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Abstract

Wind can create even greater unstable accumulations of snow in mountainous areas than heavy snowfalls. But knowing wind conditions is not sufficient to predict these accumulations because their formations also depend on the snow quality of the snowpack surface upwind of the release zone. Consequently, assessment of snowdrift is required to improve avalanche forecasting. In accordance with this assumption, a new acoustic sensor was developed. The sensor includes a mechanical part designed to form a closed acoustic enclosure. The acoustic enclosure contains microphones connected to an electrical amplifying and filtering device. Because the output information delivered by the instrument is proportional to the wind velocity and to the flux of solid particles (ice grains) drifted by the wind, the instrument is called an anemo-driftometer. Prototypes of the instrument were first tested in a wind tunnel and then at an experimental site in the Alps. Then an operational version, called FlowCapt, was developed and connected to an automatic weather station at 2700 m in the Aminona ski resort (Switzerland). During the winter, snowdrift is recorded on the test site along with other meteorological parameters, and avalanche activity to provide extensive on-site calibration and testing of the sensor. The experiment demonstrates that the instrument is a useful component of the avalanche forecasting chain. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Snow drifting; Snow engineering; Avalanche forecasting; Acoustics; Jet roof

1. A new snowdrift sensor to improve avalanche forecasting

To improve the reliability of local avalanche warning systems, parameters directly related to avalanche danger or slab stability have to be measured close to and within the potential avalanche release zones that endanger the area to be protected. Because wind can create even greater unstable accumulations of snow in mountainous areas than heavy snowfalls, snowdrift is a very predictive parameter. Wind speed measurements are not sufficient to predict these accumulations which also depend on the snow quality of the snowpack surface all around measurement stations. Knowing snowdrift by direct measurements is subsequently of high importance for avalanche forecasting.

At present time, snowdrift can be measured by ski patrol men (Fig. 1) with the so-called Driftometer (Bolognesi et al., 1995). This simple instrument makes possible quantitative snowdrift assessments, but it requires the presence of a human observer on

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Fig. 1. The Driftometer catches blown snow particles into a collector through a tube by the combined effects of filter and pressure fall. Weighing the collector directly gives a snowdrift index.

the sites. If manual measurements are not possible, snowdrift would have to be estimated from other parameters with significantly lower reliability.

The new FlowCapt™ acoustic sensor gives the possibility of a continuous and automatic recording of the snowdrift (~ kg m^{-2} s^{-1}). Installed upwind of the release zone, FlowCapt provides additional information on the snow accumulation process within the release zone, deformability of the forming slab and erodibility of the snow surface. Because it was shown that snowdrift data increases the reliability of avalanche predictions (Bolognesi, 1996), this information is used by the decision support system NivoLog™ to establish local avalanche predictions.

2. Principle of the FlowCapt anemo-driftometer

The FlowCapt anemo-driftometer determines both wind velocity and snow particles flux. The detection principle is based on mechanical-acoustical coupling. The sensor is composed of closed pipes containing electro-acoustic transducers and a powering, filtering and amplifying unit. When the sensor is placed into a snow particles flux, the particles shock the sensor pipes. inducing acoustical pressure. The pressure is picked-up by the transducers. The electrical outputs are filtered and time-averaged in given frequency ranges to provide a signal proportional to particles flux Q (kg m^{-2} s^{-1}). The formal relation between the measured acoustic pressure and the snow particles flux Q requires the determination of the mechanical-acoustical coupling equations for the sensor, according to suitable hypothesis about particle impacts. The wind velocity is determined on a similar principle: the wind interacts with the body of the sensor and induces acoustic pressure into air enclosures. Suitable sensitivity can be obtained optimising the body shape and structure to the expected wind velocities.

