Glacial Surface energy Balance by means of a portable Calorimeter

Michele Motta
Earth's Sciences Department
University of Studies
Turin, Italy
michele.motta@unito.it

Abstract — **This paper analyzes the shallow energy balance of the Lys and Indren Glaciers. We have used a calorimeter operating with artificial ice, which is placed on the glacier. It well represents the sensible heat flux and the phase changes, at the interface ice-air. So, we have calculated the melting/evaporation rate for the main kinds of weather. On the basis of the comparison with the data supplied by a pair of calorimeters in different working conditions (as sunny and shady conditions), we have also calculated the energy balance in special conditions: low evaporation with low sun radiation and very high humidity, high evaporation with low temperatures and in the shade, föhn, rain, several kinds of artificial cover. On the basis of the results, the correlation between sensible heat flux and air temperature is high; both the correlations between ablation and air temperature and between surface ablation and radiation are good. This proves that both the calorimeter operating properly and the sensible heat flux is a significant part of the surface ablation. The evaporation is important for the energy balance, and it is not unimportant in the mass balance. For Lys and Indren Glaciers, the loss due to ablation includes a mass of steam that is between 1% (rainy weather) and the 10% (föhn) of the total leak of mass. During the fine weather, the mass of steam is about the 2-6%. The artificial covers well protect the ice, also because they promote better in proportion the evaporation that spends more energy than melting.**

Keywords;Glacier; energy balance; ablation; Western Alps;

I. INTRODUCTION

The study of energy balance is essential to understand the interactions between climate change and glacial dynamics. It is also useful to measurement of mass balance. An important part of the energy flows involves phase changes, then ablation processes. So, the measurement of the energy balance can be useful to verify the congruence of experimental data, and the mass balance obtained with traditional methods [1, 2, 3].

II. RESEARCH PURPOSES

We measure in different weathers energy balances of the glaciers of the southern slope of Rosa Mount (Lys, Indren), to quantify:

- variation of evaporation-fusion ratio as a function of temperature, air humidity and radiation;
- relationship between radiative and thermal exchanges as a function of weather.

It's more than likely, that the fragmentation of a large glacier in small isolated glaciers accelerate the process of deglaciation [4]. However, in support of this hypothesis, there is no experimental evidence until now. It would a valid test that, when the sun radiation is low, a good part of the energy exchanges, take place in the form of heat flux between air and ice. This can show that, the increased heating of the air over the slopes surrounding the ice, causes directly a strong ablation at the glacier.

III. MATERIALS AND METHODS

The calorimeter developed and used for this work is derived from tests performed since 1996 [5], with different shapes and materials, to get the highest accuracy obtainable under experimental conditions, and a measuring time long enough to minimize measurement errors, but to conclude the trial within a day.

The calorimeter is a waterproof container, almost elliptical to minimize edge effects, with 0.0166 m² area, albedo comparable to that of pure natural ice (0.5-0.6) and thermal conductivity of an order of magnitude lower.

We pours 100 g of water in the calorimeter, and cools them to -20°. When the ice is ready, we puts him in a hole that has the same shape and is dug in glacier. We measures the time of full fusion and, at the same time, the cloudiness, Q energy, radiation, temperature and relative humidity at 10-15 cm from the ground (with a Delta Ohm Data Logger).

When the calorimeter starts working, the heat absorption initially leads the ice at 0 °C. The amount of heat so absorbed shall be equal to the heat capacity of ice multiplied by the difference between the initial temperature of the ice and 0 °C, multiplied by the mass of ice.

Since start of melting, the calorimeter absorbs the heat of fusion, plus the heat of evaporation. The latter is determined, at the end of the experiment, if we measures the remainder of liquid water. The weighing is done together with the container, to avoid random errors caused by adhesion of drops to the container; afterward we subtract this mass from the initial mass of ice.

The study was financially supported by Research Project PRIN "Interactions of climate, mountain and hilly environment: global change effects and natural hazards in NW Italy".

Generally, the calorimeter works until total melting. If the energy absorption is so low, that by prolonging the fusion, the experimental conditions vary (weather changes ...), we must stop the operation and measure the liquid water obtained. Since a part of it sticks to the ice, the weight of the residual ice is slightly overestimated.

