AN OVERVIEW OF SAR SENSORS AND SOFTWARE AND A COMPARATIVE STUDY OF OPEN SOURCE (SNAP) AND COMMERCIAL (SARSCAPE) SOFTWARE FOR DINSAR ANALYSIS USING C-BAND RADAR IMAGES

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ABSTRACT: Synthetic Aperture Radar (SAR) Interferometry has several proven applications in seismology, volcanology, land movement, glaciology, hydrology, forestry sciences and numerous other fields. SAR techniques can solely be handled by experts in RADAR image processing. In addition, commercial software and high-quality radar data can be expensive and out of reach for most early researchers in this field. While many new SAR sensors are being launched, a look at their compatibility with different SAR processing software packages is also important. Thus an overview of past, present and future SAR sensors and software packages is discussed in this work. To understand the strength and limitations of open source and commercial SAR processing software, Differential Interferometry SAR (DInSAR) land displacement maps were created. The open-source software SNAP and commercial software SARscape were used to generate the land displacement maps. Sentinel-1A data over London between April 2015 and April 2018 was used. The land movement results obtained, shows that SNAP results are in good agreement to SARscape results. To compare the results, we made all attempts to keep the user input parameters consistent in both the experiments like multilooking factor, phase unwrapping principle, and filtering methods. However, some differences are unavoidable because of the Ground Control Points (GCPs) selection, co-registration, or spectral shift filtering steps. A difference of 1 mm/year in subsidence was observed in the results obtained from the two software packages. This is the first study that compares SNAP and SARscape software using Sentinel-1A data for London. We can conclude that open source and free of cost SAR software can be handy tools for DInSAR processing, especially for beginners who do not have access to expensive commercial software. We believe that more open source, free of cost datasets and software packages, will attract a larger number of early stage researchers in this field. It will enable an expansion of the use of DInSAR principle for different applications.

1. INTRODUCTION

Monitoring of surface movement is very important for city planners and managers, as it can be very dangerous for infrastructures such as canals, roads, railways, bridges, pipelines, and buildings. Even though accurate monitoring methods for surface displacement are present in geotechnical engineering, but conventional geotechnical instruments are limited within a small area. For example, precise continuous monitoring over an extensive area can be achieved using GPS but still monitored area is limited to few square kilometers. Also, surface displacement monitoring on dangerous area or on disaster area is difficult using conventional methods as these require installation of monitoring devices on the site. These limitations can be mitigated using Differential Interferometry Synthetic Aperture Radar (DInSAR).

DInSAR refers to interferograms, which has phase related to surface deformation only, and from which phase related to the topographic contribution has been deleted (Ferretti, Prati, and Rocca 2000). It can monitor ground deformation for vast areas without requirement of any devices on the ground. Also, DInSAR can be useful in case of disasters like landslides and earthquakes, where conventionally installed measurement devices might be . It also provides weather independency, sunlight independency (active sensor) and high (basin-level or greater) spatial coverage (Refice et al. 2001; Smith 2002).

The primary aim of this work is to improve the understanding of existing SAR software and products. For over three decades, various publications have highlighted the capability of differential interferometry to monitor ground movement in vertical direction with millimeter level accuracy (Gabriel, Goldstein, and Zebker 1989; Crosetto and Crippa 2005; Colesanti and Wasowski 2006). But this technique can be mainly used by specialists in InSAR processing as data and software availability for processing can be a major limitation, especially for novice users. Also, most SAR tools and software packages are often hard to work by a new user, and expert skills of InSAR imagery may be needed. Thus, we attempt to overview most widely used datasets and software packages. Some work has been done for InSAR software comparison (Simonetto and Follin 2012; Simonetto 2008) using same data by different users, but SARscape and SNAP has not been studied together before. The strength, weakness and output of each processing step has been compared in this work. We believe that more open source, free of cost datasets and software packages will attract a larger number of early stage researchers in this field and will enable an expansion of the use of DInSAR techniques for different applications.

