Snow and ice cover on a shallow boreal lake: The effect on in-water processes

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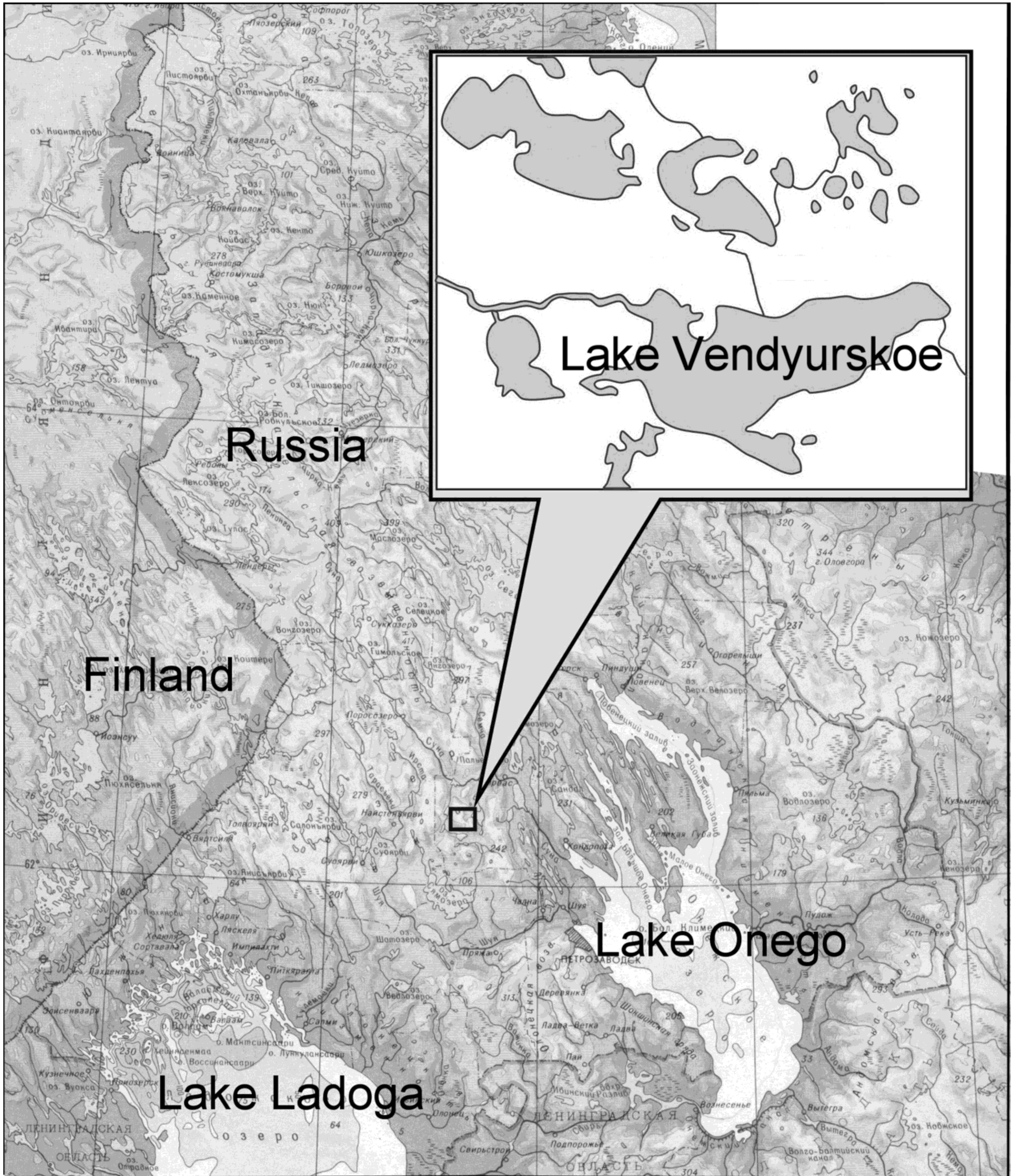
Lake workshop – 2015, Evora, Portugal

Outline

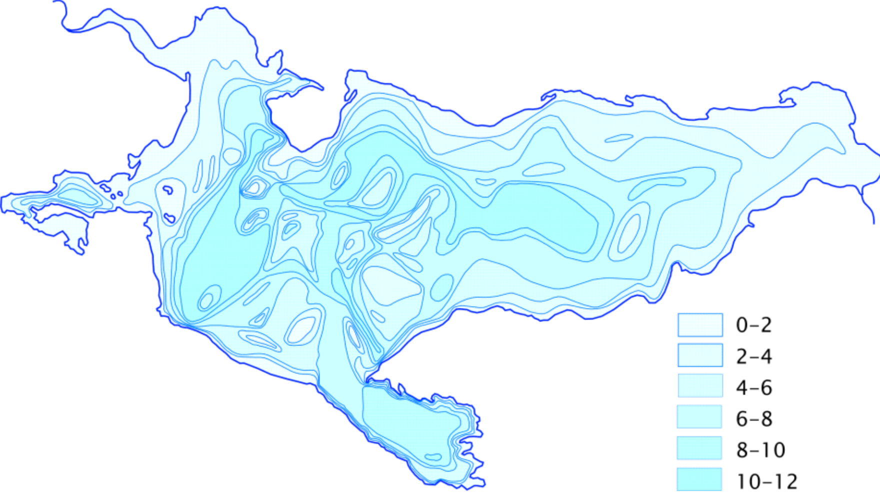
- *Data used*
- *Size of lakes as a reason for different ice structure?*
- *Optical properties of lake ice*
- *Discussion*


Lake Vendyurskoe
Sweden
Finland
Norway
Lake Onego
Lake Ladoga
Russia

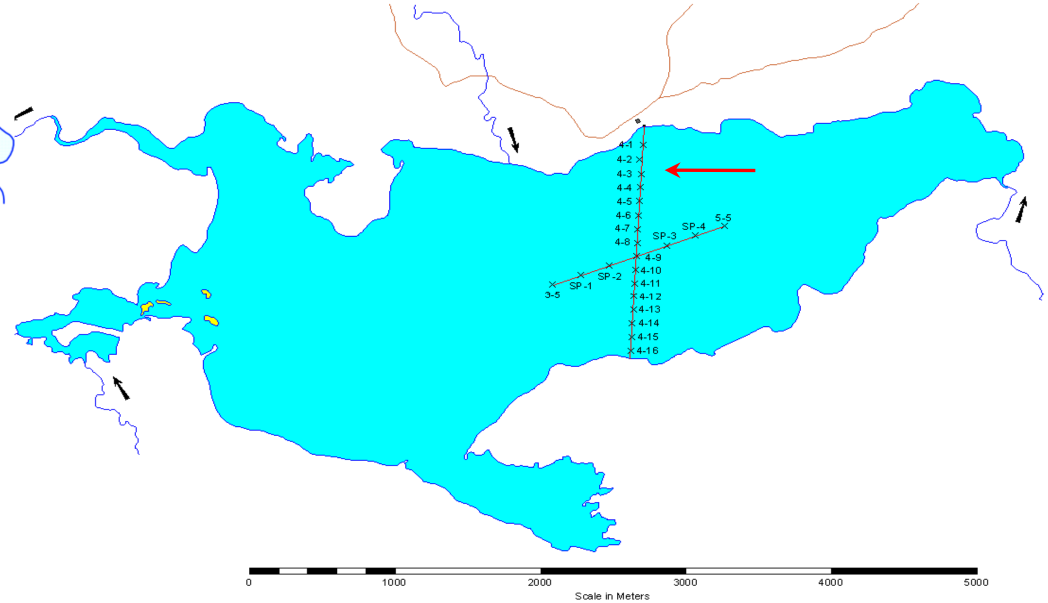

Lake Vendyurskoe
Russia
Finland
Lake Onego
Lake Ladoga

General information about Lake Vendyurskoe

Lake Vendyurskoe is located in Northwestern Russia
- latitude 62°10’-62°20’N, longitude 33°10’-33°20’E;
- lake basin of glacial origin;
- max and mean depth –13.4 and 5.3 m;
- area – 10.4 km^2;
- volume – 54.8 $\cdot 10^6$ m^3;
- drainage basin area – 82.8 km^2;
- water exchange coefficient (for 1 year) – 0.3-0.4;
- Secchi disk reading – 3±0.5 m;
- several small inflows and one outflow;
- bottom sediments consist of sand (up to 2-3 m) and silt containing organic mud (with a thickness of 0.4-1.0 m);
- ice-covered period – 5-6 months;
- mesotrophic status.



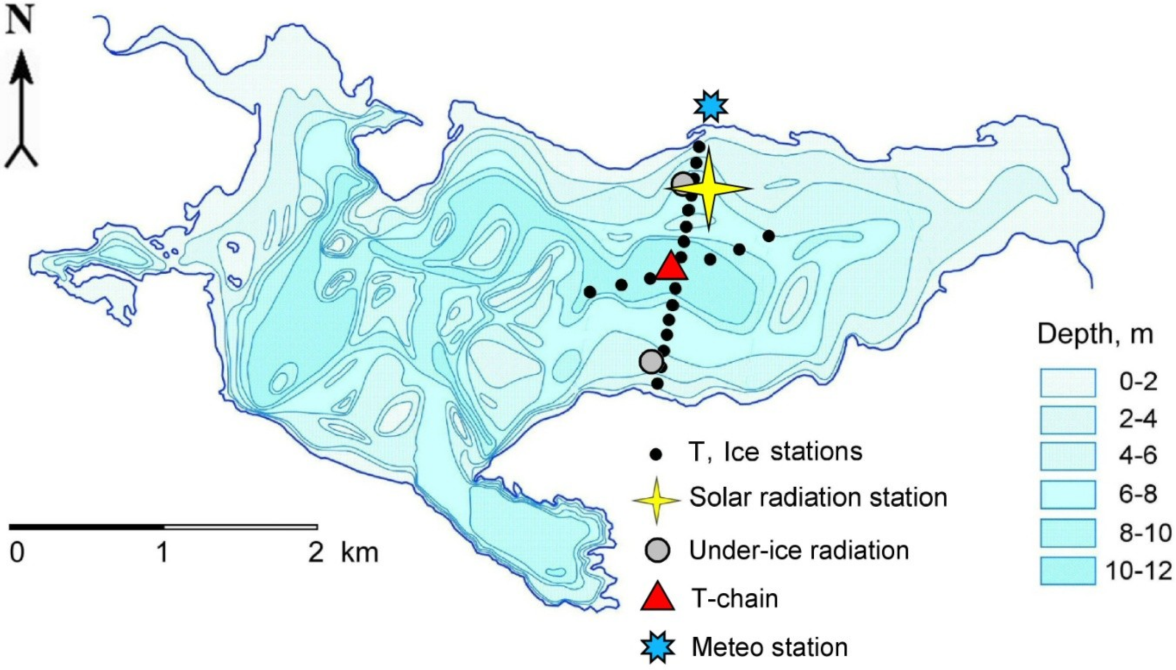
Bottom topography of lake Vendyurskoe



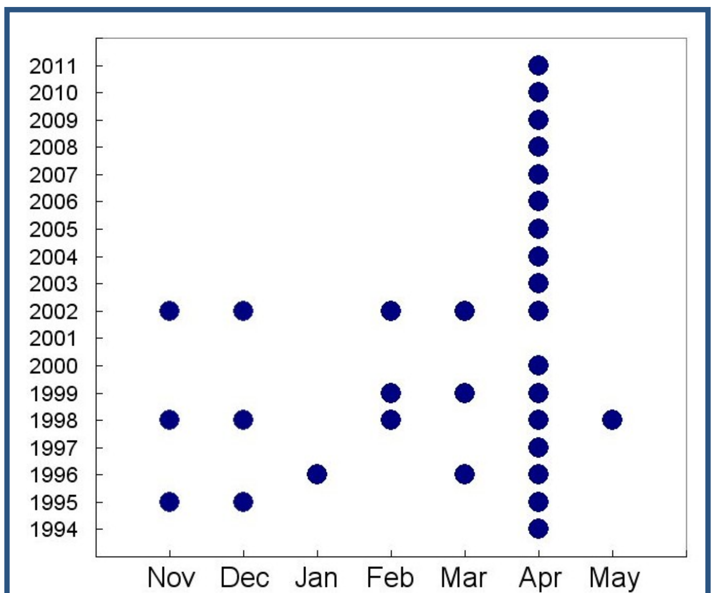
Current location of measurement stations

Start: Six cross-sections, more than 50 measurement stations

Now: More than 20 measurement stations


N
Depth, m
0-2
2-4
4-6
6-8
8-10
10-12
T, Ice stations
Solar radiation station
Under-ice radiation
T-chain
Meteo station
0
1
2 km


