Thesis's summery of Master course by Musiari Juriy

Optical and radar satellite monitoring of the Southern Patagonia Icefield

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INTRODUCTION

Glaciers are an important global natural resource and one of the main factors of climate change both on a global scale and on a regional/local scale. Among the different parameters that characterize glaciers, the velocity of displacement of the glacial surface is a fundamental element because it is deeply related to the changes in the glaciers themselves and the basis of the estimation of relevant factors in the dynamics of the glacial system, such as: glacier stability, erosion, mass balance and hydro balance.

The aim of the activities carried out within this thesis was to characterize spatially and temporally the deformative framework induced by the dynamics of glaciers, at different scales of analysis, through methods and approaches based on remote sensing. This survey, implemented in collaboration with the staff of the CTTC (Centre Tecnològic de Telecomunicacions de Catalunya), examined as a study area the entire surface of the Southern Patagonia Icefield (SPI), located in the homonymous region of Patagonia between Chile and Argentina, along the Cordillera of the Southern Andes. It is the third largest continental ice mass in the world with a total area of about 13,000 km² (Aniya et al., 1996) and consists of a complex set of 48 main glaciers, as well as a hundred minor glaciers. As remote sensing materials useful for the investigation, optical and radar satellite images were adopted, respectively acquired from passive sensors, the first ones, and active sensors, the second ones. These images are the result of the acquisition by satellite systems of the Sentinel-1 and Sentinel-2 missions of the Copernicus ESA project.

Remote sensing techniques are proposed as a valid alternative to in-situ investigation, as they provide synoptic information, always up-to-date and accessible on a global scale. The approaches used to calculate glacier velocities were Image Correlation and Offset-Tracking, using the following satellite image processing programs: SNAP and ENVI (COSI_Corr) (Leprince et al., 2007).

The result of this work was in fact translated into the mapping of the velocities of ice flows, expressed in meters per day, relating to a specific period of the year. The glacial surface deformations of the entire SPI have been estimated for the late summer - early autumn, year 2021; while at the scale of detail, considering the two glaciers Viedma and Tyndall, seasonal variations in surface speeds between 2021 and 2022 were analysed.

The results were analysed and discussed, highlighting the limitations and advantages of the two different processing techniques. Finally, since there is no data measured on the ground, the results obtained have been validated by the information made available by the CTTC, which has been operating for years in the field of remote monitoring of the areas covered by glaciers in South America. The analysis carried out in the following study testifies, naturally within the specific and intrinsic limits of remote sensing techniques, the feasibility and usefulness of systematic and regular remote monitoring using optical and radar satellite data to estimate glacial flow rates of a complex and extensive geomorphological system such as the Southern Patagonia Icefield.

