Modelling of the Seasonal Snow Cover: the Example of the Safran-Crocus-Mepra Tool

Pierre Etchevers and the CEN team

CNRM-GAME/Centre d’Etudes de la Neige

Introduction

- In most Europe and Northern America countries, avalanche forecasting is done at regional scale
- Information needed is real-time observations of snow state and surface meteorological parameters
- Based on observation networks (collected by forest services, ski resorts, guids, automatic stations,…)
- Main limitations :
  - Terrain variability => strong variability of meteo and snow (elevation, aspect, …)
  - Observation difficulties in alpine environment (low temperature, stong winds,…)
  - Observation systems : automatic (meteo, snow surface), manual (snow internal properties) or always in research field (snowdrift).

⇒ **Density of observed data very heterogeneous with regions, elevations, periods**

Introduction

How to improve the information available for regional forecaster ?

- To renforce the observation networks : costs limitation.
- In alpine environment, snowpack evolution is mainly controlled by meteorological parameters
- The French Meteorological Service has developed a tool based on meteorological input in order to estimate the snowpack characteristics
  - Complete geographical coverage (at model resolution)
  - Present state and evolution

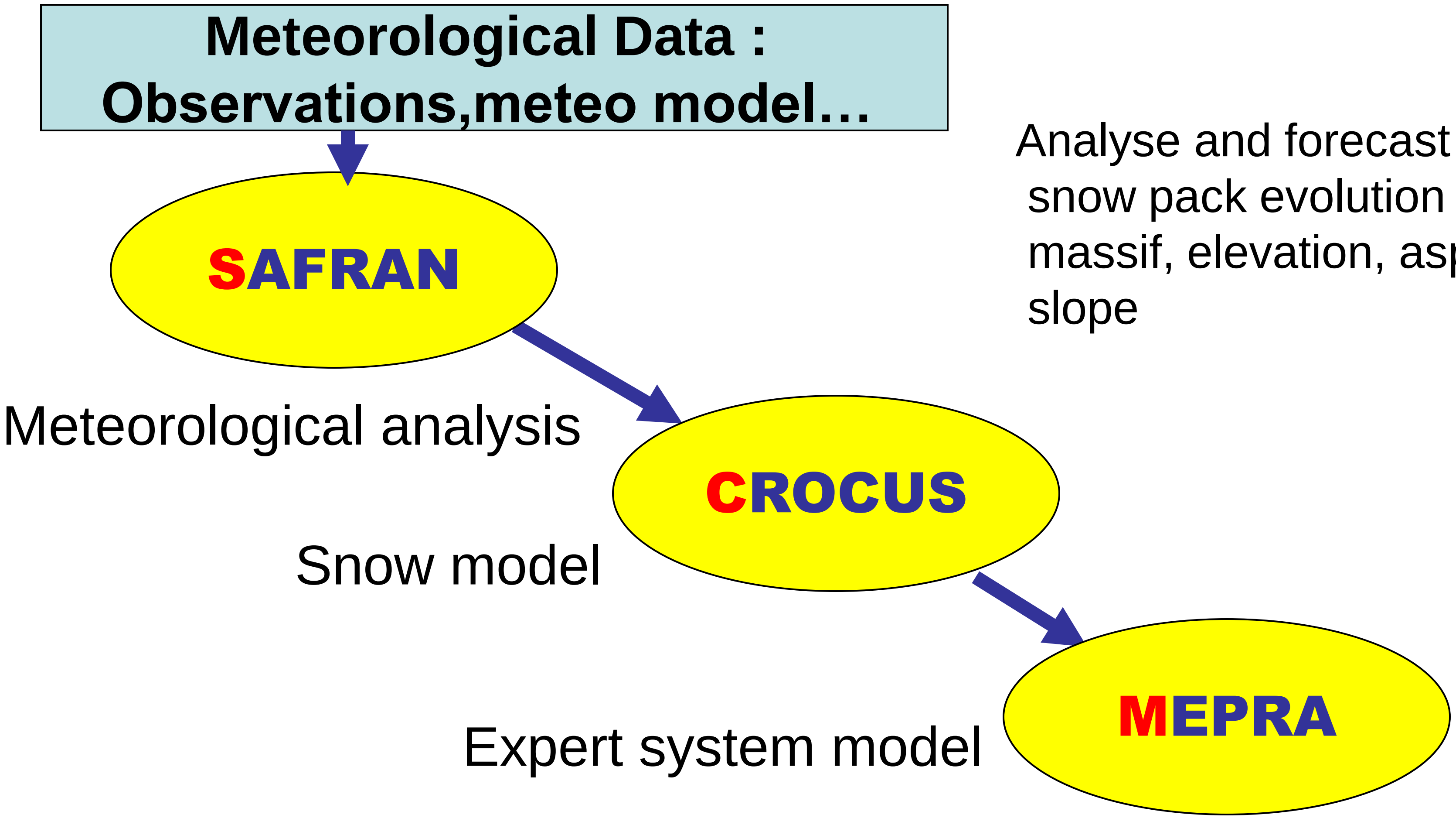
Overview

- The Safran-Crocus-MEPRA (SCM) suite
- Operational use
- Research applications
- Remote sensing outlook
- Conclusions

The Safran-Crocus-Mepra Tool

Regional avalanche forecasting tool

Durand et al., 1999



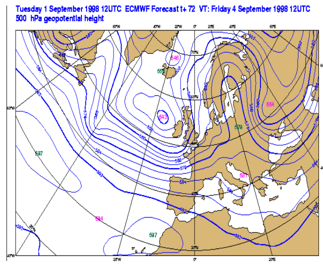
Analyse and forecast of the snow pack evolution by massif, elevation, aspect and slope

Main Characteristics/Limits of the SCM suite

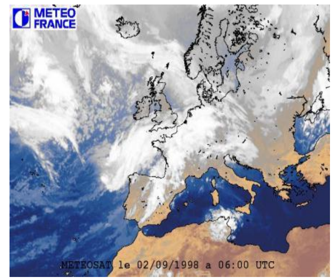
- **Homogeneous massifs** (~400 km2) with different elevations (~10), aspects (7) and slopes (3)
- No realistic orography but « idealized » slopes
- Hourly simulation of complete snow profiles (T, δZ, ρ, LWC, stratigraphy, stability) under the assumption that, for this scale, the snowpack evolution is completely controlled by the **atmospheric forcing**
- Analysis : input data limited to atmospheric data (no direct snowpack observations)
- Forecasting : based on Numerical Weather Prevision models ARPEGE / ALADIN (no local small scale features forcing)
- Rough simulation of snowdrift effects (change of fresh snow type)

SAFRAN

Durand et al., 1993



Meteorological NWP model



Fresh snow and weather Obs.

Classical meteo Observations and atmospheric sounding

Analysis /6H

24H Analysis for précipitation

Hourly Interpolation for all the parameters

Satellite

Radar (in dev.)

Hourly meteorological parameters affecting snowpack evolution

- Meteorological analysis for mountain regions
- notions of massif, altitude, aspect
- 2 days forecast version by adaptation of NWP models
- OI and variationnal methods used

•temperature and humidity
•wind velocity/ direction
•radiative fluxes
•snow and rain precipitation
•cloudiness

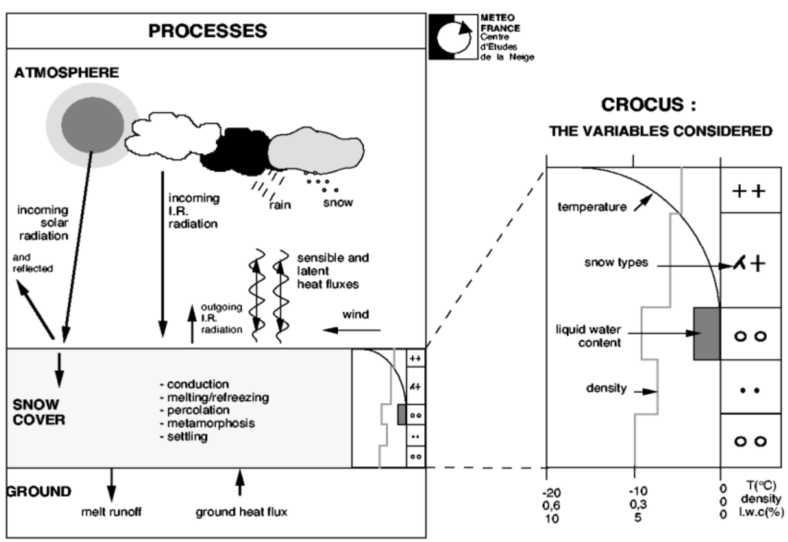
METEO FRANCE
Toujours un temps d'avance

CROCUS

Brun et al., 1989, 1992

- 1D numerical snow model
- Accurate snow stratigraphy (1 to 50 layers)
- Simulates snowpack main features, including albedo, snow grain size, liquid water content,...

Hourly meteorological parameters



CROCUS

Snowpack internal profile

METEO FRANCE
Toujours un temps d'avance

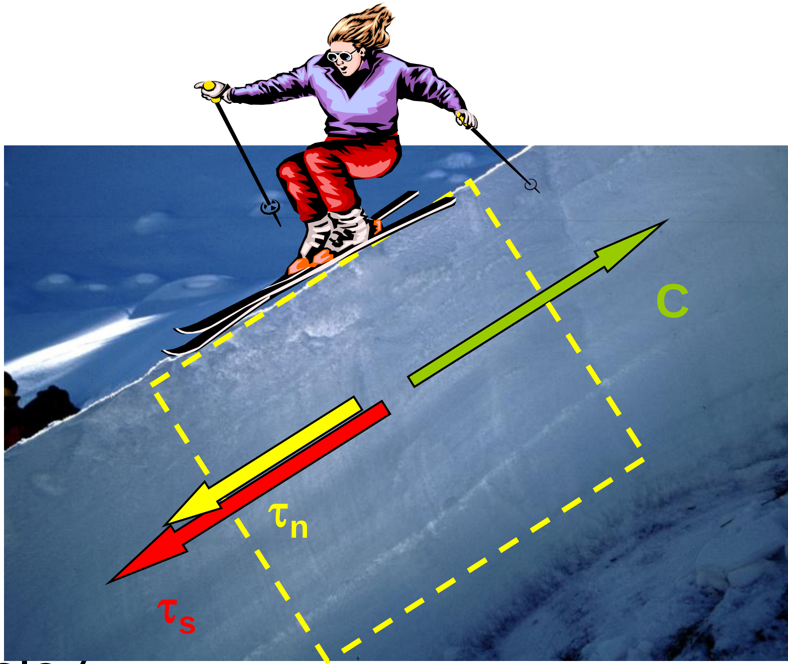
MEPRA

Giraud., 1995

1D mechanical analysis

- ***Additional mechanical characteristics*** : ram resistance profile, shear strength profile (C), estimation of the applied shear stress (τ_n for snow, τ_s for skier)

- ***Stabilty indexes***
  - Natural $$S = \frac{C}{\tau_n}$$
  - Accidental $$S' = \frac{C}{\tau_n + \tau_s}$$

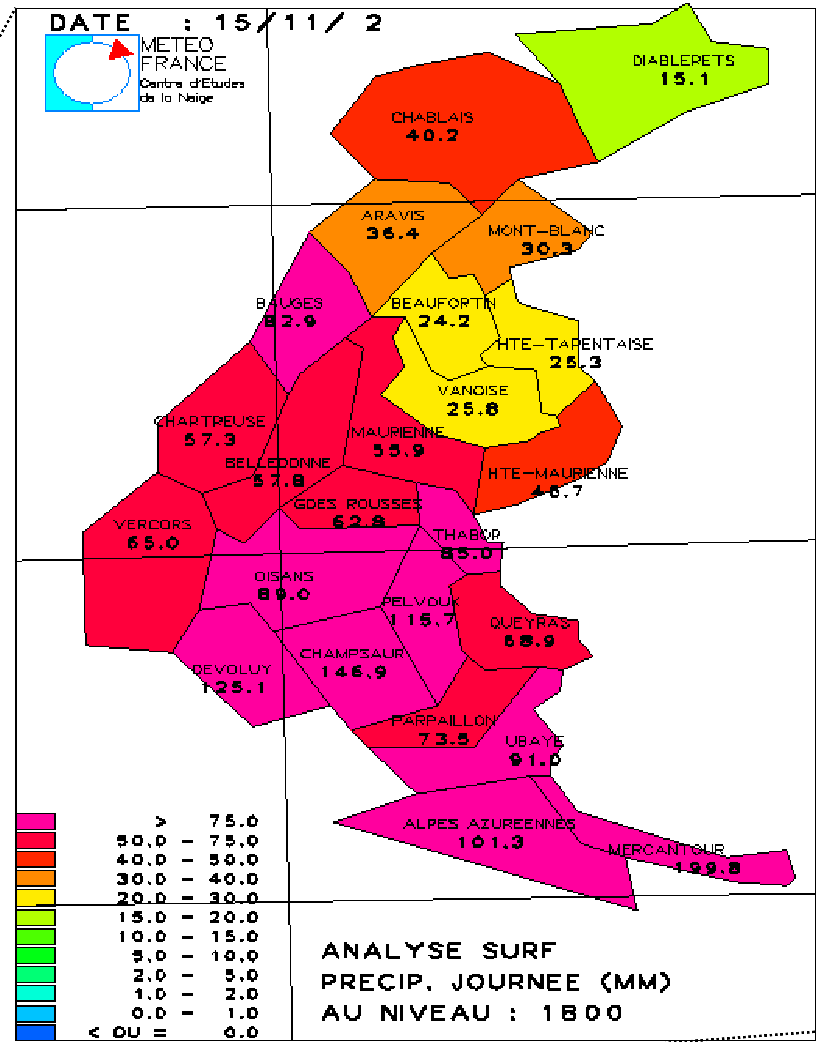


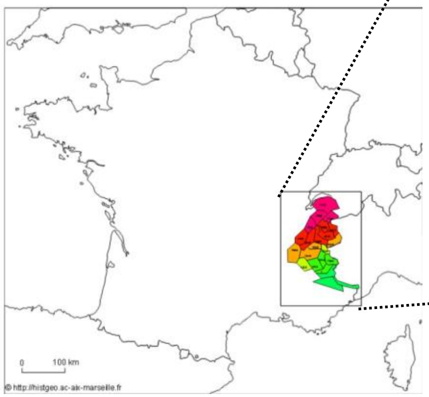
- ***MEPRA results*** :
  - Natural avalanche risk on a 6 level scale (very low, low, moderate increasing, moderate decreasing, high, very high)
  - Accidental avalanche risk on a 4 level scale (very low, low, moderate,high)
  - Avalanche types (fresh dry, fresh wet, fresh mixed, surface slab, surface wet, bottom wet)

