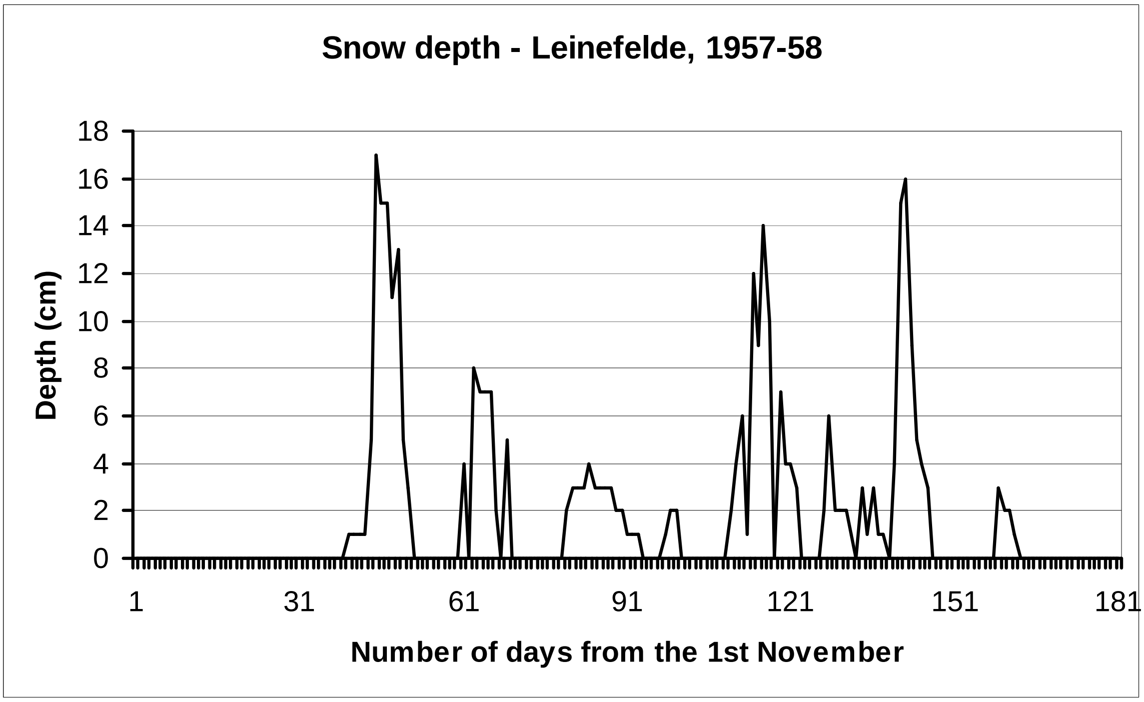
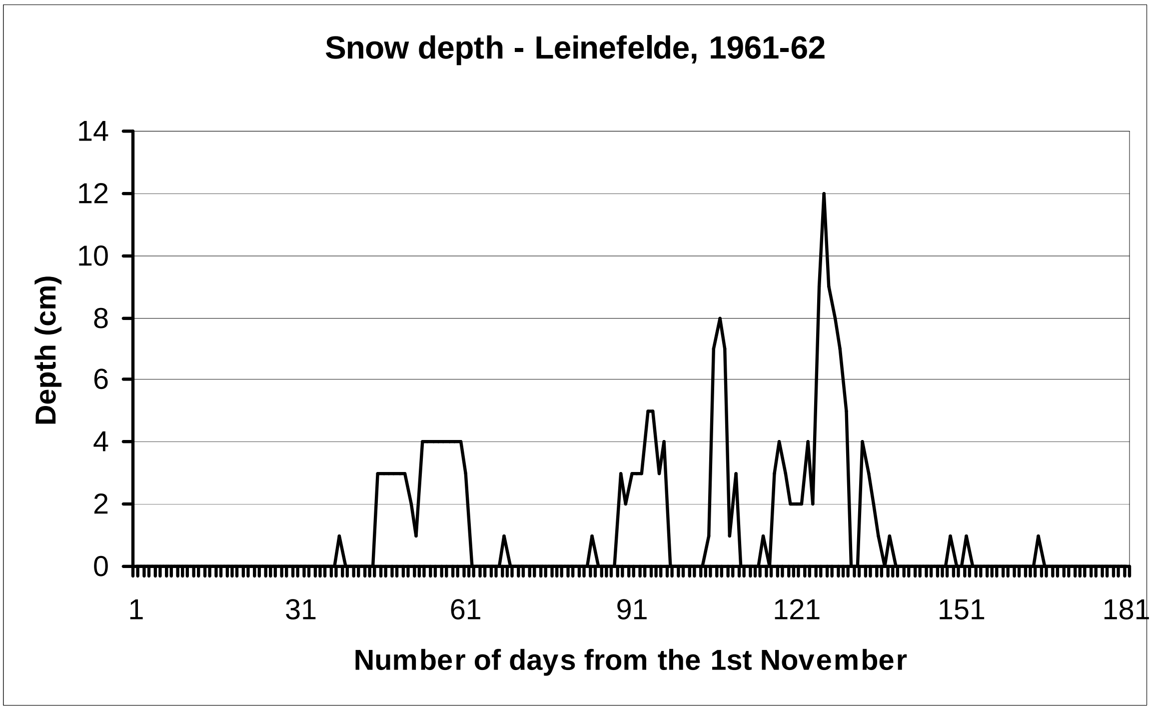
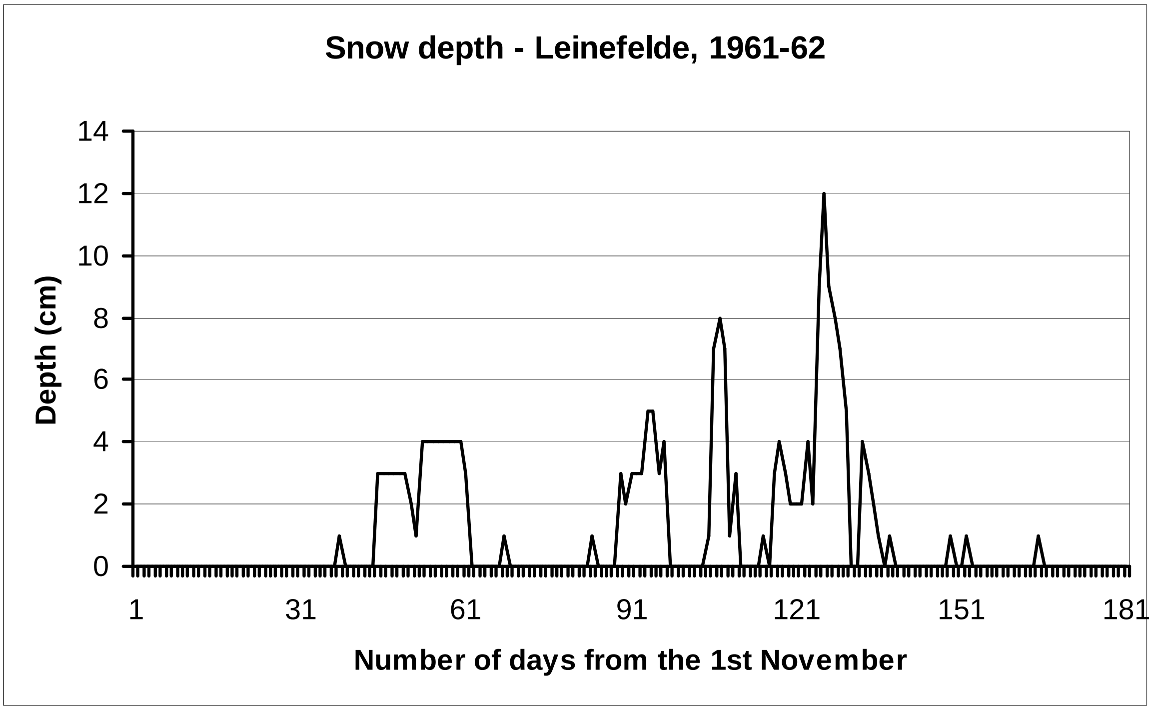
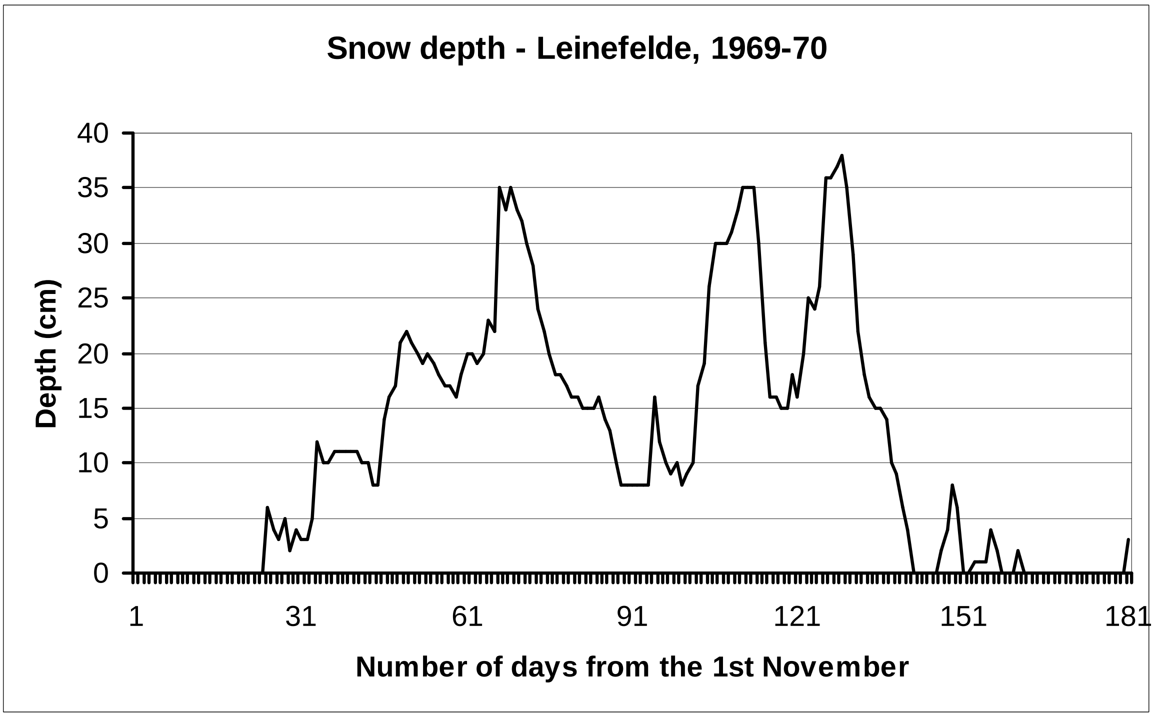
Annex 1 Time series

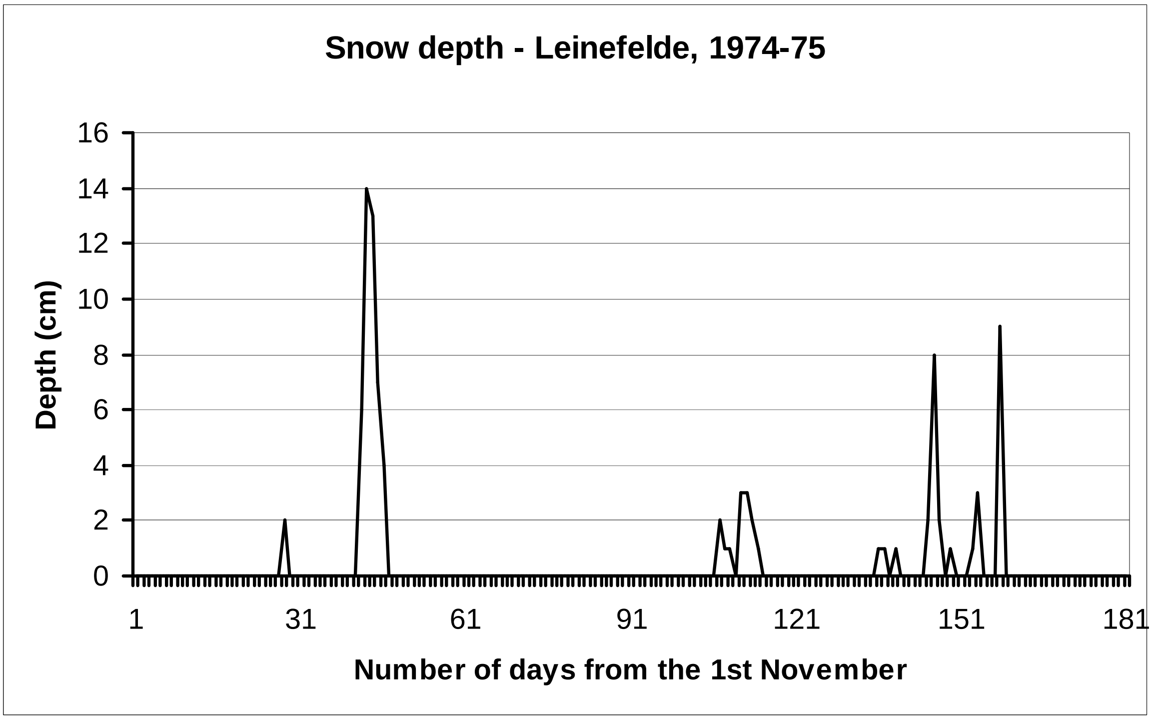
In the present annex are shown some examples of time series of snow depths measured at several climatic stations, spread over Europe.

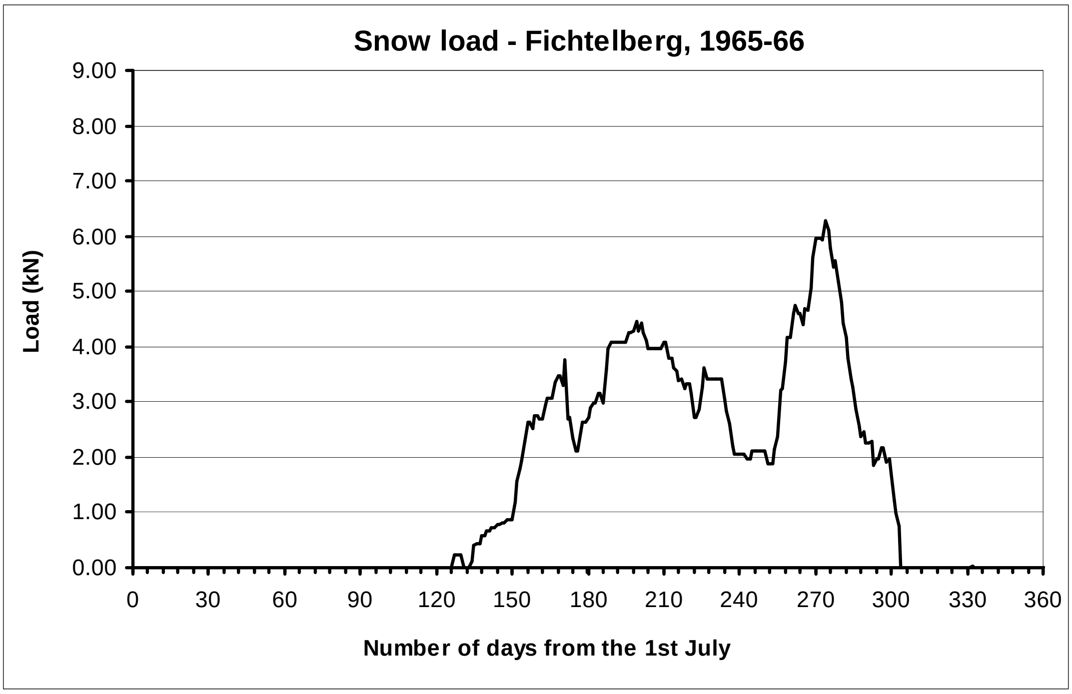


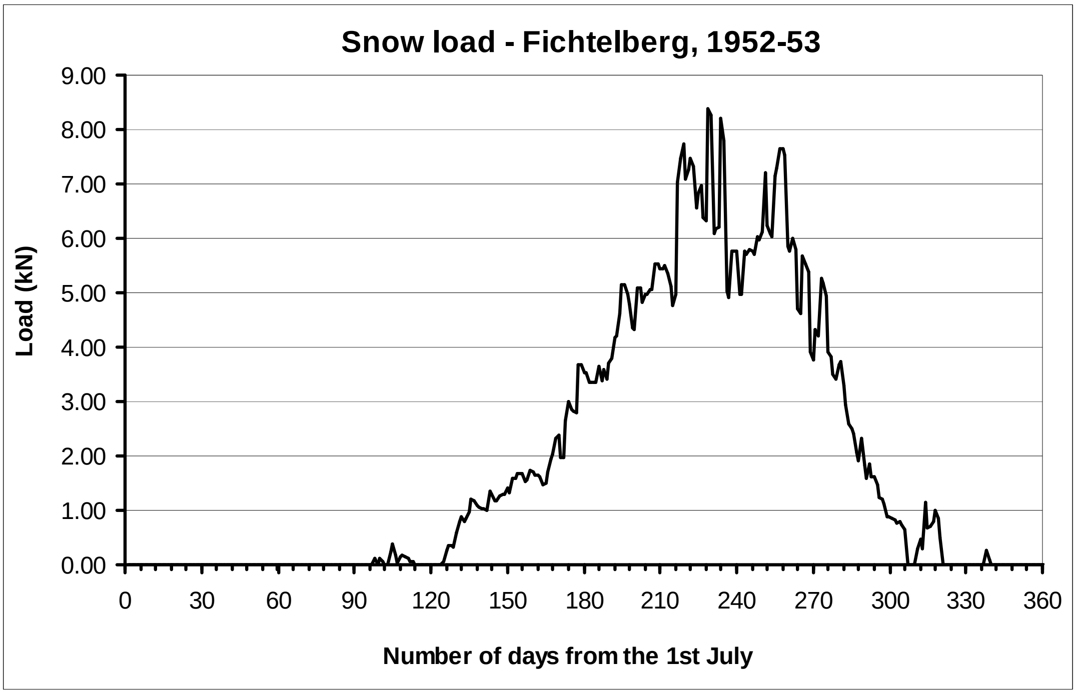



Snow depth - Leinefelde, 1961-62
Depth (cm)
14
12
10
8
6
4
2
0
1
31
61
91
121
151
181
Number of days from the 1st November

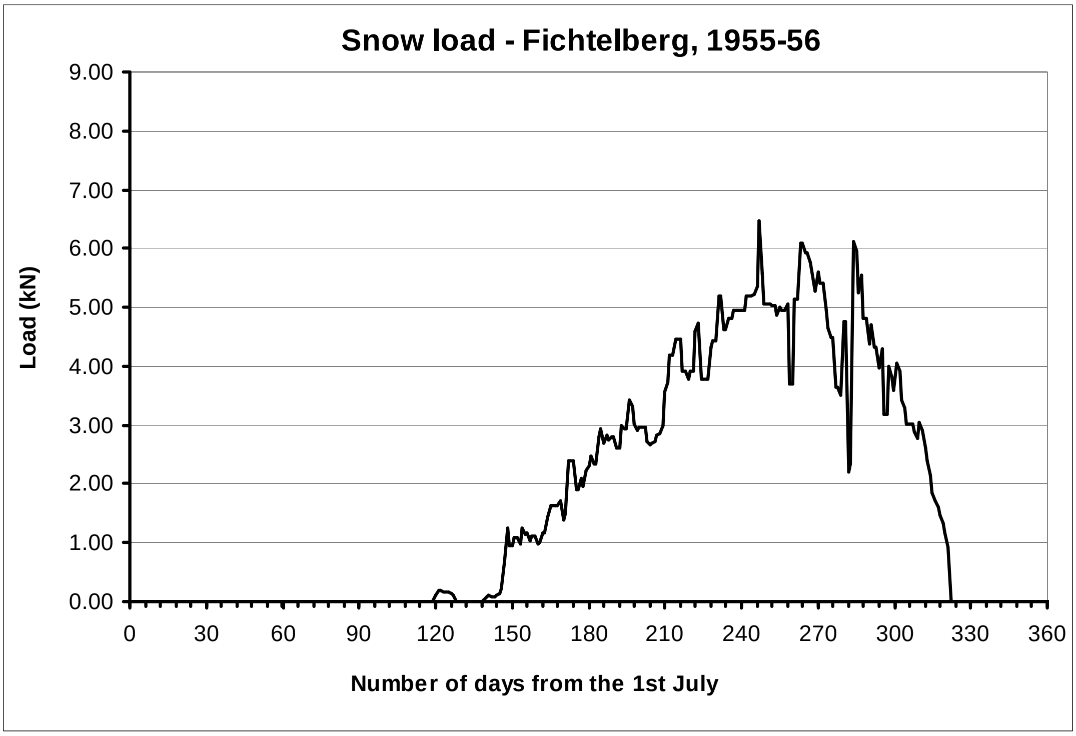

Snow depth - Leinefelde, 1969-70
Depth (cm)
40
35
30
25
20
15
10
5
0
1
31
61
91
121
151
181
Number of days from the 1st November


Snow depth - Leinefelde, 1974-75
Depth (cm)
0
2
4
6
8
10
12
14
16
1
31
61
91
121
151
181
Number of days from the 1st November


Snow load - Fichtelberg, 1965-66
Load (kN)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
0
30
60
90
120
150
180
210
240
270
300
330
360
Number of days from the 1st July

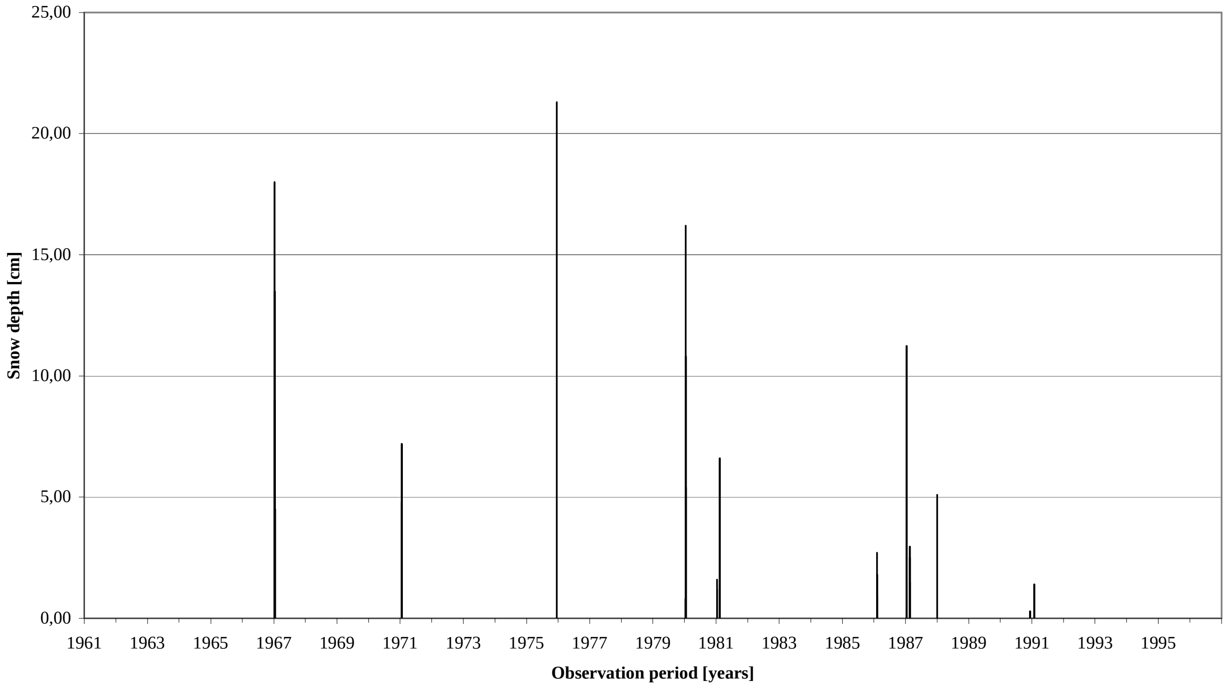


Snow load - Fichtelberg, 1952-53
Load (kN)
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0
30
60
90
120
150
180
210
240
270
300
330
360
Number of days from the 1st July

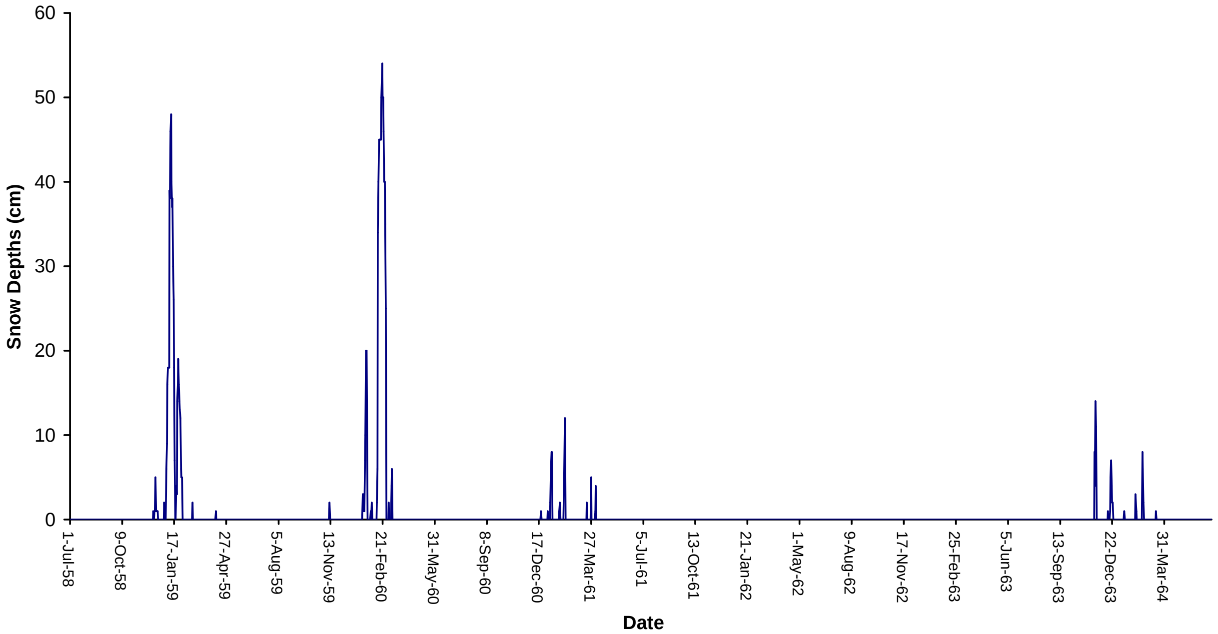


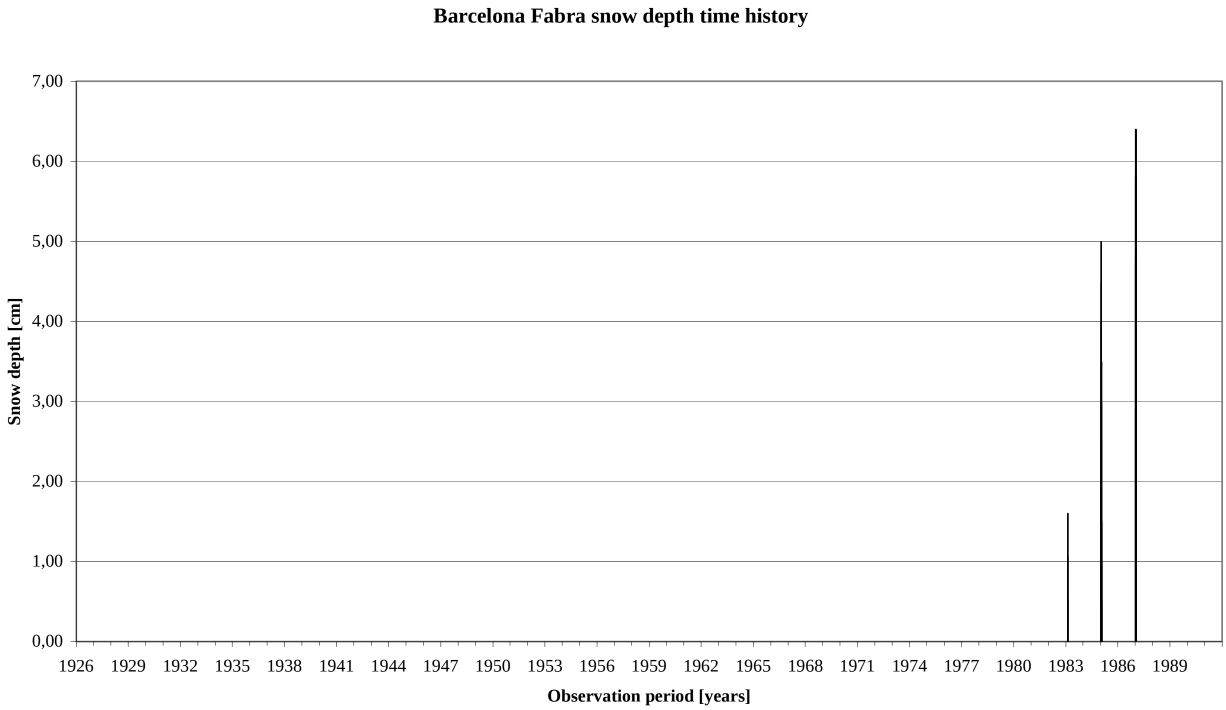
Snow load - Fichtelberg, 1955-56
Load (kN)
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0
30
60
90
120
150
180
210
240
270
300
330
360
Number of days from the 1st July

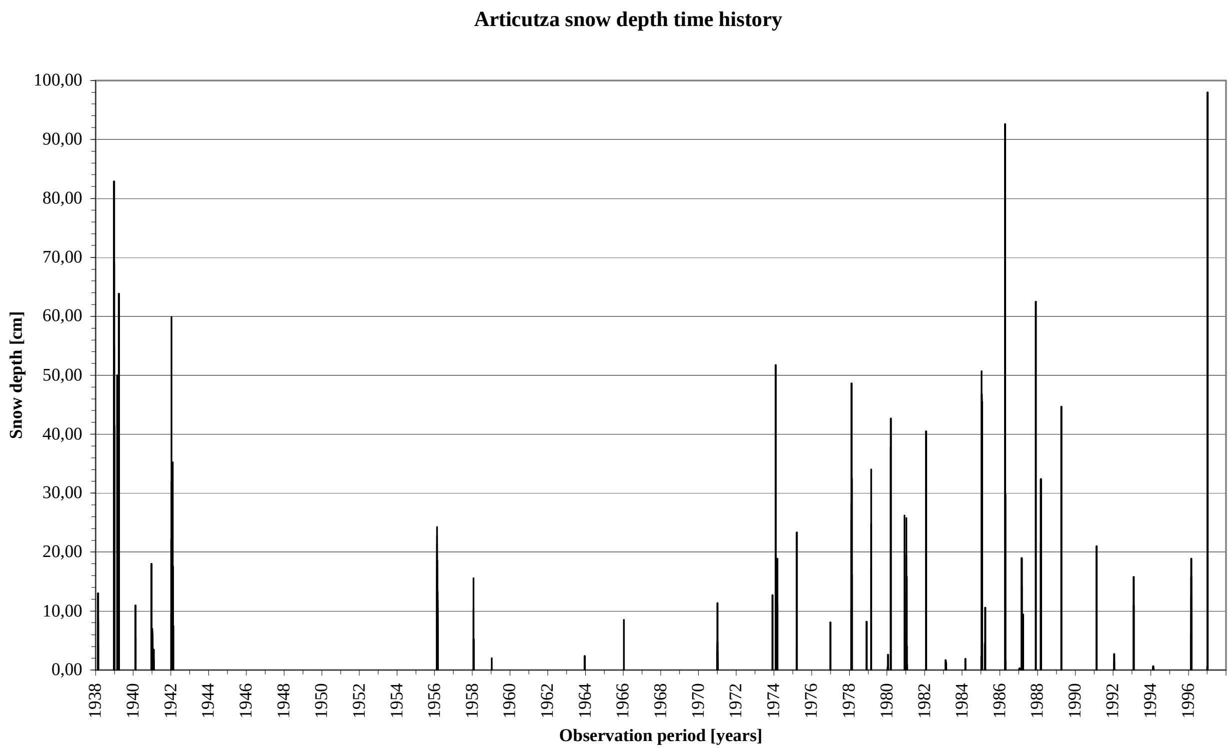
Madrid Cuatro Vientos Aerodromo snow depth time history

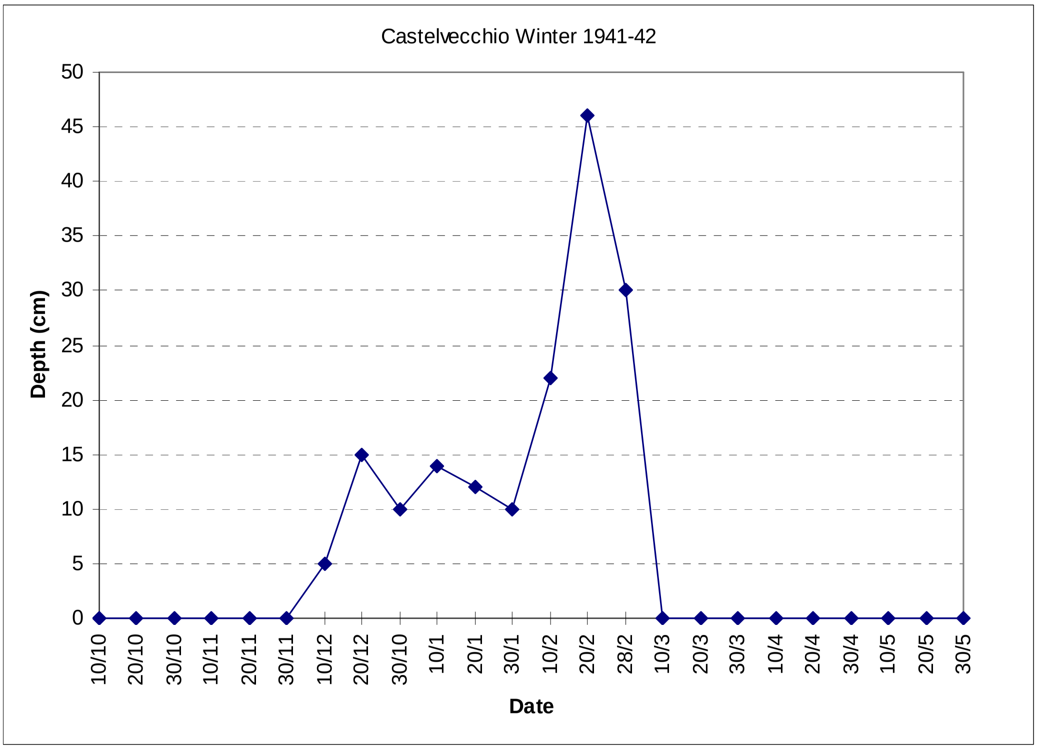


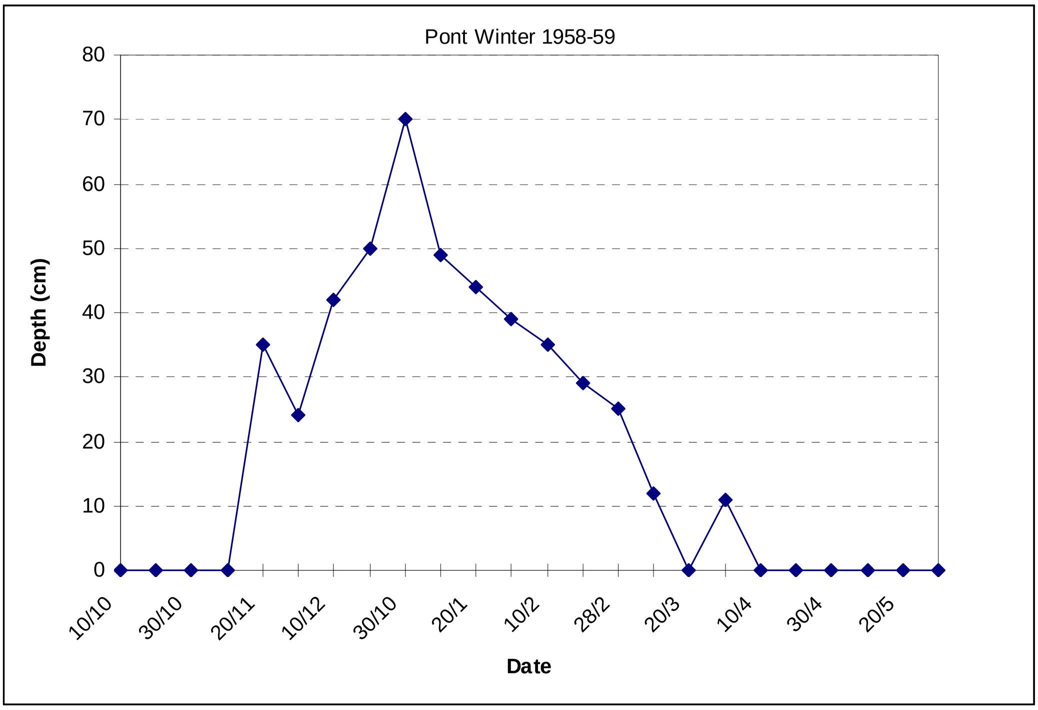
Snow Depth Time Series for Glenlivet
6 Winters (58/59 to 63/64)




Barcelona Fabra snow depth time history
7,00
6,00
5,00
4,00
3,00
2,00
1,00
0,00
Snow depth [cm]
1926 1929 1932 1935 1938 1941 1944 1947 1950 1953 1956 1959 1962 1965 1968 1971 1974 1977 1980 1983 1986 1989
Observation period [years]


Articutza snow depth time history
100,00
90,00
80,00
70,00
60,00
50,00
40,00
30,00
20,00
10,00
0,00
Snow depth [cm]
1938 1940 1942 1944 1946 1948 1950 1952 1954 1956 1958 1960 1962 1964 1966 1968 1970 1972 1974 1976 1978 1980 1982 1984 1986 1988 1990 1992 1994 1996
Observation period [years]


Castelvecchio Winter 1941-42
Depth (cm)
0
5
10
15
20
25
30
35
40
45
50
10/10
20/10
30/10
10/11
20/11
30/11
10/12
20/12
30/10
10/1
20/1
30/1
10/2
20/2
28/2
10/3
20/3
30/3
10/4
20/4
30/4
10/5
20/5
30/5
Date


Pont Winter 1958-59
Depth (cm)
0
10
20
30
40
50
60
70
80
10/10
30/10
20/11
10/12
30/10
20/1
10/2
28/2
20/3
10/4
30/4
20/5
Date

Annex 2 Tables for calculation of combination factor ψ_0

Combination factor based on extreme value distribution, type I for maxima (Gumbel)

V	r	Turkstra's rule	Design value method
		ψ_0	ψ_0
0,3	1	0,60	0,60
0,3	2	0,53	0,54
0,3	3	0,48	0,51
0,3	4	0,45	0,49
0,3	5	0,43	0,47
0,4	1	0,55	0,55
0,4	2	0,46	0,48
0,4	3	0,42	0,45
0,4	4	0,38	0,42
0,4	5	0,35	0,40
0,5	1	0,51	0,51
0,5	2	0,42	0,44
0,5	3	0,37	0,40
0,5	4	0,33	0,37
0,5	5	0,30	0,34
0,5	6	0,27	0,33
0,5	7	0,25	0,31
0,5	8	0,24	0,30
0,5	9	0,22	0,28
0,5	10	0,21	0,27
0,6	1	0,48	0,48
0,6	2	0,38	0,41
0,6	3	0,33	0,36
0,6	4	0,29	0,33
0,6	5	0,26	0,31
0,6	6	0,23	0,29
0,6	7	0,21	0,27
0,6	8	0,19	0,25
0,6	9	0,17	0,24
0,6	10	0,16	0,23
0,7	1	0,46	0,46
0,7	2	0,36	0,38
0,7	3	0,30	0,33
0,7	4	0,25	0,30
0,7	5	0,22	0,27
0,7	6	0,20	0,25
0,7	7	0,17	0,24
0,7	8	0,15	0,22

0,7	9	0,14	0,21
0,7	10	0,12	0,19
0,8	1	0,44	0,44
0,8	2	0,33	0,36
0,8	3	0,27	0,31
0,8	4	0,23	0,28
0,8	5	0,19	0,25
0,8	6	0,17	0,23
0,8	7	0,14	0,21
0,8	8	0,12	0,19
0,8	9	0,11	0,18
0,8	10	0,09	0,17
0,9	1	0,42	0,42
0,9	2	0,32	0,34
0,9	3	0,25	0,29
0,9	4	0,21	0,26
0,9	5	0,17	0,23
0,9	6	0,14	0,21
0,9	7	0,12	0,19
0,9	8	0,10	0,17
0,9	9	0,08	0,16
0,9	10	0,06	0,14
1	1	0,41	0,41
1	2	0,30	0,33
1	3	0,24	0,27
1	4	0,19	0,24
1	5	0,15	0,21
1	6	0,12	0,19
1	7	0,10	0,17
1	8	0,08	0,15
1	9	0,06	0,14
1	10	0,04	0,12

Combination factor based on extreme value distribution, type III for minima (Weibull)

V	r	Turkstra's rule	Design value method
		ψ_0	ψ_0
0,3	1	0,75	0,75
0,3	2	0,68	0,70
0,3	3	0,63	0,66
0,3	4	0,59	0,63
0,3	5	0,55	0,61
0,4	1	0,68	0,68
0,4	2	0,59	0,61
0,4	3	0,53	0,56
0,4	4	0,48	0,53
0,4	5	0,44	0,50
0,5	1	0,61	0,61
0,5	2	0,51	0,53
0,5	3	0,44	0,48
0,5	4	0,39	0,44
0,5	5	0,35	0,41
0,6	1	0,54	0,54
0,6	2	0,43	0,46
0,6	3	0,37	0,41
0,6	4	0,32	0,37
0,6	5	0,28	0,34
0,7	1	0,49	0,49
0,7	2	0,37	0,40
0,7	3	0,30	0,35
0,7	4	0,26	0,31
0,7	5	0,22	0,28
0,8	1	0,43	0,43
0,8	2	0,32	0,35
0,8	3	0,25	0,29
0,8	4	0,21	0,26
0,8	5	0,17	0,23
0,9	1	0,39	0,39
0,9	2	0,28	0,30
0,9	3	0,21	0,25
0,9	4	0,17	0,22
0,9	5	0,14	0,19
1	1	0,35	0,35
1	2	0,24	0,26
1	3	0,18	0,21
1	4	0,14	0,18
1	5	0,11	0,16

Combination factor based on Log-normal distribution

V	r	Turkstra's rule ψ_0	Design value method ψ_0
0,3	1	0,63	0,63
0,3	2	0,55	0,57
0,3	3	0,50	0,53
0,3	4	0,47	0,51
0,3	5	0,44	0,49
0,4	1	0,54	0,54
0,4	2	0,46	0,48
0,4	3	0,41	0,44
0,4	4	0,37	0,41
0,4	5	0,35	0,39
0,5	1	0,47	0,47
0,5	2	0,38	0,40
0,5	3	0,33	0,36
0,5	4	0,30	0,33
0,5	5	0,27	0,31
0,6	1	0,41	0,41
0,6	2	0,32	0,34
0,6	3	0,27	0,30
0,6	4	0,24	0,28
0,6	5	0,22	0,26
0,7	1	0,37	0,36
0,7	2	0,28	0,30
0,7	3	0,23	0,26
0,7	4	0,20	0,23
0,7	5	0,18	0,21
0,8	1	0,33	0,33
0,8	2	0,24	0,26
0,8	3	0,19	0,22
0,8	4	0,16	0,20
0,8	5	0,14	0,18
0,9	1	0,29	0,29
0,9	2	0,21	0,23
0,9	3	0,17	0,19
0,9	4	0,14	0,17
0,9	5	0,12	0,15
1	1	0,26	0,26
1	2	0,18	0,20
1	3	0,14	0,17
1	4	0,12	0,15
1	5	0,10	0,13

Annex 3 Statistical data from different regions for calculation of ψ_0

1 Alpine region

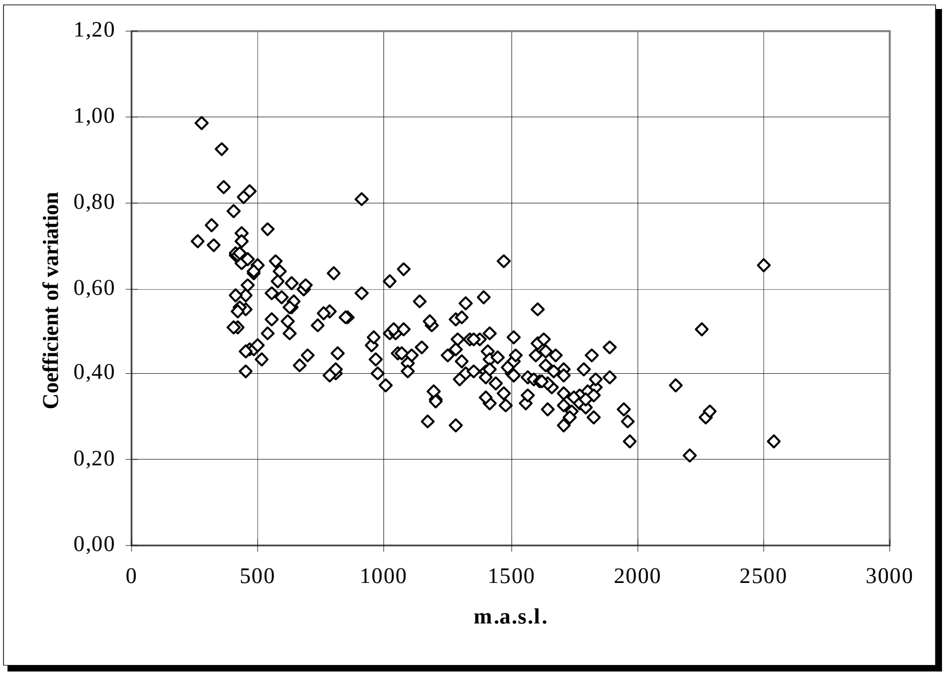
1.1 Switzerland

CoV varies between 0,2 and 1,0.
For stations with altitude less than 1000m CoV varies between 0,4 and 1,0.
For stations with altitude greater than 1000m CoV varies between 0,2 and 0,8 but for most stations CoV is greater than 0,3.
For stations with altitude less than 1000m number of load repetitions *r* mostly equals 2.
For stations with altitude greater than 1000m the mountain climate is prevailing and *r* is equal to 1,0.

According to Gumbel distribution and Design Value Method:

CoV	r	ψ_0	altitude
0,2	1	0,68	> 1000 m a.s.l.
0,3	1	0,60	> 1000 m a.s.l.
0,4	1	0,55	< 1000 m a.s.l.
0,4	2	0,48	< 1000 m a.s.l.

Therefore ψ_0 becomes equal to 0,6 for altitude less than 1000m and equal to 0,5 for altitude greater than 1000m.



1.2 Italy

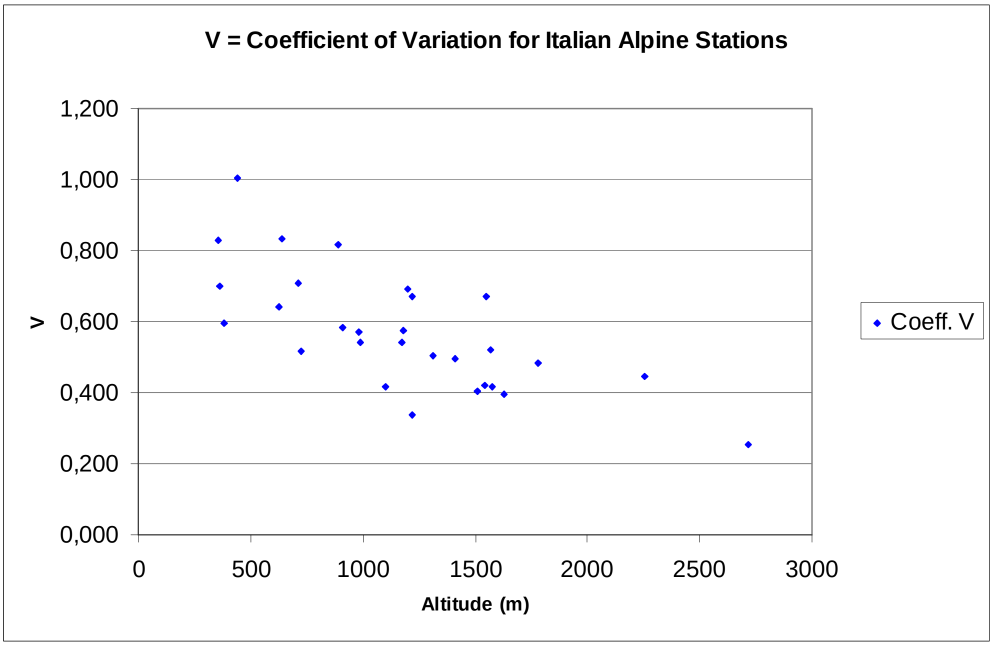
Number of repetitions *r* is between 1 and 5, but mostly: 1 < *r* < 2.
CoV is equal to 0,5 - 1,0 for low altitude (less than 1000 m above sea level).
CoV is equal to 0,4 - 0,7 for high altitude (greater than 1000 m a.s.l.) with exception of two stations

with CoV = 0,3.
Values 0,5 and 0,4 can be chosen as lower bound (results on the safe side) respectively.

CoV	r	ψ_0	altitude
0,5	1	0,51	< 1000 m a.s.l.
0,5	2	0,44	< 1000 m a.s.l.
0,4	1	0,55	> 1000 m a.s.l.
0,4	2	0,48	> 1000 m a.s.l.

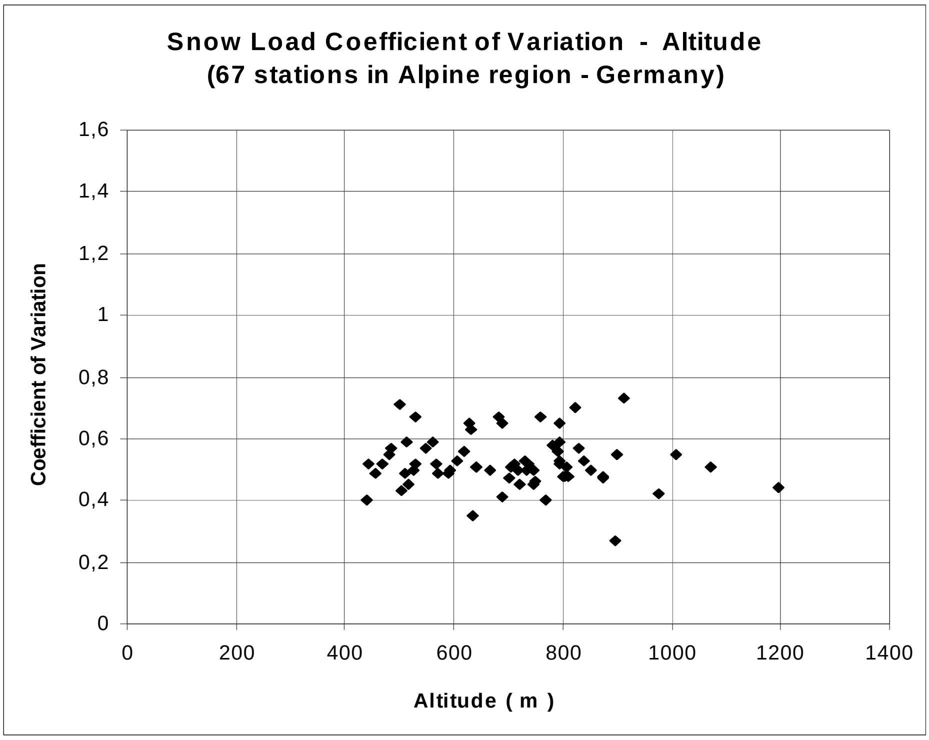
Only two stations give r = 5 and simultaneously CoV = 0,5-0,6. But these results are on the unsafe side (lower bound of results for ψ_0).

As overall values for Italian part of Alpine region the value $\psi_0 = 0,5$ can be proposed for altitude less than 1000m and the value $\psi_0 = 0,55$ for altitude greater than 1000m.



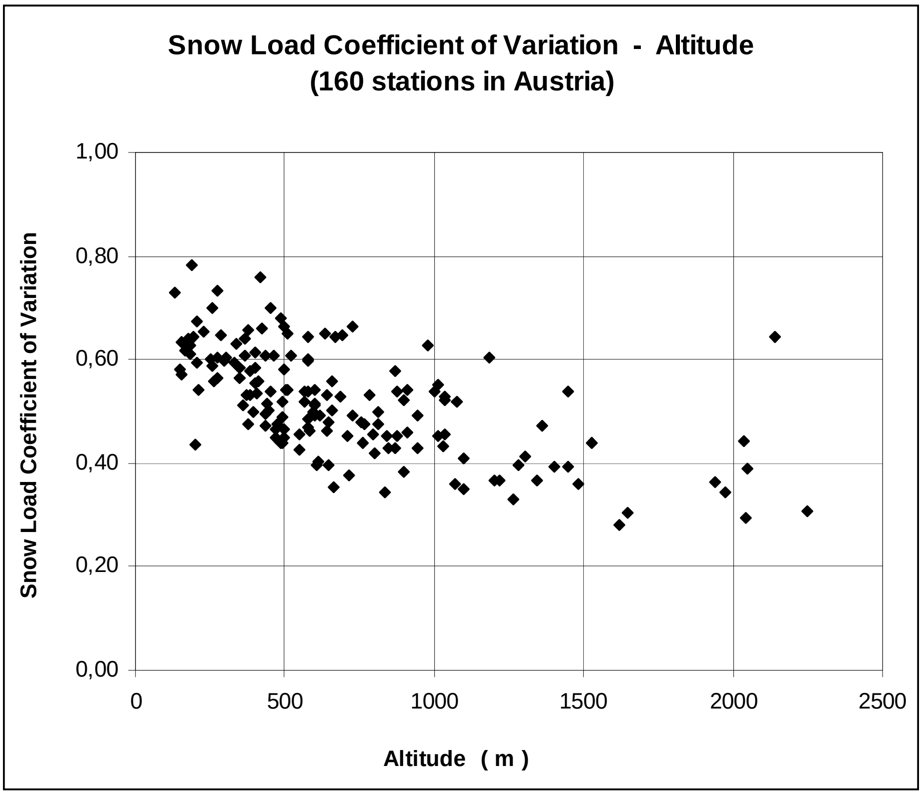
1.3 Germany

67 stations of Alpine region in Germany located on altitude between 450m and 1200m. CoV does not depend on altitude and varies between values of 0,3 and 0,7. The most stations have values between 0,4 and 0,6. Only two stations have CoV less that 0,4. Therefore value 0,4 can be set for region. Number of repetitions r can be set as 1 taking into account the mountain climate of the most stations. Then coefficient $\psi_0 = 0,55$ can be set.



1.4 Austria

CoV varies between 0,3 and 0,8.
There is a weak dependence the values of CoV from altitude. The mean value of CoV decreases from 0,6 (for altitude less than 500m) to 0,4 (for altitude 2000m).
There is no investigation on number of load repetitions *r* (no daily data available - only monthly maxima). But taking into account that in Austria the mountain climate is prevailing *r* can be suggested to be equal to 1,0 for high altitude and *r* can be set as 1 or 2 for low altitude.
Taking value of CoV equals 0,3 (as unfavourable value) ψ_0 becomes equal to 0,6 for altitude greater than 1000m and ψ_0 becomes equal to 0,5 (CoV = 0,4; *r* = 1 or 2) for altitude less than 1000m.



1.5 France

Two stations with altitude about 870m were analysed. They give CoV values of 0,41 and 0,45. The values of r vary mostly between 1 and 3. Taking r = 1 as the lower bound ψ_0 becomes equal to 0,55.

Table: ψ_0 values for different countries in Alpine region and proposed values for whole region

	Country	ψ_0	Additional information
1	Switzerland	0,6 0,5	altitude: > 1000m < 1000m
2	Italy	0,55 0,5	altitude: > 1000m < 1000m
3	Germany	0,55	
4	Austria	0,6 0,5	altitude: > 1000m < 1000m
5	France	0,55	
	Alpine Region	**0,6** **0,5**	**altitude:** **> 1000m** **< 1000m**

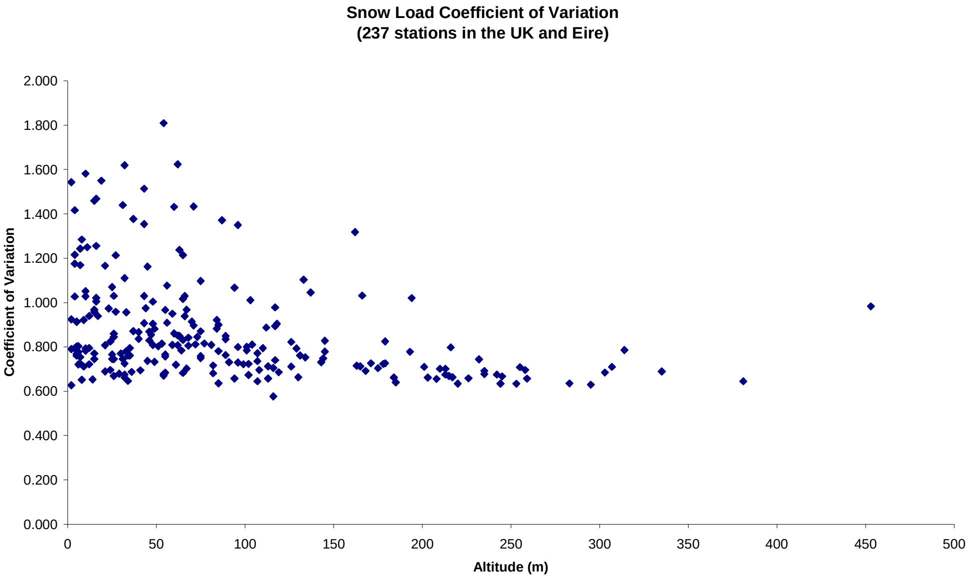
2 UK and Eire

237 stations in UK and Eire have the altitude between 0m and 450m. CoV varies between 0,6 and 1,8. For stations with r >= 3 events per winter CoV does not deviate with altitude and varies within narrow corridor between values of 0,6 and 0,8. Taking CoV = 0,6 and r = 3 the coefficient ψ_0 = 0,36 can be set.

For stations with one event r per winter CoV does not depend on altitude and greater than 1,0 for most stations.
For stations with two events r per winter CoV does not depend on altitude and varies mostly between values of 0,7 and 1,6. Only two or three stations have CoV between 0,6 and 0,7.

CoV	r	ψ_0
1,0	1	0,41
0,6	2	0,41
0,7	2	0,38

Therefore overall ψ_0 value equals 0,4 can be set.

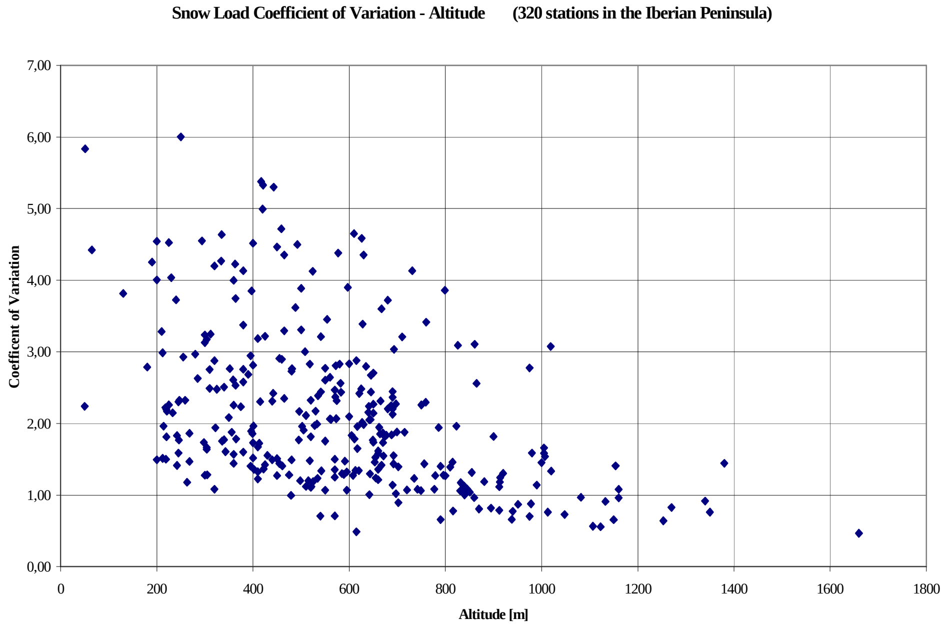


3 Iberian Peninsula

The values of CoV for 320 stations vary between 0,5 and 6,0. Mean value is equal to 2,1. But a lot of stations have CoV between 1,0 and 2,0 and some stations with altitude greater than 500m have CoV = 0,5.
r is calculated to be equal to 1,0 for most stations.
Taking the lower bound for CoV (to be on the safe side):

CoV	r	altitutde	ψ_0	
1,0	1	<= 500m		0,41
0,5	1	> 500m	0,51	

Therefore as overall values for ψ_0 value of 0,4 (for altitude <=500m a.s.l.) and value of 0,5 (for altitude > 500m a.s.l.) can be proposed.



4 Mediterranean Region

The investigation based on Italian stations gives following results.

The values of CoV vary between 0,1 and 1,5 but for most stations between 0,4 and 1,1. Values of CoV do not depend on altitude (altitude varies between 0m and 1500m, only two stations are higher than 1500m).

Only 4 stations have CoV less than 0,4. Therefore lower bound can be set as a value of 0,4 and this one can be used for further work.

Number of repetitions *r* is between 1 and 4, mostly: $1 <= r <= 3$.

