Snow properties retrieval in Alpine regions with full polarimetric Radarsat-2 data (C-band)

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- SOAR #1341 Program, Canadian Space Agency and MDA, 2009-2011

- PNTS # 0910 Program, CNES (French Space Agency)and INSU, 2009-2010

GOAL / SCOPE

- Dry snow mapping and Liquid Water Content (LWC) estimation using full-polarimetric image information.

- Multi temporal Radarsat-2 full-polarimetric parameters analysis

- What relationship can be set between this evolution and snow/meteorological parameters temporal trends.

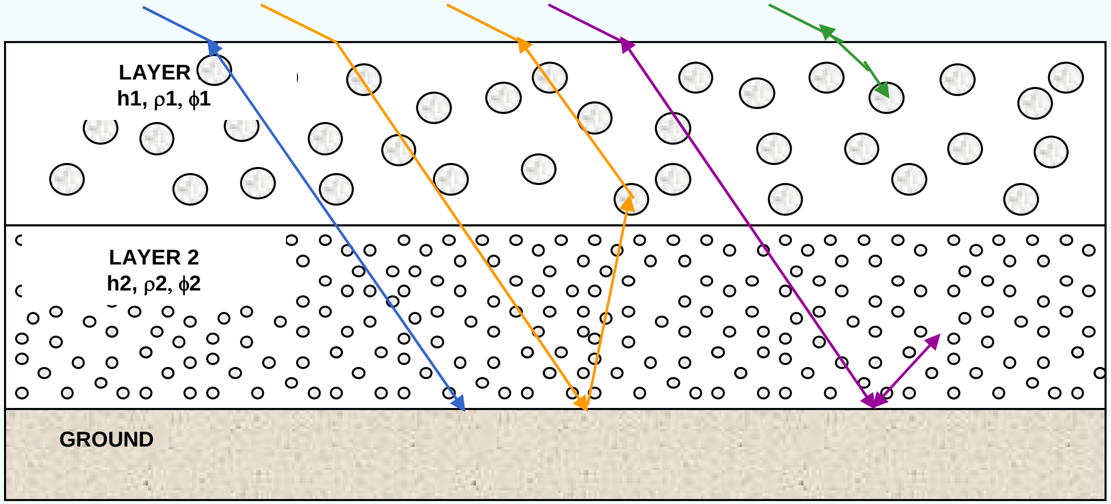
OUTLINE of PRESENTATION

1. Background
2. Data description and study area
3. Pre-processing
4. RS2 Polarimetric Methodology
5. Early results
6. Conclusion and Footsteps

1. BACKGROUND

1.1. SNOW BACKSCATTERING : Multi-layer Model.
Dense Medium Radiative Transfert theory

(Ulaby & Fung, 1986)



h: Snow depth, ρ: Snow density, ϕ: Particles diameter

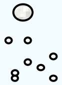
Backscattering mechanisms

- **Surface Scattering**
- **Volume Scattering**
- **Double Bounce**
- **Triple Bounce**

Surface Scattering

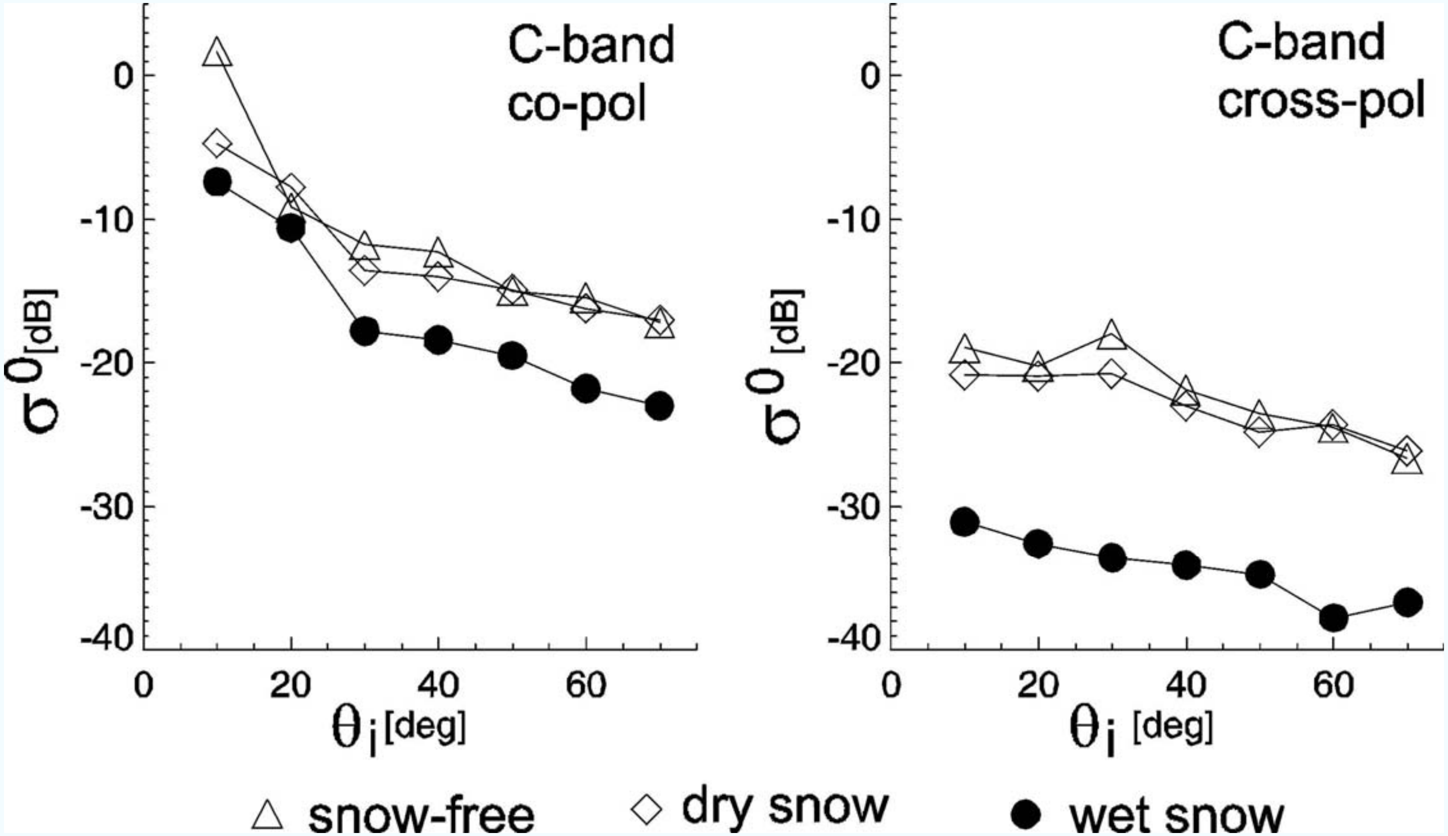
- **Integral Equation Method (IEM)**
- **Kirchhoff method**

Volume Scattering



Spherical Particles (Rayleigh scattering approximation)

1.2. C-band Backscattering of Snow-Covered Ground



Test site: Leutasch, Tyrol
Ground-based scatterometer measurements
Dry snow depth: 0.5 – 1.0 m
Background target : Meadow

(By courtesy of H. Rott, 2005)

1.3. Polarimetric Representation :
Target decomposition theorem

- Coherent Scattering Matrix $\mathbf{S}$

$$\mathbf{S} = \begin{bmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{bmatrix}$$

- Target Vector

$$\mathbf{k} = \frac{1}{\sqrt{2}}\left[S_{hh} + S_{vv}, S_{hh} - S_{vv}, 2\,S_{hv}\right]^T$$

- Kennaugh Matrix $\mathbf{K}$

$$\mathbf{K} = \frac{1}{2}\left\langle \mathbf{U}^{\mathbf{T}}\mathbf{S} \otimes \mathbf{S}^{*}\mathbf{U} \right\rangle$$

- Coherency Matrix $\mathbf{T}$

$$\mathbf{T} = \left\langle \mathbf{k}\mathbf{k}^{*T} \right\rangle$$

- Eigenvector based decomposition

polarimetric parameters : $\alpha / H / A$

Polarimetric parameters decomposition

Alpha (α): describes the scattering type. Angle varies from 0° to 90°. Depends of the target dielectric properties (ε) and sensor Incidence Angle.

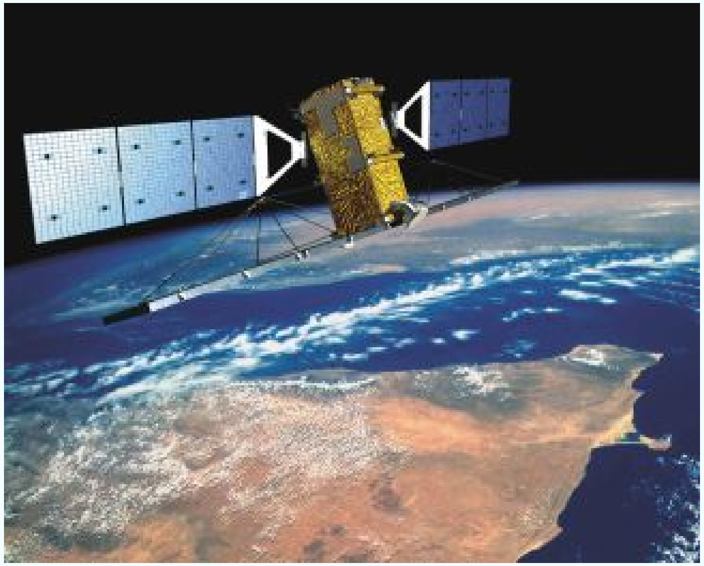
Entropy (H) : indicates random profile from global backscattering on the target.

