

SENTINEL-1A TOPS INTERFEROMETRY APPLICATION OVER THE DEAD SEA

Yuxiao QIN, Daniele PERISSIN

School of Civil Engineering, Purdue University

ABSTRACT

Comparing with its former C-band fellows ERS and Envisat, Sentinel data is favored for its short revisit days (12 days) and free distribution policy. Moreover, TOPS mode can cover a much larger monitoring area (250 km in azimuth) while maintaining a relative high range/ azimuth resolution (4m*20m in general). The advantages of TOPS mode made it become the default mode for Sentinel-1. This paper describes the general processing chain for sentinel-1A TOPS mode from importing, coregistration to generating interferograms and its application in monitoring ground subsidence over the Dead Sea region. The data that comes from TOPS's steering antenna will require some additional processing steps comparing with the stripmap mode. In this paper we apply the TOPS data over the Dead Sea region. A number of interferograms are generated to monitor the local ground subsidence and sinkholes. Distinct ground subsidence is clearly visible on TOPS interferograms.

Index Terms— Sentinel-1A, TOPS, interferogram, Dead Sea, Sinkhole

1. INTRODUCTION

The Sentinel-1A satellite was launched in April 2014. Upon its launching, the satellite is scheduled to retrieve SAR data world widely with a revisit time of 12 days. The data is delivered to the public for free. This peculiar distribution policy of ESA makes the Sentinel satellite a major opportunity for long-term consecutive monitoring projects.

Comparing with previous C-band SAR satellites, Sentinel-1A is preponderant in several ways. Firstly, the shorter revisit time of 12 days comparing with ERS and Envisat (35 days) will greatly lower the temporal decorrelation between adjacent acquisitions and improve the spatial coherence significantly. After the launching of its twin, sentinel-1B, scheduled in 2016, the revisit time will be further shortened. Secondly, the spatial resolution has also been improved. For TOPS mode, the default spatial resolution is 20*4m comparing with the 80*20m of Envisat ScanSAR mode. The fine resolution will allow more details of ground features and monitoring of smaller scale ground objects. Thirdly, Sentinel satellite has a precise control of its

orbit. Orbit positioning control for Sentinel-1 is defined using an orbital earth fixed tube of 50 m RMS in radius around a nominal operational path. The satellite is kept inside this tube for most of its operational lifetime. The precise control of satellite orbit will greatly reduce the effect of spatial decorrelation effect in interferograms. In the fourth place, differs from the previous SAR satellites that operate in stripmap mode in default, Sentinel-1A's default operating mode is TOPS mode. One of the most significant differences that distinguish TOPS mode from stripmap is that the antenna will steer from backward to forward in azimuth direction and steering between different subswath in range direction. An illustration of TOPS's working mechanism is shown in Figure 1. The steering of antenna will sacrifice the azimuth resolution to a reasonable degree, meanwhile increasing the range illuminating area. The steering mode of TOPS also differs from ScanSAR mode of Envisat. By steering the beam from backward to forward in the azimuth direction for each burst, the scalloping effect that occurs in ScanSAR will be avoided and resulting in homogeneous image quality throughout the swath. Taken together, TOPS mode inherits the merit of ScanSAR of a larger coverage, meanwhile minimize the defect of scalloping effect. The default TOPS mode will cover three subswaths that extends to 250 km in azimuth direction. The large coverage of TOPS mode is applicable for large scale ground motion monitoring.

Meanwhile, SARPROZ is a very powerful and versatile software that implements a wide range of SAR, InSAR and Multi-Temporal InSAR processing techniques, and it has implemented the whole processing chain for importing TOPS, coregistration, getting interferometric pairs. It is also capable of processing TOPS dataset for multi-temporal analysis when enough dataset over the same area is collected.

In this application we collected 15 TOPS images from November 2014 to September 2015 over the Dead Sea to monitor the ground displacement. Dead Sea is known for its continuous subsidence and drop of water level, along with a number of sinkholes located at the area [1,2,3,4,5]. The subsidence also seems to have a drastic acceleration in recent years [3,4,5].

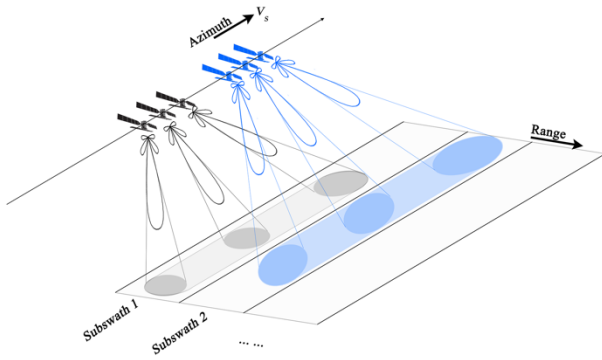


Figure 1 The mechanism of TOPS mode. The Beam will steer front-to-backwards within one subswath and then switch to the next.

