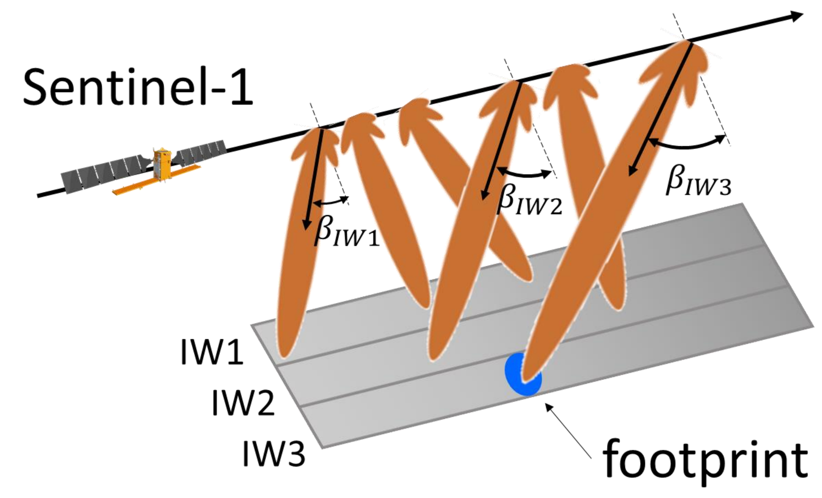
Phase sources separation in multi-squint SAR interferometry constellations

MOTIVATION

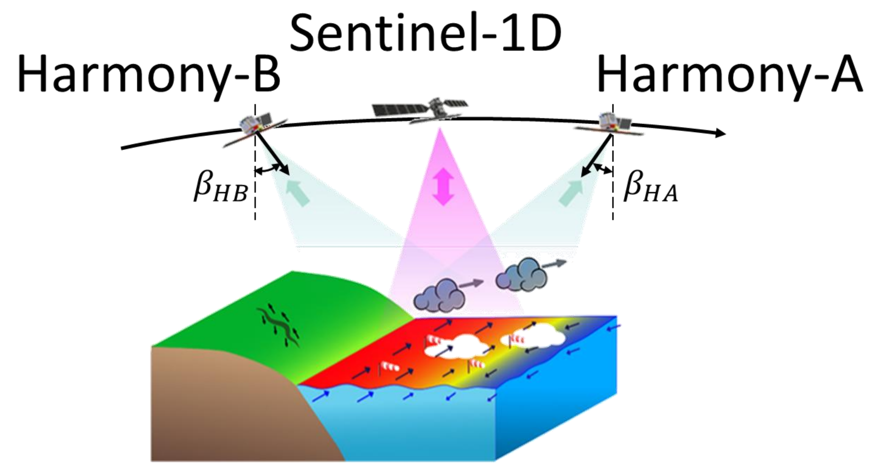
Modern Synthetic Aperture Radar (SAR) imaging systems are designed to increase ground coverage using multi-swath acquisition modes (ScanSAR, TOPS) and measure surface displacements, such as those associated with earthquakes and volcanic activities, using:

(1) The line-of sight (LOS) variation due to the azimuth steering of the antenna beam (e.g. ESA Sentinel-1 TOPS)

(2) Multiple LOSs from multiple spacecraft flying in stereo configuration (e.g. "Harmony", ESA's Earth Explorer 10 Candidate Mission)



(1)
Sentinel-1 TOPS acquisition mode



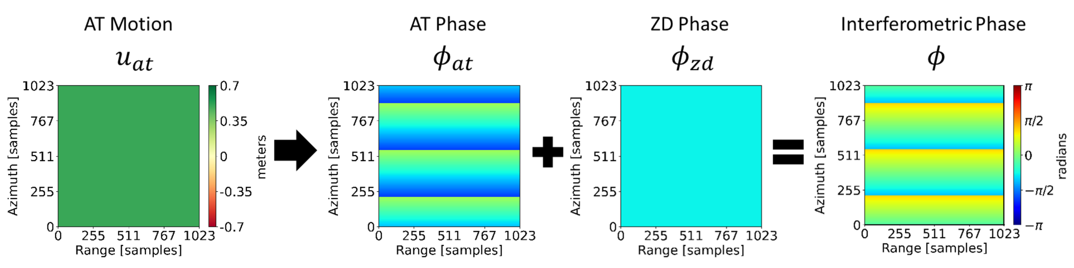
(2)
Harmony STEREO configuration mode

Both systems present phase distortions in the interferometric phase due to multiple sources (e.g. static limited geometric accuracies, ionospheric and tropospheric turbulences, and surface displacements). These phase contributions overlap and it becomes difficult to separate them using state-of-the-art algorithms. The goal of my dissertation is to use innovative deep learning algorithms to improve the separation of the interferometric phase contribution.