Operationnal use and validation

SAFRAN results

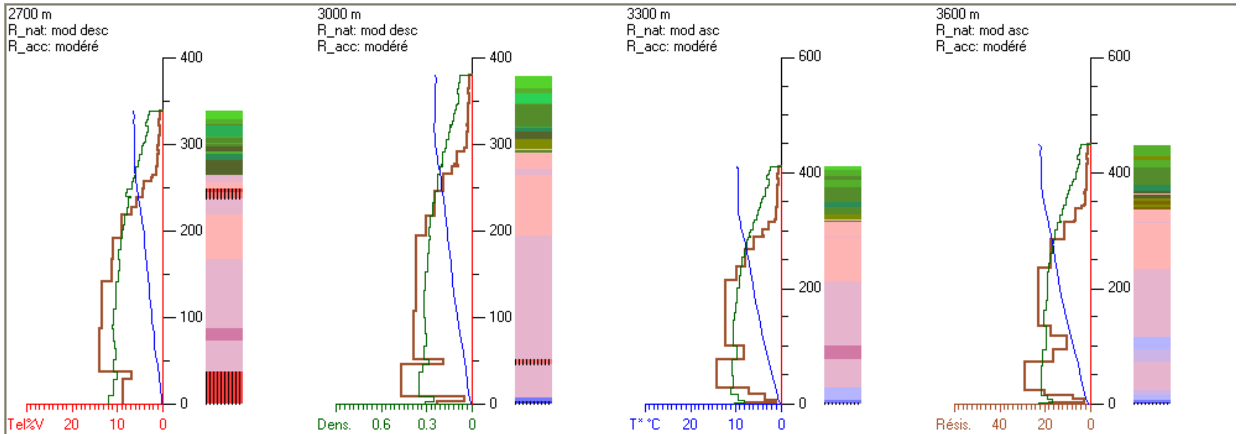
Analyzed daily precipitation for French Alps (23 massifs)

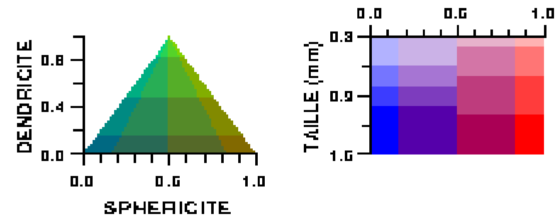




Crocus results : snowpack state

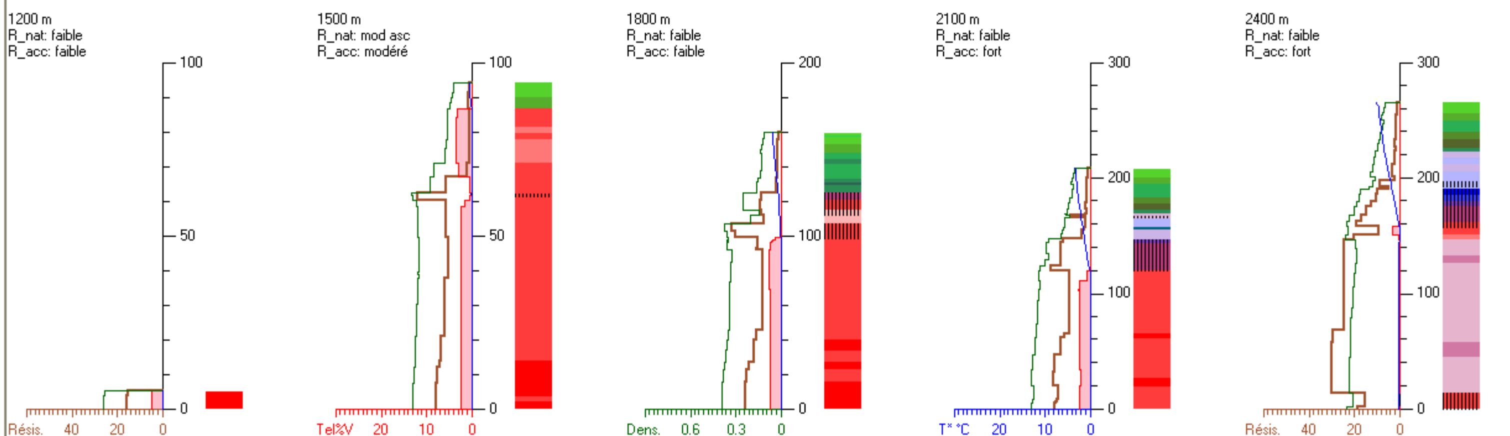
2700 m **3000 m** **3300 m** **3600 m**





Mont-Blanc North 40° 4th April 2010 6h

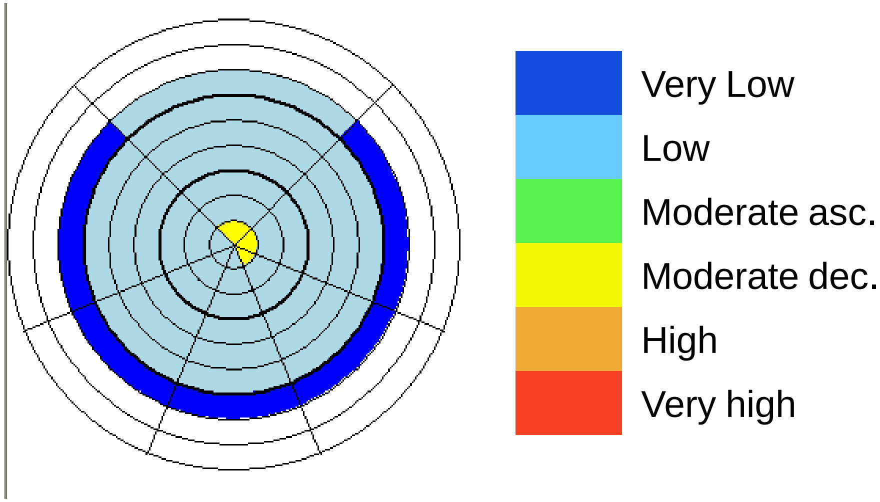
1200 m **1500 m** **1800 m** **2100 m** **2400 m**



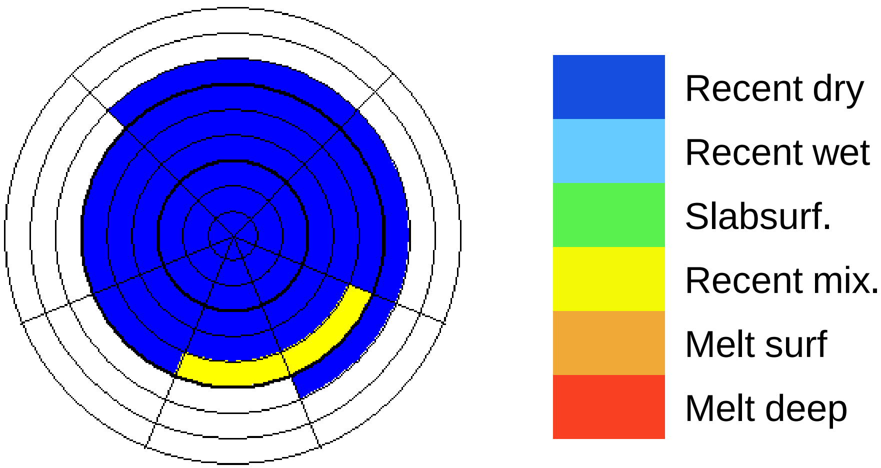
Mepra results

Natural avalanche hazard

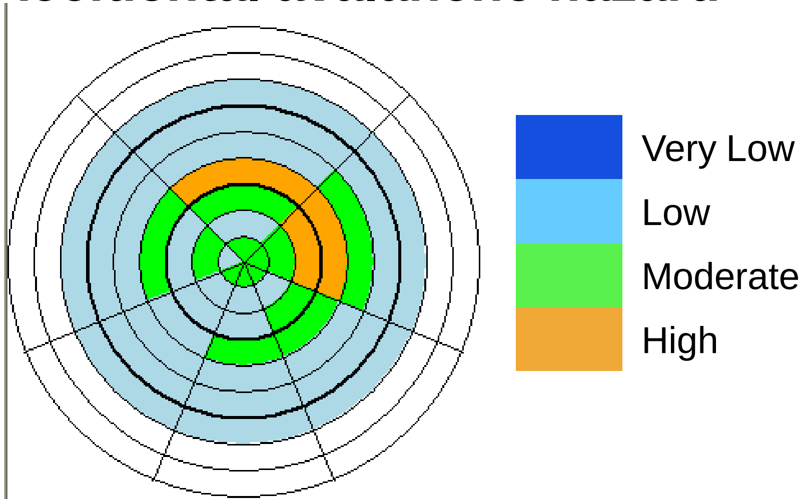
Belledonne 40° 06/04/2010 6h

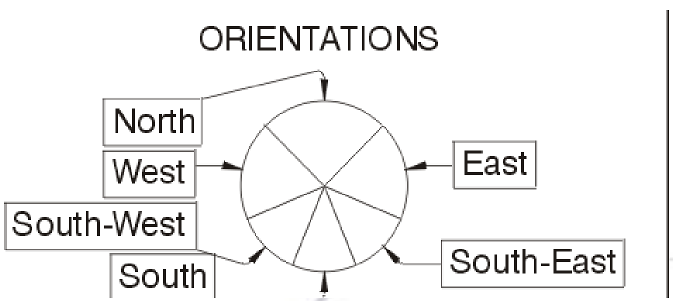


Avalanche Type



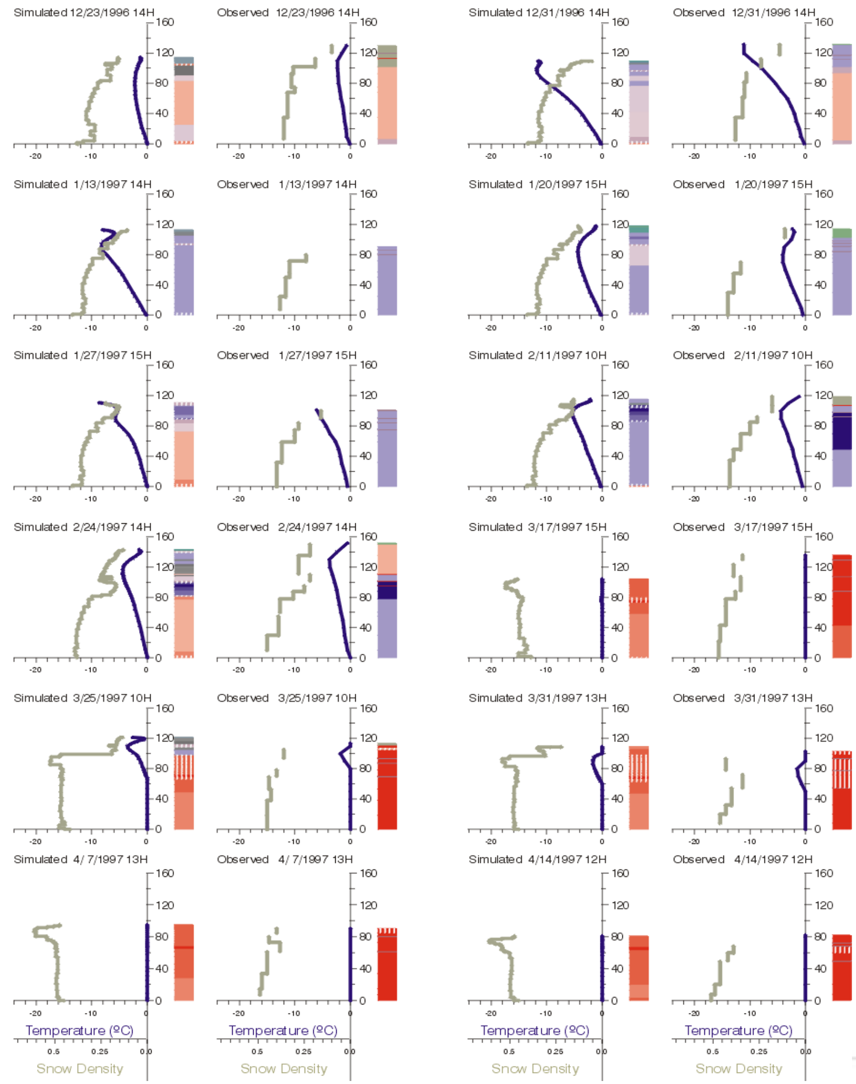
Accidental avalanche hazard





Validation

- Systematic validation of snow simulation by observed data (independent)
- Local validation of meteorological results
- Stability indexes validated by avalanche forecasters and ponctual comparison



