Detailed snow-pack modelling and its application to snow-cover monitoring, hydrology, road meteorology and climate

Muscaten Workshop

Kuopio, 24-26 March 2010

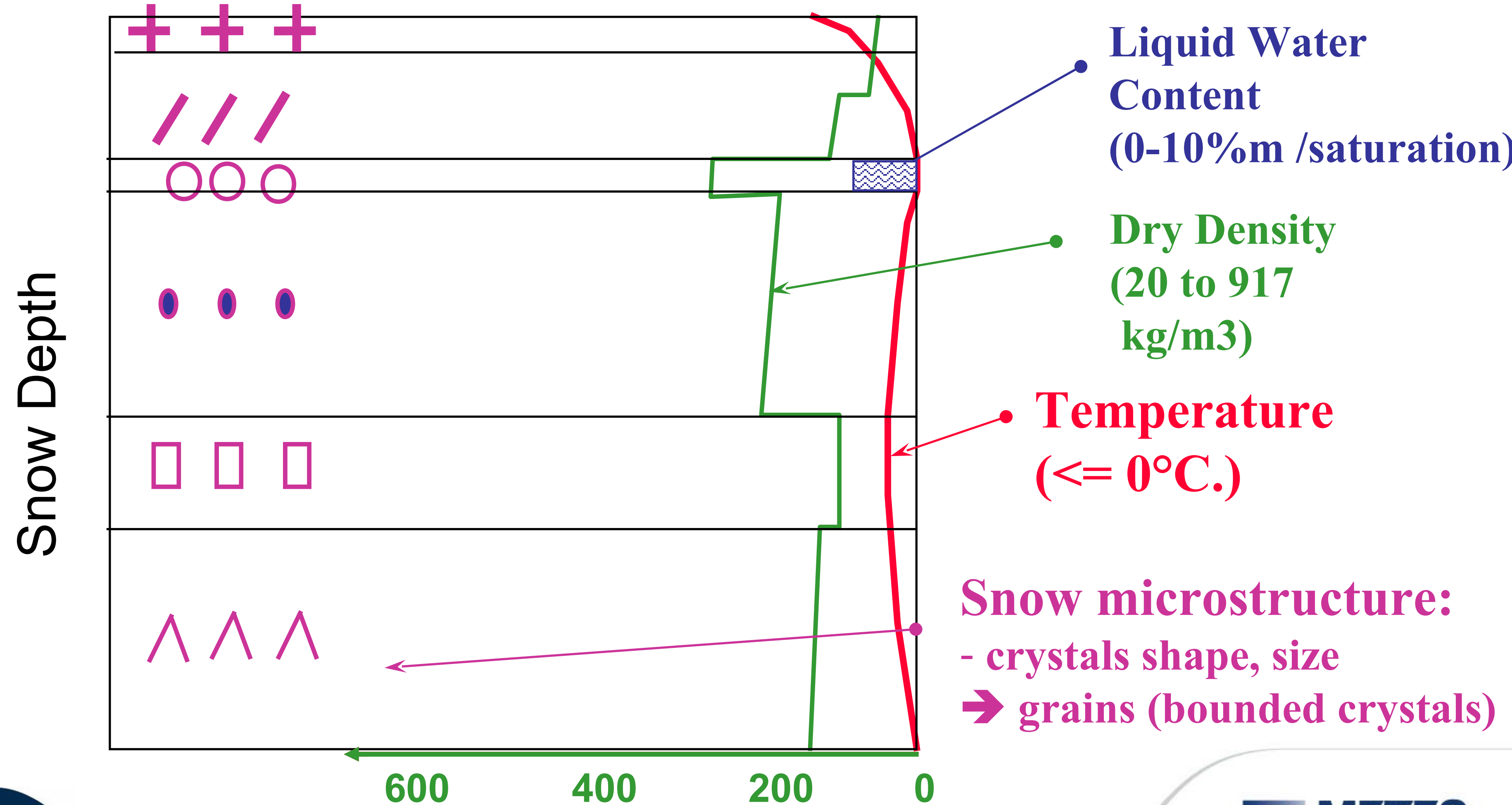
Éric Brun

Climate Group, CNRM/GAME Météo-France and CNRS

Outline

- **Key snow processes**
- **Main characteristics of Crocus, a detailed snow model**
- **Some applications**:
  - Safran/Crocus/Mepra : snow monitoring in the Alps and the Pyrenees for operational avalanche forecasting
  - Impact of climate change on snowcover and hydrology
  - A research project for modeling snow deposition on roads
- **Future developments and open issues for NWP and climate projections**

Description of an “idealized” snowcover in open land areas



+ impurities: dust, vegetation debris, chemical species ...

Physical internal processes controlling mass and energy exchanges (1/2)

Thermal diffusion : low conductivity function of density and microstructure – low capacity (density, T)

Water flow : * permeability function of density, microstructure
* capillarity forces function of microstructure and density ➔ irreducible water content
* capillarity barriers ➔ saturated layers

Phase Changes : melting-freezing:

- macro: melting point function of impurities/chem.
- micro : wet snow metamorphism

sublimation/condensation:

- dry snow metamorphism

Physical internal processes controlling mass and energy exchanges (2/2)

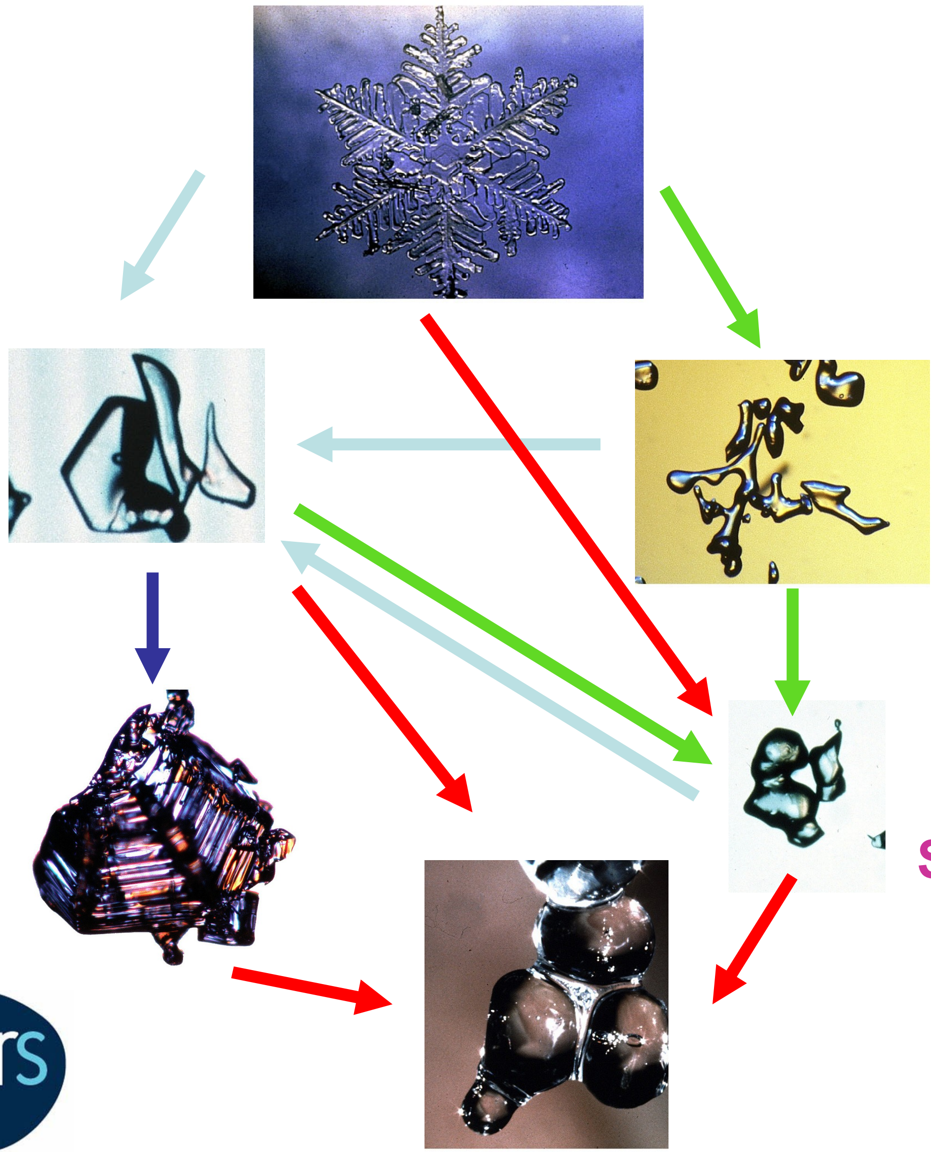
Compaction : Newtonian viscosity function of density, temperature, microstructure , liquid water content, metamorphism

Light penetration: function of microstructure , density and impurities content

Air flow : occasionally under pressure variations (wind pumping) and thermal convection

→most physical properties vary over a range larger than one order of magnitude

Snow metamorphism



Weak temperature gradient
(0 to 5 °C./m)

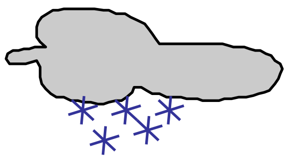
Medium temperature gradient
(5 to 15 °C./m)

High temperature gradient
(> 15 °C./m)

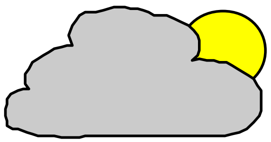
Wet conditions
(LWC > 1% mass)

Strong influence on albedo, light penetration, viscosity, conduction, water flow

Main external processes controlling snow pack evolution

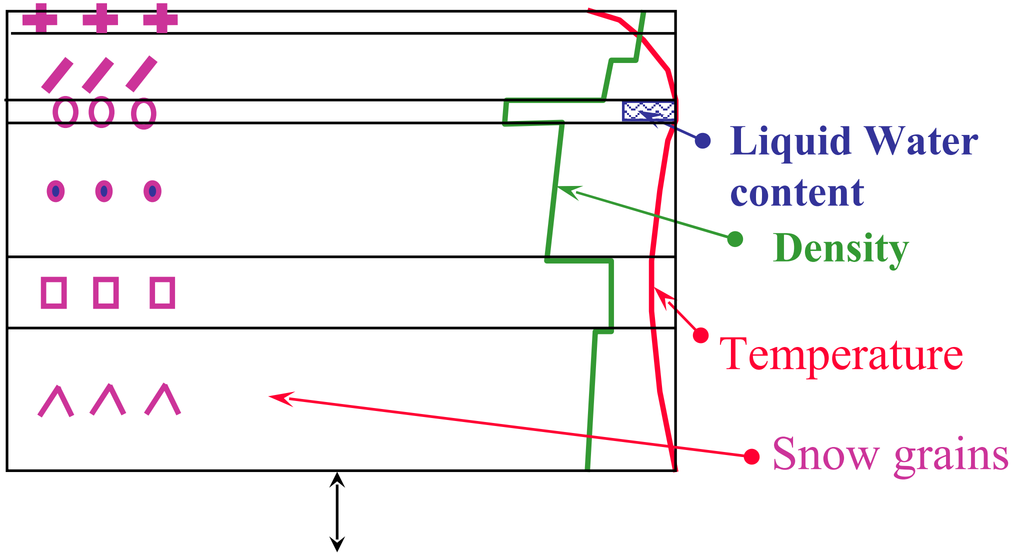


Snow /rain precipitation



Radiative balance (short and long-wave)

turbulent fluxes (sensible and latent heat) and snow drift



Ground thermal flux

run-off

Crocus: a detailed snow model designed for snowpack monitoring

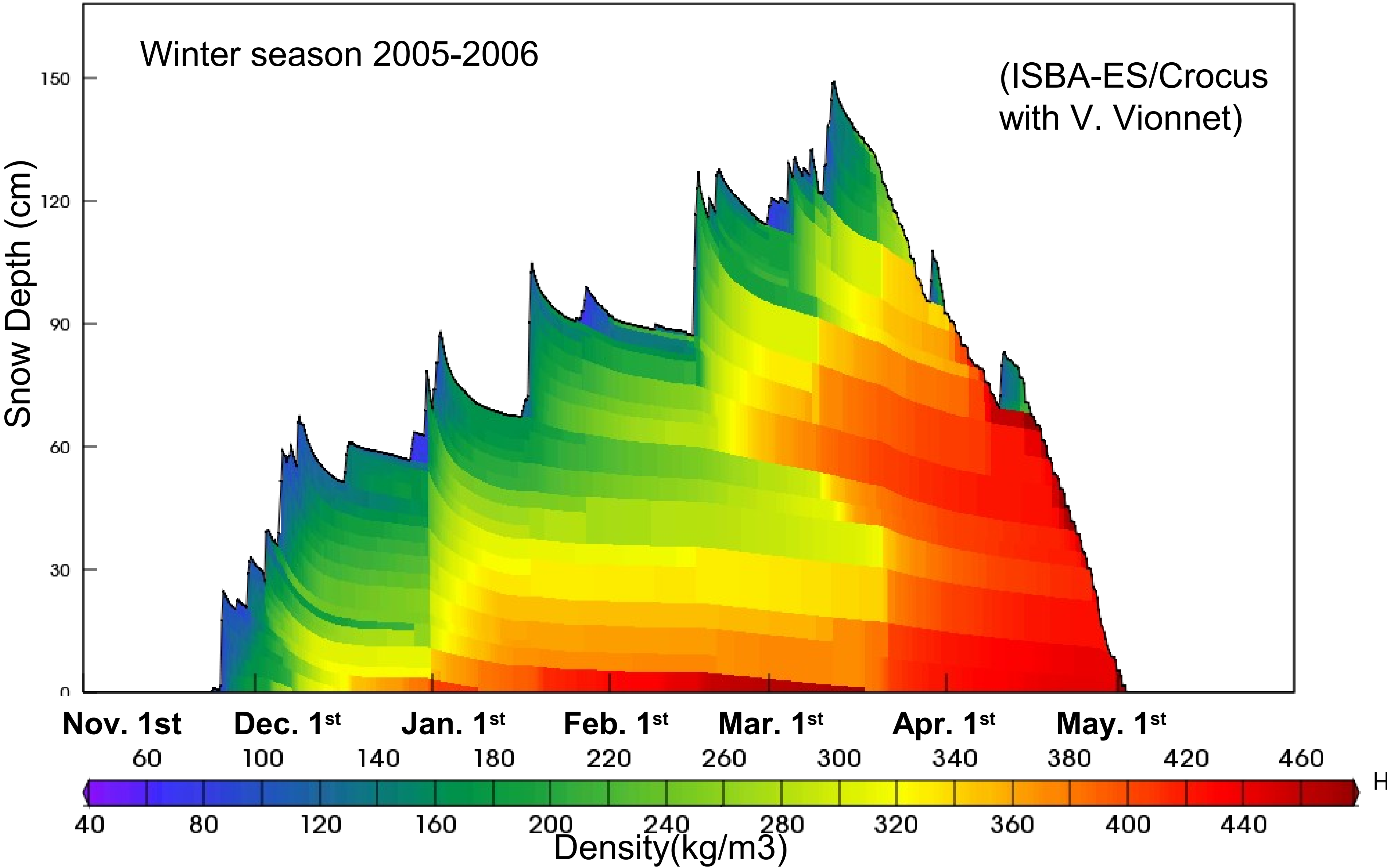
Snowcover state variables:
- Temperature, Density, Liquid water content, Grains type and size, Age

