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ANTONELLA SENESE (*), GUGLIELMINA DIOLAIUTI (*), GIAN PIETRO VERZA (**)
& CLAUDIO SMIRAGLIA (*)

SURFACE ENERGY BUDGET AND MELT AMOUNT FOR THE YEARS 2009 AND 2010 AT THE FORNI GLACIER (ITALIAN ALPS, LOMBARDY)

ABSTRACT: SENESE A., DIOLAIUTI G., VERZA G.P. & SMIRAGLIA C., *Surface energy budget and melt amount for the years 2009 and 2010 at the Forni Glacier (Italian Alps, Lombardy)*. (IT ISSN 0391-9838, 2012).

This paper reports the surface energy budget and the melt amount evaluated at one location at the Forni Glacier (Italian Alps, Lombardy) during the years 2009 and 2010. The analysis was supported by high resolution meteorology and energy data collected by an Automatic Weather Station (named AWS1 Forni) which has been running at the glacier surface (2669 m, ellipsoidal elevation) since 26 September 2005. The AWS is also equipped with a sonic ranger to measure snow depth and its variability. It resulted that in the years 2009 and 2010 the glacier melt at about 2700 m of altitude was equal to –11.32 m w.e.; these results were confirmed by comparisons with field ablation data collected nearby the AWS during the summer season 2009 and 2010.

KEY WORDS: Forni Glacier (Alps); Energy Budget; Ice and Snow Melt; Automatic Weather Stations.

RIASSUNTO: SENESE A., DIOLAIUTI G., VERZA G.P. & SMIRAGLIA C., *Quantificazione del bilancio energetico e dell'ablazione alla superficie del Ghiacciaio dei Forni (Lombardia) per gli anni 2009 e 2010*. (IT ISSN 0391-9838, 2012).

Si riportano i dati di bilancio energetico superficiale e di fusione calcolati per gli anni 2009 e 2010 sul Ghiacciaio dei Forni (Alpi Italiane, Lombardia) a partire dai dati meteorologici ed energetici rilevati dalla stazione meteorologica automatica AWS1 Forni posta alla superficie del ghiacciaio (a 2669 m di quota ellissoidica) ed in funzione dal 26 Settembre 2005. La stazione misura anche lo spessore del manto nevoso e ne registra la variabilità. È risultato che nei due anni considerati la fusione nivoglaciale a circa 2700 m di quota è stata pari a –11.32 m w.e. I valori di fusione ottenuti attraverso il calcolo del bilancio energetico sono risultati in ottimo accordo con i dati di terreno ottenuti da paline ablatometriche poste nelle estati 2009 e 2010 sulla superficie del ghiacciaio in prossimità della stazione AWS1 Forni.

TERMINI CHIAVE: Ghiacciai dei Forni, Alpi; Bilancio Energetico; Fusione di Ghiaccio e Neve; Stazione Meteorologica Automatica.

MICROCLIMATE OF GLACIER: FROM THE FIRST PIONEER INVESTIGATIONS TO THE ACTUAL ALPINE MEASUREMENTS

In spite of the oldest series of direct mass balance measurements in the world was from the Claridenfirn in Switzerland (Vincent & *alii*, 2004) where observations have been carried out since 1914, the first studies performed to describe and analyse glacier microclimate started later, only after the second world war. At the end of the forties Ahlmann (1948) studied processes and mechanisms involved in the strong glacier reduction he observed around the North Atlantic Ocean. Moreover in the same period, a comprehensive study of water, ice and energy budgets was started on several glaciers in Oetztal, Austria, and greatly expanded during the International Hydrological Decade in the 1950s (Hoinkes & Untersteiner, 1952; Hoinkes, 1955), during which several long-term mass balance series were initiated (Hoinkes & Steinacker, 1975; Reinwarth & Escher-Vetter, 1999).

Actual systematic investigations of the meteorological parameters on melting glaciers were performed only from the 1960s (Capello, 1959-1960; Ambach, 1963; Björnsson, 1972; Wendler & Weller, 1974; Munro & Davies, 1978; Hogg & *alii*, 1982; Munro, 1989; Ohata & *alii*, 1989; Ishikawa & *alii*, 1992). These studies provided supraglacial meteorological data and energy fluxes measurements only

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(*) *Dipartimento di Scienze della Terra «A. Desio», Università degli Studi di Milano, Via Mangiagalli 34, 20133 Milano, Italy* (antonella.senese@unimi.it, guglielmina.diolaiuti@unimi.it).

(**) *Comitato EvK2CNR, via San Bernardino 145, Bergamo, Italy* (gianpietro.verza@evk2cnr.org).

