Baikal Neutrino Telescope - an Underwater Laboratory for Astroparticle Physics and Environmental Studies

N.Budnev, Irkutsk State University

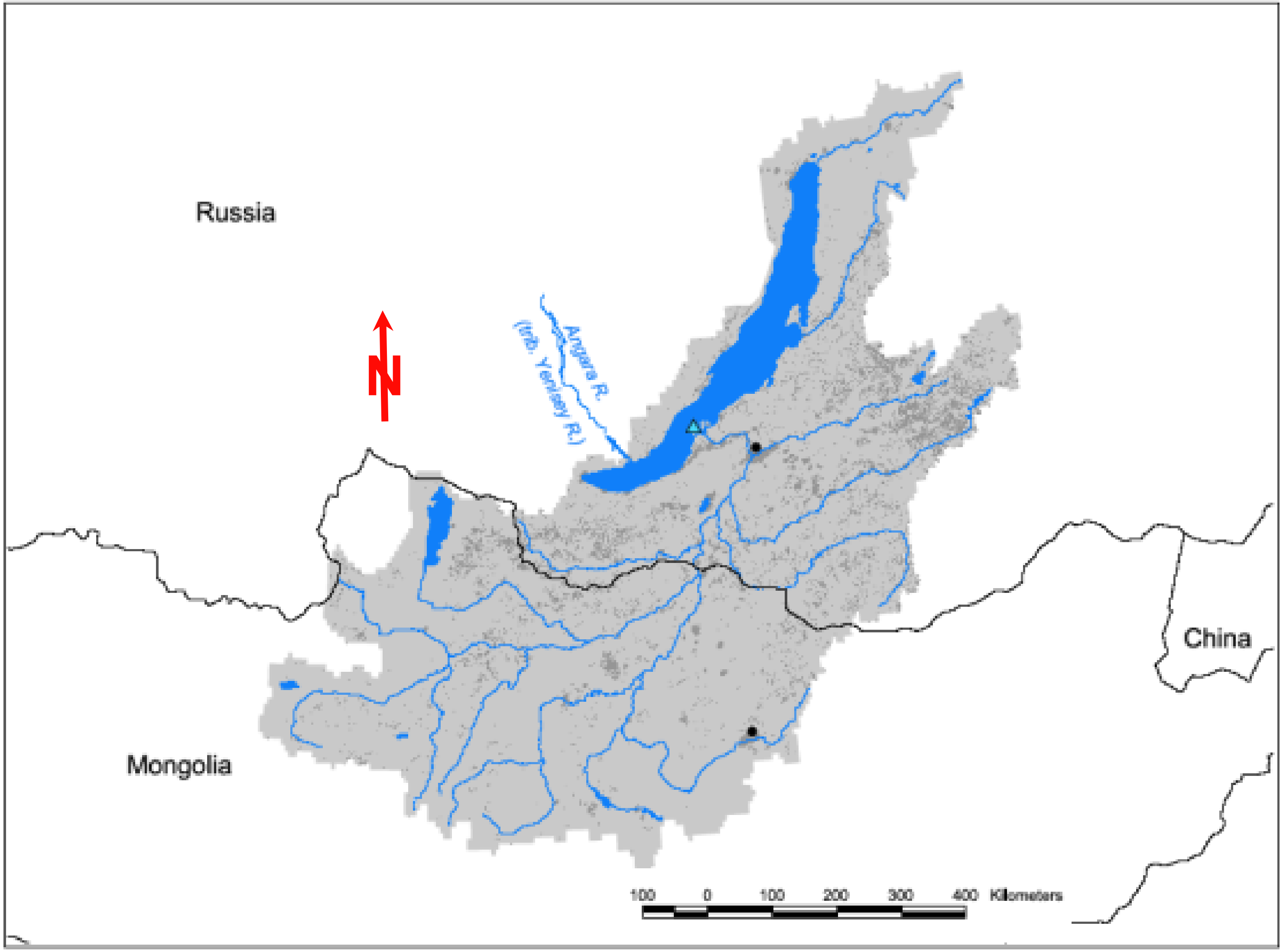
The Baikal Collaboration

1. Institute for Nuclear Research, Moscow, Russia.
2. Irkutsk State University, Irkutsk, Russia.
3. DESY-Zeuthen, Zeuthen, Germany.
4. Skobeltsyn Institute of Nuclear Physics MSU, Moscow, Russia.
5. Joint Institute for Nuclear Research, Dubna, Russia.
6. Nizhny Novgorod State Technical University, Nizhny Novgorod, Russia.
7. St.Petersburg State Marine University, St.Petersburg, Russia.
8. Kurchatov Institute, Moscow, Russia.

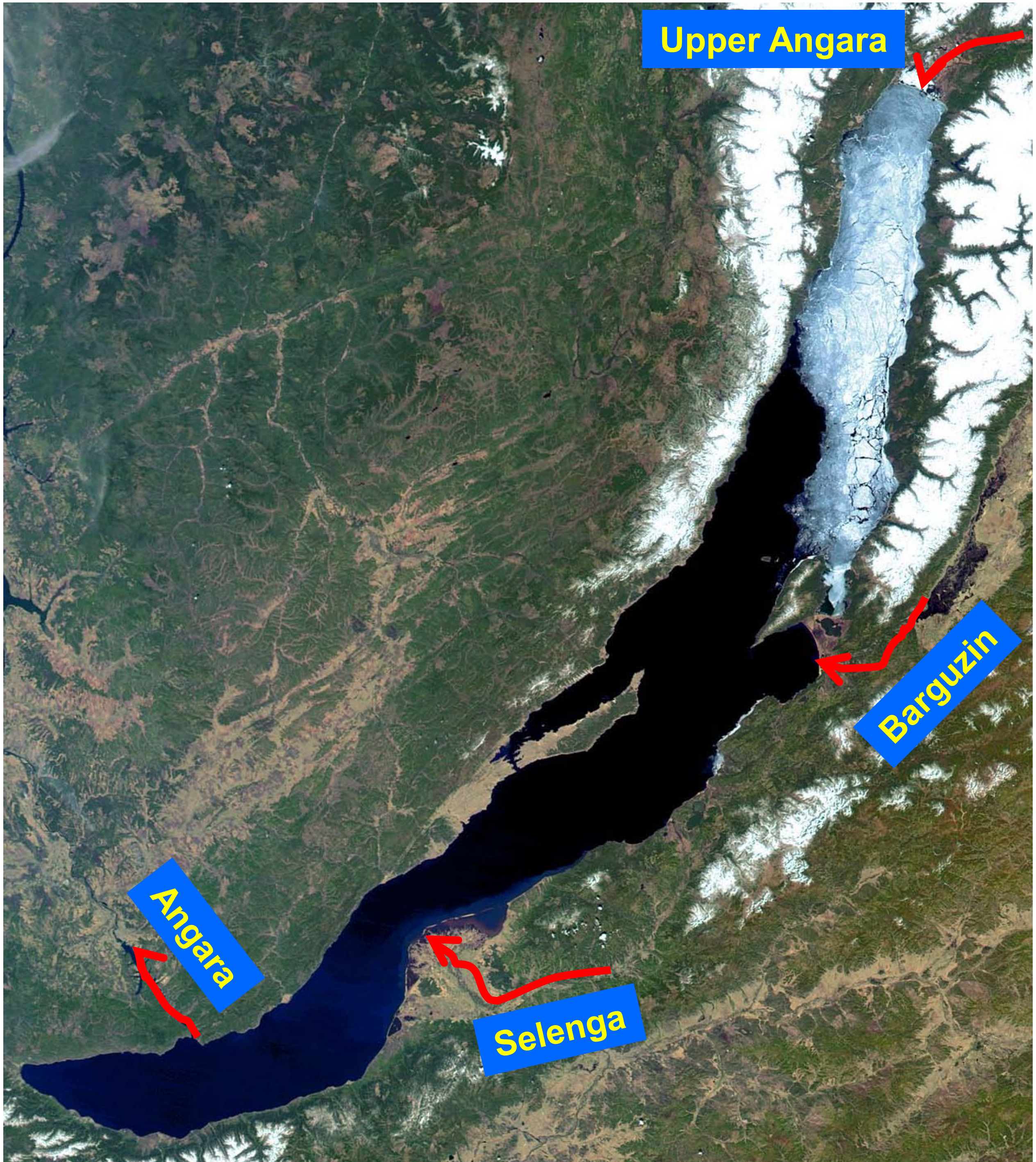
In co-operation for environmental research:

1. Swiss Federal Institute for Environmental Science and Technology, (EAWAG)
2. Limnological Institute SO RAS
3. Geoelectromagnetic Research Centre (GEMRC IPE RAS)…………………

Baikal watershed 571’000 KM^2 (lake area 32’000 KM^2)



May
1996



Length – 720 km,

width –
30-50 km,

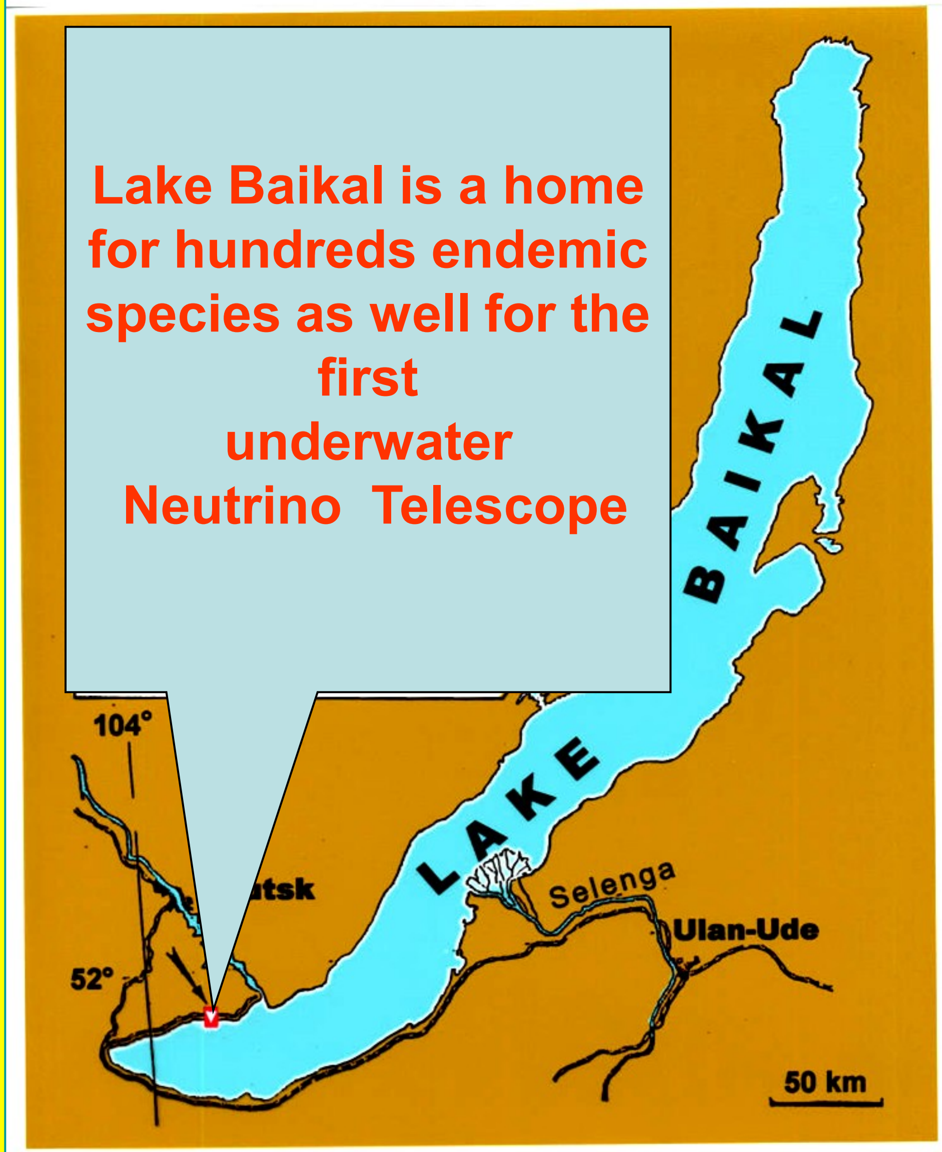
depth –
1.3-1.64km

Age - 20 – 60
million year

20% of fresh
water
(50% of drinking
water)
of whole world

The water body
of the lake is
fully oxygenated

Lake Baikal is a home
for hundreds endemic
species as well for the
first
underwater
Neutrino Telescope



Why Baikal water
is so clean?
Why conditions for
life are so good?

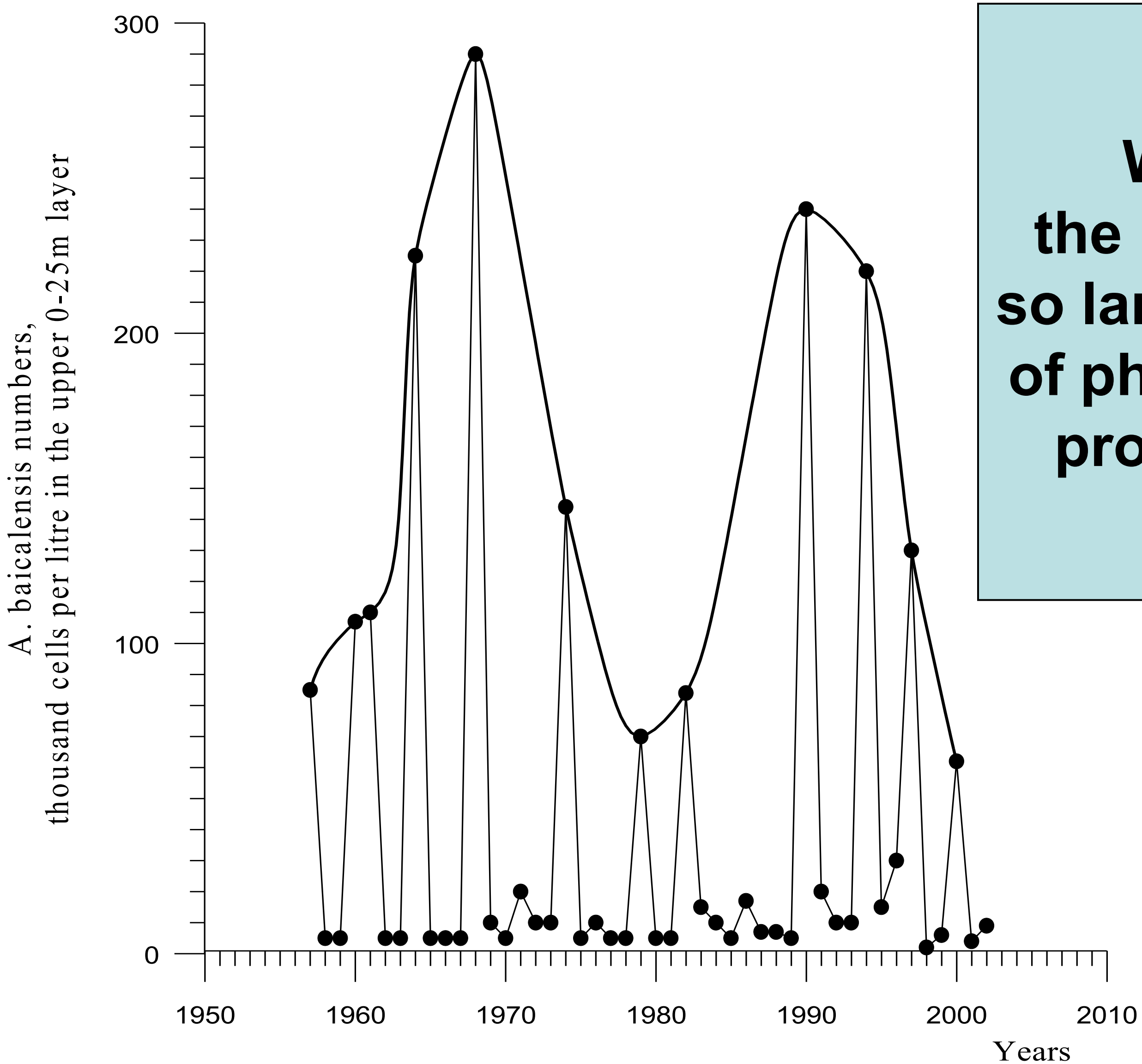
The first research people of Lake Baikal

B.Dybovsky
(1835 - 1930)

V.Godlevsky
(1831-1900)

G.Vereshagin
(1889-1944)

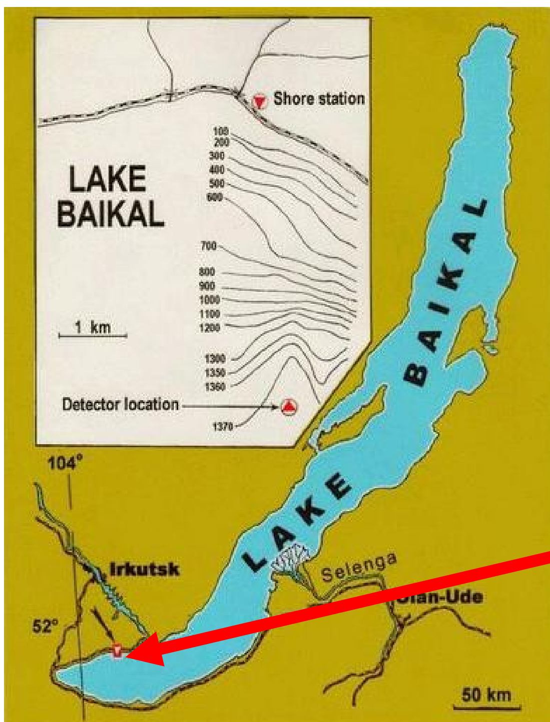
Productivity of the *Aulacoseira baicalensis* in different years

