DEM Generation from Multi-View Satellite Images in Sub-Sahel Region

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Keywords: Remote Sensing, DEM Generation, Cubesat Satellites, Stereo-Modelling, 3D Modelling.

Abstract

Floods are causing a significant loss of human lives and valuable resources in West Africa. In particular, Niger and Burkina Faso were highly affected areas in past years. In order to predict flood, an accurate Digital elevation model (DEM) is required for flood mapping. At the studied area in Niger, up to this date, the LiDAR DEMs are scarcely available, and the only available DEMs are global DEMs like global SRTM DEMs with a resolution of 10m. These global DEMs are not accurate enough to be used for flood mapping. So, in this context, this study investigates the potential of multidate, multi-view stereo pairs PlanetScope images for the generation of DEM. Three DEMs were generated from images with slightly different view angles to see the effect of view angles of images on 3D modelling. One of the DEM generated by PlanetScope images was compared with DEM generated by high-resolution drone imagery and shows the normalized Median of Absolute Deviation (NMAD) of the elevation differences of 10m. Results show that planetScope images are useful assets for generating multiple DEMs due to their high temporal resolution. Such DEMs could be extremely useful for studying dynamic phenomena or monitoring disaster events like floods.

1. Introduction

PlanetScope satellites constellation consists of approximately 130 CubeSats (10cm x 10cm x 30cm) . The First generation of PlanetScope satellites was launched in 2018 and are able to image whole landmass of Earth nearly every day. The orbital altitude of satellites is about 450-580 km and are placed in sun synchronous orbits with inclination angle of 98 degrees.

PlanetScope satellites are configured to collect images in a nadirlooking direction. Due to nadir angle-looking configuration of PlantScope satellite, small scene to scene offset and small Base to height ratio (less than 1:10) of planetScope images do not make them ideal for generating 3D models. However, various studies have been carried out to develop the 3D models from the PlanetScope images. In 2018, DEM was created from the multiple PlanetScope images using volumetric stereoreconstruction techniques (Ghuffar, 2018). In 2021, DSMs were produced by pair-wise image matching using the PlanetScope images with low view angles for identifying ground features (Huang et al., 2022). In 2022, DSM was produced by dense image matching of PlanetScope images and used for studying the dynamics of the glacial site (Aati et al., 2022).

This study investigates the potential of high-resolution DEM generation with low view angles (0.3-1.2 degrees) over a study area where a river is passing by. Such high-resolution DEM will be useful for flood simulation within the framework of SLAPIS Sahel (Slapis Sahel - Climateservices.It CNR-IBE, 2023). Three DEMs were created in flood-prone study areas from high spatial resolution (3-4m) satellite Images, as required for developing an early flood prediction system. The goal of SLAPIS Sahel research project is to reduce the hydrometeorological climate risks and to develop an early warning flood system in Sirba river basin, which lies at the borders of Niger and Burkina Faso in west Africa. Sirba River is a tributary of Niger River that flows in the Niger and Burkina Faso borders. Sirba Basin covers an area of about 39,138 km^2 (Belcore et al., 2022). This work aims to explore the capability of PlanetScope data for 3D stereo reconstruction and compare the accuracy of 3D models generated from PlanetScope images to 3D model generated from the high-resolution drone imagery.

1.1 SLAPIS Sahel Project Overview

SLAPIS Sahel is a research and training program to predict and monitor the flood and to train the local government in Niger and Burkina Faso to take timely necessary actions to combat against the floods. The Goal of the SLAPIS Sahel project is to reduce the hydrometeorological climate risks and to develop an early warning flood system in Burkin Faso and Niger that was often flooded by the Sirba River in past years (1998-2018) in the Monsoon season. This project aims at SDG 13 to combat climate change, specifically focus on Target 13.3 (Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning).

2. Study Area

Three squared kilometres of flood-prone village area along the Sirba was studied because of availability of ground truth data as a reference. This study area was chosen because of the availability of ground truth data. A campaign of measurements was carried out using high-resolution drone imagery in February 2018 by drones. The study area is shown in Figure 1 below.

