Tracking melt-freeze crust evolution in Val d'Aran (Catalan Pyrenees)

Jon Apodaka[1], Montserrat Bacardit[2], Iván Moner[2] and Jordi Gavaldá[2].
[1] University of Barcelona (UB) and University Autonomous of Barcelona (UAB)
[2] Lauegi Prediction Center (Val d'Aran)

ABSTRACT: In the Pyrenees, melt-freeze and wind crusts are a very common element in the snow cover. Such layers have an important role in both dry and wet slab avalanche triggering. The crusts are characterized by a complex metamorphism and associated snow cover stability increase or decreases over time. To learn more about melt-freeze crusts, during 2013 late winter and early spring, we have been tracking different specific crusts in the Val d'Aran snowpack. The methodology is based on the following field observation: conducting stratigraphic profiles of the snow and other quantitative and qualitative measures of objective monitoring crusts. Quantitative variables are hardness (hand and penetration resistance), shear strength and density and qualitative description of the crust. Have also been conducted stability tests and were collected meteorogical data. The tracking was conducted out for 8 weeks, from February 27 to April 23, at three locations representative of the region of Val d'Aran in a north and south aspects. The objectives of the study are to evaluate the status of the crust as critical layers in the snowpack and the effectiveness of different stability test and compare the results obtained in Canada with the ones of the Pyrenees. The results show that in the tracking measurements in the crust, the density increases with time, the shear strength increases and hardness increase the over time decreases to degrade the crust. The crust indexes have a tendency to increase due to degradation of the layer.

KEYWORDS: melt-freeze crust, tracking, evolution, nivology, Val d'Aran, Pyrenees.

1 INTRODUCTION

In the Pyrenees (Europe southwestern) melt-freeze crusts are a very common element in the snowpack. These crusts are typical of the climate in the Pyrenees will not only appear in sunrooms south-facing slopes but also are on northern slopes and often in all dimensions (Moner, I. et al., 2011).

The crust is a layer of hard snow that forms as a result of the melt-freeze process, a temperature sufficiently high to allow the snow melts in surface and create a layer of melt-water which may then refrozen, increasing the resistance of the layer. The crust also forms when rain falls freezes on existing snow surface, creating a layer do frozen, or wind.

Is a discontinuity between layers of snow that can favor triggering avalanches. They are impervious layers with a temperature gradient that favors strong metamorphism of snow in the contact areas, where weak layers are formed as the facets.

During eight weeks of winter 2012-2013 framed within a final dissertation on Geological hazards, has been tracking the main crusts that have formed in the Val d'Aran, Western Pyrenees, during the period of study.

The weather that has occurred during this winter season, causing abundant snowfall, has led to the largest thicknesses recorded of snow since it has register from Catalonia (Fig. 1). These conditions have not led to periods favorable for the formation of melt-freeze crust how in previous years.

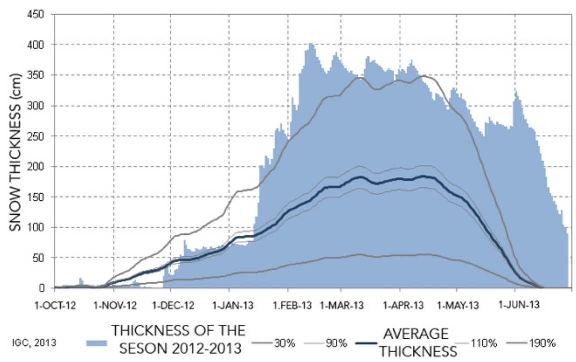

Figure 1. Snow depth evolution during the 2012-2013 season in Bonaigua the automatic meteorological station at 2.266 meters altitude. / (Meteorological Service of Catalonia)

Corresponding author address: Jon Apodaka Saratxo. Geologist, Natural Hazards Specialist; tel: +34 639865773; *www.arriskeus.com*; email: jonapodaka@gmail.com

This study was carried out by tracking crusts, making different observations and data collection, be a basic similar study that Ryan Buhler, Sascha Bellaire, Michael Smith and Bruce Jamieson, Departments of Civil Engineering and Geosciences of the University of Calgary (Canada) presented at the International Snow Science Workshop 2012, held at the Denaina Center of Anchorage, Alaska (USA).