Simulated processes:
-Thermal diffusion, Phase changes , Compaction
- Spectral albedo, Light penetration, Water flow, Water retention
- Metamorphism
- Dynamic evolution of the number and thickness of numerical layers
- Snow/soil thermal and liquid fluxes

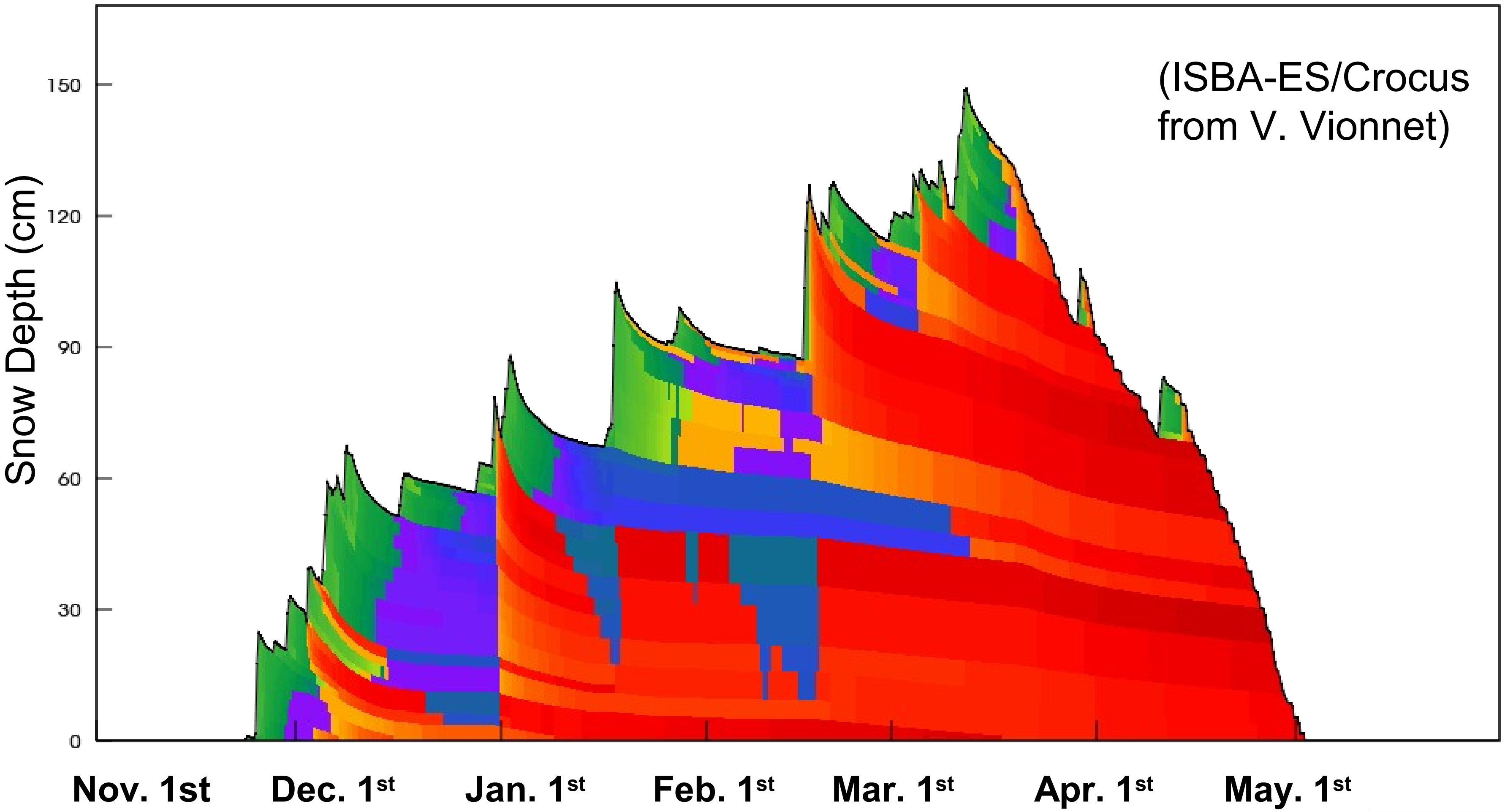
Forcing data:
- Incoming short-wave (3 bands) and long-wave radiation
- Snow-rain precipitation
- Air temperature and humidity
- Wind velocity

Main limitations: 1-D model, no blowing snow
no vegetation, no air flow

An example of a simulated density using observed forcing data (Col de Porte, 1320 m a.s.l)

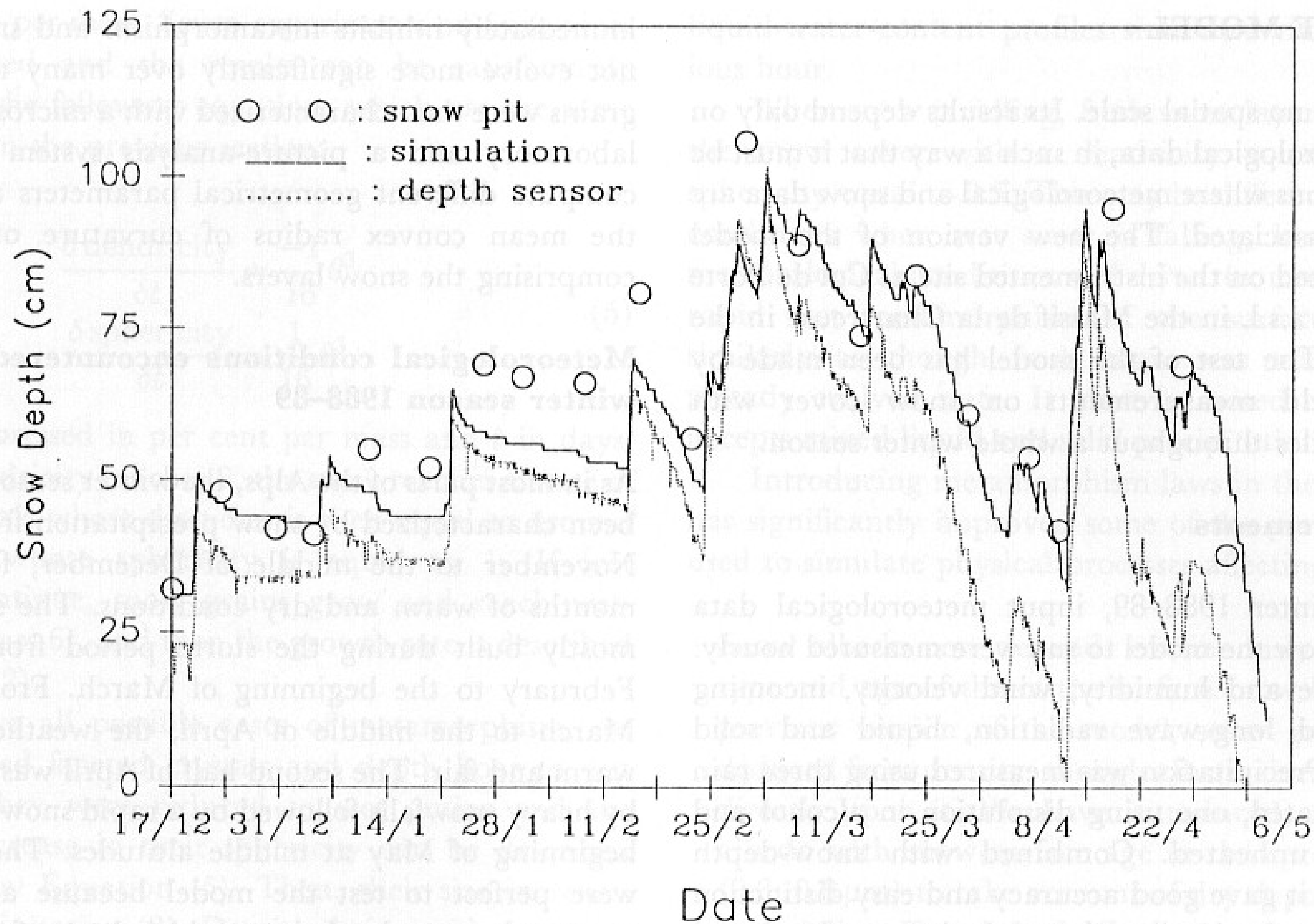


An example of a simulated layering from observed forcing data



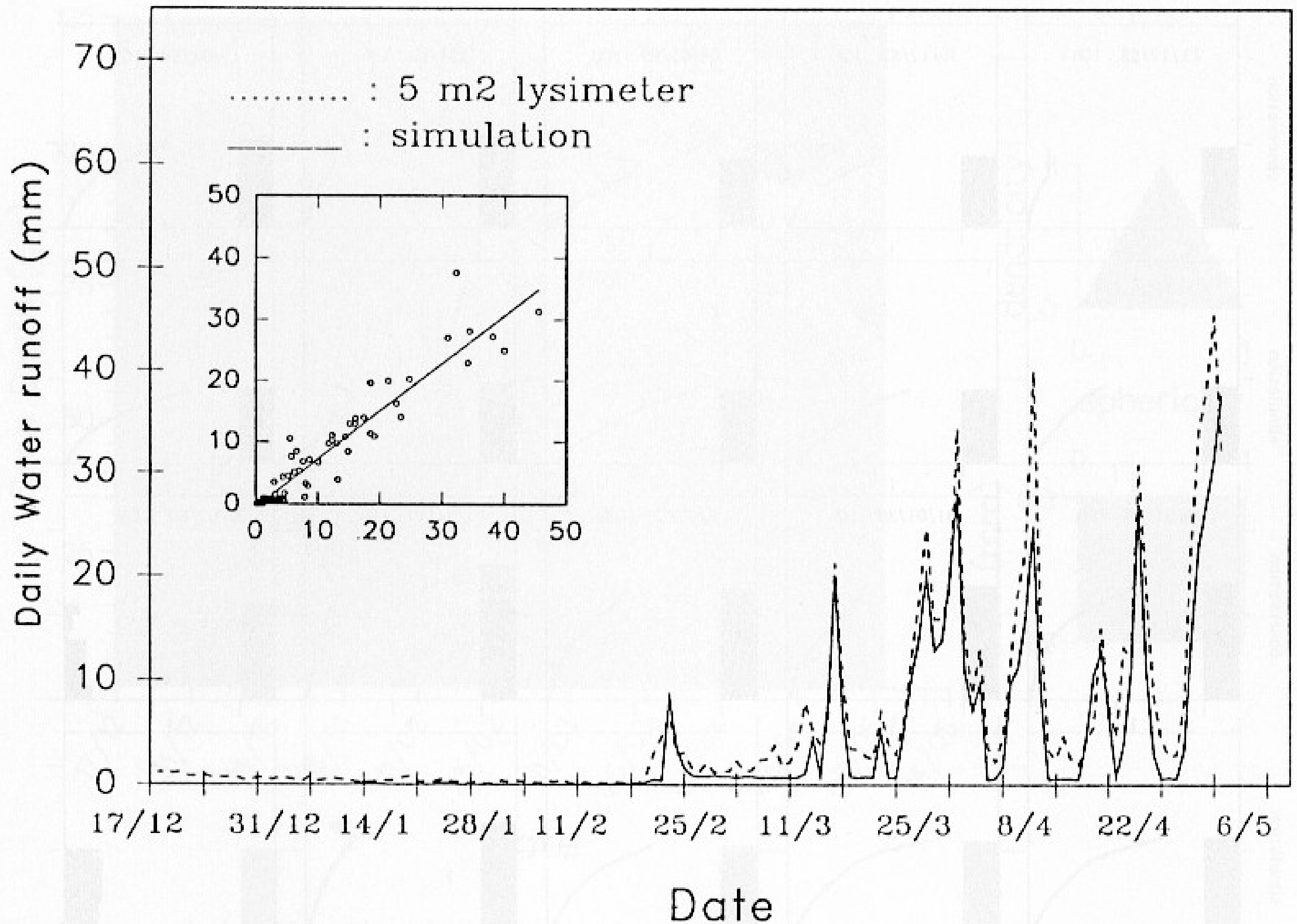
Winter season 2005-2006

Model evaluation on an instrumented site Col de Porte, French Alps 1320m a.s.l



(Brun et al., 1989, 1992)