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for short periods (one or more ablation seasons) and only on accumulation basins: Hintereisferner, Austria (Van de Wal & *alii*, 1991), West-Greenland (Oerlemans & Vugts, 1993), Pasterze, Austria (Greuell & *alii*, 1997), Vatnajökull, Iceland (Oerlemans & *alii*, 1999). The data obtained in these experiments have made clear that longer series of measurements from ablation zones are also needed. Especially on larger glaciers, melting on the lower parts is not restricted to the summer season. A better calibration of mass balance models could be achieved if data over longer time periods would be available. Thus from 1987 longer dataset are recorded on the melting zones of the Greenland ice-sheet, of Hardangerjokulen (Norway) and of Morteratschgletscher (Switzerland) (Oerlemans, 2000; Oerlemans & Klok, 2002; Klok & Oerlemans, 2004). Up to now the longest glacier data series is obtained from the Automatic Weather Station (from here AWS) located on the Morteratschgletscher; due to the possibility of regular visits and to the favourable atmospheric conditions (little icing) a good quality meteorological data set is obtained during the last 2 decades (Oerlemans, 2001; 2009).

On short period melting areas also of debris covered glaciers were analysed through AWS for evaluating energy fluxes and supraglacial meteorology features (see the experiment on the Miage debris covered glacier, Mont Blanc, Italian Alps, further details in Brock & *alii*, 2010).

After the recognizing of AWS importance, these stations have been deployed over a wide variety of glaciated surfaces (e.g. continental ice sheets, valley glaciers, sea ice and icebergs) and have a variety of applications, including climate variability assessment, in support of operational weather forecasting, model validation and in avalanche information support. AWS applications share a common challenge of obtaining continuous and reliable measurements both unattended and often in extreme environments. AWSs have facilitated growth in the branch of glacio-meteorology.

The collection of meteorological data recorded by permanent AWSs, in fact, is essential for measuring energy fluxes at the glacier-atmosphere interface and snow accumulation, for calculating the energy available for snow/ice melt, for the validation of mass balance models, meteorological models (regional/mesoscale) and satellite products, for constructing parameterizations for energy balance models (Oerlemans & Vugts, 1993; Greuell & *alii*, 1997; Oerlemans & *alii*, 1999; Oerlemans, 2000; Klok & Oerlemans, 2002; Oerlemans & Klok, 2002; De Ruyter de Wildt & *alii*, 2003; Klok & Oerlemans, 2004; Senese & *alii*, 2012).

The meteorological parameters are also fundamental to characterize glacier surface and sky conditions. For example albedo and cloudiness are the most important parameters that determine the amount of solar radiation adsorbed at the surface (apart from geometric effects like shading): at the glacier surface the solar radiation mainly drives ice and snow melt. From the incoming radiation the cloud conditions can normally be inferred qualitatively: days with overcast conditions are marked by lower values of incoming solar radiation and higher ones of incoming longwave radiation. In fact, clouds and water vapour make the atmospheric emissivity larger. On the contrary glacier outgoing longwave radiation shows less pronounced variations.

THE ITALIAN AWS NETWORK AND THE AWS1 FORNI

During the last decades, in Italy some AWSs (collecting data during different periods) were located in the glacierized areas on rock exposures, nunataks or buildings (such as mountain huts), thus making the meteorological data representative of high mountain atmospheric conditions but not very useful for analysis of the supraglacial micrometeorology.

On the Italian Alps, glacier meteorological experimentation through permanent AWSs started on 26th September 2005 with the AWS installed at the Forni Glacier surface (Upper Valtellina, Lombardy Alps) (Citterio & *alii*, 2007, Diolaiuti & *alii*, 2009; Senese & *alii*, 2010; 2012). Then, by the Glaciology Group of the University of Milan in Summer 2007 a second AWS was set up at the melting surface of the Dosdè Glacier (Piazzi Campo Group, at a height of 2850 m a.s.l., Lombardy Alps) and in Winter 2007 a third AWS was installed at the accumulation basin of the Geant Glacier (Mont Blanc Group, at a high of 3430 m a.s.l.) (fig. 1). All these AWSs (i.e.: Forni, Dosdè and Geant) have been developed in the framework of the SHARE (Stations at High Altitudes for Research on the Environment) project managed by the EvK2CNR Committee (Diolaiuti & *alii*, 2009). Afterwards, other AWSs were installed by other research groups on different Italian glaciers (among the others on the Vedretta della Mare, Trentino). The dataset recorded on Forni Glacier represents the longest one from an Italian AWS.

Forni is the largest Italian valley glacier (ca. 12 km^2 of surface area in the Ortles-Cevedale group, Stelvio National Park). The glacier has a northward down-sloping surface and an elevation range between 2600 and 3670 m a.s.l. The AWS here located (named AWS1 Forni) has been set up on the ablation tongue at the WGS84 coordinates 46° 23' 56.0" N, 10° 35' 25.2" E, 2669 m (ellipsoidal elevation) at the base of the Eastern icefall (see tab. 1). The AWS location is a good compromise between the needs for minimizing local topography effects and lowering the probability of avalanches destroying the AWS. The station is located on the lower glacier sector, about 800 m far from the glacier front. Moreover the AWS1 Forni is presently supported by the SHARE Stelvio project (SHARE STELVIO). The station is also part of the CEOP-GEWEX network.

