A COMPUTERIZED SYSTEM DESIGNED FOR LOCAL AVALANCHE HAZARD FORECASTING IN TIGNES, SAVOIE, FRANCE.

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ABSTRACT

The SERVICE DES PISTES DE TIGNES (Tignes Ski Patrol) began developing a computerized system with the help of Edouardo Garreaud in 1986, to explore new possibilities in avalanche forecasting.

Snow-meteorological observations had been recorded since 1971.

The goal was and is to process snow-meteorological observations in the most efficient way possible in order to present accurate conclusions for the community of Tignes (1550-3350 M). The ski area includes approximately 11,000 hectares of skiable terrain and over 125 lifts giving access to L´Espace Killy (Tignes and Val d´Isere).

Tignes is situated in the inter-alpine zone, subject to a wide range of snow-meteorological conditions.

- Snow-meteorological observations are recorded three times daily at Tignes Le Lac, 2080 M.
- Observations recorded automatically at 2400 M.
- Wind speed and direction recorded at 2700 M.
- Weekly snowpack profiles at 2400 M.
- Complimentary snowpack profiles.
- Recording of all avalanche activity.
- Observations are then entered into the computer.
- Statistical calculations for similar days in the past.

A practical result of this system is an analysis of the snow-meteorological situation for the past week and an evaluation of the local avalanche hazard each day. A bulletin is prepared to inform the general public.

These evaluations are constantly verified in the field by the forecaster.

This computerized system is still developing towards the ultimate goal of bringing together accurate local forecasting and efficient public communication, through for example, the use of local TV and minitel.

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Tignes is located in the Alps. The Alps are a mountain chain that runs 1200 Km in length and 120 to 200 km in width, from the Mediterranean Sea to Vienna Austria. Six countries include the Alps within their borders; Yugoslavia, Austria, Germany, Switzerland, Italy and France. The highest point of the chain is the Mont Blanc at 4,807m located 50 km from Tignes. People have been living in the Alps since the neolithic period of civilization (10,000 BC) (Hudry 1980). The Alps are the most populated mountain chain in the world (Encyclopedia Universalis 1990). 29% of the ski areas in the world are situated in France, covering a total area of 1200 sq km, the most for one country in the world. French ski resorts have the capacity to lodge 1,120,000 people and include 4000 ski lifts (64% are located in the Northern French Alps) that serve sixty one ski areas (Assoc. Ski France 1990).

The French avalanche forecasting system was realized in 1970 and 1971 in the wake of "l´annee noire" (the black year). Avalanches during the winter of 1969-1970 claimed over 100 lives in France alone (Rey 1986). Like most of France´s federal institutions, the avalanche forecasting network is very organized and highly centralized. The head office is Le Centre d´Etude de la Neige (Center for the Study of Snow) in Grenoble (C.E.N. is itself part of the French national meteorological company called Meteo-France). The network has branches, which are themselves meteorological centers in each department (a "departement" is the rough equivalent of a small American state e.g. La savoie, at a total surface area of 6,000 sq km, is appoximately one sixth the size of Montana. The branches that process snow-meteorological data are spread throughout France in Les Pyrenees ,La Corse, Le Massif Central, Jura-Vosges and Les Alpes. Each branch is responsible for giving a forecast for its specific region. The center in Bourg-St-Maurice, in the department of La Savoie (Alps) is responsible for the massifs of Les Bauges, Le Beaufortain and La Vanoise as well as the valley regions that surround the Vanoise i.e. La Tarentaise and La Maurienne (Tignes is located in La Haute (high) Tarentaise limit of La Vanoise). A bulletin is announced everyday of the winter for each massif.

Avalanche forecasting in Savoie is based principally upon data provided by 20 snow-meteorological posts located for the most part at ski patrol centers throughout each massif or valley region. According to Mr. Chabert, director of the Bourg Saint Maurice snow-meteorological center, almost 4000 snow-meteorological observations and 400 snow-profiles are processed each winter. The center is responsible for avalanche hazard forecast bulletins that cover a total area of approximately 5000 sq km (1950 sq mi).

Savoie, which is made up of approximately 80% mountainous terrain, is easily recognized by the massif of the Vanoise which is shaped like a hen-its plume is the border of Italy, its back formed by the Isere River (Tarentaise valley), its underside formed by the Arc River (Maurienne valley), next to the top of its head is Albertville (city of the 1992 Winter Olympic Games)

