17th ALPINE GLACIOLOGY MEETING

AN INTEGRATED ANALYSIS OF GLACIER EVOLUTION

E. Motta[1], F. Diotri[1], U. Morra di Cella[2]

[1]Fondazione Montagna sicura - www.fondms.org - emotta@fondms.org

[2]ARPA Valle d'Aosta - www.arpa.vda.it - u.morradicella@arpa.vda.it

PRE DE BARD GLACIER

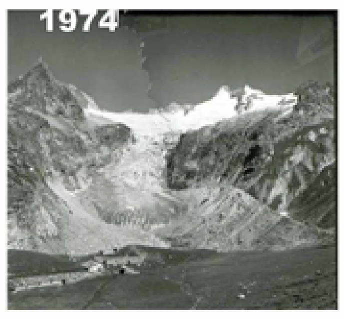
The Pré de Bard glacier has been monitored by Fondazione Montagna sicura and ARPA Valle d'Aosta since 2005. In the framework of several projects, some activities have been carried out in order to study glacier dynamics and testing new technologies.

Pré de Bard lies on the Italian side of the Mont Blanc Massif (Aosta Valley, Italy), between 3500 m and 2200 m a.s.l., and has mainly SE aspect. The tongue, 3,6 km long, reaches the bottom of the Val Ferret. It has an uneven morphology, with two big ice-fall between 3000-2700 m and between 2500-2300 m a.s.l.. The glacier terminus lies below this second ice fall. Debris covers most part of the terminus and is scattered in the middle part of the glacier, between the two ice falls.

At the end of August 2012, the intense ablation and the bedrock morphology resulted in the separation of the lower part from the upper glacier body. Therefore, the terminus is becoming dead ice and Pré de Bard, so far one of the two last valley glaciers of the italian Mont Blanc Massif (with Miage glacier), is evolving in an hanging glacier.

In this poster, a summary of the main outcomes and the syntheis of morphological evolution of the glacier since 2005 are presented.

Here we see the Pré de Bard in: a watercolour of Lory, 1826 (top left); a photo taked by Cerutti, 1974 (top right); two photos taked in the frame of the "Ghiacciai sorvegliati speciali" by Fondazione MS in 2004 and 2012 (middle and botom).



WHY THE PRE DE BARD GLACIER?

- One of chief Italian Mont Blanc glaciers;
- low altitude of glacier front (2050 m a.s.l. in 2005: high melting rate and rapid glacier dynamics);
- mountain road close to the terminus (easy to reach the glacier, instrument transportation, possibility of frequent measurements);
- well known glacier: availability of historic documents and easy-to-use in popularization.

COMPARATIVE ANALYSIS FROM MULTI-TEMPORAL PHOTOS

PERIOD: 2004 - today.

MAIN OBJECTIVES:
Morphological analysis of glacier and snow cover evolution by means of comparison of repeated pictures; creating a well documented photographic database of glaciers changes. "*Ghiacciai della Val Ferret sorvegliati speciali*" project focuses on Val Ferret glaciers, that include Pré de Bard.

METHODS:
Photographic benchmarks have been fixed on the opposite side of the valley and pictures are taken avery year at the beginning, middle and end of the ablation season.

RESULTS:
We have collected more than 65 useful images for a qualitative morphological evolution analysis of Pré de Bard glacier. The ice reduction is clearly recognizable, as well as the increasing debris covering on the front surface.

MASS BALANCE AND FRONTAL RETREAT

PERIOD: balance year 2007/08 - today; the position of the glacier front is monitored since 2005.

