# Solar radiation and albedo regime in ice-covered lakes: Probable use and misuse of observational data in numerical modeling


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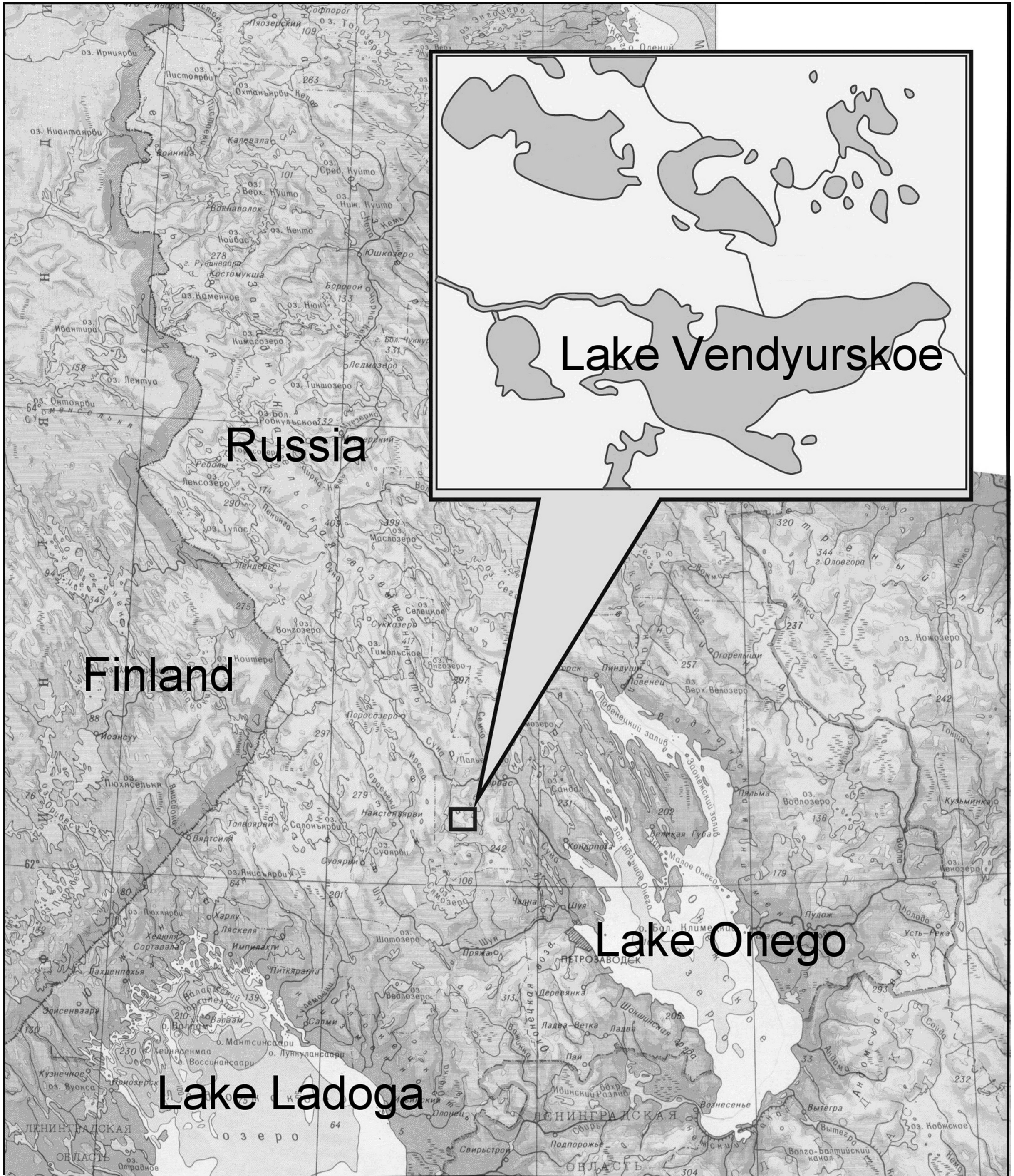
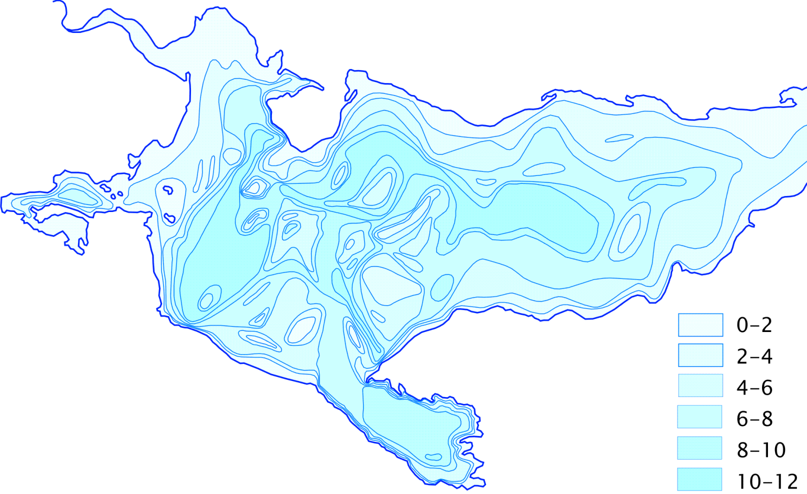
# Outline

- ***Data used***
- ***Probable confusions***
- ***Preliminary conclusions [discussion]***

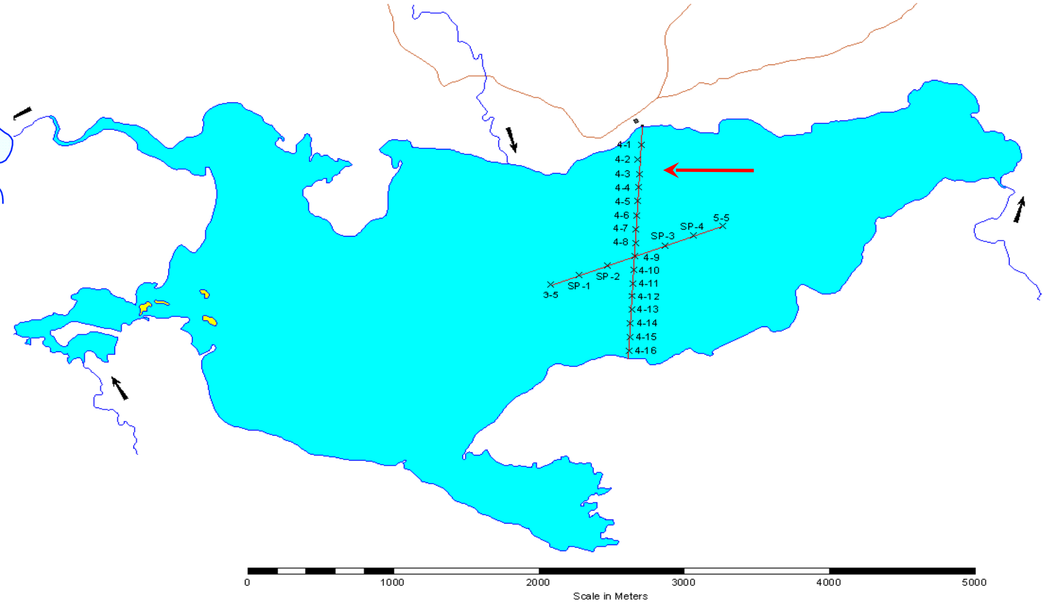
Lake Vendyurskoe
Sweden
Finland
Norway
Lake Onego
Lake Ladoga
Russia



Lake Vendyurskoe
Russia
Finland
Lake Onego
Lake Ladoga




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

# General information about Lake Vendyurskoe

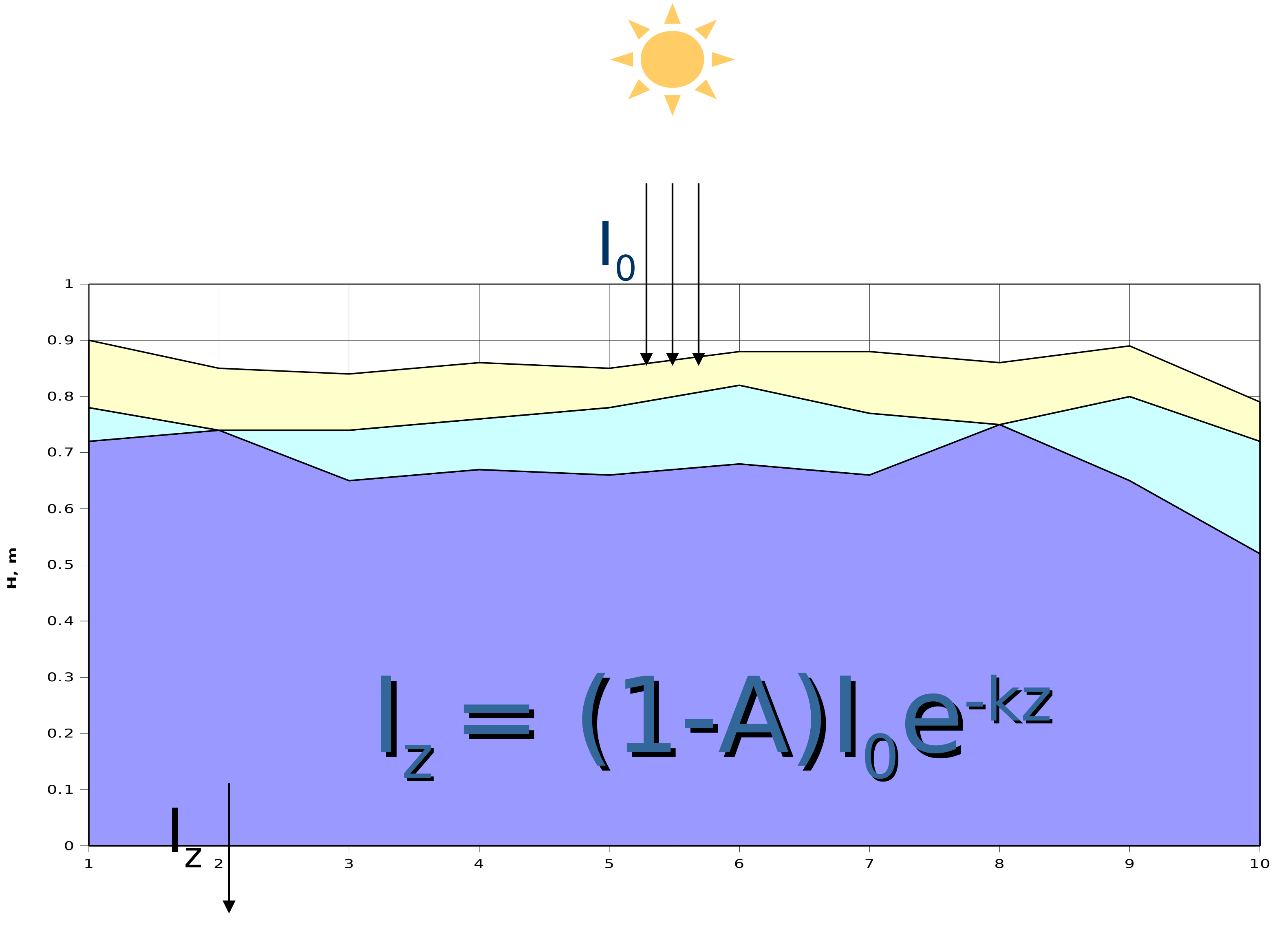
Lake Vendyurskoe is located in the norhtwest part of Russia
- latitude 62°10’-62°20’N, longitude 33°10’-33°20’E;
- lake basin is of glacial origin;
- max and mean depth –13.4 and 5.3 m;
- area – 10.4 km$^2$;
- volume – $54.8 \cdot 10^6$ m$^3$;
- drainage basin area – 82.8 km$^2$;
- water exchange coefficient (for 1 year) – 0.3-0.4;
- Secchi disk reading – 3-4 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 lake.