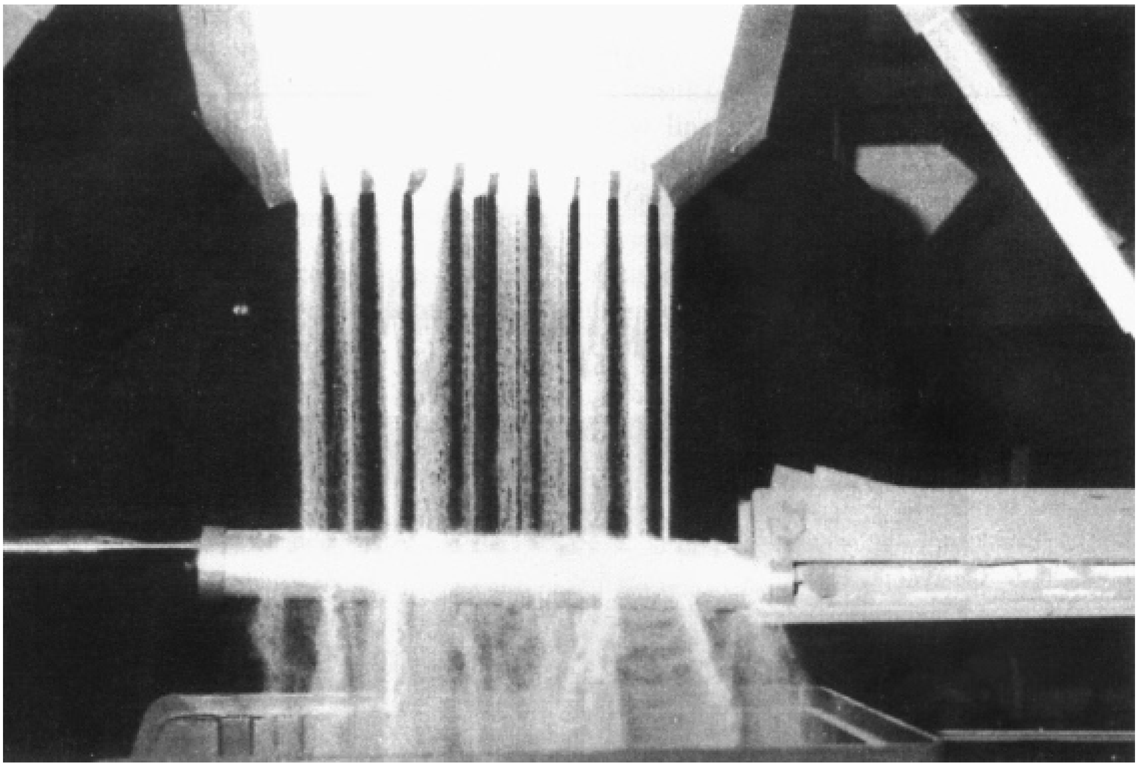


Fig. 2. Calibration with controlled particles flux on test-bench, at LEMA-EPFL (from Castelle, 1994).

Because snowdrift happens during windy periods, it is necessary that the sensor strongly discriminates wind from snowdrift. This property can be obtained by an appropriate design of the mechanical-acoustical

