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Detection of archaeological sites hidden by a forest canopy using Sentinel-1 time-series

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Introduction

- Airborne Laser Scanning (ALS) effective at discovering new structures on known sites covered in vegetation.
- Costly, use for detecting fully unknown sites discouraged.
 - Requires an additional way to find probable sites location.
- **Objective:** detection of archaeological sites hidden by a forest canopy, through:
 - Temporal speckle filtering
 - Diversity of points of view provided by Sentinel-1



Figure 1: Picture of the Pyramid of the Sun.
© Nateirma



Figure 2: Picture of the High Temple.
© Martin Falbisoner

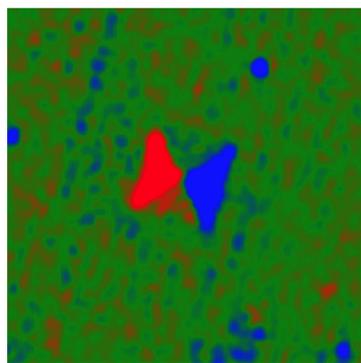


Figure 3: Picture of a jungle. © Simon Burchell

- Arbitrary colormap
- Red is West
- Blue is East
- Green is both
- Flat horizontal areas
- Borders between red and blue spots



a)



b)

Figure 4: a) Optical image of the Pyramid of the Sun [1]. b) Output of the technique over the same area. The red spots represent a higher backscatter from the West (ascending pass), the blue ones a higher backscatter from the East (descending pass) and the green background covers the areas with similar intensity from both directions.

Method

1. Temporal Speckle Filtering

- Spatial speckle filtering degrades spatial resolution [2]
 - Impairs detection of small targets
- Temporal speckle filtering degrades temporal resolution [3]
 - Not an issue, structures don't move
 - Here: Mean of the backscattering σ along time axis for one year of data
 - For every spatial pixel (x, y) , $\sigma(x, y) = \frac{1}{N} \sum_{t=1}^N \sigma(x, y, t)$

2. Ascending / Descending Ratio

- Sentinel-1 satellite: heliosynchronous orbit (fig. 5)
 - Two points of view: Ascending and Descending
- Projection of the images to a common geographical grid
- Ratio of Ascending images over Descending images
 - Highlights East-West dissymmetries
 - $Q\sigma^\circ = \sigma^\circ_{asc} / \sigma^\circ_{des}$ (or in dB: $\Delta\sigma^\circ_{dB} = \sigma^\circ_{asc,dB} - \sigma^\circ_{des,dB}$)
 - Arbitrary colormap
 - Here, red is West, blue is East, green is both.

Process presented in fig. 6 and 7, and applied to an archaeological site surrounded by jungle in the next part.

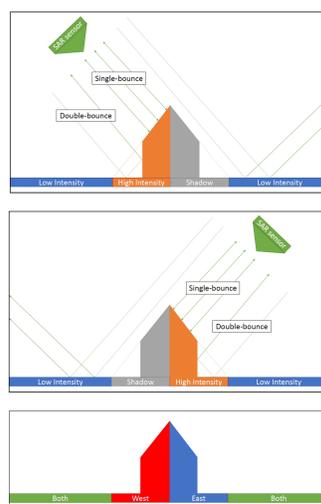


Figure 6: Illustration of the radar scattering mechanisms in play (ascending at the top, descending in the middle) and the ratio image (bottom).

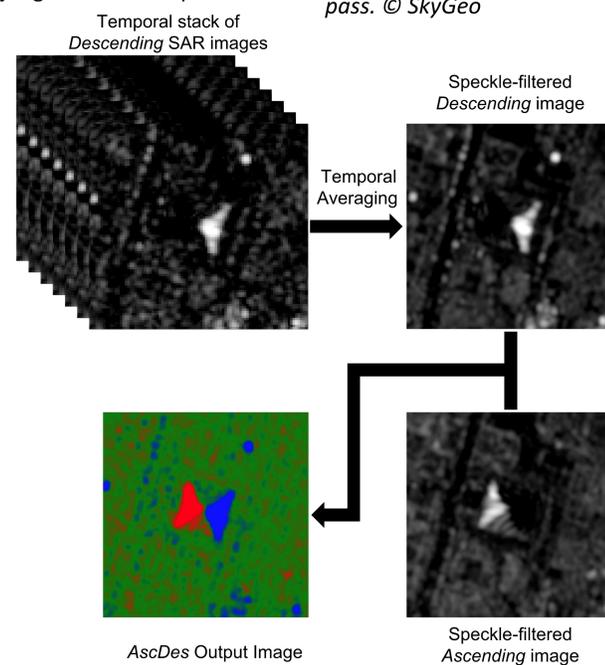


Figure 7: Graph of the process, applied to the Pyramid of the Sun, Teotihuacan, Mexico.