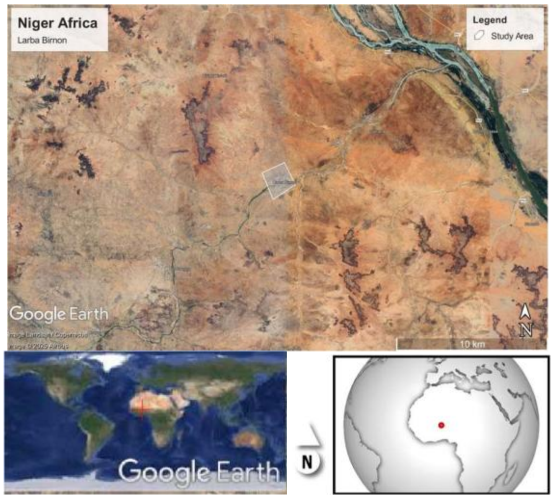

Figure 1. Study area of 3 km2 in white polygon in Larba Birnon, Niger Africa.

3. Materials and Data Collection

Planetscope provides scenes with a pixel resolution of 3m and a ground sample distance of about 3-4m. There are three different versions of PlanetScope satellites operating around the Earth: Dove Classic, Dove-R and superDove.

PlanetScope basic scenes captured by Dove Classic satellites are scaled on top of atmosphere radiance and sensor-corrected images but without performing any type of geometric involved in the imaging process. However, PlanetScope images are provided with rational polynomial coefficients (RPCs) to perform the geometric correction by users. These coefficients are used to correlates the points from images to real ground and contains the offsets from the nadir looking direction, recorded during the capturing of image by sensor. PlanetScope basic images have frame size of 24km x 8km. The planetScope images have a spectral resolution of 4 bands, including the red, green, blue and near-infrared bands. PlanetScope basic scenes have pixel size of 3m and ground sample distance of 3-4.1 m.

PlanetScope satellites collect images along and across their tracks. Considering their orbits, planetScope scenes not only have scene-to-scene overlapping but also have lateral overlapping with slightly different view angles. (*Planet Imagery Product Specifications PLANET.COM*, 2023).

Dove classic scenes, that have been used in this study had footprint of 24km x 8km, with approximate capture time difference of 1 second along track of satellites. The scenes are available to download either as 3 bands (RGB) or 4 bands (RGB+NIR). . Images downloaded from the Planet Explorer and used in this work for DEM generation had 4 bands comprising RGB and NIR bands.

PlanetScope scenes, which have been used in this study, had consecutive scene to scene overlap of 8% and about 80-90% of lateral overlapping. Such maximum overlapping images are most suitable for stereo 3D modelling. PlanetScope images chosen had more than 80% overlapping. Image matching can be performed basically in a single band. The near infrared (NIR) band was chosen for image matching due to presence of river, as water is string absorbent of water in NIR band. So, image matching was performed in NIR (Ghuffar, 2018).

In February 2018 drone survey Belcore et al., 2022 was carried out over the same studied area shown in Figure 1, by using an optical camera that had a resolution of 23.3 MP. The camera collected images at a resolution of 3.9cm/pixel. Images were georeferenced using the Ground control points, which were collected by a GNSS dual frequency receiver for georeferencing the data. GCPs had a precision of $\pm$ 4 cm and an accuracy of 17cm. A DSM was created from the high-resolution drone imagery using the structure from motion technique. DSM generated from the drone imagery had a resolution of 7cm.

PlanetScope Images were filtered from the same month in February 2018, in which a drone survey was carried out, so that DEM generated from the PlanetScope could be compared with DEM generated from the drone imagery.

Images were filtered in planet explorer images with full area coverage, 0% cloud coverage and small off-nadir angle in the range of 0-5 degrees were chosen. Images were filtered with small off-nadir angles of 0-5 degrees as low view angles result in large convergence angles suitable for 3D modelling. First stereopair listed in Table 1 with largest view angles is shown in Figure 2:

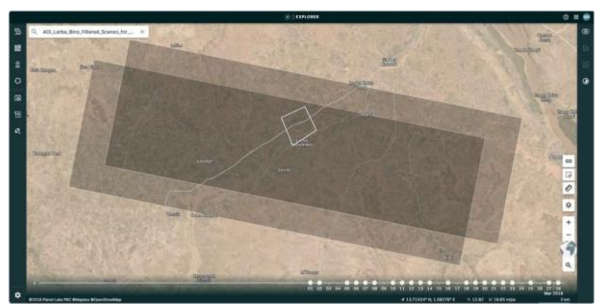

Figure 2. Footprint of stereopair-1 Images in Planet explorer over the studied area (in white rectangle).