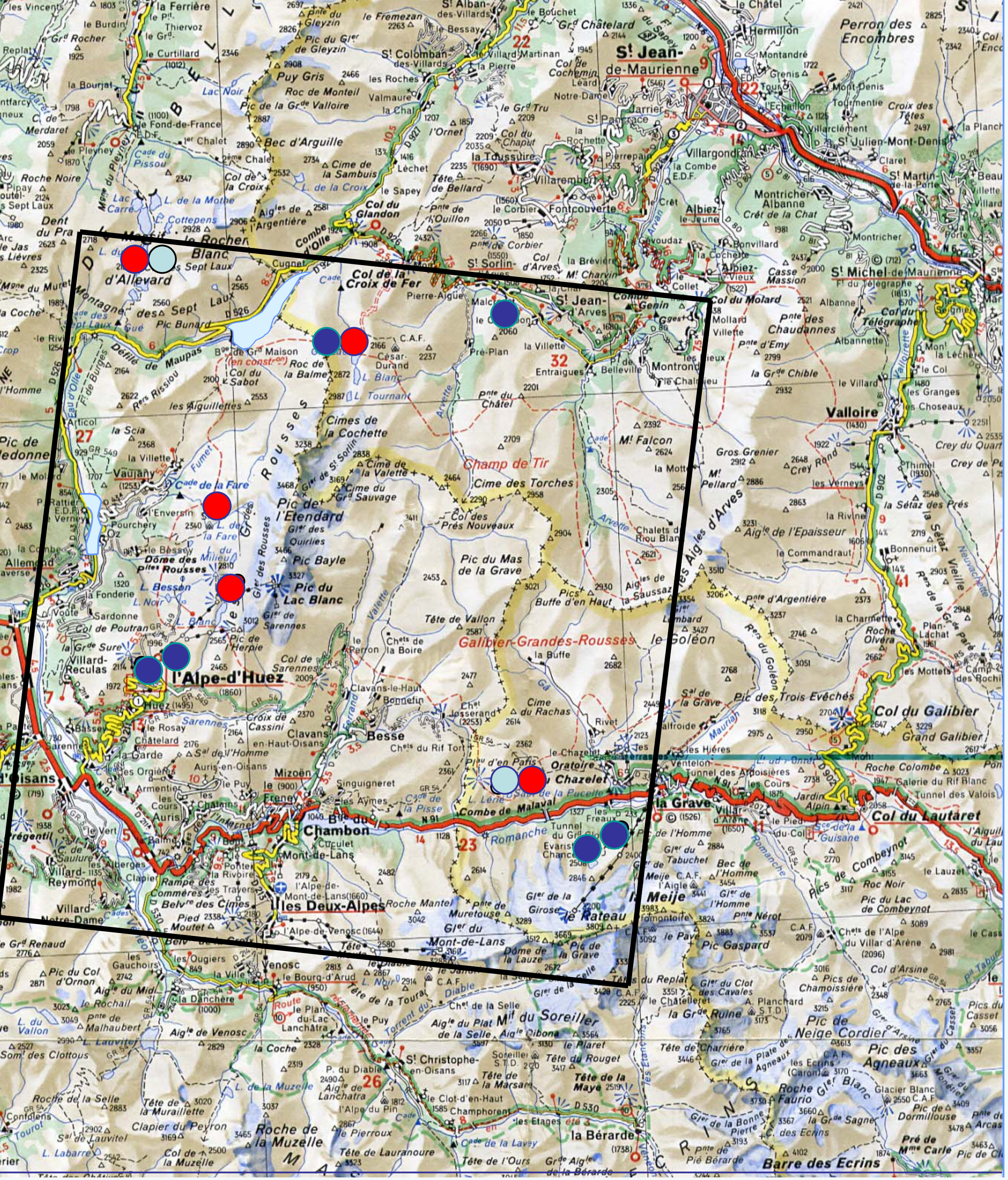
Anisotropy (A) : describes importance of secondary backscattering mechanisms.

(Cloude and Pottier, IEEE Trans. on Geosci. and Rem. Sens.,1996 ; 1997)

2. DATA DESCRIPTION and STUDY AREA

Radarsat-2 : C-band (5.4 Ghz)
Full polar. Launched 14 dec 2007.
© RSI / MDA.





RADARSAT-2

Quad-Pol Mode (HH+VV+HV+VH)

Dates 2009 : **5** (4 snow, 1 summer)
Date 2010 : **1** (dry snow)

- Resolution : 4 m (fine), 450 km²
- Inc Ang° : 38.51, Beam : FQ19
- Start time : 05:42 UTC (Desc)
- Lat/Long Center :
  45° 08'N / 6° 10'E

NRC sensor EDF (2)

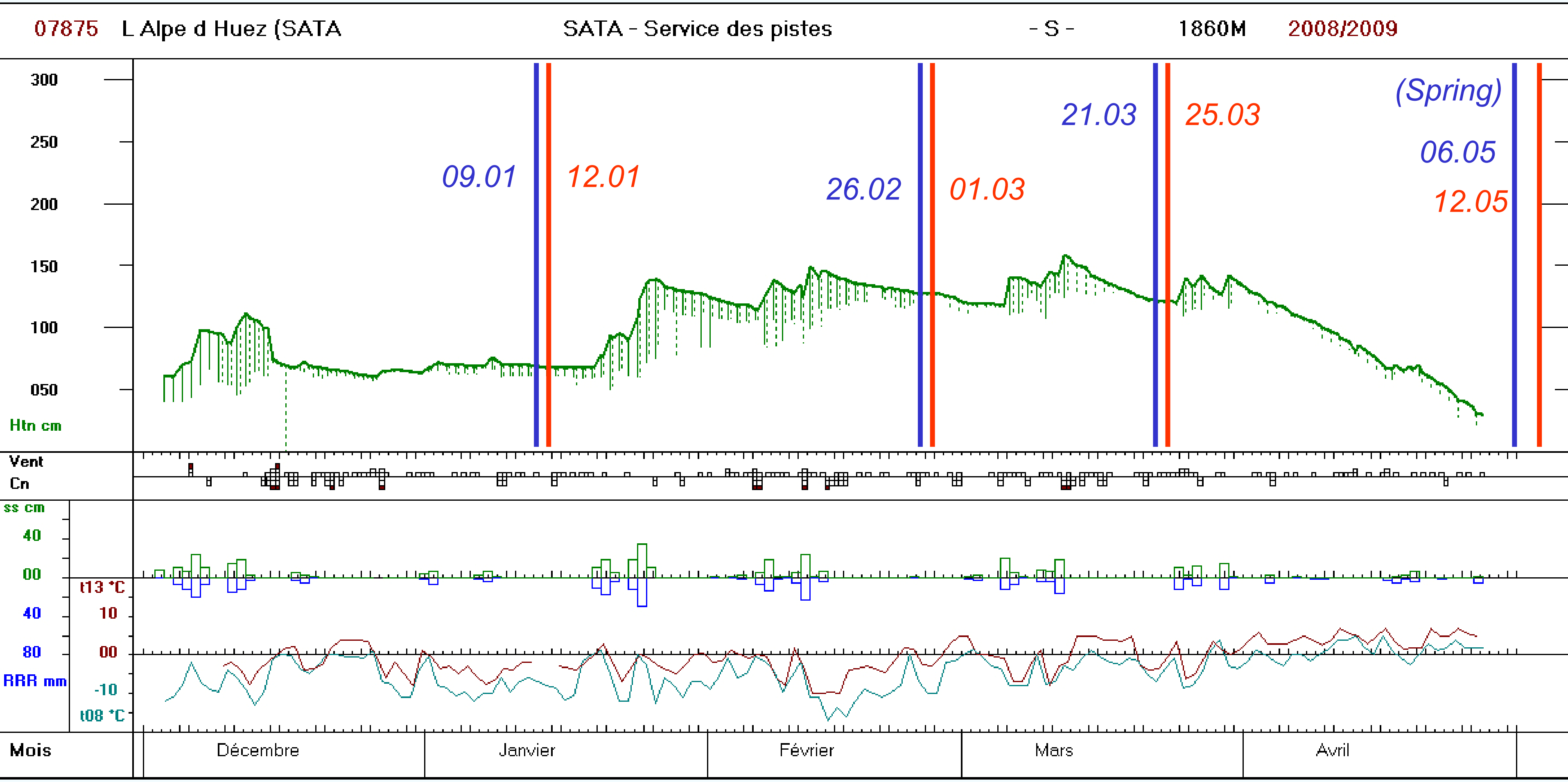
EDF snowpits (6)