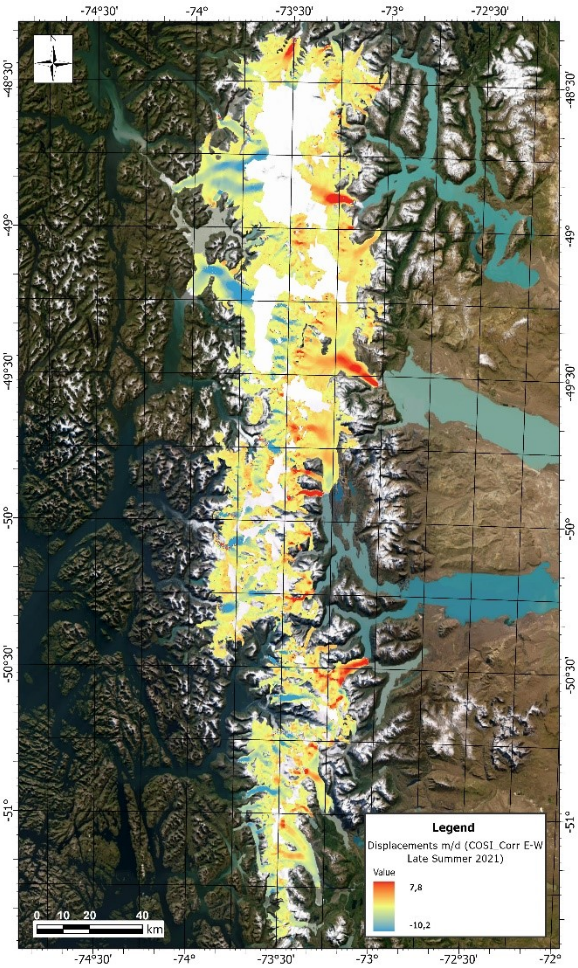
MATERIALS AND METHODS

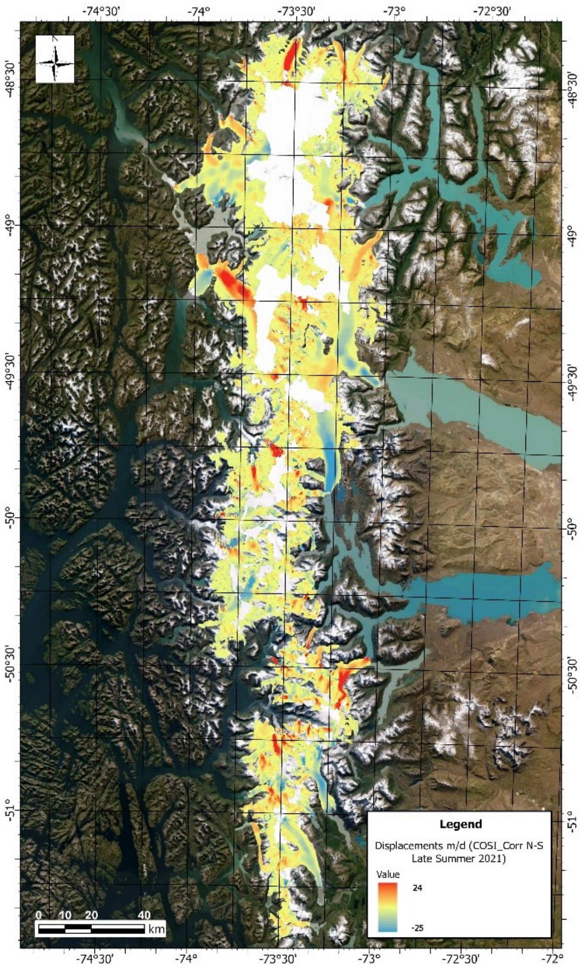
The starting data for this study are satellite images, such as radar and optical, made available thanks to the acquisitions of satellites launched by the Sentinel-1 and Sentinel-2 missions of the European Commission's Copernicus project.
In particular, the GRD (Ground Range Detected) products of the Sentinel-1 SAR (Synthetic Aperture Radar) images and the MSI (Multi Spectral Instrument) products of the Sentinel-2 images are exploited. Opensource and free access portals for the search selection and download of remote sensing materials have been used. These portals are ASF Data Search (ASF – Data Search Vertex, 2022) for the S-1 SAR images and SciHub Copernicus for the S-2 images (Copernicus Open Access Hub, 2022).
The satellite images were acquired and processed using two different processing software: SNAP for Sentinel-1 (ESA, 2023) and ENVI (an extension called COSI_Corr) for Sentinel-2 images. The survey methodology adopted to estimate the velocities of glaciers has also been twofold: the first technique, applied to the amplitude information contained in the radar images is the one called Offset-Tracking, the second, or the Image Correlation works instead on optical images, providing information of planimetric displacement, ie in the east-west and north-south directions.

Initially, the technique of differential SAR interferometry (DInSAR) was used to estimate the surface velocities of glacial masses, exploiting the phase information of S-images1 SLC, which for the intrinsic limits of this methodology has not reported sufficient and complete results to map the study area.
On COSI_Corr, the most used and recommended window size in literature has been exploited as a scene window for correlations between images (Yang et al., 2019). Both methods allow to measure the surface deformation values of the ice masses. These deformations refer to specific time intervals that coincide with the acquisition of the satellite data used. A total of 24 Sentinel-1 images (12 pairs) and 16 Sentinel-2 images (8 pairs) were used for the entire mapping. Particular attention has been paid to the choice of satellite images, mainly for the S-2 optical images, which due to their inherent acquisition characteristics that are affected by atmospheric noise. In the elaboration of computerised displacement maps by both programs, those with significant decorrelation were excluded. Furthermore, the correlations carried out for the small-scale time analysis, between 2021 and 2022, of the Viedma and Tyndall glaciers, were performed at maximum resolution.