# What we have measured?

## (1994-1997; 1994-2010; 2000-2010; 2008-)

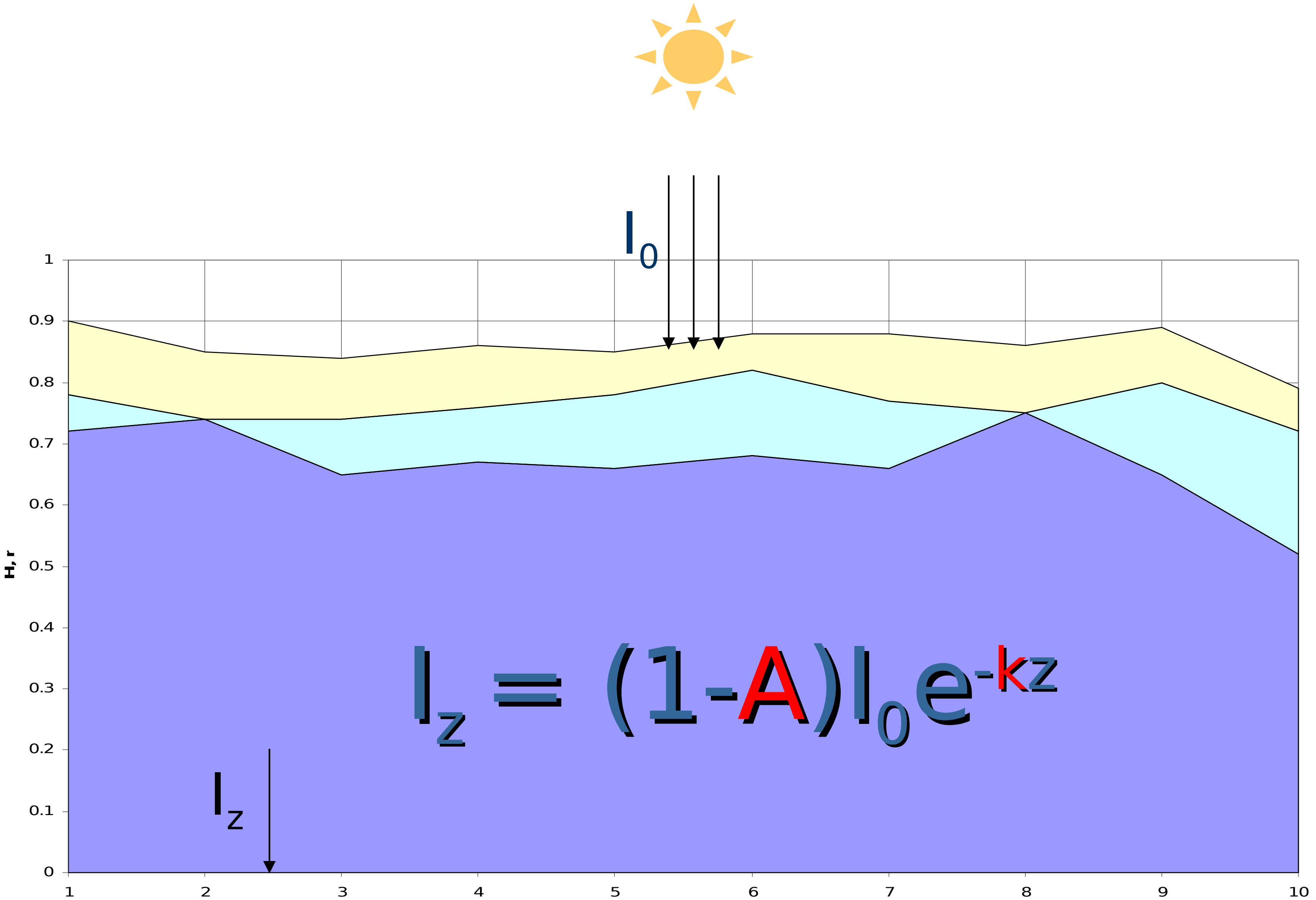
- Water temperature and conductivity, incl. the fine structure in the vicinity of interfaces
- snow and ice cover depth, solar radiation (incoming, reflected, at the lower ice boundary)
- currents, ice cover fluctuations; atmospheric pressure (from 2009 – by RBR-TDR)
- weather parameters, dissolved oxygen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

# Early-spring warming




$$I_z = (1-A)I_0 e^{-kz}$$

# Early-spring warming

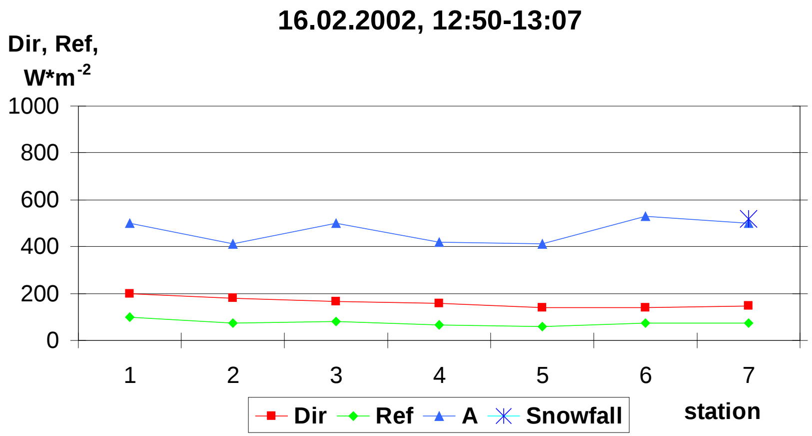


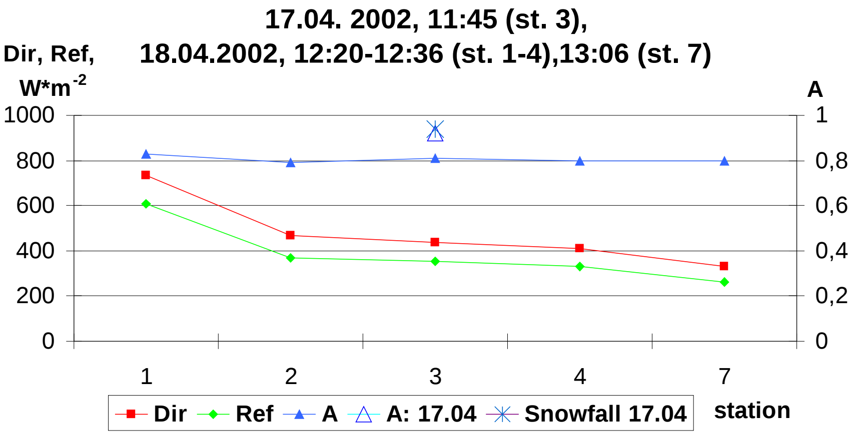

$$I_z = (1\text{-}A)I_0e^{-kz}$$

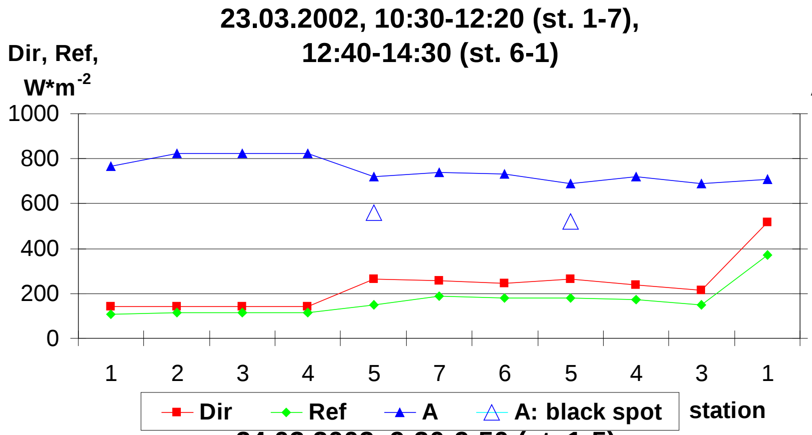
# Albedo

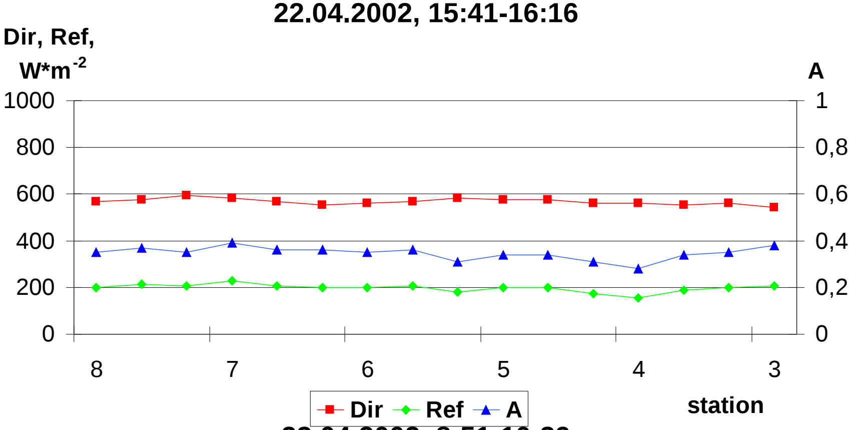
# Albedo in February-April 2002 along cross-section 4

