# Cell size influence on DEM volume calculation

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*Abstract*—**In this work, we analyze how the variation of cell size influences the volume calculated from LiDAR-derived DEMs in two coastal Late Holocene dune fields located in southern Brazil. Cell size varied from 1 to 100m. The RMSE of the resampled DEMs about the original LiDAR (with 0.5m resolution) increases linearly with cell size, while the R-squared decreases following a second-order trend. The volume does not show a simple linear or exponential behavior, but fluctuates, with positive and negative deviations from the original DEM. This can be explained by a randomness on the position of the cell about the landforms and a relationship between cell size and landfom size. Volumes from SRTM deviated less than 10% about the reference data and are considered suitable as input for numerical simulations of Quaternary coastal evolution models, as these values should be within the expected range for time spans of hundreds to thousands of years.**

## I. Introduction

Volume calculation from Digital Elevation Models (DEMs) is a very important tool on the study of aeolian sedimentary deposits. Numerical simulations of dune field evolution can be greatly improved if the volume of a certain area is known within an acceptable deviation from its true value. In this work, we analyze how the spatial resolution of DEMs derived from a high-resolution LiDAR dataset influences the output of volume calculations and the implications of the results on the applicability of SRTM on such studies. The calculation of sediment volumes using SRTM would be very useful to study the Quaternary aeolian sedimentation in Brazil, where more than two hundred dune fields are recognized.

## II. Study Area

The study area is located in Santa Catarina State, southern Brazil (Fig. 1). The Garopaba (northern sub-area) and the Itapirubá (southern sub area) dune fields may be of Late Holocene age (under 1000 years BP) and the result of climatic changes [1,2,3].

Both dune fields have an active portion comprised of unvegetated, undisturbed barchanoid chains with ideal conditions for studying the relationship between cell size and volume estimation on DEMs.

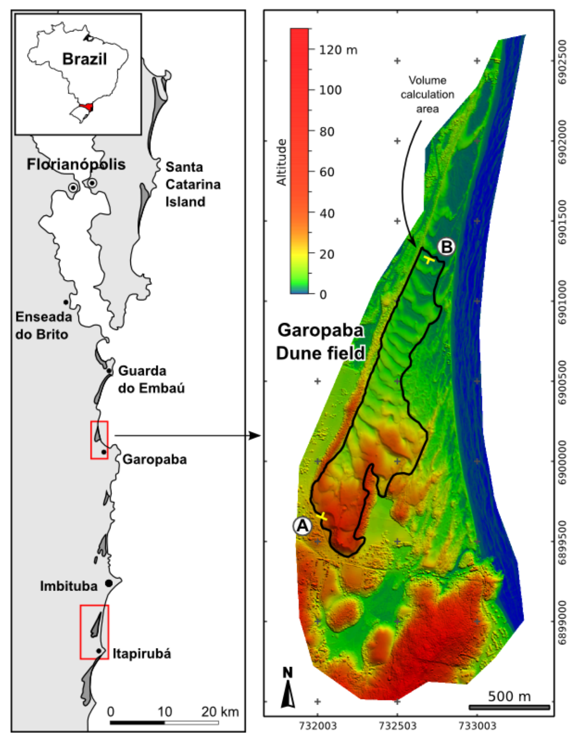


Figure 1. Location of the study area. The Garopaba dune field DTM is shown on the right, as well as the area selected for volume calculation and the end points of the topographic profiles (A-B).

## III. METHODS

### A. LiDAR processing

LiDAR data was collected by Geoid Laser Mapping company using an Optech ALTM 3100 sensor with a saw-tooth scanning pattern, density of about one point per 0.5m, measured from an altitude of 1200 m (4000 ft). Bare ground data were available with vertical accuracy of 0.15 m and horizontal accuracy of 0.5 m. Ground point data was converted to ASCII xyz points with ASPRS libLAS 1.6 [4] and imported into GRASS-GIS[1] [5,6] as vector points. A Digital Terrain Model (DTM) representing the ground surface with 0.5 m spatial resolution was created by interpolation of the vector points with bicubic splines [7,8].