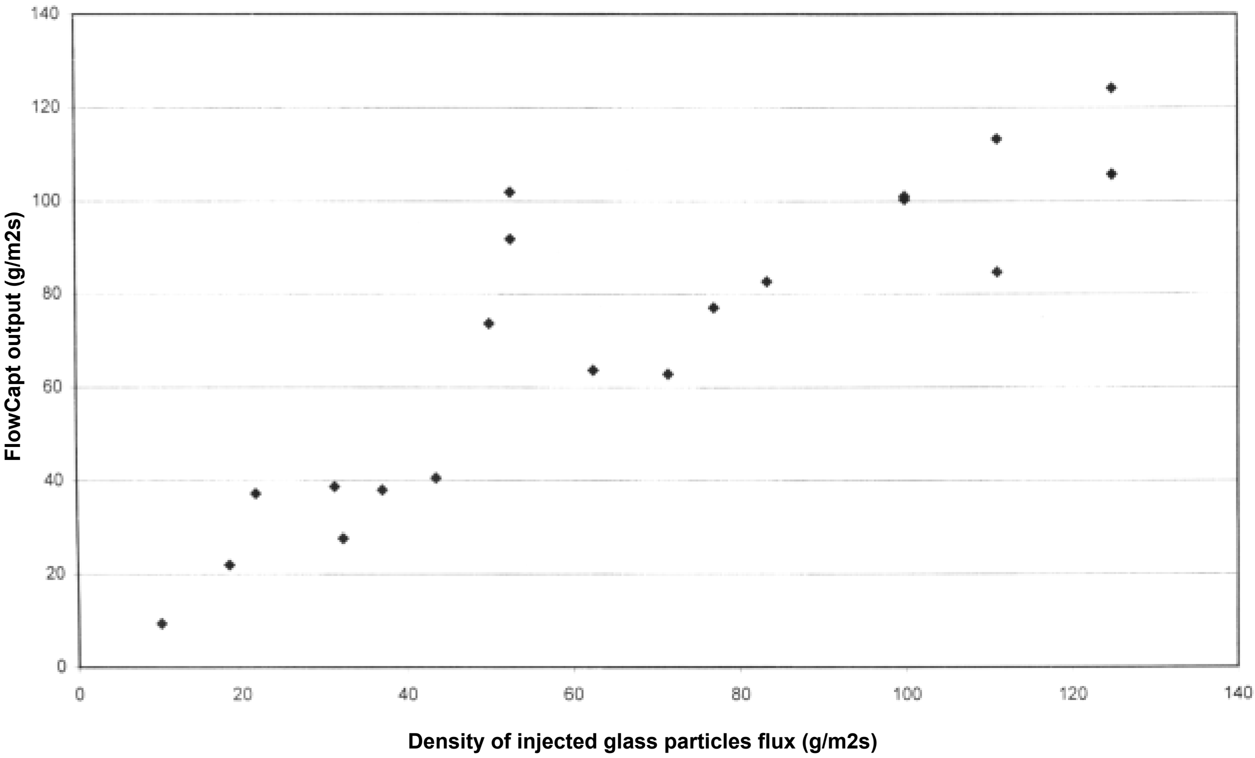
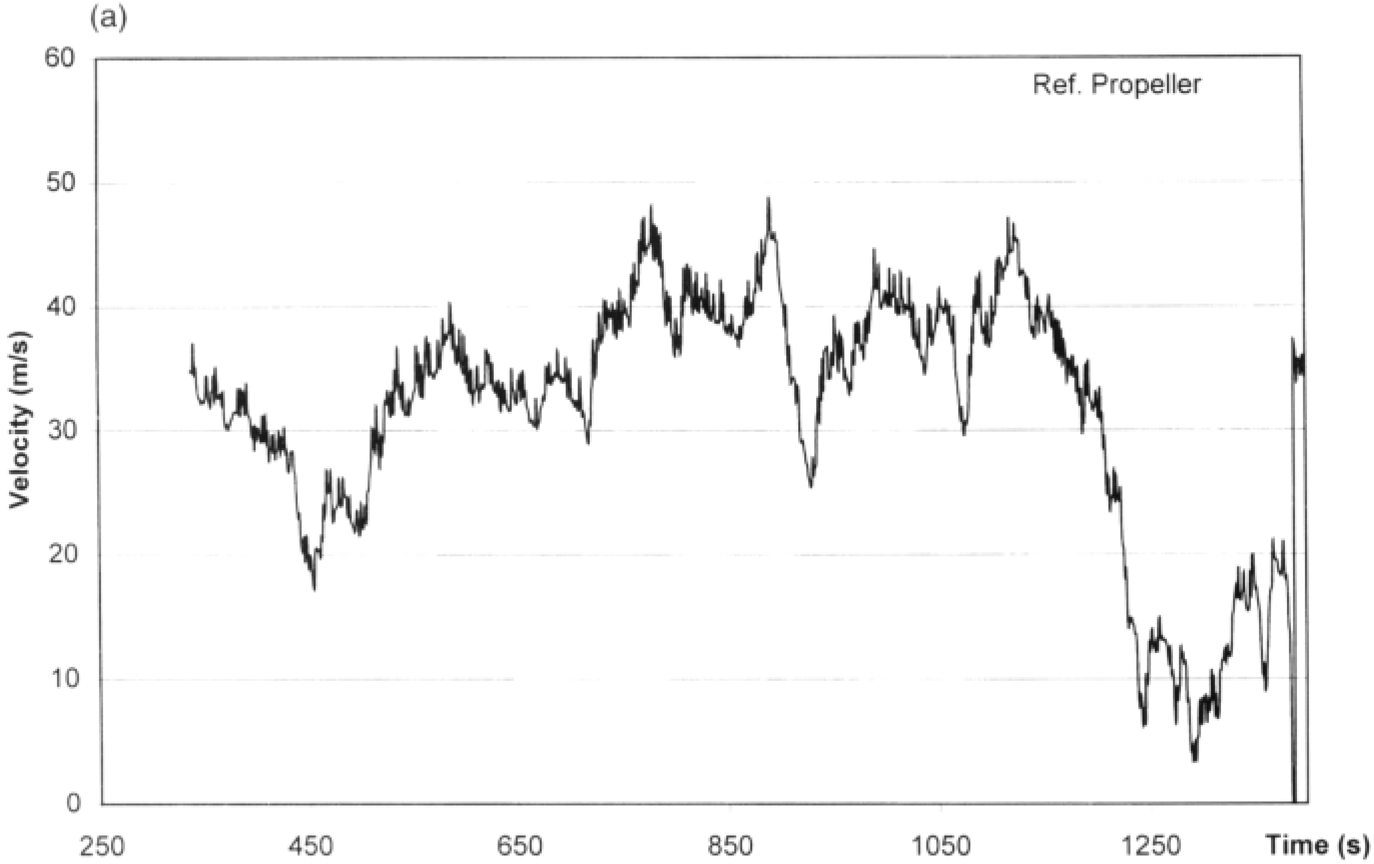


Fig. 3. Measurement on bench-test of a controlled 8 m/s, 20-100 µm glass particles flux with FlowCapt



