From Space to Earth: physical and biological impacts of glacier dynamics in the marine system by means of Remote Sensing at Almirantazgo Bay, Antarctica

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ABSTRACT:

To determine the biological and physical mechanisms between Lange glacier and its pro-glacier marine system located in Almirantazgo bay, King George Island, Antarctica, specific variables were determined through remote sensing approaches shown in this work. These preliminary results will allow relating the dynamics of both systems, the glacier, and the marine ecosystem. The information for the estimation of surface flux velocity of the glacier was derived through Radar satellite images (Sentinel-1) by means of offset tracking, the bathymetry was derived from a Multi-beam Echo Sounder, and the Digital Elevation Modell was obtained by means of a Remotely Piloted Aircraft; Finally, the biological parameters were derived from MODIS and OLCI images for the analysis of satellite data to have a first insight to the characteristics of the marine system. This information will help to build the first frame needed to study through remote sensing approaches, the mechanisms that govern the interface among "Lang Glacier" and the" Almirantazgo Bay" at King George Island, Antarctica.

1. INTRODUCTION

Glacial discharge from Antarctica is key to the marine system impacting different ocean ecosystems (Meredith & others, 2018). The Antarctic Peninsula and nearby islands are one of the areas that show high responses to global temperature increase (Vauhghan, 2003), and therefore are particularly vulnerable. Changes in the frontal area of glaciers enhance calving events affecting the coastal marine system and its surroundings, mainly due to the input of sediments, organic compounds and fresh water from the glacier to the ocean. The transport of materials and the effects of freshening generate profound alterations in the natural environment such as changes in the physics, chemistry, and biodiversity of the marine ecosystems (Milner & other, 2017). The possibility of determining the components that glaciers import into the ocean will allow us to correlate changes caused by glacial materials and freshwater with the marine surface temperature, salinity, oxygen and other fundamental parameters such as bio-optical properties, in order to identify possible impacts on primary production within the glaciomarine systems in different time and space scales.

The monitoring by means of satellite Remote Sensing is one of the most efficient sources of information for glaciological studies in hard to reach places, allowing the possibility to carry out studies on difficult and large areas with an adequate resolution.

This paper shows a summary of the preliminary results of the characterization of Lange glacier dynamics, as some fundamental parameters to evaluate the nearby marine system state by means of remote sensing. Radar satellite images (Sentinel-1) were used to estimate the superficial flux velocity of the glacier through Offset Tracking. The Digital Elevation Modell was obtained using a Remotely Piloted Aircraft (RPA), Quadcoptero equipment, and the bathymetry was derived from a Multi-beam Echo Sounder, Kongsberg of 80 and 200 kHz to capture data with greater spatial coverage and frequency. Finally, the marine data for the characterization of the area was derived from MODIS and OLCI. All the information used in this study was obtained through remote sensing applications in order to build the first steps to understand the processes that govern the interface among Lange glacier and the marine system through remote applications.

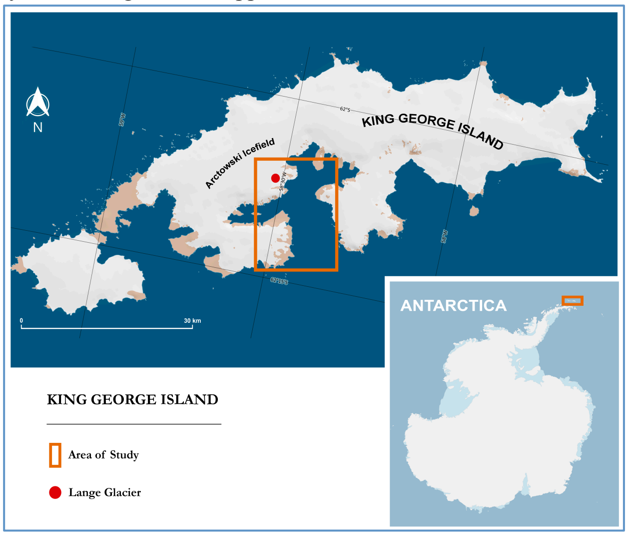

Figure 1. Location of Lange glacier: Left King George Island and red point Lange Glacier.

