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Ground Deformation Identification related to 2018 Lombok Earthquake Series based on Sentinel-1 Data

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Abstract. Lombok Island was hit by a series of earthquakes in July and August 2018 with magnitude 6 class. This series of earthquakes resulted in fatalities and material losses that even reached Sumbawa Island to the east of Lombok Island. The earthquake was triggered by Flores back arc thrust resulting in ground deformation. Ground deformation can be identified by satellite-based remote sensing method. The Sentinel-1A and Sentinel-1B satellites are two satellites carrying C-band SAR sensors with a temporal resolution of 12 days each for the same orbit, and the difference in time between the two is 6 days. Therefore, ground deformation related to seismo-tectonic or volcanic activities can be identified by interfering two SAR images (interferometric synthetic aperture radar or InSAR) at least in 6 days. By utilizing Sentinel Application Platform (SNAP) a free open source software (FOSS) and combining with other InSAR software, an interferogram that represents line of sight displacement (LOS) between ground and satellite can be generated. Line of sight displacement can then be interpreted as ground deformation signals. It is shown that the series of Lombok earthquake cause an uplift up to 70cm and subsidence up to 25cm. This deformation affects areas around epicentre. A field survey was conducted to obtain information directly and it was seen that the ground deformation that was identified with the InSAR technique were consistent with the findings in the field. This shows the advantages of remote sensing in terms of ability to cover a wide area in a short time.

Keywords: deformation, Lombok, earthquake, InSAR, Sentinel, SNAP

1. Introduction

Ground deformation is changing of earth surface and related to whether seismo-tectonic processes such as earthquakes, faulting, volcanism, landslide; anthropogenic processes such as ground water pumping and mining; or other environmental phenomena such as glaciation and deglaciation. Most of these processes are associated with the plate movement caused by the mantle convection, which can be explained by the theory of plate tectonics [1]. Ground deformation occurred soon after the earthquake happen is known as coseismic deformation. Study on coseismic deformation is important to



understand the mechanism of the earthquake and its effect. Recently, there are two techniques to estimate the ground deformation that are terrestrial based survey i.e. by Global Navigation Satellite System (GNSS) observation; and remote sensing technique i.e. spaceborne based interferometric synthetic aperture radar (InSAR).

The utilization of InSAR for ground deformation have been studied [2], [3], [4] and continuously improved in terms of sensor development and data processing strategies [5]. However, the general problem with this system is that the temporal resolution is limited by the orbital passages of the satellites over the same area. This implies that InSAR method is an episodic method and impossible to implement as a real-time method, but on the other hand it provides a good spatial coverage or provide more spatially continuous information.

Indonesia is located in a junction of four world's major plates, namely Eurasian, Australian, Pacific and Philippines plates. These plates subduct and collide with each other and have resulted in high seismic activity in Indonesia along the plate boundary, rugged topography, and volcanism [6]. In the western part of the Indonesian region, the Australia plate subducts beneath the Eurasia plate along the Java trench with velocity 7 cm/year [7], while the eastern part the tectonic setting is dominated by collision of the continental part of the Australia plate with the Banda arc and the Pacific oceanic plate with velocity 11 cm/year [8]. This tectonic setting implies high frequency of earthquake occurrences in Indonesian region.

On July and August 2018, series of earthquake struck Lombok Island, one island in South Banda Block [9] system or Flores Thrust [10]. The earthquake series starting on July 29th 2018 with magnitude 6.4 as foreshock, August 5th 2018 with magnitude 7.0 as the first main shock, August 9th 2018 with magnitude 6.2 as a significant aftershock, and August 19th 2018 preceded by foreshock magnitude 6.3 and magnitude 6.9 as second main shock ten hours later.