Meteo-France - LTHE snow statigraphy (5)

0 2,5 5 km

2.1. Images 2009 Acquisition

(No fresh snowfall or consequent melting between winter SAR and optical registration)

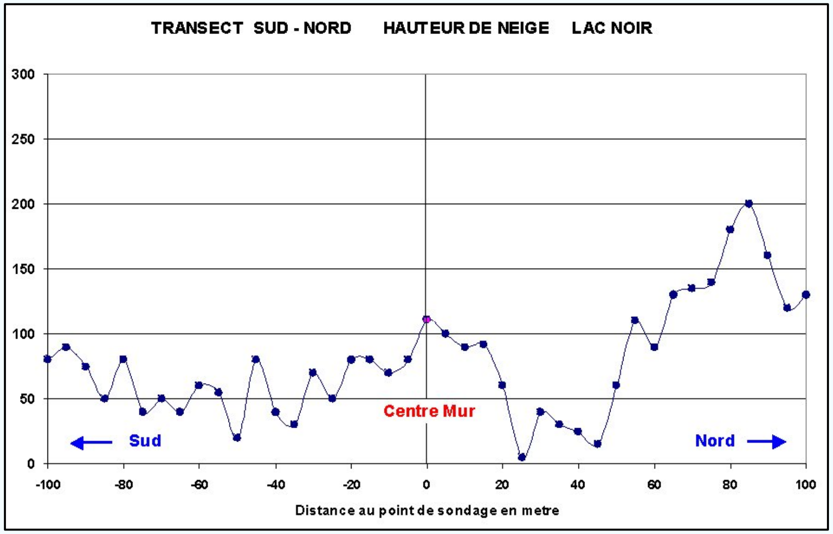


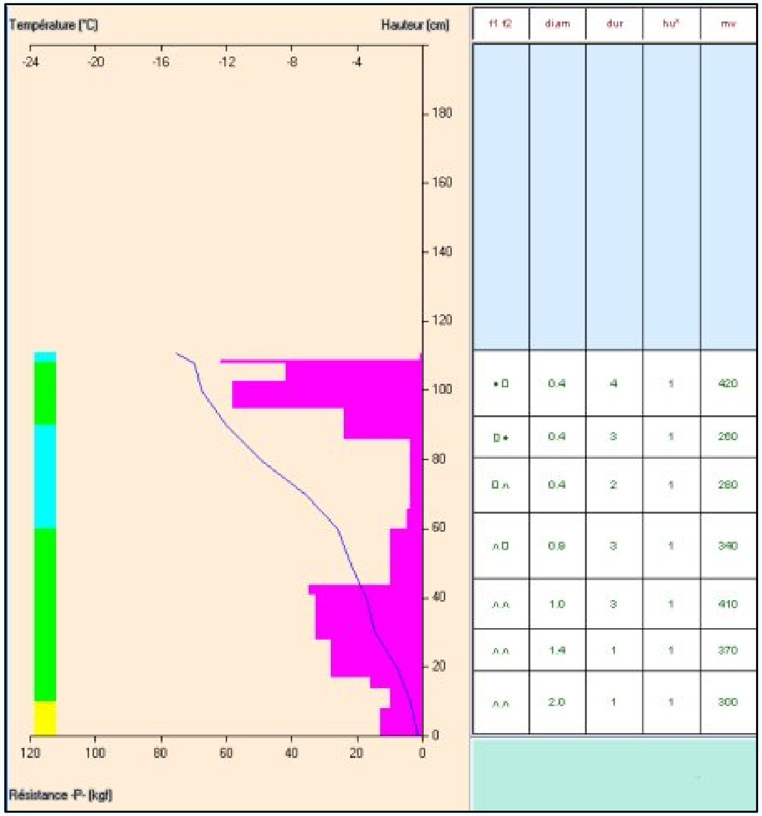
RS2 Image

Landsat 7 Image

2.2 *In-situ* snow measurements (Météo-France)

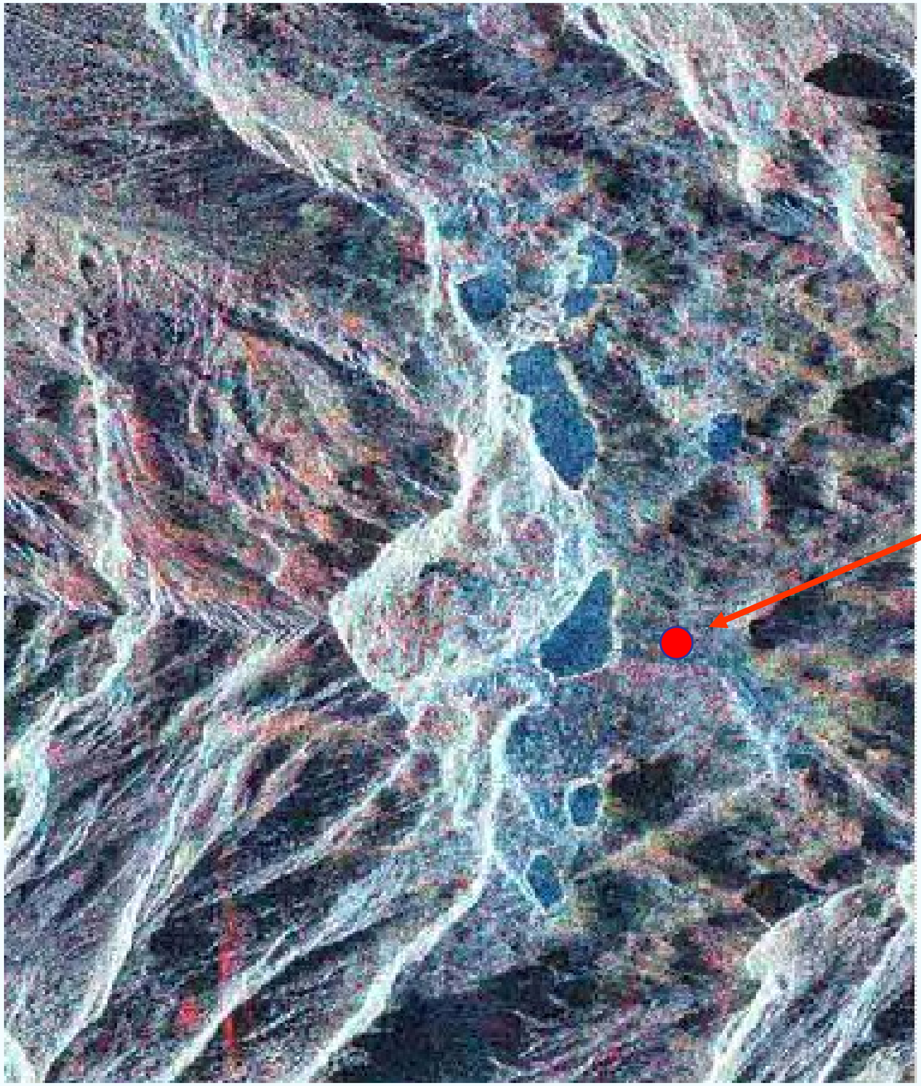
(January 12, 2009)





Snow stratigraphy profile and physical parameters (T°, ϕ, ε, σ , ..)

Cosmic-ray Snow Gauge (EDF) : h, σ, SWE.



Agnelin Site (RS2 image)

	Lac Noir	Agnelin
Date	25.03.2009	25.03.2009
Altitude	2436 m	2230 m
Heure TU	9h	
Nb carottages	4	
Hauteur Neige moyenne (cm)	52	
Plage de hauteurs (cm)	35 à 65	
Densité moyenne	0,28	
Valeur en Eau moyenne (mm)	146	
Valeur en eau NRC (mm)	137	745
Hauteur NRC (cm)	52,5	208