2. STUDY AREA

Lange Glacier (LG) is located (Lat. 62°7.8'55"S Long. 58°29'37"W) (Figure 1) on the Arctoswki Ice field, Norwest from King George Island (KGI), the largest of the South Shetland Island, situated in the northern area of the Antarctic Peninsula.

The calving fluxes on "Lange Glacier" (LG) represent the largest contribution of ice to the ocean, specifically over Almirantazgo Bay (AB), then will be study through remote sensing, the different glaciological and oceanographic

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parameters that will allow to determinate the glacio-oceanographic interaction.

3. METHODS AND DATA

3.1 Surface Velocity

Synthetic Aperture Radar (SAR) is an active system that works with radiofrequency, this method has the capability to penetrate clouds so it is possible to obtain data regardless of cloud coverage nor the time of the day or night. SAR employs a short modified antenna that through some recording and processing techniques synthesizes the effect of a very long antenna (Lillesand, 2007). The potential of SAR interferometry to map displacements with high-resolution has shown good results in glaciology (Strozzi, 2002). SAR Interferometry determines the phase difference between two complex radar observations with high precision from different positions. It extracts information about the topography of the Earth and allows accurate measurements of the radiation´s path due to the fact that is a coherent signal (Ferreti, 2007). Measurements of two images using offset techniques for estimating motion between SAR images is denominated “Offset Tracking” (Jun Lu, 2016).

The structure of a glacier is defined by a combination of physical processes that occur inside and on the surface that directly influences its dynamics such as frontal variation, changes in surface velocity, ablation, calving, and mass balance, among others. In order to estimate the surface flux velocity of the “Lange” glacier, we used the radar processing module from SNAP©, an open-access software from the European Space Agency (ESA). For this purpose, we used two satellite radar images (SAR Sentinel 1-B) of the same area with a difference of 15 days of acquisition. The images were downloaded from the Copernicus Open Access Hub and processed with the “Offset Tracking” module from the Sentinel Application Platform (SNAP) (ESA, 2016). In this paper we used:

- S1A_IW_GRDH_1SSH_2019O314T081714
- S1A_IW_GRDM_1SSH_20190326T081706

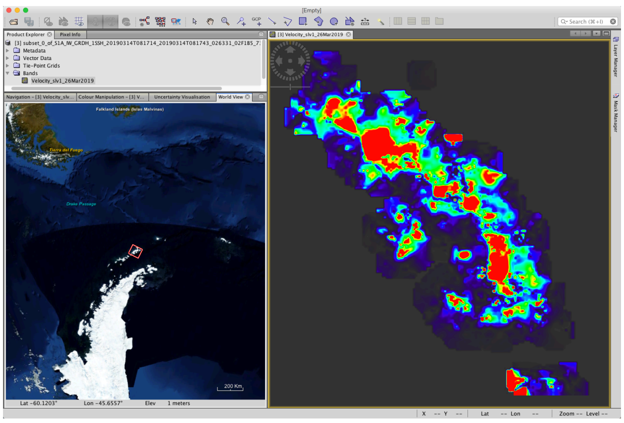

Figure 2: Surface Velocity Flux of Arctoswki Ice field at King George Island. LG “Offset Tracking” process through SNAP software.

Both images were Sentinel 1-A from 14 and 26 March 2019 respectively, acquisition mode: Interferometry Wide Swath (IW), Level 1, and Ground Range Detected Type (GRD). For the offset tracking module from SNAP, we used two SAR images from the same area; the module looks for matching points within a defined area and then cross-correlates them. Therefore the images for each pixel and on the same time interval calculate the correlation value, assuming that the ice displacement is defined by the position of the vector with maximum correlation. The scale shows a Surface Velocity Flux between 0,03 to 1,95 (m/day) and LG (Figure 3).

