Session on Forecasting of extremely rapid Mass Movements

From Causes to forecasting snow avalanches

Irasmos conference 2008

Integral Risk Management of Natural Hazards

"A Merge of Theory and Practice"

Gérald Giraud and Cecile Coleou, CEN/Météo-France

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Introduction

- short and descriptive presentation of the WP1 snow avalanche part of IRASMOS project
- WP1 = “From causes to forecasting” for snow avalanches with 3 objectives :
  - ✓ To review and compile the causes and trigger mechanisms
  - ✓ To test the applicability of triggers and thresholds
  - ✓ To put and evaluate international state-of-the-art methods and technologies of modelling and forecasting process of triggering mechanisms, runout and potential damage

Plan

I. SNOW CRISTAL TYPES and PROPERTIES

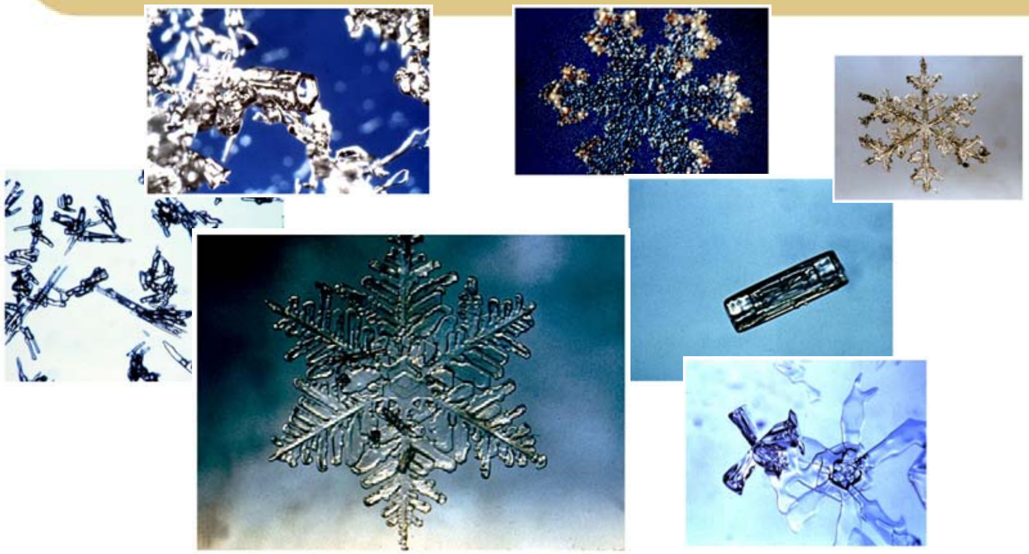
II. INSTABILITY FACTORS

III. AVALANCHE DESCRIPTION and DEFINITION

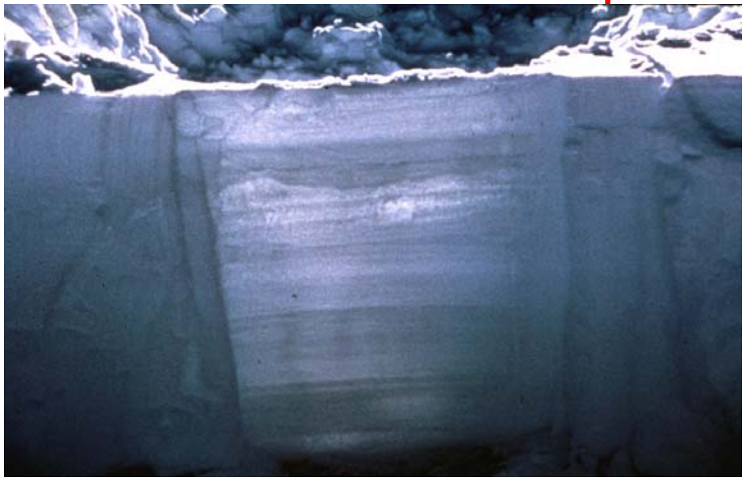
IV. TRIGGERING CAUSES and MECHANISMS

V. AVALANCHE WARNING AND FORECASTING METHODS

I. SNOW PROPERTIES and CRISTAL TYPES

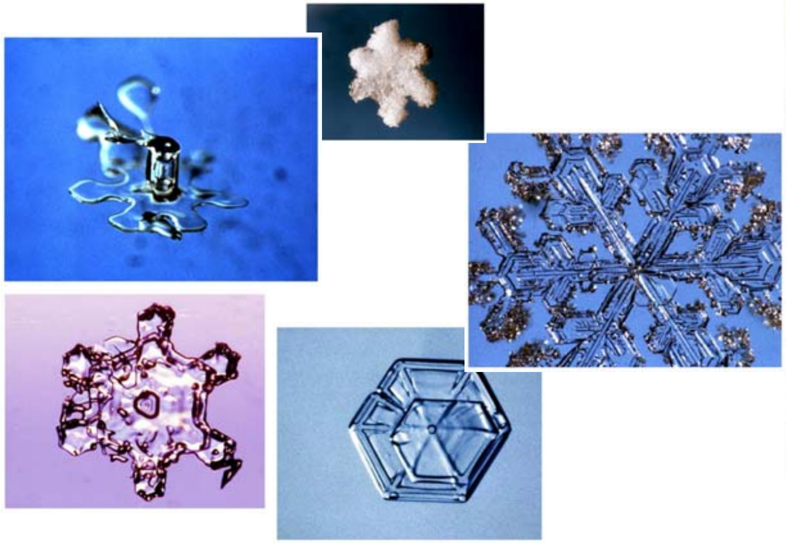


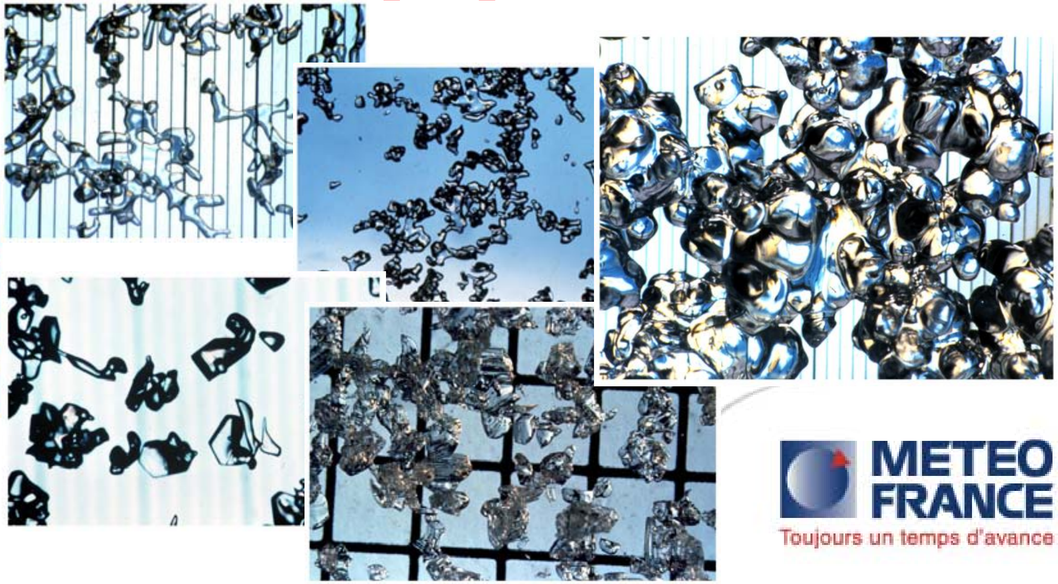
• a stratified snowpack



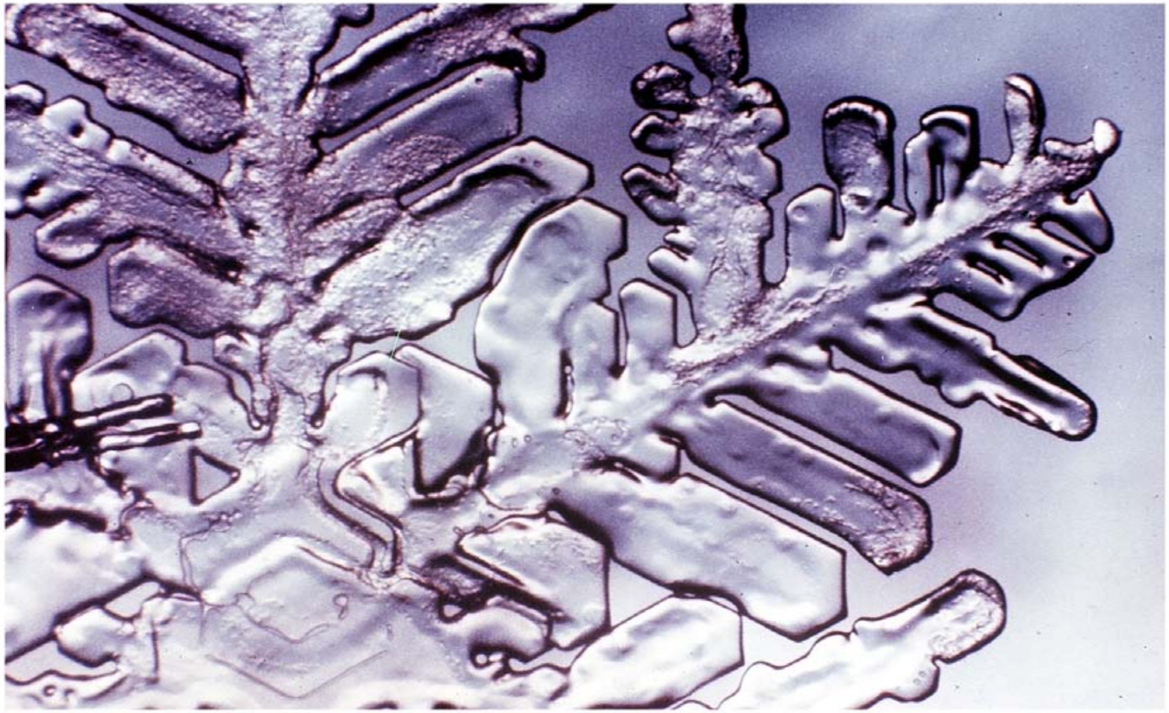
- A very widely material

- In perpetual evolution





SNOW PROPERTIES and CRISTAL TYPES

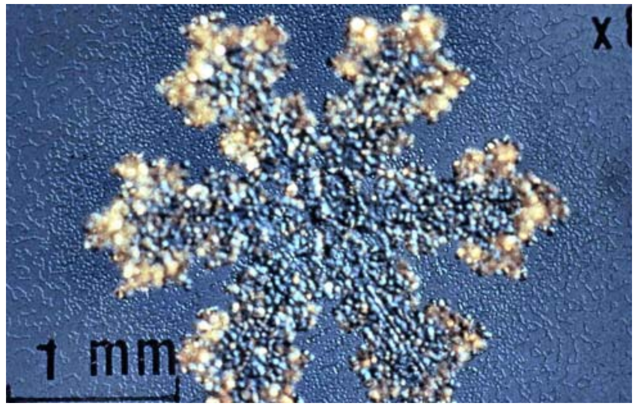


Precipitation particles +

SNOW PROPERTIES and CRISTAL TYPES

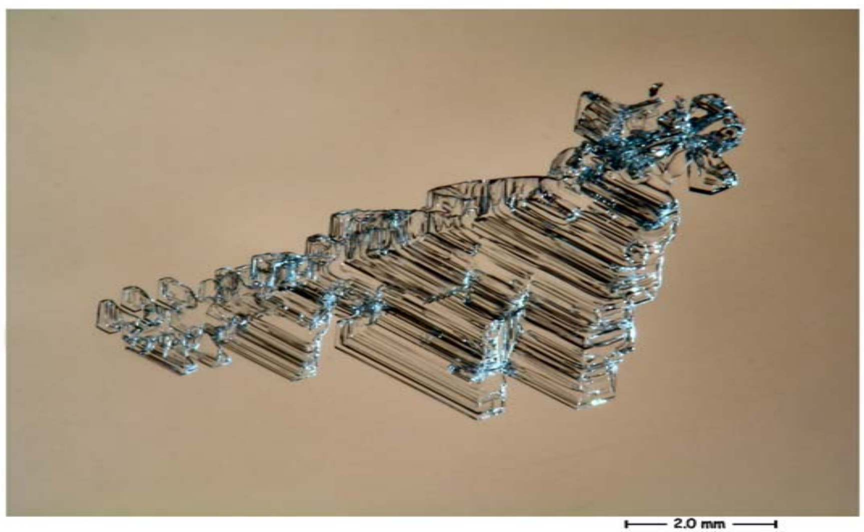
Frosted (rimed) crystals Precipitation Particles