Model evaluation on an instrumented site
Col de Porte, French Alps 1320m a.s.l



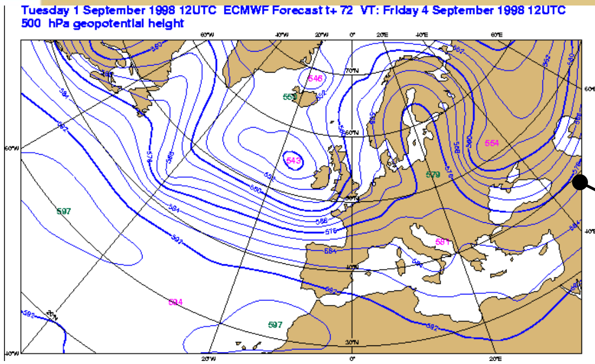
(Brun et al., 1989, 1992)

Application to snowcover monitoring and avalanches forecasting

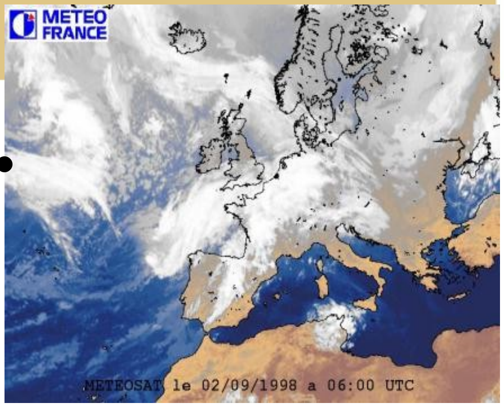
Safran/Crocus/Mepra:

- Snowpack real-time modeling in the Alps, the Pyrenees and Corsica
- Use of analyzed and forecasted forcing data hindcast : H0-24 to H0 and forecast: H0 to H0 +48
- Stability diagnosis from simulated snow profiles

SAFRAN : an analysis system designed for mountains



NWP outputs



Remote-sensing

real-time SAFRAN analysis

Snow-Avalanche human network

Mountain AWS

Analysis of past weather conditions :

- Temperature and humidity
- Wind velocity
- Incoming radiative fluxes
- Precipitation (snow/rain)

On different elevations and aspects

Hourly time step

French Alps, Pyrenees and Corsica

No use of snow depth observations!

(Durand et al., 1992)

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vanoise 25/03/2010 6H

versant: N pente: 40 degres

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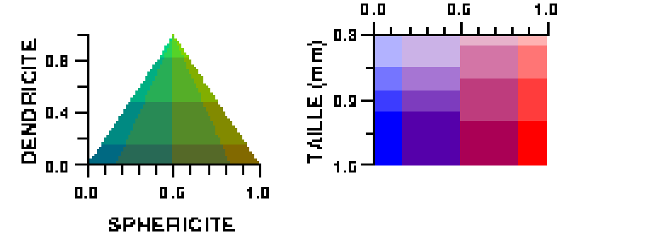
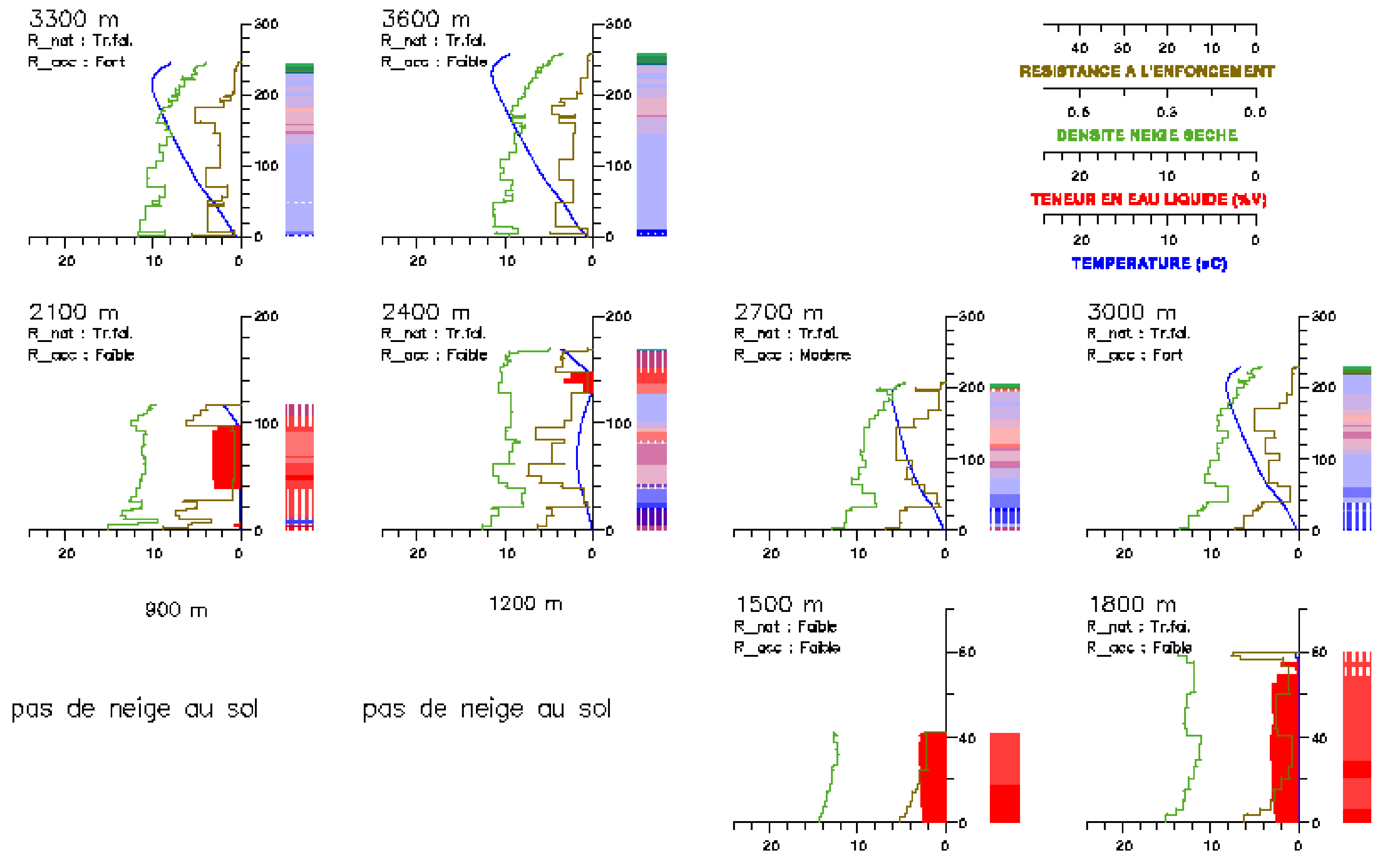
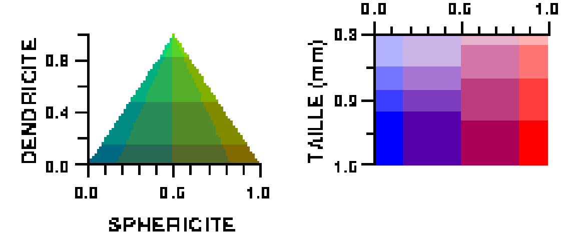
Centre d'Etudes de la Neige

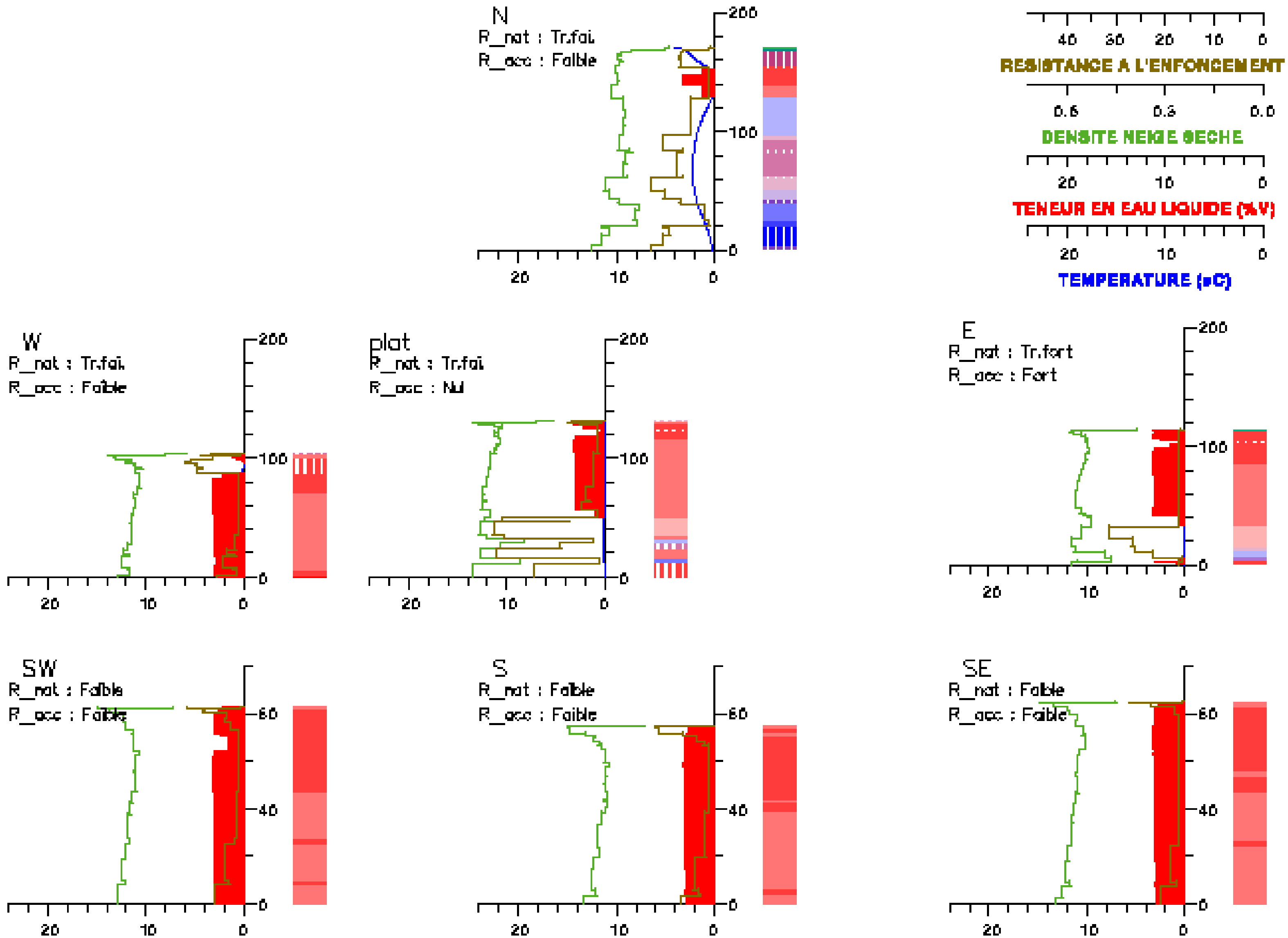




vanoise 24/03/2010 12H

altitude: 2400 pente: 40 degres

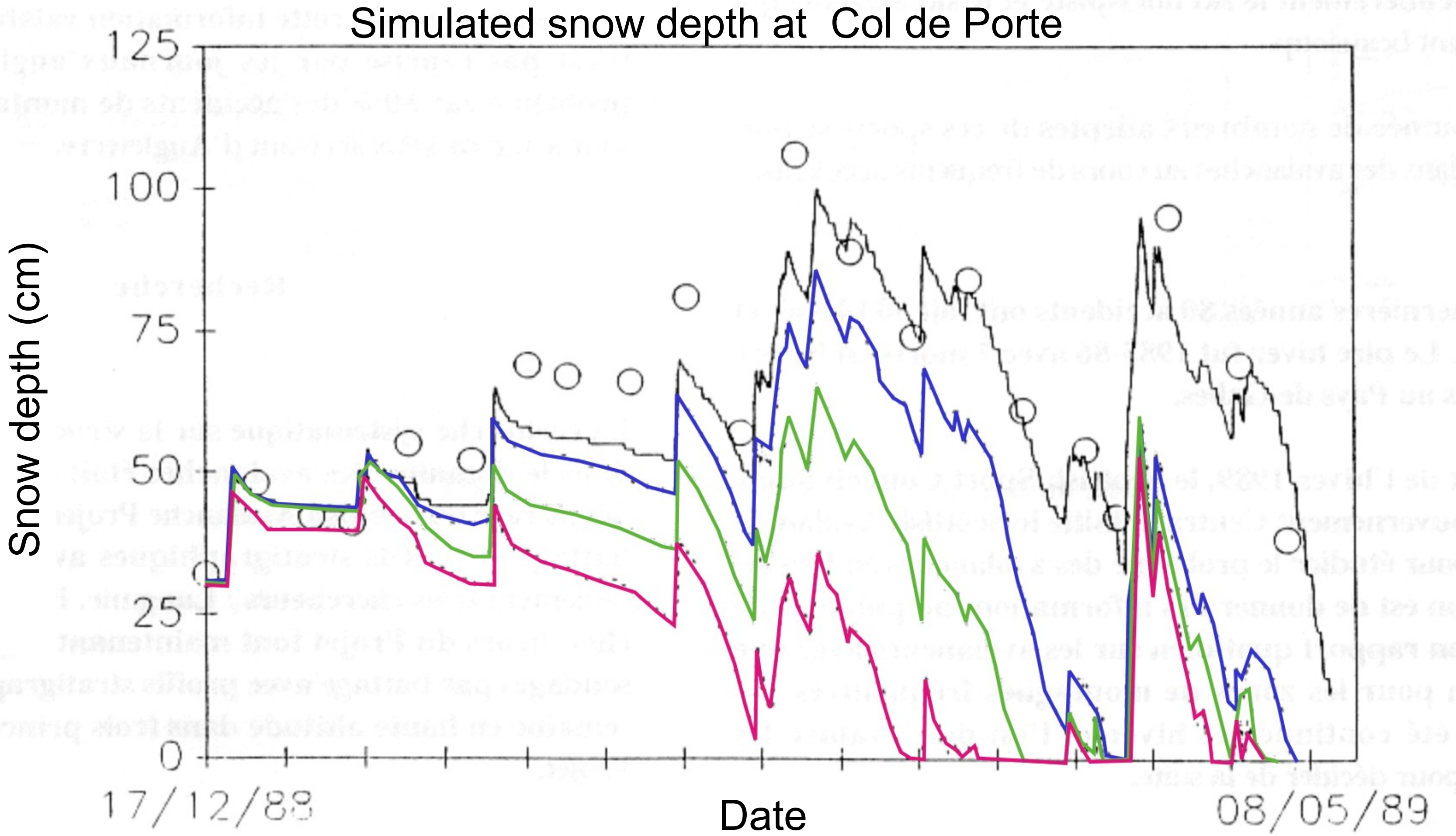




Application impact studies of climate change on snow cover

- A case study on an instrumented site
- Extension to the Alps and Pyrenees
- A case study on an alpine river
- A case study on an alpine glacier