2. SAR SENSORS AND SOFTWARE PACKAGES

2.1 SAR Sensors

SAR sensors can be mounted on airplanes, shuttles or satellites but we will limit our discussion to satellite sensors only. SAR satellite orbits in low earth, polar, sun-synchronous orbit. The data acquisition can be made independent of cloud coverage, at any time of day and night, and has both amplitude and phase components (Unavco 2020). The radar satellites work at specific wavelengths and L, C, and X-bands are the predominate ones. First radar satellite sensor was Seasat, set in motion in June 1978 by National Aeronautics and Space Administration, Jet Propulsion Laboratory (NASA/JPL), but its lifetime was less than 4 months (Seasat 2020). Though Seasat itself was operational for a very short duration, but it led foundation for world scientists to explore the new area of SAR satellite sensors. It resulted in launching of numerous SAR sensors which provided valuable information about earth surface and space geodesy.

The first commercially successful SAR sensor mission was European Remote Sensing Satellite (ERS-1) launched on 17 July 1991 by European Space Agency (ESA). It was launched at an altitude of approximately 785 km, which was operational for almost one decade (ERS 2020). ERS-1 operated in C band of the MW radiations and comprised many instruments with different principles which gained and disseminated information about Earth’s land, water, ice and atmosphere. ERS-1 was followed by many SAR sensors (Table 1) and the latest proposed SAR satellite sensor is NASA-ISRO Synthetic Aperture Radar (NISAR). It is a joint venture between NASA and ISRO and the first ever dual frequency radar imaging satellite (NISAR 2020). NASA will contribute L band SAR, while ISRO will contribute S band SAR. The NISAR mission life is planned to be 3 years and will provide vital information about Earth’s crust, ecosystem, climate change, coastal waters and hazard management. Table 1 summaries important past, present, and future projected SAR satellite missions. The list is not exhaustive, but it promises that a consistent SAR data is available.

Table 1: SAR Sensors

Sensor	**Time Period**	**Repeat cycle (days)**	**Wavelength (cm), band**	**Polarization**	**Supporting Agency**
Seasat	June 1978 to October 1978 (110 days life time)	3	23.44, L band	HH	National Aeronautics and Space Administration/Jet Propulsion Laboratory (NASA/JPL)
ERS-1	1991-2000	35	5.66, C band	VV	European Space Agency (ESA)
JERS-1	1992-1998	44	33.53, L band	HH	Japan Aerospace Exploration Agency (JAXA)
SIR-C/X-SAR	April 1994 – October 1994	10	23.5, L band 5.8, C band 3.1, X band	L&C (Quad) X (VV)	NASA/JLP, Deutsches Zentrum für Luft- und Raumfahrt DLR (Germany), Italian Space Agency (ASI)
RADARSAT-1	1995 - 2013	24	5.66, C band	HH	Canadian Space Agency (CSA)
ERS-2	1995 - 2011	35	5.66, C band	VV	ESA
Envisat/ASAR	2002-2012	35	5.63, C band	Dual	ESA
ALOS-1	2006-2011	46	23.62, L band	Quad	JAXA
RADARSAT-2	2007-Present	24	5.55, C band	Quad	CSA
COSMO/SkyMed	2007	16	3.125, X band	Dual	ASI
TerraSAR-X	2007 – present	11	3.125, X band	Quad	DLR
TanDEM-X	2010 - present	11	3.125, X band	Quad	DLR
RISAT-1	2012 - 2017	25	5.60, C band	Quad	Indian Space Research Organization (ISRO)
KOMPSat-5	August 2013 - present	28	X band	Dual	Korea Areospace Research Institute (KARI)
ALOS-2	2013 – present	14	23.62, L band	Quad	JAXA
Sentinel – 1	2014-present	12	C Band	Dual	ESA
PAZ	Feb 2018 - Present	11	X band	Quad	Instituto National de Técnica Aeroespacial (INTA), Spain
SAOCOM	June 2018 - present	16	L band	Quad	Comision Nacional de Actividades Espaciales, Argentina
NISAR	Planned (2021)	12	24, L Band (NASA) 9.3, S band (ISRO)	Quad	ISRO and NASA

2.2 SAR Software Pacakages

DInSAR is gaining popularity as deformation monitoring technique, and the availability of new processing software is also increasing. For selecting a software for SAR data analysis important considerations are the cost of license (either commercial or free of charge), the cost of service and maintenance (like hotline or mailing list), the oftenness of update, and compatibility with different platforms (Linux, Unix, Windows, MacOSX). It also depends on the software abilities like data handling capacity, multiple image processing and time series analysis. It further depends on processing capabilities like SAR focusing, unwrapping, geocoding and resampling, supported sensors and access to source code (Simonetto and Follin 2012).

