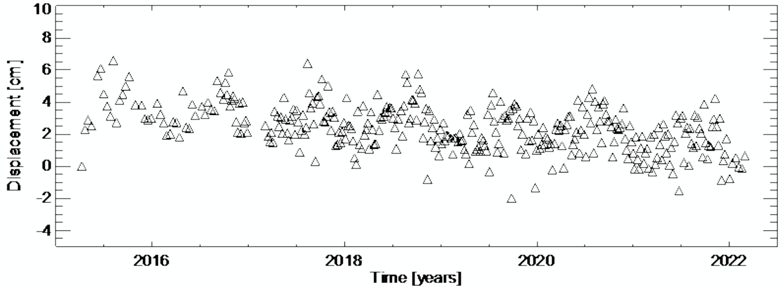
Case Study 1: the Etna volcano

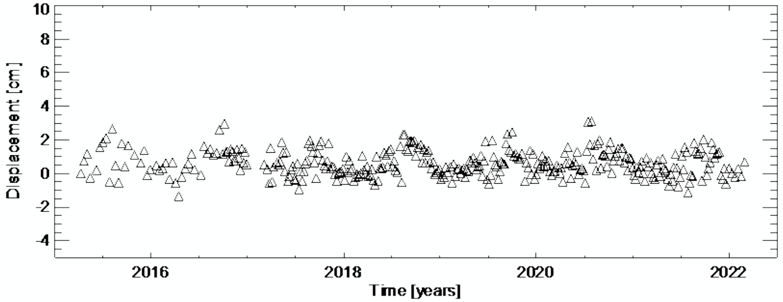
Mean deformation velocity map



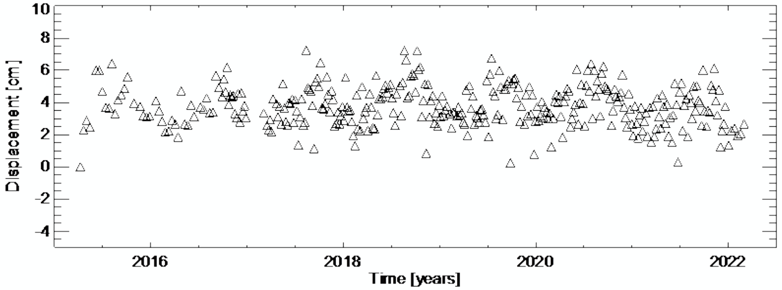
P-SBAS non filtered deformation time-series