and the beak is formed by the Isere and the Arc where they come together just before Chambery (capital of the department of Savoie). The ski area Tignes-Val d´Isere, also known as l´Espace Killy because Jean-Claude Killy grew up in Val d´Isere, is located at the end of the Haute Tarentaise Valley. This region is located in the inter-alpine zone. The climat is therefore "montagnard" or alpine, which gives rise to many different micro climates subject to an extremely variable range of weather conditions. La Haute Tarentaise is generally influenced by the eastern arm of the atlantic sub-tropical high pressure system (known as the anticyclone des Acores) and by Atlantic maratime polar and maratime tropical low pressure systems that originate off the coast of Iceland (known as the depression d´Island). Otherwise, systems moving in from the south, which are less frequent, deposit pinkish sands carried in by the Sirocco Winds that originate in the Sahara Desert. This sand creates a weak layer within the snowpack. Arctic systems originating in Siberia are also less frequent but not negligible nor is the "return from the east" of the Atlantic storms. The Foehn wind also influences the region on occasion. The following averages for the last 30 years were obtained for the meteorological center in Bourg St Maurice located at an altitude of 800 m (the seasonal weather station in Tignes is located at 2080 m - approximately 20 km from Bourg St Maurice): The average annual temperature is +8.8 ´c. The average temperature for January is -0.4 ´c contrast with an average temperature of +17.7 ´c in July. Average annual precipitation is 952 mm (approximately 1100 mm in Tignes) -with an average of 153 days of precipitation recorded. Also recorded are annual averages of 2019 hours of clear skies, 42 days of Foehn, and 27 days of thunder stormes. Most of the winter in Tignes is experienced above the valley cloud level (Station Meteorologique Departementale de Bourg St Maurice).

The Tarentaise valley includes some of the largest ski areas in the world. In just a few decades, this once quite agricultural valley has been transformed into a boombing tourist center which will host almost all of the Winter Olympic events in 1992. The ski area Tignes-Val d´Isere is capable of lodging 55,000 people. It provides just under 130 ski lifts that give access to approximately 110 sq km (35 sq mi) of skiable terrain covering a relief of 1550 m to 3550 m in altitude. Approximately 95% of the area is above tree line and over 80% is "hors-piste" (off-trail) skiing terrain. Hors-piste and out of bounds skiing is not only legal, it is encouraged as a selling point for the ski area. Avalanche control is practiced only where trails or important structures may be at risk.

Tignes makes up approximately half of the total ski area of the Espace Killy. The original Tignes was a small agricultural community of approximately 400 people in 1945. Tignes as the ski resort dates back to the early 1930´s. Between 1946 and 1952 an enormous dam was built that, at the time, supplied France with five percent of its total electricity. The remains of the original town are now located at the bottom of the resulting

lake, Lac du Chevril. The Church and the Town Hall were relocated to the edge of the lake, creating the center of a town which is now called Tignes les Boisses. Only 20 of the original 400 Tignards stayed in the area after the relocation. It wasn't until 1967 that the "purpose built" ski resort of Tignes le Lac, located next to a small lake above the Lac du Chevril, began to emmerge as the ski resort giant that we see today. Since 1967 Tignes has grown from 1500 'beds' to 30,000 available for the Olympics in 1992. During this period, the Town Hall moved to Tignes le Lac. To accommodate this growth, enormous trenches, walls and various other structures have been put in place in order to protect the resort community from the many existing avalanche paths that threaten a relatively large percentage of the town and the surrounding villages. Because of the destruction caused by avalanches during the 1969-1970 season, the French government asked the Minister of Agriculture to create a map of probable avalanche paths. The result was a combined effort between the French Natonal Forest service and the Institut Geographique National. The Forest Service processed information on all avalanche events recorded during the last century as well as surveys from the local population. The Institut Geographique National conducted a photo-interpretation study. The map that resulted turned out to be extremely useful as a reference to the Service des Pistes who were able to modify the original map, according to the avalanche paths that concerned them, and create - P.I.D.A (Plan d'Intervention pour le Declenchement des Avalanches -Avalanche Control Plan). An avalanche control team of 40 pisteurs is divided into five groups and assigned to secure the five different sectors of Tignes. Approximately 80 avalanche paths are controled during and after each significant snowfall. Between three and six thousand kg of explosives are used each season for avalanche control alone. According to statistics obtained from A.N.E.N.A. for the last ten years, Tignes experiences an average of 1.4 "hors piste" avalanche related deaths per year. The Service des Pistes is also responsible for these out of bounds rescues.

Along with the responsibilities of avalanche control, Le Service des Pistes de Tignes is in charge of taking care of 65 marked pistes (trails) that total 120 km in length. This means taking charge of securing the trails from avalanche danger as well as grooming and all other security mesures. The service des pistes is also involved in the security of the entire resort. The coordination of the 80 professional pisteurs is effectuated from the Central Office of the Service des Pistes which is under the direction of Bernard Foucher. The Service des Pistes itself is, in fact, under the responsability of the Mayor of Tignes.

La Prevision Locale des Risques d'Avalanches (Local Avalanche Hazard Forecasting) was made possible by the openess and willingness of the Service des Pistes de La Plagne (La Plagne Ski Patrol). La Plagne is a ski resort located near Tignes in the Haute Tarentaise. For several years this ski patrol, under the direction of Andre Martzolf, had been trying to merge snow-meteorological parameters with hazards inherent of

avalanches. However, these observations were only emperical.

In 1978, Edouardo Garreaud (glaciologist) was hired by the Service des Pistes de La Plagne with the goal in mind to create what eventually would become the system for Local Avalanche Hazard Forecasting.

In 1980, le Service des Pistes de La Plagne signed a contract of cooperation with the Centre d´Etude de la Neige. The goal of this contract was research on creeping and gliding of snow, seismic detection of avalanches, automatic recording of meteorological parameters in altitude, integration of parameters connected to avalanche hazards such as, albedo... At the same time this contract included the goal of developing a statistical model that would permit the discrimination of the day analysed into A DAY WITH AVALANCHES or A DAY WITHOUT AVALANCHES. This same model, also had to be able to analyze the meteorological parameters for a certain day through an analogue program in order to find a similar day in the past with a known behavior of avalanches. The analysis is achieved by a search through the data base for the day that most resembles the day in question. This model is being used in Tignes today.