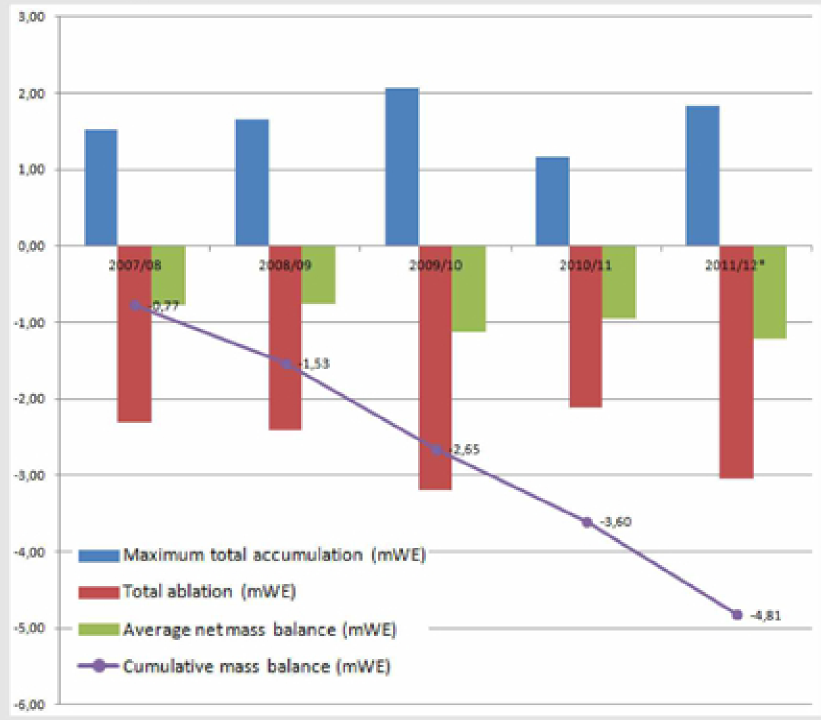
MAIN OBJECTIVES:
Measuring the mass balance of the whole glacier to oversee the glacier evolution and climate trend in the Mont Blanc Massif.

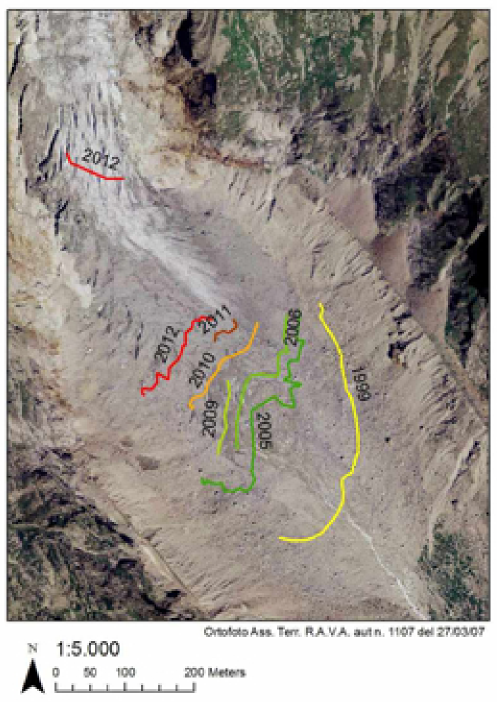
METHODS:
We carry out direct measurement of average net balance, with snow pits in the accumulation area and stakes in the ablation area. We measure the annual glacier front position by mean of GPS surveys.

RESULTS:
From the beginning of the activities, the mass balance results negative: we can assess a total loss of over 14 millions m^3WE.

Due to the ongoing morphological transformations, it was not possible to install and monitor stakes in the end zone of the tongue, that has steep slope and is subject to rockfalls from above. Therefore, the measurement of the mass balance for the balance year 2011/12 was carried out only in the upper sectors of the glacier. The value of the average net mass balance that results, referred to the surface on which the measures are performed, is still comparable with the values obtained in previous years; in the graph a change in the calculation procedure is indicated with an asterisk. HOWEVER we must keep in mind that the frontal sector of the glacier gave an important contribution to the ablation calculation.

The average frontal retreat is about 25-30 m per year, even if there was a slowdown in the trend between 2006 and 2009.