28 4 2009

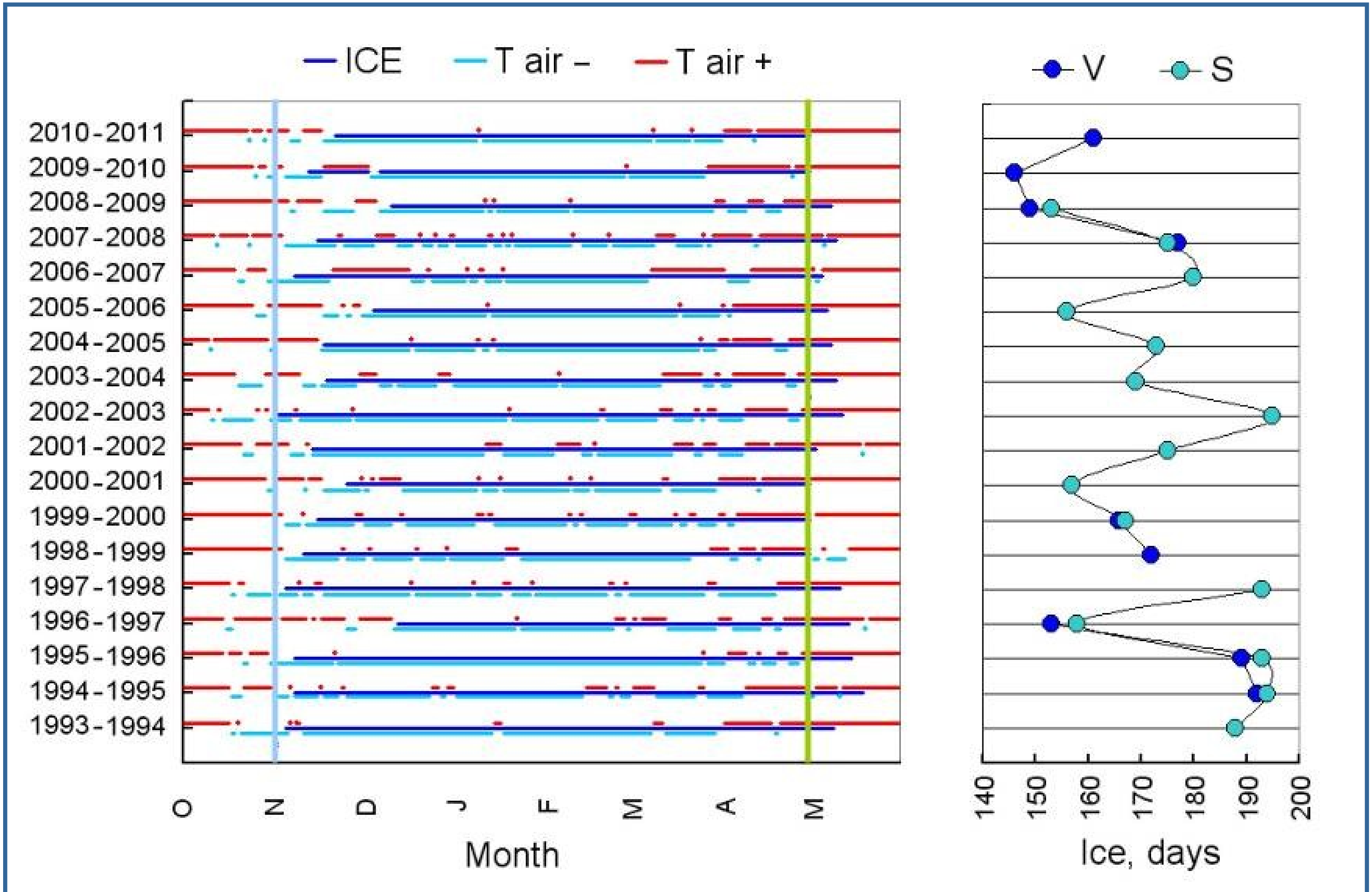

2011
2010
2009
2008
2007
2006
2005
2004
2003
2002
2001
2000
1999
1998
1997
1996
1995
1994
Nov
Dec
Jan
Feb
Mar
Apr
May

We have measured:

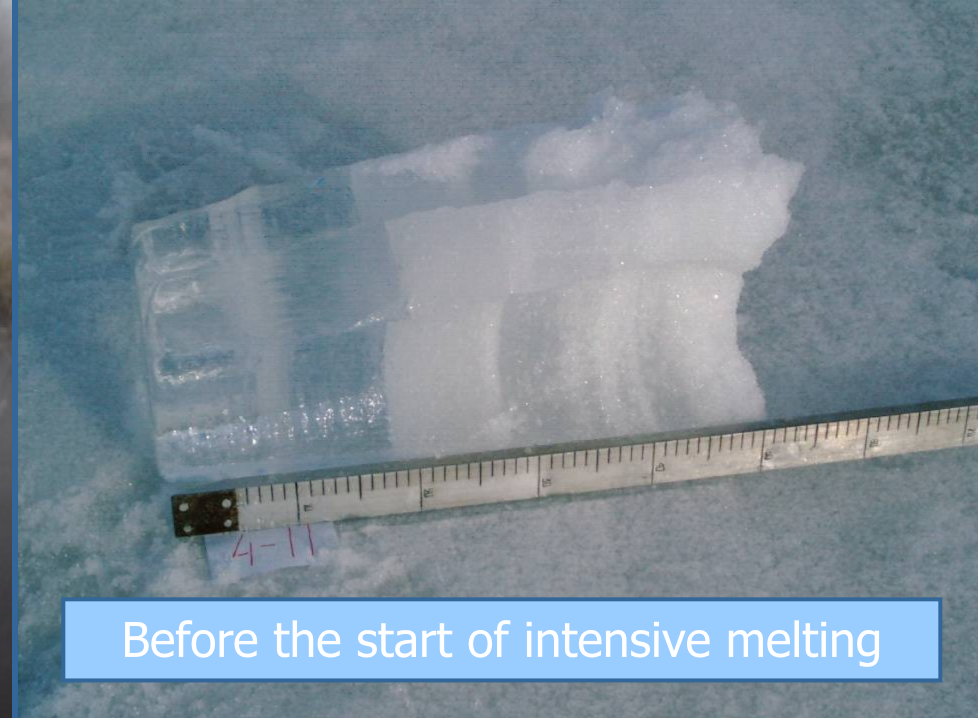
(1994-1997; 1994-; 2000-; 2008-)

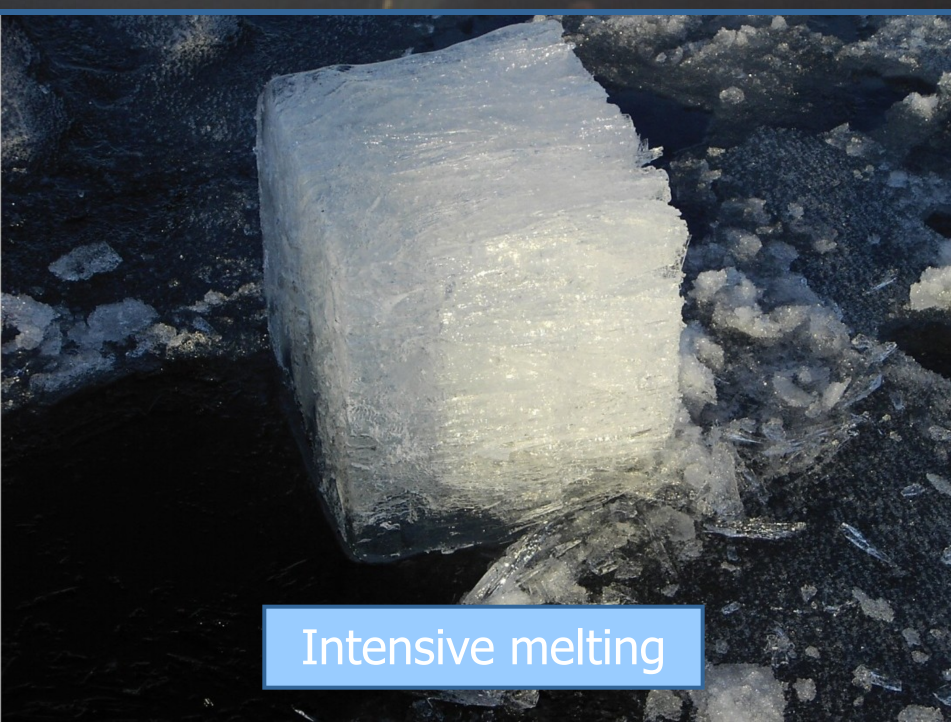
- Water temperature and conductivity, incl. the fine structure in the vicinity of interfaces
- snow and ice cover depth; solar radiation (incoming, reflected, and at the lower ice boundary); atmospheric pressure (from 2009 – by RBR-TDR)
- Currents; ice cover fluctuations
- weather parameters, dissolved oxygen
- spectral distribution of chlorophyll "a" (four groups); PAR

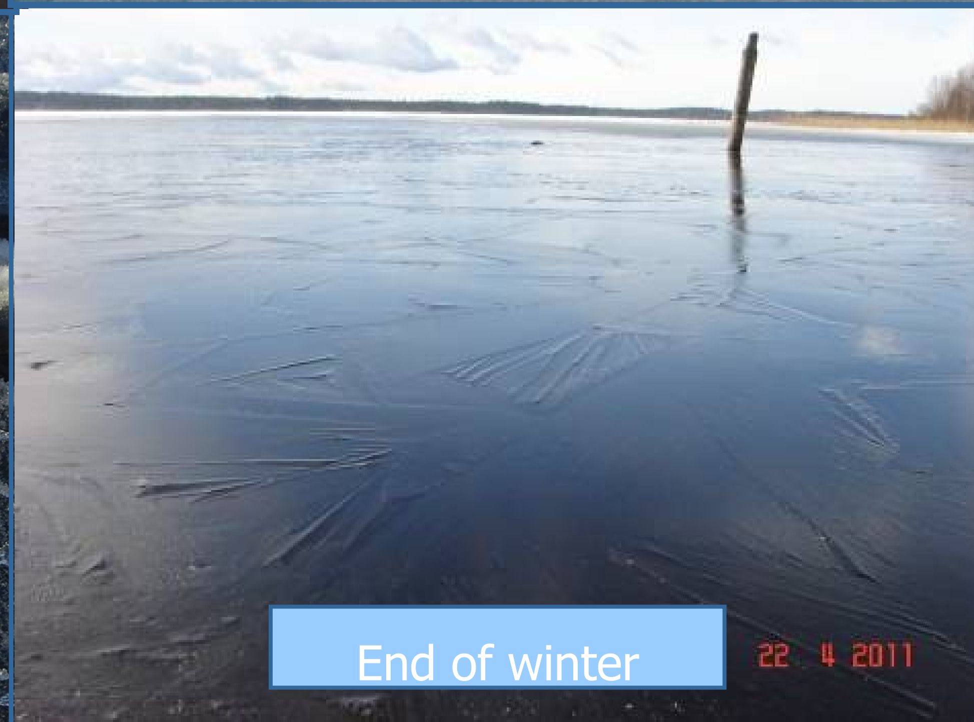
The dates of freezing and breaking ice and duration of ice-period on lakes Vendyurskoe (V) and Syamozero (S)