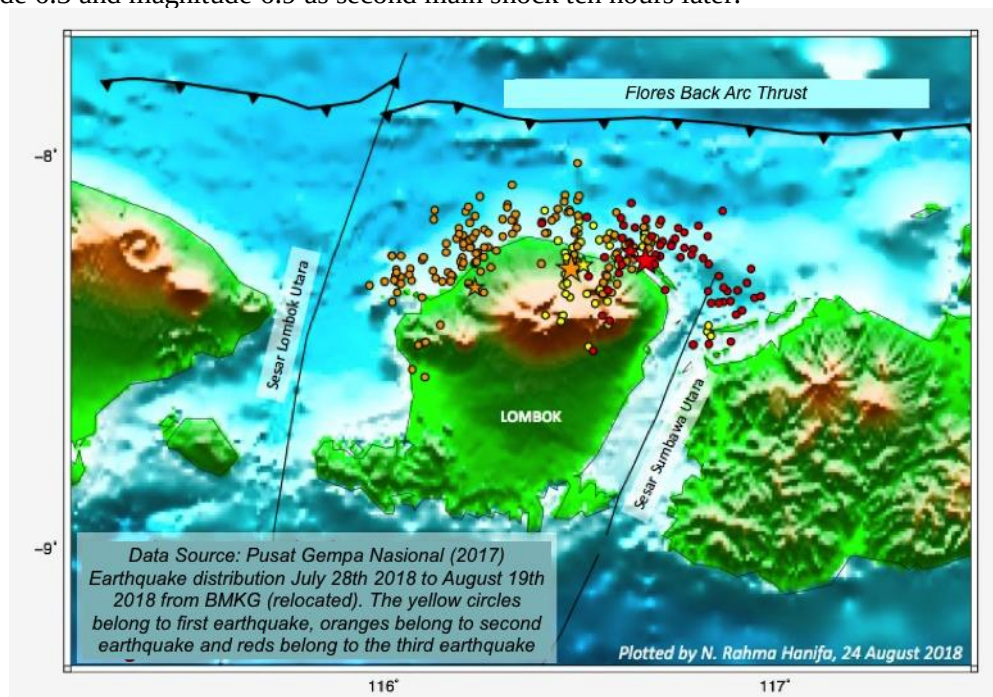


Figure 1. Distribution of Lombok earthquake series

This paper represents the ground deformation related to Lombok earthquake series based on InSAR technique. InSAR is developed to derive digital elevation model for one particular area or one particular point in Earth's surface. The product of this technique is an interferogram which is obtained by cross-multiplying, pixel by pixel, of two SAR image (two SLCs). By isolating the phase information related to deformation signals, the ground deformation can be derived.

2. Data and Method

To identify ground deformation related to Lombok earthquake series based on InSAR technique, five SAR scenes data that covered the affected region and earthquake occurrence time that is observed by Sentinel-1 satellite system are downloaded from European Space Agency (ESA) data portal (<https://scihub.copernicus.eu/dhus/#/home>) illustrated in Figure 2 and listed in Table 1.