VOLUME VARIATION BY MEANS OF DTM ANALYSIS

PERIOD: 2005-2007

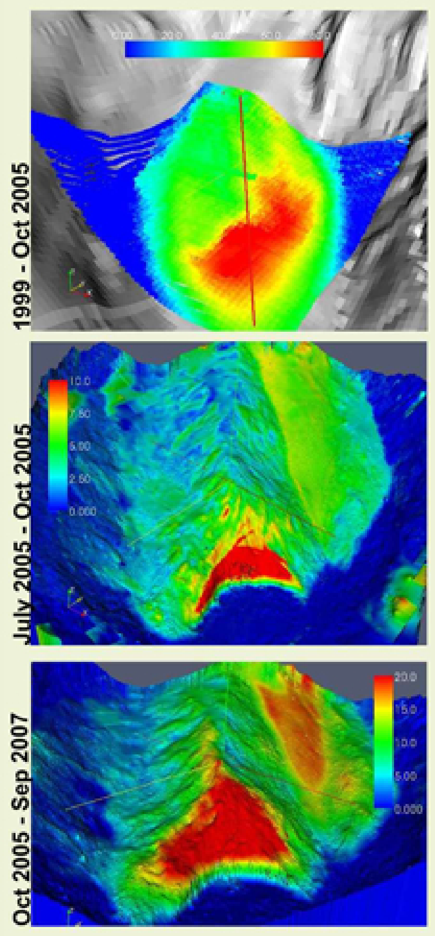
MAIN OBJECTIVES:
- Testing new technologies to glaciological purposes (terrestrial LIDAR);
- assessing glacier water resource and its evolution;
- comparing the results with ablation stakes measurements.

METHODS:
By means of LIDAR acquisitions (in July and October 2005 and in September 2007), we obtained 3 DTM 0,5 m spaced, GPS referenced, of the Pré de Bard terminus (15-20 cm accuracy). For a further investigation, we compared these models with the DMT of Autonomous Region of Aosta Valley of 1999, 10 m spaced, and we obtained the mass balance for the period 1999-2007. On this DTM, we modeled the average incoming solar radiation on the glacier front.

RESULTS:
In some areas the volume loss is much lower than elsewhere. At the same time, the frontal retreat in the left portion of the terminus is bigger than in the right bank side. These effects are due to the debris cover and to the different sunshine. According to the model of the incoming solar radiation, the left sector of the front receives approximately 20% less of sun.

Data	DTM Jul05 - Oct05 value	DTM Oct05 - Sep07 value	DTM RAVA99-Sep07 value
Investigated area (m^2)	137458	143335	223062
Average altitude of investagated area (m a.s.l.)	2150	2150	2150
Day of ablation cosidered (day)	101	706	2250
Ice volume loss (m^3)	405910	904664	10119734
Water equivalent volume (m^3)	363519	814198	9107761
Annual average net balance (mWE)	-2,65	-2,85	-6,65

Thicknes of ice loss (in meters) obtained by DTM substraction:



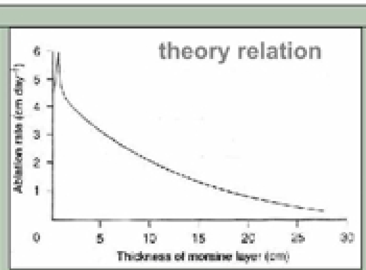
ABLATION DYNAMICS DETAILED ANALYSIS

PERIOD: 2005-2007

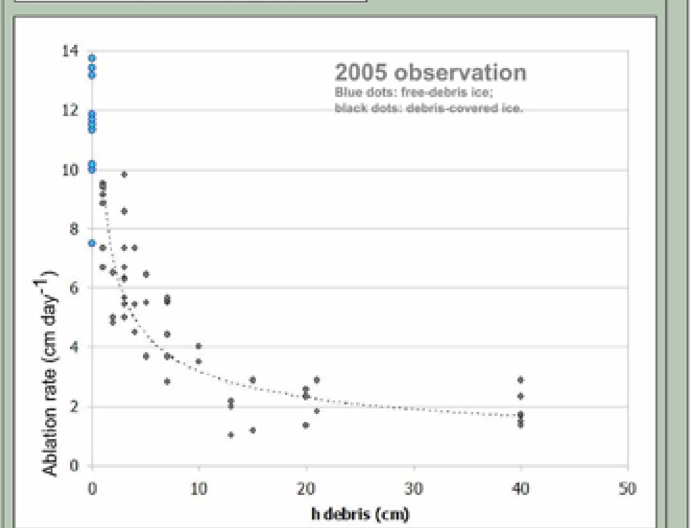
MAIN OBJECTIVES:
- Measuring with traditional method the mass balance of the glacier terminus;
- investigating the ablation in relation to the thickness of the debris cover;
- investigating the temporal trend of melting rates;
- comparing the results whit DTM volume variation.

