Seminar CS³
REMOTE SENSING DATA FOR ENVIRONMENTAL MONITORING

Assessment of Recent Flow, and Calving Rate of the Perito Moreno Glacier using Landsat and Sentinel2 Images

Stucchi, L. [1], Bocchiola D. [1], Chirico, F. [1], Senese, A. [2], Azzoni, R. S. [2], Santagata, T. [2], Ventura, F. [3], Diolaiuti G.A [2].

1. Dipartimento di Ingegneria Civile e Ambientale (DICA), Politecnico di Milano
2. Dipartimento di Scienze della Terra «A. Desio», Università degli Studi di Milano
3. Macromicro Associazione, Roma

Corresponding author: Leonardo Stucchi, leonardo.stucchi@polimi.it

POLITECNICO MILANO 1863

Department of Civil and Enviromental Engineering (DICA) Politecnico di Milano, Piazza Leonardo da Vinci 32, 20133 Milano, ITALY

1. ISSUES

Recent climate change in the central Andes caused reduction of snow cover and reduced ice cover therein, with expected further retirement in the future, and the question arises whether South Patagonia will also undergo such phenomena.
Patagonia is a main landmass at low latitude, and it is close to Antarctica, and, as a consequence, glaciers here located are of great significance and highly relevant for studies focusing upon climate history and ice-climate interactions. Many of these glaciers flow radially from the ice field core, mostly calving into fjords on the western side, and into lakes on the eastern side. During the last 50 years, out of the 22 major calving glaciers in Patagonia, 9 have been fluctuating within ±1 km, and 12 have been retreating considerably, within a range of -1 to -13 km.

Here we assess flow velocity, and calving rate of one of the most iconic Patagonian glacier, the **Perito Moreno**, which, unlikely most of the calving glaciers of the area, is not retreating and can be considered as stable. Nevertheless, the glacier snout oscillated frequently, causing damming of the proglacial lake, collapse of the ice dam, and subsequent outburst floods.

Meteorological information is sporadic in this region, and ice dynamics is very little explored. Given the lack of *in situ* information, we have to rely on remote sensing data, here visible band satellite images, combined with measures of ablation available in literature and data collected during the international expedition «On the trails of glacier», to develop a model for calving and flow dynamics.

2. GOALS

The aims of this study are to assess:

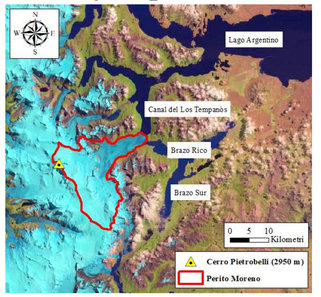
❖ Glacier velocity field which, unlikely most of Alpine glacier, is very high and can reach in the ablation tongue the order of 3-4 meters a day. Therefore it is detectable even by narrow time pictures (1 week).

❖ Glacier calving rate

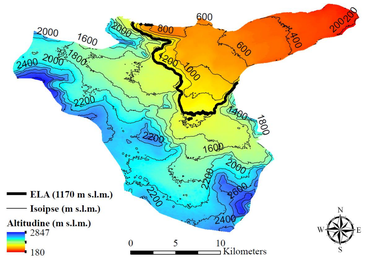
➢ Upon such bases, we calibrated and validated *ImGRAFT templatematch* software which allow, through the use of satellite images, to elaborate glacier change of position using crevasse as a reference. Then, using two formulas for ice mass balance, we evaluated calving rate.

3. CASE STUDY: PERITO MORENO GLACIER

- Glacier area: 259 km²
- Length: 30 km
- Altitude range: 187 m – 2950 m a.s.l.
- Latitude range: -50.46°– 50.60°



- The ice dam rises water level on the *Brazo Rico* lake to increase up to 30 meters above the level of the *Canal de Los Tempanos*. This delta of the height of the dammed water increases pressure over the glacier that periodically breaks through the ice barrier causing the flooding of *Lago Argentino*.

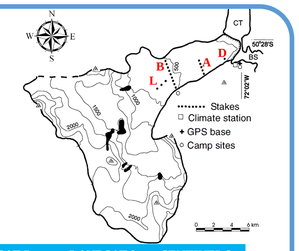


- Some pictures provided by Fabiano Ventura reporting spectacular ice dam collapse whose flood water volume is estimated to be 8 x 10^5 m^3 , higher than the volume of many alpine reservoir.