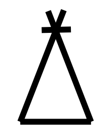
+



Surface hoar

V

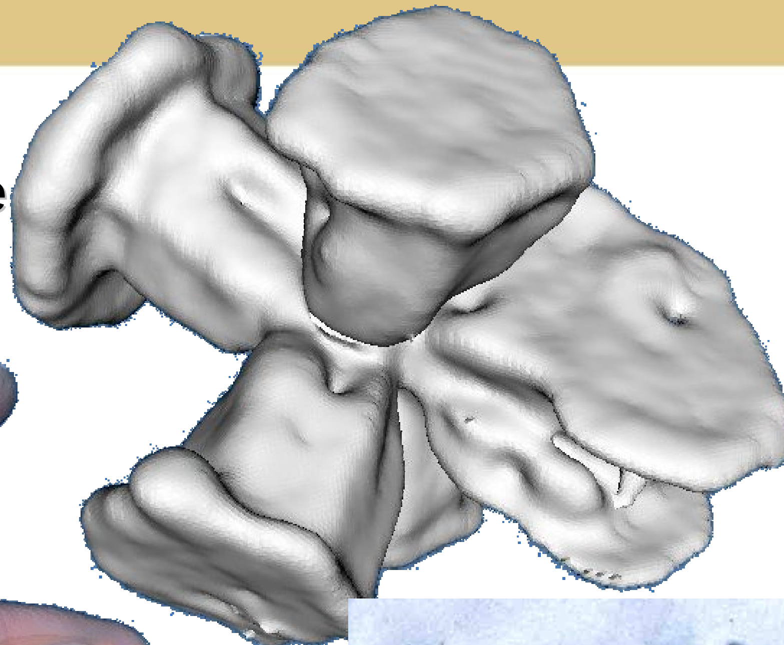


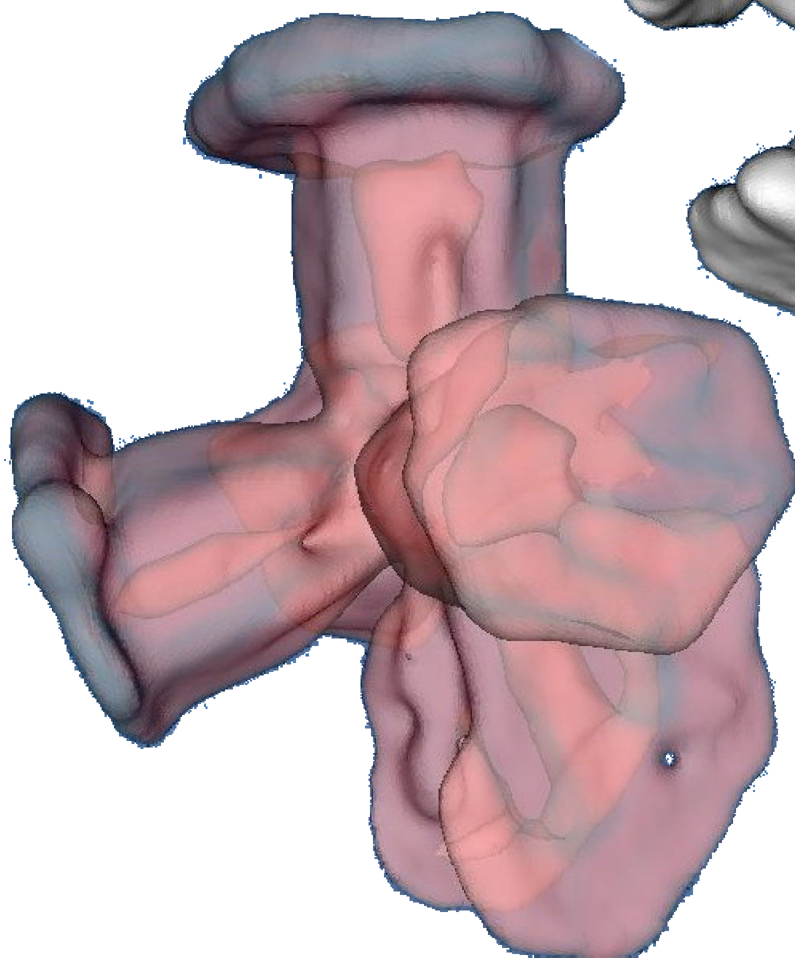


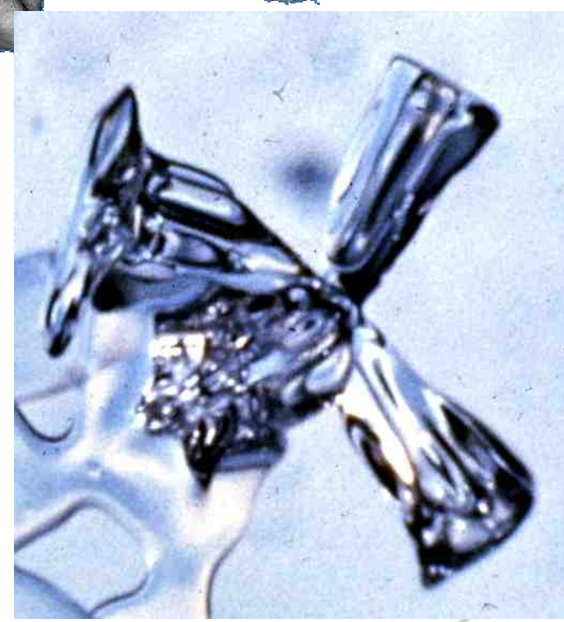
Graupel

SNOW PROPERTIES and CRISTAL TYPES

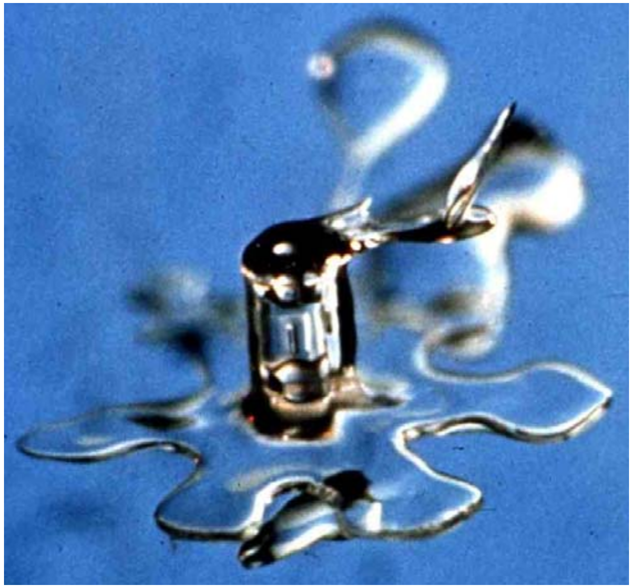
3D X ray
microtomographic picture



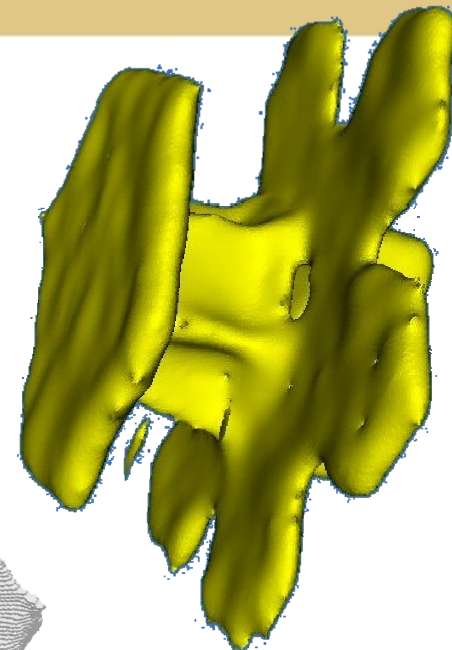


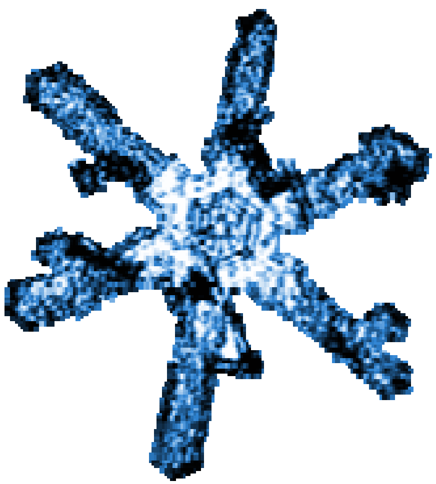


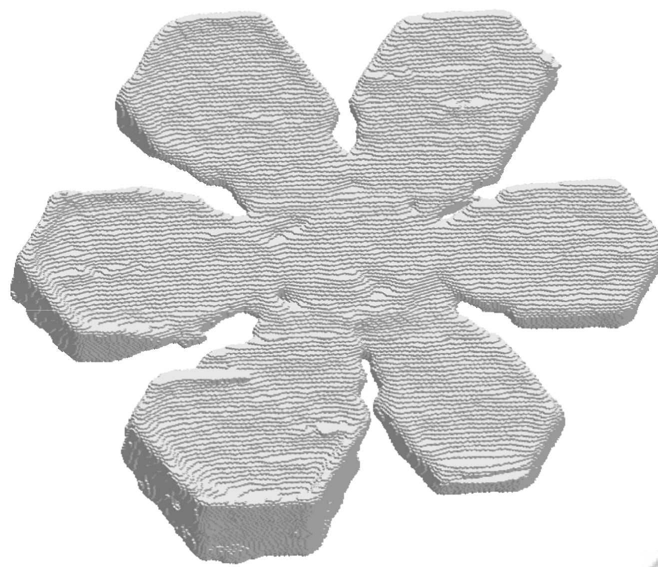
SNOW PROPERTIES and CRISTAL TYPES



3D X ray microtomographic picture







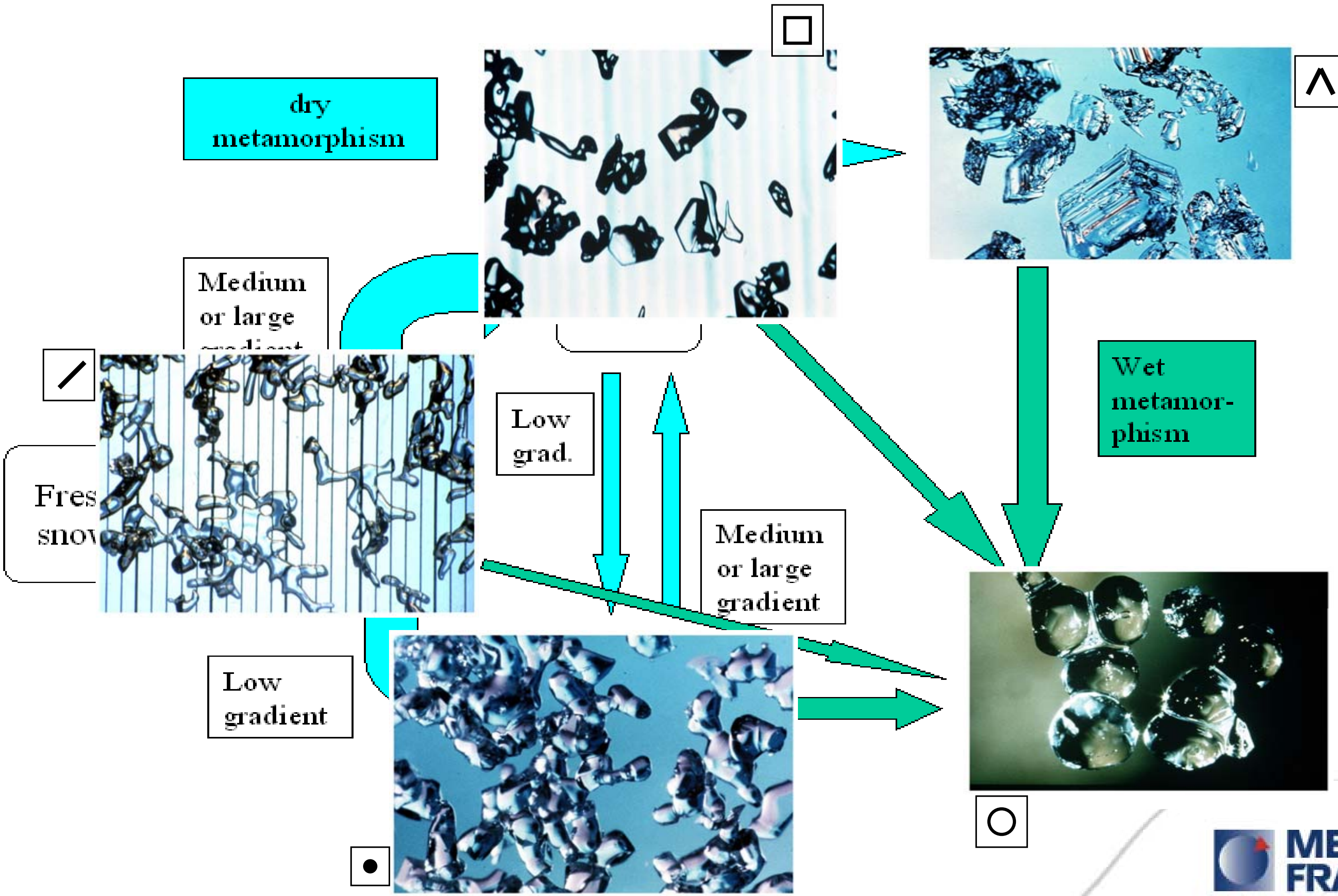
Metamorphism

On the ground, snow crystals in permanent evolution due to :

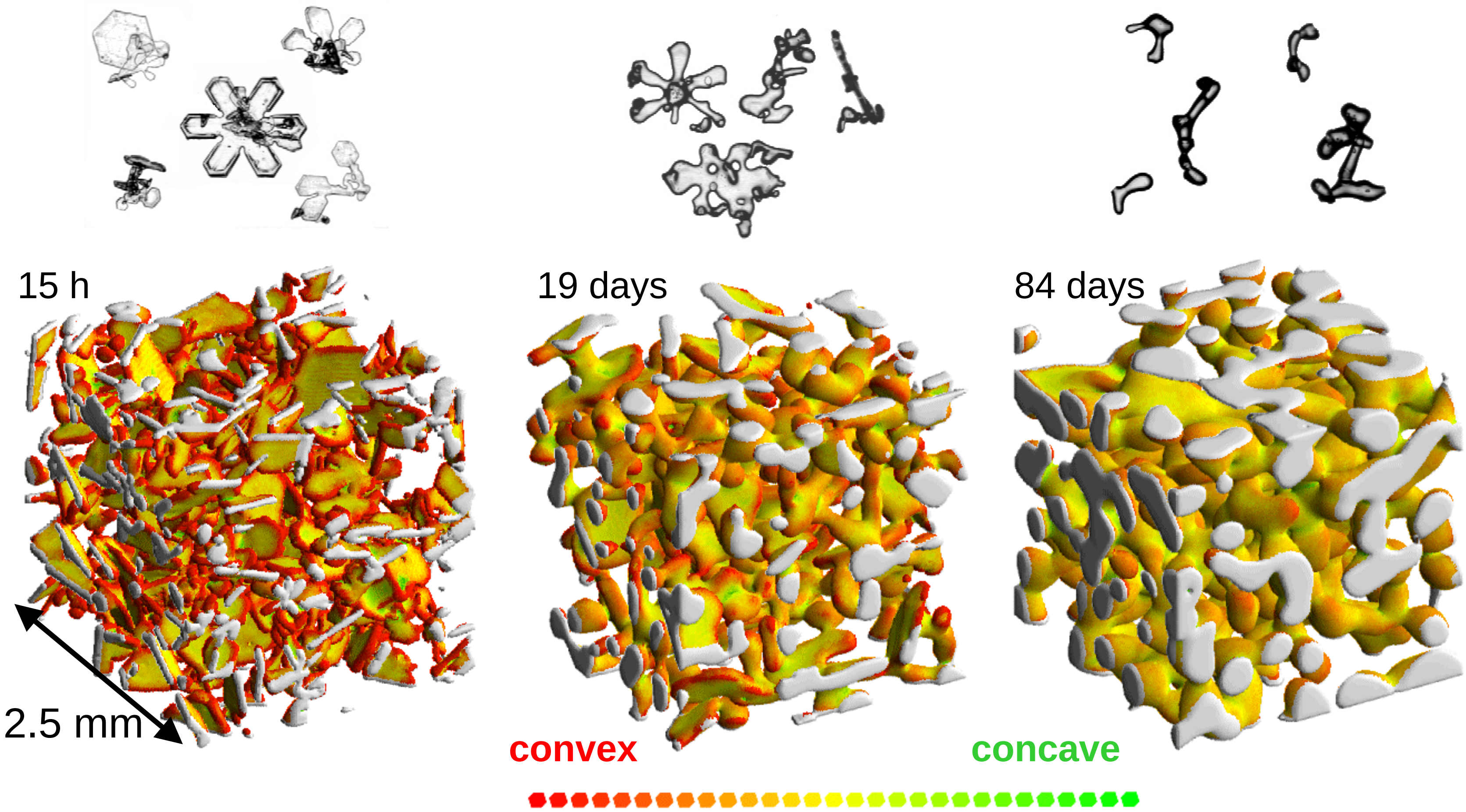
- mechanical metamorphism : settlement and snowdrift

- thermodynamical metamorphism : temperature (heat flow)

Thermodynamical metamorphism according to grain types



snow microstructural evolution under isothermal conditions



International Classification for Seasonal Snow on the Ground

Table I.2. Main morphological classes for grain shapes.

Class	*Symbol*	*Abbrev*[1]	*Colour*
Precipitation Particles	+	PP	(green)
Machine Made snow	◎	MM	(yellow)
Decomposing and Fragmented precipitation particles	⁄	DF	(dark green)
Rounded Grains	•	RG	(pink)
Faceted Crystals	□	FC	(light blue)
Depth Hoar	∧	DH	(blue)
Surface Hoar	∨	SH	(magenta)
Melt Forms	○	MF	(red)
Ice Formations	▬	IF	(cyan)

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II. INSTABILITY FACTORS

Main causes for an unstable snowpack :

✓ Topographical : type of slope (angle..), aspect, vegetation and ground, snow surface conditions, altitude

✓ Meteorological : snowfall, rain, wind, solar radiation and snowpack structure

III. AVALANCHE DESCRIPTION and DEFINITION

Triggering Classification :