IV. Measurement of the melting/evaporation ratio

During the experiments, the evaporation varied between 1 and 10% (föhn conditions), rising to 54% in the shade and with low temperatures. In "normal" conditions, the 2-4% of initial mass will evaporate: this one is the 12-23% of the energy exchanged by evaporation + fusion, since the heat of evaporation is much higher of the fusion heat.

V. Low evaporation because of low radiation and very high humidity

On 10.08.2010, in conditions of fog and weak wind (1.61-4.83 km/h), on Lys Glacier we putted two calorimeters, one of which was protected by a large reflective cover, whose height was such as to not hinder the sensible heat flux. We got the following energy balance.

- Energy absorbed by the calorimeter unshielded: 2.0 MJ/m²

of which 10.0% is due to temperature variations, 82.6% to the melting, and the 7.4% to evaporation

- Energy absorbed by the calorimeter sheltered: 1.8 MJ/m²

of which 10.8% is due to temperature variations, 89.2% to the melting, and the 0% to evaporation.

Therefore, with high humidity, the evaporation is still sensitive, where there is radiation and positive air temperature.

VI. High evaporation because of cold temperatures and shade

On 25.09.2011, with clear sky and damp, cool (fig. 1) breeze (3.22-11.27 km/h), we measured the energy balance on a glacier area in the shade.

The calorimeter has absorbed 973 kJ/m², of which 14.3% for temperature variations, 39.3% for melting, 46.4% for evaporation.

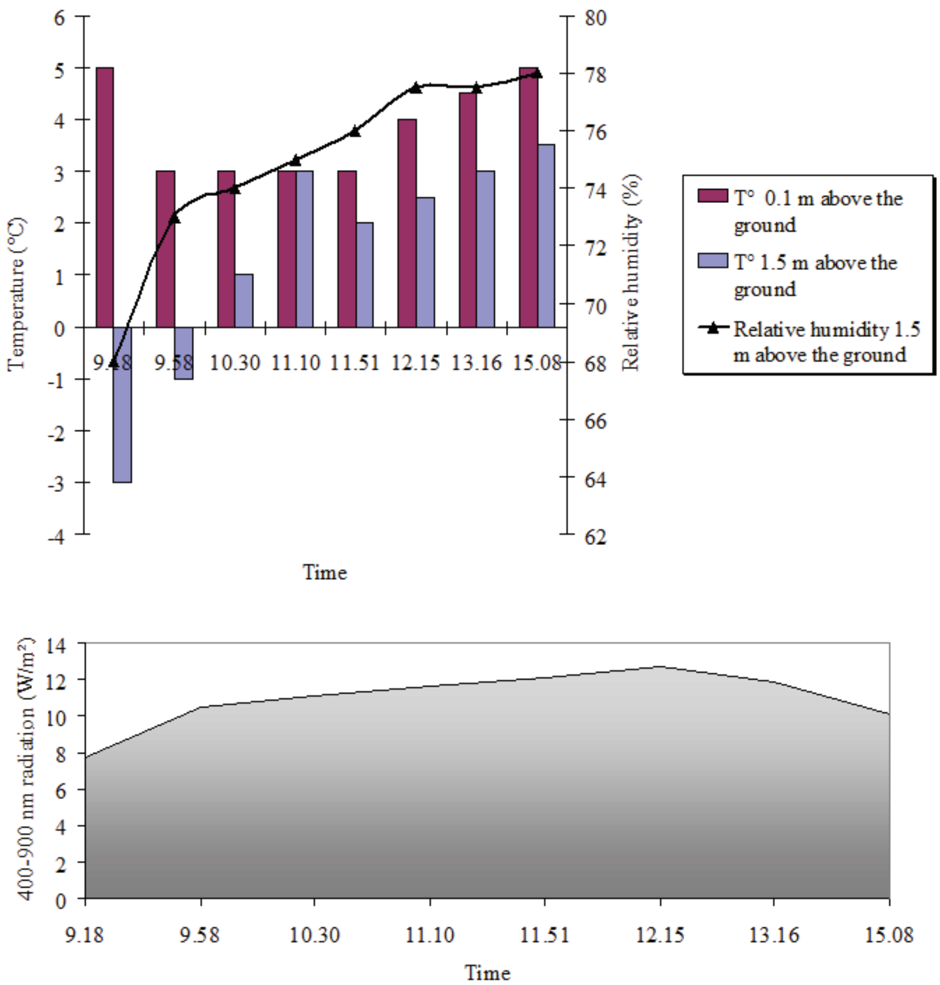

Figure 1. Test of the 2011.09.25. At the top: air temperature and relative humidity variations. Below: visible light variations.