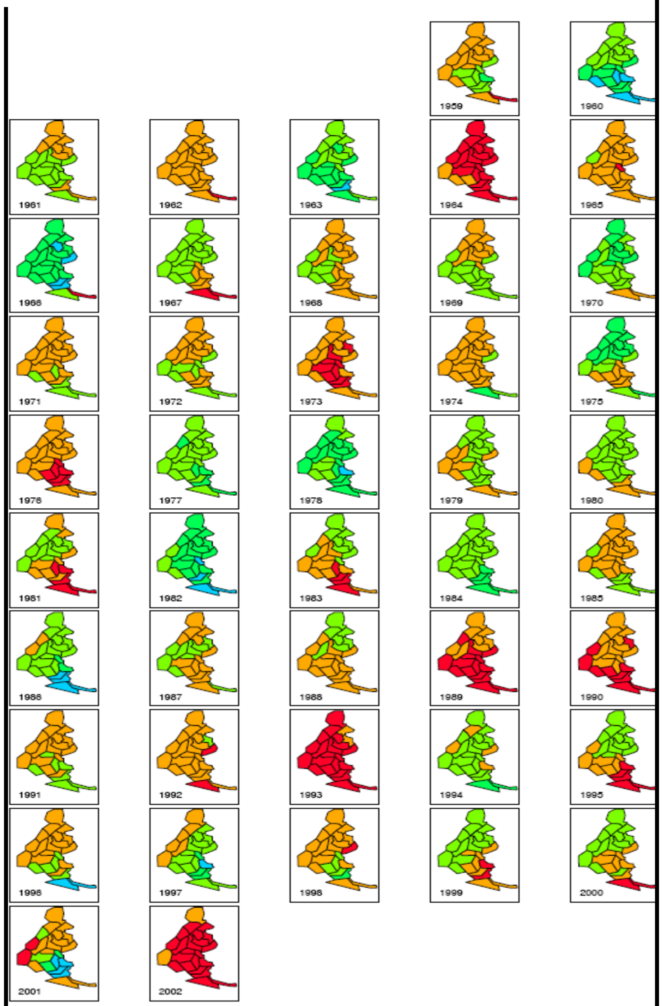
Snow profils comparison

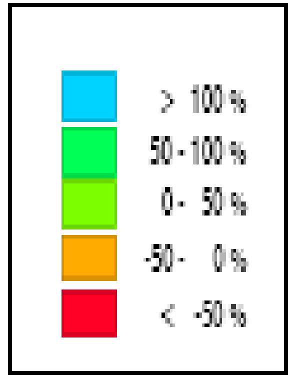
Research applications

Snow climatology

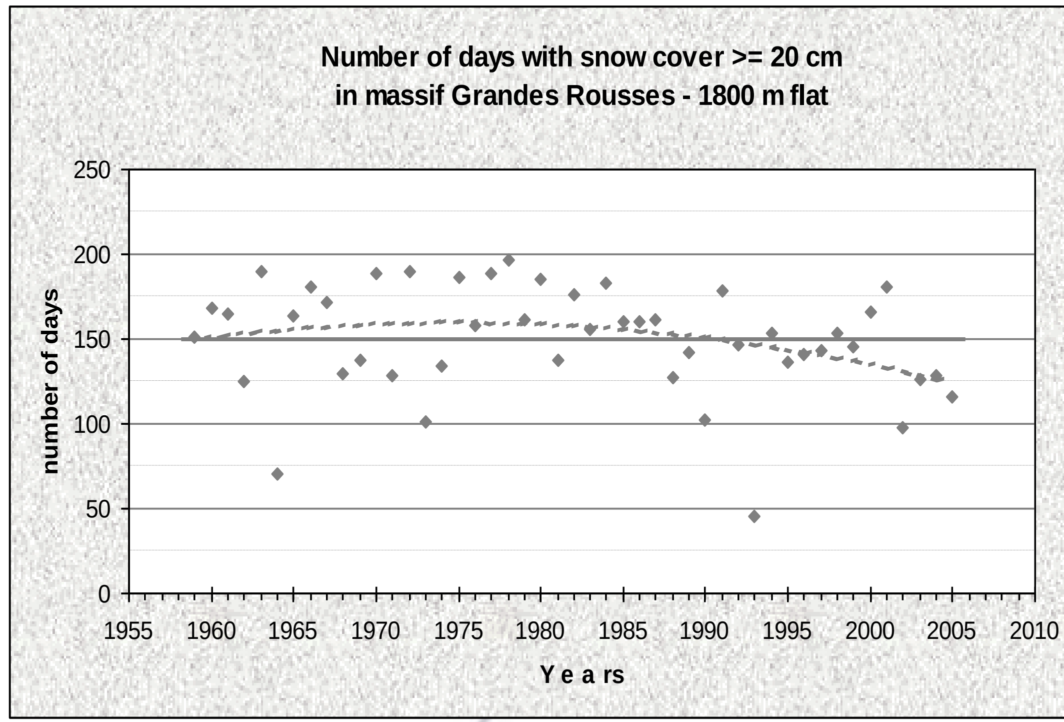
Durand et al.., 2009

Snow depth deviation from long-term mean (1800 m asl)





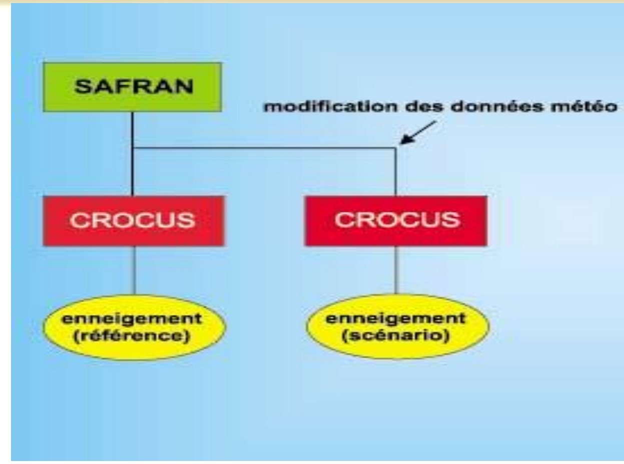
- Based on ERA 40 reanalysis
- Continuous met and snow series from 1958 to present



METEO FRANCE
Toujours un temps d'avance

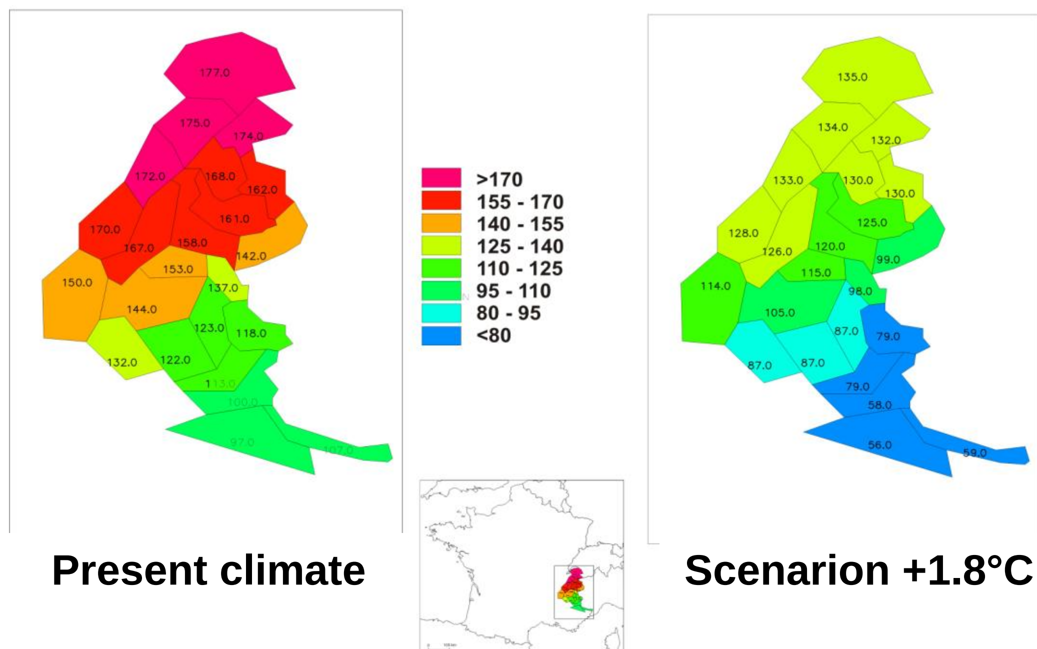
Snow and climate change

Martin et al.., 2001



- Impact on climate evolution on snowpack features (max snow depth, snow duration, snow extend,...) and hydrologic effects

Snow duration (1500 m)



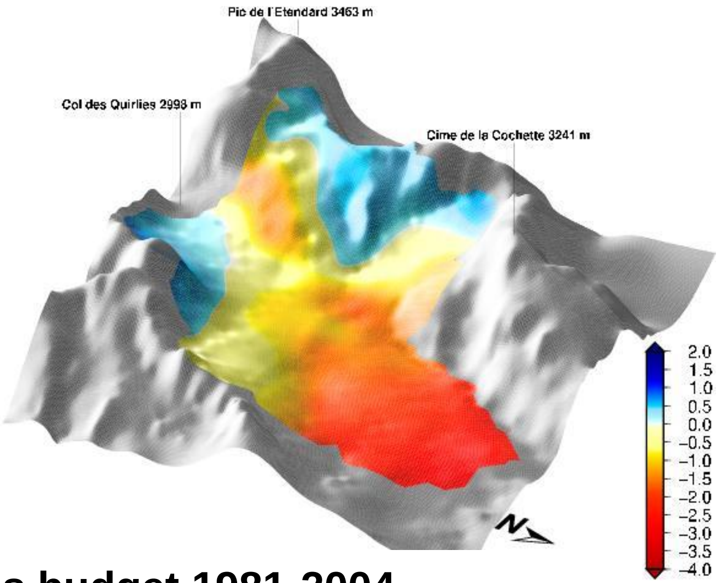
- Based on climatic scenarios produced by GCM

- Research projets (FP7-ACQWA, national programs)

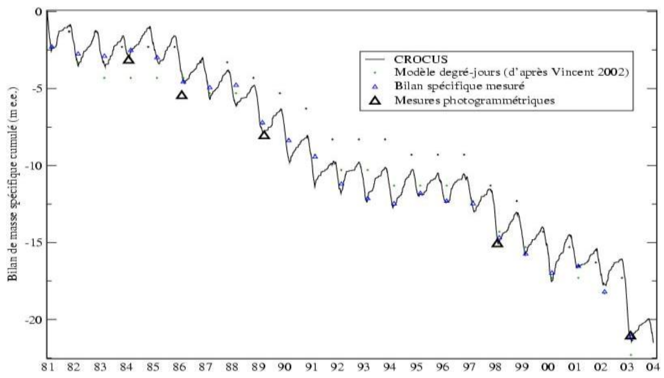
Hydrological and glacier modelling

Gerabaux et al.., 2005, Lejeune, 2009

- Distributed glacier mass and energy budgets modelling with Safran/Crocus : example of Saint-Sorlin glacier (resolution 1 day/30 m)



Mass budget 1981-2004



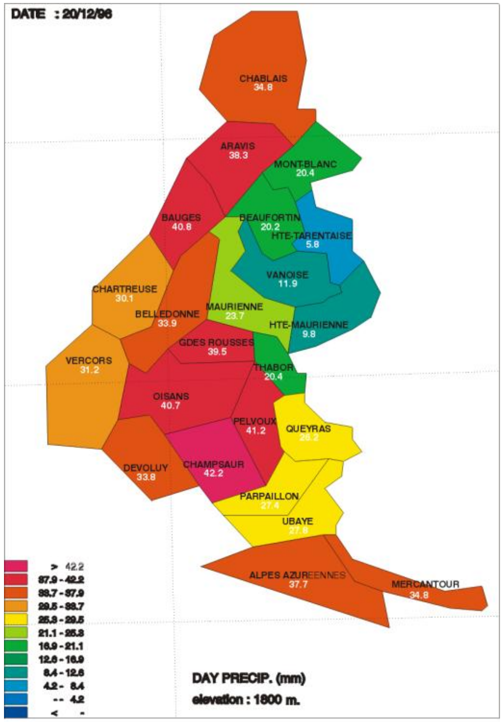
- Hydrological applications : see for instance poster "*Adaptations of a Physical-Based Hydrological Model for Alpine Catchments. Application to the Upper Durance Catchment*" presented by **M. Lafaysse**