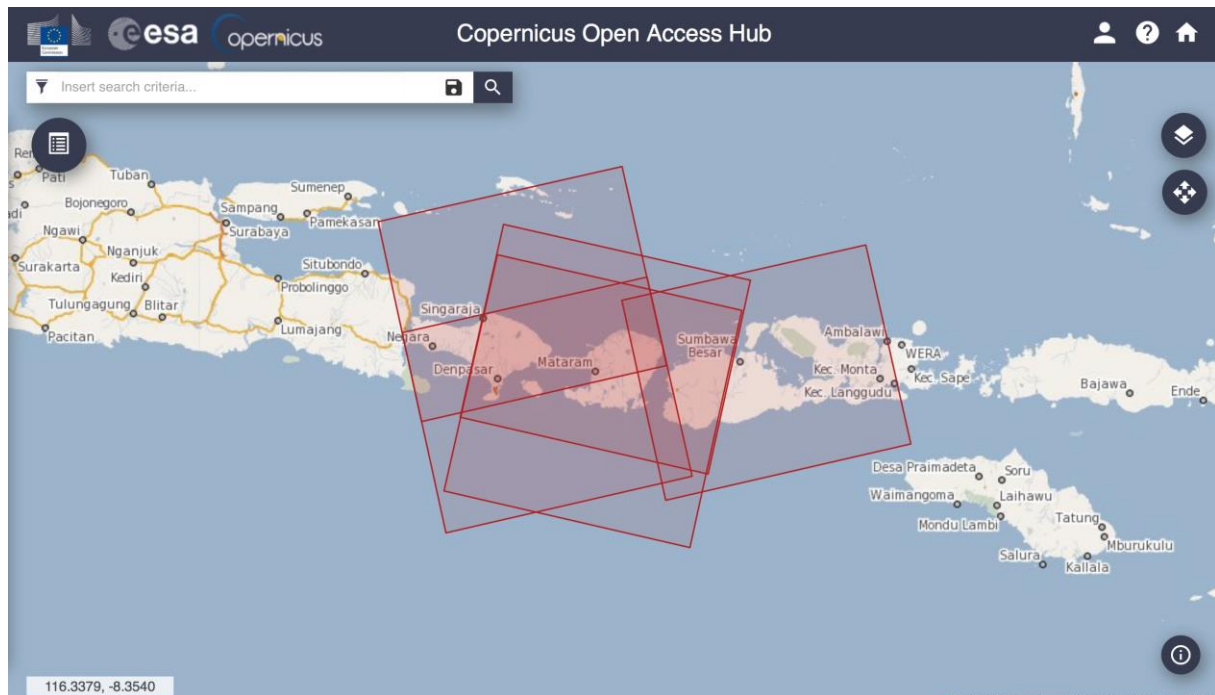


Figure 2. Illustration of Sentinel data portal

Table 1. SAR data sets and its InSAR pairs

Scene ID	Local Time Observation	InSAR pair for earthquake
S1B_IW_SLC__1SDV_20180724T215223_20180724T215259_011958_016031_735F	July 25th 2018: 05:52 AM, Descending orbit	Master for Mw 6.4 July 29th 2018 earthquake
S1A_IW_SLC__1SDV_20180730T215301_20180730T215330_023029_027FF4_17F1	July 31st 2018: 05:53 AM, Descending orbit	Slave for Mw 6.4 July 29th 2018 earthquake Master for Mw 7.0 August 5th 2018 earthquake
S1B_IW_SLC__1SDV_20180805T215224_20180805T215259_012133_01657B_089F	August 6th 2018: 05:24 AM, Descending orbit	Slave for Mw 7.0 August 5th 2018 earthquake
S1B_IW_SLC__1SDV_20180817T215225_20180817T215300_012308_016AE7_CA51	August 18th 2018: 05:52 AM, Descending orbit	Master for Mw 6.3 and 6.9 August 19th 2018 earthquake
S1A_IW_SLC__1SDV_20180823T215302_20180823T215331_023379_028B27_A36E	August 24th 2018: 05:02 AM, Descending orbit	Slave Mw 6.3 and 6.9 August 19th 2018 earthquake

The Sentinel-1 satellite system is a constellation of two satellites, namely Sentinel-1A and Sentinel-1B that bring C-band SAR sensor and is developed by European Space Agency (ESA). The Sentinel-1A was launched on April 3rd 2014, whereas the Sentinel-1B was launched on April 25th 2016, both with temporal resolution is 12 days and supports four different operational imaging modes that are providing different resolution and coverage: Interferometric Wide swath (IW) mode, Extra Wide swath (EW) mode, Strip-Map (SM) mode, and Wave (WV) mode [11], [12], [13].

These data sets are processed by utilizing Sentinel Application Platform Toolbox or SNAP - S1TBX [14] a free open source software (FOSS), and GAMMA SAR Software under Nagoya

University licence. The processing chain consisted of orbit file correction, radiometric calibration, coregistration, interferogram calculation, topographic phase removal, interferogram filtering and geometric correction.

