## NIVEXC: an electronic snow-pole for real-time monitoring of avalanche starting zones

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ABSTRACT: Knowledge of amount of new snow, total snow depth and internal property of snowcover in avalanche release zones are well known to be key factors for effective avalanche prediction. However, in case of snow storms and dangerous conditions, manual snow-cover investigations in the upper part of avalanche paths are unfeasible for safety reasons. Nevertheless, monitoring from valley bottom or helicopter by means of traditional snow-poles is often not possible because of bad weather conditions. NIVEXC allows to overcome the mentioned problems, as it is an autonomous electronic snow-pole provided with a vertical array of sensor and suitable for installation in avalanche starting zones. NIVEXC is able to record and real-time transmit to a remote server important snow cover properties, such as total snow height, snow precipitation amounts and rates, temperature profiles. This innovative device will be described and first results from a full-scale installation during winter season 2012-13 will be presented.

KEYWORDS: avalanche forecasting, starting zone monitoring, snow depth measurement, temperature profile.

#### 1 INTRODUCTION

Knowledge of snow-cover properties in avalanche release areas is of great help for avalanche forecasting. However, due to severe conditions typical of starting zones, the development of instruments for automatic monitoring of snow cover in these zones is a difficult task and only few experiences do exist nowadays.

NIVEXC is an electronic snow-pole, for measuring total snow depth, snow precipitation rates and temperature profile in avalanche starting zones which has been recently developed with a joint effort of two Italian companies, FLOW-ING & INSIS. Main features of NIVEXC are robustness, reliability, low operating cost, ease of installation and maintenance.

NIVEXC technical details are briefly described at § 2. First full-scale installation and preliminary results are presented at § 3.

### 2 THE INSTRUMENT

NIVEXC pole is made by a cold shaped aluminium box frame, 3.00 m long and 8 cm wide. The box tube frame has been designed according to Eurocode#9. Snow cover loads have been estimated on the base of Swiss Guidelines (Margreth, 2007). In order to optimise structural design and to reduce lateral displacements and vibrations, NIVEXC pole has been designed with

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tel: +39 (0)187 500158; fax: +39 (0)187 529777; email: m.barbolini@flow-ing.com a full joint at the bottom and provided with a double bracing system placed at 2/5 and 4/5 of its height.



Figure 1. A picture of an operational NIVEXC pole; the pole is coloured in black with 10 cm thick yellow stripes applied at 40 cm step in order to allow also visual monitoring of snow depth from the valley bottom (see Figure 5).

The pole is provided with 14 windows along its length, with a 20 cm gap from one another. Each window is suited to hold a "sensor box" that presently includes three different types of sensors: (i) a pair of optical sensors (IR led and photodiodes), functional to snow depth measurements, (ii) a temperature-dependent resistors (RTD), functional to temperature profile measurements and (iii) a pair of electrodes, used to cross-validate snow depth data coming from optical sensors.

Measurements from each sensor are logged to an internal memory and then transmitted to a remote server through a wireless connection. The stored data are accessible through a dedicated web platform.

NIVEXC pole includes three different types of data communication channels: RF Link channel, free mobile GPRS/UMTS and satellite channel. Depending on the installation zone the most appropriate system is chosen according to the cost and availability of telecommunication services existing in the area, by means of a proprietary protocol specifically designed to minimize the payload traffic.

Thanks to energy-wise technical solutions the whole system can operate autonomously for a entire winter season with power supplied by a standard battery pack placed into a waterproof box buried in the ground (see Figure 2). In the box are placed also the control unit (a digital card running the system management software) and the modem (a single system is used integrating a UHF radio modem, a GSM/GPRS modem and a ORBCOMM satellite modem).

The length of the pole can be adjusted depending on the specific climatic and topographic conditions (standard range is 3 to 4 meters), and accuracy of measures can be improved by increasing the number of windows and "sensor boxes" along the pole (a prototype 3 m long with 10 cm gap between windows and 28 sensor boxes has already been tested). Frequency of measures and number of daily data transmission can be set in function of the user needs, and can be remotely varied during operation.