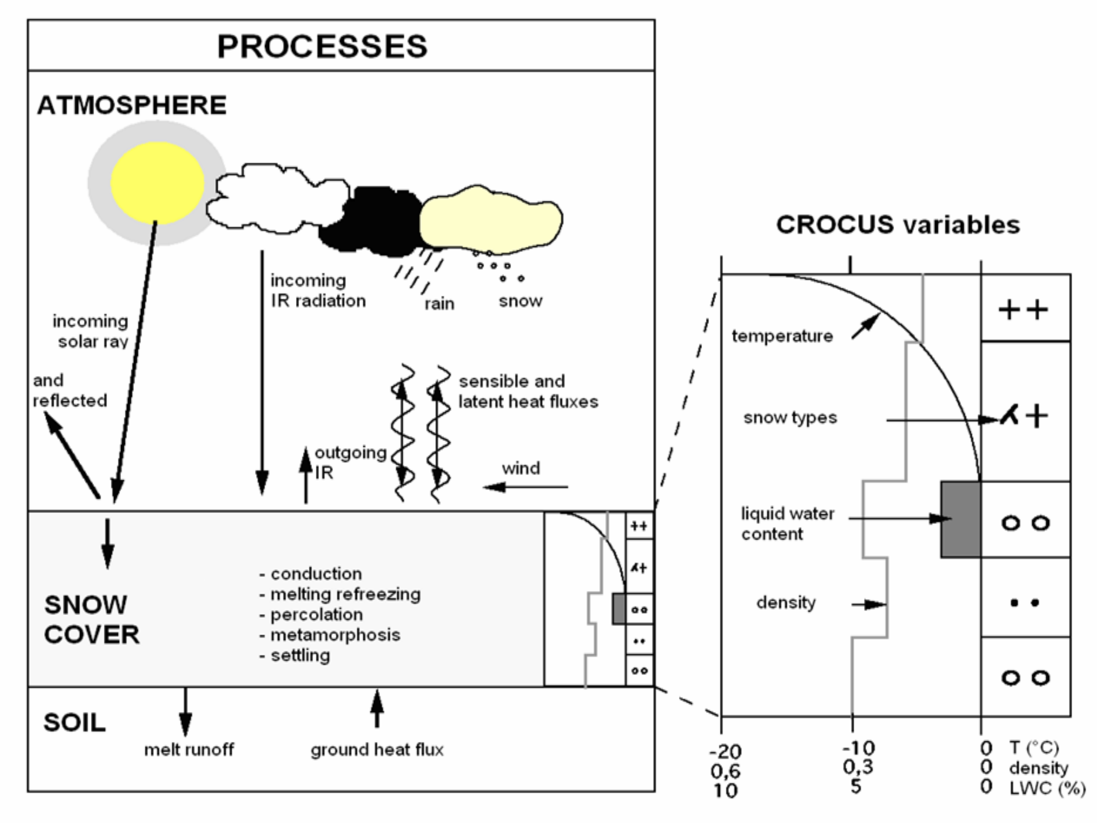
(March 25, 2009)

2.3. **Safran/CROCUS Chain**

Snow Metamorphism Model *(Brun et al. ,1992).*

Safran : Energy and mass evolution of the snow cover at massif scale

CROCUS: Temperature, density, liquid-water content and layering of the snowpack



☺ **Detailed snow information and operationally used (avalanche forecasting)**

☹ **Limited segmentation (300m elevation, 6 orientations, 3 slopes), no local wind effects**

3. PRE-PROCESSING

IMPORTANT

Due both to high mountain context (slope effects) and SAR acquisition geometry, it is necessary to adjust ancillary dataset (DEM, optical images) into the Slant Range geometry of Radarsat-2 dataset, to preserve all polarimetric information during the ancillary data combining process with SAR SLC mode at fine resolution level.

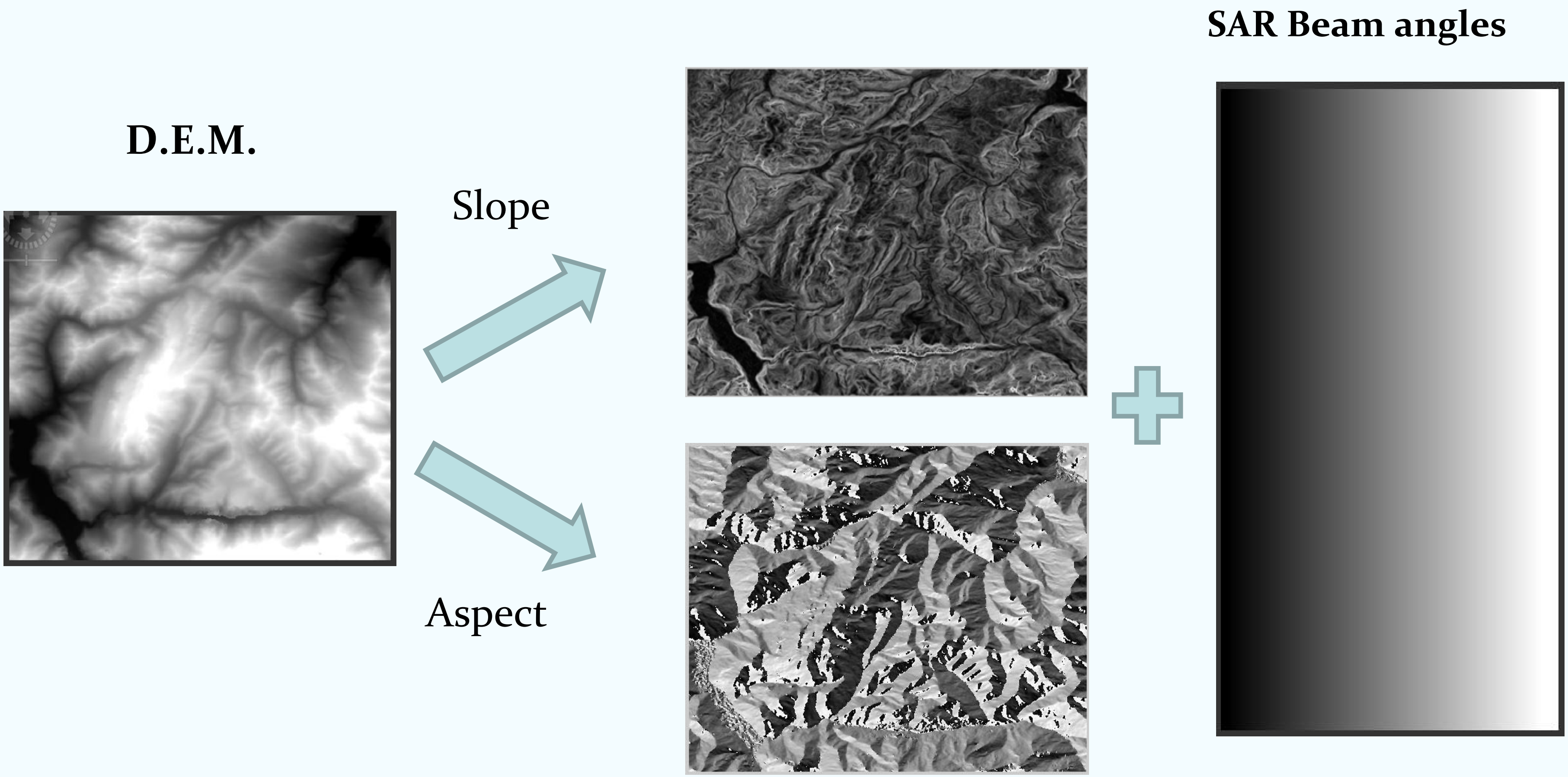
Then, in a second step, polarimetric decomposition results (i.e. snow cover) will be geocoded into Ground Range mode for planimetry validation (topographic maps, optical images).

For each RS2 date :

* Local Incidence Angle calculation : **NEST- 3C** ESA Toolbox (http://earth.esa.int/nest) : layover and shadow bitmask, geometry import and export. A sensibility comparison is set between 3 DEMs : *SRTM-90m*, *ASTER-30m* and *French National Geographic Institute-50m (IGN)*.

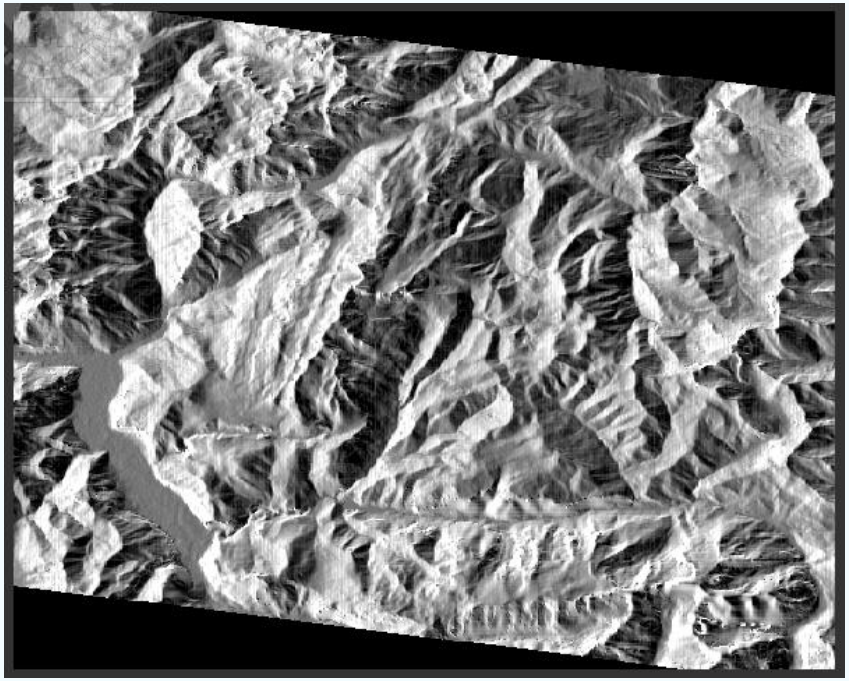
* Reprojection process of DEMs and Optical images in the SAR topology : complementary algorithms development were necessary (Matlab).