(1) PHASE SOURCE SEPARATION IN INSAR BURST MODES

Introduction

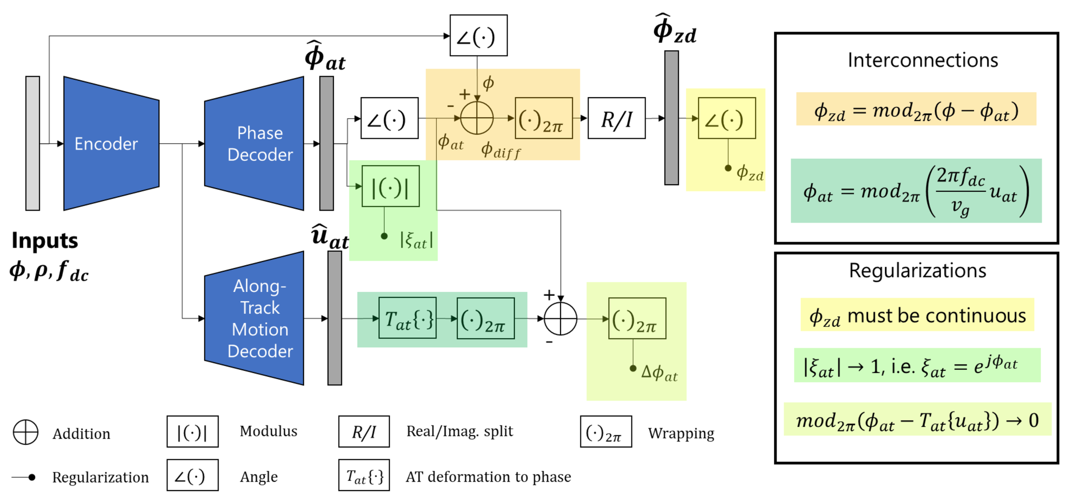
Sentinel-1 (S-1) is the first SAR mission of the ESA Copernicus Programme. It mainly operates in TOPS mode, an advanced burst mode in which the antenna beam is electronically rotated from backward to forward in the flight direction within each burst. The antenna steering creates a variable sensitivity to the surface displacement along the azimuth direction that is difficult to decouple in along-track (AT) and zero-Doppler (ZD) phase contributions. In a nutshell:



Given a constant AT surface displacement (u_{at}), the associated phase (ϕ_{at}) presents jumps in the overlapped areas, proportional to the amount of deformation, and a residual ZD phase (ϕ_{zd}) responsible for the motion in the slant range direction, continuous and in this case constant.