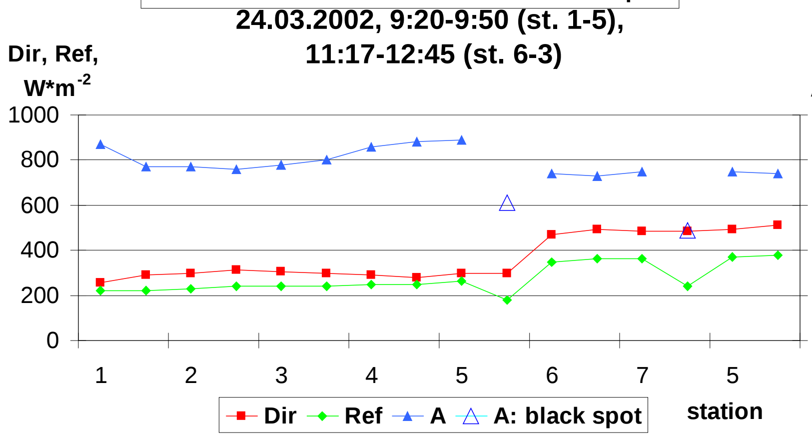
| State of snow-ice cover | Weather conditions, visibility | Albedo |
|---|---|---|
| New 5-cm thick snow | Snow veil, wind | 0.92-0.94 |
| Wet sticking snow | Air temperature +3-4°C. Thin clouds veiling the sun. | 0.79-0.83 |
| Thin crust of ice over old snow, fine-rough surface, glossy spots | Sunny, 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 |