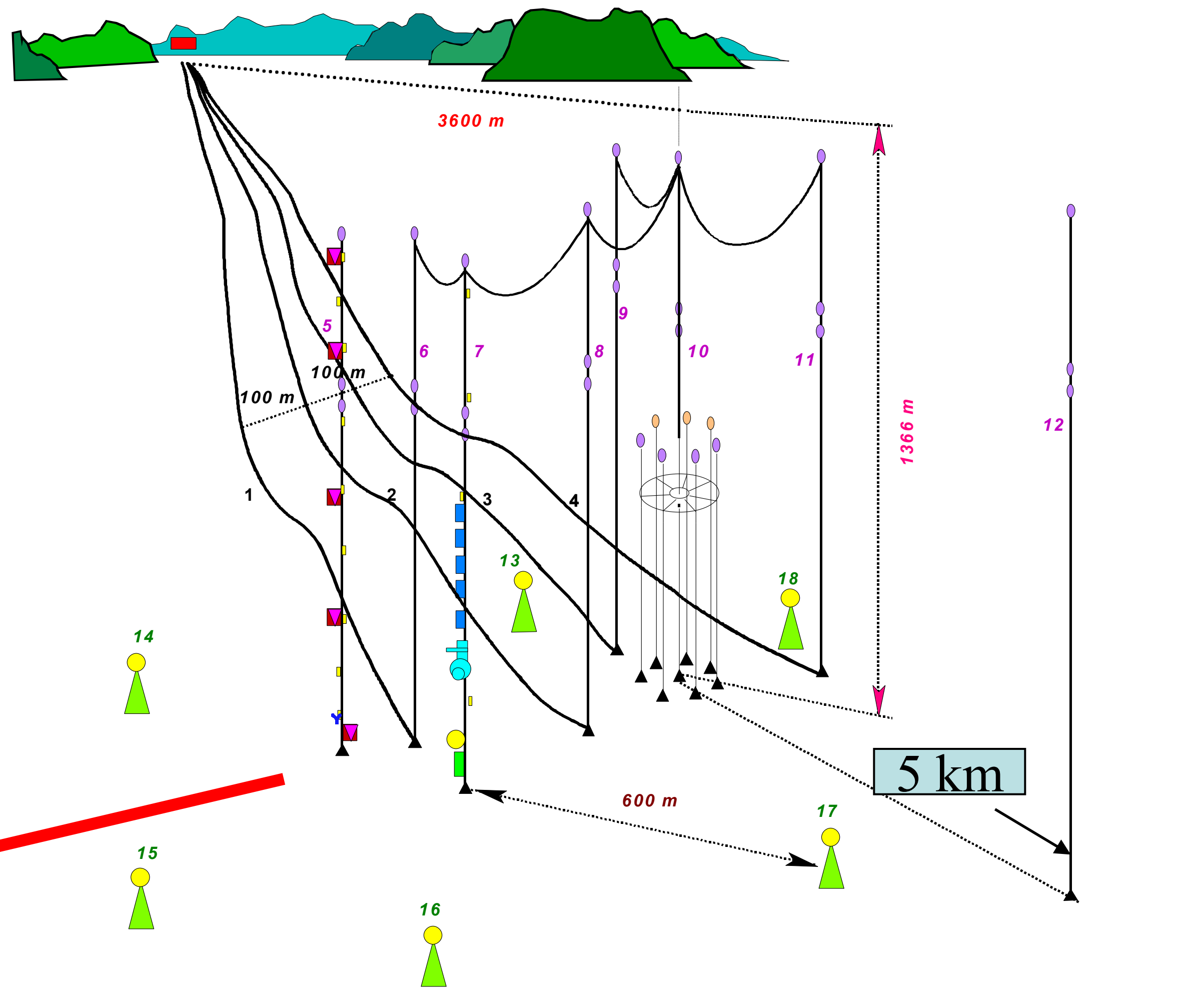


What are the reasons for so large variability of phytoplankton productivity?

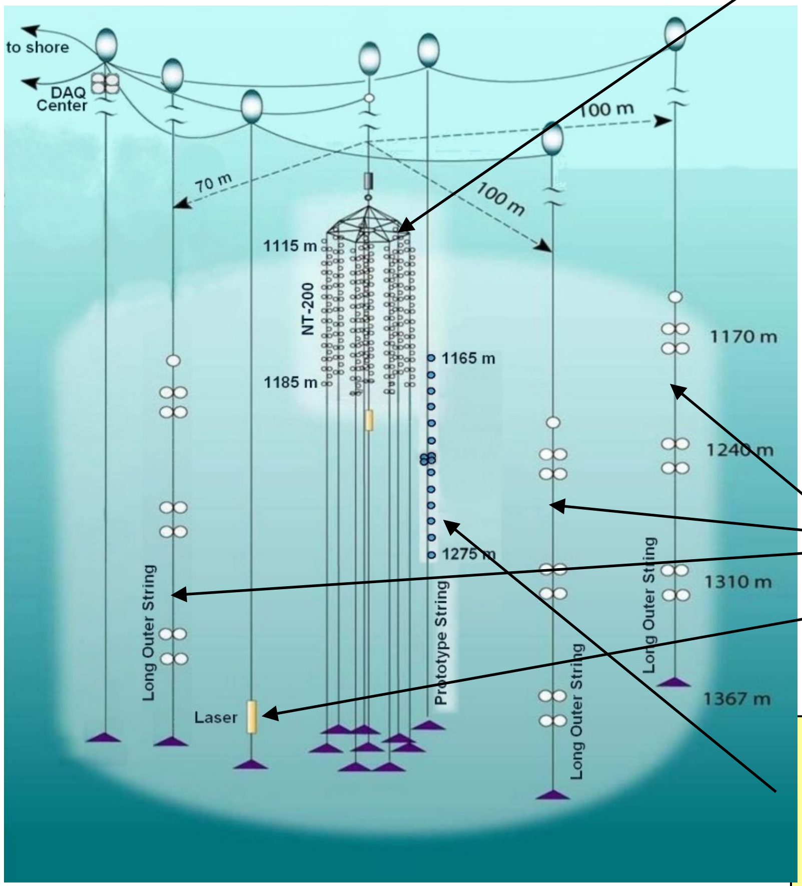
Schematic view on the deep underwater complex of Baikal Neutrino Telescope

10-Neutrino Telescope NT-200
7-hydrophysical mooring
5-sedimentology mooring
12-geophysical mooring
13-18-acoustic transponders
1-4 cable lines





The Baikal Neutrino Telescope



NT200 *running since 1998*

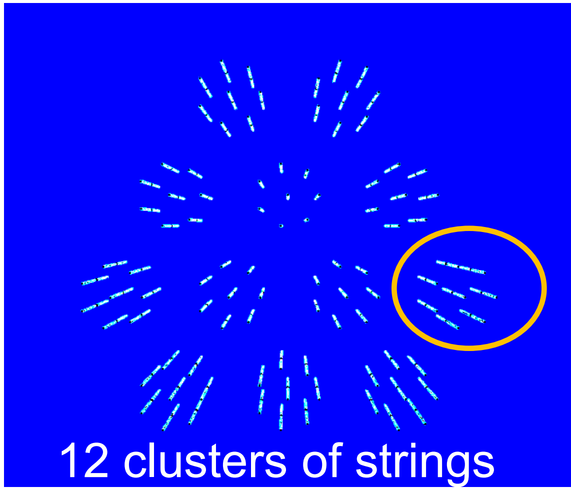
- 8 strings with 192 optical modules
- 72m height, R=20m, 1070m depth, V_{geo}=0.1Mton
- μ effective area: >2000 m² (E_μ>1 TeV)
- Shower Eff Volume: ~1 Mton at 1 PeV

NT200+ *commissioned April, 2005*

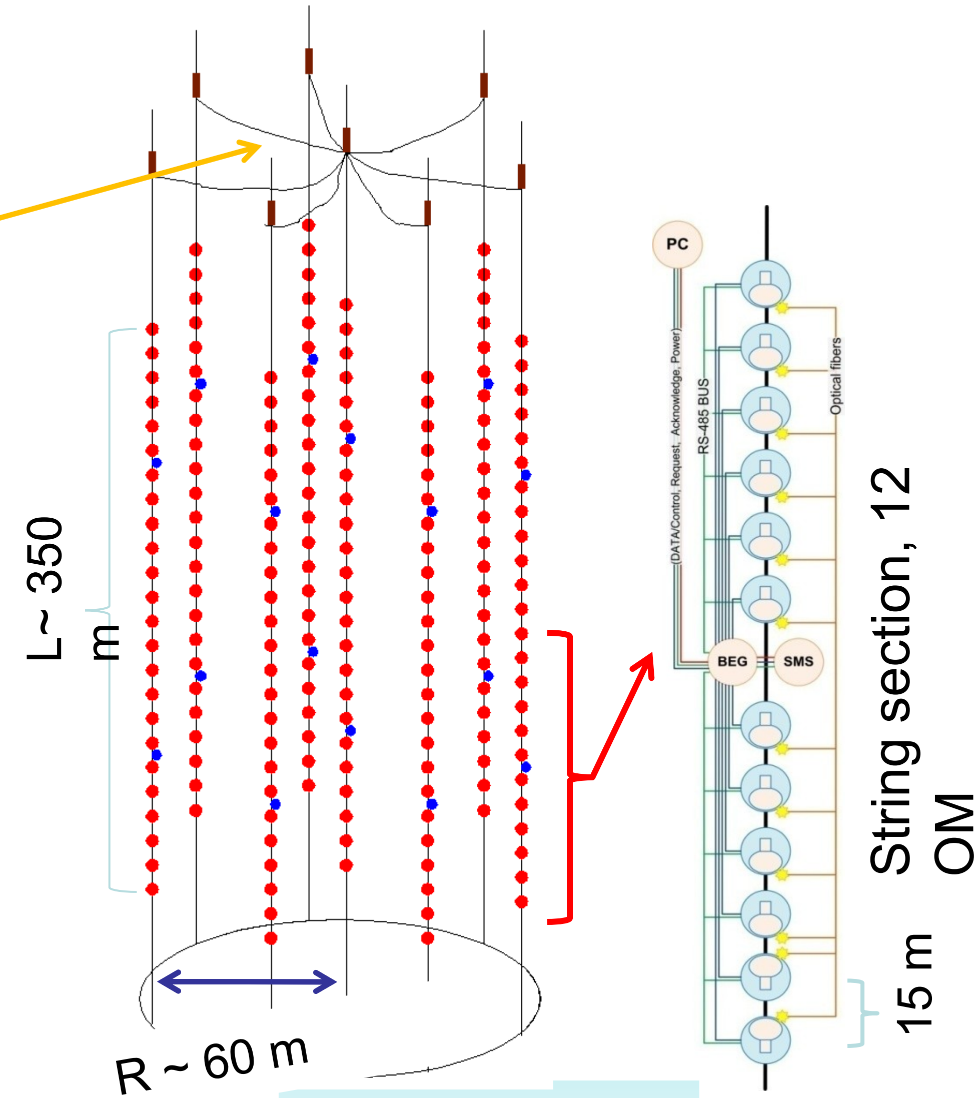
- 3 new strings, 200 m height, 36 OMs
- 1 new bright Laser for time calibration

Experimental string of BAIKAL - GVD (km3 scale telescope) R&D since 2008, deployment 2012 - 2017

BAIKAL - GVD
–the km3-scale Baikal detector



Top view



Cluster of strings

Layout:

~2300 Optical Modules at 96 Strings

String: 24 OM → 2 Sections with 12 OM

Strings are combined in Clusters → 8 strings

Cascades (E>100 TeV): V_{eff} ~0.3–0.8 km^3

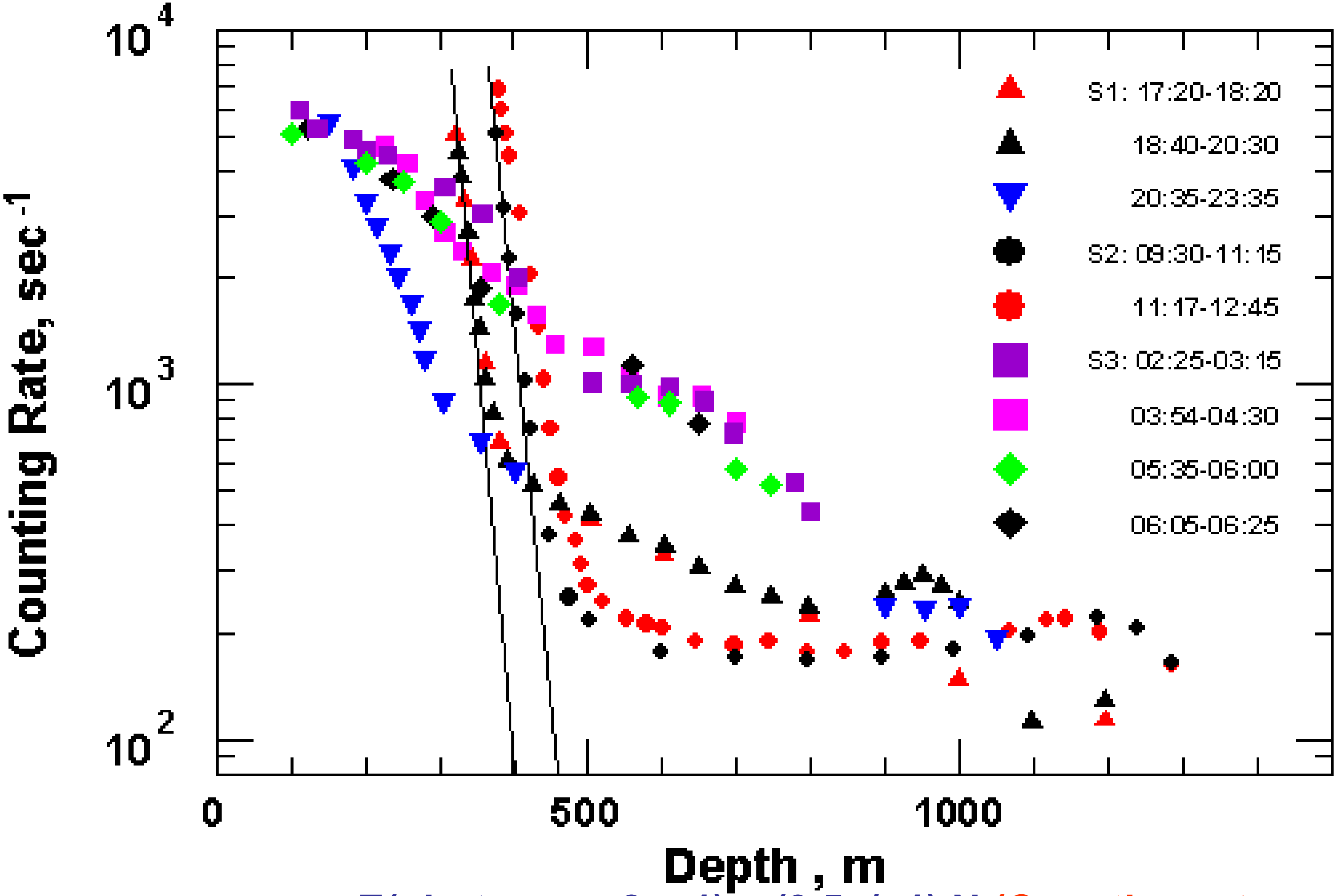
δ(lgE) ~0.1, $\delta\theta_{med}$~ 2°- 4°

Muons (E>10 TeV): S_{eff} ~ 0.2 – 0.5 km^2

$\delta\theta_{med}$~ 0.5°-1°

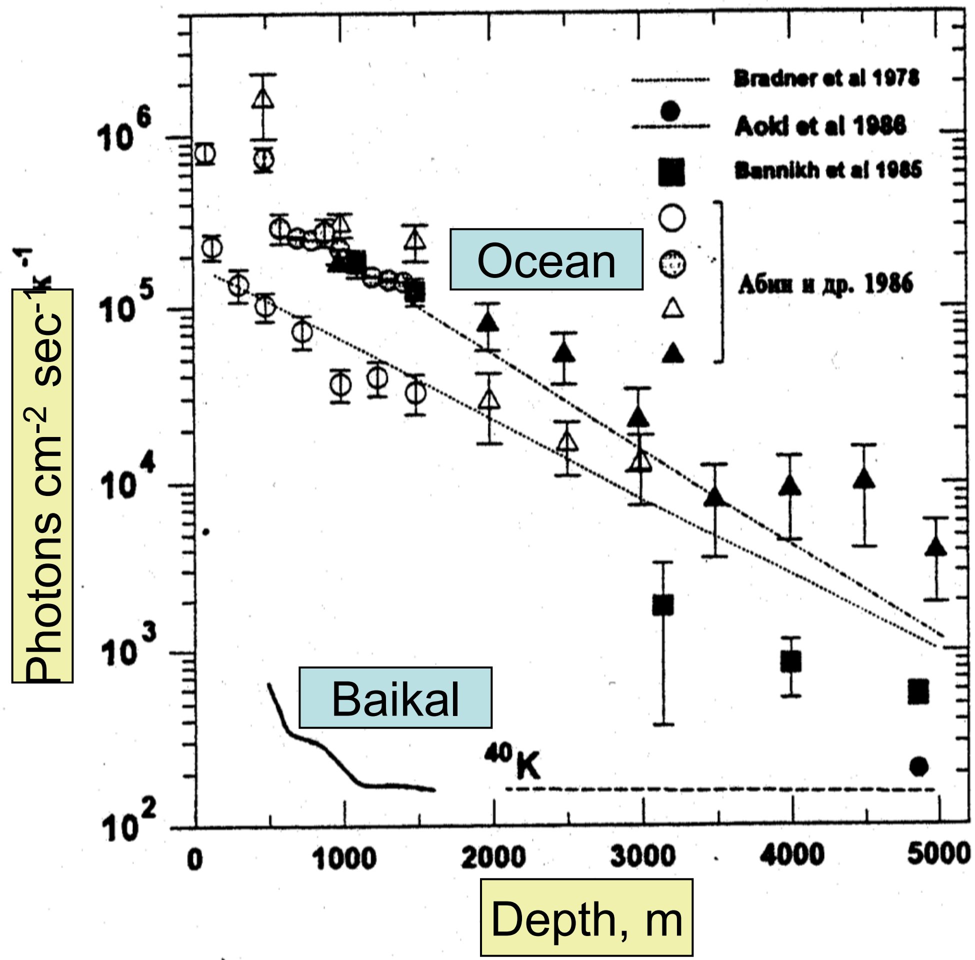
Environmental Studies in the framework of Baikal Neutrino Project

Light field in South Basin of Lake Baikal



E(photon cm-2 s-1) = (3.5+/- 1) N (Counting rate of FEU-130, diameter 3 cm)

Luminescence in ocean and Baikal water (1982 year)