Physically-based simulation of the impact of climate warming (temperature and long-wave radiation)



Air temperature anomaly: **+ 1.5 °C.** **+ 3 °C.** **+ 4.5 °C.**

(E. Brun, 1991)

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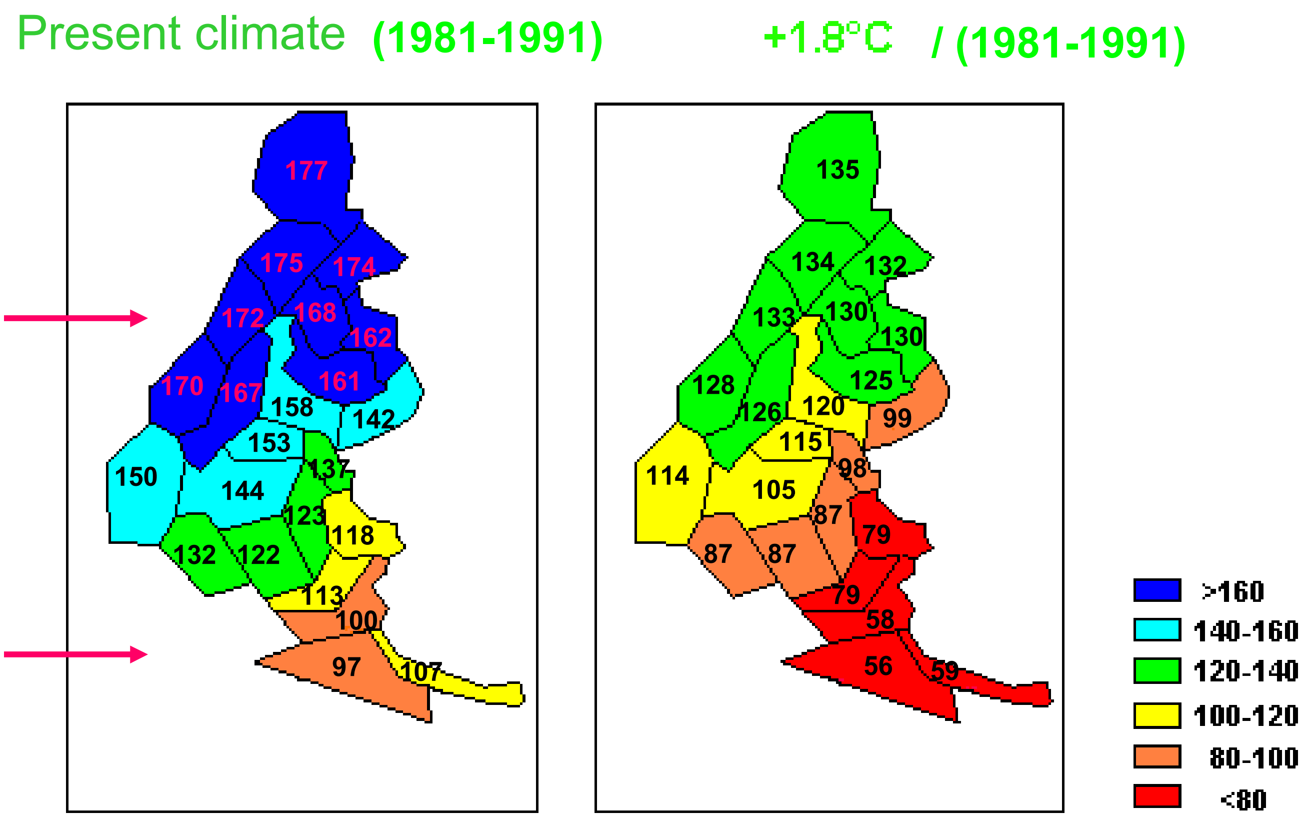
Impact of a temperature increase of 1.8°C. on the duration of snowcover at 1500 m a.s.l

Northern French Alps

Southern French Alps



Very sensitive up to 2200m a.s.l

(PhD Work E. Martin, 1994)

cnrs

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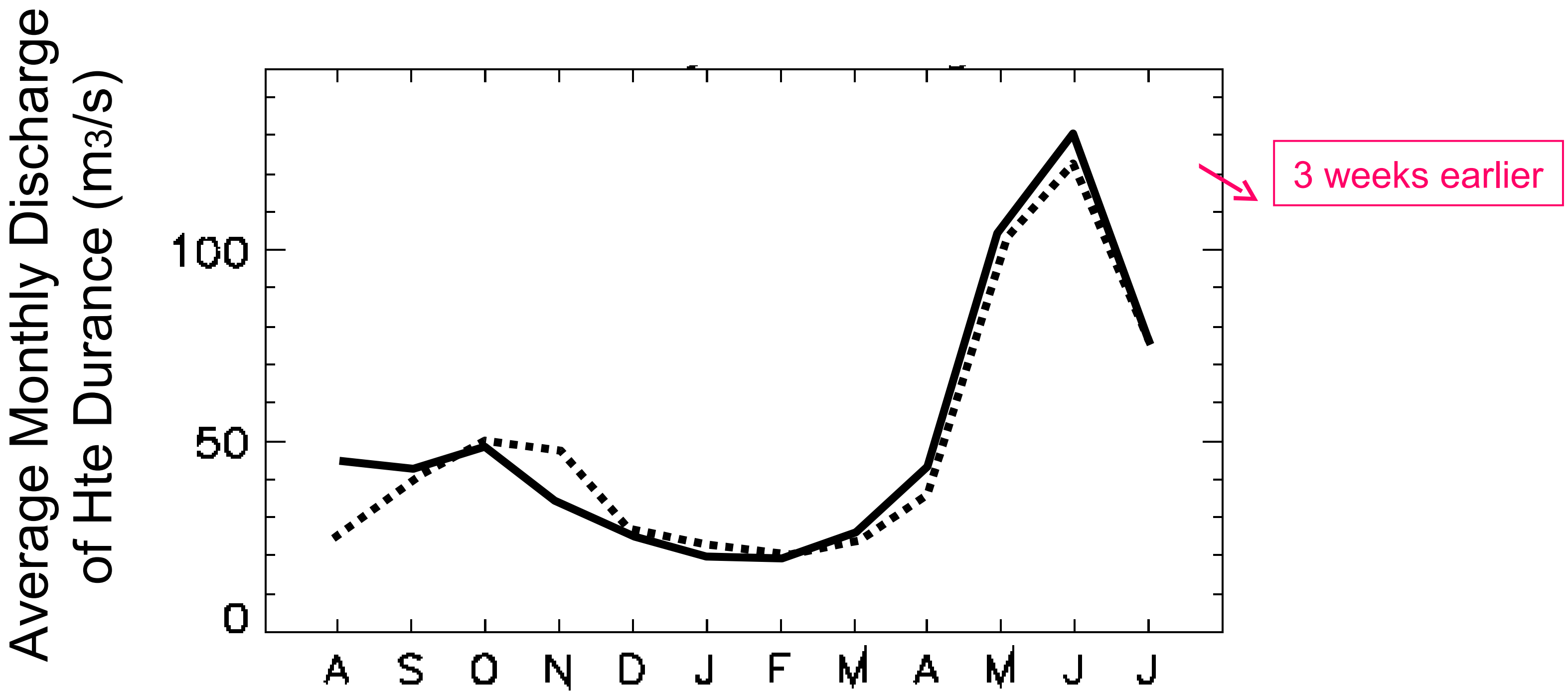
The impact on an Alpine river



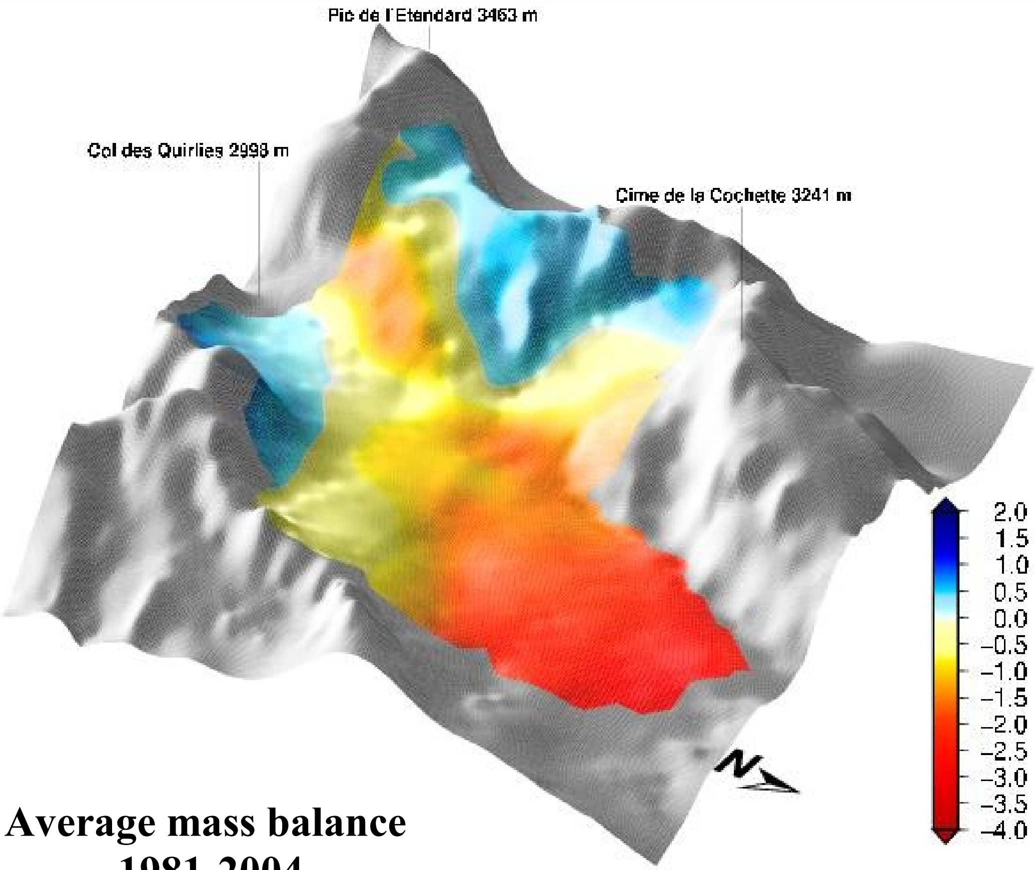
Observed discharge (present climate)

Simulated discharge (present climate)

Simulated discharge
for a doubling CO2 scenario
With different models

(P. Etchevers, 1997)