In July 1986, in order to extend the availability of the method used for Local Avalanche Hazard Forecasting to other ski areas, Mr. Garreaud left La Plagne and created a company for technical development and assistance, la D.I.S.A.M, specialized in avalanche security and glaciology. The goal of this company is to promote avalanche security and awareness as well as the study of glaciology in summer ski resorts.

Meanwhile, the Centre d´Etude de la Neige had developed a program called A.D.I.P.R.A. (Assistance Departementalisee et Informatisee a la Prevision du Risque d´Avalanches - Departmentwide Computer Aided Avalanche Hazard Forecasting) designed to facilitate the departmental network of avalanche forecasting centers already in place. As stated before, these centers are responsible for a forecast by "massif" or region. For Example, the program had to be able to process information coming in from a potential 42 snow-meteorological observation posts in the region (see COMPUTER HELPED AVALANCHE FORECASTING IN FRANCE, by Jerome Lafeuille and Eric Brun: proceedings from the ISSW, 1988).

The company D.I.S.A.M., concerned about the compatability between the data files of the Local Avalanche Hazard Forecasting in ski areas and the files of A.D.I.P.R.A. used by the departmental avalanche forecasting centers under the Centre d´Etude de la Neige, decided to abandon the programs used before in La Plagne. D.I.S.A.M. asked the Centre d´Etude de la Neige if it would be possible to adapt certain programs of the system A.D.I.P.R.A. to the method of Local Avalanche Hazard Forecasting. The local version of A.D.I.P.R.A. is a system called P.R.E.L.A.(Prevision Local d´Avalanches -Local Avalanche Forecasting), D.I.S.A.M. signed a two year contract with C.E.N.

in order to commercialize this version.

At the end of these two years, the development of the method of Local Avalanche Hazard Forecasting demonstrated to Mr. Garreaud that P.R.E.L.A. was insufficient for processing snow-meteorological observations at posts in ski resorts. As a result, D.I.S.A.M developed its own system for local forecasting called A.D.I.C.L.H.I.M.A.(Aide Informatisee a la Climatologie Hivernale de Montagne et aux Risques d'Avalanches dans les Zones Securisees - Computer Aided Climatology for winter Alpine Environments and Avalanche Hazard Forecasting in Secured Areas). The programs of P.R.E.L.A. for processing ram sonde observations and analogous model are still used in this system.

A SYSTEM FOR LOCAL AVALANCHE HAZARD FORECASTING

A.D.I.C.L.H.I.M.A. consists of six functions (Figure 1):

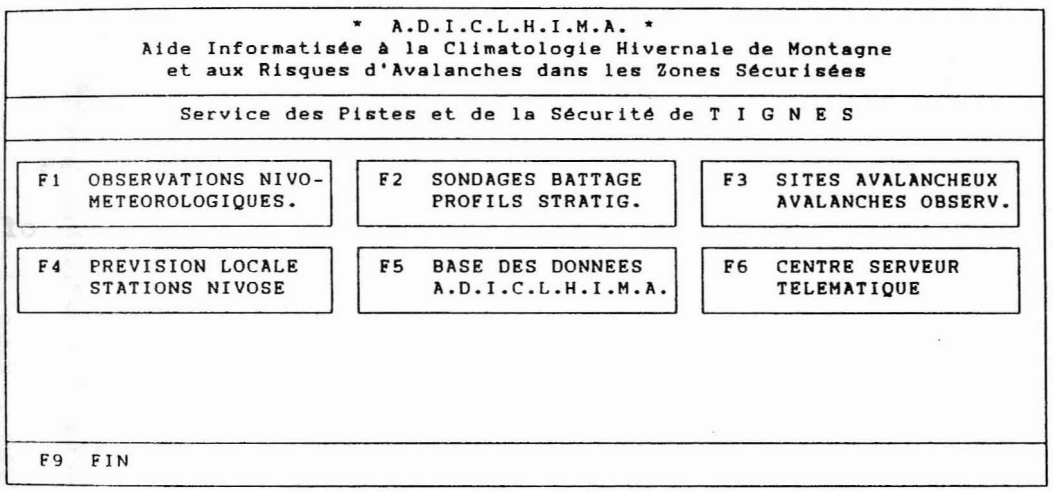

Figure 1

F1/ OBSERVATIONS NIVO- METEROLOGIQUES. (SNOW-METEROLOGICAL OBSERVATIONS).

This function includes SAISIE (DATA ENTRY), MODIFICATION, CHRONOLOGIES, and GRAPHS.

DATA ENTRY (Figure 2) is performed, without fail, three times daily at 2080 meters in altitude. The observations are recorded in the field by the same observers so that a consistency is achieved.