CoV	*r*	ψ_0
0,4	1	0,55
0,4	2	0,48
0,4	3	0,45

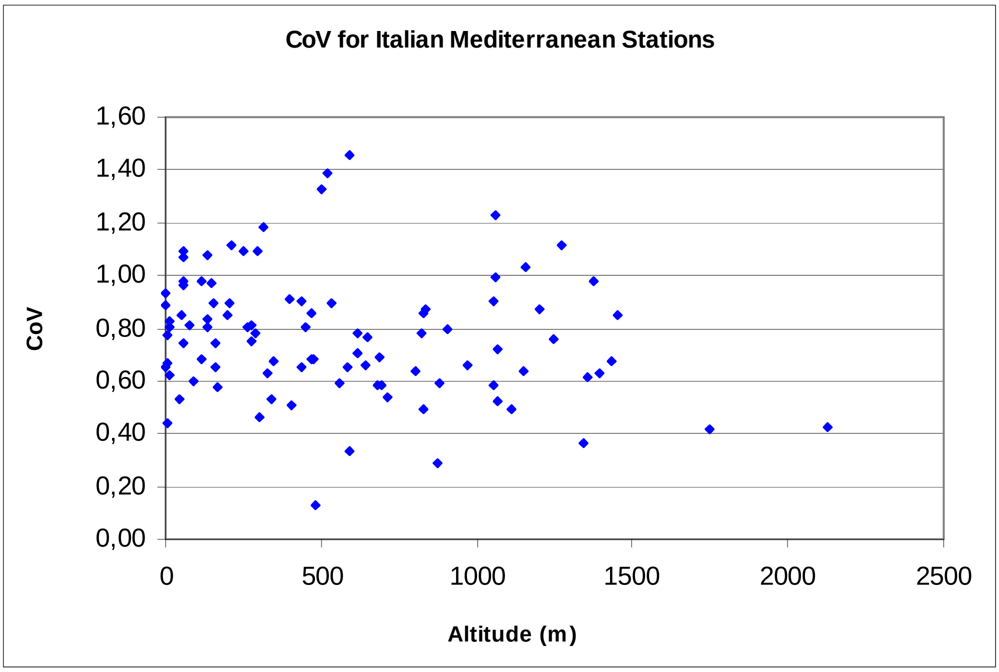
Therefore as overall value for Mediterranean region in Italy value $\psi_0 = 0{,}5$ can be proposed.
For coefficient ψ_1 the values are between 0,0 and 0,13, therefore $\psi_1 = 0{,}10$ can be set.
$\psi_2 = 0{,}0$ is calculated.

Two stations in France with altitude 36m and 48m were analysed. They give CoV values of 1,0 and 1,4. The average values of *r* are calculated as 0,4 and 0,37 for these stations (less than one event per winter).

CoV	*r*	ψ_0
1,0	1	0,41

Therefore value of ψ_0 which equal to 0,4 can be proposed.

Thus Italian ψ_0 - values can be set as the relevant ones for Mediterranean Region.



5 Central East

264 German stations give values of CoV between 0,2 and 1,2. CoV decreases with altitude. For low altitude (less than 100m) CoV is between 0,5 and 1,2. For higher altitude mean value of CoV is 0,5-0,6. But reliable lower bound is equal to 0,3 - 0,4.

It is difficult to calculate the value of *r* because of lack of daily data from Western Germany. Only stations from Eastern Germany (totally only 23 stations) have daily data. They give different results. For Fichtelberg (altitude 1213m, CoV = 0,4) *r* = 1,0. For stations with low altitude and mixed climate:

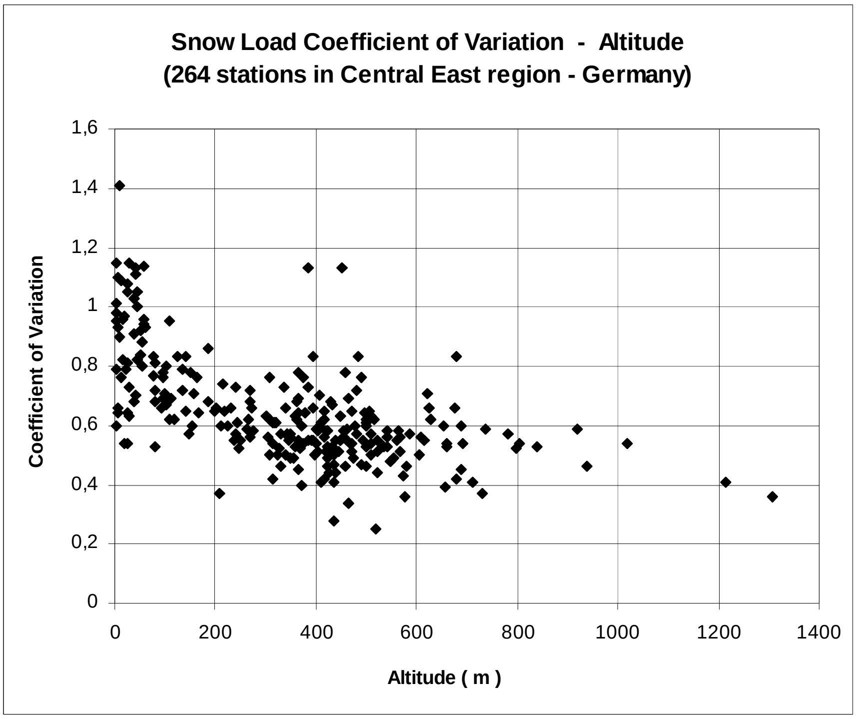
Leinefelde (CoV = 0,5) - *r* = 6,3 events per winter,

Potsdam (CoV = 0,8) - *r* = 6,6 events per winter.

6 events per winter can be considered as too favourable therefore small numbers of *r* should be also taken into account. Different values of ψ_0 for different altitude can be proposed:

CoV	*r*	ψ_0	altitude
0,4	1	0,55	high
0,5	6	0,33	low
0,5	3	0,40	low

It is difficult to choose the border between these two groups but value 500m above sea level seems to be appropriate.



6 Central West

The data from France and Netherlands were analysed.

15 stations from Netherlands give CoV between 0,6 and 1,2 but mostly between 0,7 and 1,0. therefore value of 0,7 can be proposed. The value of *r* is mostly equal to 1,0 or 2,0. Then:

CoV	*r*	ψ_0
0,7	1	0,46
0,7	2	0,38

As overall value 0,4 can be suggested for ψ_0.
The factors ψ_1 and ψ_2 can be set as 0,0.

The investigation based on 6 stations in France gives following results.
The values of CoV vary between 0,7 and 1,1, mostly - between 0,8 and 1,0. Values of CoV do not depend on altitude (altitude varies between 11m and 423m). Therefore CoV can be set as a value of 0,8 (or 0,7 as a lower bound).
Number of repetitions *r* is also calculated for these stations and varies between 0,83 (lees than one event per winter) and 5,9. To be on the safe side the values of 1 or 2 are considered.

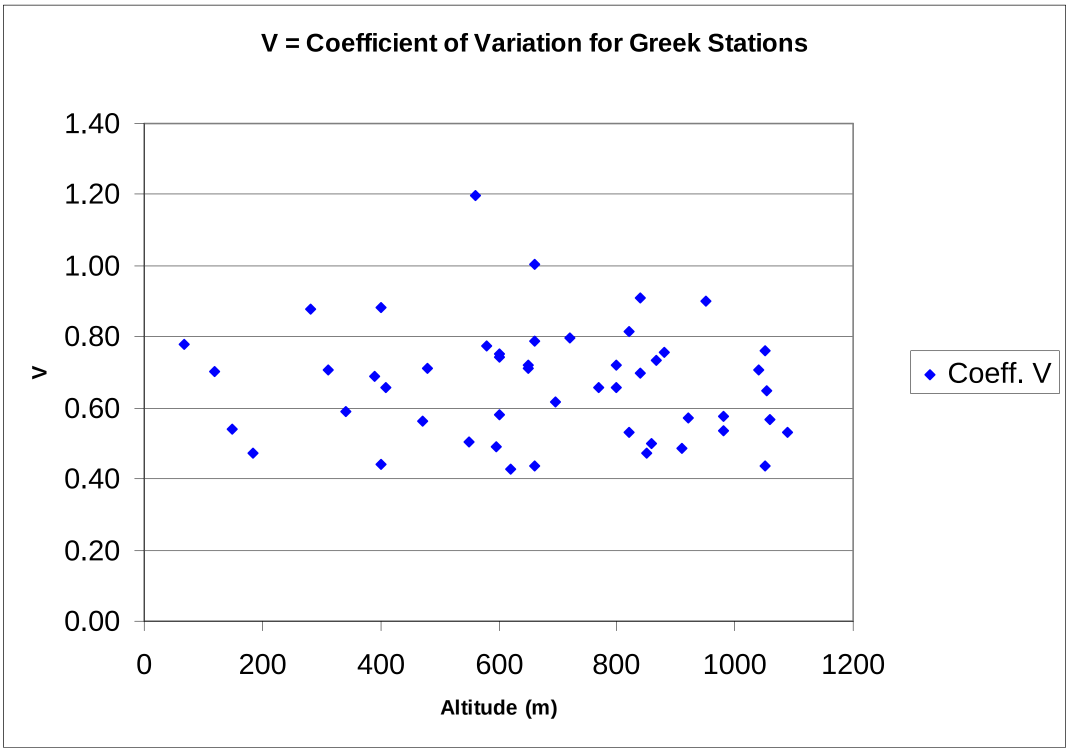
CoV	*r*	ψ_0
0,8	1	0,44
0,8	2	0,36
0,7	1	0,46
0,7	2	0,38

Therefore value ψ_0 = 0,4 found above can be proposed for whole region.

7 Greece

49 stations were available for investigation. They located at quite high altitude (mean 687 m a.s.l.). The maen value of CoV is equal 0,67.
Number events per winter *r* is mostly equal to 1 or 2. Therefore:

CoV	*r*	ψ_0
0,6	1	0,48
0,6	2	0,41



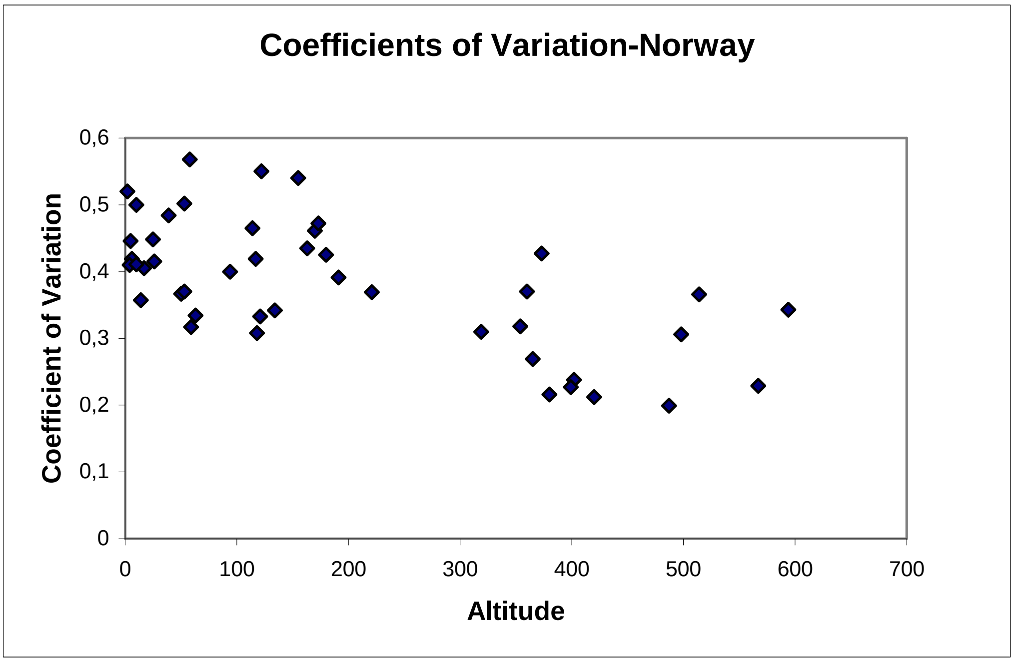
Therefore overall ψ_0 value equals 0,5 can be set.

8 Norway

45 stations are available for investigation. They located on altitude between 0,0 m and 687 m a.s.l.. The values of CoV vary between 0,2 and 0,6 and show weak dependence from altitude. All station can be subdivided into 2 groups: one with minimum CoV = 0,3 (altitude < 300m), second with minimum CoV = 0,2 (altitude > 300m).
Number events per winter *r* can be chosen equals 1 to be on the safe side. Then:

CoV	*r*	ψ_0
0,3	1	0,6
0,2	1	0,68

Therefore ψ_0 value equals 0,6 can be set for low altitude and ψ_0 value equals 0,7 can be set for high altitude.

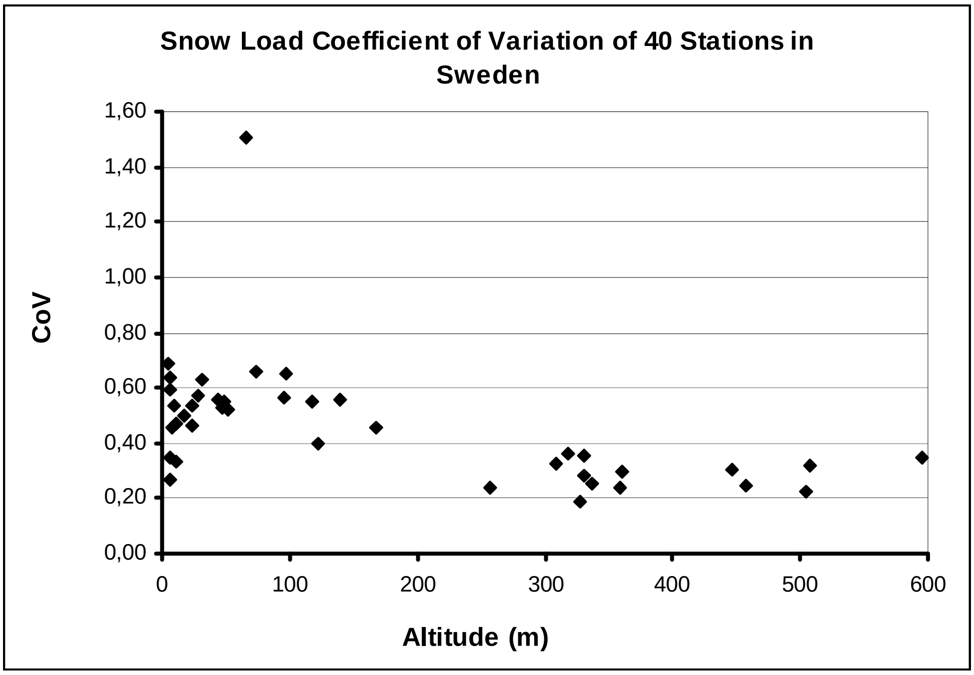


9 Finland - Sweden

40 stations from Sweden were investigated. They located on altitude between 0 m and 600 m a.s.l.. The values of CoV vary between 0,2 and 0,7 (with one exception of 1,5) and show weak dependence on altitude. All stations can be subdivided into 2 groups: one with minimum CoV = 0,2 (altitude > 250m), second with minimum CoV = 0,3 (altitude < 250m).
Number of events per winter *r* can be chosen equals 1 or 2. Then:

CoV	*r*	ψ_0	altitude
0,3	1	0,60	< 250 m
0,3	2	0,53	< 250 m
0,2	1	0,68	> 250 m
0,2	2	0,62	> 250 m

Therefore ψ_0 value equals 0,6 can be set for low altitude and ψ_0 value equals 0,65 can be set for high altitude.



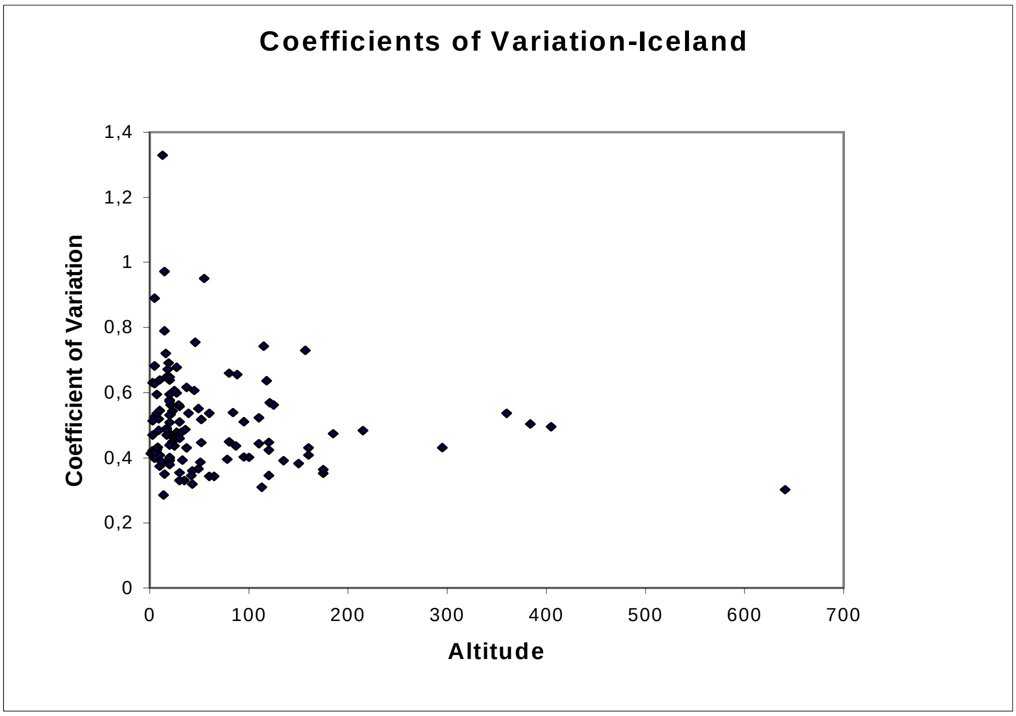
10 Iceland

The investigated stations are located on altitude between 0,0m and 650 m a.s.l. but only 5 ones have altitude greater than 200m. The values of CoV vary between 0,3 and 1,3 and do not show dependence on altitude.

Taking the minimum value of CoV = 0,3 and number events per winter *r* equals 1 the following results can be obtained:

CoV	*r*	ψ_0
0,3	1	0,6

Therefore ψ_0 value equals 0,6 can be set.



Annex 4 Ferry - Borghes model and outcrossing rate analysis for non stationary processes

A4.1 Normalization of the Wind/Snow Load Effects

The basic load effect combination formulation can be written as follows:

$$S(t) = a_1*S_1(t) + a_2*S_2(t) \qquad (3)$$

where S(t) is the resulting time-varying load or load effect, $S_1(t)$ and $S_2(t)$ are the basic time-varying load (or load-effect) components, and a_1 and a_2 are the combination constants. For design purposes, it is typically the extreme value during a certain time interval that is relevant (this applies to the Serviceability as well as to the Ultimate Limit States for the characteristic combination). This extreme value occurs for a specific point in time, i.e.:

$$S_E(t_E) = a_1*S_1(t_E) + a_2*S_2(t_E) \qquad (4)$$

where the subscript E refers to extreme value. If the two component processes are fully correlated, the extreme value of both occurs at the same time instant. However, in general the component processes are only partly correlated or completely independent. The latter case is considered here.

In codified design, the characteristic load or load-effect to be applied for the design check is typically expressed in the form:

$$S_{Ec} = a_1*\gamma_1*S_{1c} + \psi_0*a_2*\gamma_2*S_{2c} \qquad (5)$$

where the first factored load (or load-effect) is supposed to be dominant. The subscript c now refers to characterisic values. For the component processes, these can e.g be fractiles of the extreme value distributions. The factor ψ_0 is the combination factor which is equal to or smaller than one. The partial load factors γ_1 and γ_2 are generally different for different types of load.

In order to obtain a nondimensional (i.e. normalized) description which does not depend on the particular type of load-effect (such as axial force and bending moment), we divide Eq(3) by Eq(5) to obtain:

$$S(t)/ S_{ec} = (a_1*S_1(t) + a_2*S_2(t))/(a_1*\gamma_1*S_{1c} + \psi_0*a_2*\gamma_2* S_{2c}) \qquad (6)$$

which can be written in a more compact form by introducing the dimensionless ratios
$q_a = a_2/a_1$ and $q_s = S_{2c} /S_{1c}$:

$$S(t)/ S_{ec} = \{(S_1(t)/ S_{1c}) + q_a*q_s * (S_2(t)/ S_{2c})\}/\{\gamma_1 (1. + \psi_0*q_a*q_s*(\gamma_2/\gamma_1))\} \qquad (7)$$

This expression can be simplified even more by introducing the normalized load (or load-effect) variables $X_1 = (S_1(t)/ S_{1c})$ and $X_2 = (S_2(t)/ S_{2c})$ which results in :

$$S(t)/ S_{ec} = \{ X_1 + q_a*q_s * X_2 \}/\{\gamma_1 (1. + \psi_0*q_a*q_s*(\gamma_2/\gamma_1))\} \qquad (8)$$

Assuming that these normalized loads are of the same order of magnitude (due to division by the respective extreme values), the first term will “dominate” when the product of q_a*q_s is smaller than one. The ratio q_s is the characteristic extreme value of the second load divided by that of the first load. This ratio will depend on the climatic zone of relevance (e.g. ratio between wind load and snow load). However, by considering the range from 0.5 to 2.0 in steps of 0.5 (i.e. 0.5, 1.0, 1.5 and 2.0), a wide range of conditions is covered.

A4.2. Examples of Probability Functions for a Specific Case

As a specific example, a case where the wind and snow load effects are of the same magnitude is considered. The number of repetitions of the wind load for each basic snow load time period is set equal to 30 (i.e. wind load effect three days and snow load effect 90 days). The number of repetitions for the snow load effect each winter season is accordingly equal to 2. The Weibull exponent for the snow load effect in the present example is equal to 3.0 (For the wind load effect, the Weibull exponent is still equal to 1.0 corresponding to an exponential distribution as for all the other cases).

The probability density functions for the two basic time intervals (i.e. 3 days and 90 days) are shown in Figure 1. The distribution functions corresponding to the snow load effect reference period equal to 90 days are shown in Figure 2. For the wind, the distribution function correspond to that of the maximum load effect for 30 repetitions.

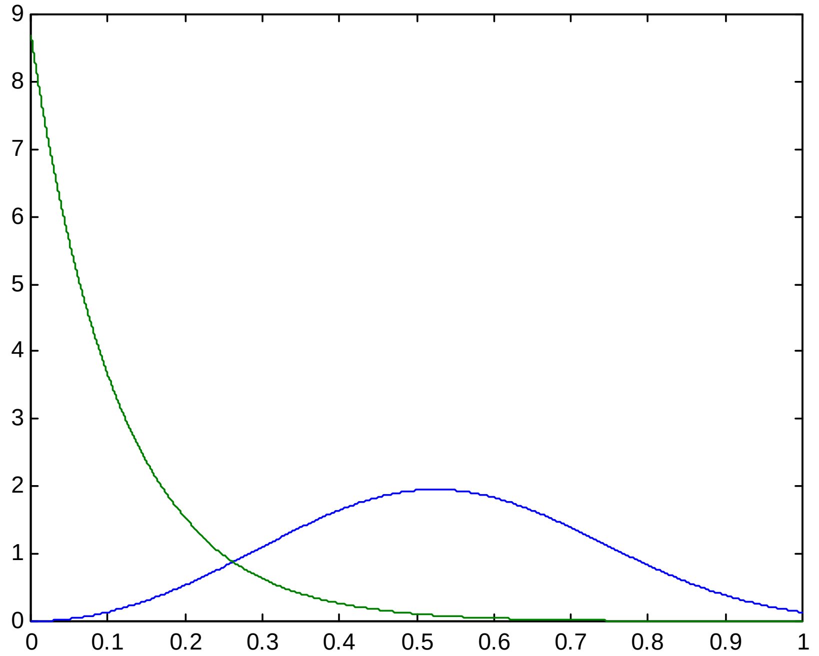


Figure 1. Normalized probability density functions for snow and wind load effects

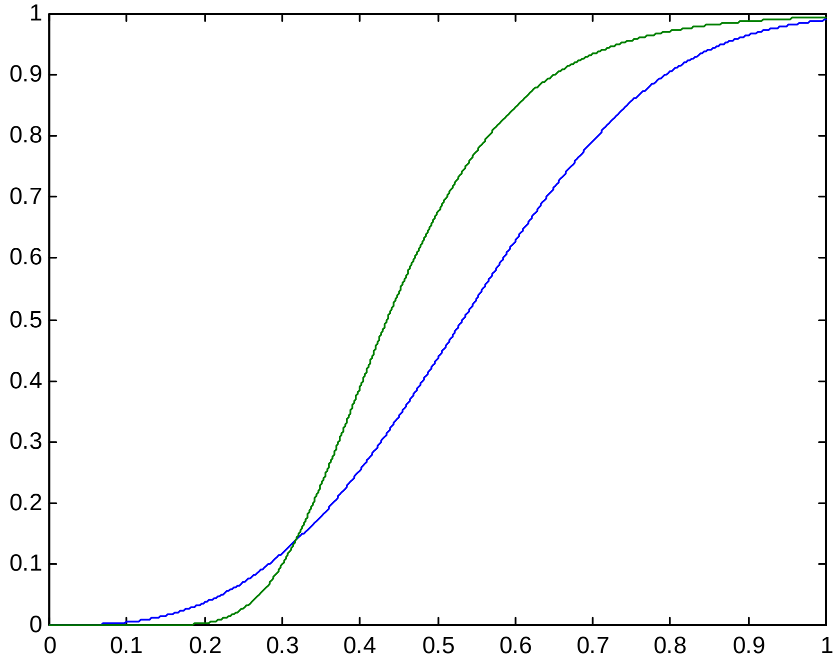


Figure 2. Distribution functions of snow and wind load effects corresponding to a reference period of 90 days. Wind load effects is maximum of 30 repetitions

The probability density and distribution functions for the combined load effect for the 90 day reference period are given in Figure 3. The corresponding probability functions for the annual maximum value of the combined load effect are given in Figure 4.

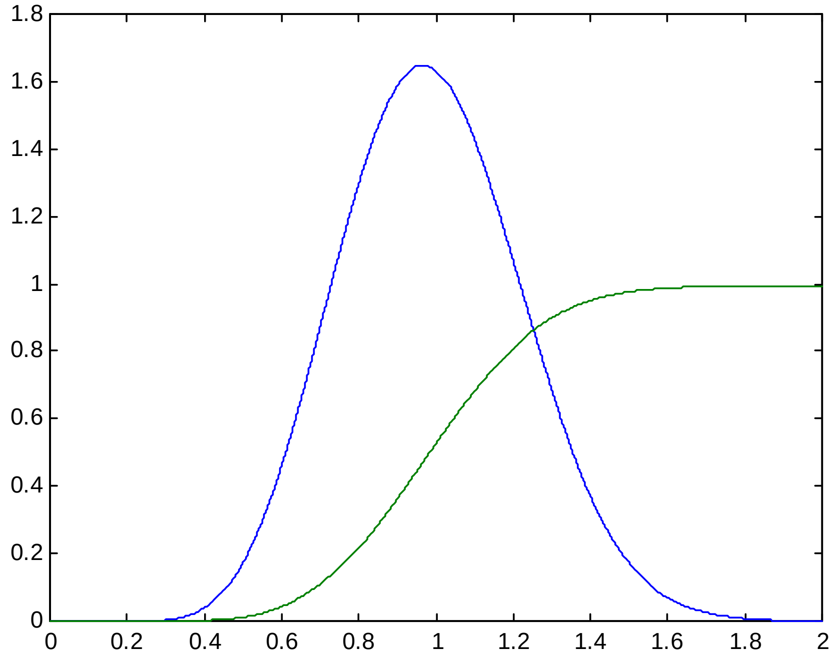


Figure 3. Probability density and distribution functions of combined load effect for period of 90 days.

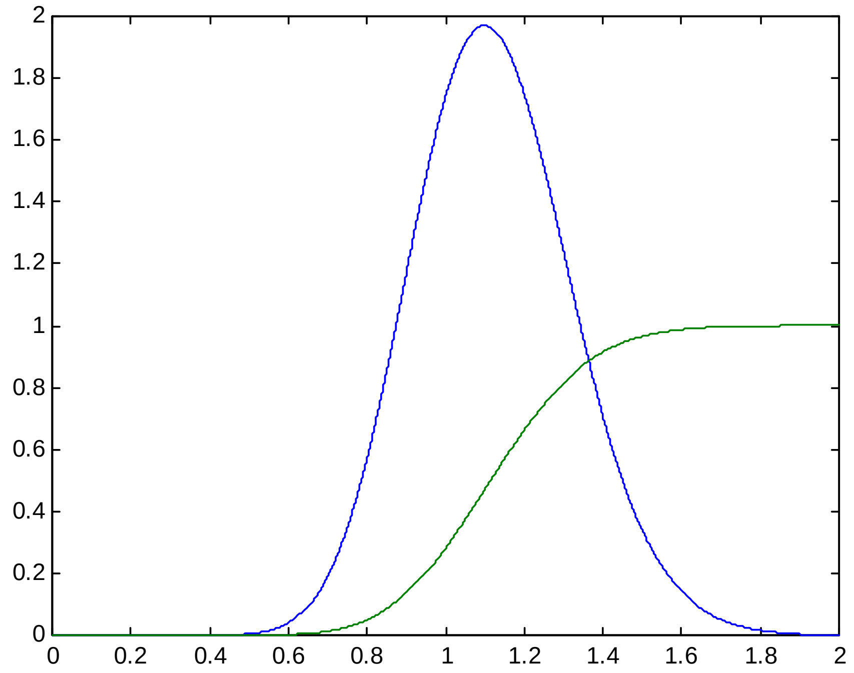


Figure 4. Density and distribution functions of annual maximum combined load effect.

Annex 5 Procedure for derivation of ψ_1 and ψ_2

A5.1 Complete example from a German station

Station Leinefelede

This station is located in the central Germany, in the North - West of province Thuringia. Geographical co-ordinates are:

latitude - 10°19' north,
longitude - 51°24' east,
altitude - 356 m above sea level.

The available data are the daily snow depth measurements from 1957 to 1993. Due to some gaps in record the total length of measurements is 26 winters.

The enclosed graphs (see Annex 1 "Time-series") show that the process of snow accumulation and depletion essentially varies from winter to winter. The climate of Leinefelde can be described as the mixed one, but for some winters we can see a typical maritime snow climate. From other hand there are winters where snow process tends to be closed to continental (or mountains climate). This is a common snow behaviour in Germany and this produces difficulties by investigation of snow loading. It was decided to model the snow in Leinefelde by using of approach of snow events. For this task the snow depth data are used. These data can be converted into load by means, for example, of conversion factor of German Meteorological Office. But it seems to be quite enough to use the depth data for the some tasks of this research phase.

Under snow event we understand the snow pack on the ground from the occurrence of the snow till this will be fully melted.

First of all for each day of winter the mean value, standard deviation and coefficient of variation were calculated from 26 winters. The results can be seen in the Table 1 and on the graphs. For some days the coefficient of variation is extremely high or even does not exist (infinity). This is due to the influence of zero-values. The zero-values disturb the hypotheses that the process is the stationary one. The mean value averaged through the whole winter is 2,8 cm and the same for standard deviation is 4,6 cm. We suppose that the process is ergodic one and the total number of days is 9490 (365x26). Duration of winter can be set as 6 months (180 days).

If we consider by analysis only days when snow was not equal to zero (threshold is 0 cm) then we can see (Tables 1 and 2) that the total amount of non-zero snow days is 1538 and the amount of non-zero days per year (mean value) is 59 days. The number of events is 229 with the mean value per winter 8,8.

If we repeat the procedure but threshold values would be taken as 1 cm then we can see that the total amount of non-zero snow days is 1294 and non-zero days per winter (mean value) is 50 days. The number of events is 164 with mean value per winter 6,3.

Table 1:

Daily data (for all 26 years):		
Load (kN/m2):	Mean =	0,04
	St. dev. =	0,10
	CoV =	2,49
Depth (cm):	Mean =	2,8
	St. dev. =	6,1
	Cov =	2,2
Daily data (for all 26 years; only days with snow, threshold value = 0 cm):		
Number of non-zero snow days:		1538
Mean value of the number of non-zero snow days per winter:		59
Load (kN/m2):	Mean =	0,12
	St. dev. =	0,14
	CoV =	1,16
Depth (cm):	Mean =	8,5
	St. dev. =	8,1
	CoV =	0,9
Daily data (for all 26 years; only days with snow, threshold value = 1 cm):		
Number of non-zero snow days:		1294
Mean value of the number of non-zero snow days per winter:		50
Load (kN/m2):	Mean =	0,14
	St. dev. =	0,15
	CoV =	1,03
Depth (cm):	Mean =	9,9
	St. dev. =	8,0
	CoV =	0,8

Table 2: Number of events per winter

Threshold value = 0 cm	
Winter	Events
1	12
2	5
3	6
4	3
5	13
6	7
7	9
8	8
9	11
10	14
11	13
12	10
13	4
14	6
15	5
16	16
17	8
18	10
19	12
20	10
21	7
22	8
23	13
24	6
25	11
26	2
Sum	229
Mean	8,8
St. dev.	3,6
CoV	0,41

Threshold value = 1 cm	
Winter	Events
1	14
2	5
3	4
4	3
5	7
6	4
7	5
8	6
9	10
10	11
11	7
12	5
13	4
14	5
15	5
16	10
17	3
18	7
19	9
20	8
21	8
22	5
23	7
24	4
25	6
26	2
Sum	164
Mean	6,3
St. dev.	2,8
CoV	0,44

The number of events per winter

The next task is determination of the number of events per winter. From the Table 3 one can see the number of events for all 26 winter at station Leinefelde. This number varies from 2 up to 14. Based on data from Table 3 the relatively frequency is shown on the Figure 1. For comparison the probability density function of Poisson distribution (with parameter λ is equal 6,3) is shown also. This function represents the number of events that occur over equal intervals of time (one winter), assuming that events occur independently at a constant average rate.

Probability density of Poisson distribution:

$$f(k,\lambda)=\frac{\lambda^k}{k!}\exp(-\lambda) \quad (1)$$

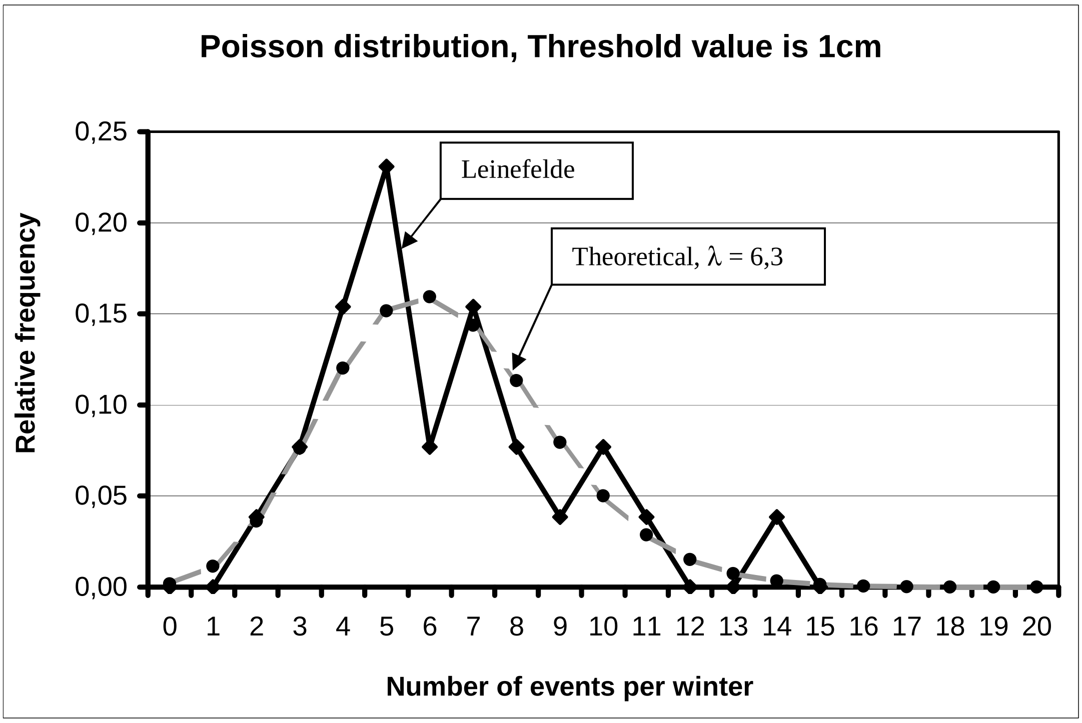
Probability function: $$F(n,\lambda)=\sum_{k=0}^{n}\frac{\lambda^k}{k!}\exp(-\lambda) \quad (2)$$

with expected value $E(k) = \lambda$ and variance $Var(k) = \lambda$; where: $\lambda > 0$, $k = 0, 1, 2, 3.......$
Parameter λ can be obtained as a ratio of observed number of occurrences to the number of intervals (winters). For Leinefelde $\lambda = 164 / 26 = 6,3$ (the mean value of events per winters).

Table 3: Number of events, theshold value = 1cm

Winter	Number of events	Events ranked in order	Histogram: Number of events per winter	Number of repetitions	Relative frequency	Theoretical probability density $\lambda = 6,3$
1	14	2	0		0,000	0,002
2	5	3	1		0,000	0,011
3	4	3	2	1	0,038	0,036
4	3	4	3	2	0,077	0,076
5	7	4	4	4	0,154	0,120
6	4	4	5	6	0,231	0,152
7	5	4	6	2	0,077	0,159
8	6	5	7	4	0,154	0,144
9	10	5	8	2	0,077	0,113
10	11	5	9	1	0,038	0,079
11	7	5	10	2	0,077	0,050
12	5	5	11	1	0,038	0,029
13	4	5	12		0,000	0,015
14	5	6	13		0,000	0,007
15	5	6	14	1	0,038	0,003
16	10	7	15		0,000	0,001
17	3	7	16			0,001
18	7	7	17			0,000
19	9	7	18			0,000
20	8	8	19			0,000
21	8	8	20			0,000
22	5	9				
23	7	10				
24	4	10				
25	6	11				
26	2	14				
Sum	164			26	1	
Mean	6,3					
St. dev.	2,8					
CoV	0,44					

Figure 1: Comparison with Poisson distribution



Duration of event

The next step was to determine the duration of events. The results for each event can be seen from Table 4. Afterwards the relatively frequency and histogram of event duration were established (see Figure 3). The distribution of event's duration was checked by fitting the different theoretical PDFs (see Figures 4-6) on the probability paper. The coefficients of variation according to probability plots are following:

0	Exponential distribution	0,8917
1	Normal distribution	0,6952
2	Log-normal distribution	0,9563
3	Gumbel distribution	0,8216
4	Weibull distribution	0,8762

Both exponential and log-normal PDFs can be considered as the best fitting ones. But the log-normal PDF does not fit the data well in the regions of the small duration (one day). Thus it seems to be reasonable to take exponential distribution as the best fitting PDF for event's duration. This corresponds also to proposals from the mathematical (statistic) literature.

The exponential distribution has a following probability density:

$$f(t,\lambda) = \lambda \exp(-\lambda t) \qquad (3)$$

and probability distribution function: $$F(t,\lambda) = 1 - \exp(-\lambda t) \qquad (4)$$

where $t > 0$ and $\lambda > 0$; t is the time between events and λ is the average rate of events.

Expected value $E(t) = 1/\lambda$ and variance $Var(t) = 1/\lambda^2$.

It is necessary to notice that by this approach t is the time between events, and event is the process of transformation of snow from zero to non-zero value. And therefore if $\lambda = 6{,}3$ then

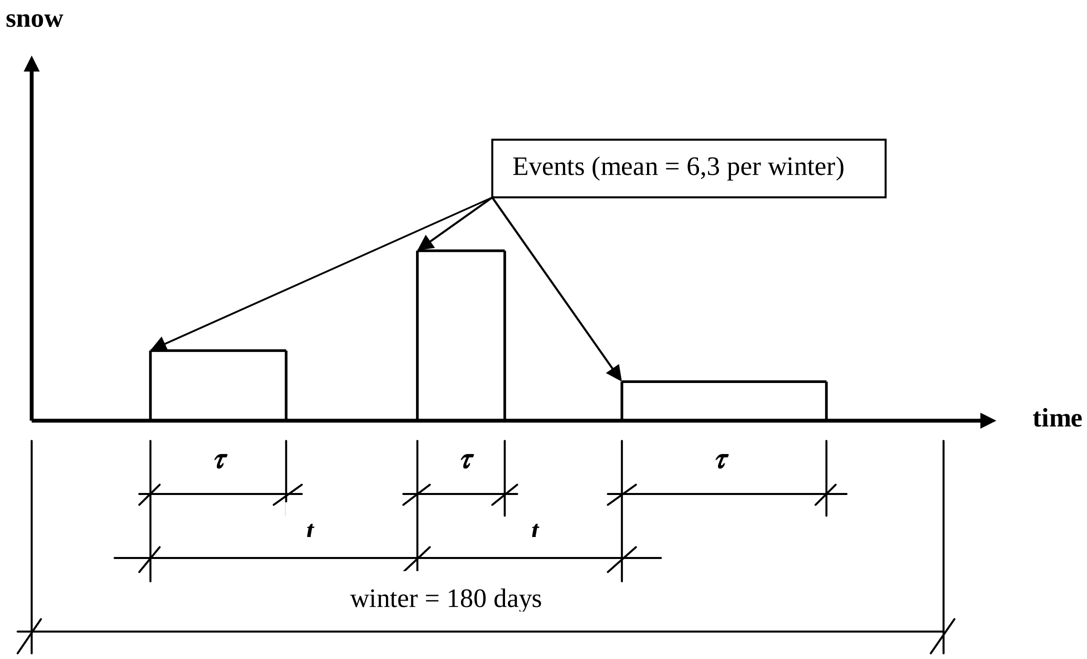
$E(t) = 1 / 6{,}3 = 0{,}1587$ winter = 0,1587x180 = 28,6 days (mean time between events).

But for duration of event itself (from Table 4):
0 mean value $E(\tau) = 7{,}9$ days
1 standard deviation $s(\tau) = 14$ days

The explanation can be seen on Figure 2. Here t is the time between events and τ is the duration of event.

There are 6,3 events per year on average with mean duration 28,6 days. But the snow available only 7,9 days per event. Therefore there are 20,7 days (28,6 - 7,9) per event without snow on average.

Figure 2: Duration of events and time between events



It was already noticed that climate in Leinefelde is typical for Germany and represents the mixed one with the influences of both maritime and continental climates. It can be seen very clear if we will look at exponential probability plot (Figure 6). The function can be subdivided into three regions:

1. Duration from 0 to 20 days, CoV = 0,9703
2. Duration from 21 to 34 days, CoV = 0,9220
3. Duration from 34 to 117 days, CoV = 0,9984

For each region the average rate of events λ and mean duration of each event τ can be calculated. From probability plot the parameter λ can be obtained as the tangent of the slope of the fitting line:

1. λ_1 = [(2,5 - 0) / (20 - 0)] x 180 = 22,5 per winter.

   $E(\tau_1)$ = 1 / λ_1 = 0,0444 winter = 8 days

2. λ_2 = [(3,3 - 2,5) / (34 - 20)] x 180 = 10,26 per winter.

   $E(\tau_2)$ = 1 / λ_2 = 0,0975 winter = 17,5 days

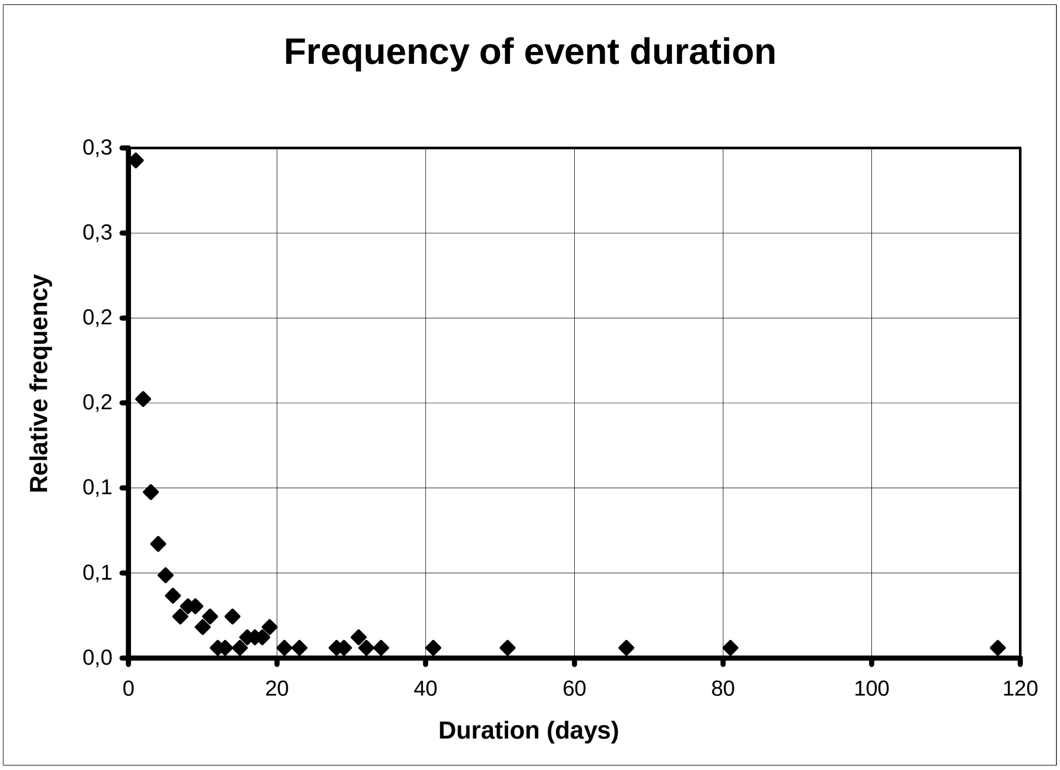
3. λ_3 = [(5,1 - 3,3) / (117 - 34)] x 180 = 3,9 per winter.

   $E(\tau_3)$ = 1 / λ_3 = 0,256 winter = 46,1 days

Table 4: Duration of each events, 26 winters, threshold value is 1 cm

Number of winter	Number of events per winter	Duration of each event in days													
1	14	8	1	5	1	11	2	3	4	4	5	1	1	7	3
2	5	3	3	12	7	2									
3	4	3	15	7	8										
4	3	51	2	1											
5	7	7	9	9	3	1	14	3							
6	4	1	5	1	81										
7	5	14	23	3	14	2									
8	6	4	5	4	17	29	2								
9	10	21	6	1	4	19	1	11	1	2	1				
10	11	1	3	1	1	6	1	2	5	10	3	1			
11	7	2	8	5	17	6	16	4							
12	5	2	19	28	10	5									
13	4	117	4	2	1										
14	5	31	1	1	13	1									
15	5	9	1	1	34	4									
16	10	1	3	6	2	1	1	2	11	2	2				
17	3	9	16	3											
18	7	1	5	1	3	3	1	1							
19	9	1	4	1	4	1	18	10	1	1					
20	8	2	3	11	8	18	2	1	1						
21	8	6	1	3	8	2	1	31	1						
22	5	2	9	67	1	2									
23	7	32	1	1	1	1	4	1							
24	4	2	2	14	19										
25	6	1	6	2	2	2	1								
26	2	2	41												

Figure 3: Relative frequency and histogram of event duration



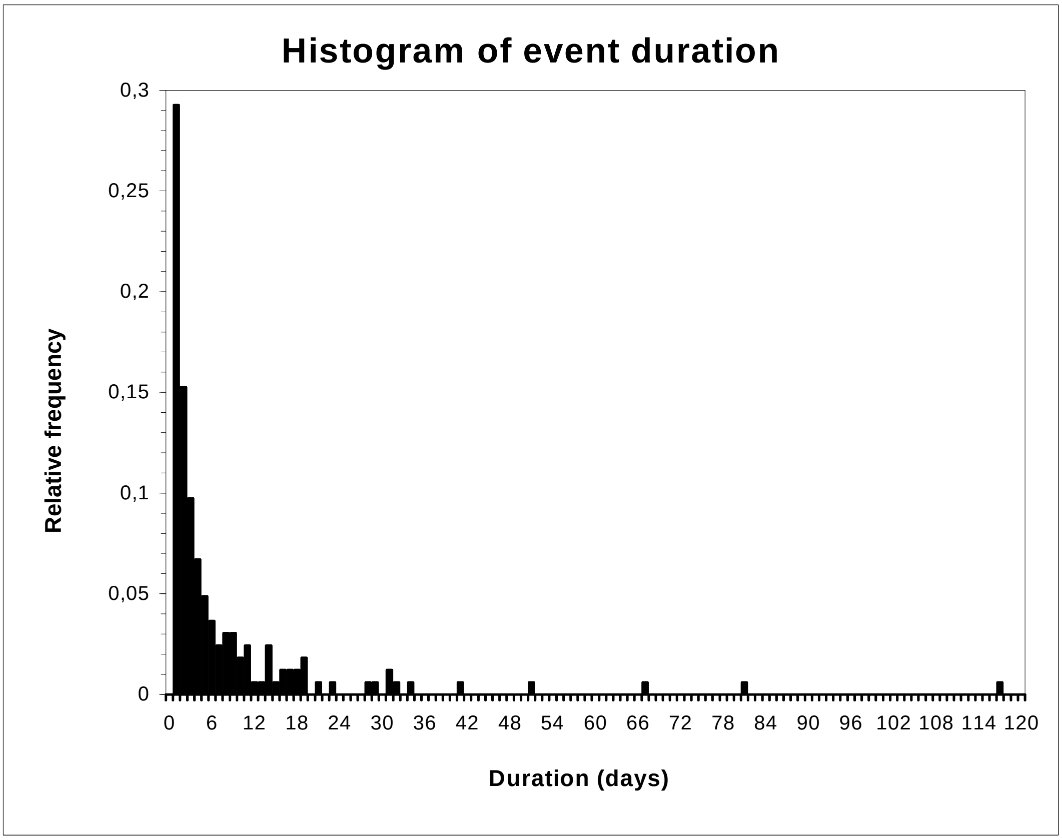
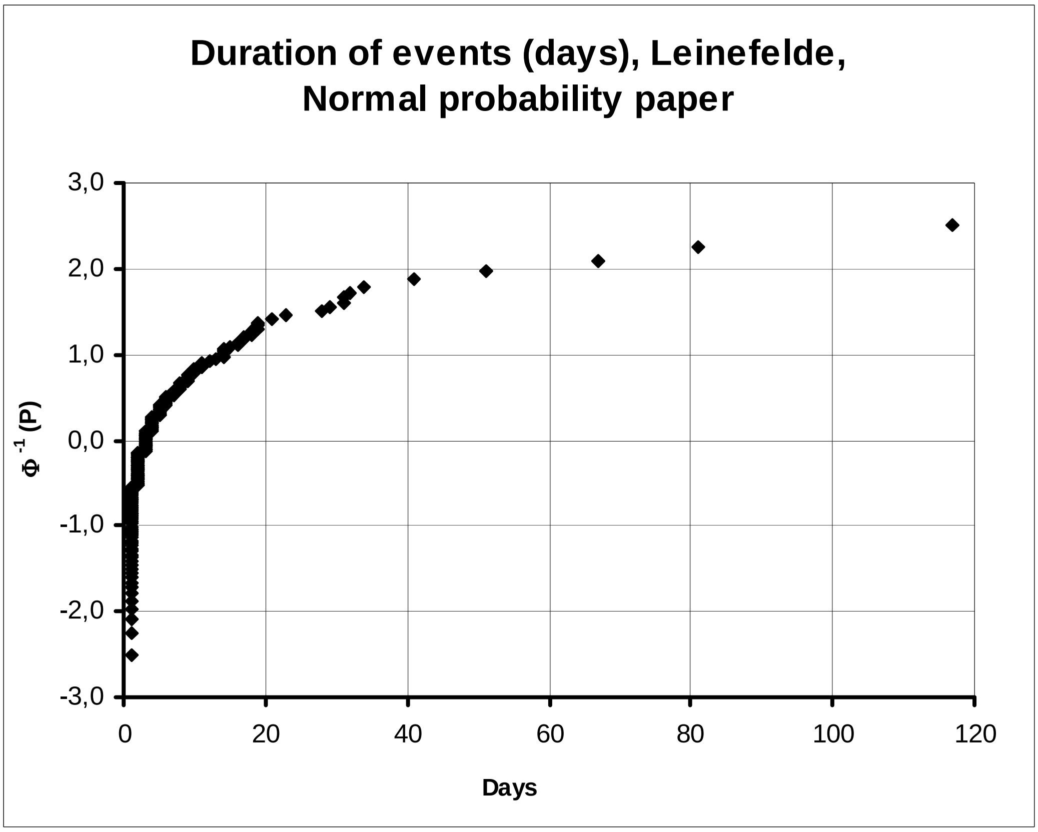


Figure 4: Normal and Log-normal probability plots for event's duration



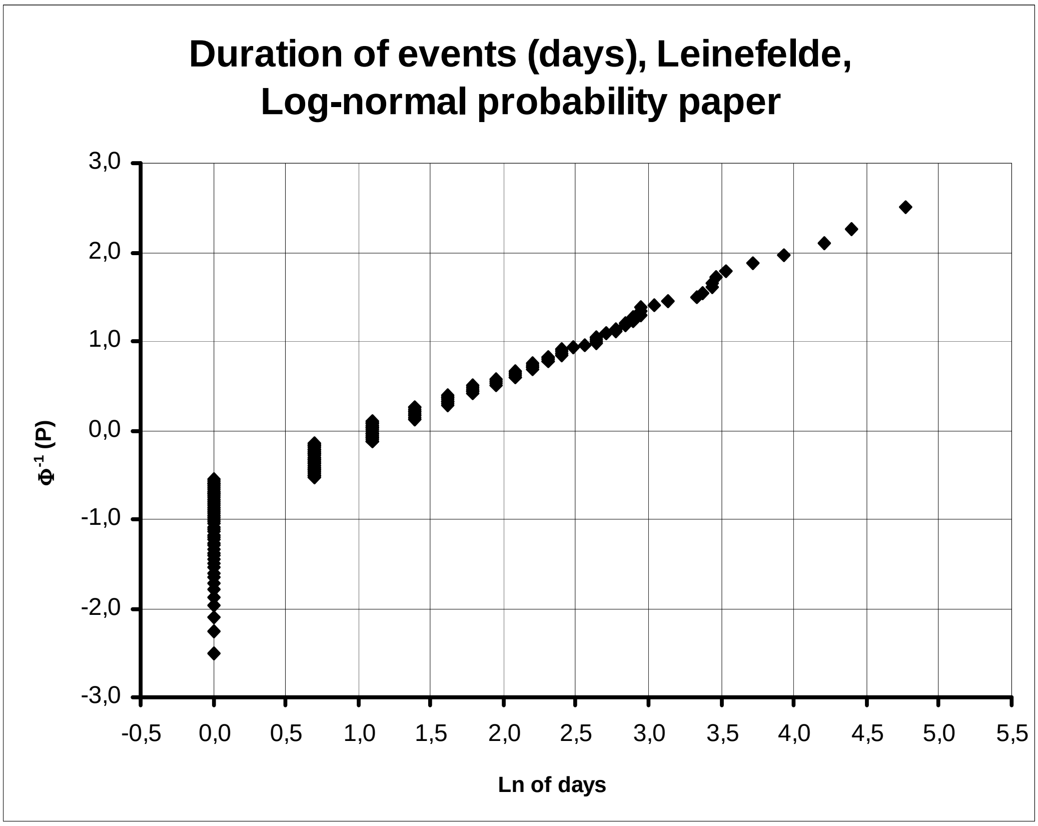
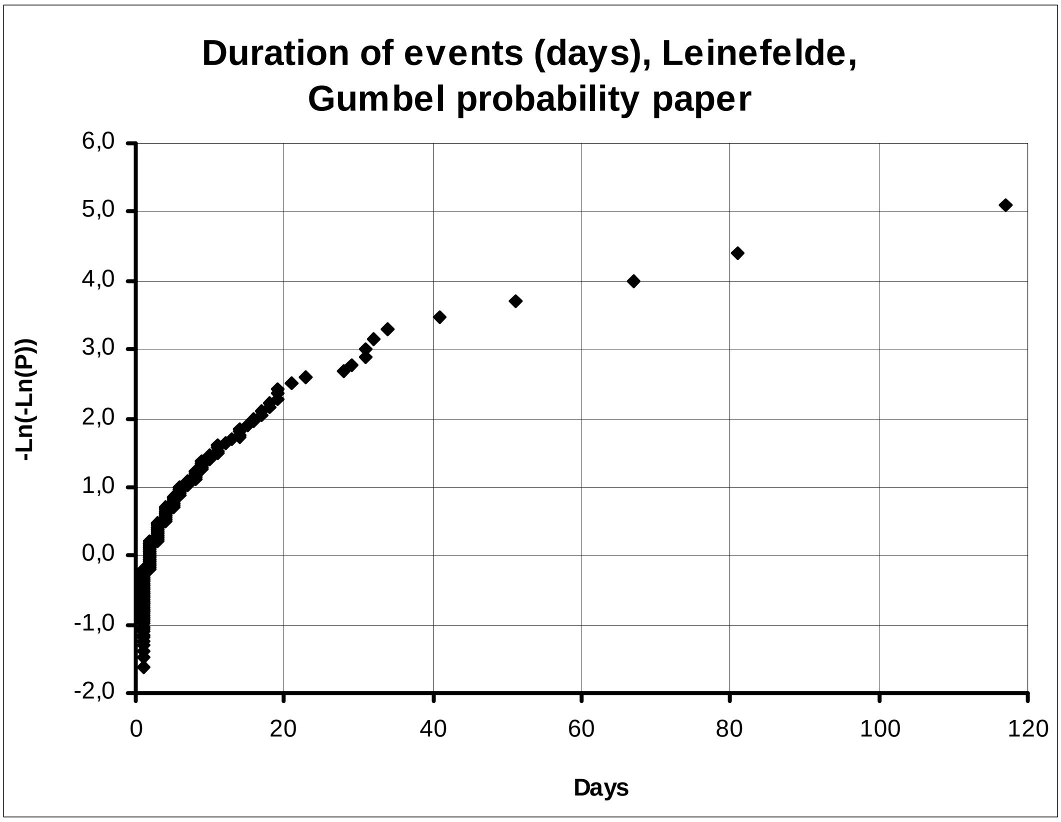


Figure 5: Gumbel and Weibulll probability plots for event's duration



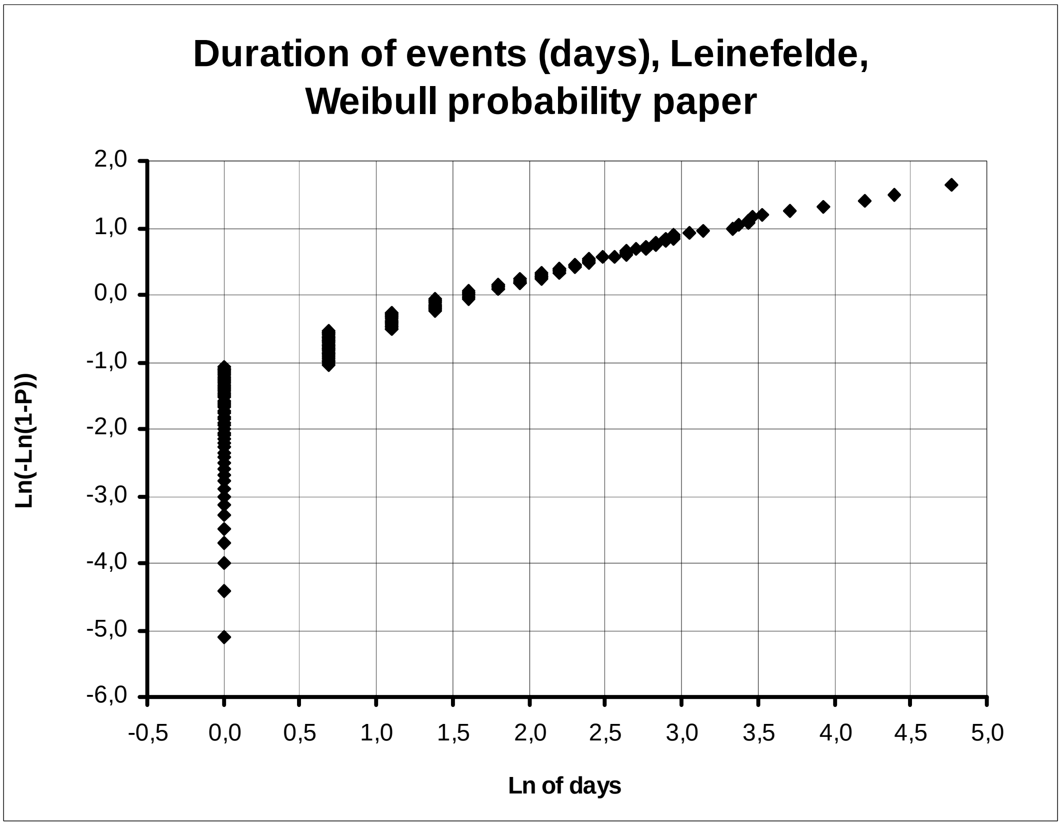
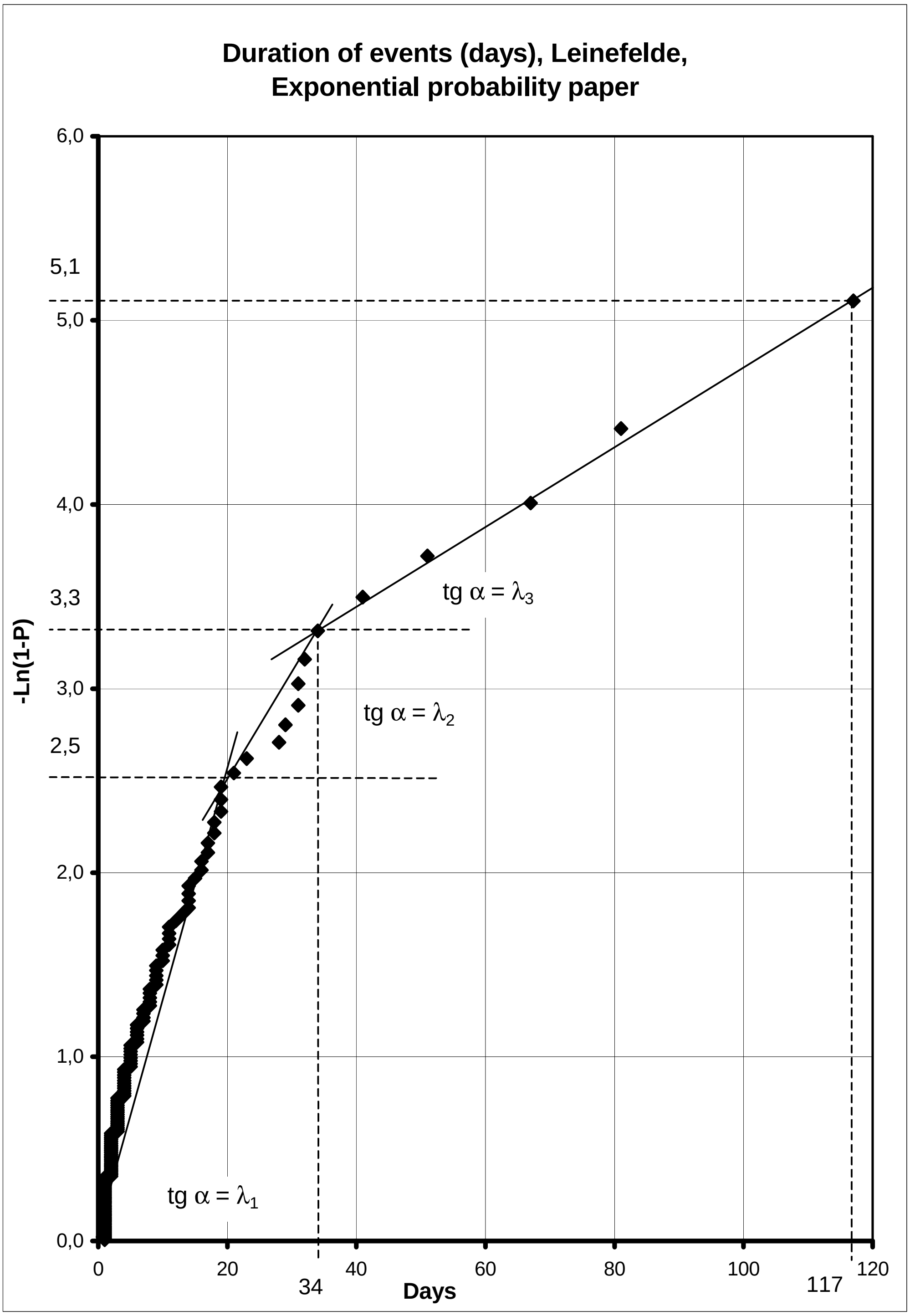


Figure 6: Exponential probability plots for event's duration



Maximum of event's snow load

The maximum of event's snow load was also investigated. Totally 164 events were considered. For each event the maximum snow load was found by means of load factor of DWD (German Meteorological Office). The moments are:

0 the mean value - 0,1 kN/m^2,
1 the standard deviation - 0,1 kN/m^2

For snow depth:
the mean value - 7,6 cm,
the standard deviation - 7,3 cm

The different PDFs were compared by means of coefficient of correlation of probability plot (see Figures 7-9):

0	Exponential distribution	0,9798
1	Normal distribution	0,8360
2	Log-normal distribution	0,9690
3	Gumbel distribution	0,9333
4	Weibull distribution	0,8976

From these values and Figures 7-9 it appears that exponential distribution fits best the event's snow maximum data.