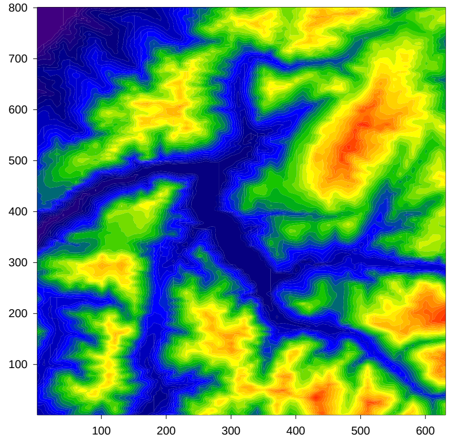
METEO FRANCE
Toujours un temps d'avance

Outlook and future developments

Increasing resolution

Downscaling





Massif scale : ~ 500 km^2

Time step : 1 hour

Symbolic topography

Local scale : ~ 1 km^2

Time step : 30 min

Fine scale orography

Avalanche path scale : ~ 100 m^2

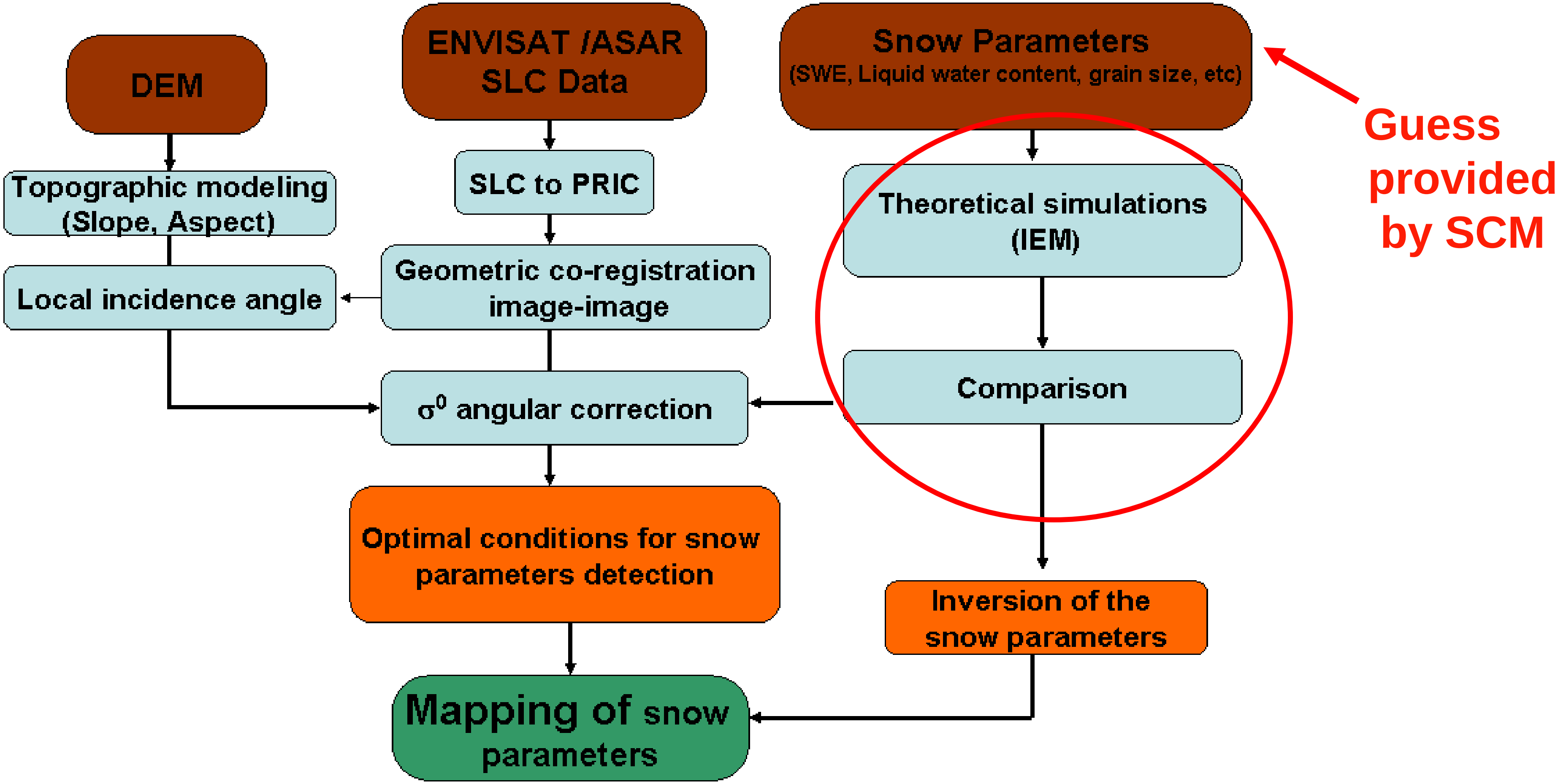
Time step : ~ 5 min

METEO FRANCE
Toujours un temps d'avance

Remote sensing data

- High spatial and temporal resolution
- Observations of snowpack properties (need of a model to be linked to snow physical properties)
- Visible range : snow surface properties (albedo, grain size)
- Radar range : snowpack internal properties (density, SWE, liquid water content,...)
  - C, X, Ku band, full polar
- Example of application with the ENVISAT data

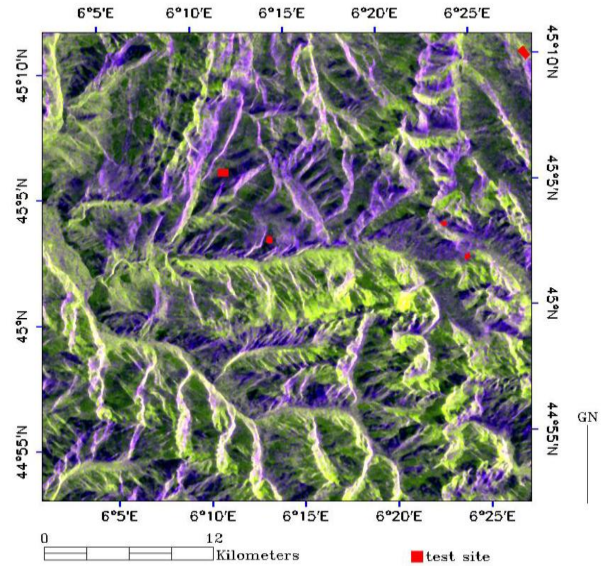
General principle

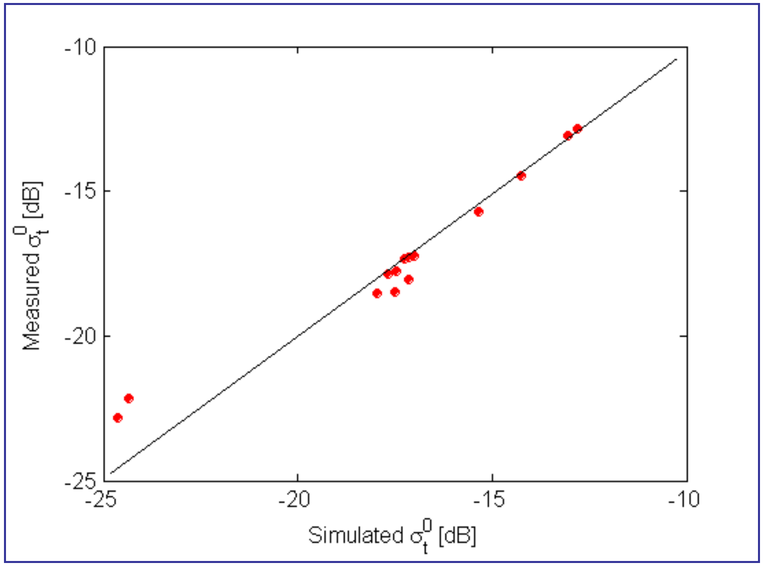


Results

Niang et al.., 2007

Results obtained with ENVISAT/ASAR data (C band , HH VH)





	sites	Densité (crocus)	TEL (crocus)	TEL (terrain)	TEL (descente)	Écart en TEL	densité (terrain)	Densité (descente)	Écart en densité	Nbres itérations
08-avr-04	Lautaret	410,75	0,0035	0,028	0,017	1,14E-02	387,343	431,570	44,227	3
	Besse	372,1	0,0036	0,018	0,013	5,14E-03	381,594	389,700	8,106	3
	Lac noir	303,69	0	0,014	0,018	4,41E-03	322,710	365,550	42,840	5
13-mai-04	Lautaret	444,22	0,0085	0,051	0,063	1,15E-02	535,104	471,420	63,684	11
	Besse	473,04	0,0095	0,034	0,031	3,48E-03	485,152	417,150	68,002	7
	Galibier	371,72	0,0072	0,023	0,019	3,72E-03	400,605	475,1	74,495	43
	Rochilles	371,72	0,0072	0,043	0,023	1,95E-02	414,429	439	24,571	17

Outlook of ENVISAT data inversion

- Feasibilty of the inversion for snow density and liquid water content

- Improvements
  - Need of validation of the direct model with more accurate data (SAR, full polar)
  - Inversion of remote sensing data using a sophisticated snow model (2 or more layers)

- Future developments
  - Snowpack charateristics mapping in alpine context
  - Large scale information (provided by models like SCM suite) mixed with small scale information (derived from microwave satellite sensors)

Conclusions

Conclusions

- SCM: valuable avalanche forecasting tool for regional forecasters : meteo, snow, stability
- Research tool for snow-linked applications : snow hydrology, snow climatology, glacier modelling
- Downscaling mprovement : strong interest in remote sensing data in order to increase the modelling resolution and to add small scale information

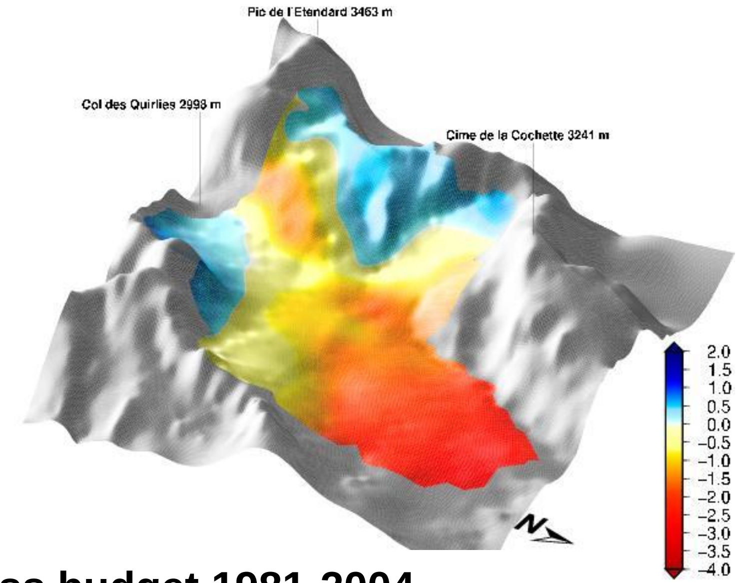

Thank you for your attention !

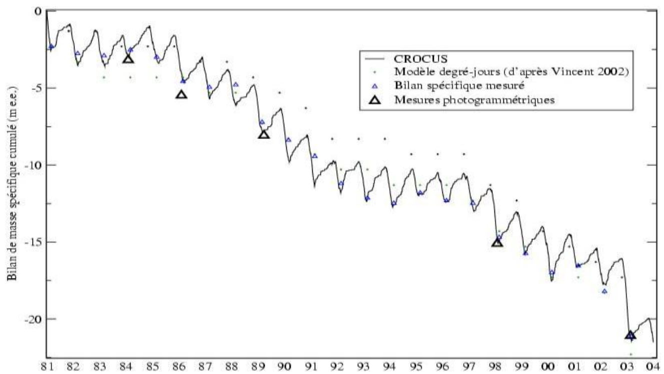
METEO FRANCE
Toujours un temps d'avance

Hydrological and glacier modelling

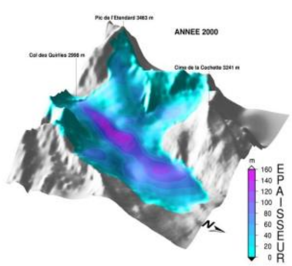
Gerabaux et al.., 2005, Lejeune, 2009

- Distribued mass and energy budgets modelling with Safran/Crocus : example of Saint-Sorlin glacier (resolution 1 day/30 m)

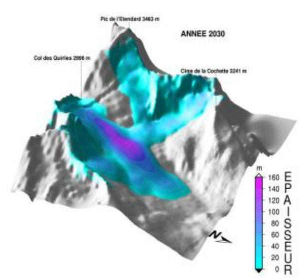




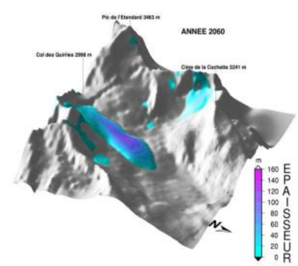
Mass budget 1981-2004



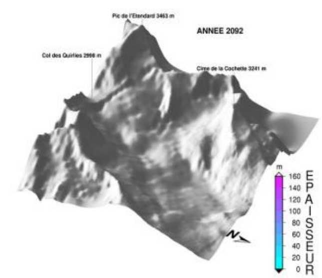
2000



2030



2060



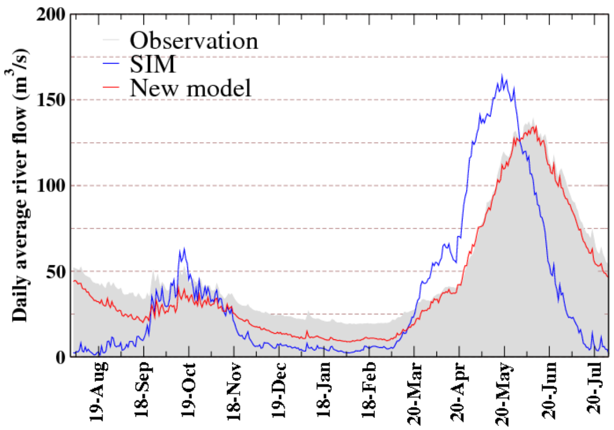
2090

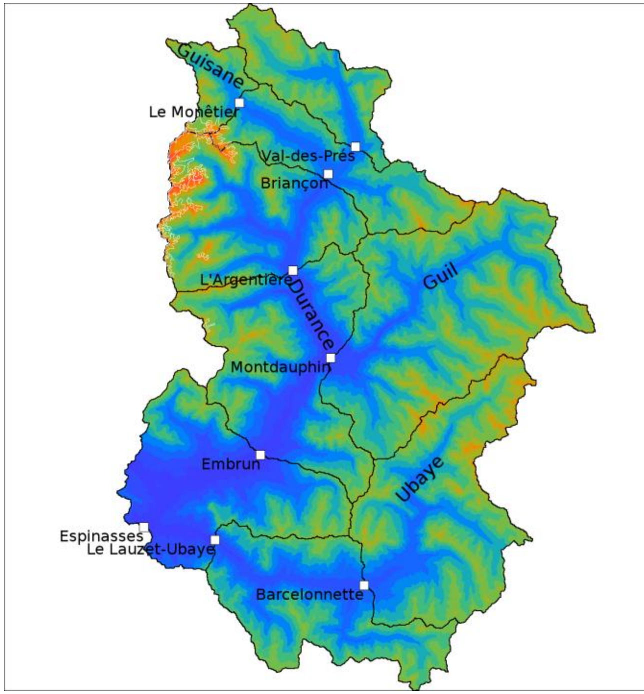
Hydrological applications

Etchevers et al.., 2001, Starsser and Etchevers 2002

- Distributed modelling of high alpine cachtments : snowpack, water ressources, river discharges
- Safran – (Crocus) - Isba / Resolution : 1 day / 5 km
- See for instance :