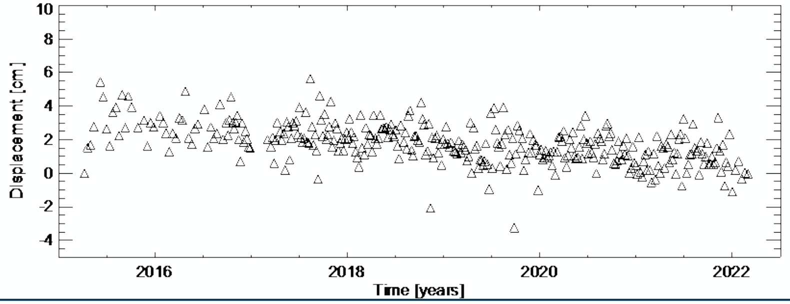
ERA-5 correction time-series



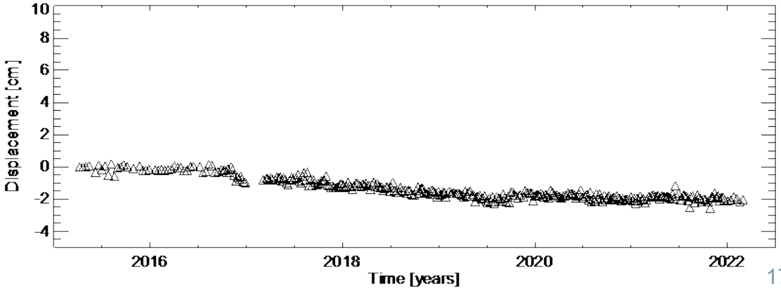
P-SBAS correction time-series



ERA-5 filtered deformation time-series



P-SBAS filtered deformation time-series



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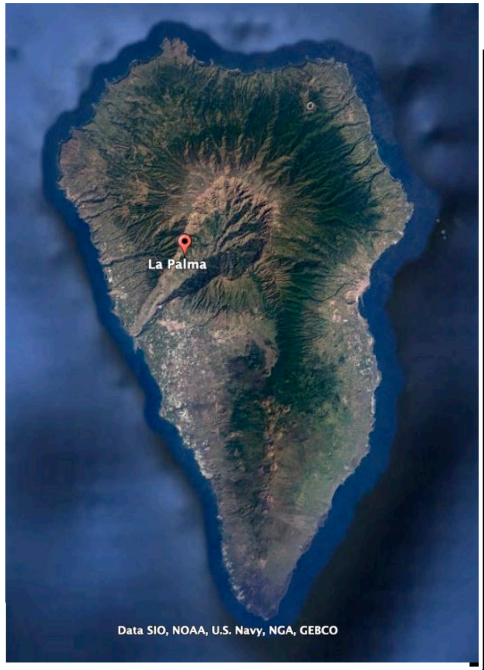
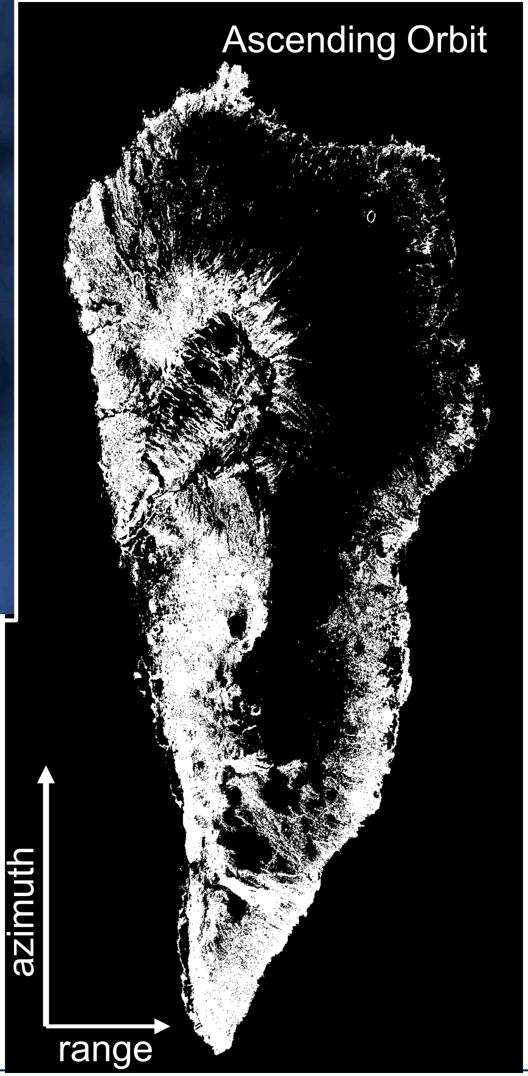
Case Study 2: La Palma Island





Area of Interest	La Palma Island	
Sensor	Sentinel-1 A/B	
Orbit	Ascending	Descending
Extent of the analyzed area	74km x 34km	69km x 34km
N. of S1 images	269	272
Time Span (mm/dd/yyyy)	08/01/2017 – 02/10/2021	16/01/2017 – 04/10/2021
Acquisition Time	7:13 p.m.	7:10 a.m.
N° P-SBAS interferograms	761	773
Pixel size	40m x 40m	
Number of coherent points	230677	281862
Maximum Elevation	2423 m	

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Case Study 2: La Palma

ERA-5 corrections performance evaluation: statistical analysis results

Statistical metric	Ascending Dataset	Descending Dataset
Phase Standard Deviation Reduction	**76 %** of the Interferograms	**82 %** of the Interferograms
Correlation between uwrapped interferometric phase and topography	**73 %** of the interferograms show a decreased correlation with topography after the ERA-5 APS correction **74 %** of the interferograms show a decreased slope after the ERA-5 APS correction	**76 %** of the interferograms show a decreased correlation with topography after the ERA-5 APS correction **78%** of the interferograms show a decreased slope after the ERA-5 APS correction
Variogram Analysis	in the **68%** of the interferograms, variogram shows a decreased sill after the ERA-5 APS correction in the **69%** of the interferograms, variogram shows an improved range value after the correction	in the **75%** of the interferograms, variogram shows a decreased sill after the ERA-5 APS correction in the **78%** of the interferograms, variogram shows an improved range value after the correction

