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A STUDY OF RIVERBED DYNAMICS USING REMOTE SENSING: A 3D CASE STUDY OF RIVIÈRE DES GALETS, LA RÉUNION ISLAND

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ABSTRACT

La Réunion Island suffers severe erosion due to high tropical rainfall and steep volcanic slopes. Using aerial and SPOT imagery we monitor horizontal and vertical changes in the morphology of Rivière des Galets on the west coast of the island. SPOT imagery from 2000 to 2008 is used to monitor the evolution of the delta and construct a multi-seasonal flow pattern of the river thalweg. Stereographic aerial photography from 2006 and 2008 is used to construct high resolution DEMs which allows the calculation of displaced sediment volume in the river. Cross-sectional profiles for three successive years, collected by differential GPS, provide accurate validation of the results.

Index Terms — Remote Sensing, Erosion, Stereophotogrammetry, Delta, Geomorphology

1. INTRODUCTION

The island of La Réunion suffers severe erosion due to its torrential tropical rainfall, steep slopes and unconsolidated volcaniclastic sediments. Knowledge of erosive rates and landscape evolution is of vital importance in terms of disaster risk management as well as being of significant value to a range of industries in both the public and private sector. On La Réunion, where geological hazards are a undeniable reality [1], this is paramount. Current research on active surface processes on La Réunion Island remains limited [2] and the use of remote sensing for the study of 2D and 3D geomorphological processes even more so.

In this paper we demonstrate the use of spaceborne and airborne remote sensing techniques for the quantification of vertical and horizontal changes in the Rivière des Galets riverbed and delta. A database of SPOT 4 and 5 imagery spanning the last eight years is employed for the analysis of horizontal phenomena, while two sets of stereographic aerial photographs allow the construction of multi-seasonal digital elevation models (DEMs). Differential GPS measurements provide additional validation.

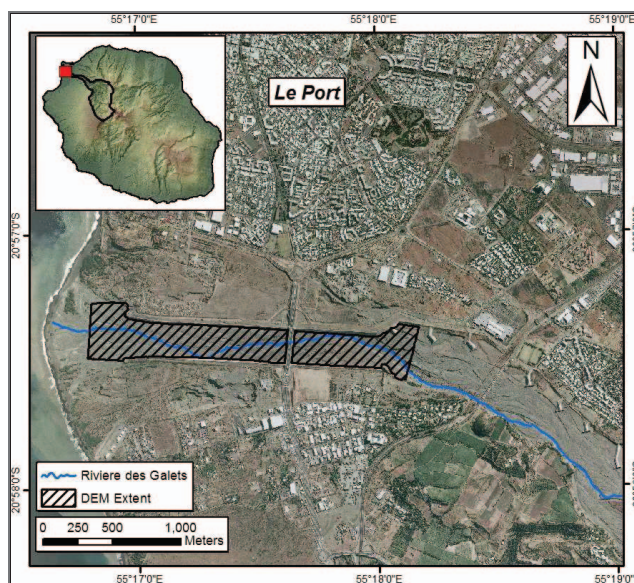


Figure 1. The lower reaches and delta of the Rivière des Galets.

2. STUDY AREA AND DATA

La Réunion Island is situated in the western Indian Ocean, 700 kilometers east of Madagascar. It receives tropical rainfall and its annual rainfall ranges from around 2,000mm on the sheltered west coast, to more than 10,000mm on the east coast. Most of this precipitation occurs as large cyclonic events in the wet season from December to March. Rivière des Galets is located on the northwest side of the island, and drains the Cirque du Mafate region. Figure 1 shows the location of the study area: the lower reaches and the delta.

What is referred to in this paper as the Rivière des Galets delta is, in fact, the youngest section of a much larger alluvial fan. The currently active part of the delta is situated to the south of the old deltaic zone, and has been forced to remain there following the construction of artificial levees in 1992. These form the northern and southern boundaries of the DEM extent (Figure 1), and has allowed the reclamation of large, formerly unstable areas for residential use.

A collection of 72 orthorectified SPOT 4 and 5 images from 2000 to 2008 is used in this study, courtesy of the CNES Kalideos Programme. Aerial photography of the riverbed was captured in December 2006 and May 2008 from ultralight aircraft using Nikon D100 and Canon Mark III digital cameras, respectively. Four cross-sectional profiles across the river were performed by differential GPS in December 2006, and repeated in December 2007 and July 2008.

3. METHODOLOGY

In the following sections we demonstrate the use of airborne and spaceborne imagery for monitoring geomorphological changes in the lower reaches of Rivière des Galets, discussing the progradation of the delta, the seasonal variation in the location of the thalweg and the displacement of sediment volumes.