Three DEMs were extracted from 3 stereo pairs with slightly decreasing view angles from pair-1 to pair-3. Stereo pairs were chosen with maximum overlapping in the study area with no cloud coverage and small view angles of 0-5 degrees. The base to height B/H of images used for 3D modelling were between 01. The PlanetScope image acquisition parameters have been listed in Table 1.

Table 1: Acquisition parameters for the PlanetScope imagery over the study area arranged by decreasing view angle

Stereo pair No.	Acquisition Date (dd/mm/yyyy)	PlanetScope Satellite ID	Acquisition Time (hr: min: sec)	Pixel resolution (m)	GSD (m)	Angle (degrees)	Azimuth angle (degrees)
1	06/02/2018	100e	09:47:06	3	3.9	**1.1**	105.1
	11/02/2018	103e	09:47:26	3	3.9	**0.9**	188.6
2	05/02/2018	1014	09:46:47	3	3.9	**0.9**	115.9
	25/02/2018	1044	09:47:40	3	3.9	**0.9**	172
3	23/02/2018	0f18	09:47:33	3	3.9	**0.3**	217.7
	01/02/2018	0e0f	09:49:19	3	3.9	**0.7**	271.2

4. DEM Generation: Workflow and Analysis

Downloaded images along with RPC files were input inside the Envi software (ENVI Remote Sensing Software for Image Processing & Analysis, version 6.0.). for DEM generation. The workflow adopted for the generation of DEM in image space from planetScope images is shown in Figure 3 below.

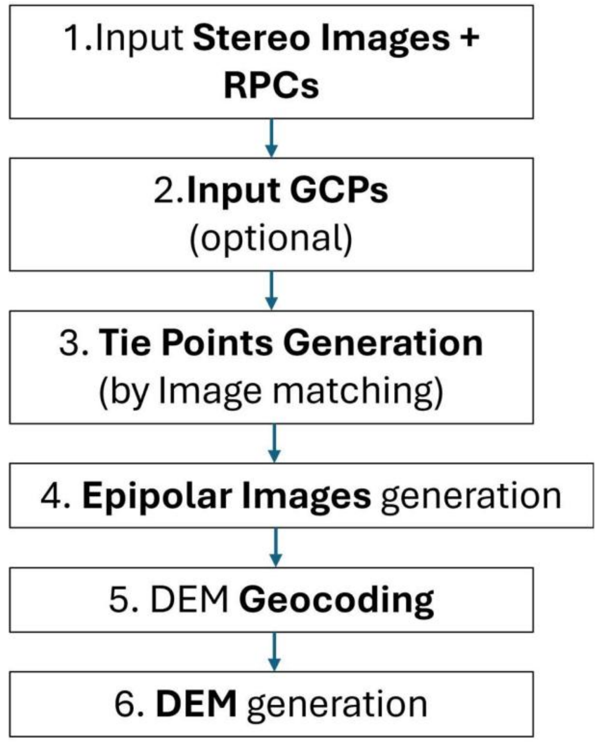

Figure 3. Workflow for DEM extraction from PlanetScope Images.

First, the PlanetScope stereo pair (left and right images) were input along with the RPC (rational polynomial coefficients) file in the Envi software DEM extraction module. Maximum and minimum elevations of images were firstly estimated by the Envi software using RPC file provided by planet labs while downloading images as a metadata file. The first stereopair images had an overlapping of 90%, as can be seen in Figure 4 :

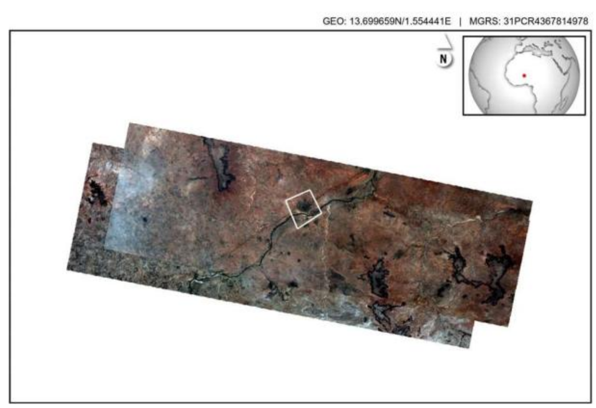

Figure 4. PlanetScope stereopair-1 from February 2018 (In white is studied area of interest 3 km2).