Here we have provided a list of important and widely used commercial and free of charge open source software. The open source means that the source code is available, while free of charge might have restricted use and may be completely free. Our list is not comprehensive, as many times research institutes develop their own software tools and packages and do not share them for public use. For example, Altamira information in Barcelona (Altamira 2020). Also, it is worth to note that the provided information about different software has been reported from documents available in open domain and all the software have not been tested by authors. The readers can also refer to (Crosetto and Crippa 2005; Gens 1999; Simonetto and Follin 2012) for more details about different SAR processing software tools and packages available.

The open source free software included are SNAP, StaMPS, DORIS, ROI_PAC, ISCE, and GMTSAR. SNAP has a user friendly graphical user interface, and it is a common architecture for all Sentinel toolboxes, which is ideal for exploitation of earth observation data. SNAP is excellent for DInSAR analysis but the greatest limitation with SNAP at present is that it does not support multiple images time series analysis. But it can alternatively prepare the interferometric inputs for further processing by external open source software packages, such as StaMPS. The software StaMPS is mainly dedicated to Persistent Scatterer (PS) technique. Details and strengths of all the software have been tabulated in Table 2.

The commercial software included are ENVI SARscape, SARPROZ, GAMMA, DIAPASON, and Imagine Radar Mapping Suite. These are user-friendly, semi-automated, and powerful software. These implements a wide range of Radar techniques including SAR, InSAR, DInSAR and time series techniques like Persistent Scatterer (PS) InSAR and Small BAseline Subset (SBAS) InSAR. All these software supports most satellites/data formats like ERS1&2, Radarsat1&2, ENIVISAT, ERS1&2, ALOS, Sentinel-1, TerraSAR-X, Alos, Cosmo SkyMed, and Kompsat-5. The major advantage of these software is continuous maintenance and updates, which allows supporting of latest launched SAR sensors. Details and strengths of all the software have been tabulated in Table 3.

Several other software and tools exist for InSAR processing each with their own advantages and limitations. For example: POLSARPRO is focused on SAR data acquired in the quad polarimetric mode and allows their Pol-INSAR processing. Geospatial Data Abstraction Library (GDAL) is an open source translator library for raster geospatial data formats. It offers reader for certain SAR data, for instance, CEOS SAR image files (Simonetto and Follin 2012).

This study has compared open source SNAP and commercial SARscape software. SNAP is selected because it has a user friendly graphical user interface (GUI). The other open source software are mostly command line based packages, which complicates their use especially for novice users. Also, SNAP is compatible with all operating systems (32 and 64 bit Windows, Mac OS X and Linux), and its latest version of 7.0.0 is only around 0.5 GB in size for windows_64 bit. The hardware system requirements to run the software are also rather minimal (4 GB ram is sufficient). SARscape is selected as we could get access to the software via ESA Eohops programme. The SARscape is expensive and requires high end hardware machine to run efficiently but it is highly efficient in SAR focusing, InSAR, DInSAR, PS, and SBAS and supports all the latest SAR sensors. Also, processing using SARscape is semi-automated and can be efficiently used for validating SNAP results.

Table 2: SAR Open Source Software

SNAP	**StaMPS**	**DORIS**	**ROI_PAC**	**ISCE**	**GMTSAR**
Developed by European Space Agency (ESA)	Developed by Stanford University	Developed by TU DELFT	Developed by JPL/Caltech	Developed by Stanford/Caltech /JPL	Developed by Scripps Institution of Oceanography and San Diego State University
Strengths: InSAR, DInSAR, geocoding, Unwrapping	Strengths: PSInSAR	Strengths: InSAR, DInSAR, no unwrapping	Strengths: SAR focusing, InSAR, DInSAR	Strengths: SAR focusing, InSAR, DInSAR, provides precise geolocation	Strengths: SAR focusing, InSAR, DInSAR
Supports: Radarsat1&2, ENIVISAT, ERS1&2, ALOS,Sentinel-1, TerraSAR-X	Supports: Radarsat1&2, ENIVISAT, ERS1&2, ALOS, Sentinel-1, TerraSAR-X	Supports: Radarsat1&2, ENIVISAT, ERS1&2, ALOS, Sentinel-1, TerraSAR-X	Supports: Radarsat1&2, ENIVISAT, ERS1&2, ALOS, Sentinel-1, TerraSAR-X	Supports: Radarsat1&2,ENIVISAT, ERS1&2, ALOS, Sentinel-1, TerraSAR-X Latest	Supports: Radarsat1&2,ENIVISAT, ERS1&2, ALOS, Sentinel-1, TerraSAR-X
Latest Release SNAP 7.0.0 (2019)	Latest Release 4.1b1 (2018)	Latest Release: V5.0.3 Beta (2017)	Latest Release:V3.0.1 (2017)	Release: V2.2.0 (2018)	Latest Release: V6.0 (2020)
Unix/Linux/Windows/MacOSX	Unix/Linux/MacOSX	Unix/Linux/MacOSX	Unix/Linux/MacOSX	Unix/Linux/Mac OSX	Unix/Linux/Mac OSX