On the AWS1 Forni are installed sensors (all consistent with World Meteorological Organization, WMO) measuring the main meteorological parameters (for sensor specifications see table 2). The whole system is supported by a four-leg, 5 m high stainless steel mast standing on the ice surface according to the construction and setting proposed and tested by IMAU (Oerlemans, 2001). The AWS stands freely on the ice, and adjusts to the melting surface during summer.

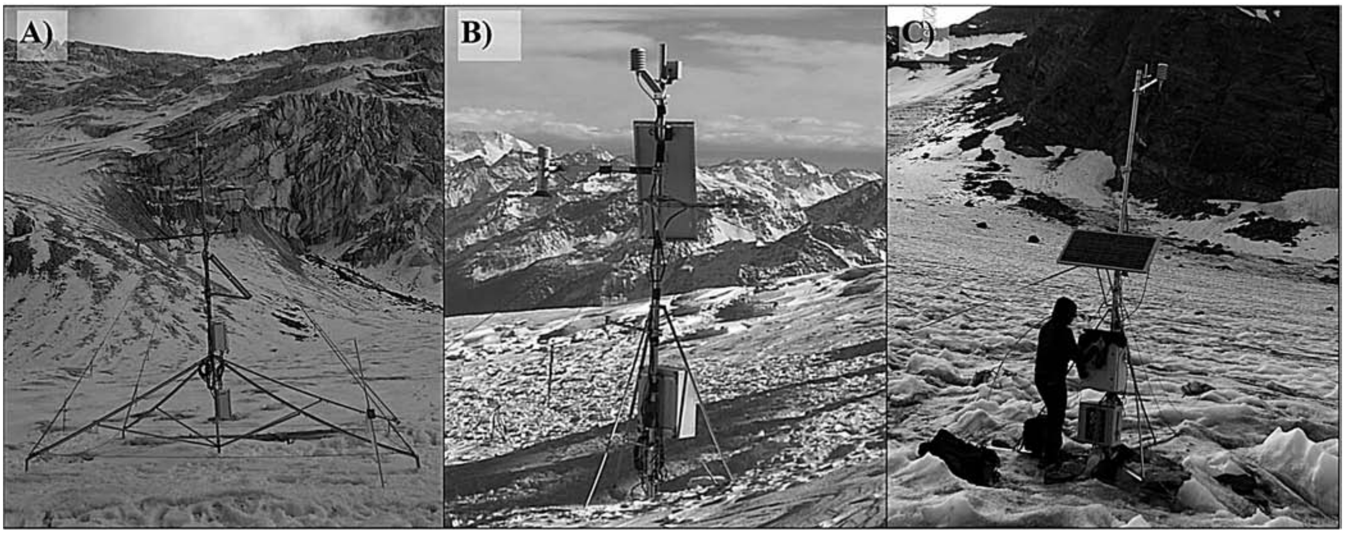

FIG. 1 - The Italian AWS Network. From the left: AWS on Forni (A), on Geant (B) and on Dosdè (C) Glaciers.

TABLE 1 - Site characteristics, meteorological and energy balance data of the Forni Glacier (data are averaged by annual mean values from 2006 to 2010). In the last two columns the meteorological and energy balance data refer to the year 2009 and 2010

Coordinates	46° 23’ 56” N; 10° 35’ 25” E
Elevation range (m a.s.l.)	2600 - 3670
Length (km)	4.7
Area (km2)	12
AWS elevation (m a.s.l.)	2631

	Annual mean (2006-2010)	**2009**	**2010**
SW_{net} (W m^{-2})	67	68	66
LW_{net} (W m^{-2})	-36	-36	-31
SH (W m^{-2})	17	16	15
LE (W m^{-2})	-4	-3	-1
R_S (W m^{-2})	38	43	47
SW_{in} (W m^{-2})	154	160	163
SW_{out} (W m^{-2})	93	92	102
$SW_{in\ extra}$ (W m^{-2})	267	267	267
Air temperature (°C)	-1.4	-1.6	-2.1
Snow albedo	0.77	0.76	0.78
Ice albedo	0.23	0.24	0.23
Wind speed (m s^{-1})	4.9	5.0	4.5

TABLE 2 - Sensor specifications installed at the AWS1 Forni

Variable	**Range**	**Accuracy**	**Recording rate**	**Sensor**	**Manufacturer**
Air Temperature	–30 - +70 °C	±0.001°C	30 min.	Naturally ventilated thermohygrometer	LSI-Lastem DMA570
Relative Humidity	0 - 100 %	±1%	30 min.		
Air Pressure	400 - 800 hPa or mBar	±10hPa	60 min.	Barometer	LSI-Lastem DQA223
Solar Radiation	0.3 - 3 αm	±5% of the value	30 min.	Net radiometer	Kipp and Zonen CNR-1
Infrared Radiation	5 - 50 αm	±5% of the value	30 min.		
Snow level	0 - 1000 cm	±2 cm	60 min.	Sonic Ranger	Campbell SR50
Liquid precipitation	0 - 1000 mm	±1mm	30 min.	Unheated pluviometer	LSI-Lastem DQA035
Wind Speed	0 - 50 m s^{-1}	±1%	60 min.	Anemometer	LSI-Lastem DNA022
Wind Direction	0° - 360°	±1°	60 min.	Anemoscopic	LSI-Lastem DNA022