Two approaches are possible:

0 Moment's method. Then parameter $\lambda = 1 / E(S) = 1 / 0{,}1 = 10{,}0$ [1/(kN/m^2)].
Equation of probability plot:

$Z = -\,\mathrm{Ln}\,(1-P) = \lambda\, x$
Because event occurs 6,3 times per winter on average, then for characteristic value of snow load (with MRI of 50 yeras):
$P = 1 - 1 / (6{,}3\mathrm{x}50) = 0{,}9968$
and reduced variable $Z = 5{,}7526$.

Respectively $X_k = 0{,}57$ kN/m^2.

This value is too small. The characteristic value for station Leinefelde from Phase I, based on annual maxima data and Gumbel distribution is 0,90 kN/m^2.
It can be seen also from Figure 9 that moment's line does not fit the data well.

0 Least Square Method. Then parameter $\lambda = 6{,}67$ and $E(S) = \sigma(s) = 0{,}15$ kN/m^2.
Equation of probability plot:
$Z = -\,\mathrm{Ln}\,(1-P) = \lambda\, x$

And characteristic value of snow load is equal $X_k = 0{,}86$ kN/m^2.

This value is close to value of Phase I, based on annual maxima data and Gumbel distribution (0,90 kN/m^2). It can be seen also from Figure 9 that LSM line fits the data very well.

It is possible also to calculate two other values:

0 With return period one year (Infrequent value). Then

P = 1 - 1 / 6,3 = 0,8413 and Z = 1,8405.

Respectively $X_{1\ year}$ = 0,28 kN/m^2 (based on LSM parameters) and reduction factor ψ_1' = 0,28/0,86 = 0,33.

0 With return period about two months. Then

P = 1 - 1 / 2 = 0,5 and Z = 0,6931.

Respectively $X_{2\ months}$ = 0,10 kN/m^2, and, is this value is assumed to be the frequent one, then the reduction factor ψ_1 = 0,10/0,86 = 0,12.

The values of these two factors appear seem to be too small and questionable.

The infrequent value can be also calculated taking into account all possible number of events per winter, not only the mean value 6,3 events. This number n follows the Poisson distribution.

Z = - Ln (1 - P) = - Ln (1/n),
$X_{inf,n}$ = - Ln (1/n) / λ for n = 0,1,2,3......

$$X_{\inf} = \sum_{n=0}^{\infty} \frac{\lambda^n}{n!} \exp(-\lambda) X_{\inf,n} \qquad (5)$$

This approach gives us the result $X_{inf,n}$ = 0,278 kN/m^2 which is very close to 0,28 kN/m^2 (see above). This confirms the possibility to use mean number of 6,3 events per winter for calculations.

Probability that snow depth greater than given level

According to classification of section 4.2 the bins method of Model 2 is used for derivation of ψ_1 and ψ_2 factors.
For 26 winters the maximum snow depth was found - 38 cm. This value was subdivided into 100 levels with the step of 0,38 cm. The total amount of days is 26 x 365 = 9490. Then for each level the number of days when snow depth less than given value is calculated. This value divided by 9490 gives us the probability that snow depth less than given level (see Figure 10). It can be seen that the function begins with probability 0,84. It means that it was no snow during 84% of all time of these 26 years.

To find theoretical solution the data was fitted by the different PDFs. They were compared by means of coefficient of correlation of probability plot (see Figures 10 - 12):

0		
1	Exponential distribution	0,9506
2	Normal distribution	0,9804
3	Log-normal distribution	0,8578
4	Gumbel distribution	0,9524
5	Weibull distribution	0,8987

From the Figures 10-12 is clear that none from these distributions can be considered as the best fitting PDFs. Gumbel and exponential PDF fit well the lower and middle parts of probability plot but not the upper tail. Therefore experimental Cumulative Distribution Function is taken into account for calculation. Also Normal distribution can be considered for comparison because fits totally data better as Gumbel and exponential function. From real data the fractiles from 0,90 till 0,99 are calculated and shown in the table 5.

Table 5: Fractiles obtained from CDF

Prob. of exceeding	Prob. of non exceeding	Depth (m)	Density (kN/m^3)	Load (kN/m^2)	ψ_1
0,1	0,9	0,04	1,65	0,07	0,08
0,09	0,91	0,04	1,65	0,07	0,08
0,08	0,92	0,05	1,66	0,08	0,10
0,07	0,93	0,07	1,69	0,12	0,14
0,06	0,94	0,08	1,70	0,14	0,16
0,05	0,95	0,10	1,72	0,17	**0,20**
0,04	0,96	0,12	1,74	0,21	0,24
0,03	0,97	0,16	1,79	0,29	0,33
0,02	0,98	0,19	1,82	0,35	0,40
0,01	0,99	0,25	1,88	0,47	0,55

The values of snow depth are converted to snow load by means of load factor of DWD (German Meteorological Office).
The fractile of P = 0,05 is mostly used for the frequent value. This value is equal to 17 kN/m^2.

Therefore the factor ψ_1 can be determined as:

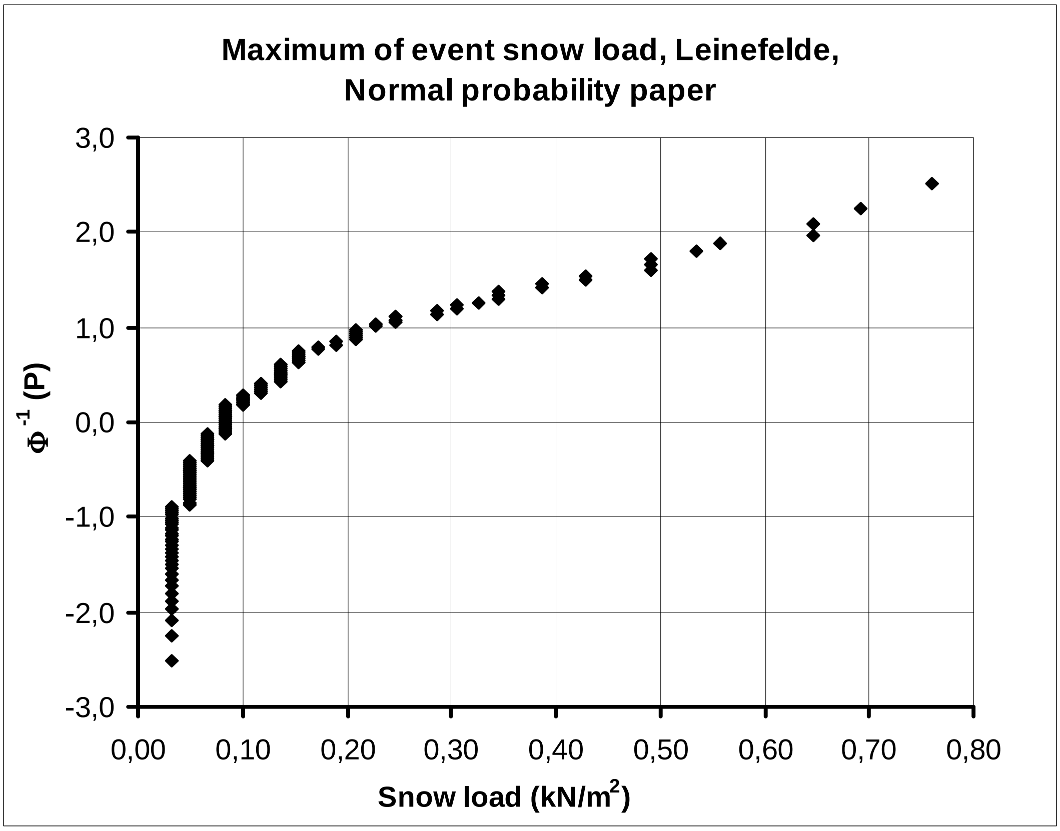
$$\psi_1 = 0{,}17/0{,}86 = 0{,}20$$

where 0,86 kN/m^2 is the characteristic value of snow load for station Leinefelde from Phase IA of current work.

Comparison for Normal distribution (Figure 12)
Fractile of P = 0,05 corresponds reduced variable z=1,645. For this ordinate the trend line defined by Least Square Method gives value of snow depth between 10cm and 11cm. This is practically the same as by means of experimental CDF (see Table 5). Therefore in this case the Normal distribution gives the same result for ψ_1.
The quasi-permanent value of snow loads is defined as 0,5-fractile of CDF gives results equals zero. The same is obtained by all theoretical distributions (Figure 10-12). Therefore the second possibility can be used. The quasi-permanent value of snow loads can be defined as value averaged over one year (365 days). Therefore snow depth can be summarized for all snow days during 26 winters and divided by 9490 (number of total days). This method gives the quasi-permanent value for:
snow depth - 1,38 cm
snow load - 0,022 kN/m^2

Then $\psi_2 = 0{,}022/0{,}86 = 0{,}03$

Figure 7: Normal and log-normal probability plots for event's maximum load



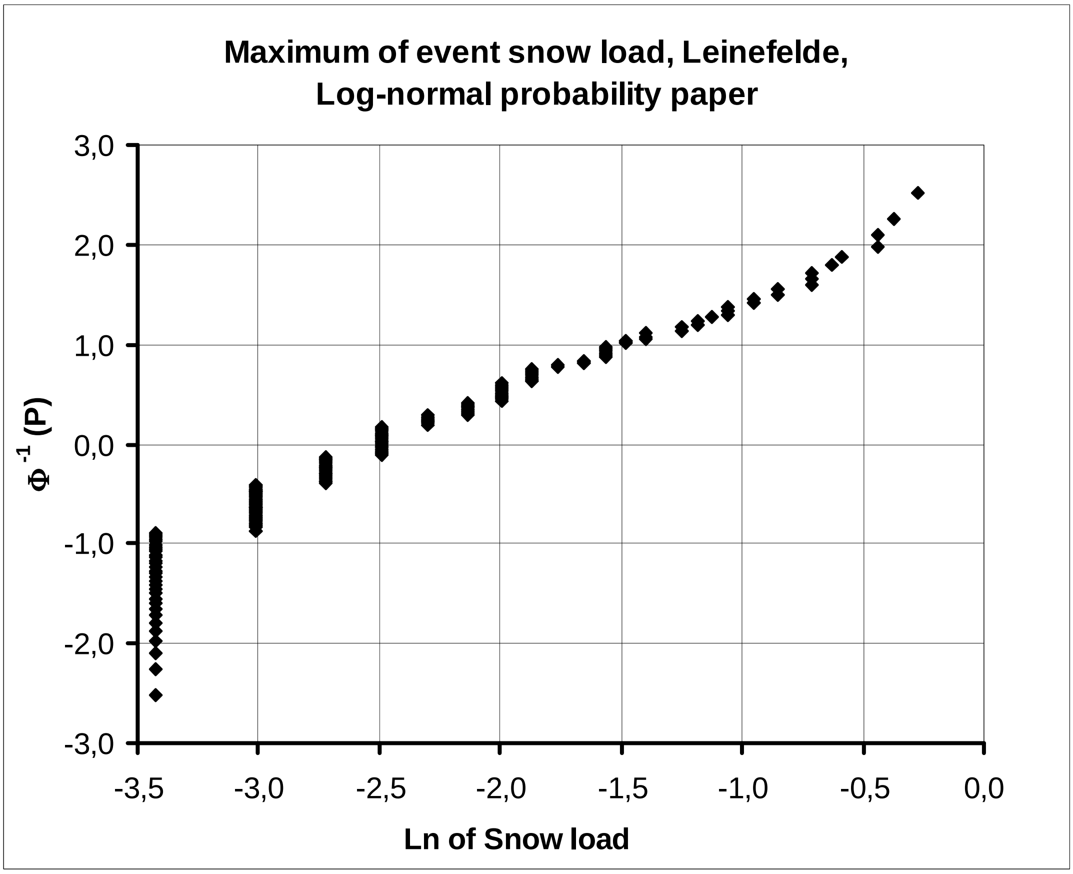
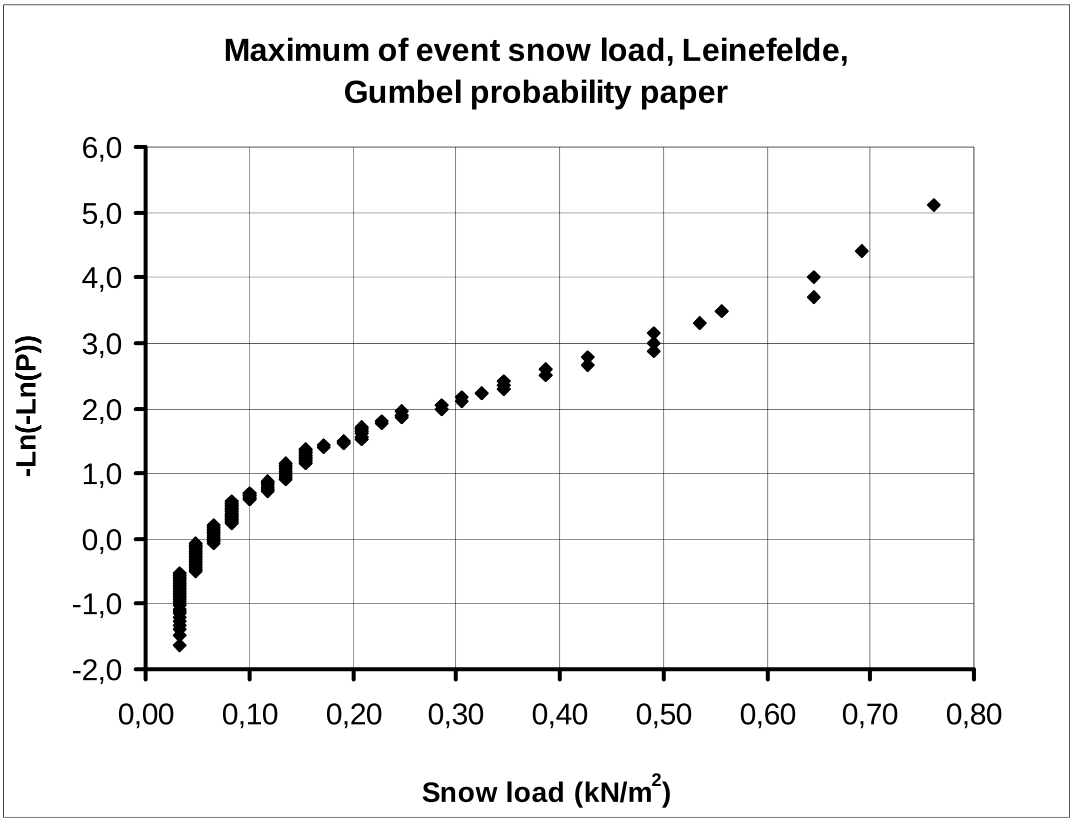


Figure 8: Gumbel and Weibull probability plots for event's maximum load



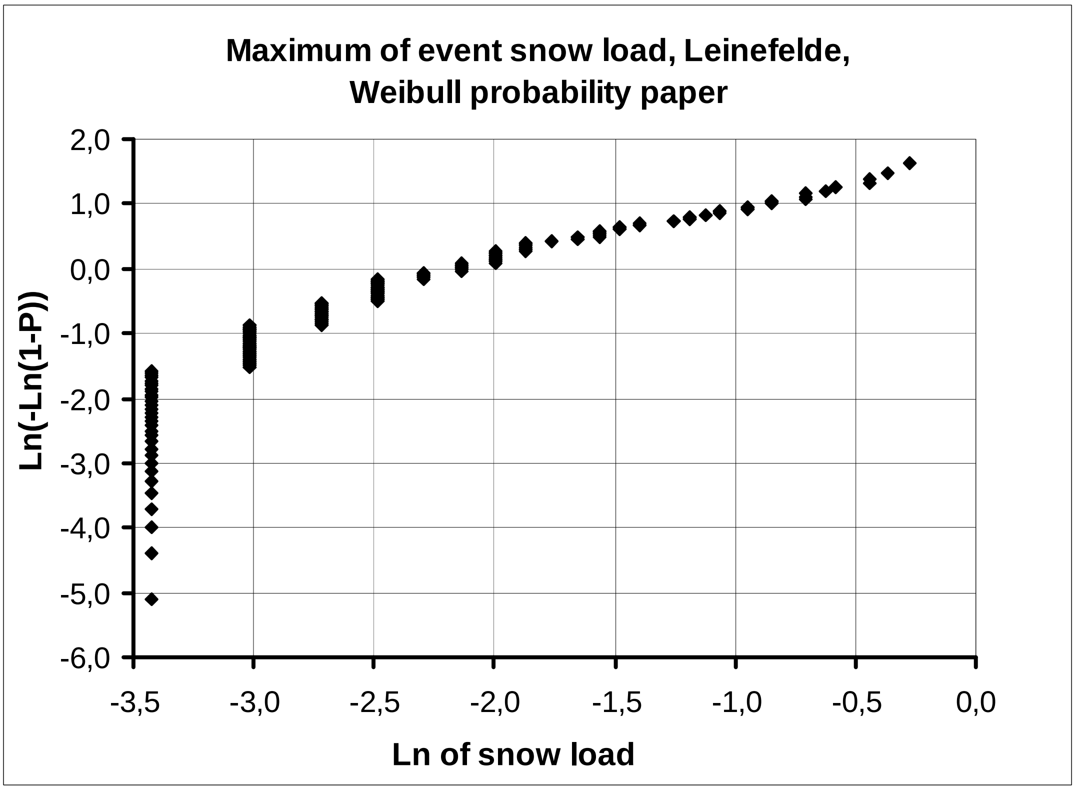


Figure 9: Exponential probability plots for event's maximum load

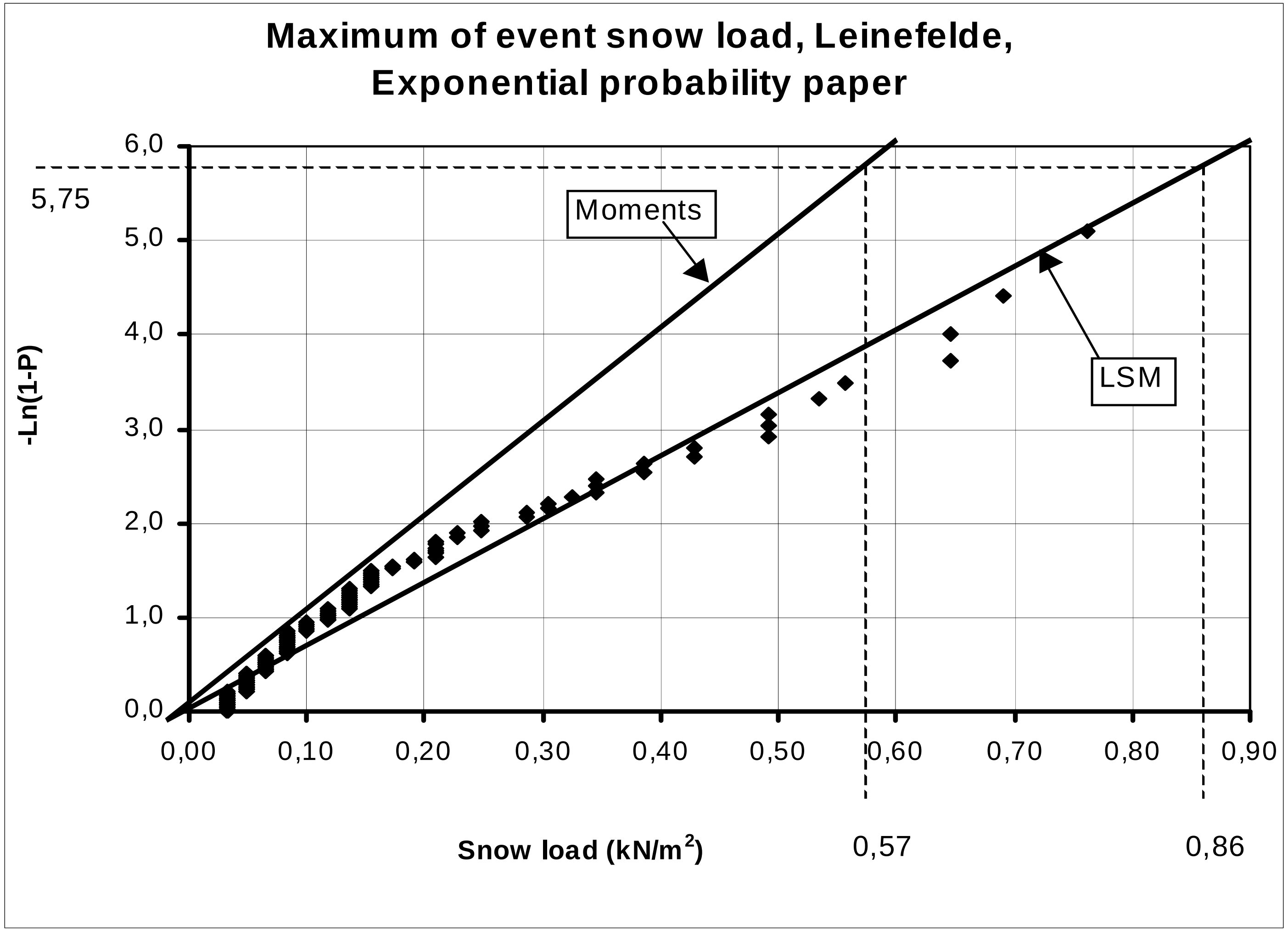
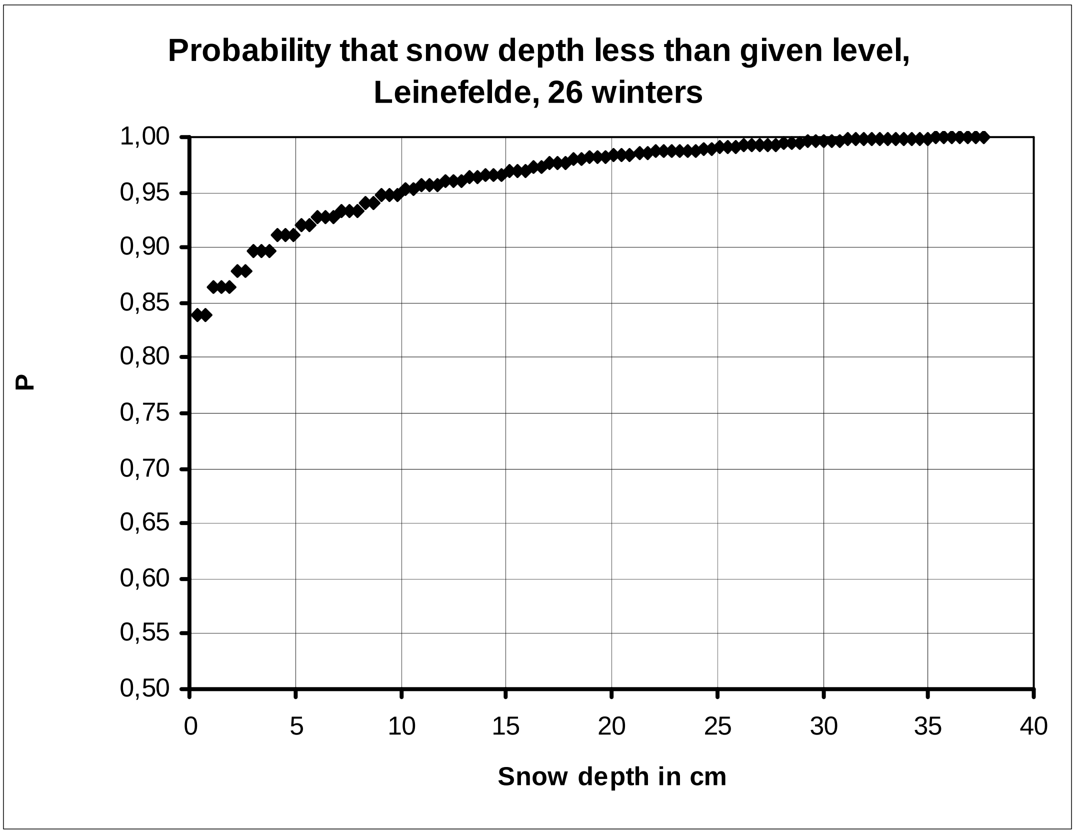


Figure 10: Probability that snow depth less than given level and exponential probability plots



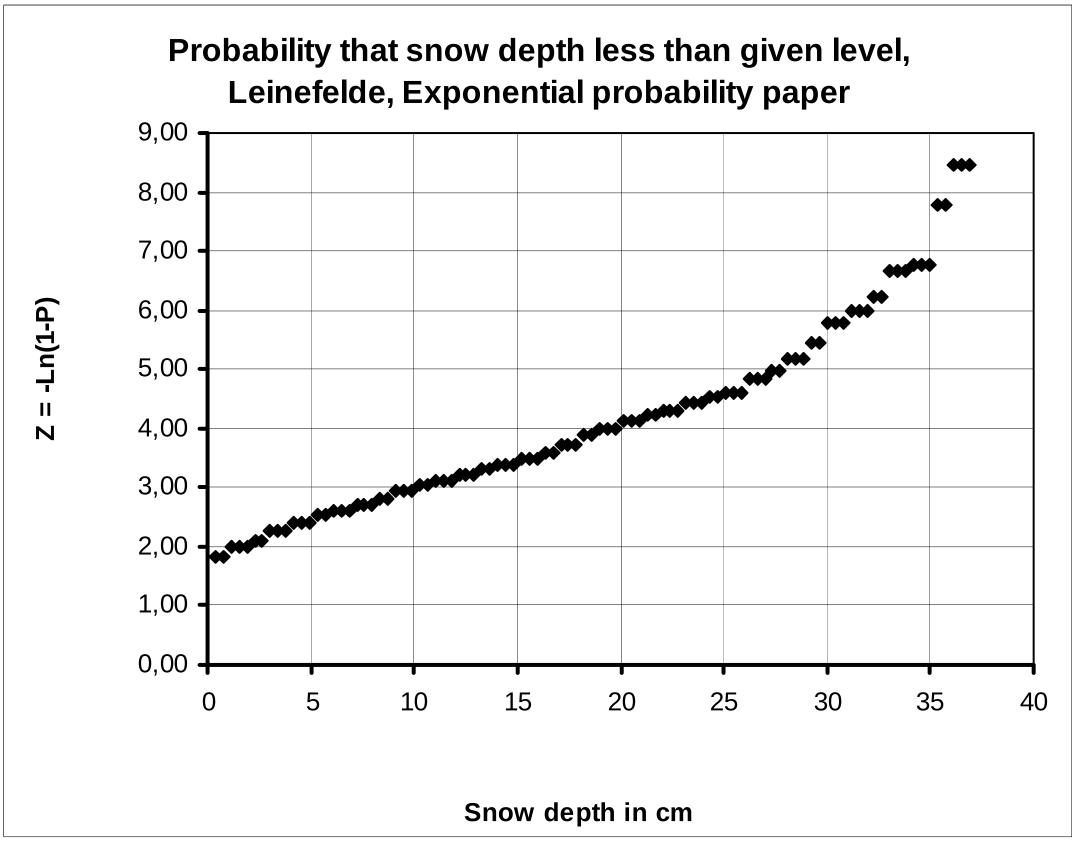
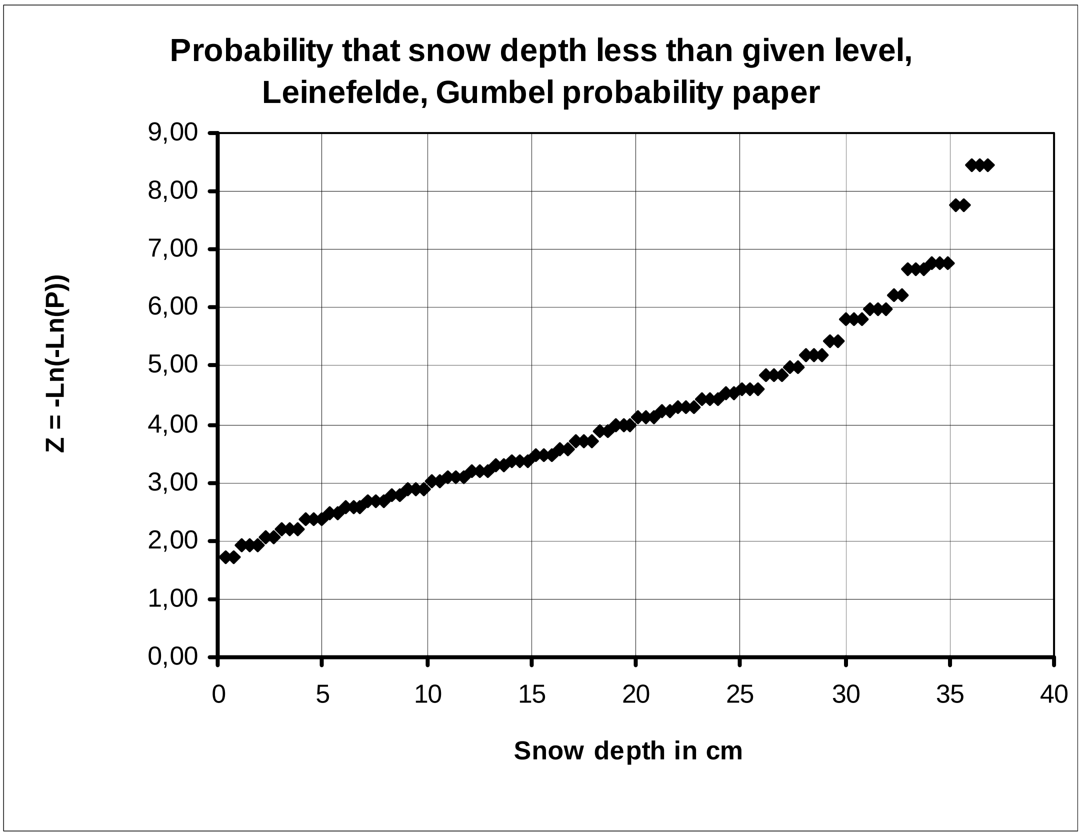


Figure 11: Probability that snow depth less than given level: Gumbel and Weibull probability plots



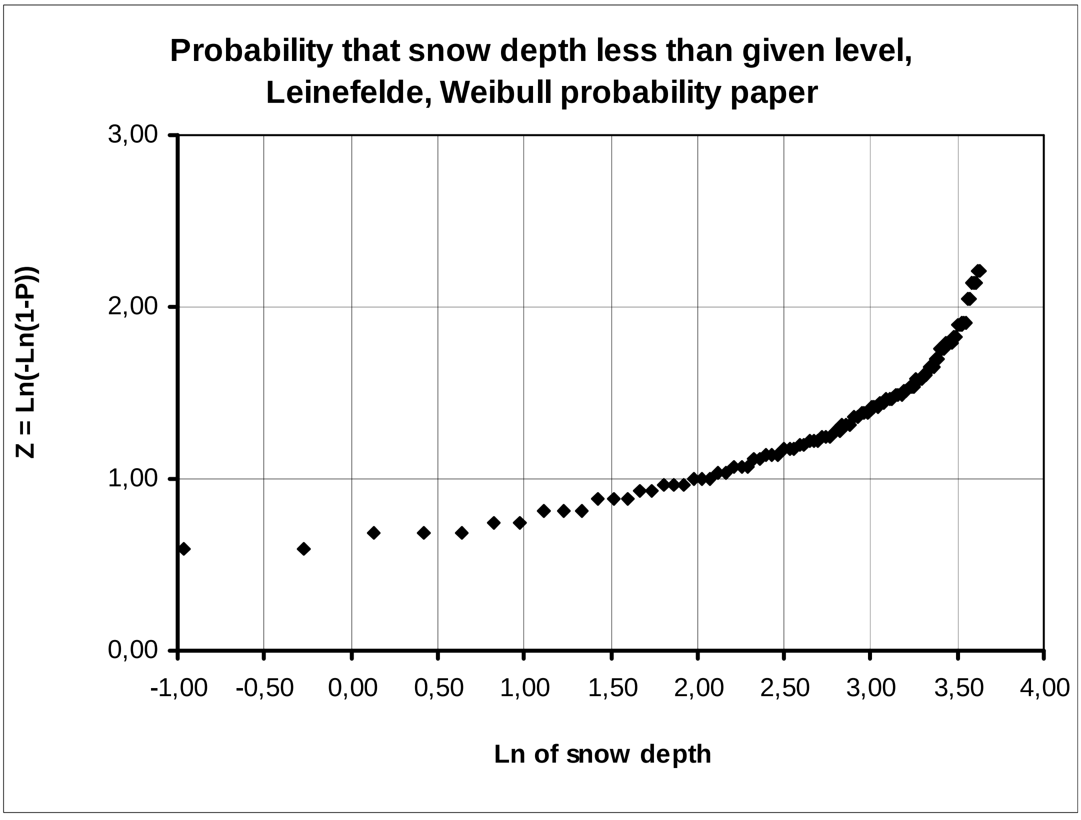
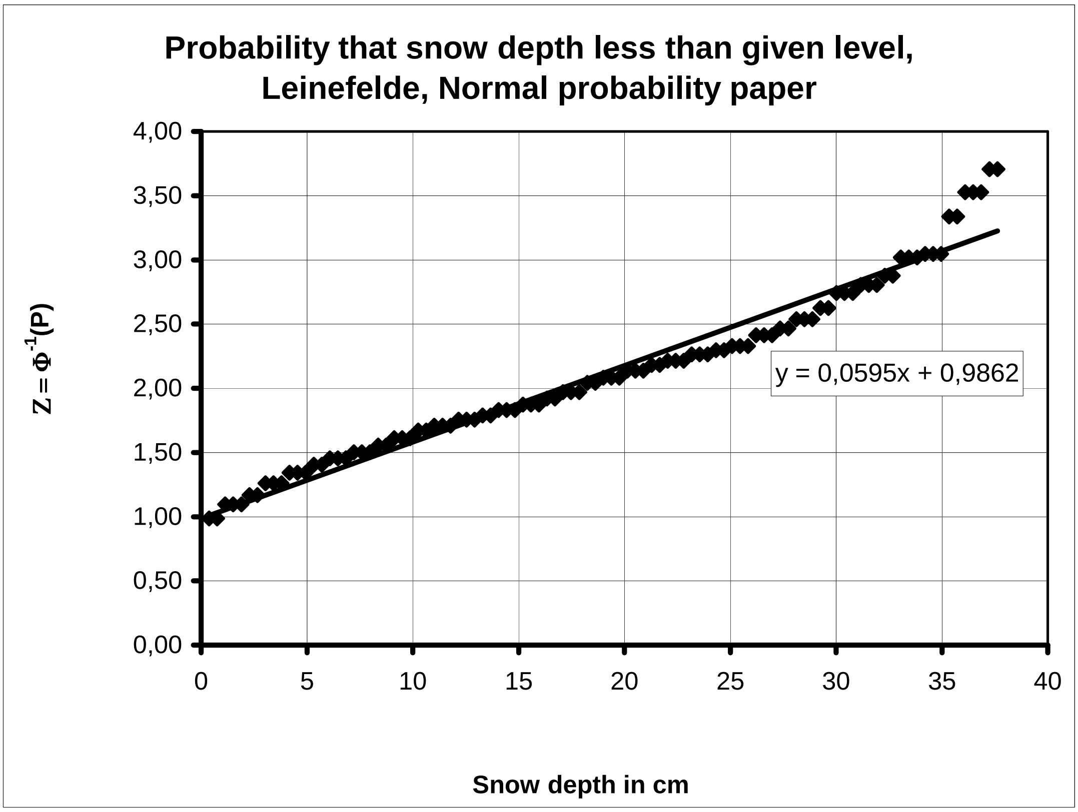
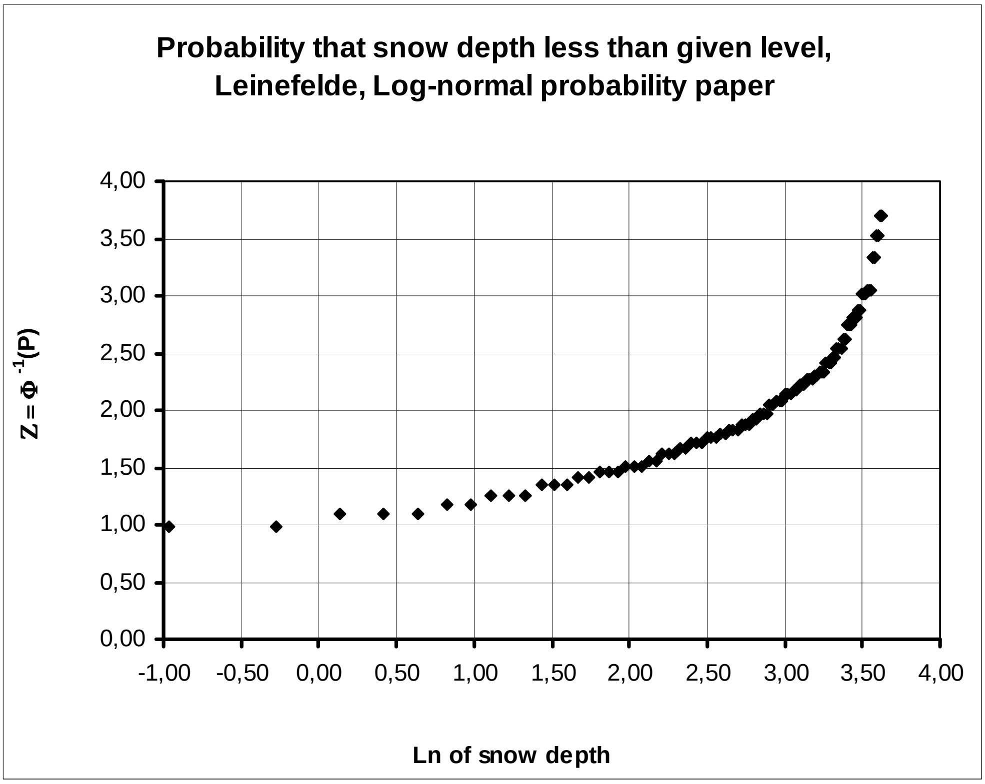


Figure 12: Probability that snow depth less than given level:

Normal and Log-normal probability plots





A5.2 Resuming examples from different climatic regions

Examples of data samples for derivation of combination factors $\psi 1$ and $\psi 2$ are given in Figures 12 to 24. These are based on daily measurements. Essentially, the characteristic values corresponding to 50% and 95% fractiles can be identified directly from the data samples. However, for stations with extremely short record lengths (i.e. just a few years) the sample values may be somewhat unreliable. The data samples correspond to “total time normalization”, which is referred to as Model 2 in Section 4 of the main text.

For all the samples, a Gumbel probability paper is employed to provide a uniform frame of reference. Fitted distributions represented by straight lines based on regression analysis are also given in each case. The choice of probability paper is somewhat arbitrary, and other types of distributions such as Normal or Weibull may give better fits in a number of cases. It must be noted that the relative ranking of the regression coefficients for the different types of distribution will generally also be different if the Model 1 approach is adopted (corresponding to a different normalization of probabilities than for Model 2).

A summary of the stations for which data samples are reported and the corresponding Figure numbers are given in Table A.V-1.

Table A.V-1. Summary of stations for which data samples are given

Name of Measurement Station	Corresponding Figure number	Length of sample (in years)
Gatwick, UK	13	33
Wick, UK	14	30
Leinefelde, Germany	15	26
Fichtelberg, Germany	16	50
Holar, Iceland	17	34
Reykjavik, Iceland	18	34
Blindern, Norway	19	42
Susendal, Norway	20	41
Madrid, Spain	21	36
Articutza, Spain	22	47
Oropa, Italy	23	41
Parma, Italy	24	41

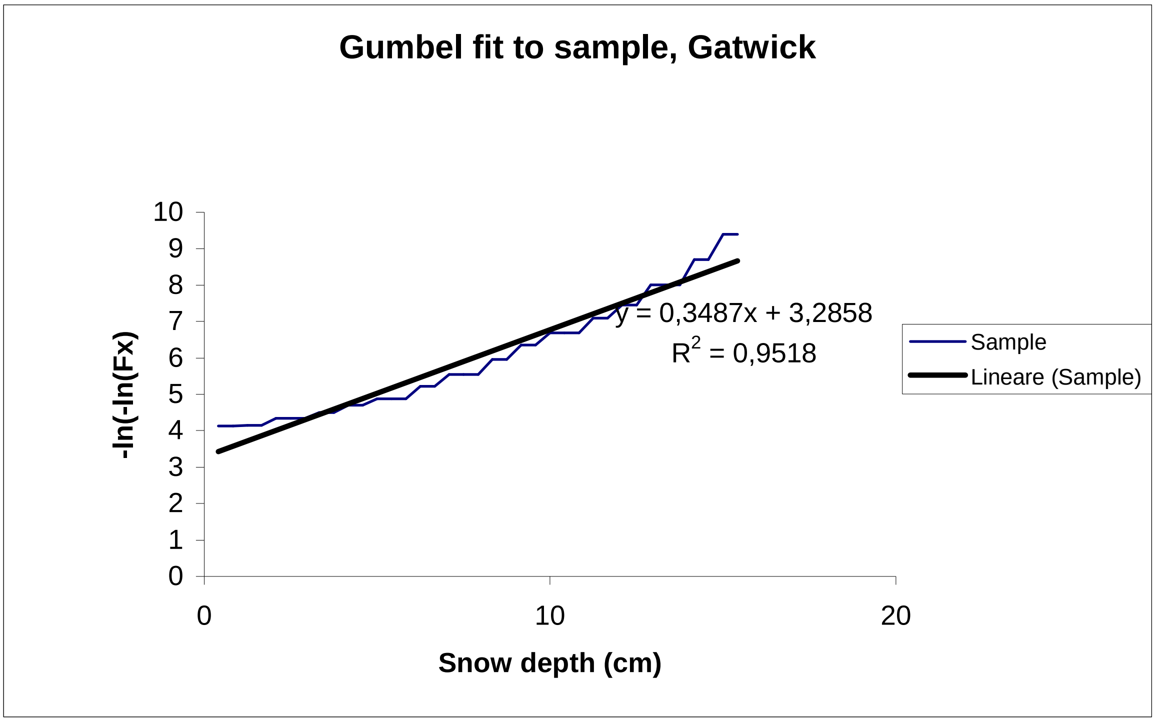


Figure 13. Gumbel fit to measured sample. Gatwick

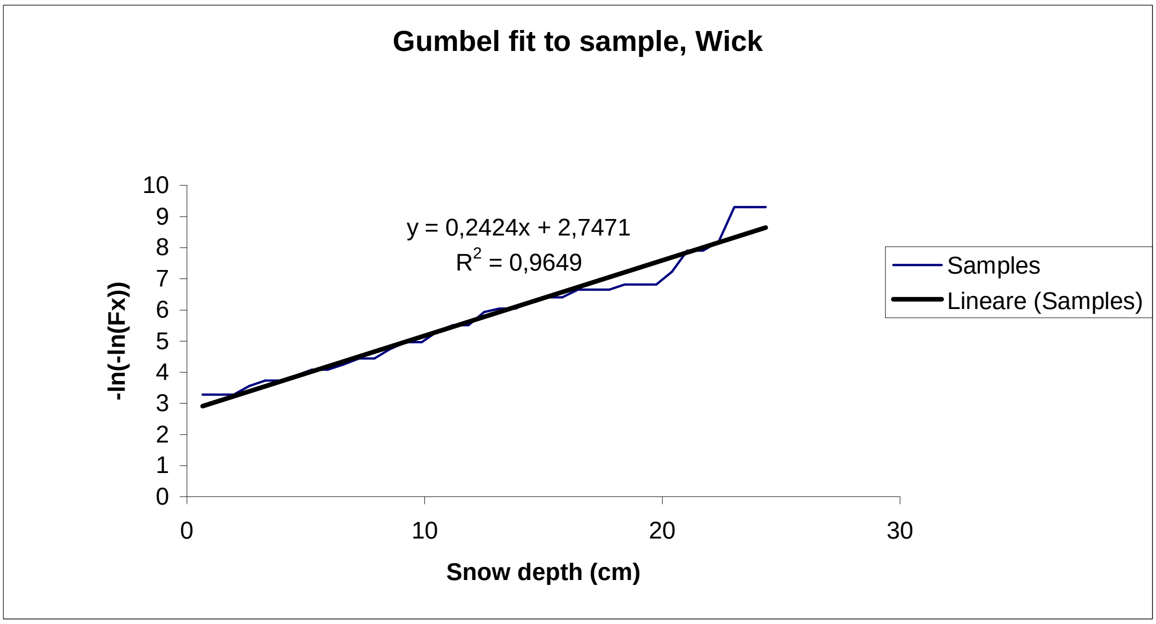


Figure 14. Gumbel fit to measured sample. Wick, UK

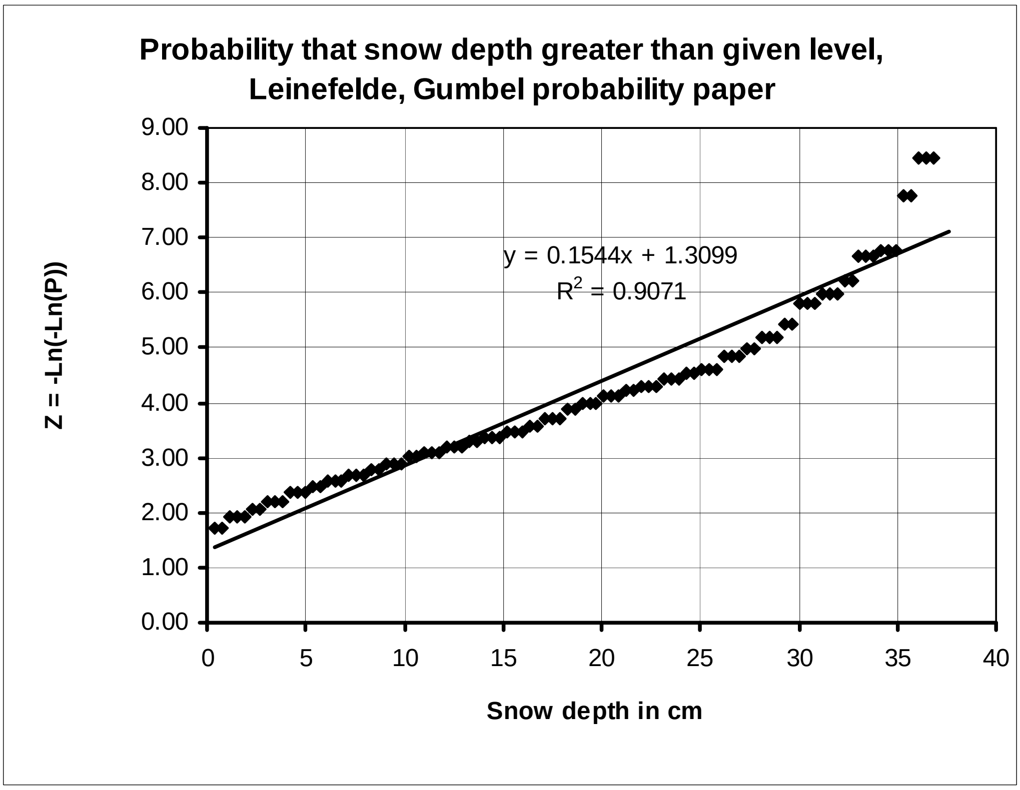


Figure 15. Gumbel fit to measured sample for Leinefelde

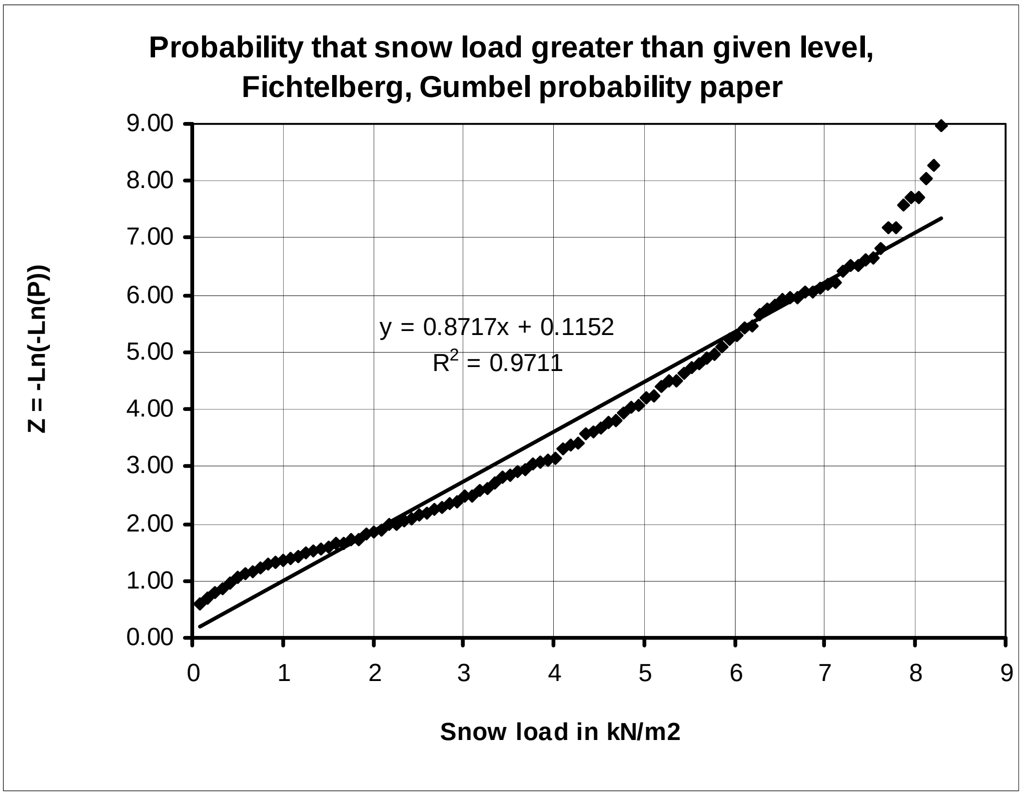


Figure 16. Gumbel fit to measured sample for Fichtelberg

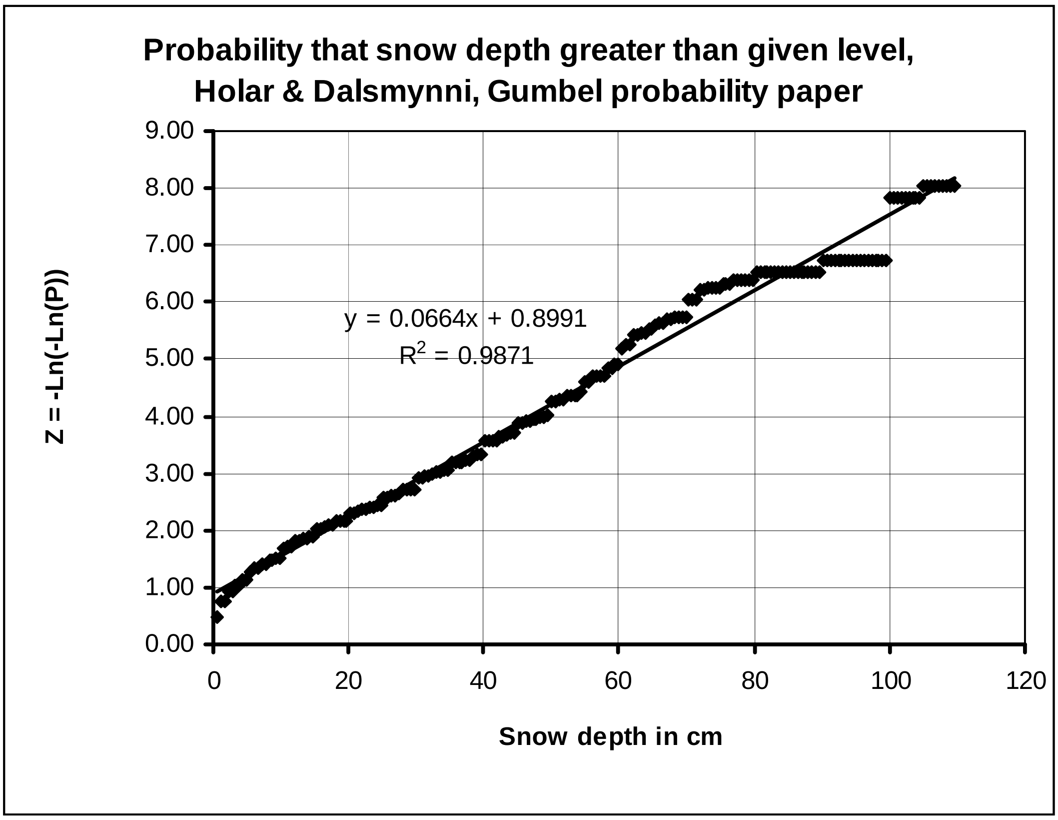


Figure 17. Gumbel fit to measured sample. Holar and Dalsmynni, Iceland

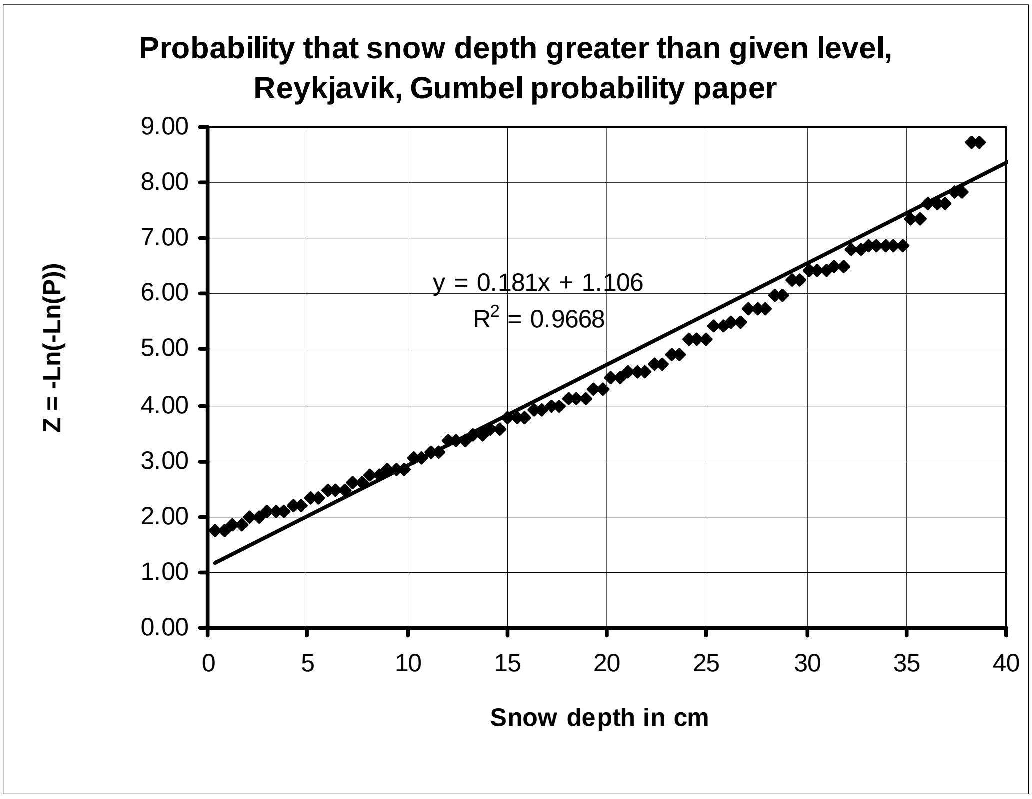


Figure 18. Gumbel fit to measured sample. Reykjavik.