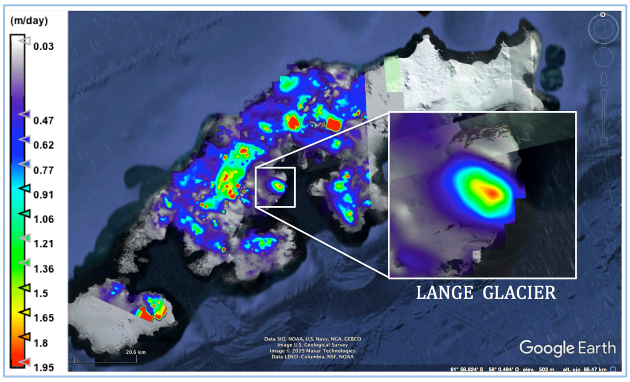

Figure 3: Surface Velocity Flux by SNAP terrain correction over Google Earth (Lange glacier velocity in m/day).

3.2 Digital Modell Elevation

The technological evolution allows us to have RPA*, which results in the generation of geospatial information using aerial photogrammetry techniques on different areas, the elaboration of orthomosaics and Digital Elevation Models have been extremely useful (Escalante, 2016). Multirotors are particularly efficient when they are applied to difficult geomorphologies.

Parameters	Setting
RPA company	RAS
Model	Antártico
Flight time	20 min
Camera	Sony Alfa 6000
Survey area (Polygon)	80 hectare
Flight Angel	202 degree
Flight line	6 pro polygon
Flight height	300 m
Velocity	5 m/seg
Resolution	9.35 GSD
Horizontal Overlap	80%
Vertical Overlap	70%
Total Batteries	Two by default
Total Photos	300 pro Polygon

Table 1 : Photogrametrics parameters of the mission

In general, the RPA is an extremely flexible tool for a flight mission due to its precision supported by geodetic equipment and the reduction of exposure, diminishing the risk of accidents. Wigmore (2016) mentioned that RPA technology represents a viable and potentially transformative method to study the change of glaciers at special high resolution.

The aerial photogrammetric survey was carried out using a RPA Quadcoptero equipment of Peruvian manufacture, designed to suit the mission. The flight system consists of a Hex Pixhawk

Figura 4: RPA, develop from Robotic Air Systems manufacture (Peru).

cube flight controller (Figure 4) and carbon fiber, which allowed scheduled and light navigation. The first task was to design the flight mission using the Mission Planner Program © with the parameters mentioned above.

Once the flight missions were completed, the photographs obtained were processed with the Pix 4D program, the processing flow consisted of three stages: Precision calibration and geolocation, Cloud of dense points and mesh, orthomosaic and three-dimensional model. All the steps were processed in high resolution.

The following products were obtained: Ortomosaic with GSD of 9.35 cm (Figure 5), contour lines with an interval of 10 meters, digital elevation model with a resolution of 9.35 cm per pixel and three-dimensional model (Figure 6).

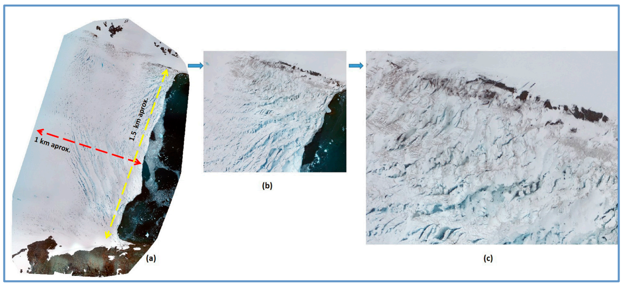

Figure 5. View of orthomosaic at different scales: (a) 1: 10,000 (b) 1: 2,000 and (c) 1: 1,000

3.3 Bathymetric Survey

In front of the LG is located the Almirantazgo Bay (AB) that has a variable bathymetry, which is shallower near to the glacier front with depths between 10 to 220 m (Figure 6), increasing from 300 to 1000 m in adjacent sub bays. From the central portion of the bay to the output towards Bransfield Strait, are located deeper points with depths between 1200 and 1800 m.