In this contribution we focus on meteorological data collected in the years 2009 and 2010 by the AWS1 at Forni Glacier surface (further details on previous data available on Citterio & *alii*, 2007; Diolaiuti & *alii*, 2009; Senese & *alii*, 2010; 2012).

METHODS

AWS1 Forni has been running continuously since its installation with only one interruption between 5th and 11th October 2008. In this study we analyze the energy budget and the melting amount over 2 years. Moreover we also spent some attention on the main glacier meteorological features derived from the AWS data analysis.

To calculate the surface energy balance, the hourly radiation data were analyzed. At the glacier surface, solar radiation is the most important energy balance component driving ice and snow melt. Therefore the albedo (from here α) is an important and noteworthy parameter of glacier surface to be analyzed in terms of temporal variability.

The definition of albedo is based on the concept of irradiance, i.e. the total energy flux incoming in through a hemisphere. The reflection of solar radiation by the glacier surface is the outgoing of a complicated scattering process in the upper layer of the glacier. In fact, albedo is related to thickness and the age of the snowpack, and it depends in a complicated way on crystal structure, surface morphology, dust and soot concentrations, moraine material, the presence of liquid water in veins and at the surface, solar elevation, cloudiness, etc. (e.g. Wiscombe & Warren, 1980a; 1980b; Takeuchi, 2002; Brock, 2004). In addition the spatial and temporal variation of the albedo is large. This is clear looking at satellite images of sufficiently high resolution that have the advantage to cover the entire glacier area but they are actual and valid only for their acquisition time, moreover the glacier areas in the shade cannot be used to derive the albedo value (see Klok & *alii*, 2003). Another limit of satellite images is that the total amount of reflected radiation cannot be directly measured by satellite, then a mathematical model of the Bi-directional Reflectance Distribution Function (BRDF, see also Nicodemus, 1965) has to be used to translate a sample set of satellite reflectance measurements into estimates of directional-hemispherical reflectance and bi-hemispherical reflectance. (e.g. Strahler & Muller & *alii*, 1999). The land surface of the Earth, in fact, exhibits anisotropy in the spatial and angular distribution of scattered radiation due to the presence of topography and landscape objects on the land surface.

To know with a high degree of time resolution the albedo value and its variation on the melting area of a valley glacier the most suitable way is a net radiometer measuring the four radiative components like the sensor installed on our AWS; for calculating albedo the two short wave components (incoming and reflected) should be analysed.

To calculate albedo, firstly the incoming and outgoing shortwave radiation data (SW_{in} and SW_{out}, respectively, and measured by the CNR1 pyranometers) are filtered in order to remove erroneous values (e.g.: during snowfall, snowflakes sticks on the upward looking sensor whereas the downward looking sensor remains free of snow, consequently SW_{out} values exceed SW_{in}); then the following relation is applied:

$$\alpha = SW_{out} / SW_{in}$$

The incoming and outgoing longwave radiation (LW_{in} and LW_{out}, respectively), are measured by the CNR1 pyrgeometers. The acquired data represent the flux at each sensor surface, and the values have been converted to the ground and atmospheric (upward and downward) directional flux by Stephan-Boltzmann's law also considering the temperature of the CNR1 sensor (measured by the instrument and stored by the AWS data logger).

For the calculation of the turbulent heat fluxes, the bulk aerodynamic formulas are used according to the methods introduced by Oerlemans (2000) and also described by Senese & *alii* (2012).

The surface energy flux (R_s) at the glacier-air interface determining the net energy available for heating and melting of snow/ice, is calculated by the sum between radiative and turbulent fluxes:

$$R_s = SW_{net} + LW_{net} + SH + LE$$

where SW_{net} and LW_{net} correspond to the net radiation (shortwave and longwave respectively), SH and LE to the sensible and latent heat fluxes.

We calculated the glacier mass loss only for the hours characterized by both positive net energy (R_s) and glacier surface temperature (this latter derived from outgoing LW values):

$$M = -R_s / Lm$$

where Lm corresponds to the latent heat of melting (3.34×10^5 J kg^{-1}). Field measurements by ablation stakes installed nearby the AWS were performed during summer 2009 (from 24th July to 30th August 2009) and 2010 (from 28th July to 25th August 2010) to validate the melting computation.

RESULTS

The wind regime in the near surface glacier layer can be better understood with scatter plots of wind speed, wind direction and air temperature (hourly values) (e.g. Oerlemans & Grisogono, 2002).