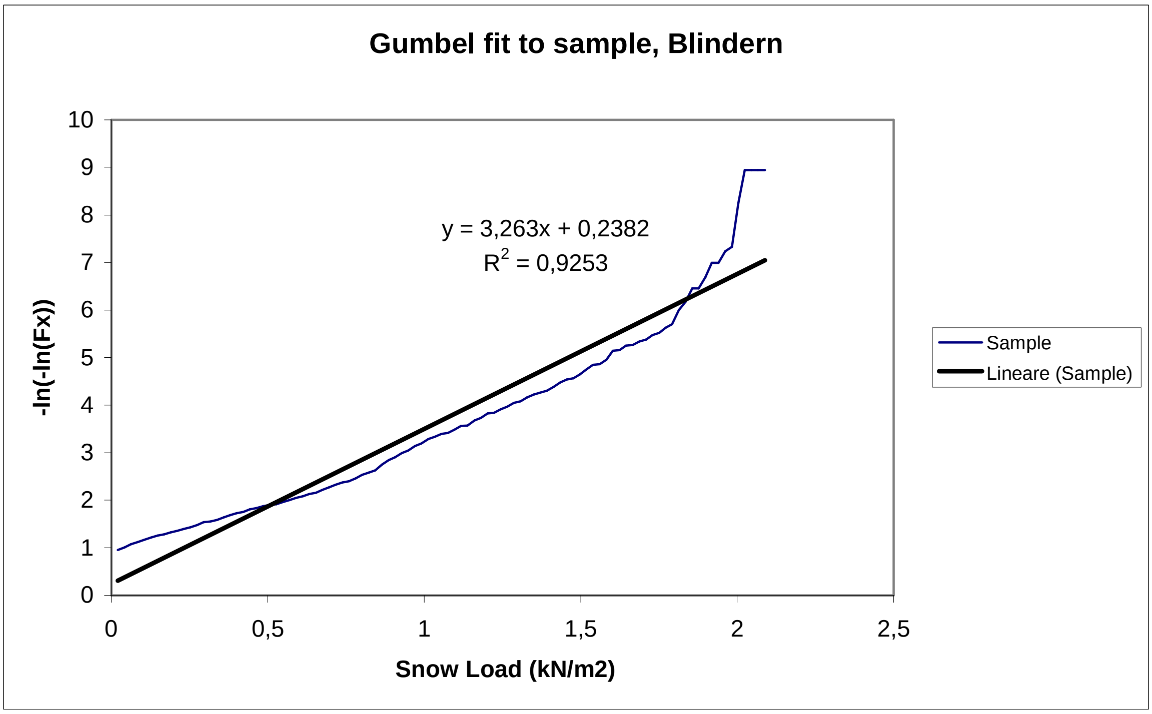


Figure 19. Gumbel fit to measured sample. Blindern, Oslo

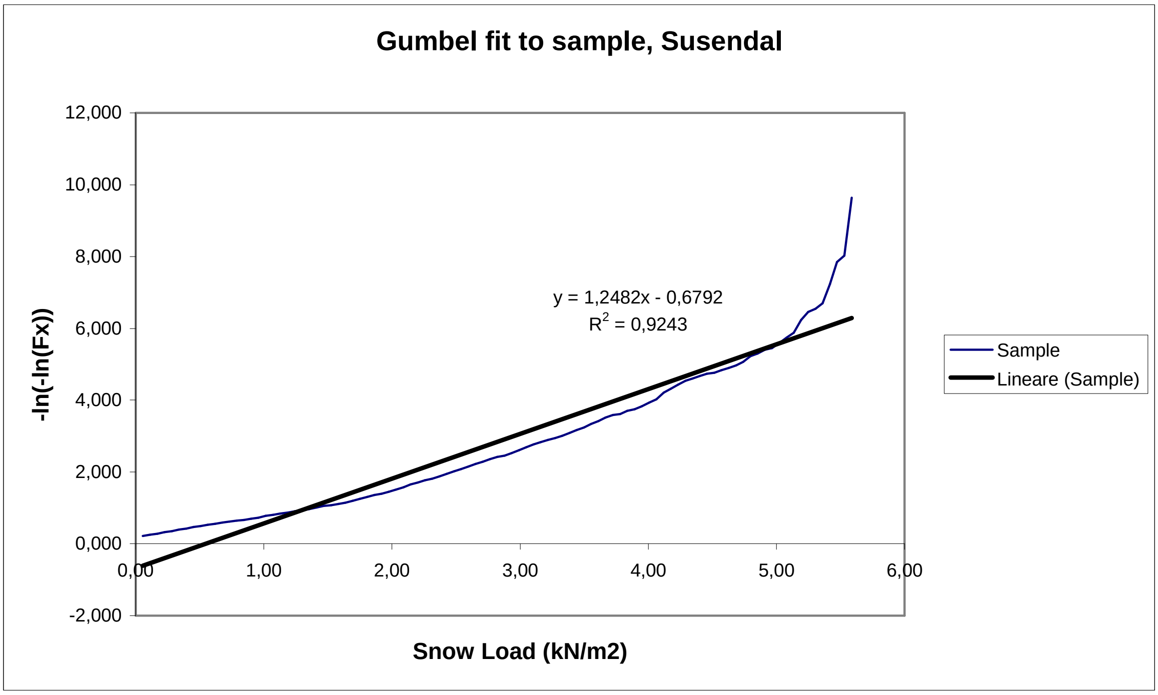


Figure 20. Gumbel fit to measure sample. Susendal, Norway

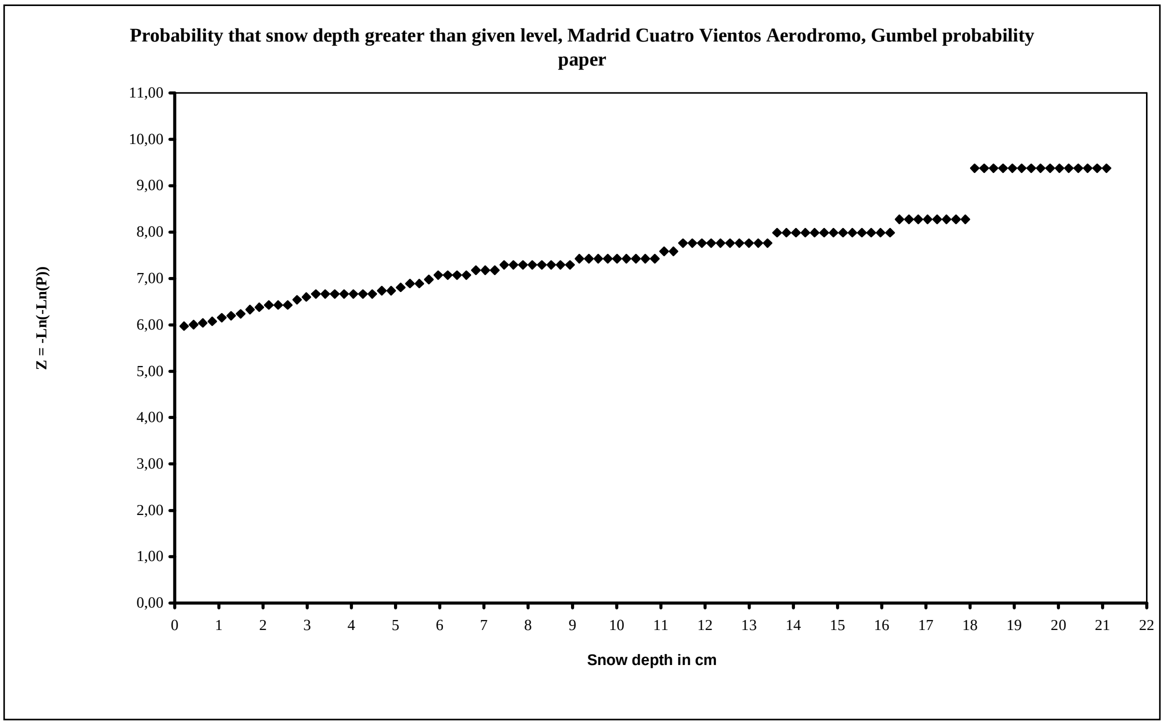


Figure 21. Measured sample in Gumbel probability paper. Madrid Cuatro Vientos Aeorodromo

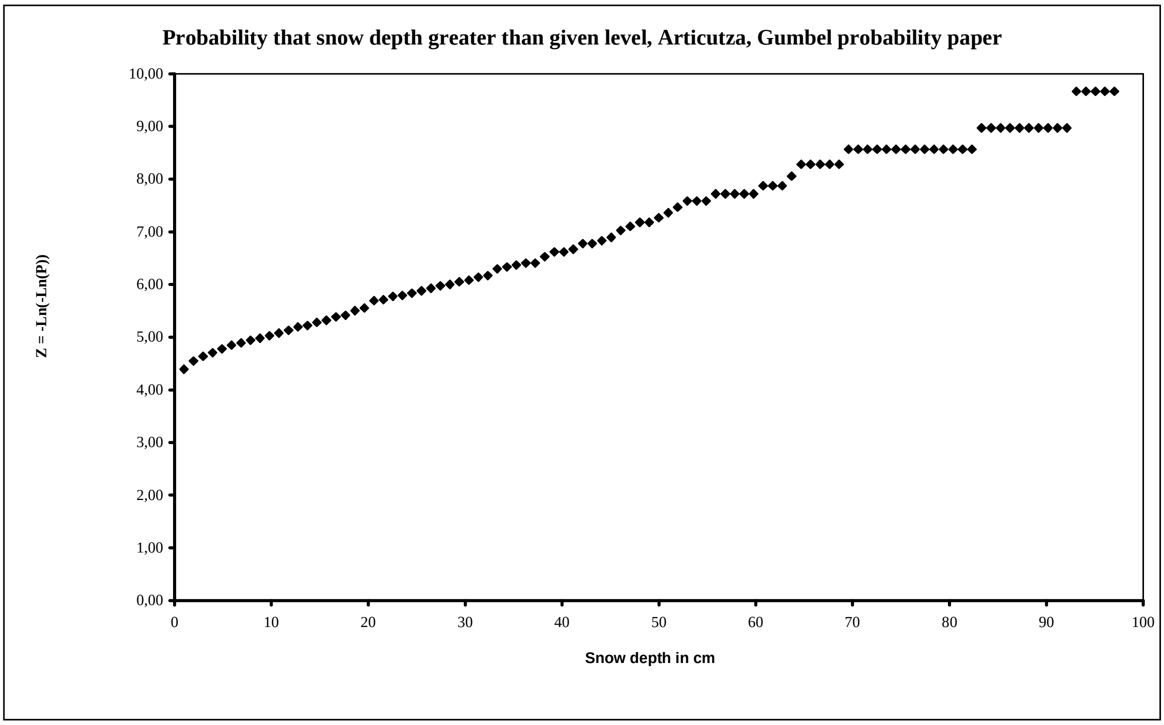


Figure 22 Measured data sample plotted in Gumbel probability paper. Articutza, Spain

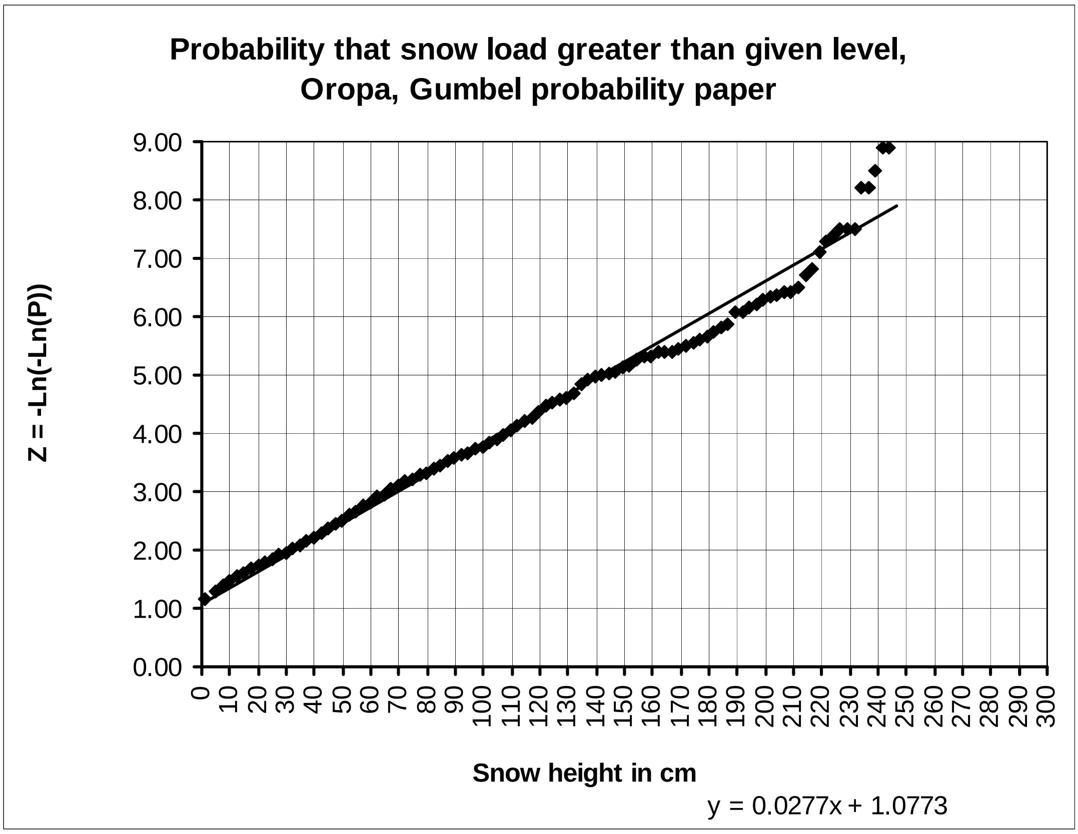


Figure 23 Measured data sample plotted in Gumbel probability paper. Oropa, Italy

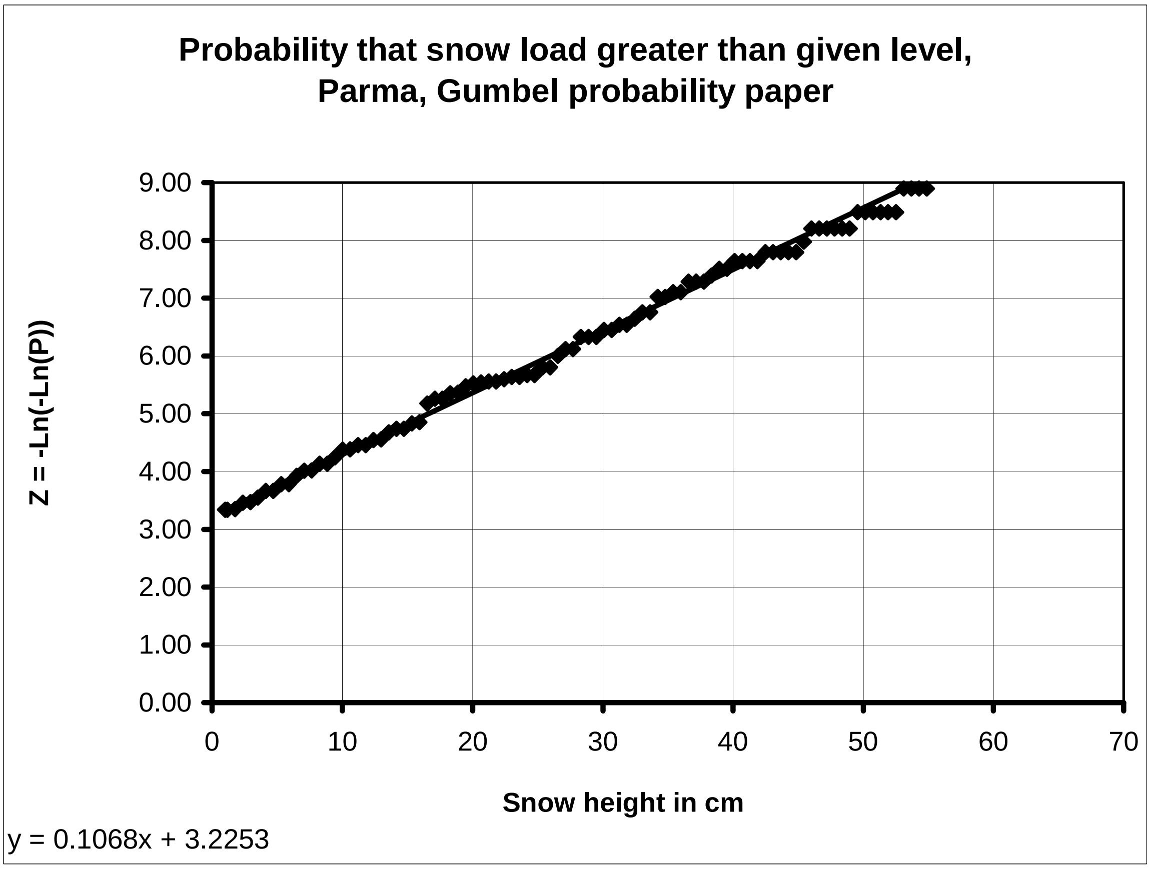


Figure 24 Measured data sample plotted in Gumbel probability paper. Parma, Italy

Annex 6 Measuring devices

A.6.1 Introduction

This annex describes briefly the measuring techniques and the relevant documentation for the roof snow load measurements during the winter 1998/99. Site measurements were performed in Italy Appennine and Dolomites, Great Britain, Germany and Switzerland.

A.6.2 Depth and load measurements

- Measurement poles mounted on the roof (see figure 3-1)
  - Description and arrangement of measurement tool: On a roof several poles are installed: on a gabled one at least 2 poles 1 on each side), better 5 poles (2 on each side, 1 on top of the roof). To know the shape and the distribution of the roof snow layer photographs have to be taken. If the financial means allow more poles can be mounted, for a gabled roof up to 21 (3 rows of 3 poles on each side and 1 on the top). They have to be fixed by ropes to the roof or mounted on wooden plates fixed to the roof or loaded by sand bags to be stable. If one rope fails the poles should not fall down.
  - Measurements: poles with marking every 2 or 5 or 10 cm, measurements will be vertical and not perpendicular to the roof surface
  - Measurement procedure: There should be reasonable possibilities to read the poles for the measurements from either the ground surface or a nearby elevated position to be reached without danger.
  - Material: wooden better than steel (heat transfer)
  - Accuracy: 1 to 2 cm
  - Advantages, Disadvantages: easy system, reading of snow depth with glasses even from considerable distance
  - Costs: cheap

- Measurements with mobile poles on the roof
  - Description: The building and the roof must be chosen such that a person can make the measurements with mobile poles similar to the usual poles used for measuring the depth of snow layers on the ground. Safe access to the roof is a very important consideration in selecting the building.
  - Measurements: as above
  - Material: as above
  - Accuracy: as above
  - Advantages, Disadvantages: possible problems with safe access to the roofs, other aspects see above
  - Costs: cheap

- Measurements with pressure pads or load cells
  - Description: The roof is equipped with pressure pads or load cells. On flat roofs Great Britain has some experience with pressure pads. ISMES will place at least one load cell on each side of a gabled roof.
  - Measurements: electronic, continuously, transmitted to a local recorder (UK) or to a station (ISMES)
  - Material: pressure pads made from rubber, filled with anti-freeze (UK); steel load cells (ISMES)
  - Accuracy: will have to be checked by snow load measurements as described above
  - Advantages, Disadvantages: continuous measurements without the presence of persons
  - Costs: expensive

- Measurements of the snow layer on the ground

  The measurements of the snow layer on the ground can be performed with the same equipment as for the measurements on the roof, normally mobile poles are used.

- Terrestric pictures
  - Description: Photographs are taken from the roof (in front), 6 x 6 cm Rolleiflex
  - Accuracy: for optimal circumstances: ± 1 cm, else ± 10 cm
  - Advantages, Disadvantages: limited accuracy
  - Costs: ECU 15’000.- for camera, PC, due to cost reasons this possibility is not used

A.6.3 *__Density measurements__*

- Tubes for density measurements on roofs
  - Description: The building and the roof must be chosen such that a person can make the measurements with the EMPA-tubes with a defined diameter and length. Again safe access to the roof is a very important consideration in selecting the buildings. For roofs without access only density measurements on the ground are performed.
  - Measurements: according to specification of EMPA-tube, several density measure-ments will be possible throughout the winter period if an accumulation of snow on the roof and on the ground is likely to occur.
  - Material: according to specification of EMPA-tube
  - Accuracy: according to specification of EMPA-tube
  - Advantages, Disadvantages: simple tool, possible problems with safe access to the roofs
  - Costs: cheap

- Other measuring techniques

  There are several other measuring techniques for the snow density. All of them are quite expensive.

- measurements of the density of the snow layer on the ground

  The EMPA-tubes can be used as well.

Annex 7 Data sheet for observations

In this annex the EXCEL-datasheet for snow observation data is explained as presented in section 4.4.. Several numbers do not have to be filled in by the observer because they are calculated in the EXCEL-datasheet by formulas. The explanations for these cells are printed in *italic letters*.

The sheet should be protected to prevent unauthorized deletion of the formulas. To create new columns or rows for additional observations or measuring points the sheet has to be unprotected. If formulas should be changed (input of measured data instead of calculation) the sheet has to be unprotected as well.

For every building or roof a separate data sheet must be created. The data sheet can be copied by the „sheet move/copy“ command in the menu „edit“. New data sheets have to be positioned behind the two analysis sheets for gabled and flat roofs.

A.7.1 Location and building

Location	Name	Name of the location
	No	Number of the location according to the following scheme: cc.sc.bc (cc=country code: IP=Italy Pisa, II=Italy ISMES, GB=Great Britain, G=Germany, CH=Switzerland; sc=station code; bc=building code, sc and bc according to each country)
Building	Name/Address	Name and/or address of the building
	Altitude	Altitude above sea level [m]
	Longitude/Latitude	Geographical position of the building [°]
	Roof type	Gabled or flat roof
	Roof material	Material of the roof (tiles, wood, stone, etc.)
	Insulation	Yes/no, if yes, material (polystyrene, stonewool, glaswool, etc.)
	Thickness of insulat.	Thickness of the insulation [mm]
	Temp. of building	Average temperature of the interior of the building [°C] during the whole measuring campaign or for periods with similar temperature ranges

Environment	Avg. temperature	Average temperature during the relevant snowfall period, 1 measurement/day in the morning (CH)
	Main wind direction	General main wind direction at the location (along a valley, etc.), from meteorological station
	Avg high windspeed	*Average of the wind speed values above 4 m/s of the observations (1 measurement/day in the morning in CH) during the relevant snowfall period*
	Degree-days	*The number of the days with temperatures higher than 0 °C from the beginning of the measuring campaign to the measurement of the relevant day multiplied by the number of degrees above 0 °C.*
	Exposure	Information about high buildings or trees or special topography nearby the building (wind swept or wind protected on several sides)
	Duration:	*Total duration of wind speed higher than 4 m/s of all observations [h] (calculated in the EXCEL-datasheet)*

A.7.2 Dimensions of the building

Sketch of the building and the immediate environment according to the example with the relevant dimensions. The dimensions can be entered in the EXCEL-datasheet or in the sketch.

A.7.3 Observations

(For each observation one column is filled out)

Date	Date of the observation
Time	Time of the observation
Observer	Name of the observer
Ev. separate notices (Sheet No.)	If separate notices are necessary, they should be numbered and the numbers will be entered
Ev. Photographs (No)	If photographs are taken, they should be numbered and the numbers will be entered

A.7.4 Weather conditions since last observation

(For each observation one column is filled out)

Temperature (degree-days)	The number of the days with temperatures higher than 0 °C since the last observation resp. since start of snow (only if snow lying) will be multiplied by the number of degrees; data from meteorological station Example: 4 days with 1 °C, 2 days with 3 °C, 1 day with 4 °C 4*1 + 2*3 + 1*4 = 14 degree-days
Avg. wind speed higher than 4 m/s	Average of the wind speed values above 4 m/s (if possible hourly mean values) since last observation [m/s]; data from meteorological station
Duration of high wind speed	Duration of wind speed higher than 4 m/s since last observation [h]; data from meteorological station
Main wind direction	Main wind direction since last observation; data from meteorological station
Duration of cloud cover	Duration of covered sky [h] since last observation (only during snow cover); data from meteorological station

A.7.5 Ground snow data

(For each observation one column is filled out)

Average height	Observation of the depth of ground snow layer
Density	Observation of the density of the whole snow layer [kg/m^3]
Water equivalent	*Water equivalent of the whole snow layer [mm] (calculated by depth and density in the EXCEL-datasheet)*

A.7.6 Relevant roof shape coefficient

Maximum value of the roof shape coefficients of the observation with the maximum ground snow depth.

A.7.7 Roof snow data

(For each observation one column is filled out; a measurement should be taken at least every 2 weeks and after snow falls of at least 10 cm, in high altitudes more frequently)

Part of roof covered with snow	Estimate of the part of the roof covered with snow
Point No	Number of the measuring point on the roof (all poles are numbered and the numbers are entered in the sketch, arabian numbers)
Roof side	Number of the roof side (roman numbers) flat roofs: I; gabled roofs: I for the leeward side; II for windward side
$\mu_{I\ max}$	*Maximum of the calculated roof shape coefficients for all observations on roof side I (calculated in the EXCEL- datasheet) (flat roofs, leeward side of gabled roofs)*
$\mu_{II\ max}$	*Maximum of the calculated roof shape coefficients for all observations on roof side II (calculated in the EXCEL- datasheet) (windward side of gabled roofs)*
Snow depth	Observation of the depth of snow layer on the roof for this measuring point [cm]
Density	Observation of the density of the whole snow layer on the roof (if possible, otherwise density data of the ground snow layer) [kg/m^3]
Water equivalent	*Water equivalent of the whole snow layer [mm] (calculated by depth and density in the EXCEL-datasheet)*
Water equivalent	If water equivalent directly measured see introduction of this appendix 4.7.
Shape coefficient	*Roof shape coefficients for each observation and point (calculated in the EXCEL-datasheet)*

A.7.8 Sketch of the building and environment

In a sketch the general situation of the building and the environment is documented. The dimensions of the building, distance to other buildings and trees etc., the north direction, the location of the poles on the roof and their numbers etc. are entered.

If a measuring point for the ground snow layer is nearby the building, it will be shown on the sketch or, at least, the direction and the distance to this point.

In the head of the sketch the name and the number of the location, the name and address of the building, the name of the observer and the date are entered.

Annex 8 Snow measurements in the United Kingdom

This annex outlines the measurement programme carried out in the UK by BRE during the winter of 1998/99.

A.8.1 Location of sites

The sites that were selected by BRE for this winter's survey are detailed in table 4.5.1 in section 4.5.2 of the main report. That table provides information on the location, properties of the roofs and the proposed data measurement.

Sites for this years survey were identified by contacting the Met Office, British Telecom and the Ministry of Defence. A leaflet was also inserted into a monthly issue of the magazine 'Weather' to identify meteorologists who live in areas that experience regular snowfall and would be willing to assist with measurements.

A.8.2 Measuring devices

A.8.2.1 Graduated poles

The poles are made from 19 mm diameter softwood dowel covered in striped tape. The tape was printed with alternating black and grey stripes, 25 mm thick. The tape is designed for oil rigs so is suitable for areas subjected to extreme weather conditions.

In previous studies the graduated poles had been glued to the roof surface however when subjected to high winds some of them were blown off. To overcome this problem a system was developed to tension the poles to the roof. The system comprises of two steel cables and tensioning bolts connected to the eaves on either side of the building. The poles are mounted in wooden blocks and placed under the cables on the roof surface. The cables are then tensioned holding the poles securely on the roof. Additional cross bracing is then added to stop the poles being blown over (see figure A.8.2-1).

A.8.2.2 BRE pressure pad system

The BRE pressure pad system was installed at two locations during this winter's survey.

At the Cairngorm Ski Centre five snow load pressure pads were installed to measure the snow load on the roof. The pressure pads were installed on the flat roof of the offices in the bottom chairlift.

At Glenshee Ski Centre eight snow pads were installed, in two separate groups, on the roofs of the main building housing the cafeteria and managers flat. One group of four pads was situated on the patio next to the wall of the kitchen whilst the second group of 4 pads was positioned against the living room wall at the back of the building.

At both sites all the pads were arranged on a plywood sheet to ensure a level surface and also to prevent water on the roof reaching the underside of the pads (see figure A.8.2-2).

Previous studies have shown the system is affected by changes in temperature. Thus, for the study during the winter 1998/99 small heaters were installed in the transducer housings. The aim of this was to maintain a constant temperature inside the housing and reduce the effects caused by changes in the external temperature.

A.8.2.3 Remote camera system

In previous field trials, a CCTV (Close Circuit Television) system linked to a time lapse video recorder was used to monitor the snow depth on the pads. Although the system worked reasonably well the video tape had to be changed at regular intervals and placed too much reliance on supporting staff.

In order to reduce the need for somebody to change the video tape a remote camera system was developed. The system comprises a digital camera housed in a heated container connected to a PC (see figure A.8.2-3). Using software installed on the PC the camera can be instructed to take pictures at specified intervals and to store on the hard disk of the computer. By using an additional piece of software the computer can be connected to a modem allowing the pictures to be downloaded via the telephone.

Three remote camera systems were installed during the winter 1998/99, one at Cairngorm and two at the Glenshee ski centre. The two cameras at Glenshee were connected to a modem to allow the down loading of the pictures.

A.8.2.4 Hand–held measuring system

At some of the sites chosen for the winter 1998/99 it was not feasible to install fixed graduated poles. In order for the observers to still record the roof snow depth a hand held system was developed.

Using a lightweight extendable aluminium pole with a graduated pole inserted in the end the observers were able to record the roof snow depth from ground level (see figure A.8.2-4).

Due to accessibility problems and Health and Safety regulations the taking of roof snow water equivalents by the owners at the majority of sites is currently not possible.

A.8.3 Snow load and depth measurement

An observer was employed at each site to take measurements and/or look after the automatic monitoring equipment. BRE staff travelled to the sites on a number of occasions to check the equipment and results. The snow events resulting in a roof snow depth greater than 2 cm at the UK sites are detailed in the following sections. Unfortunately the UK experienced a mild winter resulting in very few snow events. Only a small number of the sites actually had snow and when they did the overall depths were very low.

Site 1 Cairngorm Ski Centre

At the Cairngorm Ski Centre, Scotland roof snow depths were measured on five roofs. The centre is extremely exposed and often subjected to blizzard conditions.

During this winter there were several snow events resulting in undrifted ground snow depths of up to 20 cm. However due to high winds during or after the majority of these events little or no snow accumulated on most of the roofs.

Despite these high winds four events were recorded by the remote camera system which resulted in snow depths greater than 5 cm.

Snow event		Maximum snow depth (cm)	Details
No	Date		
1	4-7/12/98	12	Max snow depth occurred on 5/12/98. Thaw began and snow depth reduced to max. of 6.5 cm. BRE staff cleared pads to carry out in-situ calibration 7/12/98.
2	23-25/2/99	10	Snow drift occurred against vertical obstruction. Other depths recorded <1cm.
3	26/2/99 – 2/3/99	6.5	Snow drift occurred against vertical obstruction.
4	3/3/99 – 13/3/99	21	Uneven snow drift across pads. Snowfall followed by thaw, then further snowfall.

Site 2 Glenmore Lodge

Snow event		Maximum roof snow depth (cm)	Details
No	Date		
1	16/2/99	6.75	Ground snow depth 7.6 cm. Some roofs susceptible to sliding. All snow thawed by end of day.
2	23/3/99	8.1	Ground snow depth 7.6 cm. Uneven drifts across some roofs. Sliding snow also caused varying depths. All snow thawed by end of day.

Site 3 Glenshee Ski Centre

Glenshee Ski Centre (Side pads)			
Snow event		Maximum snow depth (cm)	Details
No	Date		
1	23/12/98 - 3/1/99	18	Snow depth moderately level across pads.
2	11/1/99 - 4/2/99	76	Snow drifted across pads. Two poles not visible.
3	25/2/99 - 19/3/99	40	Snow drifted across pads

Glenshee (Back pads)			
Snow event		Maximum snow depth (cm)	Details
No	Date		
1	17/1/99	40	Drifted snow against vertical surface. Snow depth decreasing to zero on pads furthest from vertical obstruction.
2	9/2/99	21	Drifted snow with maximum depth away from vertical obstruction.
3	24/2/99	32	Drifted snow with maximum snow depth against vertical obstruction. Pads completely covered. Minimum snow depth 10 cm.

Site 7 Eskdalemuir Met. Office Observatory

Storage building (Flat roof)			
Snow event		Maximum roof snow depth (cm)	Details
No	Date		
1	27-29/12/98	4	Max. ground snow depth during event 8cm.
2	12/1/99	5	Ground snow depth corresponding to max roof depth, 6 cm. All snow thawed off roof by following day.

Bungalow (Duo-pitch)			
Snow event		Maximum roof snow depth (cm)	Details
No	Date		
1	27-29/12/98	6	Max. ground snow depth during event 8cm

Site 8 Callander

Location	Snow event		Maximum roof snow depth (cm)	Details
	No	Date		
31 Lagrannoch Drive	1	12/1/99	5	Ground snow depth 3 cm. Snow thawed off roof by following day.
Forest Enterprise Offices	1	22/2/99	2.7	Ground snow depth 3 cm. Snow thawed off roof by following day.
Kingshouse Hotel	1	22/2/99	5.5	Ground snow depth 7 cm. Snow thawed off roof by following day.
Lade Inn	1	12/1/99	5	Ground snow depth 5 cm. Snow thawed off roof by following day. (For both events)
	2	22/2/99		
Visitor Centre	1	12/1/99	6	Ground snow depth 6cm. Snow thawed off roof by following day.

Site 10 Weardale, Co Durham

Only one snow event occurred on the 5 March 1999. The ground snow depth was measured at 5.2 cm and the maximum roof depth at 8 cm. The snow was noted as being powdery.

Site 12 Mole-y-Crio, Wales

Garage (Duo-pitch)			
Snow event		Maximum snow depth (cm)	Details
No	Date		
1	8-13/2/99	10	Ground snow depth 10 cm.
2	14-15/4/99	2.7	Ground snow depth 3.7 cm. Roof snow depth on one side less than 1cm. Other side snow depth measured at 2.7 cm.

Car port (Mono-pitch)			
Snow event		Maximum snow depth (cm)	Details
No	Date		
1	8-13/2/99	9	Ground snow depth 10 cm.

A.8.4 All other sites

No roof snow depths greater than 2 cm were recorded at any of the other sites.

A.8.4.1 Snow density measurements

Snow density measurements recorded by our observers are given in table A.8.4-1. The characteristic value from the nearest meteorological station that BRE has records for is also given for comparison.

Due to their remote location the pressure pad systems were often subjected to power losses. Also the limited snow depth resulted in very low outputs from the transducers. Due to these problems no roof snow density measurements have been able to be calculated for the Cairngorm site. However a roof snow water equivalent measurement was recorded on the 7-Dec-98 by BRE staff. The snow density calculated from these measurements was 202.19 kg/m^3.

Table A8.4-1: Snow density determined from recorded measurements

Site		Calculated value			Characteristic value (kN/m^2)
No	**Name**	**Depth (m)**	**Density (Kg/m^3)**	**Load (kN/m^2)**	
2	Glenmore Lodge	0.076	110 –314	0.2	0.99
6	Darvel	0.05	130	0.06	0.27
7	Eskdalemuir	0.04-0.07	65 – 180	0.07	0.75
8	Callander	0.03-0.07	160 – 830	0.3	0.8
12	Moel y Crio	0.04-0.1	100 – 155	0.1	0.65

At Glenshee snow density measurements have been calculated using the outputs from three of the transducers (from the side pads) during snow event 3. These however are only estimates and cannot be compared to actual densities as no other snow water equivalent samples were taken during the trials. The calculated snow densities are given in table A.8.4-2.

Table A.8.4-2: Calculated snow density at Glenshee

Logger Channel	(No.)	3-	4+	4*
Gauge output (see note)	(V)	2.1193	1.62719	5.22968
Mass of snow (Calculated from in-situ calibration)	(kg)	39.91	35.22	32.40
Snow depth estimate from remote camera	(m)	0.3	0.27	0.25
Effective area of pressure pad	(m^2)	0.345	0.345	0.345
Density of snow	(kg/ m^3)	386	387	378
Note: Difference between the average transducer outputs, over an hour period, before and during the snow event.				

A.8.5 Data Analysis

The EXCEL-spreadsheets have been completed for two of the UK sites, Moel y Crio and Eskdalemuir. These are the only sites where BRE has the required meteorological data for each of the snow events. Copies of the worksheets from each site are given in section A.8.7.

A.8.5.1 Meteorological Data

The meteorological data for the other sites could not be recorded directly by the observers and data from the nearest Meteorological Stations are currently not available.

A.8.6 Conclusions in the UK

Unfortunately in the UK this winter there has been a small number of snow events and little data have been obtained.

The remote camera system worked reasonably well and recorded the snow events during the field trials. The system generally produced clear images and the snow depths were able to be determined from the pictures during daylight. The use of this type of system also removed the need to change video tapes.

The tensioning of the poles to the roof worked extremely well. Although installation time is increased slightly the chances of the poles being blow off are significantly lower than for other fixing methods such as gluing.

Where fixed installations were not possible, handheld equipment was used and these provided a safe means of taking roof snow depths.

The use of observers with technical knowledge and/or an interest in meteorology increased the quality and reliability of the measurements. For future work consideration should be given to using only these types of observers.

Figure A.8.2-1: Tensioning system used to hold graduated poles on to the roof

Figure A.8.2-2: BRE pressure pad system

Figure A.8.2-3: Digital camera housed in a heated container

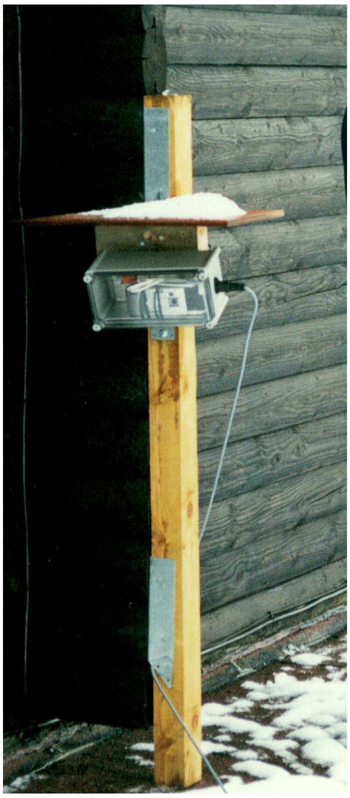


Figure A.8.2-4: BRE hand-held snow depth measuring system

A.8.7: Completed worksheets for Moel y Crio and Eskdalemuir

European Snow Load Research Program

Measuring Dokumentation

Location and building					
Location	Name	Moel-y-crio			
	No	GB.12.2			
Building	Name/Address	Car port			
	Altitude	263			
	Longitude/Latitude	3'13' W	53' 13' N		
	Roof type	Flat			
	Roof material	Corrugated steel			
	Isolation	❐ yes, material:		☒	
	Thickness of isol.	N/A			
	Temp. of building	2.5			
Environment	Avg temperature	2.5 (During snow even	Degree days	10.2	
	Main wind directi	W-NW	Exposure	Moderate	
	Avg high windspe	6.4	Duration	0.0	

Dimensions of the Building (Sketch) [m]:			
H_1	3	T_1	4
H_2	2.2	T_2	3.5
H_3		T_3	2.5
α_1	8	T_4	
α_2		t_1	8
L_1	6.15	t_2	13
L_2		t_3	3.72
B	5.4	t_4	
		a_1	7.85
		a_2	0.1
		a_3	2
		a_4	

Observations	1	2	3	4	5	6	7	8
Date	08/02/99	09/02/99	10/02/99	11/02/99	12/02/99			
Time	11	9	9	9	9			
Observer	M Walls	M Walls	M Walls	M Walls	M Walls			
Ev. separate notices (Sheet No.)								
Ev. photographs (No)								

Weather conditions since last observation		1	2	3	4	5	6	7	8
Temperature (degree-days)	[ ]	N/A	0.7	1.4	1.7	6.4			
Avg. wind speed higher than 4 m/s	[m/s]	N/A	6.2	7.8	7.0	4.6			
Duration of high wind speed	[h]	N/A	Unknown	Unknown	Unknown	Unknown			
Main wind direction		N/A	W	NW	NW	NW			
Duration of cloud cover	[h]	N/A	Unknown	Unknown	Unknown	Unknown			

Ground snow data		1	2	3	4	5	6	7	8
Average height	[cm]	10.0	8.0	7.0	6.0	2.0			
Density	[kg/m^3]	100	Unknown	Unknown	Unknown	Unknown			
Water equivalent	[mm]	10	Unknown	Unknown	Unknown	Unknown			

Relevant roof shape coefficient	**Roof side I:**	μ_1=	**0.85**	**Roof side II:**	μ_2=	**0.85**

Roof snow data			1	2	3	4	5	6	7	8
Part of roof covered with snow		[%]	100	0	0	0	0			
Point No 1	Average height	[cm]	9	0	0	0	0			
Roof side: I	Density	[kg/m^3]	100	0	0	0	0			
$\mu_{1\,max}$ $\mu_{2\,max}$	Water equivalent	[mm]	9	0	0	0	0			
0.85	Shape coefficient	[-]	0.85	0.00	0.00	0.00	0.00			
Point No 2	Average height	[cm]	9	0	0	0	0			
Roof side: I	Density	[kg/m^3]	100	0	0	0	0			
$\mu_{1\,max}$ $\mu_{2\,max}$	Water equivalent	[mm]	9	0	0	0	0			
0.85	Shape coefficient	[-]	0.85	0.00	0.00	0.00	0.00			
Point No 3	Average height	[cm]	9	0	0	0	0			
Roof side: I	Density	[kg/m^3]	100	0	0	0	0			
$\mu_{1\,max}$ $\mu_{2\,max}$	Water equivalent	[mm]	9	0	0	0	0			
0.85	Shape coefficient	[-]	0.85	0.00	0.00	0.00	0.00			
Point No 4	Average height	[cm]	9	0	0	0	0			
Roof side: I	Density	[kg/m^3]	100	0	0	0	0			
$\mu_{1\,max}$ $\mu_{2\,max}$	Water equivalent	[mm]	9	0	0	0	0			
0.85	Shape coefficient	[-]	0.85	0.00	0.00	0.00	0.00			
Point No 5	Average height	[cm]	9	0	0	0	0			
Roof side: II	Density	[kg/m^3]	100	0	0	0	0			
$\mu_{1\,max}$ $\mu_{2\,max}$	Water equivalent	[mm]	9	0	0	0	0			
0.85 (under $\mu_{2\,max}$)	Shape coefficient	[-]	0.85	0.00	0.00	0.00	0.00			

European Snow Load Research Program

Measuring Dokumentation

Location and building					**Dimensions of the Building (Sketch) [m]:**			
Location	Name	Eskdalemuir			H_1	5.8	T_1	15
	No	GB.7.1			H_2	3	T_2	
Building	Name/Address	Bungalow			H_3		T_3	
	Altitude	242			α_1	39	T_4	
	Longitude/Latitud	3° 12' W	55° 19' N		α_2		t_1	15
	Roof type	Gabled			L_1	20	t_2	
	Roof material	Tiled			L_2	8.6	t_3	
	Isolation	❒ yes, material:	Fibre		L_3	7.1	t_4	
	Thickness of isol.	7.6 cm			B_1	7.2	d_1	1.5
	Temp. of building	5			B_2	3.2	d_2	
Environment	Avg temperature	2.11 (during event)	Degree days	6.4	B_3	1	d_3	
	Main wind direction		Exposure	mod/high			d_4	
	Avg high windspe	2.3	Duration	0.0				

Observations		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Date		27/12/98	28/12/98	29/12/98					
Time		1500	1145	9					
Observer		Met. Off	Met. Off	Met.Off					
Ev. separate notices (Sheet No.)									
Ev. photographs (No)		Fig .2							

Weather conditions since last observation		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Temperature (degree-days)	[ ]	N/A	5.2	1.2					
Avg. wind speed higher than 4 m/s	[m/s]	N/A	0.0	4.6					
Duration of high wind speed	[h]	N/A	Unknown	Unknown					
Main wind direction		N/A	S-SE	SW					
Duration of cloud cover	[h]	N/A	Unknown	Unknown					

Ground snow data		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Average height	[cm]	8.0	7.0	4.0					
Density	[kg/m^3]	Unknown	73	185					
Water equivalent	[mm]	Unknown	5.1	7.4					

Relevant roof shape coefficient	**Roof side I:**	μ_1=	**0.86**	**Roof side II:**	μ_2=	**0.00**

Roof snow data			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Part of roof covered with snow		[%]	100	100	0					
Point No 8	Average height	[cm]	4	6	0					
Roof side: I	Density	[kg/m^3]	Unknown	73	0					
$\mu_{1\,max}$ $\mu_{2\,max}$	Water equivalent	[mm]	Unknown	4	0					
0.86	Shape coefficient	[-]	Unknown	0.86	0.00					
Point No 9	Average height	[cm]	4	3	0					
Roof side: I	Density	[kg/m^3]	Unknown	73	0					
$\mu_{1\,max}$ $\mu_{2\,max}$	Water equivalent	[mm]	Unknown	2	0					
0.43	Shape coefficient	[-]	Unknown	0.43	0.00					
Point No 10	Average height	[cm]	4	2	0					
Roof side: I	Density	[kg/m^3]	Unknown	73	0					
$\mu_{1\,max}$ $\mu_{2\,max}$	Water equivalent	[mm]	Unknown	1	0					
0.29	Shape coefficient	[-]	Unknown	0.29	0.00					
Point No 5	Average height	[cm]	4	4	0					
Roof side: I	Density	[kg/m^3]	Unknown	73	0					
$\mu_{1\,max}$ $\mu_{2\,max}$	Water equivalent	[mm]	Unknown	3	0					
0.57	Shape coefficient	[-]	Unknown	0.57	0.00					

European Snow Load Research Program

Measuring Dokumentation

Location and building					**Dimensions of the Building (Sketch) [m]:**			
Location	Name	Eskdalemuir			H_1	4.9	T_1	12
	No	GB.7.2			H_2	2.9	T_2	3
Building	Name/Address	Storage building			H_3		T_3	20
	Altitude	242			α_1	0	T_4	
	Longitude/Latitud	3° 12' W	55° 19' N		α_2		t_1	8
	Roof type	Flat			L_1	8	t_2	4
	Roof material	Felt			L_2	6	t_3	2
	Isolation	❒ yes, material:		☒	B_1	4.3	t_4	
	Thickness of isol.	N/A			B_2	2.5	d_1	1.5
	Temp. of building	2.11					d_2	12
Environment	Avg temperature	2.11(During event)	Degree days	6.4			d_3	12
	Main wind direction		Exposure	mod/high			d_4	
	Avg high windspe	2.3	Duration	0.0				

Observations	1	2	3	4	5	6	7	8
Date	27/12/98	28/12/98	29/12/98					
Time	1200	1145	9					
Observer	Met.Off	Met.Off	Met.Off					
Ev. separate notices (Sheet No.)								
Ev. photographs (No)	Fig 1.							

Weather conditions since last observation		1	2	3	4	5	6	7	8
Temperature (degree-days)	[ ]	N/A	5.2	1.2					
Avg. wind speed higher than 4 m/s	[m/s]	N/A	0.0	4.6					
Duration of high wind speed	[h]	N/A	Unknown	Unknown					
Main wind direction		N/A	S-SE	SW					
Duration of cloud cover	[h]	N/A	Unknown	Unknown					

Ground snow data		1	2	3	4	5	6	7	8
Average height	[cm]	8.0	7.0	4.0					
Density	[kg/m^3]	Unknown	73	185					
Water equivalent	[mm]	Unknown	5.1	7.4					

Relevant roof shape coefficient	**Roof side I:**	μ_1=	**0.57**	**Roof side II:**	μ_2=	**0.00**

Roof snow data			1	2	3	4	5	6	7	8
Part of roof covered with snow		[%]	100	100	0					
Point No 1	Average height	[cm]	4	4	0					
Roof side: I	Density	[kg/m^3]	Unknown	73	0					
$\mu_{1\,max}$ $\mu_{2\,max}$	Water equivalent	[mm]	Unknown	3	0					
0.57	Shape coefficient	[-]	Unknown	0.57	0.00					
Point No 2	Average height	[cm]	4	4	0					
Roof side: I	Density	[kg/m^3]	Unknown	73	0					
$\mu_{1\,max}$ $\mu_{2\,max}$	Water equivalent	[mm]	Unknown	3	0					
0.57	Shape coefficient	[-]	Unknown	0.57	0.00					
Point No 3	Average height	[cm]	4	4	0					
Roof side: I	Density	[kg/m^3]	Unknown	73	0					
$\mu_{1\,max}$ $\mu_{2\,max}$	Water equivalent	[mm]	Unknown	3	0					
0.50	Shape coefficient	[-]	Unknown	0.50	0.00					
Point No 4	Average height	[cm]	4	4	0					
Roof side: I	Density	[kg/m^3]	Unknown	73	0					
$\mu_{1\,max}$ $\mu_{2\,max}$	Water equivalent	[mm]	Unknown	3	0					
0.57	Shape coefficient	[-]	Unknown	0.57	0.00					

European Snow Load Research Program

Measuring Dokumentation

Location and building						Dimensions of the Building (Sketch) [m]:			
Location	Name	Moel-y-crio				H_1	3.5	T_1	4
	No	GB.12.1				H_2	2	T_2	3
Building	Name/Address	Garage				H_3		T_3	
	Altitude	263				α_1	38	T_4	
	Longitude/Latitude	3'13' W	53' 13' N			α_2		t_1	8
	Roof type	Gabled				L_1	9.35	t_2	6.15
	Roof material	Tiled				L_2		t_3	
	Isolation	❐ yes, material:		☒		B	3.85	t_4	
	Thickness of isol.	N/A						d_1	9.65
	Temp. of building	4.5						d_2	0.1
Environment	Avg temperature	2.5 (During snow even	Degree days	10.2				d_3	
	Main wind directio	W-NW	Exposure	Moderate				d_4	
	Avg high windspe	6.4	Duration	0.0					

Observations	1	2	3	4	5	6	7	8
Date	08/02/99	09/02/99	10/02/99	11/02/99	12/02/99			
Time	11	9	9	9	9			
Observer	M Walls	M Walls	M Walls	M Walls	M Walls			
Ev. separate notices (Sheet No.)								
Ev. photographs (No)								

Weather conditions since last observation		1	2	3	4	5	6	7	8
Temperature (degree-days)	[ ]	N/A	0.7	1.4	1.7	6.4			
Avg. wind speed higher than 4 m/s	[m/s]	N/A	6.2	7.8	7.0	4.6			
Duration of high wind speed	[h]	N/A	Unknown	Unknown	Unknown	Unknown			
Main wind direction		N/A	W	NW	NW	NW			
Duration of cloud cover	[h]	N/A	Unknown	Unknown	Unknown	Unknown			

Ground snow data		1	2	3	4	5	6	7	8
Average height	[cm]	10.0	8.0	7.0	6.0	2.0			
Density	[kg/m³]	100	Unknown	Unknown	Unknown	Unknown			
Water equivalent	[mm]	10	Unknown	Unknown	Unknown	Unknown			

Relevant roof shape coefficient	Roof side I:	μ_1=	1.00	Roof side II:	μ_2=	1.00

Roof snow data				1	2	3	4	5	6	7	8
Part of roof covered with snow			[%]	100	0	0	0	0			
Point No 1		Average height	[cm]	10	0	0	0	0			
Roof side:	I	Density	[kg/m³]	100	0	0	0	0			
$\mu_{1\,max}$	$\mu_{2\,max}$	Water equivalent	[mm]	10	0	0	0	0			
1.00		Shape coefficient	[-]	1.00	0.00	0.00	0.00	0.00			
Point No 2		Average height	[cm]	10	0	0	0	0			
Roof side:	I	Density	[kg/m³]	100	0	0	0	0			
$\mu_{1\,max}$	$\mu_{2\,max}$	Water equivalent	[mm]	10	0	0	0	0			
1.00		Shape coefficient	[-]	1.00	0.00	0.00	0.00	0.00			
Point No 3		Average height	[cm]	10	0	0	0	0			
Roof side:	I	Density	[kg/m³]	100	0	0	0	0			
$\mu_{1\,max}$	$\mu_{2\,max}$	Water equivalent	[mm]	10	0	0	0	0			
1.00		Shape coefficient	[-]	1.00	0.00	0.00	0.00	0.00			
Point No 4		Average height	[cm]	10	0	0	0	0			
Roof side:	I	Density	[kg/m³]	100	0	0	0	0			
$\mu_{1\,max}$	$\mu_{2\,max}$	Water equivalent	[mm]	10	0	0	0	0			
1.00		Shape coefficient	[-]	1.00	0.00	0.00	0.00	0.00			
Point No 5		Average height	[cm]	10	0	0	0	0			
Roof side:	II	Density	[kg/m³]	100	0	0	0	0			
$\mu_{1\,max}$	$\mu_{2\,max}$	Water equivalent	[mm]	10	0	0	0	0			
	1.00	Shape coefficient	[-]	1.00	0.00	0.00	0.00	0.00			

Point No 6		Average height	[cm]	10	0	0	0	0			
Roof side:	II	Density	[kg/m^3]	100	0	0	0	0			
$\mu_{1\ max}$	**$\mu_{2\ max}$**	Water equivalent	[mm]	10	0	0	0	0			
	1.00	Shape coefficient	[-]	1.00	0.00	0.00	0.00	0.00			
Point No 7		Average height	[cm]	10	0	0	0	0			
Roof side:	II	Density	[kg/m^3]	100	0	0	0	0			
$\mu_{1\ max}$	**$\mu_{2\ max}$**	Water equivalent	[mm]	10	0	0	0	0			
	1.00	Shape coefficient	[-]	1.00	0.00	0.00	0.00	0.00			
Point No 8		Average height	[cm]	10	0	0	0	0			
Roof side:	II	Density	[kg/m^3]	100	0	0	0	0			
$\mu_{1\ max}$	**$\mu_{2\ max}$**	Water equivalent	[mm]	10	0	0	0	0			
	1.00	Shape coefficient	[-]	1.00	0.00	0.00	0.00	0.00			

Annex 9 Snow measurements from Italy Apennine

A.9.1 Introduction

The present Annex illustrates the criteria for the selection of roofs monitored by the University of Pisa in the Italian Appennine, during the winter 1998/99 within the roof snow loads measurements campaign, in order to provide information about the shape coefficient for the Mediterranean region.

Attention was focused on sites, which should represent Mediterranean climate.

The measurements performed concern the experimental determination of shape coefficients for different types of roofs through the measurements of snow depth on the ground and on roofs and relative measure of snow density, on ground and on roofs.

A.9.2 Measurement techniques

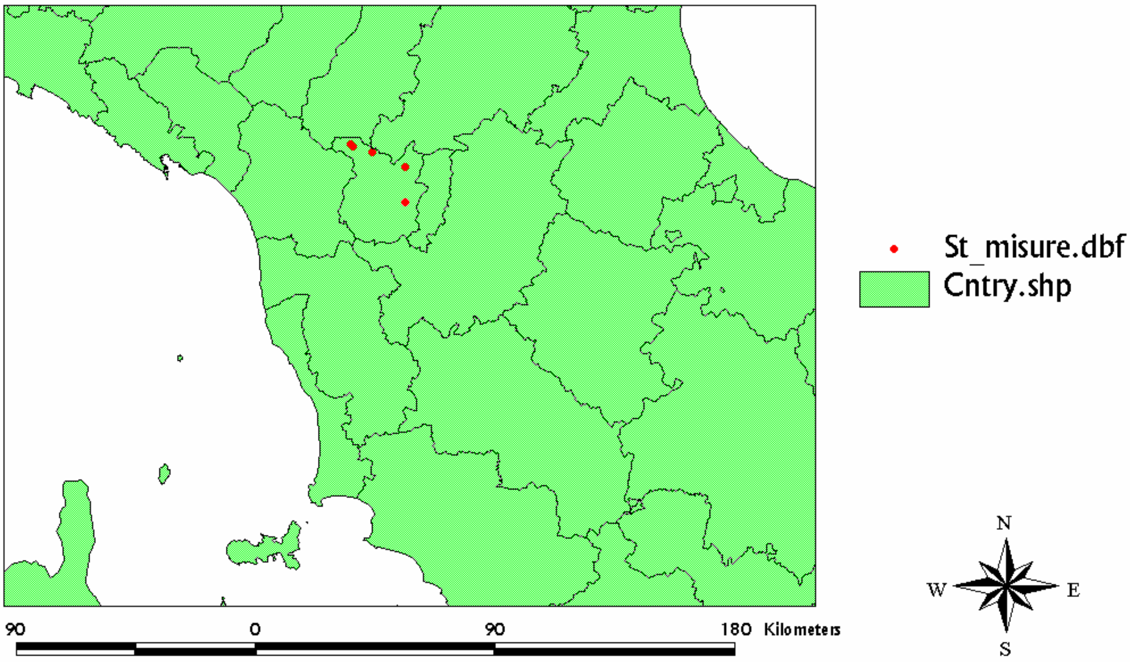
A.9.2.1 Selection of sites and roofs for depth measurements

Roofs were mainly available from public institution buildings in the district of Pistoia, a city located in Toscany quite near to Pisa, with a big competence of medium height mountainous area, in the Apennine chain (see figure A.9.2-1).

Poles for measurements were placed on public buildings such as schools, which were selected with the following criteria:

- Altitude above sea level varying from 100 m up to 1400 m;
- Probability of significant snowfalls during the winter 1998/99;
- Sites as close as possible to the meteorological stations from which which snow data could be collected;
- Roof shapes: flat and gabled roofs with slope angles not greater than 40°;
- Roof high above ground; preferably single storey buildings are selected in order to perform observations also from the ground;
- Different roofing materials to investigate their influence on snow depletion;
- Easy access to the roof surface to perform density measurements;
- Availability of a isolated area close to the building, excluding influences due to trees, high buildings etc., in order to perform ground snow load measurements.

Figure A.9.2-1: Sites for roof snow load measurements



A.9.2.2 Selected roofs

The table below illustrates the exact location of the roofs monitored during the winter 1998/99.

Table A.9.2-2: Selected roofs

	SITE	ROOF SHAPE / SLOPE	ALTITUDE A.S.L (M)	NEAREST CLIMATIC STATION	TYPE OF MEASURING DEVICE (*)	REMARKS
1	Pistoia	Flat roof	88	Pistoia	a) - b)	Single snow events
2	Campo Tizzoro	Flat roof	700	Pistoia	a) - b)	Single snow events
3	S. Marcello Pistoiese (school)	Gabled roof (slope ~ 25°)	620	San Marcello Pistoiese	a) - b)	Single snow events
4	S. Marcello Pistoiese (unused school)	Gabled roof (slope ~ 20°)	800	San Marcello Pistoiese	c)	Single snow events
5	Cutigliano	Gabled roof (slope ~ 20°)	685	Cutigliano	c)	Mainly single snow events
6	Pian degli Ontani	Gabled roof (slope ~ 25°)	~ 1200	Pian di Novello	a) - b)	Snow accumulation
7	Abetone 1 (school)	Gabled roof (slope 10°)	~ 1340	Abetone	a) - b)	Snow accumulation
8	Abetone 2 (ANAS)	Gabled roof (slope ~ 40°)	~ 1340	Abetone	c)	Snow accumulation

	SITE	ROOF SHAPE / SLOPE	ALTITUDE A.S.L (M)	NEAREST CLIMATIC STATION	TYPE OF MEASURING DEVICE (*)	REMARKS
9	Abetone 3 (Ski resort “Ovovia”)	Gabled roof (slope ~ 20°)	~ 1340	Abetone	c)	Snow accumulation
1	Abetone 4 (forester’s station)	Gabled roof (slope ~ 20°)	~ 1300	Abetone	c)	Snow accumulation
1	Abetone 5 (forester’s station)	Gabled roof (slope ~ 25°)	~ 1300	Abetone	c)	Snow accumulation
1	Abetone 6 (forester’s station)	Gabled roof (slope ~ 20°)	~ 1300	Abetone	c)	Snow accumulation
1	Abetone 7 (ski resort “Selletta”)	Gabled roof (slope ~ 22-25°)	~ 1340	Abetone	c)	Snow accumulation

(*) see the point A.9.3. below with the description of the measuring devices

A.9.3 Measurement Devices

A.9.3.1 Ground snow depth

Near to each chosen building, when possible, three graduated poles (1.5 m high) are located to form a triangle of about 3 meters side. Public access to the site where the poles are placed was prevented, in order to avoid any influence to measurements.

The snow depth on the ground is assumed to be the mean of the three measurements taken.
The poles are marked every cm.

A.9.3.2 Ground snow density measurements

Tubes for density measurements are used. Tubes, made from stainless steel, have a diameter of 67 mm and 70 cm length or a diameter of 94 mm and 120 cm length. The tube, in the case of presence of ice on the roof can be used with a drill, in order to cut the ice and pull out the complete sample.

The sample is then weighed to determine the mean density of snow cover. A minimum of three samples are pulled out from ground snow cover.

A.9.3.3 Roof snow depth measurements

On each roof a minimum number of 6 poles are installed for each gabled or flat roof. The poles (0.8 m high) are placed on roofs excluding areas in which there are sensible influences from canopies, at a fixed distance from the edges (1 - 2 m).

Poles are fixed to the roof surface in three different ways:
a) using a precast concrete plate, 4 cm depth, as base for each pole;
b) fixing two poles in a thin timber table 3 m long, loaded with two precast concrete plates;
c) fixing several poles to a 2.5 cm depth table as long as the roof’s pitch, made up by several parts connected together by steel cables or similar connection devices. The table are then anchored to the roof edge.

Figures A.9.3-1 and A.9.3-2 illustrate the installed devices.

Location of poles on the roof is chosen with respect to the geometry of the roof and to the possibility of performing the measurements from the ground.

A.9.4 Roof snow density measurements

When direct access to the roof surface was possible, density measurements are made following the same procedure as for ground measurements.

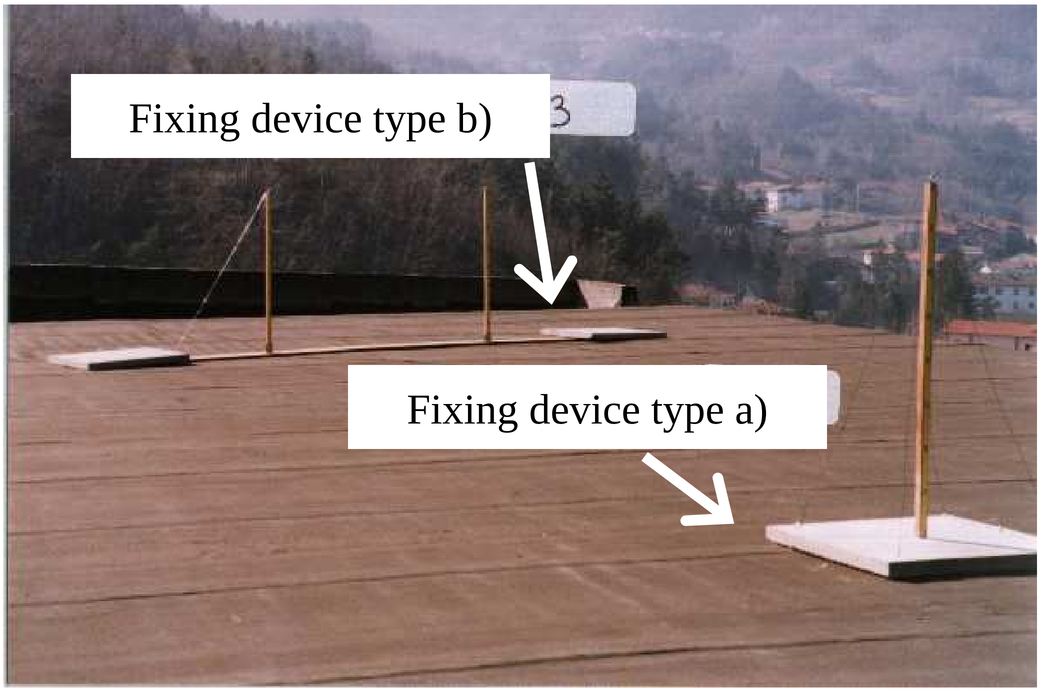


Figure A.9.3-1: Fixing devices type a) and b).

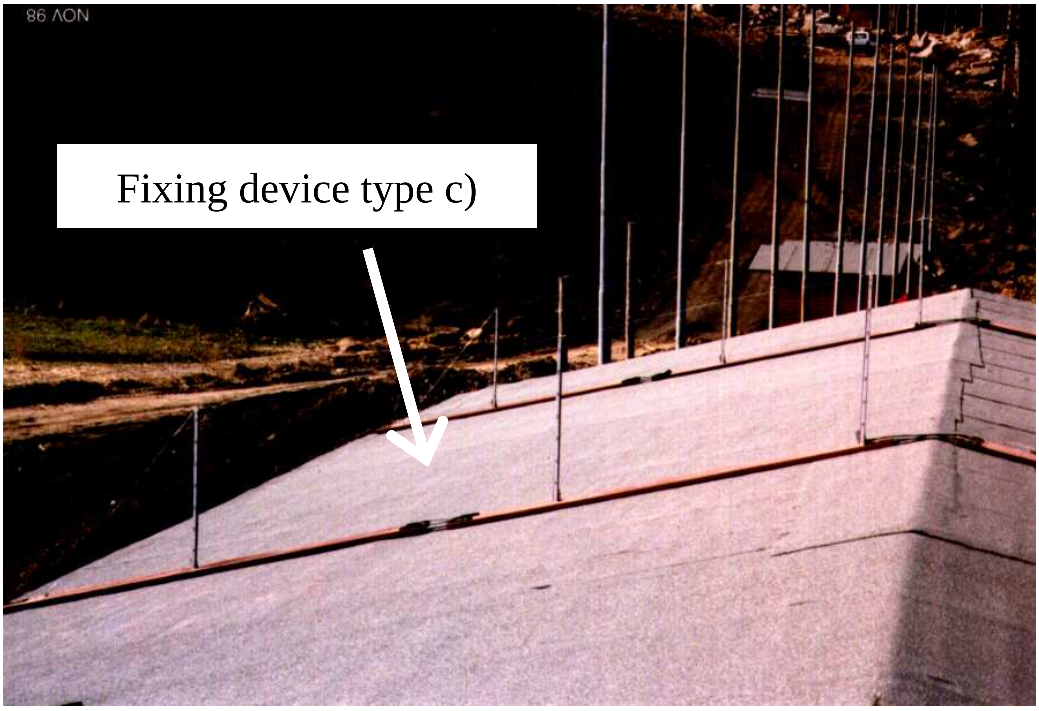


Figure A.9.3-2: Fixing device type c).

Annex 10 Snow measurements from Italy Dolomites

A.10.1 Introduction

ISMES contribution to “task d” is focused on the installation, operation and elaboration of a series of automatic meteorological and snow stations scattered on the Italian Alpinne arch, which furnished the necessary data to study the correlation between the snow load on the ground and the snow load on one of the roof pitches in different meteorological conditions and exposure of the pitches.

To accomplish the objective, ISMES equipped five stations between 1600 meters and 2090 meters above sea level in the Dolomites region, connected by radio with ISMES centre, which during the winter 1998/99, acquired the data of interest.

More in detail, some places already partially dedicated to generic meteorological measurements as part of a collaboration between ISMES and the Meteomont Service of the Headquarters of the Alpine Troops of Bolzano were used. This allowed reduction in the expenses of relief, made use of the radio links already installed and required only the installation of the transducers dedicated to the research.

These places, among other things, presented buildings with mainly with duo-pitched roofs at distances between 50 and 250 meters from the transducers. This reduced the number of sites required and roofs of such buildings were instrumented with a new dedicated system for the measurement of the data.

ISMES expresses respectful thanks to colonel S. Boriero of the Meteomont Service of the Alpine Troops Headquarter of Bolzano for the huge co-operation, the station availability and the data concession.

A.10.2 The Meteomont service

The operative and training assignments of the Alpine Troops and the natural scenery in which they operate rendered indispensable the presence of an organisation able to furnish the informative support, which is necessary to guarantee the highest safety in the mountain environment covered with snow.

In such context works the Meteomont service, which manages to get in the wider frame of the concept of prevention, safety and rescue, which all the time has been integrating part in the activities of the Alpine Troops Command.

The organisational system of the Meteomont service bases itself upon the following organs:

- the COMMAND of the fourth Alpine Troops Command, with leading, of co-ordination and control functions;
- the Meteomont Sector centres on level of Military Alpine School and Alpine Brigades, which are responsible of the service's realisation in the respective competence area;
- the METEOrological SNOW-GAUGE Monitoring network, for the acquisition of the daily and periodic observations;
- the Survey mobile groups, for the collection of the meteorological snow-gauge information in the zones not covered by the monitoring network.