The bathymetric survey in the bay facing the LG showed a valley shape, in the center of which are the deepest points with 220 m and the thickest ice (Figure 7 a-b). We found an area of sediment plumes in the bay in the front of the glacier, these results indicate that glacier front is in contact with the basal bed, in agreement with previous studies in the area (e.g. Pichlmaier *et al.*, 2004; Barboza *et al.*, 2004). Likewise, it was observed 1km from the front of the glacier some shallow areas of 20m depth in the southwest (SW) and northeast (NE) of the bay

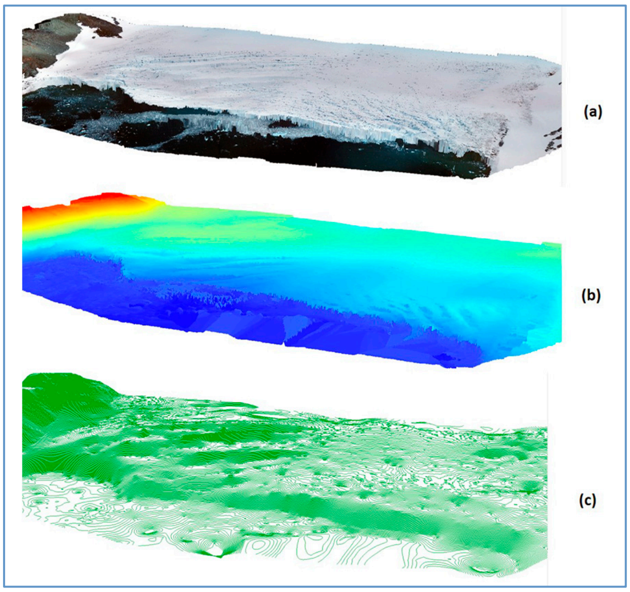

Figure 6. Views of the LG (a) Ortomosaic in 3d, (b) Digital model of elevation in 3d and (c) Level curves with an interval of 10 meters in 3d.

(Figure 7a-b), which may correspond to moraines by the glacial rock drag, sediments, and detritus deposited in the bay. These findings suggest that the front of the glacier has retreated from the past location. Indeed, the current LG front length showed a notable 600 m retreat in comparison to observations of Barboza *et al*. (2004) on LG front length 20 years ago.

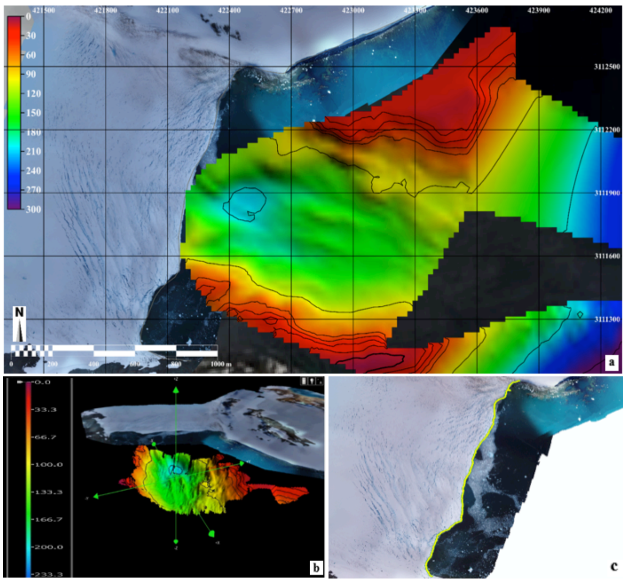

Figure 7. (a) Area of the bathymetric survey and Digital Elevation Model (DEM) in front of the Lange Glacier (LG), Admiralty Bay (AB), King George Island, Antarctica. Legend in meters. Blue ellipse in the green central area indicates the deepest point in front of the bay. (b) The three-dimensional model of LG. Legend in meters (Images obtained from CARIS Easy View (General Marítime Directorate). (c) DEM Orthophoto generated by ArcMap©10.3., in which yellow line represents the glacier front (Instituto Geográfico Nacional del Perú).