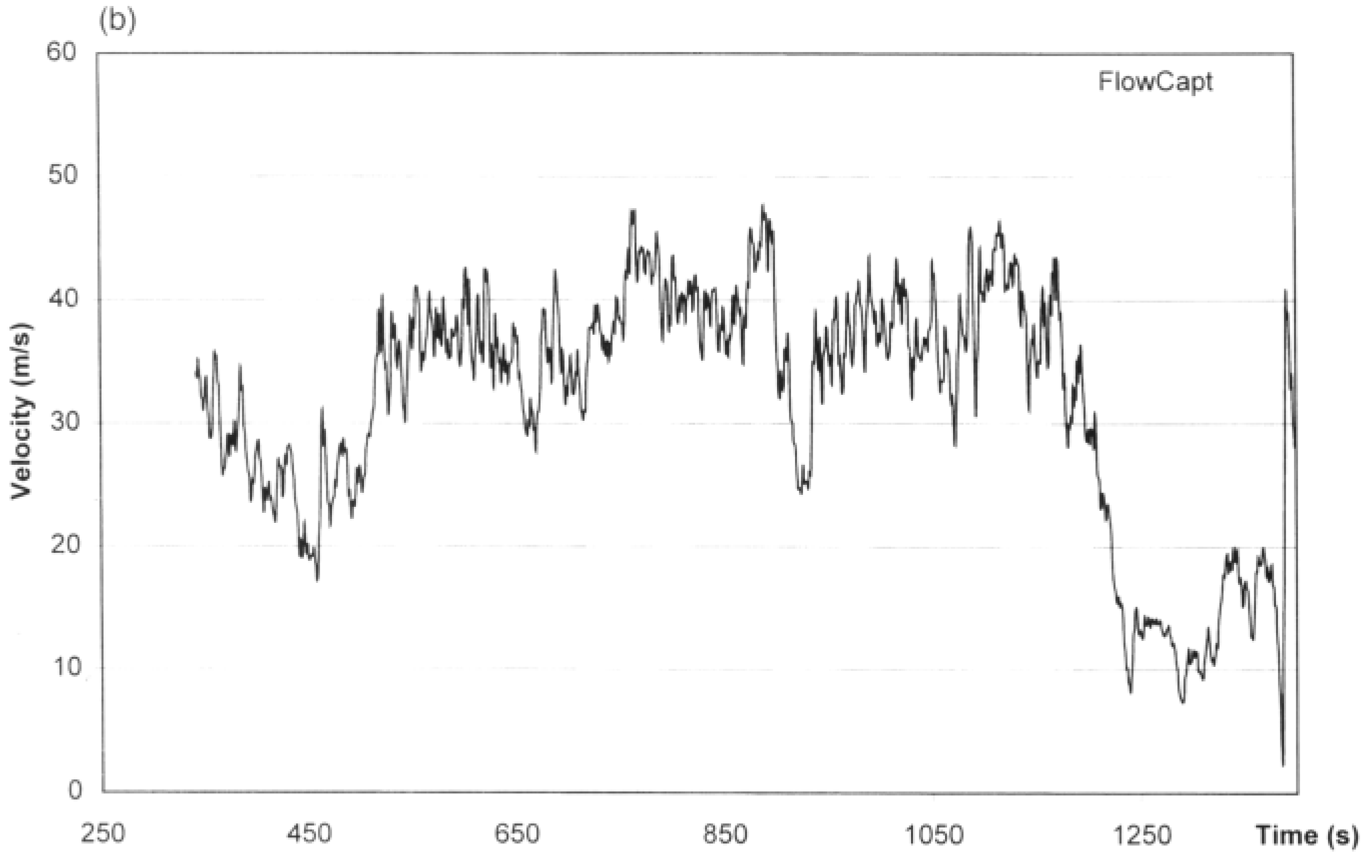


Fig 4. Wind velocity comparative measurements, with reference MiniAir5™ propeller anemometer and FlowCapt prototype.

coupling. With no mobile components and full-protected transducers (inside closed cavities), the FlowCapt is very suitable for stringent topographical and climatic environments.

3. Prototyping of the anemo-driftometer

Theoretical and experimental campaigns have been carried-out at the Swiss Federal Institute for Technology (EPFL) to develop FlowCapt prototypes (Fig. 2).

Results obtained from the validation experiments show linearity of the sensor vs. particles flux and wind speed (Figs. 3 and 4).

On the basis of the obtained results, the industrial development of the FlowCapt began. A particular attention was paid on the calibration and reliability to ensure precise quantitative snowdrift information.