Impact on an Alpine glacier

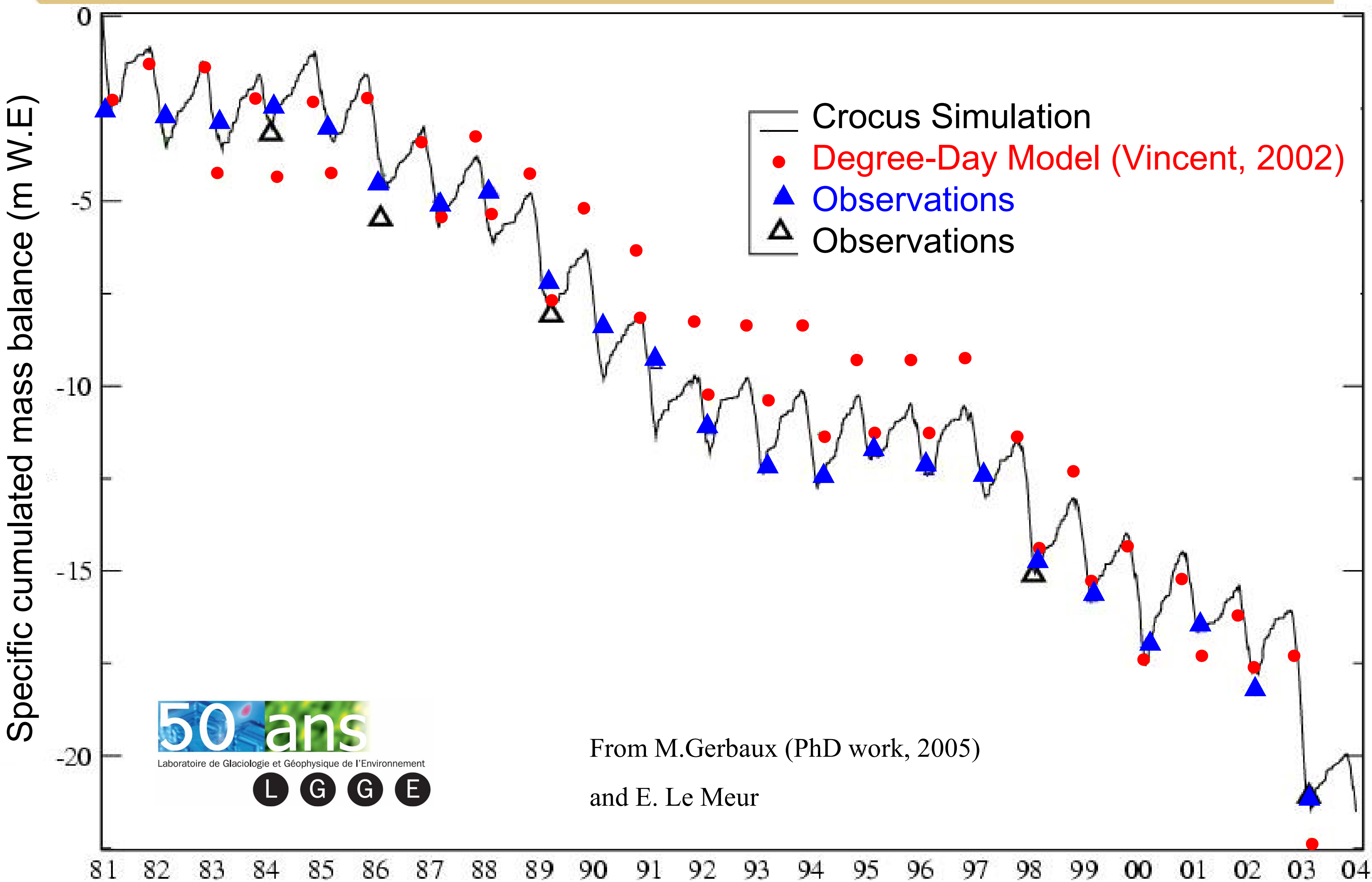


Average mass balance 1981-2004

Model output

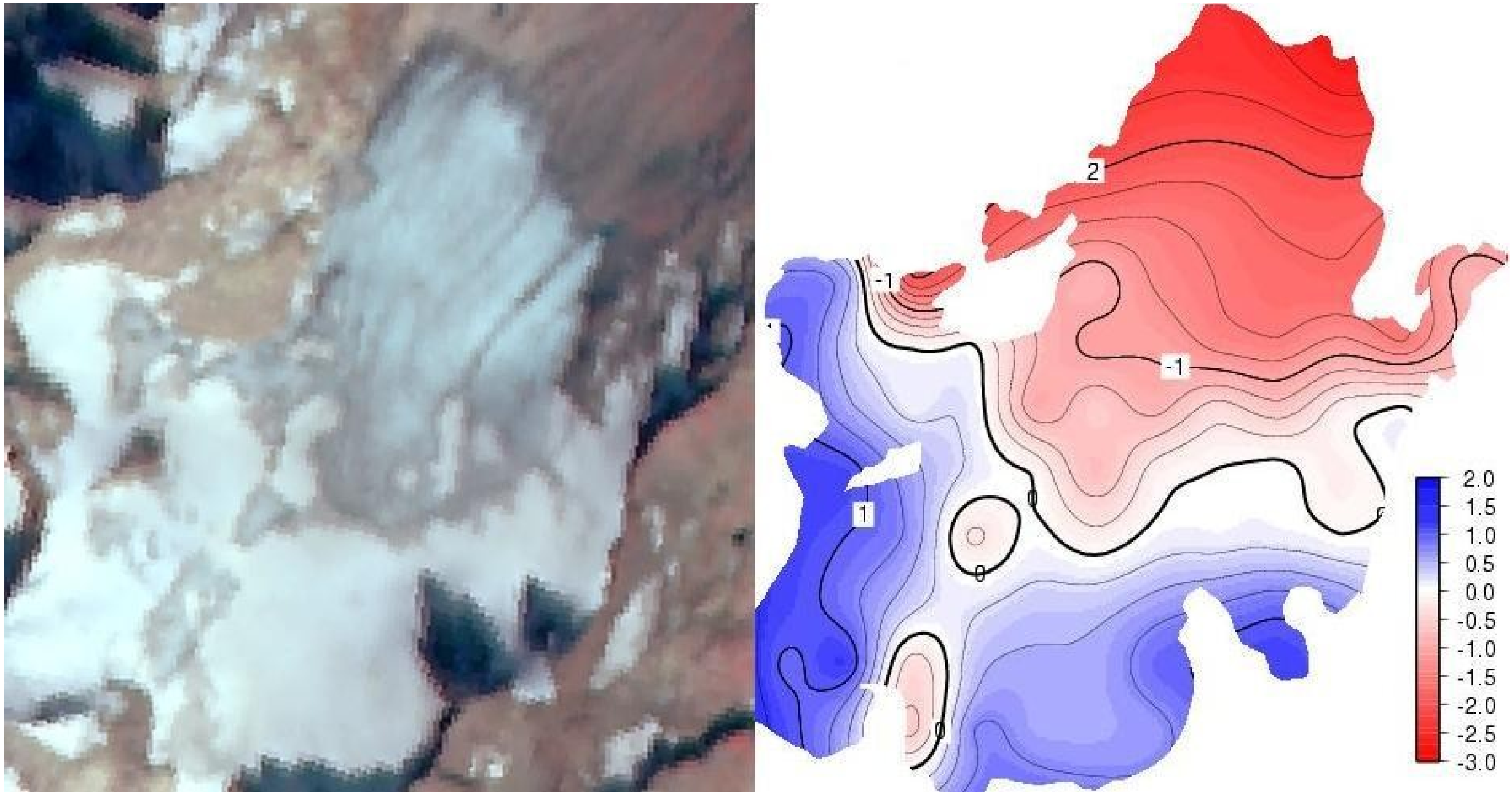
M.Gerbaux (PhD Work, 2005) et E. Le Meur

Impact on an alpine glacier/ Validation (1/2)



Laboratoire de Glaciologie et Géophysique de l'Environnement
LGGE

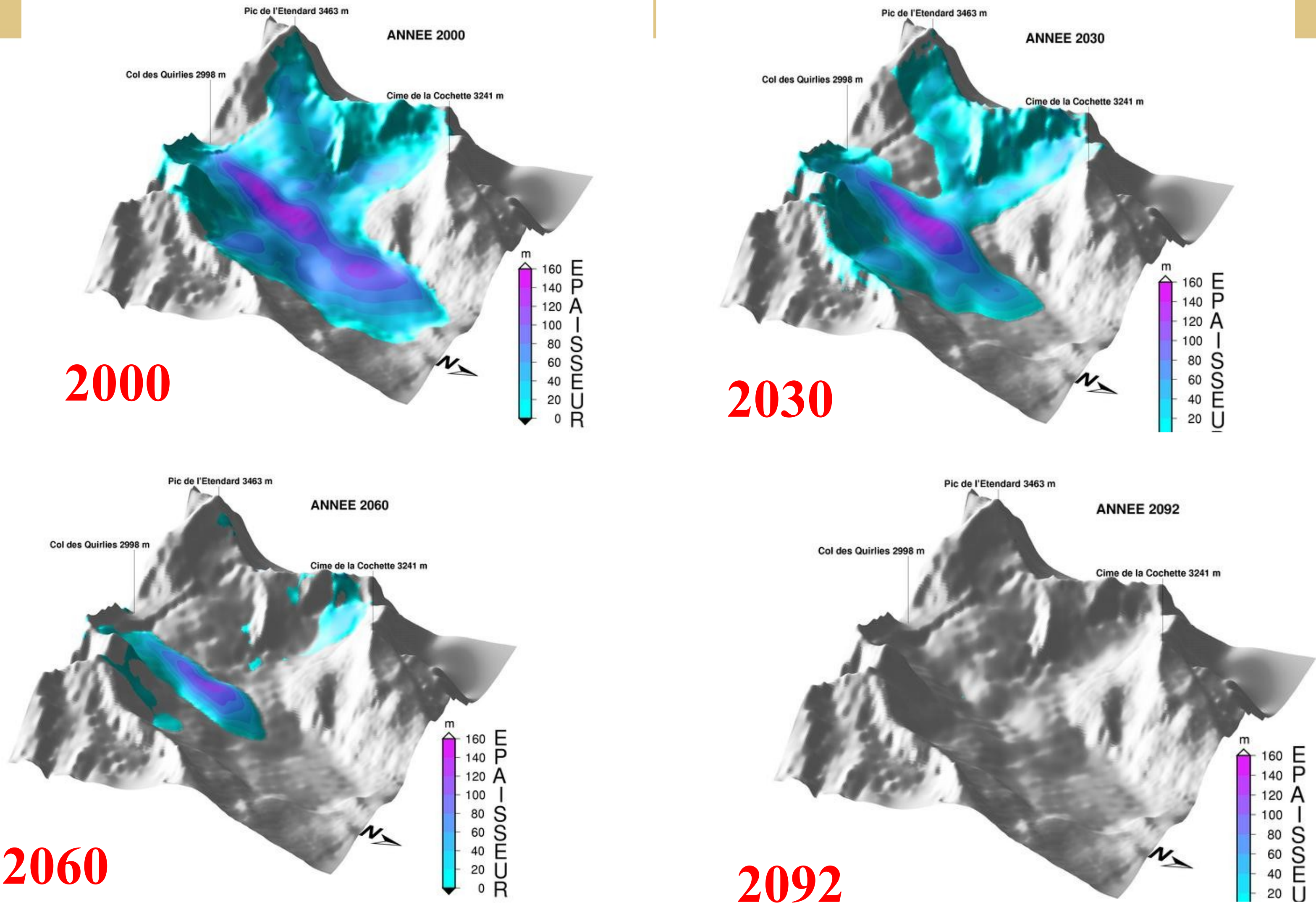
Impact on an Alpine glacier/ Evaluation (2/2)



30 September 1997

From M.Gerbaux (PhD Work, 2005) and E. Le Meur

Impact on Glacier de Saint-Sorlin (scenario B1)

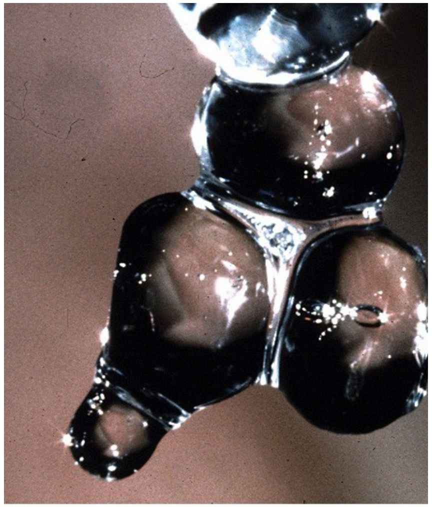


M.Gerbaux (PhD Work, 2005) and E. Le Meur

Two positive feedbacks contributing to this extreme sensitivity (1/2)

- a feedback due to the decrease of snow albedo by wet metamorphism

Surface melting ➔ wet snow metamorphism
➔ decrease of snow albedo
➔ melt rate increase



A few hours

A few days

Two positive feedbacks contributing to this extreme sensitivity (2/2)

- a feedback due to the decrease of snow albedo by the concentration of impurities

Surface melting ➔ some impurities are retained at the surface
➔ decrease of the albedo
➔ melt rate increase

A research project for modeling snow deposition on roads

- Experimentation on instrumented pavements
- Characterization of snow/pavement properties
- Coupling of Crocus with a pavement model

➔ an original model for future operational applications

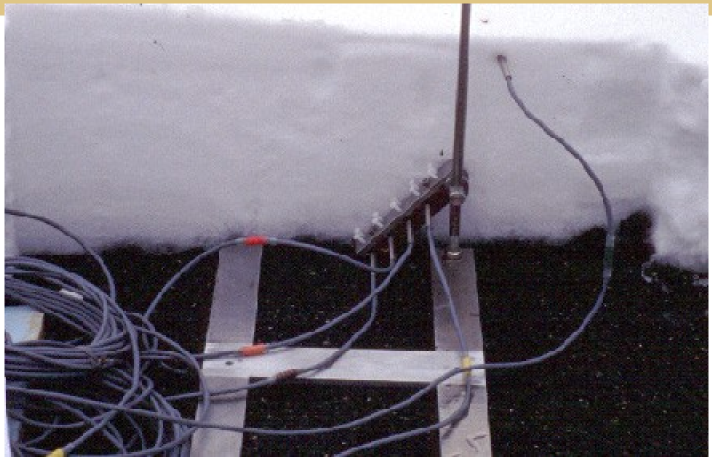
Instrumentation of experimental pavements

6 different pavement samples corresponding to the main types which are used in France

(Col de Porte, 1320m a.s.l)