### B. DEM resampling and Volume calculation

To calculate the volume of sand, a 2D raster representing the active portion of the dune fields was converted to a 3D voxel-based volume map, considering an elevation of 0 m (zero) as baselevel. The 'true' volume was taken as the volume of a map with horizontal and vertical resolutions of 0.5 m.

To evaluate the effect of spatial resolution over volume values, the vertical resolution of the 3D cell was fixed at 1 m, while the horizontal resolution varied from 1 to 100 m. At each step, the original DEM was resampled and the volume was calculated. Resampling was done by calculating the mean elevation value for the given resolution, which intends to simulate data acquired by sensors with different spatial resolutions, therefore it is appropriate that the elevation value is the average of the actual elevations within the cell [9].

SRTM data was also imported into GRASS and the volume was calculated with a horizontal resolution of 90 m and vertical resolution of 1 m.

Additionally, topographic profiles were derived from all the models, to analyze how the variation in spatial resolution would affect the representation of landforms.

## IV. RESULTS

For each resolution step, using all cell values of the resampled DEM, we calculated the volume difference, the RMSE (absolute error) and the R-squared (goodness of fit) between the resampled DTM and the LiDAR DTM, where:

$$RMSE=\sqrt{\frac{\sum_{i=1}^{n}\left(z^{resampled}-z^{lidar}\right)^2}{n}} \quad (1)$$

1 http://grass.osgeo.org

Fig. 2 shows the calculated volume of the Garopaba dune field for each resolution step as well as the volume difference between the models, as percentage of error about the LiDAR DTM, which is:

$$Deviation=\left(\frac{volume^{resampled}-volume^{lidar}}{volume^{lidar}}\right)\times 100 \quad (2)$$

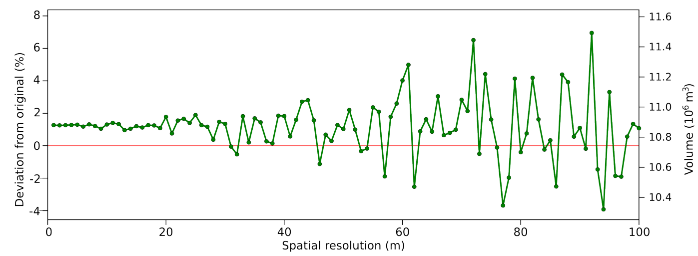


Figure 2. Volume variation with cell size and difference about the LiDAR DTM for the Garopaba dune field

The deviation in volume ranges from about +7% to -4%, and there is a fast alternation between positive and negative values. This is somewhat counter-intuitive, as one could expect the difference in volume to increase linearly or exponentially along with cell sizes. In fact, the RSME and R-squared between the resampled models and the LiDAR DTM present such behavior. In Fig. 3, the top plot shows a linear trend of increasing RSME values as the cell size increases and the bottom plot show a decrease in R-squared values that can be fit to a second-order trend.

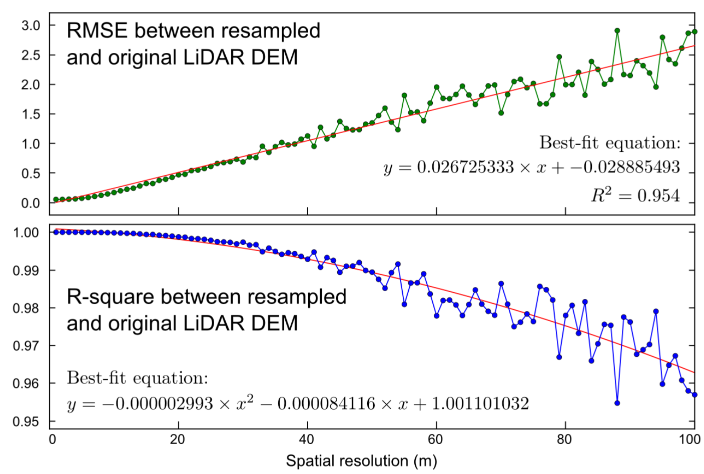


Figure 3. RSME (top) and R-squared (bottom) plots between resampled models and LiDAR data for the Garopaba dune field. Red line shows best fit of first order for RMSE values and of second order for R-squared values.