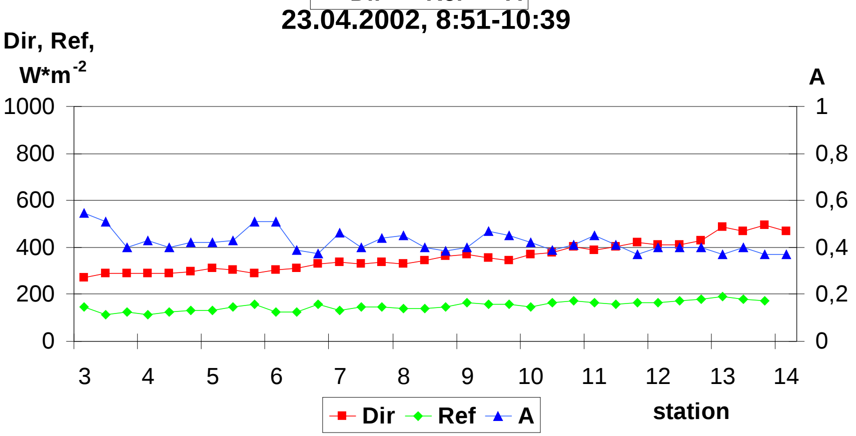


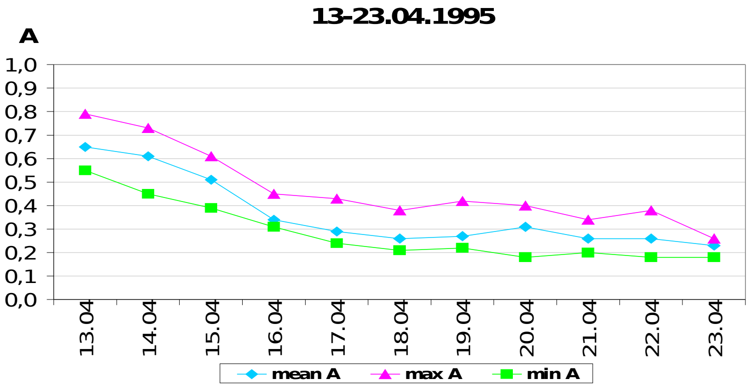



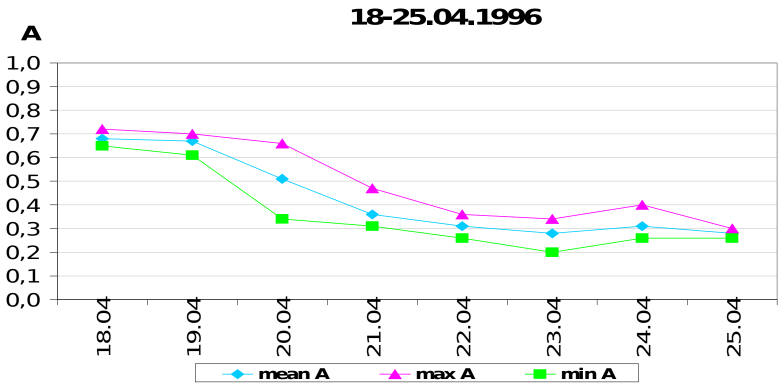



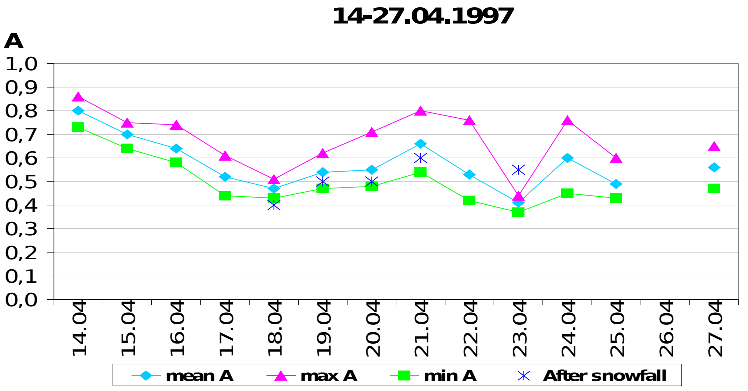



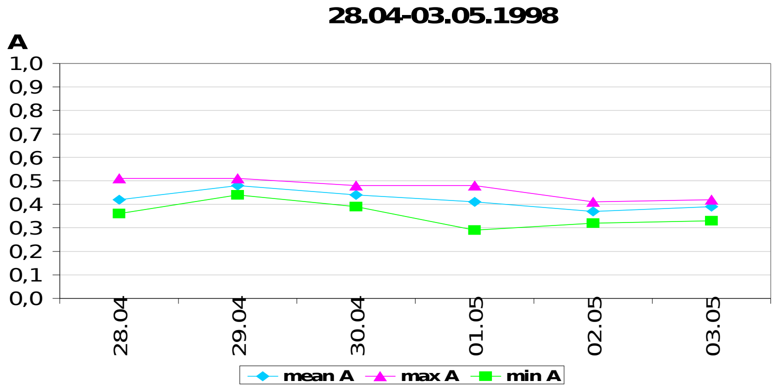



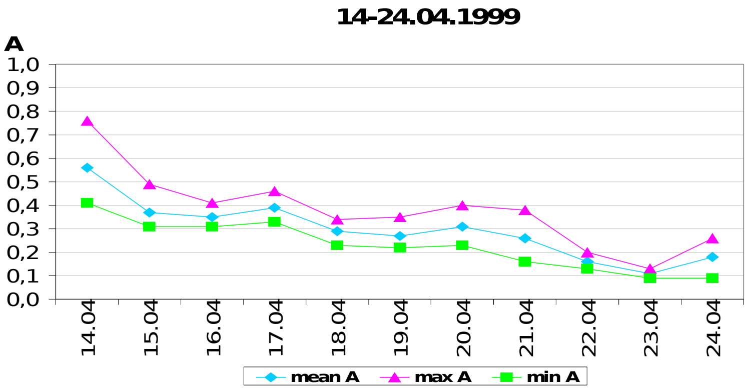

# Albedo variability in February-April 2002 (cross-section 4)

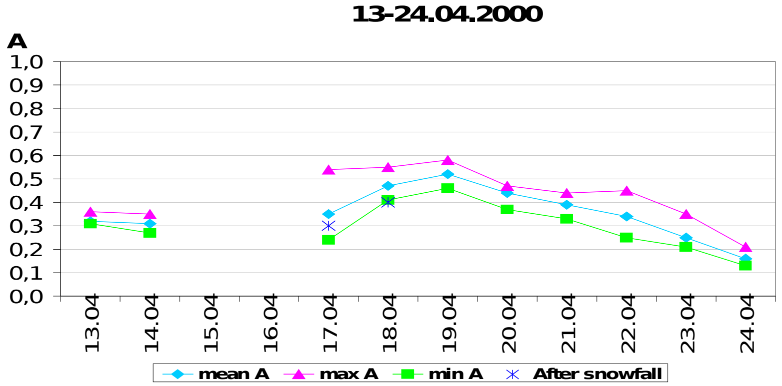


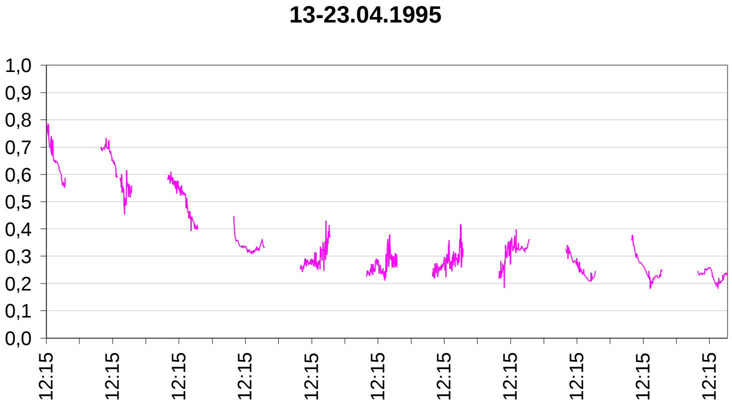



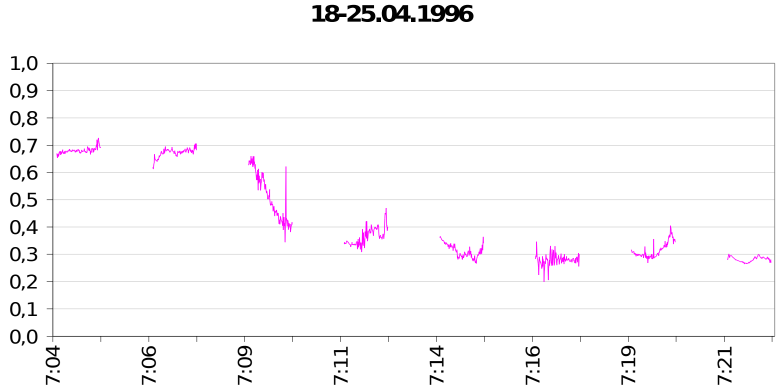