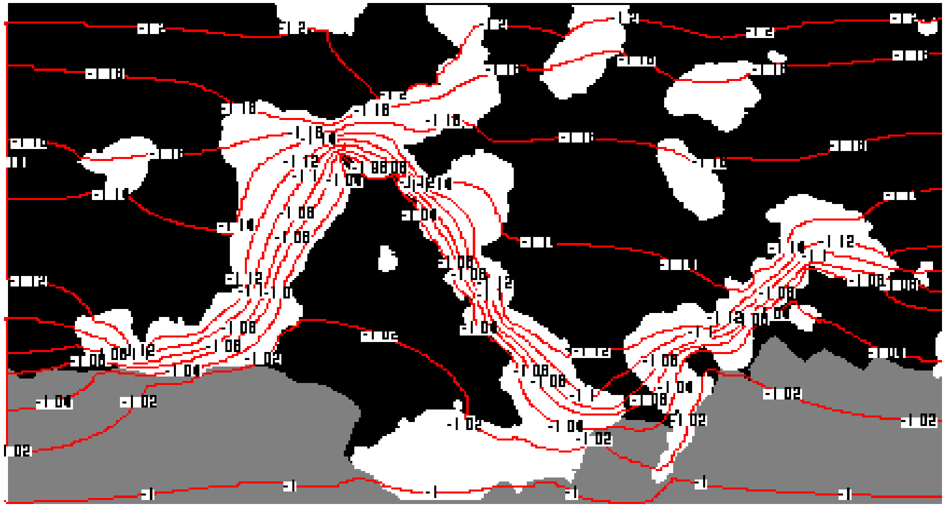
Documentation of 50 snowfalls

Detailed temperature profile, liquid saturation, ... →



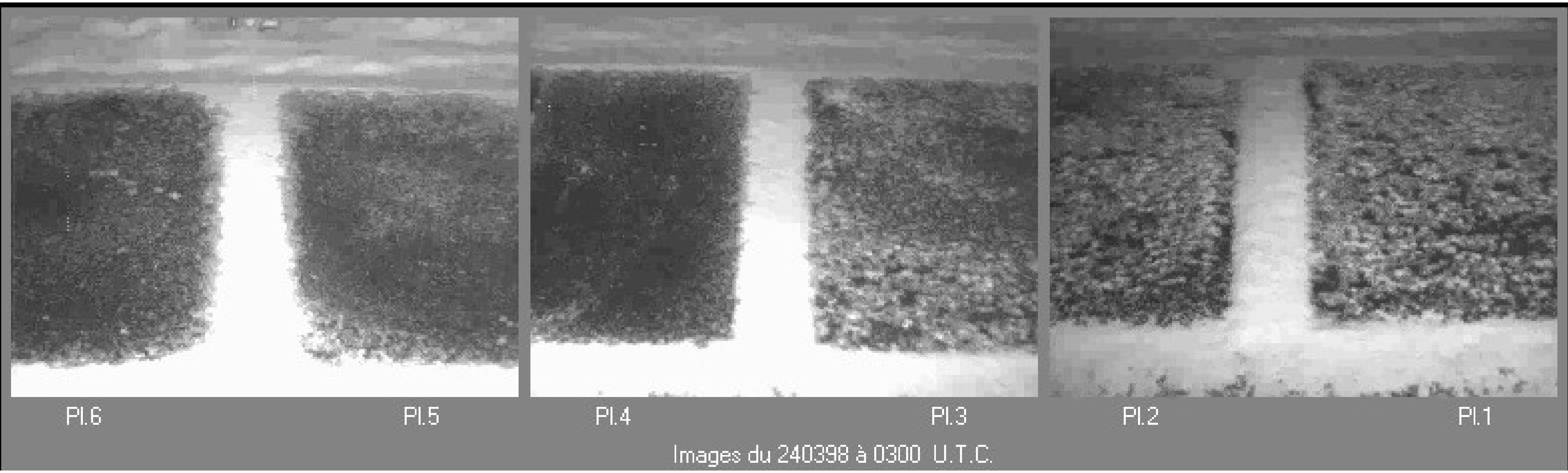
← Extraction of snow/pavement samples

Characterization of their properties: thermal resistance of the interface →

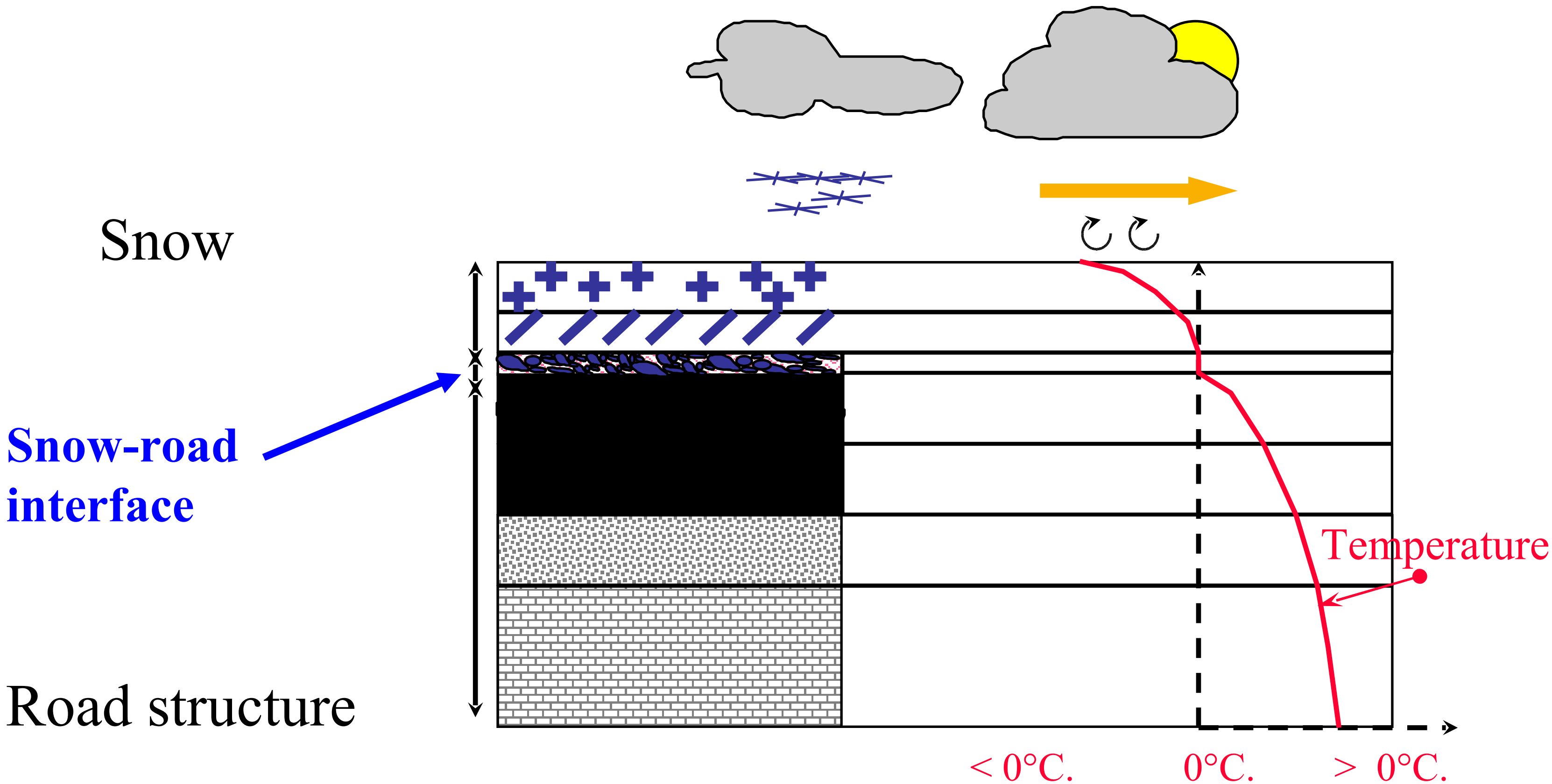


(PhD work, S. Borel, 1999)

Dependency on the type of roads



A coupled model for future applications



(Ludovic Bouilloud, PhD work, 2006)

Which kind of snow model for NWP and Earth System models ?

- 3 classes of snow models in use at Météo-France in SURFEX
  - D95 and EBA: single-layer snow-soil composite model
    ➔ climate models and NWP
  - ISBA-ES : multi-layer snow model including:
    - thermal diffusion, water flow, phase changes, light penetration, compaction, **snow/soil thermal fluxes when coupled to “DIFF”**
    - Invariable number of snow layers (3 to ...)
    ➔ process studies and hydrology
  - Crocus now based on ISBA-ES + :
    - dynamical layering (layers number and depths are variable)
    - metamorphism and snow age
    - albedo function of snow grains and age
    - wind compaction (yet only snow drift effects ➔ blowing snow (PhD V. Vionnet))
    ➔ process studies, avalanche forecast, climate impact and hydrology

Towards increasing complexity ?

- Snow and vegetation: a difficult problem
  ➔ very important for climate simulations
  ➔ more and more challenging for high-resolution NWP

Major challenges at the grid point scale (Patrick's talk):
-Albedo
-Atmosphere/ Snow/ Soil fluxes

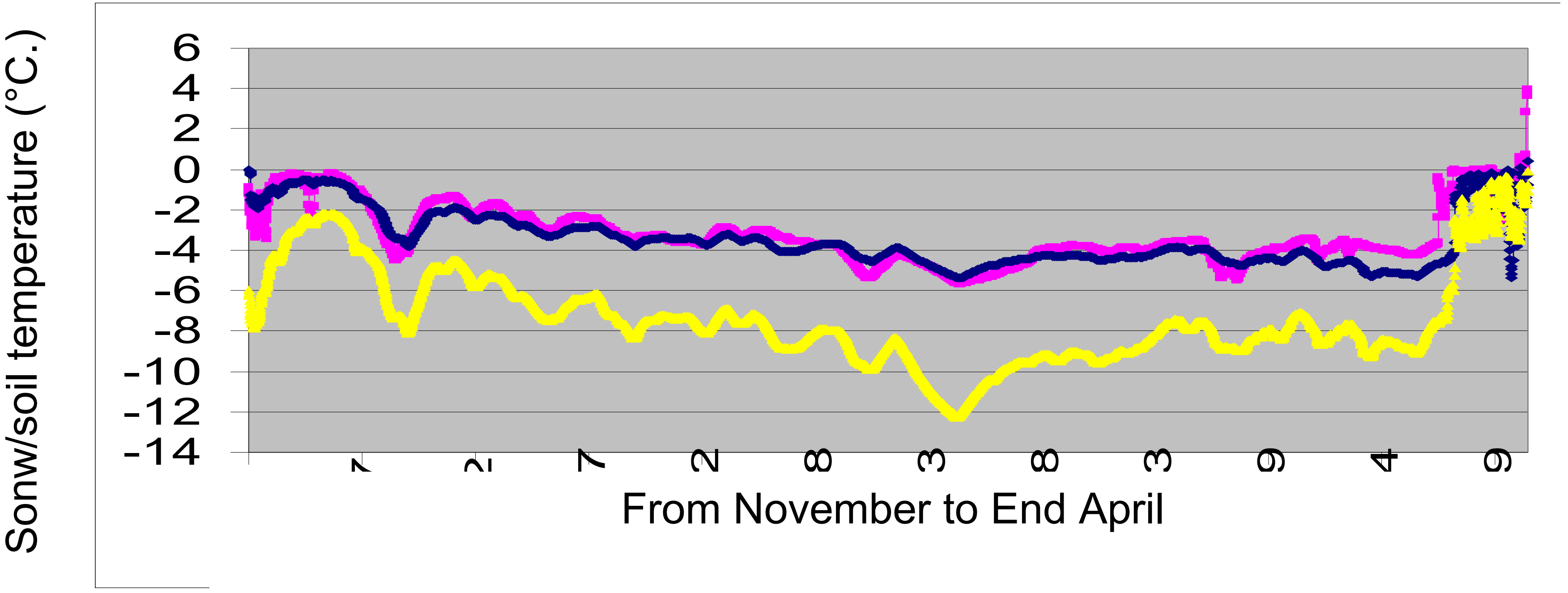
At least 2 "Surfex" patches:

1 : double energy balance with a simple snow model (Stefan)

2 : energy balance with ISBA-ES, fraction=1 and deep soil (Aaron)

Picture from the Arctic Research Centre (FMI) Web site

Importance of deep soil and snow fraction



Observation (H.W. Jacobi (LGGE)