✓ **Spontaneous avalanches**. The avalanche is due to changes in the snowpack, themselves directly related to weather and snow conditions.

✓ **Naturally released avalanches**. The avalanche is caused by an external, non-human factor (fall of cornices, seracs, rocks, passage of animals, earthquakes, etc.).

✓ **Accidentally released avalanches**. The avalanche is caused by an unintentional, human factor (skier, snowboarder, snowshoer, etc.).

✓ **Artificially released avalanches**. The avalanche is caused by an intentional, human factor (artificial triggering).

AVALANCHE CLASSIFICATION

ZONES	CRITERIA		DISTINGUISHING CHARACTERISTICS
Starting zone	**Type** of triggering		◆ **Spontaneous**. Internal causes within the snowpack (spontaneous avalanche)
			◆ **Released**. External causes (released avalanche)
			● Natural (non human), i.e. cornices, seracs, rocks, animals, etc.
			● Human
			O Unintentional (accidental)
			O Intentional (artificial)
	Type of starting zone		◆ **Point**. Avalanche starts from a point, fanning out downhill (inverted V shape)
			◆ **Linear**. Slab avalanche with a distinct fracture line at the top
	Snow **conditions**	Liquid-water content	◆ Zero. **Dry snow**
			◆ Low. **Moist snow**
			◆ High. **Wet snow**
		Cohesion	◆ Low. Avalanche of **powder** or **wet** snow
			◆ Low to moderate. **Soft slab**
			◆ High. **Hard slab**
		Type of snow	◆ **Recent**
			● Not wind transported, fresh or fragmented particles
			● Wind transported, fragmented particles or small rounded grains
			◆ **Metamorphosed** • faceted grains / round grains
	Position of the bed surface		◆ **Within the snowpack** (surface-layer slab avalanche)
			◆ **On the ground** (full-depth slab avalanche)