VII. ENERGY BALANCE IN THE CLEAR SKY AND FÖHN

On the Lys glacier, with clear sky and widespread conditions of föhn in Western Alps, on 29.11.2010 we place to Sun (radiation > 133.9 W/m², average of 351.0 W/m²) and to wind a calorimeter; another, in the shade of a reflective cover (radiation < 15 W/m²). If the radiation is very low, even the mistakes of its measure in absolute amounts are reduced to a minimum. These errors do not disturb the measurement of sensible heat flux: so, it becomes legitimate that we obtain this flux for subtract of Sun radiation from the absorbed heat employed in phase changes. The goodness of the method is confirmed by the similarity between the coalbedo measured experimentally with a radiometer and the one calculable by attributing to the sunny calorimeter the same amount of heat exchanged by conduction and convection of calorimeter, subtracting this amount from the heat absorbed by the calorimeter, and dividing the result by the Q Energy (Sun radiation) measured experimentally with the Quantum-Radiometer (tab. 1).

When it is in the shade, the ice employs a double time to melt; the evaporation decreases if compared with to melting (tab. 1).

VIII. ENERGY BALANCE IN THE RAIN

We used a couple of calorimeters, one exposed to rain, another repaired by a kind of umbrella. The latter is very high, so that it does not overshadow the calorimeter. During the experiment, we measured wind, rainwater, radiation, humidity and air temperature.

At the end of the test, the 2% of the ice mass of the repaired calorimeter was transformed in vapor; the exposed calorimeter, being fallen 2.32 mm of rainfall, had purchased 38.5 g of rainwater, in the hypothesis of an evaporation equal to that of calorimeter repaired.

TABLE I. EXPERIMENT IN THE FÖHN CONDITIONS.

29 November 2010	Exposure	
	In the sun	***In the shade***
Ablation	$760.6 \cdot 10^{-6}$ Kg/ sm²	$351.0 \cdot 10^{-6}$ Kg/ sm²
Q Energy	2,780 kJ/m²	429 kJ/m²
Absorbed energy	3,709.3 kJ/m²	2,805.3 kJ/m²
Fraction relative to starting variation of T°	5.1 %	6.8 %
Fraction relative to melting	54.2 %	71.7 %
Fraction relative to evaporation	40.7 %	11.5 %
Sensible heat absorbed		2,590.8 kJ/m²
Average of sensible heat flux		151.0 W/m²
Radiation energy flux absorbed	1,118.5 kJ/m²	
Coalbedo derived dividing Q Energy by radiation energy flux absorbed rate	0.40	
Coalbedo measured by radiometer	0.42	

Cooled to 0°, the rainwater yields energy equal to its mass multiplied by 4.186 and $\Delta T°_{starting} - 0°$, i.e. 1612 J. The time required for the melting ice was 19620" in calorimeter exposed to rain, 24660" in the sheltered one. The energy absorbed in these times was respectively 5332 and 6712 kJ/m². The melting of the ice contained in both calorimeters has demanded 131.0 W/m² in the calorimeter exposed to rain, 104.2 W/m² in the sheltered one. With the latest result we can calculate (1), i.e. the heat transferred from the air, excluding the effect of the rain.

Sensible heat exchanged (kJ/m²) = Energy absorbed by the calorimeter (2570.8 kJ/m²) – Radiation (3.64 kJ/m²)

$$= 2567.2 \text{ kJ/m}^2 \quad (1)$$

If we add in the calorimeter exposed to rain, 97.1 kJ/m² of rainwater enthalpy, the heat part not transferred by radiation becomes 2470.1 kJ/m².