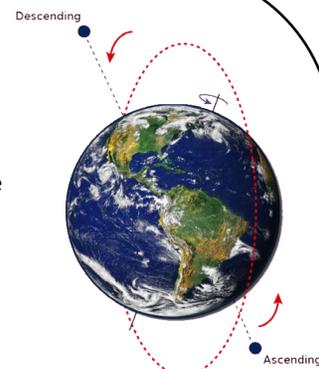


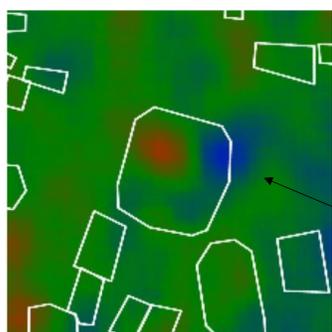
Figure 5: Illustration of the ascending and descending passes. Sentinel-1 is right-looking: it images the scene from the West during the ascending pass, and from the East during the descending pass. © SkyGeo

Application: archaeological site of Lamanai, Belize

- Mayan archaeological site, northern Belize
- Map found in an archaeological article [4]
 - Projected over optical (fig. 8 top) and SAR ratio (fig. 8 bottom)



a)



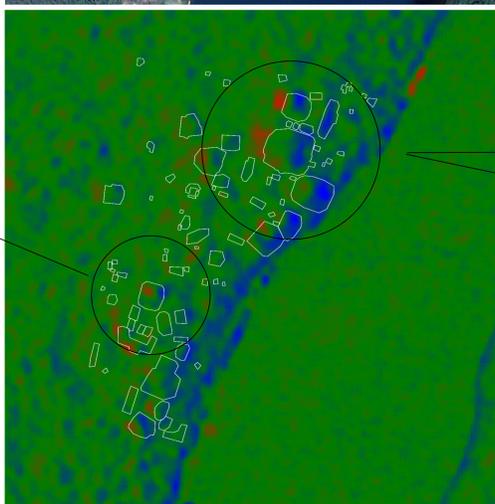
b)

Figure 9: a) Optical image [1] of the High Temple (structure N10-43), with archaeological map overlaid in red. b) Output of the technique over the same area, with the map in white.

Figure 8: a) Optical image [1] of Lamanai, with archaeological map overlaid in red. b) Output of the technique over the same area, with the map in white.

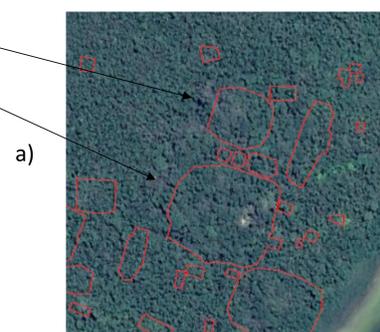


a)

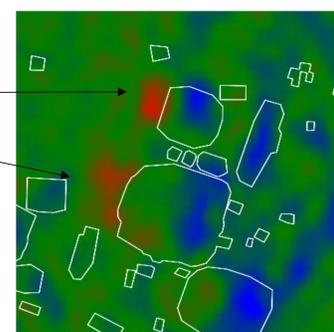


b)

- Focus on three buildings:
 - N10-43 (High Temple, fig. 3 and 9): visible from the sky, cleared of trees, restored
 - P9-25 and P8-1 (fig.10, indicated by arrows, respectively south and north): fully covered by the jungle, typical examples of the application



a)



b)

Figure 10: a) Optical image [1] of the two hidden structures (P9-25 and P8-1), with archaeological map overlaid in red. b) Output of the technique over the same area, with the map in white.

Conclusion

- Free detection of archaeological sites covered by a forest canopy on a global scale
- Reduced risk of wasting an ALS mission or an expedition by foot

References

- [1] CNES/Airbus, Maxar Technologies, 2022
- [2] J. Lee et al. "Speckle filtering of synthetic aperture radar images: A Review". In: Remote Sensing Reviews 8 (Feb. 1994).
- [3] S. Quegan and Jiong Jiong Yu. "Filtering of multichannel SAR images". In: IEEE Transactions on Geoscience and Remote Sensing 39.11 (2001), pp. 2373-2379.
- [4] Pendergast, David M. "Lamanai, Belize: Summary of Excavation Results, 1974-1980." Journal of Field Archaeology, vol. 8, no. 1, 1981, pp. 29-53