In Europe, there are no known studies on this type of layers that appear in the snow.

Tracking crusts of this work was performed in three representative locations in the Val d'Aran: Tuc deth Miei, Tuc d'Horno and Conangles Circus.

The methodology is based on field observation and meterological data collection. Were made stratigraphic profiles, conducting stability tests, the qualitative description of the crust as qualified by Buhler indices, R. et al., 2012. Were also measured conditions of hardness, shear strength and density calculation of the crust, analyzing the various data obtained over time.

The main objectives are to evaluate the status of the crusts as criticisms layers in the snowpack, the analysis of the effectiveness of different stability test: test of compression (CT), extended column test (ETC) and compare the results obtained in Canada with the Pyrenees.

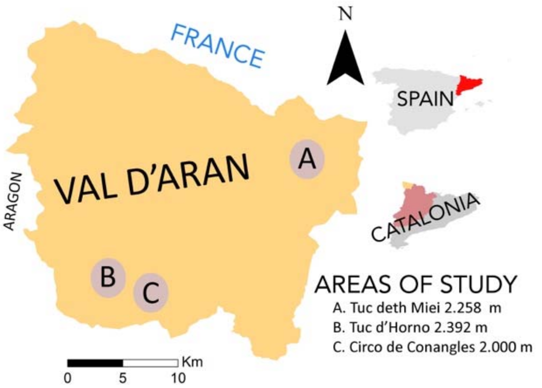

Figure 2. Geographical location of the Val d'Aran and areas of study where tracking melt-freeze crust.

2 METHODS

The Val d'Aran is a region located in the Catalan Pyrenees in the province of Lleida. Its boundaries are: north, France (Haute-Garonne); southwest, Ribagorza, Huesca; to the south, High Ribagorza, Lleida; on the east the Pallars Sobirá, Lleida. Its capital is the city of Vielha. It is the only region of Catalonia that belongs in large part to Atlantic basin and here comes the Garonne River which leads to the Atlantic Ocean (Fig. 2).

Criteria for selection

The locations chosen have relatively easy access and meet the criteria required to minimize the spatial variability of snow cover a hillside:

- Flat land to ensure consistency when given the formation constant melt-freeze crusts. A slope of low graduation that minimizes the variability associated with changes in slope angle.
- The sun exposure and wind is a thing to consider. The constant exposure to the sun is important for the formation of crusts when the evening is given freeze but you must minimize variations in sun exposure by the selection of sites with shade. Have been chosen trees areas that reduce affection winds. Thus avoiding the transport on accumulations snow and wind conditions. Also have avoided areas leeward of the crests.
- 100m^2 representative snow cover for to area.
- Profiles that are approximately 1.5m x 2 m.
- Maintain a distance of 1 meter between profiles.

Specific comments related to the monitoring of crusts

First removing the snow and subsequently performing three trials made calculating the shear frame tests of the crust.

Measuring the penetration resistance, and the hardness of the crust hand, was made using a force gauge, which has been incorporated a paint scraper 10 cm (Gavaldà, 2011). This trial is inserted perpendicularly to the parallel orientation of the strata this spatula, the proposed modified (Borstard and McClung, 2011) and thus achieving the measurement of the resistance of the hardest part of the layer avoiding subjectivity. When performing the test measurements have been made in the layer under the crust to ensure it was lower than the crust. There have been six observations for each sample, removing snow before the top of the crust.

The density of the crust is obtained by isolating a crust block using the saw, and then measured the three sides of the crust by calculating the volume and calculates the weight of the sample with a dynamometer. With these two parameters are calculated densities. Three observations are made by crust.

The qualitative description of the crust made during each observation is performed by crust index (CI). This index is divided in two different scales. On the one hand gives information about internal lamination and the other hand about the bounds of the crust.

This is an ordinal ranking to improve and unify the description of melt-freeze crust among observers. Each of the two scales has 5 definitions. The index includes six attributes used to ensure consistency of observations and reduce variability during analysis. These attributes describe the variability horizontal and vertical, planar or non-planar in the upper or lower limits and the presence of crystals with flat or angular faceted near the crust. The crust index is based on the observations recorded as entries in the field study conducted in the winter 2010-2011 by Buhler et al., 2012

In this work ending tracking when the upper crust mantle is moistened. Here, on the contrary, it was decided to continue tracking because in the Pyrenees at this time of the season it was easy to be in this situation due to increased temperatures and mantle moisten. Despite knowing in advance that moisture could significantly increase the density of the crust, with the intention of studying the behavior of the crust in these circumstances it was felt appropriate to continue monitoring in these conditions.