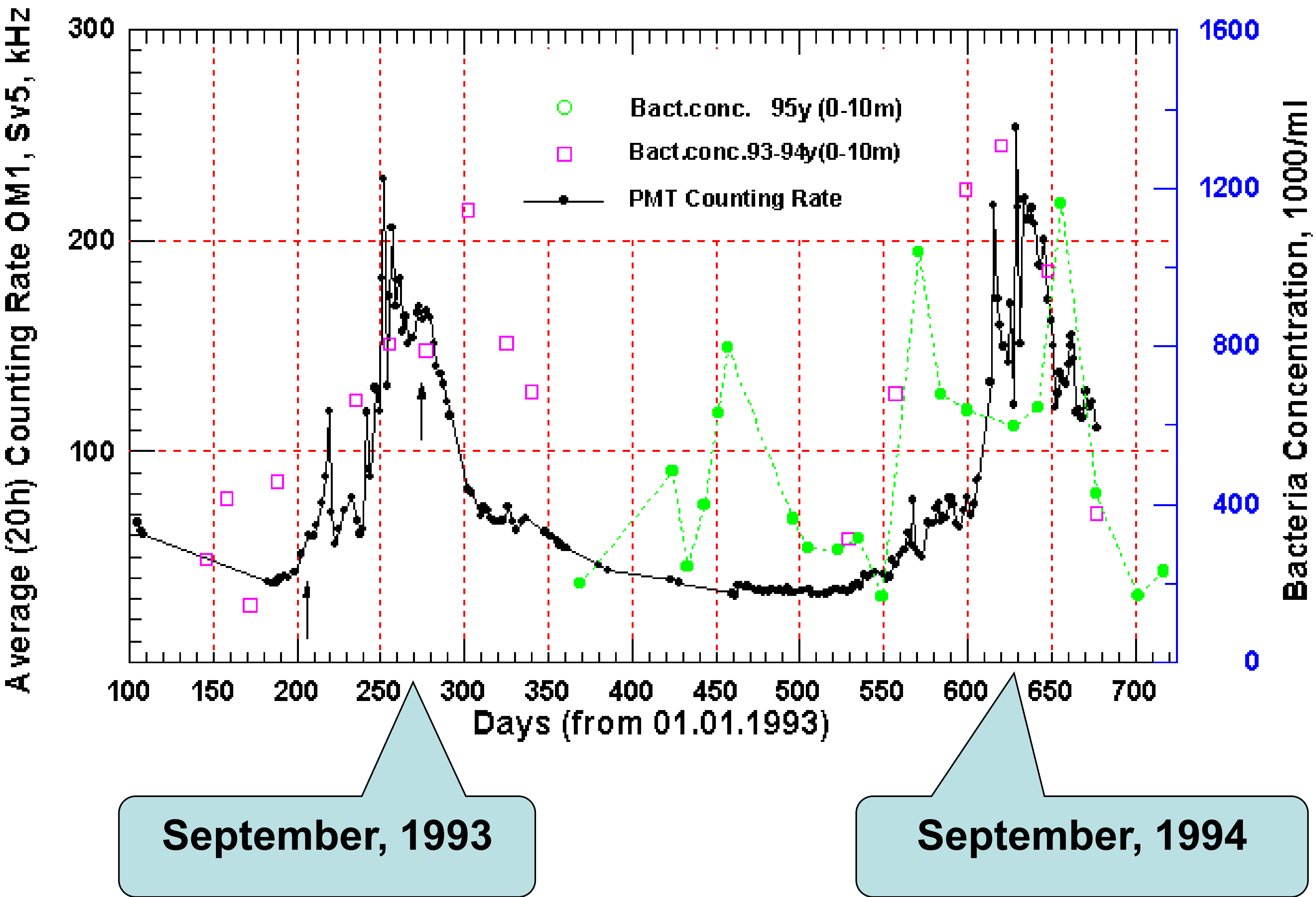
At large depth a luminescence of Baikal water have the same amount as a contribution of K^{40} decays in a light field in sea water

Water luminescence as a tool to study dynamical phenomena in Baikal water

- The luminescence is a result of oxidization of organic material (chemiluminescence).
- The luminescence matter is produced by biology at shallow depth and then transported to deep layers by water currents, turbulence and due to sedimentation, at the same time matter loses its ability to luminescence .
- **The luminescence is a natural indicator of the development of the hydrobiological and hydrophysical phenomena in Lake Baikal.**
- **Photosensors of the Baikal Neutrino Telescope are suited to record these light fields**

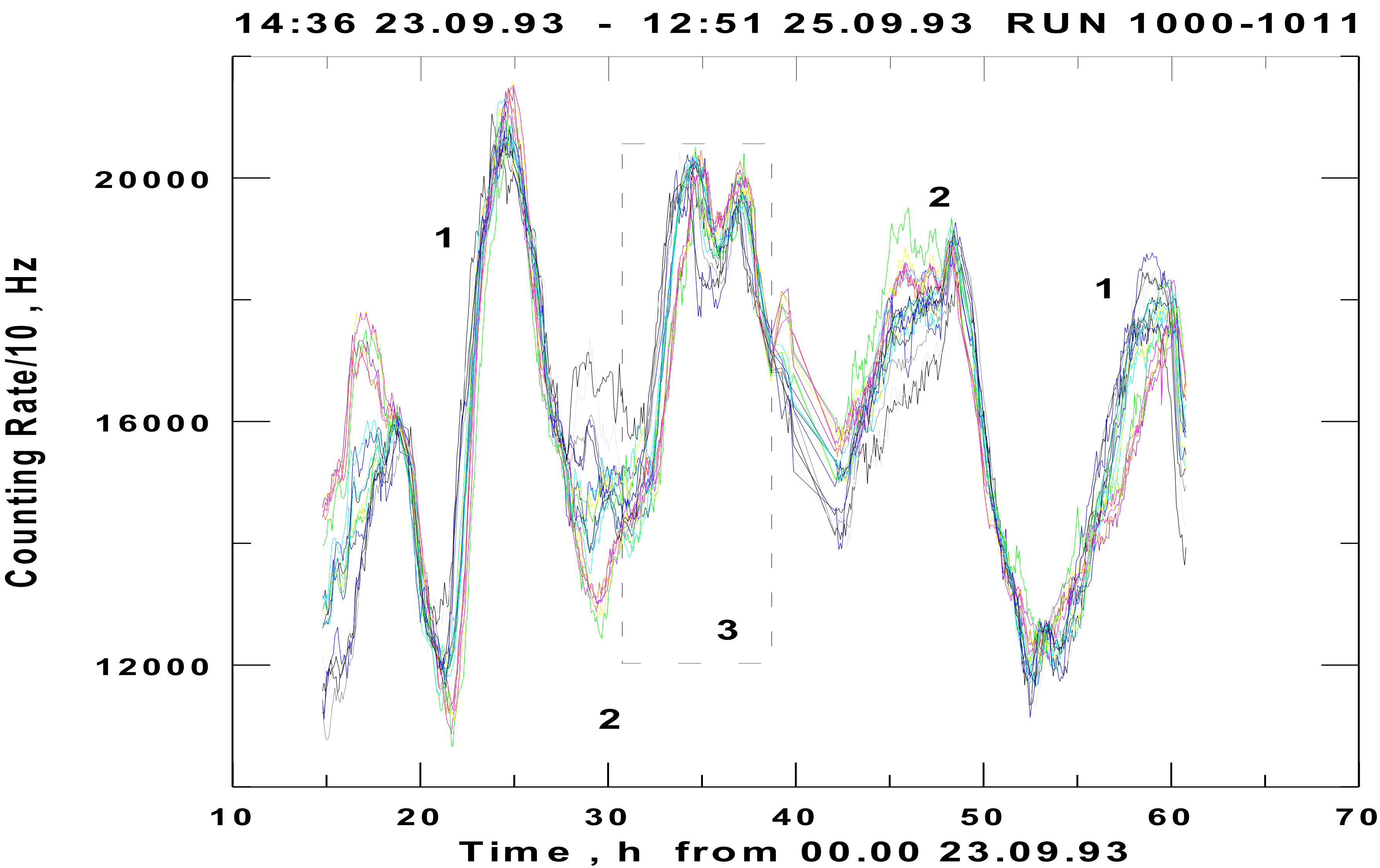
Seasonal variations of Light field:

Counting rate of an optical module of NT-200 in 1993 -1994.



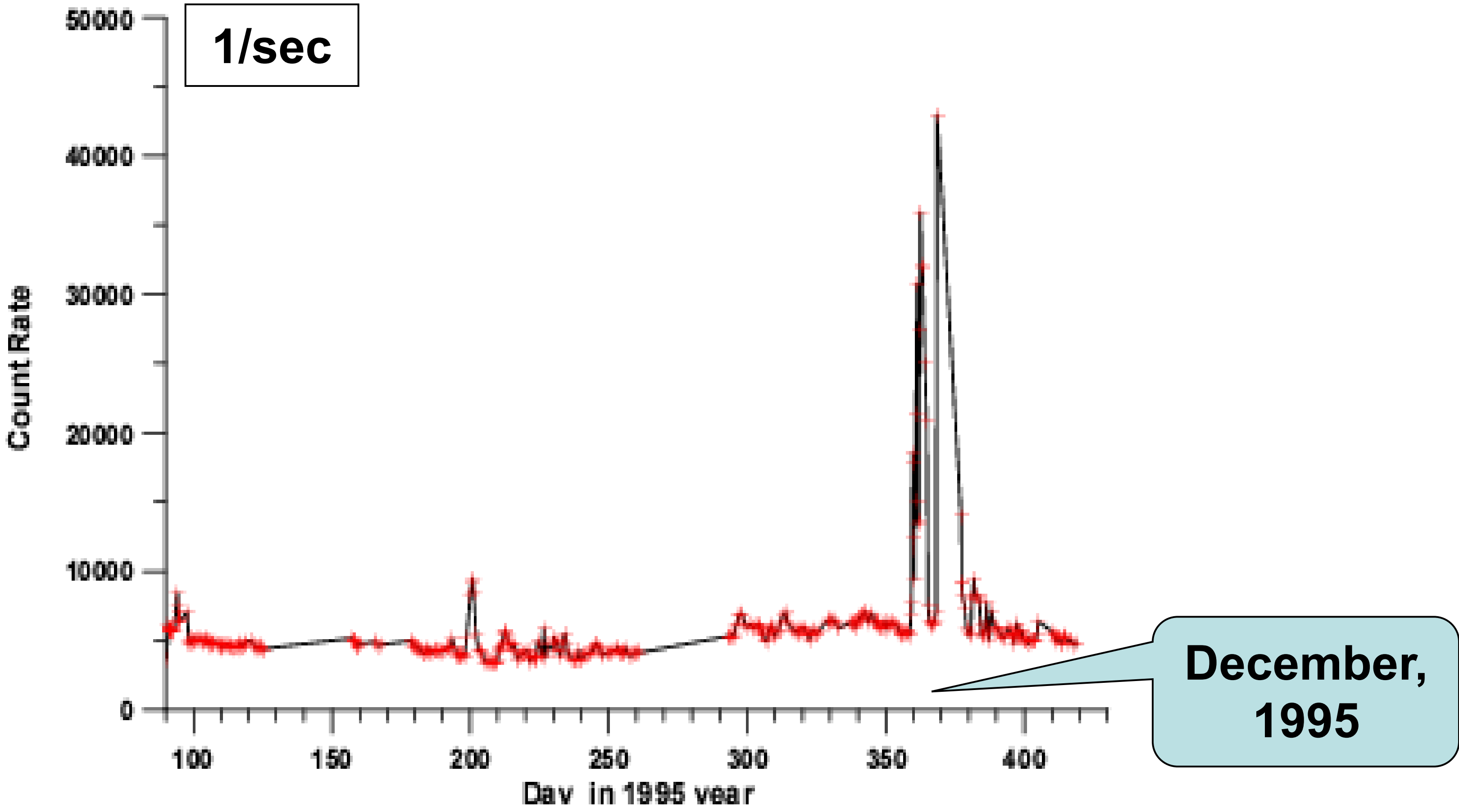
Large variations of Light field:

Counting rate of the 19 optical modules of NT-200 in September 1993.



Seasonal variations of Light field:

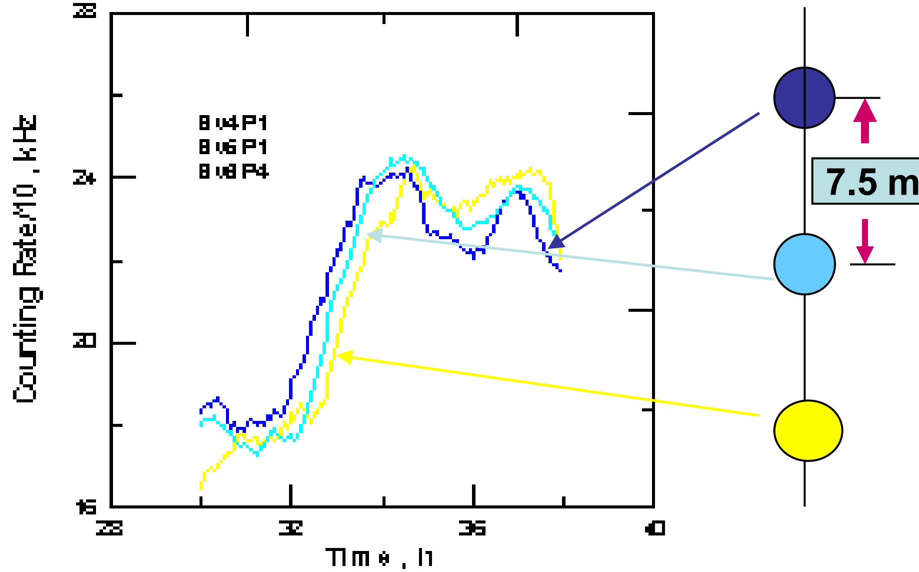
Counting rate of an optical module of NT-200 in 1995



The luminescence is a natural indicator of hydrobiological and hydrophysical activities in Lake Baikal.

High-speed vertical water motion.

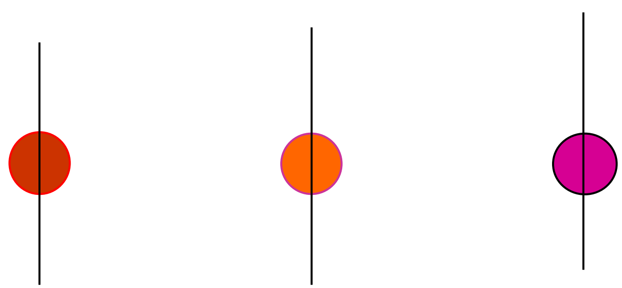
- Counting rate of the 3 optical modules of NT-200 situated
- on the same vertical string

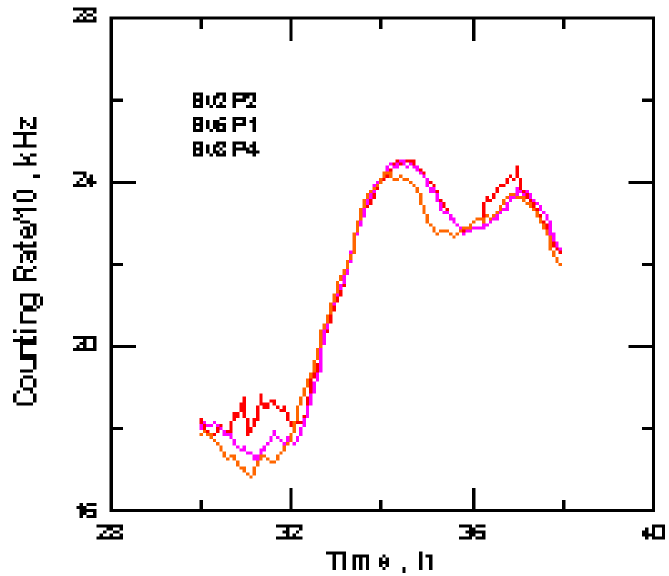


- $V_{vert} = 2$ cm/s !