Analysing wind direction data (fig. 2), it appears that the wind blows steadily from SE, hence down the glacier, that is along the glacier fall line. Even if no measurements at different elevations above the surface are available, the direction data show a similar behaviour than the one found by Smeets & *alii* (1998) on other glaciers where katabatic-type flows are described. In fact this situation characterizes several melting glacier surfaces during a large part of the summer and high latitude areas in wintertime, like Antarctica, where the boundary layer does not show a clear daily cycle. In this period of the year, temperature and vapour pressure at the surface have no a marked daily cycle. Moreover the katabatic-type flows are described as boundary layer flows, in which surface friction and the

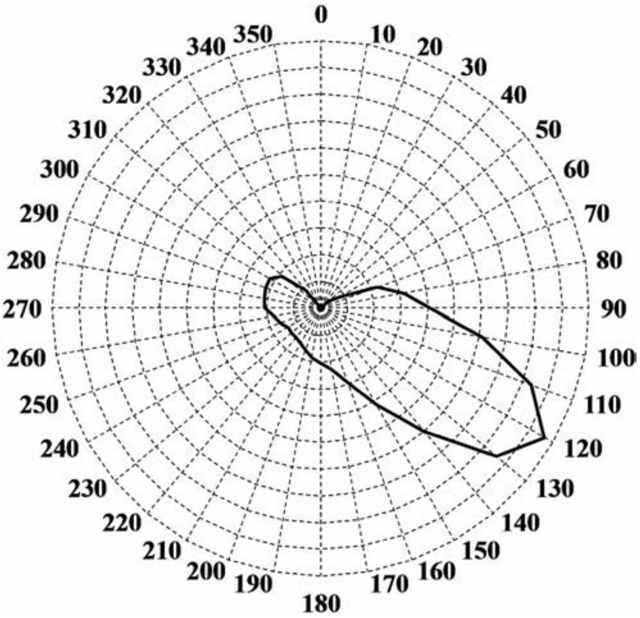

FIG. 2 - The frequency of dominant wind direction of provenance observed at the Forni AWS (dashed circular grid spaced by 1% probability of occurrence).

turbulent sensible heat flux are important components of momentum and the heat budget (Oerlemans, 2005). The cooling of air over a melting and sloping glacier surface generates a downward katabatic-type flow (Oerlemans, 2010). Therefore the forcing of a glacier boundary layer from below is fairly constant and variations in its structure will be related to what happens higher up (Hoinkes, 1954). Katabatic term, in fact, refers to winds that flow down the topographic gradient or out of a valley due to surface cooling that gives this air a greater density than the free atmospheric air. This cooling of slope surfaces, which is due primarily to a net negative surface radiative balance, produces a temperature difference between the air adjacent to the slope and the ambient air away from the slope. Winds then accelerate from the slope toward the ambient air, where gravity forces the dense flow to follow the sloping surface. Katabatic winds have been observed over sloping terrain of different scales all over the world, including Antarctica (Mawson, 1915; Ball, 1956; 1957; Rees, 1991; Bromwich & Parish, 1998; Renfrew & Anderson, 2002), Greenland (Loewe, 1935; Broeke & *alii*, 1994; Heinemann, 2002), Europe (Tollner, 1931; Ekhart, 1934; Defant, 1951; Smeets & *alii*, 1998; Oerlemans & *alii*, 1999), North America (Tower, 1903; Buettner & Thyer, 1965; Horst & Doran, 1986; Clements & *alii*, 1989; Doran & *alii*, 2002; Moni & *alii*, 2002; Haiden & Whiteman, 2005; Princevac & *alii*, 2005), and the Mediterranean (Martinez & *alii*, 2006).