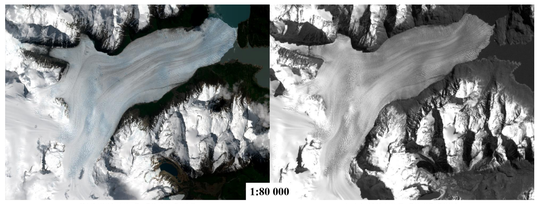
4. DATA

- ✓ GLIMS database (to assess extent of the glacier)
- ✓ Transverse profiles (A,B)
- ✓ Glacier front profile
- ✓ Ablatometric stakes (A, B, D, L)
- ✓ Temperature (A, climate station)

- ✓ Satellite images (LANDSAT, SENTINEL)
- ✓ Drone images (DJI Phantom)



	LANDSAT 4-5	LANDSAT 7	LANDSAT 8	SENTINEL 2
Years	1984 – 2011	From 1999	From 2013	From October 2015
Spatial resolution	**30 m** (visible)	**30 m** (visible) **15 m** (panchromatic)	**30 m** (visible) **15 m** (panchromatic)	**10 m** (visible)
Images frequency	16 days			7 – 13 days



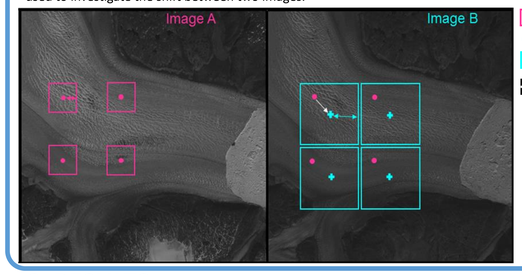
SENTINEL 2, 20/10/2017 — LANDSAT 7, 20/03/2001

- Sentinel pictures of the ablation area of Perito Moreno during spring and autumn.

5. MODELS

➢ Surface velocity field

TemplateMatch is a tool of ImGRAFT – Image Georectification And Feature Tracking used to investigate the shift between two images.



- Center of the grid
- Template area (*TemplateWidth* × *TemplateHeight*)
- Center of search region
- Search region (*SearchWidth* × *SearchHeight*)
- Initial movement (*du*, *dv*)

➢ Validation

$$SNR_{ave} = C_{ave}/C_{noise}$$

Where:
- SNR is called Signal to Noise Ratio
- C_{ave} is average correlation index
- C_{noise} is the module of the average correlation coefficient

➢ Calving rate

- We used two methods: the first is evaluated at glacier front and neglects ablation, the second one considers ablation but it is evaluated far from glacier front (about 6000 days of travel estimated), and it assumes hyphotesis of stationarity of the glacier.
- Method 1
- $CR_{M1} = Q_F - G_F$
- Method 2
- $CR_{M2} = Q_B - Q_A - G_F$

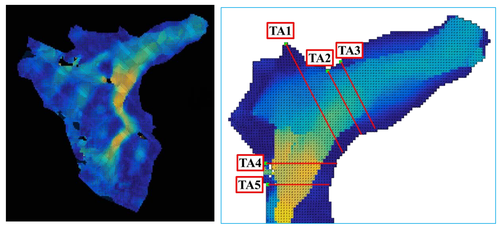
Where:
$CR_{M1,2}$ is calving rate for the two methods.
Q_f is the flow rate [$m^3 d^{-1}$] at the front of the glacier.
G_f is the net advance of the glacier front position.

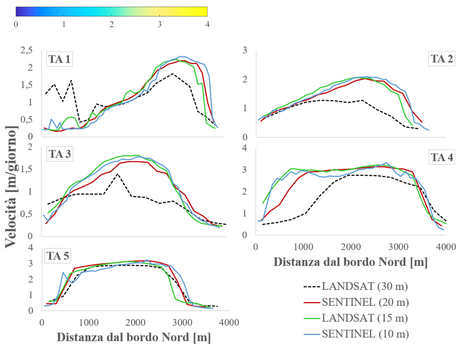
Q_B is glacier flow rate computed at profile B (see picture above)
Q_A is mass loss by ablation between profile B and glacier front

6. RESULTS

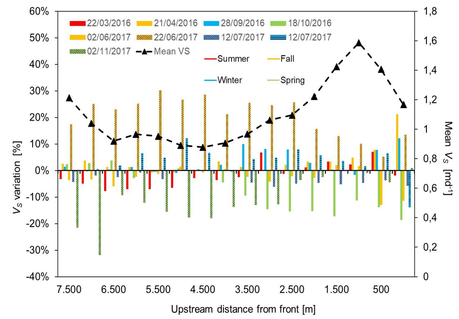
➢ Surface velocity field

Velocity profile (m/die) for entire glacier, ablation area, and for some distinctive sections according to the different satellites and resolution used.

