EUROPEAN COMMISSION
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3 WINTERS OF SNOW MONITORING WITH THE LISA INSTRUMENT IN THE SION VALLEY (CH): 2003-2006.

Alberto Martinez-Vazquez
Joaquim Fortuny-Guasch

Institute for the Protection and Security of the Citizen

SENSORS RADAR TECHNOLOGIES AND CYBERSECURITY UNIT

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Directorate-General Joint Research Centre
Institute for the Protection and Security of the Citizen

Contact information:
Alberto Martinez-Vazquez
Joaquim Fortuny-Guasch
21020 Ispra (VA), Italy
Tel: +39 0332 785134
Fax: +39 0332 785469

email: alberto.martinez@jrc.it
http://www.jrc.cec.eu.int
http://serac.jrc.it/

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Introduction

This document presents the activities carried out with the LISA system during the winters 2003-2004, 2004-2005 and 2005-2006 in the Sion Valley (Switzerland), in collaboration with the Swiss Federal Institute for Snow and Avalanche Research (SLF Davos).

The main results as well as some future lines on this campaign are also outlined.

Note that sometimes paths or filenames appear in the document in italic style, as for example *Results\Avalanches\2D*. These paths refer to the contents of the 2 DVDs accompanying to this document.

The LISA instrument

The instrument, LISA, is a ground based linear SAR fully developed and built at the Joint Research Centre (Ispra, Italy). The radar is mounted in a temperature-controlled trailer for ease of transportation and deployment. A schematic and a picture of its components can be seen in the figure 1.

The main component of the instrument is a vector network analyzer (VNA in the figure), which is used to generate the stepped-frequency continuous wave radar pulses and receive the coherent responses. A sled carrying the network analyzer, the power amplifier (AMP) and the antennas (Tx and Rx) slides along a rail 5 m long in order to synthesize a linear aperture such that the azimuth resolution is obtained. This movement is directed by a linear positioner (LP) by means of a serial interface and the appropriate control software. A mobile phone (CEL) is used to remotely control the automatic measurements through the public GSM network. This connection also allows the visualization of the instrument both inside and outside of the trailer thanks to two video cameras (WC1 and WC2) connected to an Ethernet switch (Eth SW). Two external hard disks (HD1 and HD2) implement the data archiving and backup. And finally, a personal computer (PC) operates all the systems and is used for the image processing.

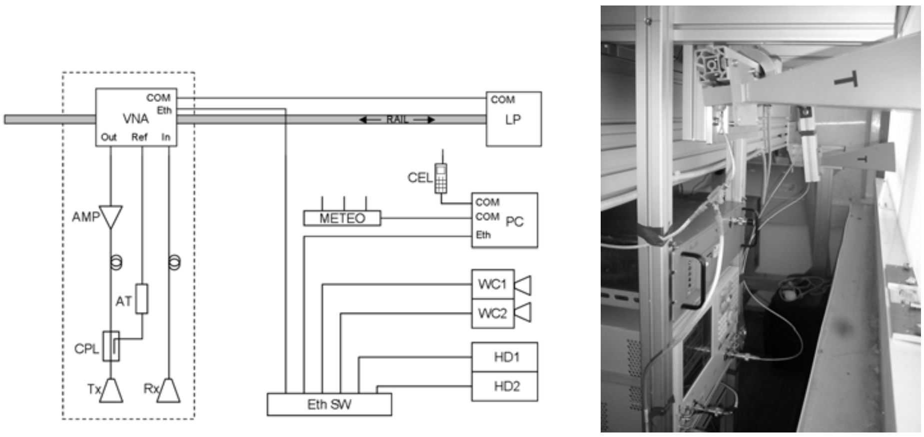

Figure 1: Schematic and RF components view of the LISA instrument

It is worth noting that the integration of all the radio-frequency components in the moving sled avoids folding the RF cables, a possible source of phase distortions in ground based SARs because of the continuous bending of the cables caused by the movement of the linear positioner.

The radar has been operated in vertical polarization at C-band through a linear aperture 3.5 m long, although the maximum aperture achievable by the system is limited by the rail length, which is 5.0 m. Regarding the band used, the system is limited by the characteristics of the network analyzer and the RF amplifier:

- The network analyzer the first winter was an 8753D from HP, covering the band 30kHz to 6GHz and featuring a dynamic range of 105 dB and an acquisition time of 500 µsec/point.

- The network analyzer used the second and third winters, E8362B from Agilent Technologies, covers 10MHz to 20GHz, featuring a dynamic range of 122 dB and an acquisition time less than 26 μsec/point.
- The solid state power amplifier, ARSA-CS50 from Advantech, features 40 W of output power with a gain up to 65 dB at C-band.

The Sion valley test site

The Swiss Federal Institute for Snow and Avalanche Research (SLF, Davos) manages a test site for avalanche experiments in the Sion valley, in the Canton Valais of Switzerland. The site consists of a concave shaped channel of 1200 m vertical drop and an average slope of 27 degrees. The avalanche path length is 2.5 km, starting from the highest elevation level at 2650 m at Creta Besse and finishing at the level of 1450 m.

Several instruments are available in the test site providing ground truth data. Three pairs of FM-CW (Frequency Modulation Continuous Wave) radars are located in the avalanche corridor to determine the height of the avalanche, its speed, turbulences and density. A network of geophones automatically triggers the measuring equipment when spontaneous avalanches occur. For impact studies a narrow wedge steel construction 20 m high is in the middle of the avalanche track. It is equipped with force transducers and pressure and strain gauges to determine the avalanche flow height through contact with the moving snow mass.

Two meteorological stations provide data concerning temperatures, wind speed and direction as well as snow height:

- Donin Du Jour: at 2 km of the slope (CH1903 coordinates 594450/129930, h=2390m).
- Montana: at 9 km of the slope (CH1903 coordinates 602960/129160, h=1590m).

In order to observe the avalanches under the best possible conditions, a bunker is located in the mountain opposite to the corridor 50 meters above the lower level of the valley. It holds a 5Mpixel digital photo camera that continuously takes a picture every 30 minutes. When a geophone detects an avalanche, the camera switches to burst mode with a rate of 1 picture every 4 seconds. The bunker is also used for recording the measurements made in the corridor and to provide the power energy to the LISA system.

The LISA system is located in the mountain opposite the avalanche corridor at an approximate level of 1780 m (330 meters above the lower level of the valley). In that way the instrument has direct visibility of the scenario, covering a cross range section of more than 2000 m. The distance of the instrument to the slope ranges approximately from 1000 m to 2900 m, hence, the area covered by the radar is nearly 2 km by 2 km as can be seen in the figure 2. The exact position of the instrument in the CH1903 coordinate system E-N is [595634 126830].

Figure 2: Picture of the field-of-view of the instrument

The field campaign

The objectives of the campaign can be summarized in the following points:

- Mapping of the snow accumulation.
- Identification of structural changes in the snow cover as mass movements or snow wetness anomalies.
- Estimation of the volume of snow displaced in natural or artificial avalanches.
- Search of precursors in natural avalanches in order to provide an early warning.

To this aim, a field campaign of three winters has been carried out, giving a total of 501 days of data acquisition. The table 1 shows the intervals in which the LISA system monitored the test site of SLF in the Sion Valley (*Results\Campaign\flistOutMonitor.txt*). The first column (`####`) is a sequential number; `Day` represents the day number in the hydrological year (1 corresponds to the first of October, 93 corresponds to the first of January, etc); `Date` is the year, month and day of the measurements; `Time` indicates the interval in which the measurements were carried out that day; `Met` and `Pho` shows if meteorological data and high-resolution photographs of the slope were available that day from the SLF instruments.

Table 1: Calendar of data acquisition by LISA

####	Day	Date	Time	Met	Pho
1	78	20031217	1635h-2349h	yes	no
2	79	20031218	0016h-2346h	yes	no
3	80	20031219	0013h-2344h	yes	no
4	81	20031220	0011h-2342h	yes	no
5	82	20031221	0009h-0656h	yes	no
6	105	20040113	1110h-2334h	yes	no
7	106	20040114	0001h-2333h	yes	no
8	107	20040115	0001h-2332h	yes	no
9	108	20040116	0000h-2358h	yes	no
10	109	20040117	0025h-2356h	yes	no
11	110	20040118	0023h-2339h	yes	no
12	111	20040119	0006h-2339h	yes	no
13	112	20040120	0006h-2336h	yes	no
14	113	20040121	0003h-2333h	yes	no
15	114	20040122	0000h-2358h	yes	no
16	115	20040123	0025h-2347h	yes	no
17	116	20040124	0011h-2344h	yes	no
18	117	20040125	0009h-2340h	yes	no
19	118	20040126	0004h-2346h	yes	no
20	119	20040127	0012h-2319h	yes	no
21	140	20040217	1328h-2355h	yes	no
22	141	20040218	0021h-0609h	yes	no
23	150	20040227	1252h-1319h	yes	no
24	167	20040315	1439h-2340h	yes	no
25	168	20040316	0008h-2336h	yes	no
26	169	20040317	0003h-2358h	yes	no
27	170	20040318	0026h-2354h	yes	no
28	171	20040319	0021h-2348h	yes	no
29	172	20040320	0015h-2344h	yes	no
30	173	20040321	0011h-2340h	yes	no
31	174	20040322	0007h-2336h	yes	no
32	175	20040323	0003h-2358h	yes	no
33	176	20040324	0025h-2354h	yes	no
34	177	20040325	0021h-2349h	yes	no
35	178	20040326	0016h-2344h	yes	no
36	179	20040327	0011h-2339h	yes	no
37	180	20040328	0006h-2340h	yes	no
38	181	20040329	0008h-2336h	yes	no
39	182	20040330	0003h-2358h	yes	no
40	183	20040331	0026h-2354h	yes	no
41	184	20040401	0021h-2349h	yes	no
42	185	20040402	0016h-2345h	yes	no
43	186	20040403	0012h-2340h	yes	no
44	187	20040404	0007h-2334h	yes	no
45	188	20040405	0001h-2356h	yes	no
46	189	20040406	0023h-2351h	yes	no
47	190	20040407	0018h-2345h	yes	no
48	191	20040408	0012h-2340h	yes	no
49	192	20040409	0007h-2334h	yes	no
50	193	20040410	0001h-2356h	yes	no
51	194	20040411	0023h-2349h	yes	no
52	195	20040412	0017h-2344h	yes	no
53	196	20040413	0011h-2339h	yes	no
54	197	20040414	0006h-2334h	yes	no
55	198	20040415	0001h-2355h	yes	no
56	199	20040416	0022h-2350h	yes	no
57	200	20040417	0017h-2345h	yes	no
58	201	20040418	0012h-2339h	yes	no
59	202	20040419	0006h-2333h	yes	no
60	203	20040420	0000h-2355h	yes	no
61	204	20040421	0022h-2350h	yes	no
62	205	20040422	0017h-2344h	yes	no
63	206	20040423	0011h-2339h	yes	no
64	207	20040424	0006h-2334h	yes	no
65	208	20040425	0001h-2356h	yes	no
66	209	20040426	0023h-2350h	yes	no
67	210	20040427	0017h-2345h	yes	no
68	211	20040428	0012h-2340h	yes	no
69	212	20040429	0007h-2335h	yes	no
70	213	20040430	0002h-2342h	yes	no
71	214	20040501	0009h-2337h	yes	no
72	215	20040502	0004h-2359h	yes	no
73	216	20040503	0026h-2352h	yes	no
74	217	20040504	0019h-2347h	yes	no
75	218	20040505	0014h-2342h	yes	no
76	219	20040506	0009h-2337h	yes	no
77	220	20040507	0004h-2359h	yes	no
78	221	20040508	0026h-1425h	yes	no
79	230	20040517	1542h-2350h	yes	no
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81	232	20040519	0012h-2340h	yes	no
82	233	20040520	0008h-2336h	yes	no
83	234	20040521	0003h-2358h	yes	no
84	235	20040522	0025h-2353h	yes	no
85	236	20040523	0020h-2348h	yes	no
86	237	20040524	0015h-2343h	yes	no
87	238	20040525	0010h-2338h	yes	no