There have been two of the most commonly used test to calculate the stability of the snow cover: compression test (CT) and extended column test (ECT).

2.3. Material used

Safety equipment and avalanche rescue techniques (shovel, probe and AVD), saw, platelet identifying/metallic, magnifying glass (8x), termometer, densimeter, penetrometer, shear frame, waterproof fieldbook, photography camera.

3 DATES

During the winter 2012-2013 have formed in the Val d'Aran 6 melt-freeze crusts: CR25/12, CR26/01, CR06/02, CR21/02, CR12/03 and CR11/04 (Table 1).

The field study of this work begins February 27 and ends on April 23, partial tracked crusts (CR21/02 and CR11/04), and tracking total (CR12/03).

4 RESULTS

The CR21/02 is formed after a few hot days where the temperatures reach of 2-5°C. With the arrival of cold winds from the northwest and a new precipitation, snow crust is buried between 25-30 cm of new snow. The subsequent days temperature increases and raining. The mantle becomes isothermal, homogenized most layers and degraded almost entirely this crust.

The CR 12/03 is a crust that has had a longer tracking during this work (Fig. 3). Is formed after three sunny days that occur after a snowfall. With the entry of very cold winds from the north recorded maximum of 9 °C and lows of -13 ºC temperatures. 70 new centimeters of snow that buried at a considerable depth and which still has importance in the stability of the snow mantle. Its location between 40-70 cm deep depending on areas and meteorological conditions that occur subsequent days make the crust evolves over about 45 days.

The CR11/04 is a small crust (6-8 cm) that forms in early to April due to the melting high temperature recorded during the day and subsequent nights freeze. In one weeks loses its properties due to increase temperatures reaching minimum of 9 ° C on April 17.

In the three melt-freeze crusts that have been partially or completely tracking until its disappearance, is observed that as time passes the density tends to increase little by little as it dries and metamorphose the snowpack. This value depends greatly on the conditions of weather when the observation was made. With the increased temperatures, the snow mantle has a tendency to be isothermal, with temperatures around 0 ºC or even positive in some cases . That is when the snow is wet, and the density increases substantially.

Table 1: Data collected during the 2012-2013 winter season. For density, shear frame test, thin-blade resistance, and crust index, the value in the table indicates the number of days on which the property was observed.

CRUST ID	CRUST TYPPE	STUDY LOCATION	ELEVATION (m)	DURATION (Days)	DENSITY	SHEAR FRAME TEST	THIN-BLADE RESISTANCE TEST	CRUST INDEX
25/12	Sun	TRACKING HAS NOT BEEN DONE						
26/01	Freezing rain							
06/02	Sun							
21/02	Sun	A/B	1850<CR	48	6	8	7	7
12/03	Sun	A/B/C	1900<CR	45	13	15	15	15
11/04	Sun	A/C	2000<CR	12	2	3	3	3

A studied crust, the hardness (resistance) also has a tendency to increase. In this case when the snow mantle is wet due to the increased of temperature and humidity changes, the resistance of the crust decreases.

The shear force is trending with the passage of time increases, but these values are also heavily influenced because the moisture of the snow mantle. This parameter depends heavily on the cohesion that has the crust with the lower limit.

The internal lamination of crust keeps it at 4 (crust index) in general. When the crust is degraded within days or humid conditions, this value decreases to 3 or 2 and the isolation of the crust to the layers having around is much more difficult. The trend in this observation is quite homogeneous, down specific conditions.

Crusts limits according to crust index values showed a clear tendency to increase with the passage of time. In crusts and observed that during tracking, you see how to start have values between 1 and 2 and with the passage of time reach values of 4, in most sites.

As the temperature gradients of the crust, the methodology for obtaining temperature data is based on continuous measurement every 5 centimeters snowpack temperature when performing a stratigraphic profile.