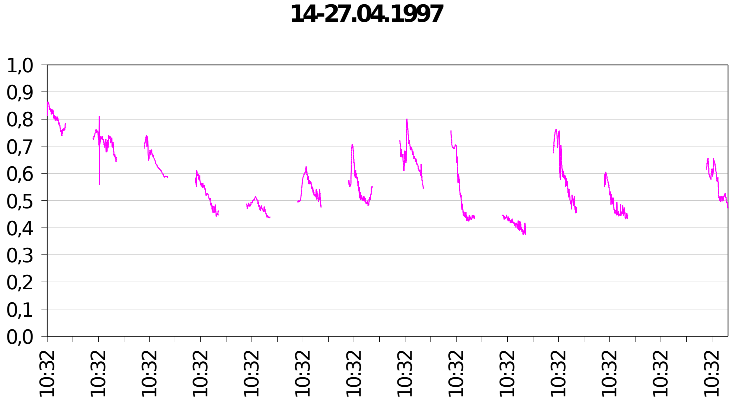



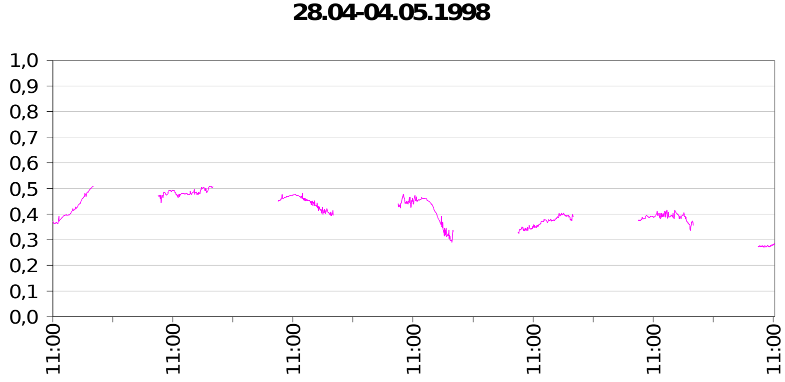



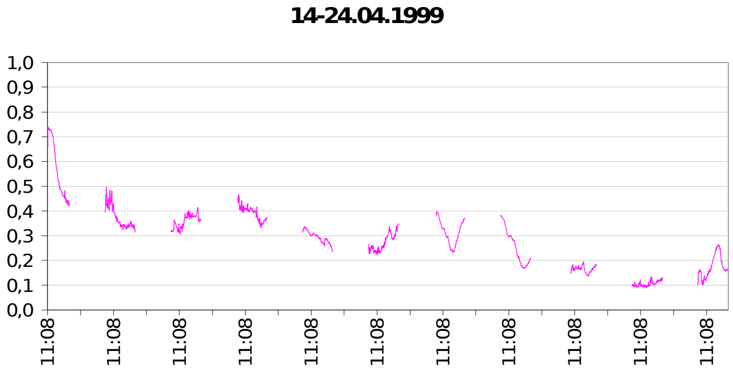

# Synoptical variability of albedo in April (st. 4-3)

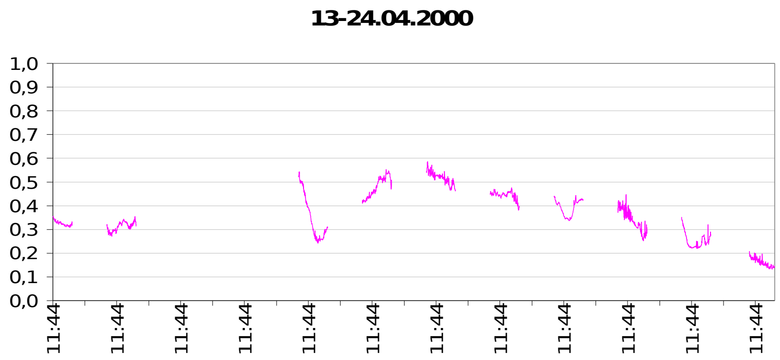


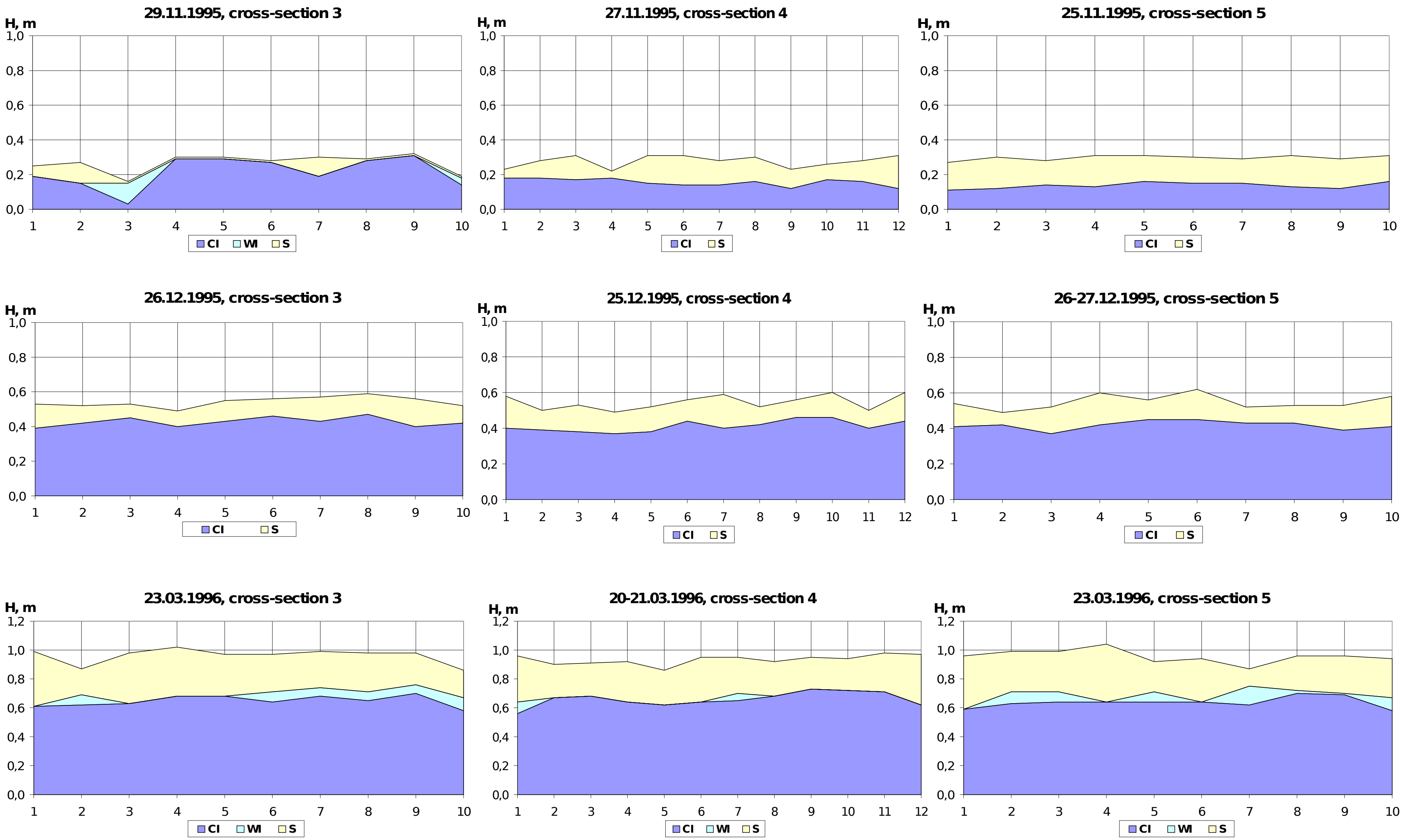



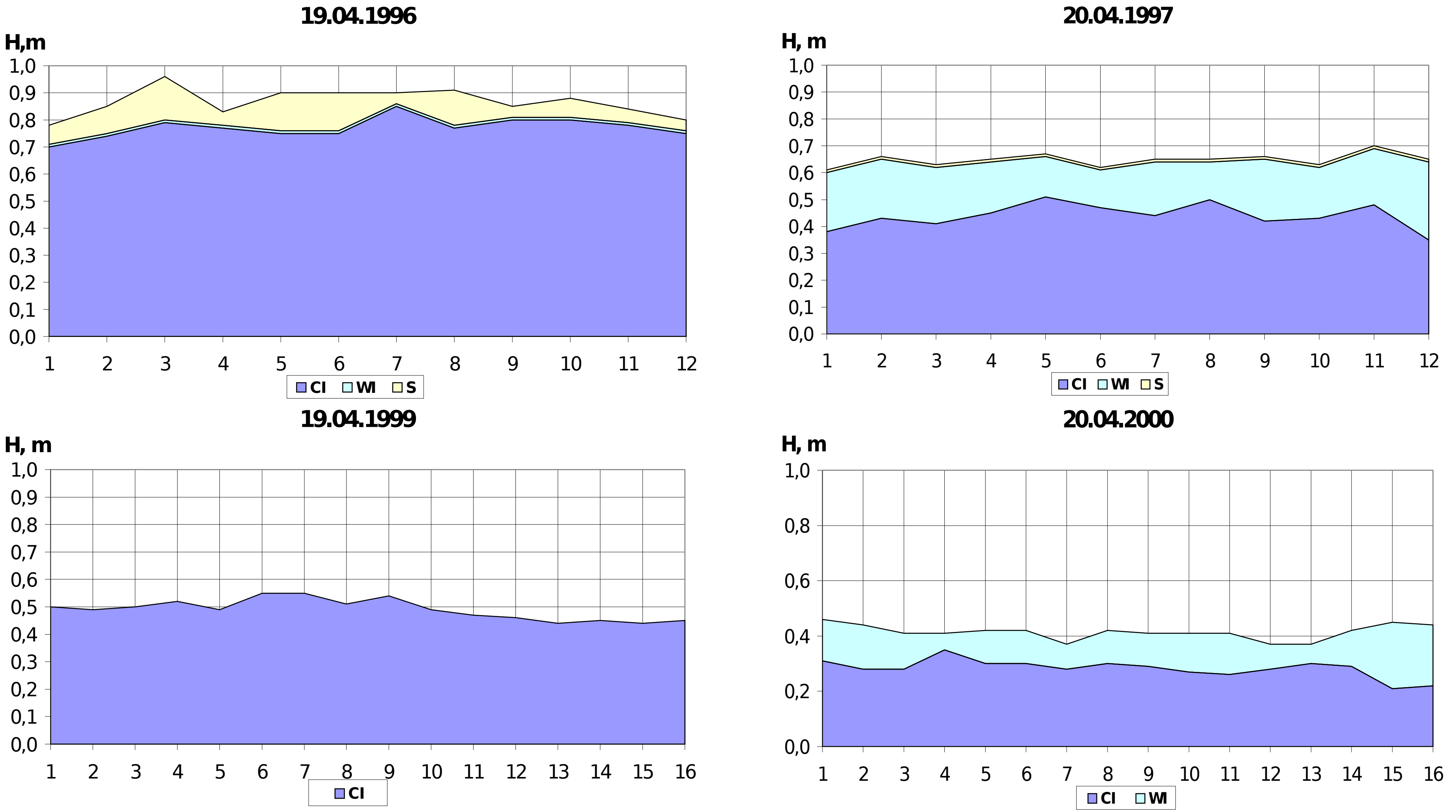



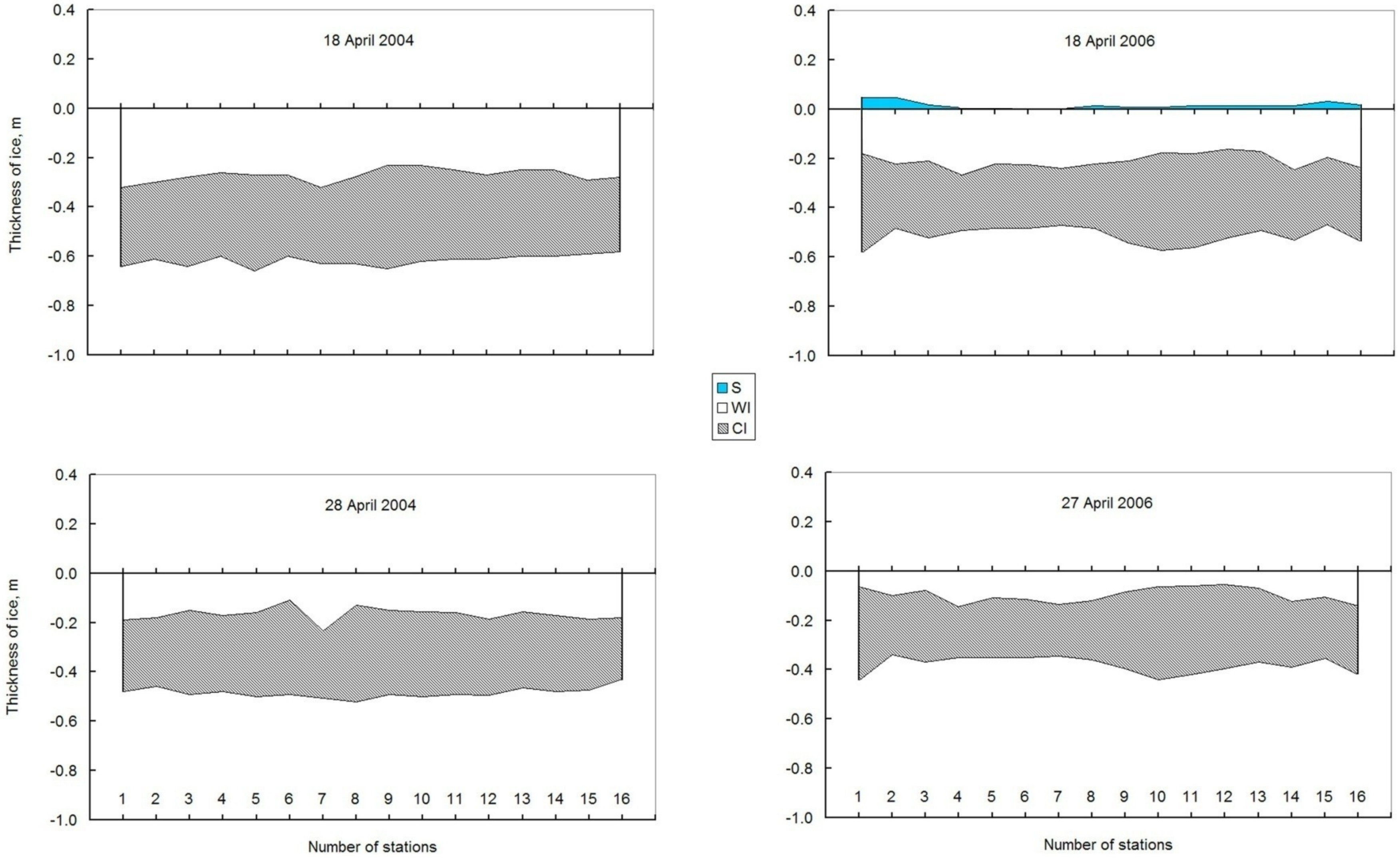

# Daily variability of albedo in April (st. 4-3)



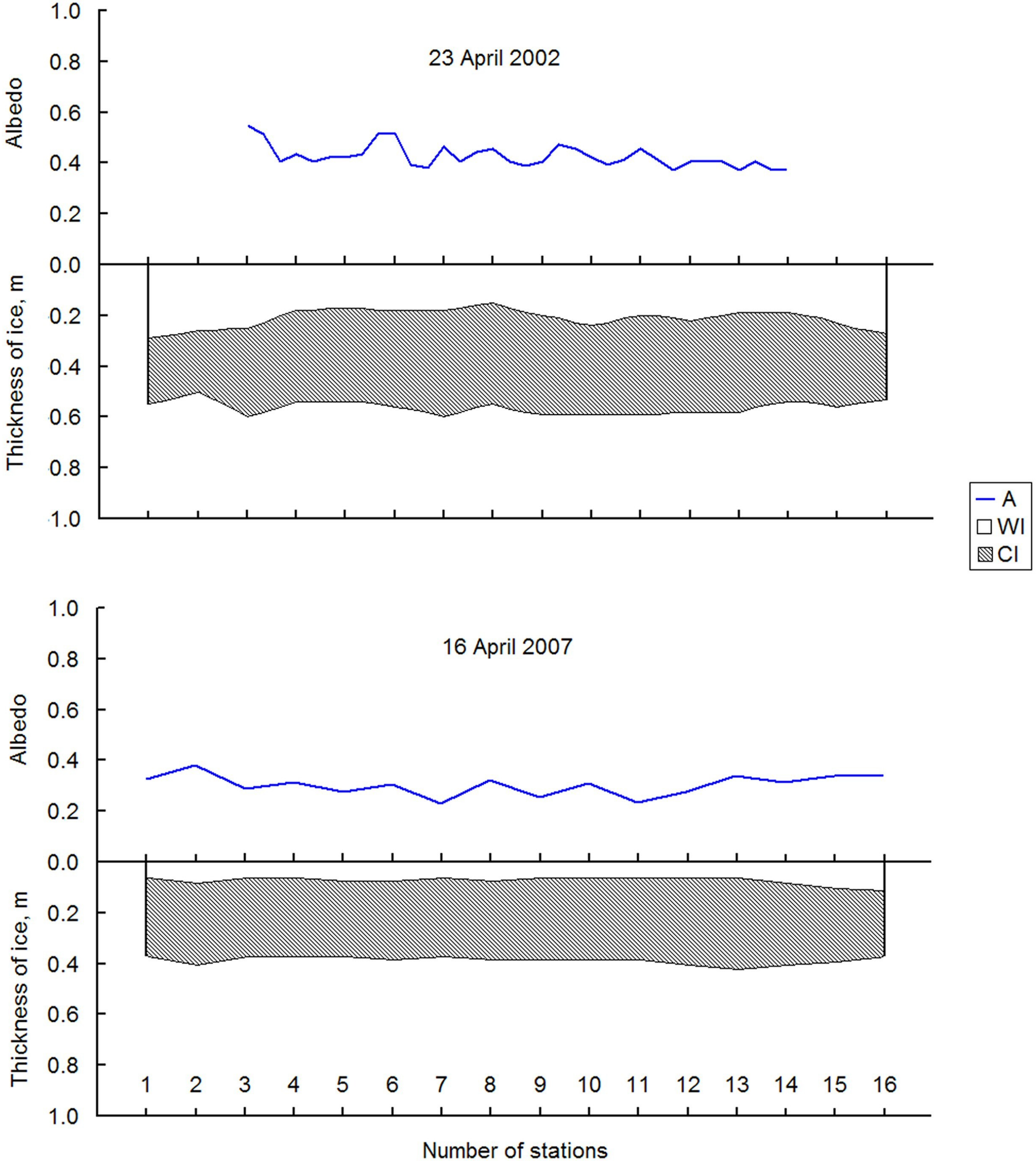