3.1. Delta progradation

Deltas form where the supply of sediment by a river is greater than the dispersal capacity of the receptor basin [3]. The Rivière des Galets delta exists because it is relatively sheltered from large wind and wave action by its location in the lee of the island's topography.

The outline of the delta was digitized manually by the same person at the same scale from SPOT 4 and 5 imagery with cell sizes of 10 or 20 metres, depending on the image mode available. In the vast majority of images, a swash zone is visible along the shoreline, making the physical land-water interface highly variable over time. A wide range of shoreline indicators are used in shoreline delineation [4], but for the purposes of this study, the delta outline was chosen as running directly along the middle of the swash zone, or at the visibly discernable land-water boundary in images with no swash zone.

Using the successive delta outlines, variations in the area of the delta could be plotted over time. Figure 2 shows the delta area (in km²) over time. On the graph, the area for image dates where no swash zone is present are connected in green, as these dates have significantly less error than the rest. Rainfall in mm is indicated in red. What is evident from Figure 2 is that there is a consistent progradational response to large rainfall events. The most notable of these are Cyclone Dina in 2002, Tropical Storm 09-20052006 in 2006 and Cyclone Gamede in 2007 (labeled 1, 2 and 3 respectively). In Figure 3 the delta area is compared to high-energy wave events (as measured by a floating buoy about 1km north of the delta). Only waves with wave energy greater than 50,000 j/m/s are shown. Unlike with rainfall, there is no clear correlation between the growth of the delta and strong wave events, suggesting that the erosion of the delta is a slow, continuous process of currents and tides, interspersed with periods of rapid accretion due to cyclonic rainfall runoff.

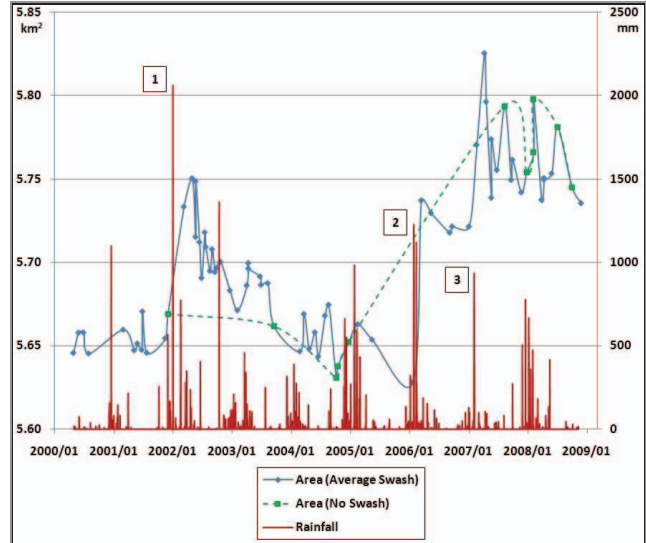


Figure 2. Variations in the delta area over time, compared with rainfall

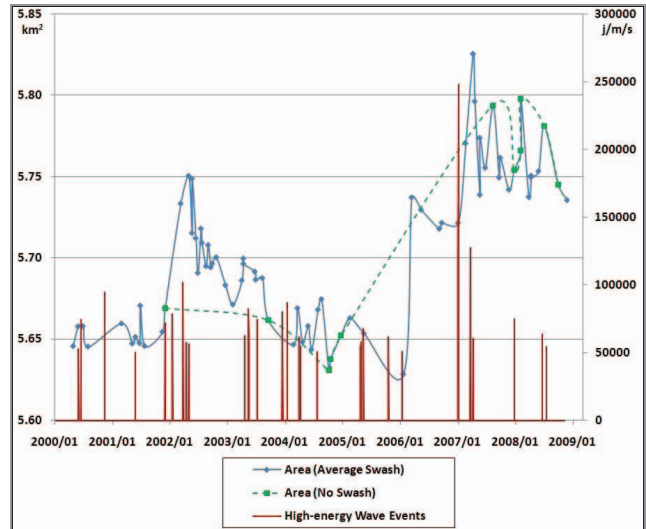


Figure 3. Variations in the delta area over time, compared with high-energy wave events

3.2. Thalweg mapping

Torrential rainfall in the rainy season causes the Rivière des Galets to flood and change its course slightly nearly every year. Once the summer rains subside, the river settles down into a narrow but steady stream for the rest of the year. This stream represents the river at its lowest point – the thalweg. Using 10m SPOT 5 imagery, the river flow pattern was digitized at the same scale for every year from 2002 to 2008. All images used were captured in May or June. By doing this it is possible to see to what extent the river changes its course every year, and to identify stable areas.