Counting rate of the 3 optical modules of NT-200 situated

- on the same depth on the different strings





Interdisciplinary environmental studies in framework Baikal Neutrino Project

- Hydro-physical processes of water circulation in lake Baikal (vertical and horizontal water exchange)
- Biorhythm and biological productivity (time dependence and space distributions of species composition and concentration of dissolved and suspended organic materials)
- Global climate changes and it influence on lake Baikal ecosystem (trends of physical and biological parameters of Baikal water)
- Geophysical phenomena (study of different dynamic phenomena, search for Foreshocks of Earthquake)
- …

The instruments and methods

- **Ice as stable platform for deployment**
- 3 - dimensional monitoring of the water luminescence
- 3 - dimensional temperature monitoring
- Long-term optical monitoring
- Long-term long base monitoring of Earth electromagnetic field.
- 3 – dimensional acoustic tomography
- Sedimentology study
- …

The instruments and methods

- **Ice as stable platform for deployment**
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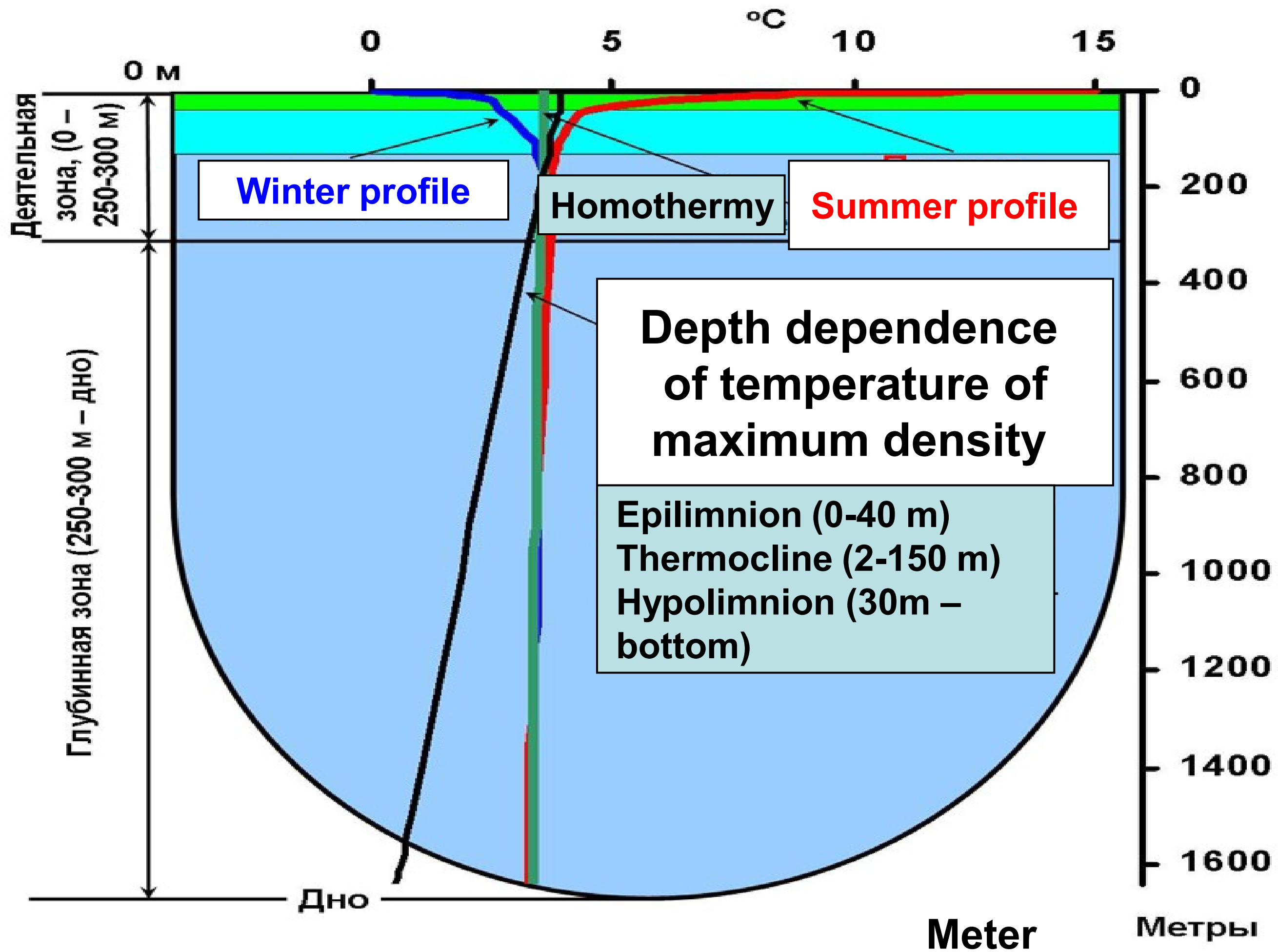
Hydro-physical processes and temperature regime of water body studies.

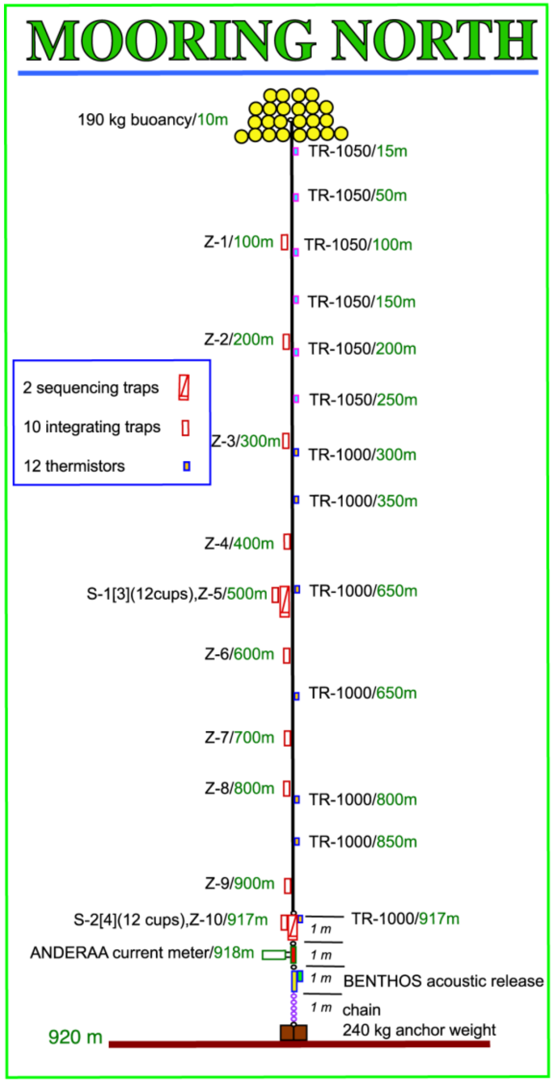
Specific temperature depth dependence in Lake Baikal as primary cause for high vertical water transfer activity.

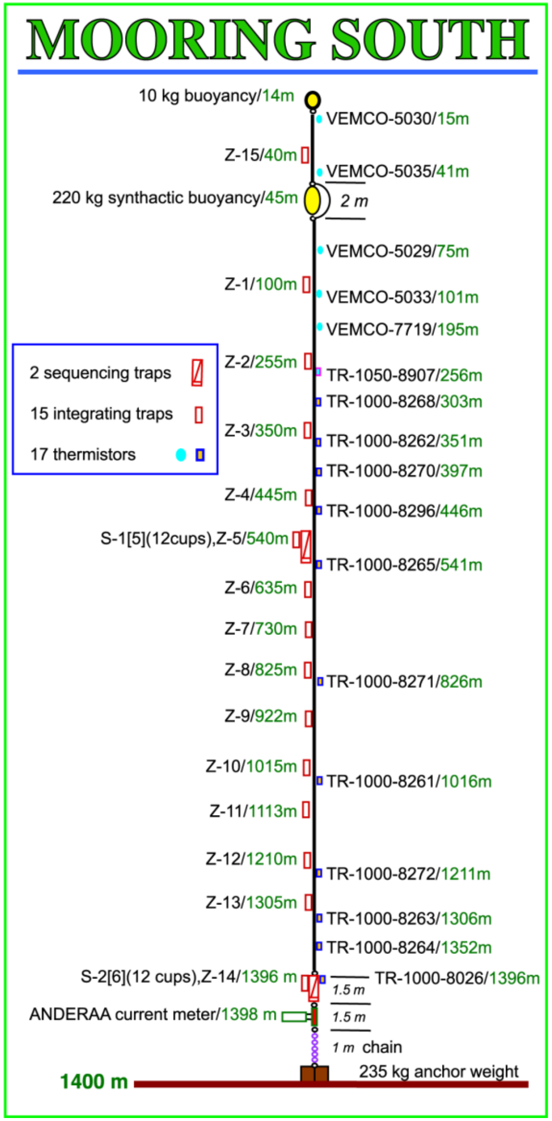
Hydro-physical processes of water circulation in Baikal are essential for oxygenation and for nutrients, organics and admixtures transfer. That's why hydro-physical processes have a considerable influence on ecosystems of the Lake.



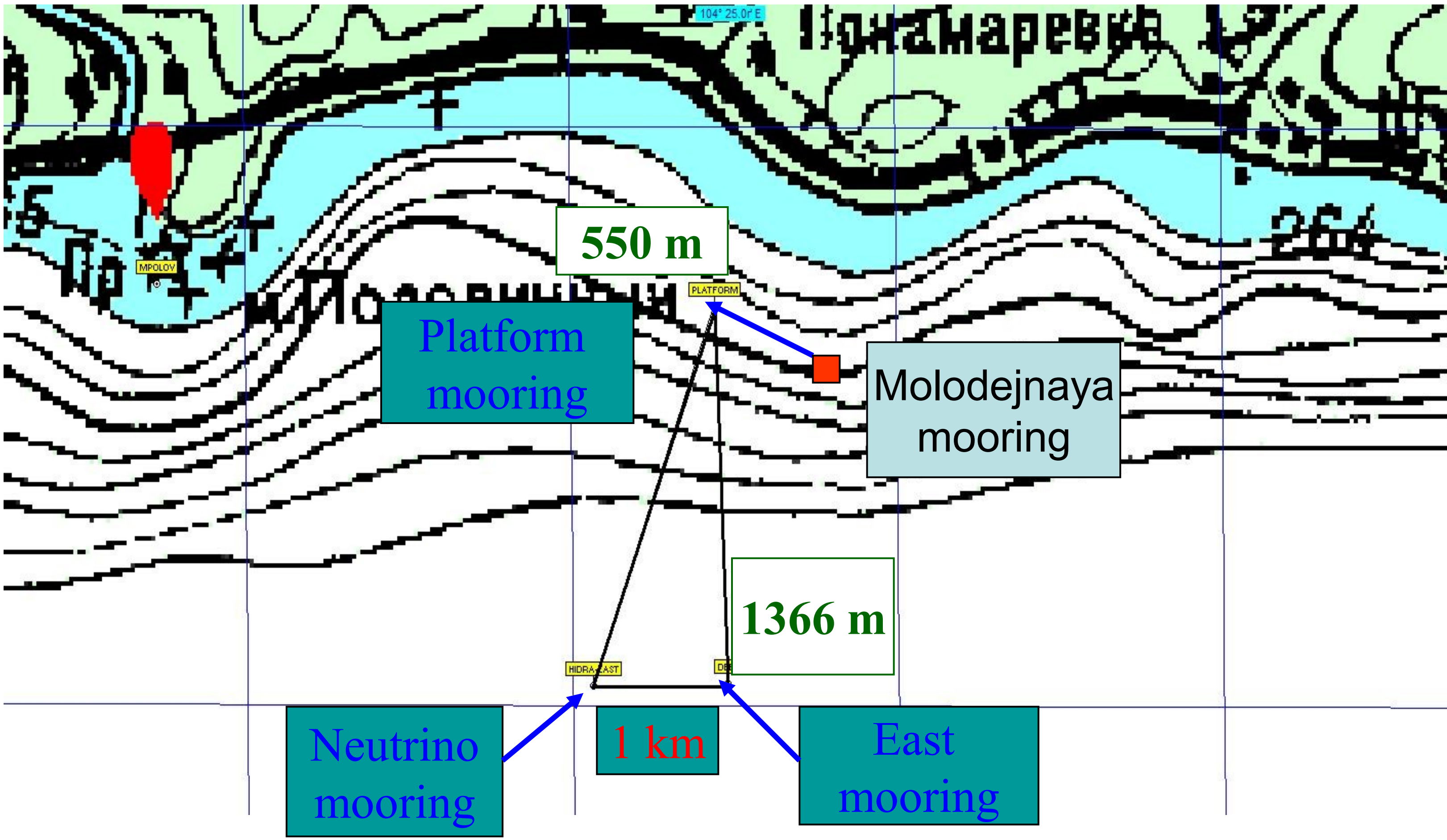
$$T_{MD} = 3.9839 - 1.9911 \cdot 10^{-2} \cdot P - 5.822 \cdot 10^{-6} \cdot P^2 - (0.2219 + 1.106 \cdot 10^{-4} \cdot P) \cdot S$$

Instrumental moorings for environmental studies (in co-operation with EAWAG)

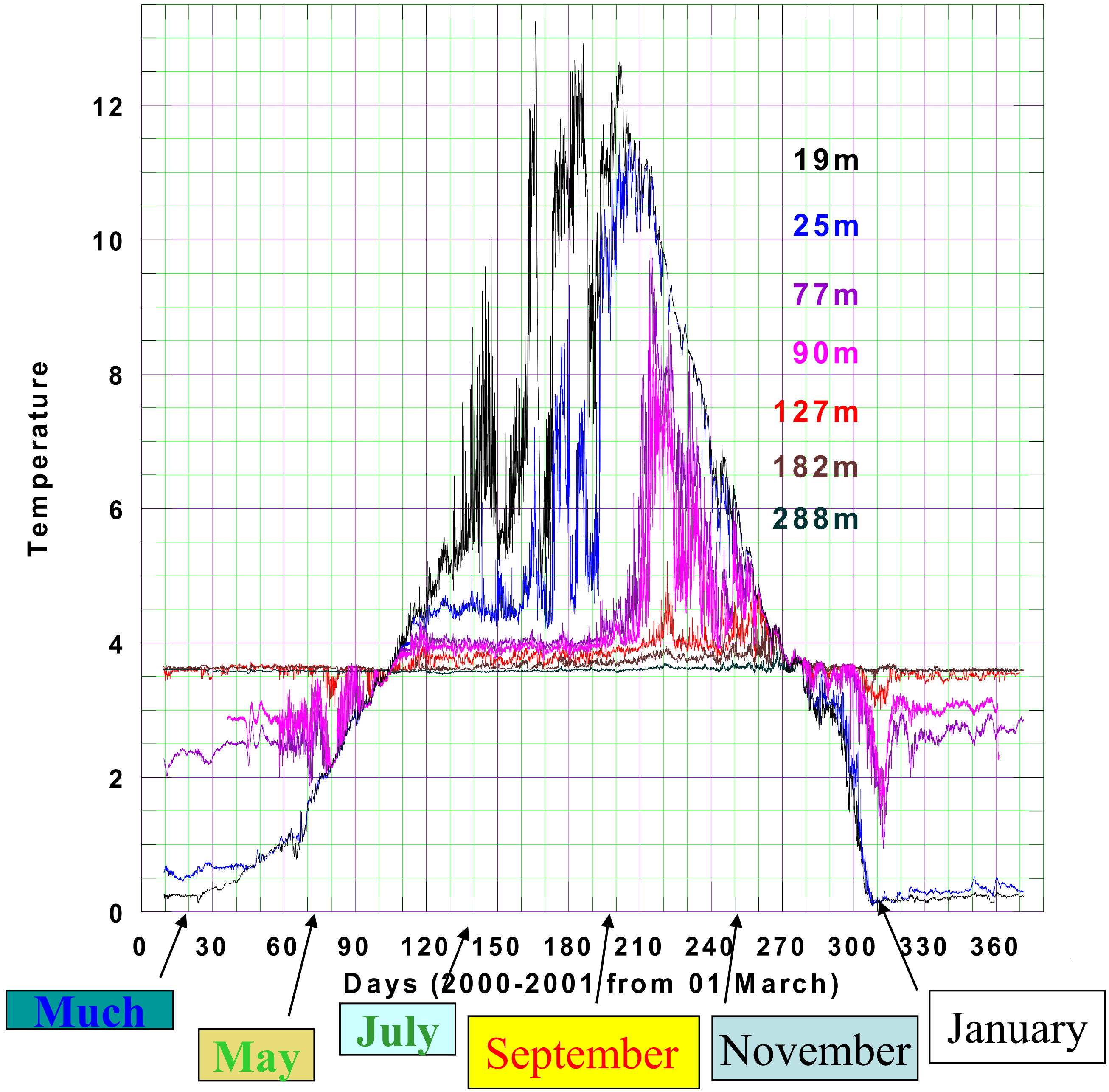




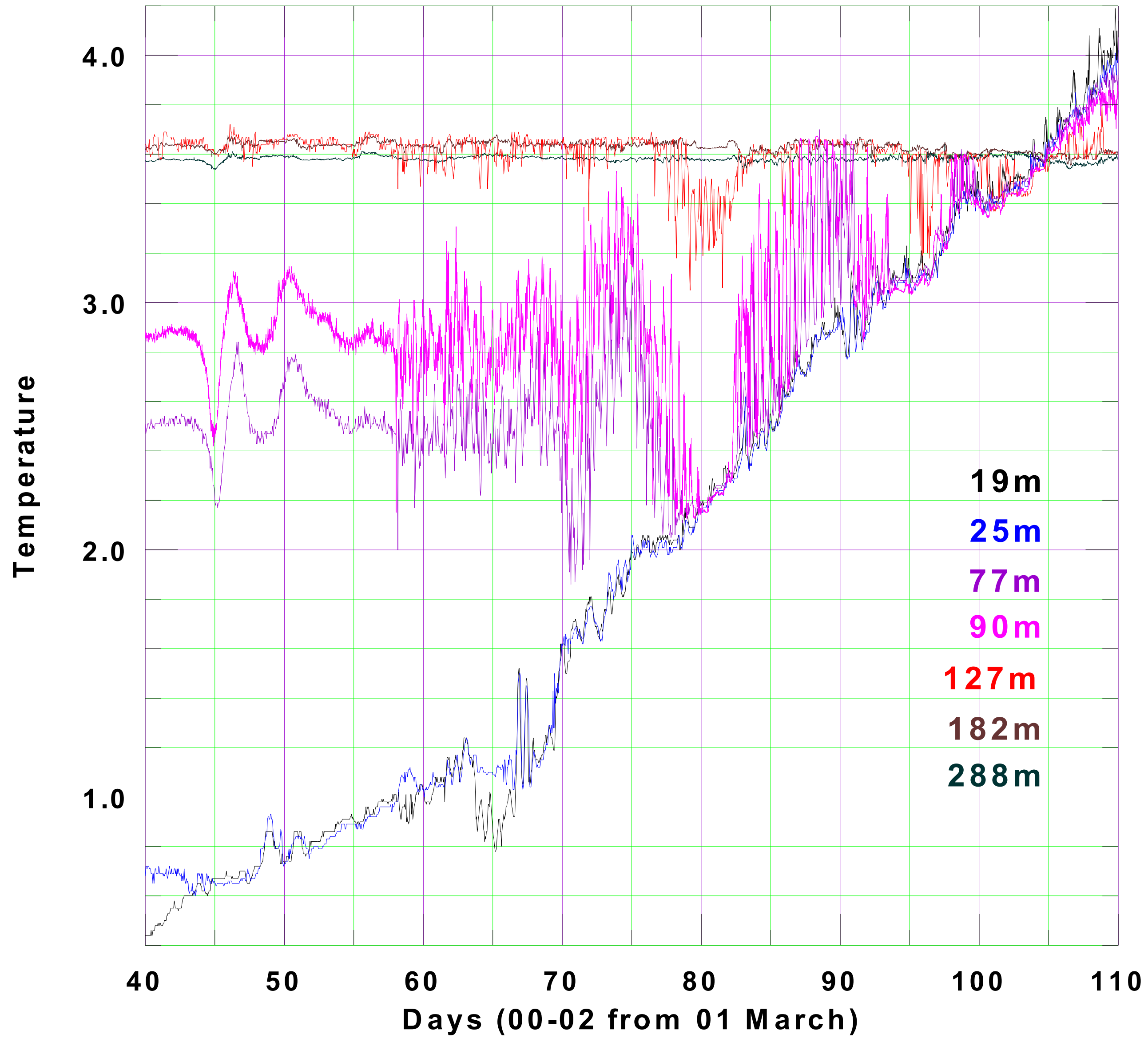
Three-dimensional long-term temperature monitoring