# Variability of snow and ice cover in early and mid-winter




# Snow and ice cover along cross-section 4 in April

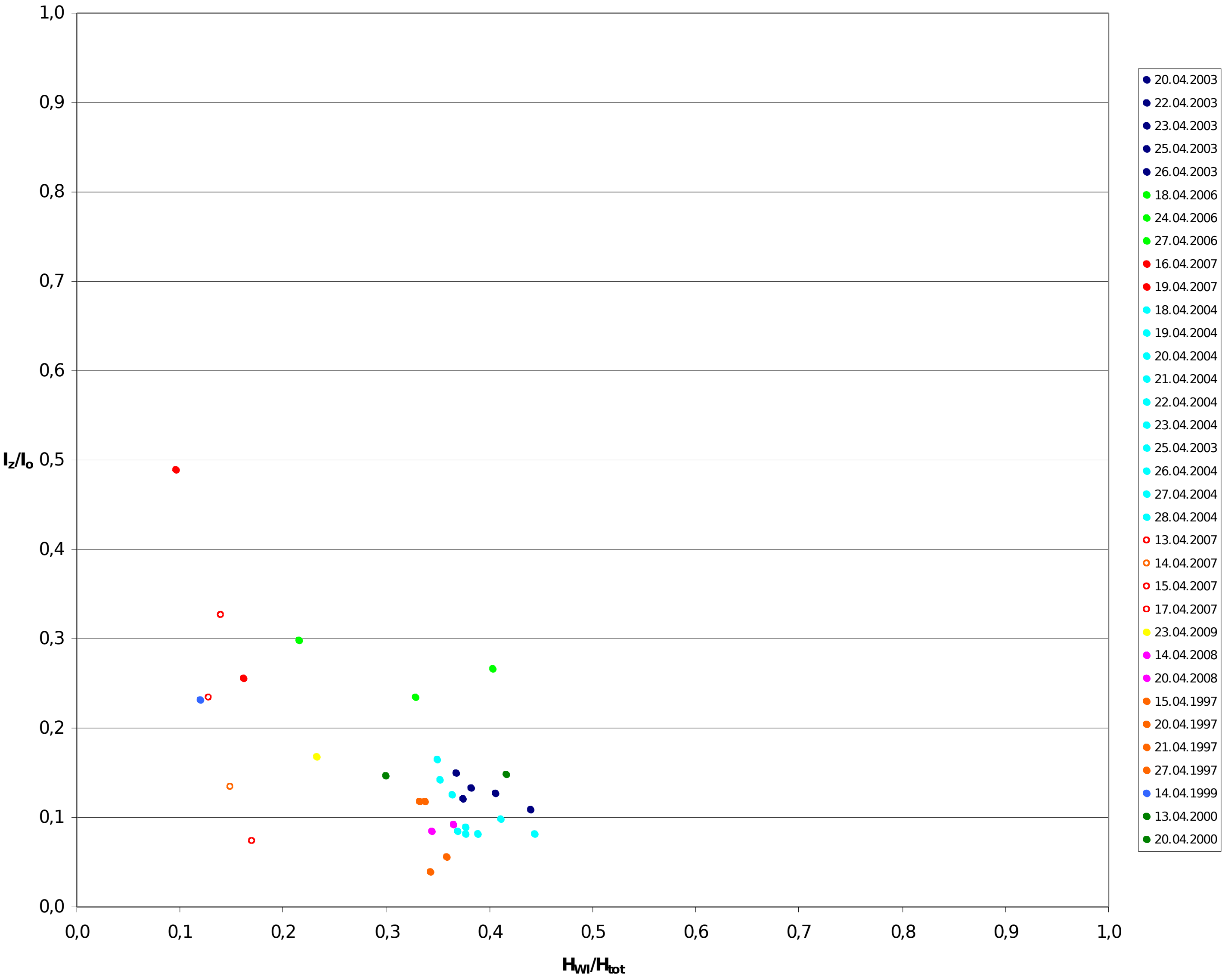



# Snow and ice cover along cross-section 4 in April

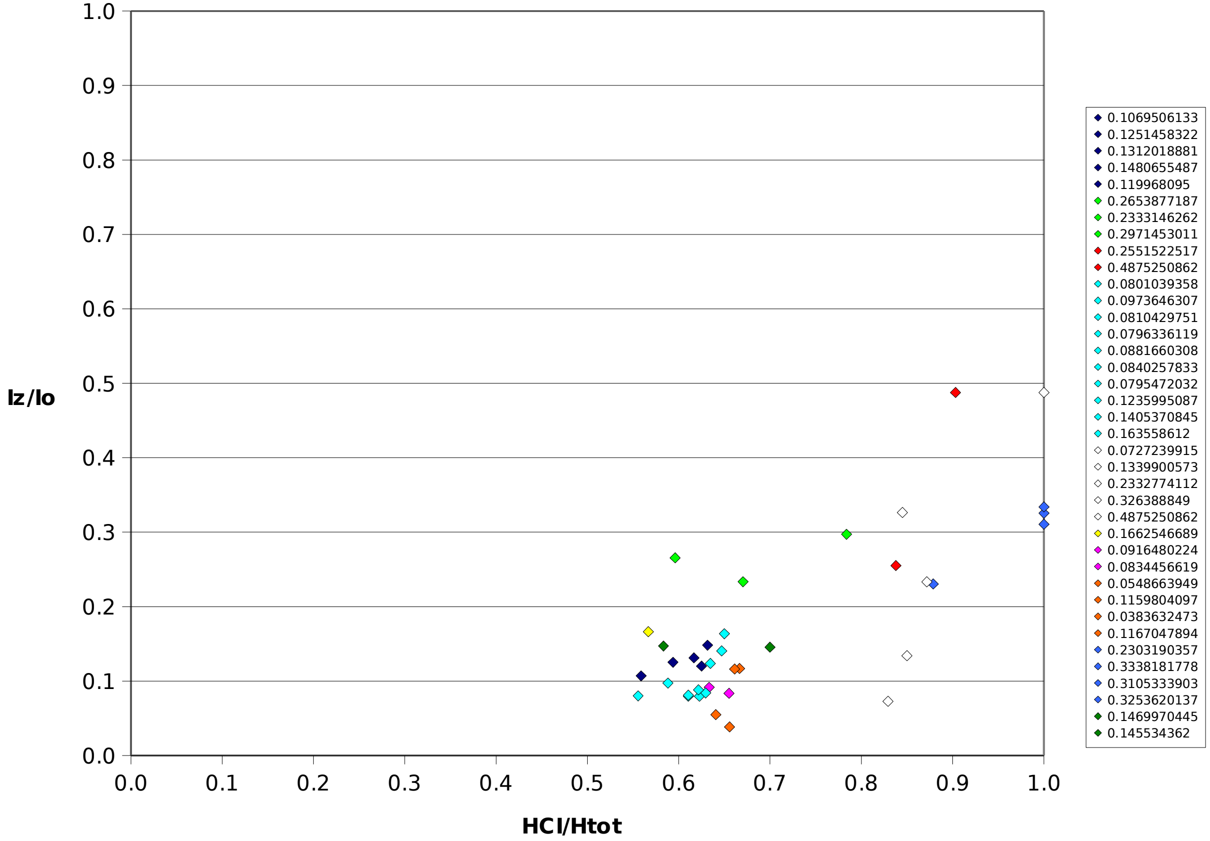


23 April 2002
16 April 2007
Albedo
Thickness of ice, m
Number of stations
A
WI
CI
1.0
0.8
0.6
0.4
0.2
0.0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