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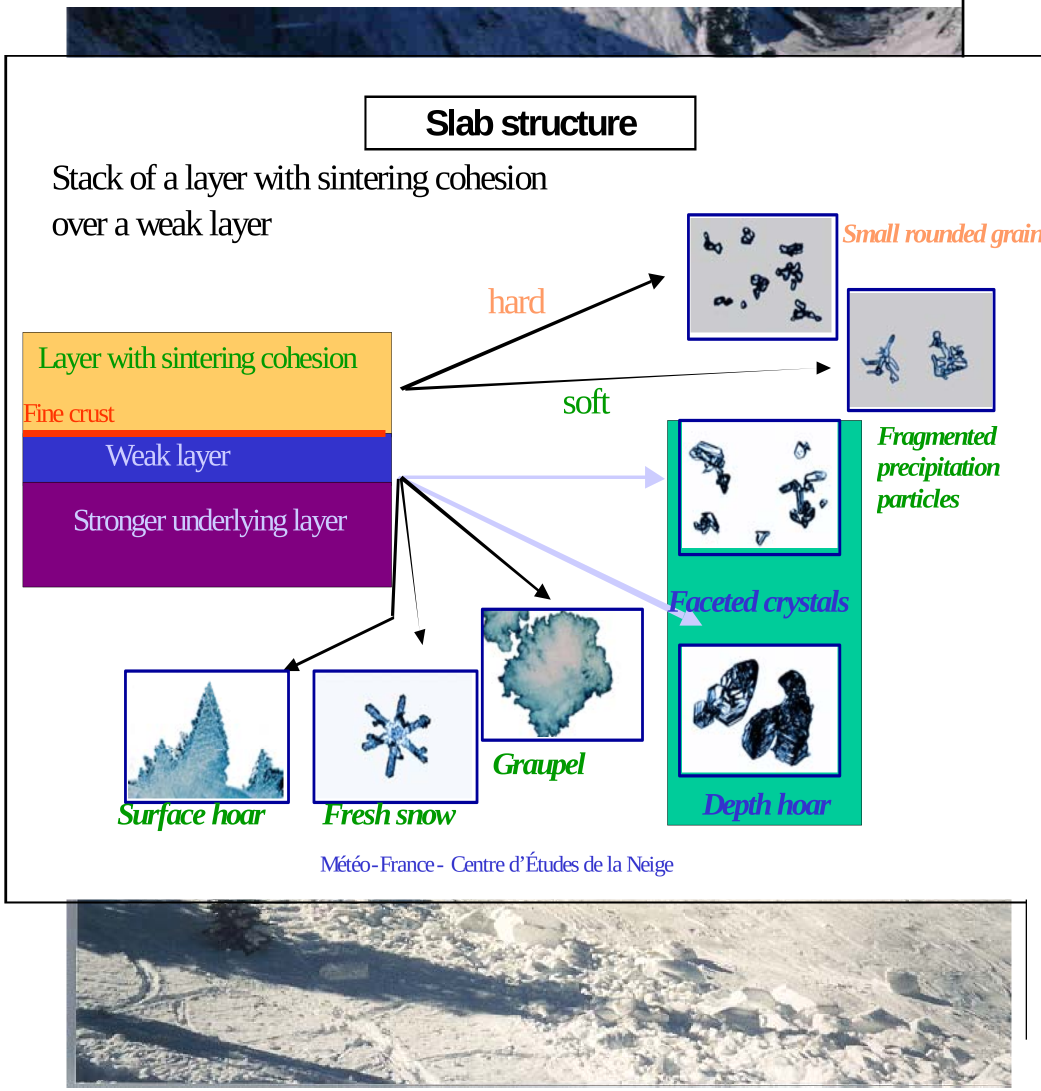
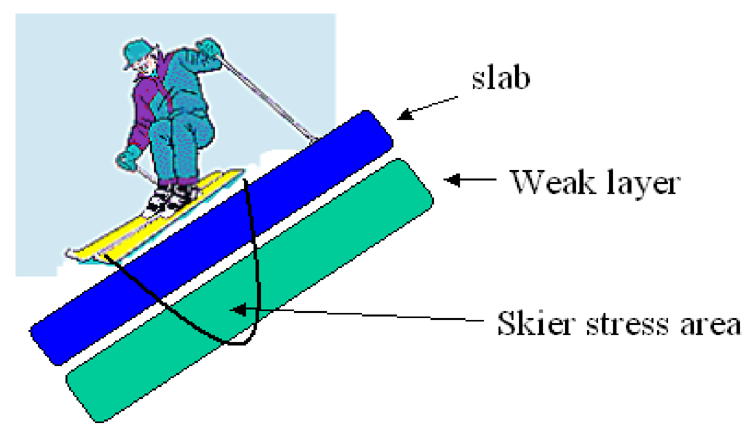
AVALANCHE CLASSIFICATION

Flow zone (Track)	**Type of terrain**	◆ **Open slope**
		◆ **Couloir** or gulley
	Dynamics (type of flow)	◆ **With cloud** of airborne snow particles:
		● at the avalanche front
		● behind the front
		◆ **Without cloud** (dense-flow avalanche)
	Snow pick-up	◆ **Yes**
		◆ **No**
	Blocks and/or other debris	◆ **Yes** (slab chunks, ice, rocks, trees)
		◆ **No**
Deposition zone (Runout)	**Surface roughness**	◆ **Smooth** (fine deposit)
		◆ **Rough** (coarse deposit with blocks, lumps, etc.)
	Snow conditions	◆ **Wet** (wet deposit)
		◆ **Dry** (dry deposit)
	Visibly contaminated deposit	◆ **Yes** (avalanche contaminated with soil, rocks, trees)
		◆ **No** (clean avalanche)

IV. TRIGGERING CAUSES and MECHANISMS



Associated thresholds :
30 to 60 cm: avalanches only on steep slopes and usual locations
60 to 90 cm: avalanches on moderate slopes (between 30, 40°) and large avalanches
>= 90 cm: widespread danger, very large avalanches



TRIGGERING CAUSES and MECHANISMS

Wet snow avalanches :

Spontaneous or released, wet grains with LWC, ponctual or linear type, block with debris flow and deposit

Thresholds are not as clearly defined as those for new snow.

10 mm over 24 hours is a minimum for a destabilisation of the upper layers.

After, destabilisation highly depends on the snowpack structure

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V. Avalanche warning and forecasting methods

Spatial scale of avalanche warning

- The massif scale (~500 km^2) for regional avalanche warning : spatial homogeneity of the meteorological parameters and snowpack in term of elevation, aspect and slope, weather and snow observations daily performed, the snowcover and its afferent dangers directly forced by the weather conditions, pb with local phenomena like snowdrift. In the different European countries, this assessment is operational with good results.

- The local scale for road avalanche warning : important role of small scale phenomena in relation with topography, needed more local observations (automatic or human) with snow drift measurements…

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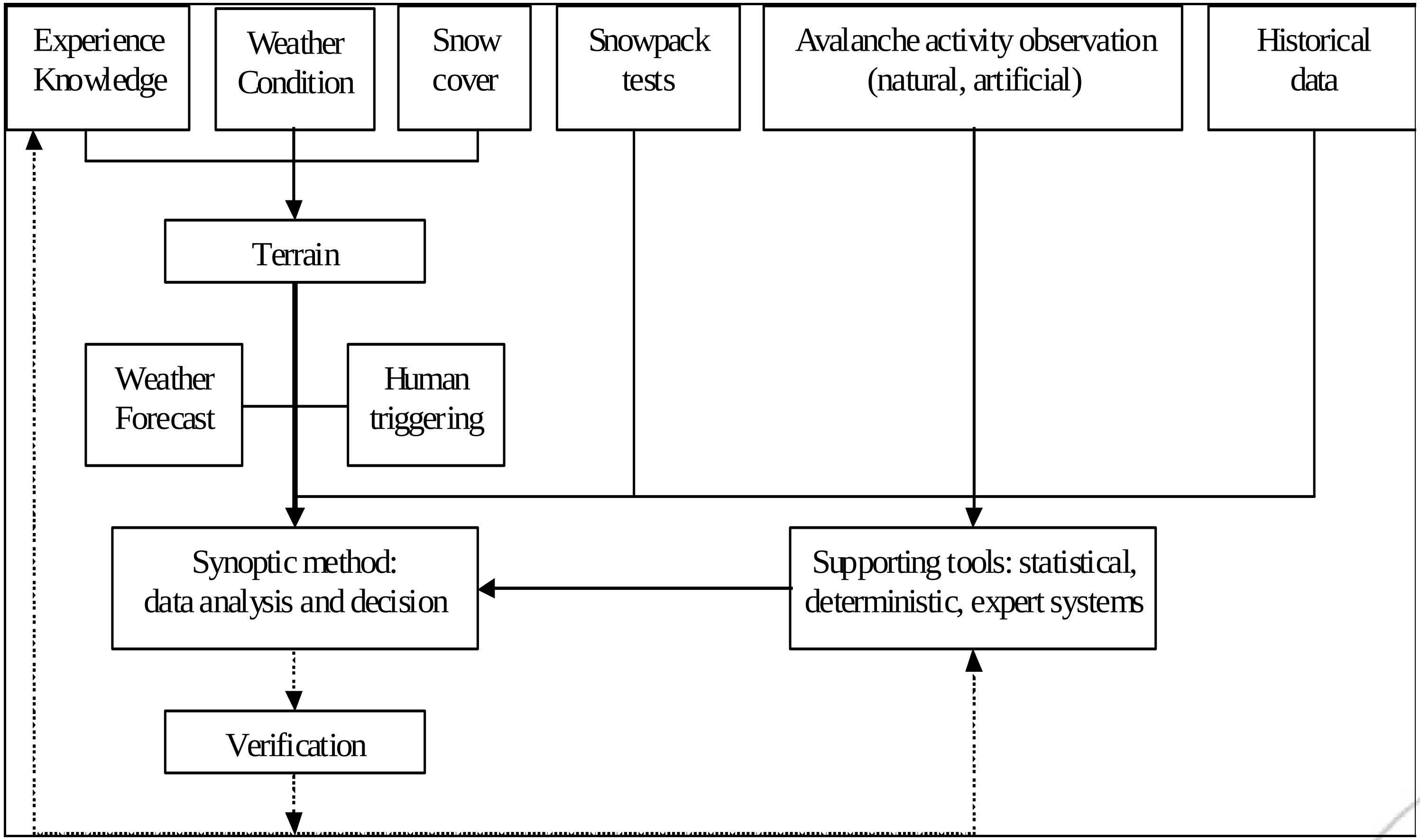
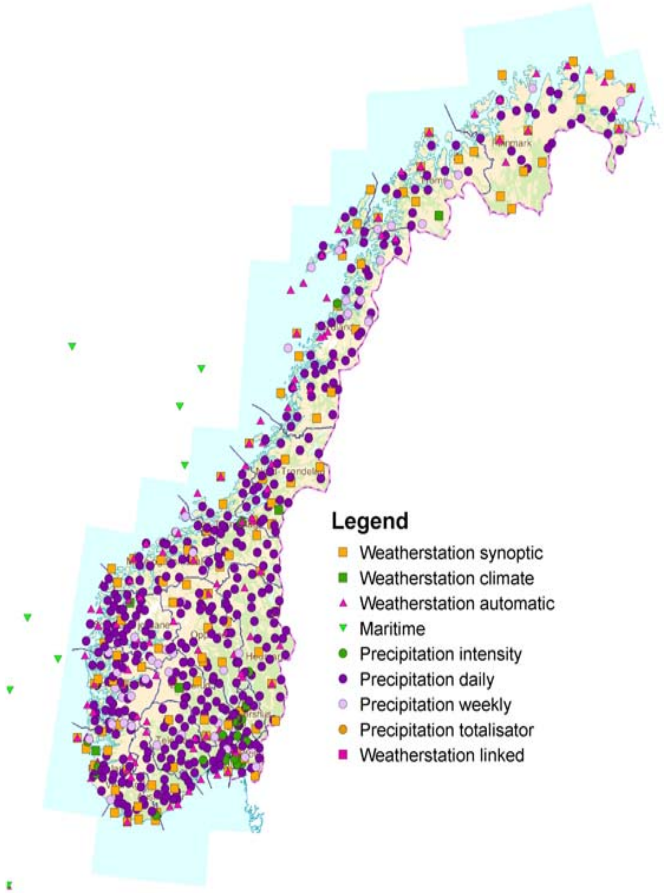
Avalanche warning and forecasting methods

The Synoptic method for forecasting the avalanche hazard with supplementary supporting tools (Shweizer and Fohn, 1994)



Avalanche warning and forecasting methods

The snow and weather network : Norway example



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Snow and hazard modelling

Since 1970's, different avalanche forecasting models have been developed and used by some European snow and avalanche centres :

- Statistical methods using discriminant analysis and nearest neighbours approaches (NXdays, Astral….)
- Numerical models to simulate snow cover processes (Crocus, SnowPack, SnowTherm…)
- Expert system or neural network to reproduce expert human reasoning

Snow and hazard modelling : statistical approaches

NXD example of a statistical tool at SLF

NXD-Lawinen : a nearest neighbours method (past situations which are mathematically close to the current situation) in order to find snow and meteorological similar days

NXD-Lawinen contains a weather, snow and avalanche database. The avalanche events of those selected days help to estimate the current avalanche danger.