It must be noted that the linear relationship between RSME values and cell size shown in Fig. 3 should be seen as an approximation for cell sizes less than 10 m, as the data points show a non-linear behavior in this area of the plot, particularly for cell sizes under 5 m. This can be important in future studies, as LiDAR technology keeps evolving towards finer resolutions.

The variation between positive and negative deviations of volume can be explained by comparing topographic profiles for each cell size with a profile of the LiDAR DTM. The profiles in Fig. 4 correspond to the central portion of the A-B profile indicated in Fig.1.

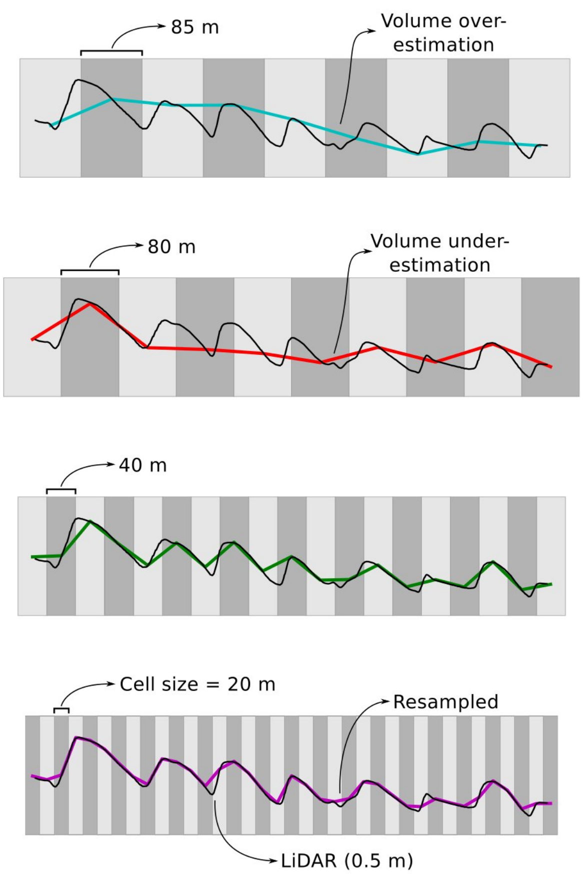


Figure 4. Topographic profiles for selected cell sizes showing effect of under- and over-estimation of volume depending on the position of the cell about the landforms.

From these profiles, one can see that depending on the size of the cell, the size of the landforms of the area, and the position of the cell about the landforms, the final volume can be over- or under-estimated.

Given the elevated costs of LiDAR surveys, it is interesting to evaluate if coarser-resolution DEMs, such as SRTM, can be used to estimate the volume of dune fields within an acceptable deviation range. Volumes calculated from SRTM 3" (aprox. 90 m) are presented in Table 1.

The deviation from the LiDAR DTM was of -6.2% for the Garopaba dune field and of +7.4% for the Itapirubá dune field.

TABLE I. VOLUMES CALCULATED FROM SRTM AND FROM LIDAR DATA

| Data | Dune field volume ($m^3$) | |
|---|---|---|
| | ***Garopaba*** | ***Itapirubá*** |
| LiDAR (0.5m) | 10 605 783 | 16 045 793 |
| SRTM (90 m) | 10 076 400 | 17 236 800 |
| Difference | -6.213 % | 7.422 % |

A topographic profile for the Garopaba dune field comparing the original LiDAR DTM, a DEM resampled to 90 m and SRTM data is shown in Fig. 5. Despite a peak artifact between 600 and 800 m from the origin of the profile, SRTM yielded a smaller volume than the original data, which means it is under-estimating the topography of the dune field .

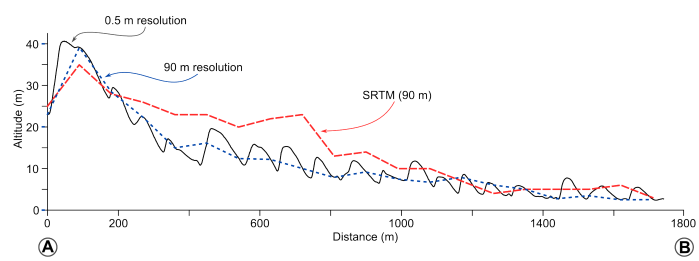


Figure 5. Topographic profile A-B.