Table 3: SAR commercial Software

ENVI SARScape	**SARPROZ**	**Gamma**	**DIAPASON**	**IMAGINE Radar Mapping Suite**
Developed by Exelis/Sarmap	Developed by Daniele Perissin Italy	Developed by Gamma Remote Sensing	Developed by French Space Agency (CNES), but now managed by Altamira	Erdas developed by Leica Geosystems Geospatial Imaging
Strengths: SAR focusing, InSAR, DInSAR, PS, SBAS	Strengths: SAR focusing, InSAR, DInSAR, PS, SBAS	Strengths: SAR focusing, InSAR, DInSAR	Strengths: DInSAR	Strengths: SAR focusing, InSAR, DInSAR, PS, SBAS
Supports: ERS1&2, Radarsat1&2, ENIVISAT, ALOS, Sentinel-1, TerraSAR X, Alos, Cosmo SkyMed, Kompsat-5, Geofen-3	Supports: ERS1&2, Radarsat1&2, ENIVISAT, ALOS, Sentinel-1, TerraSAR X, Alos, Cosmo SkyMed, Kompsat-5,	Supports: ERS1&2, Radarsat1&2, ENIVISAT, ALOS, Sentinel-1, TerraSAR X, Alos, Cosmo SkyMed, SIR-C Kompsat-5, Geofen-3	Supports: ERS1&2, Radarsat1&2, ENIVISAT, ALOS, Sentinel-1	Supports: ERS1&2, Radarsat1&2, ENIVISAT, ALOS, Sentinel-1, TerraSAR X, Alos, Cosmo SkyMed, Kompsat-5, Geofen-3
Latest Release: V5.5.3 (2020)	Latest Release: 2019.0	Latest Release: V1.8 (2020)		Latest Release: V5.5.0 (2018)
Unix/Linux/Windows/MacOSX	Unix/Linux/Windows/MacOSX	Unix/Linux/Windows/Mac OSX	Unix/Linux/Windows/Mac OSX	Unix/Linux/Windows/MacOSX

3. MATERIALS AND METHODS:

3.1 Data Used and Study Area:

The following Sentinel -1A, Interferometric Wide (IW), Single Look Complex (SLC) data acquired on 12th April 2015 and 8th April 2018 has been used in the study:

S1A_IW_SLC__1SDV_20150412T174854_20150412T174921_005454_006F45_BEBD
S1A_IW_SLC__1SDV_20180408T174913_20180408T174943_021379_024CDB_9173

The above dataset has been acquired free from Copernicus open access hub (Copernicus 2020). The data specifications are spatial resolution (range by azimuth): 5m, and wavelength: C band - 5.6 cm. The software used are SNAP 7.0. and ENVI SARscape 5.5.2.

The Interferometric Wide (IW) swath is sentinel's primary operational mode over land and acquires 3 sub-swaths using Terrain observation with Progressive Scans SAR (TOPSAR). For Interferometry we use SLC data exploiting the complex imagery of both amplitude and phase. Each sub-swath image consists of a series of bursts and the input product contains 3 IW bands, and 9 bursts (SLC 2020).

In the study, the area chosen is the administrative area of Greater London. The area is bounded by 0°30'W and 0°20'E longitudes and 51°42'N and 51°17'N latitudes covering an area of approximately 1600 km^2 in the southern part of England. According to the Copernicus EEA European urban atlas (UA), the land use within the London area is dominated by dense to medium density urban fabric. It has multiple industrial units and stretched port areas along the river Thames (EC 2011). Also, according to the 2011 population census of the UK, the total population of London is around 9.5 million and has been continuously increasing since the 1980s. The ever-increasing population is exerting a pressure on groundwater to meet the increasing demand and thus can cause the problem of land subsidence.