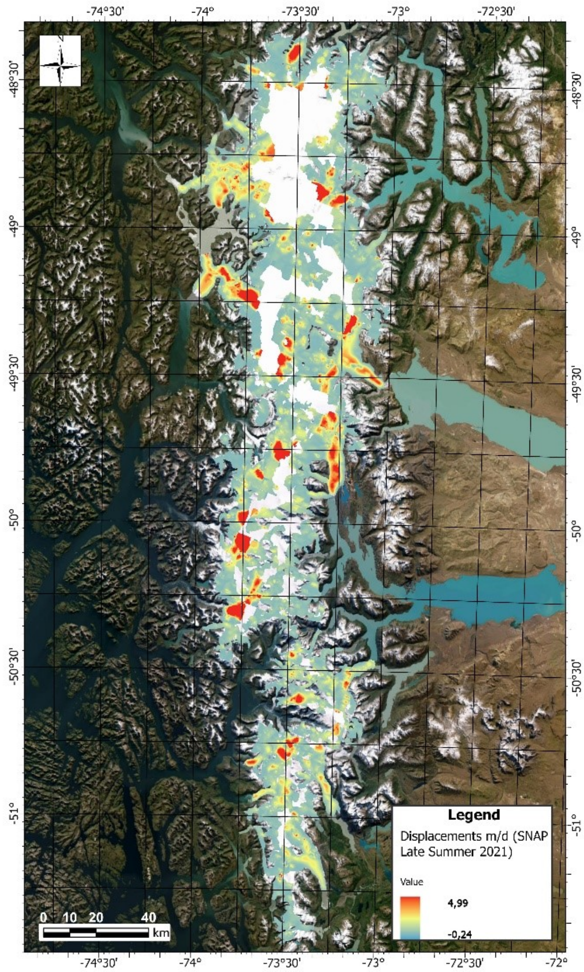
RESULTS

The results obtained have been jointly analysed, both on a synoptic scale over the entire extent of the South Patagonia Icefield in the late summer of 2021, and on a local scale for the years 2021-2022 on two specific glaciers: Viedma and Tyndall, located in the eastern side of the SPI. In this way it is possible to analyze the speed variations of the two glacial masses over time, considering in total 8 southern seasons (Graphs 1-4), starting from summer 2021.



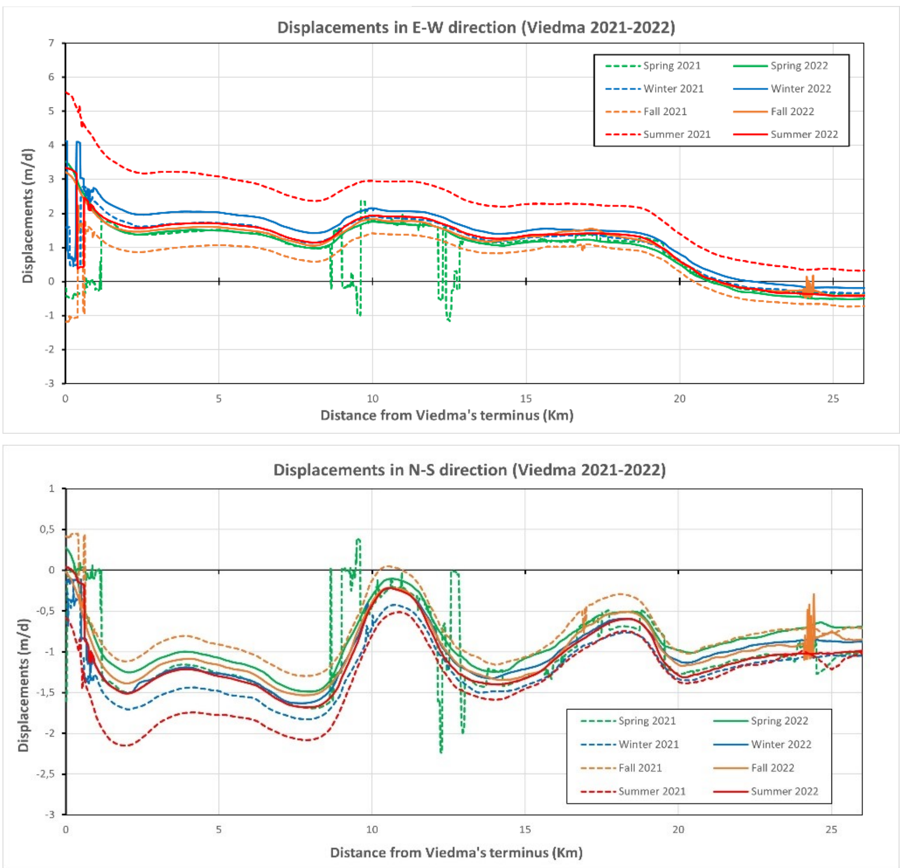


Figures 1 and 2: SPI glacier velocity maps in metres per day (ArcGis Pro). Values obtained through Image Correlation (COSI_Corr) from Sentinel-2 optical images referring to the late summer season of the year 2021. Shifts represented by red and blue respectively for the east/north and west/south directions.