Besides this it avails itself of the invaluable co-operation of:

- The METEOROLOGICAL service of the Air Force, which, through the METEOROLOGICAL Region Centre of Milan - Linate, furnishes the informative meteorological support, which is indispensable in the context of the snow-gauge valuation;
- The National corps of foresters, which manages autonomously, but with close technical and functional co-ordination, the prevision meteorological activity along the Apennine arch.

From 1989 onwards the Meteomont service has been subject to a substantial renovation and development in the meteorological snow-gauge data acquisition, registration and processing system.

The system architecture includes:

- A central archive for the computerised management of the snow-gauge data and of the military cartography of the avalanches, at the Command of the Alpine Troops Command;
- Concentrator and interrogation units, at Sector centreS level, for the acquisition, registration and processing of the data relative to the respective monitoring networks;
- Automatic survey stations, equal to nearly 50 % of the whole network; the radio broadcasting system for the link with the Sector centres.

The Meteomont Sector centres represent the service's primary operative element. In fact the task to furnish the meteorological snow-gauge assistance to the dependent units and other institutional users is assigned to them.

The principal activities carried out included the following ones:

- Organisations of the Sector centre and of the dependent meteorological snow-gauge network;
- Centralisation, registration and processing of the bulletins of meteorological prevision and snow-gauge assessment;
- Production and revision of the military avalanche's cartography.

The monitoring system is based upon the activity of a survey network consisting of 99 stations, 45 of which are automatic. The territorial distribution of the survey network was defined, in agreement with the regional and provincial organisations, so as to guarantee a widespread coverage of the areas subjected to the snow-gauge control and the integration with the civil networks.

The automatic survey station is equipped with sensors for the measurement of wind direction and intensity, temperature, humidity, barometric pressure and precipitation. It allows both the survey of the total depth of the snow mantle on the ground and the vertical thermal gradient of this snow mantle. The data acquisition is executed by means of an intelligent reading system based upon the use of programmable data loggers which interface directly with the data broadcasting system. This system constituted by digital radio units, sends directly the memory recorded data, both at request of the connected sector centre and at the overcoming of given threshold trigger values.

The manual station is constituted by a ground area, which is fenced to guarantee the snow mantle integrity and selected using particular orientation, exposure and altitude criteria. By using suitable instrumentation the assigned staff executes daily and weekly surveys.

The daily survey concerns meteorological, snow-gauge and other parameters relevant to avalanche observation, whereas the weekly one consists of a stratigraphical and penetrometric tests to detect in detail the physical and structural snow mantle characteristics.

The staff employed in the data survey service are qualified by means of a specialisation course for a period of four weeks, during which different subjects of interest are treated from both theoretical and practical considerations. These subjects include snow physics, meteorology, instruments and technical materials of survey, data codification procedures, prevention and safety in the snow-clad mountain and topography.

The METEOMONT SERVICE activity, from the point of view of the informative support for their users, is realised mainly in two technical documents of particular importance: the sector meteorological snow-gauge bulletin and the avalanche military cartography. More information on these topics can be presented by the METEOMONT SERVICE or by ISMES.

A.10.3 Integrated Meteomont station

The Meteomont reference stations are equipped with instrumentation for the acquisition of the following quantities:

1. Wind direction and speed direction;
2. Air temperature;
3. Humidity;
4. Barometric pressure;
5. Precipitation intensity;
6. Snow depth;
7. Snow temperature (at different eleven levels between 0 and 2,25 meters from the ground);
8. Snow load on the ground;
9. Snow ground instrumentation temperature.

The technical characteristics of the transducers are:

1. Wind direction and speed direction:
   direction: measurement range: 0°÷360°;
   precision: +3°;
   transducer type: potenziometric;
   Speed: measurement range: 0,5÷50 m/s;
   precision: 0,5 m/s;
   transducer type: HALL effect;
   temperature range: -40°C÷+50°C;

2. Air temperature:
   measurement range: -40°C÷+50°C;
   precision: 0,2°C;

3. Humidity:
   measurement range: 5÷100 % U.R.;
   precision: 3 %;

4. Barometric pressure:
   measurement range: 750÷1050 hPa;
   precision: 0,5 % of the measurement range;
   thermal drift: 0.1 hPa/°C;
   temperature range: -10°C÷+50°C;

5. Precipitation intensity (pluviometer):
   measurement surface (set aperture): 400 cm^2;
   precision: ± 1 mm;

6. Snow depth:
   measurement principle: ultrasounds;
   measurement range: 0÷5 m;
   precision: 2 cm;

7. Snow temperature:
   transducers number: 11;
   measurement range: -30°C÷+50°C;
   precision: 0,3°C;

8. Snow load on the ground:
   a measurement snow load system (denominated "snow pillow"), of the type already used in the stations of the system "SNOTEL" realised in the rocky mountains chain to detect the quantity of snow fallen during the winter period and the consequent planning of the water summer distribution. It concerns a load cell, with diameter of 500 millimeter, which must be positioned on a flat surface free from obstacles in the vicinity of the measurement place. This measurement, together with the detection of the ground snow depth, allows the calculation of the snow density;
9. Snow pillow temperature:
   measurement range: -30°C÷+50°C;
   precision: 0,3°C;

Every station is furnished with an intelligent reading system based on the use of a programmable data logger, which can interface with the data teletransmission system.

The data logger has the following acquisition channels:

1. n. 5 channels for the measurement of:
   - atmospheric pressure;
   - air relative humidity;
   - snow mantle level;
   - battery voltage;
   - (free);

2. n. 1 channel for the air temperature measurement;
3.
4. n. 11 channels for the measurement of the snow mantle temperature at different mantle levels;
5. n. 1 channel for the measurement of the snow pillow temperature;
6. n. 1 channel for the wind direction measurement;
7. n. 8 channels for the following quantities:
   - wind speed;
   - rain falls;
   - rain presence;
   - hoarfrost presence;
   - ice presence;
   - violation attempt signalling;
   - (free);
   - (free).

The data logger can support the transducers with continuous current, with a voltage which can be set at the values: 5, 12 e 24 VDC.

The measurement system has an automatic scale on 4 decades, with selection between 0,01 and 10 V. The A/D converter has a resolution of 12 bit plus sign, which corresponds to a resolution of 0.0024 mV at the highest sensitivity.

The management firmware of the data logger can put into action completely automatically the calibration functions of the measurement chain and this function is activated at the beginning of each measurement phase.

The connection between data logger and acquisition systems is realised by serial interface standard RS232.

A.10.4 Main hardware characteristics

The measurement channels are set with the following physical quantities:

1. Wind direction measurement:
   - 1 analogue multiple input for sensors of “resolver” type with 3 phases;
   - sensor supply 5 V;
   - highest current 10 mA;

2. Wind speed measurement:
   - 1 digital input for active sensor type “contactless”;
   - output level TTL;

3. Air temperature measurement:
   - 1 thermometric input for sensors Pt100;
   - measurement technique with an imposed constant current of 1 mA;

4. Relative humidity measurement:
   - 1 hygrometric input for active analogic sensors;
   - measurement range from 0 to 1 V;
   - sensor supply voltage 5-12 V;
   - uses 20 mA;

5. Atmospheric precipitation measurement:
   - 1 digital input for sensor with switch on-off;
   - output level TTL;

6. Snow mantle depth measurement:
   - 1 analogue input in tension with measurement range from 0 to 1 V or in current from 0 to 20 mA; sensor supply voltage 12 VDC;

7. Atmospheric pressure measurement:
   - 1 analogue input for pressure sensors with amplified output;

- measurement range from 0 to 2 V;
- sensor supply voltage variable between 5 and 24 VDC;

8. Alimentation voltage measurement:
   - 1 analogic input for voltage measurement from 0 to 15 VDC;

9. Thermal contour measurement:
   - 12 analogic differential inputs for thermometric measurement of sensors Pt100 - interconnected in series. The chain connection is realised with 15 conductors.

10. Logic states measurements:
    - 6 digital inputs for the detection of the presence of rain, hoarfrost, ice, against intrusion, test 1 and test 2;

Common characteristics of all above described channels:

1.	Measurement resolution:	0,025 % of the scale end;
2.	Measurement precision:	0,5 % between 0 and +40°C;
3.	Measurement scales:	0,02, 0,2, 2 and 15 V;
4.	A/D converter:	12 bit more sign, double slope;
5.	Speed measurement:	25 channels/second;
6.	Sensors supply:	5 V, 12 V and 24 V (100 mA);
7.	Data static memory:	120 Kbytes;
8.	Data maintenance:	with lithium battery;
9.	Serial line RS232:	full-duplex: 1200...9600 baud rate;
10.	System clock:	year, month, day, hour and minutes;
11.	Battery supply:	internal and/or external from 10 V to 15 V;
12.	Temperature range:	from -35°C to +70°C;
13.	Relative humidity:	up to 99 % with condensation formation;
14.	Container:	tin in aluminium IP67 anodised;
15.	Dimensions:	diameter 120 mm, length 450 mm;
16.	Input and output connectors:	type VPT of 10 and 19 pin.

A.10.5 Main software characteristics

The data Logger is furnished with a specific firmware able to:

1. Acquire and elaborate the quantities to be measured in agreement with modalities, which are programmable on the basis of a series of elementary operations, that are prearranged in the elaborator; the values are acquired with intervals of 3 hours;

2. Execute a statistical preelaboration on basis of variable measurement of all the selected quantities, with the aim to furnish synthetic data with high information content;

3. Furnish statistical reports which will be the result of a series of data acquired with frequency greater than the one of the measurement basis and also programmable from 15 seconds to 24 hours.

4. For the management of the data acquisition net the data logger is furnished with user-friendly software for operational system MS-DOS and IBM compatible. The programme can execute the following operations:
   1. Data logger configurations;
   2. Data logger programming;
   3. Measurement cycle activation;
   4. Data logger acquired data collection;
   5. Data acquired elaboration;
   6. Data logger autocalibration functions activation;
   7. Data logger net management;
   8. Data logger with radio inquiry;
   9. Acquired data graphic;
   10. Acquired data print;
   11. Collected files management.

Ground snow depth and snow density measurements were carried out in one station as integration of the automatic measurements by means of periodical relieves of the snow mantle, which were executed near the automatic stations in enclosed areas where the snow mantle was kept unchanged.

A.10.6 Snow roof system

A new dedicated system for the acquisition of the snow measurements on the pitches was designed and installed on the five roofs, in correspondence of the five integrated Meteomont stations. It includes two snow pillows and their temperatures. The characteristics of the snow pillows, temperature cells and acquisition system are the same of the integrated Meteomont system. The electrical power was supplied by the electric grid or by solar panel.

A.10.7 Snow pillow

The adopted developed snow pillow is the result of the studies and experiences carried out on pressure pads for geotechnics and foundation applications.

The fifteen snow pillows (three transducers per five stations) were filled up with mineral multigrade oil (-30°C÷+80°C), positioned in the ISMES climatic chamber

In the chamber a climatic cyclic test in the range from -30°C÷+30°C was executed, measuring the temperature and the current signal, as for example reported for a snow pillow. For each pressure pad a frame made up with special wood for corrosive use was prepared, which was filled up with sand. The pad was then positioned in the frame before being sealed with silicone.

A.10.8 Stations and buildings

Among the 45 automatic Meteomont stations five were selected with a building with a duo-pitched (gabled) roof within 50 to 250 meters of the station. The following constructions near the Meteomont stations were selected:

- A.8 Passo del Tonale Meteomont station and Alpine barracks
- A.9 Passo del Tonale Alpine barracks
- A.10 Negritella refuge
  - Fermeda Meteomont station and refuge
  - Scotter refuge
- A.11 Varmost alpine hut on the right from North
- A.12 7.Ground and roofs instrumentation

For each station three snow pillows were positioned respectively: one on the ground near the Meteomont station above a sand layer without the wooden frame and the other two on the opposite pitches within the wooden frame, which was fixed to the roof by means of metal ropes anchored to the eaves.

The snow pillows on the two brick roofs (Negritella and Fermeda refuges) and on the wood roof (Varmost alpine hut) were covered with jute to adapt its radiation coefficient to that of the roof.

For the same reason the snow pillows on the two steel roofs (Tonale Alpine barracks and Scotter refuge) were painted.

The snow pillows were installed both on the ground and on the two opposite pitches for the five stations and corresponding roofs.

For each building the quoted axonometry, the sketch with dimensions, and the snow pillow’s position are reported.

A.10.9 Data elaboration

The acquired data after the transmission by means of radio links were elaborated. The first step was to consider the following aspects:

1. The accuracy of the snow load cells was calculated as ratio between the current difference as to its full range ratio and the temperature difference; this is multiplied by 100 as to obtain the full range fraction in per cent;

2. The snow load cell's accuracy varied in the range 0,12÷0,28 kN/m² and was lower the greater the snow cover was, due to its thermal stabilisation effect;

3. The data units were respectively: depth [cm], density [kg/m³] and snow load [kN/m²];

4. It was considered only respectively: snow depth values above 3 cm; snow load values above respectively 0,4 [kN/m²] when there wasn't snow cover and 0,1 [kN/m²] when there was snow cover. The density was considered only when there was snow cover.

The second step was to elaborate the data for each station by means of an electronic data file made by ten sheets, which were respectively:

1. Meteo_data with the following values: date; hour; wind direction; wind speed; air temperature; air humidity and eleven temperatures in correspondence of same sensors at different heights;

2. Ground_data with the following general values: date; hour; air pressure; with the following reading ground values: snow depth; cell temperature; cell voltage and the following calculated ground values: snow relative depth; cell pressure; cell pressure without the air pressure variation; relative cell pressure without the air pressure variation; relative cell pressure without the air pressure variation corrected by the thermal effect; snow load and density;

3. Ground_graph of the ground snow load and ground snow depth versus the time;

4. Ground_density_graph of ground density versus the time;

5. First_roof_data with the following general values: date; hour; air pressure; with the following reading first_roof values: cell temperature; cell current and the following calculated first_roof values: cell pressure; cell pressure without the air pressure variation; relative cell pressure without the air pressure variation; relative cell pressure without the air pressure variation corrected by the thermal effect, snow load and ratio between the first_roof snow load and the ground one;

6. First_roof_graph of the first_roof snow load versus the time;

7. Second_roof_data with the following general values: date; hour; air pressure; with the following reading second_roof values: cell temperature; cell current and the following calculated second_roof values: cell pressure; cell pressure without the air pressure variation; relative cell pressure without the air pressure variation; relative cell pressure without the air pressure variation corrected by the thermal effect, snow load and ratio between the second_roof snow load and the ground one;

8. Second_roof_graph of the second_roof snow load versus the time;

9. Ground-roofs_loads_graph respectively of the ground, first_roof and second_roof snow loads versus the time;

10. Roof f=(ground) loads_graph of the ratios between the first_roof and second_roof snow loads and the ground one versus the time.

Meteo_data, ground_data and first_roof_data sheet examples are reported.

In the station of Tonale Alpine barracks some manual snow measurements were carried out twice a day from 8.15 December 14, 1998 till 7.50 April 30, 199 by the Meteomont Service Troops and in particular the density and the depth, which was not available in automatic way.
Therefore the resulting snow density, which was calculated as ratio between the snow load and the snow depth, was only in the case of semi-automatic type.

The initial and final automatic acquisition time per each station are reported.

The automatic data were acquired every three hours. Some interruptions occurred. Until 6.00 February 18, 1999 the elaboration was carried out completely, afterwards it was limited to data every six hours.

For each station of the following: 1) ground snow load and ground snow depth, 2) ground density, 3) ground together with first and second roof snow loads, 4) ratios between the first roof and second roof snow loads and the ground one are measured with respect to time.

The time of the manual snow density measured in the station of Tonale with the semi-automatic one are reported.

The ground snow depth and the ground snow load result in agreement.

The calculated snow density varies in the range 150÷350 Kg/m^3 according to the snow falls, melting and strengthening. In the Tonale station the manual density and the semi-automatic one, in spite of the different equipment characteristics, are adequately comparable.

The three snow pillows comparison furnishes very interesting indication particularly if combined with the available wind information.

The ratios between the first roof and second roof snow loads and the ground one are the main results.

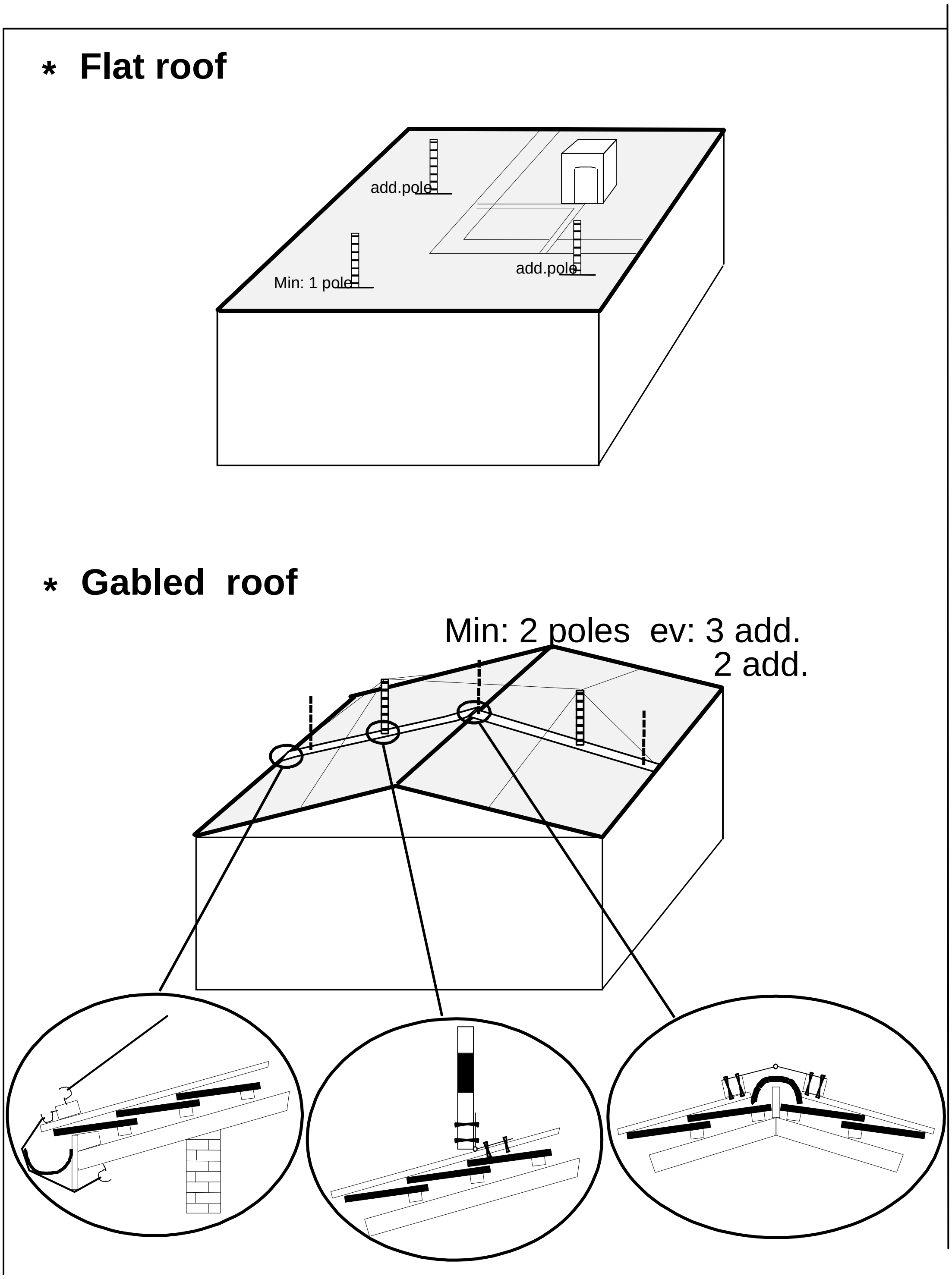
This system with its completeness provides the global snow picture; due to its three hours measurement interval it supplies admirable snow depth, loads, density and shape coefficients histories with specific information of the snow fall event which couldn’t otherwise be obtained.

Annex 11 Snow measurements in Switzerland

With the observes a short contract on their duties were established. The observers were mostly official observers of the SLF or the SMA.

In figure A.11-1 the used measuring technic on the Swiss roof is shown. No problem arised during the winter 1998/99 with this technic. It can be recommended for future work, although costs for mounting and demounting are considerable.

Figure A.11-1 Measurement technique, mounting of poles on roof



Annex 12 Snow measurements in Germany

The sites with snow roof measurements in Germany during the winter 1998/99 are summarised in the table A.12-1:

Table A.12-1: German stations with roofs for snow measurements

Place	Altitude	Building	Roof slope	Meteorological station
Carlsfeld	880 m	Barn	45 °	distance 500 m
Carlsfeld	880 m	Stable	30 °	distance 500 m
Leipzig	141 m	Garage	18 °	near

Altitude: 880 m
Latitude: 12o36'
Longitude: 50o26'

The measuring campaign was started in Carlsfeld, Erzgebirge on the 14th November 1998.

The village Carlsfeld is located near the border to the Czech Republic at the north slope of Erzgebirge mountain crest. The altitude is about 900 m above see level. There are about 150 days of frost per year (on a day of frost the temperature has to be at one time below zero degree).The average amount of precipitation per year is about 1478 mm. The general wind direction is westerly. All this causes a cold climate with reliable falls of snow. There is also a quite small amount of solar radiation especially during the winter because of the exposure.

From the topographical map (figure A.12-2) it can be seen that the site with roof snow measurements as well as the meteorological station are situated at an elevated plain between 880 m and 900 m above sea level. Around both sites one can see a relatively free space although the elevated plain is predominantly covered by spruce forest. The meteorological station is more exposed to the sun than the buildings with roof measurements. That is why the ground snow data of the two sites are usually different.

The equipment for roof snow measurements was installed by Mr Wallschläger, the owner of the site. Mr Wallschläger also made the snow observations every day. The graduated poles are made from aluminium and partly from fibre glass. Figure A.12-3 shows the positions of all the poles on the gabled roofs of two buildings. The length of the poles at the windward side (predominantly west side) is 75 cm. The length of the poles at the leeward side (predominantly east side) is 125 cm. This is because the snow is usually accumulated at the leeward side.

Relevant obstacles for building 2 is the group of trees (located westerly). For building 1 the building 0 (located northerly) may have an influence (see figure A.12-3).

The visual description of the site, the procedure of measurements and the process of snow accumulation on the gabled roofs can be seen from the pictures made on the 21th February 1999 (maximum air temperature: 20 °C below zero; ground snow depth: 62 cm; sky is cloudy).

Figure A.12-2: Topography of the measuring area

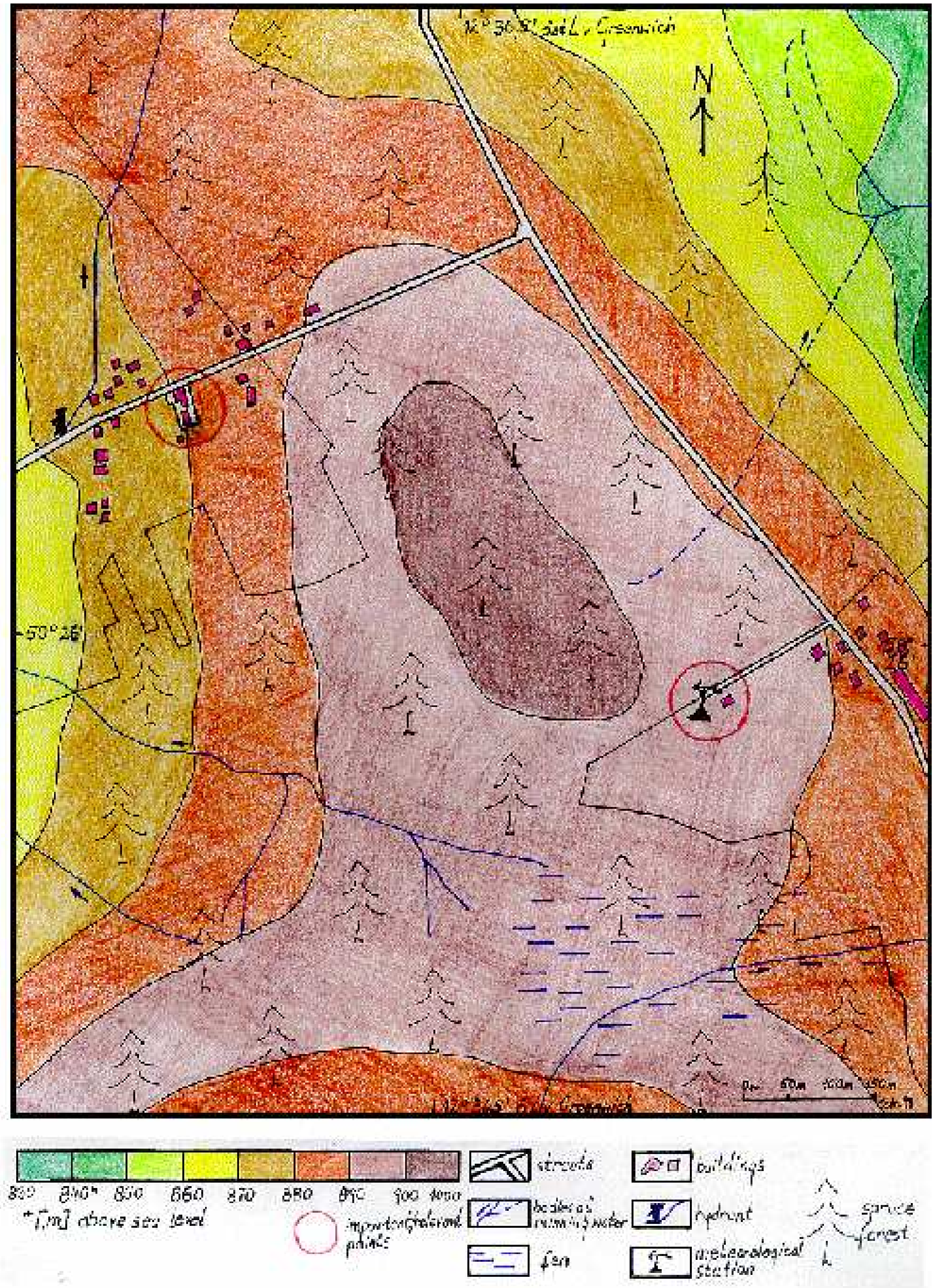


Figure A.12-3: Location of the buildings and position of the measuring equipment

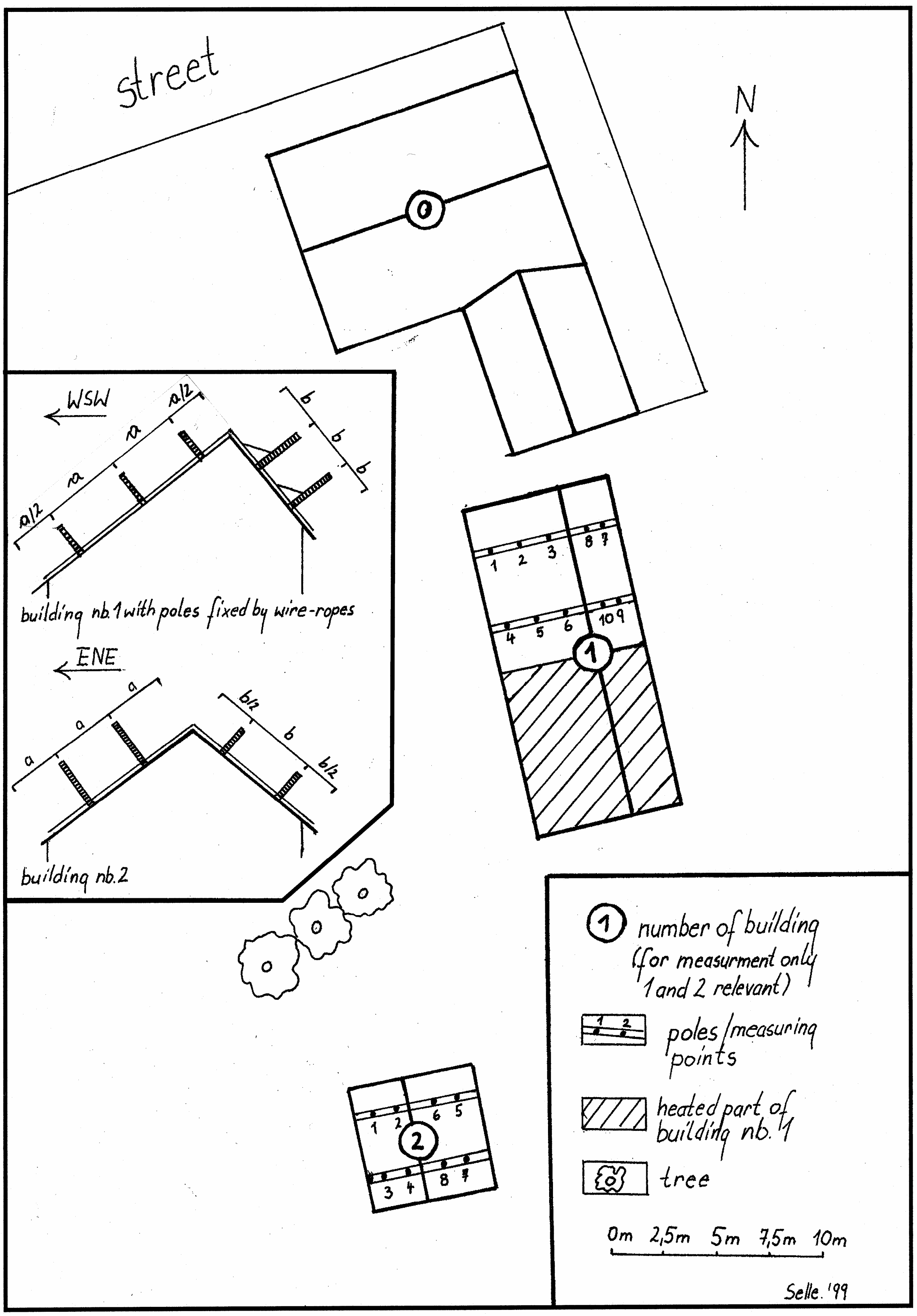


Figure A.12-4: Building 1, small amount of snow at the windward side, building 0 can be seen on the left, in NNW direction

Figure A.12-5: Building 1, windward side, roof material is roofing felt, the length of the poles is 75 cm

Figure A.12-6: Building 2, windward side, the group of trees is located in NNW direction

Figure A.12-7: Building 2, leeward side, the poles are fixed in the timber beam

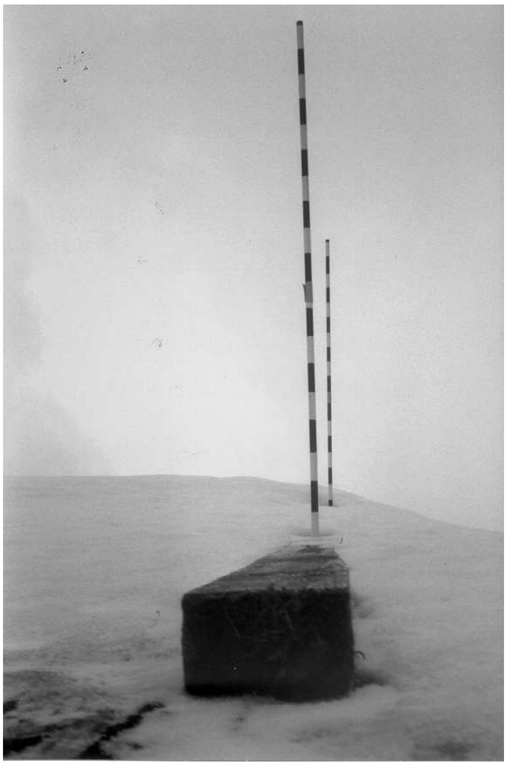


Figure A.12-8: Building 1, windward side, snow lays only above the unheated part of the building

Figure A.12-9: Building 1, leeward side

Figure A.12-10: Building 2, snow accumulation on the ground and on the roof at the leeward side

Figure A.12-11: Building 2, leeward side, differences of snow layer between southern and northern part of roof side

Figure A.12-12: Building 2, leeward side, in the background - the pole number 8 with maximum snow depth

Figure A.12-13: Site of the ground snow measurements

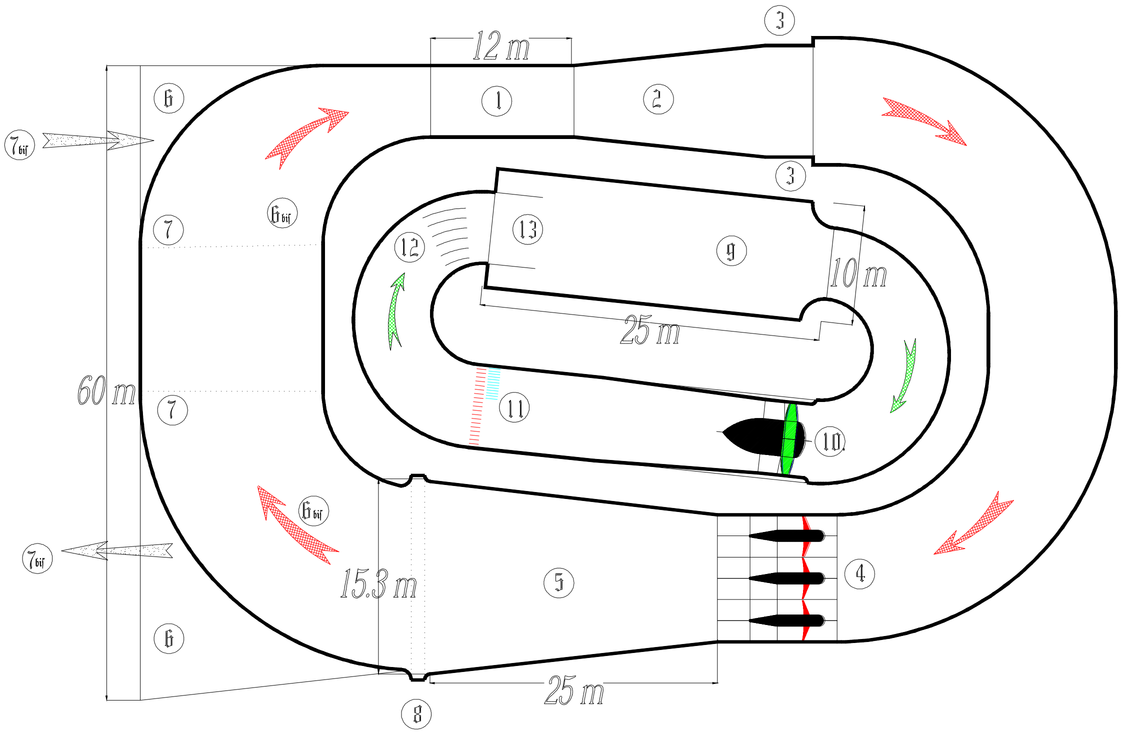
Annex 13 Wind tunnel information

A.13.1 Wind tunnel description

A.13.1.1 General description of the facility

The Climatic Wind Tunnel Jules Verne run by Aérodynamique et Environnement Climatique (AEC) Department of Centre Scientifique et Technique du Bâtiment (CSTB) aims to develop the physical knowledge and understanding of the influence of wind and other climatic parameters on buildings, structure elements, industrial pieces of equipment and vehicles.

Figure A.13.1-1: Facilities of the climatic wind tunnel Jules Verne



One of the strength of the facility shown in figure A.13.1-1 is the possibility to simulate and fully control the combinations of climatic parameters to perform tests on a full scale basis which is often the only relevant experimental scale. In order to offer the widest range of simulation possibilities, two different circuits were built:

- The external ring called dynamic circuit (or unit) enables the reproduction of the spatial and temporal evolution of natural wind up to an average of 100 km/h in the environmental test section (5). The modelled air flow can be associated with rain (up to 250 mm/h) or sand storms (the sand concentration can reach 10 g/m^3 in a 10 m^2 section). The highest air flow speed of 300 km/h is reached in the 30 m^2 cyclonic test section (1). The equipment of this test section include a six component balance associated to a turntable and a boundary layer trap. The total power of the adjustable pitch fan is 3200 kW.

- The internal ring called the thermal circuit (or unit) can reproduce thermal ambiances from -25 °C to + 50 °C and relative humidity from 30 % to 100 % in the test chamber whose cross section is 70 m^2. According to the section of the adjustable nozzle (13), the maximum air flow speed can be set from 90 km/h to 140 km/h. Snow guns are used to produce a thick snow mantle (15 cm/h) on the 200 m^2 floor of the test chamber. The snow quality related to the snow water content is adjustable. Other climatic parameters as frost, fog, hail and solar radiation can be reproduced. A roller bench (250 kW) whose rotating speed is linked to the wind speed and a burnt gas extractor are dedicated to automotive testing. The total electrical power necessary to run the thermal unit is 3000 kW spread in 1000 kW for the fan and 2000 kW for the cooling system.

A.13.1.2 Model scale snow load simulation

The chosen model scale of 1/10 suited the test section width. This rather large scale presented also a good compromise with regard to blockage effects and drifting similitude. The turbulence rate was adjusted over the snow mantle in the test section to be similar to the turbulence over an open field terrain (category II).

Exact 2-phase flow similarity is impossible to achieve and the experimental modelling of snowstorm imply approximations. Snow accumulation is dominated by global and local aerodynamic effects (boundary layer, vertical gradient, separation and reattachment zones). To simulate this process at reduced scale it is first necessary to reproduce mean and turbulent flow. In addition, it is necessary to achieve similarity of particles trajectories.

Similarity conditions can be listed as follows:

- Similarity of the mean and turbulent flow
- Similarity of local flow behaviour (Re > 10000 for sharp-edged buildings)
- Similarity of the bulk hydraulic properties of the snow phase (threshold friction velocity u_{*t}, terminal fall velocity w_f, density ratio ρ_s/ρ where ρ_s is snow density and ρ air density)
- Saltation hop length l of model snow particles significantly smaller than the overall dimensions of the roof (l << H and l << L where H and L are characteristic roof dimensions).

The snow properties summarised in table A.13.1-2 are considered. The snow properties are realistic with regard to natural European usual snow fall.

Table A.13.1-2: Properties of snow particles of natural and artificial snow

Property	**Natural snow**	**Artificial snow**
Diameter, D (mm)	0.5 to 5	0.15 to 0.3
Particle density ρ_s, (kg/m^3)	700 to 50	910
Fluid density ρ, (kg/m^3)	1.22	1.34
Terminal fall velocity W_f, (m/s)	0.03 to 0.5	0.5 to 1.2
Snow cover density (kg/m^3)	100 to 600	315 to 370

Similarity of the forces acting on the prototype and model airborne particles is necessary. The particle trajectories are similar if the ratio of gravitational forces to aerodynamic forces as well as the ratio of inertial forces to gravitational forces are the same for both model and prototype.

On the one hand, the similarity of gravity and inertial effects requires that densimetrical particulate Froude number is kept constant :

$$\left(\frac{V_h{}^2 \rho_s}{Dg(\rho_s - \rho)}\right)_m = \left(\frac{V_h{}^2 \rho_s}{Dg(\rho_s - \rho)}\right)_p ,$$

where Vh is the mean wind speed at roof level. The subscript m refers to model and the subscript p refers to prototype (full scale).
For the model particle, the densimetric Froude number range from 1.1 10^4 to 5.4 10^3 (average value : 8.2 10^3).

If one compare the modelling situation to a particular prototype experiment (D=2mm, ρ_s=50kg/m^3) the average densimetrical particulate Froude number value leads to a full scale wind velocity V_{hp} = 12.5 m/s for a model wind velocity V_{hm} = 4 m/s.

On the other hand, for gravitational to fluid force ratio the relation is : $\left(\frac{W_f}{V_h}\right)_m = \left(\frac{W_f}{V_h}\right)_p$,

where W_f is the terminal fall velocity and the V_h mean flow velocity. It leads to a full scale wind velocity V_{hp} = 1.3 m/s for a model wind velocity Vh_m = 4 m/s.

These two approaches seem contradictory, so in order to select the dominant one for snow deposition on roof the results from field measurements were compared to wind tunnel results. A snow fall with wind has been observed in Italian Alps at Fermeda from 9/01/99 to 11/01/99 [ISMES Spa, 1999]. Weather conditions and snow load measurements are showed in figures A.13.1-3 and A.13.1-4.

Figure A.13.1-3: Weather conditions at Fermeda

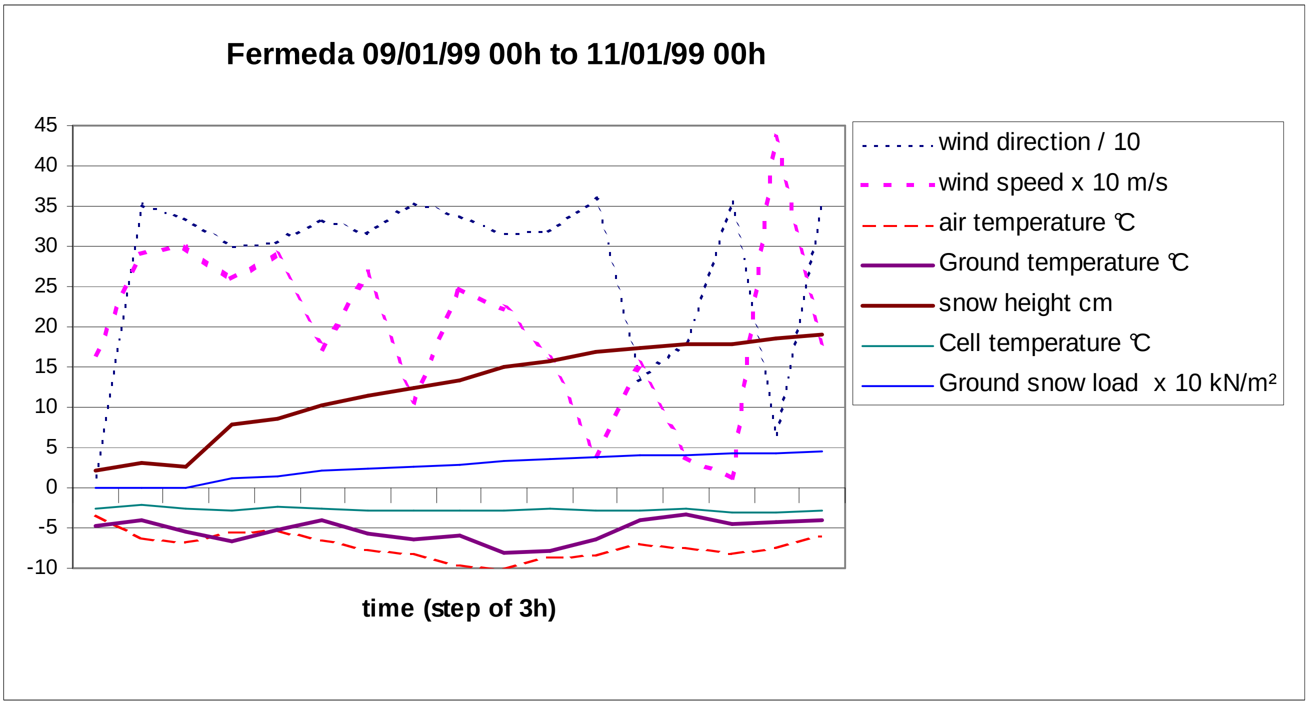
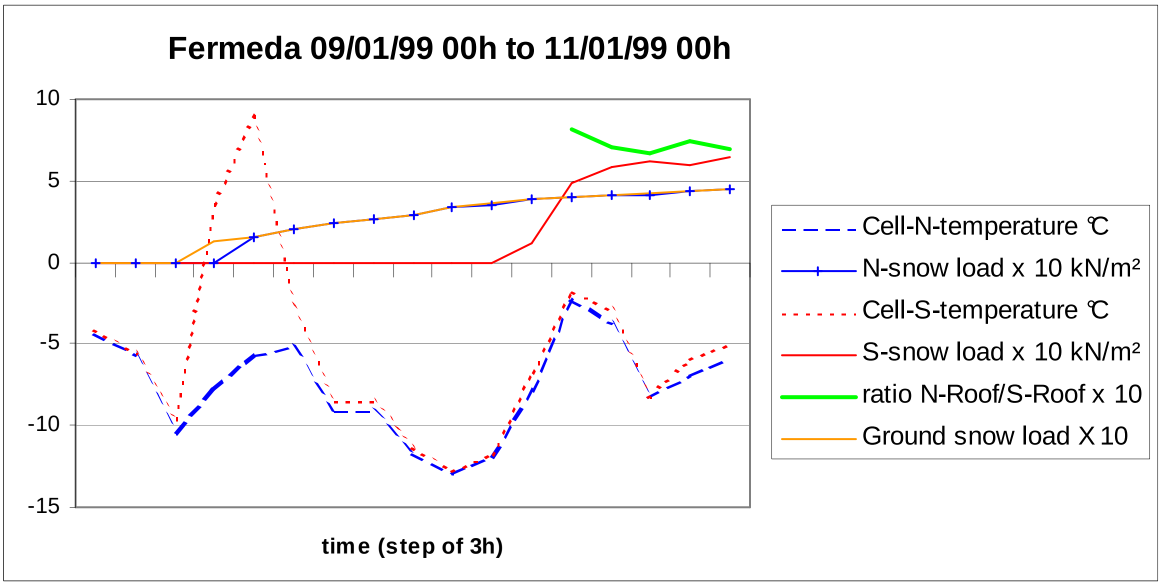


Figure A.13.1-4: Snow loads measurements at Fermeda



On site measurements lead to a ratio north roof load (windward) to south roof load (leeward) of 0.7 for an average wind during the snow fall of 2.7 m/s.

A wind tunnel test carried out with usual wind velocity for snow load simulations of 4 m/s leads to a ratio north roof load to south roof load of 0.6 (figures A.13.1-5 to A.13.1-7). This result was obtained for an equivalent snow quantity on north roof for both prototype and model (i.e. for 30 minutes wind tunnel test). The wind tunnel ratio is lower than the on site ratio, this is probably due to the higher wind velocity (more unbalanced snow loads in the wind tunnel). This comparison test indicates that wind velocity values in the wind tunnel is quite close to the real wind velocity, although the model is at 1/10 scale.

Figure A.13.1-5: Fermeda 1/10 scale model (South view)

FigureA.13.1-6: Snow cover after one hour wind 4 m/s (East view)

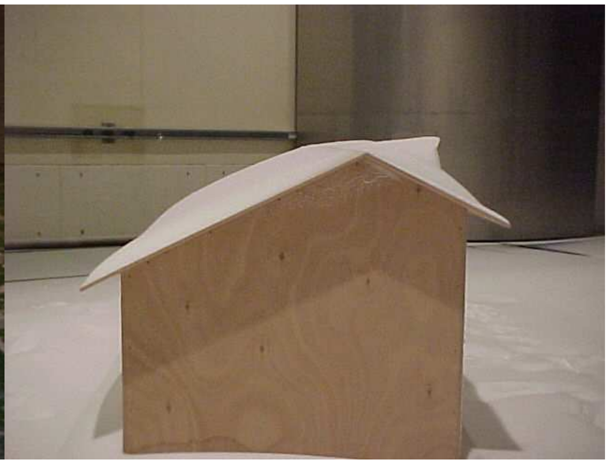
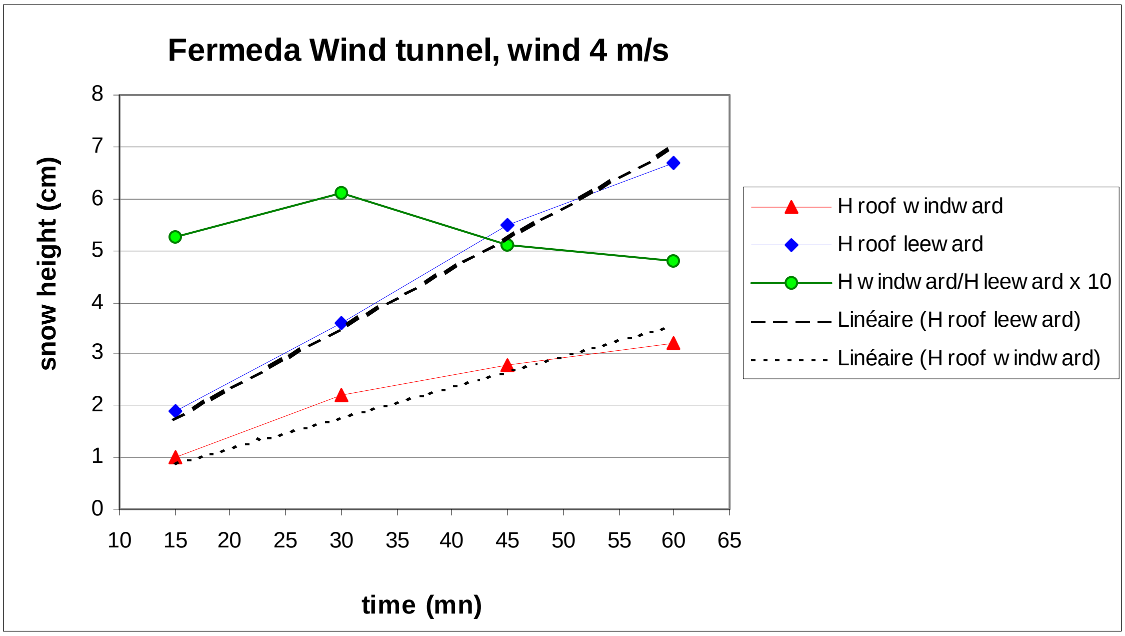


Figure A.13.1-7: Wind tunnel snow measurements



Snowstorm duration

The evaluation of the equivalent prototype snowstorm duration with respect to the model wind velocity and experiment duration is one of the main difficulties of experimental snow load modelling.

Set Δs, the quantity of snow accumulated during the storm, and Δt the duration of the snowstorm. According to Isyumov et al., 1997, the accumulation rate Δs/Δt should verify the equation:

$$\left(\frac{\Delta s}{\Delta t} \Big/ V_h\right)_m = \left(\frac{\Delta s}{\Delta t} \Big/ V_h\right)_p$$

For the Jules Verne wind tunnel, due to a rather high snow particle density in the wind tunnel air flow, the calculation of the equivalent accumulation rate does not lead to a realistic value.

Actually it seems more relevant to deduce the prototype experiment equivalent duration by comparing the results of prototype observations and model experiments.

The wind tunnel accumulation rate of snow on the ground was, for a single snow event with wind (4 m/s) of 1 hour: 12 cm/h. The equivalent prototype snow event would have induced a 120 cm snow fall.

From field observations [Boisson-Kouznetzoff (1997)], the accumulation rate in nature is included in the interval 0.5 to 5 cm/h.

This means that with respect to the wind tunnel modelling, the equivalent prototype snow event would last between 120/5 = 24 h and 120/0.5 = 240 h.

A.13.1.3 Particularities of snow load tests

Snowstorm for the unbalanced loads on roof was simulated with a wind of 4 m/s and dry snow in order to give an influence to aerodynamic effects.

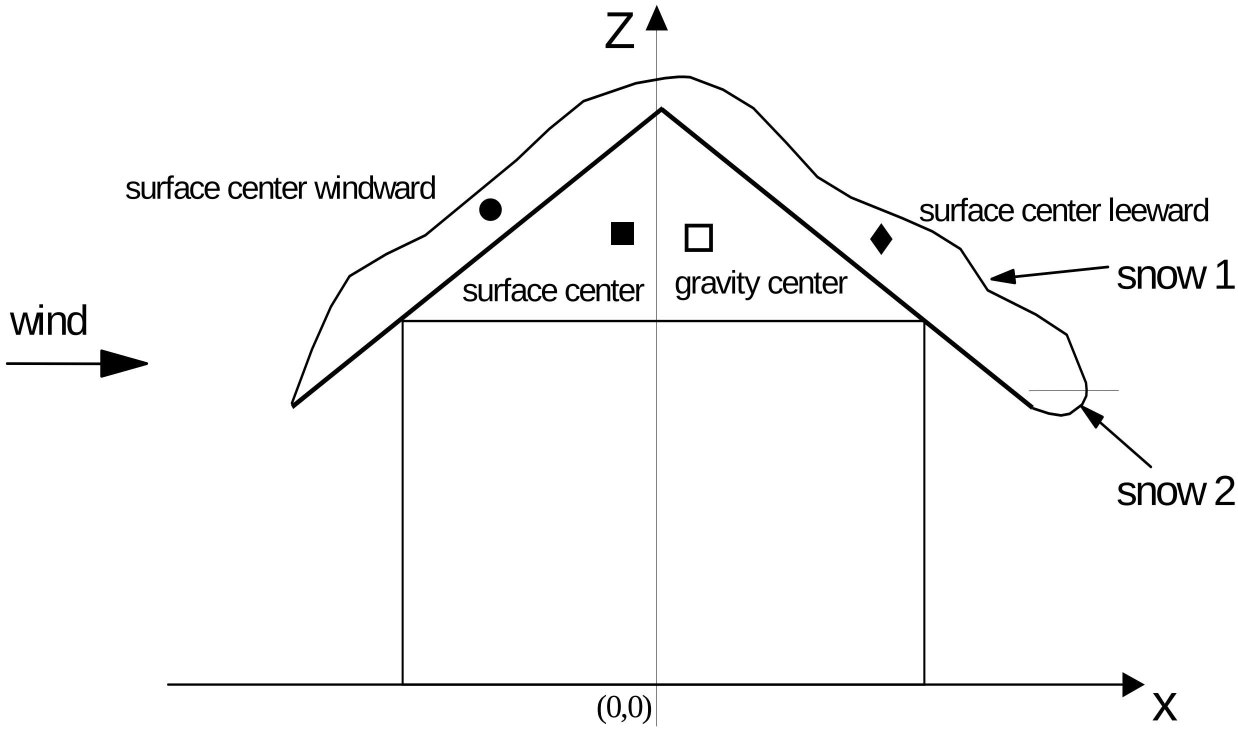
The liquid water content of the snow can be evaluated by a calorimeter. The principle of this measurement is simple: A sample of snow is taken from the wind tunnel and weighed. The temperature of the snow is measured. The snow is melted by mixing it with a known quantity of hot water (known temperature) in a calorimeter. Once the snow is melted, the final temperature of the liquid is measured. A simple heat balance, which takes into account the equivalent water mass of the calorimeter and the heat losses, enables the heat quantity necessary to melt the snow and finally the mass percentage of the liquid phase of the snow to be deduced.

Initially a complete characterisation of the snow quality was achieved in the wind tunnel. The measurements made were aimed at determining the liquid water content of the snow and its evolution with respect to the air/water ratio of the spray or the distance from the snow guns.

Snow load simulations with higher wind velocities would require a longer adjustment phase. Since the snow is produced in the wind tunnel by the freezing of water droplets and since the freezing process requires a finite period of time (~ 2 or 3 s.), it is quite obvious that if the distance between the snow guns and the model is unchanged, the increasing of the wind speed would generate a solid ice layer on the model instead of a snow mantle.

For high speed snow testing the usual procedure is to adjust the location of the snow guns in the wind tunnel in order to keep the time of flight of the droplet long enough.