2. DATA AND AREA OF INTEREST

The Dead Sea is the lowest place on earth with an elevation of -415 m, and it is located within the basins that formed along the Dead Sea fault system. A sketch map of our study area of interest and its general location on earth is shown in Figure 2. In recent years, the Dead Sea is rapidly shrinking and the ground has also been subsiding along with the drop of water level.



Figure 2 location of our area of interest: the Dead Sea.

The Sentinel-1A satellite is routinely acquiring data over the Dead Sea region in both ascending and descending track every 12 days or 24 days. The rich archive of both descending and ascending track will give us the opportunity to decompose the ground movement into vertical and horizontal direction once we conduct the multi-temporal analysis of SAR data archive. In this initial analysis we only take 15 Sentinel TOPS images of ascending pass between October 2014 and September 2015 to analyze ground subsidence and detect sinkholes. Interferograms will be generated between image pairs. The aim is to evaluate if the TOPS interferogram will have enough coherence to see local displacement details. A brief description of TOPS parameter used for this study is listed in Table 1.

Table 1 Some parameters of TOPS data used for monitoring the Dead Sea area

Revisit Days	12 days
Band	C
Wavelength	5.55cm
Range Spacing	2.3m
Azimuth Spacing	14m
Pass	Ascending
Incidence Angle	39°

3. INSAR PROCESSING CHAIN FOR TOPS

Due to the special characteristic of TOPS, the standard processes for generating interferograms between TOPS pairs is different from that of stripmap.

Specifically, there are steps that are required by TOPS. Both are originated from the backward-to-forward steering of antenna in azimuth direction.

The first step is called deramping. The steering of the antenna introduces an additional quadratic phase term in azimuth direction which Doppler frequency exceeds the azimuth pulse repetition frequency (PRF). According to the sampling theorem, in order to resample the slave images during coregistration without aliasing the data, a step name 'deramping' is required to remove this quadratic 'ramp'. After reading the single look complex (SLC) value of TOPS data and before coregistration of interferometric pairs, the quadratic ramp of each image will be calculated and removed.

The second step is coregistration. The appearance of this quadratic term indicates that, in case of even a small misregistration error between master and slave images, there would be a phase ramp in azimuth direction superimposed on the interferogram. It has been commonly acknowledged that an accuracy of 1/1000 pixels of coregistration is needed to ignore the azimuth phase ramp introduced by this quadratic term [6]. To meet this standard a general sub-pixel coregistration method will be needed. This step is usually done after the initial coarse coregistration that are used for the case of stripmap. The subpixel coregistration is usually achieved by the spectral diversity method that utilizes the overlapping parts between successive bursts. After the subpixel coregistration of TOPS, the common processing steps for generating interferograms will be identical with stripmap processing. A common processing chain for importing, deramping and coregistering TOPS data is shown in Figure 3.

In SARPROZ software the complete processing chain from importing TOPS image to multi temporal analysis has been implemented. The software is able to encapsulate the TOPS processing chain so that user will be able to import and coregister TOPS data stacks without knowing about the details behind.