D95 Simulation

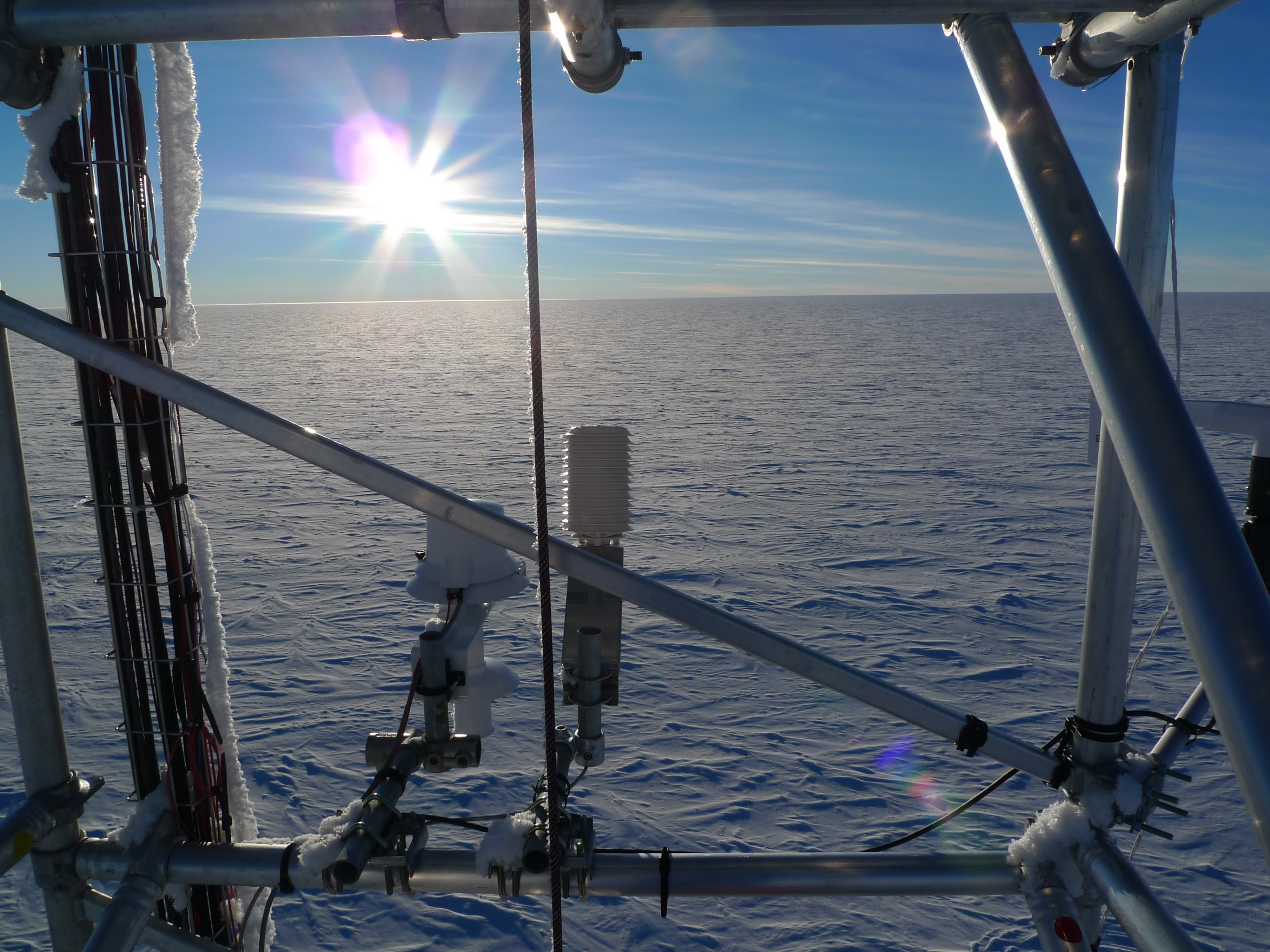
ISBA-ES/ Crocus

A new challenge for NWP: assimilation of Infra-Red sounders (IASI) over snow covered areas

- Very sensitive to surface temperature (1-2°C. !)
- Accurate resolving of the diurnal cycle is critical

→ **Concordiasi** : an ongoing IPY research project focusing on IASI assimilation over the Antarctic Plateau (Concordia base at Dome C)

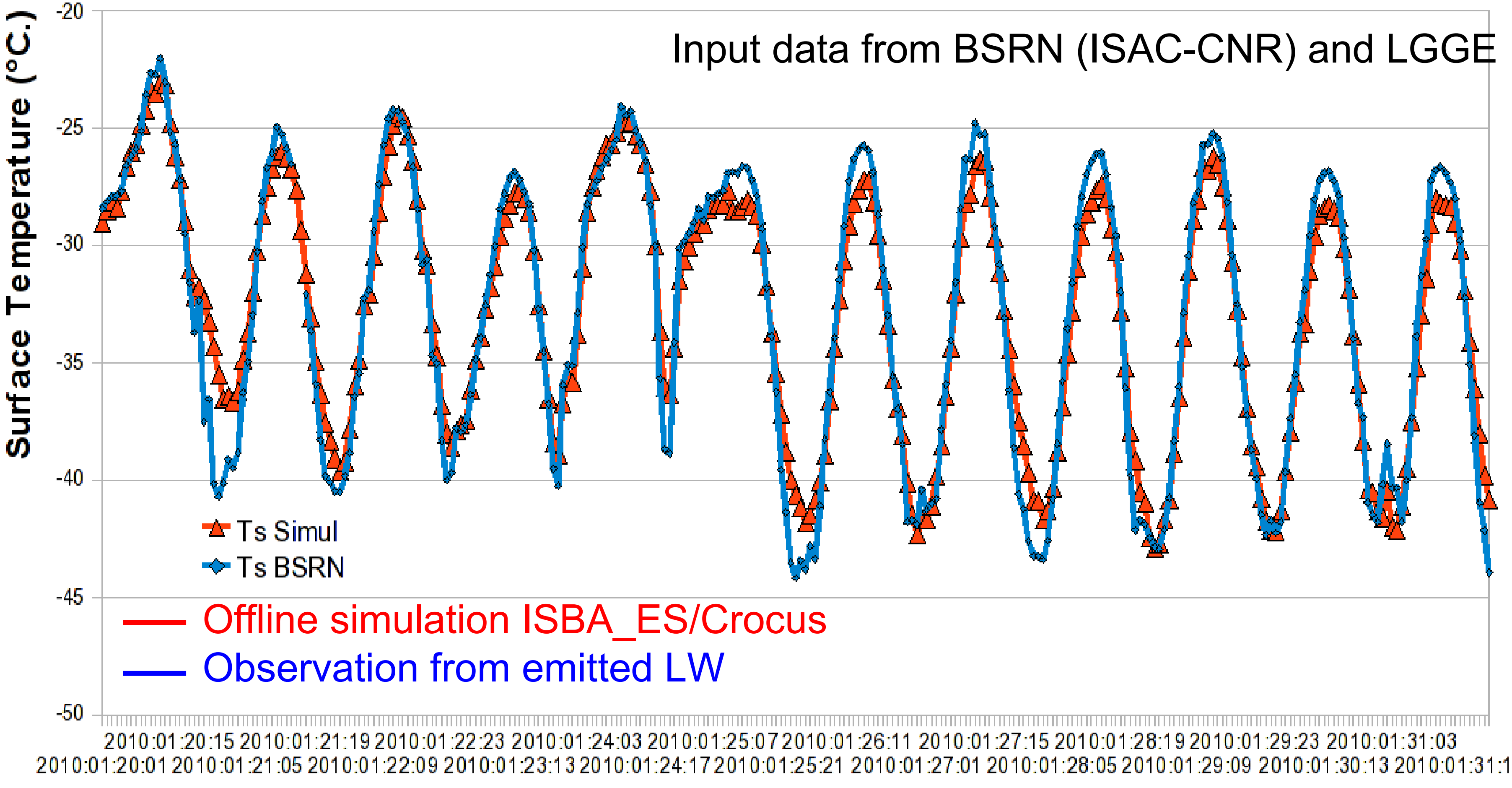
THORPEX-IPY



Dome C: a very convenient site to study snow-atmosphere interactions

BSRN radiation station (ISAC-CNR)

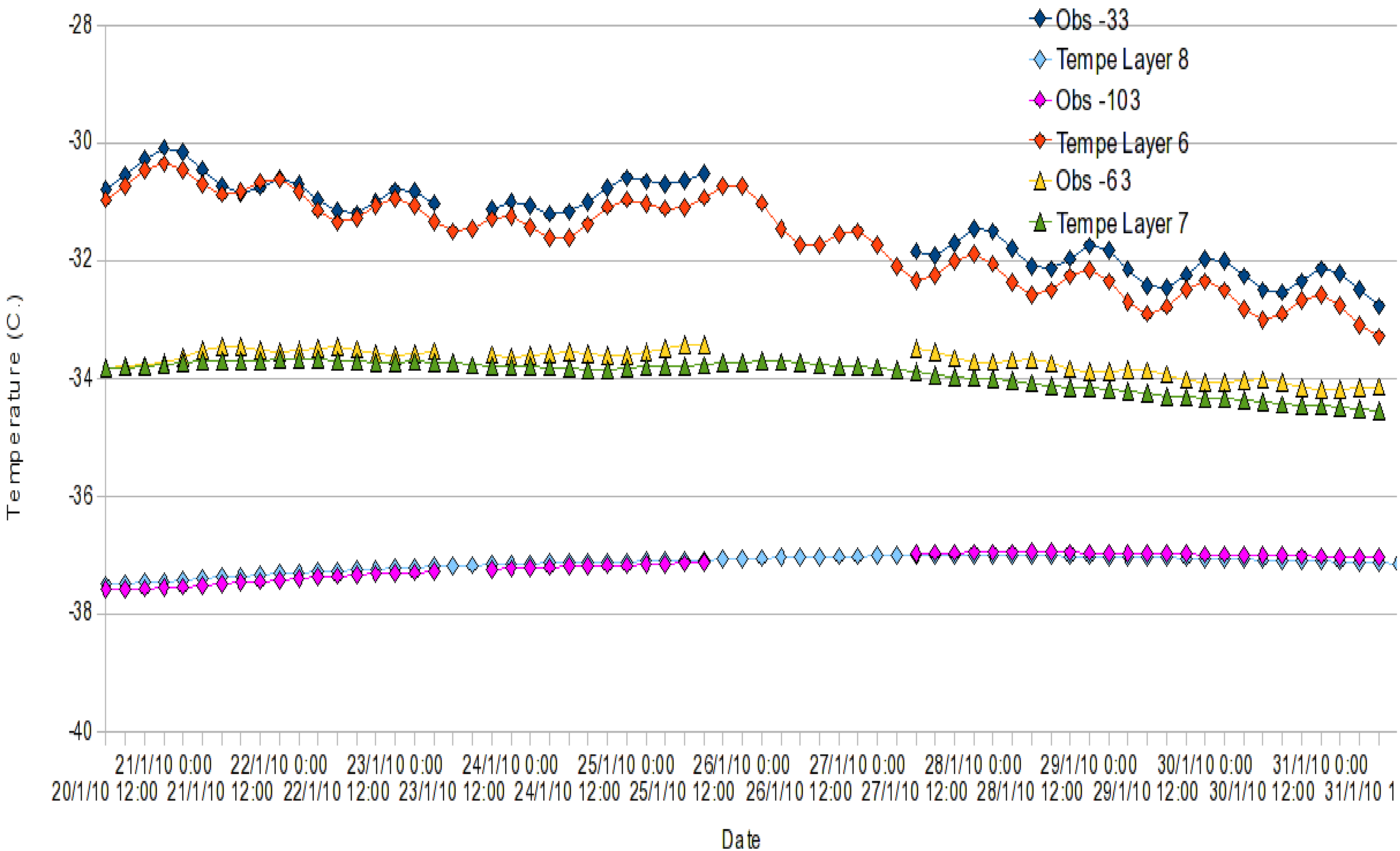
Good performance of detailed snow models ...



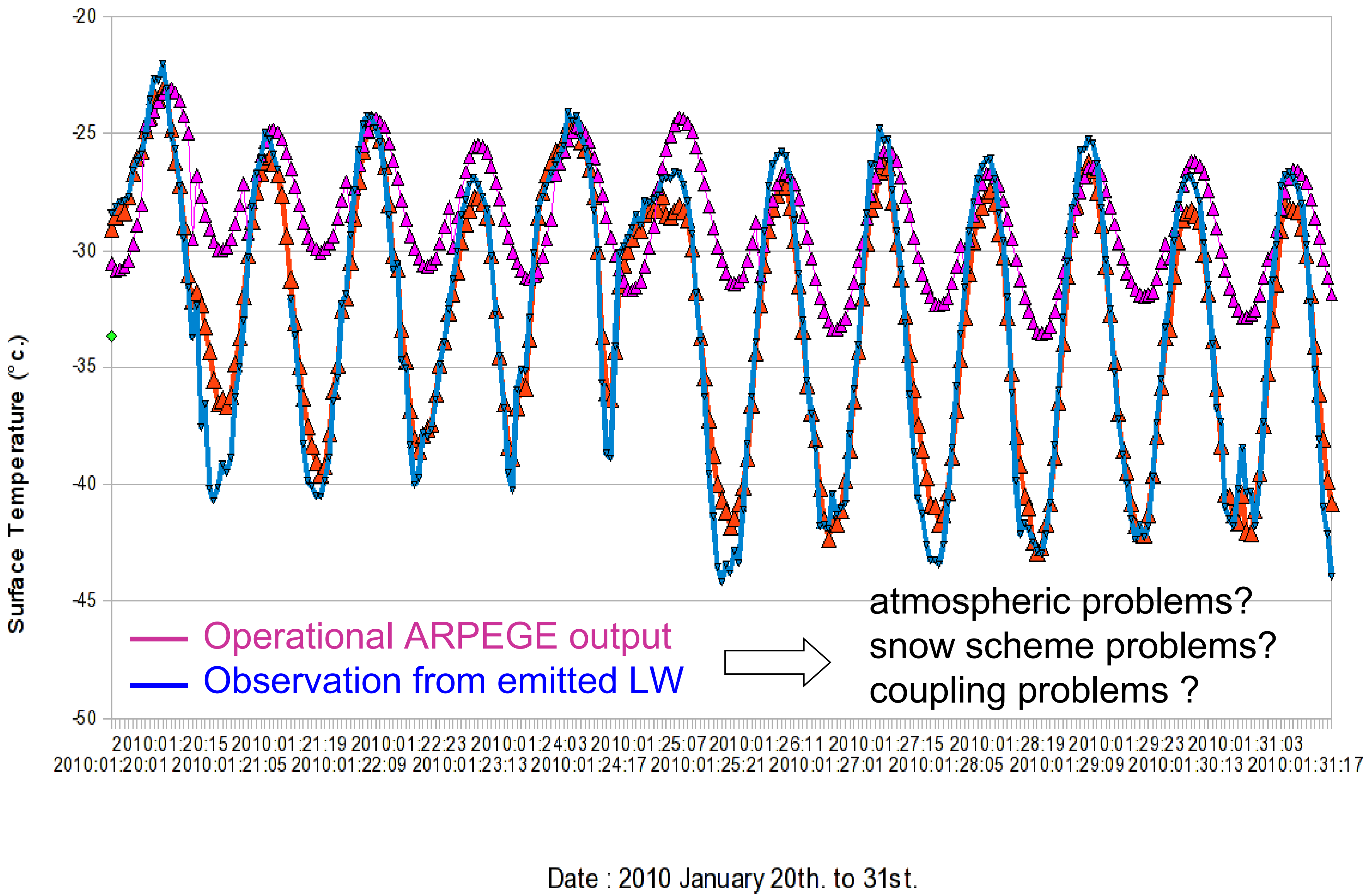
2010 January 20th. to 31st

CNRS IPEV Institut Polaire Français Paul Emile Victor — 50 ans Laboratoire de Glaciologie et Géophysique de l'Environnement LGGE — METEO FRANCE Toujours un temps d'avance