  Poster “*Adaptations of a Physical-Based Hydrological Model for Alpine Catchments. Application to the Upper Durance Catchment*“ presented by **M. Lafaysse**

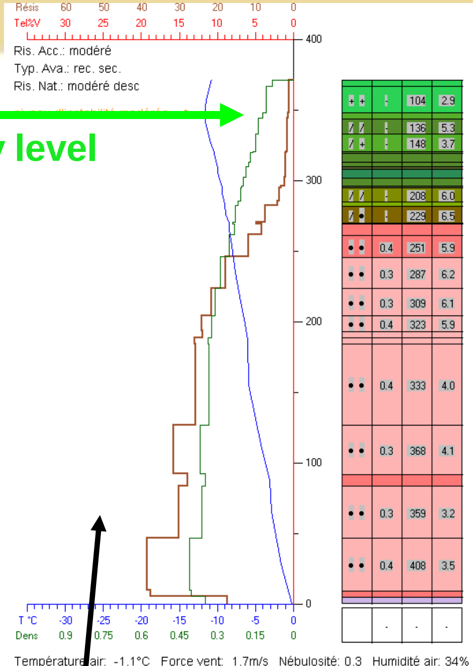




Mepra results

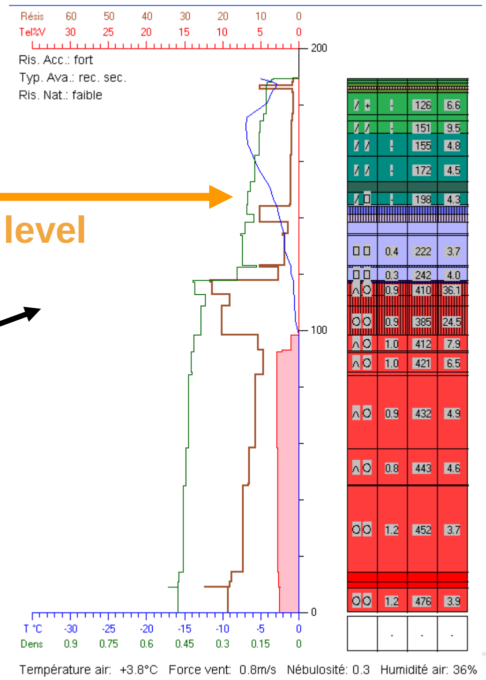
Belledonne 40° 06/04/2010 6h

3000 m



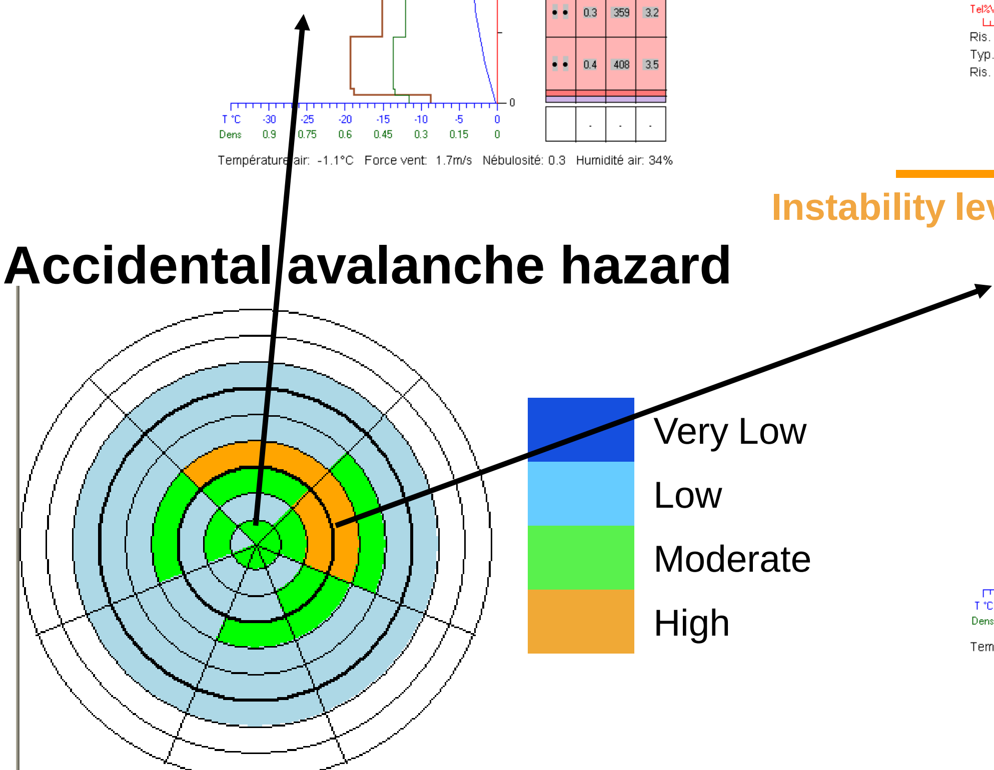
Instability level

2100 m



Instability level

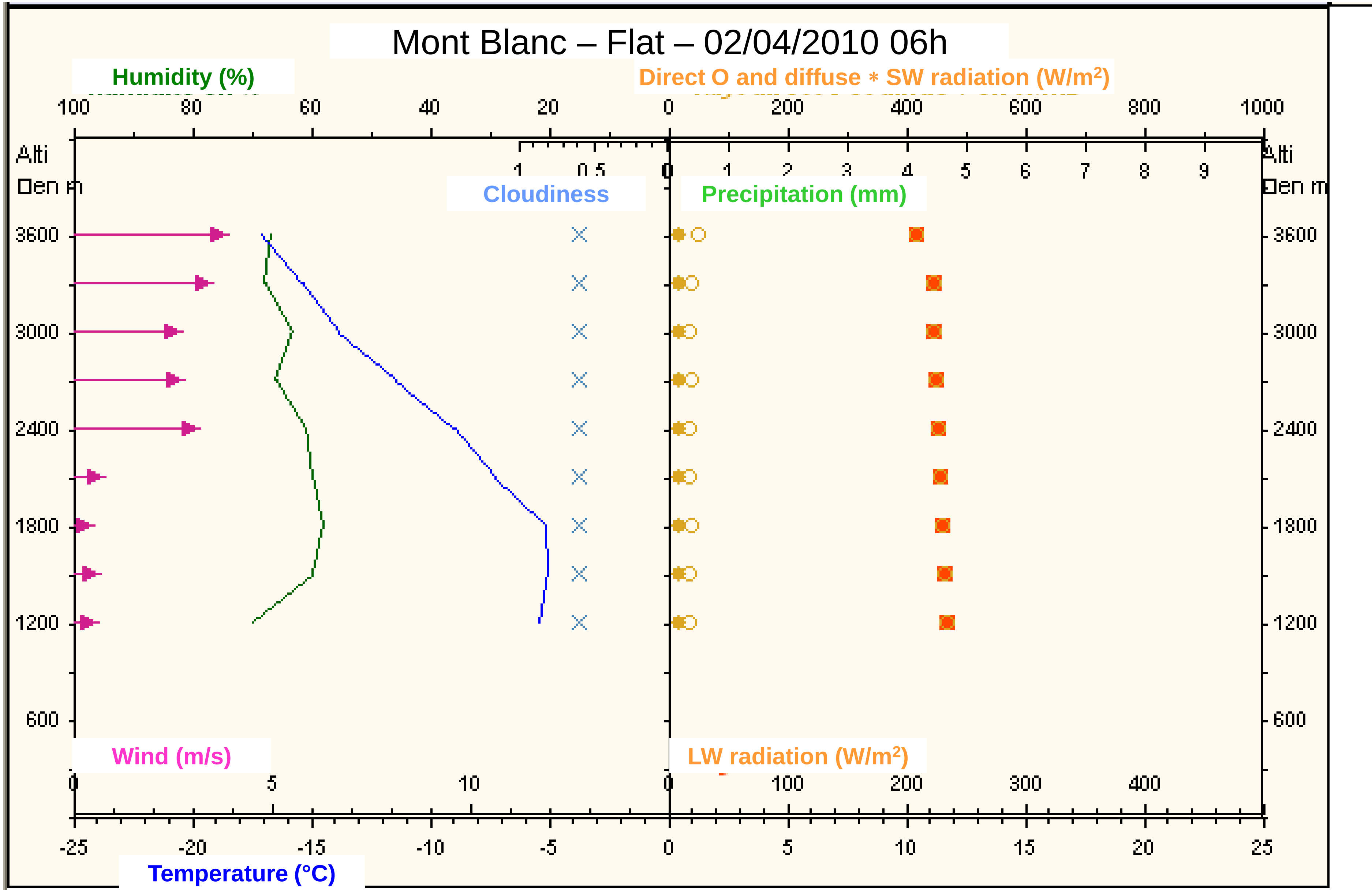
Accidental avalanche hazard



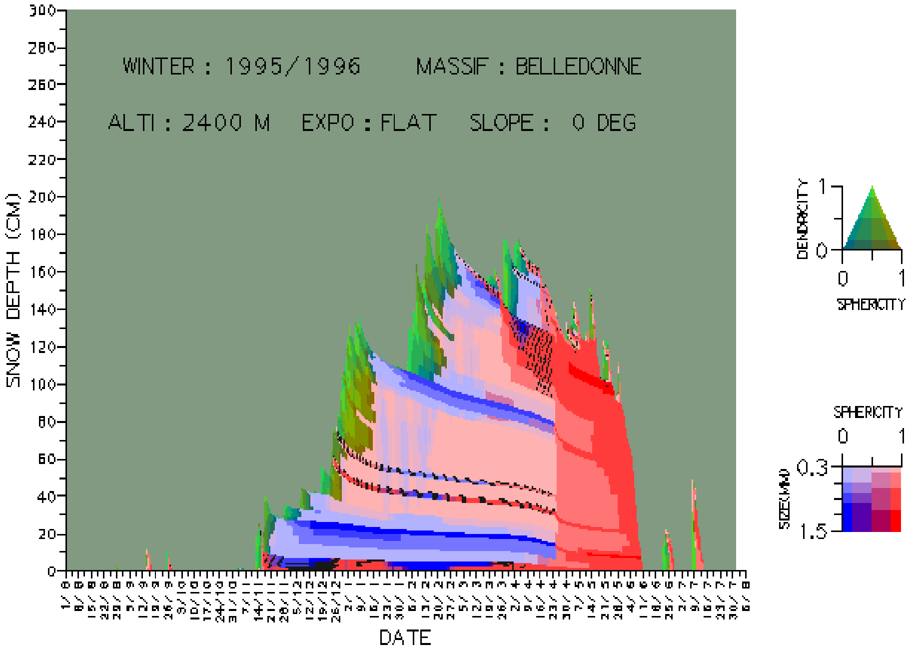
- Very Low
- Low
- Moderate
- High

METEO FRANCE
Toujours un temps d'avance

SAFRAN results : vertical profiles

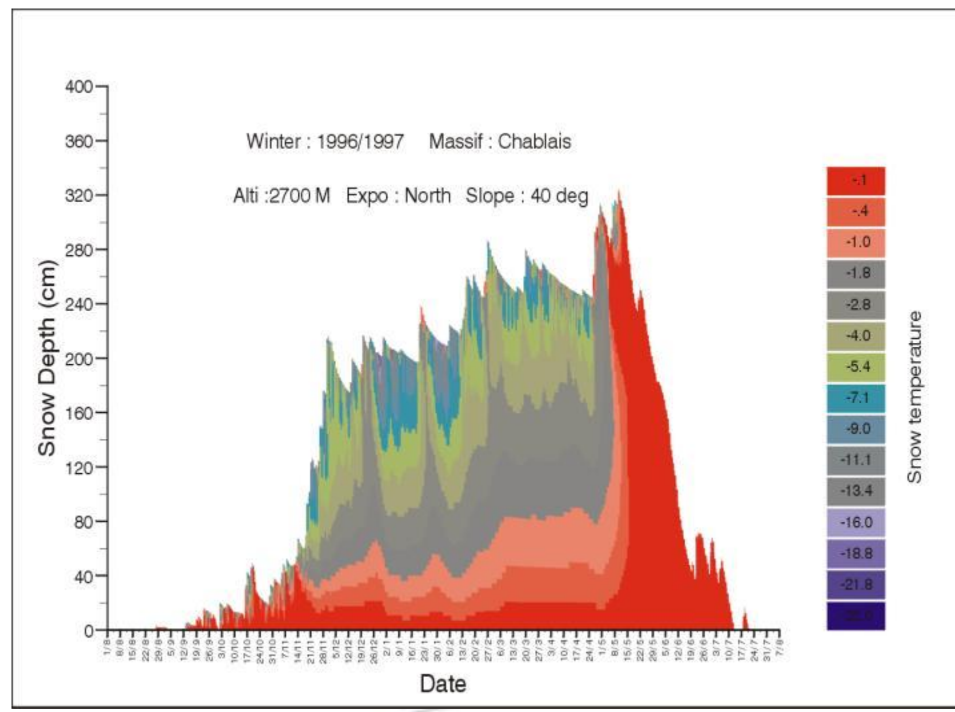


Crocus results : seasonnal evolution



Grain type

Snow temperature



METEO FRANCE
Toujours un temps d'avance

Scientific challenges

- To increase the resolution of meteorological data and include new processes : meso-scale meteorological models, snowdrift modelling