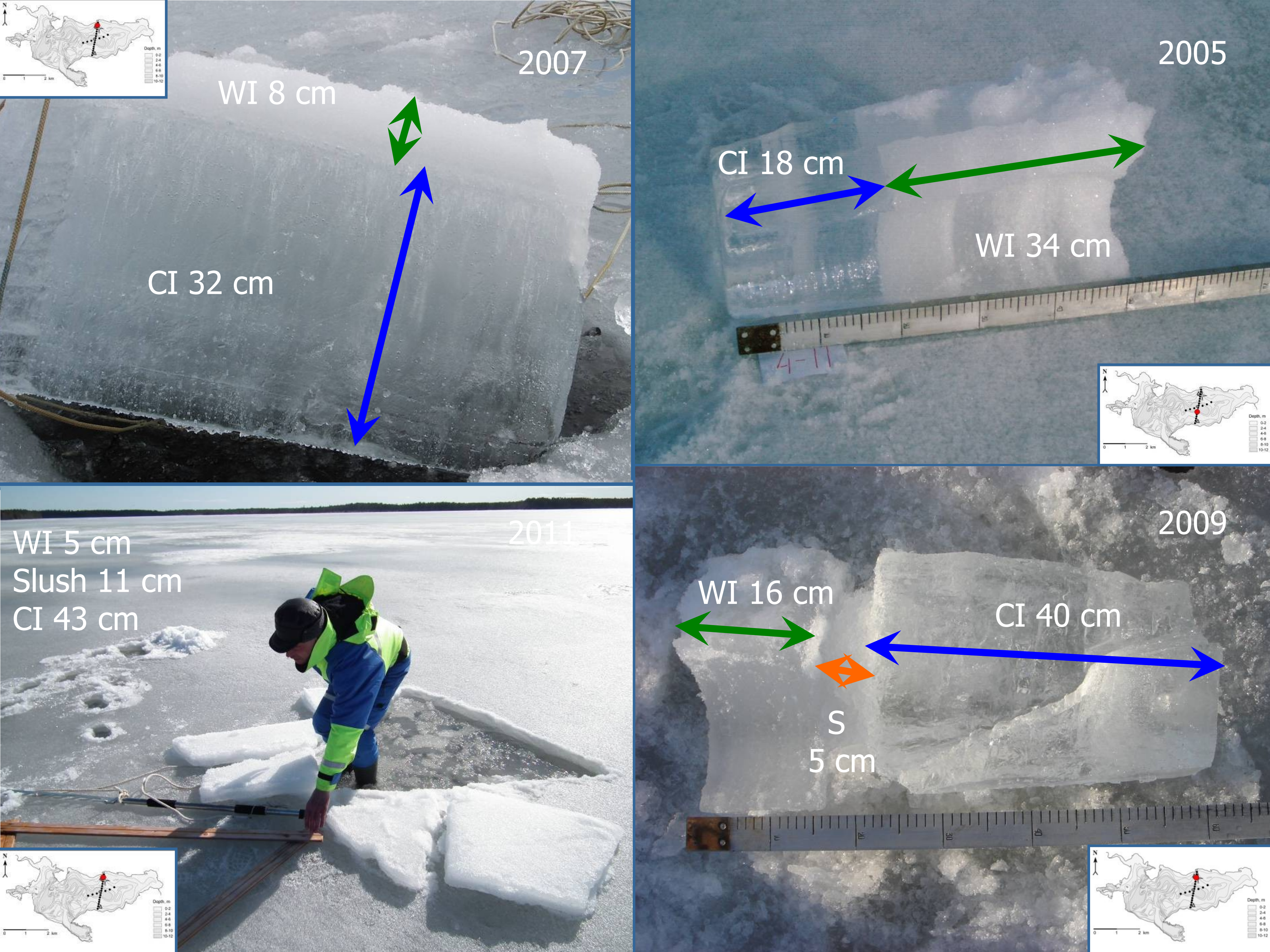


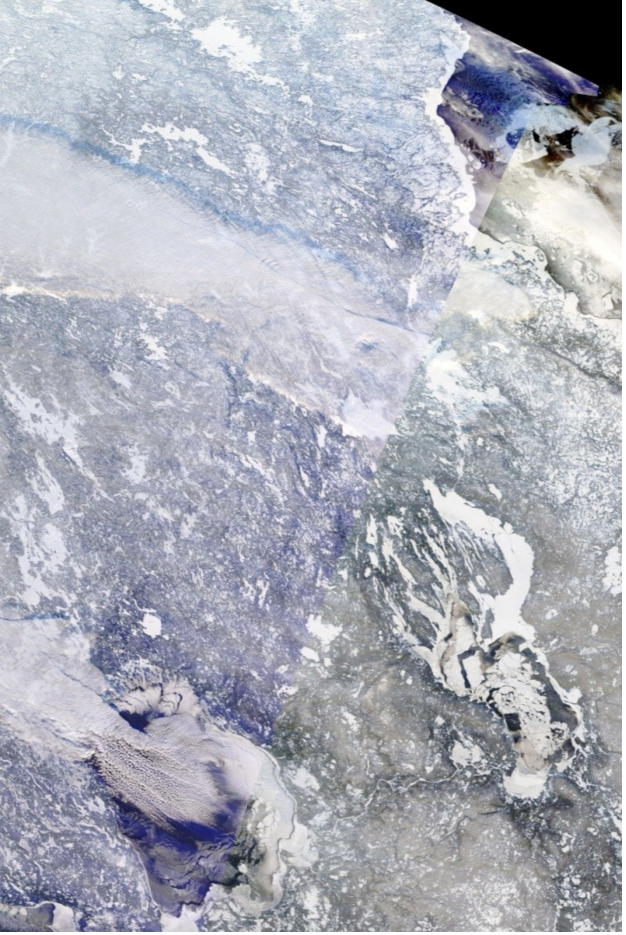

Pre-winter
2007 10 22


4-11
Before the start of intensive melting


Intensive melting

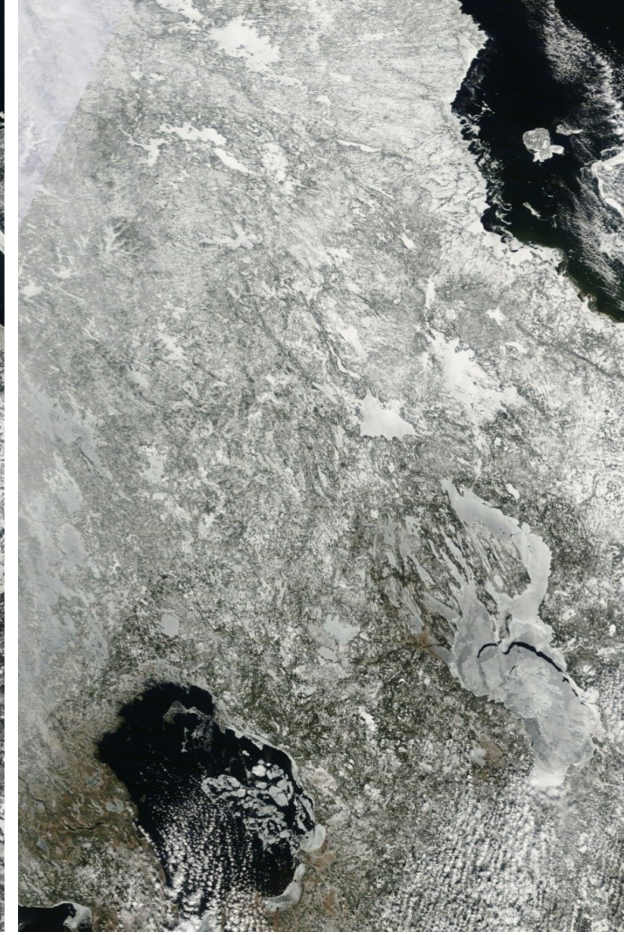

End of winter
22 4 2011


2007
WI 8 cm
CI 32 cm
2005
CI 18 cm
WI 34 cm
4-11
WI 5 cm
Slush 11 cm
CI 43 cm
2011
2009
WI 16 cm
CI 40 cm
S
5 cm



21.01.2015

16.03.2015



21.03.2015

Lakes Onezhshkoe and Ladozhshkoe

Reasons for ‘snow’ ice formation

- Flooding (typical mostly for small-area lakes)
- Day-time melting of accumulated snow

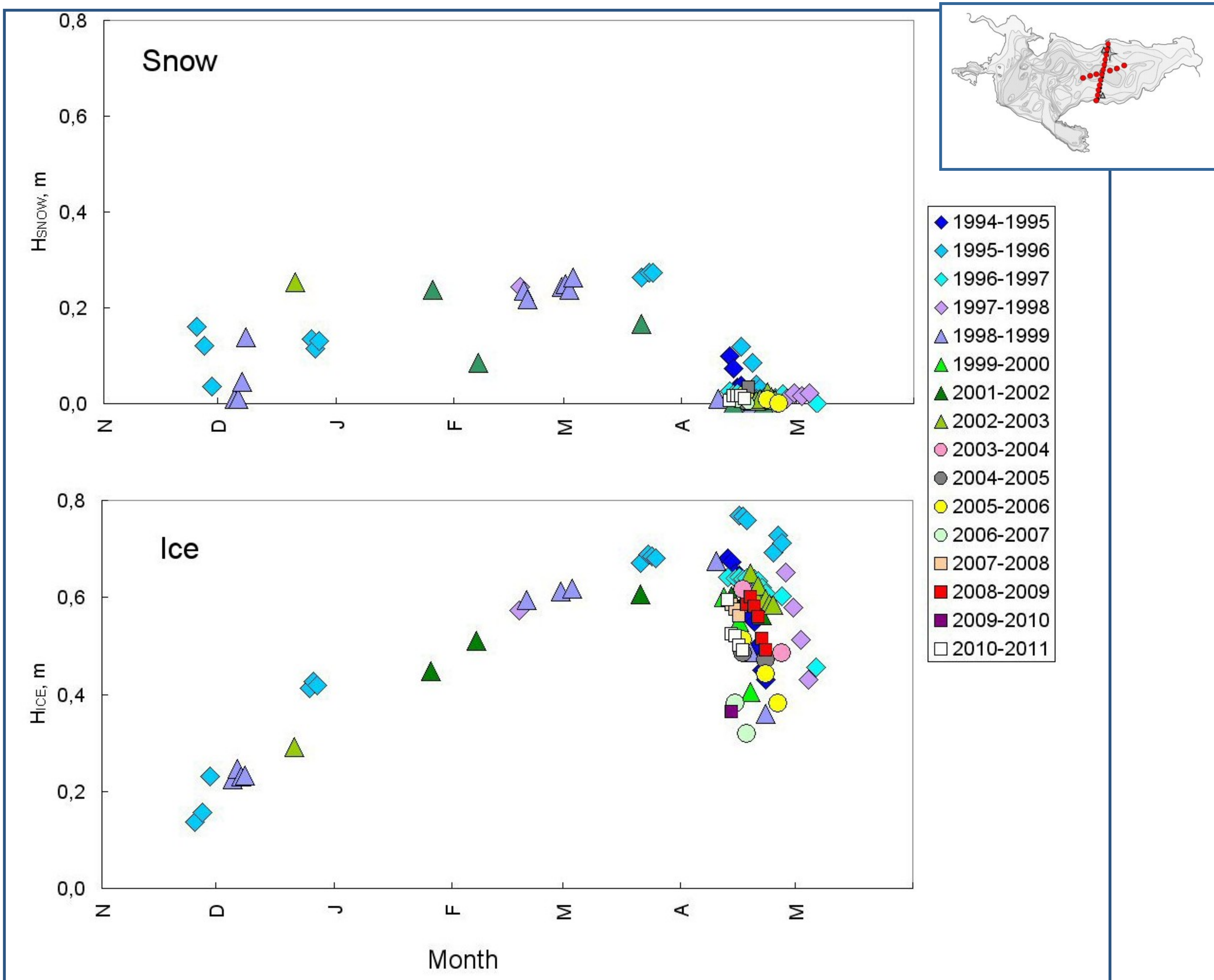
Reasons for ice flooding

- Wind fetch varies over lakes of different square area => crucial for dry snow accumulation
- Accumulation of snow atop ice cover =>
- Snow aging / deterioration => the snow density increase

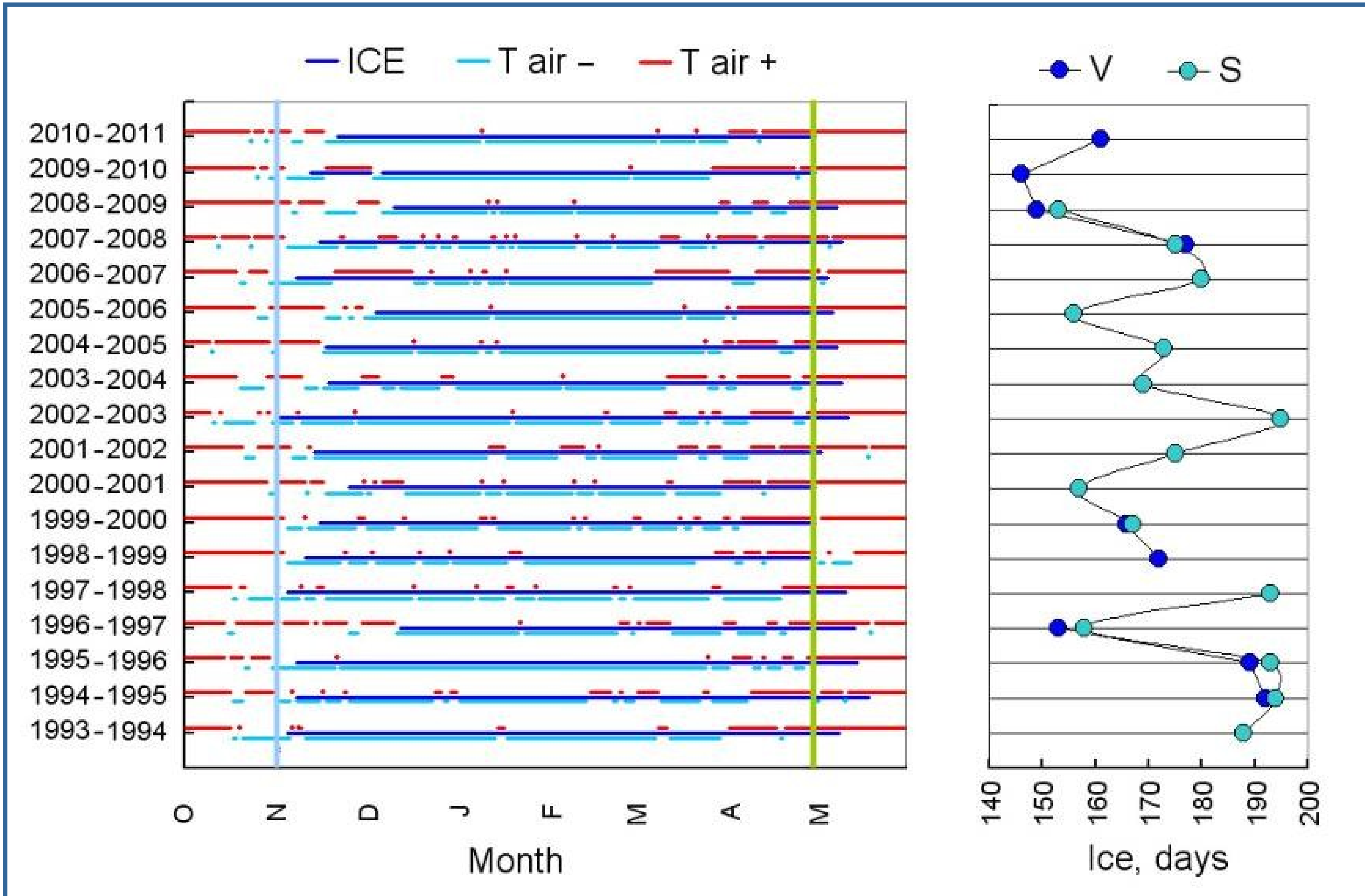
Reasons for ice flooding

$$\frac{h_s}{h_i} > \frac{\rho_w - \rho_i}{\rho_s}$$

where h_s and h_i are snow and ice thicknesses, and ρ_w, ρ_s and ρ_i water, snow and ice densities, respectively. Since $(\rho_\mathrm{w} - \rho_\mathrm{i}) / \rho_\mathrm{s} \sim 0.2$–$0.4$, the thickness of snow needs to be at least around one-third of the thickness of ice for the flooding to occur (Kirillin et al. 2012).