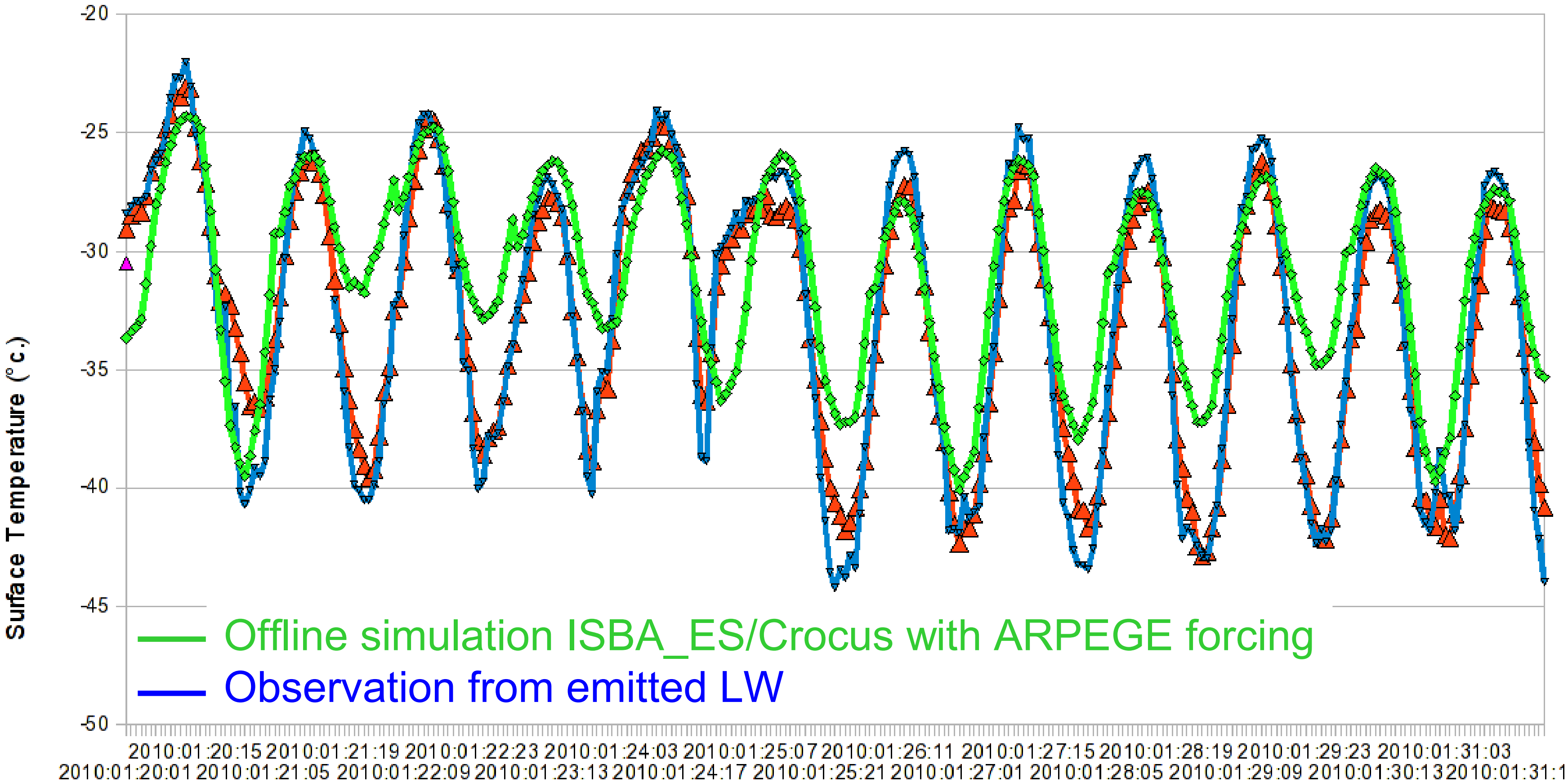
Deep temperature simulation



... but limited performance of NWP forecasts ...



... despite reasonable results when forcing a detailed model with forcing data from NWP !



➔Improvements to be expected from an evolution of snow schemes in NWP models

➔A balance to be found between computing costs, realistic physics and snow cover initialization issues

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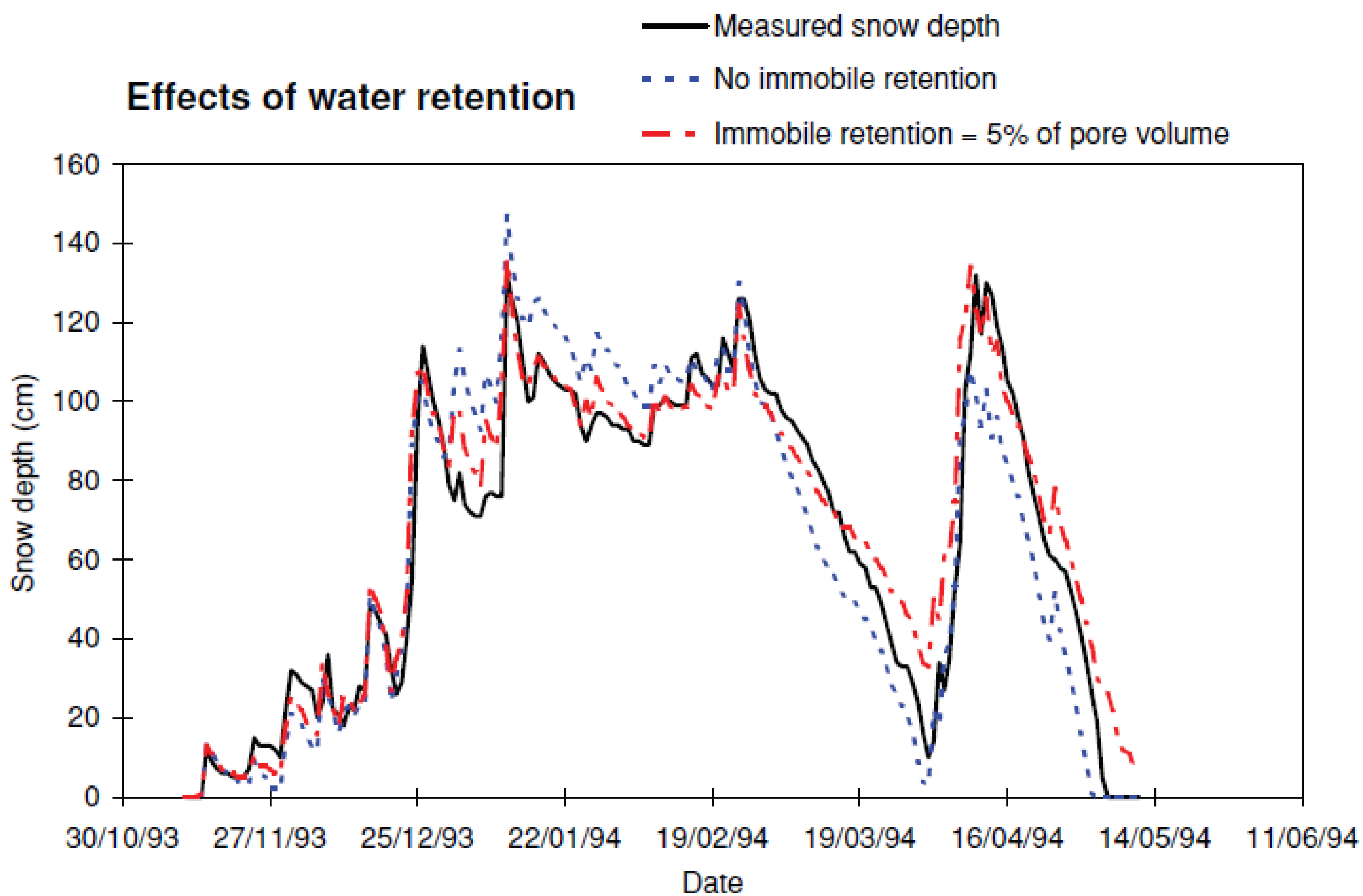
Importance of some specific processes



Very important process at the beginning of the melting-season!

vanoise 17/03/2009 12H

altitude: 2400 pente: 40 degres

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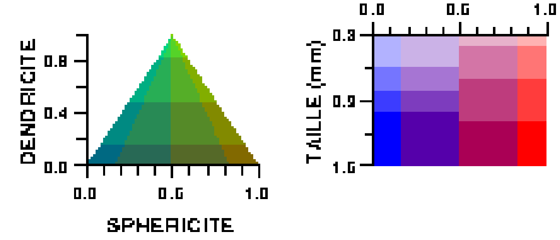

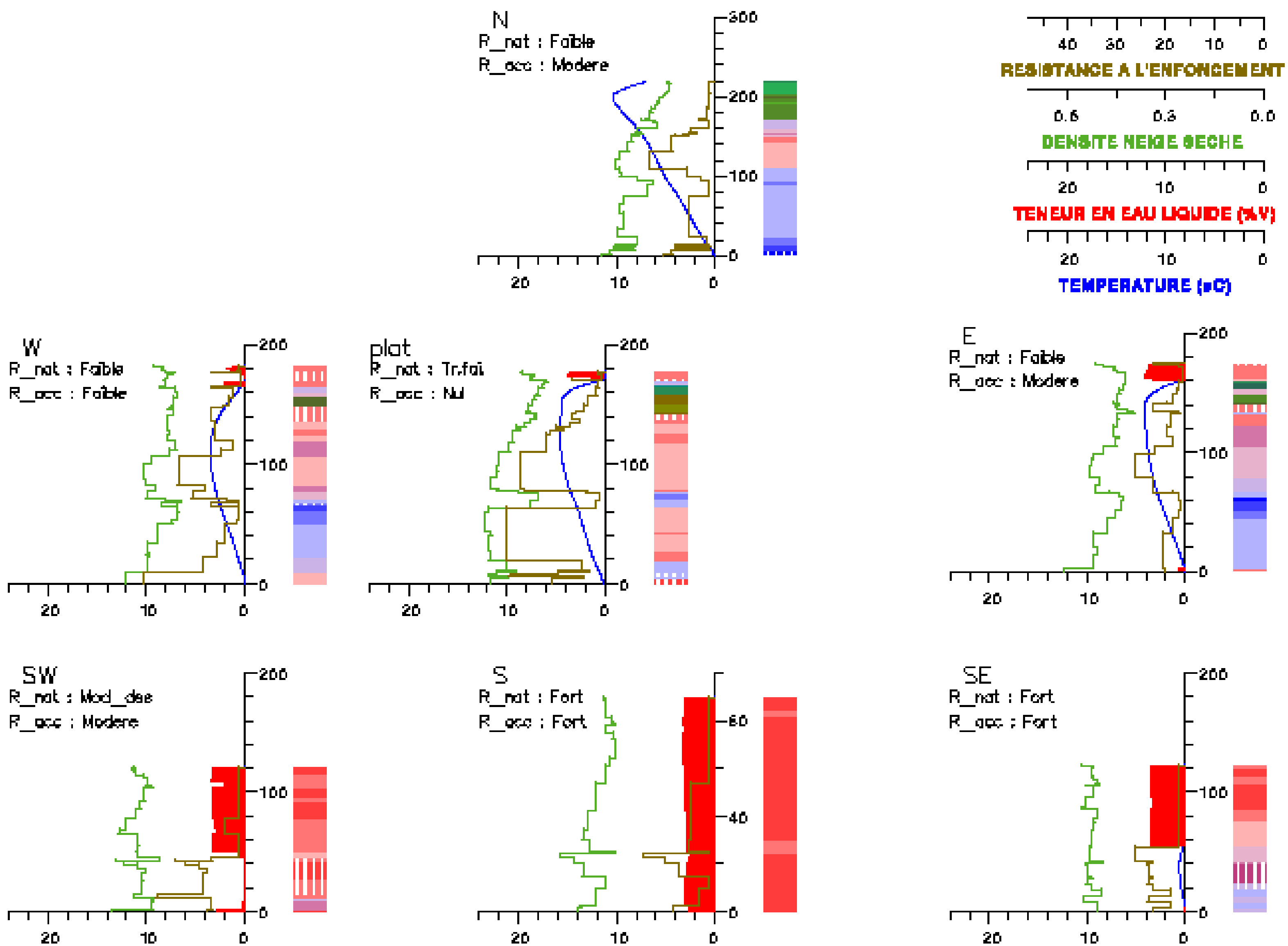

With AROME/HARMONIE and ISBA-ES/CROCUS !