# 3 RESULTS FROM FIRST OPERATIONAL WINTER SEASON (2012/13)

#### 3.1 Installation

The first NIVEXC pole has been installed in the Italian Alps, within the territory of the Marguareis Natural Park (Piedmont Region, Cuneo Province). The NIVEXC pole installation took place on November 21<sup>st</sup> 2012, in the release zone of an avalanche known as "Malavalanca dei Frati" (394819.00 m E, 4897124.00 m N, UTM 32, WGS84) at an altitude of about 1800 m a.s.l. in a slope with north exposure and 35° inclination. Installation was successfully completed in one day. Foundations of the anchoring system were made of steel bars injected with concrete mix in hand drilled holes 3 meters deep. The main foundation was set underneath the pole to which is attached by a full constraint system; the bracing system constraints were placed at 2 meters radial distance from the pole with 120° span. Structural setup was ended installing by hand the pole and fixing the bracing system. Once the pole was in place, electrical and network setup was completed in a few hours. Connection test were undertaken (Figure 2) and the system was fully operational. Frequency of measures and data transmission was set to 3 time/day (with eight hours time lap: 00:00/08:00/16:00).



Figure 2. Engineers during the phases of electrical set-up and connection tests.

## 3.2 Optical sensors

NIVEXC optical sensors provide direct realtime information regarding snow depth: sensors along the pole activate when they detect snow in front of them (Figure 3).

The bold continuous line of Figure 3 gives the variation in time of total snow depth, due to either snowfall episodes or settlements between them. Also precipitation rates can be easily estimated from optical data. For example the first snowfall episode of Figure 3 (20/01/2013) had a duration of about 24h, with an average intensity of 2,5 cm/h and a total amount of new snow of 60 cm; the third episode (28/01/2013) had a shorter duration (8 hours) and lower amount of cumulated new snow (40 cm) but a larger intensity (5 cm/h).



Figure 3. Optical sensors data for a 10 days interval (from 20/01/2013 h00:00 to 30/01/2013 h00:00). Measures are taken three time per day (00:00, 08:00; 16:00). For each measurement starred markers represent active optical sensors (that is sensors with snow in front of them). The continuous line indicates total snow cover depth.

Optical sensors were especially efficient during and immediately after heavy snowfall events. Figure 4 compares data of maximum snow depth after snowfall events obtained from the NIVEXC optical sensors with those from the visual surveys taken from valley bottom by a ranger of the Marguareis Park (Figure 5).



Figure 4. Comparison of the snow depth data from the NIVEXC optical sensors and visual surveys (time period: from 26/02/2013 h 08:00 to 08/04/2013 h 08:00). Also visual survey data taken on 15/03, during snow cover settlement, is included, for comparison with Fig. 6 and 8. Visual surveys data include error bars, representative of errors caused by weather and visibility conditions. When the visual survey was held on sunny day with good visibility, confidence range has been set to  $\pm 15$ cm. When the visual survey took place on a cloudy day with bad visibility, confidence range has been set to  $\pm 30$ cm. A good agreement was obtained, even if the optical sensors' values were always slightly higher than the values from visual surveys. This is explained with the snow cover settlement occurred in the time gap between the end of snowfall events and the surveys. This time gap is due to the poor visibility during and immediately after snowfall episodes that for most of cases made possible the observations from the valley bottom only few days after the storms.





Figure 5. (a) Ranger of the Marguareis Park during visual surveys of NIVEXC pole and (b) picture of NIVEXC pole from valley bottom taken on 11.03.2013 (photo courtesy of Erik Rolando).

#### 3.3 Temperature sensors

The NIVEXC RTD sensors return the temperature profile at each measurement. In Figure 6 temperature profiles for the three daily measures of March 15, 2013 are plotted. By plotting in the same graph the estimated snow depth (dash-dot horizontal line, see Figure 4) it is possible to observe that temperature fluctuations were greater for the sensors above the snow surface than for the ones buried in the snow (the sensor n.11/h=220cm is just above the snow cover, and is affected by the temperature of snow cover surface).



Figure 6. Temperature profiles from the three measures taken on March 15, 2013.