A.13.2 Experimental snow layer profiles for 1st sub-task



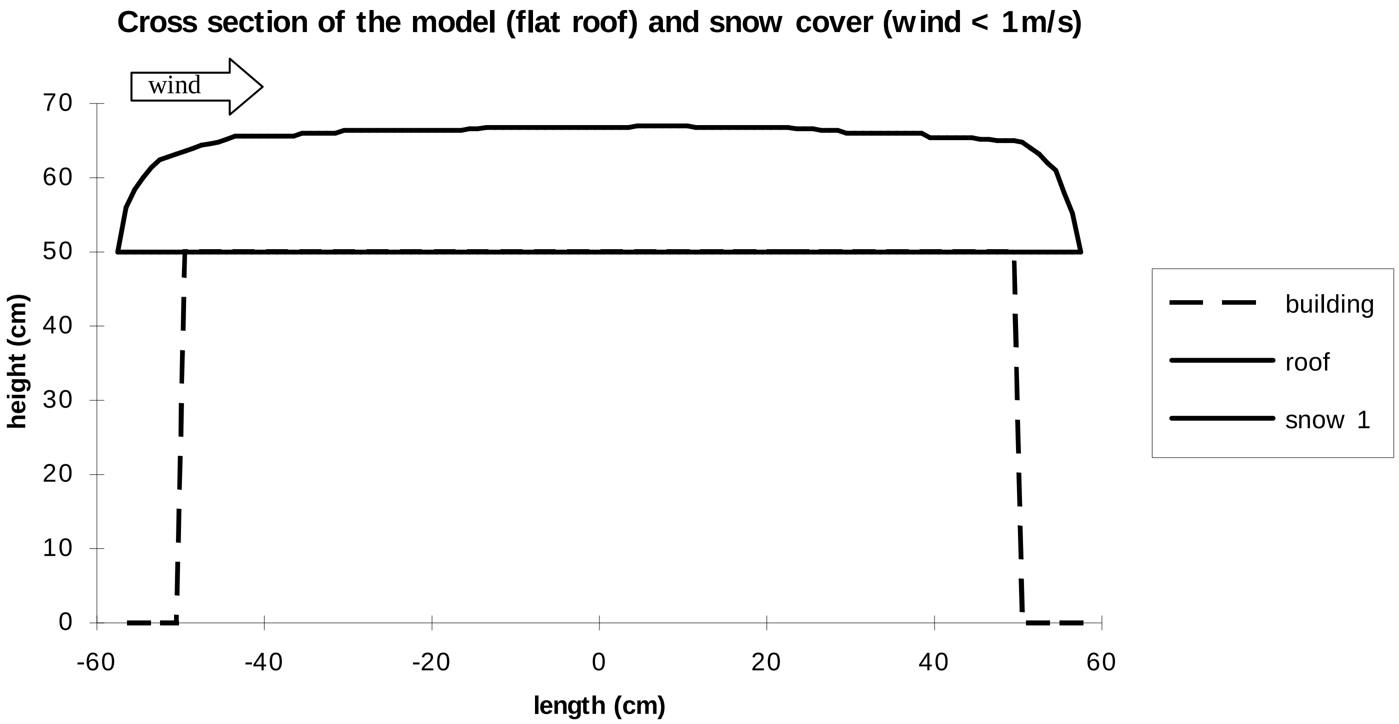
snow cover characteristic definition

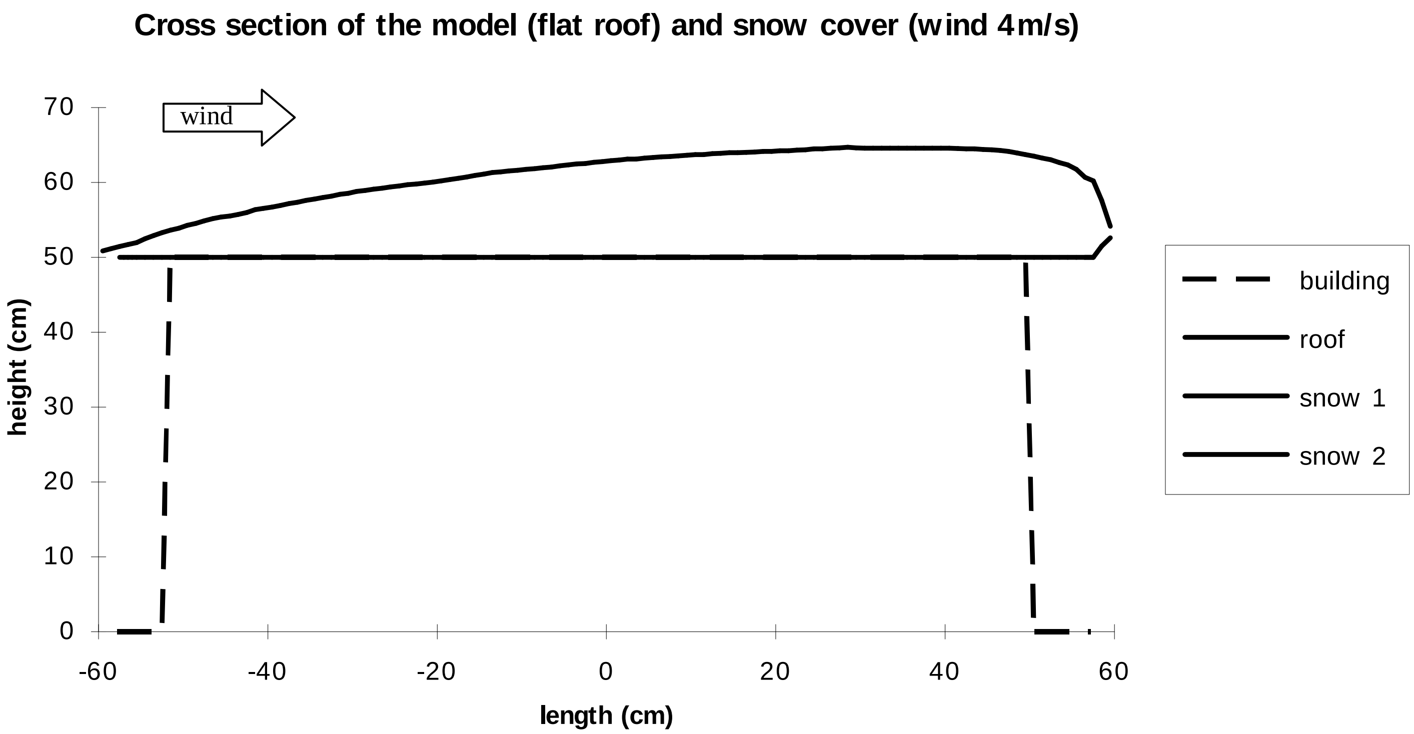
Snow density in the wind tunnel (kg/m^3)

		ground	roof windward	roof leeward
flat roof	wind <1 m/s	365	365	365
	wind 4 m/s	360	355	368
gable roof	wind <1 m/s	365	365	365
	wind 4 m/s	360	384	329

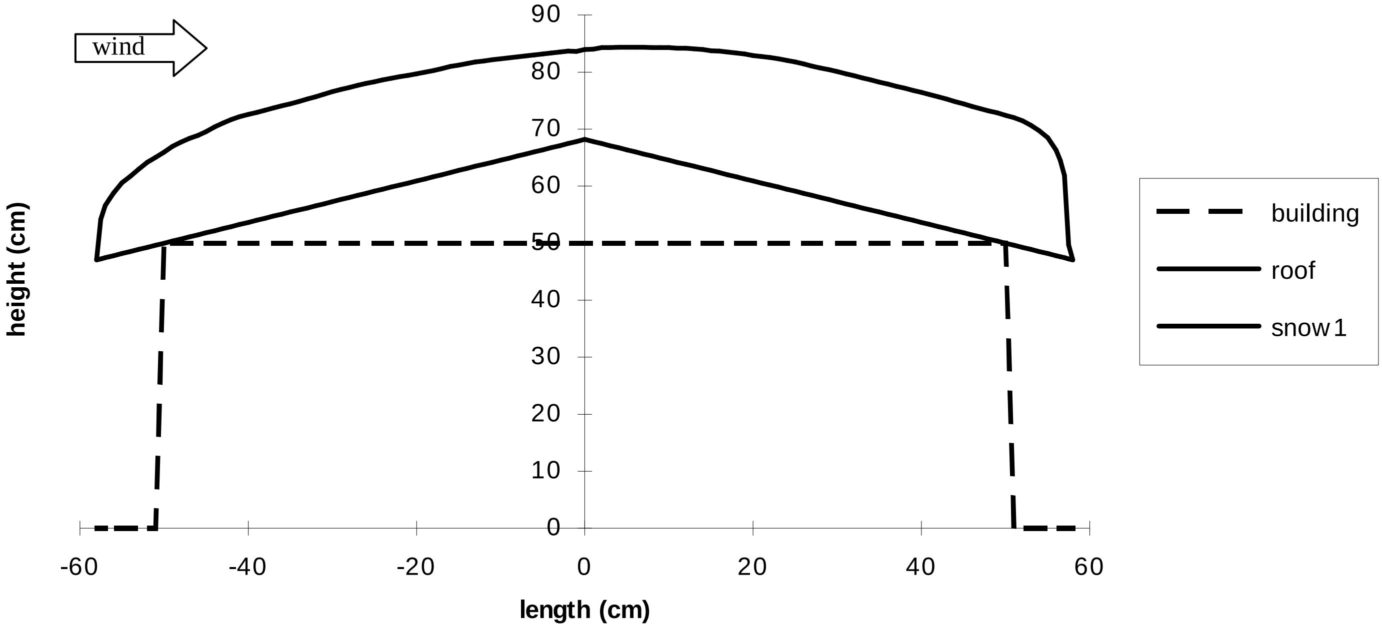
Snow cover centres position (x values in cm)

		surface centre windward	surface centre leeward	surface centre	gravity centre
flat roof	wind < 1m/s	-27.1	26.7	0.3	0.3
	wind 4 m/s	-22.2	29.2	9.9	10.3
gable roof (20°)	wind < 1m/s	-28.1	29.5	3.4	3.5
	wind 4 m/s	-30.6	33.6	10.5	8.2
gable roof (40°)	wind < 1m/s	-29.7	29.5	3.5	3.5
	wind 4 m/s	-34.0	31.6	2.4	-0.2

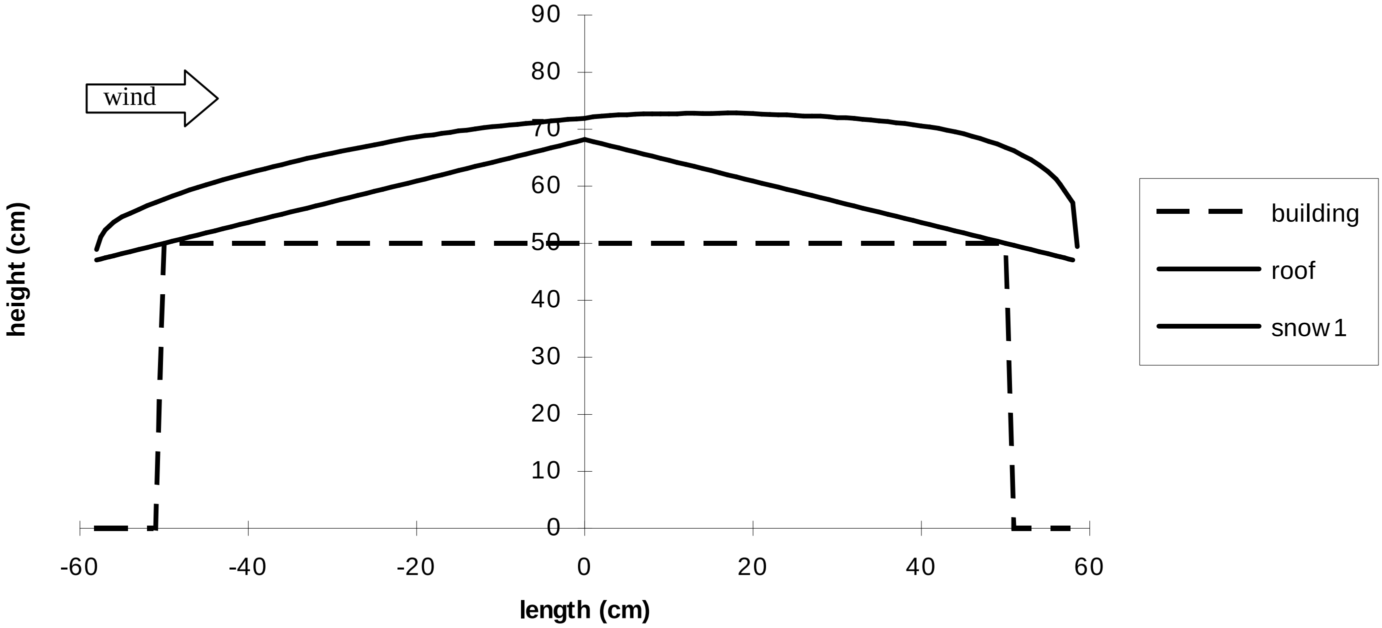

Cross section of the model (flat roof) and snow cover (wind < 1m/s)
wind
70
60
50
40
30
20
10
0
height (cm)
-60
-40
-20
0
20
40
60
length (cm)
building
roof
snow 1


Cross section of the model (flat roof) and snow cover (wind 4m/s)
wind
70
60
50
40
30
20
10
0
height (cm)
-60
-40
-20
0
20
40
60
length (cm)
building
roof
snow 1
snow 2

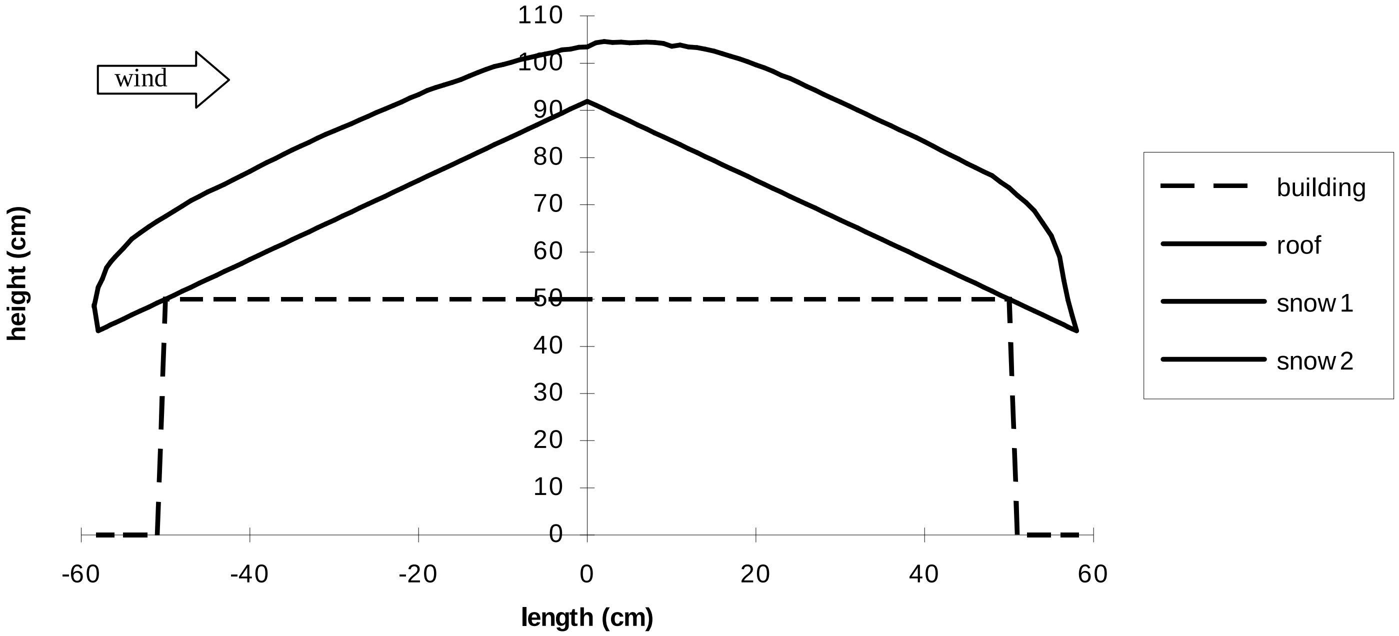
Cross section of the model (roof 20°) and snow cover (wind < 1m/s)



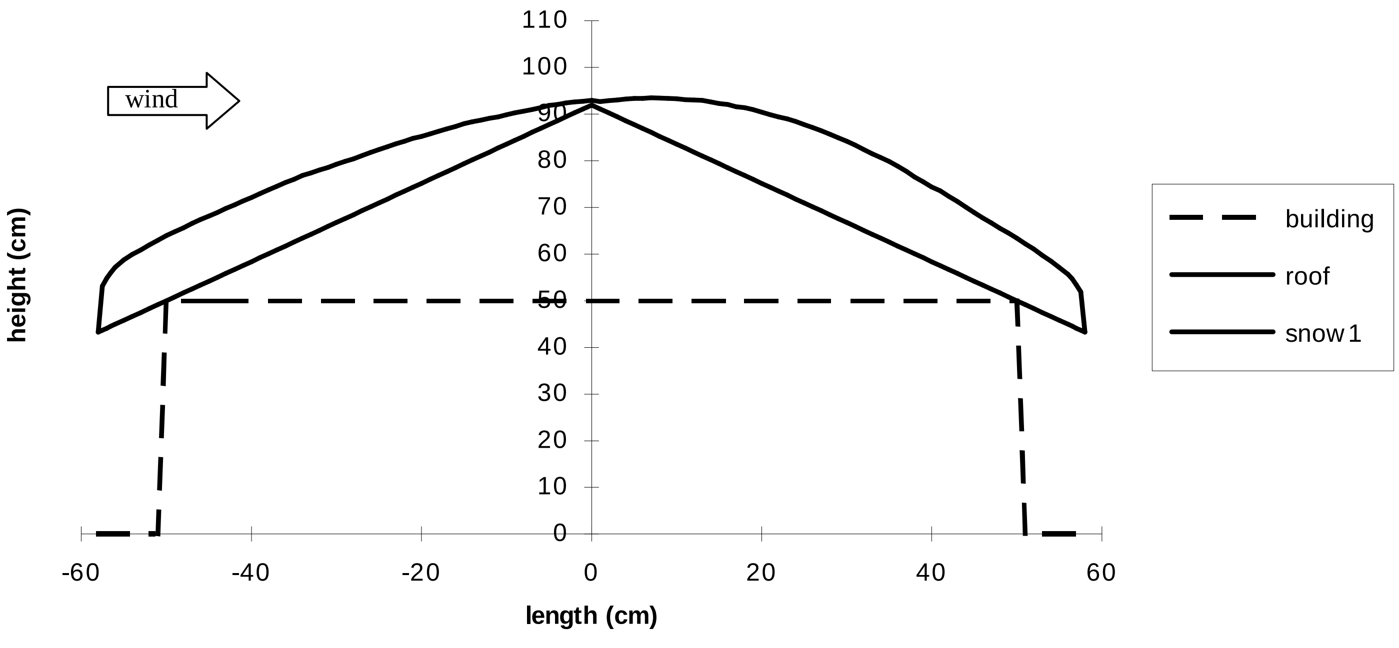
Cross section of the model (roof 20°) and snow cover (wind 4m/s)



Cross section of the model (roof 40°) and snow cover (wind < 1m/s)



Cross section of the model (roof 40°) and snow cover (wind 4m/s)



A.13.3 Discussion of the results of 1st sub-task

A.13.3.1 Interpretation and analyse of parameter relationship

Comparisons between cases are easier if the snow load data are presented with simple graphs showing combined effects of the experimental parameters. In the graphs presented below, the experimental parameters are considered equally as influencing variables. Although this approach may seem sometimes unrealistic, it is only intended to reach a better understanding of the physical process of snow loading on gabled roofs. No extrapolation should be made to roof angles outside the tested range.

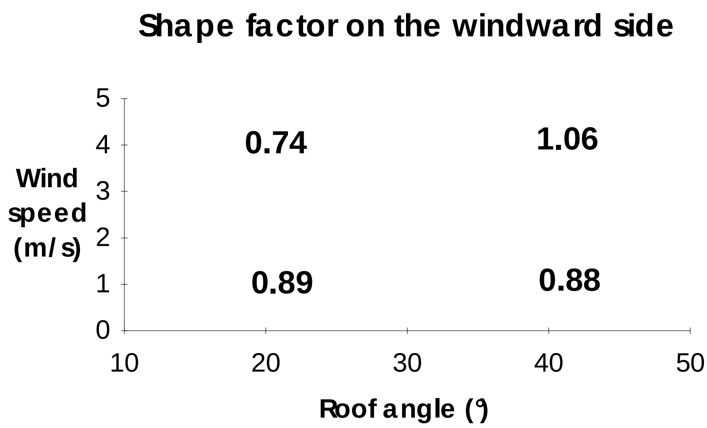
Interaction of wind speed with roof angle

Figures A.13.3-1 to A.13.3-3 enable to assess the effects of interactions of wind speeds with roof angles on the dimensionless snow load.

The windward side is first considered (figure A.13.3-1). As expected, in case of low wind speed, the snow load (~0.9) is not influenced by the roof slope, at least in the investigated roof angle range (40° is still a moderate roof angle).

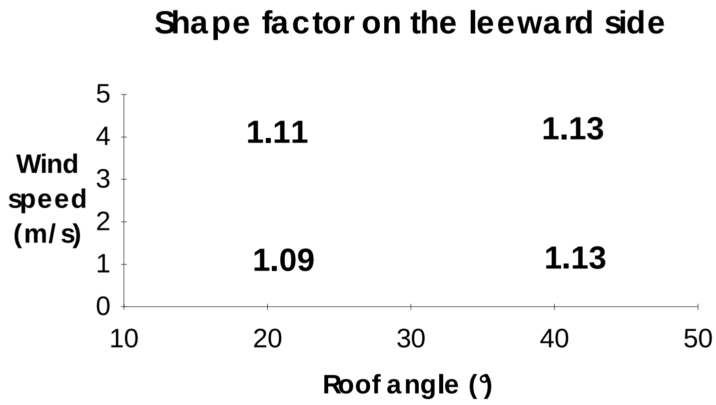
On the 20° roof, the snow load decreases while the wind speed increases (0.89 and 0.74). This is a low pressure region and depression increases with the wind speed. On the contrary, one can notice that the 40° roof does not show the same behaviour (0.88 and 1.06). The windward side of a 40° roof is a high pressure region whose effect may be combined with the impinging effect of the snow/air flow.

Figure A.13.3-1: Wind speed and roof angle interaction on the windward side



On the leeward side, one can notice that all shape factors are higher than 1. The increasing of wind speed does not modify noticeably the shape factors. The roof angle seems to be the main influencing parameter. This is probably due to the snow loading process on the leeward side; i.e. : the eddy volume created by the flow separation at the roof top is increased with the roof tilt angle, this is why the 40° roof is a more severe case than the 20° roof.

Figure A.13.3-2: Wind speed and roof angle interaction on the leeward side

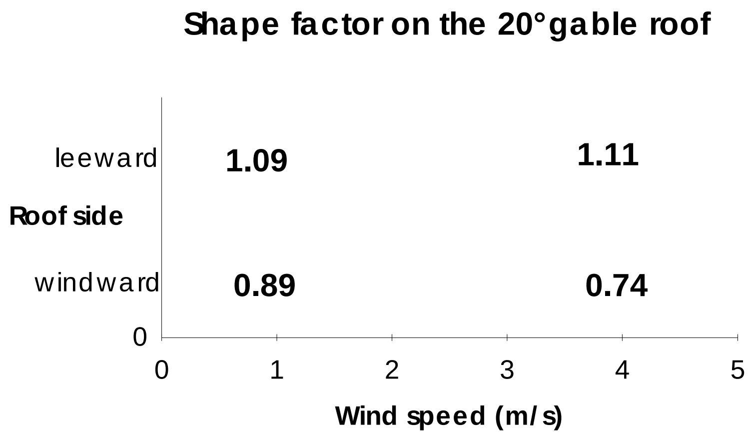


Interaction of roof side with wind speed

On the 20° roof the increase of wind speed leads to a decreasing of the shape coefficient on the windward side but no meaningful change of the shape coefficient is observed on the leeward side. When the wind speed increases, the local depression on the windward side is increased.

By considering the complete roof (windward/leeward loading), it is noticed that the increase of the wind speed increases the imbalance of the snow load on the roof. The air flow separation at the roof top does exist for the lowest wind speed and maintains its effects while the wind speed increases.

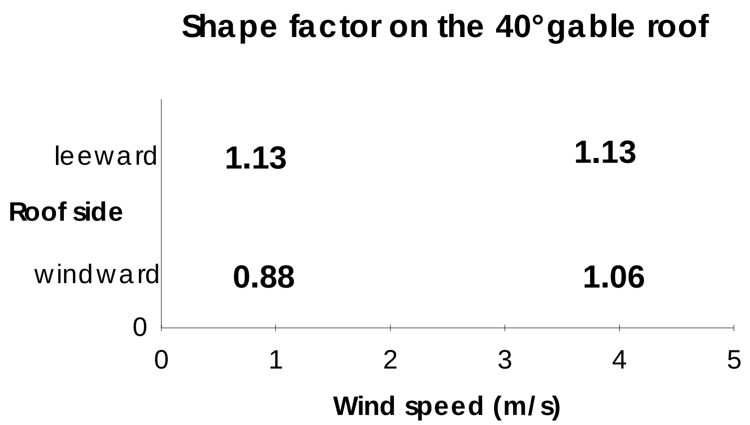
Figure A.13.3-3: Roof side and wind speed interaction on the 20° gabled roof



On the 40° roof the increase of wind speed does not change the shape coefficient on the leeward side but, due to impinging effects, increases the shape coefficient on the windward side.

Unlike on the 20° roof, it is noticed that, on the complete 40° roof, the increase of wind speed tends to equlise the windward/leeward snow loads on the roof.

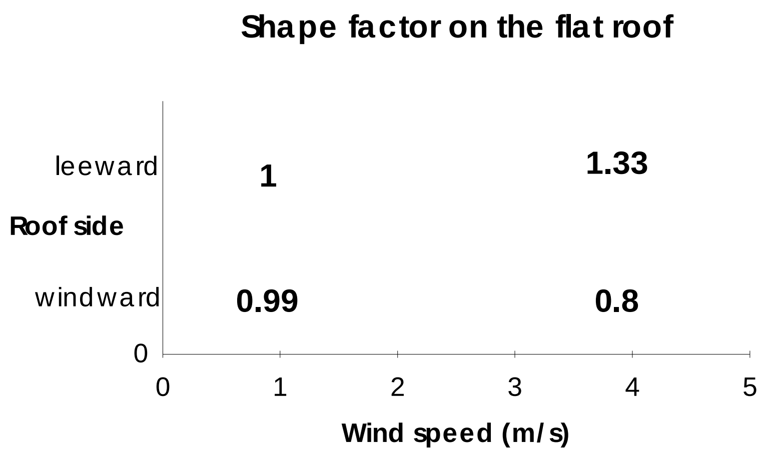
Figure A.13.3-4: Roof side and wind speed interaction on the 40° gabled roof



The flat roof does not present a directional snow load pattern at low wind speed. On the other hand, the imbalance of the snow load observed for a 4 m/s wind shows that, compared to other roofs, uneven snow loading on flat roof may exhibit the highest sensitivity to wind speed.

At the windward the shape coefficient decreasing phenomenon is similar to that observed on the 20° roof. At the leeward the shape coefficient increase may be due to a re-attachment of the flow.

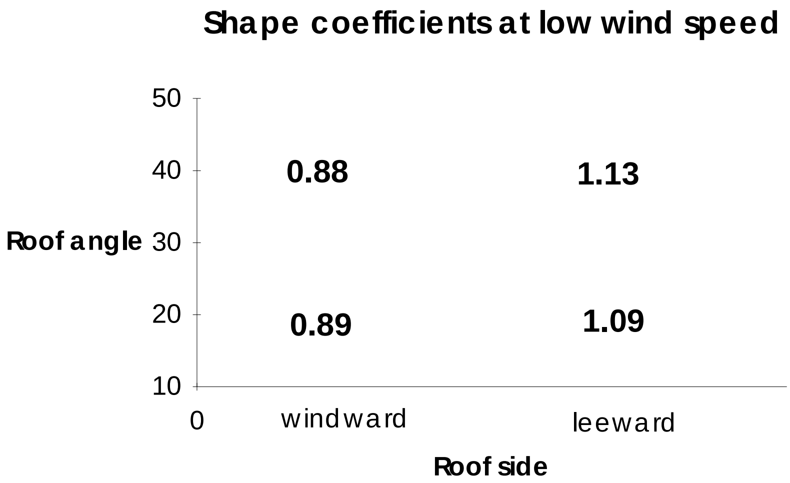
Figure A.13.3-5: Roof side and wind speed interaction on the flat roof



Interaction of roof angle with roof side

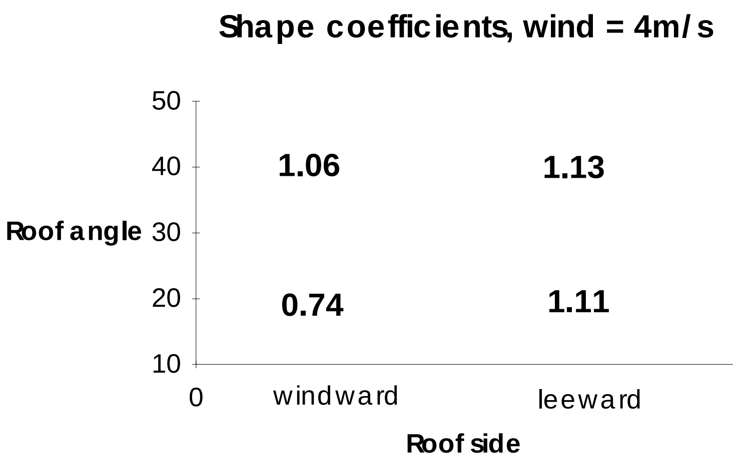
At low wind speed (<1 m/s), the roof angle does not interfere with the shape coefficient measured on the windward side (0.89 ~ 0.88), and no meaningful discrepancy between shape coefficient values can be observed on the leeward side.

Figure A.13.3-6: Roof angle and roof side interaction at low wind speed



At higher wind speed (4 m/s), a discrepancy between shape coefficients is obvious on the windward side, but once again the roof angle seems to have little effect on the shape coefficients measured on the leeward side.

Figure A.13.3-7: Roof angle and roof side interaction for a 4 m/s wind



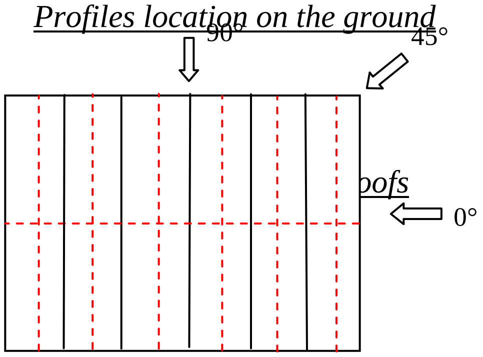
A.13.4: Snow profiles for 2nd sub-task

A.13.4.1 Introduction

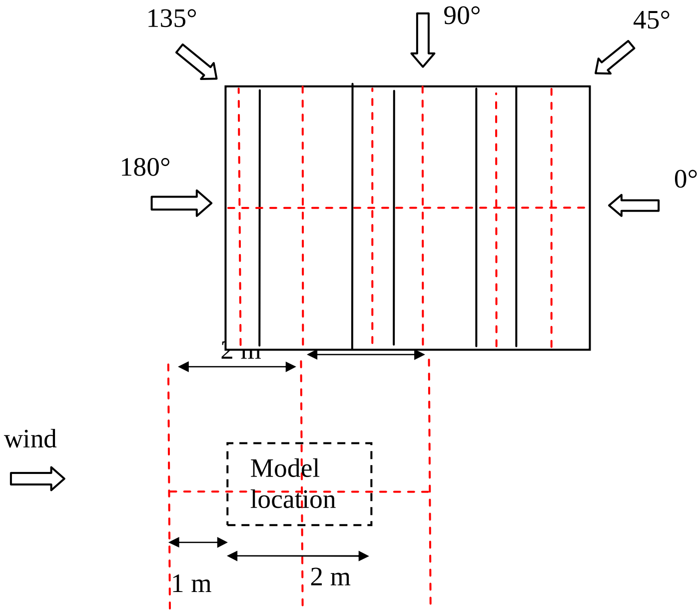
Snow profiles are taken on the ground and on each part of the roof. Location of snow profiles are often the middle of each roof part as indicated in section A.13.4.2. Profiles names are set with a first part that indicate roof shape, **RR** for round roof, **TLS1** to **TLS8** for two-level roof, **MPS** for multi-pitch symetrical roof and **MPN** for multi-pitch non symetrical roof, a second part that indicate wind direction **D1** to **D5** and a third part **Pi** or **Vi** for the profile itself. Exact location of each profile is given in the section 4.7.4.2. Drawings of the profiles are given in A.13.4.3 and a comprehensive table of results is given in A.13.4.4.

A.13.4.2 Profiles location

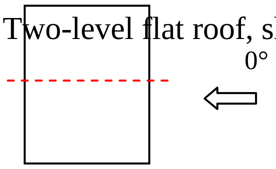
Profiles location on the ground



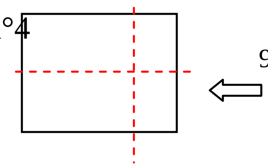
oofs



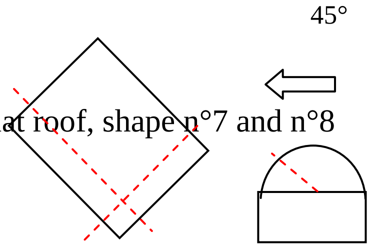
Two-level flat roof, shape n°1, 2, 3 and 5

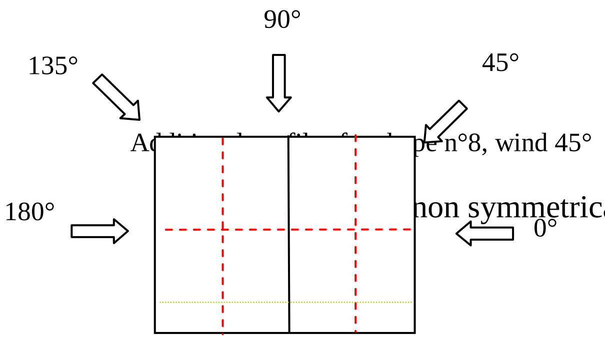


Two-level flat roof, shape n°4



Two-level flat roof, shape n°7 and n°8

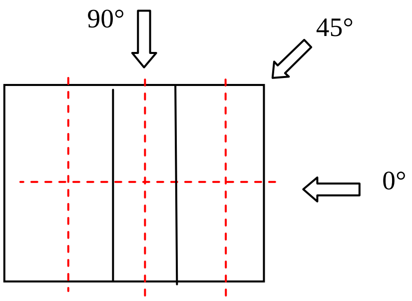


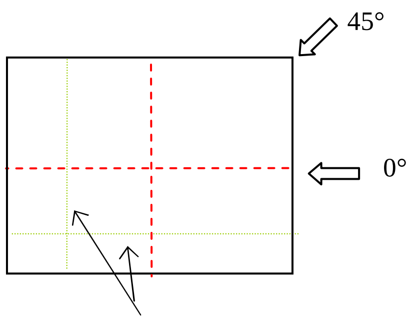


Ad pe n°8, wind 45°

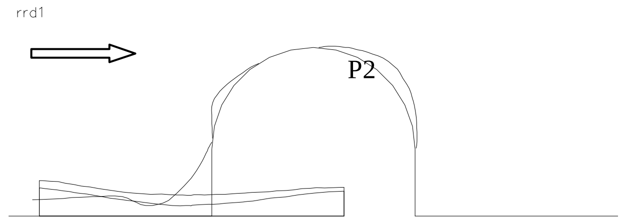
Multi-pitch symmetrical roof

non symmetrical roof

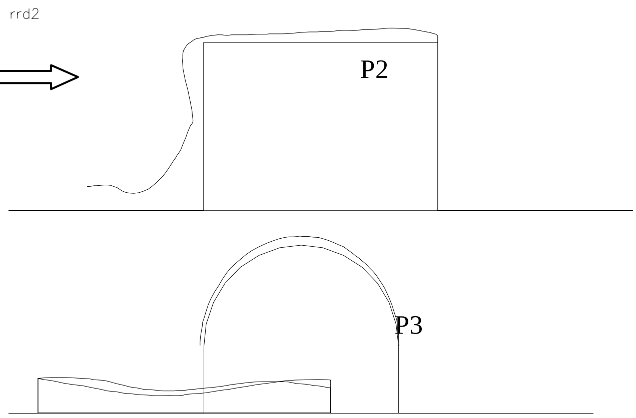




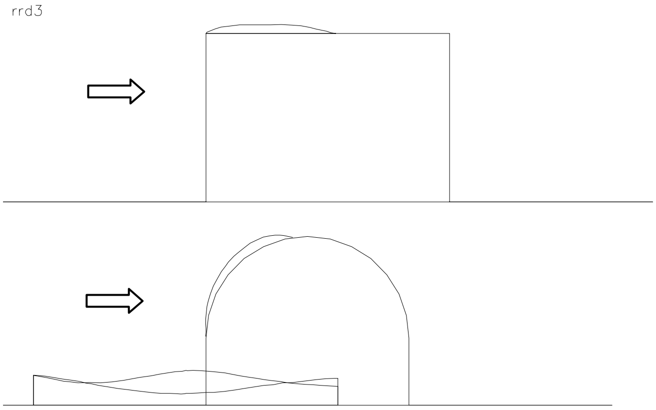
A.13.4.3 Snow profiles on roofs



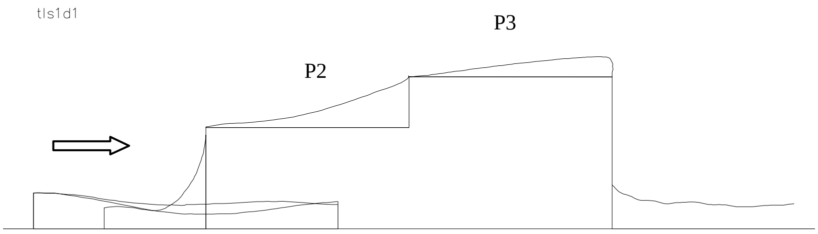
RRD1: round roof, wind 0°



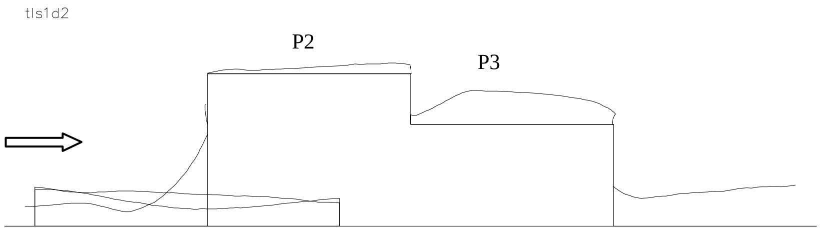
RRD2: round roof, wind 90°



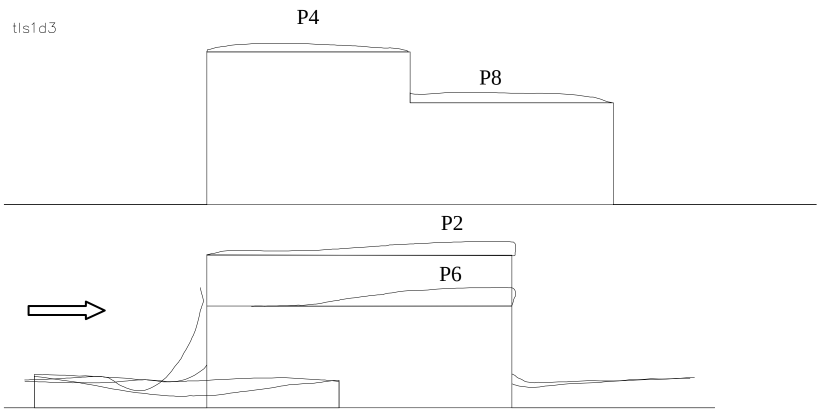
RRD3: round roof, wind 45°



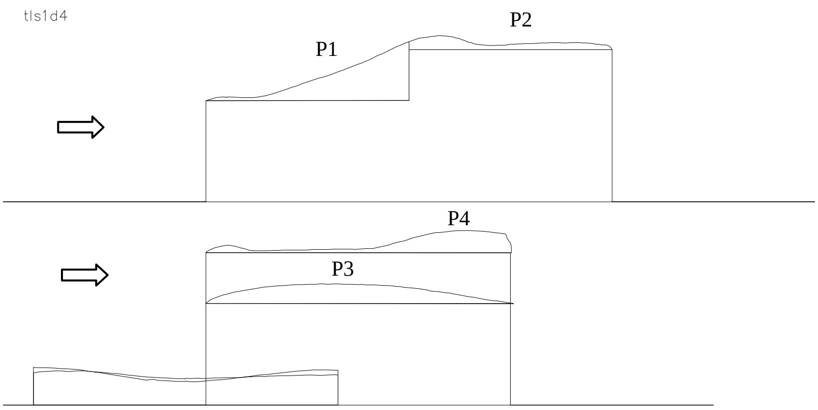
TLS1D1: two levels, shape n°1, wind 0°



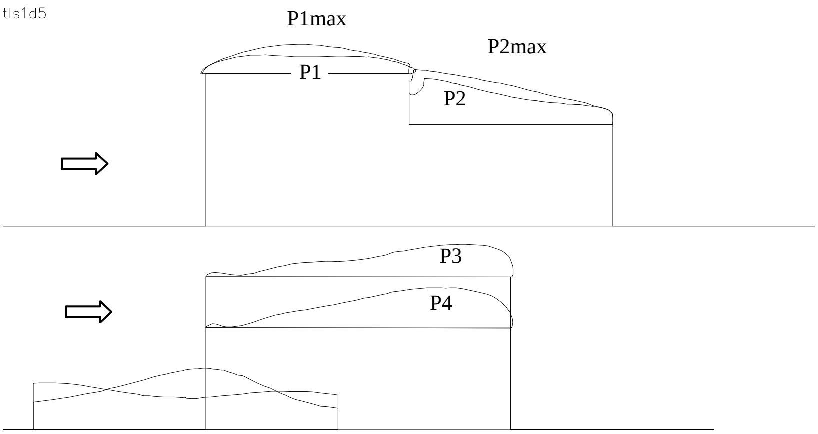
TLS1D2: two levels, shape n°1, wind 180°



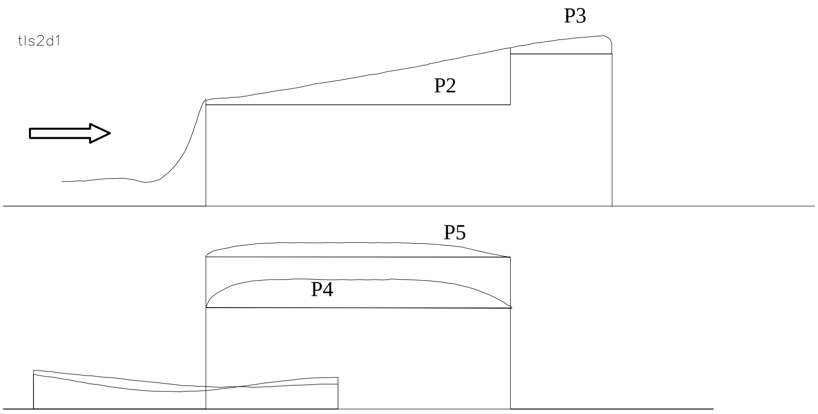
TLS1D3: two levels, shape n°1, wind 90°



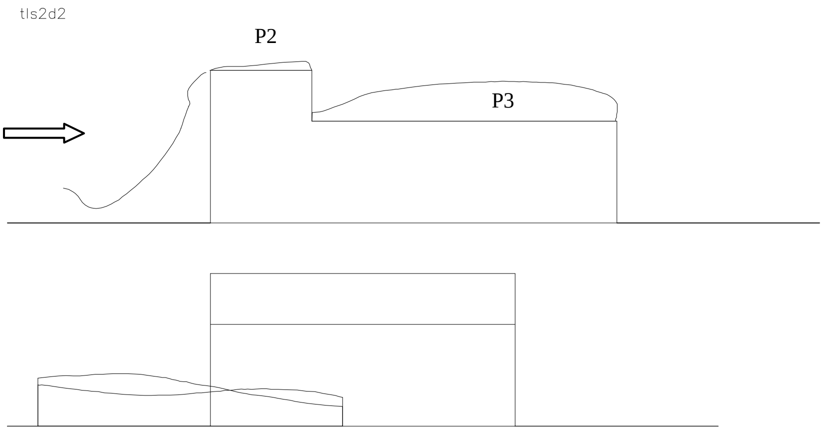
TLS1D4: two levels, shape n°1, wind 45°



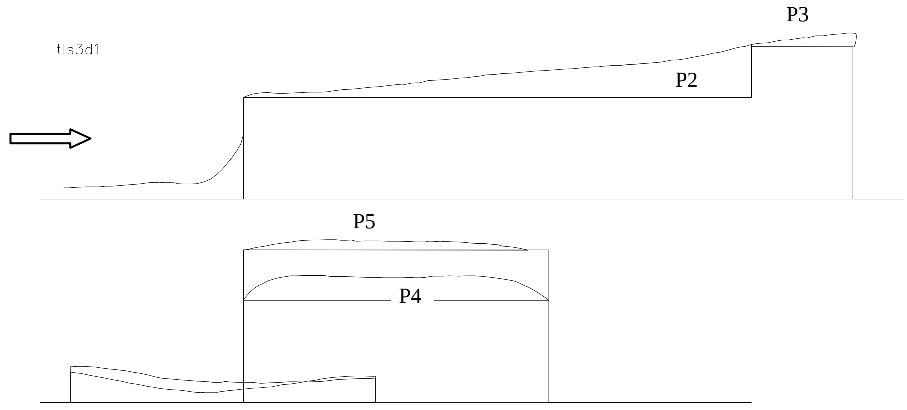
TLS1D4: two levels, shape n°1, wind 135°



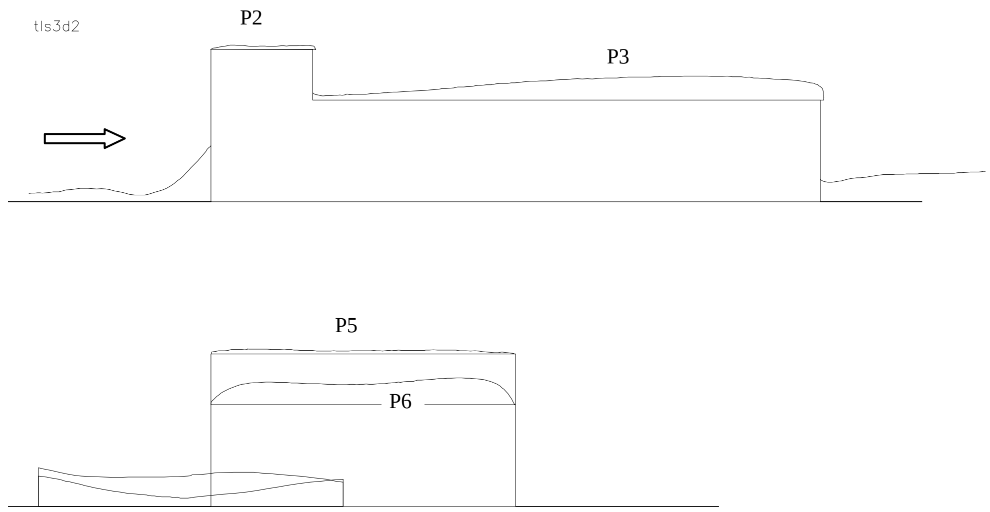
TLS2D1: two levels, shape n°2, wind 0°



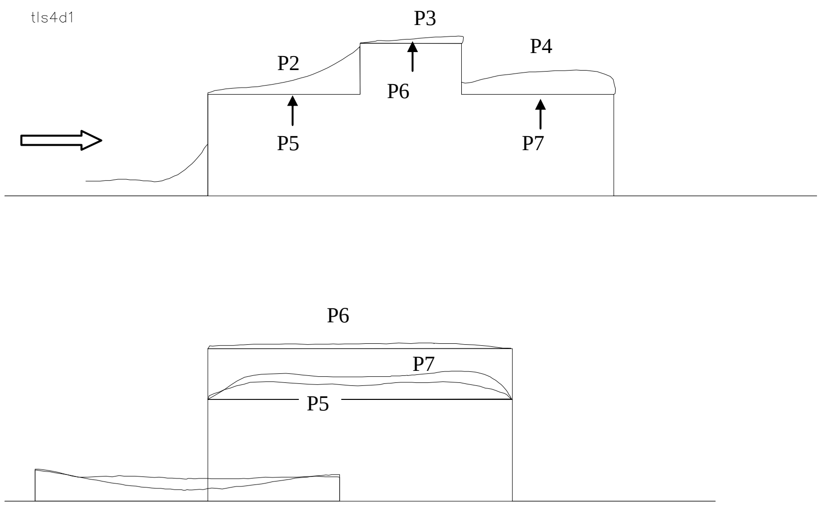
TLS2D2: two levels, shape n°2, wind 180°



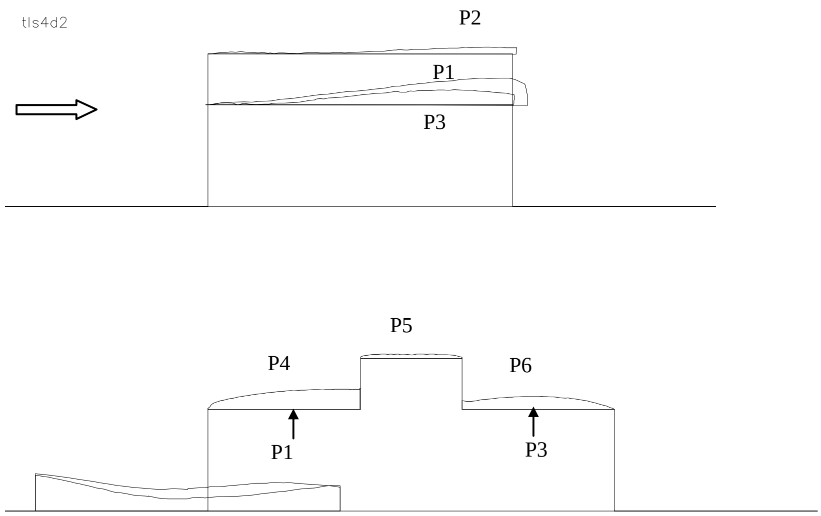
TLS3D1: two levels, shape n°3, wind 0°



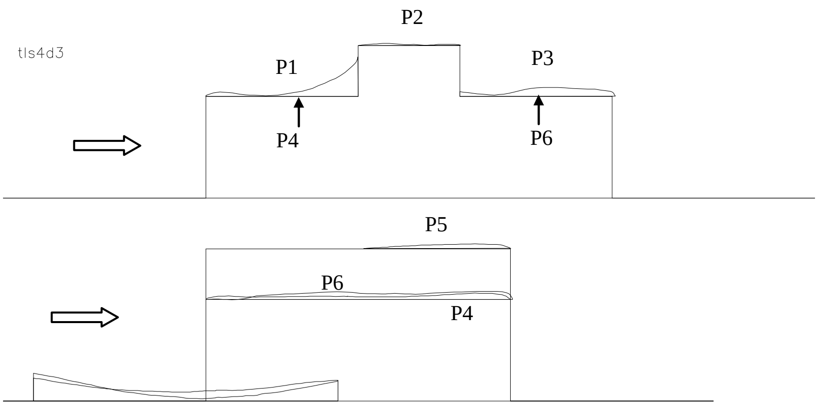
TLS3D2: two levels, shape n°3, wind 180°



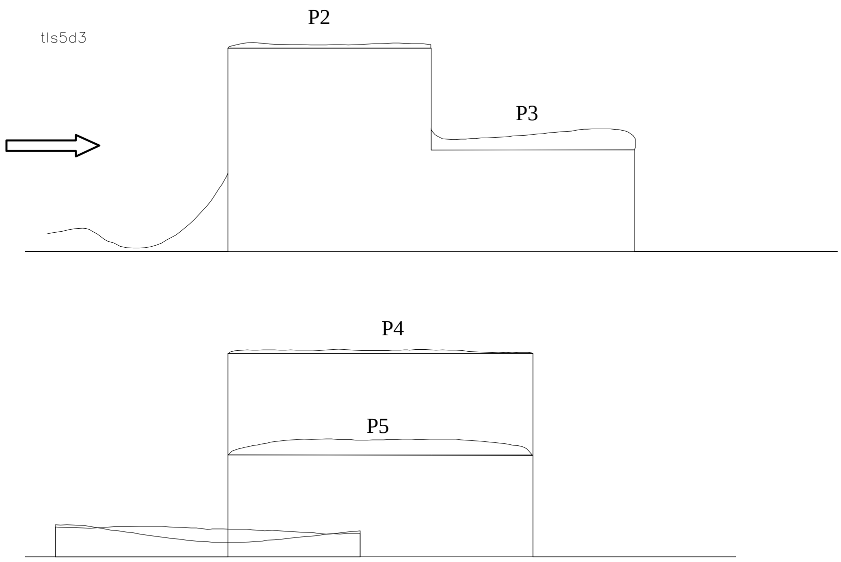
TLS4D1: two levels, shape n°4, wind 0°



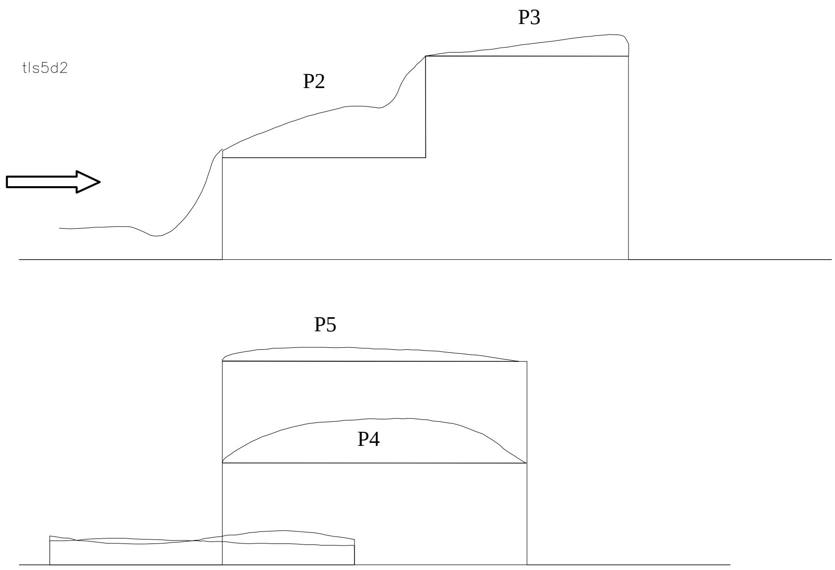
TLS4D2: two levels, shape n°4, wind 90°



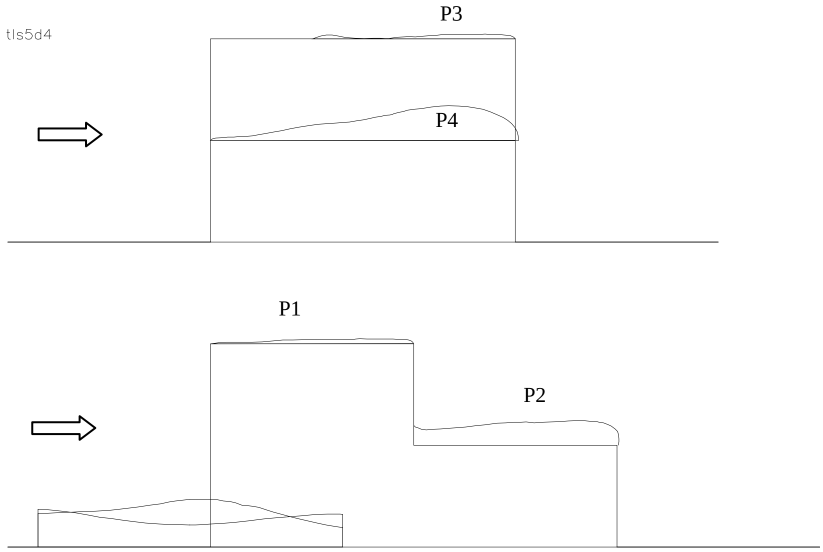
TLS4D3: two levels, shape n°4, wind 45°



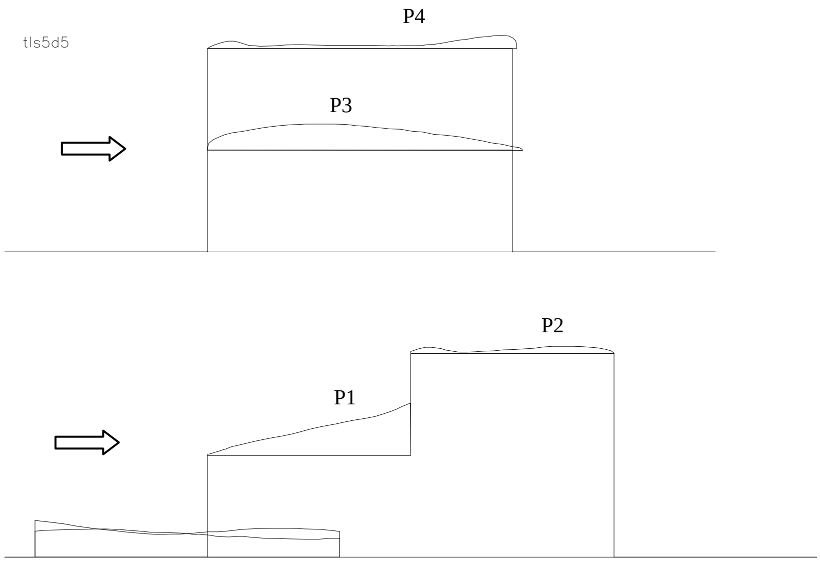
TLS5D3: two levels, shape n°5, wind 180°



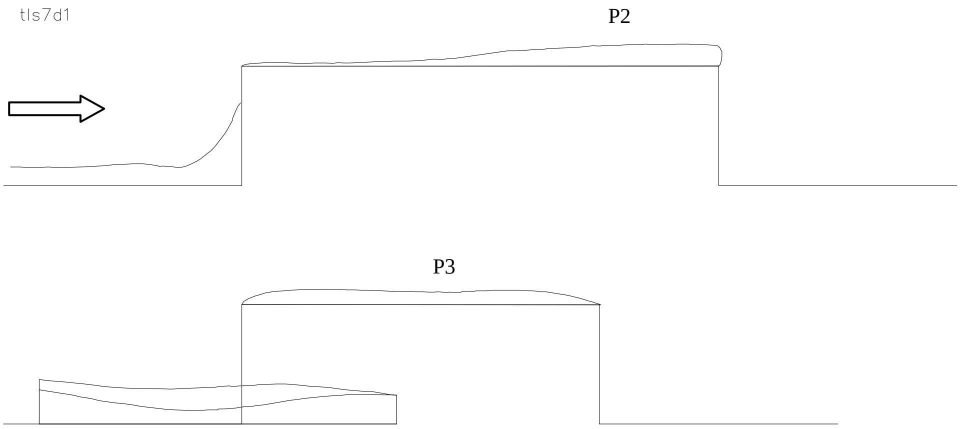
TLS5D2: two levels, shape n°5, wind 0°



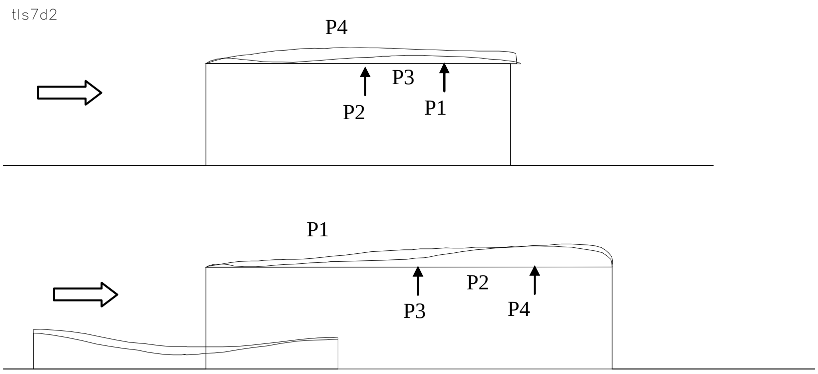
TLS5D4: two levels, shape n°5, wind 135°



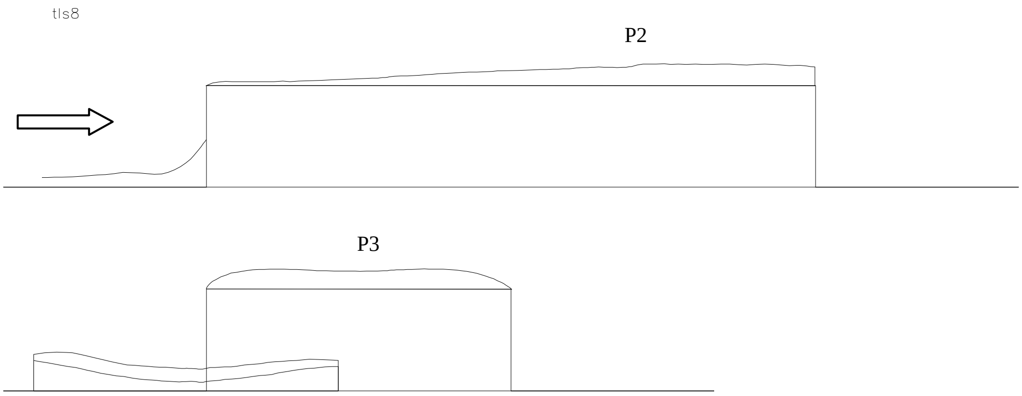
TLS5D5: two levels, shape n°5, wind 45°



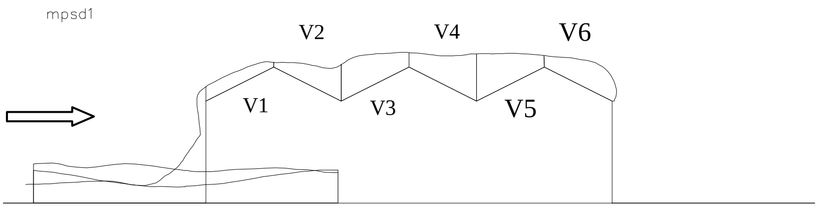
TLS7D1: flat roof , shape n°7, wind 0°



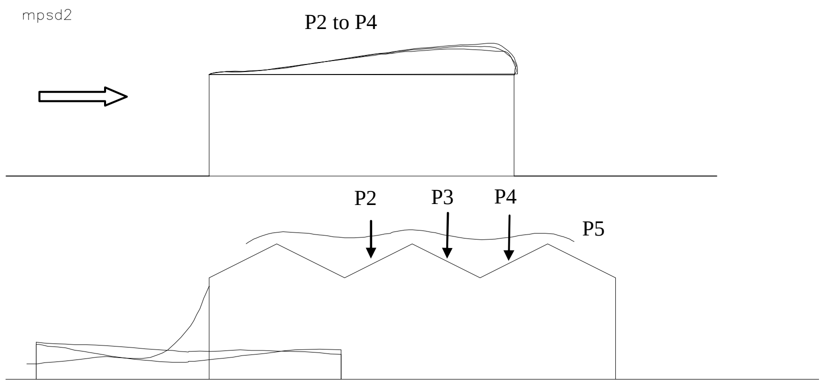
TLS7D2: flat roof, shape n°7, wind 45°



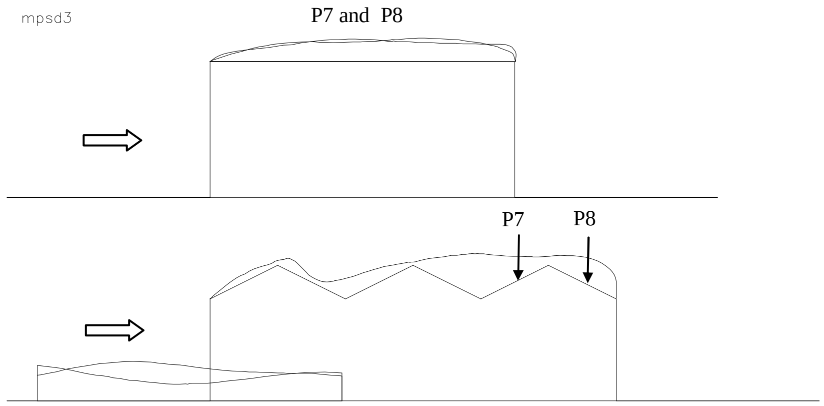
TLS8D1: flat roof, shape n°8, wind 0°



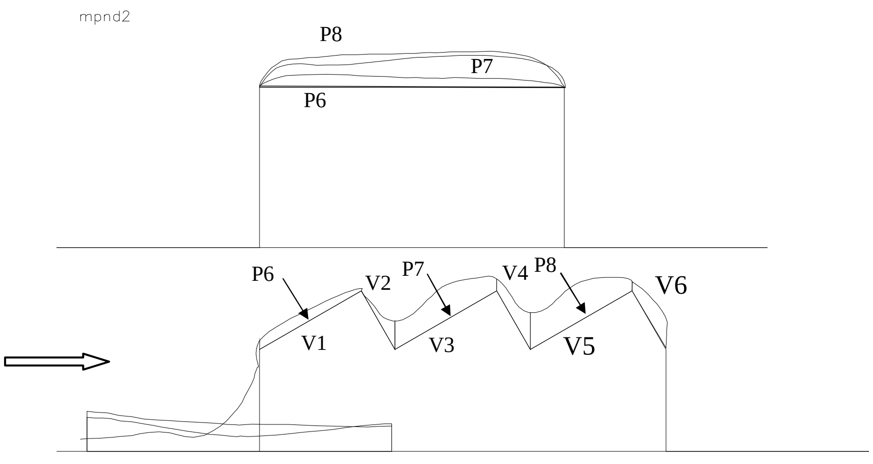
MPSD1: multi-pitch symmetrical, wind 0°



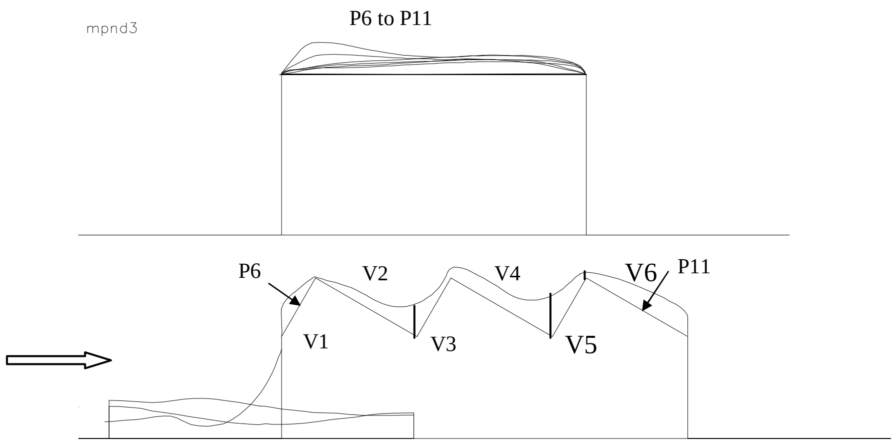
MPSD5: multi-pitch symmetrical, wind 90°



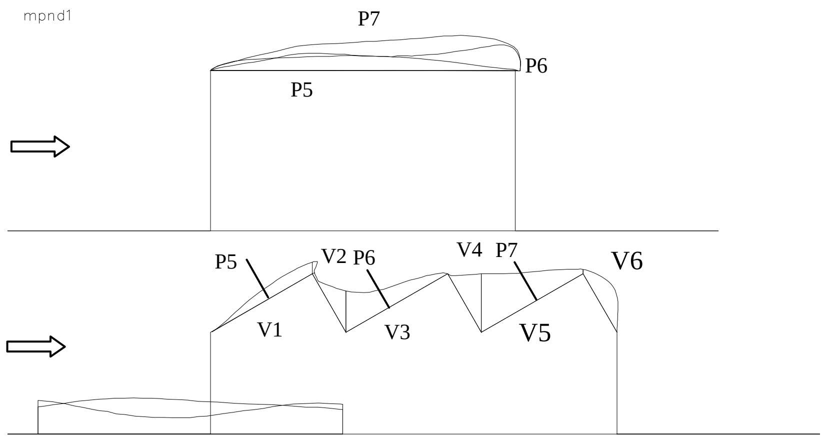
MPSD3: multi-pitch symmetrical, wind 45°



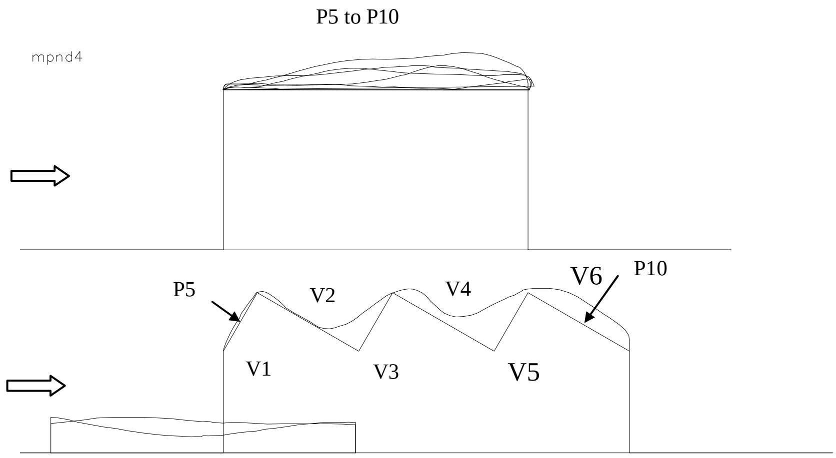
MPND2: multi-pitch non symmetrical, wind 0°



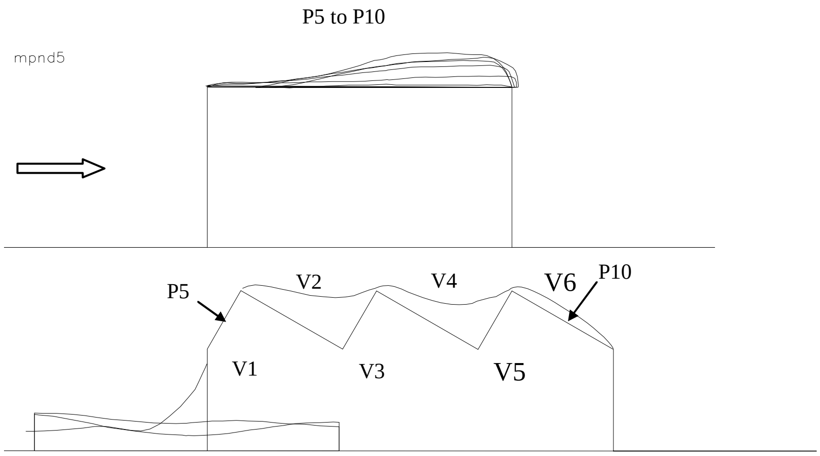
MPD3: multi-pitch non symmetrical, wind 180°