METHODS:
Several stakes measurement have been carried out, (see table). For each point we measured the debris cover thickness and calculated the total melting rate between two following stakes reading and the average daily melting rates. Individual values were grouped together according to the presence or absence of debris in the neighborhood of the stake, thus obtaining average melting value for debris covered ice and debris free ice.

RESULTS:
Melting rates are strongly dependent of debris cover thickness. Our data well agree with the theoretic relation of melting rates and debris thickness (see graphs on the right). The mass balance resulting from stakes data is 20% less than that derived from DTM analysis. This fact reflect the intrinsic difficulty of stakes method to extend a punctual value on an homogeneous area.



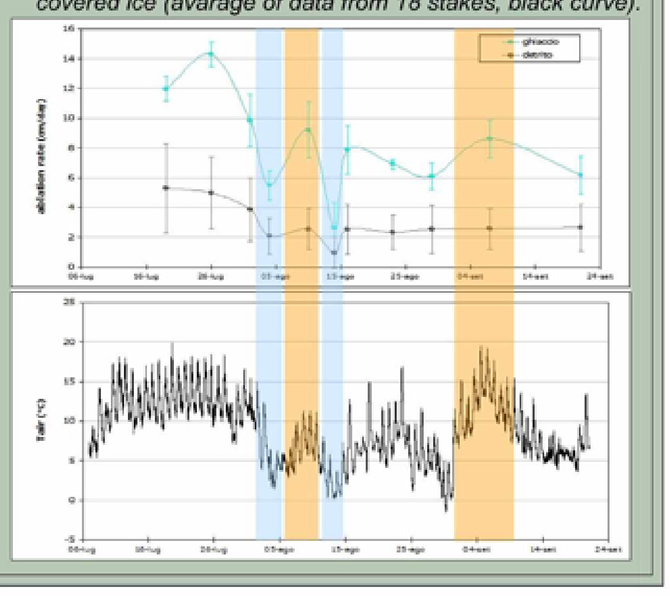
The theoretic relation between melting rate and debris thickness (Benn&Evans, 1998; Glacier and Glaciation, Arnold, London, 734) and the melting rate observed in 2005; the same results were obtained for 2006 and 2007



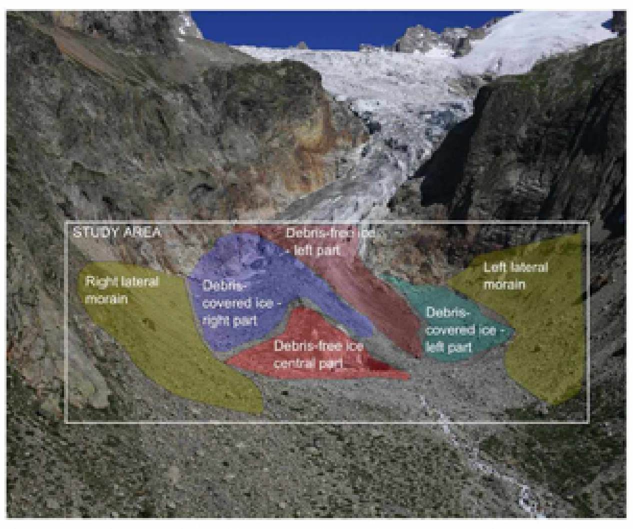
Number of stakes and observation per year.

Year	N. stakes	N. lectures	Period	Days	Time interval between measures (day)
2005	19	5	5 Aug - 23 Sep	49	9,8
2006	22	10	18 Jul - 7 Sep	51	5,1
2007	9	11	4 Jul - 11 Oct	99	9

Melting rates and air temperature relation (2006 data); lower peaks clash. The debris-free ice melting (avarage of data from 4 stakes, blu curve) rate is higher than the one of debris-covered ice (avarage of data from 18 stakes, black curve).



