Using Space-borne SAR Interferometry Technique for Eastern Mediterranean Sea Shores

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• Rapid and dynamic changes in technologies in recent decades
• Space technologies and exploration is avant-garde
• Sensing and detecting phenomena from long distance is of great importance and effect.
• Electromagnetic waves the tool for long range sensing of the phenomena
• Radar Remote Sensing an effective mean that uses Electromagnetic waves characteristics for SAR Interferometry

**Newly emerging InSAR techniques bridging the gaps…**

Radar remote sensing technology & the Synthetic Aperture Radar (SAR) technology in particular; an efficient tool for monitoring and investigation of dynamic phenomena on Earth

- **SAR interferometry proves to be a strong method for change detection, DEM generation, classification and etc.**
- For interferometry, **two radar images** of the same area with **slightly different imaging angles** are required.
InSAR is a set of successive steps to produce a **height image** called DTM. To produce a DTM, *following basic steps should be carried out successively*

1. **Data search, selection and pre-processing**
2. **Co-registration of the data sets**
3. **Coherence map generation**
4. **Interferogram generation**
5. **Phase unwrapping**
6. **DTM generation**

**DInSAR Method**

*Image credit: Parviz Tarikhi*

Coherence map generation

\[ \gamma = \frac{\sum_{NL}(A_1 \cdot A_2^*)}{\sqrt{\sum_{NL}(|A_1|^2) \cdot \sum_{NL}(|A_2^*|^2)}} \]

(\(A\): amplitude)

- The sums are over \(L=5\) looks in frequency and \(N\) spatially adjacent pixels.
- Generally large values of \(N\) will give poor spatial resolution but will help to reduce the zero coherence bias and the speckle noise.
- A value of \(N=3 \times 3\) is the compromise, which gives a zero coherence bias of approximately 0.21.
- Values of \(N\) greater than 1 introduce a negative bias for high phase slopes.
- This leads to an under-estimate of the coherence in regions of high slope.
- The coherence is always a non-negative real number limited between 0 (for totally different images) and 1 (for completely identical images).
- Due to the moving window transient, the coherence image shows a border which size is half the moving window size, consisting of null pixels.
Interferogram generation

The complex pixel \((m, n)\) of a SAR image can be written as an amplitude \(A\) and phase term \(\Phi\).

The phase term represents the difference in phase shift caused by the two-way propagation of the radar signal to the target.

\[
d\Phi = \frac{4\pi B_n}{\lambda R \sin \theta} \left[dz + \cos \theta \ dR\right] = d\phi_z + d\phi_R
\]

\(B_n\) normal baseline, \(\lambda\) radar wavelength, \(R\) range and \(dR\) change in range, \(dz\) change in surface height, \(\theta\) the local incidence angle

Then each phase fringe represents a relative change in elevation of

\[
dz = \frac{\lambda R \sin \theta}{2 B_n}
\]
Both the parallel baseline component and normal baseline component play key role in producing interferograms. Orbit baseline changes can produce varying phase shifts.

In each case the direction of the surface movement is distinguishable and the displacement in the direction of the line of sight is assessable.

by the increase of normal baseline the surface height change becomes less distinguishable.

- In each case the direction of the surface movement is distinguishable and the displacement in the direction of the line of sight is assessable.
Simplified Interferometric phase notion

- phase unwrapping is the most complicated processing step for InSAR.
- the observed phase is unwrapped in $-\pi$ and $+\pi$. 

![Diagram of phase unwrapping](image-url)
**background:**

Since **October 2010**

- applying **InSAR technique** for aquatic bodies with short temporal baseline

by the **Microwave Remote Sensing Group** based at the **Alborz Space Center** (former Mahdasht Satellite Receiving Station) of Iran’s space agency

**considerable results**-

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**to estimate**

- the stagger speed of water bodies in coastal areas
- the direction of sea surface motion in larger extent
- the change in the height of the sea surface in the satellite sensor’s LOS and the sea surface height change trend
- wave pattern and the sea surface disturbance, and
- whether the water motion is bulk and smooth or otherwise

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**Project C1P.8242**

start: **February 2011**

duration: **1.5 year**

under the **European Space Research Institute (ESRIN)** of the **European Space Agency (ESA)**
InSAR of aquatic bodies different from the SAR Interferometry of rigid bodies
but for both, the fringes show the displacement

Bam Quake, 26th December 2003...magnitude: 6.6 Richter
Coherence-DInSAR composite of the image pairs of
3 Dec. 2003 and 7 Jan. 2004
VBL587.2m-PBL267.9m-NBL522.5m-TBL35d

Combination of
Asc20040531_00200_0254 and Asc20040531_00200_0273
VBL14915.45m-PBL-116.12m-NBL-14915.00m-TBL10s

Solid-InSAR

Citadel of Bam

Liqui-InSAR

Turkey, Istanbul

Produced at ISA by the InSAR Deformation Inspection and Observation Tool (IDIOT)

Images credit: Parviz Tarikhi

Parviz Tarikhi, Using Space-borne SAR Interferometry Technique for Eastern Mediterranean Sea Shores.