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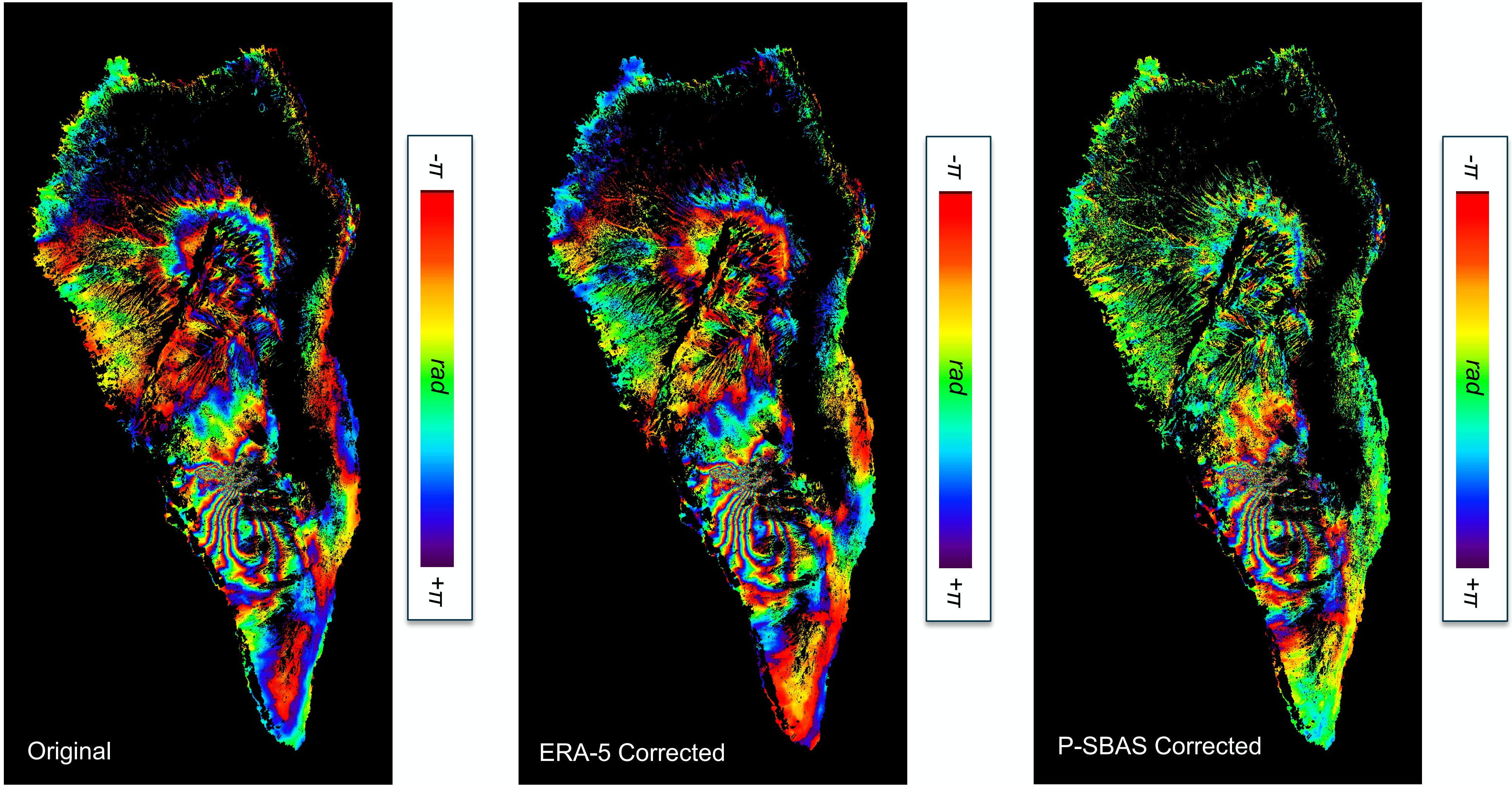
Case Study 2: La Palma Island