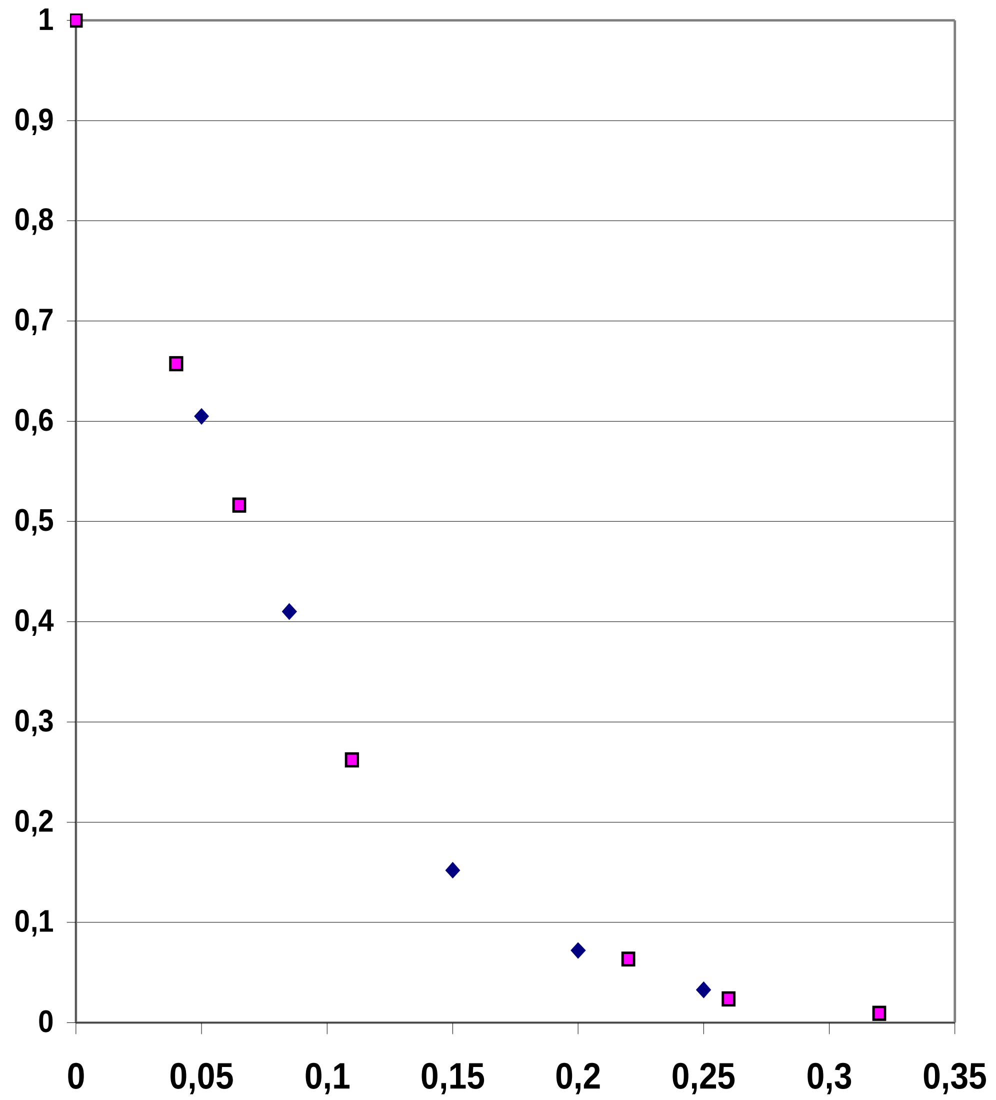
# Solar radiation



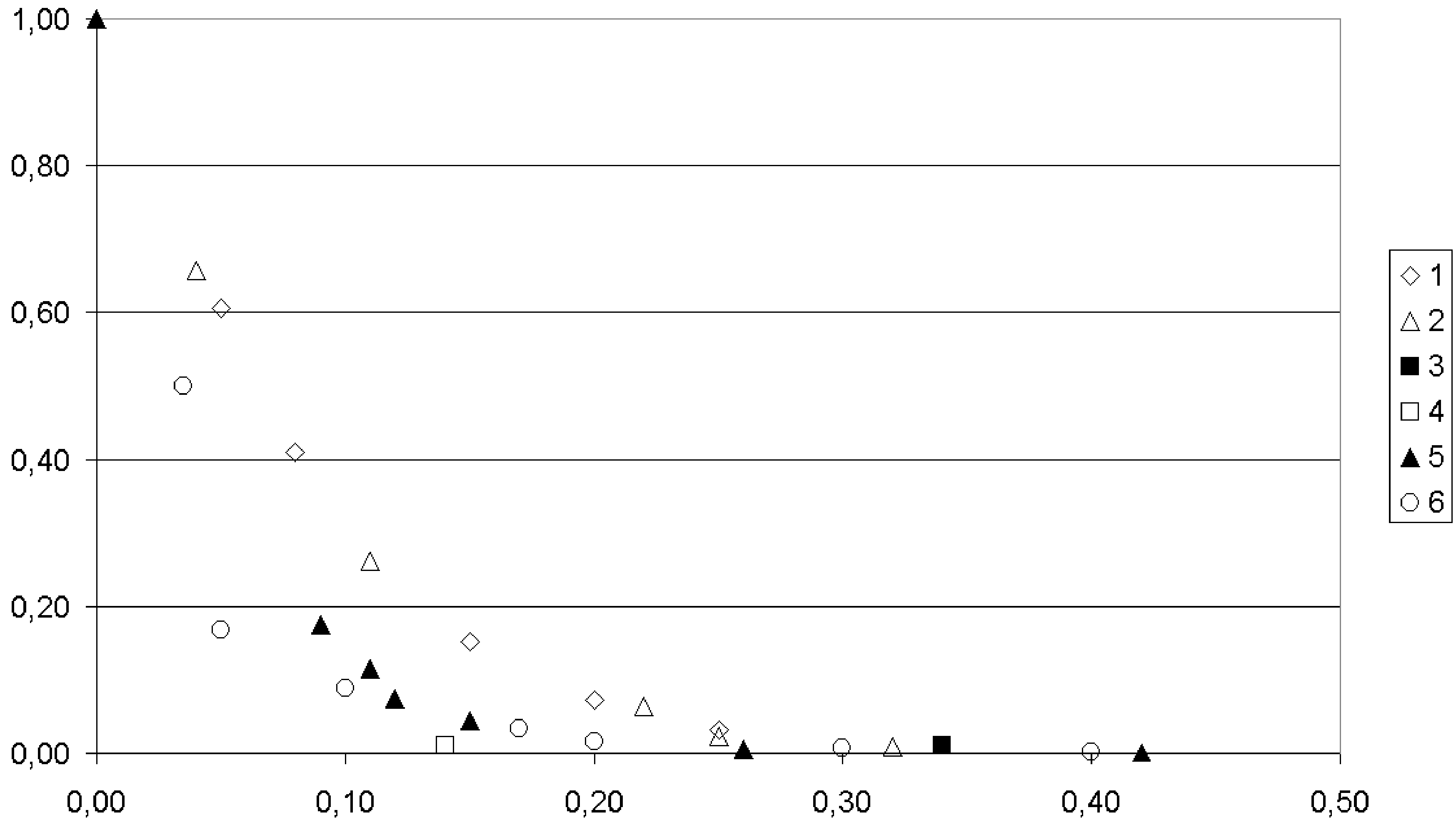

# Transmissivity of ice vs. fraction of snow ice




# Transmissivity of ice vs. fraction of crystal ice




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



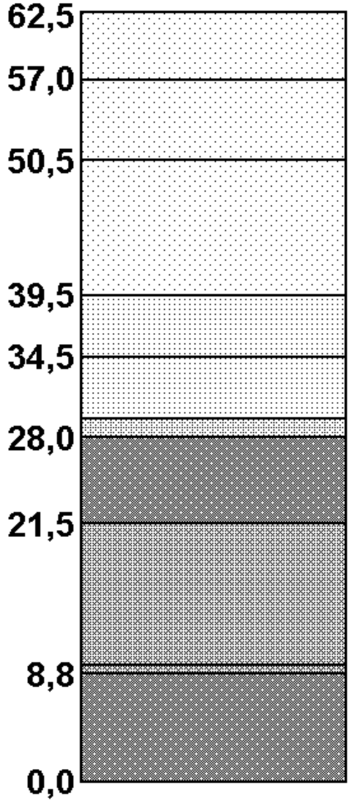

Attenuation of solar radiation by the lake snow: 1 – Vendyurskoe, 2003; 2 – Vendyurskoe, 2004; 3 – Lake Taimir [11]; 4 – Lake Onego [11]; 5 – Punnusjarvi [Krasnoe] [7]; 6 – Lake Onego [6]. X-coordinate – snow thickness, m; y-coordinate – attenuation, decimal fractions.

| Year | Snow thickness, m | EC, $m^{-1}$ |
| --- | --- | --- |
| 2003 | 0.25 | 13,71 |
| | 0.2 | 13,17 |
| | 0.15 | 12,56 |
| | 0.08 | 11,16 |
| | 0.05 | 10,05 |
| 2004 | 0.32 | 14.71 |
| | 0.26 | 14.43 |
| | 0.22 | 12.55 |
| | 0.11 | 12.18 |
| | 0.07 | 10.17 |
| | 0.04 | 10.5 |

**The average value for the 20-cm**

**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)
-

## Snow and ice

$$I_{zc1} = I_{0m} e^{-(k_s z_s + k_i z_i)}$$

## Snow, white and crystal ice

$$I_{zc2} = I_{0m} e^{-(k_s z_s + k_{wi} z_{wi} + k_{ci} z_{ci})}$$

## Snow and ice

$$I_{zc1} = I_{0m} e^{-(k_s z_s + k_i z_i)}$$

## Snow, white and crystal ice

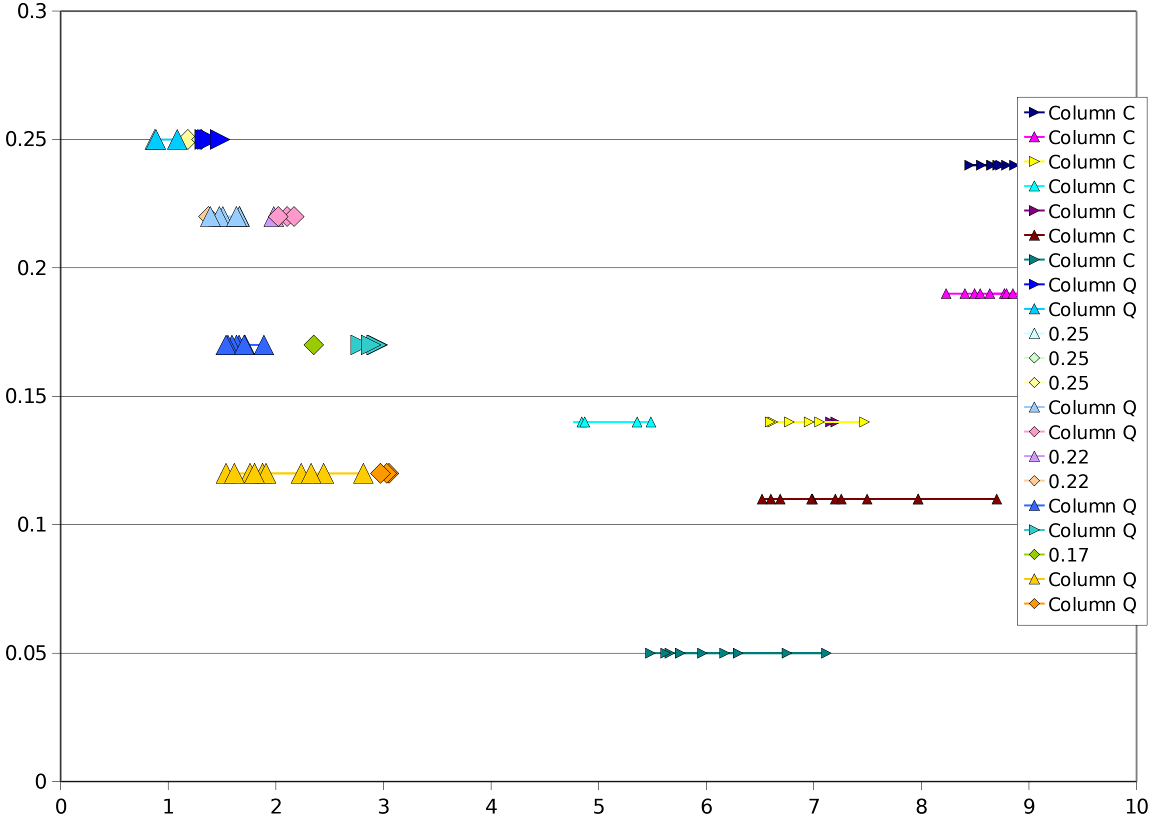
$$I_{zc2} = I_{0m} e^{-(k_s z_s + k_{wi} z_{wi} + k_{ci} z_{ci})}$$

| Date | $I_0$ | $I_{zm}$ | $z_s$ | $z_i$ | $I_{zc1}$ | $I_{zc1}/I_{zm}$ | $I_{zc2}$ | $I_{zc2}/I_{zm}$ |
|---|---|---|---|---|---|---|---|---|
| 18.04.04 | 335.4 | 27.0 | 0.01 | 0.60 | 29.34 | 1.09 | 23.78 | 0.88 |
| 19.04.04 | 223.3 | 22.3 | 0.01 | 0.57 | 21.53 | 0.97 | 18.81 | 0.84 |
| 20.04.04 | [illegible] | 20.9 | 0.03 | 0.57 | [illegible] | 0.96 | [illegible] | 0.83 |
| 20.04.04 | 177.2 | 12.3 | 0.03 | 0.57 | 13.82 | 1.12 | 11.98 | 0.97 |
| 21.04.04 | 135.6 | 11.2 | 0.01 | 0.57 | 13.33 | 1.19 | 11.56 | 1.03 |
| 22.04.04 | 254.0 | 22.0 | 0.01 | 0.56 | 15.71 | 1.23 | 24.86 | 1.13 |
| 23.04.04 | 253.3 | 21.2 | 0.03 | 0.55 | 27.0 | 1.03 | 19.90 | 0.94 |

**Accuracy ±20%**

| Date | $I_0$ | $I_{zm}$ | $z_s$ | $z_i$ | $I_{zc1}$ | $I_{zc1}/I_{zm}$ | $I_{zc2}$ | $I_{zc2}/I_{zm}$ |
|---|---|---|---|---|---|---|---|---|
| 18.04.04 | 335.4 | 27.0 | 0.01 | 0.60 | 29.34 | 1.09 | 23.78 | 0.88 |
| 19.04.04 | 223.3 | 2[illegible] | 0.0[illegible] | 0.5[illegible] | 21.5[illegible] | [illegible].97 | [illegible]8.81 | 0.84 |
| 20.04.04 | 258.0 | 20.9 | 0.03 | 0.57 | 20.11 | 0.96 | 17.44 | 0.83 |
| 20.04.04 | 177.2 | 12.3 | 0.03 | 0.57 | 13.82 | 1.12 | 11.98 | 0.97 |
| 21.04. | 135. | | | | 13.3 | | 11. | |

**Accuracy ±20%**




EC for crystal ice  EC for snow ice

# The “ice” experiment in 2005

Maykut, 1977). Below 0.1 m, only visible light remains, where the spectral dependence of $\kappa_\lambda$ is weaker, and changes in $\kappa_t$ with depth are small. Total extinction coefficients have been used in sea ice thermodynamic models (Maykut and Untersteiner, 1971) to calculate the surface heat balance and solar heating in the ice interior. To do this Maykut and Untersteiner (1971) modified the exponential decay law to the form:

$$F_d(z) = i_0 F_d(0) e^{-\kappa_t z} \quad \text{for } z > 0.1 \text{ m}$$

where $i_0$ is the fraction of the wavelength-integrated incident irradiance transmitted through the top 0.1 m of the ice and $\kappa_t$ is the total extinction coefficient in the ice below 0.1 m. Values of $\kappa_t$ below 0.1 m and $i_0$ determined from field observations (Grenfell and Maykut, 1977) are summarized in Table 1. There is more scattering in white ice than blue ice, resulting in a smaller $i_0$ and a larger $\kappa_t$.