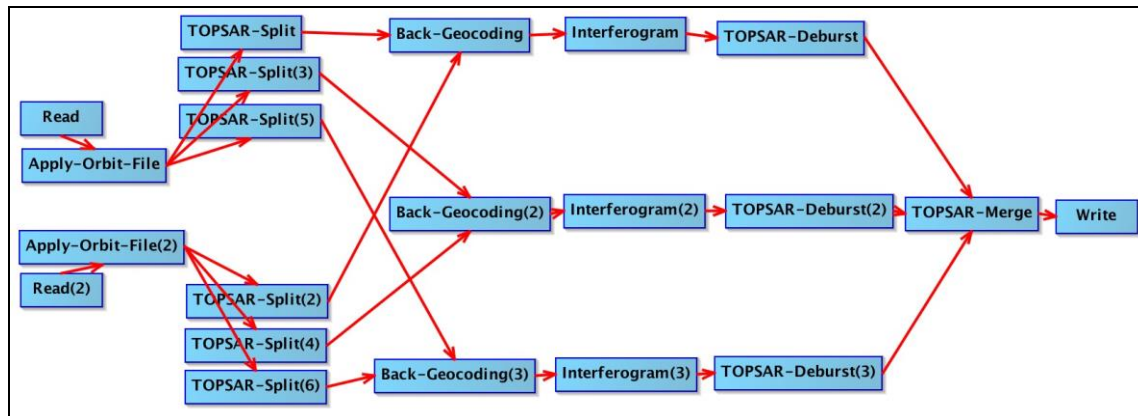


Figure 3. Illustration of InSAR processing chain for Sentinel TOPS data

Since data from Sentinel-1 is available in interferometric wide swath (IW) in Terrain Observation by Progressive Scans (TOPS), data should be selected only for that related area to reduce memory consumption during data processing. Sentinel-1 data is dual polarization mode (VV and VH) and each of polarization consisted of three interferometric wide (IW) swaths namely IW1, IW2 and IW3. Each interferometric wide swath contains number of bursts, usually 9 to 12 bursts. This information is important to understand when selecting the related area of study and is implemented in splitting the data. In this research, the area study of Lombok earthquakes are covered in 5 bursts for IW1 and IW2 only from VV polarization mode and illustrated in Figure 4.

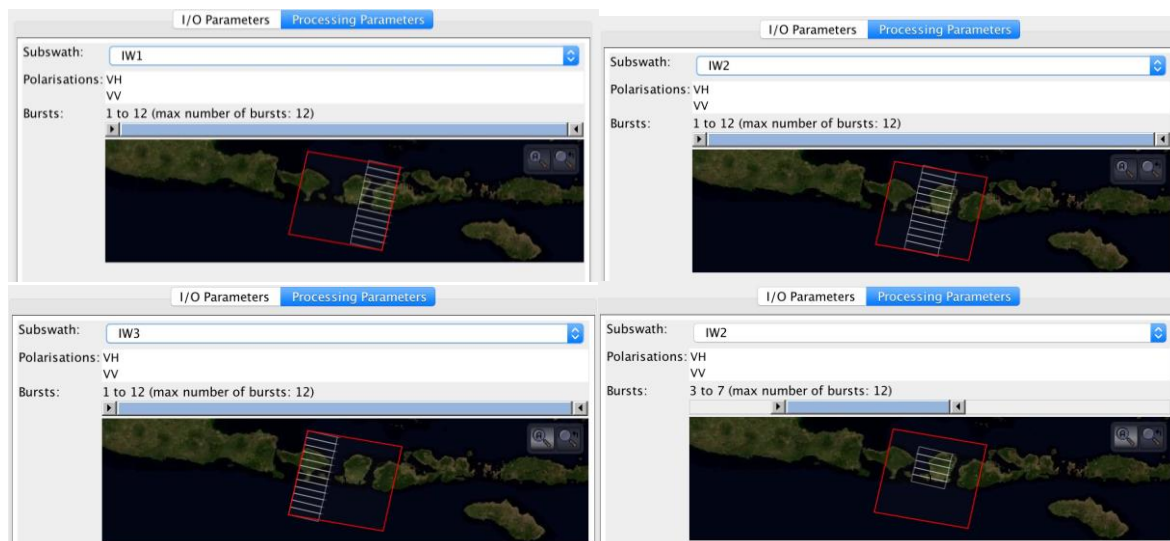


Figure 4. Illustration of IW and burst in TOPS data split in SNAP S1TBX

Figure 4 illustrates the area covered by each IW and it shows that for descending orbit, the IW count starts from the right, and the burst count starts from the top. The Single Look Complex (SLC) image is derived by splitting the IW1 and IW2 to obtain five bursts of them, merging and applying deburst step. After that, the interferometric analysis is ready to conduct, i.e. by utilizing graphic processing tools (GPT) that available in SNAP (illustrated in Figure 3) or S1_TOPS_coreg script that is available in GAMMA SAR Software.