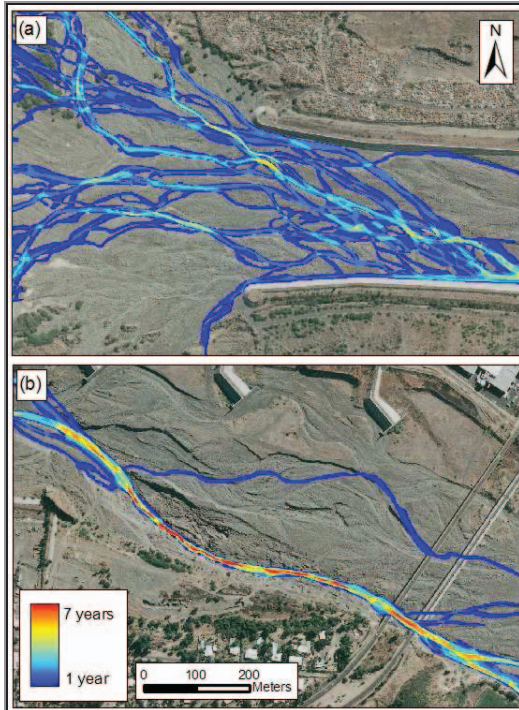


Figure 4. Multi-seasonal Boolean summation of the thalweg: a) Anastomosing flow near the delta. b) Topographically constrained flow further upstream

By assigning a Boolean value to areas covered by the dry-season stream of every year and summing the values by overlay analysis, a numerical value from 0 to 7 can be assigned to every pixel in the riverbed. Consequently, a value of zero means that over the seven year period between 2002 and 2008, the thalweg has never been located at that location, whereas a value of 7 indicates that the river flows over that location every year. Figure 4 shows this multi-seasonal summation for two areas in the riverbed. Figure 4(a) shows an area close to the delta where the local slopes are low and the river is allowed to anastomose, seldom to flow over the same location twice. Figure 4(b) shows an area 2km upstream where the river flows over bedrock and the local topography and geology forces it into a predictable, repetitive pattern.

3.3. DEM creation & subtraction

La Réunion Island's extreme rainfall and rapid erosion rates make it ideal for studies of geomorphological change, since year-on-year variations in topography are easily observed.

In December 2006 and May 2008, stereographic aerial photography of Rivière des Galets was captured from ultralight aircraft at resolutions of around 20cm and 10cm, respectively. Since the cameras used for image capture were not industry standard photogrammetric cameras, lens distortions and lack of exterior orientation parameters precluded the use of automated terrain extraction techniques.

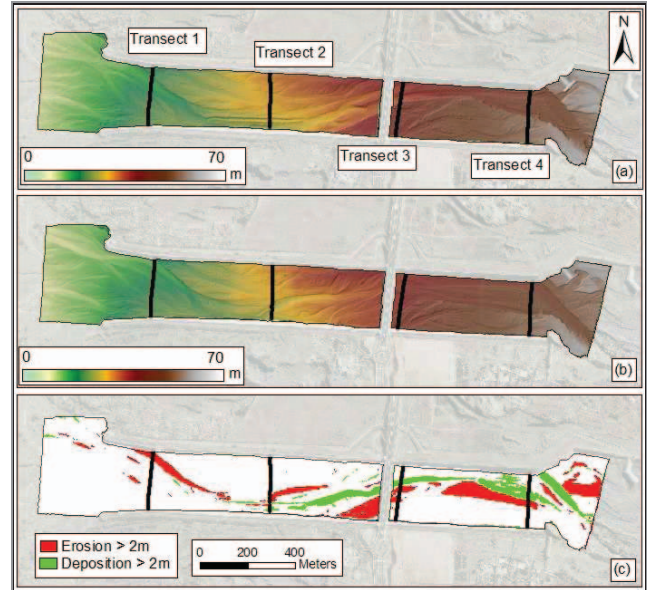


Figure 5. a) 2006 DEM, b) 2008 DEM, c) DEM difference showing erosion & deposition greater than 2 meters.