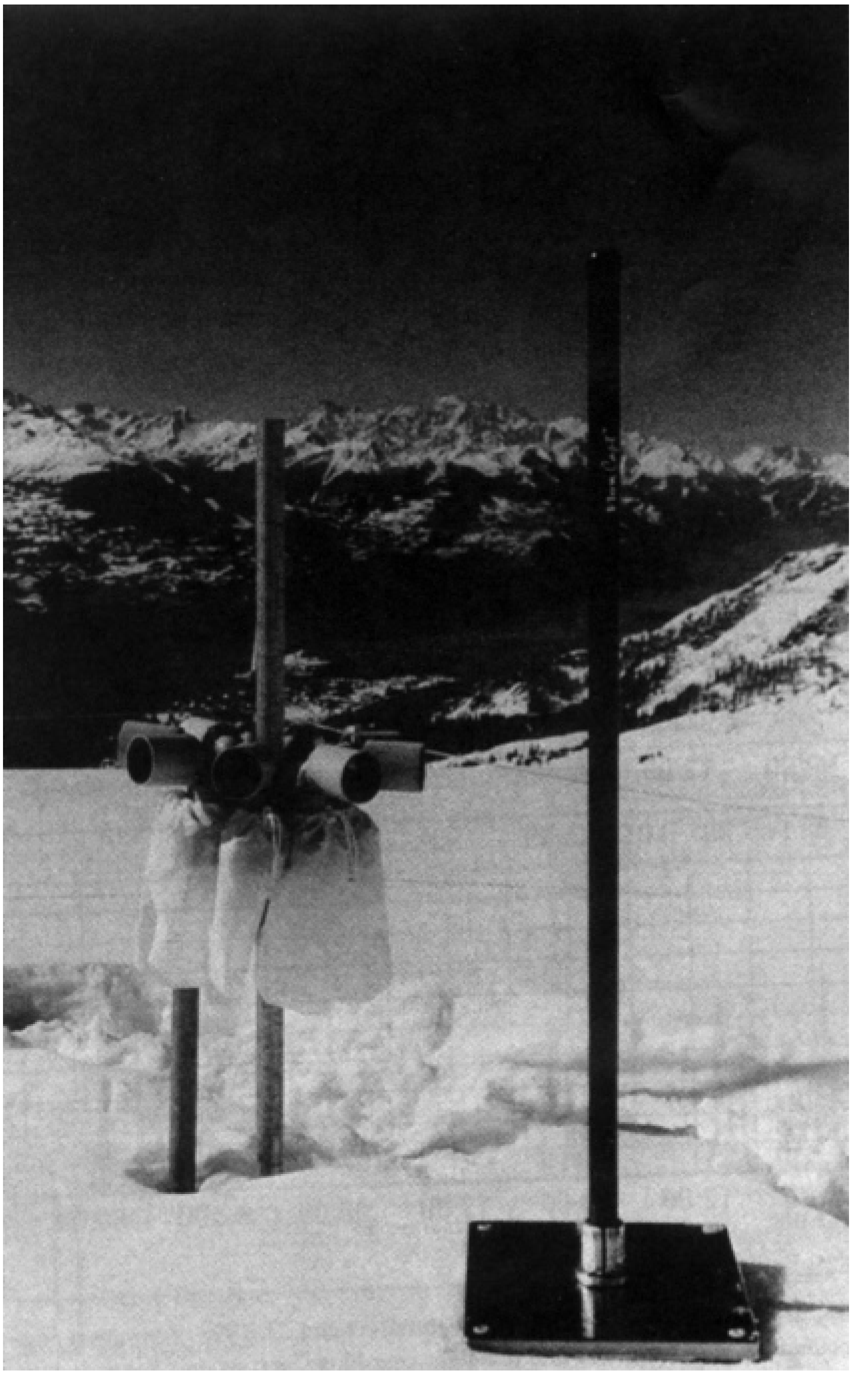


Fig. 5. Manual Driftometer measurement place.