## V. DISCUSSIONS AND CONCLUSIONS

In this work, the analysis of volume variation with cell size showed a fluctuation of calculated volume values about the reference LiDAR DTM, instead of a simple linear or exponential behavior. This can be explained by a random factor between the size of the cell, the size of the landforms and the position of the cell about the landforms.

An optimal cell size of 20 m could be interpreted from Fig.2, since this value represents a break point, after which deviation from the reference DEM becomes larger and starts to fluctuate. From the plots of Fig.3, however, one could interpret an optimal size of 30 m, after which the accuracy drops more rapidly.

Although the volume of dune fields is a very important variable in numerical simulations, it is hard to determine it in a fast and inexpensive way, considering the existence of hundreds of dune fields along the Brazilian coast. The elevated cost of LiDAR surveys is still a barrier to this kind of data, especially if one intends to study large areas.

Numerical models are necessary to study the evolution of aeolian dune fields in a hundreds to thousands years timescale because this timescale is beyond observational data. Numerical simulations deal with variations of the dune field properties (volume, area, etc.) over time spans of days to hundreds or thousands of years. In such scenarios, a fluctuation on sand volume of ~10% would be greater than the expected for short periods (days to years), but it wouldn't be greater than the expected for larger periods of time (hundreds or thousands of years).

With a deviation of volume about the LiDAR DTM smaller than +/- 10%, SRTM is considered as a viable source for volume values of dune fields. We also expect this deviation to decrease as the area (and volume) of the dune field increases.

The high periodicity of these aeolian landforms may have influenced the results we obtained. Other, more random, landscape configurations may present a different behavior, and we expect to test such hypothesis in future studies.

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## REFERENCES

[1] Martinho, C.T., Giannini, P.C.F., Sawakuchi, A.O. and Hesp, P.A., 2006. "Morphological and depositional facies of transgressive dunefields in the Imbituba-Jaguaruna region, Santa Catarina State," Journal of Coastal Research, vol. SI39, pp. 143–168.

[2] Giannini, P.C.F., Sawakuchi, A.O, Martinho, C.T. and Tatumi, S.H., 2007. "Eolian depositional episodes controlled by Late Quaternary relative sea level changes on the Imbituba-Laguna coast (southern Brazil)," Marine Geology, vol. 237, pp. 143–168.

[3] Tanaka, A.P.B., 2010. "Sedimentologia, cronologia e dinâmica progradacional das planícies costeiras de Campos Verdes e Ji (Laguna, SC)," Master's thesis, Instituto de Geociências, Universidade de São Paulo, São Paulo, Brazil., http://www.teses.usp.br/teses/disponiveis/44/44141/tde-08012011-200134/en.php [accessed 15 February 2011].

[4] Butler, H., Loskot, M., Vachon, P., Vales, M. and Warmerdam, F. 2011, "libLAS: ASPRS LAS LiDAR Data Toolkit", http://liblas.org/ [accessed 15 February 2011].

[5] GRASS Development Team, 2009. "Geographic Resources Analysis Support System (GRASS GIS) Software, Version 6.4.0,".

[6] Neteler, M. and Mitasova, H., 2008. Open Source GIS : A GRASS GIS Approach, Third Edition (The International Series in Engineering and Computer Science). Springer, New York, 773 p.

[7] Brovelli, M.A. and Cannata, M., 2004. "Digital terrain model reconstruction in urban areas from airborne laser scanning data: the method and an example for Pavia (northern Italy)," Computers & Geosciences, vol. 30, pp. 325–331.

[8] Brovelli, M.A., Cannata, M. and Longoni, U.M., 2004. "LIDAR Data Filtering and DTM Interpolation Within GRASS," Transactions in GIS, vol. 8, pp. 155–174.

[9] Grohmann, C.H., Smith, M.J. and Riccomini, C., 2010. "Multiscale Analysis of Topographic Surface Roughness in the Midland Valley, Scotland," Geoscience and Remote Sensing, IEEE Transactions on. , vol.49, pp. 1200-1213.