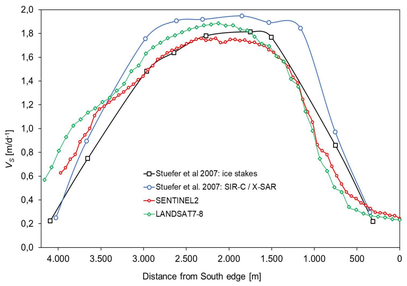




Due to the absence of debris cover, which can be easily identified and used as reference for satellite images, we had to rely on crevasses to assess glacier dynamics, whose structure tends so stay constant in time, limiting maximum time span between two pictures to 100 days.
Velocity profile is shown for sections T 1-5 for the two satellites, the results are quite consistent for each case with the exception for Landsat 30 m, where low resolution of the image had a detrimental effect on the precision of estimate.



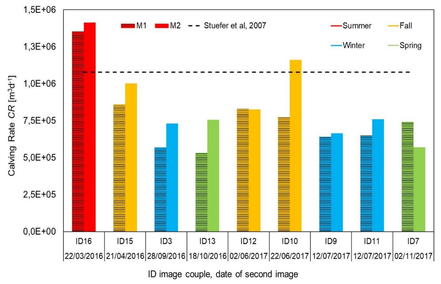
In the above picture mean velocity of Perito Moreno glacier (black line with triangle) vs percentage variation from the mean value in each section for each acquisition date, expliticing the season.



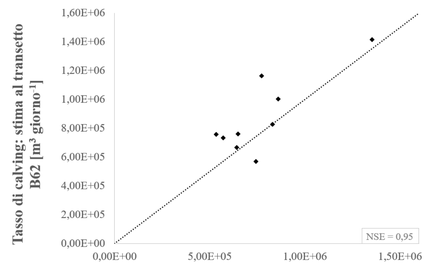
In the above picture we compared our results with the ones available in literature using ablation stakes and synthetic aperture radar, and they show good overlapping as confermed by statistical analysis values reported below.

Satellite	*Bias* [%]	NSE [.]	*RMSE* [md⁻¹]	*NRMSE- Mean* [%]	*NRMSE- Range* [%]
Sentinel2	11	0.93	0.10	8.77	6.44
Landsat7-8	16	0.85	0.15	12.28	8.70

➢ Calving rate



In the above estimated calving rate in several data according to the two methods, compared with the literature results available. The two methods are quite consistent one to each other as visible from the picture below (on y axis calving estimated with method 2 vs method 1 on the x axis), where most of the values are above the intersect meaning that values from method 2 are slightly higher.



7. CONCLUSIONS

✓ **Ice Body:**
The partial stability with mean retreat equal to 0 of the *Perito Moreno Glacier* over the last decades is a quite rare feature and it allows to study the periodical phenomenon of glacier retreat and advance. The advance of the ice dam generates, usually during Austral summer, floods due to the ice break for the pressure of water collected in *Brazo Rico*.

✓ **Glacier velocity field**
Through the matching of satellite images at different days we were able to track glacier dynamics through the seasons. These results have been compared with in situ studies on glacier movement along a section.

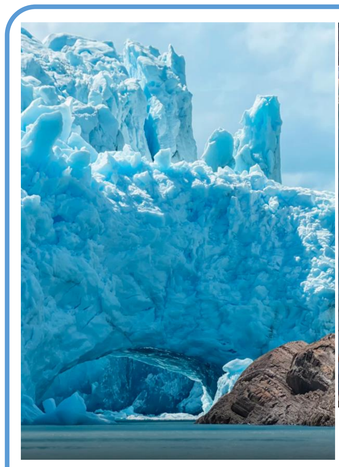
✓ **Glacier ablation rate**
Ablation rate was estimated with two methods, quite consistent with each other and with literature, and we assessed that resolution of the images plays a major role for the reliability of the results.

✓ **Further development**
Our analysis would benefit from further images with higher resolution (like UAV) and from the availability of meteorological data (temperature and precipitation).

REFERENCES

1) Chirico, F. 2017. "Valutazione della dinamica del Perito Moreno tramite immagini satellitari. [Assessment of Perito Moreno dynamics using satellite images]". MS Thesis, Politecnico di Milano, a.y. 2017. Mat. 859036. Available upon request. In Italian.
2) Bocchiola et al., 2021, Assessment of Recent Flow, and Calving Rate of the Perito Moreno Glacier using Landsat and Sentinel2 Images. **Submitted.**

8. FURTHER PICTURES



A signal of upcoming ice dam failure

Culvert below the ice dam

Touristic boat in front of the ice dam.