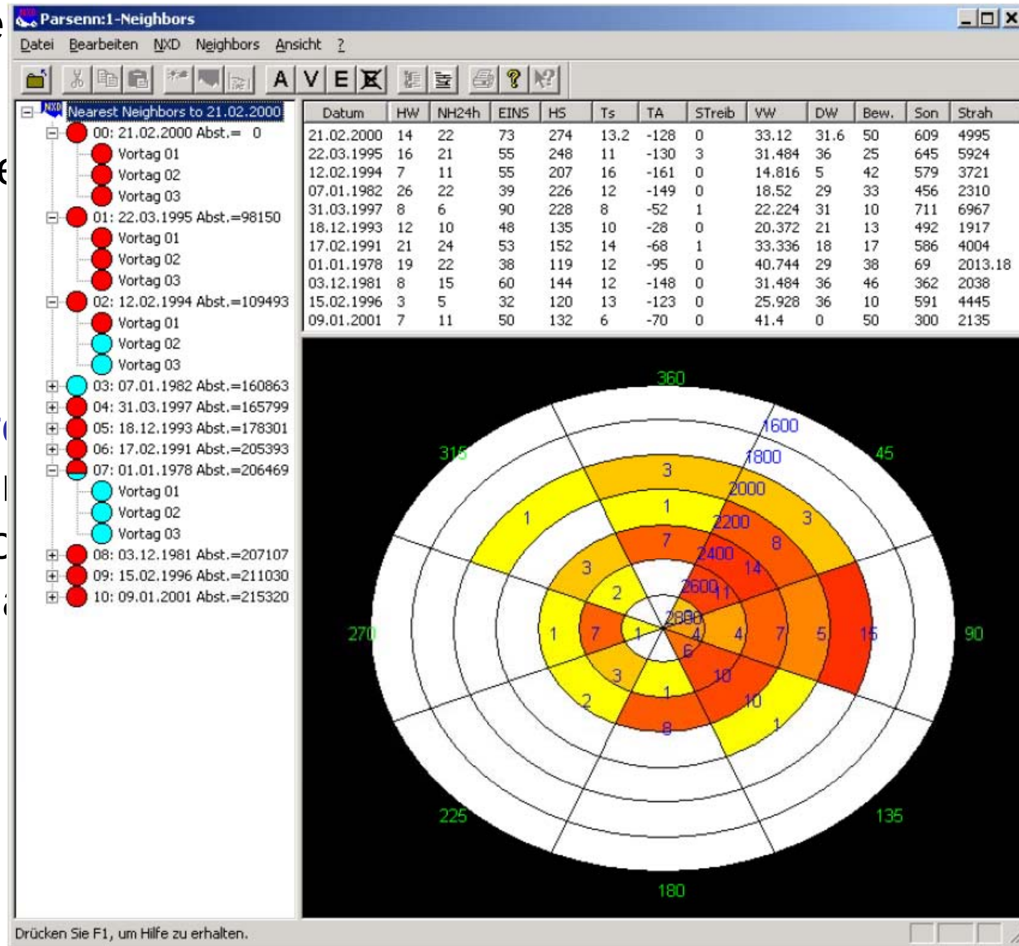
Snow and hazard modelling : statistical approaches

NXD example at SLF

3 versions of this software

- NXD2000 for a ... country roads). It provides the fore... uation. The observed avalanches ... lanche danger

- NXD-REG for r... by the Swiss avalanche warning se... d to the data sets of 60 observer static... nd future avalanche h...

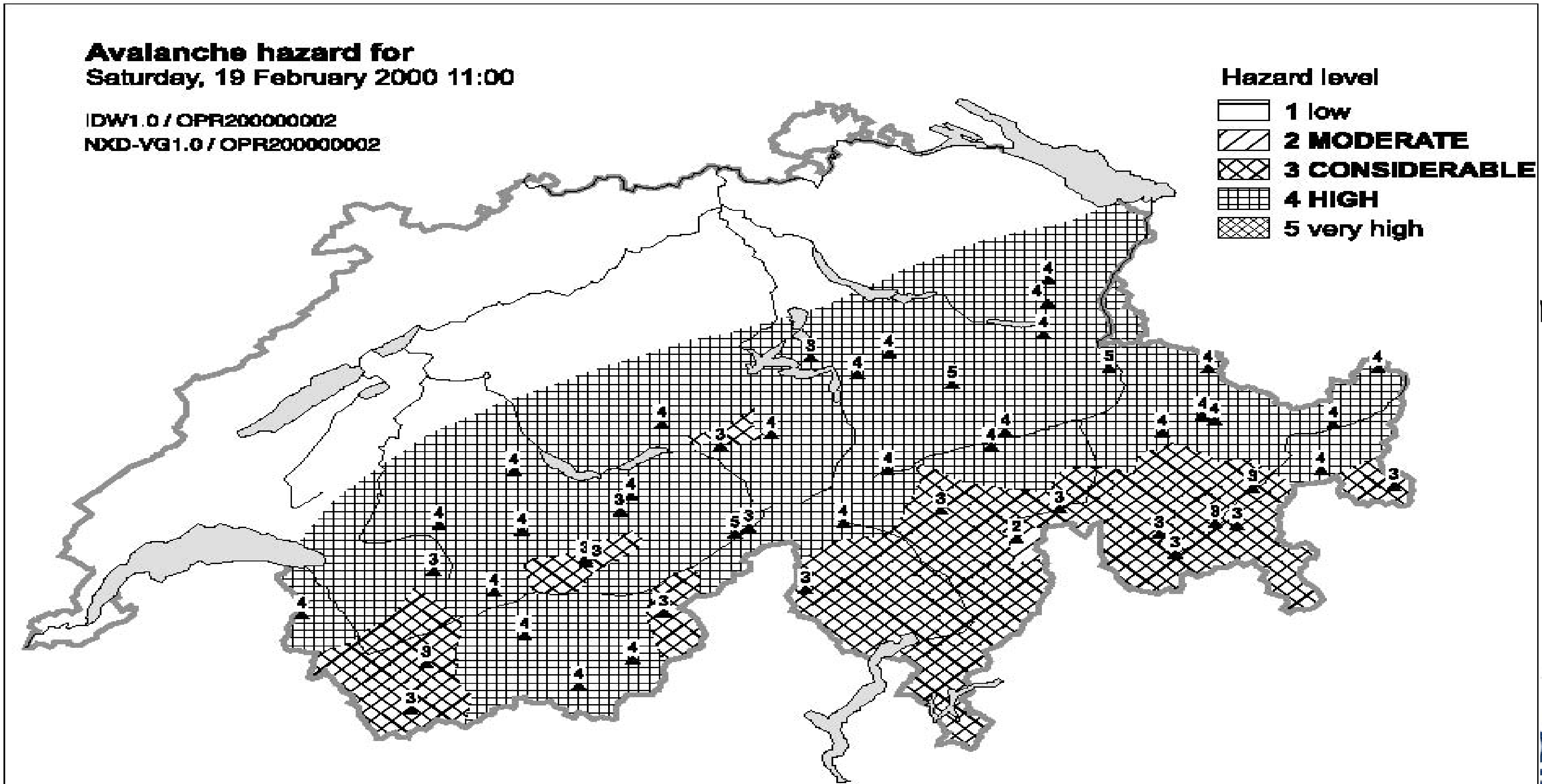


Datum	HW	NH24h	EINS	HS	Ts	TA	STreib	VW	DW	Bew.	Son	Strah
21.02.2000	14	22	73	274	13.2	-128	0	33.12	31.6	50	609	4995
22.03.1995	16	21	55	248	11	-130	3	31.484	36	25	645	5924
12.02.1994	7	11	55	207	16	-161	0	14.816	5	42	579	3721
07.01.1982	26	22	39	226	12	-149	0	18.52	29	33	456	2310
31.03.1997	8	6	90	228	8	-52	1	22.224	31	10	711	6967
18.12.1993	12	10	48	135	10	-28	0	20.372	21	13	492	1917
17.02.1991	21	24	53	152	14	-68	1	33.336	18	17	586	4004
01.01.1978	19	22	38	119	12	-95	0	40.744	29	38	69	2013.18
03.12.1981	8	15	60	144	12	-148	0	31.484	36	46	362	2038
15.02.1996	3	5	32	120	13	-123	0	25.928	36	10	591	4445
09.01.2001	7	11	50	132	6	-70	0	41.4	0	50	300	2135

Snow and hazard modelling : statistical approaches

NXD example at SLF

3 versions of this software have been developed :



Snow and hazard modelling : numerical models

SCM : the French regional avalanche forecasting tool

Meteorological Data : Observations,meteo model…

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Meteorological analysis

CROCUS

Snow model

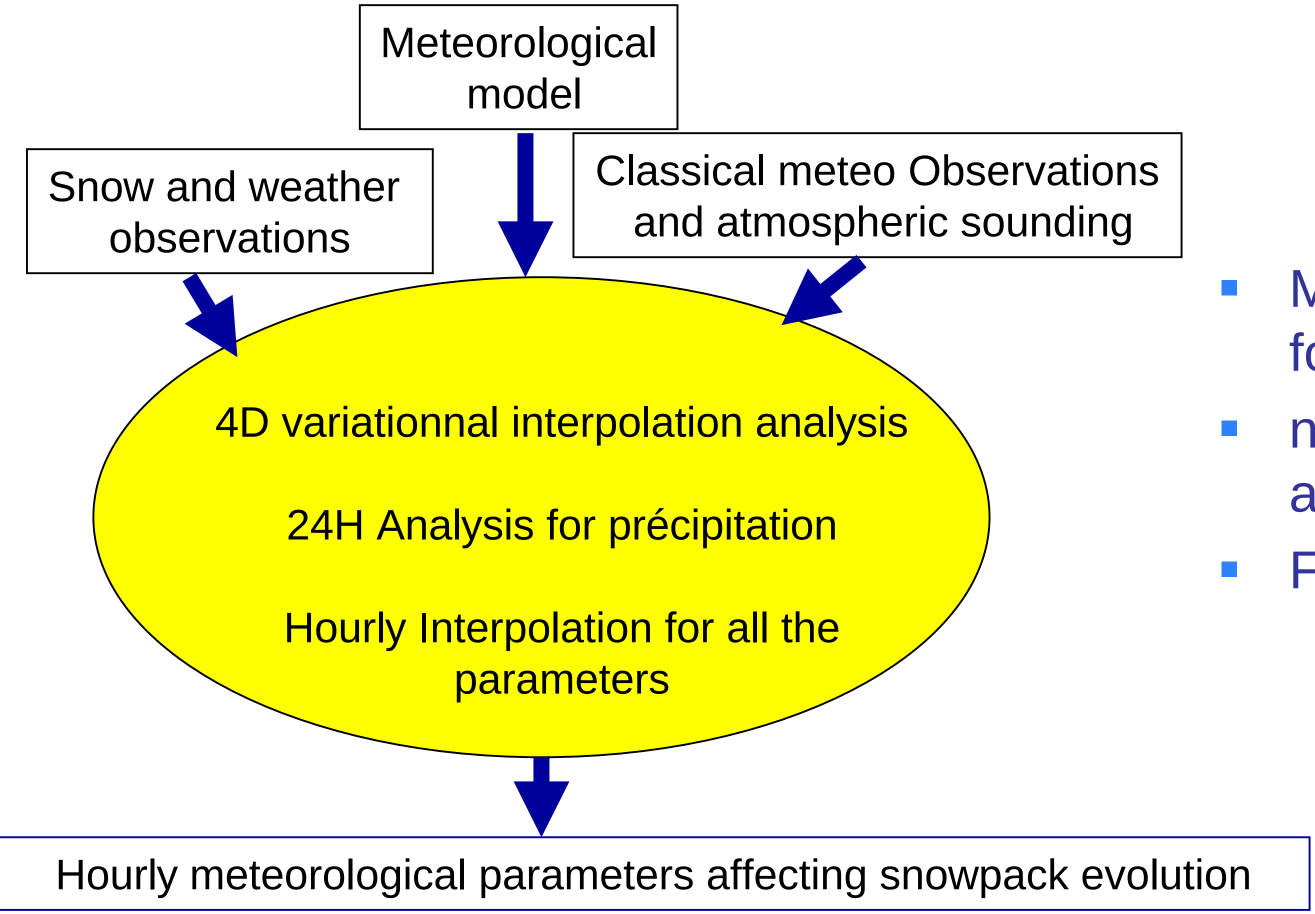
MEPRA

Expert system model

- Daily analysis and forecast the snow pack evolution by massif, elevation, aspect and slope