3.1 Local Incidence Angles
(*ESA-NEST software*)

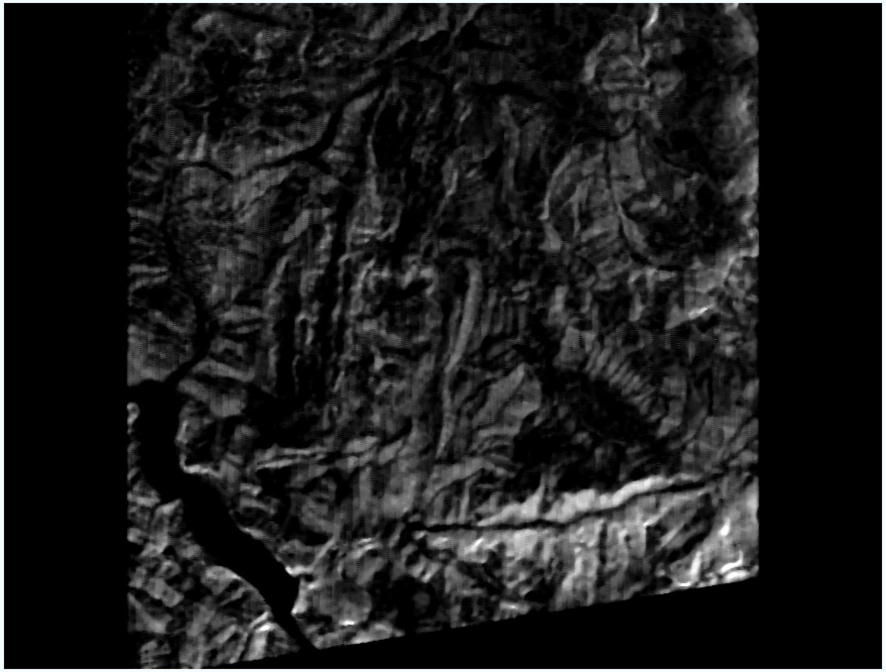


Local Incidence Angles maps

SRTM-90m DEM

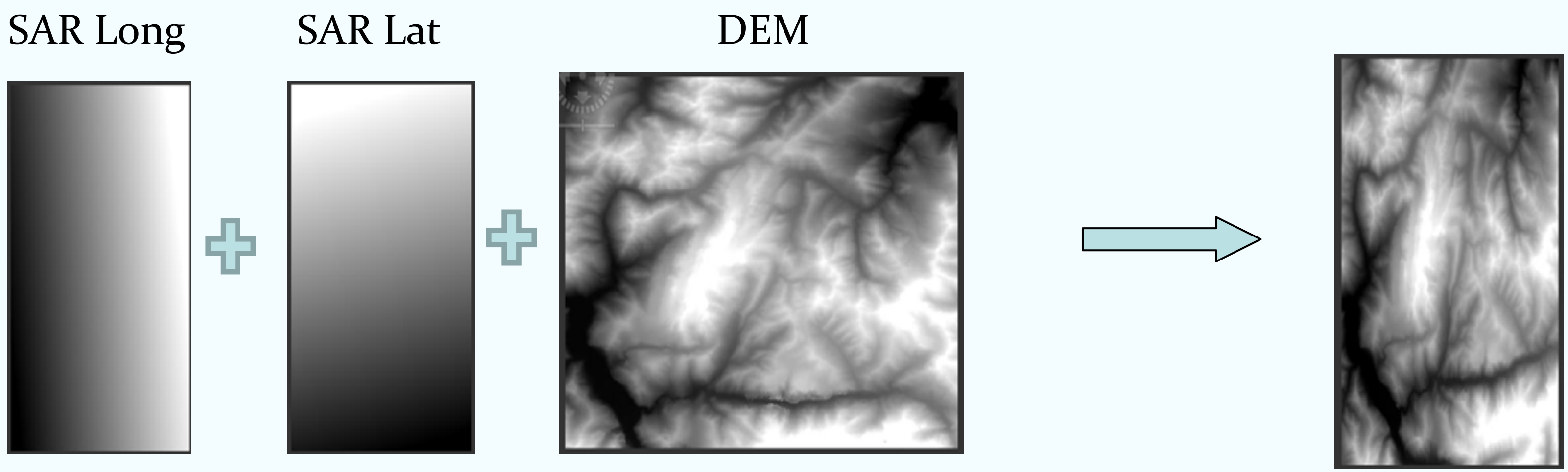


ASTER-30m vs IGN-50m
(Aster false-alert in white)

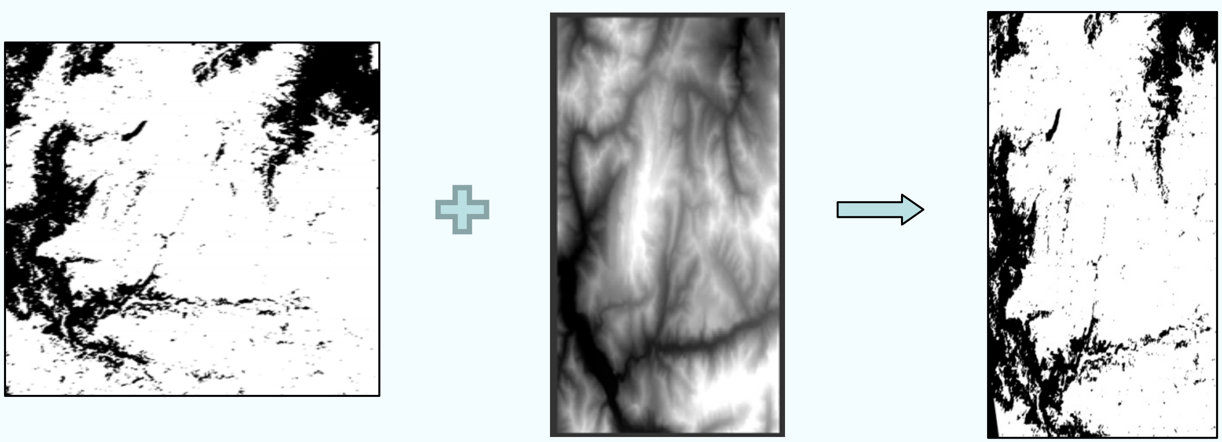


(March 01, 2009)

3.2 DEM reprojection in SAR Slant Range topology (SLC mode)



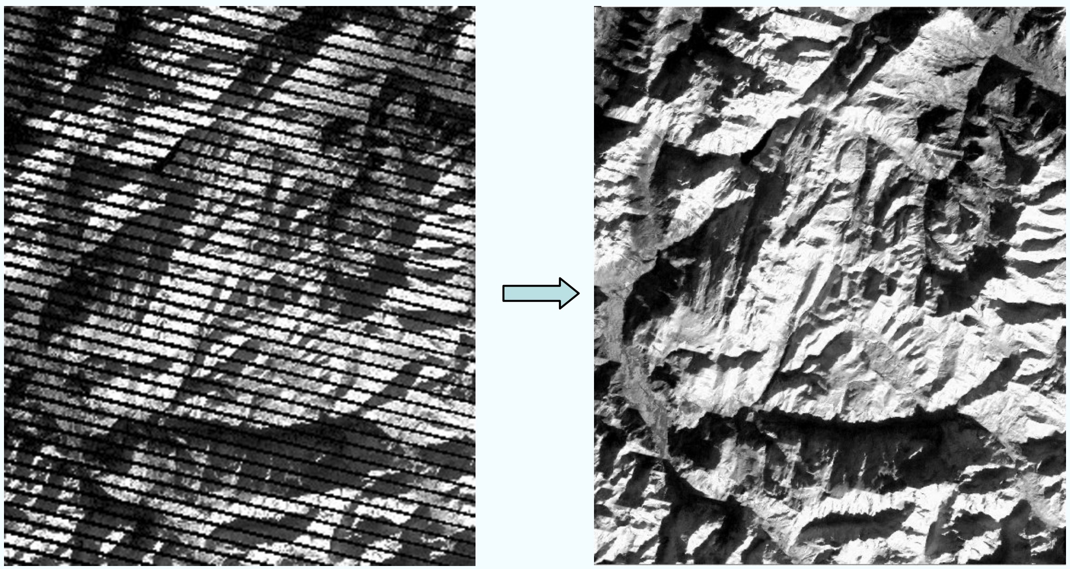
Optical data reprojection



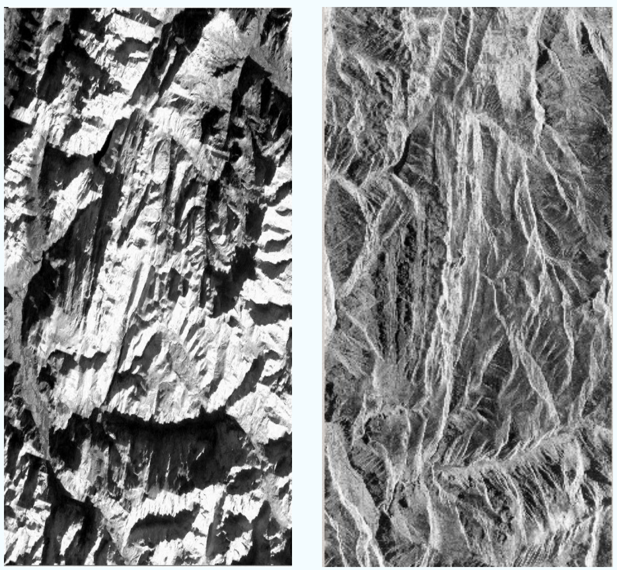
(Example: Landsat-7 March 21, 2009 vs RS2 March 25, 2009).