Thirty-seven Ground control points were measured in this studied area by a GNSS survey realized in 2018. (Belcore et al., 2022). Ground control points were identified interactively in images using the map to image projections. Ground control points were distributed all over the study areas and can be seen in Figure 5 below:

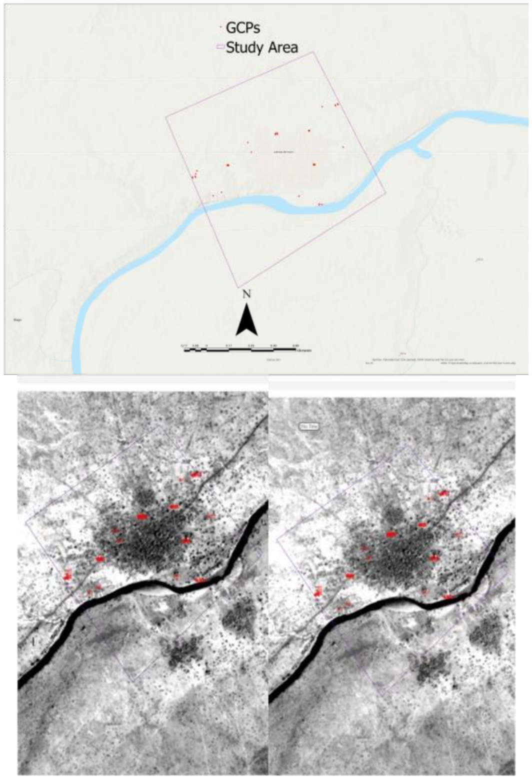

Figure 5. Ground Control on Map (upper photo), and identification in Left stereopair image (on bottom left) and right stereopair image (on bottom right).

Then Image matching was performed between the left and right images within an image pair to find Tie Points. Image matching found the conjugate points between the left and right images that correspond to the same ground features. Choosing the large tie points makes the computation time-consuming but decreases the parallax within the stereo pair . One hundred tie points were found by image matching between left and right image and are shown in Figure 6:

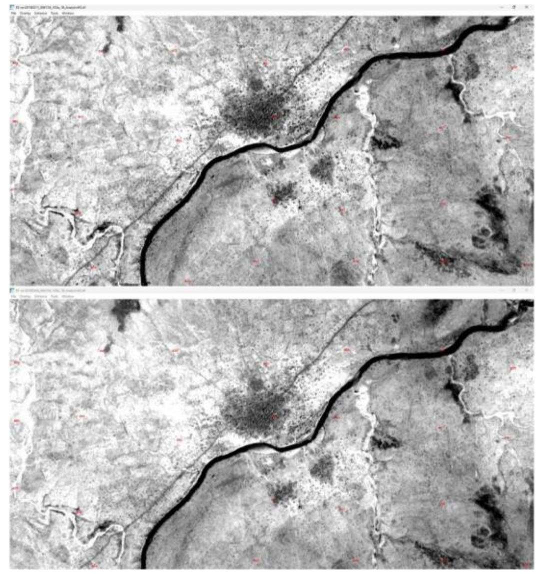

Figure 6. Tie points (red dots) in stereopair-1 images.

Epipolar Images were generated using ground control points and automatically generated tie points in the NIR band. Epipolar images are oriented in such a way that the ground point and two optical centres of images lie on the same plane. Epipolar images are images lying on a same horizontal surface and have just parallax along the one planar axis. By creating epipolar images, the space for searching for the conjugate points between the left and right stereo pair is reduced.

Lastly the epipolar images were geocoded that reprojected the images to map in the UTM 31N_WGS-84 coordinates system. The DEM extraction wizard used inside Envi software also takes into account terrain relief to perform the smoothed effect on the output DEM. Moving from low to moderate and moderate to high terrain relief the output DEM has less smoothed effect on extracted DEM. DEMs were generated by image matching between the left and right epipolar images and the level of terrain chosen as moderate. As the study area is relatively flat, level of terrain was chosen as moderate which was most suitable for most of terrain.

5. Results and Discussion

The DEM generated from the stereopair-1 is shown below in Figure 7. The DEM was further clipped to studied area of 3 km^2 over Larba Birnon as shown in Figure 8 below.