STATION : T I G N E S Service des Pistes et de la Sécurité
Prévision Locale du Risque d'Avalanches

* A.D.I.C.L.H.I.M.A. *

Poste : Tignes le Lac 904

Pour Arreter Entrez FIN Fonction : SAISIE

Observations de la Veille

jjmm	hr	hVV	Nddff	sTTA	RRRR	PrPr	wwWW	NLMH	sTTX	sTTN	SSS	ss	sTTS	EPPNC	LLLL	L
3004	08	999	01808	+026	0000	////	0000	0000	+114	-028	118	00	-005	80000	4742	3
3004	13	999	11805	+045	////	////	0000	0002	////	////	117	00	-002	51000	0000	5
3004	17	599	11802	-070	////	////	0000	1200	////	////	116	00	-003	51200	1432	5

Observations du Jour

jjmm	hr	hVV	Nddff	sTTA	RRRR	PrPr	wwWW	NLMH	sTTX	sTTN	SSS	ss	sTTS	EPPNC	LLLL	L
0105	08	999	10000	+032	0000	////	0000	0002	+095	-013	116	00	-004	80000	1432	3
0105	13	999	21803	+061	////	////	0000	0002	////	////	115	00	-004	50600	0000	5
0105	17															

Figure 2

jjmm hr=day, month, hour ; **hVV**=height of clouds above the resort, horizontal visibility; **Nddff**=cloud cover-in octas, wind direction, wind speed at the resort; **sTTA**=air temperature; **RRRR**=precipitation; **PrPr**=atmospheric pressure; **wwWW**=present meteorological conditions, meteo. conditions since the last observation; **NLMH**= low or medium layer cloud cover above the resort-in octas, type of lower height clouds, type of medium height clouds, type of the highest clouds; **sTTX**=maximum temperature; **sTTN**=minimum temperature; **SSS**=total height of the snowpack; **ss**=total fresh snow since the last reading; **sTTS**=temperature of the snow at a depth of 10 cm; **EPPNC**=state of the surface of the snowpack, penetration of the first drop of the ram sonde in cm, cloud cover in the valley, wind blowing snow in altitude; **LLLL L**=description of avalanches observed, type of avalanches, altitude of starting zone, orientation, estimation of hazard (1-8).

* A.D.I.C.L.H.I.M.A. * Poste de Tignes le Lac Inicatif 904
CHRONOLOGIE DES PRECIPITATIONS ET CUMULS DE NEIGE

dates	Hr	RR24h	RRREp	RRRMo	RRRSai	ss	s24	sEp	sMo	sSai	Nj
14 02	08	30.0	30.0	74.6	175.5	50	078	158	184	0300	4
	13					15	000	173	199	0315	
	18					11	000	184	210	0326	
15 02	08	49.5	49.5	124.1	225.0	32	058	216	242	0358	5
	13					04	000	220	246	0362	
	18					02	000	222	248	0364	
16 02	08	27.0	27.0	151.1	252.0	07	013	229	255	0371	6
	13					18	000	247	273	0389	
	18					15	000	262	288	0404	
17 02	08	21.0	21.0	172.1	273.0	14	047	276	302	0418	7
	13					00	000	276	302	0418	
	18					00	000	276	302	0418	
18 02	08	0.0	0.0	172.1	273.0	00	000	000	302	0418	
	13					00	000	000	302	0418	
	18					00	000	000	302	0418	
dates	Hr	RR24h	RRREp	RRRMo	RRRSai	ss	s24	sEp	sMo	sSai	Nj

F1 Suite F2 Observations F3 Abandon

Figure 3

CHRONOLOGIE (Figure 3): Allows the forecaster to analyze the previous five days weather events (per screen), as well as, total accumulations for the previous 24 hrs, the episode, the month and the season.

GRAPHS: For this function, two screens present daily observations for a 21 day period.

1 - maximum and minimum air temperatures, temperatures for 8:00 am, 1:00 pm and 5:00 pm, and temperatures of the snow 10 cm under the surface for each observation time.
2 - snowpack depth (cm), precipitation (mm) and the first drop of the ram sonde i.e. depth of new and/or cohesionless snow on the surface (Figure 4).