OPTICAL IMAGES : the case of Landsat-7 ETM, SLC-off data.

A/ Destriping (Fourier and inverse, low-pass Filter)



B/ Re-projection



(Landsat7-ETM 195/029 January 12, 2010 and Radarsat-2 January 07, 2010)

4. METHODOLOGY

- **For each date is applied the ESA / IETR *PolSARpro* Software.**
Are calculated : [T3] Coherency Matrix, Polarimetric decomposition parameters and Wishart unsupervised segmentation.

- **Dry snow mapping (*Martini et al., IEE Sonar and navigation, 2006)***

The presence of snow is detected over bare surfaces by means of an optimization method, based on a Polarimetric Contrast Variation Enhancement (*PCVE*). Snow covered forests are analyzed from summer to winter variations of polarimetric decomposition scores.

- **Wet snow retrieval *(Longepe et al., IEEE TGRS, 2009)***

Behaviour of the backscattering response of snow Liquid Water Content (LWC), applied to Radarsat-2 full polarimetric mode, is examined. LWC calculaded by CROCUS and Nägler's method (IEEE, 2000) are compared.

4.1. PolSARpro *v4.14* SOFTWARE (Oct. 2009)

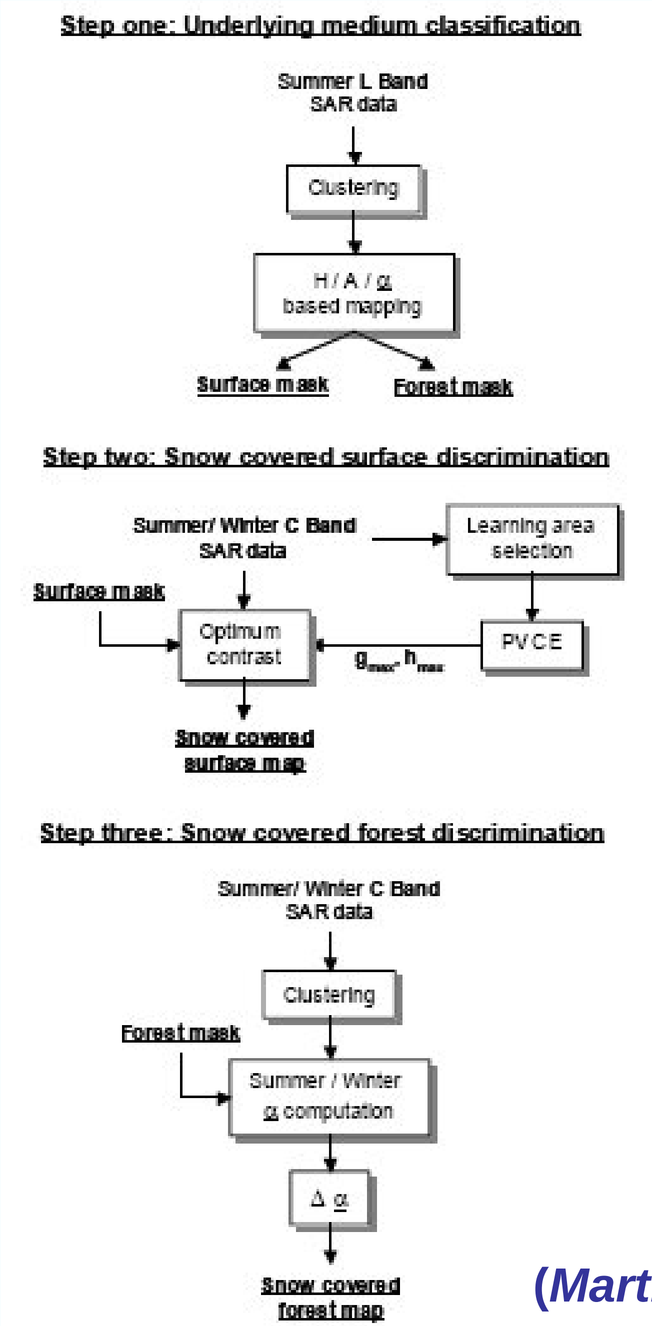
The Polarimetric SAR Data Processing and Educational Tool

http://eath.esa.int/polsarpro/

SAPHIR

* **Tool specifically designed to handle :**
  Polarimetric data and Polarimetric Interferometric data.
* **Educational Software offering a tool for self-education in the field of POLSAR and POL-InSAR data processing and analysis.**
* **Developed to be accessible to a wide range of users, from PhD students to experts in the field of Polarimetry.**

4.2. Dry snow mapping



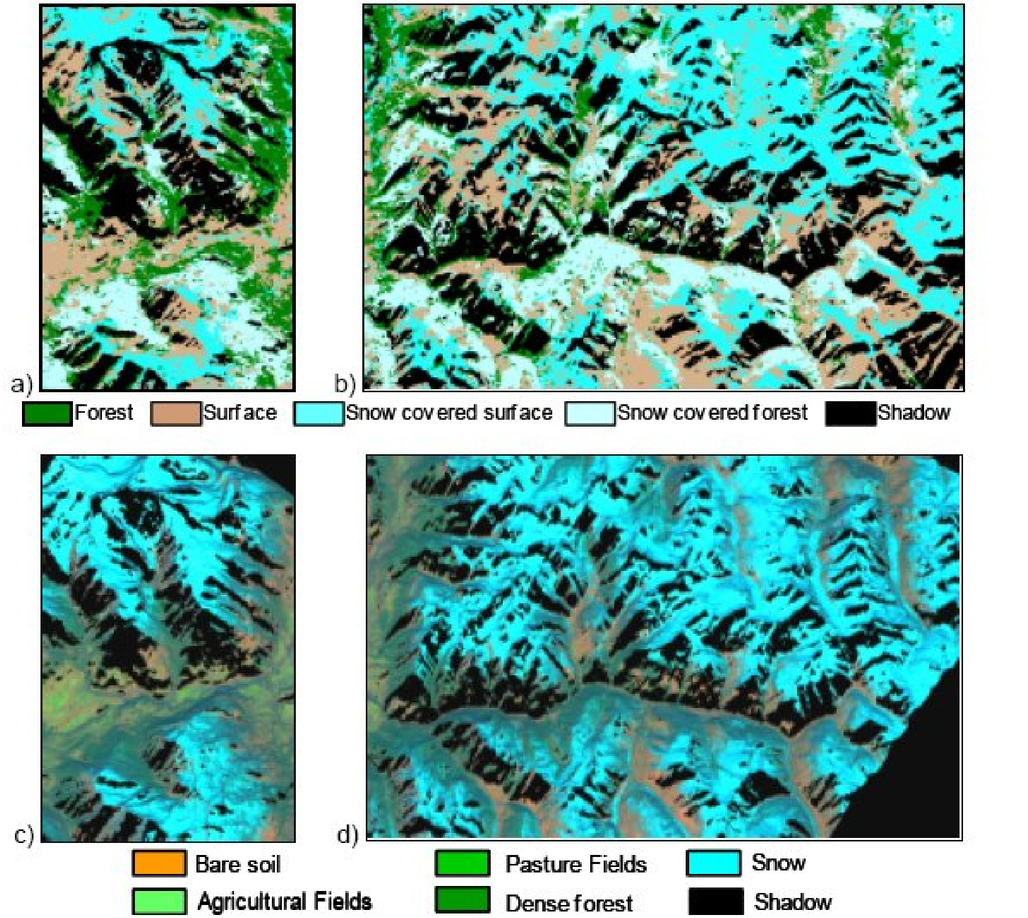


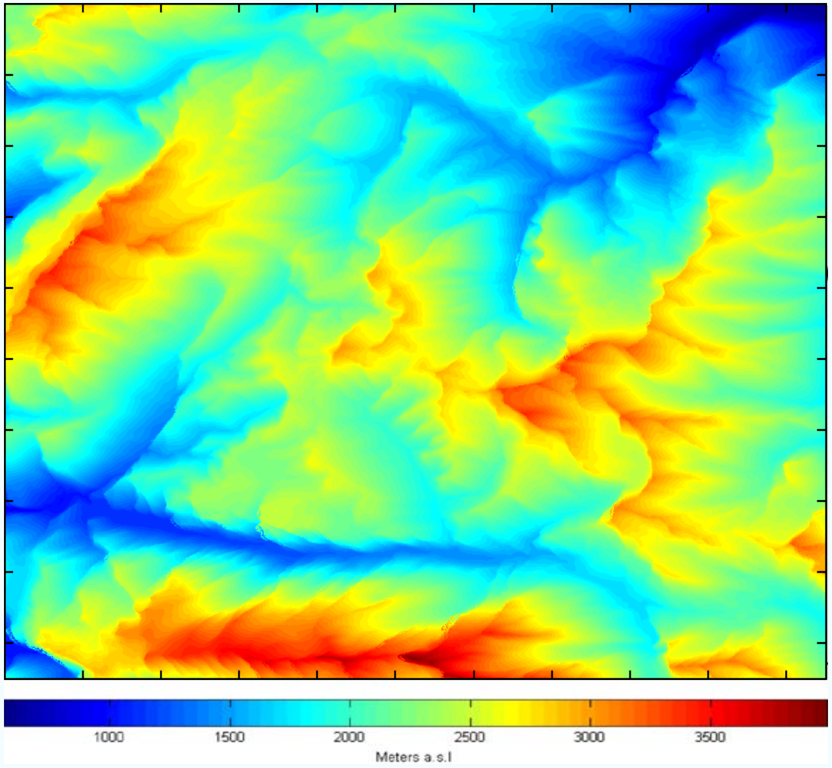
Figure 4: Global snow discrimination result over surfaces and forested areas of Risoul (a) and Izoard (b) and corresponding Landsat optical images (c) and (d)