Observation areas

3 different global areas in tropical zone, southern and northern hemisphere

Tropical Zone:
- Haiti, Dominican Republic
- North Atlantic Ocean, Golfe de la Gonave, Caribbean Sea, Lago Enriquillo
- 47 Envisat SLCI SAR data
- Acquired in 2010

Northern Hemisphere:
- Western Turkey, Black Sea, Mediterranean Sea
- 1860 Envisat SLCI SAR data
- Acquired in 2002-2010

Southern Hemisphere:
- Western Chile, South Pacific Ocean
- 37 Envisat SLCI SAR data
- Acquired in 2010
**Methodology:** Common image processing and combination techniques used for InSAR

**Software:** Erdas IMAGINE-InSAR and IDIOT applied to examine and assess the applicability of the technique for the aquatic bodies.

**Requisite:** Successful use of InSAR for aquatic bodies requires comparison of the SLC image pairs with very short temporal baselines.

**Data:** For Envisat SLCI data the temporal baseline should be ranging between 8 and 16s.
- It is based on the technology that is used by the synthetic aperture radar

- For Envisat normally the image acquisition period for each SLCI is 16 seconds. In this period the SAR transmits a microwave pulse towards the target and records the reflections.

- Sending pulses and recording the reflections is repeated regularly but because of the rotation of Earth and satellite’s orbital movement the successive forwarded pulses hit different locations on the target which are situated on the strip that is satellite’s track on the land surface in the direction of satellite movement.

- In practice there is a time overlap between two successive imaging processes that leads to the overlap of the scenes imaged successively.
- The overlap normally differs between 15 to 60 percent for ERS and Envisat SAR data.

- This short time baseline is useful for ideally generating DEMs when it is shorter than 10 s, and that the parallel component of the virtual baseline decreases.

- It is actually a way for producing accurate DEMs benefiting three-pass SAR Interferometry, however it is not as precise as the procedure used by NASA’s Shuttle Radar Topography Mission (SRTM) which obtained Earth’s elevation data to generate the most complete high-resolution digital topographic database of Earth using a radar system onboard of the Space Shuttle Endeavour during an 11-day mission in February 2000.

Coverage area of two successive SLC images
SAR Interferometry of aquatic bodies, Haiti

**up left:** Combination of the successive ascending SLC images that is acquired on March 14, 2010 with 12s temporal baseline. Parallel baseline is estimated to be 380.36m

**bottom left:** Combination of the successive ascending SLC images that is acquired on April 24, 2010 with 10s temporal baseline. Parallel baseline is estimated to be 113.01m

*Group’s early observations*

$d \sim 2.8 \times 15 = 42$ cm
InSAR technique gives an estimation of the sea surface attitude in South Western Haiti on January 19, 2010.

The shape of the sea surface deformation is considerable.

The deviation from straight lines suggests an uplift of the sea water eastward.
InSAR for Eastern Mediterranean Sea Shores

**Tropical Zone:**
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InSAR for Eastern Mediterranean Sea Shores


Imaging sea or ocean surfaces using optical sensors onboard of the space based platforms does not usually provide useful data, let alone it is carried out in nighttime passes. However it is carried out successfully using radar remote sensing satellites with good results.

Comparison of Envisat ASAR SLC images of Marmara Sea in north-western Turkey acquired on October 8, 2008 first image at 19:46:51 and the second at 19:47:02 with 11-second time baseline PBL -369.92 m
InSAR for Eastern Mediterranean Sea Shores

co-asc20050813_00472_5673-ase20050813_00472_5675-bl20037-86m-pbl-209-76m-nbl-20036-77m-tbl11s
SAR Interferometry of aquatic bodies
Western Turkey

**top left (inset):**
Combination of the successive ascending SLC images acquired on November 5, 2002 with 14s temporal baseline.
Estimated parallel baseline: 1068.59m

**left:**
Combination of the successive descending SLC images acquired on January 6, 2004 with 11s temporal baseline.
Estimated parallel baseline: 208.42m
InSAR for Eastern Mediterranean Sea Shores

Comparison of the interferometric products of the combination of 18 SLC images of the coastal zone in South Western Turkey; the sea surface attitude and the shape of the surface instantaneous deformation and its speed differs from one pair to other but the direction of the sea surface movement seems to be the same for all pairs in different times in monthly and yearly basis.
Short time baseline is useful for ideally DEM generating, when it is shorter than 10 s, and that the parallel component of the virtual baseline decreases.
Mediterranean inland lakes

Combination of the Envisat SLC ascending image pairs of 20050513_00157_0205 and 20050513_00157_0206

Acquired: May 13, 2005
Baseline: 45120.77 m
Parallel baseline: 1062.34 m
Normal baseline: 45108.27 m
Temporal baseline: 15 s
Mediterranean inland lakes

Combination of the Envisat SLC ascending image pairs of
20050513_00157_0205 and 20050513_00157_0206
Acquired: May 13, 2005
Baseline: 45120.77 m
Parallel baseline: 1062.34 m
Normal baseline: 45108.27 m
Temporal baseline: 15 s
Coherence: 0.95 (high)

Combination of the Envisat SLC ascending image pairs of
20041015_00157_0190 and 20041015_00157_0191
Acquired: April 15, 2004
Baseline: 45130.33 m
Parallel baseline: 1062.47 m
Normal baseline: 45117.82 m
Temporal baseline: 14 s
Coherence: 0.28 (low)
Hypothesis

- Use of InSAR for aquatic bodies in coastal areas and inland lakes looks promising when it is applied for the image pairs with temporal baselines shorter than 16 s.