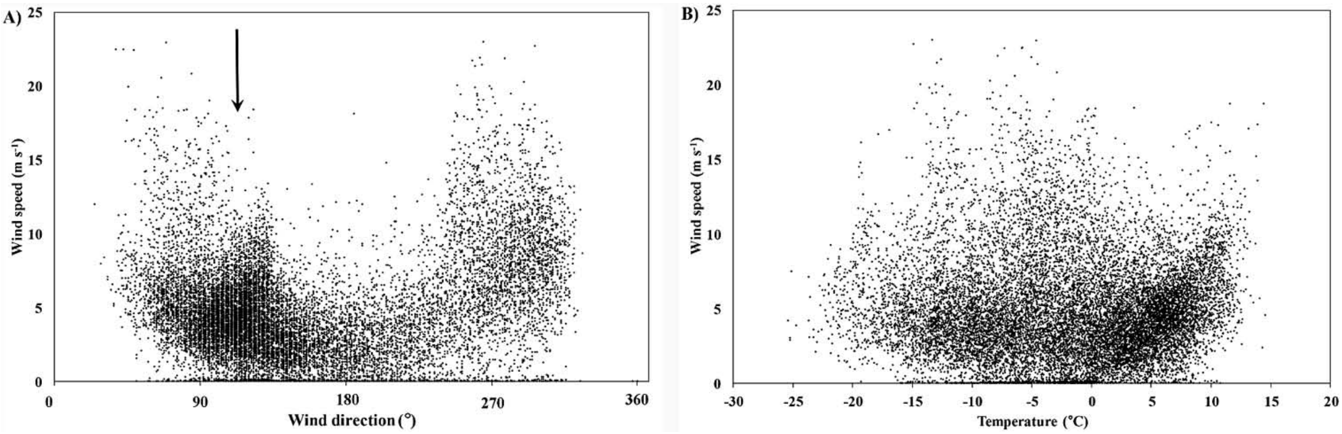

FIG. 3 - Scatter plots showing relations between wind direction (a) and air temperature (b) vs wind speed. Two years (2009 and 2010) of measurements are shown and every dot represents a hourly average value (so every plot contains 17133 points). The arrow indicates the direction of the local fall line of the glacier.

In wind direction vs wind speed (fig. 3a), the more frequent wind directions (cluster around a provenance from ca. 120°) occur with a speed of a few meters per second; these features of direction and speed are characteristics of the katabatic regime (Oerlemans, 2010). However wind directions of ca. 70° and ca. 170° also take place frequently. The faster winds reach speeds of about 20 m s^{-1} with a direction of 40°-80° and 250°-290°, always during wintertime. The wind speed shows a daily cycle more clear than the direction values. The annual mean speed results in agreement with values of previous years (tab. 1): a mean value of 5 m s^{-1} (in 2009) and 4.5 m s^{-1} (in 2010), both similar to 4.9 m s^{-1} averaged from 2006 to 2010.

Analysing wind speed and air temperature (Ta) hourly data (fig. 3b), a positive trend between air temperature and wind speed is found and the increase is clearly nonlinear. In fact higher wind speeds become more frequent for higher temperatures when Ta is above melting point. Considering the speeds higher than 5 m s^{-1}, the 46% occurs with positive temperatures, increasing the speed threshold to 10 m s^{-1} the percentage decreases until the 25%.

Analysing the hourly albedo values (fig. 4), the duration of ice ablation period is calculated for both the years: it results from 29th June 2009 to 10th October 2009 (104 days) and from 29th June 2010 to 24th September 2010 (88 days). The switch from winter to summer conditions is very clear: the presence or absence of snow is the most important factor in determining albedo variations on the time scale of days and longer (Senese & *alii*, 2012). Then it's possible to detect the summer snowfall events by steep increases of albedo values (e.g. from 0.2 to 0.8). During 2009 ablation season 2 snowfalls result from our data (totally covering 5 days featuring snow albedo values) and

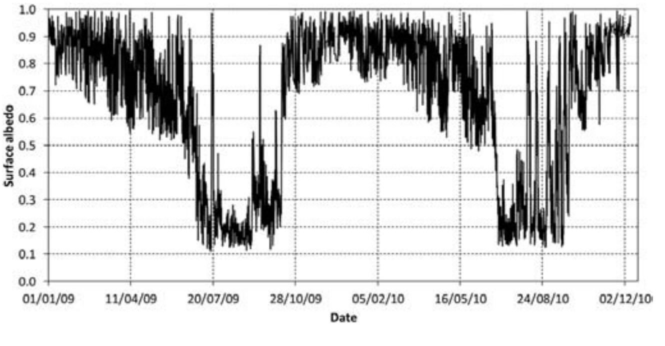

FIG. 4 - Hourly albedo values during 2009 and 2010.

during 2010 ablation season 5 snow fall events are found (covering 16 days). The snow presence affects the melting rate increasing the outgoing shortwave radiation and consequently decreasing the absorbed energy.

Figure 5 shows scatter plot of incoming (SW_{in}) versus reflected (SW_{out}) solar radiation for two-year periods as hourly measured by AWS1 Forni. There is a clear grouping in the diagram and characteristic albedos for snow/firn and ice are emerging (with a mean value of 0.76 during 2009 and 0.78 during 2010 regarding snow, and 0.24 and 0.23 in 2009 and 2010, respectively, for the ice). These mean values are comparable to the mean values averaged from 2006 to 2010 (tab. 1). This picture also shows that the snow albedo tends to decrease for larger values of the incoming radiation. This mainly concerns data points from late spring/early summer, when incoming radiation is large, air temperatures are high and snowfall rarely occurs. The snow structure has now been transformed into large grains and there is normally some accumulation of dust on the surface (Oerlemans, 2010).

All the four components of energy balance (fig. 6) are characterized by similar trends of the annual cycle over the presented period (from January 2009 to December 2010). All the hourly maximum values occur during summer, and all hourly minimum during winter except the values of net longwave radiation (LW_{net}). In particular, hourly net LW data (fig. 6a) vary between slightly positive values (close to 0 W m^{-2}, typical of cloudy days) and negative values (up to –100 W m^{-2}, realistic values due to the 0°C glacier surface): the large fluctuations from day to day are mainly related to cloudiness, especially in wintertime.