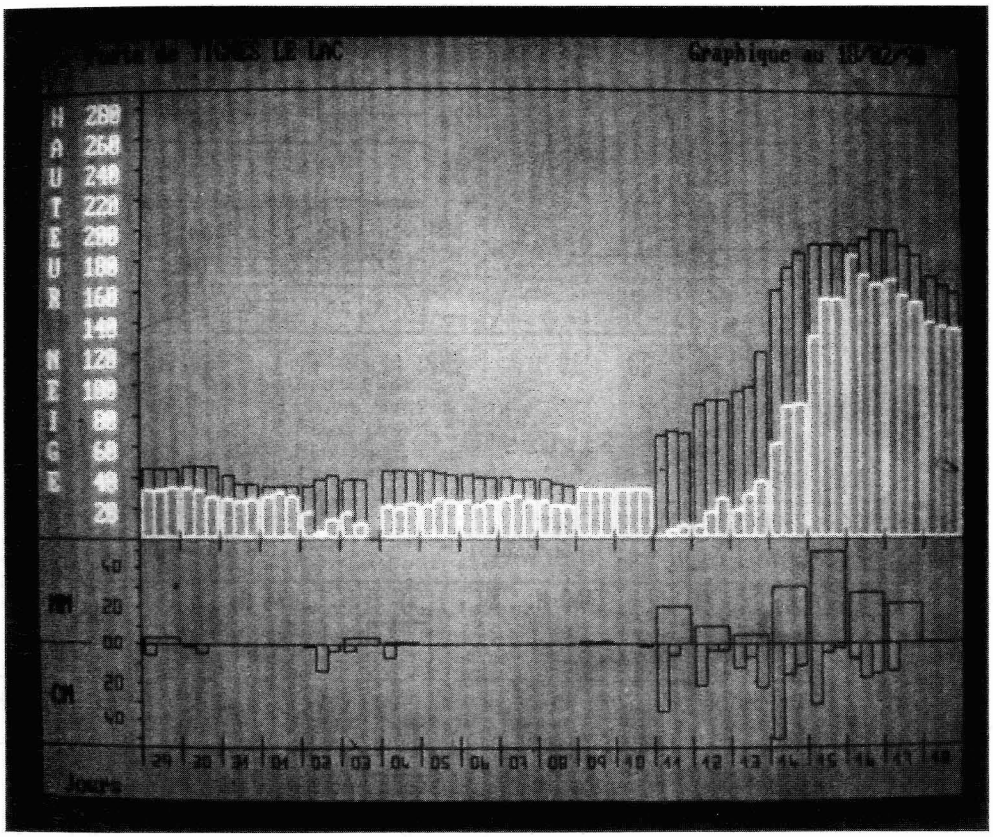

Figure 4

F2/ SONDAGES BATTAGE (RAM SONDE
PROFILS STRATIG. STRATIGRAPHIC PROFILES)

This function includes DATA ENTRY, MODIFICATIONS, A GRAPH WITH ONE PROFILE, A GRAPH WITH THREE PROFILES.

GRAPHS: Snow profiles are taken weekly at a control site near the Station Nivose II 2400 m. Other profiles are taken at random at the discretion of the forecaster. Snow profile observations are entered directly into the system. The system then calculates all the parameters; ram sonde readings, snow temperatures, snow densities etc. The result is (Figures 5 and 6).