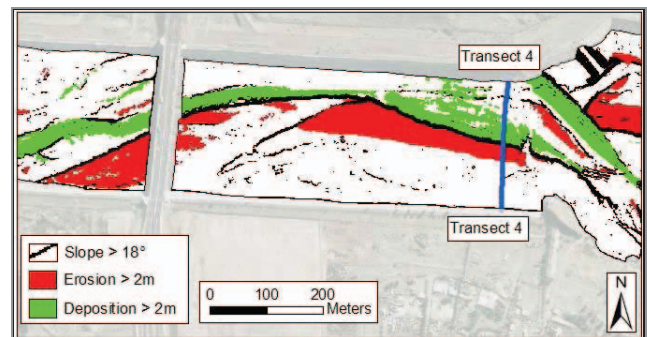


Figure 6. Detail of DEM difference, showing 2006 DEM slopes larger than 18°.

By using the *Poivilliers F* software developed by the French *Institut Geographique National* (IGN), the cameras were accurately calibrated, and Z values were extracted manually from image pairs. Once a sufficiently dense spacing of Z values had been achieved, DEMs with 1m cell size and less than 1m vertical error could be reliably interpolated for both 2006 and 2008 (Figure 5 (a) and (b)).

A cut-fill analysis of the two surfaces reveal a total of around 450 000m³ of erosion and around 270 000m³ of deposition in the 18 months between the two dates. This yields a net erosion of around 180 000m³ of material over 18 months. If averaged over the DEM surface, it constitutes a net vertical drop of 30cm across the entire area. Figure 5(c) shows areas with more than 2m vertical erosion or deposition. Figure 6 shows a section of the erosion-deposition map in more detail together with slopes larger than 18° from the 2006 DEM. More so than the location

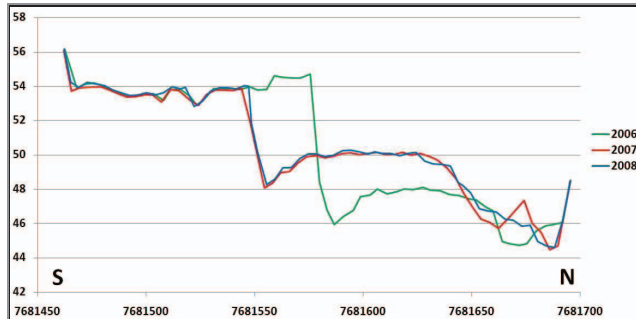


Figure 7. Differential GPS Transect Nr 4 for 2006, 2007 and 2008.

of the thalweg, it seems that local slope is a fair indicator of erosion prone areas, since all red zones in Figure 6 border on areas of steep slope.

Differential GPS Transect Nr 4 is shown in Figure 7, and illustrates the erosion of the terrace visible in Figure 6. Note the significant change from the December 2006 profile to the December 2007 profile and the similarity between the December 2007 and July 2008 profiles. This is due to Cyclone Gamede which hit La Réunion in February 2007 and holds the record as the cyclone to produce the most precipitation in recorded history on the island.

4. DISCUSSION & CONCLUSION

With high spatial and temporal resolution imagery becoming more & more readily available, remote sensing is an ideal tool for the monitoring of dynamic fluvio-deltaic systems such as Rivière des Galets.

Using SPOT imagery, the delta of this river has been shown to prograde by nearly 10 000m² per year, predominantly as a result of sedimentation from cyclonic rainfall events. Surprisingly, large wave events do not have a noticeable effect on the area of the delta. However, the effect of long-shore drift (where wave motion plays a significant role) was not addressed in this study. The problem of the identification of a viable shoreline indicator for the accurate delineation of the delta remains. While objective shoreline detection techniques such as multispectral classification is recommended [4], issues such as sun glint, cloud and whitecapping makes this difficult when working with SPOT data. In order to relate swash width to a land-sea boundary in the absence of swash, data on beach slope, tides and wind would be required.

We have shown the dynamic nature of the thalweg which shifts its course every year and remains consistent only where constricted by bedrock. Since the flow rates of water during the dry season is too low to cause significant erosion, the location of the thalweg is not a reliable indicator of erosion susceptibility.

Significantly, we have demonstrated that stereographic imagery from non-metric cameras can be used to construct

high-resolution DEMs suitable for geomorphological applications. Though more time-intensive than automated terrain extraction, the manual elevation extraction technique used allows for more accurate multi-seasonal measurements, since the Z value at any known location can be accurately extracted year after year. The Poivilliers F software also effectively compensates for lens distortions.

The value of 180 000m³ of eroded material obtained by differencing the 2006 and 2008 DEMs is significant, but pales when it is considered that the area from which that volume was removed is less than one percent of the total catchment area of Rivière des Galets. Ideally, an efficient way to monitor the sediment budget of the entire catchment should be developed, albeit at a lower scale.

La Réunion Island is a unique environment for the application of high-resolution imagery to geomorphological processes, and warrants more research than it currently receives.

5. ACKNOWLEDGEMENTS

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