The net shortwave radiation (fig. 6a) is asymmetric with respect to the summer solstice. It decreases more gradually in fall than in spring. During the transition from snow to ice, the lowering of the albedo occurs when the flux of SW_{in} is large, determining a very steep increase in the net solar radiation.

During the ablation season the latent heat flux (fig. 6b) is generally positive, during the rest of the year the negative values are due to low humidity in combination with a minimal temperature difference between the surface and the air (Oerlemans, 2000). The negative net energy values (R_s) (fig. 6c) characterize the winter periods and night-time, when snow/ice melting is absent.

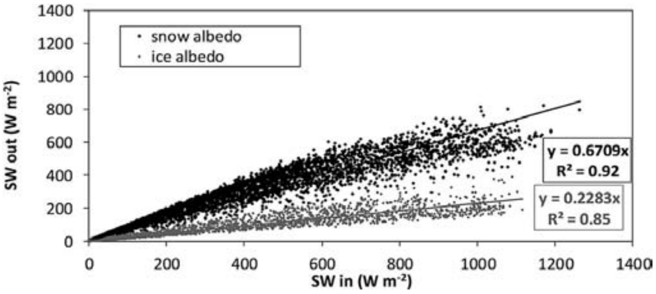

FIG. 5 - Hourly albedo values characterizing exposed ice and snow covered surface, during 2009 and 2010.

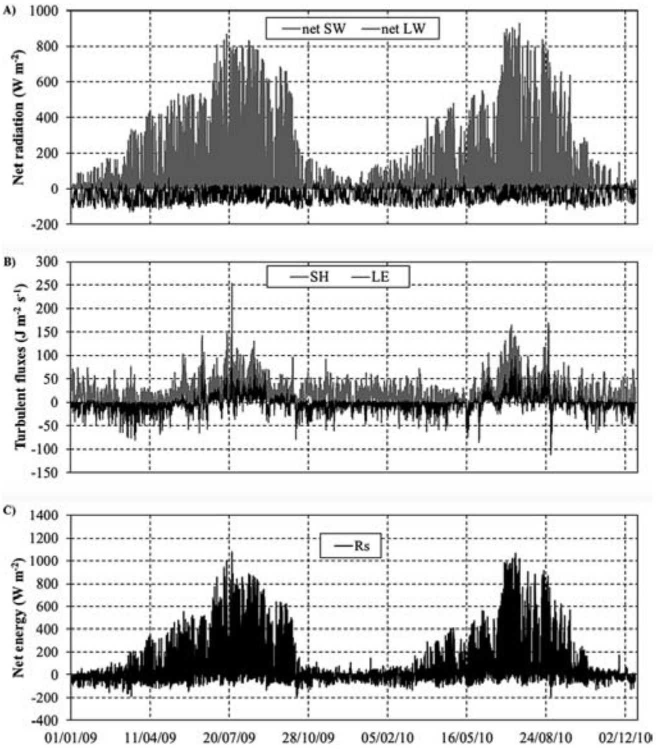

FIG. 6 - Daily values of net shortwave (SW_{net}) and longwave (LW_{net}) radiation (a), turbulent fluxes of sensible (SH) and latent (LE) heat (b) and surface net energy available for heating and melting of snow/ice (c) from January 2009 to December 2010.

These results are in agreement with finding during the other years (from 2006 to 2010) (tab. 1). In fact the annual mean values averaged between these 5 years result as 67 W m^{-2} regarding the SW_{net} (in particular 68 W m^{-2} during 2009 and 66 W m^{-2} during 2010), –36 W m^{-2} regarding the LW_{net} (in particular –36 W m^{-2} during 2009 and –31 W m^{-2} during 2010), 17 W m^{-2} and –4 W m^{-2} of SH and LE, respectively (16 W m^{-2} and –3 W m^{-2} during 2009 and 15 W m^{-2} and –1 W m^{-2} during 2010), finally a R_s value of 38 W m^{-2} (43 W m^{-2} and 47 W m^{-2} in 2009 and 2010, respectively).

Considering only the hours characterized by positive net energy (R_s) and melting surface temperature, the total calculated mass loss during summer 2009 and 2010 is –11.32 kg m^{-2} (or m w.e.) (fig. 7). To validate the melting computation, these results are compared to field measurements during summer 2009 (from 24th July to 30th August 2009) and 2010 (from 28th July to 25th August 2010). The melting value measured by the ablation stakes installed nearby the AWS (–1.91 m w.e. during 2009 and –1.02 m w.e. during 2010) results in agreement with the calculated one (–1.97 m w.e. during 2009 and –1.07 m w.e. during 2010), thus the applied model is correct (fig. 8).