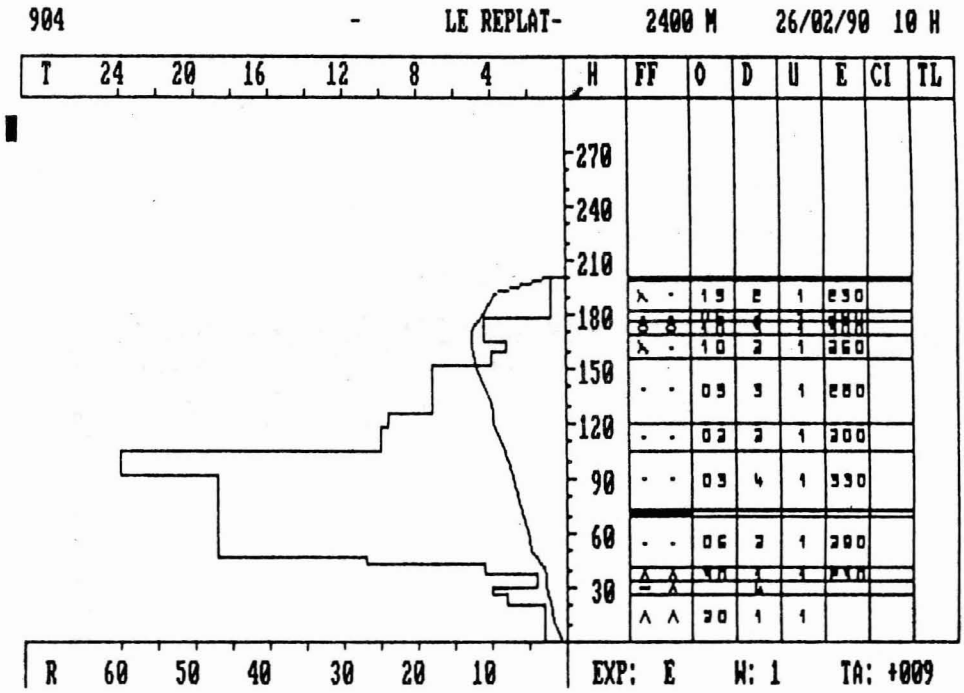

Figure 5

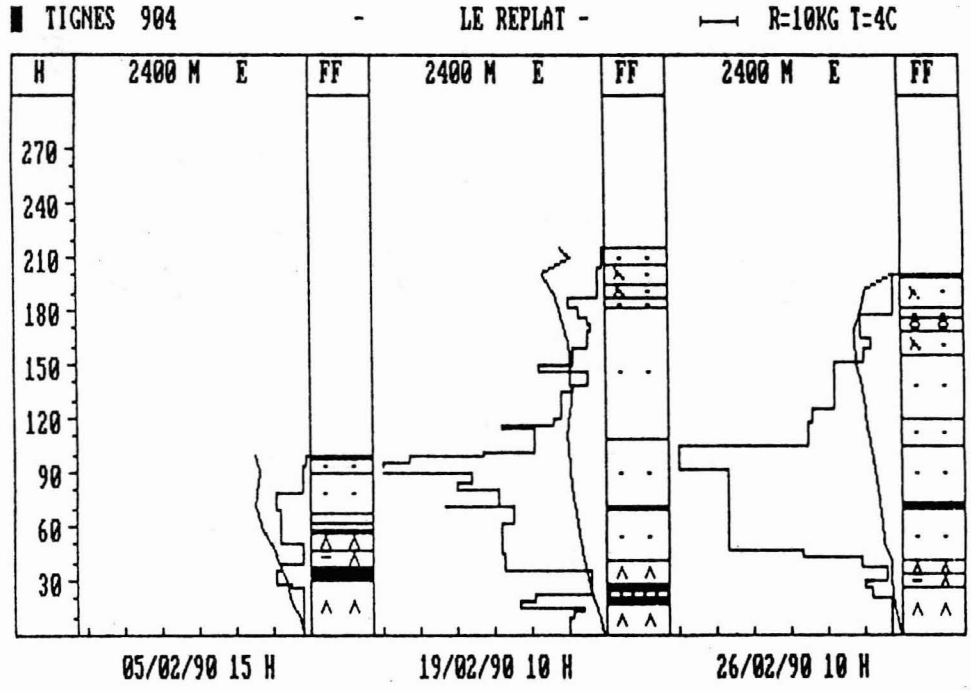

Figure 6

F3/ SITES AVALANCHEUX (AVALANCHE PATHS
AVALANCHES OBSERV. AVALANCHES OBSERVED.)

This function includes: DATA ENTRY, MODIFICATION, and TRAITMENT (PROCESSING) for AVALANCHE PATHS and AVALALANCHES OBSERVED.

DATA ENTRY-avalanche paths: Characteristics of each avalanche path are entered; sector number, avalanche number, path name, altitude of starting zone, altitude of run out zone, average slope angle of starting zone, average total slope angle, type of avalanche path, orientation of slope, ground surface, type and means of release, type of defense structure.
129 avalanche paths in Tignes are recorded for the five sectors, and an outlying sector.

DATA ENTRY-avalanches observed (Figure 7).

* * * EVENEMENTS AVALANCHEUX * * *

DATE : jjmmaa Hauteur Cassure (cm) : Ecc	HEURE: hhmm	COMMUNE: Ccc Largeur Maximale de l'Avalanche (m): Aaaa	SECTEUR: S	NUMERO : Nnn
TYPE D'AVALANCHE : A Naturelle . . . . . 0 Accidentelle . . . . 1 Superficielle . . . . 2 Artificielle 3	QUANTITE D'EXPLOSIF : Q Sans Explosif . . . . 0 Moins de 2,5 Kg. . . . 1 Plus de 2,5 Kg. . . . 2 Plusieur Tirs . . . . 3 Tir de Corniche . . . 4	TYPE DE DEPART : D Ponctuel . . . . . 1 Linéaire . . . . . 2 Mixte 3	
TAILLE AVALANCHE : T Petite . . . . . 1 Moyenne . . . . . 2 Grosse . . . . . 3 Exceptionelle 4	DEPOT : D Partie Superieure . . . 1 Partie Centrale . . . 2 Parte Inferieure . . . 3 Au-delà de Limites . . 4	ECOULEMENT : E Aérosol . . . . 1 Blocs . . . . . 2 Mouillée . . . . . 3 Blocs + Aérosol . . 4 Poudreus e 5	
DEGATS OCCACIONES : 0 Dégât Matériels ... 2	Sans Dégât ..... 0 Corpo+Matériels 3	Corporels 1	

Donnée Inconue = 9

Figure 7

PROCESSING DATA - avalanches observed: by date, by path, by paths without avalanches for a certain period.

F4/ PREVISION LOCALE (LOCAL FORECASTING
STATION NIVOSE II STATION NIVOSE II)

This function includes data entered by the automatic snow-meteorological station NIVOSE II, a search through an ANALOGOUS MODEL for a similar day to the day in question, and finally the Local Avalanche Hazard Forecasting BULLETINS.

STATION NIVOSE II: This automatic observation site is located at 2400 m near the snow profile control site. Readings are taken continuously 24 hours a day. Air temperature, snow depth, wind direction and speed are recorded instantaneously each hour, as well as, the maximum wind speed and its direction for that hour. Average wind speed is recorded for each ten minutes. The most frequent wind direction is recorded for each hour. These observations are transmitted automatically each hour to the computer (Figure 8). Another Nivose II station will be installed at 2700 meters in an exposed area at the summit of La Toviere.

STATION : TIGNES — Service des Pistes et de la Sécurité.