Snow and hazard modelling : numerical models

SAFRAN

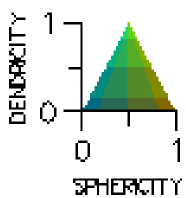


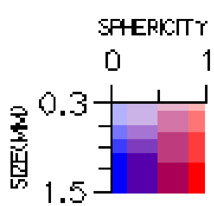
- Meteorological analysis for mountain regions
- notions of massif, altitude, aspect
- Forecast version

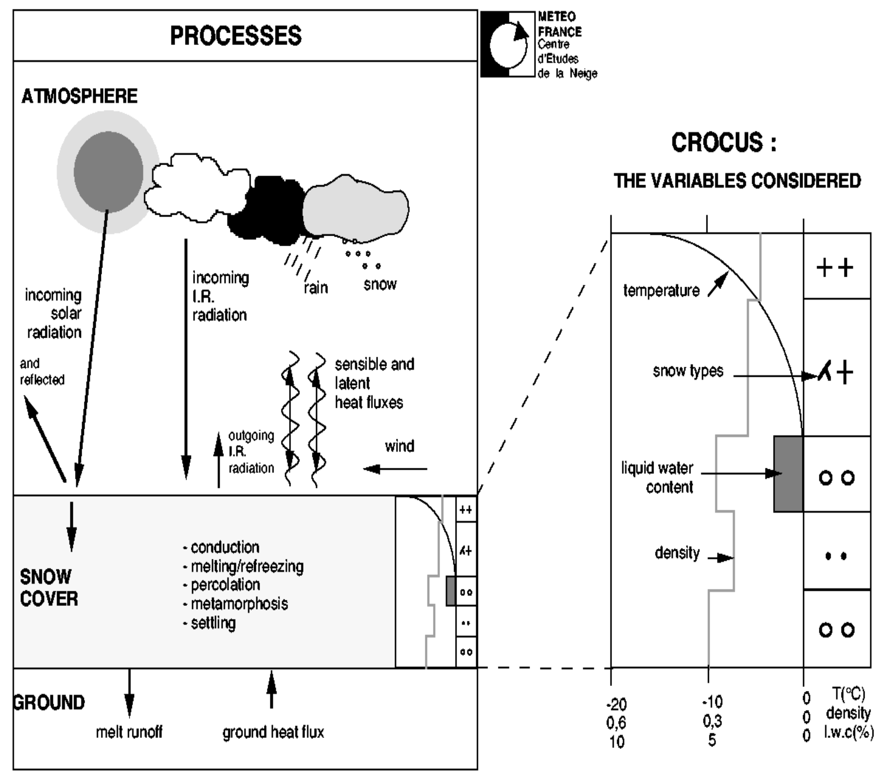
Snow and hazard modelling : numerical models

CROCUS : 1D Snow Model

- Simulation of the internal state of the snow pack
  - Temperature
  - Density
  - Liquid water content
  - Metamorphism and layering
- **One dimensional Model**





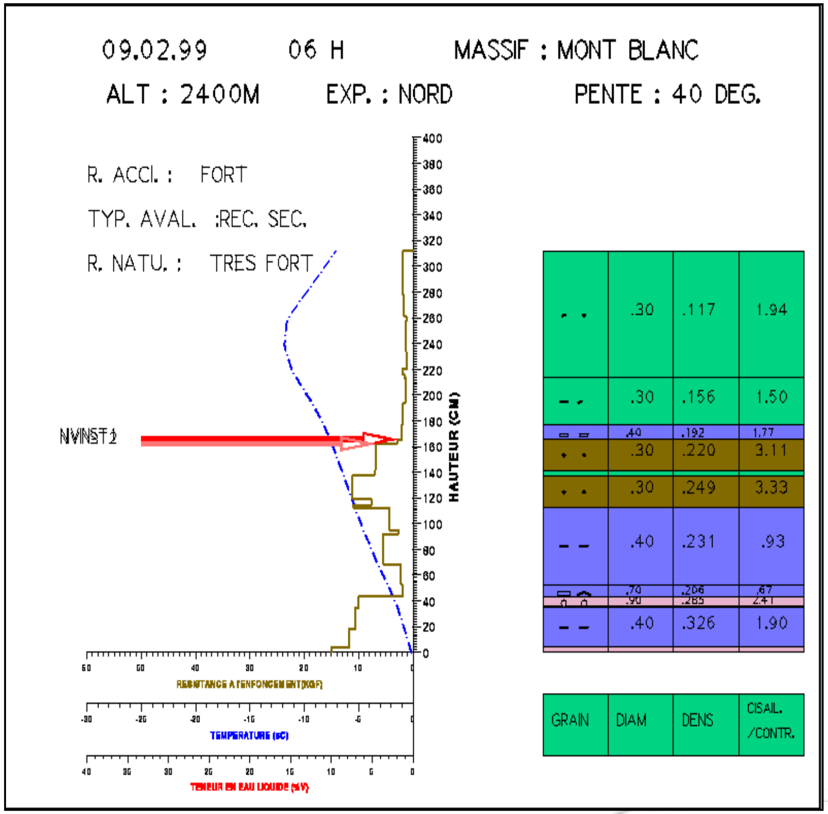


Snow and hazard modelling : numerical models

MEPRA

1D mechanical analysis

- Additional mechanical characteristics ,
- From ram resistance profile to shear strength profile



- Stability index $S = \frac{C}{\tau_n}$

  and $S' = \frac{C}{\tau_n + \tau_s}$

- Natural avalanche risk on a 6 level scale and accidental avalanche risk on a 4 level scale
- Avalanche types : wet, recent, mix

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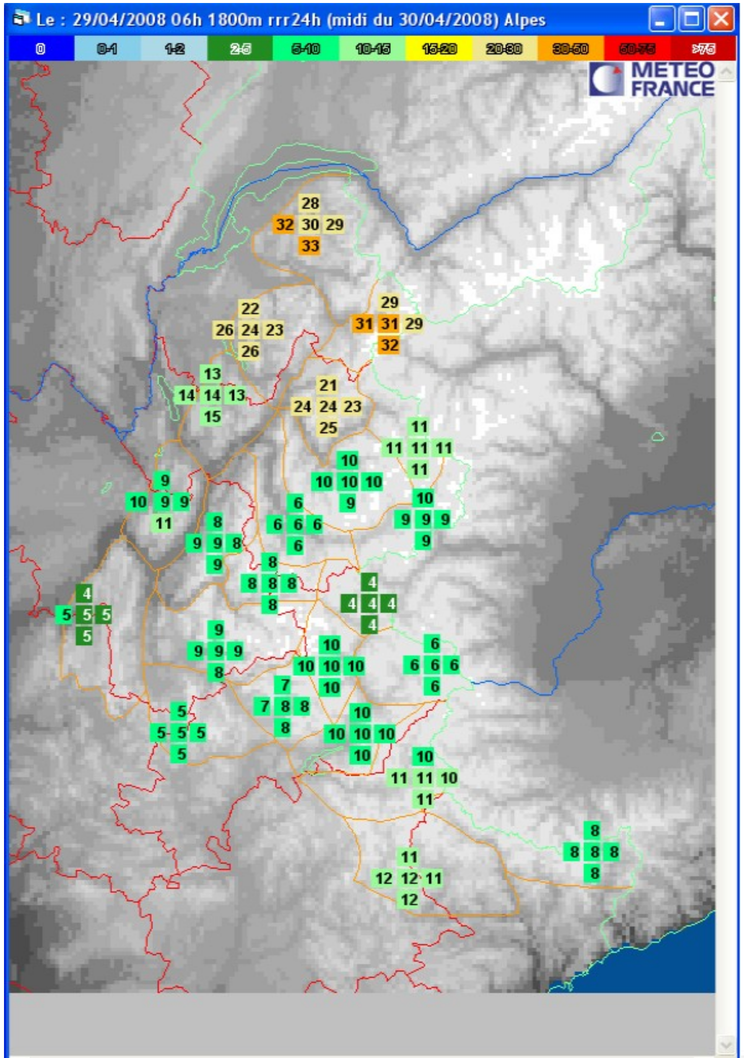
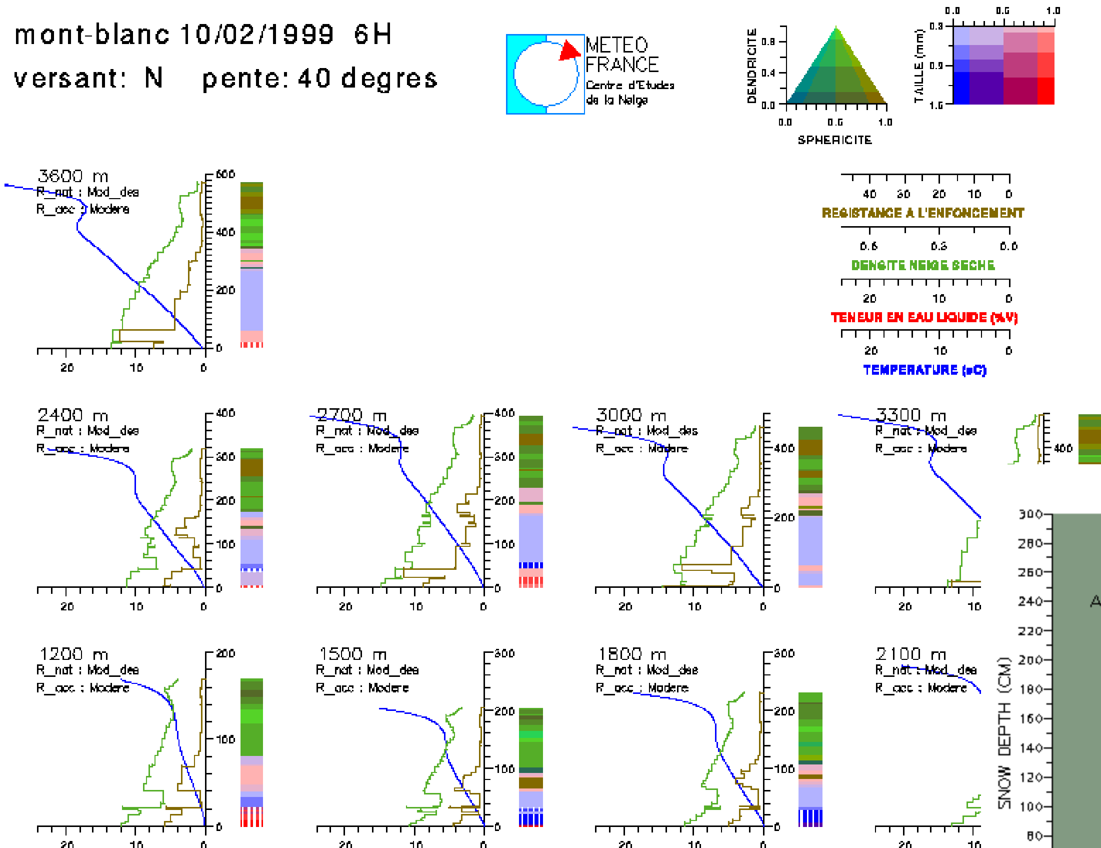
Snow and hazard modelling : numerical models