The temperature in the near-surface zone

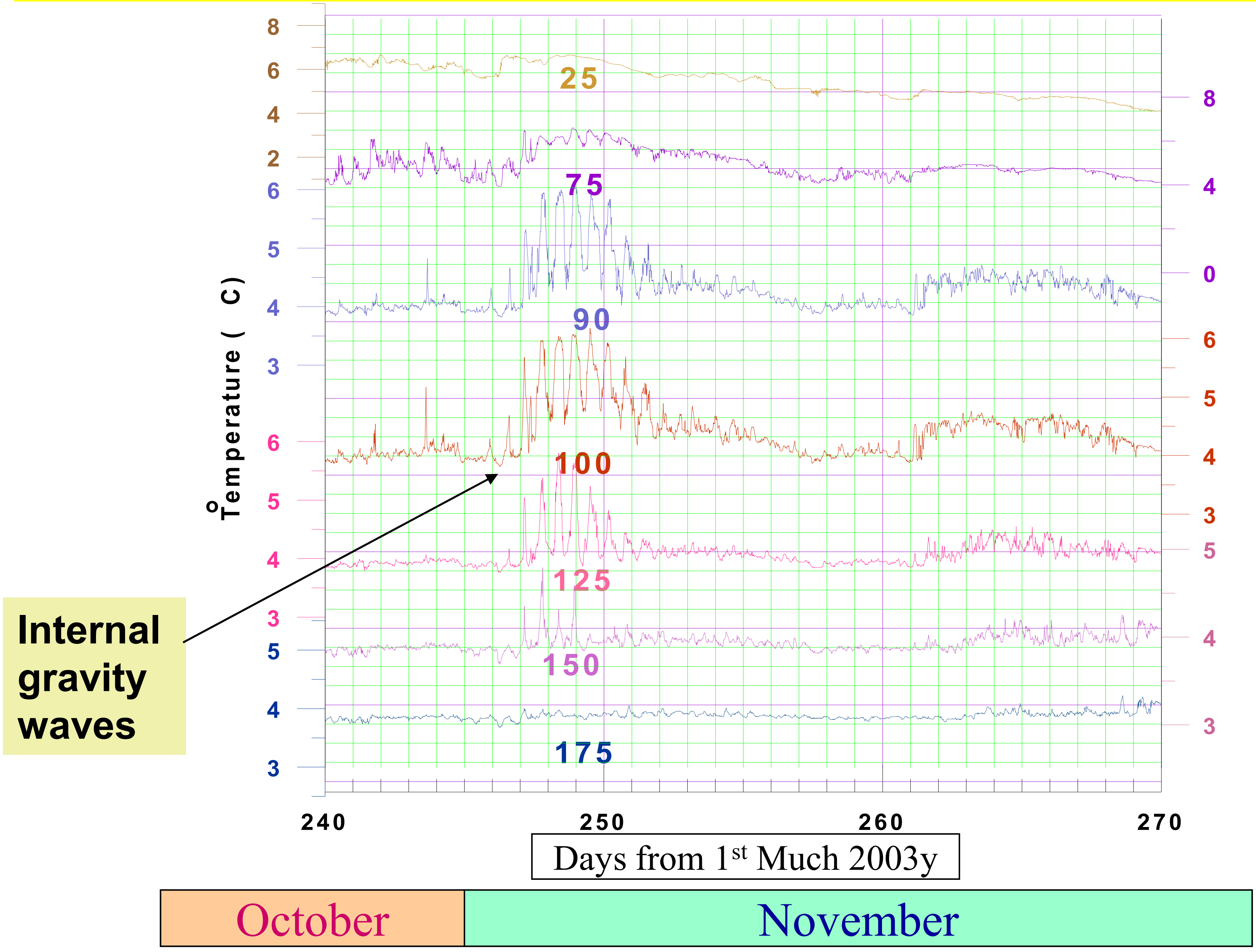


Inertial waves excitation in spring

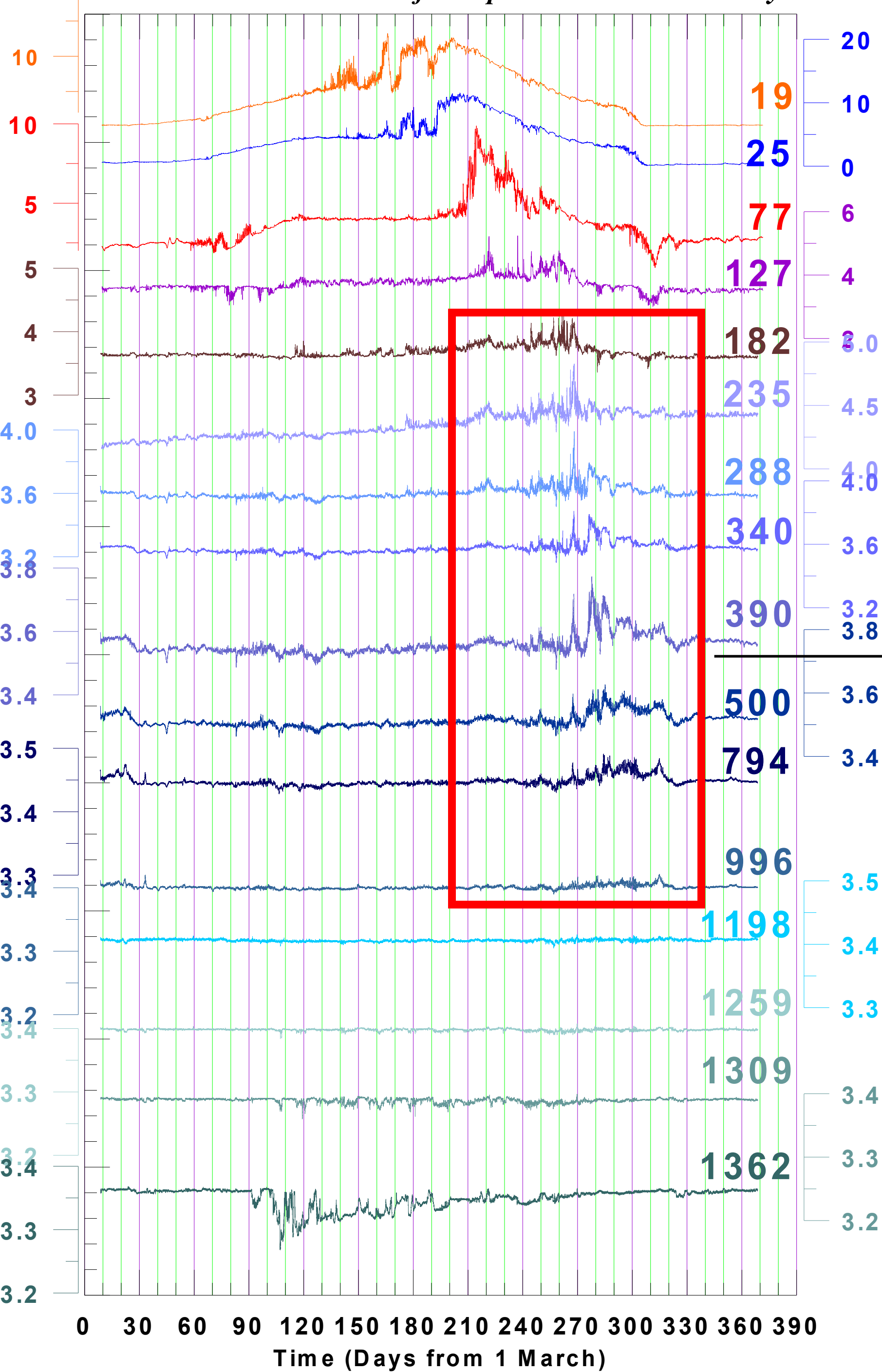


May

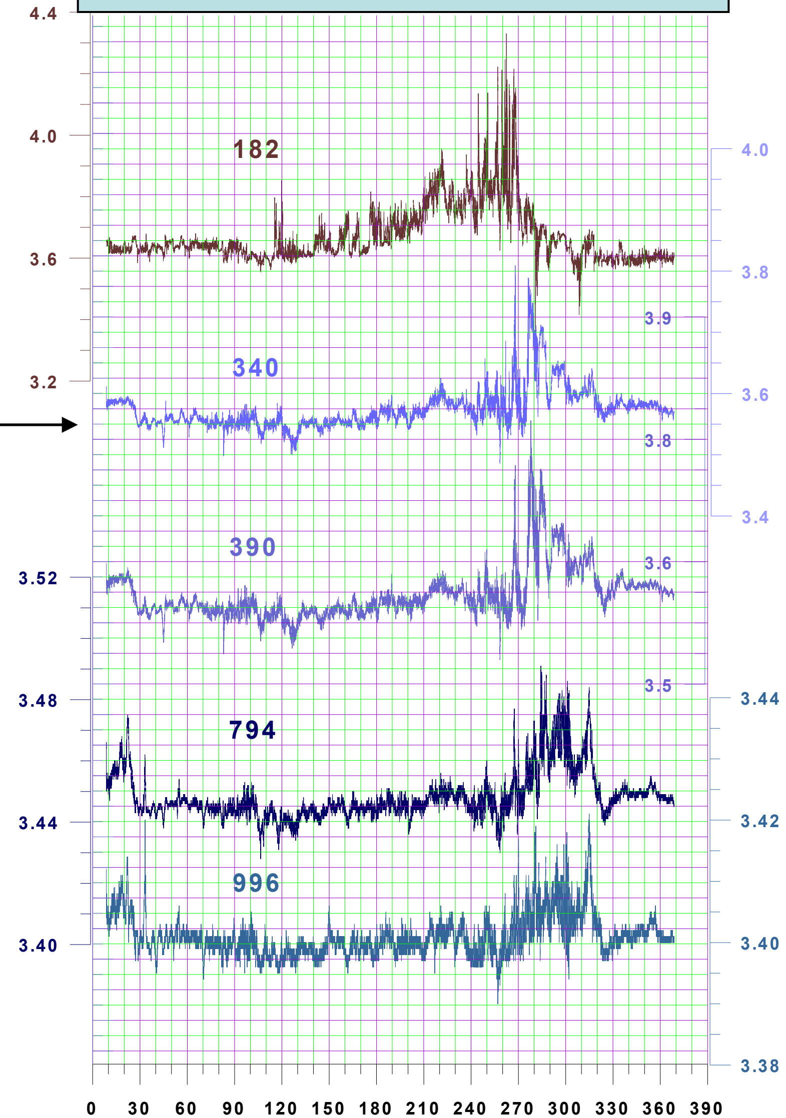
Inertial gravity waves excitation in autumn