88	239	20040526	0005h-2334h	yes	no
89	240	20040527	0001h-2357h	yes	no
90	241	20040528	0024h-2353h	yes	no
91	242	20040529	0020h-2348h	yes	no
92	243	20040530	0015h-2343h	yes	no
93	244	20040531	0010h-2337h	yes	no
94	245	20040601	0004h-2359h	yes	no
95	246	20040602	0026h-2354h	yes	no
96	247	20040603	0021h-2349h	yes	no
97	248	20040604	0016h-2344h	yes	no
98	249	20040605	0011h-2340h	yes	no
99	250	20040606	0007h-2336h	yes	no
100	251	20040607	0003h-2358h	yes	no
101	252	20040608	0025h-2354h	yes	no
102	253	20040609	0021h-2350h	yes	no
103	254	20040610	0017h-2346h	yes	no
104	255	20040611	0013h-2342h	yes	no
105	256	20040612	0009h-2337h	yes	no
106	257	20040613	0004h-2358h	yes	no
107	258	20040614	0025h-2353h	yes	no
108	259	20040615	0020h-2348h	yes	no
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111	262	20040618	0005h-2333h	yes	no
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127	278	20040704	0011h-2340h	yes	no
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129	280	20040706	0003h-2359h	yes	no
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305 : 282 : 20050709 : 0005h-2350h : yes : no
306 : 283 : 20050710 : 0001h-2358h : yes : no
307 : 284 : 20050711 : 0009h-2355h : yes : no
308 : 285 : 20050712 : 0006h-2355h : yes : no
309 : 286 : 20050713 : 0007h-2349h : yes : no
310 : 287 : 20050714 : 0000h-2350h : yes : no
311 : 288 : 20050715 : 0002h-2358h : yes : no
312 : 289 : 20050716 : 0010h-2355h : yes : no
313 : 290 : 20050717 : 0007h-2353h : yes : no
314 : 291 : 20050718 : 0005h-2348h : yes : no
315 : 292 : 20050719 : 0000h-2349h : yes : no
316 : 293 : 20050720 : 0001h-2350h : yes : no
317 : 294 : 20050721 : 0001h-2355h : yes : no
318 : 295 : 20050722 : 0007h-2359h : yes : no
319 : 296 : 20050723 : 0011h-2351h : yes : no
320 : 297 : 20050724 : 0002h-2352h : yes : no
321 : 298 : 20050725 : 0004h-2352h : yes : no
322 : 299 : 20050726 : 0004h-2353h : yes : no
323 : 300 : 20050727 : 0004h-2359h : yes : no
324 : 301 : 20050728 : 0010h-2359h : yes : no
325 : 302 : 20050729 : 0011h-2359h : yes : no
326 : 303 : 20050730 : 0011h-2349h : yes : no
327 : 304 : 20050731 : 0000h-2350h : yes : no
328 : 305 : 20050801 : 0002h-2353h : yes : no
329 : 306 : 20050802 : 0005h-2355h : yes : no
330 : 307 : 20050803 : 0007h-2357h : yes : no
331 : 308 : 20050804 : 0009h-2358h : yes : no
332 : 309 : 20050805 : 0009h-2349h : yes : no
333 : 310 : 20050806 : 0000h-2354h : yes : no
334 : 311 : 20050807 : 0005h-2358h : yes : no
335 : 312 : 20050808 : 0010h-2351h : yes : no
336 : 313 : 20050809 : 0003h-2357h : yes : no
337 : 314 : 20050810 : 0008h-2350h : yes : no
338 : 315 : 20050811 : 0002h-2353h : yes : no
339 : 316 : 20050812 : 0004h-2356h : yes : no
340 : 317 : 20050813 : 0008h-2349h : yes : no
341 : 318 : 20050814 : 0001h-2352h : yes : no
342 : 319 : 20050815 : 0004h-2354h : yes : no
343 : 320 : 20050816 : 0006h-2356h : yes : no
344 : 321 : 20050817 : 0008h-2359h : yes : no
345 : 322 : 20050818 : 0011h-2349h : yes : no
346 : 323 : 20050819 : 0001h-2350h : yes : no
347 : 324 : 20050820 : 0002h-2352h : yes : no
348 : 325 : 20050821 : 0004h-2353h : yes : no
349 : 326 : 20050822 : 0005h-2354h : yes : no
350 : 327 : 20050823 : 0005h-2355h : yes : no
351 :  62 : 20051201 : 1628h-2356h : yes : no
352 :  63 : 20051202 : 0007h-2355h : yes : no
353 :  64 : 20051203 : 0007h-2355h : yes : no
354 :  65 : 20051204 : 0007h-2254h : yes : no
355 :  66 : 20051205 : 0003h-2243h : yes : no
356 :  67 : 20051206 : 0033h-2250h : yes : no
357 :  68 : 20051207 : 0053h-2253h : yes : no
358 :  69 : 20051208 : 0132h-0645h : yes : no
359 :  73 : 20051212 : 1333h-2351h : yes : yes
360 :  74 : 20051213 : 0003h-2359h : yes : yes
361 :  75 : 20051214 : 0012h-2354h : yes : yes
362 :  76 : 20051215 : 0006h-2356h : yes : yes
363 :  77 : 20051216 : 0008h-2355h : yes : yes
364 :  78 : 20051217 : 0007h-2351h : yes : yes
365 :  79 : 20051218 : 0003h-2328h : yes : yes
366 :  80 : 20051219 : 0044h-2310h : yes : yes
367 :  81 : 20051220 : 0055h-2348h : yes : yes
368 :  82 : 20051221 : 0000h-2350h : yes : yes
369 :  83 : 20051222 : 0002h-2353h : yes : yes
370 :  84 : 20051223 : 0005h-2350h : yes : yes
371 :  85 : 20051224 : 0002h-2354h : yes : yes
372 :  86 : 20051225 : 0006h-2357h : yes : yes
373 :  87 : 20051226 : 0010h-2331h : yes : yes
374 :  88 : 20051227 : 0049h-2350h : yes : yes
375 :  89 : 20051228 : 0001h-2348h : yes : yes
376 :  90 : 20051229 : 0000h-2350h : yes : yes
377 :  91 : 20051230 : 0004h-2356h : yes : yes
378 :  92 : 20051231 : 0008h-2354h : yes : yes
379 :  93 : 20060101 : 0006h-2351h : yes : yes
380 :  94 : 20060102 : 0004h-2354h : yes : yes
381 :  95 : 20060103 : 0006h-2352h : yes : yes
382 :  96 : 20060104 : 0004h-2355h : yes : yes
383 :  97 : 20060105 : 0010h-2353h : yes : yes
384 :  98 : 20060106 : 0005h-2352h : yes : yes
385 :  99 : 20060107 : 0004h-2350h : yes : yes
386 : 100 : 20060108 : 0002h-2348h : yes : yes
387 : 101 : 20060109 : 0000h-2350h : yes : yes
388 : 102 : 20060110 : 0002h-2350h : yes : yes
389 : 103 : 20060111 : 0002h-2356h : yes : yes
390 : 104 : 20060112 : 0008h-2350h : yes : yes
391 : 105 : 20060113 : 0002h-2357h : yes : yes
392 : 106 : 20060114 : 0009h-2351h : yes : yes
393 : 107 : 20060115 : 0004h-2356h : yes : yes
394 : 108 : 20060116 : 0008h-2358h : yes : yes
395 : 109 : 20060117 : 0010h-2357h : yes : yes
396 : 110 : 20060118 : 0009h-2348h : yes : yes
397 : 111 : 20060119 : 0000h-2359h : yes : yes
398 : 112 : 20060120 : 0010h-2351h : yes : yes
399 : 113 : 20060121 : 0002h-2359h : yes : yes
400 : 114 : 20060122 : 0011h-0937h : yes : yes
401 : 126 : 20060203 : 1322h-2356h : yes : yes
402 : 127 : 20060204 : 0007h-2353h : yes : yes
403 : 128 : 20060205 : 0004h-2350h : yes : yes
404 : 129 : 20060206 : 0001h-2359h : yes : yes
405 : 130 : 20060207 : 0010h-2356h : yes : yes
406 : 131 : 20060208 : 0007h-2354h : yes : yes
407 : 132 : 20060209 : 0005h-2352h : yes : yes
408 : 133 : 20060210 : 0003h-2350h : yes : yes
409 : 134 : 20060211 : 0001h-2359h : yes : yes
410 : 135 : 20060212 : 0010h-2357h : yes : yes
411 : 136 : 20060213 : 0008h-2355h : yes : yes
412 : 137 : 20060214 : 0006h-2353h : yes : yes
413 : 138 : 20060215 : 0004h-2351h : yes : yes
414 : 139 : 20060216 : 0003h-2358h : yes : yes
415 : 140 : 20060217 : 0009h-2356h : yes : yes
416 : 141 : 20060218 : 0007h-2353h : yes : no
417 : 142 : 20060219 : 0004h-2350h : yes : no
418 : 143 : 20060220 : 0001h-2358h : yes : yes
419 : 144 : 20060221 : 0009h-2355h : yes : yes
420 : 145 : 20060222 : 0006h-2351h : yes : yes
421 : 146 : 20060223 : 0002h-2359h : yes : yes