3.2 Methodology

Here, the SNAP user environment is explored to generate DInSAR land displacement map using two S-1A images and a DEM. The same experiment is repeated using SARSCAPE environment. Figure 1 shows the overall methodology used in the study.

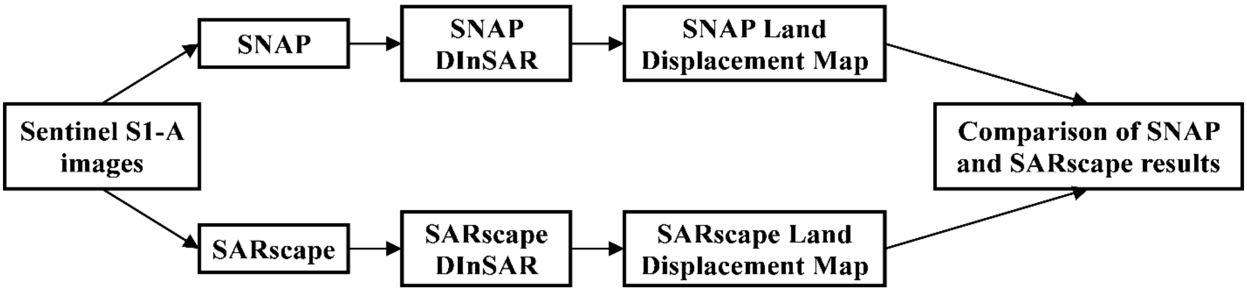

Figure 1: Methodology used in the experiment

For SNAP processing, the first step is to apply the orbit files in Sentinel-1A products, to provide accurate satellite position and velocity information. Then Sentinel-1 back-geocoding operator is used to co-register the two S-1 split products of the same sub-swath using a DEM and the orbits of the two products. Enhanced Spectral Diversity (ESD) operator is used for azimuth and range correction of the co-registered product, and interferogram is generated along with a coherence image. Re-sampling is done in azimuth and range direction to produce a debursted interferogram, which contains interferometric phase band and the coherence band. TopoPhaseRemoval operator is used to remove topographic phase from the debursted interferogram. Multilooking is done to minimize the speckle and to enhance the readability of the image. Phase filtering is performed for decreasing the phase noise from mutilooked product. The output obtained after these steps is multi-looked and filtered differential interferogram. This product is free of topography component but the phase component has fringes only between –pi to +pi and thus a phase unwrapping (Ghiglia and Pritt 1998) is required to get the absolute phase differences. After phase unwrapping, the final displacement map is generated from the interferometric phase.

For SARSCAPE the processing steps are rather simpler and semi-automatic in a user friendly environment (Sahraoui, Hassaine, and Serief 2006). It involves importing generic SAR data to make data in SARscape readable format. Master image, slave image and a DEM file are given as input to generate interferogram. Then it does adaptive filtering and coherence, phase unwrapping, manual GCP selection, refinement and reflattening, and phase to displacement conversion.

4) Results and Discussion:

The results obtained from both the software are discussed and compared in this section. Figure 2a and 2b, shows coherence map from SNAP and SARscape, respectively. A coherence map is an indirect measure of quality of the interferogram. The values on coherence map vary between 0 and 1, and represents the similarity between each pixel on two images. The patches with greater coherence appear as brighter, and the patches of lower coherence appear as darker. The black areas, which are closer to zero, represents the vegetative areas (marked as A1 and B1 in Figure 2). The white areas which are closer to 1 represent buildings and urban areas (marked as A2 and B2 in Figure 2). We can see both the images give consistent results, though coherence level in SARSCAPE is better than SNAP. The coherence has maximum value of 0.996, and statistical mean of 0.59 for SARscape, as compared to maximum value of 0.989, and statistical mean of 0.55 for SNAP. This discrepancy might arise because of results from co-registration or spectral shift filtering steps.