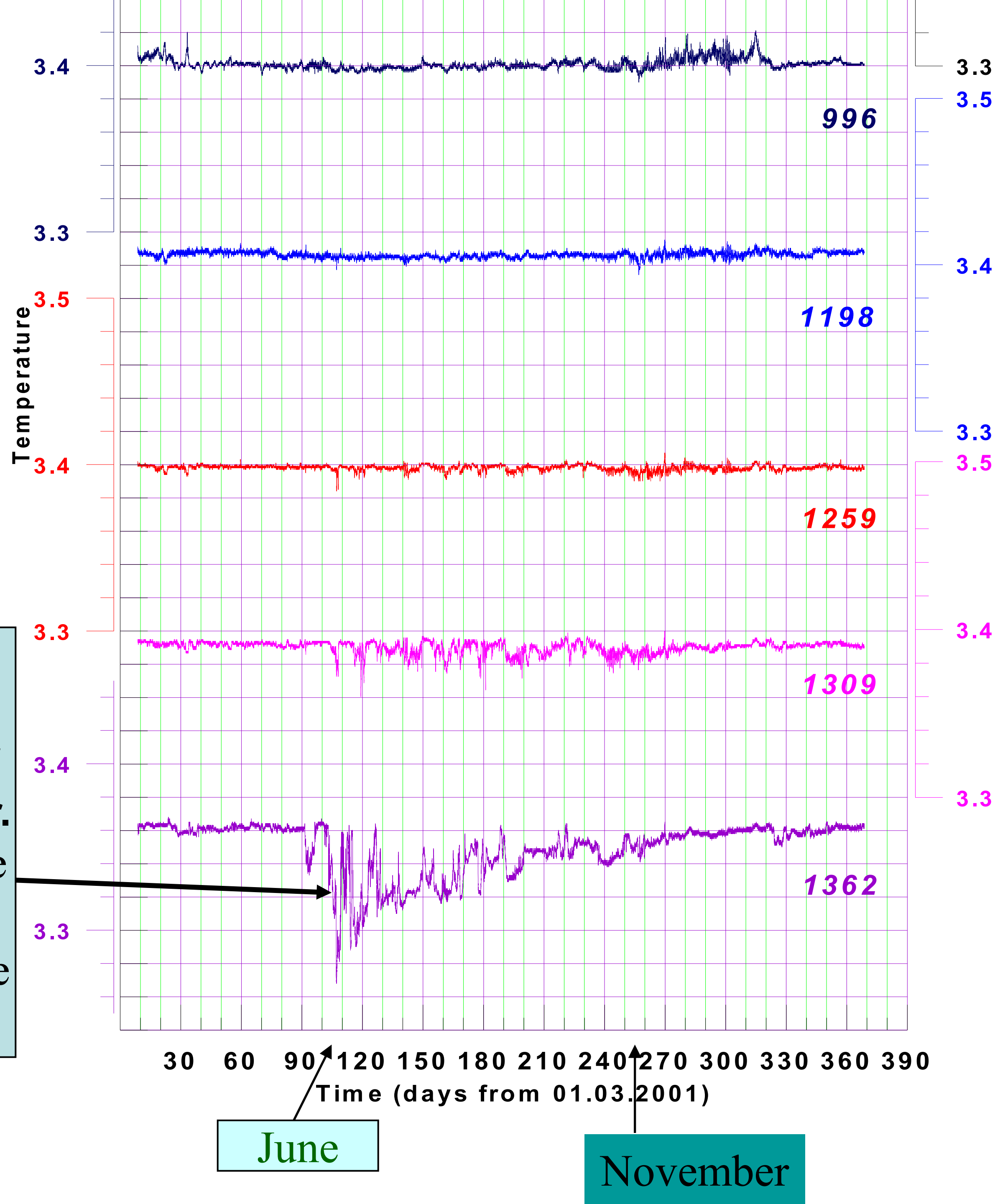


Vertical destribution of temperature 2000-2001y



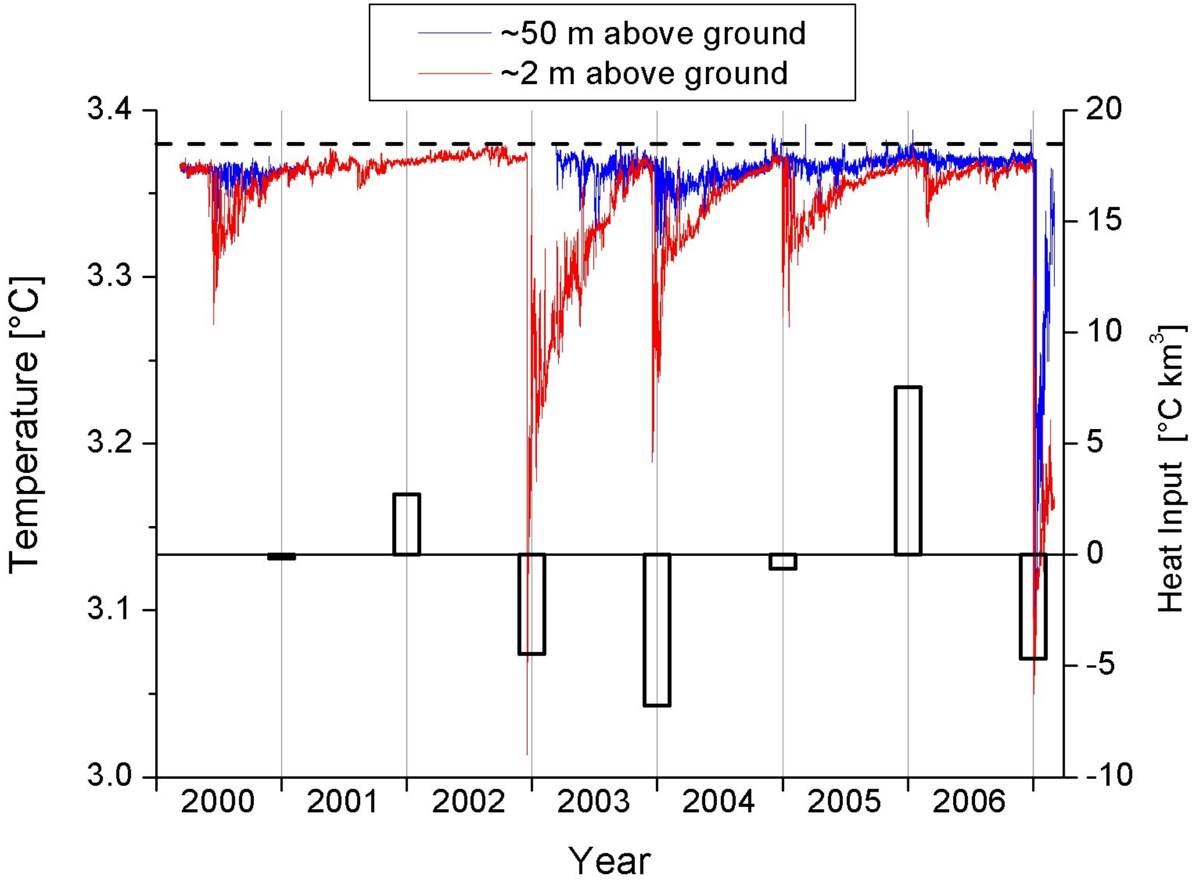
Powerful intrusion of "warm" water



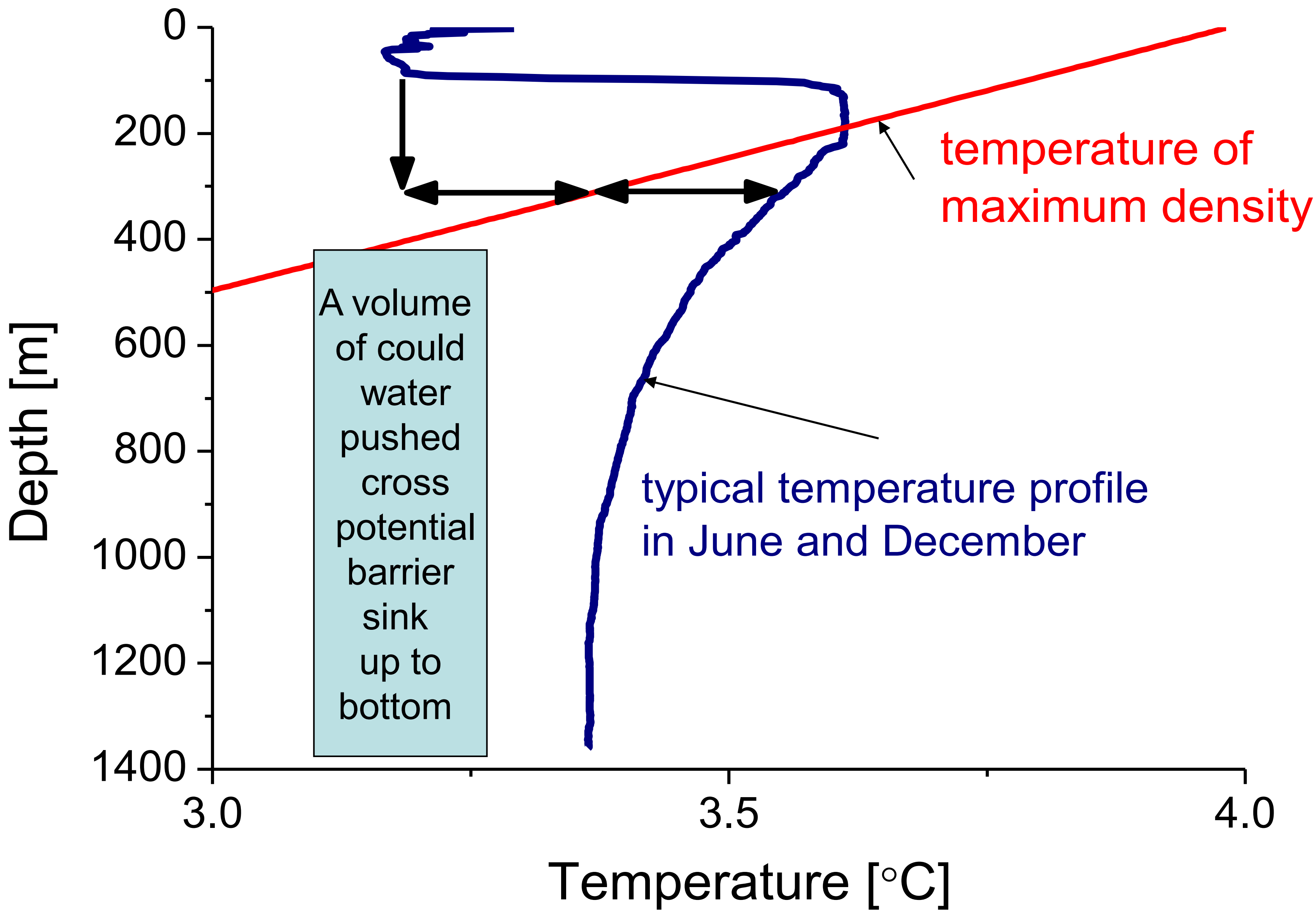


Powerful intrusion of could water.
Temperature decreased by 0.1 degree

Observed temperatures 2 m and 50 m above the bottom from March 2000 to March 2007.



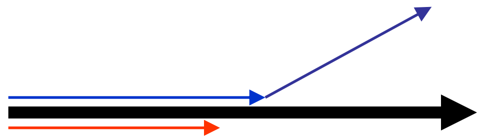
The horizontal dashed line indicates the background temperature of 3.38 °C. The vertical bars show the change in the heat content (given as the product of temperature and volume) between 1300 and 1400 m depth from October to March



0
200
400
600
800
1000
1200
1400
Depth [m]
3.0
3.5
4.0
Temperature [°C]
temperature of maximum density
typical temperature profile in June and December
A volume of could water pushed cross potential barrier sink up to bottom

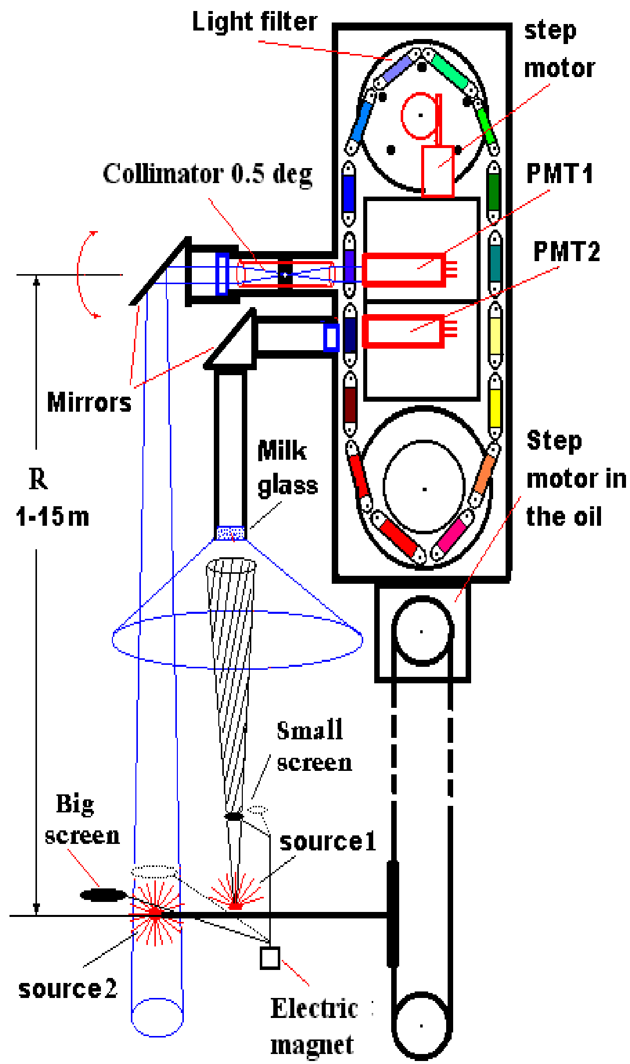
- Long-term optical monitoring

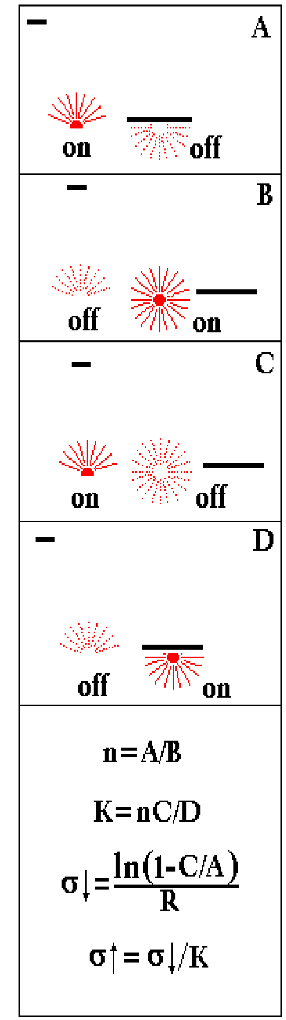
Optical water properties - long term investigations



$$E(x) = E_0 \exp[-(a+b)x]$$

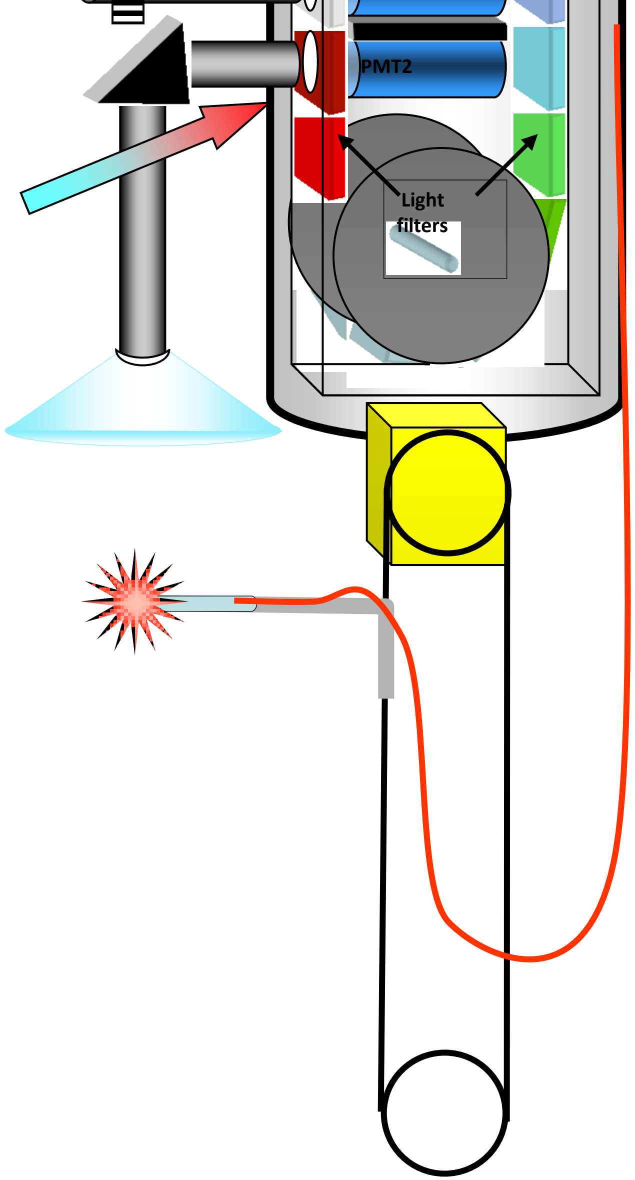
- E – photon flux
- a – absorption coefficient (depend on concentration of dissolved matter),
- b – scattering coefficient (depend on concentration of suspended matter),