Descending orbit: Co-eruptive Wrapped Interferogram16092021S1B_22092021S1A



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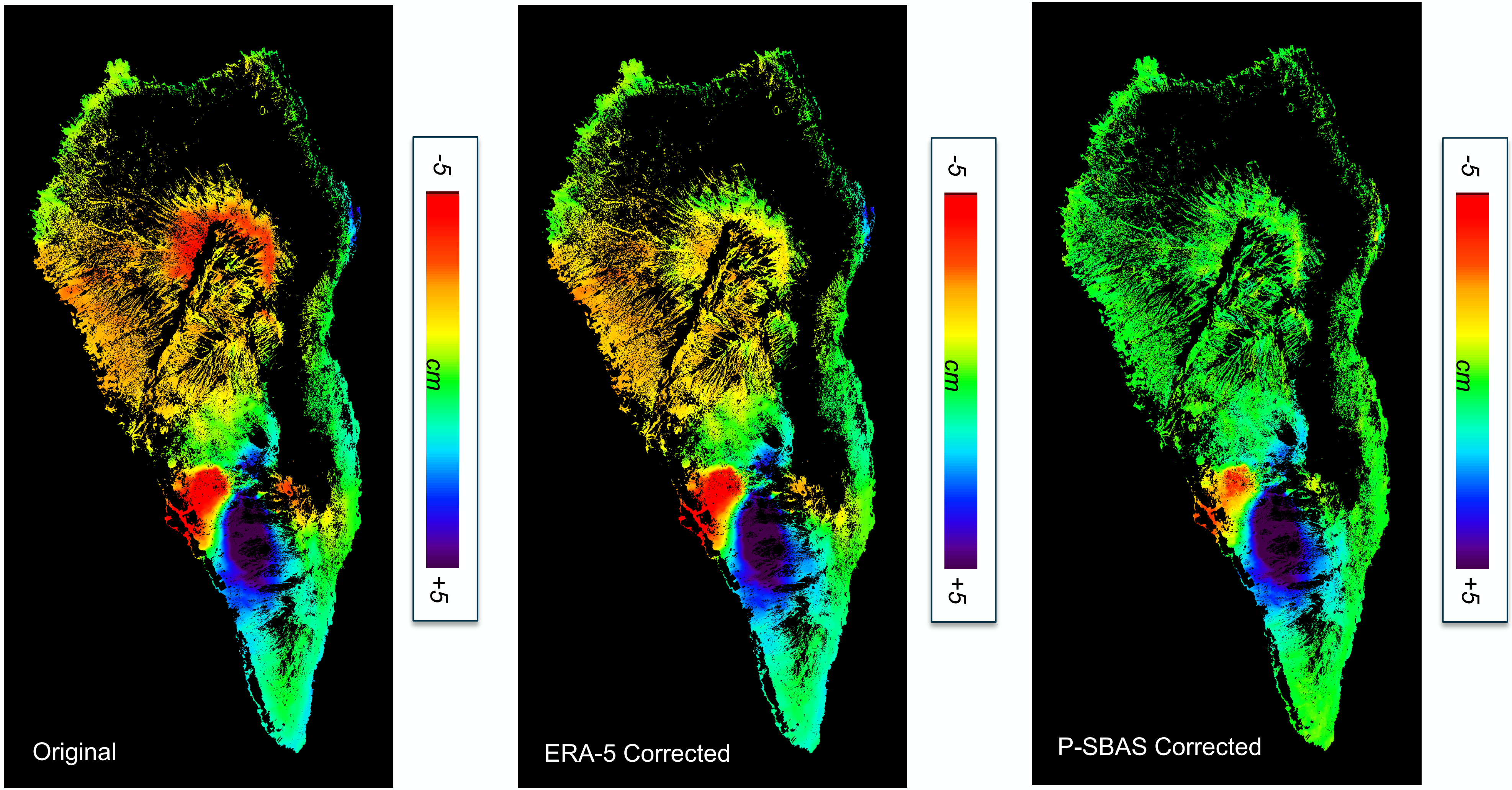
Case Study 2: La Palma Island