* * A.D.I.C.L.H.I.M.A. * * — Prévision Locale du Risque d'Avalanches

NIVOSE II : Consultation du Fichier NIVO-MESURES

		Mesures Instantanées				maximun		vent moyen pas de 10 minutes						
DATES	HH:MM	sTTA	SSS	ss	ddd\ffff	DDD\FFFF		FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	DDD
16/02	15:10	-3.3	245	//	NW 2.1	W	11.7	1.6	2.5	2.3	4.6	2.8	4.3	WNW
16/02	14:10	-3.5	241	//	SE 4.1	WNW	10.5	3.8	5.0	3.5	2.8	2.5	3.1	ESE
16/02	13:10	-3.2	238	//	WSW 3.1	W	11.3	3.0	2.3	1.7	2.2	6.0	4.3	WNW
16/02	12:10	-4.8	238	//	SSE 0.0	N	13.3	3.2	3.7	4.6	4.3	4.1	3.5	ESE
16/02	11:10	-4.9	238	//	E 4.8	W	15.1	3.8	3.6	4.4	4.2	4.1	3.0	W
16/02	10:10	-4.4	233	//	WNW 3.3	W	14.9	5.9	5.5	4.1	3.1	3.3	5.6	W
16/02	09:10	-5.5	234	//	NW 6.9	NW	12.0	3.0	4.4	3.5	3.0	2.4	3.1	W
16/02	08:10	-5.1	227	//	W 5.8	W	8.7	0.8	0.8	3.5	3.0	1.6	0.0	W
16/02	06:10	-10.0	222	//	SSE 0.4	E	2.9	0.9	1.6	0.7	0.9	0.4	0.9	E
16/02	05:10	-10.0	224	//	NW 1.1	SW	8.4	4.3	4.5	3.8	2.6	1.4	0.5	SW
16/02	04:10	-9.5	226	//	SSW 5.8	SW	11.1	3.3	2.8	3.1	5.0	3.9	3.7	SW
16/02	03:10	-7.7	227	//	WSW 5.2	SW	11.3	2.1	2.9	3.8	3.2	5.1	4.3	WSW
16/02	02:10	-8.1	227	//	SSW 2.9	NW	12.5	3.3	3.0	1.7	2.3	1.6	3.1	SSW

Vent Maximun Moyen en 12 heures : 43 Km/h

Suite ... [F1] * Abandon... [F2]

Figure 8

ANALOGOUS MODEL: In simple terms, this function looks for days of past snow-meteorological conditions that are similar to the day in question. The model uses the data base of FUNCTION/ 1. A list of similar days and their resulting avalanche activity is produced. This list aids the forecaster in his analysis of the day for which the avalanche hazard rating needs to be decided.

BULLETINS: Local Avalanche Hazard Forecasting informs the general public, guides, ski instructors etc. of the present state of the snowpack as well as the local avalanche hazard. This information is presented in the form of a daily bulletin (Figures 9a and 9b) as well as a weekly summary (Figure 10) that includes graphs of the snow profile (Figures 5 and 6). Special advisories are presented upon the demand of the Mayor's office.

Generally, this information, in its entirety, is available on bulletin boards throughout the resort; the three tourist offices, outside the office of the Service des Pistes and at the local Information Center "Point. S". This material is also available upon demand by fax, etc.

Figure 10

SERVICE DES PISTES DE TIGNES (2100 m)
PREVISION LOCALE DU RISQUES D'AVALANCHES

February 27, 1990

SNOW METEOROLOGICAL ANALYSIS

from the 10th to the 27th of Feruary, 1990

Principal Meteorological Events.

Between the evening of February 10th and the morning of February 17th, we experienced some of the most extreme winter weather conditons of the last twenty years. A total snowfall of 278 cm at 2100 m in altitude was recorded for this period. During this period, rain and snow alternated for 48 hours with percipitation in the form of rain up to 2000 m.

All precipitation was accompanied by very strong winds.

From the 17th to the 25th of February, meteorological conditions were characterized by the presence of a high pressure system and much warmer temperatures. The rise in temperature reached a maximum of +8.0° c during the day at 2100 m on the 24th and the 25th of Feruary. However, the nightime temperatures were negative. This phenomenon of alternating air temperatures resulted in a cycle of melting and freezing of the snow surface.

The last two days of this period mark the beginning of a new episode of snowfall that has already deposited 29 cm in the ski resort.

Violent winds accompany this new episode. The average maximum wind speed recorded for each hour at 2400 m in altitude between 12:00am and 12:00pm on 02/27/90 is 90 km/h.

Evolution of the Snowpack.

Except for the bottom layer and the top layer made up of 40 cm of new snow, the snowpack is well consolidated. In effect, the warming trend that followed the last snowfall episode (278 cm in 7 days) provoked a strong consolidation of the middle layers of the total snowpack. The consolidated layers are under the effect of equitemperature metamorphism which is responsible for the formation of fine angular grains of very strong cohesion. As a result, lateral anchoring of the snowpack is reinforced - permitting stability and an equilibrium of the entire snowpack. This effect is less extensive on shaded slopes and above 2500 m.

The bottom layer is still unstable and fragile because it is composed of depth hoar grains.

The cohesionless surface layer, as well as the snow falling at the moment, is subject to violent winds abvove 2500 m and is easily transported by the wind. As a result, numerous wind slabs are forming.

Figure 9b

SERVICE DES PISTES ET DE LA SECURITE DE TIGNES (2100 m)
PREVISION LOCALE DES RISQUES D'AVALANCHES

LOCAL AVALANCHE HAZARD FORECASTING
FOR THE SKI AREA OF TIGNES

February 18, 1990

Total accumulations since the 11th of February have reached 229 cm in five days, of which 89 cm fell in 24 hours on the 14th. Natural avalanches running far out of their normal run out zones have been recorded since the night of the 13th and all day on the 14th, creating significant destruction. Accumulations, totaling 43 cm during the night of the 14th and 15th, combine with relatively warm temperatures (0°) and strong winds (70 kph) from the west to form large and very humid slabs (accumulations of more than three meters are observed at 2400 m of altitude).