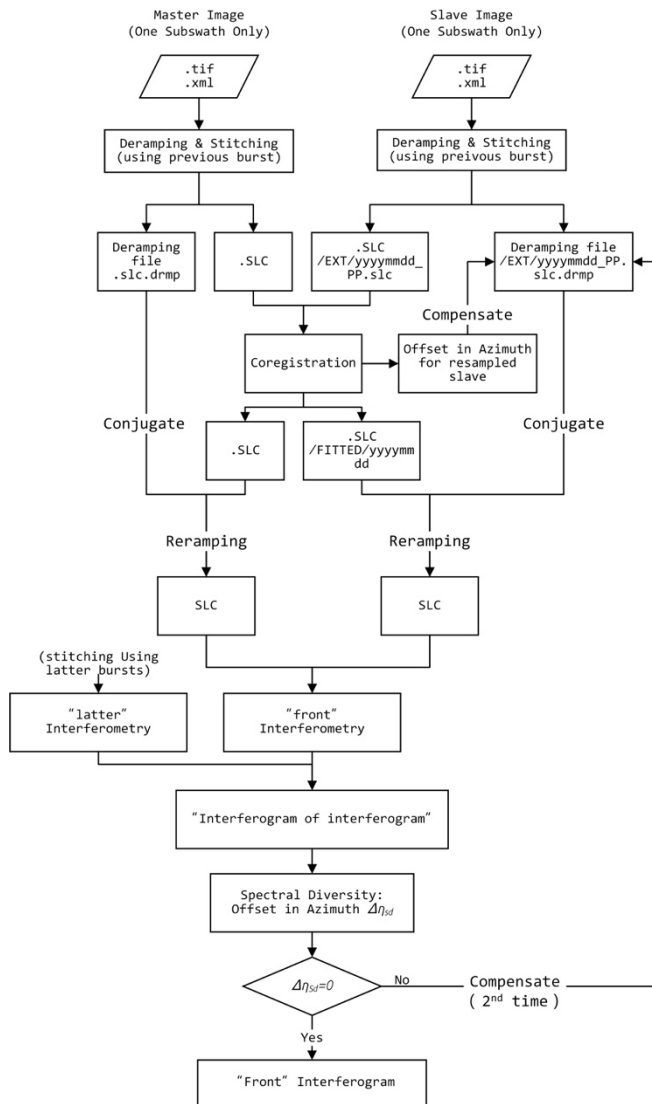


Figure 3 Flow chart of the common TOPS processing chain.

4. RESULTS AND DISCUSSIONS

Out of all the interferograms generated after removing DEM and flattening phase, a very special interferogram with a longer temporal baseline is shown here. The interferogram is generated between 23rd October 2014 and 15th May 2015, where the normal baseline is 24 m. It is worth noticing that even with a temporal baseline of approximately 7 months, the interferogram still shows a very high coherence. This is partial due to the precise orbits of Sentinel that reduces spatial decorrelation, and partial due to the dry-and-bare-land of the Dead Sea region.

For the purpose of analysis local ground subsidence, in the interferogram we zoom in two small areas. In both of the small areas very clear fringes along the shore are clearly visible. Since the interferogram is already DEM-free using

SRTM data, the fringes here very possibly indicate local ground movement. It is worth mentioning that the fringes here are quite unlikely to be height residuals coming from the low elevation accuracy of SRTM since the height ambiguity here is 617 m. Also from previous studies [4] we are aware that both of the small areas are constantly having very strong ground movement.

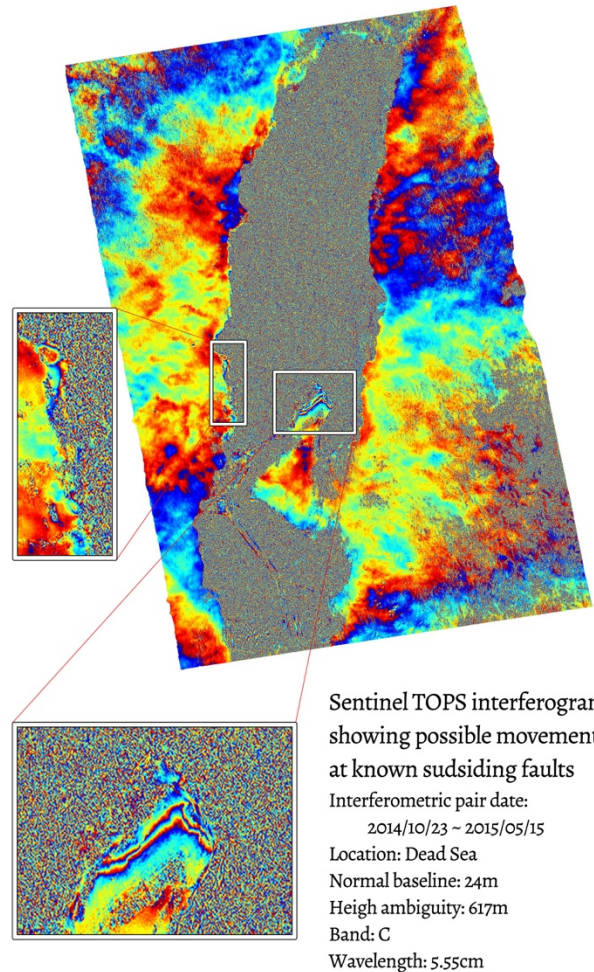


Figure 4 Interferogram generated between TOPS image acquired on 23rd October 2014 and 15th May 2015. The normal baseline of two dates is 24m which converts to a height ambiguity of 617m. DEM component is removed using SRTM data along with the flattening phase component.

Beside the ground subsidence that undergoes in the whole, another problem of the Dead Sea region is sinkholes. The water level drop has been followed by a ground water level drop, causing brines that used to occupy underground layers near the shoreline to be flushed out by freshwater. This is believed to be the cause of the appearance of large sinkholes along the western shore. Incoming fresh water dissolves salt layers, rapidly creating subsurface cavities that subsequently collapse to form these sinkholes. Here we show two examples of fringes in interferograms that

appears to be sinkholes that subsides rapidly over time, both located at the west shore of Dead Sea.