422 : 147 : 20060224 : 0010h-2354h : yes : yes
423 : 148 : 20060225 : 0005h-2348h : yes : yes
424 : 149 : 20060226 : 0000h-2354h : yes : yes
425 : 150 : 20060227 : 0005h-2348h : yes : yes
426 : 151 : 20060228 : 0000h-2355h : yes : yes
427 : 152 : 20060301 : 0006h-2351h : yes : yes
428 : 153 : 20060302 : 0002h-2358h : yes : yes
429 : 154 : 20060303 : 0009h-2354h : yes : yes
430 : 155 : 20060304 : 0005h-2350h : yes : yes
431 : 156 : 20060305 : 0001h-2355h : yes : yes
```

432	157	20060306	0006h-2349h	yes	yes
433	158	20060307	0002h-2349h	yes	no
434	159	20060308	0001h-2354h	yes	no
435	160	20060309	0006h-2358h	yes	no
436	161	20060310	0009h-2349h	yes	no
437	162	20060311	0001h-2353h	yes	no
438	163	20060312	0005h-2357h	yes	no
439	164	20060313	0009h-2349h	yes	no
440	165	20060314	0001h-2353h	yes	no
441	166	20060315	0004h-2356h	yes	no
442	167	20060316	0008h-2359h	yes	no
443	168	20060317	0011h-2351h	yes	no
444	169	20060318	0003h-2355h	yes	no
445	170	20060319	0007h-2358h	yes	no
446	171	20060320	0010h-2349h	yes	no
447	172	20060321	0001h-2352h	yes	no
448	173	20060322	0004h-2356h	yes	no
449	174	20060323	0007h-2359h	yes	no
450	175	20060324	0011h-2350h	yes	no
451	176	20060325	0002h-2354h	yes	no
452	177	20060326	0006h-2352h	yes	no
453	178	20060327	0004h-2356h	yes	no
454	179	20060328	0008h-2359h	yes	no
455	180	20060329	0011h-2350h	yes	no
456	181	20060330	0002h-2353h	yes	yes
457	182	20060331	0005h-2356h	yes	yes
458	183	20060401	0008h-2348h	yes	yes
459	184	20060402	0000h-2351h	yes	yes
460	185	20060403	0003h-2355h	yes	yes
461	186	20060404	0007h-2359h	yes	yes
462	187	20060405	0011h-2350h	yes	no
463	188	20060406	0002h-2354h	yes	yes
464	189	20060407	0006h-2357h	yes	yes
465	190	20060408	0009h-2349h	yes	yes
466	191	20060409	0001h-2354h	yes	yes
467	192	20060410	0006h-2357h	yes	yes
468	193	20060411	0009h-2349h	yes	yes
469	194	20060412	0001h-2354h	yes	yes
470	195	20060413	0005h-2358h	yes	yes
471	196	20060414	0010h-2352h	yes	yes
472	197	20060415	0004h-2357h	yes	yes
473	198	20060416	0008h-2349h	yes	yes
474	199	20060417	0001h-2355h	yes	yes
475	200	20060418	0007h-2349h	yes	yes
476	201	20060419	0000h-2355h	yes	yes
477	202	20060420	0007h-2349h	yes	yes
478	203	20060421	0001h-2356h	yes	yes
479	204	20060422	0008h-2351h	yes	yes
480	205	20060423	0003h-2359h	yes	yes
481	206	20060424	0011h-2354h	yes	yes
482	207	20060425	0006h-2359h	yes	yes
483	208	20060426	0011h-2352h	yes	yes
484	209	20060427	0004h-2358h	yes	yes
485	210	20060428	0010h-2352h	yes	yes
486	211	20060429	0003h-2358h	yes	yes
487	212	20060430	0010h-2354h	yes	yes
488	213	20060501	0006h-2349h	yes	yes
489	214	20060502	0001h-2356h	yes	yes
490	215	20060503	0008h-2352h	yes	yes
491	216	20060504	0003h-2348h	yes	yes
492	217	20060505	0000h-2353h	yes	yes
493	218	20060506	0005h-2359h	yes	yes
494	219	20060507	0011h-2353h	yes	yes
495	220	20060508	0005h-2359h	yes	yes
496	221	20060509	0011h-2352h	yes	yes
497	222	20060510	0004h-2348h	yes	yes
498	223	20060511	0000h-2353h	yes	yes
499	224	20060512	0005h-2348h	yes	yes
500	225	20060513	0000h-2355h	yes	yes
501	226	20060514	0007h-0742h	yes	yes

The figure 3 shows in a compact way the days in which the LISA system monitored the test site in the Sion Valley and also the days in which avalanches were detected both by the LISA instrument and by the geophones (GP) of SLF installed in the slope. This information is extended later in the sections Avalanche monitoring and Assessment of avalanches in pages 17 and 23 respectively.

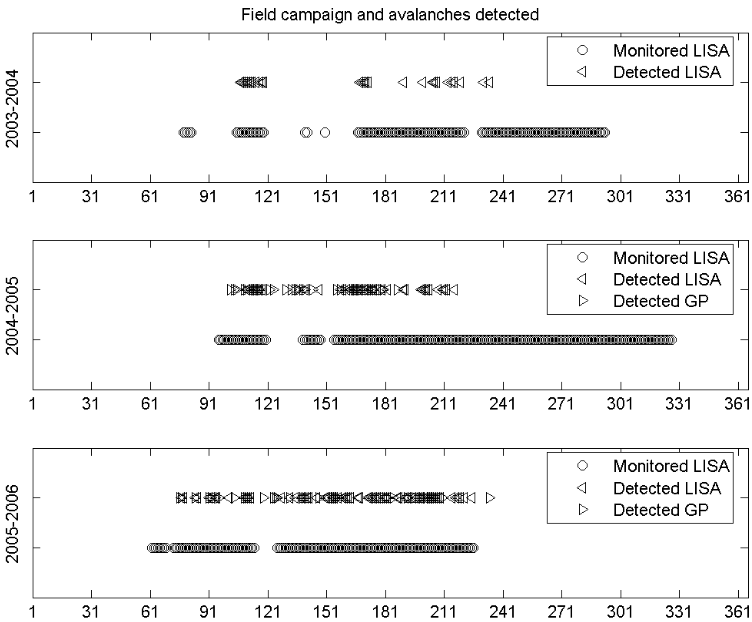


Figure 3: Days of data acquisition (in the hydrological year) and avalanches detected

Data collection

Two kinds of data products have been acquired from the LISA container: visual imagery and radar imagery.

Concerning the visual imagery, a digital camera with resolution 640x480 pixels has been taking pictures of the LISA field-of-view day and night every 30 minutes. This camera has been installed in December 2005, so this kind of data is only available for the winter 2005-2006.

Regarding the radar imagery, the instrument has been operated for the whole campaign in vertical polarization with a central frequency of 5.83 GHz (C-band) and a bandwidth of 60 MHz, sampled in 1601 points. The aperture synthesized along the x-axis was 3.5 m long in 251 steps. This gives a spatial resolution in azimuth of $\Delta x \approx 7.3$ m, and a spatial resolution in range of $\Delta r \approx 2.5$ m. The raw data has been focused in a 601x601 pixels image over a 2200x2200 m rectangle by means of an in-house near-field FFT-based algorithm,

Since the winter 2005-2006 a second antenna in reception, vertically separated 40 cm from the first antenna in reception, has been installed and used to generate topographic maps with the LISA imagery. This has doubled the amount of data acquired (two Rx channels instead of one).

Data archive

Concerning the visual imagery, a total of 14345 pictures are available from 2005/12/12 to 2006/05/15 (156 days approximately) in JPEG format. This archive occupies 263 MB.

The radar raw data contains a total of 127.610 files, from 2003/12/17 to 2006/05/14 (501 days). This archive occupies 190 GB. During the winter 2003-2004 raw data was acquired at a rate of 1 image (2 files: data + parameters) every 30 minutes. During the winter 2004-2005 an improvement of the network analyzer made it possible to acquire raw data at a rate of 1 image (2 files) every 11 minutes. Finally, during the winter 2005-2006, using the same instrument than the precedent year but 2 reception channels, raw data was acquired at a rate of 2 images (4 files) every 11 minutes.

Two different massive sub-products are obtained from the radar raw data of all the days of data acquisition: focused images and coherence maps for avalanche detection.

A total of 63.636 focused images are available for the same period as the raw data (501 days). This archive occupies 171 GB.

Concerning the coherence maps for avalanche detection, a total of 203.963 files are available for the same period as the raw data (501 days). This archive occupies 8 GB and is divided in 3 different products: JPEG images of the absolute value and phase of the complex coherence (*Refresh_001*); processed JPEG images of the absolute value of the complex coherence for features extraction; TIFF images after segmentation for avalanche detection and classification.

In addition, the images of the absolute value of the complex coherence corresponding to the natural and artificial avalanches monitored are copied in an independent folder for an easier browsing. In particular, each avalanche can be seen in three different ways:

- Two-dimensional radar images in the coordinates-frame of the instrument, in JPEG format (*Results\Avalanches\2D*), both for the absolute value and phase of the complex coherence.

- Three-dimensional radar image overlapped to an ortho-photo of the area, in JPEG format (*Results\Avalanches\3D*).
- Three-dimensional radar image overlapped to an ortho-photo of the area, in PPM format (*Results\3DVisor\Avalanches*). These files can be opened with an specific vision software (3DVisor), offering the possibility to zoom, rotate and pan the scene to better appreciate the avalanche paths.

The results

Different types of results have been derived from the data acquired during the three years campaign. It is worth noting that the nature of the system used allows the coverage of a local but wide area (2 km x 2 km), with a pixel resolution of approximately 7.3 m x 2.5 m. The radar works perfectly well during day and night hours, and it assures a good performance even under bad weather conditions (rain fall, snow fall, fog, etc.). These characteristics overcome the techniques classically used for the continuous monitoring of the snow cover: visual imagery and on-site geophones. In the figure 4 can be seen the location of the LISA instrument as well as its field-of-view (rotated red box) and a mask of the signal power typically received.

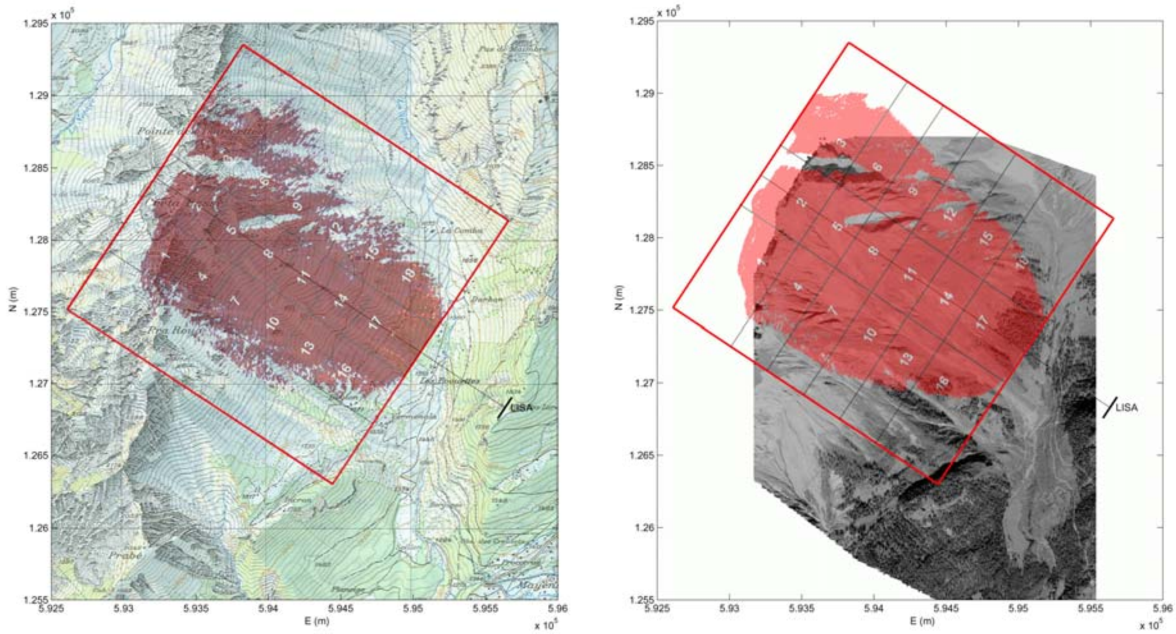


Figure 4: Field-of-view of the instrument over a map an ortho-photo of the area

Snow height retrieval

The estimation of the snow height is given by a linear equation where the linear term is directly depending on the interferometric phase. An additive constant (offset) has to be assigned directly from the snow height value provided by a local meteorological station (ground-truth calibration), while the multiplicative factor has been computed in order to minimize the absolute value of the difference between the estimated snow height and the ground-truth data.

The multiplicative parameter in the linear model is mainly dependent on the radar wavelength (λ_0), the incidence angle (θ_i) and the dielectric constant of the snow (ε). Considering that the wavelength and the incidence angle are kept constant in all the measurements, the only main dependence of that factor is with the dielectric constant. The model used for the estimation of the snow height assumes dry snow, so the dielectric constant depends only on its density. Knowing the model, λ_0 and θ_i, it should be possible to invert the snow density from the obtained multiplicative constants. This work has not yet been done and forms part of the follows up presented at the end of this report.

The retrieval of the snow height has been carried out in two different points of the slope as can be seen in the figures 5 and 6. Results on both points have been averaged over a neighbourhood surface of approximately 50 x 50 m.

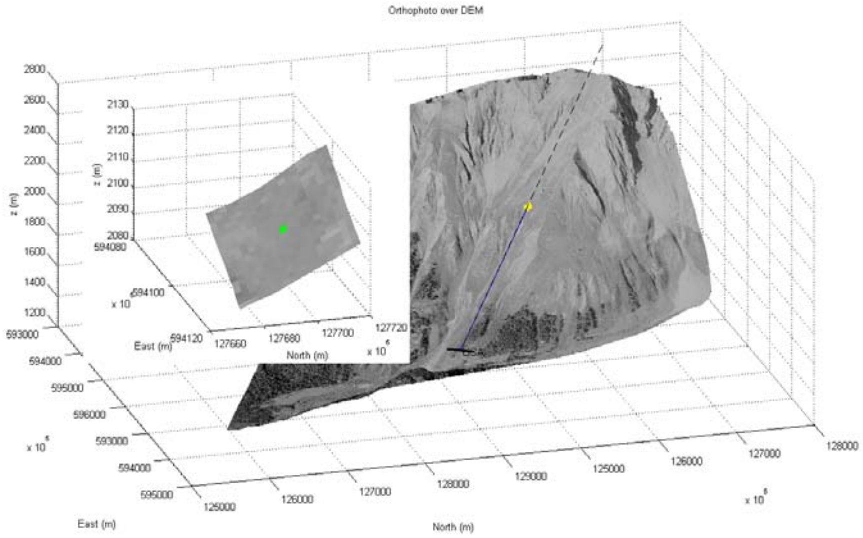


Figure 5: Point 1 for the snow height retrieval and detail of the local slope

The point 1 has coordinates [E,N,z] = [594118.13, 127694.95, 2104.47], while the point 2 has coordinates [E,N,z] = [594566.50, 127740.68, 1950.04].

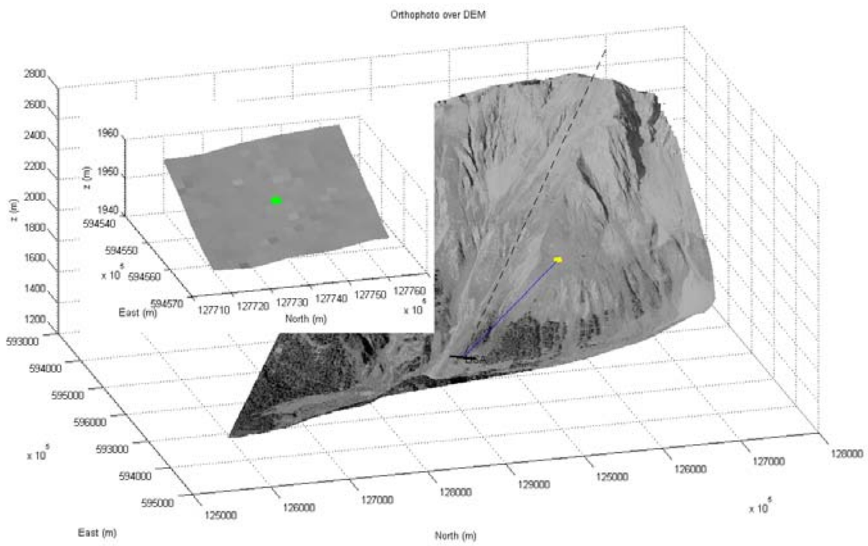


Figure 6: Point 2 for the snow height retrieval and detail of the local slope

Several tests have been done for the period ranging from 2005/01/04 to 2005/04/30 (93 days of data available). The before mentioned algorithm has been applied making use of one ground truth calibration per day. The figure 7 shows the results for the day 2005/01/22 for both points, where the calibration point (ground-truth data) corresponds to the 00:00h of the same day.

The upper plot shows 2 quality indicators. They vary from 0 to 1, being 1 the best quality. `pixThr/pixTot` is the ratio of pixels with coherence above 0.7 over the total number of pixels in the rectangle (13x13, equivalent to 50x50 m). `Coh>0.7` is the averaged coherence in the rectangle, considering only pixels with coherence above 0.7.

The lower plot shows the snow height estimated from the interferometric phase and, if available, ground-truth data from the meteo station.

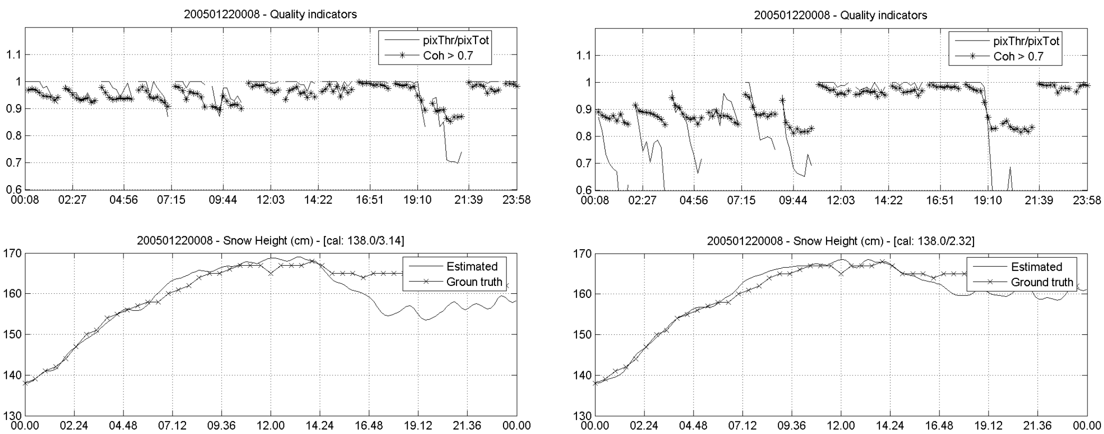


Figure 7: Snow height retrieval, 1 day period for points 1 and 2

Even if the meteorological station is far away 2 km from the slope and at a height of 2390, a good agreement is found between the snow height estimation and the ground truth data for both points. A statistical analysis has been conducted, showing that for the period studied a good agreement has been found in 63 days out of the 93 composing the period, for both points 1 and 2 (have a look at *Results\Campaign\flistOutSnowH-*.txt*). This demonstrates the robustness of the algorithm, both concerning the distance to the meteorological station and the local slope of the point under study.

Considering the good results, further tests have been conducted in order to reduce the number of calibrations performed. Figure 8 shows the snow height retrieved for a period of 4 days ranging from 2005/04/11 to 2005/04/14, with only one calibration point (ground-truth data) corresponding to the 00:00h of the first day.

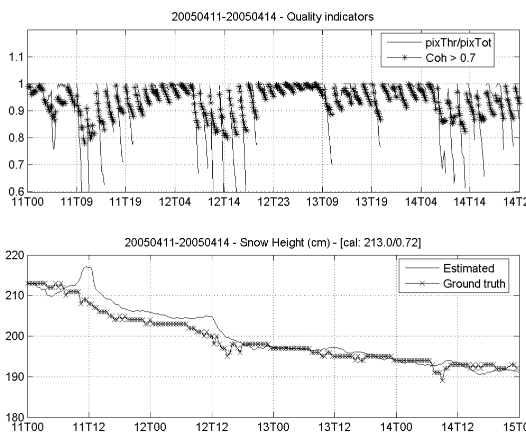


Figure 8: Snow height retrieval, 4 days period for the point 2

Even if good results can also be achieved in some cases, a statistical analysis over the same period presented above reveals an important decrease in the number of matchings between the estimations and the ground-truth data. Thus, the best calibration period appears to be 1 day.

Avalanche monitoring

Thanks to the automatic and continuous measurements performed a huge number of natural avalanches have been monitored, as well as some artificially triggered. A catalogue has been created containing the date and time of the avalanches, their size and the coordinates of the starting point according to the grid shown in figures 9 and 4.

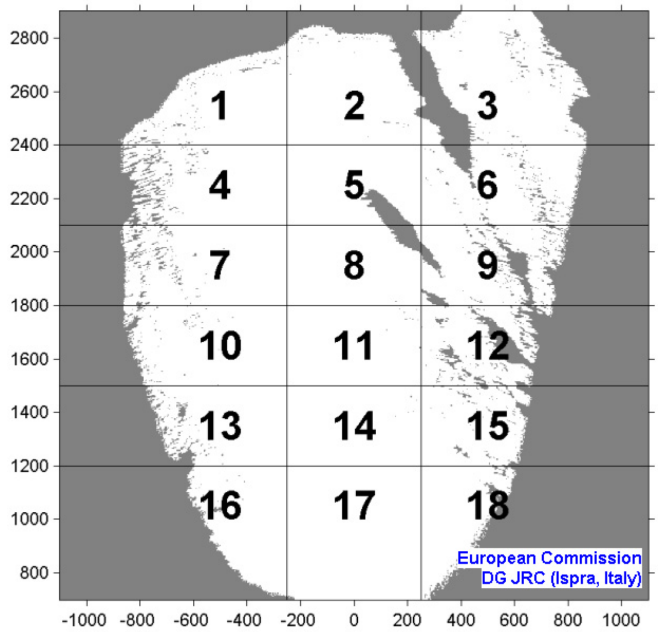


Figure 9: Grid of the LISA field-of-view in 18 positions

The table 2 shows the list of artificial avalanches monitored by the LISA system. The column `Pos` indicates the position of the starting point of the avalanche according to the figure 9, `Axis` is the dimension in meters of the avalanche path (horizontal x vertical), and `Area` is the area in square meters of the avalanche path (the table is also available at *Results\Campaign\flistLISAdetect-artif.txt*).

Table 2: Artificial avalanches monitored