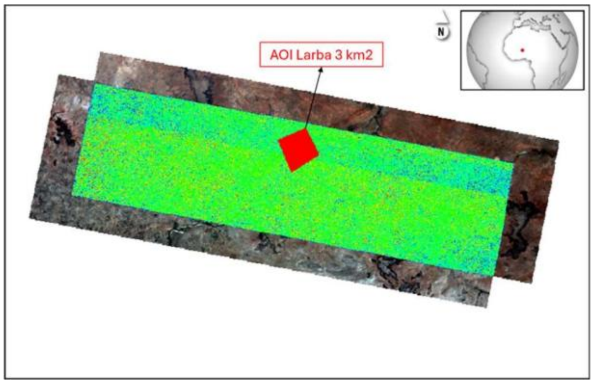

Figure 7. Unclipped DEM from stereopair-1.

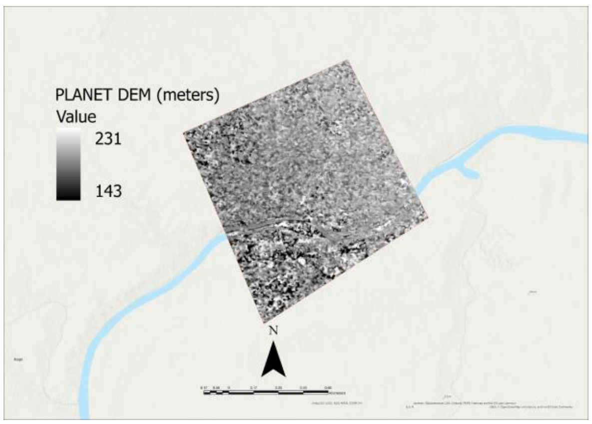

Figure 8. Clipped DEM over studied area (Larba Birnon) generated by PlanetScope images.

Three DEMs were created by slightly different view angles to see the effect of different view angles on 3D modelling. The three stereopairs footprint used for generation of three DEMs listed in Table 1 are shown in Figure 9:

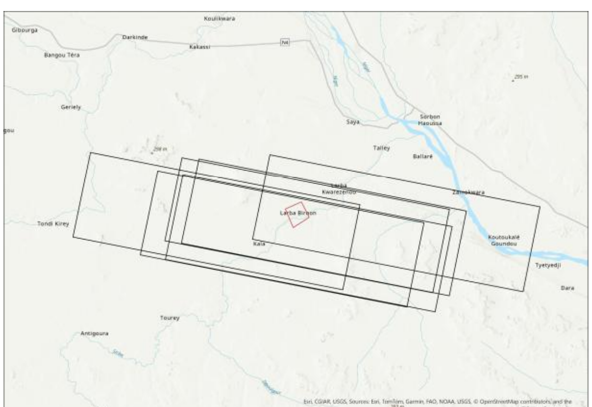

Figure 9. Footprint (in black) of 6 Planetscope Images over studied area (in red).

Following the similar workflow for DEM generation as done for stereopair-1, the process for DEM generation was repeated for the second and third stereo pair of images with lesser view angles of 0.9 degrees each for pair-2 and 0.3 and 0.7 for stereo pair-3 respectively. The stereo pair-1 had the highest view angles (Left:0.9, right:1.1) degrees and moving on stereo pair-2 had Middleway view angles (Left:0.9, right:0.9), and stereo pair 3 had the lowest view angles (Left:0.7, right:0.3) degrees. The time difference between the left and right stereo pair had least effect on the DEMs generated. Although the image pair-3 has maximum time difference of 22 days, but the DEM generated was better than first and second stereopair. The DEMs generated from stereo pair-2 and 3 are as shown in Figure 10:

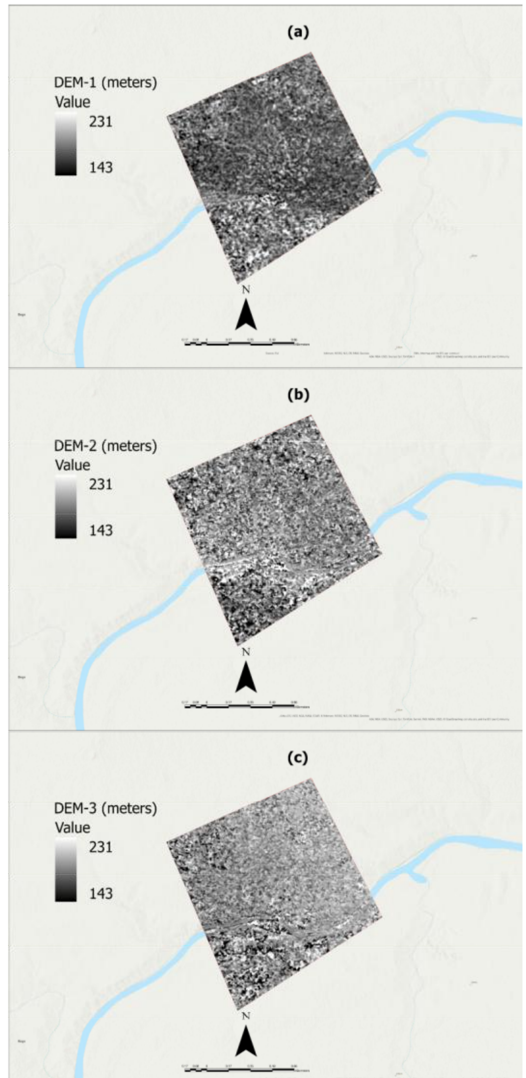

Figure 10. (a) DEM generated by stereopair-1, (b) DEM generated by stereopair-2, (c) DEM generated by stereopair-3.

In the end, the DEM extracted from PlanetScope images was compared with DEM extracted by high-resolution drone imagery and showed a Normalized Median of Absolute Deviation (NMAD) of the elevation differences of 10m. The comparison between the two DEMs is shown in Figure 11 below:

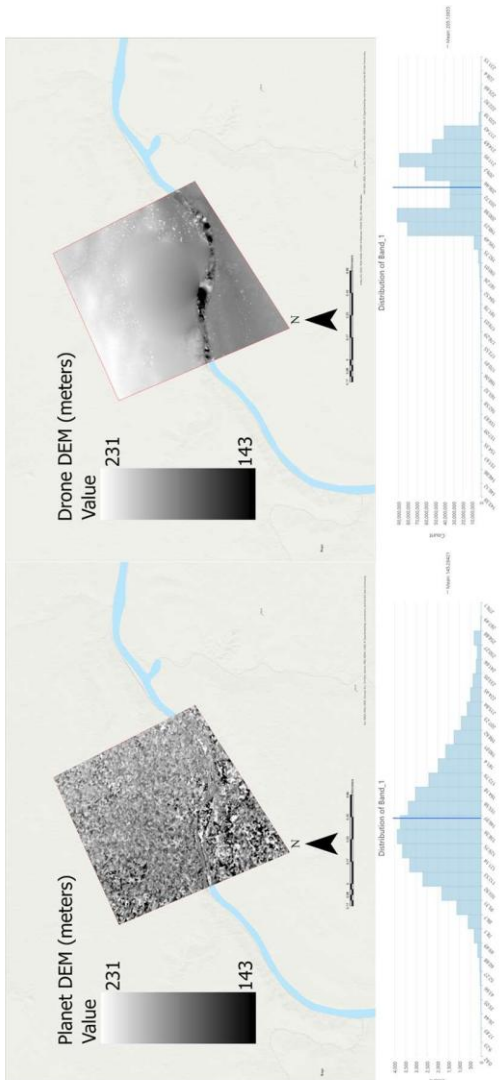

Figure 11: DEMscomparisonPlanet(4mresolution)onleftvsDroneDEM(7cmresolution)onrightandHistograms comparisonofBand-1containingtheelevationvaluesPlanetScopeDEMhistogram(onleft)andDroneDEM

6. Conclusion

It was concluded that, by increasing the view angles of input stereopairs larger than one degree the DEM gets nosier. DEM extracted by using the stereopairs with small view angles results in better identification of river. PlanetScope stereopair with large time difference within stereopair still gave satisfactory results.

Moreover, it was observed that increasing the number of tie points improves the quality of DEM; however, it increases the computational effort and time to find the tie points between the left and right image pair. The goal of the work was to have a highresolution DEM that could be used for flood simulation . The DEM generated had an accuracy of 4m better than the global DEMs like ALOS or SRTM DEMs. Planetscope images due to their high temporal resolution could be valuable asset for making 3D models from multidate images and to study a disaster phenomenon.

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