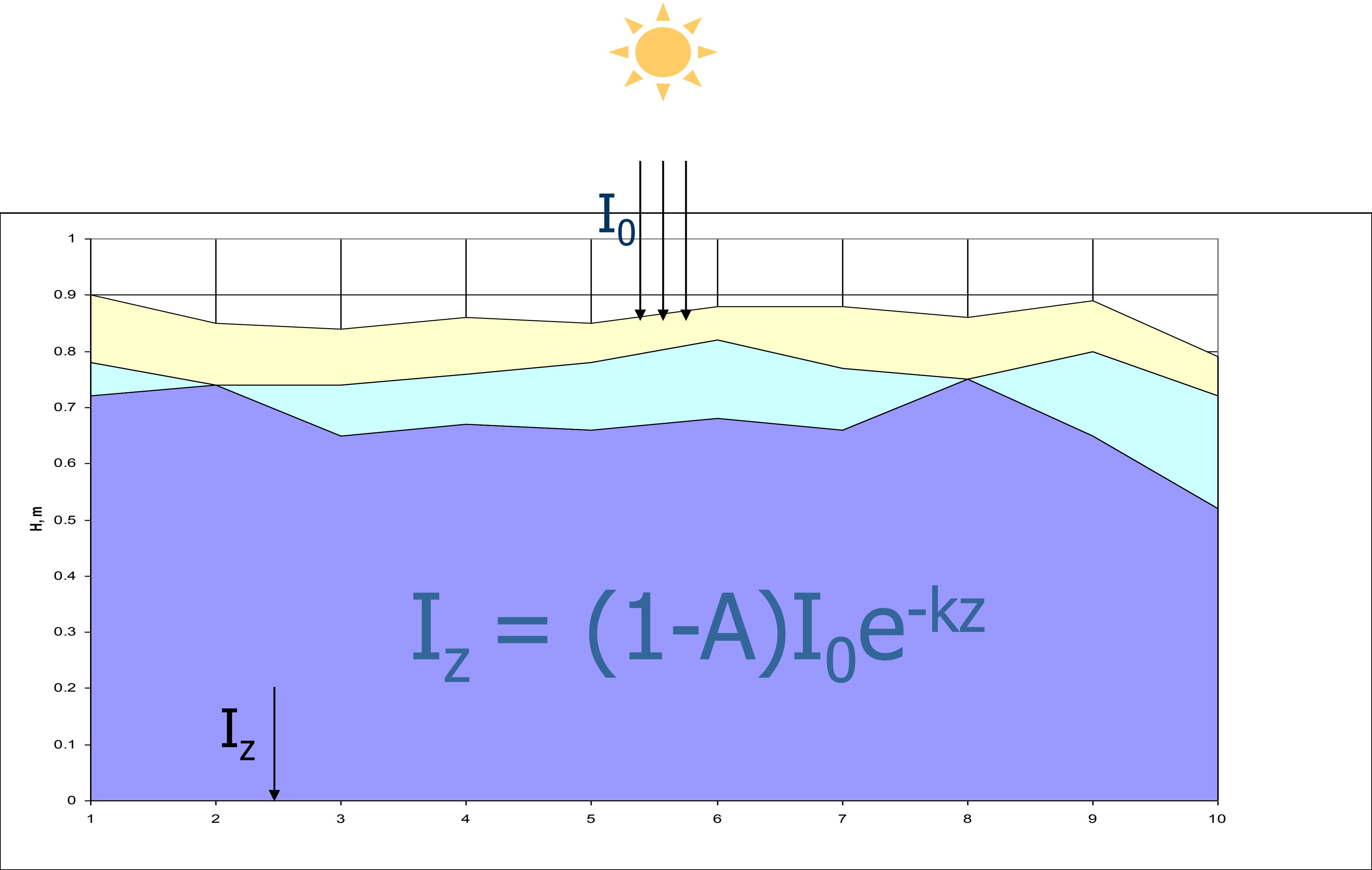

Snow
Ice
HSNOW, m
HICE, m
0,8
0,6
0,4
0,2
0,0
N
D
J
F
M
A
M
Month
1994-1995
1995-1996
1996-1997
1997-1998
1998-1999
1999-2000
2001-2002
2002-2003
2003-2004
2004-2005
2005-2006
2006-2007
2007-2008
2008-2009
2009-2010
2010-2011

The dates of freezing and breaking ice and duration of ice-period on lakes Vendyurskoe (V) and Syamozero (S)

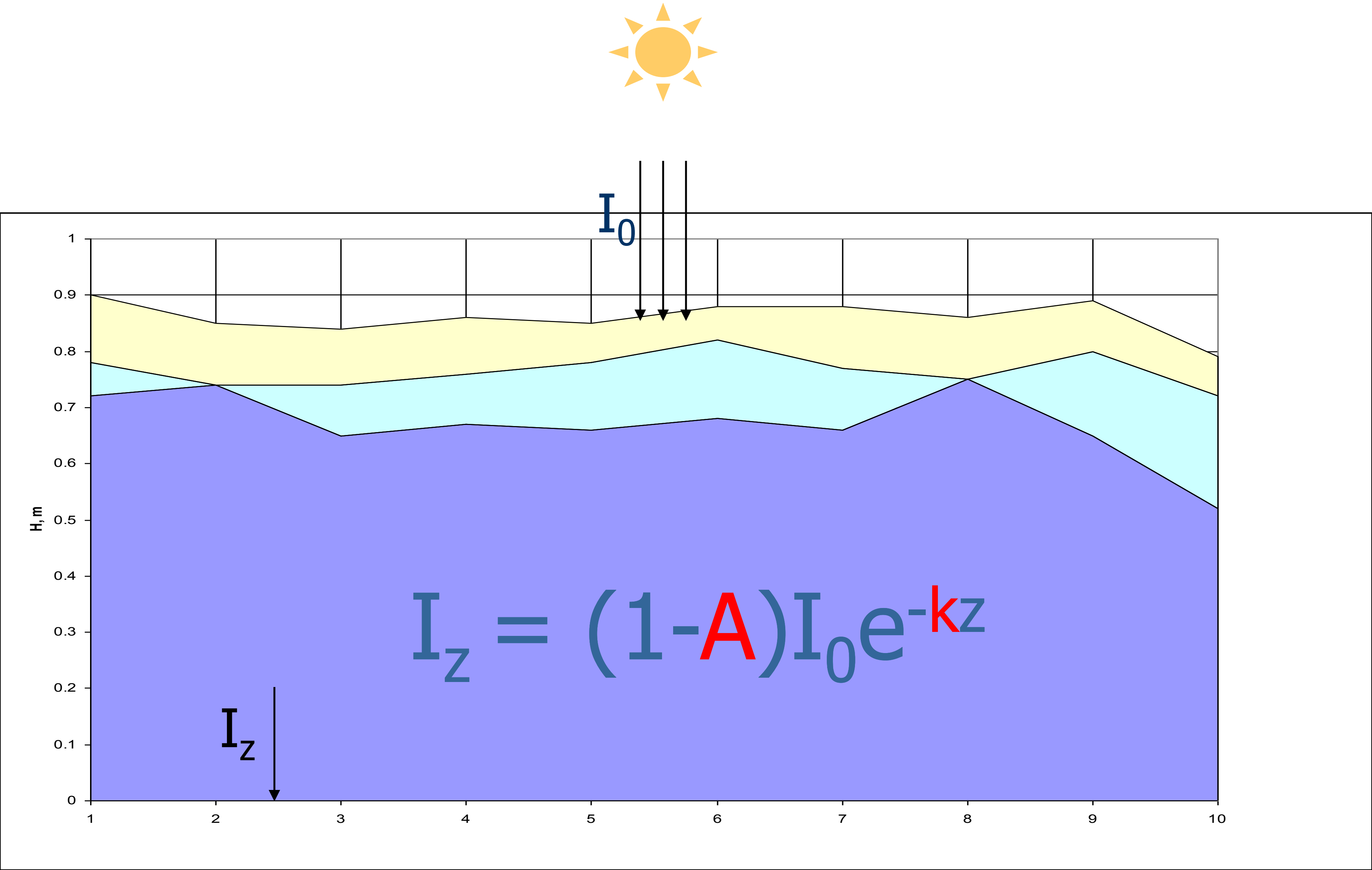


As seen from the former Figure, from November until early February h_s/h_i is around 0.5 and even larger quite often. Thus, pre-conditions for flooding exist. Besides, the ‘snow’ ice may grow due to day-time melting of the accumulated snow during ‘low-pressure’ events accompanied by positive air temperatures (Leppäranta and Kosloff 2000).

Early-spring warming



Early-spring warming

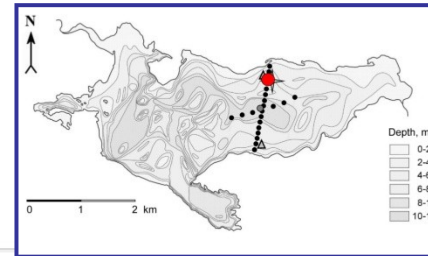


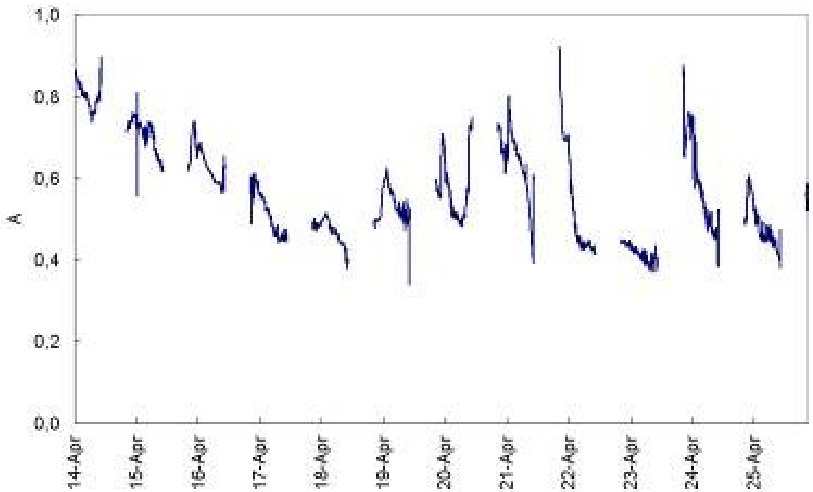
Albedo

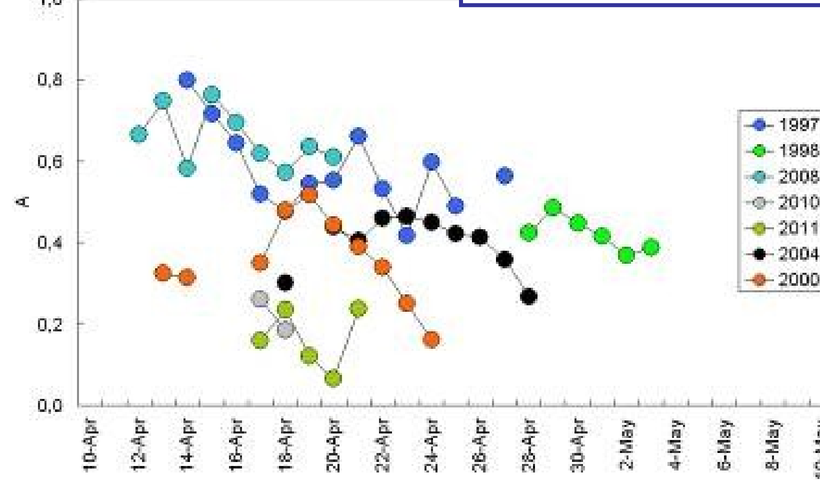
Albedo in February-April 2002 along cross-section 4

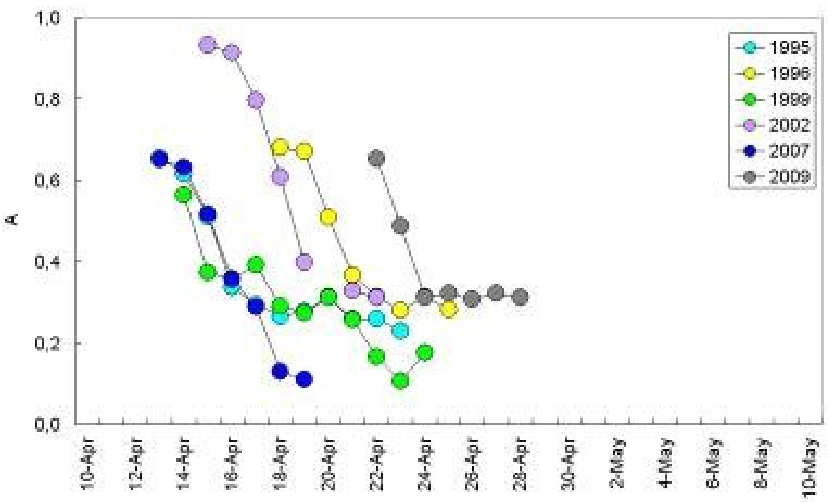
State of snow-ice cover	Weather conditions, visibility	Albedo
New 5-cm thick snow	Snow veil, wind	0.92-0.94
Wet sticking snow	Air temperature +3-4°C. Thin clouds veiling the sun.	0.79-0.83
Thin crust of ice over old snow, fine-rough surface, glossy spots	Sunny, cloudless sky	0.76-0.89
Thin crust of ice over old snow	Total cloudiness	0.76-0.82
Thin crust of ice over bright snow	3-point cloudiness	0.71-0.74
Thin crust of ice over bright snow	Total cloudiness, strong wind	0.69-0.76
Thin crust of ice over bright snow – dark spot	Strong wind, powder snow all over the lake	0.56-0.61
White solid frozen surface	No wind, cloudless sky	0.40-0.54
Solid surface of white frazil	No wind, cloudless sky	0.37-0.45
Wet surface of white frazil, below white ice	Sunny, 1-point cloudiness (cirrus)	0.28-0.42