The mass balance is, respectively for the calorimeter exposed and sheltered from the rain, 319.3 10-6 Kg/sm² and 10-6 Kg 254.0/sm² = 27.6 mmWE/day and 22.0 mmWE /day

It follows that 2.32 mm of rain fallen have increased of 5.6 mmWE/day the ablation. We could obtain (2):

$$\text{Ablation}_{rain} = 0.24 \cdot T°_{\ rainwater} \cdot \text{mm rain} \quad (2)$$

While the analogous (3), obtained theoretically by energy exchanges,

$$334 \text{ J/g} = X \cdot T°_{\ rainwater} \cdot 4.186 \text{ J/g} \quad (3)$$

must have as coefficient X, 0.12. The gap between 0.12 and 0.24 is mainly due to the fact that the rainwater carries energy in the form of momentum. With average velocity of drops of 4-8 m/s, the momentum carried by rainwater (0.5 mv²) is 18.5-74.2 kJ/m²

Finally, the hypothesis that the ablation on rainy days is poor, appears confirmed, because ablation is just over half of the one on days of good weather in the same period.

IX. PROTECTIVE COVERS EFFECT

In August 2010 we measured the mass and energy balance in four portions of the Indren glacier, who have the same slope angle (10°) and exposure (S), but different cover: nothing (bare ice), composite insulator (trisoform ACTIS), white geotextile 6 mm thick, and a layer of industrial sawdust about 1 cm thick. Under the bare ice, the ablation was 11-16 times more that under trisoform (fig. 2); under the geotextile, ablation was 24%-67% of that on bare ice, as under the sawdust. All covers are more effective as more is strong the ablation.

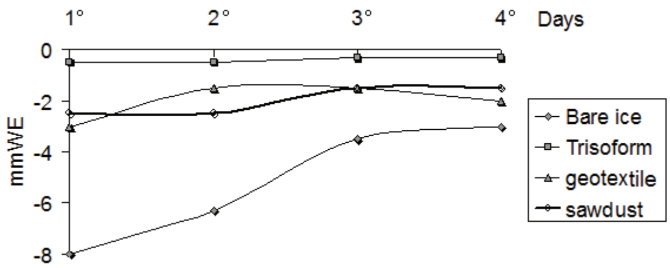

Figure 2. Measure of ablation (y axis) at the Indren, under several kind of covers, for five days.

Figure 3. The portions of the Indren Glacier that we have measured.

The covers change the evaporation/melting ratio. Under the geotextile, the evaporation arrives at 11%, below the sawdust comes to 25% of the mass that change phase. This explains why the sawdust is so effective, despite its albedo is lower than that of ice and geotextile.

X. STATISTICS CORRELATIONS

The correlation between heat sensible flux and the air temperature is high (fig. 4): apparently, close to the ground the variations caused by wind in heat flow are normally quite unimportant.

Fig. 5 shows a correlation between air temperature and ablation. The reason is both the indirect relationship between radiation and air temperature and the relationship described earlier.

It seems confirmed the correlation between surface ablation and visible light radiation (fig. 5, below), already noted on the Lys Glacier (since a correlation between the moraine cover, and the surface ablation [6, 7]).

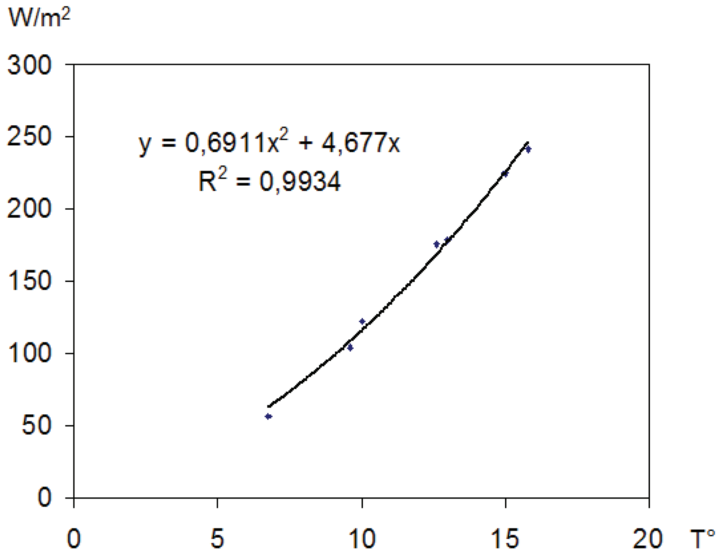

Figure 4. Heat sensible flux (y axis, W/m²) versus air temperature (x axis, T°).