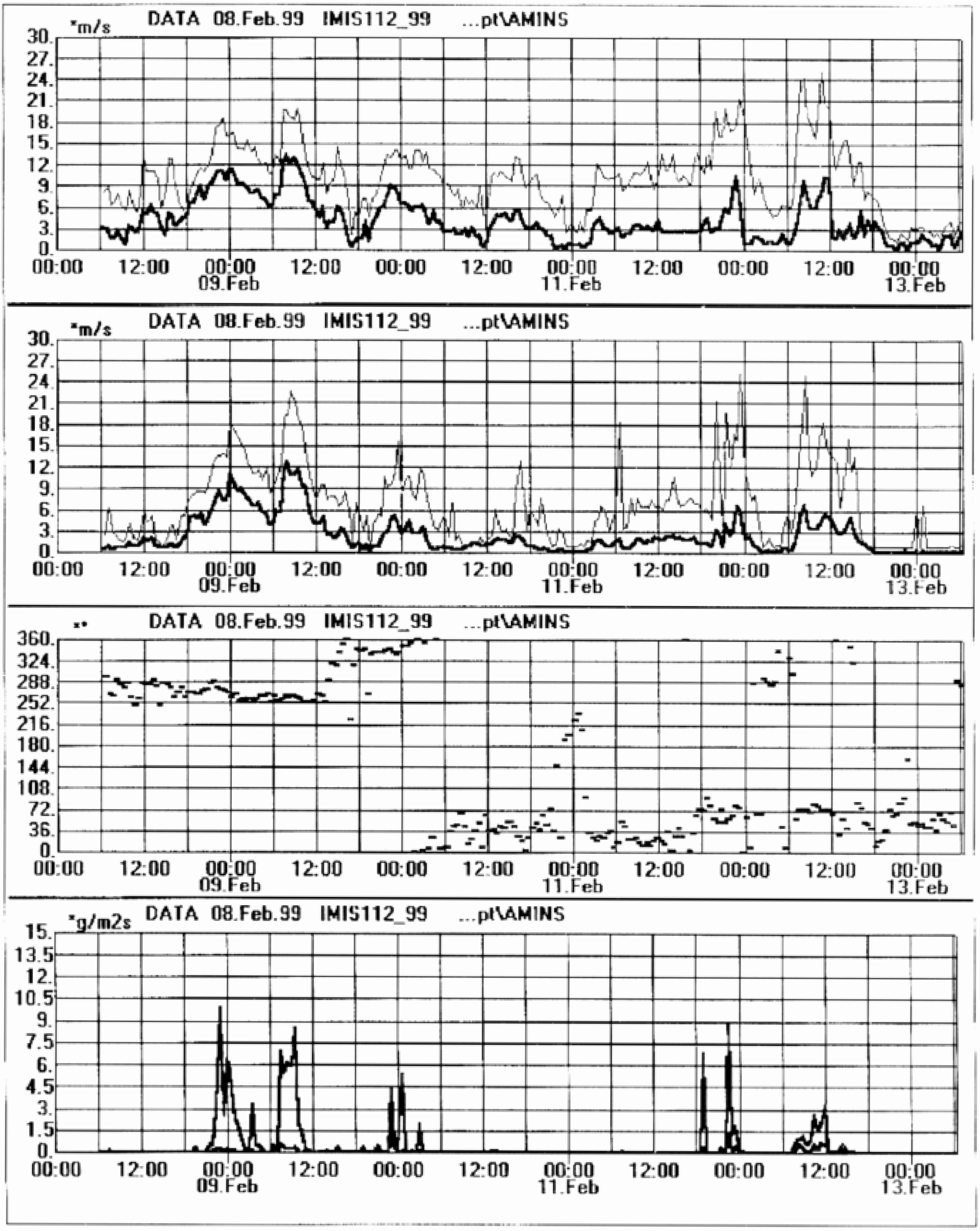


Fig. 6. Wind and snowdrift recorded at Aminona ski resort, between February 9 and 13, 1998. Top: mean and maximum wind speeds values as measured with a reference propeller anemometer placed at 6 m height near FlowCapt; second: mean and maximum wind speeds values as measured with FlowCapt at the ground level; third: wind direction; bottom: saltation and diffusion flux as measured with FlowCapt (saltation on 0—1 m segment, diffusion on 1—1.2 m segment).

The sensitivity of the sensor to wind velocity was calibrated in a wind tunnel, by comparison with reference anemometers. To calibrate snowdrift, no suitable reference instrument exists. Thus, it is necessary to define a specific method to find the calibration parameters under various conditions: (1) sensitivity measurements in bench tests with controlled particles flux, (2) continuous meteorological and snowdrift measurements for two winters on a test site, (3) comparison of the FlowCapt response to Driftometer indexes during storms (Fig. 5).

4. Operational use

In December 1997, FlowCapt has been installed on a standard automatic remote station (Gubler, 1996), at Aminona ski resort (Switzerland). The station is located at an altitude of 2700 m on a south facing slope of Mt. Bonvin. Values are recorded every minute (time constant = 1 s). Snowdrift is integrated from ground to 1 m height and between 1 and 1.2 m (Fig. 6).

The upper sensor additionally measures wind speed. The station (Fig. 7) is equipped with a set of sensors and a number of features that allow for a significant improvement of the assessment of the actual local avalanche danger: snow surface temperature measured by a special infrared radiation thermometer, surface reflected short wave radiation, ground temperature, wind, air temperature and humidity allow for a direct on-site indexing of the formation of weak layers, one of the key parameters for the formation of dry slab avalanches (cloudiness, near surface energy flux balance, dendricity and sphericity (Brun et al., 1992) grain size of surface layer, formation of surface rime, surface melt).

The snow profiler measures the snow stratigraphy at an index point within the release zone, settlement, snow accumulation, fracture height and penetration / damming of meltwater as well as refreezing. The indication of damming of meltwater at a certain depth within the snow cover at a time resolution of about 30 min improves the short-term forecasting of wet slabs and surface slides. A specially prepared,