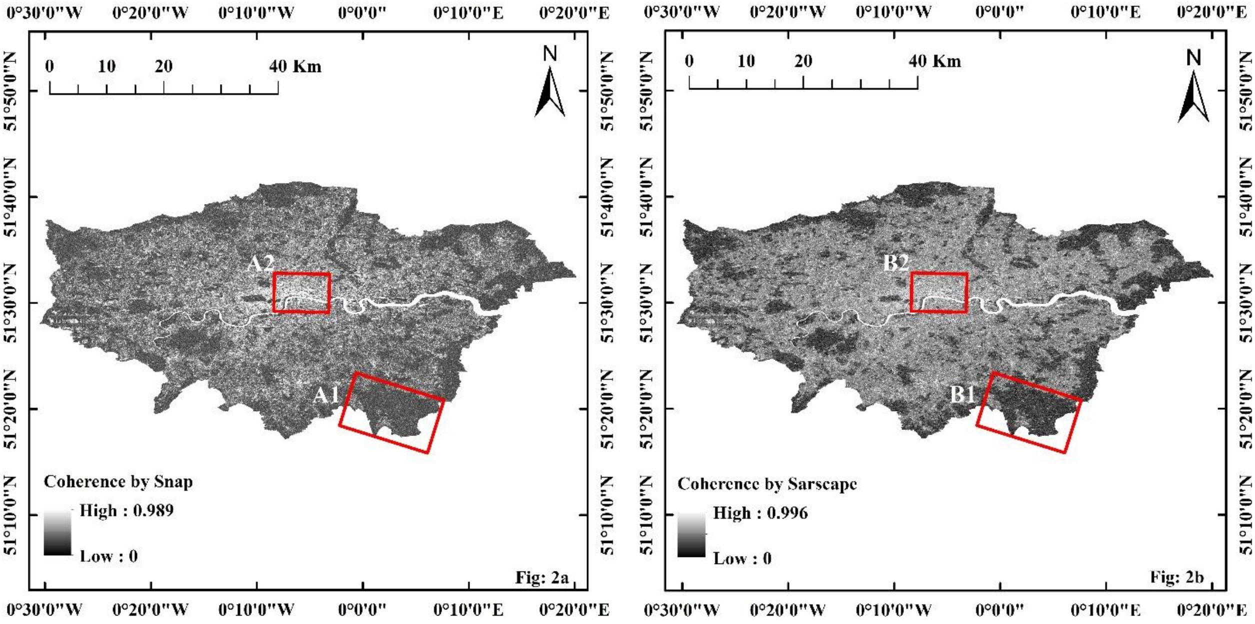

Figure 2: Coherence Maps from SNAP (a) and SARscape (b)

In SNAP, debrusting was required separately to get a spatially continuous interferogram, which represents the phase difference between the two images. For SARscape, debrusting is not required separately, as this process is done during the data import section only. In SNAP, the interferogram obtained from first processing contains both topography and deformation, so topophaseremoval operator is applied to get an interferogram that contains only the deformation. A multi-looking factor of 8 in azimuth and 2 in range direction is used in both the software. The filtering method which we used in both the software is Goldstein method given by Goldstein & Werner in 1998 (Goldstein and Werner 1998). In SARscape, manual selection of Ground Control Points (GCP's) is required before orbit refinement stage. Such a process is not required in SNAP. The orbit refinement stage removes orbital residual patterns in SAR fringes. The residual fringes in azimuth direction are compensated by the following surface (Colesanti and Wasowski 2006):

$$S\ (i, j) = \text{complex}\ [\cos(2\pi\ tl\ i + 2\pi\ tc\ j), \sin(2\pi\ tl\ i + 2\pi\ tc\ j)] \qquad (1)$$

The phase component at this stage has fringes only between –pi to +pi and thus a phase unwrapping is required to quantify deformation maps. SNAP uses SNAPHU application while SARscape has inbuilt unwrapping application. Minimum cost flow method has been used for unwrapping in both the software. After unwrapping, we can get the displacement maps, which are geocoded to get the final results (Figure 3).