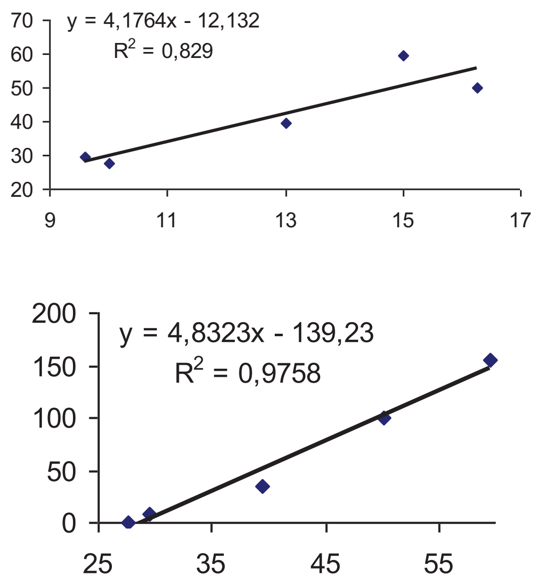

Figure 5. Results of five energy balances, which were measured with several cloudiness conditions, always without föhn or rain, on the Lys Glacier. Above, ablation (mmWE per day; i.e. how many millimetres of rain are equivalent to the mass of ice that is lose) versus the air temperature average (°C); below, surface ablation (x axis, mmWE per day) versus 400-900 nm radiation (y axis, W/m²). Both the equations of the trendline and R^2 are showed.

XI. Conclusions

The radiation is the main factor of surface ablation, as stated in the bibliography. Nevertheless, even the sensible heat flow is important, and under certain conditions causes stronger ablation than sun radiation.

The rain carries heat and kinetic energy; but the contemporary low radiation compensates largely these effects, making ablation during rainy days less strong than sunny days.

The evaporation according to measurements represents: at the Lys, between 7.4% (damp weather) and 40.7% (föhn conditions) of the energy required to eliminate ice phase; at the Indren, from 16.5% to 20.5%. Normally, during fair weather and in the sun, it is the 13-28%. Yet the greater the evaporation in the shade: with low temperatures, is more important than the melting.

In mass balance, we should not neglect the measurement of the evaporation. According to the experiments, we estimate that, in the Alps, the vapor is between 1% (damp weather) and 10% (föhn conditions) of the mass that is lost to ablation; and, with good weather, the vapor is the 2-6%.

Finally, the good correlations indicate reliability and repeatability of results of the calorimeter. The freezing-ice used owns the better uniformity of features to verify the correlations of this work, but it not owns always albedo enough similar to that of natural ice, if we wanted to measure the actual energy balance of whole glacier.

References

[1] Motta M., “La misura dell'ablazione nel bilancio di massa del ghiacciaio del Lys (Monte Rosa, Valle d'Aosta),” vol. 4. Torino: Archivio Comitato Glaciologico Italiano, 2001, pp. 61-74.

[2] Motta L. and M. Motta, “Distribution and pattern of shallow melting at the local glaciers of Terra Nova Bay (Antarctica) coast,” Annals of Glaciology, vol. 39, pp. 483-489, 2005.

[3] Motta M., Diolaiuti G., Vassena G., and C. Smiraglia, “Mass Balance and Energy Balance at Strandline Glacier (Terra Nova Bay, Antarctica): Methods and Preliminary Results,” Terra Antartica Reports, vol. 8, pp. 21-28, 2003.

[4] Motta L. and M. Motta, “A model for the sudden extinction of cirque and valley glaciers based on a case in the Western Alps,” Annalen der Meteorologie, vol. 30, pp. 97-101, 1994.

[5] Motta M., “Misura del bilancio energetico superficiale mediante parcelle sperimentali sul Ghiacciaio del Lys,” Proceedings Simp. Il Ghiacciaio del Lys: un approccio interdisciplinare, Milano 12 luglio 2002, pp. 29-35, 2002.

[6] Motta M., “Studio del rapporto accumulo - ablazione in un ghiacciaio alpino di grandi dimensioni: l'esempio del Ghiacciaio del Lys (M. Rosa),” Geogr. Fis. Din. Quat., vol. 18 (2) [1995], pp. 305-313, 1996.

[7] Motta L. and M. Motta, “Measurement of the superficial ablation components on the Lys Plateau (Monte Rosa, Northern Italy),” Proceedings 24th Int. Conf. on Alpine Meteorology, pp. 153-158, 1998.