3. Result and Discussion

The backscatter image of Lombok Island that is derived from five bursts of IW1 and IW2 are illustrated in Figure 5.

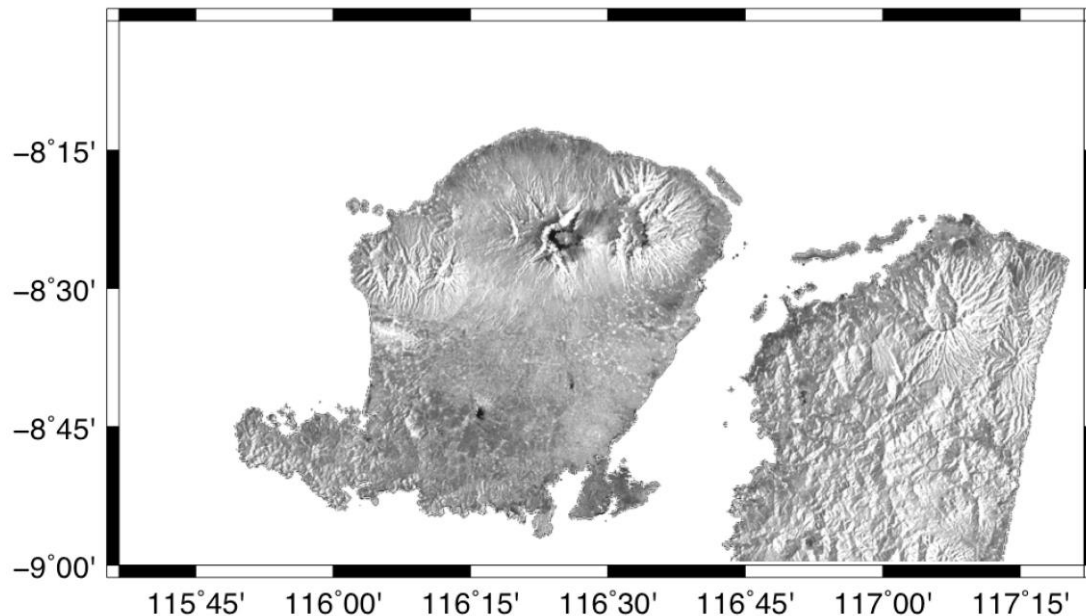


Figure 5. Illustration of backscatter image of 5 bursts from IW1 and IW2 Sentinel-1 data in VV polarization mode

There are 5 interferograms that can be analysed to understand the ground deformation related to July-August Lombok earthquake series. The first interferogram is ground deformation signal produced purely by the July 29th Mw6.4, the second one is by the August 5th Mw7.0 only, the third one is by the August 19th Mw6.3 and Mw6.9 only, the fourth one is by combining the first and the second earthquake and the last one is a combination of the earthquake series. The interferograms are illustrated in Figure 6.

As explained in Table 1, interferogram 1 is derived from Sentinel-1B July 25th and Sentinel-1A July 31st 2018 that covers the July 29th Mw 6.4 earthquake. The interferogram 2 is derived from Sentinel-1A July 31st and Sentinel-1B August 6th 2018 that covers the August 5th Mw 7.0 earthquake. The interferogram 3 is derived from the Sentinel-1B August 18th and Sentinel-1A August 24th 2018 that covers the August 19th Mw 6.4 and 6.9 earthquakes. All of these interferograms have 6 days time difference. The interferogram 4 is derived from Sentinel-1B July 25th and Sentinel-1B August 6th 2018 that covers the first two earthquakes, and the time difference between two observations is 12 days. The interferogram 5 is derived from Sentinel-1B July 25th and Sentinel-1A August 24th 2018 that covers all the earthquakes series, and the time difference between two observations is 30 days. The interferogram 1 and 2 are produced by SNAP S1TBX software, whereas the others are produced by GAMMA SAR Software. Both softwares can derive interferogram with clear fringes that are associated with coseismic deformation signals.