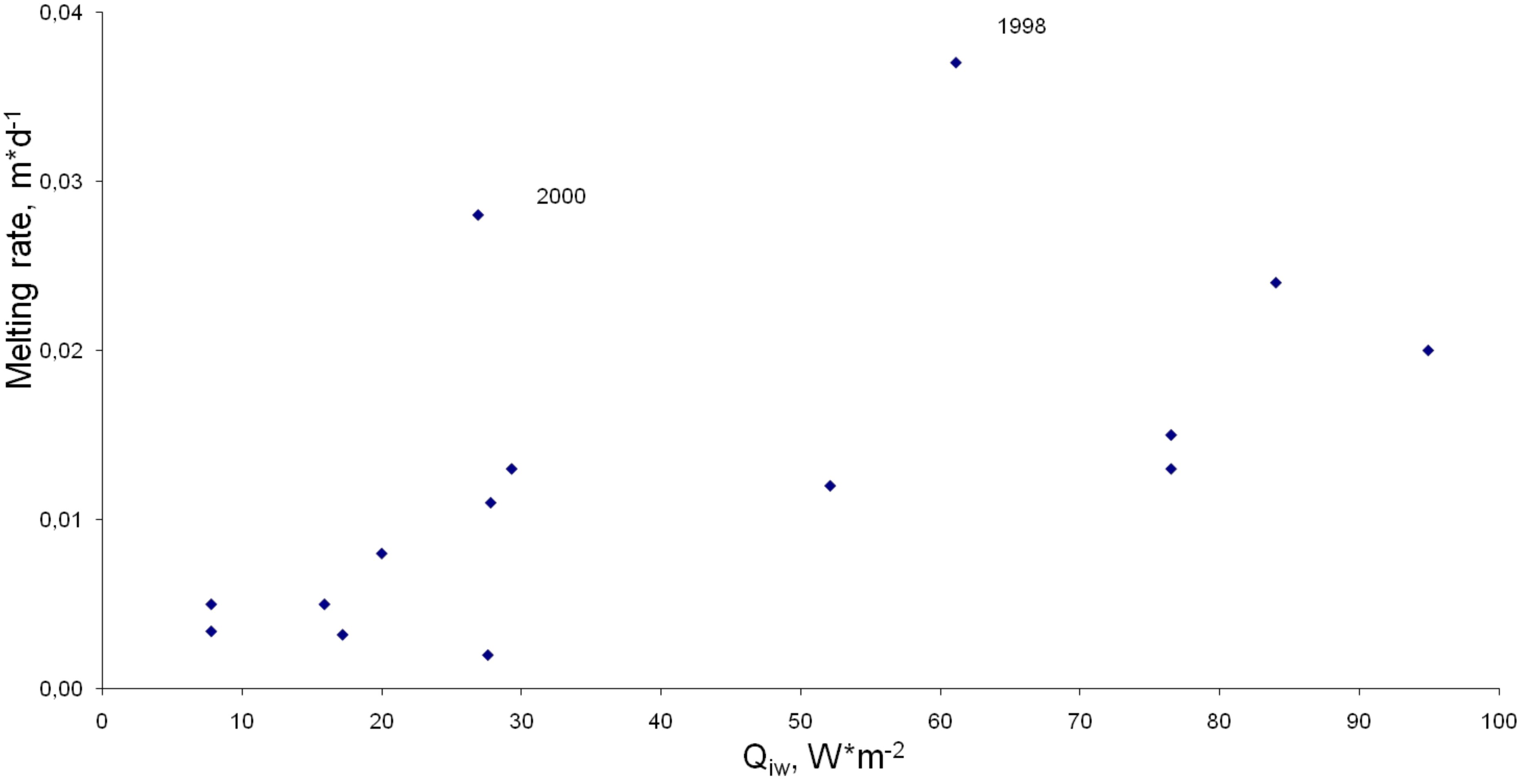
*Table 1. Values of $i_0$ and $\kappa_t$ (Grenfell and Maykut, 1977).*

| *Case* | *$i_0$* | *$\kappa_t$ ($m^{-1}$)* |
|---|---|---|
| Clear | | |
| Blue ice | 0.43 | 1.5 |
| White ice | 0.18 | 1.6 |
| Cloudy | | |
| Blue ice | 0.63 | 1.4 |
| White ice | 0.35 | 1.5 |

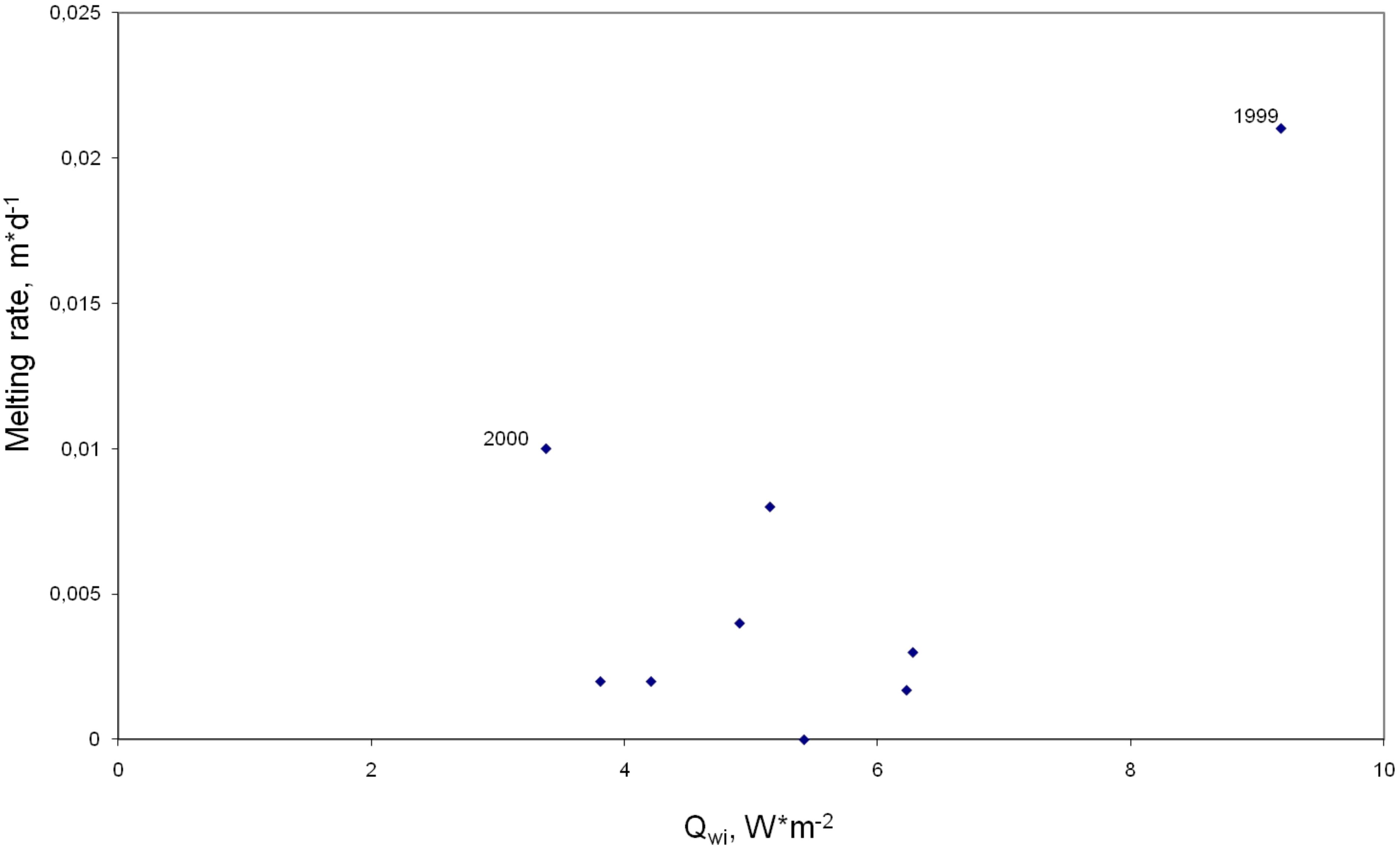
**4.5 Beam spread**

While much of the observational emphasis has been on measurements of transmitted solar irradiance to determine transmittance and extinction coefficient, measurements using artificial light sources have also been made. In particular, studies were conducted examining the spreading of a collimated beam as it passes through sea ice (Trodahl et al., 1987; Gilbert and Schoonmaker, 1990; Voss and Schoonmaker, 1992; Voss et al., 1992). In these experiments a collimated beam of light was incident on either the surface or bottom of the ice and the spatial distribution of the emergent irradiance was measured. Examining the peak magnitude and the spatial distribution of irradiance provide information on scattering and absorption in the ice. Laboratory studies indicate that scattering in the ice is quite strong, with the radiation field quickly becoming diffuse, and that there is increased attenuation and scattering for colder ice (Gilbert and Schoonmaker, 1990; Voss and Schoonmaker, 1992). Beam spread measurements, when combined with radiative transfer models, show promise as a means of determining scattering coefficients and phase functions from multiply scattering sea ice.

Taken from Perovich 1998




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




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

# Discussion

- Effective extinction coefficient: Rather more questions than statements
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Спасибо за внимание!

Thanks for your attention!