Descending Orbit: Co-eruptive Unwrapped Interferogram16092021S1B_22092021S1A



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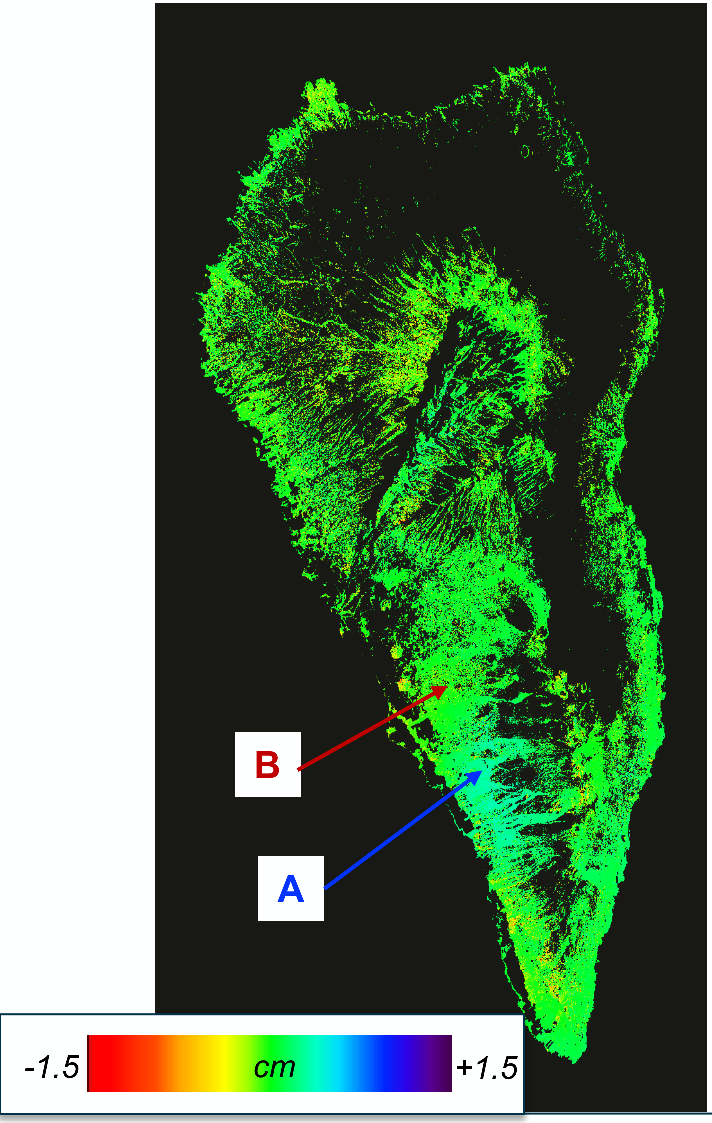
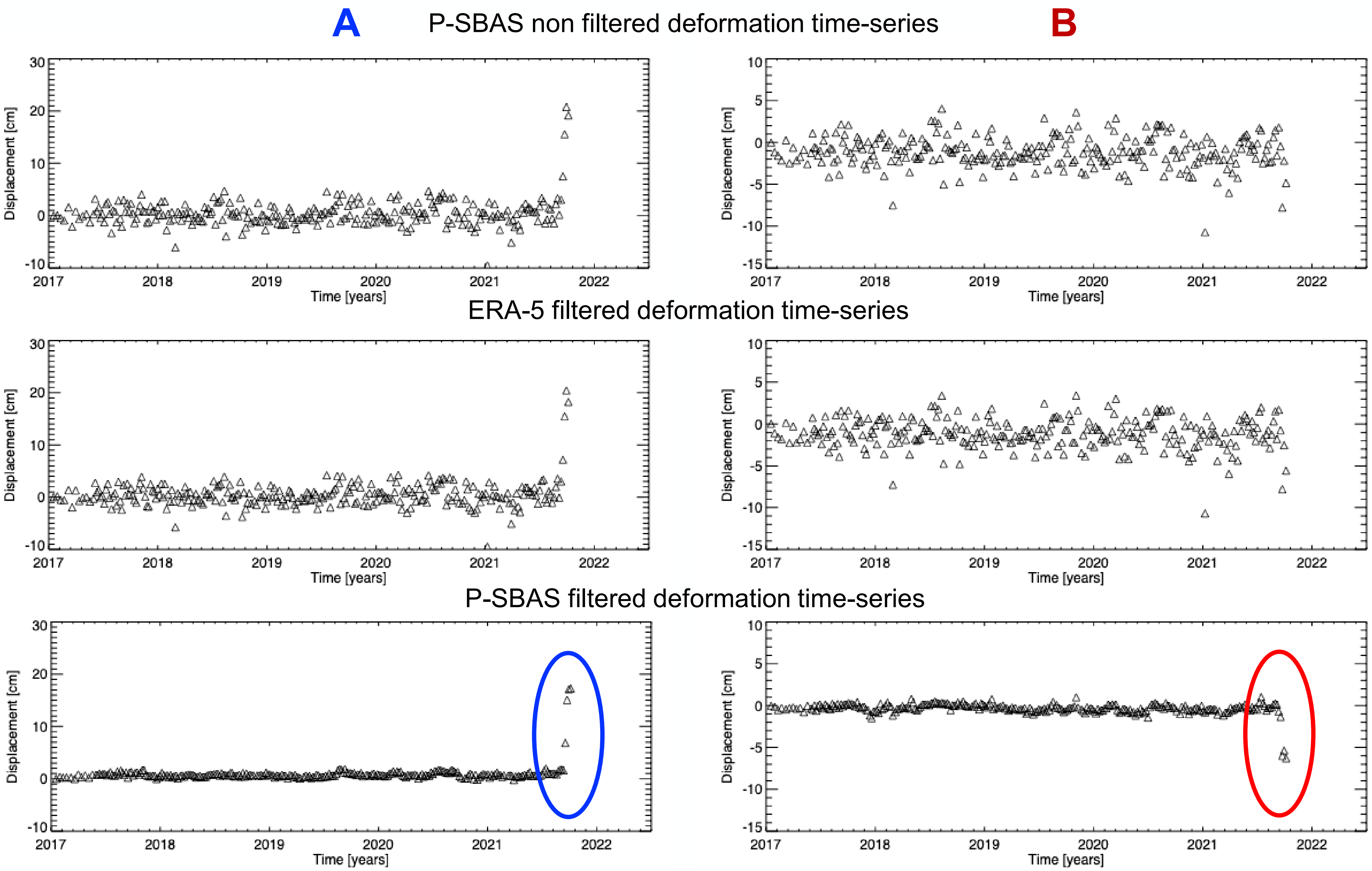
Case Study 2: La Palma