- It can be explained by the basic theory of the interferometry of optical surfaces using the interference of light which, under specific conditions, can produce visual patterns disclosing surface "topography" down to a fraction of a wavelength. Although it is a general discussion, it fits the case of the surface of aquatic bodies that in some sense act as transparent media interacting with radar waves.

- Generally, the interferometer is an optical device combining two wave-fronts - one reference, perfect, and the other produced by the test surface - in order to produce the interference pattern making test surface visible quite well below the sub-wavelength size level.

- The simplest and traditional interferometer consists of two surfaces positioned at a slight angle one to another.

- As light passes through the two pieces that is a transparent medium (disregarding the refraction at actual angles), at every section where the gap increases by about 1/2 wave, waves tend to interfere destructively, forming dark lines called interference fringes.

- The shape of lines depends directly on the surface shape.

- If both surfaces are flat, then the interference lines are straight.
Hypothesis (cntd.)

- If one or both surfaces are curved, the dark lines of destructive light interference will be of circular form provided the surface possesses rotational symmetry.

- Surface irregularities will cause deviation of the interference lines from straight, curved or circular line form and can be measured to a small fraction of a wavelength.

- Since conic aberrations cause different form of wave-front deformations, they also show distinctly different interferometric patterns.

- Since wave-front deformation relative to a reference sphere varies with focus point within the aberrated focus zone, interferogram patterns will be different for best focus in comparison to other focus points for each particular aberration.

- The fringe spacing in a single-pass interferometer corresponds to $\lambda/2$ differential on the surface, or $\lambda$ on the wave-front; in a double-pass interferometer fringe spacing corresponds to half as large surface/wave-front differential.

**Interference pattern formation for curved surfaces**
Hypothesis (cntd)

... the same explanation applies for the moving surface layers of aquatic bodies that practically act as the optical/transparent surfaces when beamed by radar waves.
Conclusion and Suggestions

The results achieved by combining the available SAR image pairs of the areas that are acquired successively with maximum temporal baseline of 16 s looks noteworthy for the aquatic bodies.

Although it is usually assumed that the application of InSAR is not worthy for water bodies, the results suggests different idea.

Instantaneous movement of aquatic bodies is synoptically recognizable using this technique with sub-centimeter accuracy. It is potentially useful for both the oceanographic and Earth observation studies.

The direction of sea water movement as well as rate of displacement can be estimated using this technique.

Knowing the direction of the motion of sea water surface and its long term trends could be useful for coastal zone management and the interaction of sea water and coastal areas, which all are of environmental and socio-economic importance and benefits.

There could be other potential benefits that need to be further investigated and studied.

The parallel baseline and normal baseline components play key role in producing interferograms.

By increasing the coverage area of the successive SAR images access to the information about the behavior of the sea water movement in larger extent would be possible.

Using single-pass InSAR, the data for same area from different view angles can be acquired. The temporal and normal baselines are then tend to zero and as a result the parallel baseline component remains only that would make precise assessments of the aquatic body displacement and its direction of motion possible.
Conclusion and Suggestions

A suggestion could be the use of a system similar to NASA’s STS-99 mission that used two SAR antennas with 60-m separation to collect data for the Shuttle Radar Topography Mission (SRTM), however the imaging procedure by two antennas can be carried out with a small delay ranging between 8 and 15 seconds. This could be considered as a single pass along-track InSAR for which there is a non-zero temporal baseline; the idea still needs to be further examined and tested for various cases and different locations. To this mean new study and work opportunities in the top and leading research organizations and institutions is needed.

The wavelength used by radar antenna could also play a key role. Making the similar experiments, which has been carried out by C-band SAR systems, for SAR systems that work in other bands particularly L- and X-bands is expected to show new and considerable results.

SAR satellites are still few in number, which is the main limitation in the stream of imagery, and the requirements for collection of repeat images that can be used to generate interferograms are stringent. As a result, useful image pairs, even in large archives of imagery, are not common.

The successful application of InSAR requires seamless cooperation among several agencies. Further development of this promising technique depends on expanding and strengthening interagency and international cooperation/coordination in the acquisition of SAR data, including the launching of additional L-band or multiband SAR satellites.

For this application of SAR Interferometry the title of Liqui-InSAR is proposed that refers to the use of SAR interferometry technique for liquid bodies in general that is distinguishable from the SAR Interferometry of solid bodies for which the expression of Solid-InSAR is proposed and that deals with the non-fluid features like soil, sand, vegetation, rocks, snow and other cryo-spheric phenomena.
Thank you!