(Martini et al., IEE Sonar and navigation, 2006)

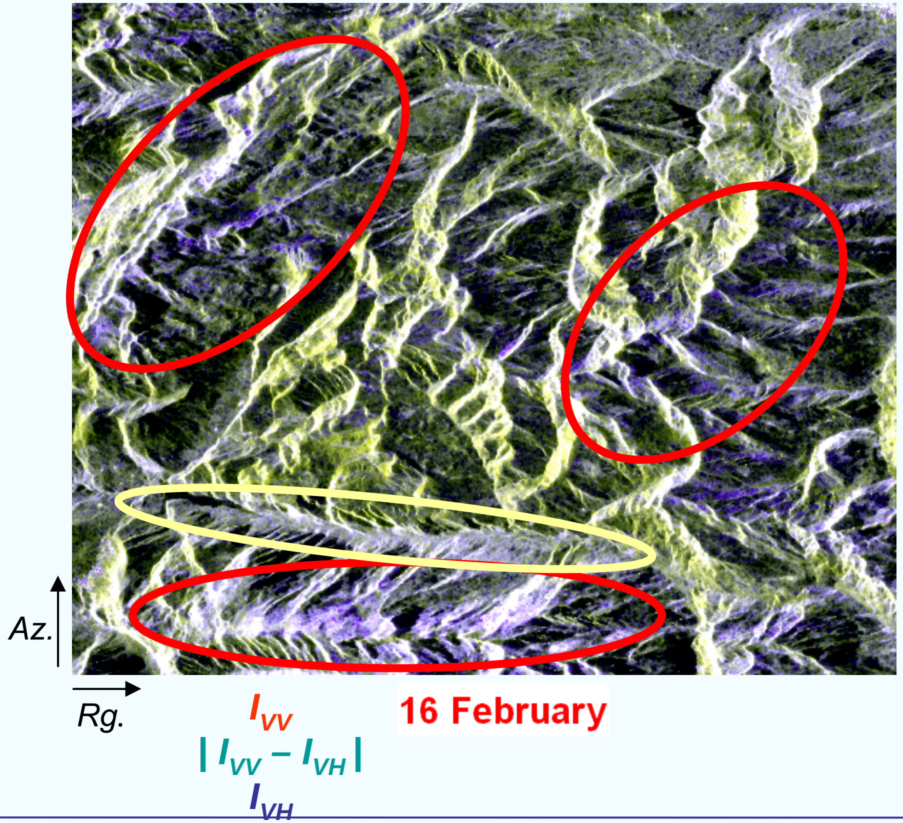
4.3. Wet snow characterization over mountainous regions (dual-polarization C-band Envisat-ASAR data)

- **a/ C-band ASAR acquisitions**
  - 8 images (5 asc. & 3 desc.) from February to July 2004 with dual Polarization VV / VH

DEM in slant range geometry

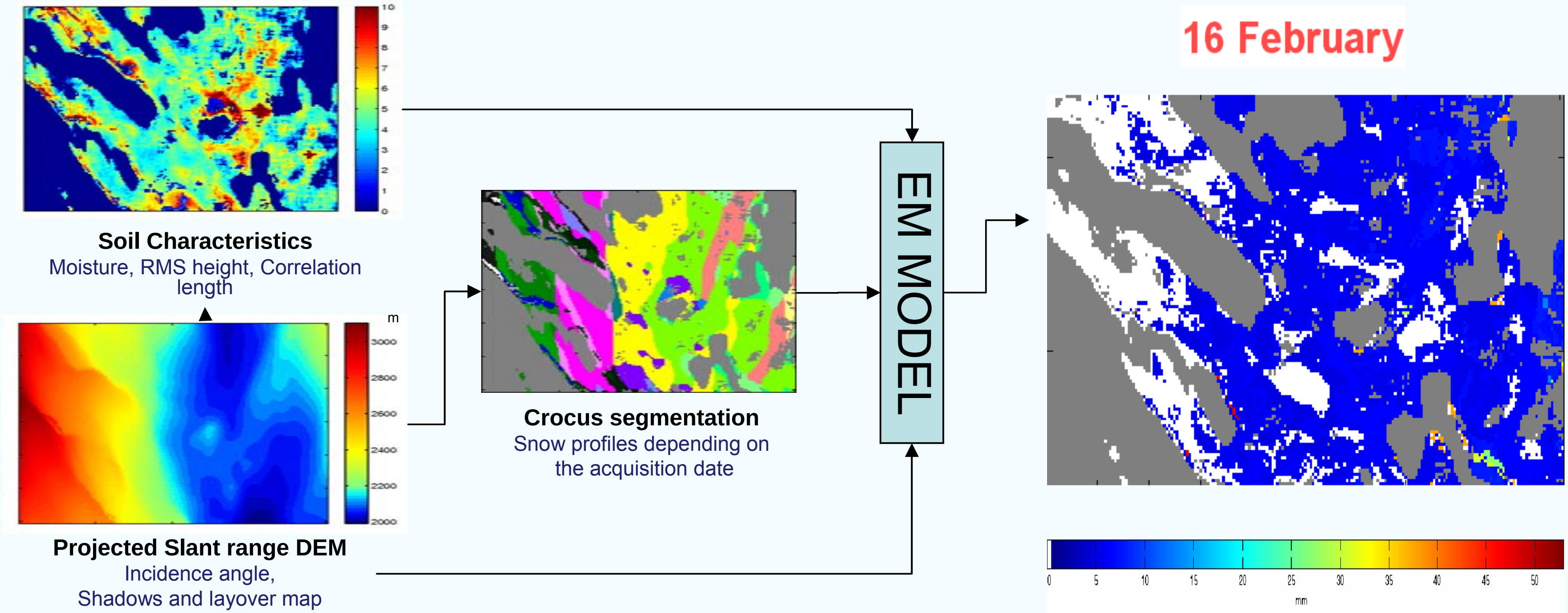


Polarimetric SAR information



b/ methodology for refined snowpack characterization

Simulation at a local case study (7 km²), toward a new methodology…



– Lack of spatial accuracy due to the limited resolution of the Crocus model

✓ Successfully mapping of wet snow extents over all kinds of snowpack
- Detection of slightly wet snow (LWC < 15 mm)
- Refinements of snow spatial variability

N. Longepe, S. Allain, L. Ferro-Famil, E. Pottier and Y. Durand :
"Snow pack characterization in Mountainous Regions using C-band SAR and a meteorological Model". IEEE ,Trans. on Geosci. and Rem. Sens., 2009

5. EARLY RESULTS

(work under progress)