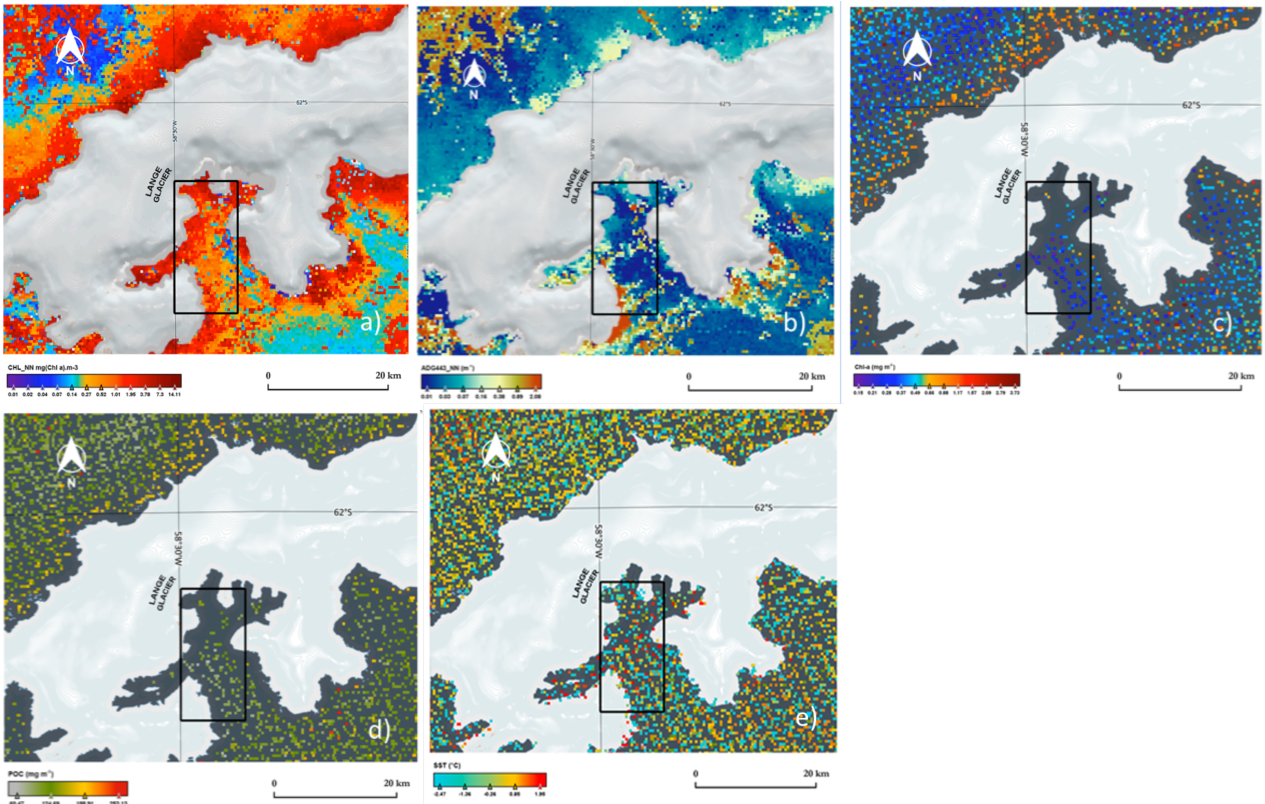

Figure 8. Monthly mean composites from February 2019: a) Chl-a OLCI, b) CDOM OLCI, c) Chl-a- MODIS d) POC MODIS and e) SST MODIS.

In order to assess the depth and thickness of the LG under the sea, we used a Defender-type boat provided from the vessel "ARC 20 de Julio" to conduct this bathymetric survey. The activity was supported by the Colombian Antarctic Program, the National Navy of Colombia, and the General Maritime Directorate (Colombian Maritime Authority). A multibeam echo sounder Kongsberg of 80 and 200 kHz was used to capture data with greater spatial coverage and frequency. In addition, a tide gauge was installed in the vicinity of the LG (Lat. 62°05'29"S Long. 58°28'06"W). The acquisition and processing of the dataset were carried out using the CARIS© Easy View 4.4.1. and HYPACK© software. We also used bathymetric data provided from Carrasco vessel, from Navy of Peru and Peruvian Antarctic Program. The bathymetry recorded in the bay in front of the LG showed depths between 10 and 220m (Figure 6). The deepest zone is located in a small sector in the northeast (NE), at the central part of the glacier front. A shallow zone of 20m depth is located at 1km from the glacier front (Figure 6a - b). The orthophoto generated showed that LG front wall length is around 1.4 km (Figure 6c).