MPND1: multi-pitch non symmetrical, wind 45°



MPND4: multi-pitch non symmetrical, wind 135°



MPND5: multi-pitch non symmetrical, wind 90°

A.13.4.4 Comprehensive table of results

Name	Wind direction	Hmax (cm)	D(Hmax) (cm)	Lroof (cm)	D(Hmax)/L	H ave surface/L	μ_H ave Have/Href	μ_H max Hmax/Href
MPND2V1	0°	6	15	50	0.31	5	0.42	0.53
MPND2V2		14	17	17	0.98	5	0.42	1.16
MPND2V3		17	23	50	0.46	14	1.13	1.44
MPND2V4		18	17	17	0.98	11	0.89	1.51
MPND2V5		19	22	50	0.45	15	1.28	1.60
MPND2V6		15	15	17	0.90	11	0.93	1.23
MPND2P6		6		150		4	0.35	0.50
MPND2P7		16		150		13	1.05	1.33
MPND2P8		18		150		15	1.24	1.49
MPND3V1	180°	14	1	17	0.07	9	0.72	1.18
MPND3V2		16	50	50	1.00	6	0.53	1.36
MPND3V3		16	0	17	0.00	8	0.68	1.36
MPND3V4		20	50	50	1.00	10	0.85	1.70
MPND3V5		24	0	17	0.00	12	0.97	2.03
MPND3V6		13	44	50	0.88	10	0.79	1.04
MPND3P7		7		150		5	0.38	0.58
MPND3P8		8		150		5	0.39	0.66
MPND3P9		8		150		6	0.47	0.66
MPND3P11		10		150		7	0.57	0.83
MPND3P6		10		150		7	0.59	0.83
MPND3P10		16		150		10	0.81	1.33
MPND1V1	45°	7	35	50	0.69	5	0.40	0.60
MPND1V2		20	17	17	1.00	9	0.74	1.70
MPND1V3		20	0	50	0.00	9	0.78	1.70
MPND1V4		29	17	17	1.00	14	1.13	2.39
MPND1V5		29	0	50	0.00	15	1.28	2.39
MPND1V6		19	15	17	0.87	13	1.06	1.59
MPND1P5		7	69	150	0.46	5	0.43	0.58
MPND1P6		13	142	150	0.95	8	0.63	1.08
MPND1P7		17	123	150	0.82	13	1.06	1.41
MPND4P7	135°	11	65	150	0.43	6	0.51	0.91
MPND4P5		3	17	150	0.11	1	0.12	0.25
MPND4P8		12	106	150	0.71	5	0.41	1.00
MPND4P10		12	99	150	0.66	9	0.73	1.00
MPND4P6								
MPND4P9		18	118	150	0.79	12	1.02	1.49
MPND5P10	90°	2	88	150	0.59	1	0.06	0.17
MPND5P5		6	134	150	0.89	4	0.29	0.50
MPND5P7		11	139	150	0.93	6	0.51	0.91
MPND5P6		13	126	150	0.84	7	0.58	1.08
MPND5P9		15	136	150	0.91	8	0.68	1.25
MPND5P8		17	118	150	0.79	9	0.76	1.41

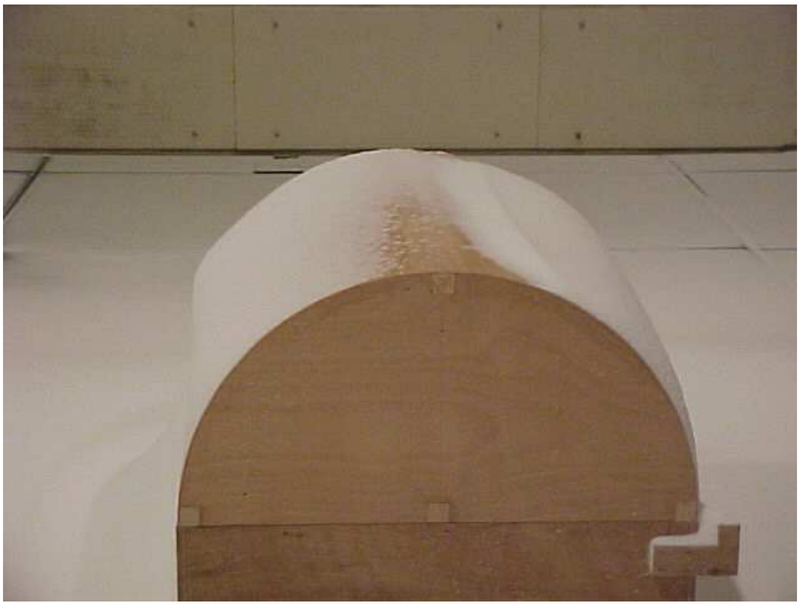
Name	Wind direction	Hmax (cm)	D(Hmax) (cm)	Lroof (cm)	D(Hmax)/L	H ave surface/L	μ_H ave Have/Href	μ_H max Hmax/Href
MPSD1V1	0°	7	8	33	0.23	6	0.53	0.62
MPSD1V2		18	33	33	1.00	10	0.79	1.49
MPSD1V3		19	3	33	0.10	14	1.19	1.54
MPSD1V4		23	33	33	1.00	15	1.21	1.92
MPSD1V5		23	0	33	0.00	15	1.24	1.92
MPSD1V6		14	29	33	0.86	12	1.01	1.18
MPSD2P4	90°	13	121	150	0.81	8	0.64	1.08
MPSD2P2		14	125	150	0.83	8	0.68	1.16
MPSD2P3		15	137	150	0.91	8	0.70	1.25
MPSD3P7	45°	12	103	150	0.69	9	0.72	1.00
MPSD3P8		11	68	150	0.45	9	0.71	0.91
TLS1D1P2	0°	25	100	100	1.00	9	0.73	2.08
TLS1D1P3		10	94	100	0.94	6	0.48	0.83
TLS1D2P2	180°	5	91	100	0.91	3	0.26	0.42
TLS1D2P3		17	32	100	0.32	13	1.08	1.41
TLS1D3P6	90°	9	124	150	0.83	4	0.37	0.75
TLS1D3P2		7	143	150	0.95	4	0.35	0.58
TLS1D3P4		4		100		3	0.26	0.33
TLS1D3P8		5		100		4	0.35	0.42
TLS1D4P3	45°	10	57	150	0.38	7	0.56	0.83
TLS1D4P4		11	127	150	0.85	5	0.39	0.91
TLS1D4P2		7	14	100	0.14	4	0.31	0.58
TLS1D4P1		29	100	100	1.00	11	0.90	2.41
TLS1D5P4	135°	20	120	150	0.80	12	0.99	1.66
TLS1D5P3		16	125	150	0.83	9	0.76	1.33
TLS1D5P1		9	31	100	0.31	8	0.66	0.75
TLS1D5P1 MAX		15	48	100	0.48	11	0.91	1.25
TLS1D5P2		23	8	100	0.08	14	1.18	1.91
TLS1D5P2 MAX		27	3	100	0.03	18	1.52	2.24
TLS2D1P2	0°	28	150	150	1.00	14	1.16	2.32
TLS2D1P3		9	46	50	0.92	7	0.55	0.75
TLS2D1P4		14				12	0.98	1.16
TLS2D1P5		7				6	0.47	0.58
TLS2D2P3	180°	20	95	150	0.63	16	1.30	1.66
TLS2D2P2		4	45	50	0.90	3	0.23	0.33
TLS3D1P2	0°	26	250	250	1.00	11	0.93	2.16
TLS3D1P3		7	49	50	0.98	4	0.37	0.58
TLS3D1P4		13				11	0.88	1.08
TLS3D1P5		5				3	0.28	0.42
TLS3D2P6	180°	13				10	0.87	1.08
TLS3D2P5		3				2	0.14	0.25
TLS3D2P2		2	11	50	0.22	2	0.15	0.17
TLS3D2P3		12	84	250	0.34	8	0.69	1.00

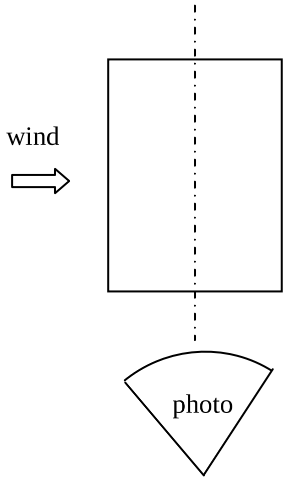
Name	Wind direction	Hmax (cm)	D(Hmax) (cm)	Lroof (cm)	D(Hmax)/L	H ave surface/L	μ_H ave Have/Href	μ_H max Hmax/Href
TLS4D1P5	0°	9				7	0.58	0.75
TLS4D1P7		14				11	0.90	1.16
TLS4D1P6		3				2	0.17	0.25
TLS4D1P2		23	75	75	1.00	8	0.67	1.91
TLS4D1P3		4	48	50	0.96	2	0.18	0.33
TLS4D1P4		12	57	75	0.76	10	0.83	1.00
TLS4D2P4	90°	10				8	0.66	0.83
TLS4D2P5		2				2	0.16	0.17
TLS4D2P6		6				5	0.41	0.50
TLS4D2P3		8	122	150	0.81	4	0.35	0.66
TLS4D2P1		13	147	150	0.98	8	0.64	1.08
TLS4D2P2		3	136	150	0.91	2	0.14	0.25
TLS4D3P1	45°	20	75	75	1.00	4	0.32	1.66
TLS4D3P2		1	14	50	0.28	1	0.05	0.08
TLS4D3P3		4	45	75	0.60	3	0.24	0.33
TLS4D3P4		3	132	150	0.88	2	0.14	0.25
TLS4D3P6		4	137	150	0.91	3	0.23	0.33
TLS4D3P5		2	133	150	0.89	1	0.06	0.17
TLS5D3P4	180°	8				7	0.55	0.66
TLS5D3P5		2				1	0.12	0.17
TLS5D3P2		3	12	100	0.12	2	0.17	0.25
TLS5D3P3		10	84	100	0.84	8	0.64	0.83
TLS5D2P4	0°	22				16	1.34	1.83
TLS5D2P5		7				5	0.40	0.58
TLS5D2P2		50	100	100	1.00	22	1.83	4.15
TLS5D2P3		11	91	100	0.91	6	0.47	0.91
TLS5D4P1	135°	2	73	100	0.73	2	0.13	0.17
TLS5D4P2		12	80	100	0.80	5	0.45	1.00
TLS5D4P4		17	117	150	0.78	10	0.81	1.41
TLS5D4P3		2	135	150	0.90	1	0.07	0.17
TLS5D5P1	45°	26	100	100	1.00	13	1.04	2.16
TLS5D5P2		4	80	100	0.80	1	0.07	0.33
TLS5D5P3		13	57	150	0.38	9	0.77	1.08
TLS5D5P4		6	145	150	0.97	3	0.21	0.50
TLS7D1P3	0°	7				5	0.44	0.58
TLS7D1P2		9	182	200	0.91	5	0.41	0.75
TLS7D2P2	45°	10	162	200	0.81	5	0.43	0.83
TLS7D2P1		11	174	200	0.87	7	0.60	0.91
TLS7D2P3		4	107	150	0.71	3	0.21	0.33
TLS7D2P4		8	76	150	0.51	6	0.53	0.66
TLS8P3	0°	10				8	0.70	0.83
TLS8P2		11	225	300	0.75	7	0.56	0.91

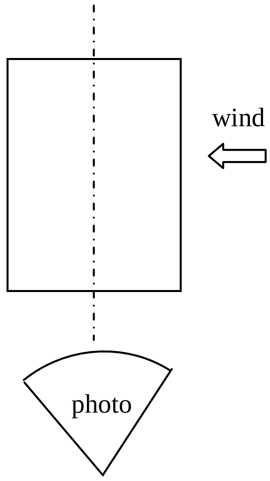
A.13.5 Pictures of each experiment

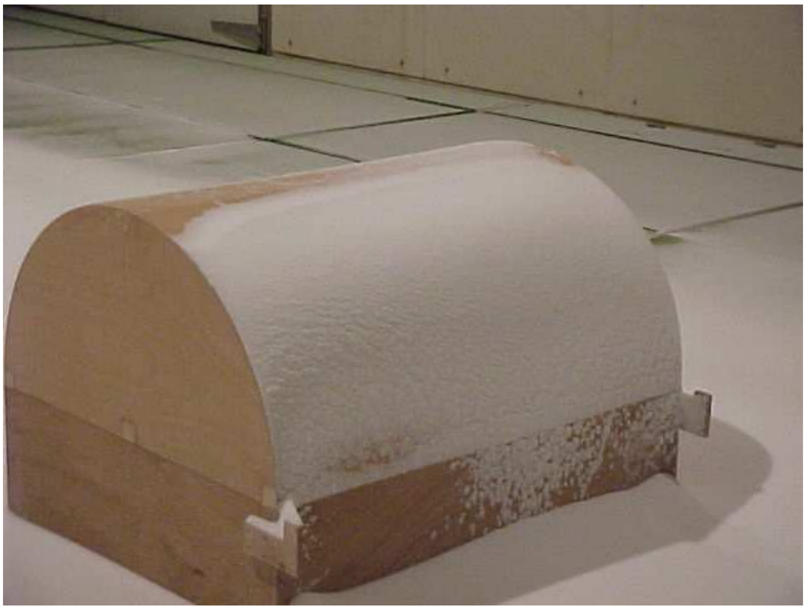
During the 2nd sub-task on snow loads on reference building configurations numerical pictures were taken for each case. A selection of three pictures is given for each case with the point of view location.

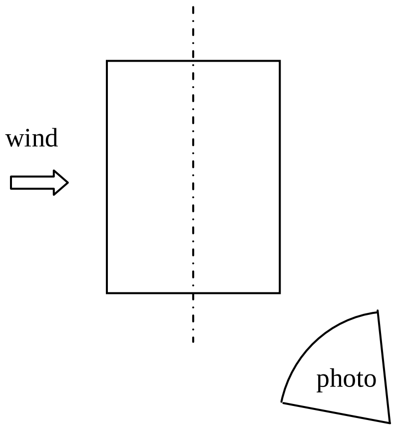
Round roof, wind 0° (perpendicular to cylinder axis)



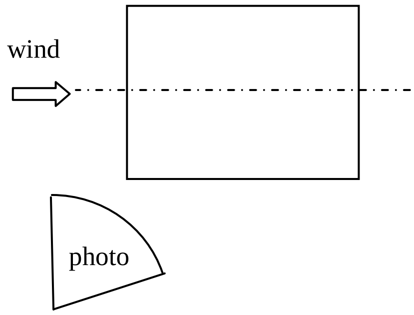


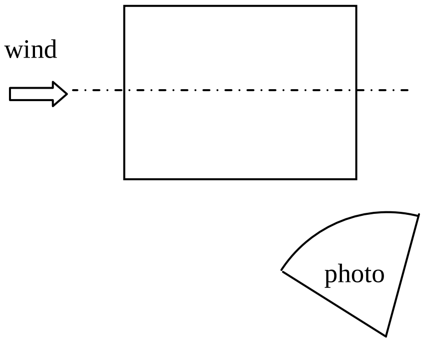


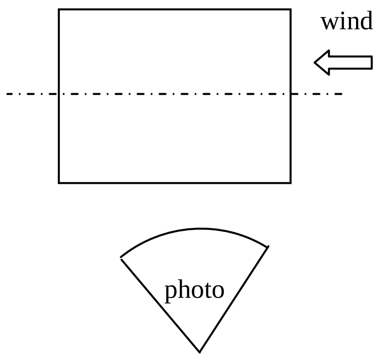




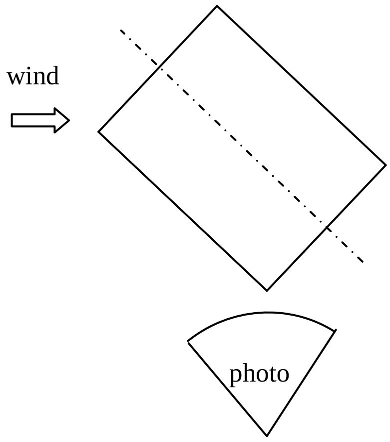
Round roof, wind 90° (parallel to cylinder axis)

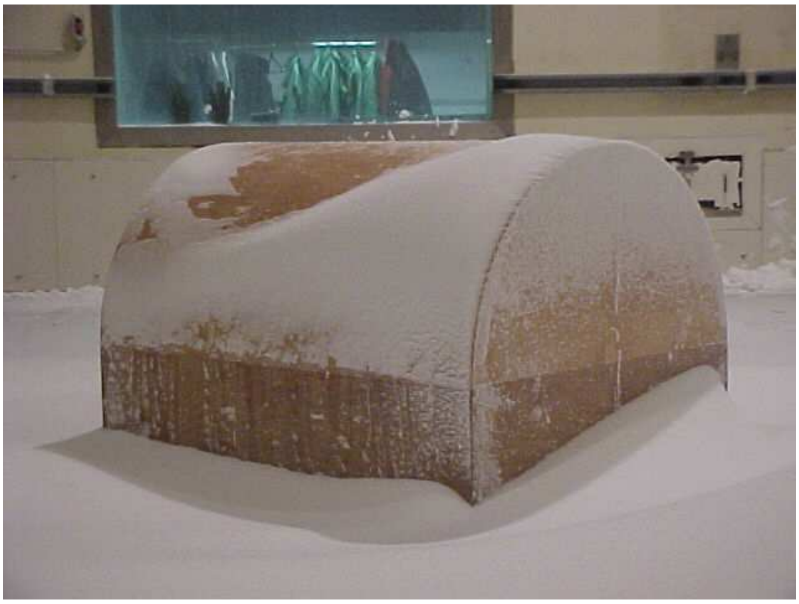


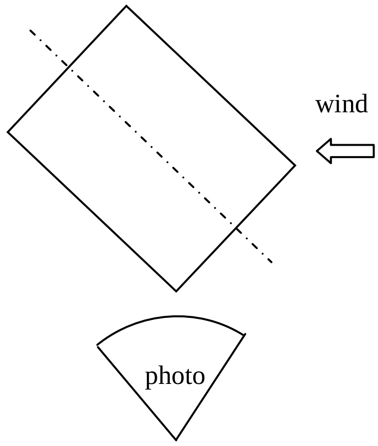


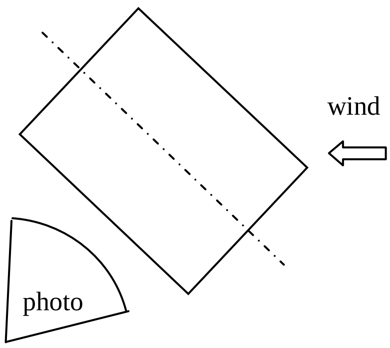


Round roof, wind 45°

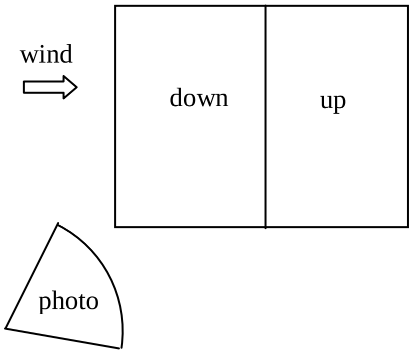


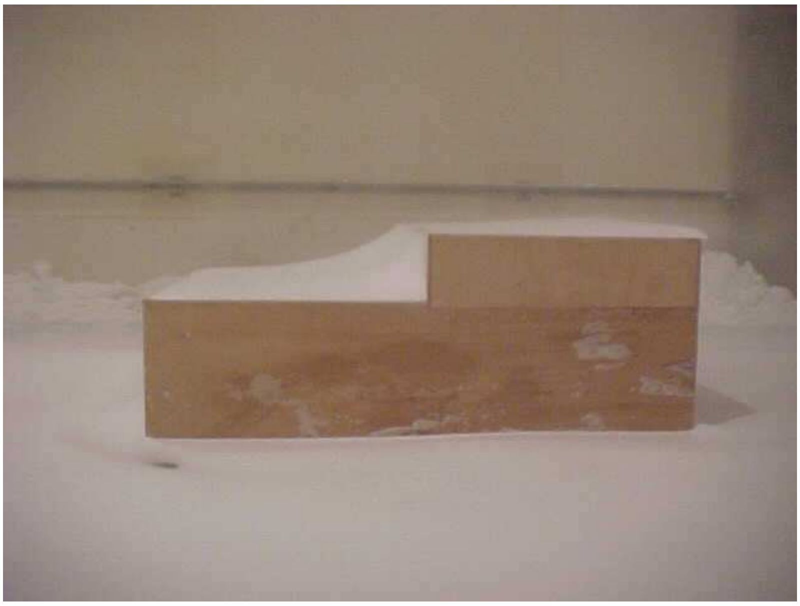


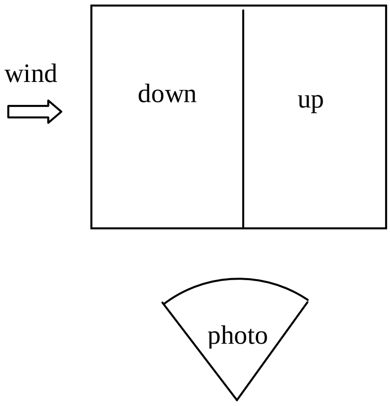


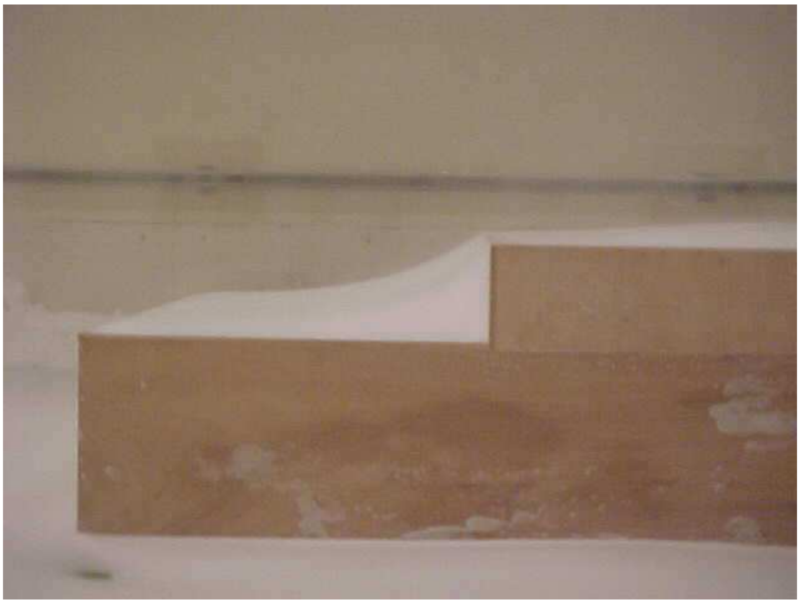


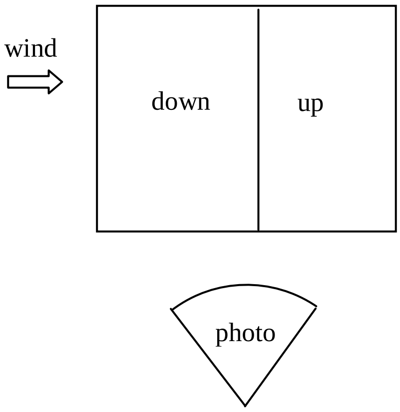
Two level shape 1, wind 0° (lower part windward)



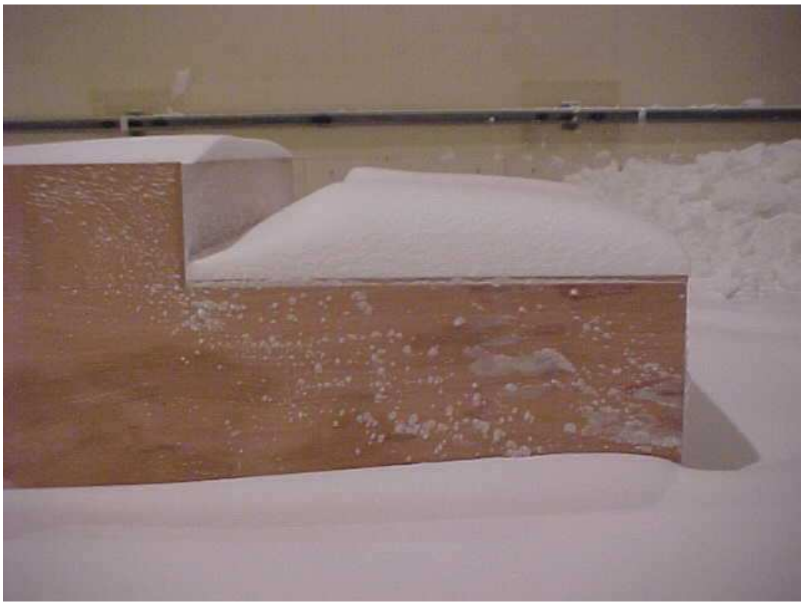


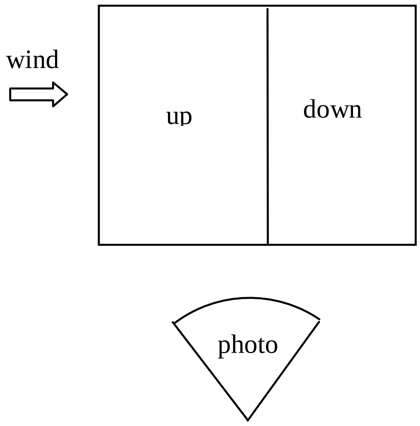


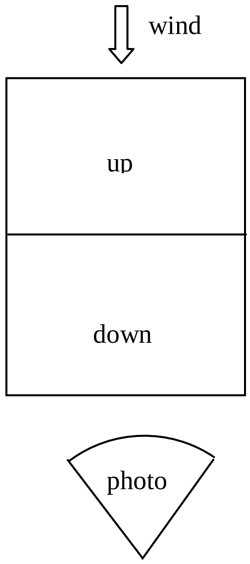


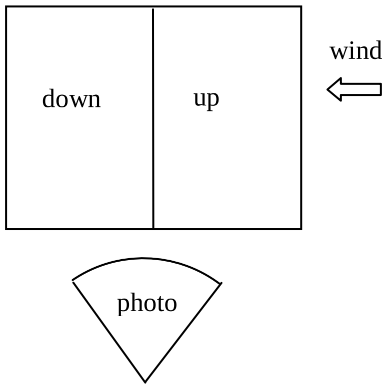


Two level, shape 1, wind 180° (upper part windward)

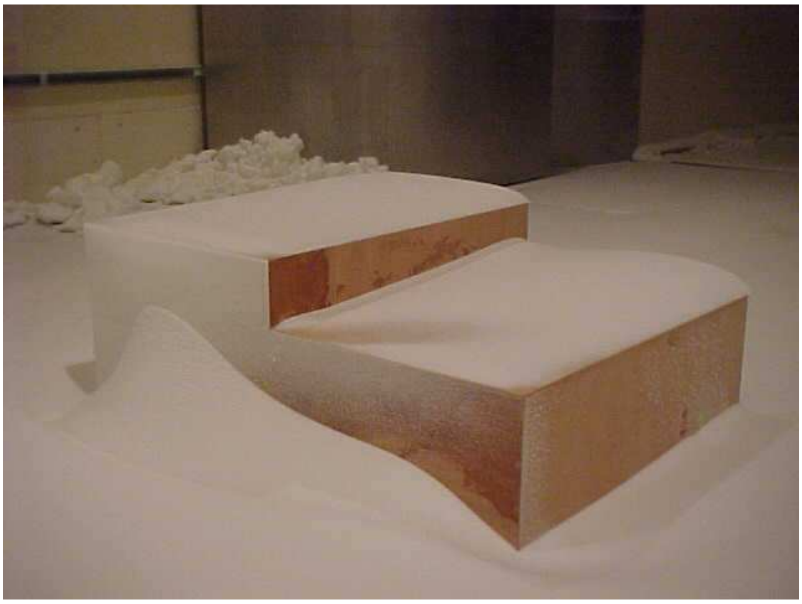


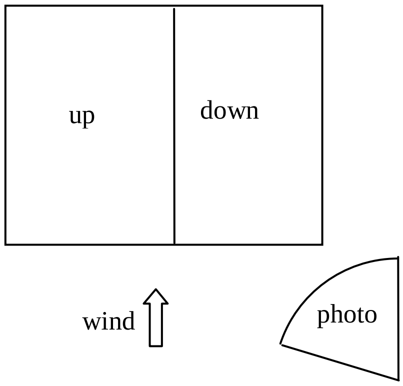


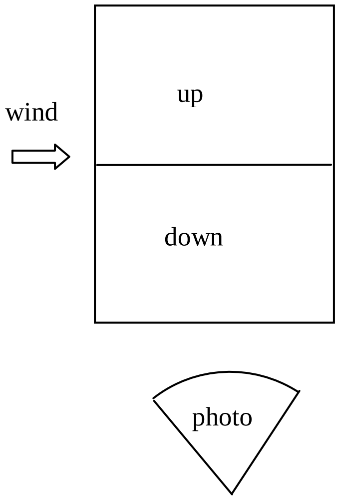


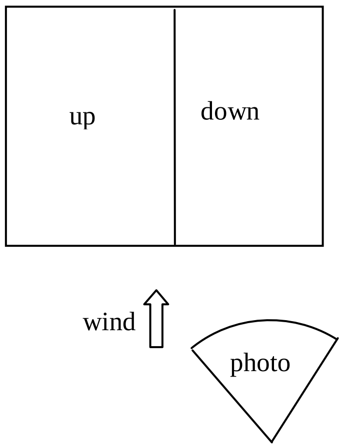


Two level, shape 1, wind 90°

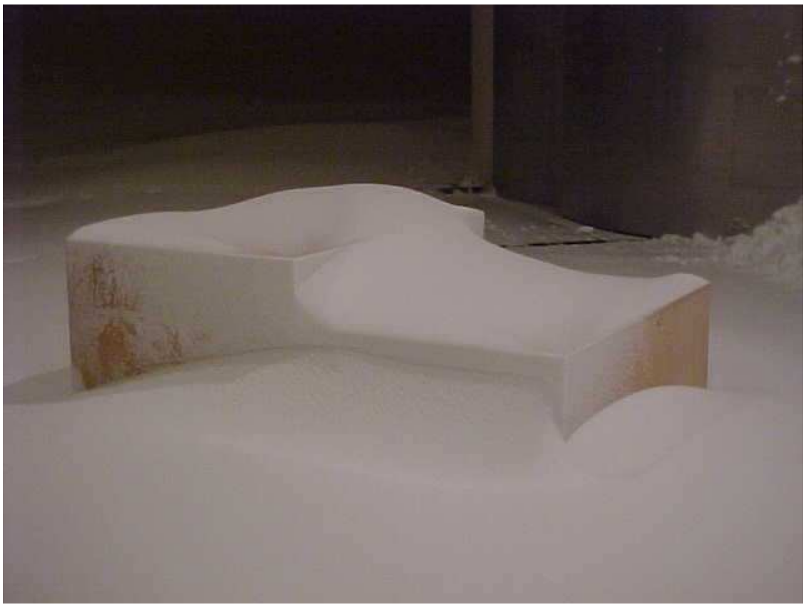


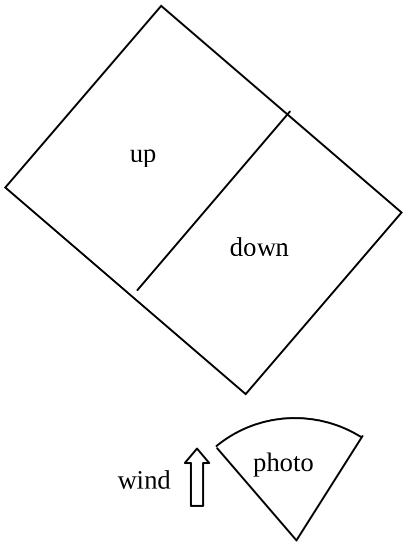


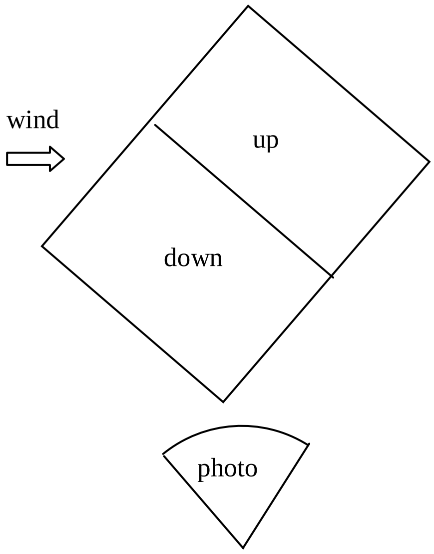


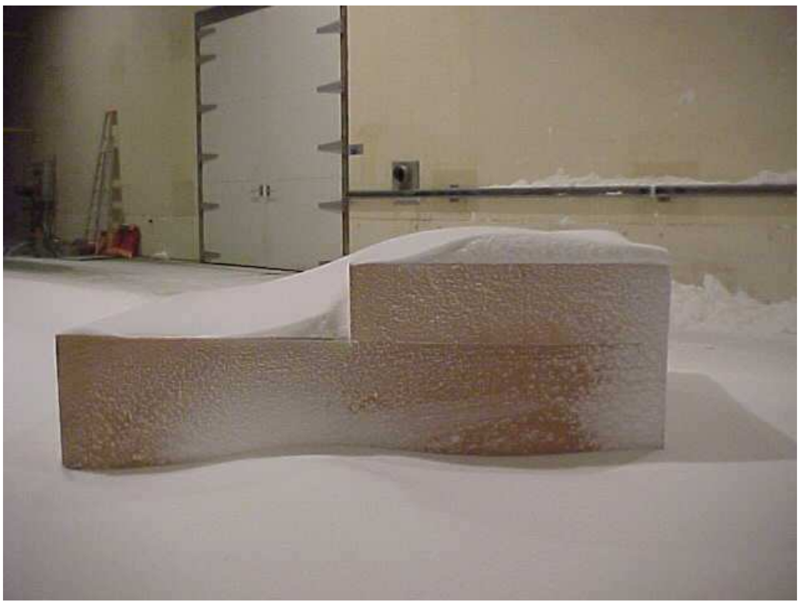


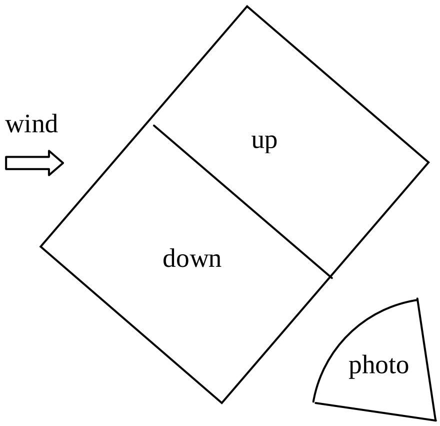
Two level, shape 1, wind 45° (lower part windward)



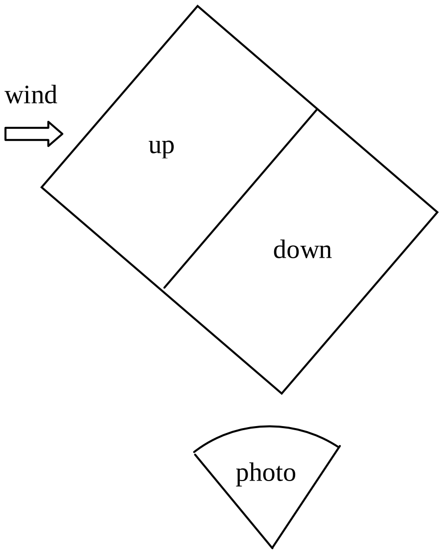

up
down
wind
photo

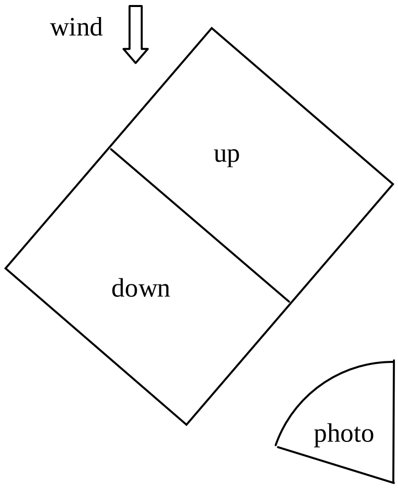

wind
up
down
photo

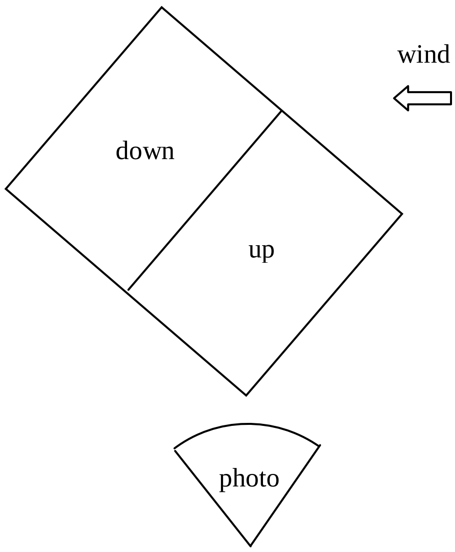



wind
up
down
photo

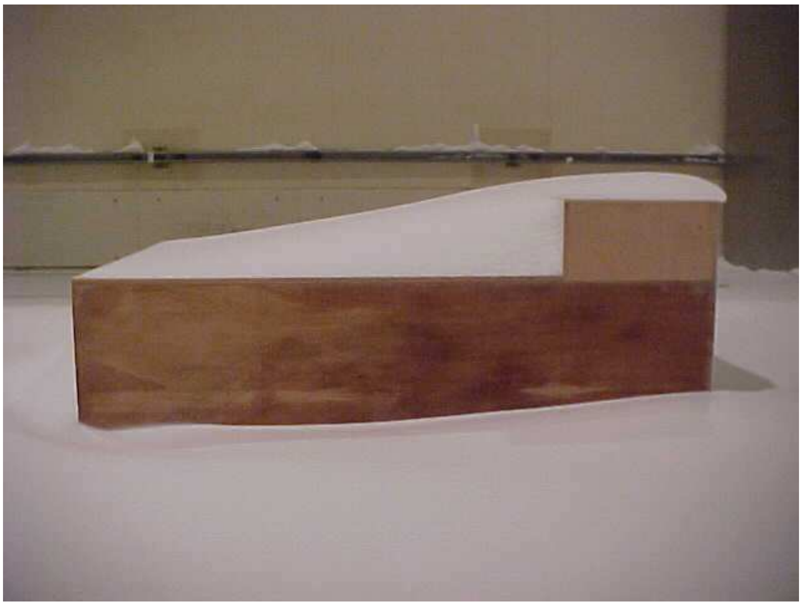
Two level, shape 1, wind 135° (upper part windward)

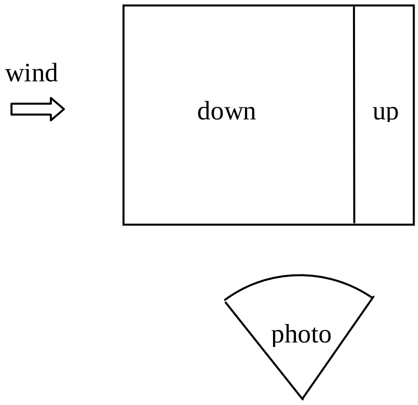


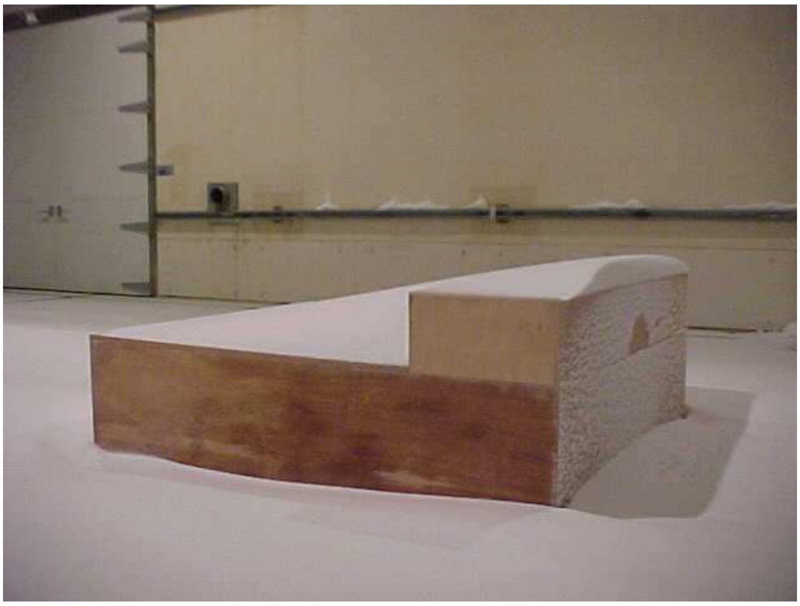


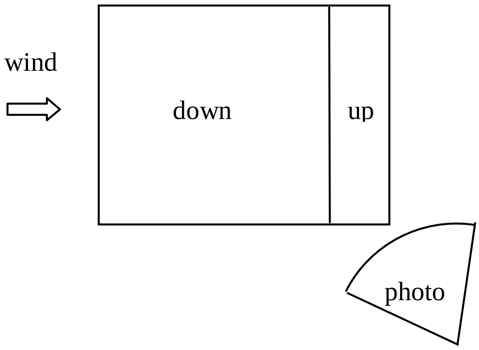


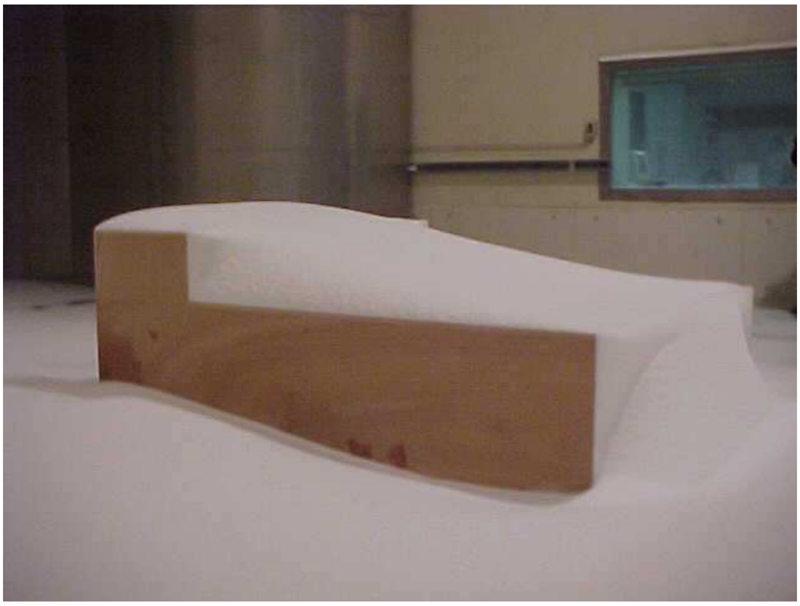
Two level, shape 2, wind 0° (lower part windward)

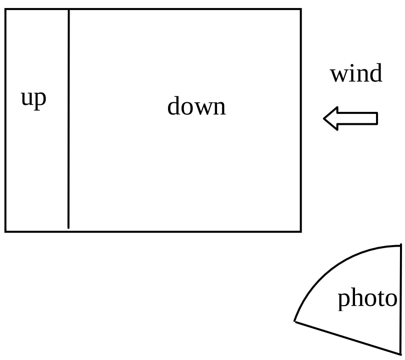




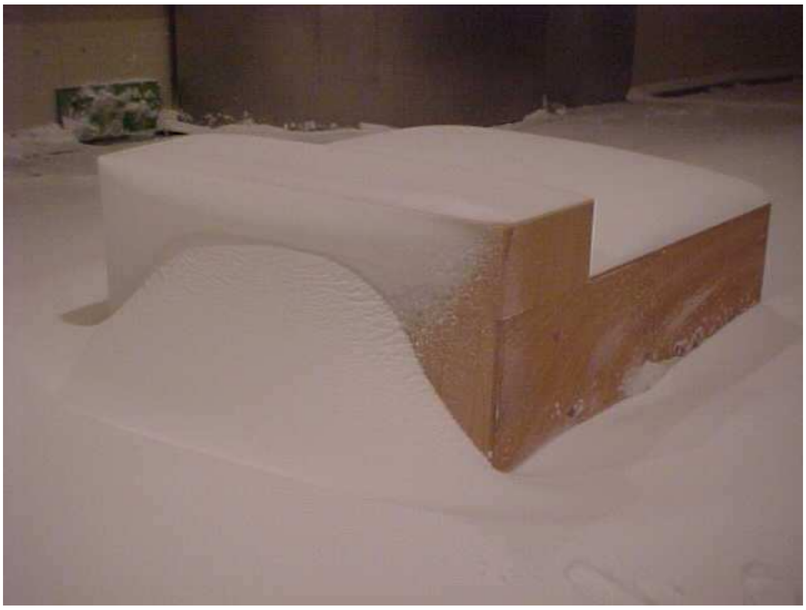


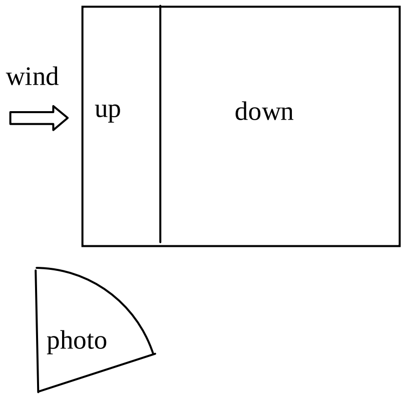


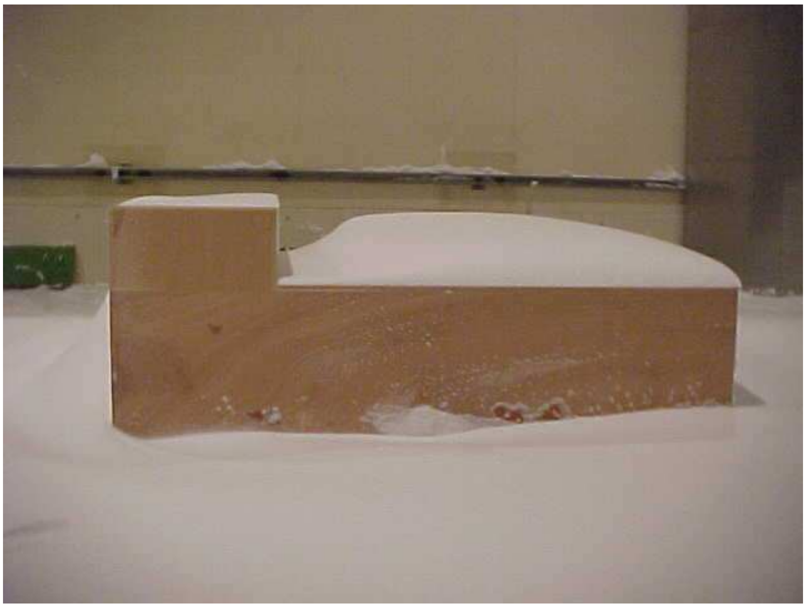


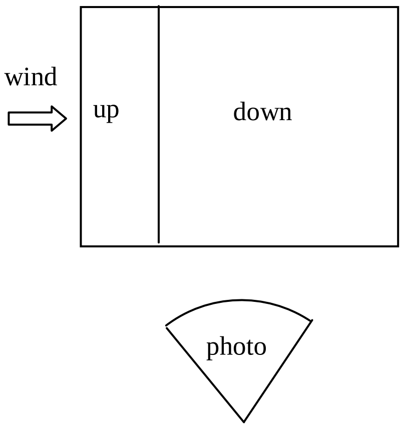


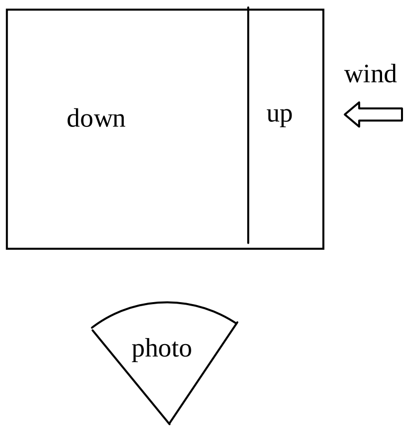
Two level, shape 2, wind 180° (upper part windward)



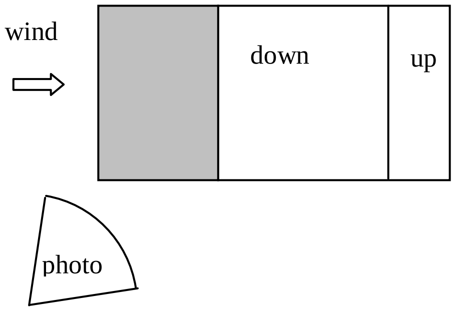


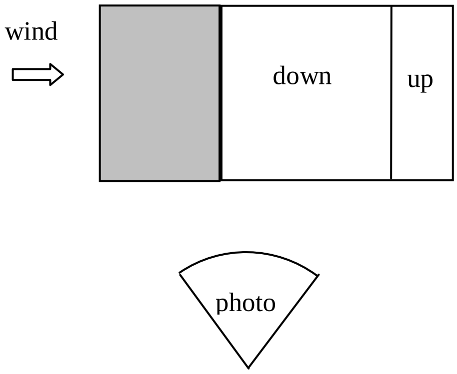


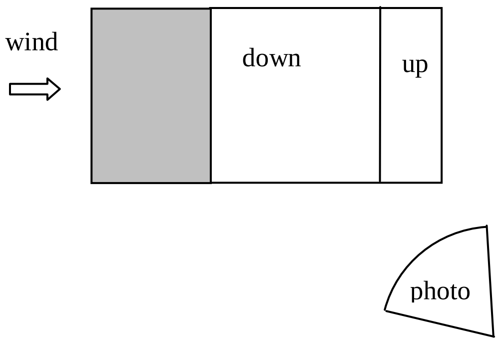




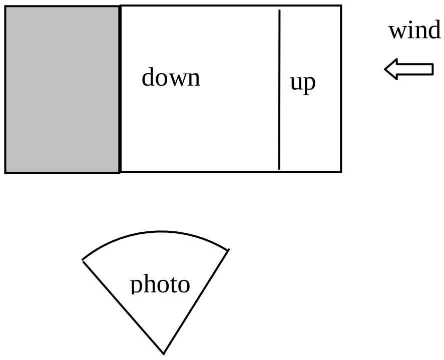
Two level, shape 3, wind 0° (lower part windward)

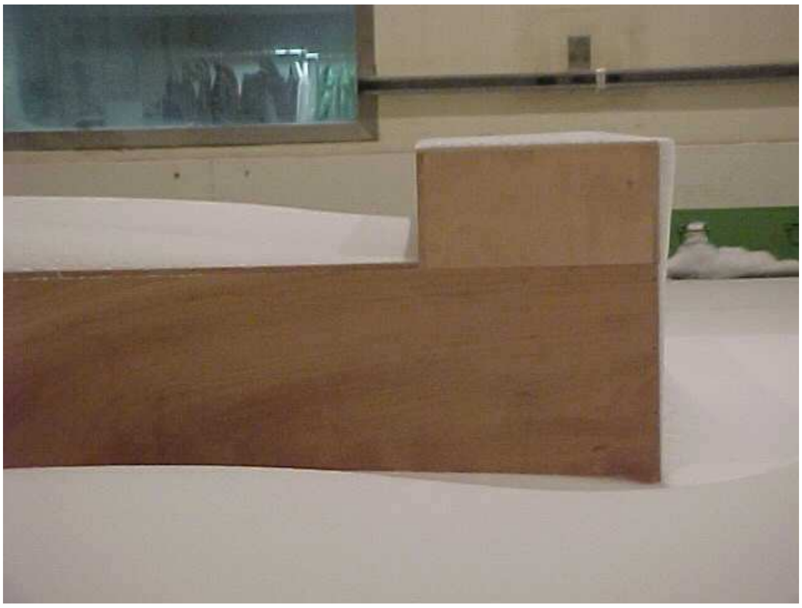


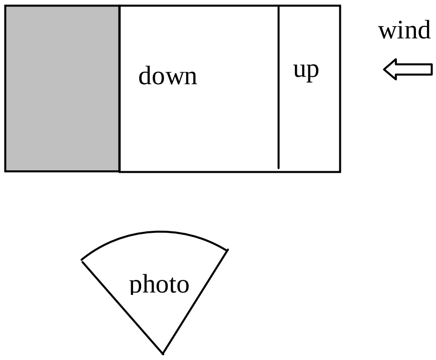


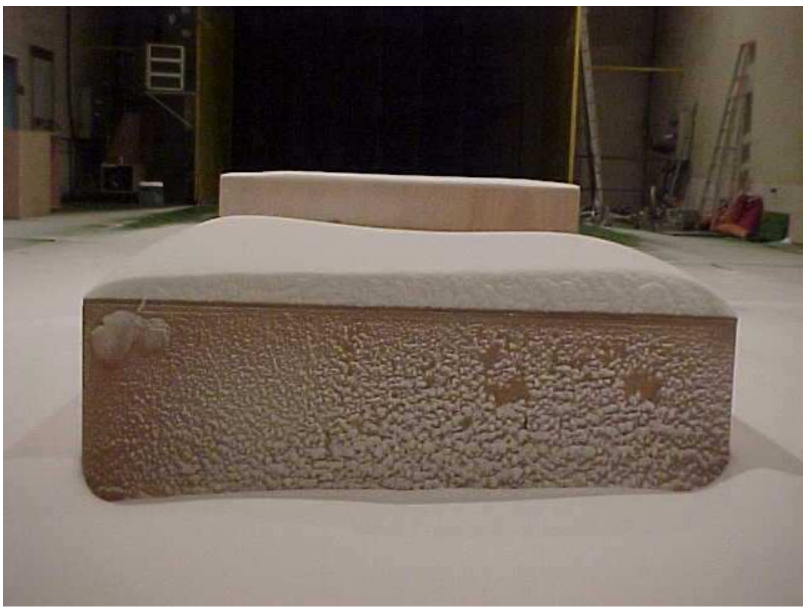


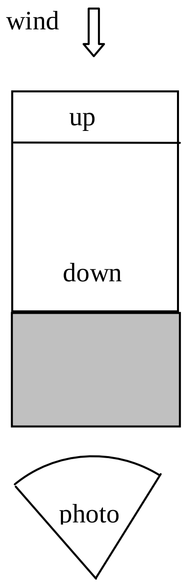
Two level, shape 3, wind 180° (upper part windward)



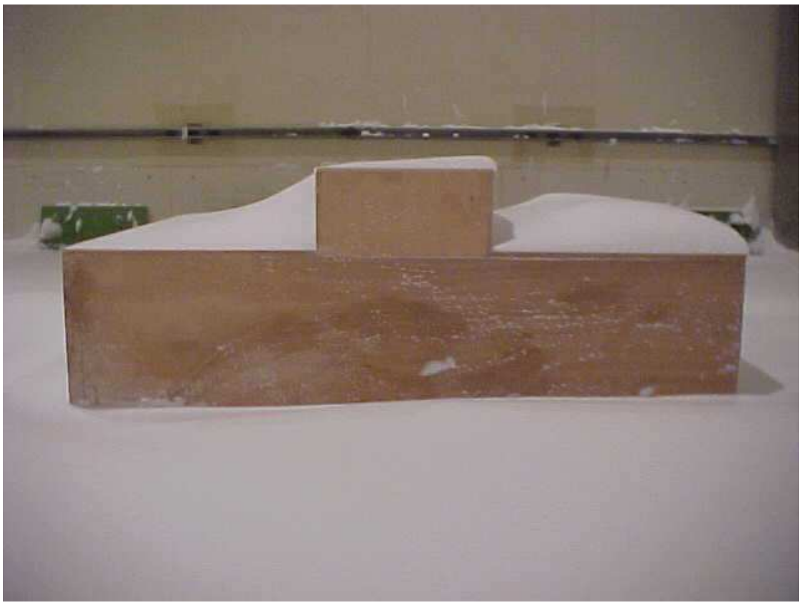


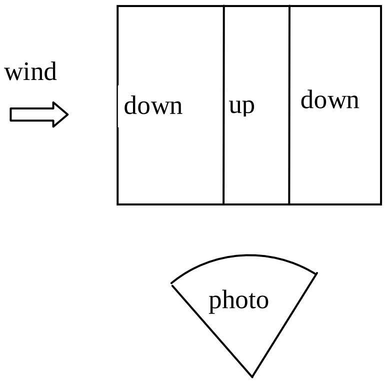


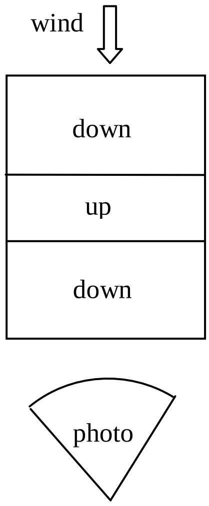


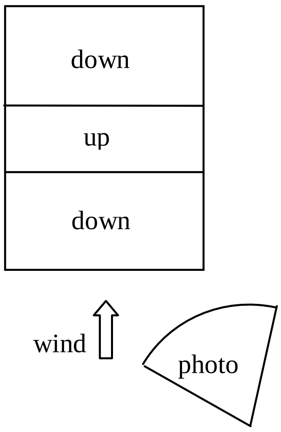


Two level, shape 4, wind 0°

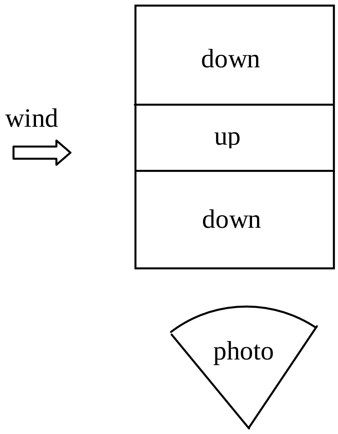


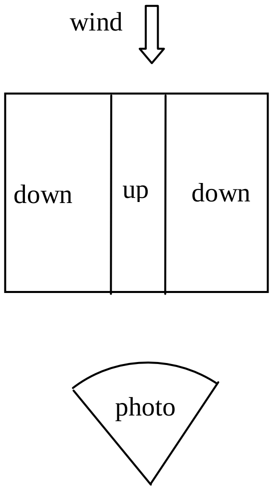


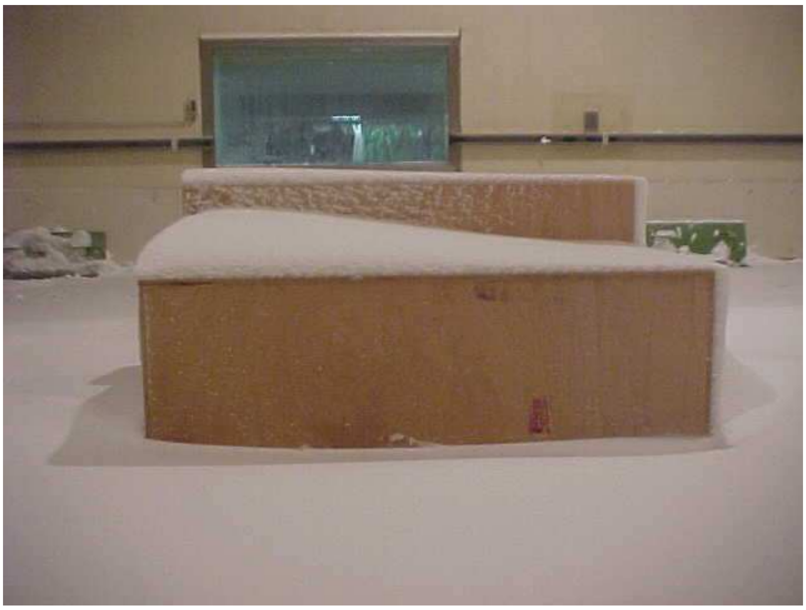


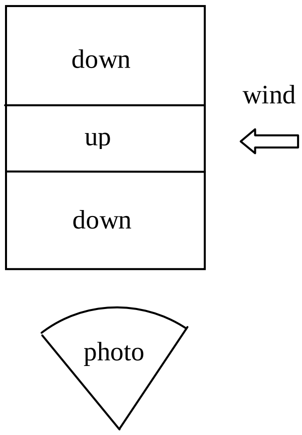


Two level, shape 4, wind 90°

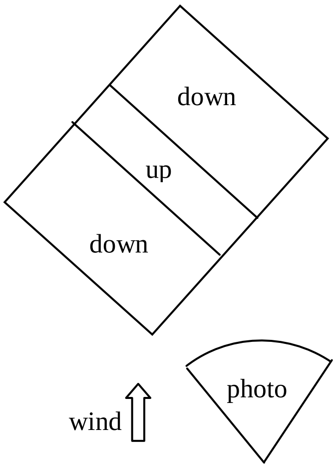


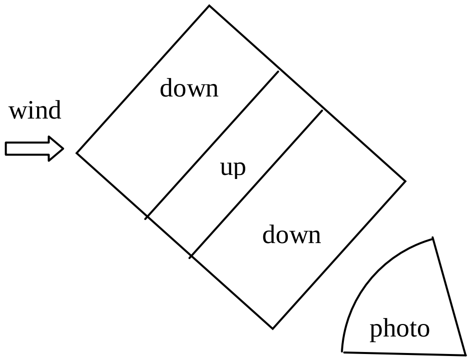


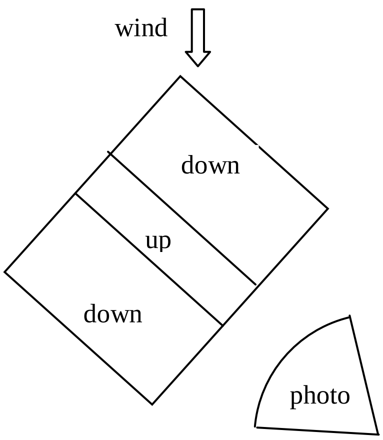




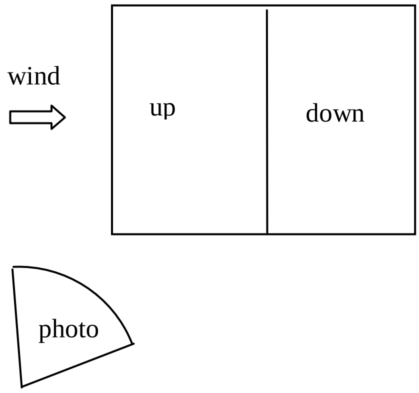
Two level, shape 4, wind 45°

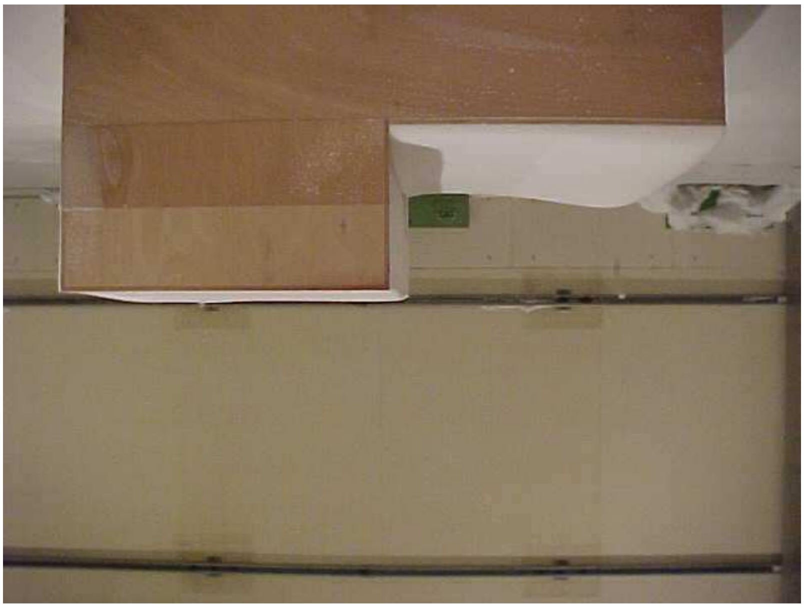


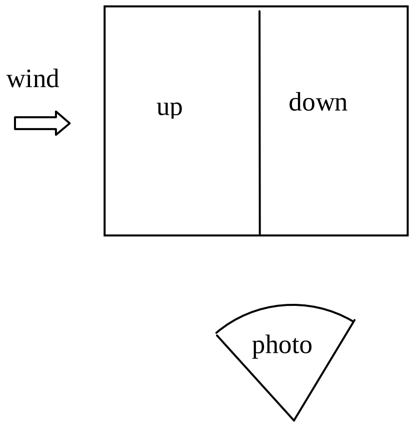


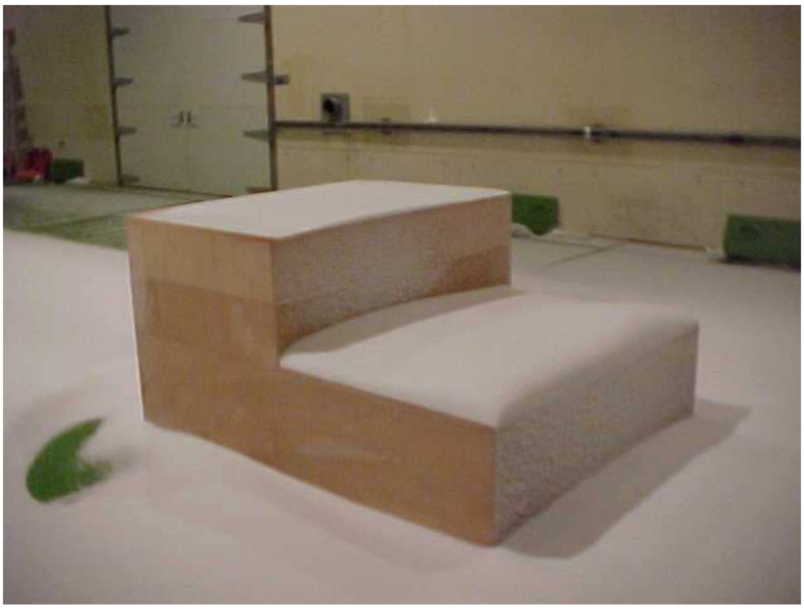


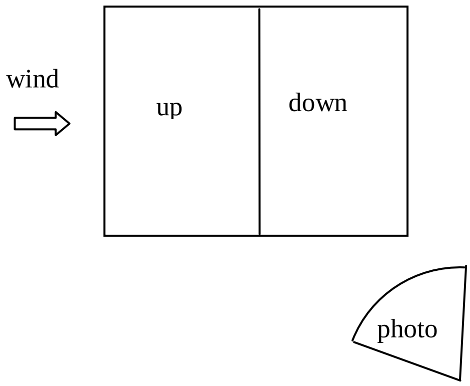
Two level, shape 5, wind 0° (lower part windward)