In this way we wanted to provide thermal data to study the temperature gradient that occurs in the crust, its limits and in the adjacent layers. In the first place I look for the option of getting a thermal image to perform these measurements accurately but after trying and not get, decided on this alternative. A proposal that has not yielded the expected results because in the crust, was very difficult to penetrate the thermometer and due to the low accuracy of this and the thickness of a few centimeters of these. It has been impossible to observe thermal changes that occur in the inside, the limits and the adjacent layers.

During the study has been made some stability test and observation of its efficacy.

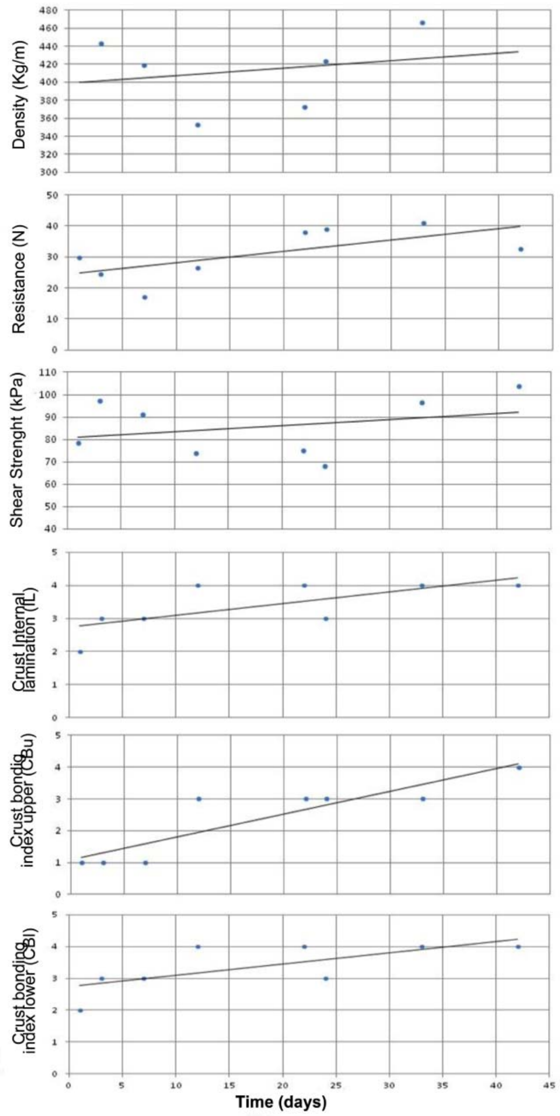

Figure 3. Time series data for 12 March 2013 melt-freeze crust at the flat study site on Tuc deth Miei. In sequence, the plots are density, thin-blade resistance test, shear frame test, crust internal lamination index (IL), crust bonding index upper (CBu) and crust bonding index lower (CBl).

5 DISCUSSIONS

The choice of areas of study is very important when it comes to track the evolution of melt-freeze crusts. In south orientations disappear very soon and in north orientations can track.

Knowing the evolution of crust, internal lamination as the relation with the limits can give meaningful data in predicting stability of snow mantle and his observation is visual. The isolation of the crust, is made in a short time and values disclosed are well defined. We must continue familiar with this type of observations and analyze whether they really can get even more information than using the cumbersome testing the hardness or shear, which require specific material and more time.

The observation of the upper and lower limits, the latter especially, gives us important information on the crust may act as an important sliding surface and if it has a tendency to spread.

The data collected in the observations are summarized in the results section almost entirely concordant with those presented by Buhler et al., 2012., Work done in Canada. Measurements show that melt-freeze crust density, penetration resistance and shear strength increases as the crust changes over time. Crust index give very helpful objective values when estimating local danger level. The results are similar to those that show in the Canadian study.

As far as the shear strength is concerned, selected a different tool to perform this test when compared with the study with which it is compared. That is why the results of this work give much higher shear values, but both have a tendency to increase. Future studies could more accurately know the difference between a tool and another.

The crust index do not show the same trend as some of the results of the study in which we compare, as there crusts having values crust internal lamination decreasing, in part, by meteorological conditions that have occurred since its formation.

As for the stability test is concerned, along observations sometimes positive results were recorded in both compression test (CT) and in the extended column test (ECT). The compression test is the most often gives positive results, identified how "false positives" and that often underestimate the actual stability of the snow mantle.