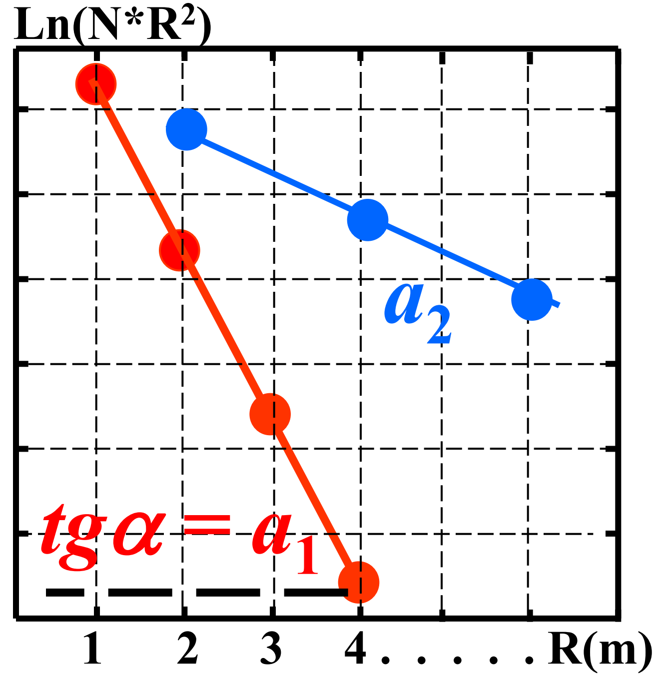


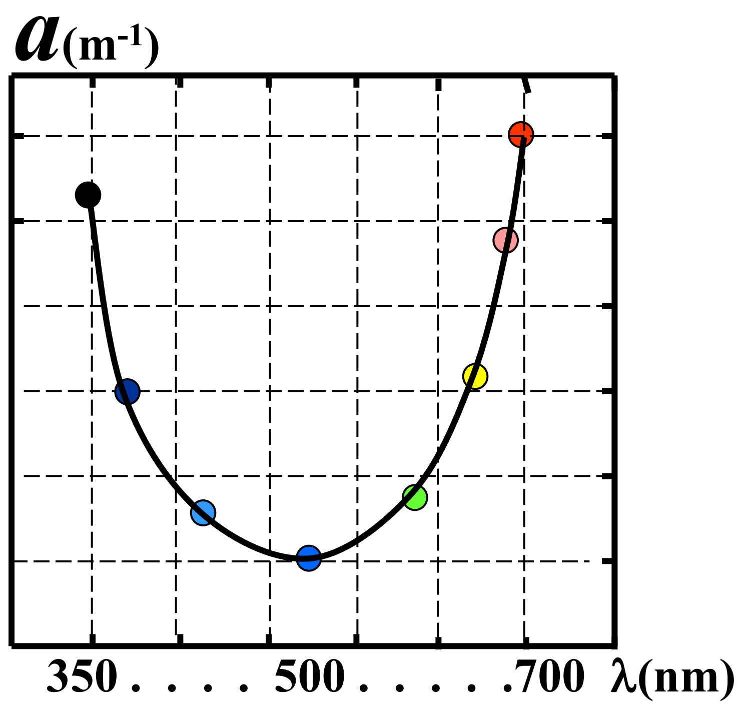


Absorption spectra

$a(\lambda)$

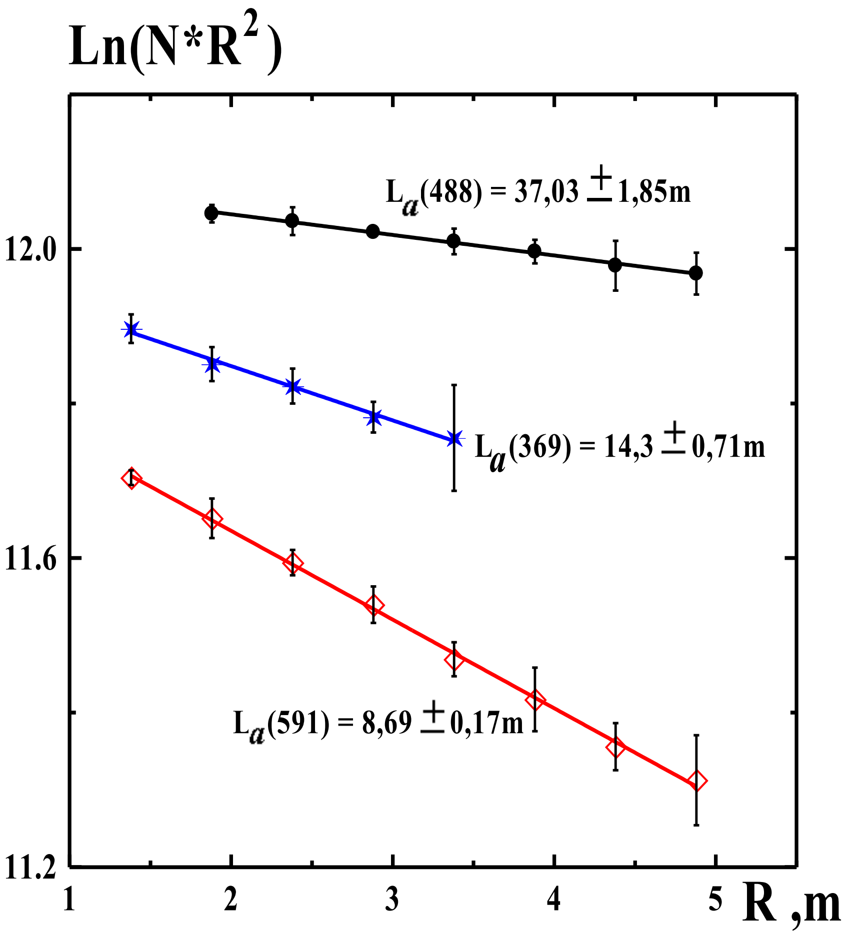






$$N(R) \sim N_0 \exp\left(- a\, x\right)/R^2$$

Absorption



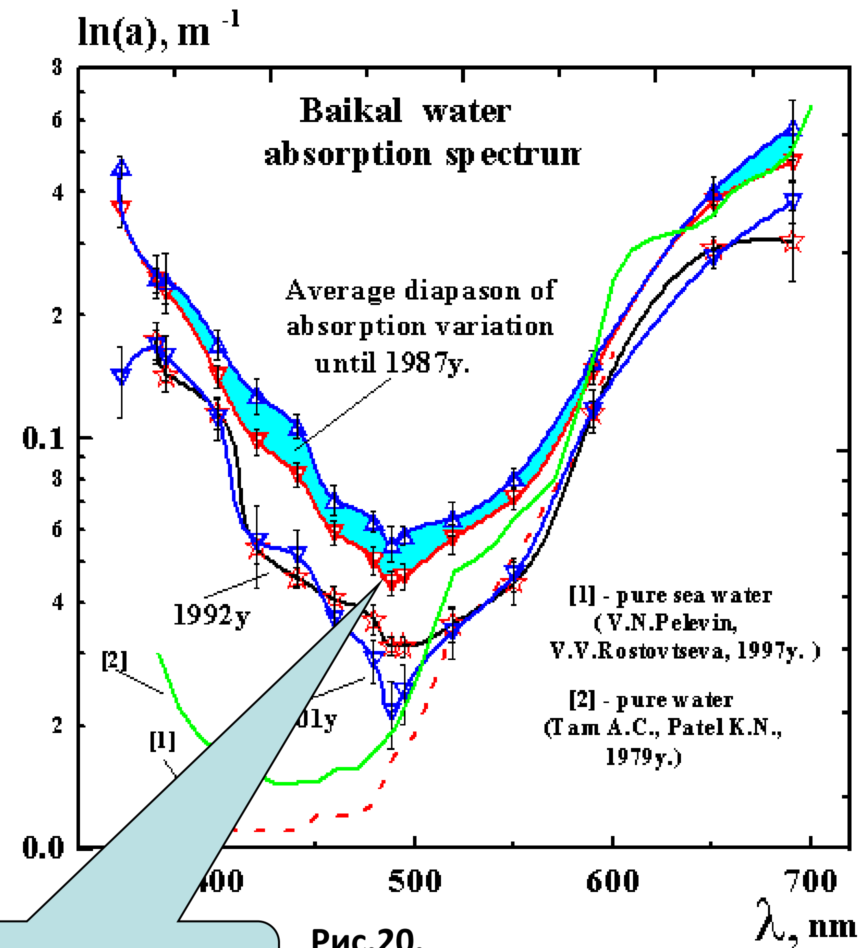
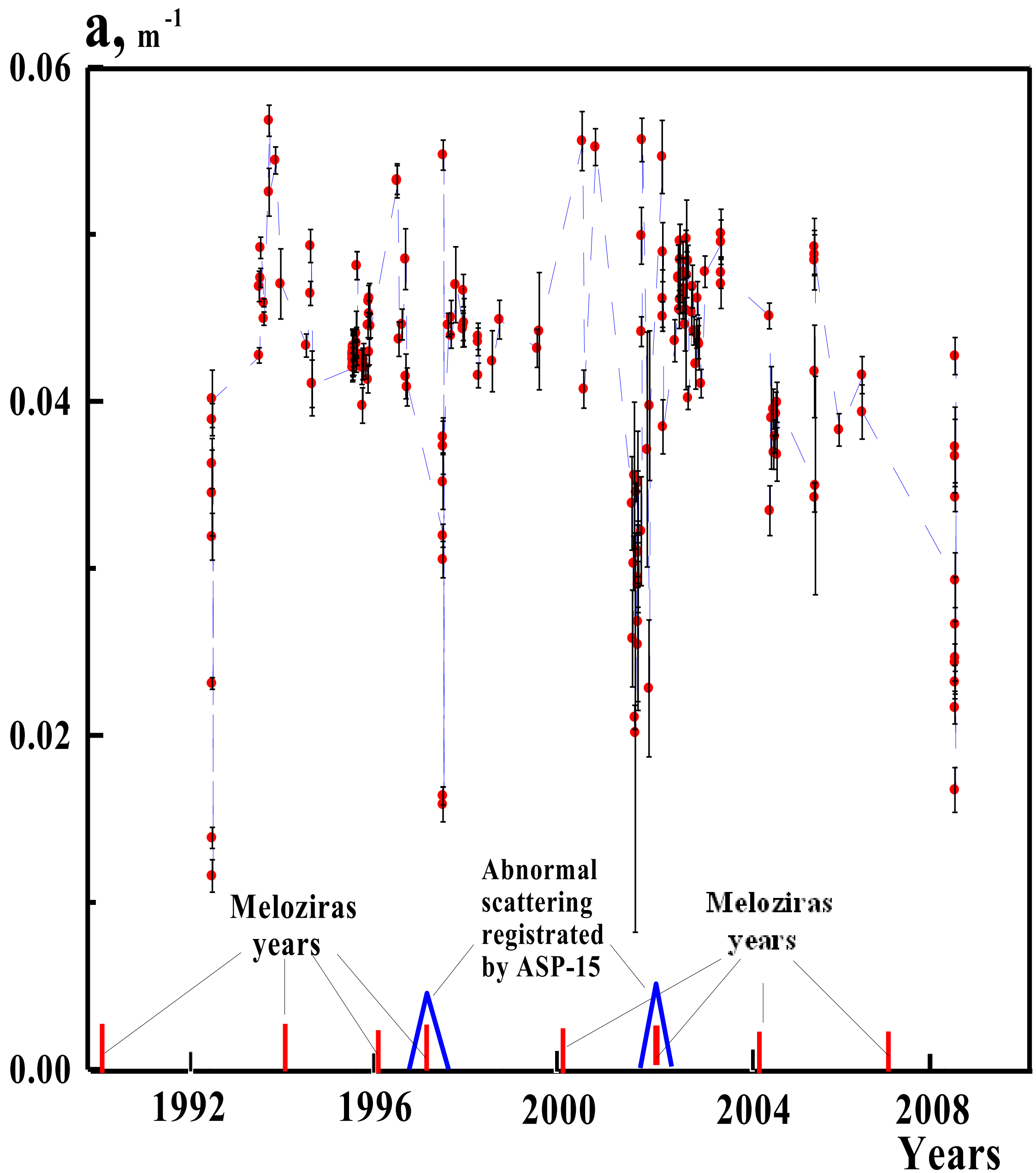


Рис.20.

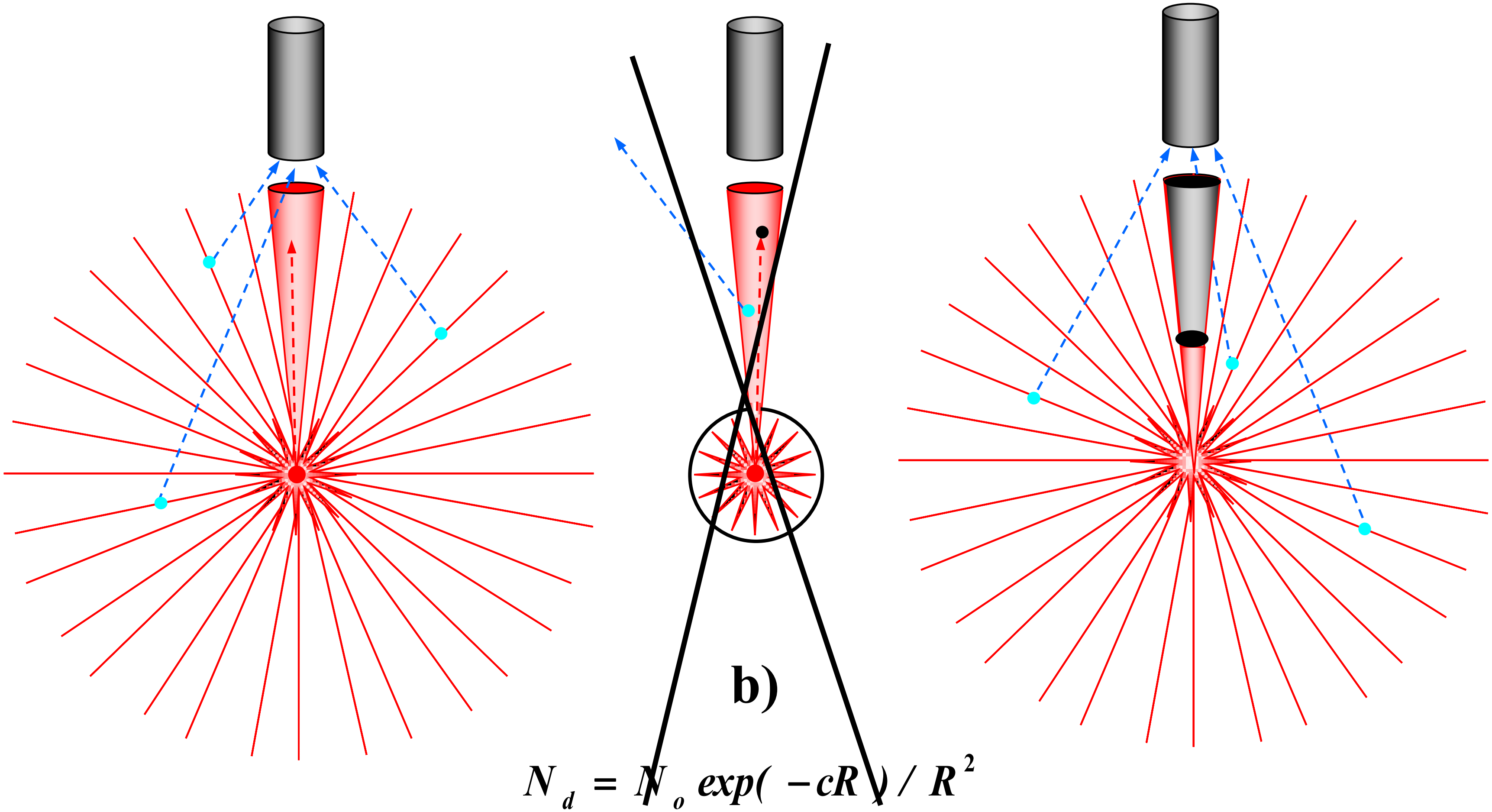
Absorption length
La=1/a =(20- 25) m

Absorption coefficient 488nm at 1000m depth



Scattering spectra

$b(\lambda)$



$$N_d = N_o \, exp(-cR) / R^2$$

a)

c)

$$N_t = N_o \, exp(-aR) / R^2$$

$$N_s = N_o \, [exp(-aR) - exp(-cR)] / R^2$$

$$b = -\frac{ln(1 - N_s / N_t)}{R}$$

Scattering coefficient profiles at shallow depths

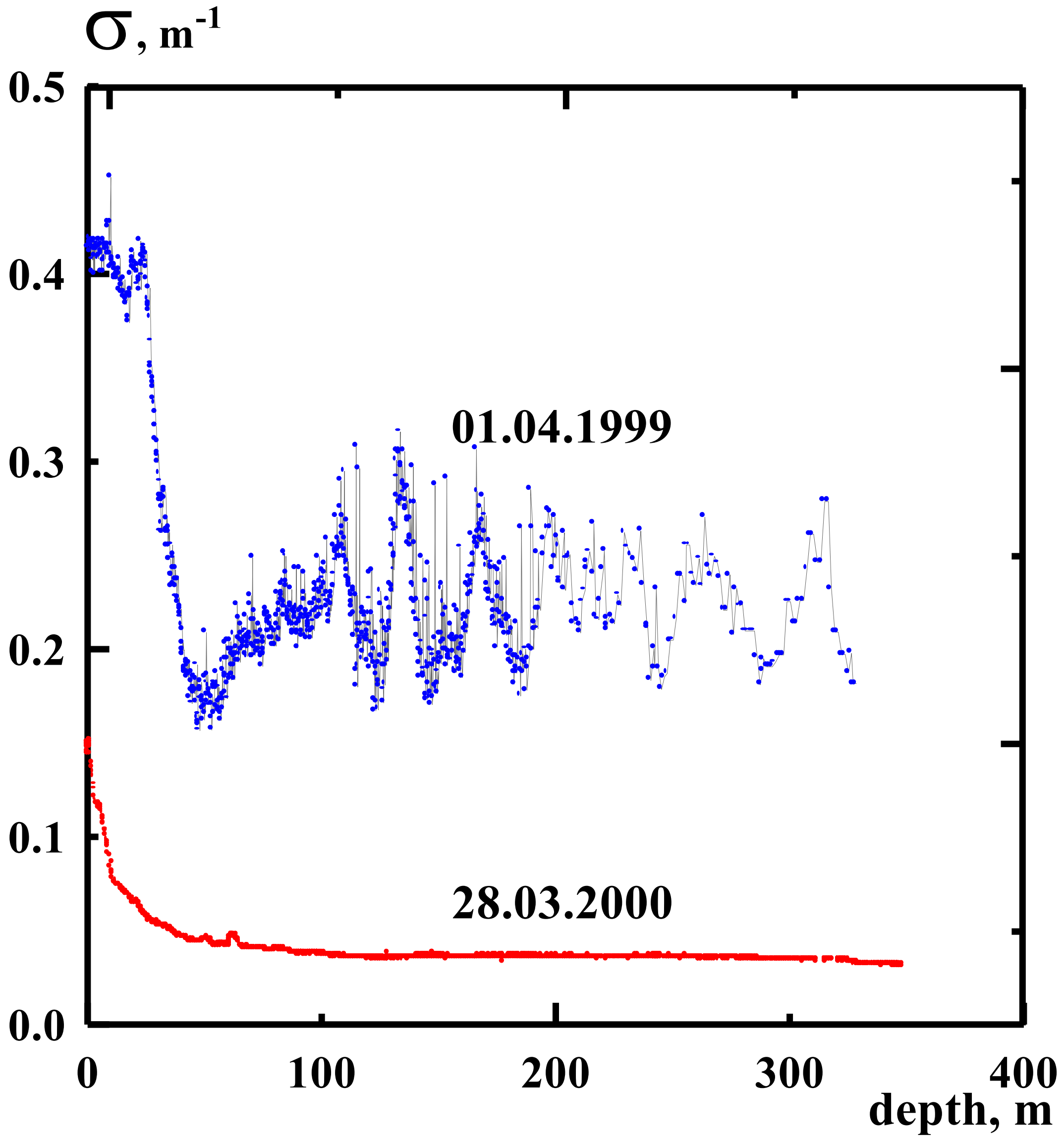
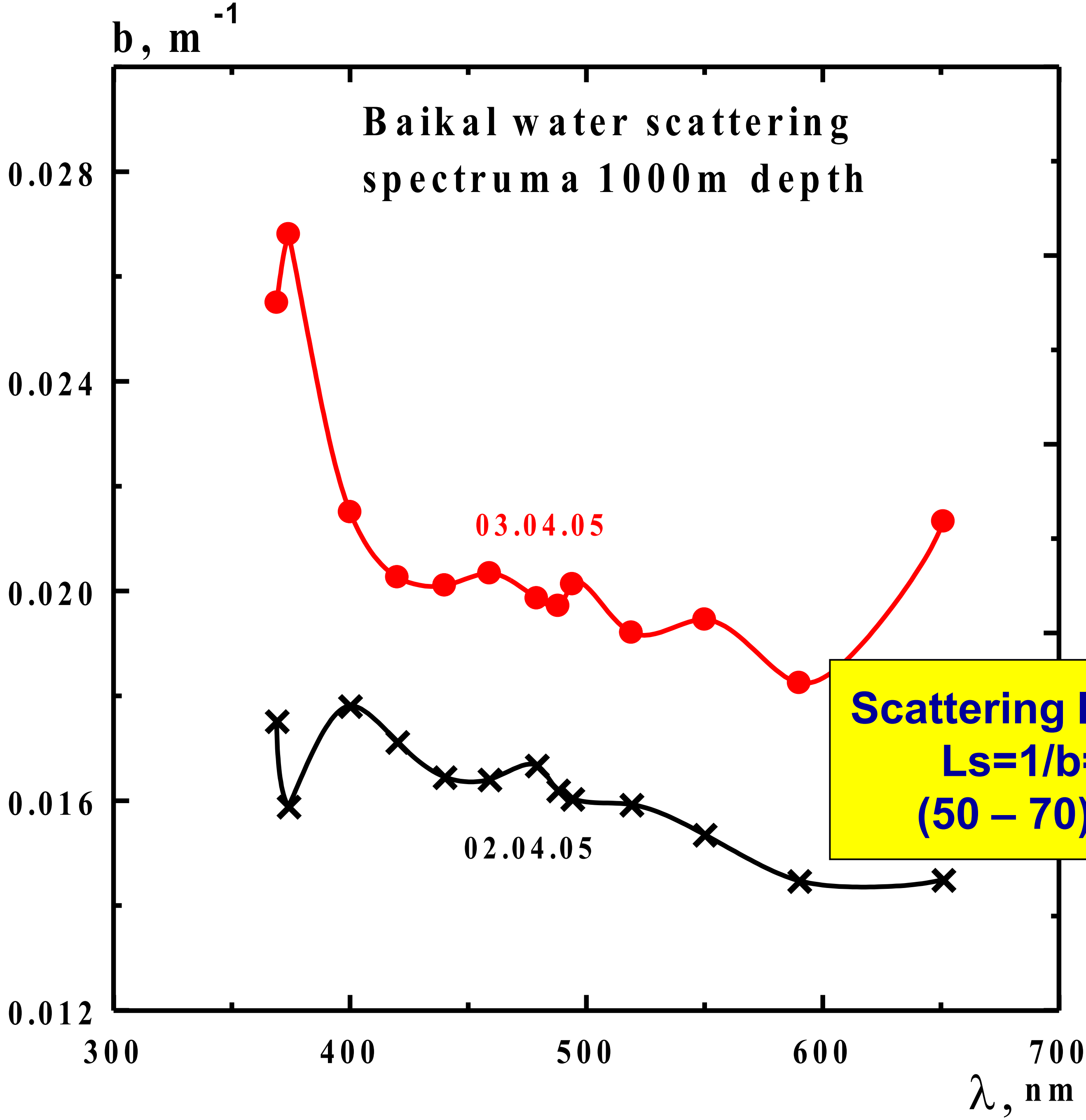