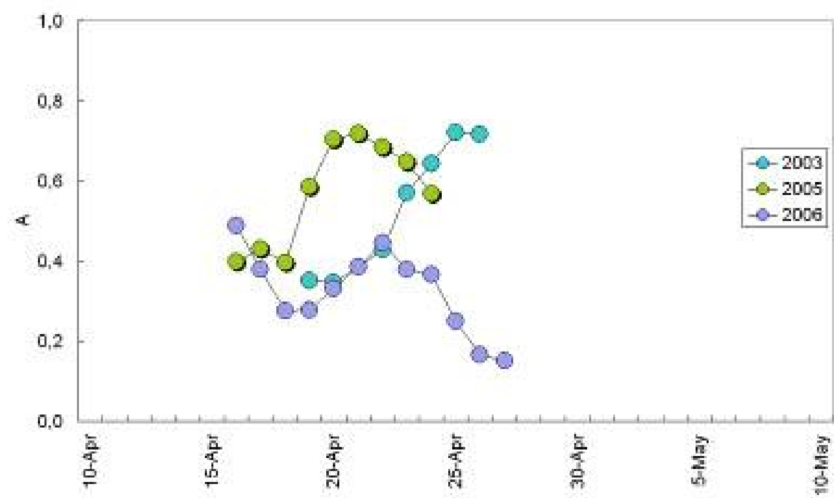
Albedo in spring: temporal variability

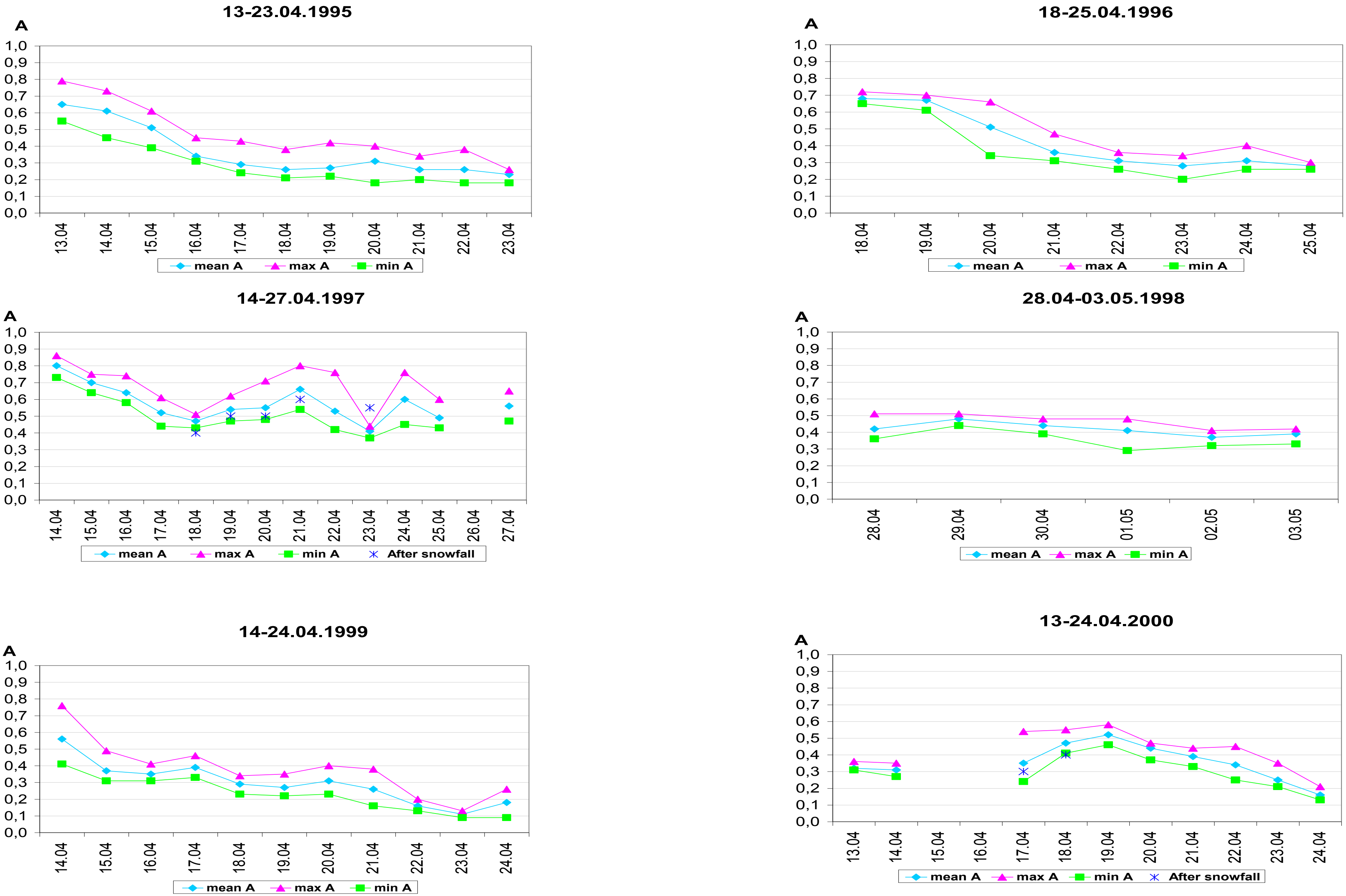




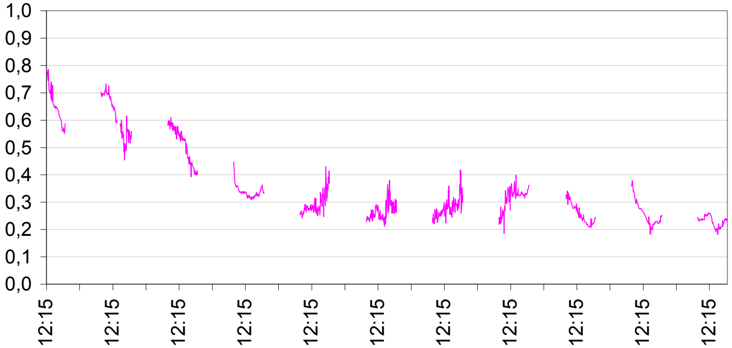




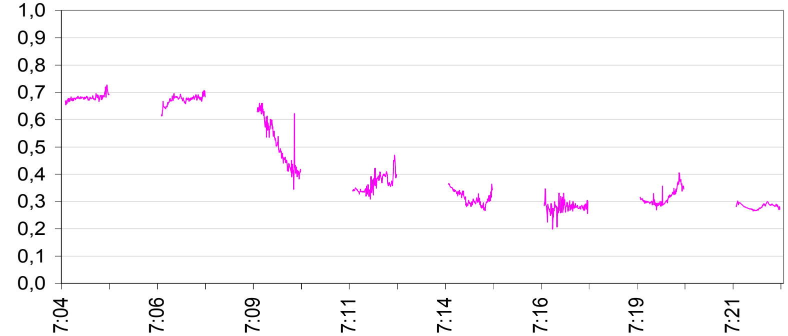




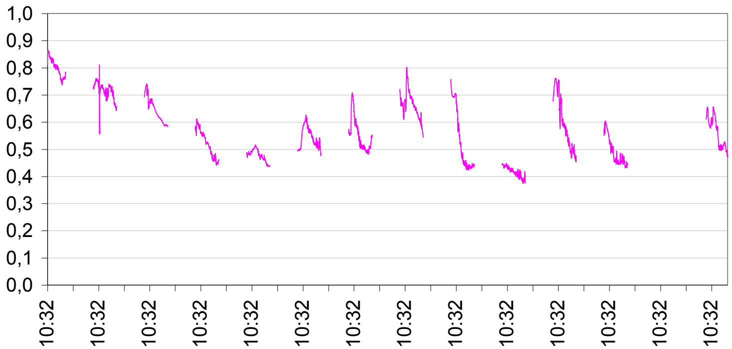
Synoptical variability of albedo in April (st. 4-3)