It is important when performing the test, do not cut very hard crusts or layers of a thickness exceeding 10 cm, thus avoiding giving false results.

These layers can give stability to mantle if not fracture and this depends on the *bridging.*

Temperature gradient in the mantle and that different parameters influence clearly changes the properties of the crust. Among the parameters influencing find the temperature, time, depth, density, and snowpack layers.

Knowing the status and properties of the crust may be important in three main cases:

The existence of melt-freeze crust may favor without cohesion grain formation on its surface and insufficient cohesion with layer which is above (Atwater, 1954).

The crusts that are buried more than 20 cm from the surface may trigger avalanches activity because the percolation of liquid water is stopped in the crust. That's why these crusts studied could be related to large fusion avalanches have occurred in the Val d'Aran during this winter season.

6 CONCLUSIONS

It has established a methodology for tracking melt-freeze crusts. This method has been applied in 3 melt-freeze crusts during winter 2012-2013 in Val d'Aran, Catalan Pyrenees.

Measurements show that melt-freeze crust density, penetration resistance and shear strength increases as the crust changes over time. Crust index give very helpful objective values when estimating local danger level. The results are similar to those that show the Canadian study.

In this study was not able to get a thermal imaging camera to capture thermal evolution data with which you can get very important information for these studies.

Possible dates and areas of study to be reviewed in future studies on the subject.

Having a thorough knowledge of the properties, evolution and behavior of melt-freeze crust is essential for understanding the properties snowpack and avalanche danger prediction.

ACKNOWLEDGEMENTS

Thanks to Montse for everything that has helped me during these months of work. Thanks also to Ivan and Jordi, master teachers, family, the girlfriend and all the friends who have accompanied me these intense months.

REFERENCES

American Avalanche Association, 2010. Snow, Weather, and Avalanches: Observation Guidelines for Avalanche Programs in the United States. American Avalanche Association and USDA Forest Service National Avalanche Center. 152

Atwater, M., 1954. Snow avalanches. Scientific American 190 (1). 26-31

Birkeland, K., 2012. Crust thoughts. The Avalanche Review. American Avalanche Association. cover, 20

Borstad, C.P., McClung, D.M., 2011. Thin blade penetration resistance and snow strength. Journal of Glaciology, 57 (202), 325-336

Buhler, R., Bellaire, S., Jamieson, B., 2012 Tracking melt-freeze crust evolution. International Snow Science Workshop (ISSW). Anchorage (Alaska). 8.

Canadian Avalanche Association., 2007. Observation guidelines and recording standards for weather, snowpack and avalanches. Canadian Avalanche Association. Revelstoke, Brithis Columbia (Canada). 89.

McClung D.M., Schaerer P.A., 2006. The Avalanche Handbook. 3rd Edition. The Mountaineers, Seattle, WA. 307.

Fierz, C., Armstrong, R.L., Durand, Y., Etchevers, P., Greene, E., McClung, D.M., Nishimura, K., Satyawali, P.K. AND Sokratov, S.A., 2009. The International Classification for Seasonal Snow on the Ground. IHP-VII Technical Documents in Hydrology N°83, IACS Contribution N°1, UNESCO-IHP, Paris

Gavaldà. J., Moner, I., Bacardit. M., 2011. Tècniques de ,mesura de la duresa de la neu. Actes de les 4es Jornades Tècniques de Neu i Allaus Homenatge a Xavier Bosch i Martí. Vielha (Lleida). 111.

Shea, C., 2012. Hot crust, cold crust. The Avalanche Review. American Avalanche Association. 28.

Smith, M., Jamieson, B., Fierz, C., 2009. Observation and modeling of a buried melt-freeze crust. International Snow Science Workshop (ISSW). Whistler, British Columbia. 9.

Smith, M., Jamieson, B., 2009. Tracking changes in buried melt-freeze crusts. International Snow Science Workshop (ISSW). Davos (Switzerland). 107-111.

Smith, M., Jamieson, B., 2010. Near infrared photography to quantify temporal changes in melt-freeze crusts. International Snow Science Workshop (ISSW). Squaw Valley (Canada). 409-414.

Tremper, B.,2008. Staying alive in avalanche terrain. 2nd Edition. The Mountaineers, Seattle, WA. 318.