CONCLUSIONS

The data collected by permanent AWS permit to quantify the complete energy balance and the melt amount with

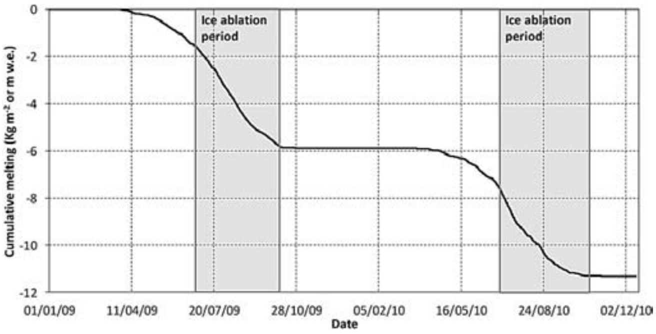

FIG. 7 - Cumulative melt calculated over the 2-year period. Values are obtained from hourly data analysis. The period characterized by ice ablation are marked in light grey.

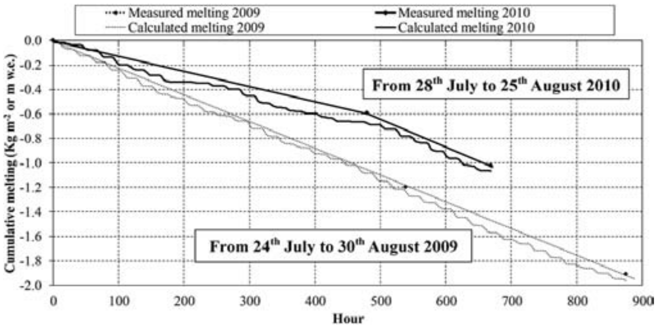

FIG. 8 - Comparison between field measurements during summer 2009 (from 24th July to 30th August 2009) and 2010 (from 28th July to 25th August 2010) and calculated melt values in the same periods.

a high time resolution, also including the turbulent fluxes that affect the glacial ablation for the 20%-30% (Senese & *alii*, 2012), and to describe the surface albedo variability. Moreover sky and surface conditions can be deduced from measured meteorological parameters.

During 2009 and 2010 the results obtained from AWS1 Forni prove to be consistent with results from other 3 years of data acquisition (i.e. Citterio & *alii*, 2007; Senese & *alii*, 2010; 2012).

The wind blows steadily down the glacier from SE that is along the fall line. The wind regime is characterized by a provenance from ca. 120° and a speed of a few meters per second, generally featured katabatic-type flows. Moreover higher wind speeds are found not directly correlated with a particular range of temperature.

Analysing albedo data, the ice ablation periods result long of 104 days (2009) and 88 days (2010). During 2009 ablation season 2 snowfalls are observed (totally covering 5 days featuring snow albedo values) and during 2010 ablation season 5 snow fall events are detected (the snow persisted at the glacier surface for 16 days in total). Moreover the snow albedo (with a mean value of 0.77 between the 2 years) tends to decrease for larger values of the incoming radiation. The characteristic albedo for ice is found equal to 0.24 (in 2009) and 0.23 (in 2010).

Regarding energy balance, the solar radiation (SW_{net}), the turbulent fluxes (SH and LE) and the net energy (R_s) are characterized by similar trends with maximum during summer and minimum during winter. Instead the net longwave radiation (LW_{net}) results varying between slightly positive values and values up to -100 W m^{-2}.

During 2009-2010 the total calculated mass loss results -11.32 kg m^{-2} (or m w.e.). The comparison of the measured and modelled ice ablation shows differences of less than 0.06 m w.e. and therefore indicates that the model applied is correct.

Consequently the AWSs installed on glaciers are essential for calibrating and validating the glacier energy balance models, to characterize quantitatively the glacier boundary layer conditions, to describe wind regime. On the Italian Alps, the first permanent supraglacial meteorological experimentation is represented by the AWS1 Forni which has been running since September 2005 thus giving the longest dataset from an Italian glacier. In addition other two permanent AWSs are set up in 2007 (on Dosdè and on Giant Glacier). This Italian AWS network obtained the award from international scientific community and concerned to three important network (SHARE, SHARE ITALY and CEOP).

The next research steps will be to install a second AWS on the Forni Glacier to survey the micrometeorology and the energy fluxes in the accumulation basin (at about 3000 m asl) and to extend the computation of the energy budget over the whole glacier surface thus distributing glacier melt. Last but not least our results show that glacier energy budget is also controlled by surface albedo. Its seasonal changes are driven by snowfalls, snow metamorphosis, surface wetness and dust deposition. On this latter, the current literature (Flanner & *alii*, 2009) suggests the possibility that atmospheric soot (dust and black carbon) is playing a role in driving the spring decrease of snow albedo also on Alpine glaciers' surfaces (in addition to the high air temperatures and increased incoming radiation). Therefore another next step of our research will be to analyze with further details the glacier surface over a one-year period, also sampling snow and ice to find any correlations between surface reflectivity and atmospheric soot presence.

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