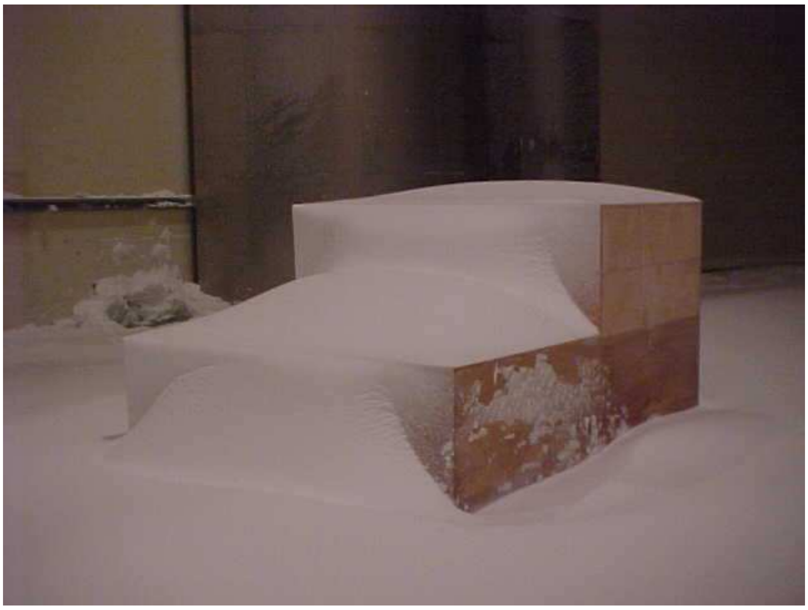


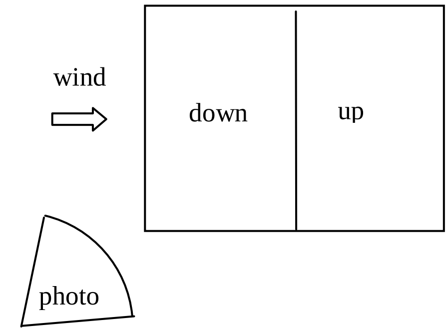


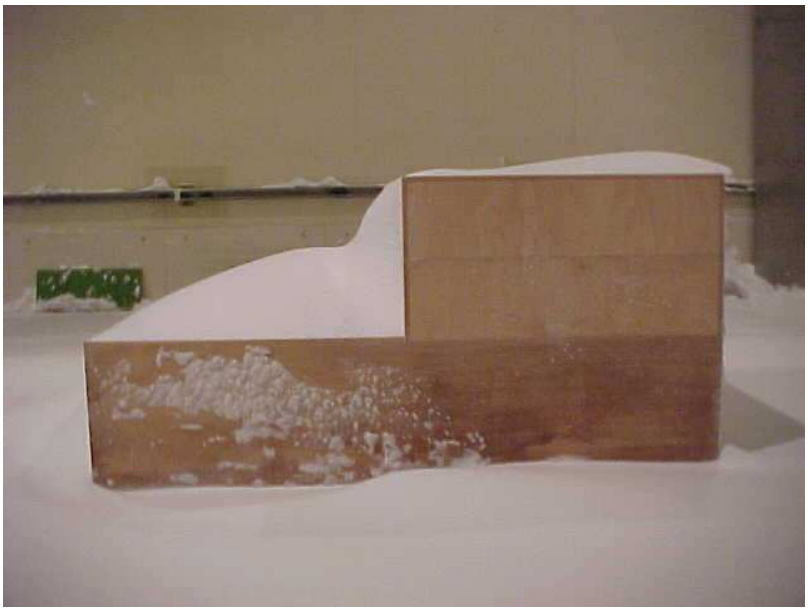


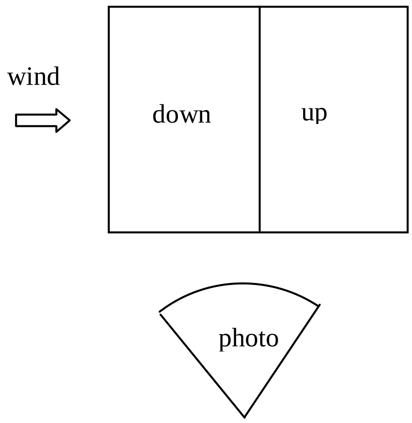


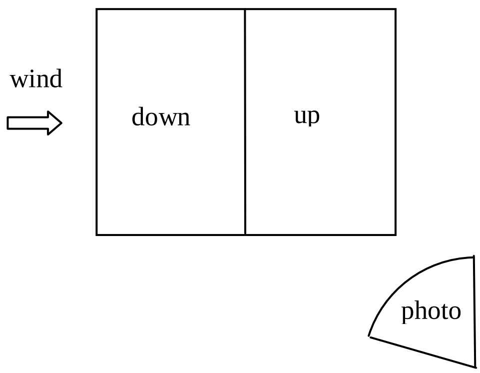
Two level, shape 5, wind 180° (upper part windward)



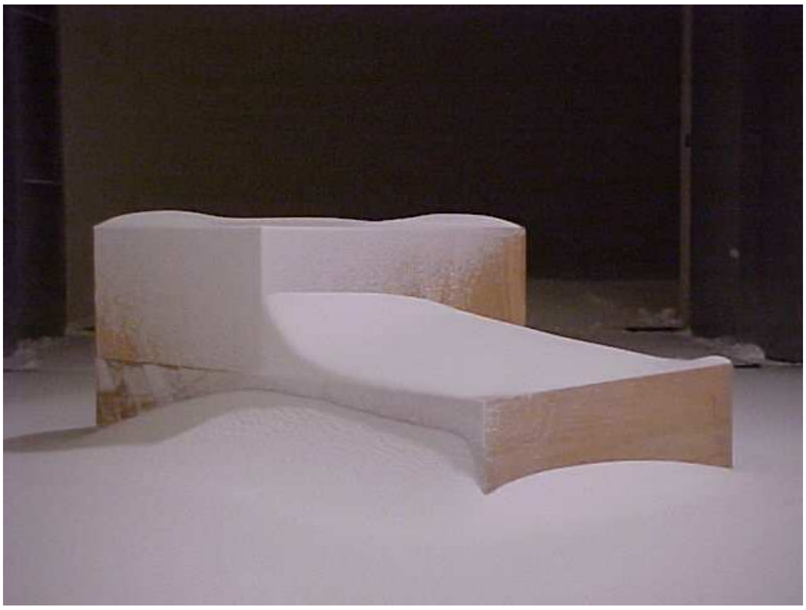


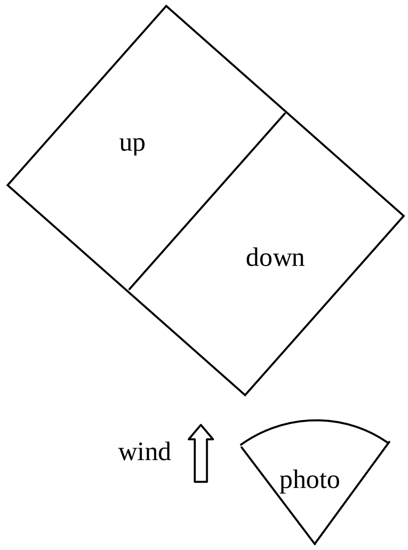


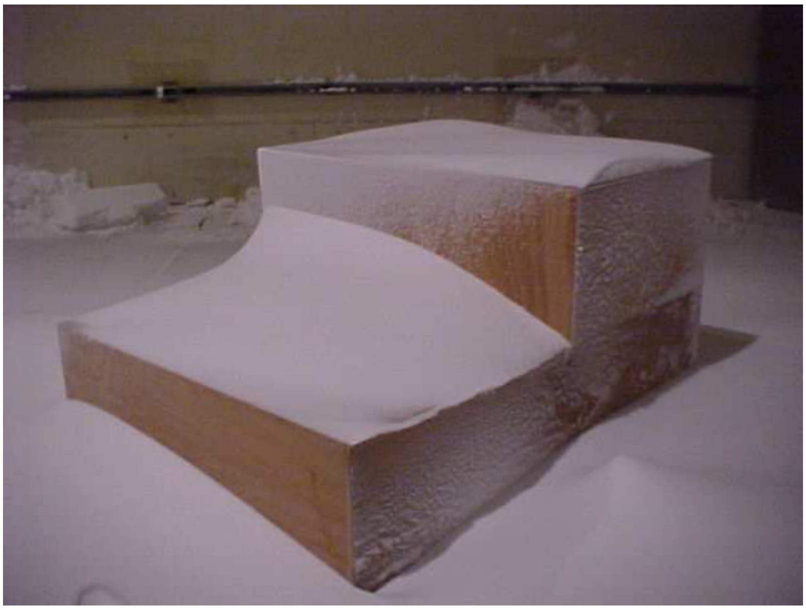


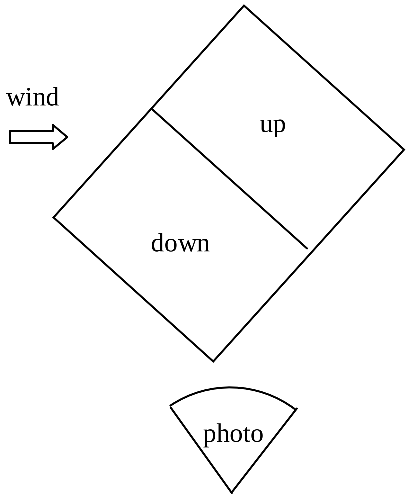


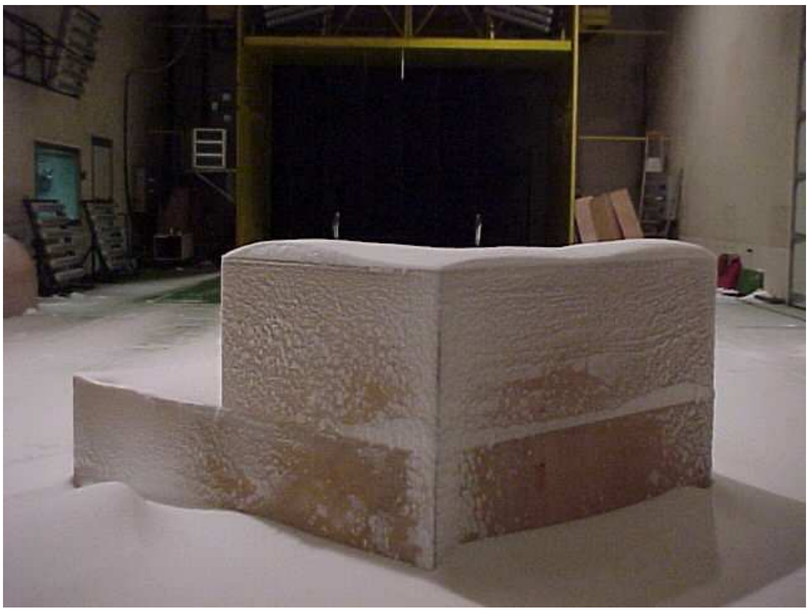
Two level, shape 5, wind 45° (lower part windward)

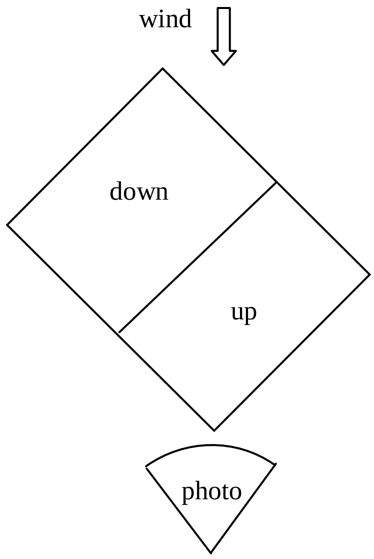




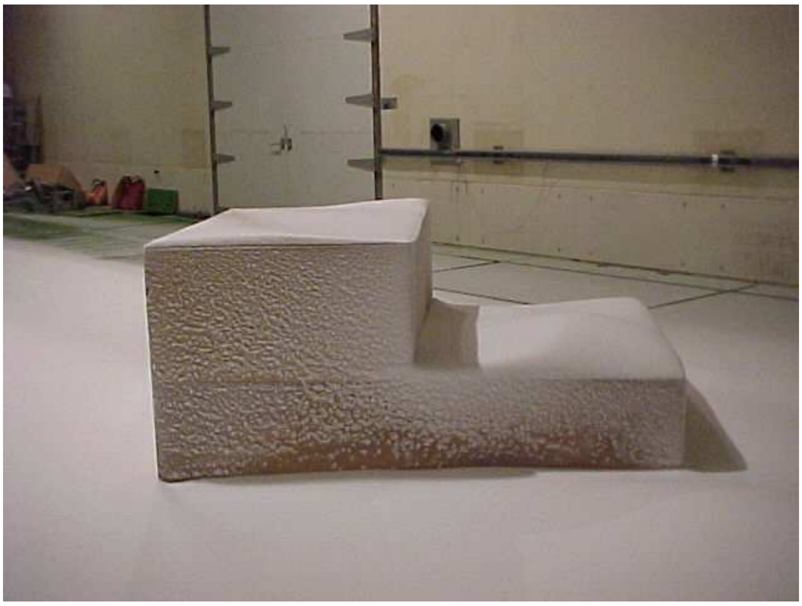


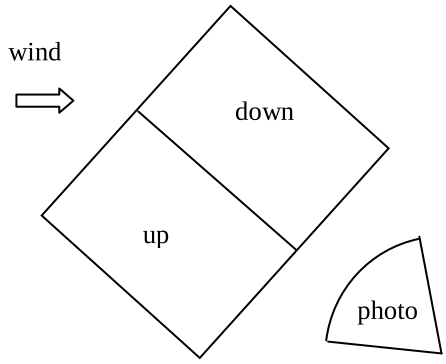


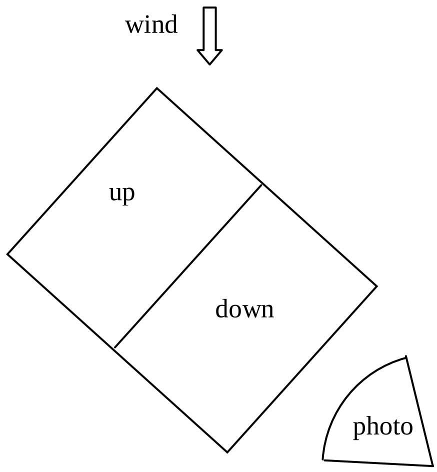


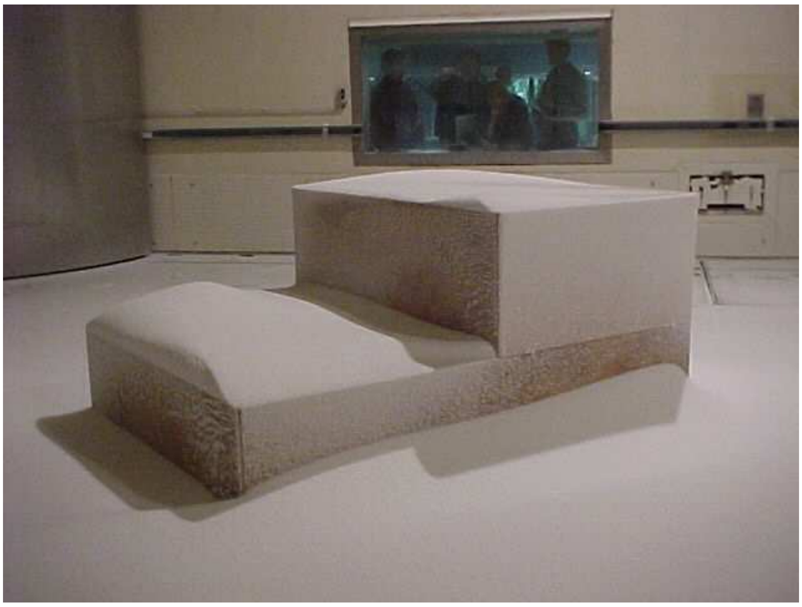


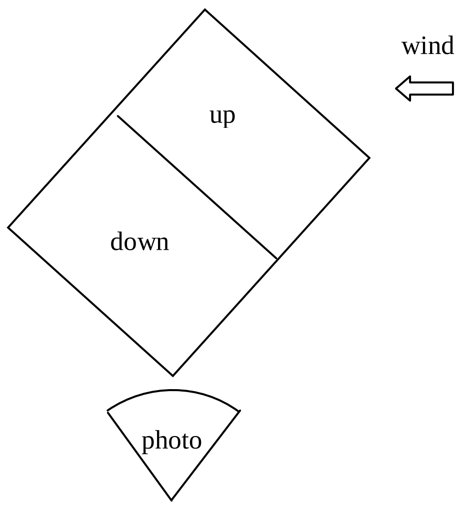
Two level, shape 5, wind 135° (upper part windward)



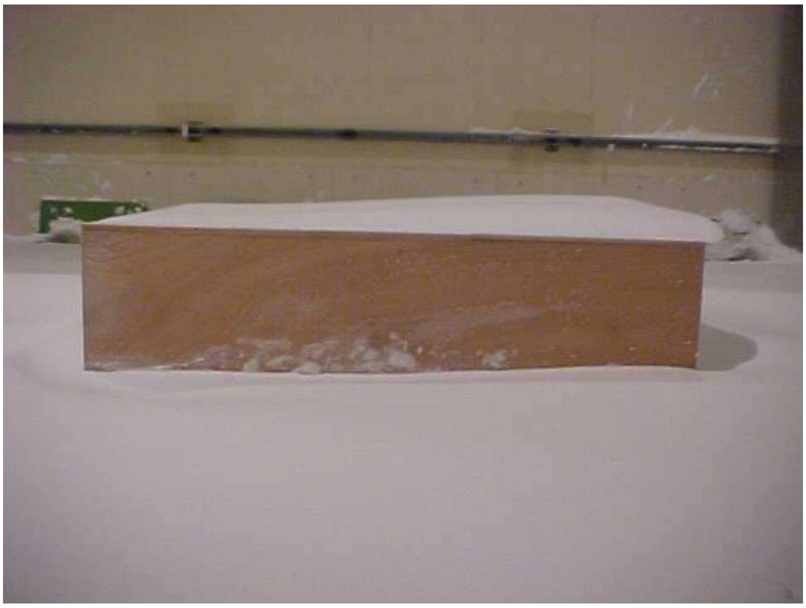


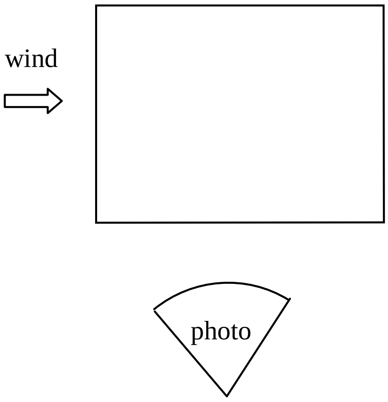


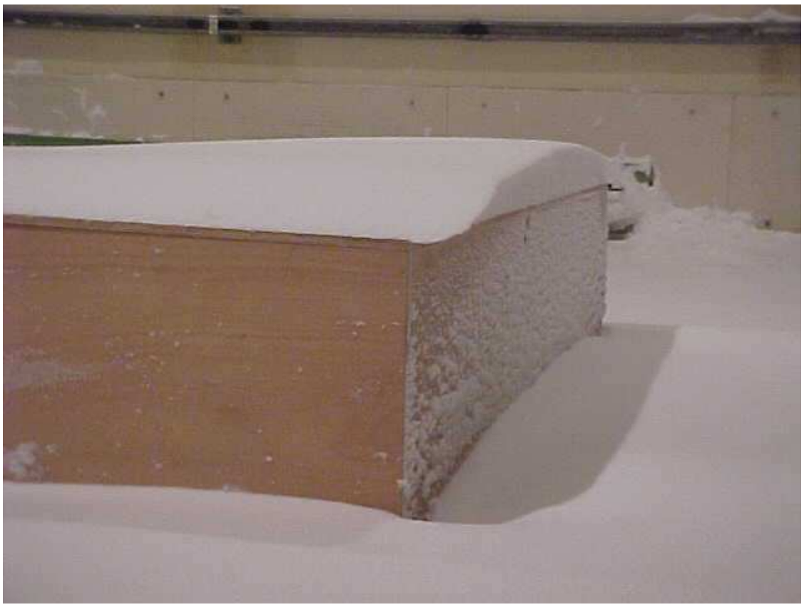


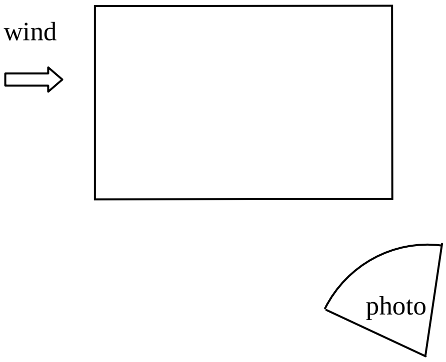


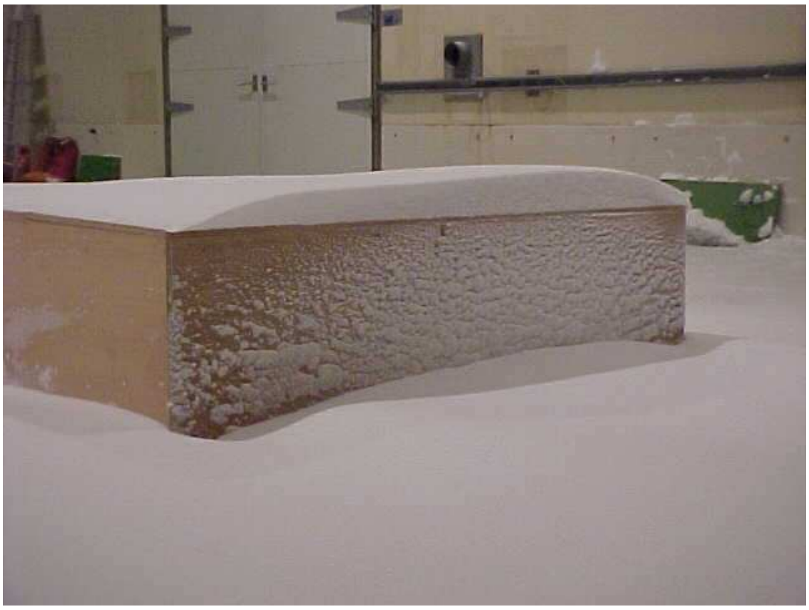
Two level, shape 6 (reference flat roof) wind 0°

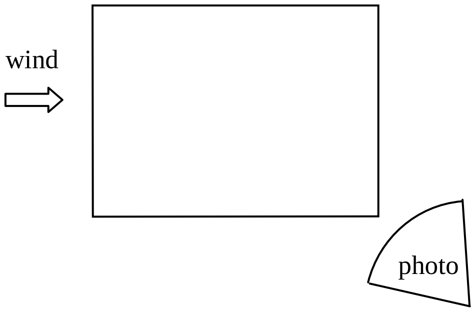




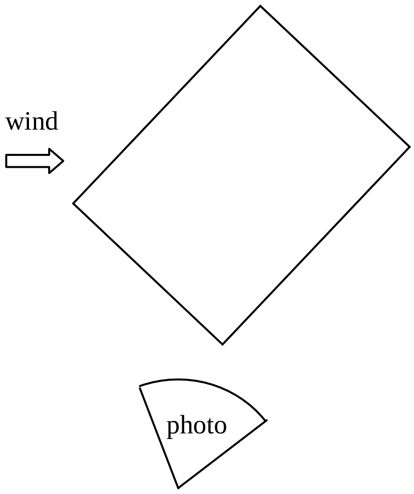


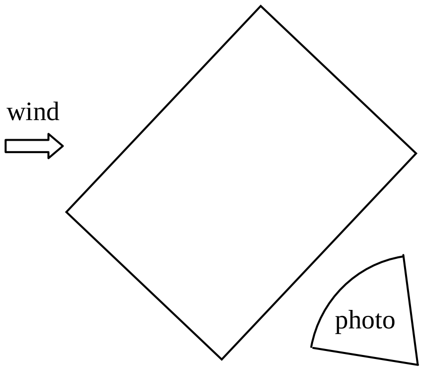


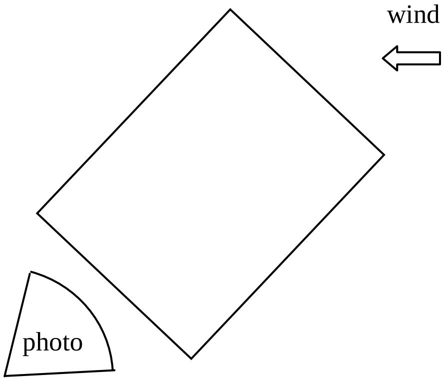




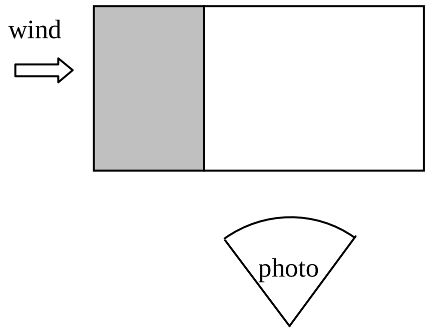
Two level, shape 6 (reference flat roof) wind 45°

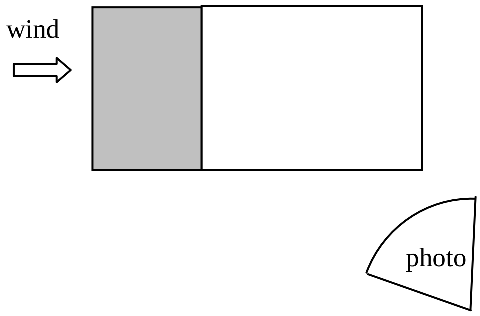


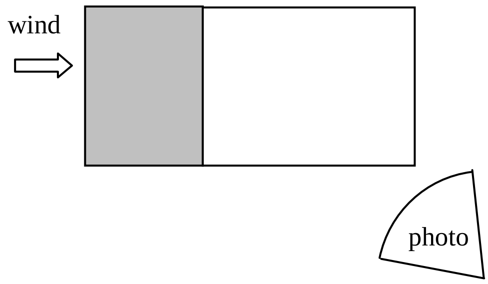




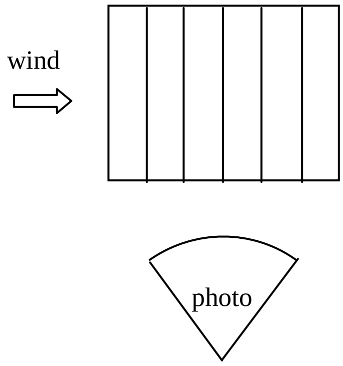
Two level, shape 7 (long flat roof) wind 0°

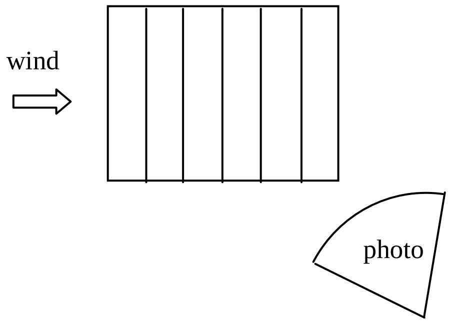


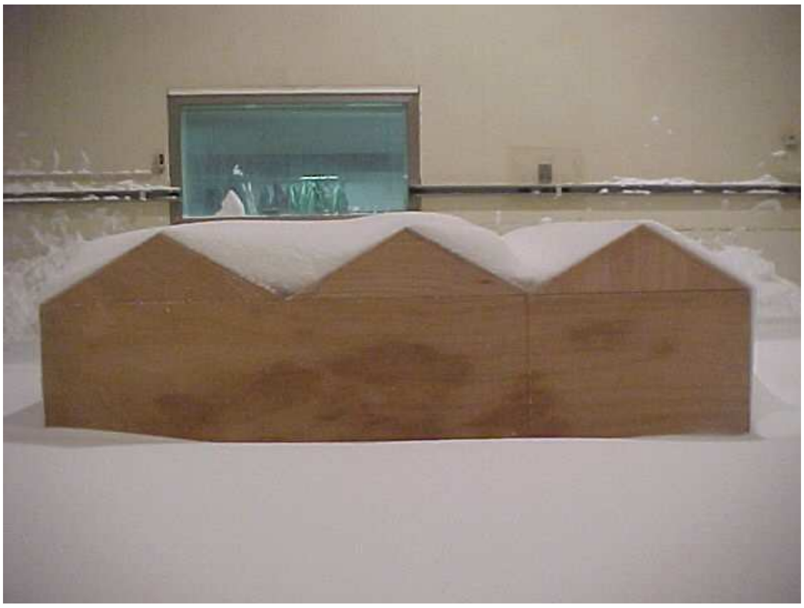


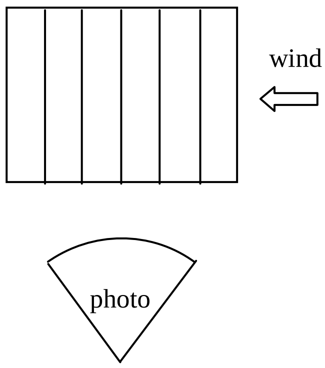


Multi-pitch symmetrical roof, wind 0°

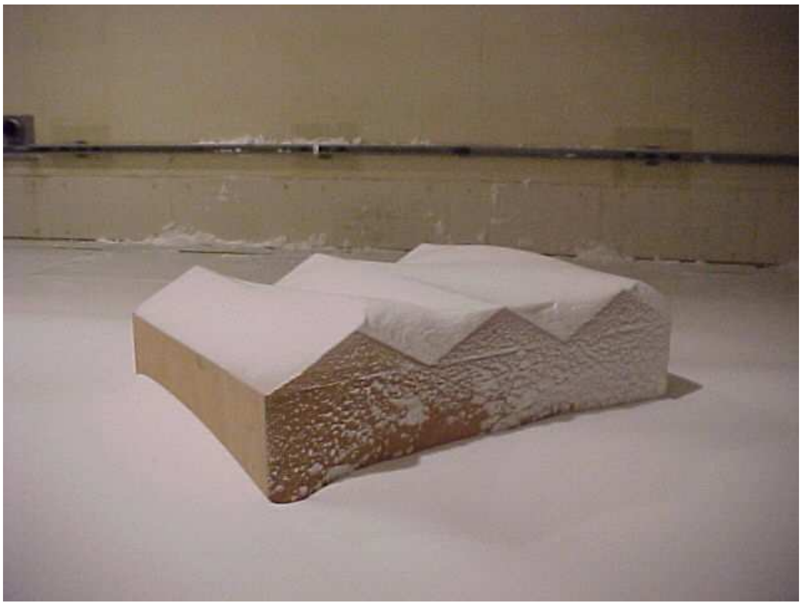


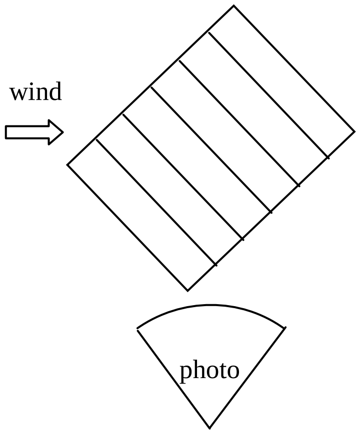


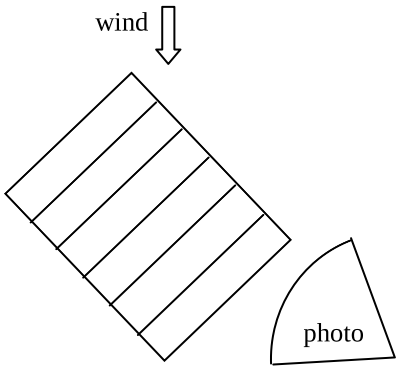


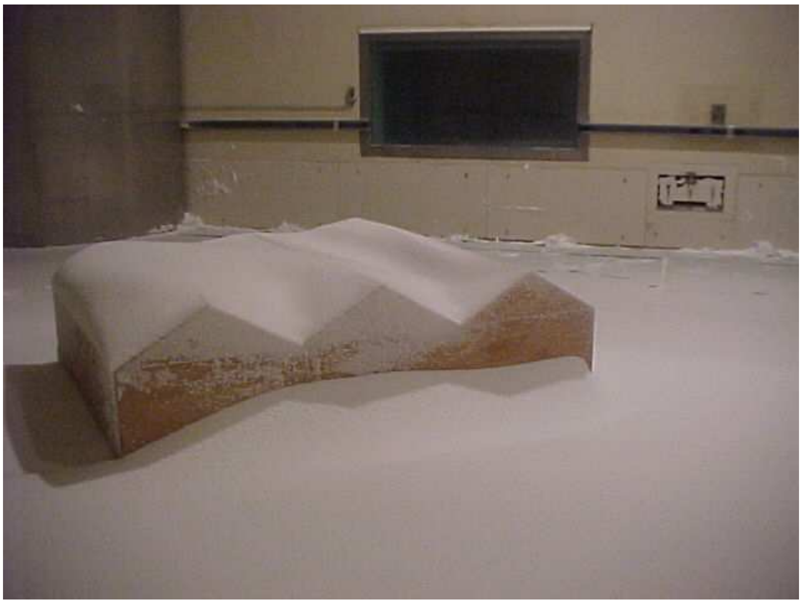


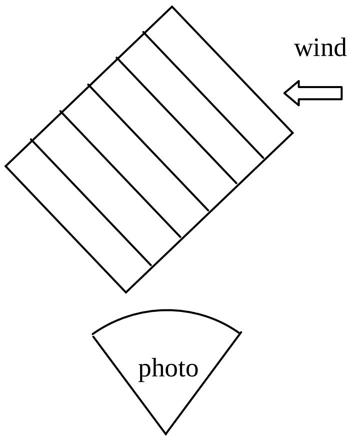
Multi-pitch symmetrical roof, wind 45°



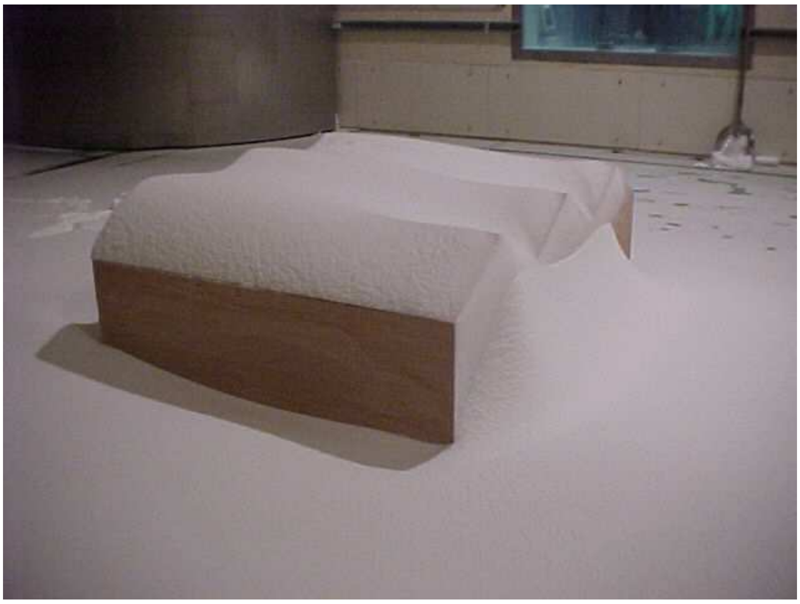


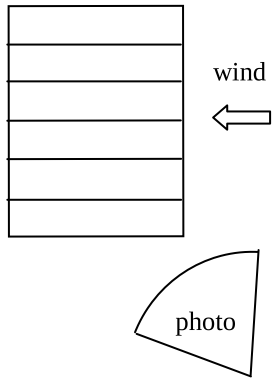


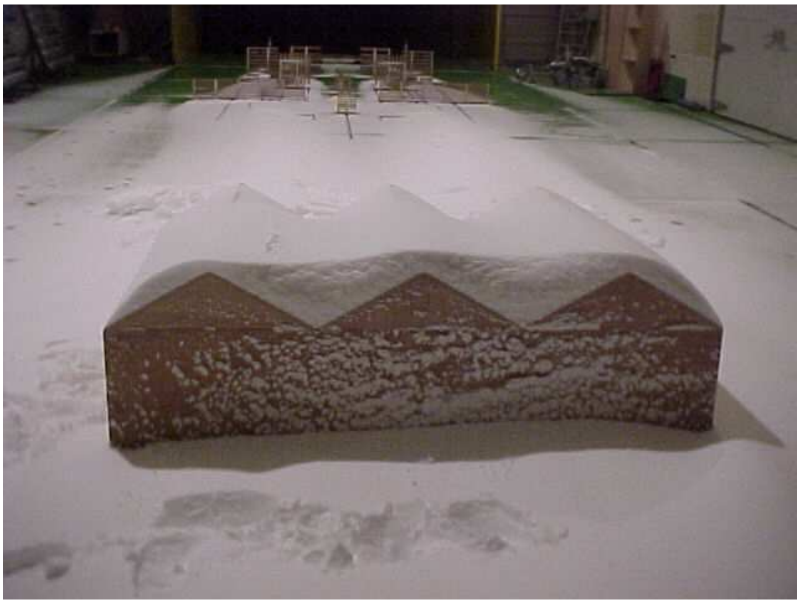


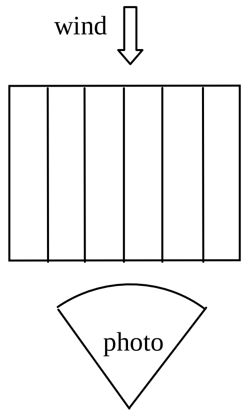


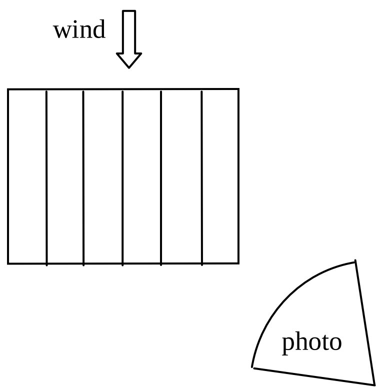
Multi-pitch symmetrical roof, wind 90°



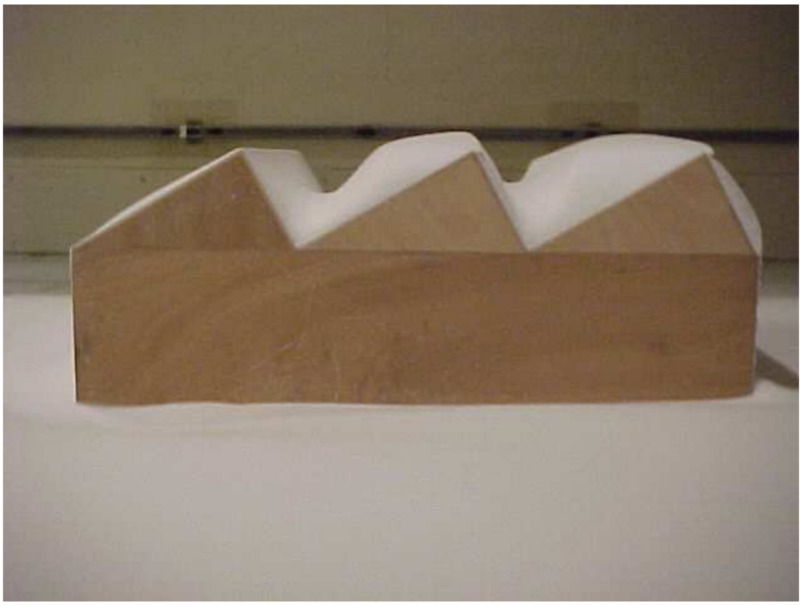


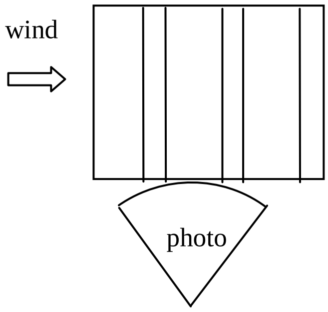


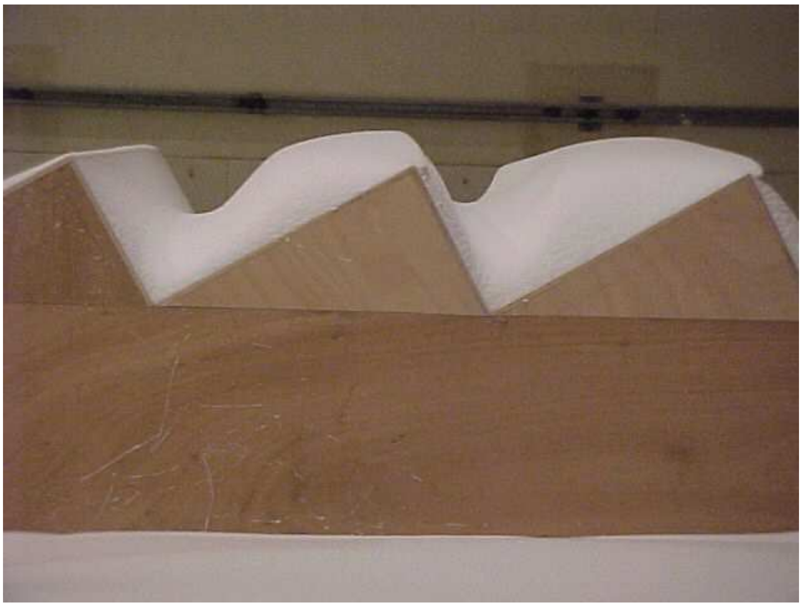


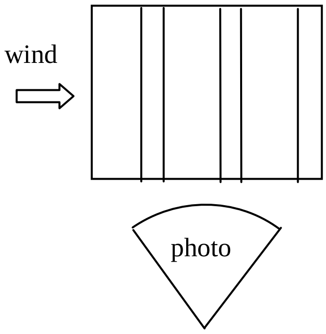


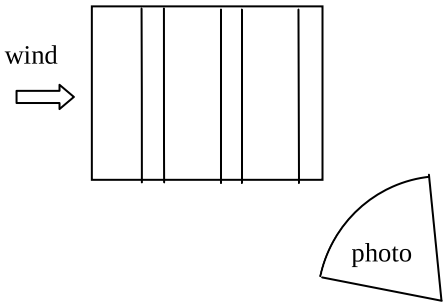
Multi-pitch non symmetrical roof, wind 0°



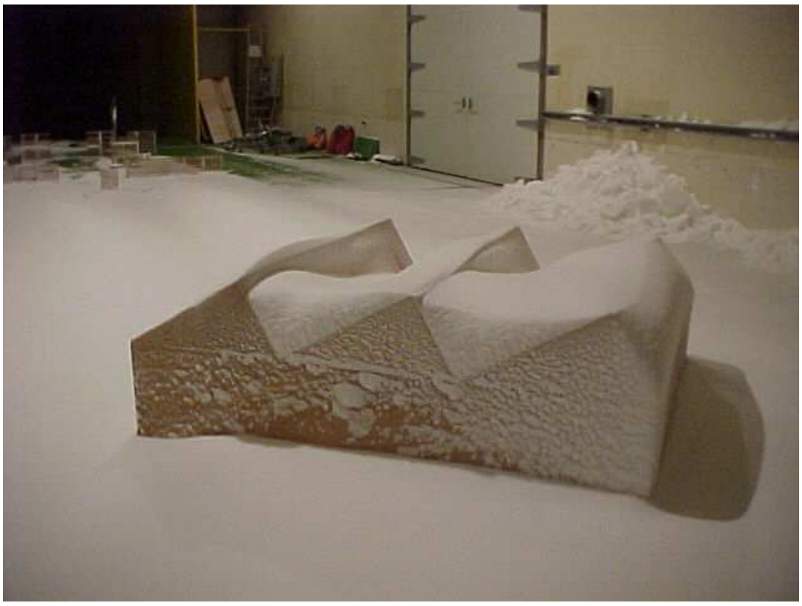

wind
photo

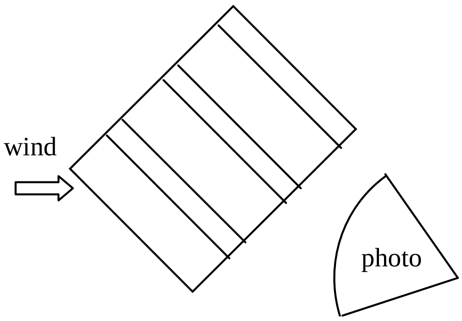


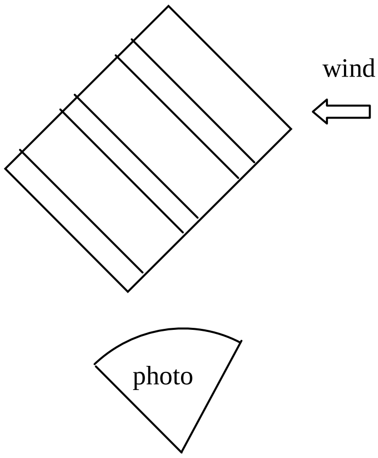

wind
photo

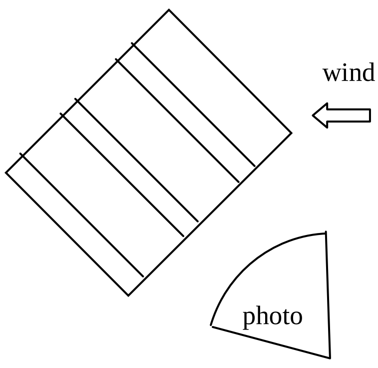

wind
photo

Multi-pitch non symmetrical roof, wind 45°

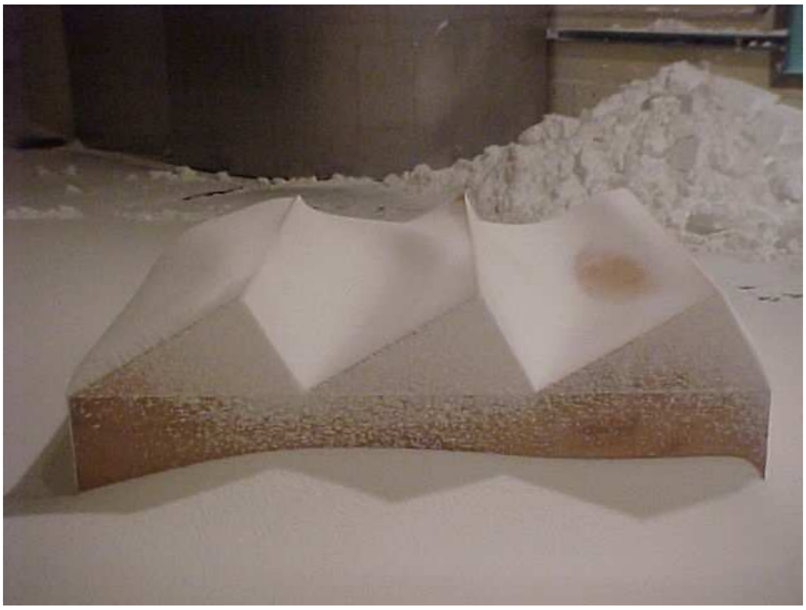


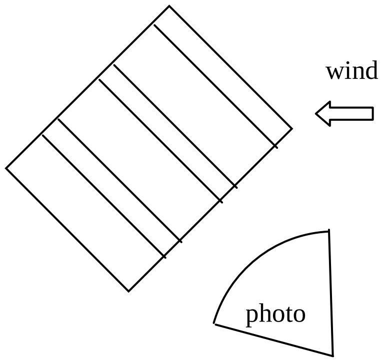


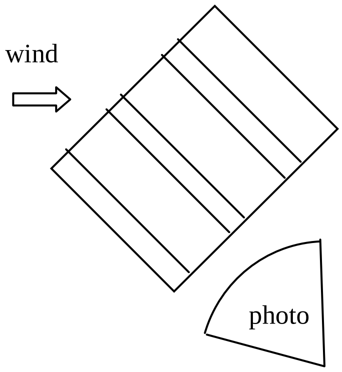


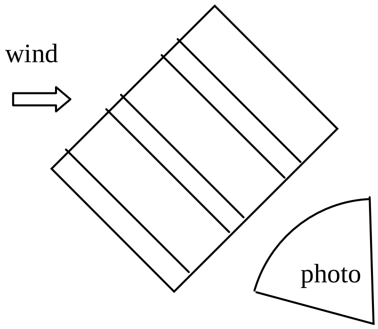


Multi-pitch non symmetrical roof, wind 135°

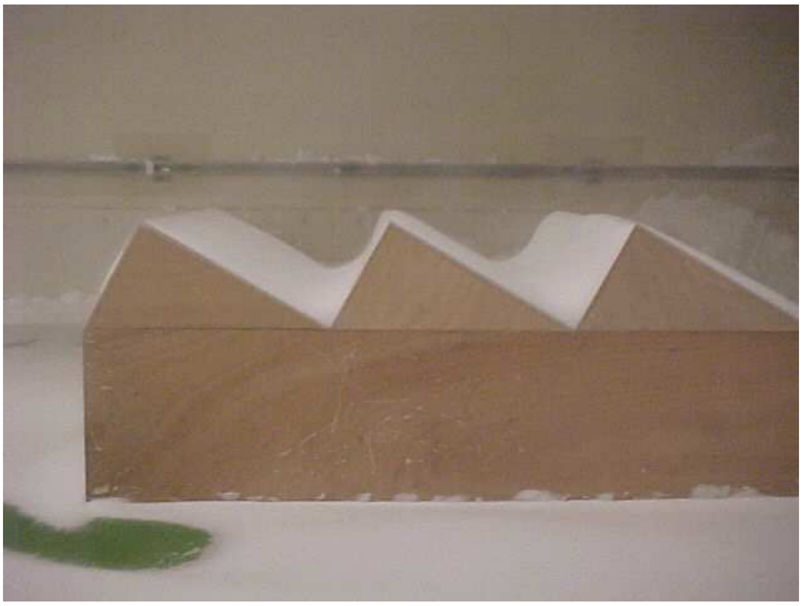


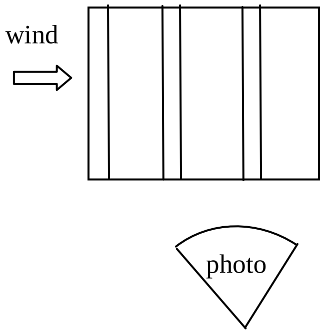


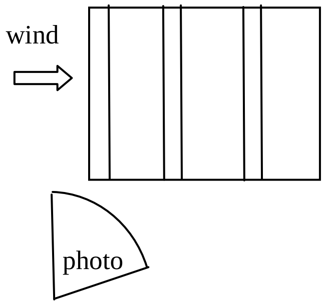




Multi-pitch non symmetrical roof, wind 180° (1/2h)



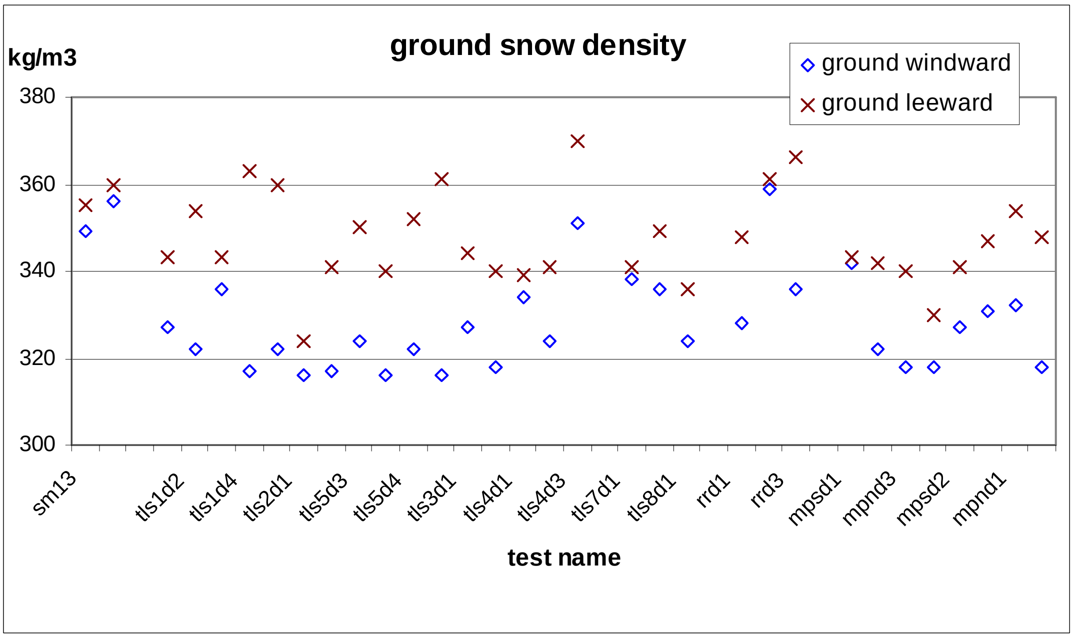




A13.6 Discussion about snow density measurements for 2nd sub-task

Snow density measurements have been made on the ground and on the roof windward and leeward. The results show a dispersion of snow density values on the ground (values between 315 kg/m^3 and 370 kg/m^3) and on the roofs (values between 310 kg/m^3 and 385 kg/m^3). This variation (figure A13.6.1) are small with respect to snow density absolute value without model which is about 360 kg/m^3 (variation between -14% and +4%).

Figure A13.6.1 : ground snow density for all the tests



In some cases tendencies can be noticed. For a flat roof without obstacle snow accumulation occurred on the leeward part with a snow density of 380 kg/m^3, figures A13.6.2 and A13.6.3, which is 6% greater than ground snow density reference (density without model: 360kg/m3).

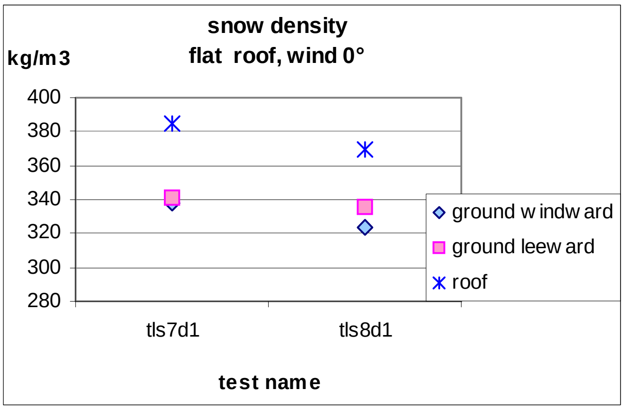


Figure A13.6.2 : snow density on flat roof with wind 0°

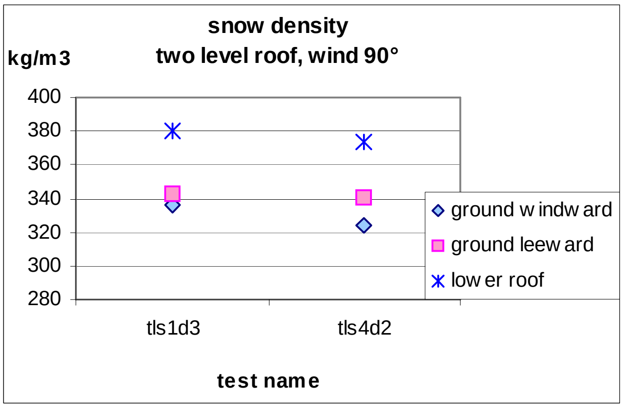


Figure A13.6.3 : snow density on roof with wind 90°

If snow density and influence of an obstacle is correlated, the height of the obstacle can be a significant parameter. For two-level flat roofs height of the roof to the ground or height of the upper roof to lower roof can be taken into account as show in figure A13.6.4. Reference density for the ground is density without model and reference density for the roof is density on the flat roof (shapes n°7 and 8). It seems that the higher the obstacle is, the lower the density is, both windward or leeward as shown on figures A13.4.5 and A13.4.6.

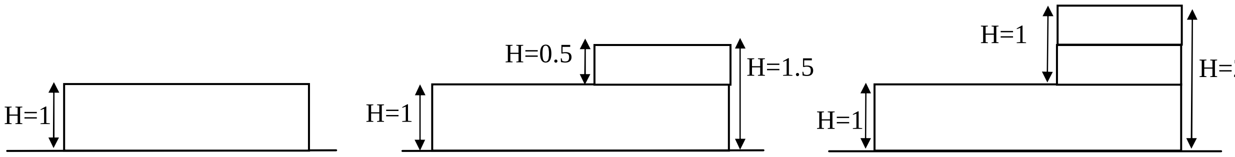


Figure A13.6.4 definition of obstacle height

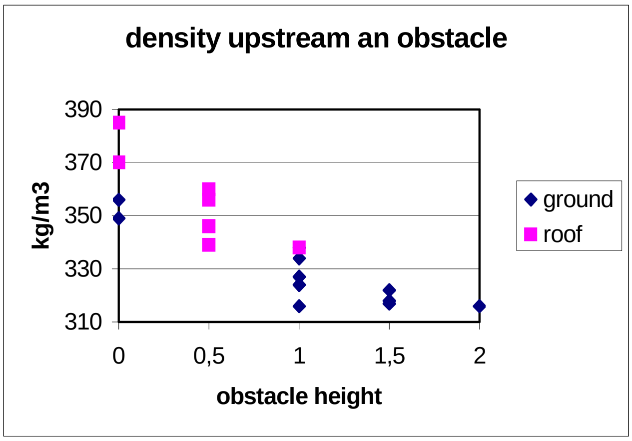


Figure A13.6.5 density upstream an obstacle

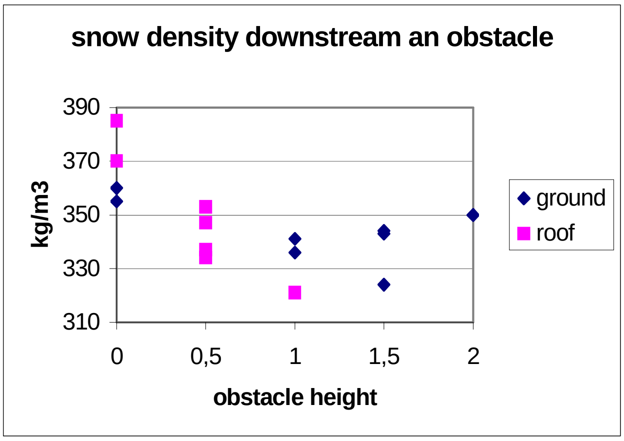


Figure A13.6.6 density downstream an obstacle

These tendencies for snow density variations observed in the wind tunnel should be compared with natural snow observation (see section 4.6.6). This validation is necessary to know the influence of differences between artificial and natural snow (particle size and shape, snow density).