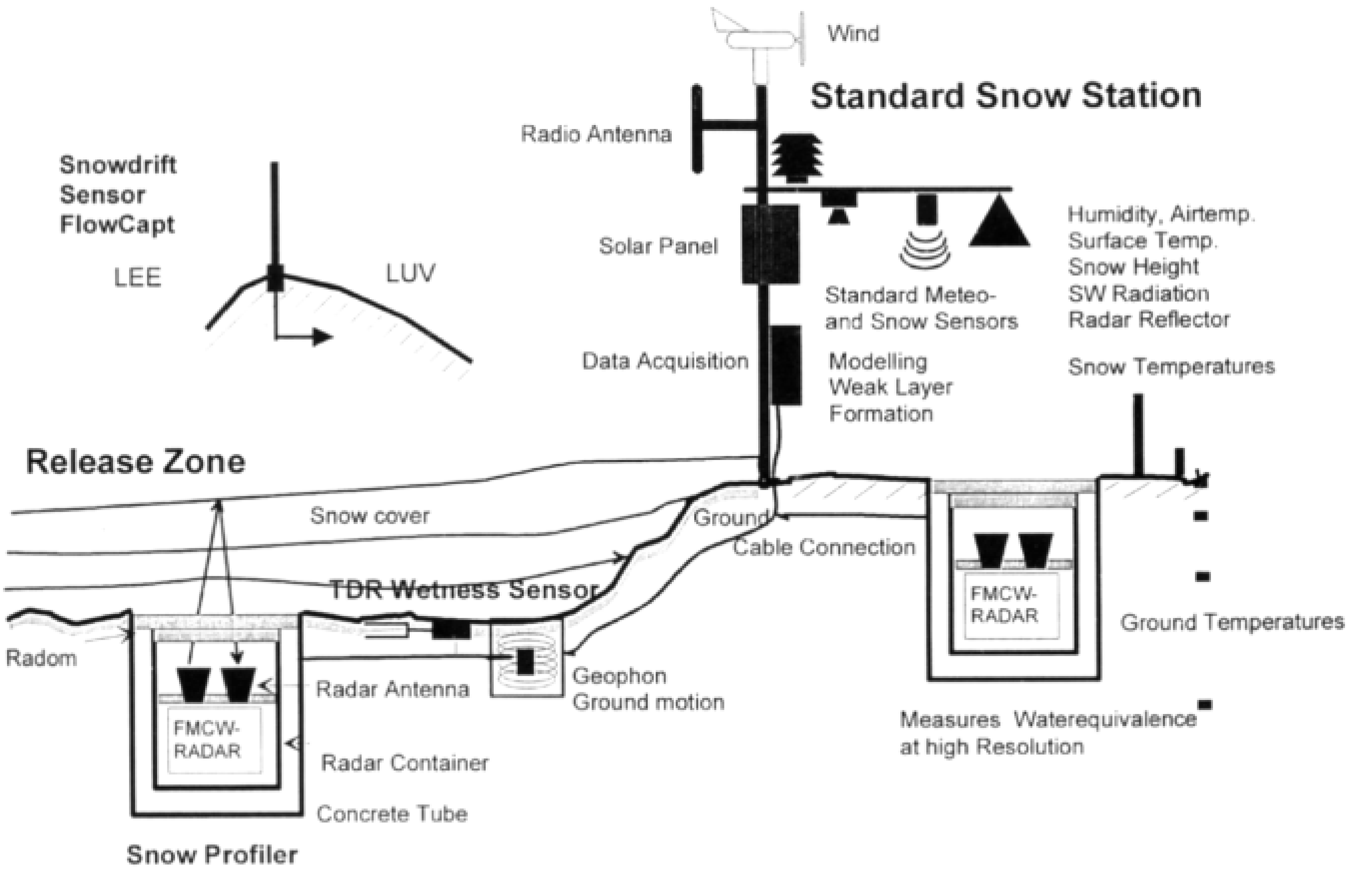


Fig. 7. Swiss Standard Remote Snow Station with additional sensors.

low-priced TDR sensor attached to the ground surface indicates the arrival of meltwater at the snow ground interface, an important parameter for the assessment of the danger from full-depth avalanches. In the near future, this sensor will possibly also provide additional information on the state of the base layer. A geophone attached to the system indicates avalanche activity and checks remote control of explosives for artificial avalanche releases (Gubler, 1995). A reliable sensor for a direct measurement, if initial fracturing as a precursor for slab avalanche formation, is still missing but is currently under development.

5. Combination with jet roof

Protecting the FlowCapt with a jet roof is crucial for many applications where the optimal placement of the sensor regarding to snow drift is close to a ridge within the flow path of drifting snow. At these locations, often large cornices may form. In such cases, snow accumulation on the sensor is significantly reduced by placing the instrument below a jet roof (Fig. 8).

The jet roof locally increases wind and drifting speed and therefore avoids permanent snow accumulations in the vicinity of the sensor. A combined structure has been developed and is currently being installed on a site in the Swiss Alps.

6. Interfacing possibilities

The FlowCapt system is battery powered and includes all necessary electronics to be externally powered by a solar panel or other AC or DC current sources. Total power consumption including the CR500 logger is 40 mW. Interfacing to other systems or base stations include radio and GSM trans-