```
%=========================================
%Date        Time   Pos    Axis       Area
%-----------------------------------------
2004/01/19  10.31h   1   325x1750  369850
2004/01/19  10.58h   2   800x1650  671750

2005/02/17  10.09h   1   150x1650  179700
2005/02/17  10.30h   1    75x750    46850
2005/02/17  10.41h   2   250x450    70150
2005/02/17  10.51h   2   275x1925  366000

2006/03/06  09.54h   1   475x1425  540150
2006/03/06  10.44h   2  1300x1775  1054400
2006/03/06  11.06h   1   150x1800  270000
```

The figures 10 to 12 show the absolute value of the complex coherence of the artificial avalanches monitored during the 3 winters. Each avalanche is represented both in the two-dimensional coordinate frame of the LISA instrument and in a three-dimensional view overlapped to an ortho-photo of the slope. The avalanches produce a clear reduction of the absolute value of the coherence on the affected paths, decreasing the average value from 0.95 to

0.55. The interferometric phase, although not shown here, becomes completely random on the avalanche paths. These patterns allow an easy automatic detection and classification based on contour and brightness detection.

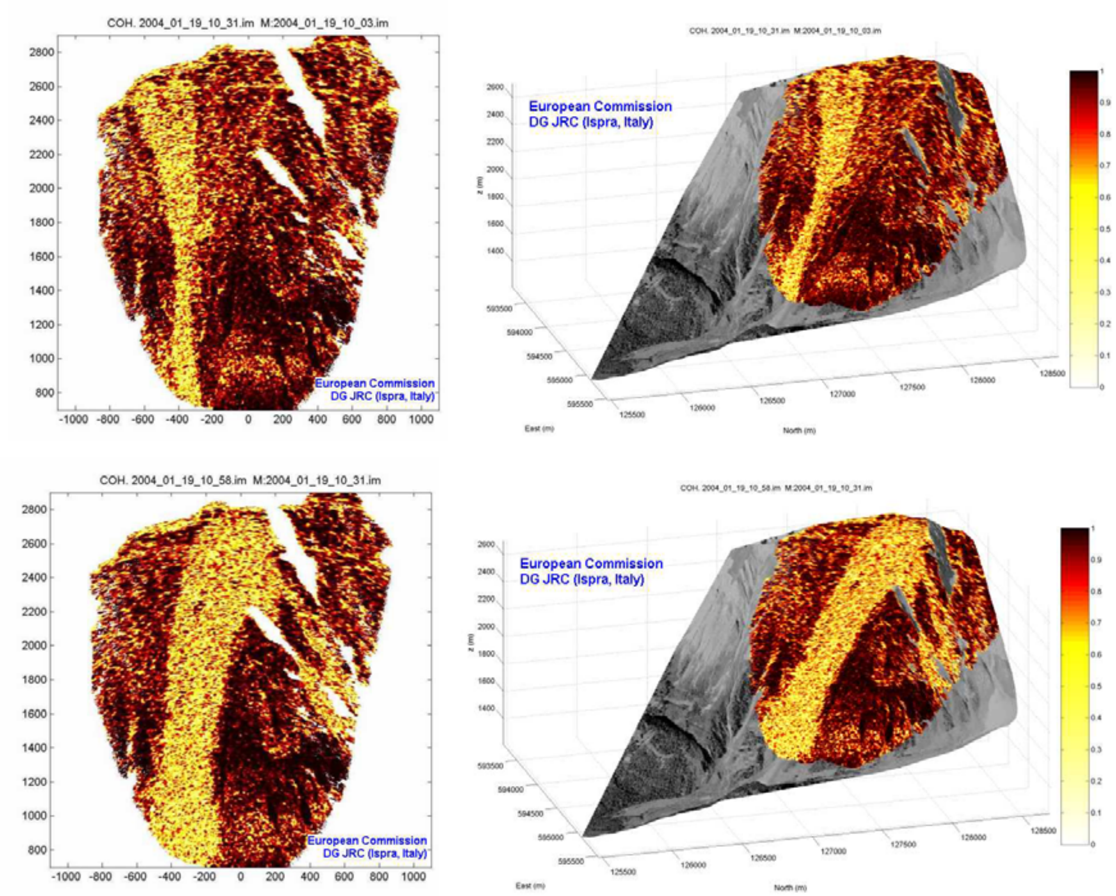
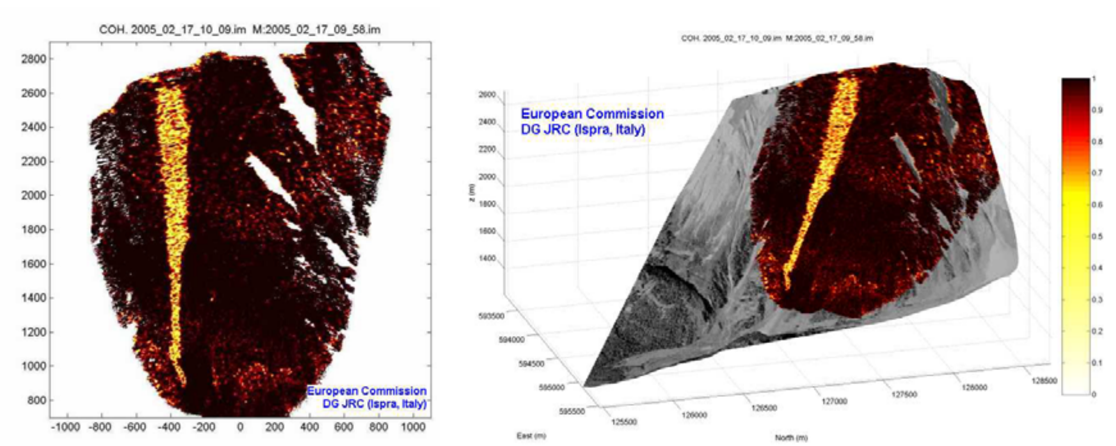


Figure 10: Artificial avalanches seen by LISA for the winter 2003-2004

The absolute value of the complex coherence ranges from zero to one, where zero indicates a complete lose of coherence (the scene has changed dramatically from one image to another) and one indicates that only small changes of the phase may have occurred (the scene is almost identical to the previous one).



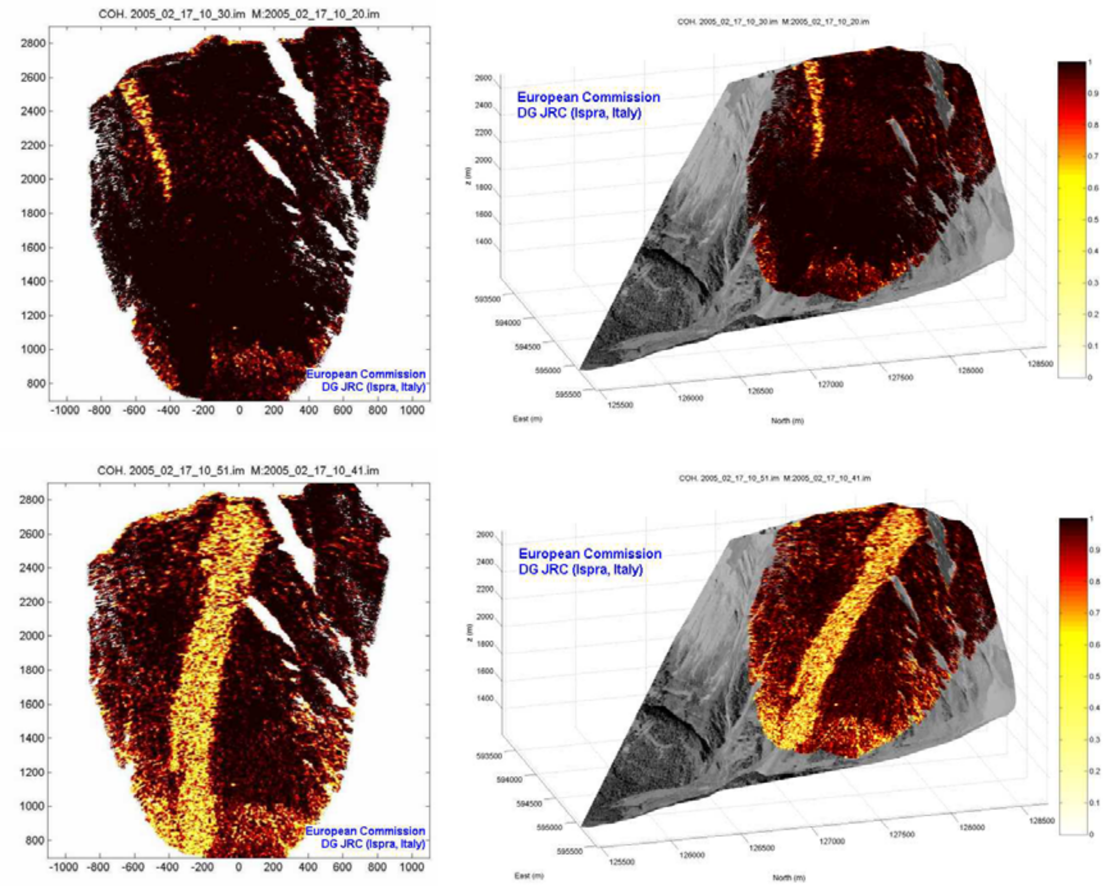
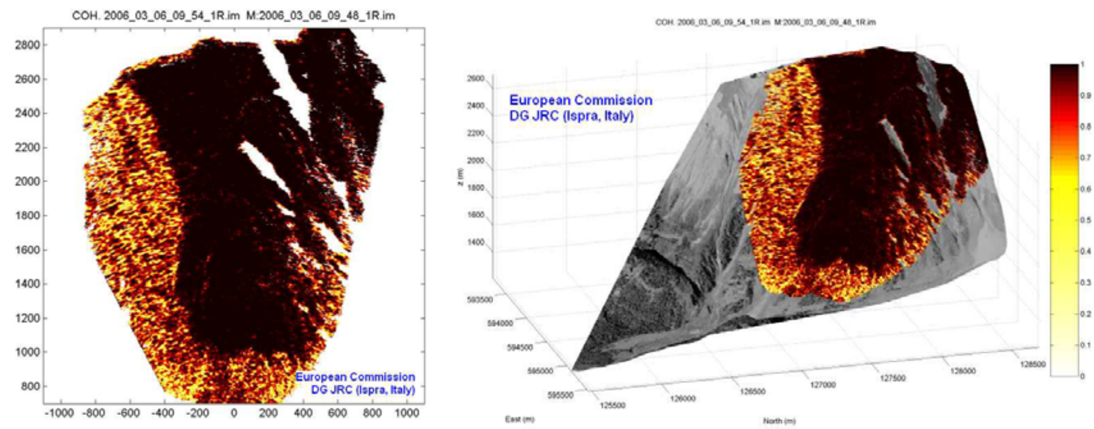


Figure 11: Artificial avalanches seen by LISA for the winter 2004-2005

Note on the titles of the images the day and time (formatted YYYY_MM_DD_hh_mm) of the data used for the computation of the complex coherence (interferogram). Concerning the axis, the two-dimensional figures use a local coordinate frame where the horizontal axis represent the azimuth in meters and the vertical ones represent the range also in meters. The three-dimensional figures are labelled according to the CH1903 coordinate system, where z (m) is the height retrieved from a Digital Elevation Map (DEM) of the area provided by SLF.



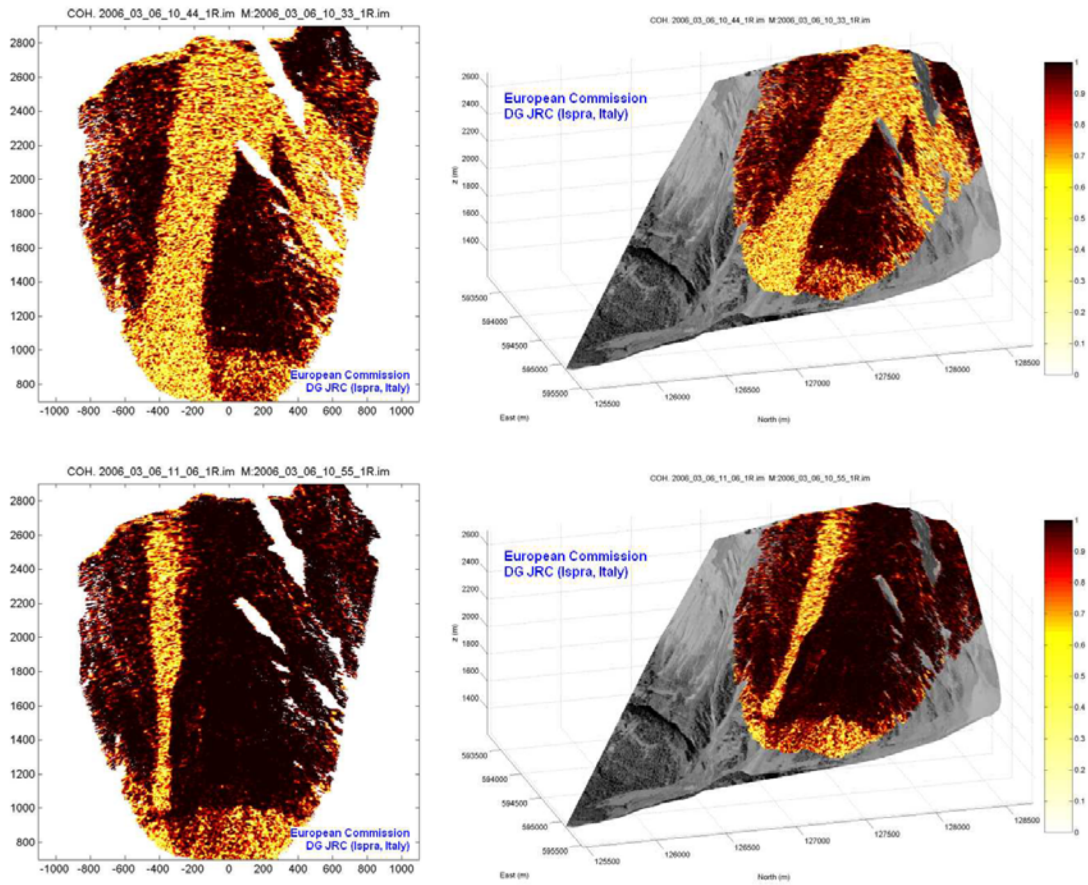


Figure 12: Artificial avalanches seen by LISA for the winter 2005-2006

In a similar way to the previous table, the table 3 shows the list of major natural avalanches monitored by the LISA system during the campaign. This list is available at *Results\Campaign\ flistOutAvalanche-biggest.txt* while the complete list with all the avalanches monitored can be found at *Results\Campaign\ flistOutAvalanche.txt*.

Table 3: Major natural avalanches monitored

####	Day	Date	Pos:	Axis
5	107	20040115 09.31h	1	350x1600
12	170	20040318 13.58h	2	100x1400
45	171	20040319 17.29h	1	100x1175
76	114	20050122 00.08h	2	675x1400
81	114	20050122 02.48h	1	550x1625
93	114	20050122 02.59h	1	450x1175
96	114	20050122 03.31h	3	225x1050
99	114	20050122 04.35h	2	325x1600
120	116	20050124 17.48h	2	275x1900
141	117	20050125 04.29h	1	275x1000
169	166	20050315 13.04h	1	225x1225
199	190	20050408 15.15h	5	125x1075
217	91	20051230 22.57h	2	500x1475
260	92	20051231 02.28h	4	300x1150
276	92	20051231 05.59h	2	1175x1575
277	92	20051231 11.31h	1	125x1275
284	94	20060102 20.56h	1	125x1225
291	109	20060117 19.56h	3	275x1000
298	110	20060118 05.06h	2	1050x1350
299	110	20060118 06.43h	1	300x1300
305	110	20060118 08.55h	4	250x1125
331	139	20060216 03.56h	1	400x1400
332	139	20060216 04.19h	1	200x1600
339	139	20060216 10.48h	2	1225x1475
345	141	20060218 05.53h	1	100x1400
349	141	20060218 09.13h	3	200x1100
350	141	20060218 10.09h	2	150x1600
351	141	20060218 10.20h	4	425x1200
360	152	20060301 04.00h	1	550x1100
370	154	20060303 06.17h	1	225x1625
376	154	20060303 07.12h	1	275x1400
387	154	20060303 13.42h	5	350x1400
389	154	20060303 22.14h	2	775x1550
392	155	20060304 00.27h	1	625x1050
394	155	20060304 08.37h	3	325x1050
402	159	20060308 13.27h	1	525x1250
403	159	20060308 13.39h	3	500x1000
407	159	20060308 16.24h	2	400x1125
409	159	20060308 22.43h	2	525x1225
410	159	20060308 23.54h	4	225x1125
413	161	20060310 16.32h	1	150x1125
416	161	20060310 17.07h	1	75x1125
422	163	20060312 00.05h	2	100x1275
426	163	20060312 01.26h	1	100x1275
427	163	20060312 01.38h	1	200x1200
428	163	20060312 02.13h	2	75x1050
435	174	20060323 09.50h	2	100x1000
443	176	20060325 11.07h	1	200x1000
446	177	20060326 12.04h	2	150x1725
448	177	20060326 14.26h	1	100x1525
462	182	20060331 08.02h	1	75x1025
463	182	20060331 14.53h	1	100x1150
466	187	20060405 14.00h	1	200x1550

479	199	20060417 14.51h	2	125x1650