What we study in 2005-07



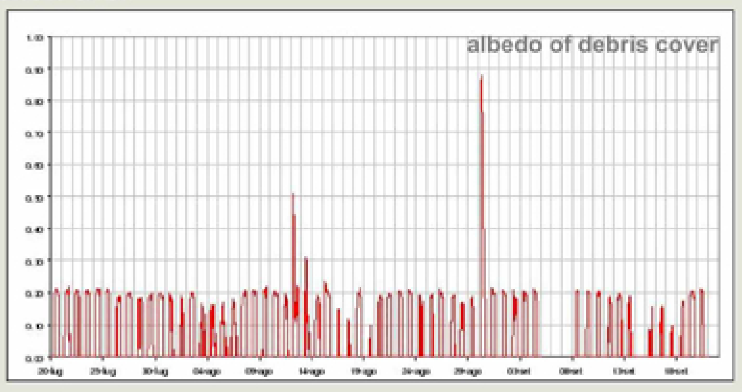
THE DEBRIS COVER PROPERTIES

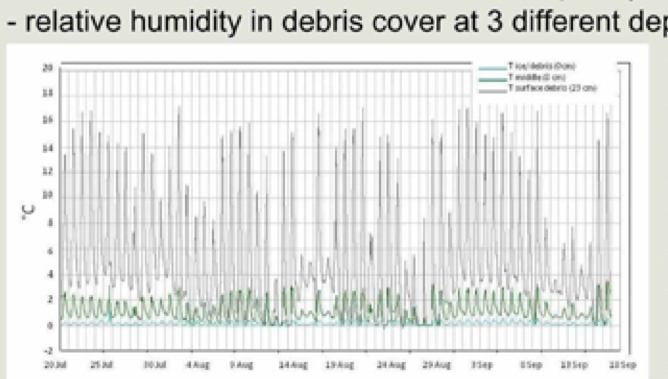
PERIOD: 2005-2007

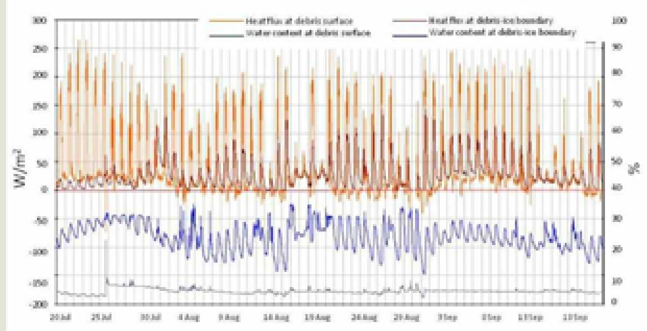
MAIN OBJECTVIES:
- Characterization of the debris cover effect on the melting;
- testing technologies for the thermal surface properties monitoring.

METHODS:
We set the instrumentation to obtain:
- air temperature and relative humidity at 2 different altitudes;
- incoming and net radiation [0.2-100 μm] and albedo [0.305-2.8 μm];
- debris cover temperature at 3 different depths: air-debris boundary (23 cm to the ice), 8 cm to the ice, debris-ice boundary (0 cm to the ice);
- heat flux in debris cover at 3 different depths (as above);
- relative humidity in debris cover at 3 different depth (as above).

RESULTS:
The average albedo on the debris covered ice is about 0,2, unless of two peaks occuring during two summer snowfalls.







The upper part of the debris layer has a small water content, on average always less than 10%. Conversely, at the ice-debris boundary the water content is higher (between 20 and 30% throughout the period of observation), surely influenced by the presence of the impermeable ice layer. The maximum daily water content is delayed with respect to the maximum daily heat fluxes. The high daily temperature range at the surface (maximum temperatures around 17 ° C) is strongly attenuated to 8 cm thick debris and is limited to a weak oscillation in contact with the ice. In case of decimetrical debris cover, the insulating effect is undeniable. There is a delay in reaching peak of maximum daily temperature, known in the literature, attributable to the debris thermal inertial. A scarcely positive temperature (<0.5 ° C) prevails in the vicinity of the drebis-ice boundary. This is, however, a favorable condition for the ice melting. This characteristic is also confirmed by the presence of heat fluxes, detected by the plate placed at the debris-ice boundary, that is always positive (although weak), index of heat that is transmitted by the detritus to ice regardless of the intensity of the incident radiation, from the presence of more or less circulating water and extent of heat flux in the upper portion.

The ablation, debris cover properties and DTM studies was carry out in the framework of LIDARdataVal project, with the contribution of Politecnico di Torino. The mass balance measurements are included in the institutional task of ARPA Valle d'Aosta and Fondazione Montagna sicura - Montagne sûre. The comparative analysis of photos ("*Ghiacciai sorvegliati speciali*" project) also is an institutional task of Fondazione Montagna sicura - Montagne sûre.