The first one is shown in Figure 5. The fringe shape and scale is very similar in both interferograms. The small scale of the clearly visible fringe pattern suggest that it is less likely to be DEM residuals or atmospheric effect. Connecting with the local news of sinkholes and subsidence, this is possibly the pattern of the local ground movement.

The second one is shown in Figure 6. Again the shape and pattern of this fringe located at the west bank is quite consistent throughout the interferograms. Considering the scale of the fringe, it is likely to be subsidence of a sinkhole. For further evaluate the reliability of these signals appeared on the interferograms, a local ground survey is needed for identify the subsidence and evaluate the magnitude.

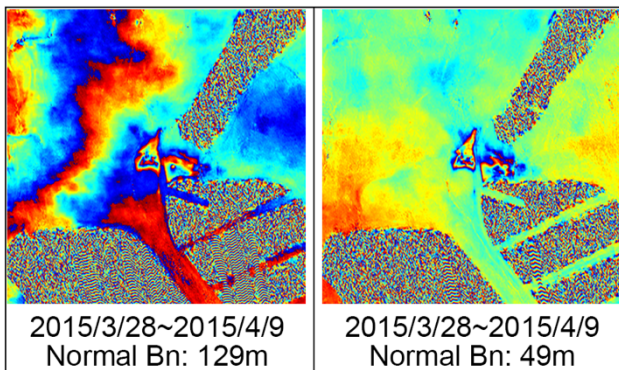


Figure 5 The fringes pattern discovered that is located at the conjunction part of north and south Dead Sea. The fringes are visible and consistent throughout a number of interferograms in 2015 indicating local displacement.

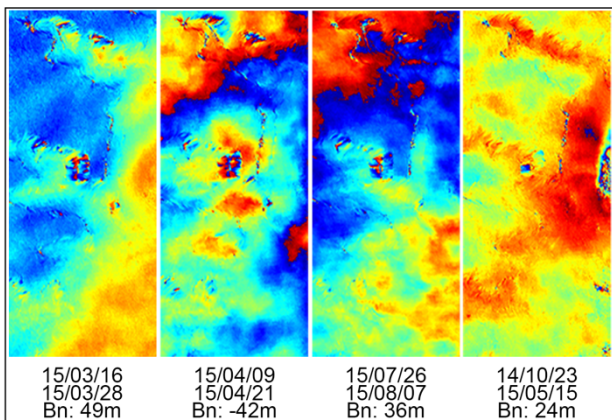


Figure 6 A small fringe discovered at the west bank of Dead Sea. The fringe is very small but it is consistently visible throughout most of the generated interferograms. The consistent fringe here indicates local ground displacements.

5. CONCLUSION AND FUTURE WORK

The initial analysis shows that TOPS is capable of generating high quality interferograms with high spatial coherence over the Dead Sea region and reveal a great deal of details about local subsidence and sinkholes.

For the next step of the monitoring work, two aspects will be needed. The first is the validation of the signals observed on interferograms by means of local survey team. In the second place, we can also observe from above that the local atmospheric condition plays an important role in the interferogram. To distinguish the atmospheric effect from local ground subsidence, we will need to collect more image over the same area and take the multi-temporal analysis technique to remove the atmospheric effect.

6. ACKNOWLEDGEMENT

We thank European Space Agency (ESA) for providing us Sentinel-1A data for research purpose in this project. This work was partially supported by the School of Civil Engineering, Purdue University.

7. REFERENCES

- [1] Baer, Gidon, et al. "The lowest place on Earth is subsiding—An InSAR (interferometric synthetic aperture radar) perspective." *Geological Society of America Bulletin* 114.1 (2002): 12-23.
- [2] Closson, Damien, et al. "Salt-dissolution-induced subsidence in the Dead Sea area detected by applying interferometric techniques to ALOS Palsar Synthetic Aperture Radar images." *Geodinamica Acta* 23.1-3 (2010): 65-78.
- [3] Baer, Gidon, et al. "New Modes of Sinkhole Formation along the Dead Sea Shorelines (Israel): Observations from InSAR, LiDAR, Time-lapse Camera, and Water Analysis." *Fringe 2015 InSAR workshop*, 23-27 March, 2015, ESA-ESRIN Frascati, Italy.
- [4] Closson, Damien, et al. "Dead Sea Salt Karst Dynamics Revealed by Multi-Temporal Radar Interferometric Techniques." *Proc. of AOGS 2015*, Jan 2015, Singapore.
- [5] Nof, R. N., et al. "Rising of the lowest place on Earth due to Dead Sea water-level drop: Evidence from SAR interferometry and GPS." *Journal of Geophysical Research: Solid Earth* (1978–2012) 117.B5 (2012).
- [6] Prats-Iraola, Pau, et al. "TOPS interferometry with TerraSAR-X." *Geoscience and Remote Sensing, IEEE Transactions on* 50.8 (2012): 3179-3188.