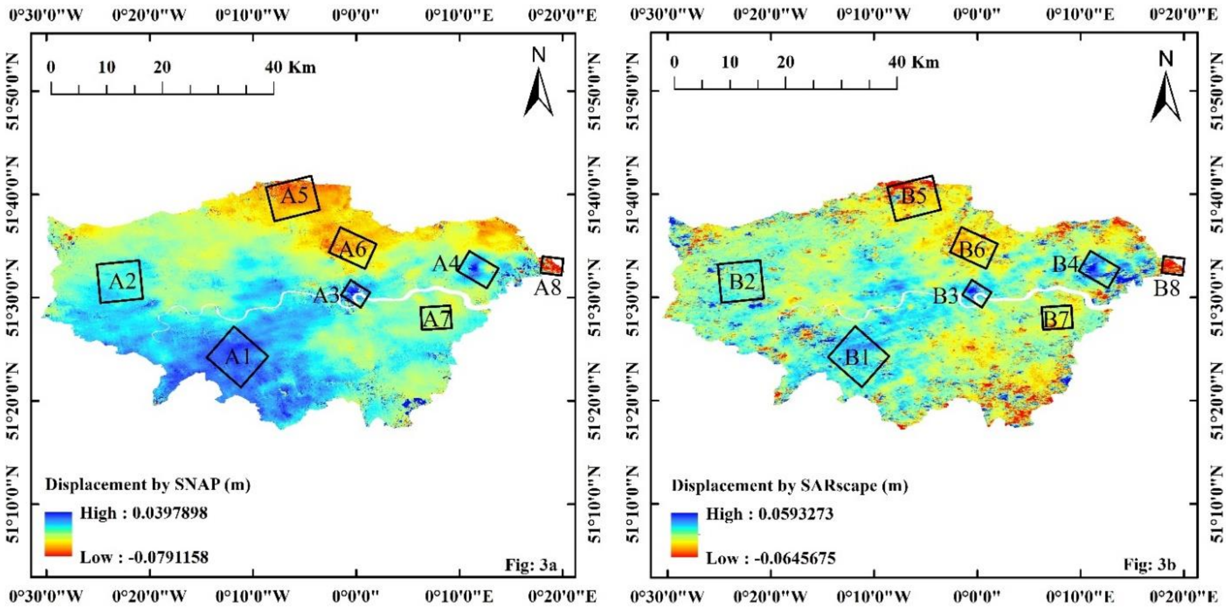

Figure 3: Land displacement maps from SNAP (a) and SARscape (b)

It can be seen that the displacement pattern obtained is consistent in both the figures 3a and 3b, though the exact value of displacement varies for place to place. The west, central and south London is largely showing land uplift, while north and south-eastern London is mainly showing land subsidence. It can be seen that areas marked as A1-A4 and B1-B4 are showing land uplift, while the areas marked as A5-A8 and B5-B8 are showing land subsidence. There are a variety of controlling factors which influences the rates of land level change. These range from near-surface to deep-seated mechanisms and from less than a decade to over 100,000 years' duration. The mean land movement over entire London between April 2015 and April 2018 obtained from SNAP is -5 mm/year, while that obtained from SARscape is -4 mm/year. The apparent difference of 1 mm/year in subsidence obtained from the two software's can be attributed to co-registration, spectral shift filtering, unwrapping or uncorrected orbital inaccuracies. The land movement values obtained in this study are in close agreement as suggested by the literature (Bonì et al. 2017;

Bischoff et al. 2019).

To validate the results, the difference from the two software should be less than the theoretical measurement potentiality of the data. This is given by (Simonetto 2008):

$$\sigma_e = \frac{\lambda}{4\pi} \sigma_{phase} \qquad (2)$$

Considering appropriate number of looks, phase noise (σ_{phase}) can be given with reference to coherence level. Since our coherence level is nearly 0.6, a phase noise of 60^O is selected(Ferretti et al. 2007). Thus, for a wavelength of 5.6 cm, theoretical accuracy of our measurements should be less than 4.6 mm. Thus our result from both the software can be validated.

5) Conclusions:

Working with SAR data is not simple and can be challenging specially for novice users, with no expertise in SAR imagery. Open source software and free datasets can motivate more people to work with SAR technology. The experiments here highlights that open source software can give excellent results, which are highly comparable to expensive commercial software. To compare the results, all attempts were made to keep the user input parameters consistent in both the experiments like multilooking factor, phase unwrapping principle, and filtering methods. But some differences are unavoidable because of GCP selection, co-registration or spectral shift filtering steps. The difference of 1 mm/year land displacement between two experiments can negatively affect the understanding of new users, as ideally same results is expected from same set of data. Only a little work had been done using same data by different software, and more work on cross-verification will be helpful for the growth of DInSAR technique. Our study validates the use of SNAP for DINSAR and provides a good understanding of SARscape. Also, results have been verified with the published literature. The authors suggest that freely available software and datasets will encourage more researchers to work with InSAR technology.

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