- To improve the snow model physics : micro-scale snow physics, mechanical modelling

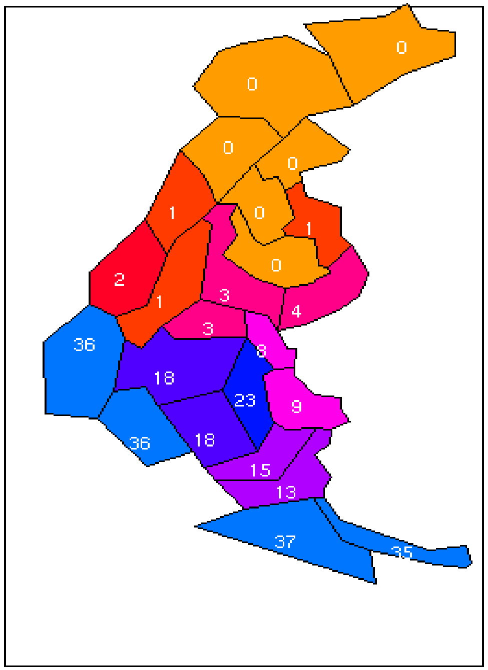
- To use snowpack observations : new type of observations, increased quality, better repetitivity => remote sensing

- To develop methods of assimilation adapted to snow modelling
  - ⇒ Presentation by **R. Essery**
  - ⇒ "*Retrieving Glacier Albedo Using Remote Sensing and Albedo Assimilation into a Snow Model to Simulate Mass Balance*" by **M. Dumont**

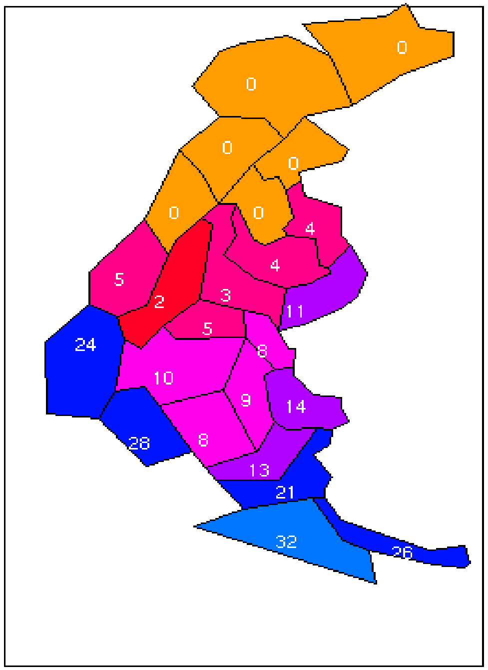
SAFRAN results

24h forecasted precipitation (1800m, 11/01/99)

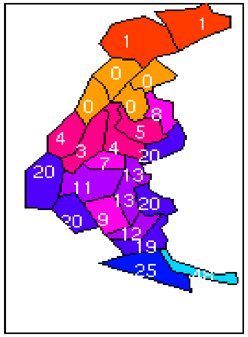
Analysis

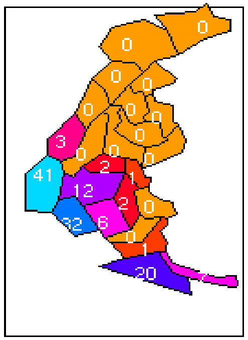


Forecast



ALADIN forecast



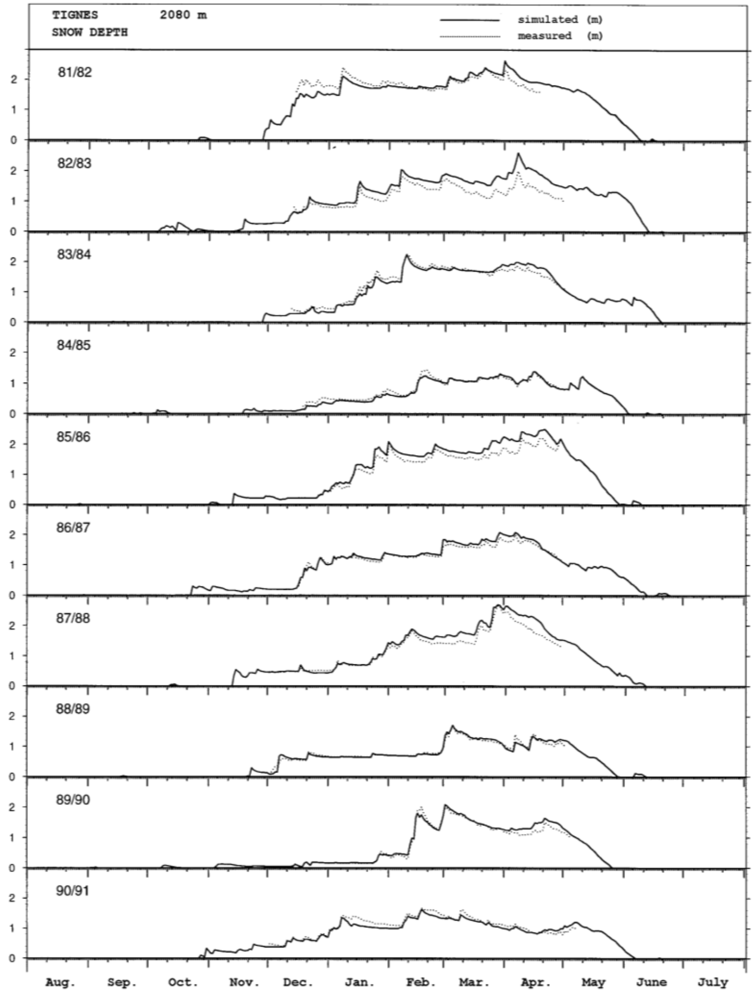


Analog forecast

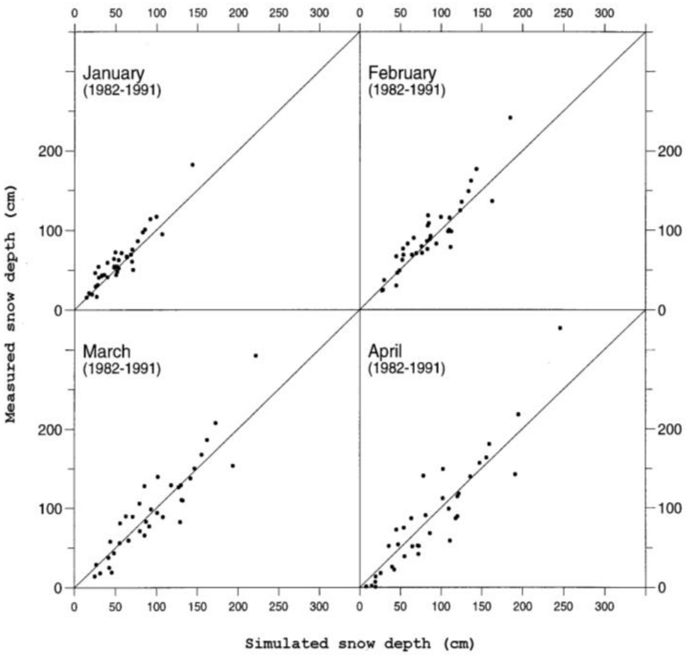
METEO FRANCE
Toujours un temps d'avance

Safran-Crocus validation : example

Snow depth validation for 37 tests sites in the French Alps (10 years)



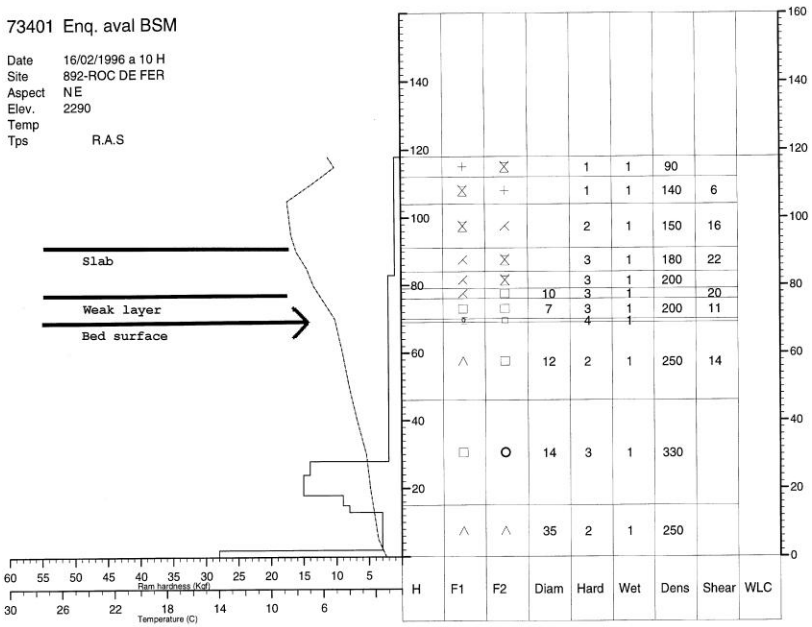
10 years of measured (dotted) and simulated (solid) snow depths at the Tignes ski resort, Vanoise massif, 2080m.

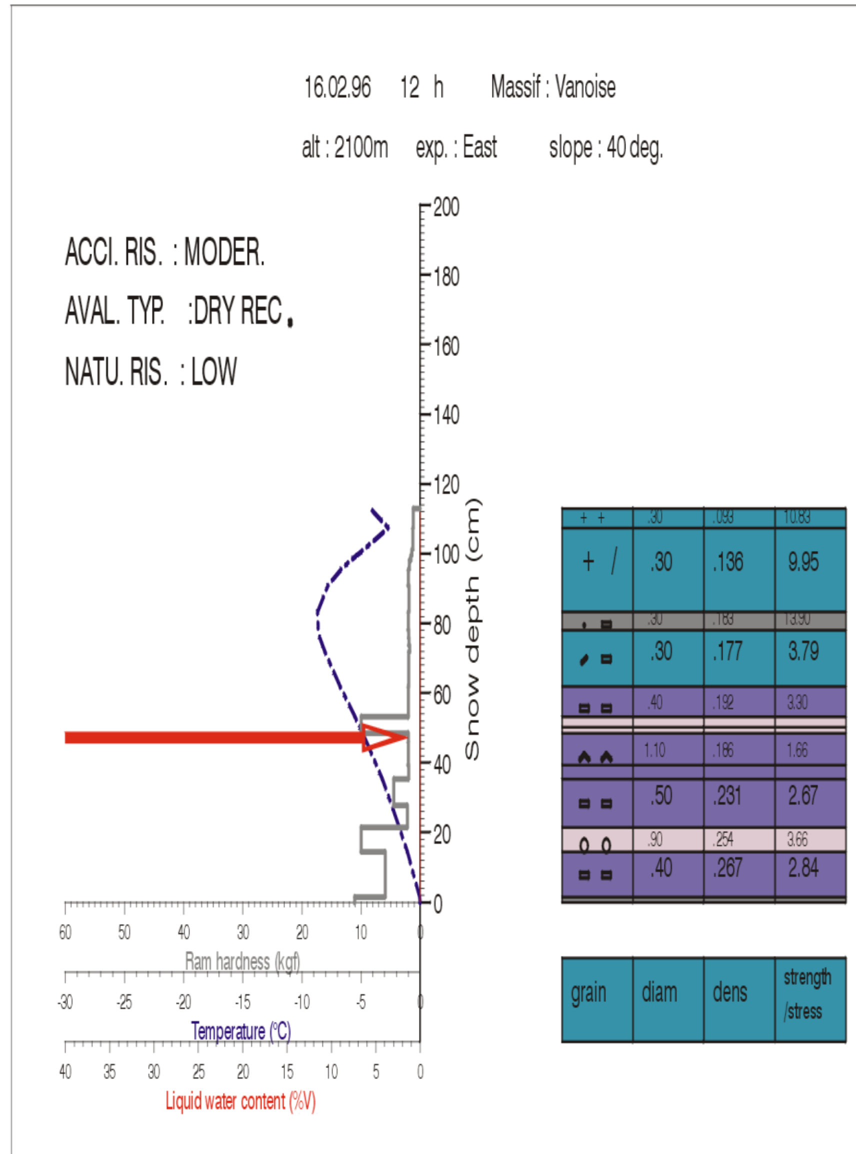


Scatter diagrams of measured and simulated means snow depth on 37 test sites during 4 different months over 10 winter seasons