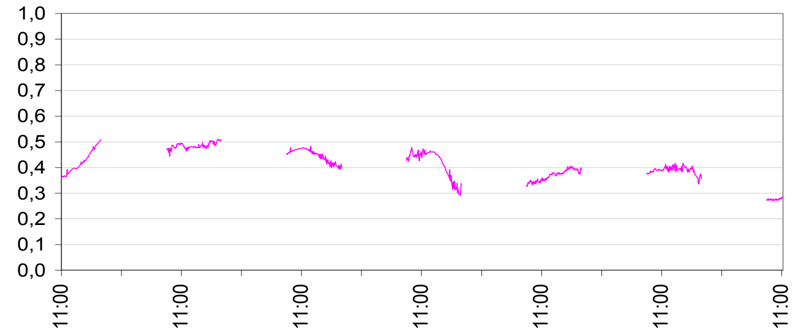
13-23.04.1995



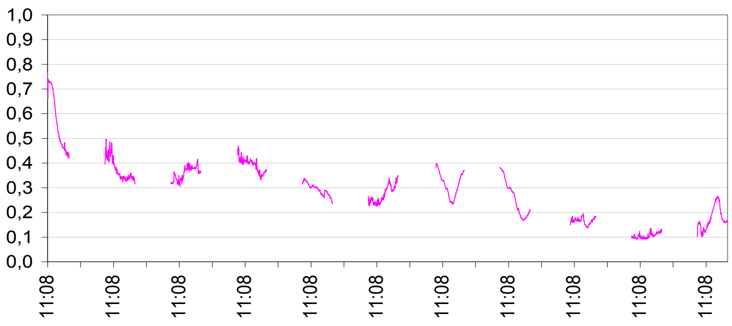
18-25.04.1996



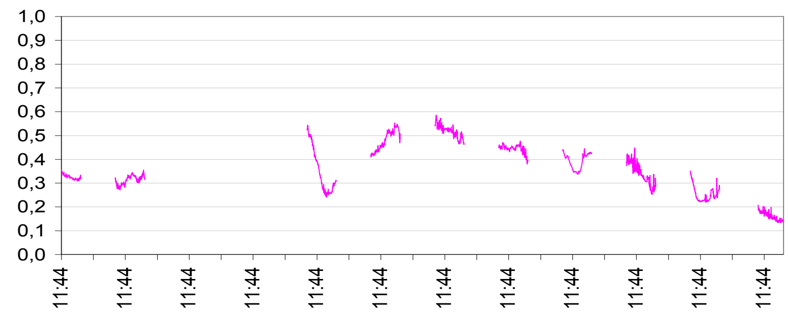
14-27.04.1997



28.04-04.05.1998

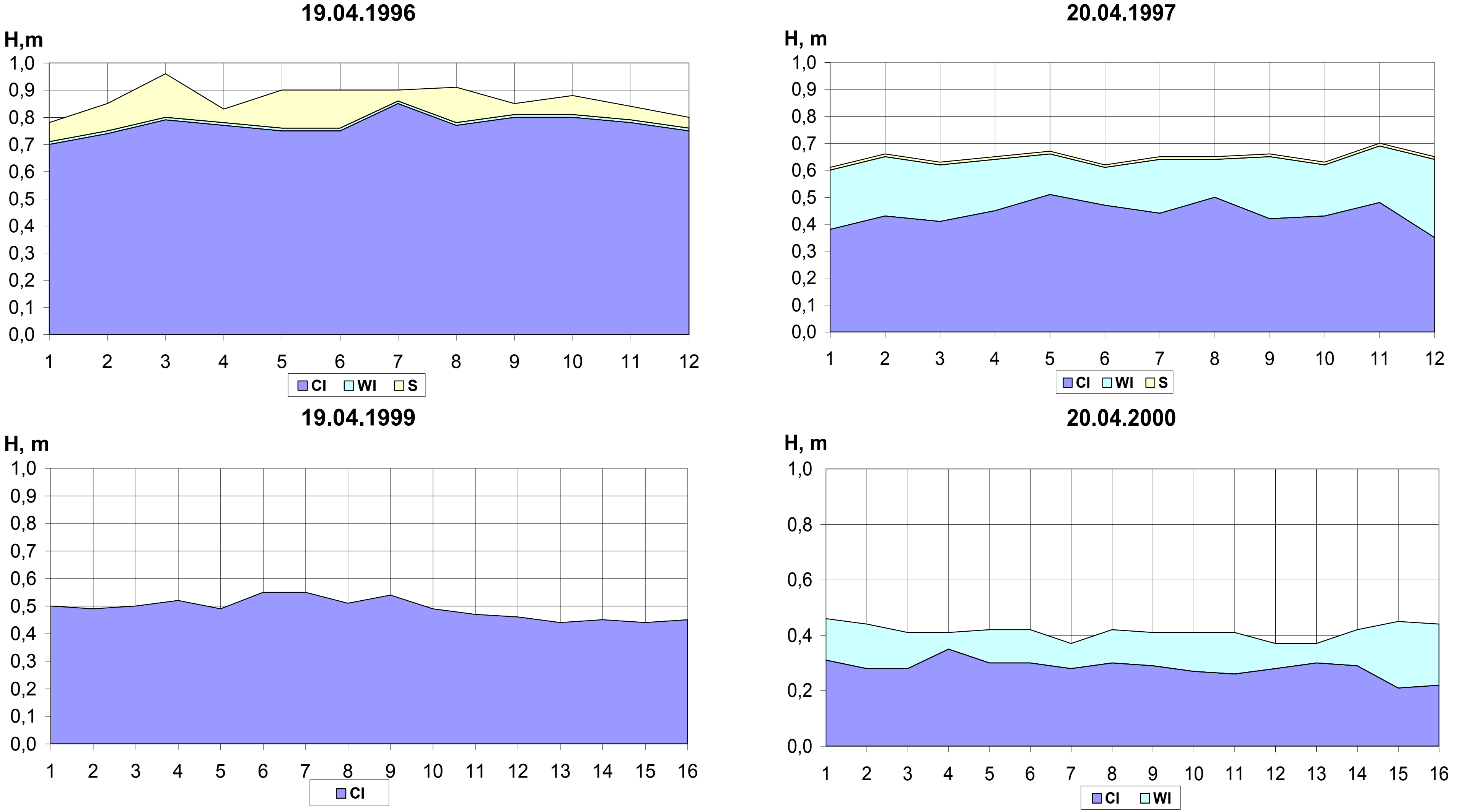


14-24.04.1999

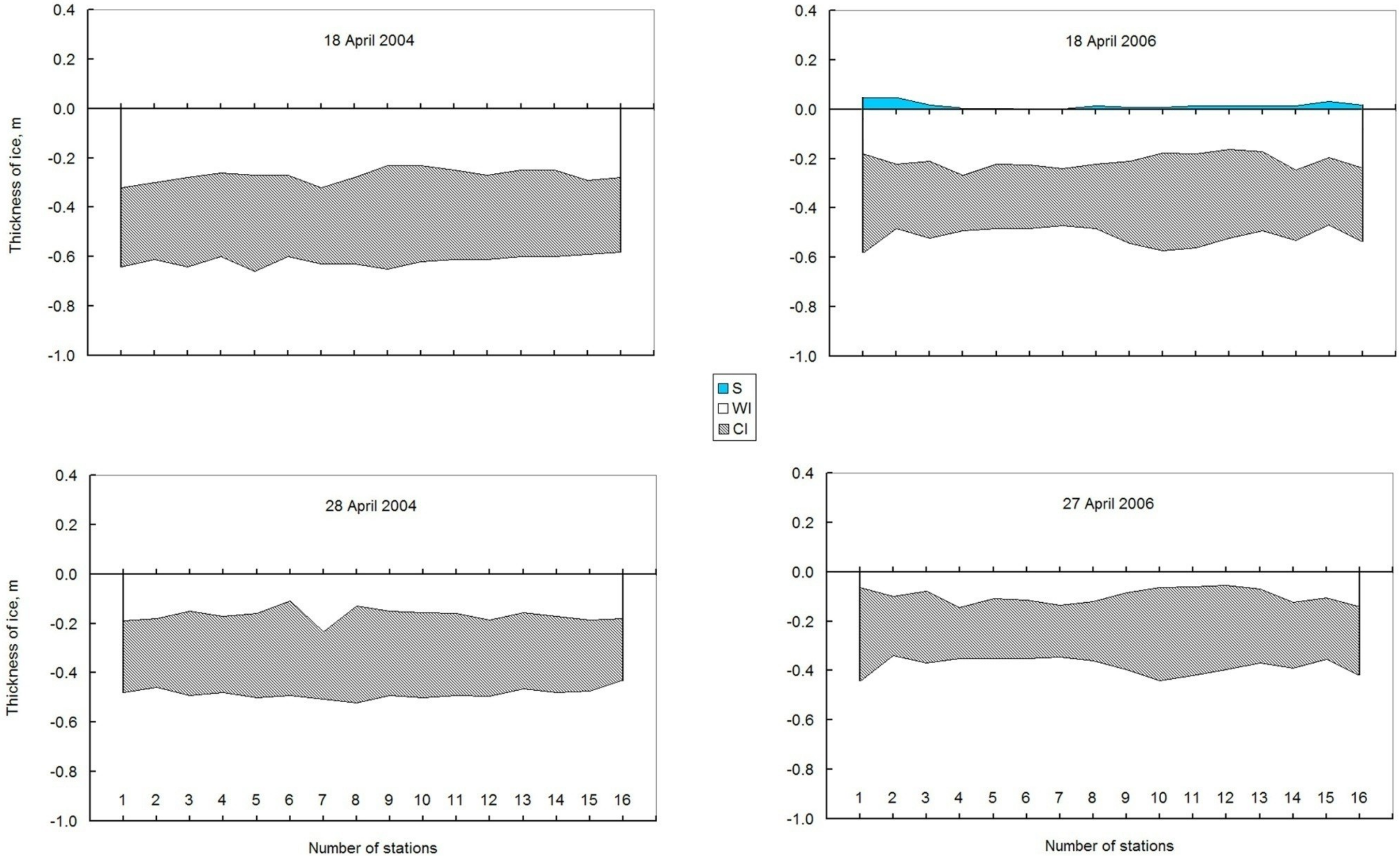


13-24.04.2000

Daily variability of albedo in April (st. 4-3)



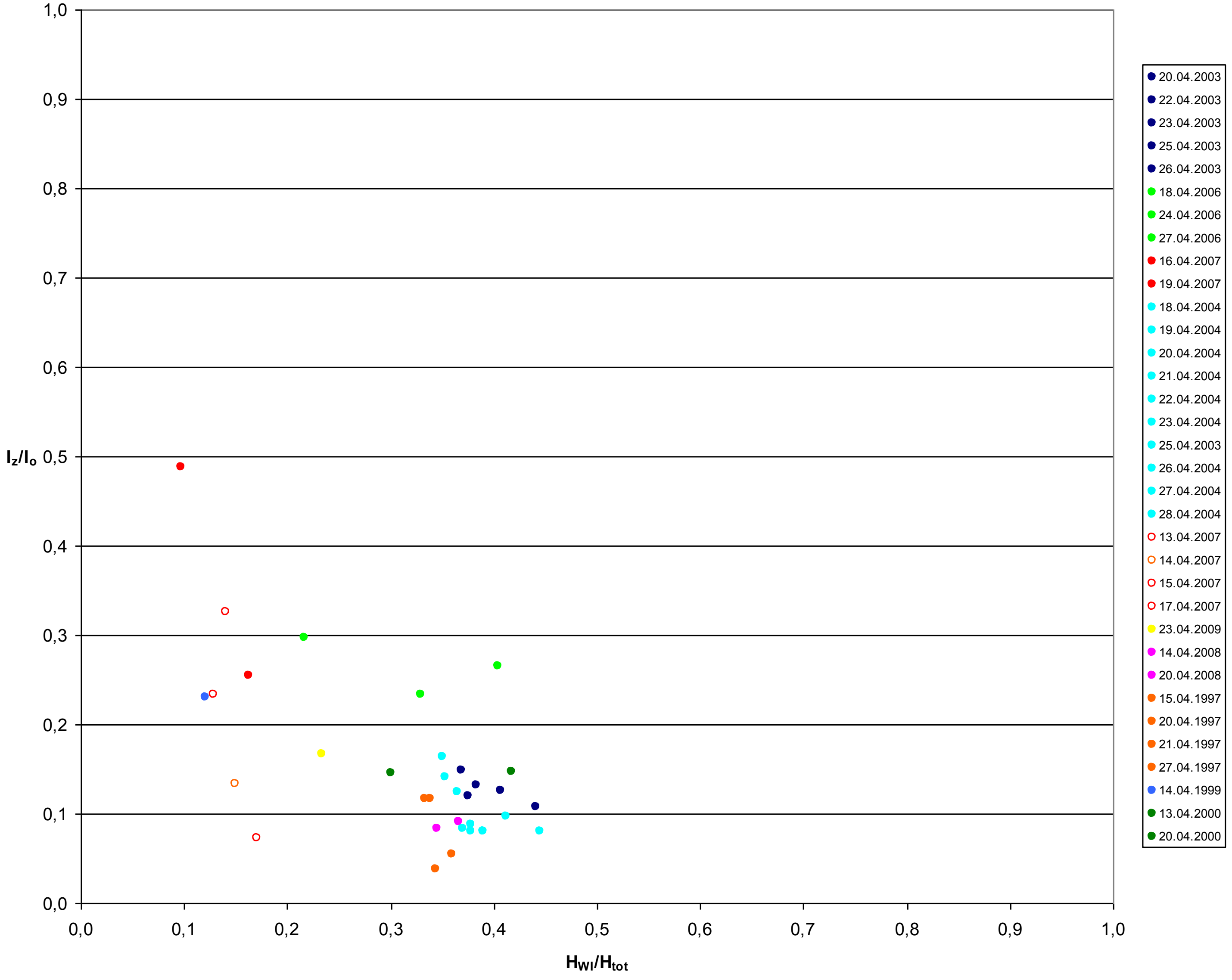
Snow and ice cover along cross-section 4 in April



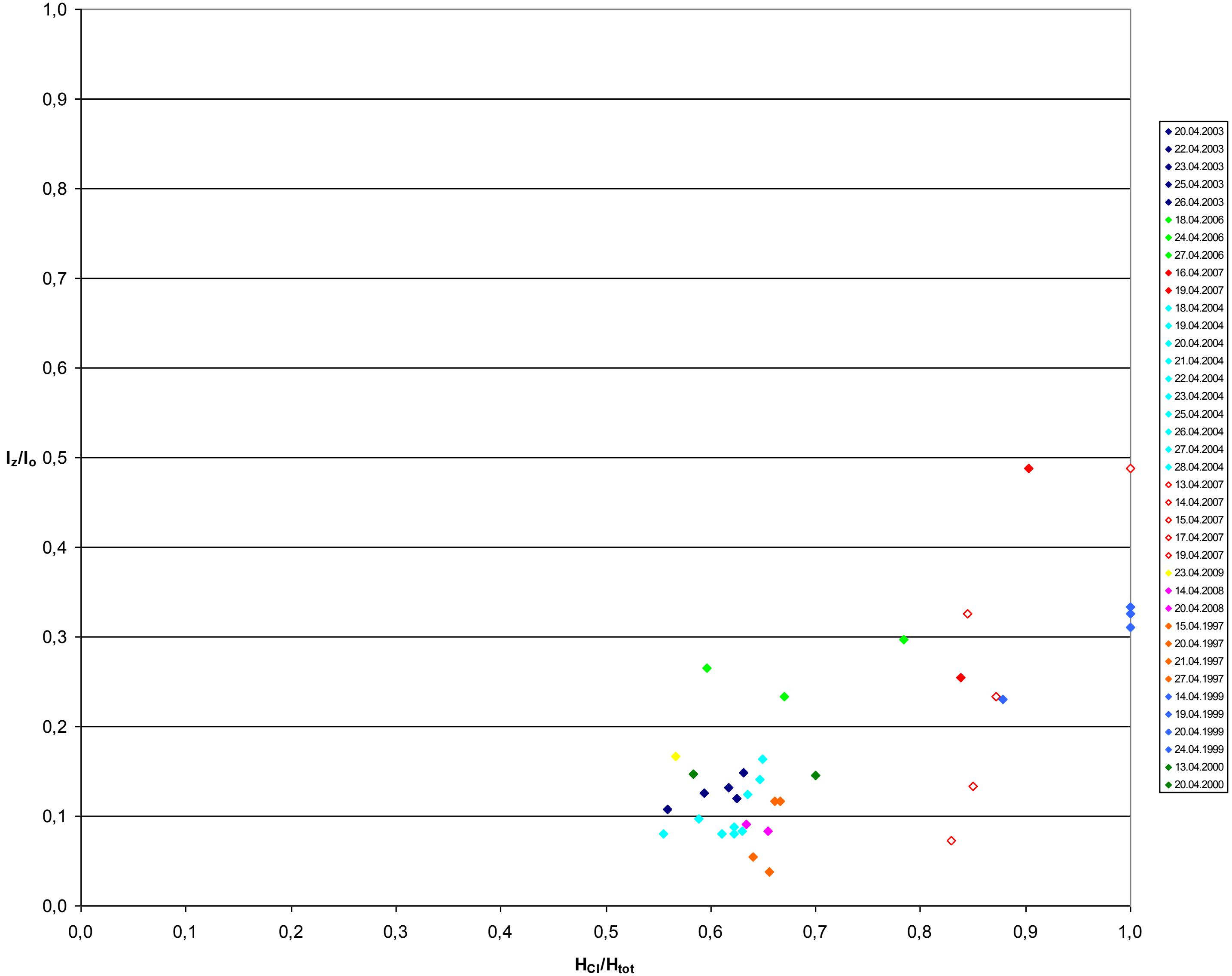
Snow and ice cover along cross-section 4 in April

Solar radiation

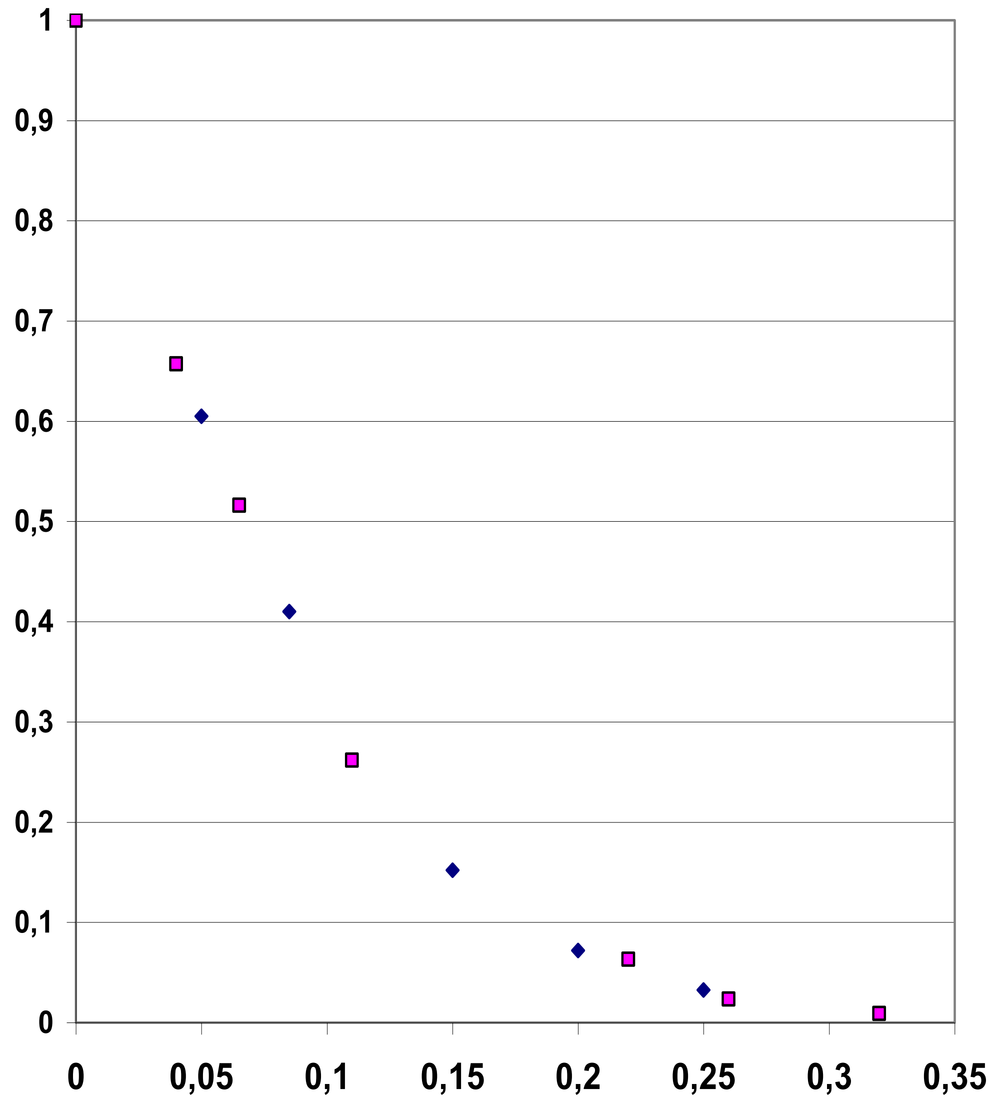
(data used is average for 10-18 h unless specified)