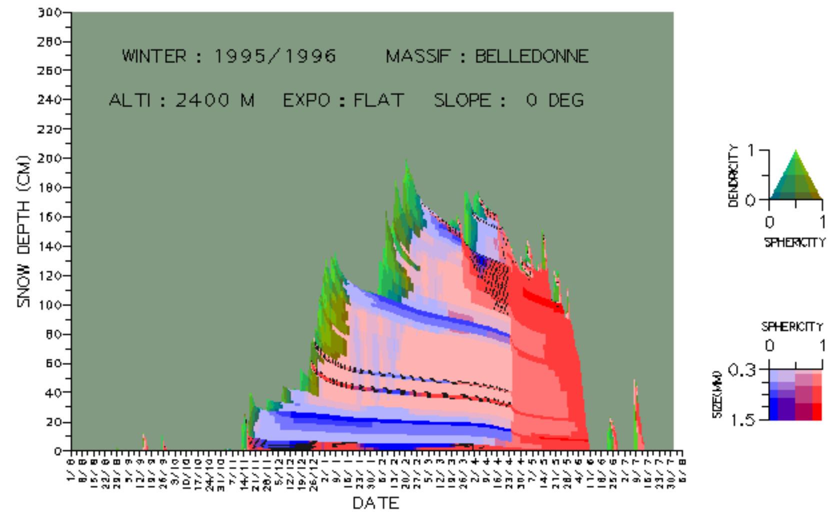
SAFRAN Results



Snow and hazard modelling : numerical models

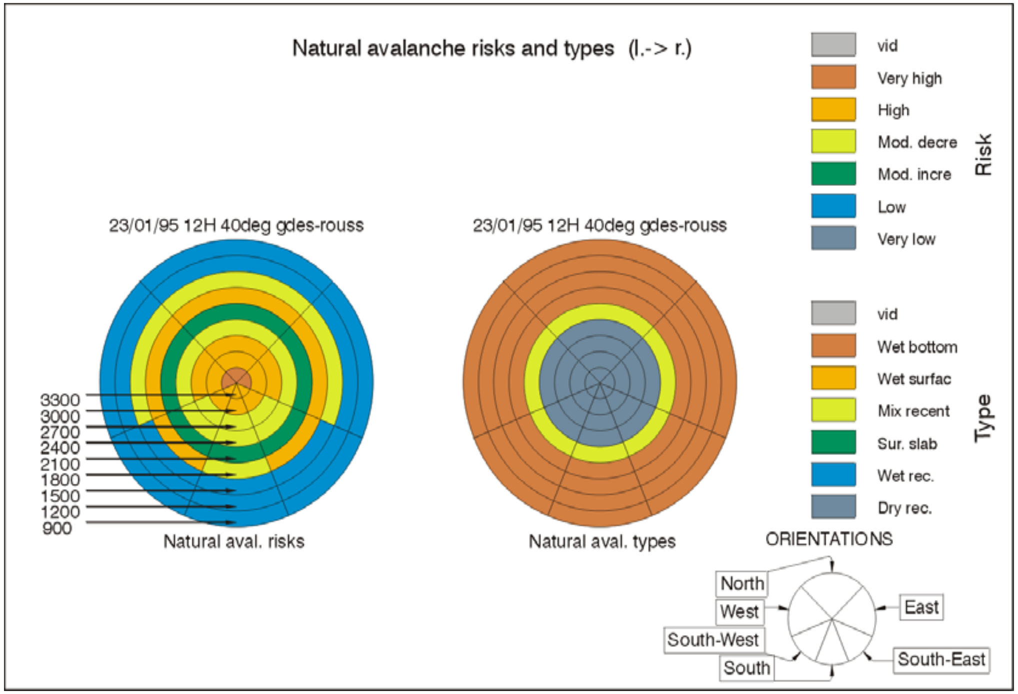
CROCUS results

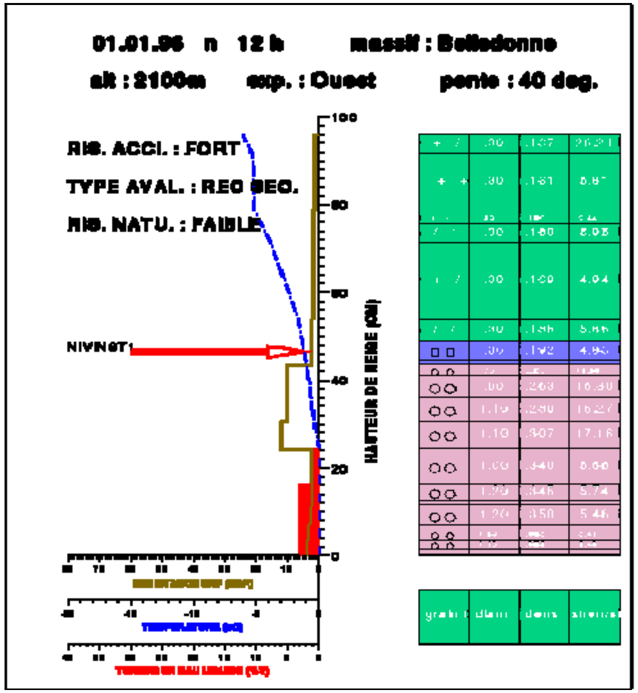




Snow and hazard modelling : numerical models

MEPRA results





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Snow and hazard modelling : numerical models

Other snow models

Models for avalanche forecasting :

SNOWPACK model: developed by SLF, notion of microstructure (bond size), wind pumping, surface hoar, snow drift index…

SNOWTHERM model : developed by CREEL (USA)

Models for hydrology, atmopherical circulation, climate …. :

CSIRO (Australia), CLASS (Canada), IAP94 (China), ISBA (France), TSCM (Japan), SPONSOR or SWAP (Russia), UKMO (UK) , VISA or SNOW-17 (USA)

Avalanche warning and forecasting methods

Avalanche forecasting = avalanche hazard for a given region
using the European avalanche risk scale + avalanche bulletin

Europäische Lawinengefahrenskala

Escala Europea de Perill d'Allaus

Medzinárodná stupnica lavínového nebezpecenstva

échelle Européenne de risque d'avalanche

	GB	SL	I	E	D	F	SK
1	low	majhna	debole	feble / débil	gering	faible	malé
2	moderate	zmerna	moderato	moderat / moderado	mäßig	limité	mierne
3	considerable	znatna	marcato	marcat / marcado	erheblich	marqué	zvýšené
4	high	velika	forte	fort / fuerte	groß	fort	veľké
5	very high	zelo velika	molto forte	molt fort / muy fuerte	sehr groß	très fort	veľmi veľké

Evropska petstopenjska lestvica nevarnosto proenja sneznih plazov

Escala Europea de peligro de aludes

European avalanche hazard scale

Scala Europea del pericolo di valanghe

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Avalanche warning and forecasting methods

Bavarian matrix

Lawinenwarnzentrale

Probaility of Avalanche Release

Distribution of Hazard Sites

	generally only with large surcharge	particularly with large surcharge (possibly also with small surcharge)	already with small surcharge **possible**	with small surcharge **probable**	or	Spontaneous release of samll avalanches possible	Spontaneous release of medium, in some cases large avalanches possible	Spontaneous release of many medium, in several cases large avalanches probable	Spontaneous release of many large avalanches probable
single hazard sites (specifiable in avalanche report *)	1	2	2	2		1	2		
hazard sites on **some steep slopes** (specifiable in avalanche report *)	2	2	3	3		2	3	3	
hazard sites on **many steep slopes** (specifiable in avalanche report *)	2	2	3	4		2	3	4	4
hazard sites on many steep slopes **)	2	3	4	4		3	4	4	5
Hazard sites **also in moderately steep slopes**				5			4	5	5

*) specifiable with respect to altitude, exposition and/or relief

**) the hazard sites are too numerous or too diffusely distributed to be specifiable with respect to altitude, exposition and/or relief

Auxiliary matrix for the avalanche report

02.06.2005

Remark:
This Matrix has been adopted as a working instrument by the European Avalanche Warning Services in Davos, 2005.
Fiels, which are still white, are not yet finally discussed.

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Avalanche warning and forecasting methods

Main avalanche hazard information in Europe

Not so different from one country to another with :

❖ a common daily avalanche bulletin with meteorological and snowpack stability information, an estimation of the avalanche risk (nowcasting and forecasting) at a regional or massif scale at least from December to April

❖ information about avalanche hazards, snow cover conditions, snow depths at # elevations, fresh snow accumulation… on country map (see web site on each country or www.avalanche.org)

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Avalanche warning and forecasting methods

Territorial organisation of avalanche hazard forecasting in Europe

Very different for one country to another depending often on administrative organisation with 2 main kinds :

❖ A system with a central office providing information on the whole country (Switzerland, Norway and France)

❖ A system based on the territorial organisation devoted to regional centres sometime depending on regional public administration (Italy, Austria…)

Avalanche warning and forecasting methods

New developments and technology

Surface or space remote sensed observations (mapping and zoning application, snow parameter observations…)

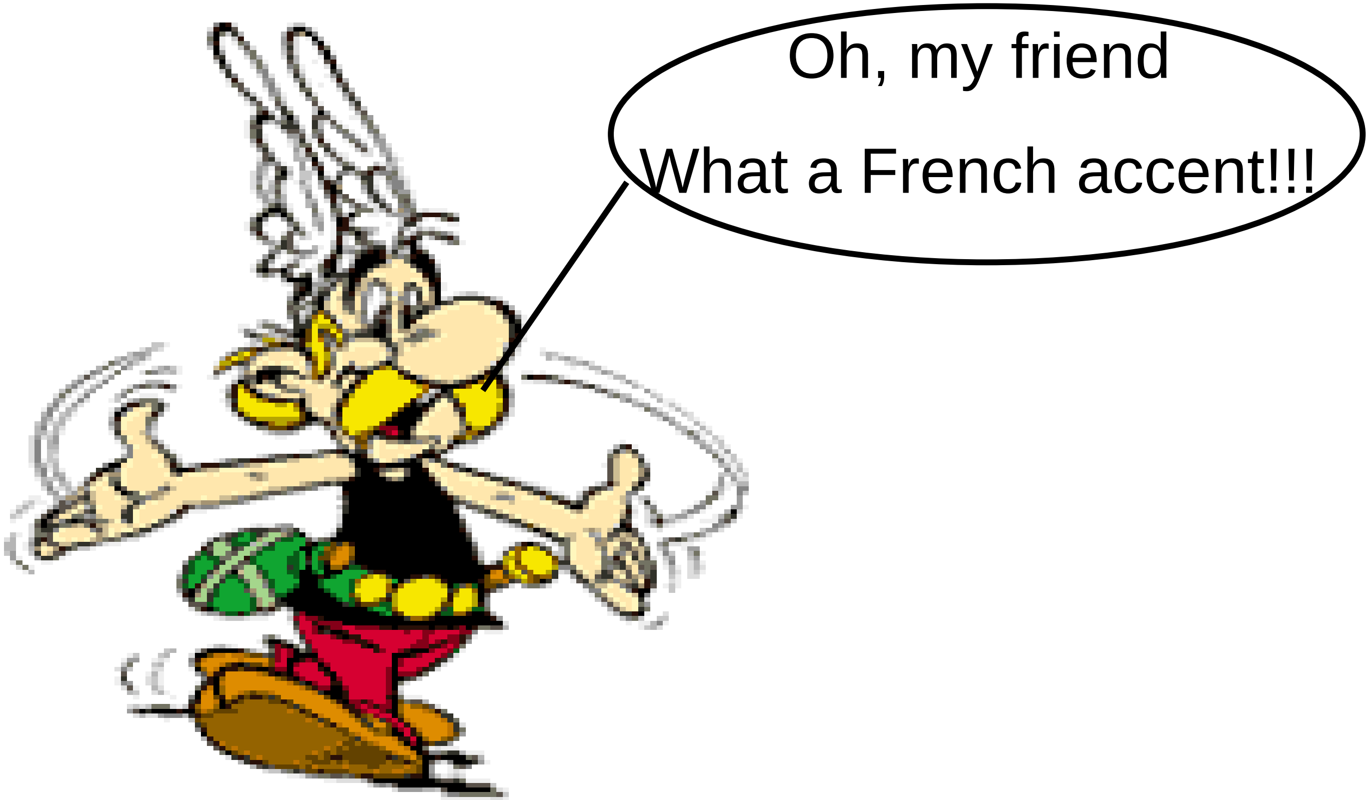
Numerical modelling of snow including snow drift at different scales