METEO FRANCE
Toujours un temps d'avance

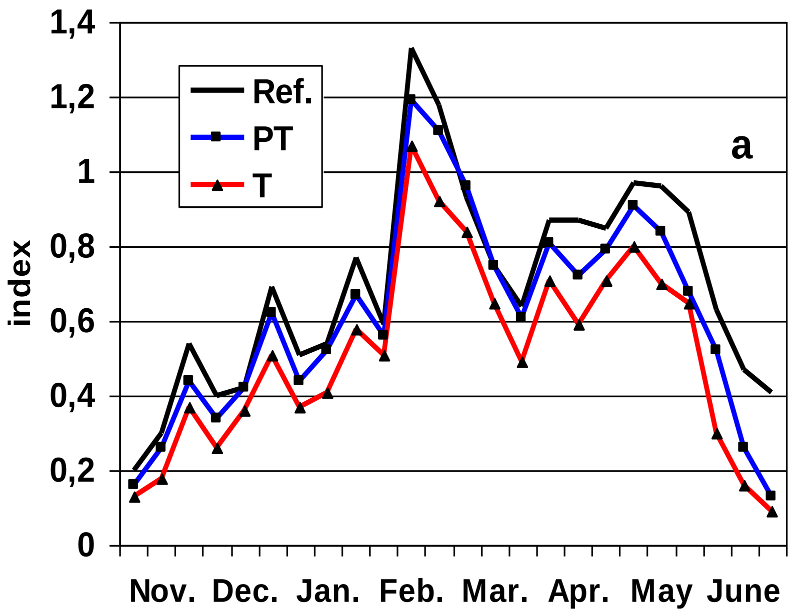
Snow stability : local comparison



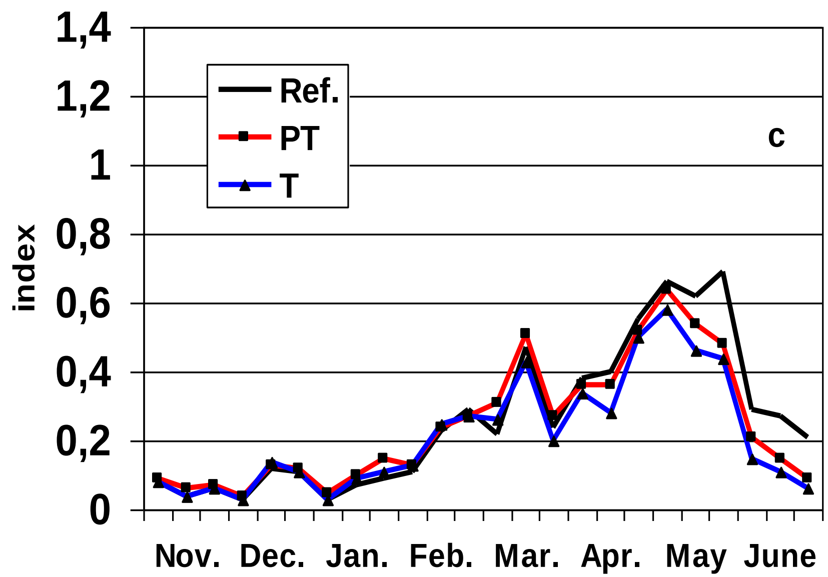


Avalanches and climate change

Martin et al.., 2001



All avalanches



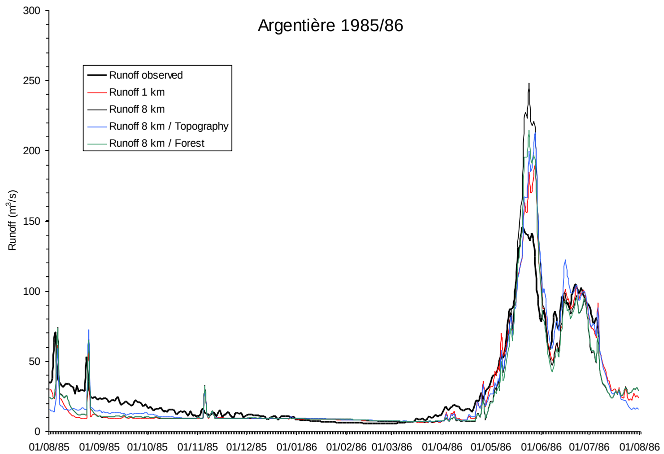
Melting Avalanches

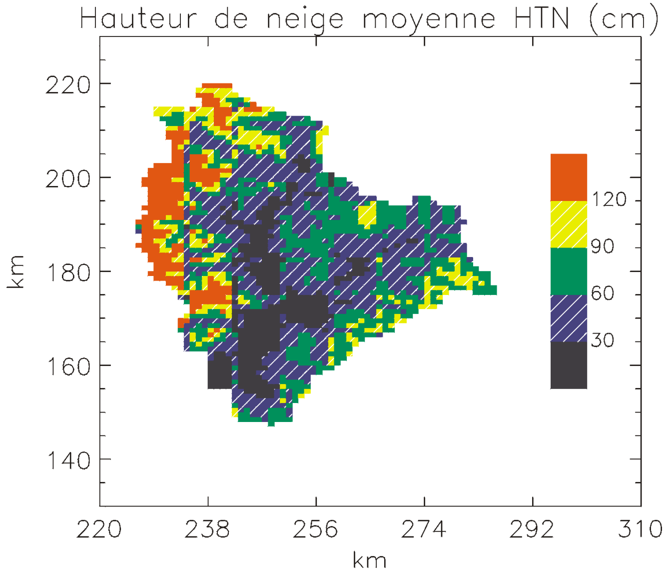
- Rainfall +10%   Température +1.8°C

Hydrological applications

- Distributed modelling of high alpine cachtments : snowpack, water ressources, river discharges

- Safran – (Crocus) - Isba



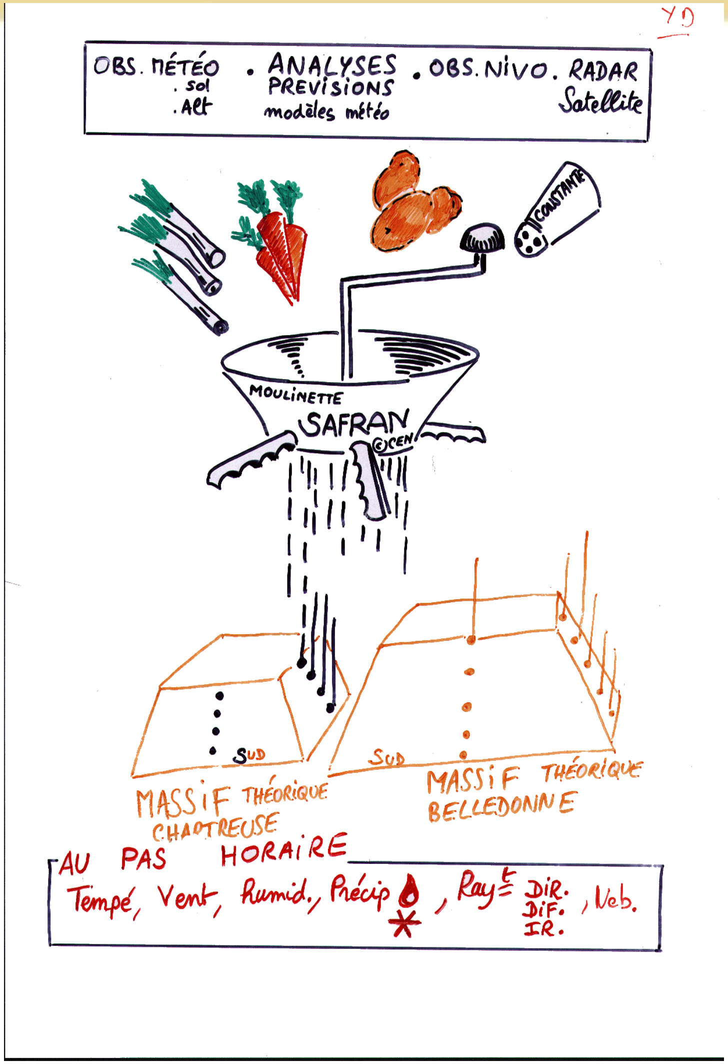


- See for instance :

  Poster "Adaptations of a Physical-Based Hydrological Model for Alpine Catchments. Application to the Upper Durance Catchment. " presented by **M. Lafaysse**

METEO FRANCE
Toujours un temps d'avance

SAFRAN



- O/I scheme and Intermittent Analysis (6h) with ARPEGE or ALADIN as guess-field for :

1. Wind (Div. + Rot.) (verticale profile + surface)
2. Humidity (vertical profile + surface)
3. Cloudiness (3 layers)
4. Temperature (verticale profil + surface)

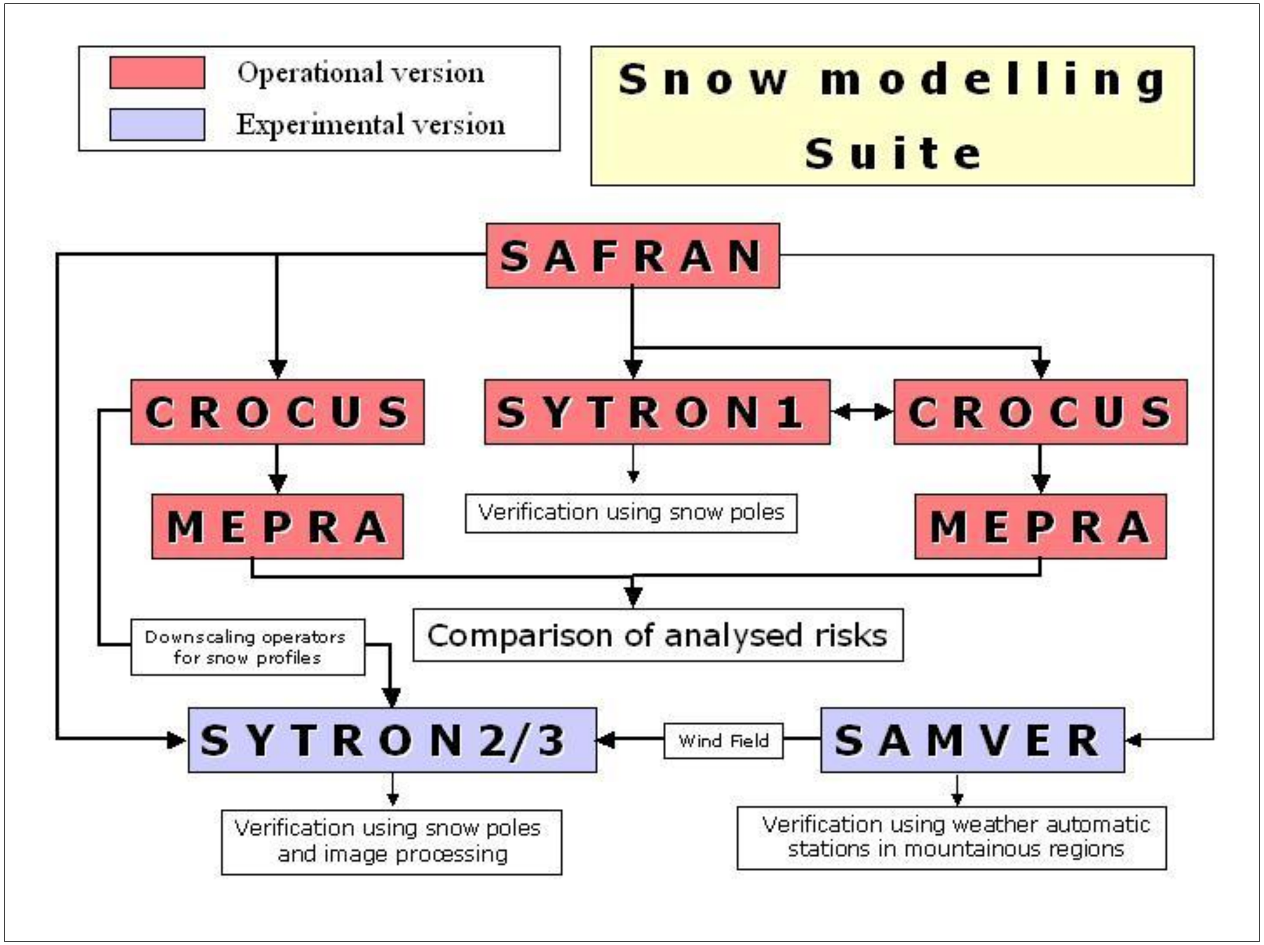
- 24h Rainfall Analysis based on climatology and typical synoptic patterns.

- Variational Analysis at 1 hour step on 6h windows.