3.4 Biological Parameters

To have a first insight into the impacts that Lange glacier (LG) may cause in the marine system in Almirantazgo Bay (AB), L2 products from MODIS and OLCI were used for the acquisition and analysis of satellite data. The images used are of free access through the official portals (Ocean Color Web and Copernicus Hub) of Aqua and Sentinel-3 missions respectively.

Images corresponding to February 2019 were obtained to get a monthly average concentration of chlorophyll (Chl-a/OLCI) (Figure 8a), colour dissolved organic matter (CDOM/OLCI) (Figure 8b), chlorophyll (Chl-a/MODIS) (Figure 8c), particulate organic carbon (POC/MODIS) (Figure 8d) and sea surface temperature (SST/MODIS) (figure 8e). This average was obtained through "binning", a tool included in the SNAP© software which allows adding daily, monthly and annual data to create composites L3 of different temporal scales of any parameter available or of interest. Both MODIS and OLCI images were processed at 300 m of resolution.

4. DISCUSSION AND CONCLUSION

Based on the obtained information in the present study it will be possible to build the first frame of data to begin with studies related to LG dynamics and its interaction with the AB through remote sensing approaches. The preliminary results of the glacier surface velocity flux and the bathymetry of the bay jointed to the Digital Elevation model will allow us to estimate the calving flux from LG. On the other hand, due to the high cloud coverage and relatively reduced temporal resolution, poor results were obtained for the marine parameters; nevertheless, the spectral profiles (see Figure 9) from the front of the glacier to the exit of "AB" slightly showed a gradual pattern in the optical properties as in the SST, which demonstrates that LG could influence the constituents and regimes that govern the marine system. Therefore it is necessary to carry out *in situ* measurements to characterize the physical, chemical, biological and optical properties of this area, in order to validate the available satellite data and to fill out the gaps that exist, mostly in Antarctic coastal areas.

In this context, the next fieldwork in LG will allow us to obtain the concentration of dissolved organic carbon (DOC) within the glacier to calculate the total contribution of the DOC to the marine system; This information along with other parameters such as temperature, salinity, O_2, Chl-a, CDOM, DOC, POC, and optical properties of the marine system, will be correlated to the efficiency of primary productivity and compared with satellite products and data available for validation.