5.1. Optical Images 2009 dataset (15m)

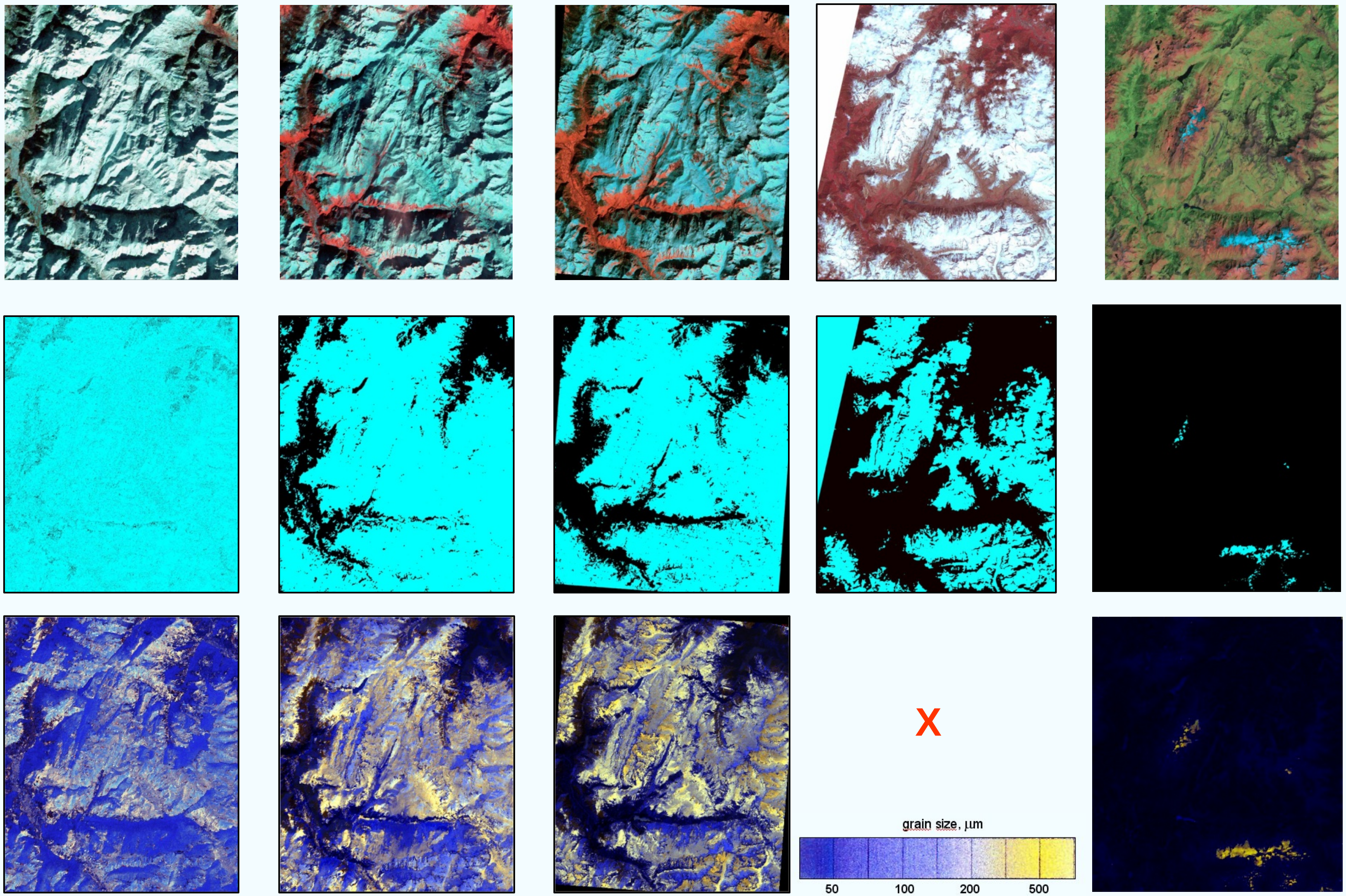
WGS84 – UTM 32 N

09.01 - ETM7 | *26.02 - ETM7* | *21.03 - ETM7* | *06.05 - Spot2* | *05.08 - ETM7*

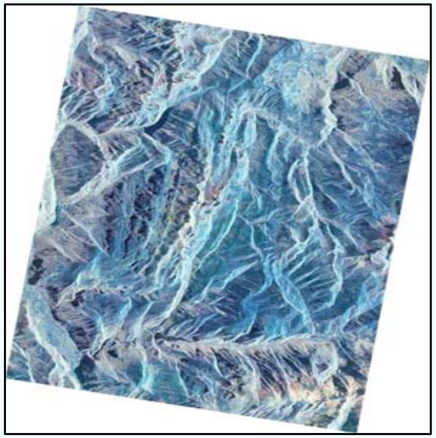
Color Compo.

Snow Maps *(Cosinus Cor.)*

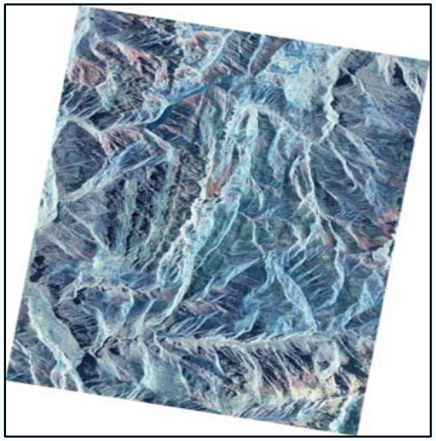
Surface Grain Size *(DISORT)*



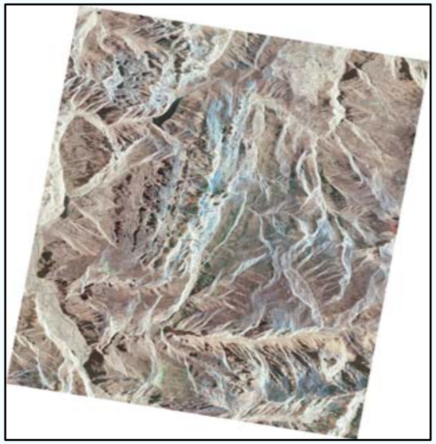
5.2. Radarsat-2 2009 images : Polarisation temporal evolution



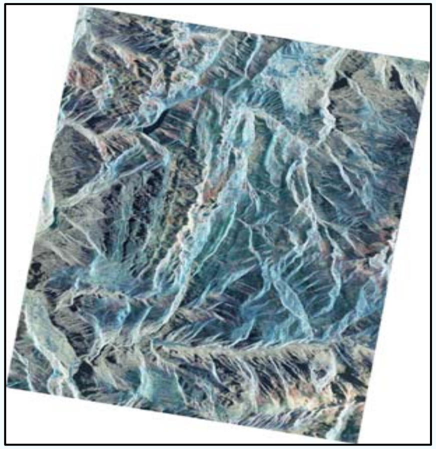
12/01/2009



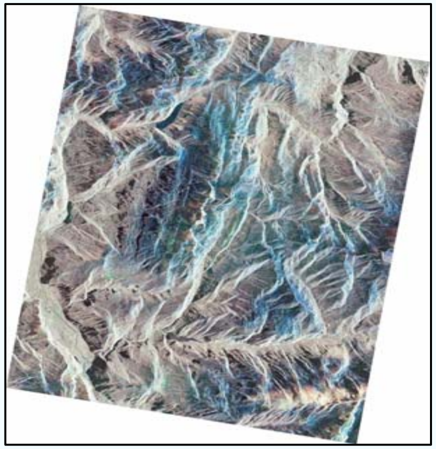
01/03/2009



16/08/2009 *(snow free, only glaciers)*



25/03/2009



12/05/2009

Coherency Matrix

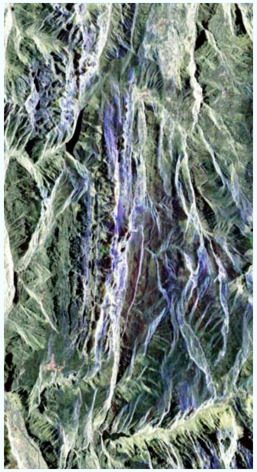
$$\mathbf{T} = \begin{bmatrix} T11 & T12 & T13 \\ T21 & T22 & T23 \\ T31 & T32 & T33 \end{bmatrix}$$

Surface (T11)

Double Bounce (T22)

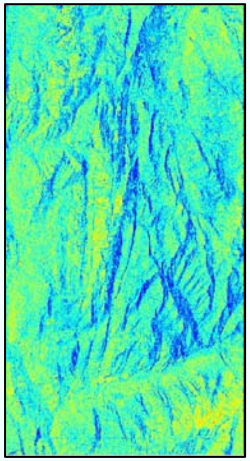
Volume (T33)

5.3. Polarimetric decomposition

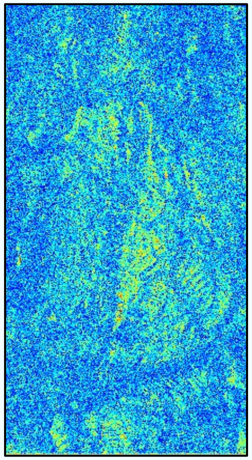


$S_{HH} - S_{VV}|$
$|2S_{VH}|$
$|S_{HH} + S_{VV}|$

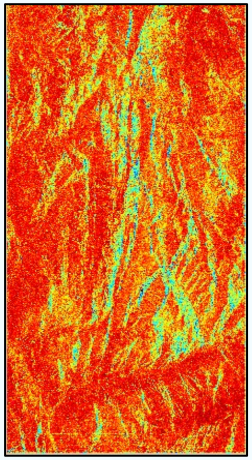
PolSARPro software



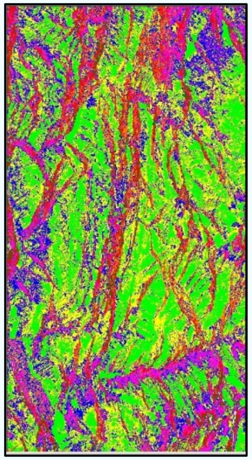
Alpha (α)



Entropy (H)



Anisotropy (A)



Wishart unsupervised segmentation

(January 12, 2009)

Conclusion and footsteps

⇨ Importance of appropriate Input data = Preprocessing .

⇨ Satisfactory stability of Radarsat-2 Local Incidence Angles (6 dates) . *If few influence on polarimetric statistical evolution,*
ε dominant ?

⇨ Possibility to analyse full-polarimetry parameters evolution for 3 dates under dry snow dominant conditions.
Witch snow parameters can be correlated to polarimetric multi temporal evolution trends ?

⇨ Possibility to estimate Liquid Water Content (LWC) from May image (wet snow dominant) using E.M methodology.

Picture Mth. Laval 12/01/2009

Thanks for your attention …