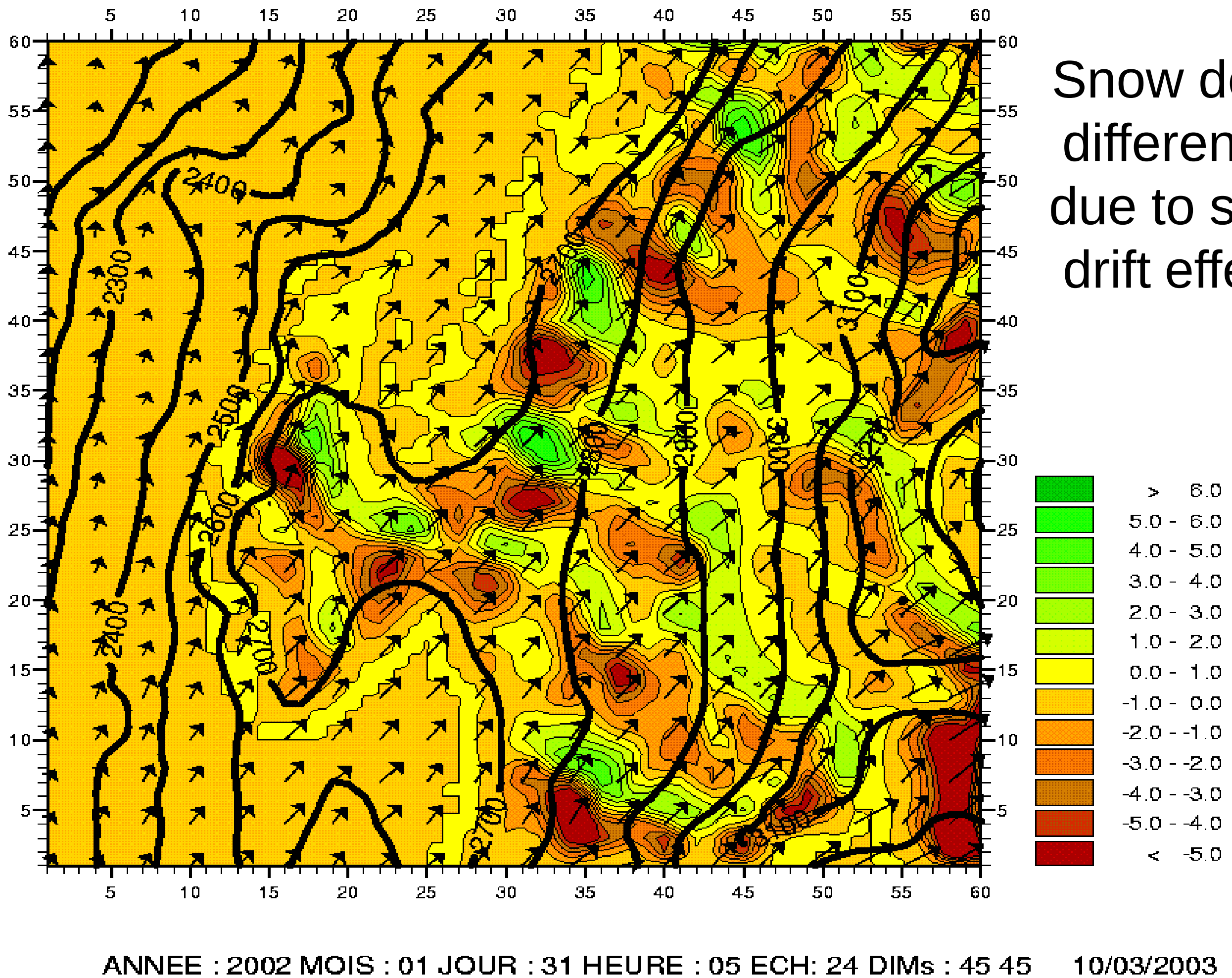
- Several algorithms and modelling for :

1. Radiations
2. Diurnal Variations
3. Vertical Snow-Rain Limits

METEO FRANCE
Toujours un temps d'avance

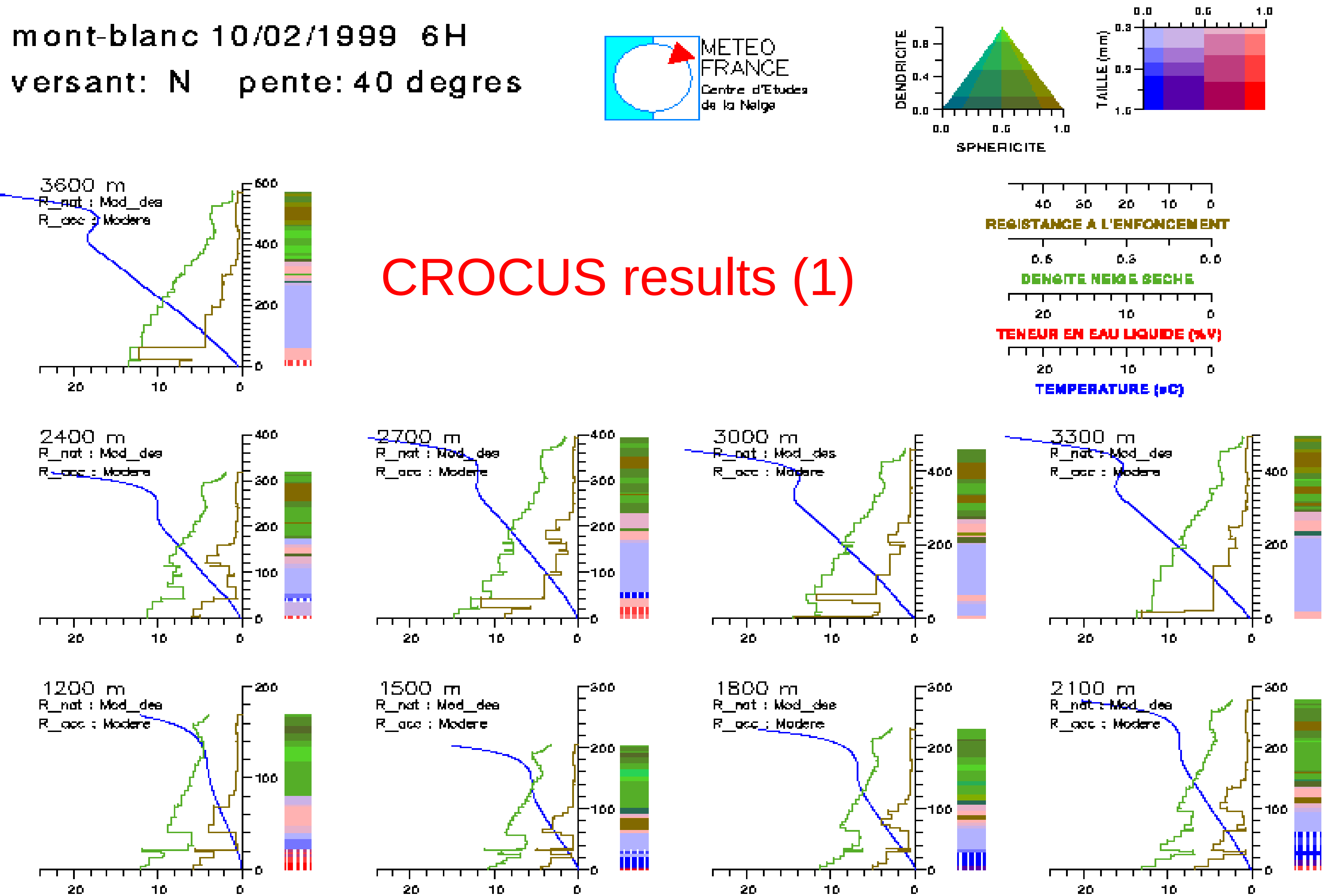

Operational version
Experimental version
Snow modelling Suite
SAFRAN
CROCUS
SYTRON1
CROCUS
MEPRA
Verification using snow poles
MEPRA
Comparison of analysed risks
Downscaling operators for snow profiles
SYTRON2/3
Wind Field
SAMVER
Verification using snow poles and image processing
Verification using weather automatic stations in mountainous regions

Snow Drift



Snow depth differences due to snow drift effects

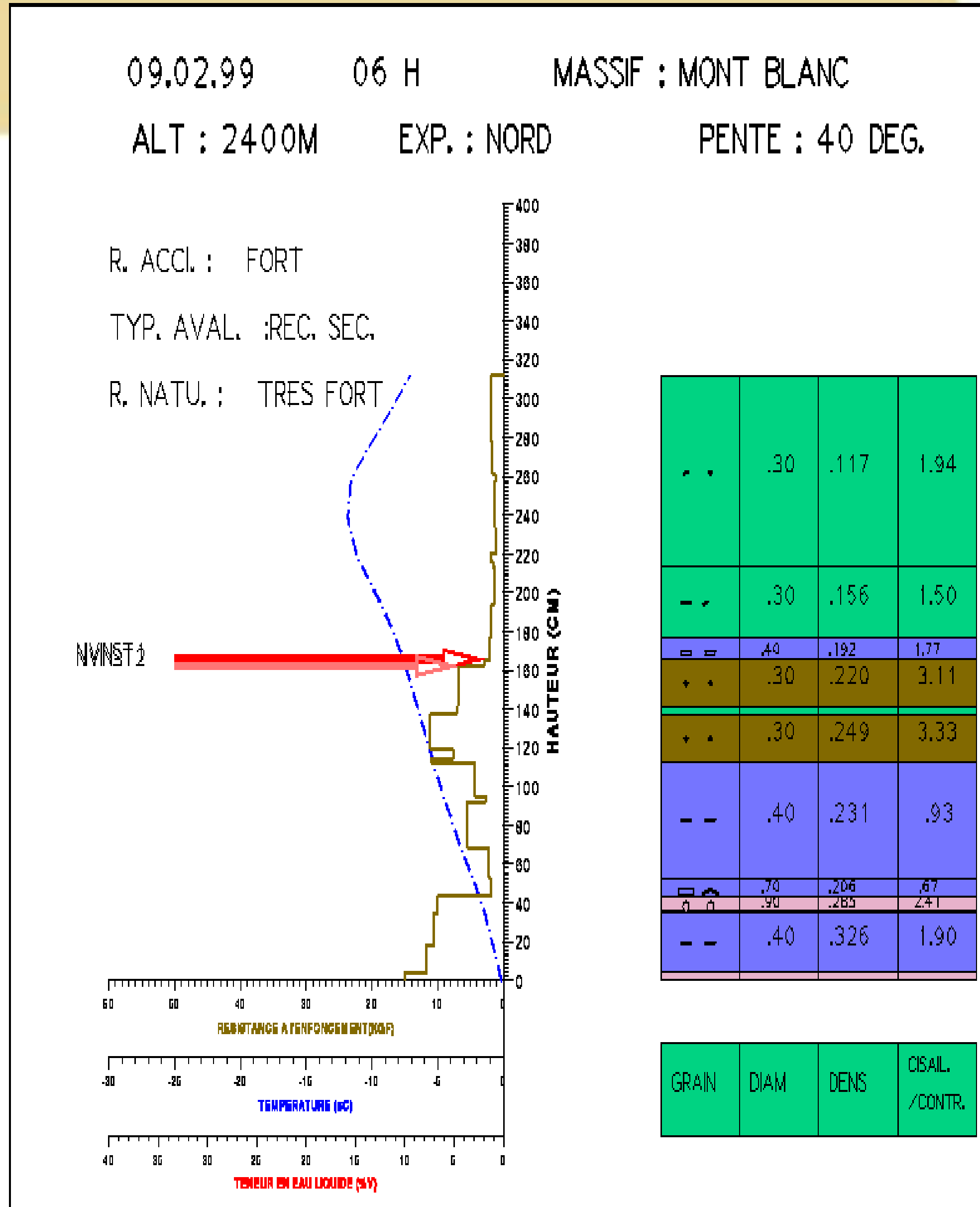
CROCUS results (1)



METEO FRANCE
Toujours un temps d'avance

MEPRA
operational results (2)

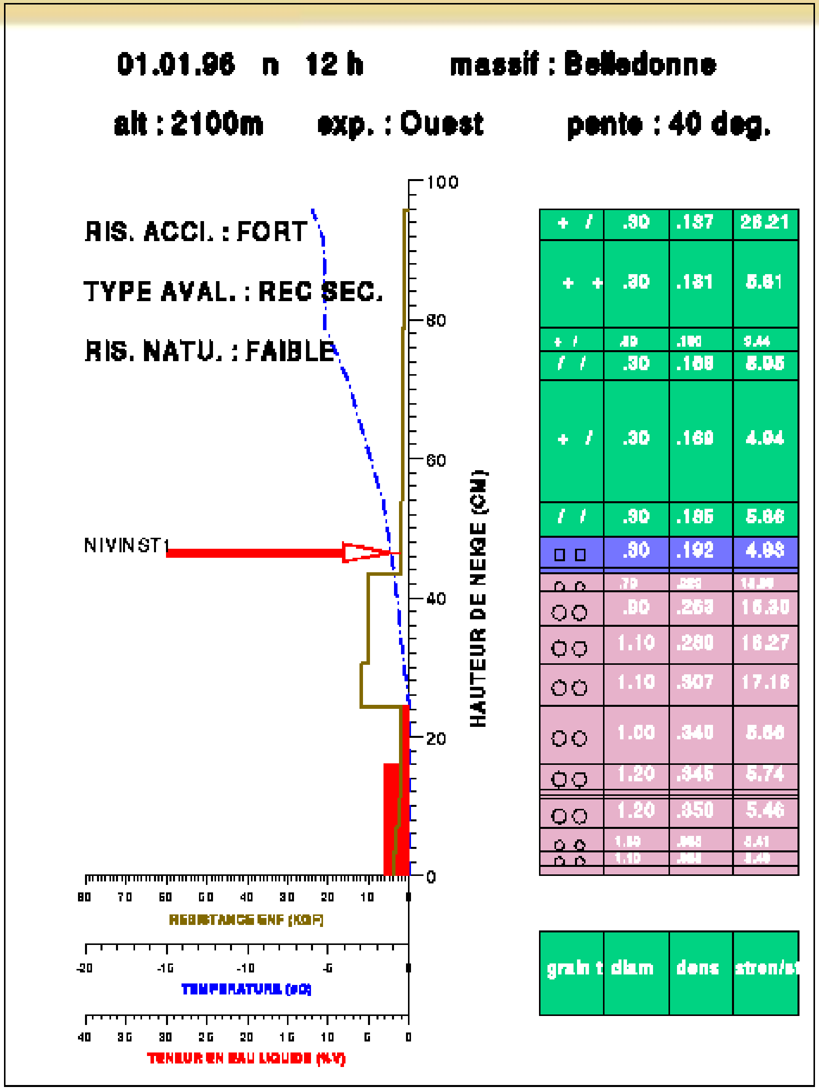
MEPRA : risk of spontaneous (natural) avalanches due to an unstable fresh snow amount



MEPRA results : seasonnal evolution

MEPRA : detection of an unstable layer

In this case (1st January 1996), the model has detected a snow structure favourable to an avalanche triggering by overloading (e.g. skiers). A weak layer is buried under 40 cm of new snow constituting a slab after some cohesion processes.



METEO FRANCE
Toujours un temps d'avance