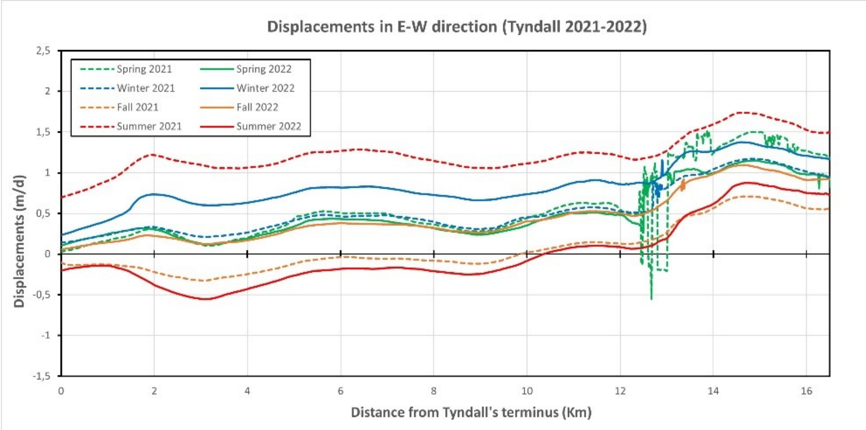
The computerised COSI_Corr (Figure 1 and 2) and SNAP (Figure 3) values for outlet glaciers and mountain (valley and circus) glaciers speeds vary from 1-3 m/day to 5-7 m/day in the most extreme cases. Changes in the morphology underlying glaciers, latitude, time intervals considered, the presence of snow and ice on the ground are among the main factors influencing the magnitude of displacement of glacial masses. There are certainly anomalous values (outliers) developed by the programs used that can pollute the analysis of the results. These values are due to instrumental noise and decorrelation in the application of techniques. From the relative graphs obtained, the speeds of the Viedma and Tyndall glaciers in the two years considered do not vary significantly between the seasons and are respectively 1.5-3 m/day and 0.5-1.5 m/day; the distance between the two glaciers is about 240 km and the Tyndall, further south, is affected by the different latitude.

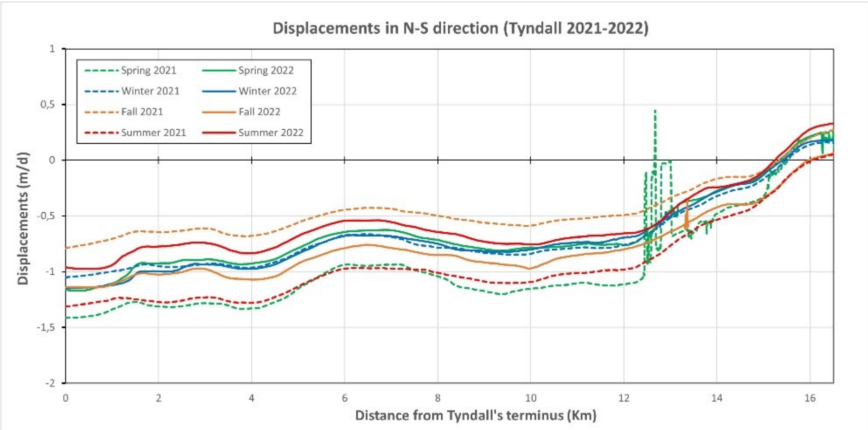
Figure 3: SPI glacier velocity map, expressed in meters per day, obtained by Offset Tracking (SNAP) from Sentinel-1 radar images referring to the late summer season of the year 2021.



Graphs 1 and 2: Shifts in meters per day relative to the Viedma Glacier in east-west and north-south direction between 2021-2022.

Graphs 3 and 4: Shifts in meters per day relative to the Tyndall Glacier in east-west and north-south direction between 2021-2022.





CONCLUSIONS

In conclusion, the remote sensing techniques employed have led to the creation of velocity maps expressed in meters per day of the displacement of glaciers of the entire study area (SPI). Estimated glacial surface displacement rates from the late summer season of 2021 generally vary from 2-3 m to 5-6 m per day. It is further emphasized that the Offset-Tracking on SNAP has calculated values of surface deformation generally lower than those estimated by the Image Correlation on COSI_Corr. The choice of optical images Sentinel-2 suitable for processing was more challenging than that of radar images Sentinel-1 due to the inherent natural feature of satellite acquisition. The remarkable availability and usability of Sentinel images has ensured the study of speed variations over time at local scale for the Viedma and Tyndall glaciers. Finally, related to the last analysis mentioned at detail scale, a limited seasonal variability in glacier speeds between 2021 and 2022 was observed.

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