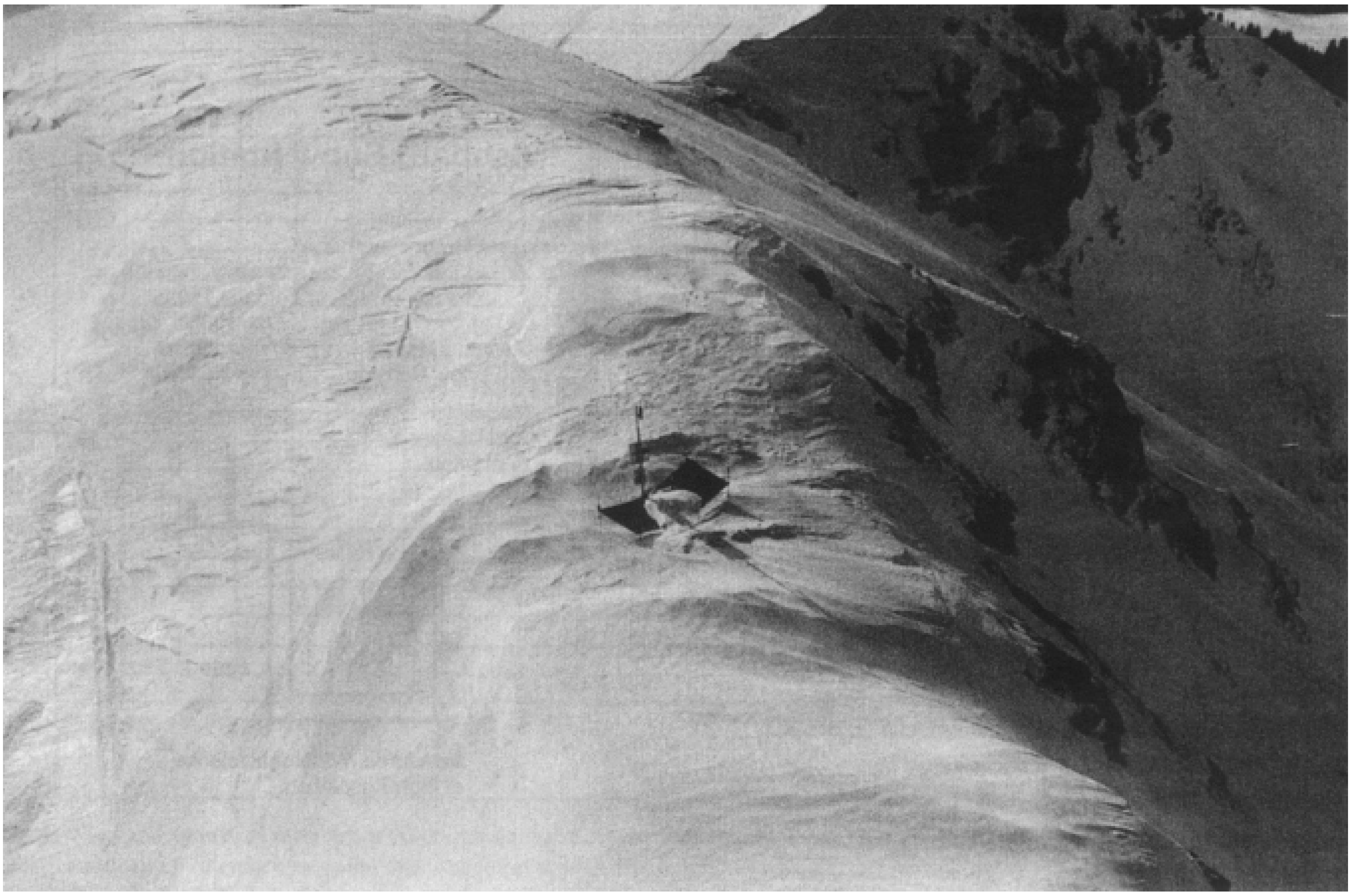


Fig. 8. Top — Jet roof, communication mast and FlowCapt placed on a ridge for road management (Diablerets).

mission, SDI serial protocol, and analog output signals. These features make the sensor extremely useful for remote installations.

As snowdrift quantities is a parameter of high importance to analyze the avalanche release probabilities, the current work consists in interfacing FlowCapt with the *NivoLog* avalanche forecasting support system (Bolognesi, 1998). This link between hardware and software is a first step towards an automatic prediction system.

7. Conclusion

FlowCapt, an acoustic sensor, is the first automatic anemo-driftometer. It can be connected to weather automatic stations located in stringent environments to provide quantitative snowdrift measurements, which are significant data to predict avalanches. Thus FlowCapt is an essential component of the automatic avalanche forecasting chain: sensor–automatic weather station–decision support system.

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References

Bolognesi, R., 1996. The driftometer. Proc. of the Int. Snow and Science Workshop, Banff.

Bolognesi, R., 1998. Prévention des avalanches: le système NivoLog. ANENA Revue No. 71.

Bolognesi, R., Daultier, J.-M., Naaim, F., Ousset, F., 1995. Une évaluation quantitative du snowdrift pour la prévision locale des avalanches. ANENA Revue No. 69, March 1995.

Brun, E., David, P., Sudul, M., Brunot, G., 1992. A numerical model to simulate snow-cover stratigraphy for operational avalanche forecasting. J. Glaciol. 38 (128), 13-22.

Castelle, Th., 1994. Transport de neige par le vent en montagne: approche expérimentale du site du col du lac blanc, PhD thesis 1303, Génie civil EPFL.

Gubler, H., 1995. An integrated system for artificial avalanche control. Proc. ANENA, Chamonix Symposium, pp. 201—206.

Gubler, H., 1996. Remote avalanche warning-, alarm- and control systems, fundamentals, applications and experience. Proc. of the Int. Snow Science Workshop, Banff, pp. 165—172.