Snow microstructure and micro mechanic model

Development of dynamic numerical downscaling operators

3D macro mechanical modelling

END



Thanks for your attention and to all the European partners, a special thanks to the co-ordinator

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Snow and hazard modelling : numerical models

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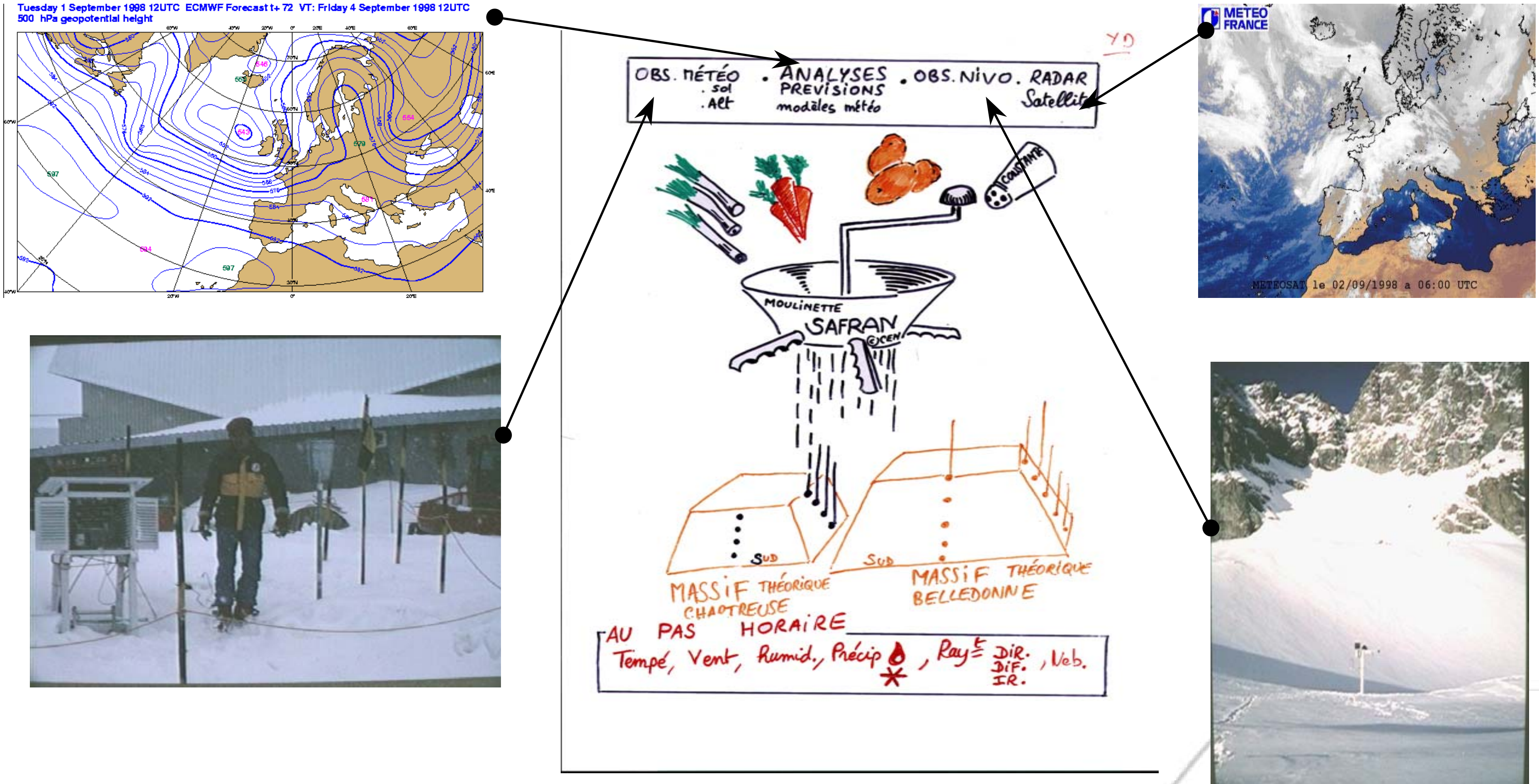
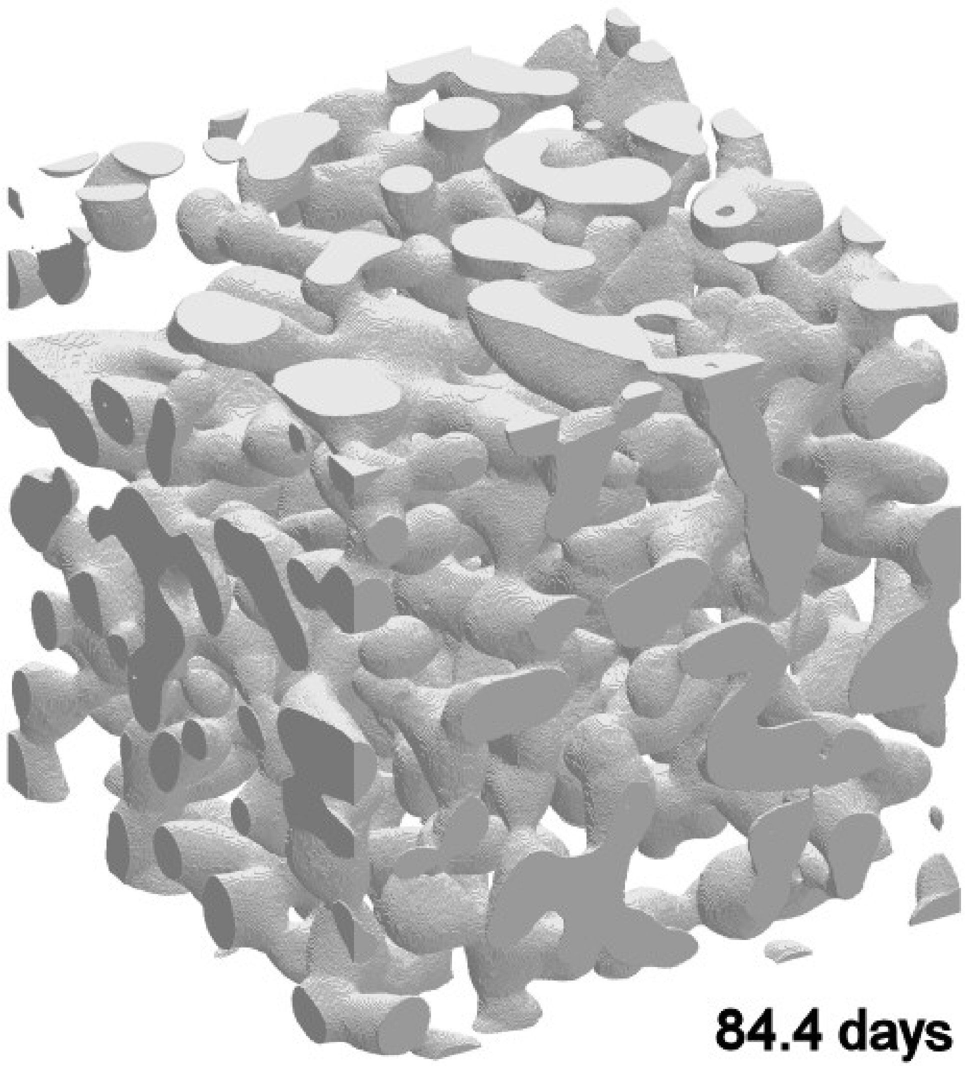
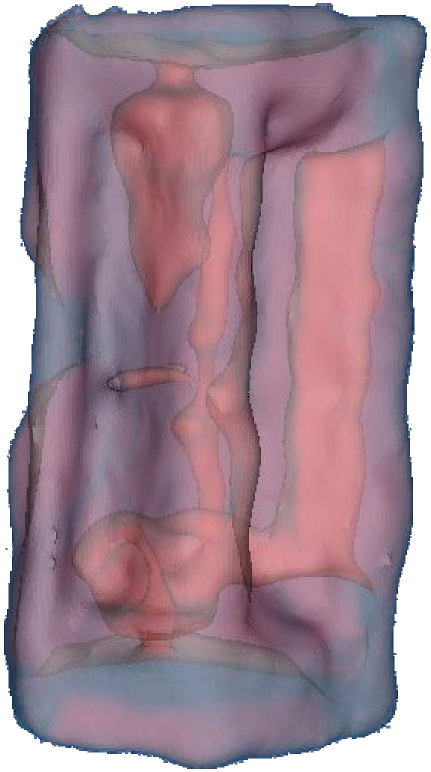


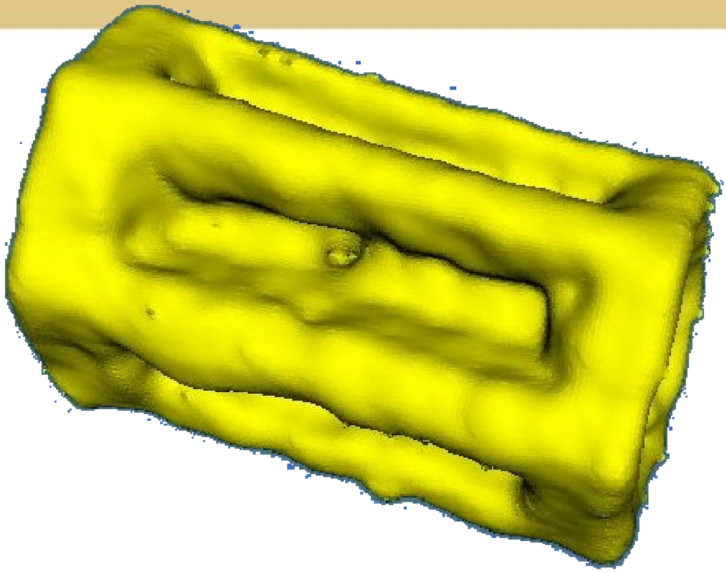
snow microstructural evolution under isothermal conditions



SNOW PROPERTIES and CRISTAL TYPES

3D X ray
microtomographic picture





METEO FRANCE
Toujours un temps d'avance

Snow and hazard modelling : numerical models

SafranCrocusMepra chain

- Valuable avalanche forecasting tool for regional forecasters : meteo, snow, stability and risks
- « analyse » mode with all the meteorological data
- 24 and 48 H forecast with the runs of the ARPEGE or ALADIN French meteorological model
- Validations :
  - Meteorological (Col de Porte, Lac Blanc)
  - Snow depths
  - Snow profiles
  - By the avalanche forecasters

METEO FRANCE
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