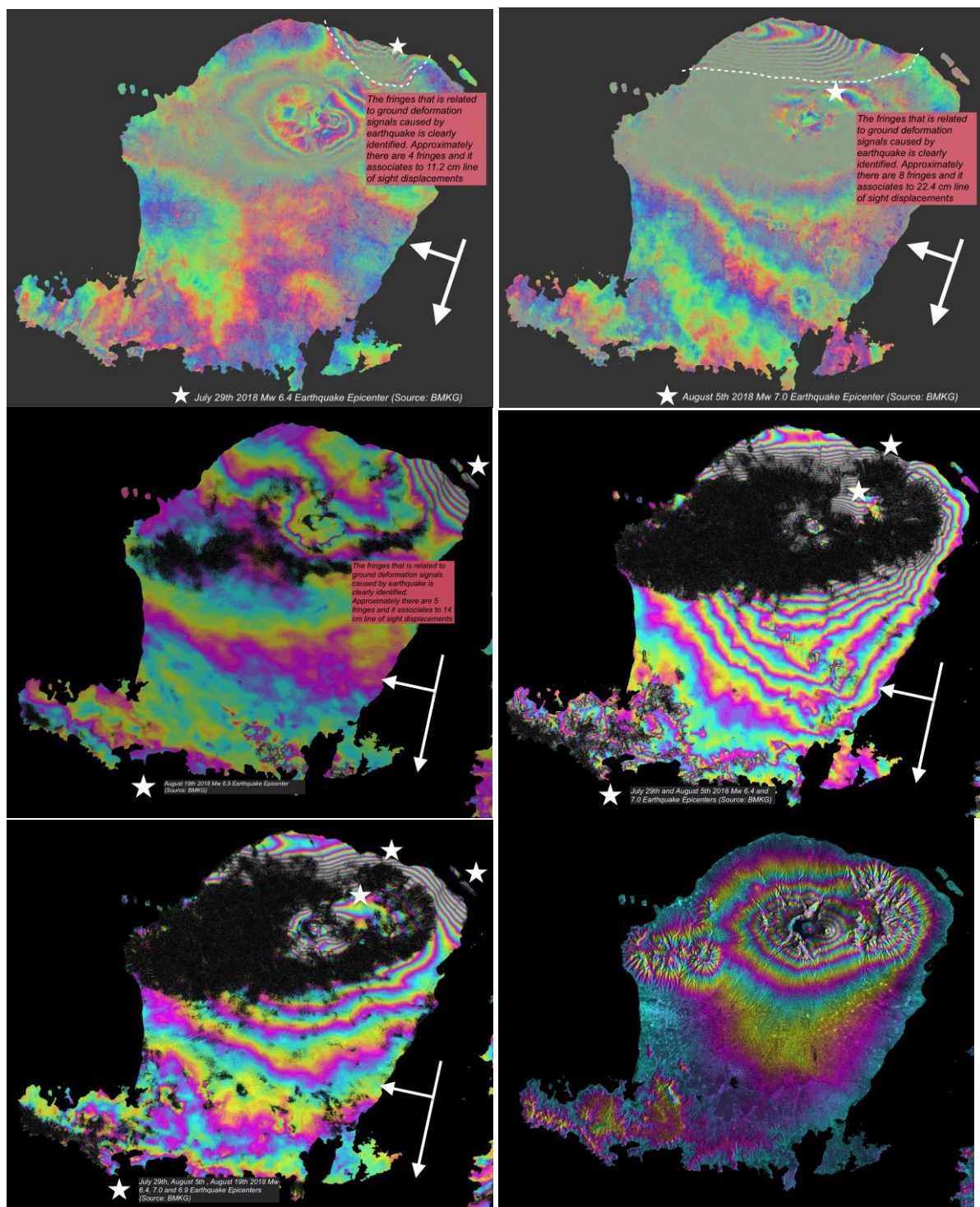


Figure 6. Illustration of interferogram that is produced by InSAR technique. The first five interferograms illustrates the coseismic deformation signals, whereas the last figure illustrates the topographic signals of Lombok Island