Methodology: Δ-Net

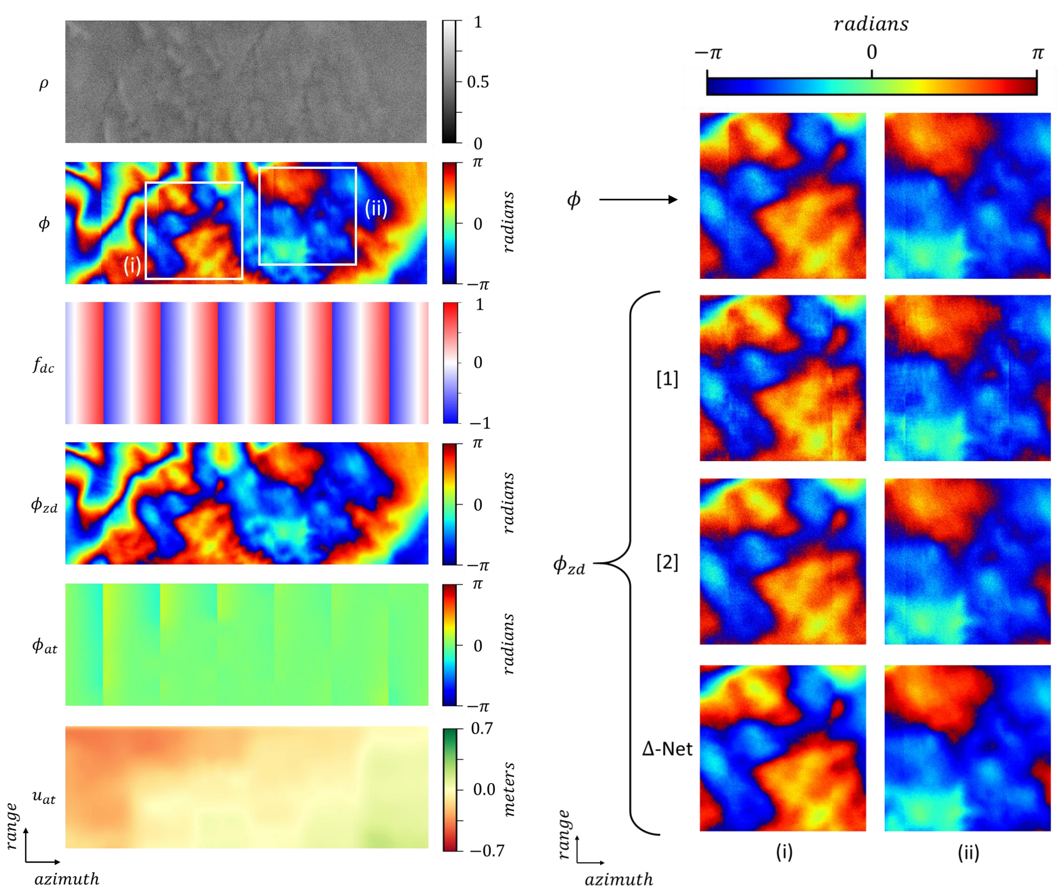
To preserve the dependencies of the phase contributions, we designed a multi-task CNN in a supervised learning fashion to jointly reconstruct the AT phase (ϕ_{at}), the ZD phase (ϕ_{zd}), and a proxy for the AT surface displacement (u_{at}).



The input variables are the interferometric phase (ϕ) as real and imaginary parts, the associated coherence (ρ), a map describing the sensitivity of the TOPS primary image retrieved by adding a linear azimuth dependency to each S-1 Doppler centroid range variant vector (f_{dc}).

Experimental results

Results over an inland glacier flow in Greenland using S-1 TOPS data show the outstanding performance of the Δ-Net in estimating displacements ranging from a few centimeters to tens of centimeters.



Δ-Net solves the limitations of speckle tracking [1] to properly estimate small displacements and offers greater robustness in handling diverse deformation patterns compared to burst overlap differential phase-based methods [2].

OUTLOOKS

- The Δ-Net could be exploited for monitoring glaciers in the Arctic, e.g., over Greenland by using S-1 data, measuring large deformations over ice land areas, e.g., glacial flows, but also over solid earth, e.g., earthquakes.
- The Δ-Net could mitigate the phase jumps present in TOPS interferograms in the presence of along-track motion in the scene as a generalization of the ESD technique.

(2) PHASE SOURCE SEPARATION IN INSAR STEREO CONFIGURATION SYSTEMS

- Simultaneous estimation of deformation and tropospheric delay with multi-squinted SAR interferograms using deep learning.

$$\begin{aligned}
&\text{Sentinel-1D} \quad \phi^{S1} = \phi^{S1}_{disp} + \phi^{S1}_{tropo} + \phi^{S1}_{iono} + \phi^{S1}_{geom}\\
&\text{Harmony-A} \quad \phi^{HA} = \phi^{HA}_{disp} + \phi^{HA}_{tropo} + \phi^{HA}_{iono} + \phi^{HA}_{geom}\\
&\text{Harmony-B} \quad \phi^{HB} = \phi^{HB}_{disp} + \phi^{HB}_{tropo} + \phi^{HB}_{iono} + \phi^{HB}_{geom}
\end{aligned}$$

PUBLICATIONS

A. Pulella, P. Prats-Iraola and F. Sica, "Multitask Learning for Phase Source Separation in InSAR Burst Modes," in *IEEE Transactions on Geoscience and Remote Sensing*, vol. 62, pp. 1-21, 2024, Art no. 4704821, doi: 10.1109/TGRS.2024.3401775

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[1] Rolf Scheiber, Marc Jager, Pau Prats-Iraola, Francesco De Zan, and Dirk Geudtner, "Speckle Tracking and Interferometric Processing of TerraSAR-X TOPS Data for Mapping Nonstationary Scenarios," in *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, vol. 8, no. 4, pp. 1709–1720, 2015.

[2] Nestor Yague-Martinez and Pau Prats-Iraola, "Accurate Azimuth Ground Deformation Estimation from Sentinel-1 Time Series," in *IEEE Geoscience and Remote Sensing Letters*, vol. 19, pp. 1–5, 2022.

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