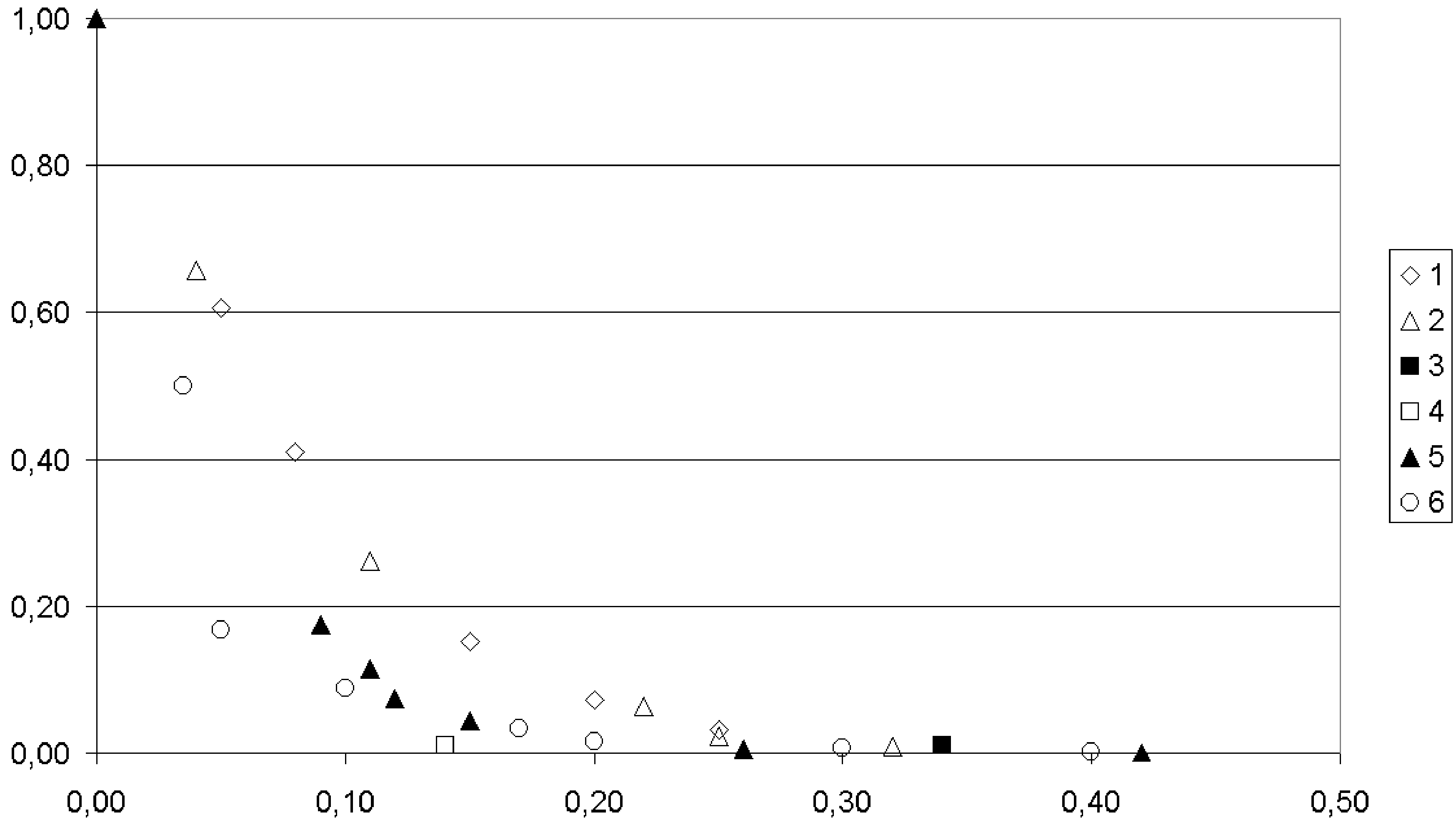
Transmittance of ice vs. fraction of ‘snow’ ice



Transmittance of ice vs. fraction of crystal ice

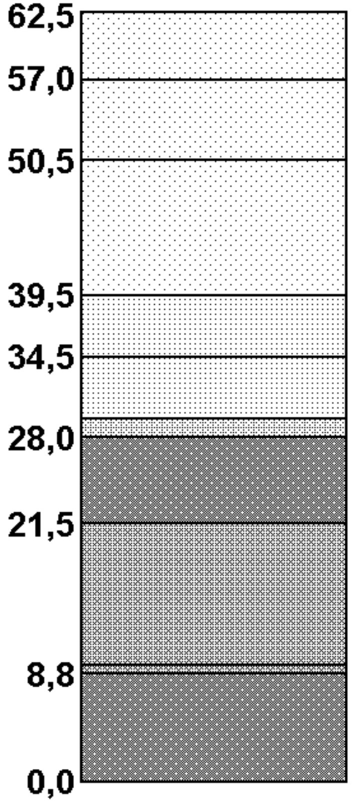


Rate of SR penetration vs. snow cover thickness, taken from experiments (diamonds stand for 2003, squares for 2004)



Transmittance of solar radiation through the lake snow: 1 – Vendyurskoe, 2003; 2 – Vendyurskoe, 2004; 3 – Lake Taimir [11]; 4 – Lake Onego [11]; 5 – Punnusjarvi [Krasnoe] [7]; 6 – Lake Onego [6]. X-axis – snow thickness, m; Y-axis – attenuation, decimal fractions.

Ice sample of 72x61x62.5 cm size taken in Lake Vendyurskoe (April 2004)



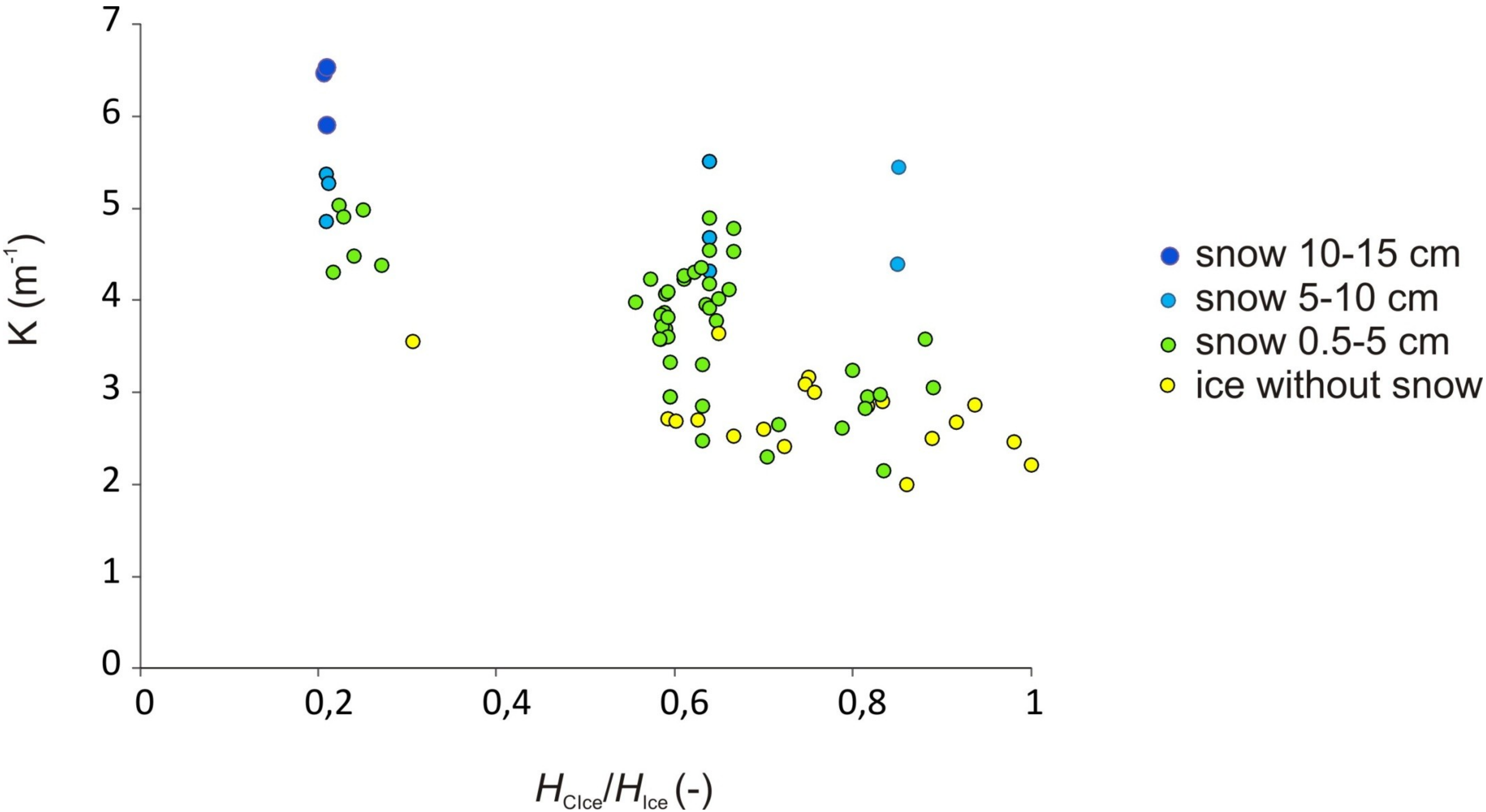
Vertical distribution of layers studied within the ice sample, cm

Ice	I(z)/I(0)	Thick-ness, m	EC, m^{-1}
W	0,722	0,045	7,243
W	0,415	0,11	7,996
W	0,481	0,107	6,847
W+C	0,047	0,625	4,886
W+C	0,066	0,57	4,756
W+C	0,105	0,505	4,459
W+C	0,244	0,395	3,569
W+C	0,347	0,345	3,067
W+C	0,452	0,295	2,695
C	0,537	0,28	2,220
C	0,591	0,215	2,445
C	0,810	0,088	2,393

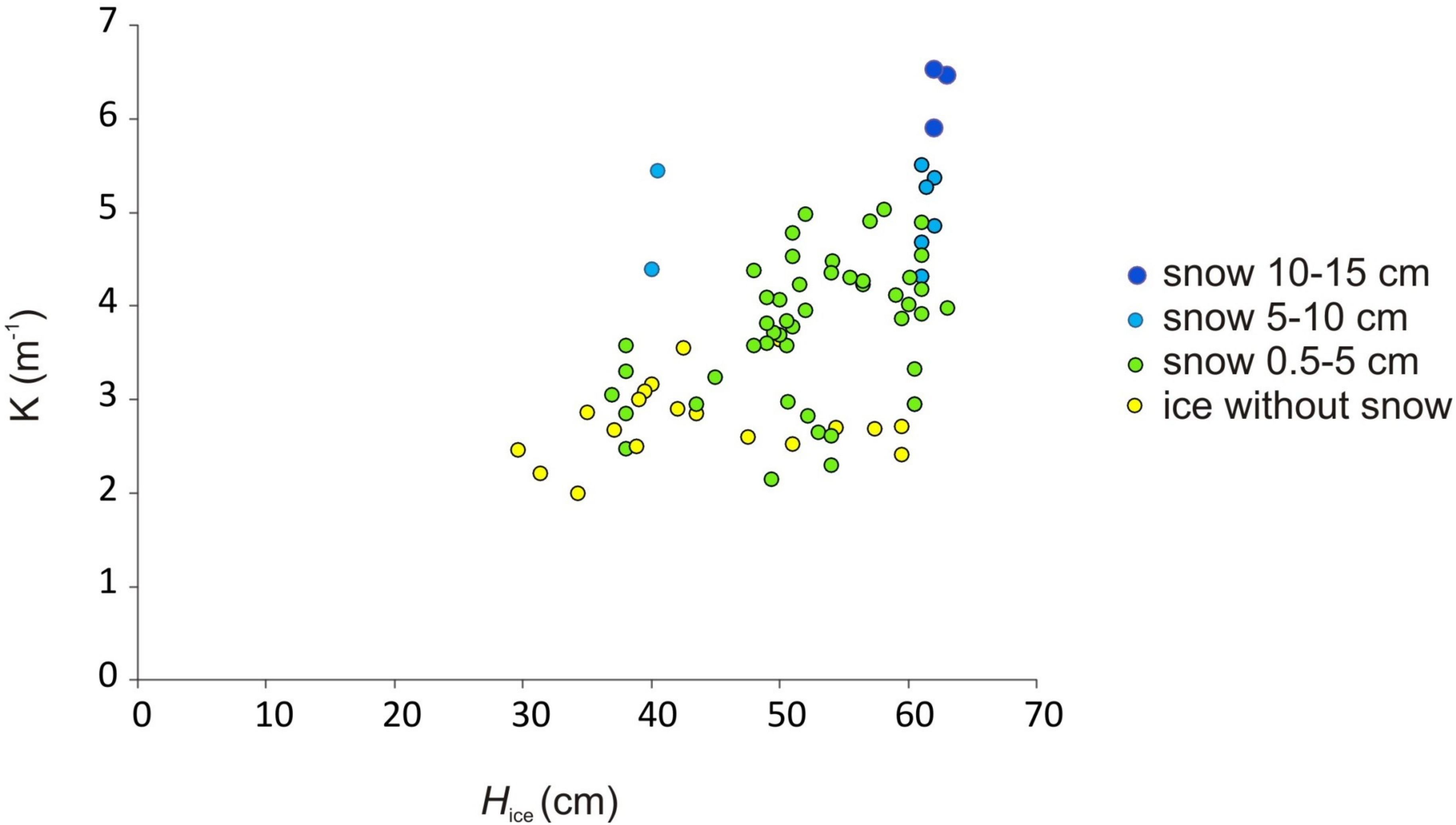
W – white ice; C – crystal ice

Estimates of effective extinction coefficients (EEC)