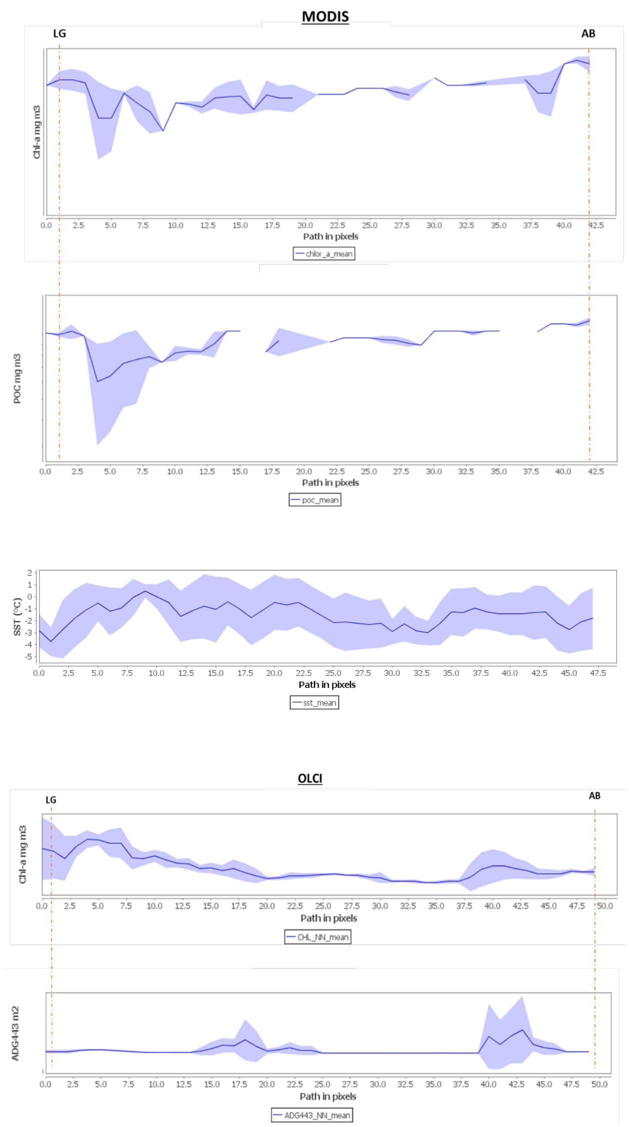

Figure 9. Spectral profiles between the front of LG and the exit of AB (MODIS and OLCI).

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REFERENCES

Barboza, H., De Bortoli, A., Simoes, J., Da Cunha, R. and Braun, M. 2004. Bidimensional numerical simulation of the Lange Glacier, King George Island, Antarctica: preliminary results. Brazilian Antarctic Research. ISSN 0103-4049 Pesquisa Antártica Brasileira 4: 67-76.

ESA, 2016 "Euopean Space Agency (ESA), Copernicus Scientific Data Hub," http://www.copernicus.eu/.

Escalante Torrado, J. O., Cáceres Jiménez, J., & Porras Díaz, H. (diciembre de 2016). Ortomosaicos y modelos digitales de elevación generados a partir de imágenes tomadas con sistemas UAV. *Tecnura, 20*(50), 119-140. http://dx.doi.org/10.14483/udistrital.jour.tecnura.2016.4.a09

Ferreti, A., Monti-Guarnieri, A., Prati C and Rocca F., "Insar principles: Guidelines for sar interferometry, processing and interpolation," ESA publications TM-19,2007.

Jun, L., Veci, L., Esa Senstinel-1 Toolbox: Offset Tracking Tutorial Issuef August 2016 Copyright© 2016 Array Systems Computing Inc. http://step.esa.int

Lillesand, T.M., Kiefer, R.W. and Chipman, J.W. (2007) Remote Sensing and Image Interpretation (6th edn). New York: John Wiley & Sons. ISBN 978-0-470-05245-7

Meredith M. P., Falk U., Bers A.V., Mackensen A., Schloss I.R., Ruiz Barlett E., Jerosch K., Silva Busso A., Abele D., 2018: Anatomy of a glacier meltwater discharge event in an Antarctic cove. Phil. Trans. R. Soc. A 373:20170163. http://dx.doi.org./10.1098/rsta.2017.0163
Vaughan, D.G., Marshall, G.J., Connolley, W.M. et al. Climatic Change (2003) 60: 243. https://doi.org/10.1023/A:1026021217991

Milner A.M., Khamis K., Battin T.J., Brittain J.E., Barrand N.E., Füreder L., Cauvy-Fraunié S., Gíslason G.M., Jacobsen D., Hannah D.M., Hodson A.J., Hood E., Lencioni V., Ólafsson J.S., Robinson C.T., Tranter M., and Brown L.E. PNAS September 12, 2017 114 (37) 9770-9778; first published September 5, 2017 https://doi.org/10.1073/pnas.1619807114

Pichlmaier, M., Aquino, FE., Santos da Silva, C. and Braun, M. 2004. Suspended sediments in Admiralty Bay, King George Island (Antarctica). Pesq. Antart. Bras. 4: 77-85.

Strotzzi, T., Luckman, A., Murray, T., Wegmüller, U., Werner C.L., Glacier Motion Estimation Using SAR Offset – Tracking Procedures. IEEE Transaction on Geoscience and Remote Sensing, 40(11).pp. 2384-2391. ISSN 0196-2892 https://doi.org/10.1109/TGRS.2002.805079

Wigmore, O. & Mark, B. (2016): UAV mapping of debris covered glacier change, Llaca Glacier, Cordillera Blanca, Peru. In *Proceedings of the 73rd Annual Meeting of the Eastern Snow Conference*.