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Conclusions and Future Works

- Based on the performed statistical analysis, the ERA-5 APS corrections applied to large datasets of interferograms are effective in 70%-80% of cases

- In particular, the ERA-5 APS corrections allow to correct well the phase component correlated with the topography, whereas are not able to filter-out small spatial scales (turbulent) component and the temporal high-frequency phase component that is, instead, well estimated through the second step of the P-SBAS atmospheric filtering

- **Using ERA-5 corrected time series as input for the second step of the P-SBAS atmospheric filtering**

- **Evaluation and comparison with the ETAD layers for atmospheric corrections!**

Thank you for the attention!

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The APS has been calculated by exploiting the ECMWF ERA-5 data following the approach of evaluating the atmospheric phase delay term, $\boldsymbol{\varphi}_{atm}$, by integrating the total refractivity *N(T, P, e)* along the path joining the ground location of the pixel for which the atmospheric artifacts are calculated, r_{ground}, and the location of the satellite when the image was acquired, r_{sat} . *[Jolivet et al., 2011]*

$$\varphi_{atm} = \frac{-4\pi}{\lambda} 10^{-6} \int_{r_{ground}}^{r_{sat}} N(r)\, dr$$

where λ is the satellite wavelength and *N* is a function of the temperature T, the partial pressure of dry air, *P*, and the partial pressure of the water vapor, *e*.

R. Jolivet, R. Grandin, C. Lasserre, M. P. Doin, and G. Peltzer, “Systematic InSAR tropospheric phase delay corrections from global meteorological reanalysis data,” *Geophysical Research Letters*, vol. 38, no. 17, 2011, doi: 10.1029/2011GL048757.

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