486	204	20060422 11.50h	4	100x1400
490	205	20060423 11.21h	7	100x1050
492	205	20060423 12.56h	4	125x1250
499	207	20060425 01.27h	5	175x1050
506	215	20060503 16.45h	2	275x1050

As mentioned in the section Data archive (page 12), the images of the absolute value of the complex coherence corresponding to all the avalanches monitored are available in independent folders for an easier browsing.

- *Results\Avalanches\2D* contains the two-dimensional radar images, both for the absolute value and phase of the complex coherence.
- *Results\Avalanches\3D* contains the three-dimensional radar images overlapped to an ortho-photo of the area.
- *Results\3DVisor\Avalanches* contains the three-dimensional radar images overlapped to an ortho-photo of the area, to be opened with an specific vision software (3DVisor).

Following is a short statistic of the avalanche events monitored. The figure 13 shows the histogram of the day (in the hydrological year) in which the avalanche events occurred. The plot on the left is a simple histogram while the plot on the right is the same histogram weighted by the size of the avalanches.

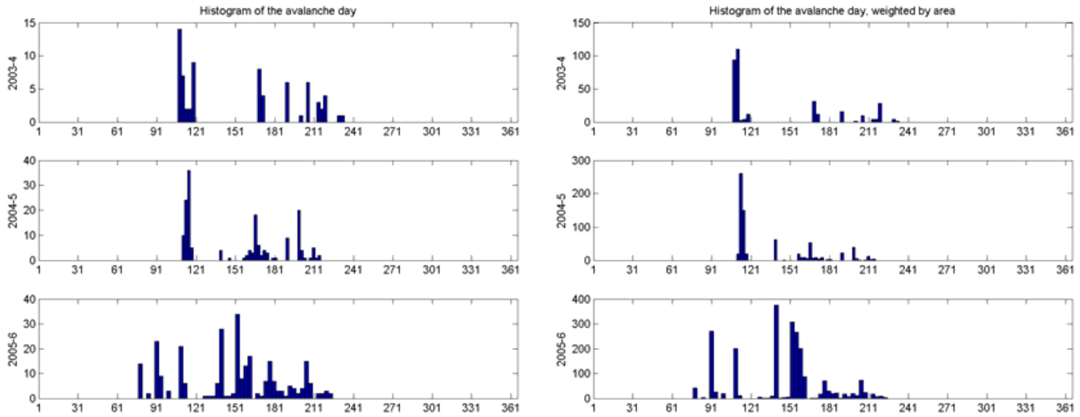


Figure 13: Histogram of the avalanche day in the hydrological year

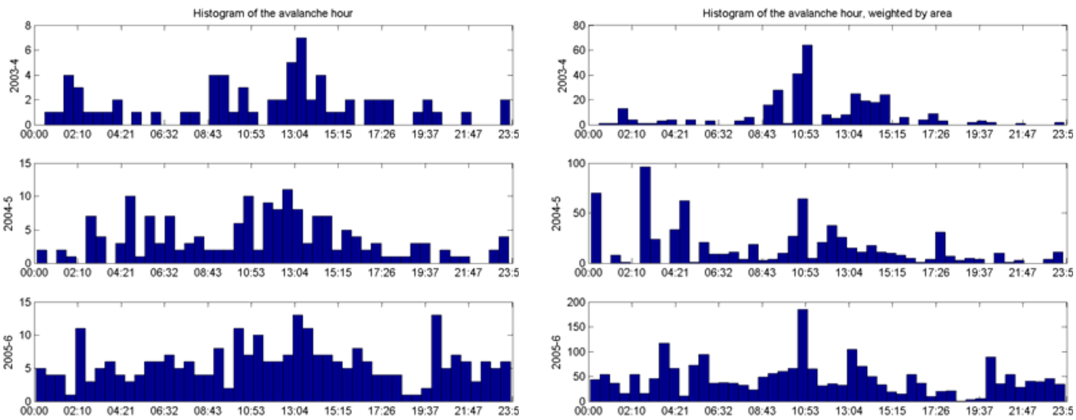


Figure 14: Histogram of the avalanche hour

The figure 14 shows the histogram of the time in which the avalanche events occurred, also as a simple histogram and a histogram weighted by the size of the avalanches. The figure 15 shows the histogram of the starting point of the avalanches according to the grid in figures 9 and 4.

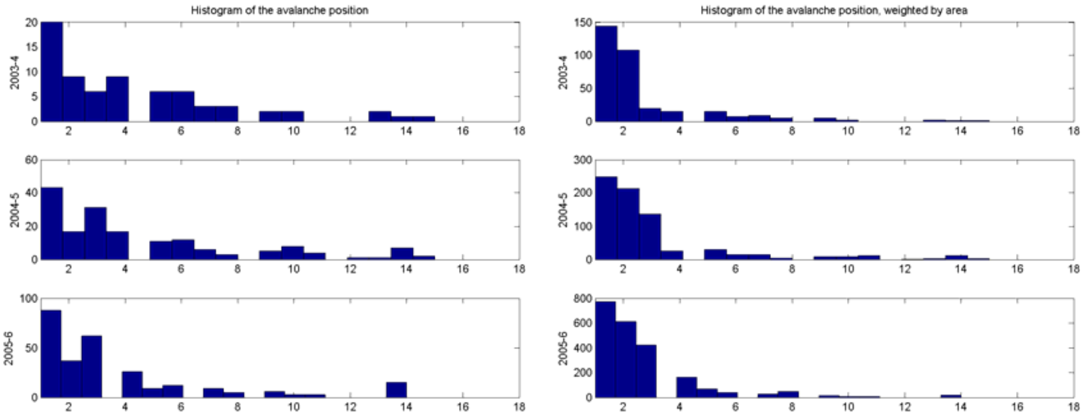


Figure 15: Histogram of the avalanche position

Finally, the figure 16 shows the histogram of the area in square meters of the avalanches monitored.

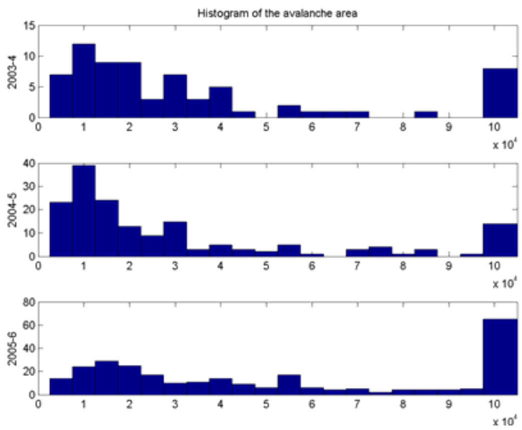


Figure 16: Histogram of the avalanche area in square meters

Concerning the day of the avalanches, it seems that January and March are the most active months during our campaign, while the distribution over the hour is roughly uniform. The most active starting points for the avalanches correspond to positions 1, 2 and 3, that clearly are situated at the highest levels of the slope. It is worth noting also position 14, where many small avalanches occur. This positions is very close the pole 20 m high for impact studies in the middle of the avalanche path.

The histogram of the area involved in the avalanche paths shows typical areas below 20000 m^2 and a considerable number of very big avalanches with an area bigger than 100000 m^2. Although the artificial avalanches are also included in these statistics (typically 2 or 3 artificial avalanches per year), from the table 3 and the figure 16 it is evident that an important number of very big natural avalanches occur in the test site (typically 10 to 20 very big natural avalanches per year).

Assessment of avalanches

The SLF has provided two ways to assess the avalanches detected by the LISA instrument:

- Alarms triggered by a net of geophones installed in the slope.
- Visual imagery acquired by a high resolution digital camera.

Since the alarms triggered by the geophones can be logged in text files that later on can be easily parsed and processed with automatic procedures, this is the method we have chosen for the analysis presented in this subsection.

Visual imagery, instead, has two main problems:

- Lack of pictures during nocturnal hours or under bad weather conditions.
- Need of an expert operator to interpret the images due to the low contrast inherent to snowed surfaces.

The file *Results\Campaign\flistOutAvalanche.txt* shows three tables:

- Avalanches detected by LISA.
- Avalanches detected by the net of geophones.
- Fusion of the LISA and geophones data.

Concerning the avalanches detected by LISA, this has already been presented in the precedent subsection. The list of avalanches detected by the geophones is generated from the visual pictures that are acquired by the digital camera in burst mode when a geophone detects vibrations. The most interesting result is the fusion of the LISA and geophones (GP) data.

The column `####` is a sequential number identifying the avalanche; `Day` is the day of the hydrological year in which the avalanche has occurred; `Date` shows the date and time of the avalanche event, `id` is an identification for the source of the information: `LD` = LISA detected, `GP` = geophone detected; `(1)` indicates if LISA data was available that day, and `(2)` indicates if the avalanche detected by LISA was also detected by the geophones.

The most interesting part is the final summary, which is also reproduced in the table 4.

Table 4: Summary of avalanches detected by LISA and geophones