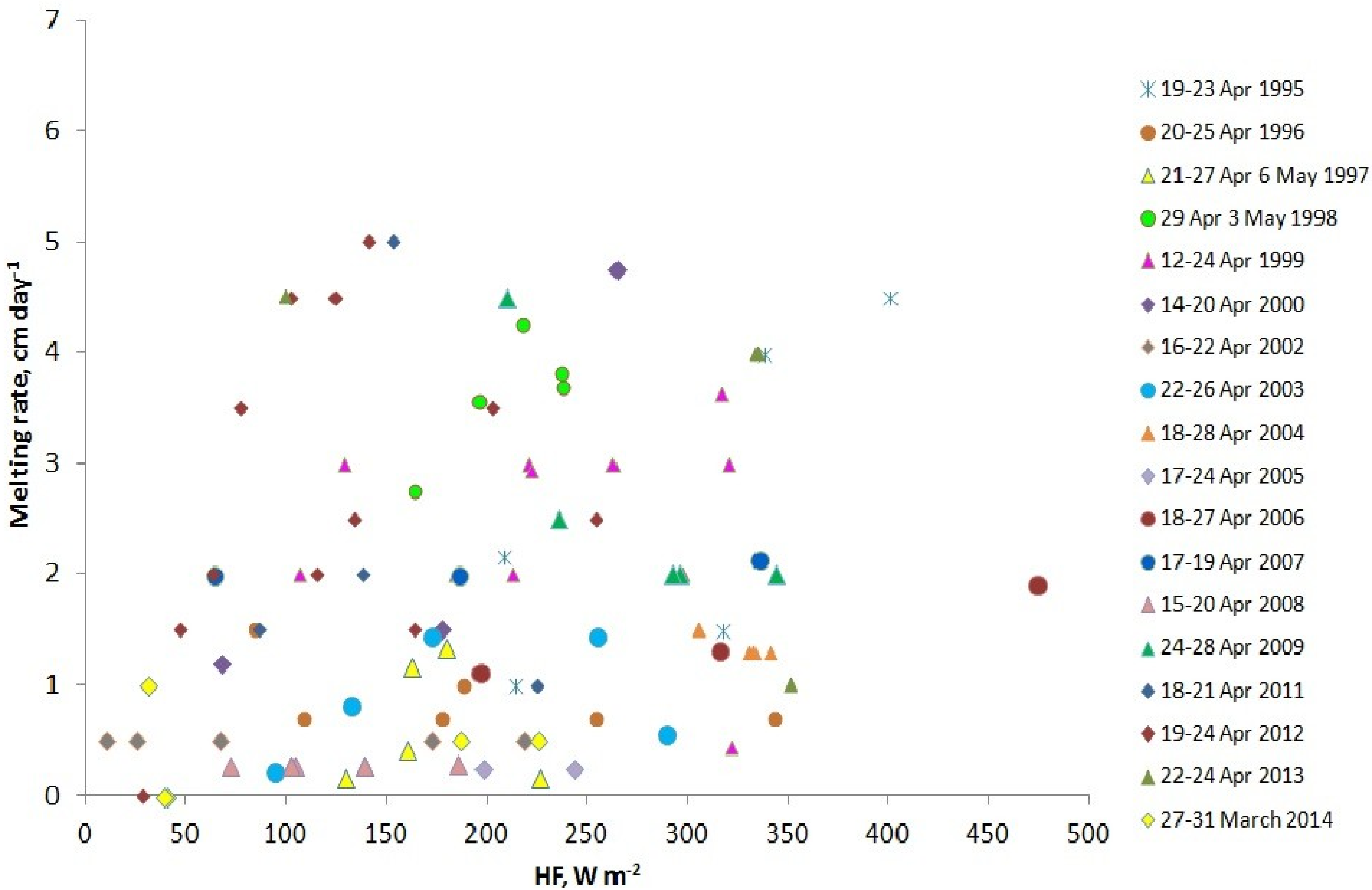
- For snow ~11.6 m^{-1} (from SExp 1&2)
- For white ice ~ 6.9 m^{-1} (from IExp)
- For crystal ice ~2.4 m^{-1} (from IExp and data collected)
- For 'non-distinguished' ice ~3.9 m^{-1} (from IExp and data collected)



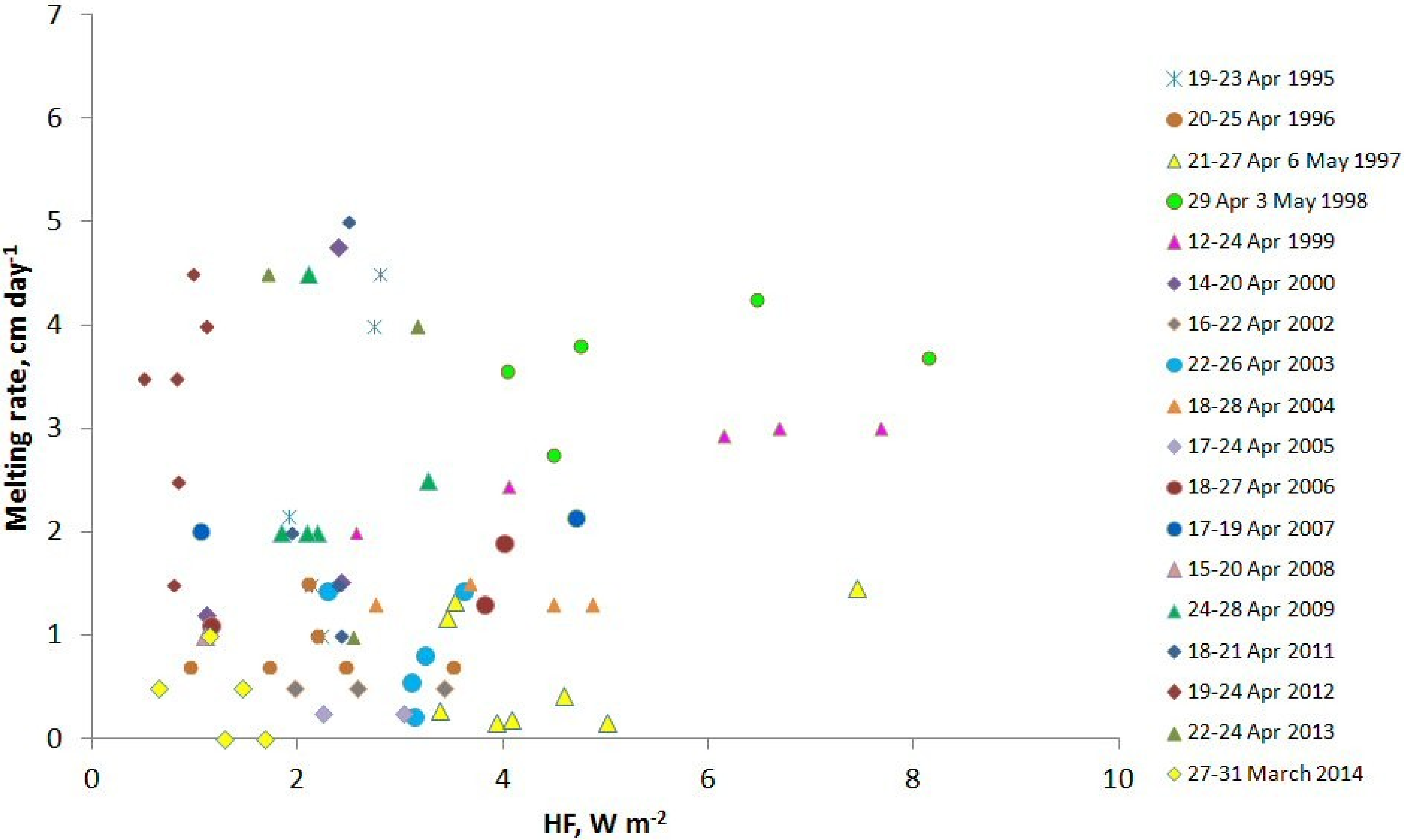
Extinction coefficients for the ‘cover’ vs. fraction of crystal ice under different surface conditions



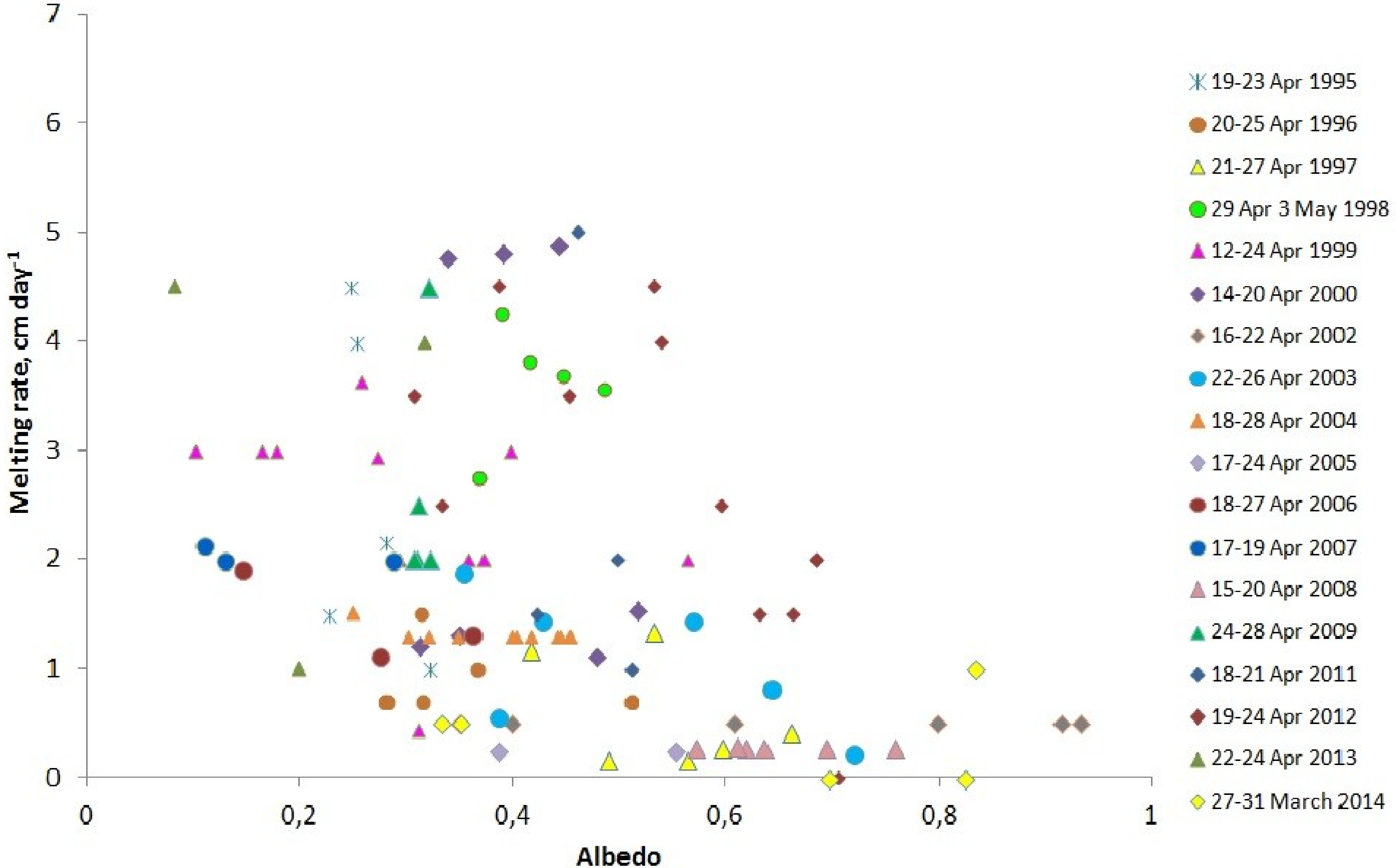
Extinction coefficients for the ‘cover’ vs. ice thickness under different surface conditions



Melting rate of total ice vs. radiative air-to-ice heat flux



Melting rate of total ice vs. water-to-ice heat flux



Melting rate of total ice vs. albedo

Discussion

1. Multi-layered ice on small lakes => choice of the extinction coefficient for a cover (knowledge on snow thickness dynamics is required);
2. otherwise, use EEC for 'non-distinguished' ice?
3. off-line sensitivity experiments with a lake NWP module (FLake or whatever) to analyse the effect of albedo and in-ice attenuation of solar radiation on ice melting =>
4. the latter results eventually in melting from below through the growing increase of the under-ice temperature gradient => if its effect is comparable with melting rate from atop =>
5. parameterisation of the under-ice radiatively driven convection, not taken into account by any lake model currently used in NWP, might be of importance.

Discussion

Concerning (3/5) [off-line sensitivity experiments with a lake NWP module / parameterisation of the under-ice radiatively driven convection], it might be worth to consider a possibility to find financing for such activity/ies. A better knowledge and, eventually, a more precise forecast of ice disappearance dates may lead to substantial NWP improvement for a modest price.

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- Russian Fund of Basic Research (projects 13-05-00338 and 14-05-91761-AF)
- ESSEM COST Action ES1404

Support is gratefully acknowledged. We are also very thankful to our colleagues who collected the observational data in quite tough field conditions.

Спасибо за внимание!

Obrigado pela sua atenção!

Thanks for your attention!