By counting the color fringes, it is shown that the series of Lombok earthquake cause an uplift up to 70cm and subsidence up to 25cm. This deformation affects areas around epicenter. A field survey is conducted to verify the deformation and the results are illustrated in Figure 7 below.

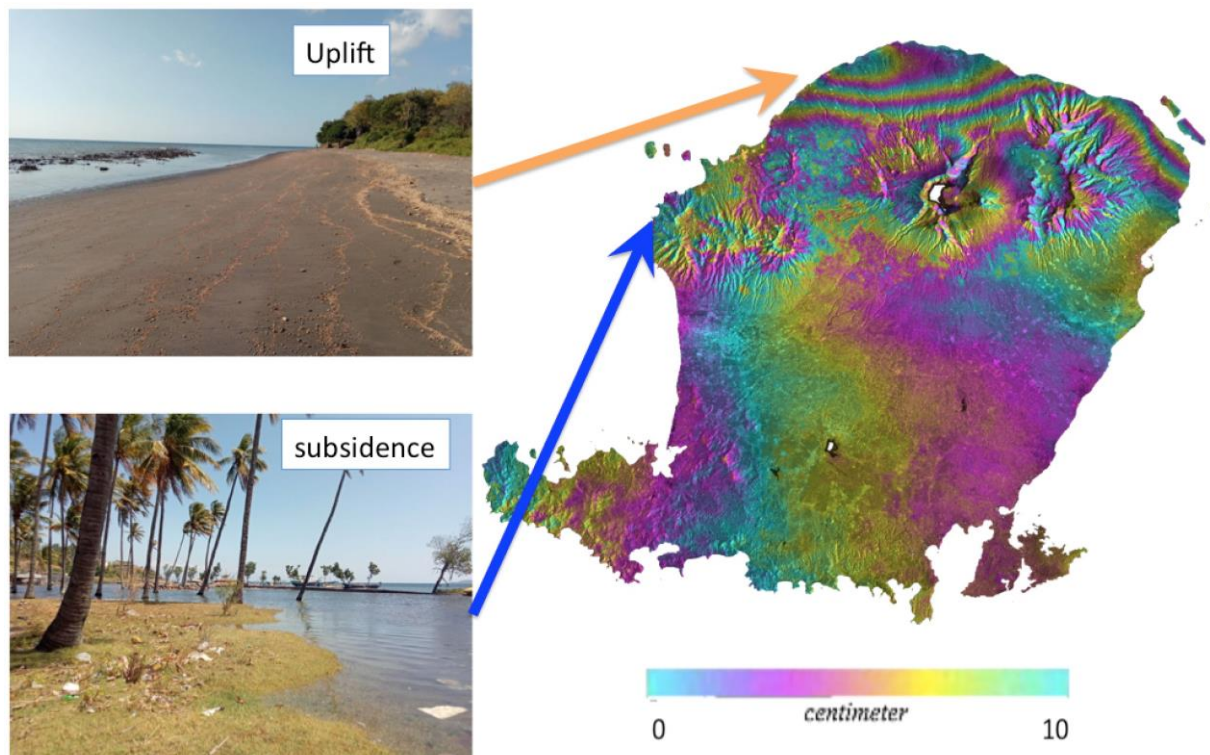


Figure 7. Illustration of total coseismic deformation signals of Lombok earthquake series and the field observation survey

4. Conclusions

This research shows the ability of high temporal resolution of Sentinel-1 satellite constellation to detect ground deformation signals related to coseismic displacement of Lombok earthquake series. This information is useful to identify the deformed areas and then to model the earthquake source and mechanism. Conventional InSAR data processing method is good to derive coseismic deformation signals even for mountainous region like Lombok Island.

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