```
==============================================
Winter 2003-2004: 20031001-20040930
    Field campaign days with LISA........: 142
    Avalanches detected by LISA..........: 70
    Avalanches detected by Geophones.....: 0
Winter 2004-2005: 20041001-20050930
    Field campaign days with LISA........: 208
    Avalanches detected by LISA..........: 168
    Avalanches detected by Geophones.....: 50
Winter 2005-2006: 20051001-20060930
    Field campaign days with LISA........: 151
    Avalanches detected by LISA..........: 275
    Avalanches detected by Geophones.....: 64

Total avalanches detected by LISA........: 513
Total avalanches detected by Geophones...: 114

Avchs detected by GP with data from LISA.: 95
    Matching LISA-Geophones..............: 56/95
```

From this table the first thing to point out is the major number of avalanches detected by the LISA instrument, at least 3 times more for the winters 2004-2005 and 2005-2006, even if the instrument was not acquiring data over all the days of the winter seasons. In all the data set there are only 95 avalanches detected by the net of geophones that correspond to days in which the LISA instrument was operating. The assessment of the avalanches detected by LISA will be carried out only for these avalanches. A first fully automatic assessment points out that 56 out of 95 avalanches detected by the geophones are also seen and confirmed by LISA imagery.

This means that 39 out of 95 avalanches seen by the geophones are not confirmed by LISA data. These avalanches can be identified in the table of *Results\Campaign\flistOutAvalanche.txt* with the following parameters: `id = GP & (1) = yes & (2) = no`. The table 5 analyzes this problem in more detail, where a comment has been added at the very right of every avalanche after a manual inspection of the LISA imagery for the days and dates under question.

Table 5: Manual inspection of avalanches not initially detected by LISA

id: LD=LISA detected; GP=Geophone detected
(1) LISA data available this day
(2) Detection matching LISA-Geophones

####	Day	Date	id	(1)	(2)	
71	102	20050110 08.55h	GP	yes	no	Not confirmed by LISA imagery
72	104	20050112 18.36h	GP	yes	no	Not confirmed by LISA imagery
73	105	20050113 21.16h	GP	yes	no	Not confirmed by LISA imagery
74	109	20050117 14.08h	GP	yes	no	Not confirmed by LISA imagery
141	116	20050124 09.10h	GP	yes	no	Not confirmed by LISA imagery
154	117	20050125 11.30h	GP	yes	no	Not confirmed by LISA imagery
171	139	20050216 17.13h	GP	yes	no	Not confirmed by LISA imagery
172	140	20050217 07.56h	GP	yes	no	Not confirmed by LISA imagery
181	144	20050221 10.47h	GP	yes	no	Not confirmed by LISA imagery
183	156	20050305 09.40h	GP	yes	no	Not confirmed by LISA imagery
185	158	20050307 14.28h	GP	yes	no	Not confirmed by LISA imagery
231	172	20050321 16.31h	GP	yes	no	Not confirmed by LISA imagery
236	174	20050323 14.57h	GP	yes	no	Not confirmed by LISA imagery
243	180	20050329 11.12h	GP	yes	no	Not confirmed by LISA imagery
245	187	20050405 08.40h	GP	yes	no	Not confirmed by LISA imagery
289	76	20051215 14.55h	GP	yes	no	Possible, bad weather
306	84	20051223 10.32h	GP	yes	no	Possible, bad weather
308	91	20051230 10.40h	GP	yes	no	Not confirmed by LISA imagery
345	96	20060104 10.47h	GP	yes	no	Not confirmed by LISA imagery
349	104	20060112 16.55h	GP	yes	no	Not confirmed by LISA imagery
375	111	20060119 08.05h	GP	yes	no	Not confirmed by LISA imagery
384	126	20060203 14.29h	GP	yes	no	Not confirmed by LISA imagery
386	132	20060209 08.06h	GP	yes	no	Not confirmed by LISA imagery
429	147	20060224 10.38h	GP	yes	no	Not confirmed by LISA imagery
475	156	20060305 17.59h	GP	yes	no	Possible, bad weather
476	157	20060306 07.52h	GP	yes	no	Not confirmed by LISA imagery
477	157	20060306 08.13h	GP	yes	no	Not confirmed by LISA imagery
550	182	20060331 11.39h	GP	yes	no	Possible, bad weather
554	185	20060403 15.47h	GP	yes	no	Not confirmed by LISA imagery
555	185	20060403 16.03h	GP	yes	no	Not confirmed by LISA imagery
560	192	20060410 10.45h	GP	yes	no	Possible, bad weather
568	196	20060414 12.20h	GP	yes	no	Possible, bad weather
569	196	20060414 13.10h	GP	yes	no	Possible, bad weather
574	198	20060416 22.15h	GP	yes	no	Not confirmed by LISA imagery
577	200	20060418 09.40h	GP	yes	no	Not confirmed by LISA imagery
580	202	20060420 16.30h	GP	yes	no	Possible, bad weather
594	204	20060422 16.30h	GP	yes	no	Possible, bad weather
606	206	20060424 10.05h	GP	yes	no	Possible, bad weather
614	210	20060428 13.33h	GP	yes	no	Not confirmed by LISA imagery

The manual inspection shows that 10 avalanches out of 39 seen by the geophones where not detected by LISA in its initial semi-automatic mode, but that the rest, 29, appear to be false alarms of the geophones.

Concluding, the LISA system is able to see almost all the avalanches detected by the geophones: 56 out of 66 in semi-automatic mode and 66 out of 66 with manual supervision. In addition, the LISA imagery is able to assess the validity of the avalanches retrieved by the geophones and to overcome the limitations of the visual pictures taken with the high resolution digital camera. This implies a much higher number of avalanches retrieved: 513 avalanches detected with LISA against 114 detected by the geophones (both figures not supervised by an operator).

There is one important point that will be commented also at the end of the report in the follows up of the campaign, and is the necessity to assess the avalanches detected by LISA with the visual imagery when available. As stated at the beginning of the subsection, this is a task that corresponds to an expert used to deal with such kind of images.

Avalanche precursors

Although the maximum interest from the civil protection point of view in the use of a ground-based radar for the monitoring of the snow cover is the retrieval of avalanche precursors for the triggering of an early warning, this task has not yet been deeply addressed.

The reason is mainly the complexity of the job involved and the necessity to combine knowledge both from the radar and the snow fields of expertise. To this aim, a closer collaboration between SLF and the JRC needs to be effectively set up.

The analysis of the radar imagery performed to the moment has shown a relatively high correlation between big spontaneous avalanches and a number of minor avalanches occurred in the hours before the big one. This needs to be confirmed and correlated with the meteorological data available, but can serve as a starting point for the search of precursors.

Hazards maps

A practical product derived the last year of the campaign is the hazard map obtained with the superposition (histogram) of the avalanches path in a whole winter season. These maps can be seen in the figures 17 to 19 for the three winter seasons of the campaign.

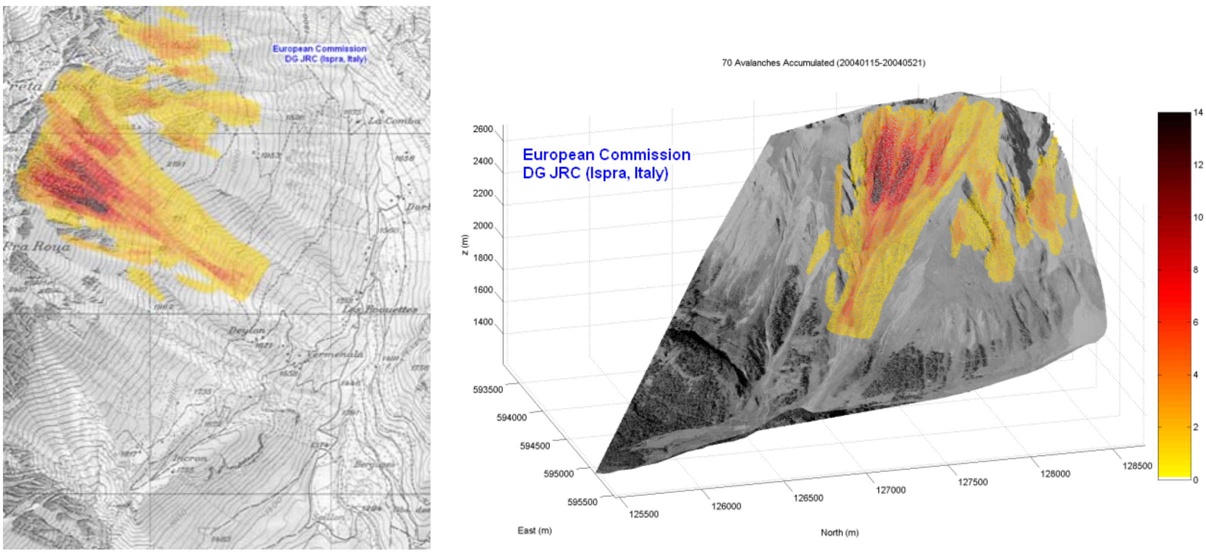


Figure 17: Hazard map of the 2003-2004 winter

Red means that a high number of avalanches passed by the pixel of interest, yellow means a moderate number of avalanches occurred in the pixel, while transparent (this is, the map or photo is completely visible with no color superposition) means no avalanche at all occurred in this pixel.

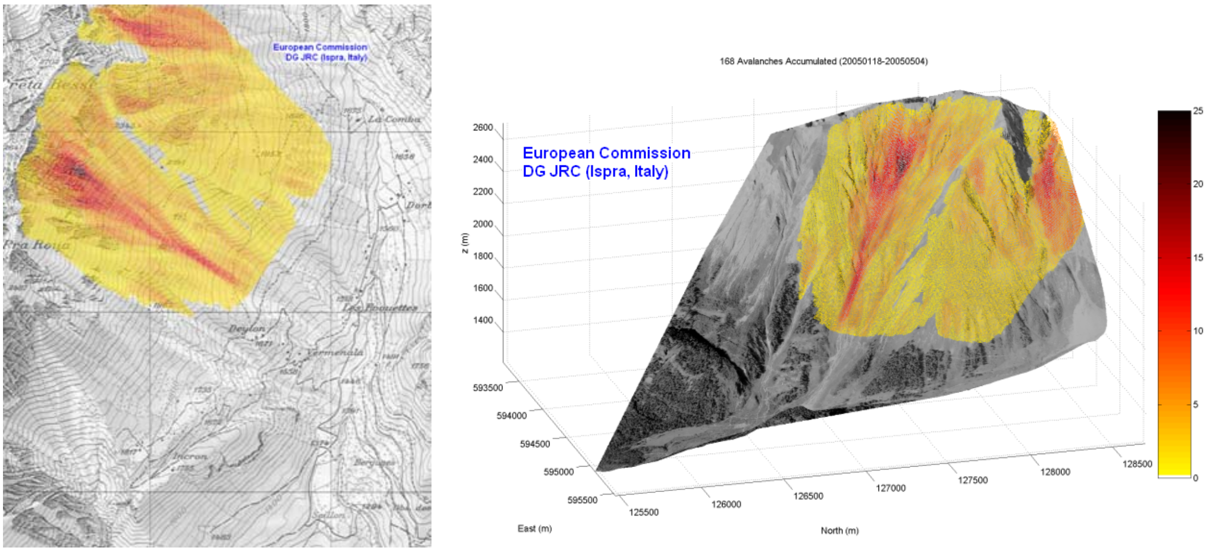


Figure 18: Hazard map of the 2004-2005 winter

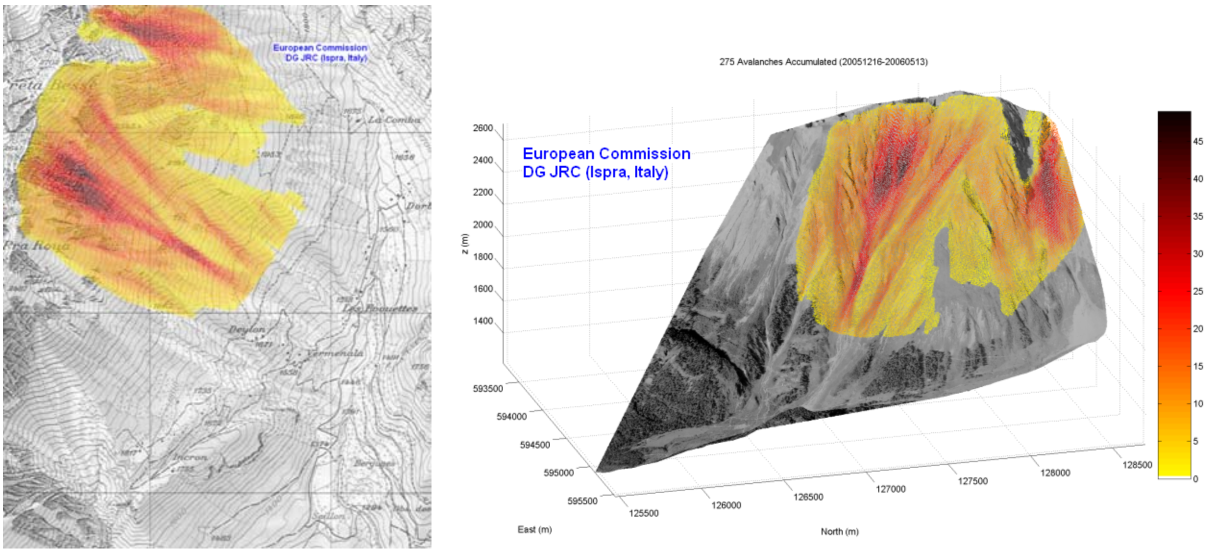


Figure 19: Hazard map of the 2005-2006 winter

It is interesting to note how the pixels with more avalanche activity (red ones) correspond to the natural corridors in the hill, characterized by a big slope. These pictures can also be visualized with the three-dimensional vision software at *Results\3DVisor*. The images are available at *Results\3DVisor\Hazard*.

Avalanche volume retrieval

During the winter 2005-2006 a second channel in reception has been used, with its corresponding antenna vertically separated 40 cm to the original one. This has allowed the generation of topographic maps with the LISA system. The figure 20 shows an example of Digital Elevation Map (DEM) generated with LISA in its topographic mode the 2005/12/01 at 16h28 local time.

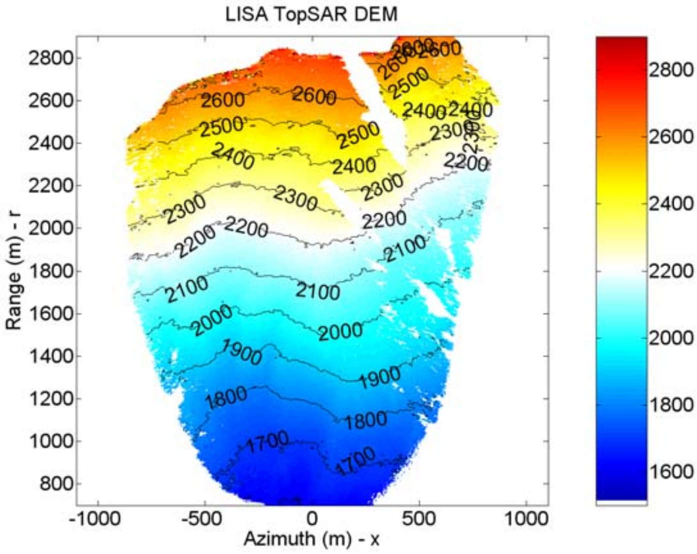


Figure 20: Digital Elevation Map generated with the topographic mode of the LISA instrument

Figure 21 presents the histogram of the differences between the DEM generated with the LISA system and the DEM provided by the SLF obtained with airborne radar imagery. It can be seen that the average difference is close to -4. This is not a major problem because this offset could be removed in the processing chain. The difficulty arises with the cues of the distribution, which have a standard deviation bigger than 10 meters. This poses a major problem concerning the accuracy of the technique used for the generation of the DEMs and its use for the avalanche volume retrieval.

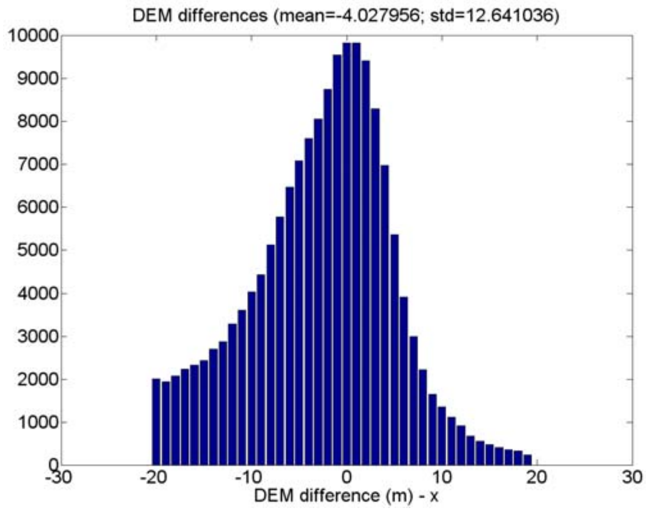


Figure 21: Histogram of the differences between the LISA and ground-truth DEMs