Data obtained from temperature sensors may also be plotted as a function of time (Figure 7), giving the trend of the temperature fluctuation in a given position (that is at a specific depth within the snowpack) during a given time period (week, month or season). The damping of the temperature fluctuations caused by the snowpack observed in Figure 6 is noticeable also in Figure 7 and can be used for an indirect estimate of snow cover depth (Ingólfsson and Grímsdóttir, 2008). A specific algorithm has been developed to that purpose. However, because of the crater that could form around the pole sometimes the temperature measured by sensors close to snow cover surface are inaccurate due to the influence of air temperature. This causes errors also in the indirect estimate of total snow cover depth by temperature data.

Temperature profiles obtained by NIVEXC pole can also be used to estimate temperature gradient in the snow-pack and to survey over time the presence of conditions favourable to the formation of faceted forms and week layers, extremely critical for snow cover stability evaluations (MClung and Schaerer, 1993).



Figure 7. Plot of the air mean temperature and the temperature values measured by the first five sensors from the ground (1 to 5, from 20 cm to 100 cm respectively) during the time period between 20/01/2013 h 00:00 and 30/01/2013 h 00:00. Sensors 1 to 5 remained buried in the snow during all the considered time period.

#### 3.4 Electrodes

The NIVEXC electrodes pairs give a measure of a voltage, according to the following relation:

$$V_m = V_{cc} \cdot \left[\frac{1}{\left(R/R_T\right) + 1}\right] \tag{1}$$

where  $V_m$  is the measured voltage,  $V_{cc}$  is the voltage of battery (12V), R is the internal resistance of the electrical circuit and  $R_T$  is the (variable) resistance of the medium between two electrodes (snow or air).

The voltage measured between the electrodes pairs is different for the sensors buried in the snow (where  $V_m < V_{cc}$ ) and the ones above the snow surface (where  $V_m \cong V_{cc}$ ). Consequently, also electrodes sensors give an indication about the snow cover depth, as it can be observed in Figure 8. The value measured by sensor above snow surface gives also an information about the residual voltage of battery.

It also the case that measured values of  $V_m$  by sensors inside snow cover have shown a highly variable pattern (see Figure 8); this is probably due to the effect of properties of snow layers in contact with electrodes on respective values of  $R_T$ . This aspect is presently still under study.



Figure 8. Example of voltage profile measured by electrodes (measure taken on 15/03/2013).

#### 4 CONCLUSION AND OUTLOOK

First operational winter season of NIVEXC pole has given very positive feedbacks and has proven the ability of this innovative instrument of real-time observation of important snow cover parameters in avalanche starting zone.

NIVEXC optical sensors have the advantage to allow direct real-time measure of the snow cover depth. Indirect estimate of snow cover depth using NIVEXC temperature data is also possible, but in our experiences has limitations for real-time estimates and could be inaccurate in case of crater formation around the pole.

Main advantage of NIVEXC can be summarised as follows:

- simplicity and robustness (all sensors are located inside the pole and protruding element of any type – including solar panel - are avoided, reducing potential for damage and ice crusts formation);
- reliability (the measure of most important parameter, the total snow cover depth, can be cross-validated with data from three different types of sensors);
- ease of installation and maintenance (usually limited to battery change and bracing cables tensioning);
- low operational cost (proprietary protocol specifically designed to minimize the payload traffic) and power consumption (energy-wise technical solutions);
- flexibility of use (frequency of measure can be remotely varied during winter season according to forecasting needs and weather condition).

Furthermore, thanks to its modular approach based on a mechanical support with a set of windows for sensor placement, a battery system for power supply, an electronic control unit and a multi-channel link for communication NIVEXC enable the concept of an infrastructure suitable for real-time monitoring of avalanche starting zone with ideally any kind of snow-cover sensors.

At present research efforts are focused in the study of measures obtained from electrodes, in order to evaluate ability of these sensors to give also information on layer density and/or water content. Also the development of new types of sensor for density estimate to be included in the "sensor box" is under progress. Measurements campaigns and sensor development and tests will be kept going in the next winter seasons. Nevertheless, it is believed that NIVEXC pole could yet effectively support avalanche forecasting and hazard management.

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