The marked warming trend accompanied by heavy rain up to 2500 m on the 15th has provoked a humidification of the snowpack which has accentuated the surcharge, and rotted out the lower layers all the way to the ground surface. This destabilization of the snowpack has resulted in many wet snow avalanches of exceptional size that are sliding on the ground surface. Avalanches have been running out of their normal limits to the edges of the resort villages - necessitating the evacuation of numerous buildings.

The slightly lower temperatures during the last few hours has not had a stabilizing effect on the snowpack; the strong snowfalls (30 to 50 cm) predicted for the day WILL ONLY ELEVATE THE HAZARD ALREADY AT IT S MAXIMUM: HAZARD 8, SITUATION AVALANCHEUSE EXCEPTIONELLE.

PLEASE RESPECT THE CLOSURE OF ROUTES AND FOLLOW CLOSELY THE ADVICE FOR TRANSPORTATION RECCOMENDED BY THE SKI PATROL AND THE POLICE.

Figure 9a

* * T I G N E S . * *
SERVICE des PISTES et de la SECURITE
PREVISION LOCALE des RISQUES d'AVALANCHES
* * *

METEO DU : 16/02/90 à 8:00 Heures

Dernière chute de neige le : 16/02/90 Epaisseur : 7 cm.

TEMPS A LA STATION : Neige Forte
Visibilité Horizontale : 100 Mètres

TEMPS AU DESSUS DE 2 500 : Neige Forte
Visibilité Horizontale : 100 Mètres

Poste d'Observation Nivo-Météorologique de Tignes
Orientation Est " 2080 M. d'Altitude

TEMPERATURES Centigrades	
Maximale (hier)	+01,5
Minimale	-07,5
08:00 Heures	-07,3
Surface de Neige	-00,7
VENT à 2 700 M. en Km/h.	
Vent Instantané	0
Direction	
Vent Moyen sur 8H	0
Direction	

PRECIPITATIONS en (mm)	
Cumul 24 Heures	027,0
Cumul 06 Jour(s)	027,0
Cumul du Mois	151,1
Cumul Saison	0252,0
CHUTES DE NEIGE en cm.	
Neige à 8h00	07
Cumul sur 24 H	013
Cumul 06 Jour(s)	229
Cumul du Mois	255
Cumul Saison	0371

HAUTEUR TOTALE DE NEIGE : 190 cm

EPAISSEUR DE NEIGE SANS COHESION : 07 cm. Etat, Fraiche sèche

INDICE DU RISQUE D'AVALANCHES (1 à 8) : 8

SITUATION AVALANCHEUSE EXEPTIONNELLE	AVALANCHES NOMBREUSES, ET EN RAISON DES ENORMES ACCUMULATIONS, FORTE PROBABILITE DE TRES GROSSES AVALANCHES A CARACTERE EXEPTIONNEL.

The hazard rating and definition are announced every day on the radio (a complete bulletin is announced on high hazard days), as well as through an internal telematic system (internal minitel and television).

F5/ BASE DE DONNEES (DATA BASE
A.D.I.C.L.H.I.M.A. A.D.I.C.L.I.H.M.A.)

This function is, in fact, still being structured. The objective for this function is to bring together all the observations recorded since 1970 and organize them in the system so that they are available quickly and easily to the forecaster, as well as, to other functions in the system i.e. the analogous model, statistics ...

F6/ CENTRE SERVEUR (CENTRAL TELEMATIC
TELEMATIQUE SERVER)

This function is also synonomous of the future goals for Local Avalanche Hazard Forecasting. The use of minitel (Video Tel)* will allow anyone anywhere in France, and in the future anywhere in the world, to tap into a reservoir of snow avalanche information in Tignes at any time. Bulletins, graphs, lessons on snow and avalanche awareness, the most recent snow stability evaluations etc. will all be available, in the comfort of your own home.

Television and cable T.V. bulletins are in the works as well.

The easy access to the entire data base combined with more effective diffusion of information will allow for in depth summaries of snow-meteorological data to be available to a wide variety of people. Certain information can be kept confidential and still be transmitted and then accessed by code. These improvements will be to the benefit of the entire community, especially avalanche control teams and other professionals involved in related occupations in Tignes.

*Minitel (Video Tel) is a sort of computerized phonebook with a screen. The system is hooked into the phone system. The information that can be accessed is close to infinite and can be interactive as well.

The people responsible for putting this presentation together are:

-Edouardo Garreaud, who provides the essentials i.e. the method and programs that make up the system for Local Avalanche Hazard Forecasting, A.D.I.C.L.H.I.M.A.
-Lionel Navillod, who works at the Service des pistes de Tignes as the snow-meteorological observer and forecaster, trained by Edouardo to take responsibility for all mesurements, data entry and everything that has to do with the daily operations of the system in Tignes.
-Henry Schniewind, whose undergraduate work in snow, avalanches and meteorology at Montana State University along with his knowledge of the French and English languages makes his participation very important to the overall presentation.

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Vincent Bonnet, Pisteur and snow-meteorological observer, whose work with the Local Avalanche Hazard Forecasting in Tignes has helped and inspired everyone involved.

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