While the avalanches are identified thanks to the systematic computation of interferograms using the double-pass interferometric mode of the LISA instrument (baseline of 11 minutes), an attempt to obtain the snow volume displaced in an avalanche has been done using the topographic capabilities of the LISA instrument. Once the avalanche instant is determined, the unwrapped interferometric phase obtained with the single-pass interferometric mode of the instrument (baseline of 40 cm) is used to compute the DEMs of the focused zone just before and after the avalanche has occurred.

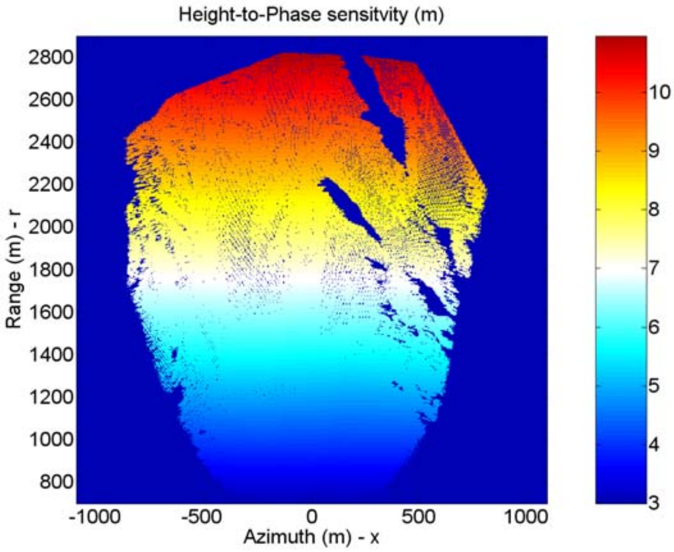


Figure 22: Height-to-phase sensitivity of the LISA instrument in Sion

The differentiation of both DEMs gives as a result the volume of snow displaced in the avalanche event. Unfortunately the results are very noisy because of the low height-to-phase sensitivity of the instrument configuration. The figure 22 shows the sensitivity of the topographic mode of the instrument all along the focused area assuming a phase noise of 0.2 rad. This error is inherent to the small baseline of the instrument, so in its current configuration the only way to overcome this problem is through processing techniques like using images averaged before and after the avalanche.

The computation of the snow volume involved in an avalanche is, thus, not yet currently solved although there is work in progress to achieve better results.

Follows up

To the moment the field campaign has represented an important effort from the data acquisition point of view. This includes continuous improvements of the instrument and its satellite components such as the improvement of the data acquisition and pre-processing velocity, the implementation of reliable data archiving procedures, the set-up of remote control mechanisms to allow the unattended operation of the instrument and the increase of the working periods by fixing minor software and hardware problems.

This suggests that it is time now to concentrate on the processing and analysis side. Several results have been presented in this report, although there is room in most of them to improve their accuracy and the necessity of manual supervision. This is particularly true for the snow height/volume retrieval and the spontaneous avalanche detection and characterization schemes.

New techniques can also be developed, not yet addressed mainly because of lack of time. Knowing the model of the microwave penetration in dry snow, the wavelength and the incidence angle, it should be possible to invert the snow density, although ground-truth data would be necessary in order to assess the results. Another important unresolved task is the search of avalanche precursors, as mentioned in a precedent subsection.

From a more practical point of view, a pending task is still the necessity to systematically assess all the avalanches detected by LISA with the visual imagery and meteorological data of SLF when available. This job is expected to be carried out by an expert from SLF, since the field of expertise of the SERAC Unit of the JRC is out of this scope.

Although the LISA instrument has performed excellently during these 3 winters field campaign, there is also one aspect that could be improved with considerable advantageous consequences. A reduction of the acquisition time would imply a higher quality on the images generated and the possibility to study in more detail the dynamics of avalanches. This could also evidence avalanche precursors not available with the current data archive. The SERAC Unit is currently working on this improvement through the use of antenna array systems instead of mechanically moved antennas and the evaluation of new hardware platforms.

Conclusions

The field campaign described in this report has provided, to the knowledge of the authors, the first archive of ground based synthetic aperture radar (GB-SAR) imagery for the study of the snow cover. Different radar signatures are present in the archive, such as those corresponding to natural avalanches, artificially triggered avalanches, snow fall, snow drift, etc. corresponding to three winter seasons, and accompanied by ground truth data (meteorological, visual photography and geophone alarms).

This variety of data has allowed to the moment the study of different aspects of the snow cover, such as the snow height retrieval and the avalanche monitoring and cataloguing. But the potential to fine tune the techniques used up until now or to elaborate new products is extremely high due to the huge amount of information available.

There is still work to be done from the software/processing point of view: a deeper study of the radar images together with the ground truth data may lead to the univocal discrimination of avalanches with respect to heavy snowfall or snow drift because of the weather conditions, and to the identification of some new precursors of avalanches based on ground-based SAR imagery in order to forecast them. New techniques for image segmentation and classification need to be developed in order to reduce the intervention of human operators in the avalanche detection scheme, and the generation of DEMs with LISA data needs to be improved in order to allow the calculation of the snow volume involved in an avalanche.

On the hardware side, a faster instrument would be appreciated. Currently, radar images are generated at a rate of 1 image approximately every 11 minutes. This time is enough to trigger an alert when precursors of avalanches are available. If this is not the case, only a system able to obtain a SAR image in less than 1 minute could be used to automatically alert the bottom of the slope that an avalanche is coming.

Thus, the main conclusion is that the potential to use GB-SAR systems for the monitoring of the dry snow is out of any doubt, although there is still work to be done either from the processing and the hardware points of view.

Acknowledgements

The authors would like to thank François Dufour and Urs Gruber from SLF (Davos, Switzerland) and Giuseppe Antonello, David Shaw, Dario Tarchi, Marco Basso, Jorge Morgado and Gian Luigi Ruzzante from DG JRC (Ispra, Italy) for their collaboration in this campaign.

List of publications

During this field campaign several scientific publications have been produced, most of them consisting in conference papers with its corresponding attendance.

[1] A. Martinez-Vazquez; J. Fortuny-Guasch; U. Gruber; *Monitoring of the Snow Cover with a Ground-Based Synthetic Aperture Radar*. 4th EARSeL Special Interest Group on Land Ice & Snow (LIS-SIG) Workshop eProceedings 4 2/2005, Bern (Switzerland), February 2005.

http://las.physik.uni-oldenburg.de/eProceedings/vol04_2/04_2_martinez1.html

[2] A. Martinez-Vazquez; J. Fortuny-Guasch; *Monitoring Structural Changes and Stability of the Snow Cover with a Ground-Based Synthetic Aperture Radar*. URSI 2005 Commission F Symposium, Barza d'Ispra (Italy), April 2005.

http://ursi-f-2005.jrc.it/fullpapers/URSI-F-2005-Art_7.3.pdf

[3] A. Martinez-Vazquez, J. Fortuny-Guasch; *Avalanche And Snowfall Monitoring With A Ground-Based Synthetic Aperture Radar*. 4th International Workshop on ERS SAR Interferometry FRINGE 2005, November 2005.

http://earth.esa.int/workshops/fringe2005/proceedings/papers/23_martinezvazquez.pdf

[4] A. Martinez-Vazquez, J. Fortuny-Guasch; Snow Cover Monitoring in the Swiss Alps with a GB-SAR. IEEE Geoscience and Remote Sensing Society Newsletter, March 2006, pp.11-14.

http://www.grss-ieee.org/files/grsNL0306.pdf

[5] A. Martinez-Vazquez, J. Fortuny-Guasch; Feasibility of Snow Avalanche Volume Retrieval by GB-SAR Imagery. Geoscience and Remote Sensing Symposium, 2006. IGARSS '06 Denver. Proceedings.

Conference Attendance

[1] Risk Mitigation of Slope Instability Workshop, Ispra (Italy), 2004, 30 September to 1 October.

[2] EARSeL Special Interest Group on Land Ice & Snow (LIS-SIG) 4th Workshop, Bern (Switzerland), 2005, 21-23 February.

[3] URSI Commission F Symposium on Microwave Remote Sensing of the Earth, Oceans, Ice and Atmosphere, Barza d'Ispra (Italy), 2005, 20-21 April.

[4] FRINGE 2005 Workshop. Advances in SAR Interferometry from ENVISAT and ERS missions, ESA ESRIN Frascati (Rome, Italy). 2005, 28/November - 2/December.

[5] IEEE International Geoscience and Remote Sensing Symposium, Denver (Co), USA, 2006, 21/July - 4/August.

European Commission

EUR 22533 EN – DG Joint Research Centre
Institute for the Protection and Security of the Citizen

3 WINTERS OF SNOW MONITORING WITH THE LISA INSTRUMENT IN THE SION VALLEY (CH): 2003-2006.

INSTITUTE FOR THE PROTECTION AND SECURITY OF THE CITIZEN
3rd October 2006

Authors: Alberto Martinez-Vazquez, Joaquim Fortuny-Guasch

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EUR - Scientific and Technical Research series; ISSN 1018-5593

Abstract
This document presents the activities carried out with the LISA system (LInear SAR, developed at the DG JRC) during the winters 2003-2004, 2004-2005 and 2005-2006 in the Sion Valley (Switzerland), in collaboration with the Swiss Federal Institute for Snow and Avalanche Research (SLF Davos). The main results concerning the snow height retrieval and avalanche monitoring as well as some future lines on this campaign are also outlined.

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