Рис.5 Глубинный ход показателя рассеяния в оз. Байкал



Scattering length
Ls=1/b=
(50 – 70) m

Scattering phase function

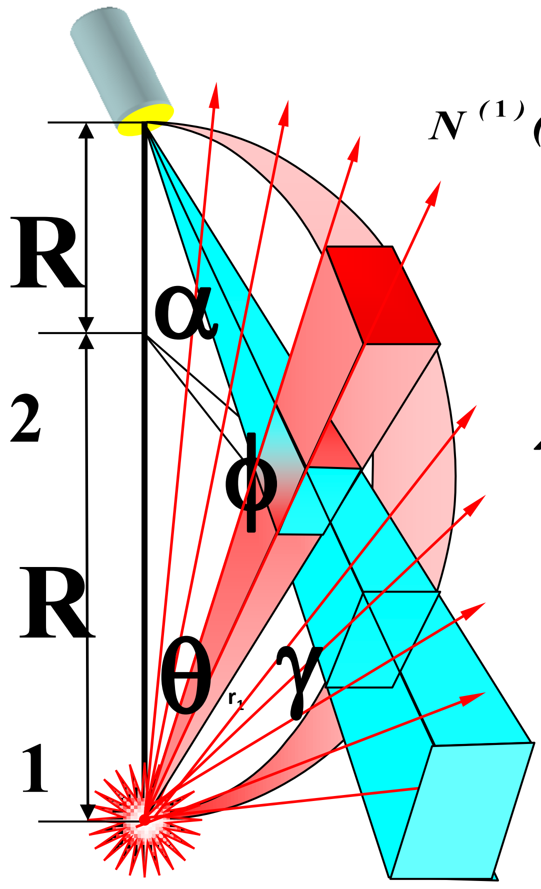
$\chi(\gamma,\lambda)$

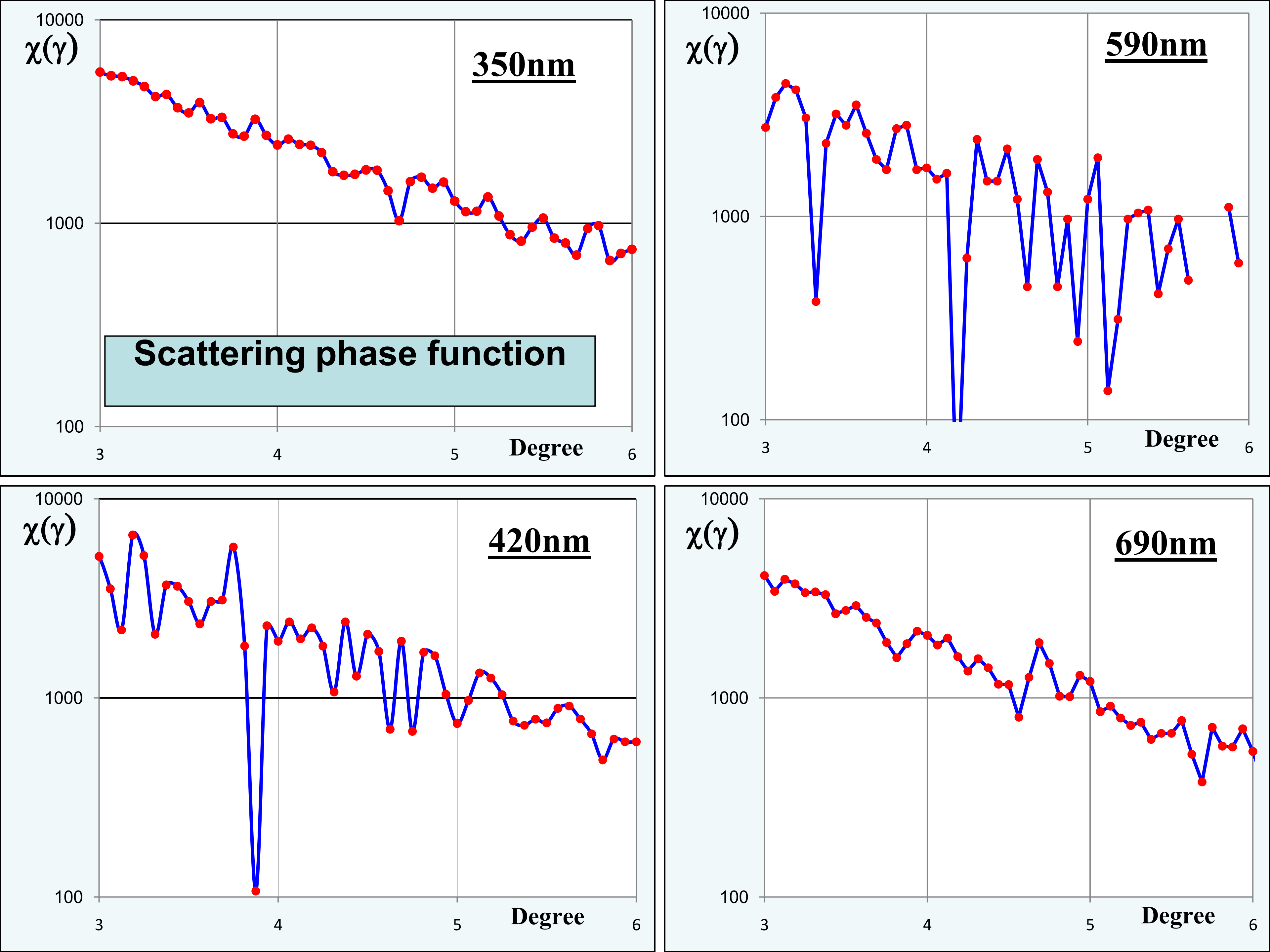
Our method of χ(γ) measurement using isotropic point-like source

$$N^{(1)}(\alpha, R) = N_o \frac{b \bullet S}{R \bullet \sin\alpha} \int_{\alpha}^{\pi-\alpha} \chi(\alpha+\theta) \exp(-cR) \frac{\sin(\alpha+\theta)}{\sin\alpha + \sin\theta} d\theta$$

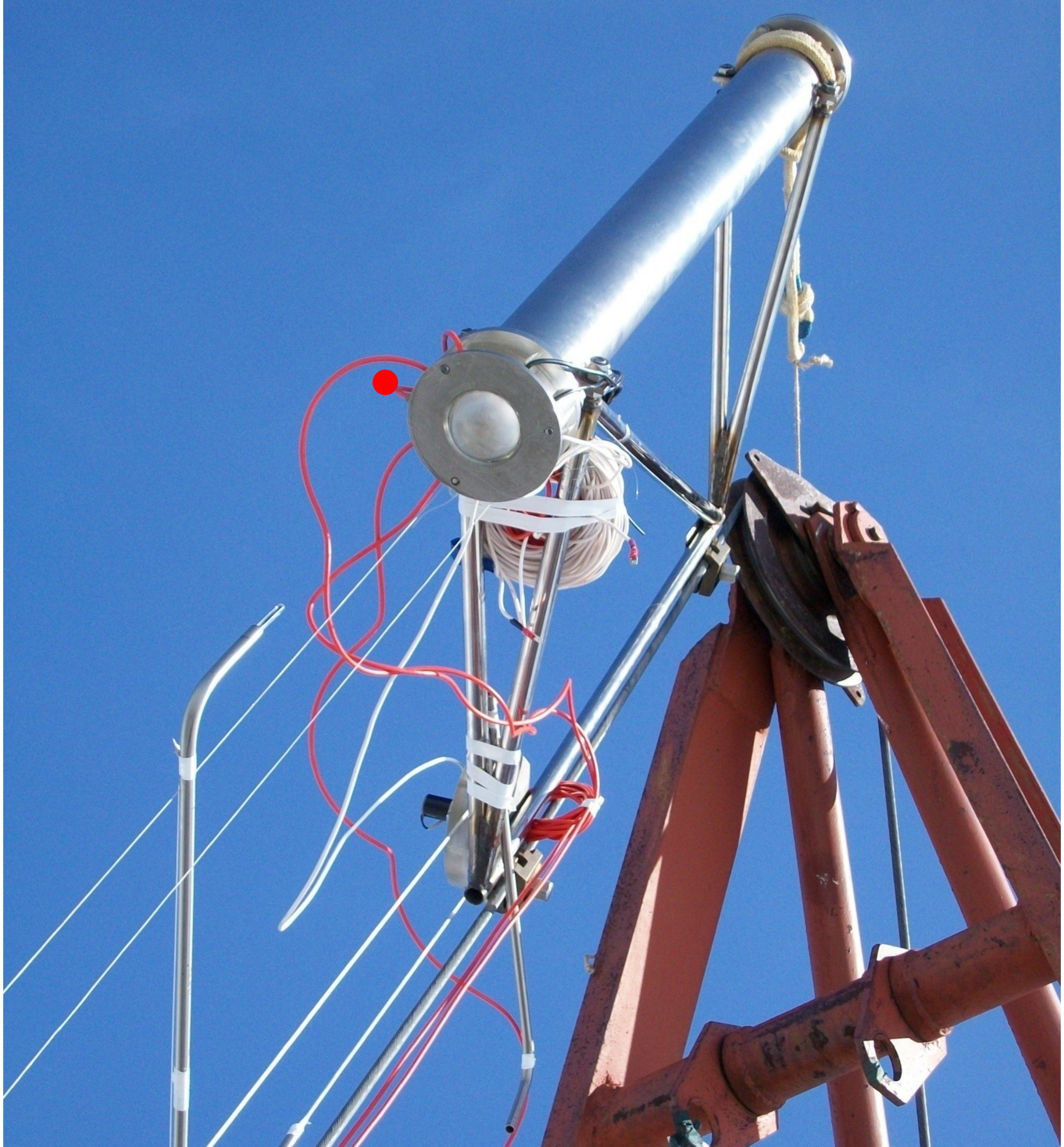
$$N^{(1)}(\alpha, R) \approx N_o \frac{b \bullet S}{R \bullet \sin\alpha} \int_{0}^{\pi-\alpha} \chi(\alpha+\theta) d\theta$$

$$\chi(\alpha) \approx \frac{d[N(\alpha, R)\sin\alpha]}{d\alpha}$$



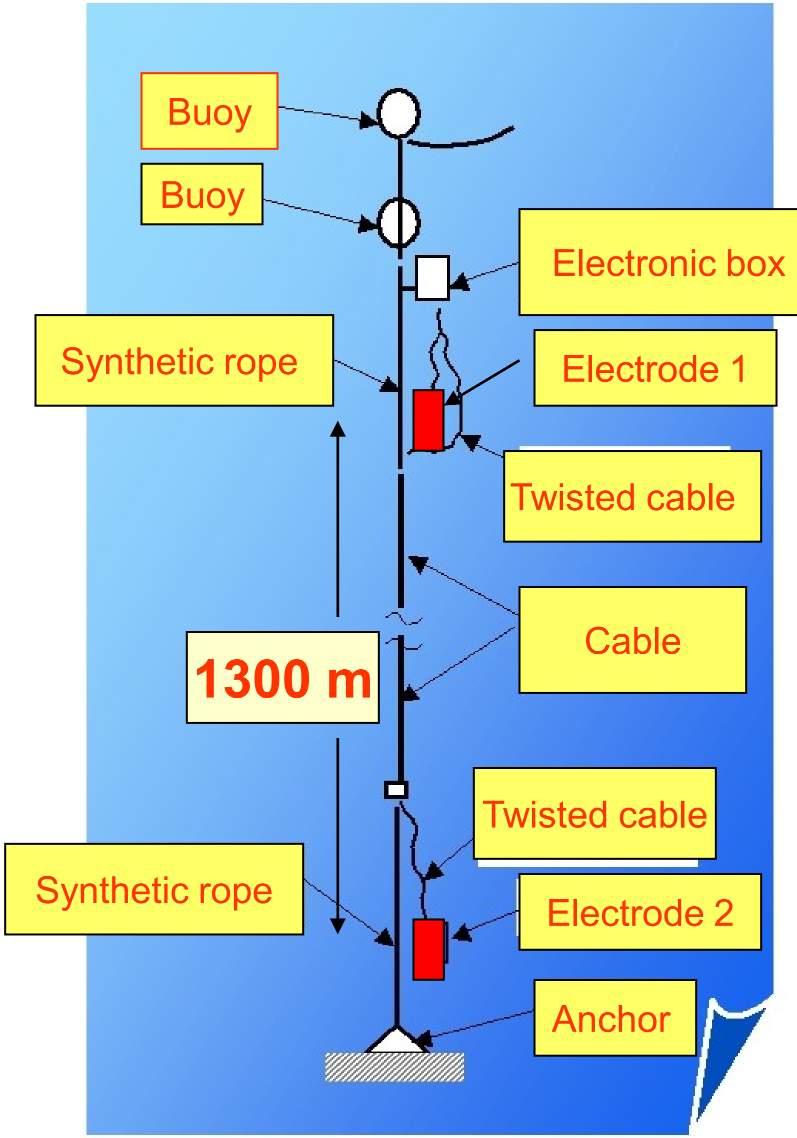


χ(γ)
350nm
Scattering phase function
Degree
590nm
420nm
690nm
10000
1000
100
3
4
5
6



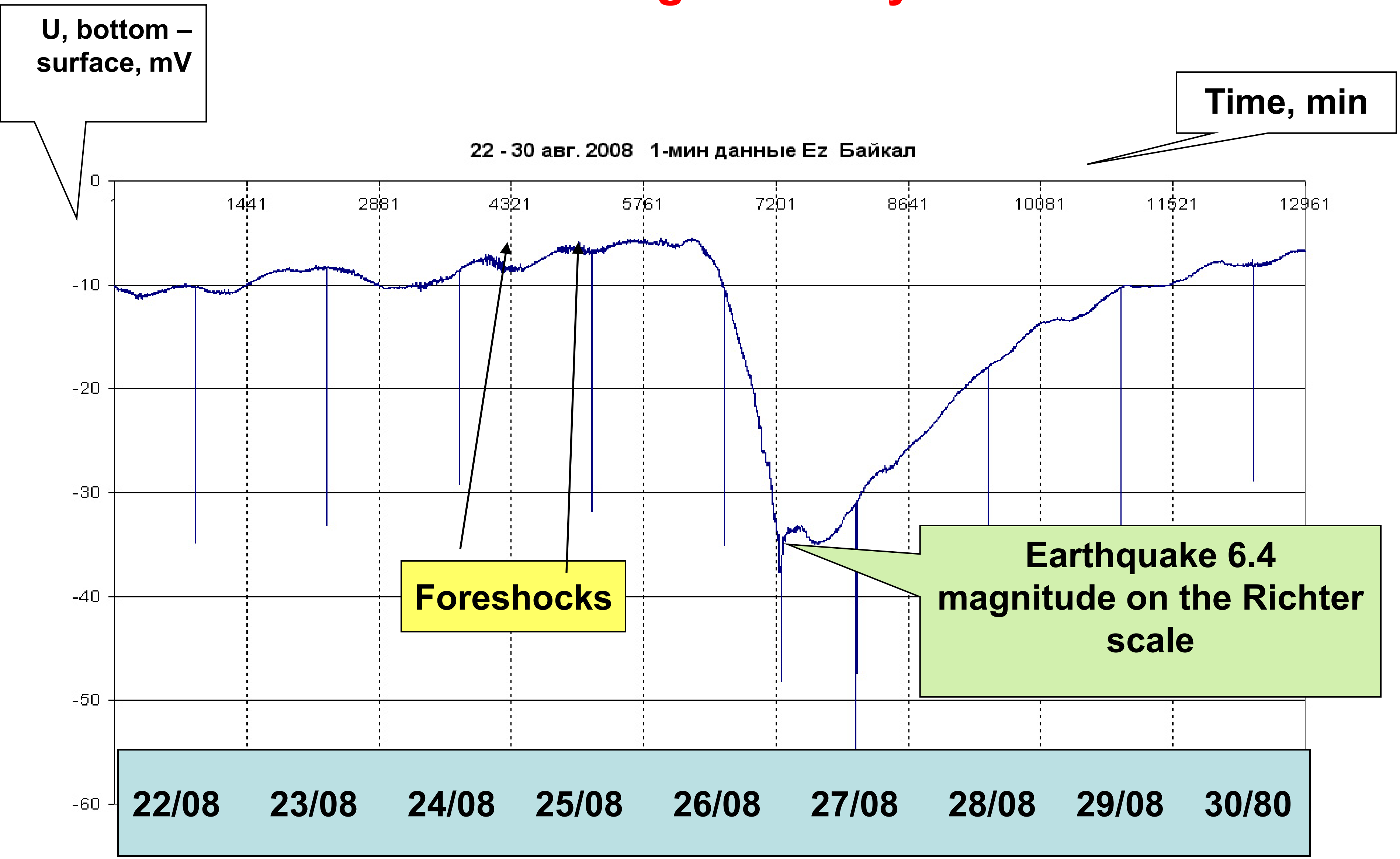
- Long-term long base monitoring of Earth electromagnetic field.

Geophysical Mooring

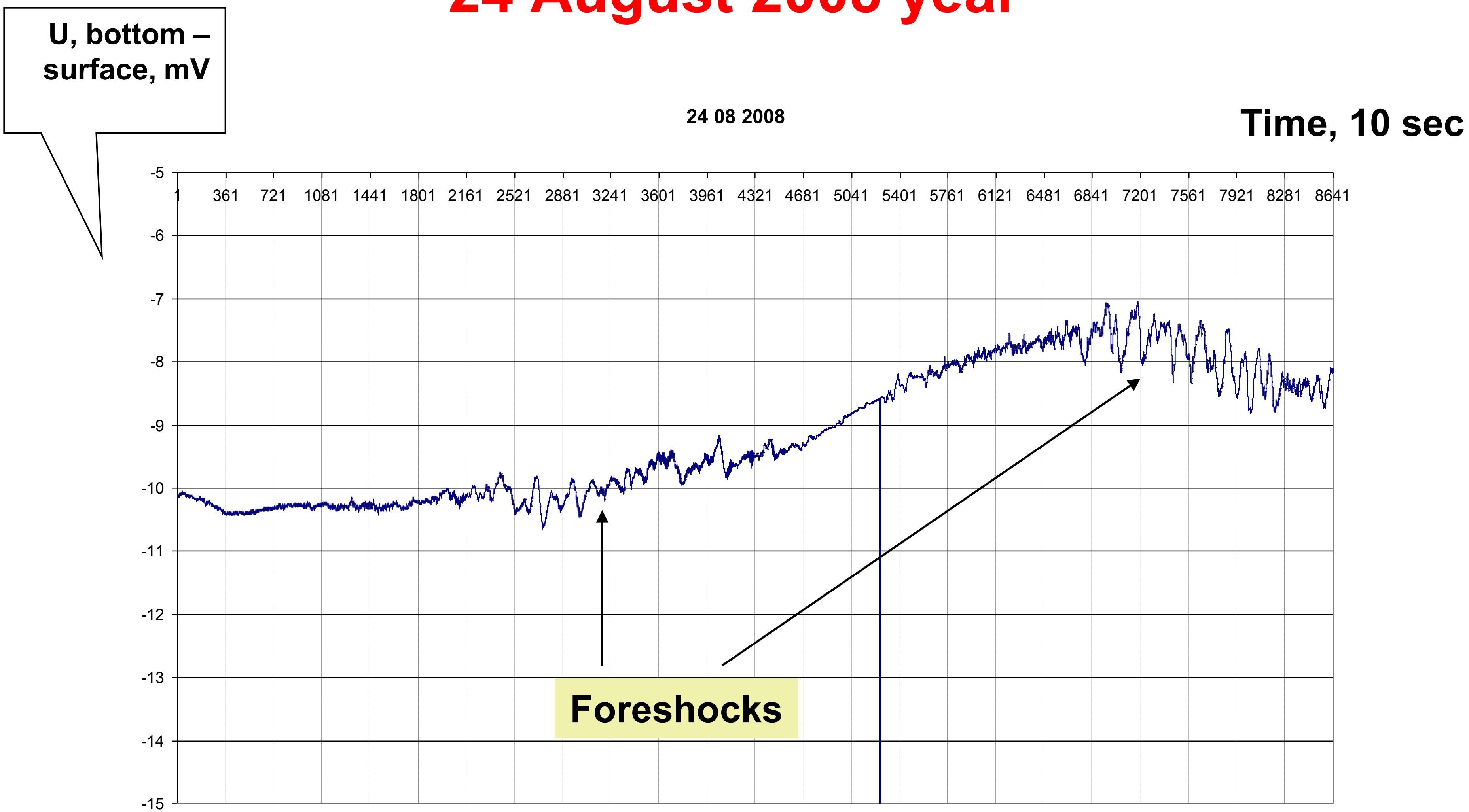


Surface – bottom electric potential difference

22 – 30 August 2008 year.

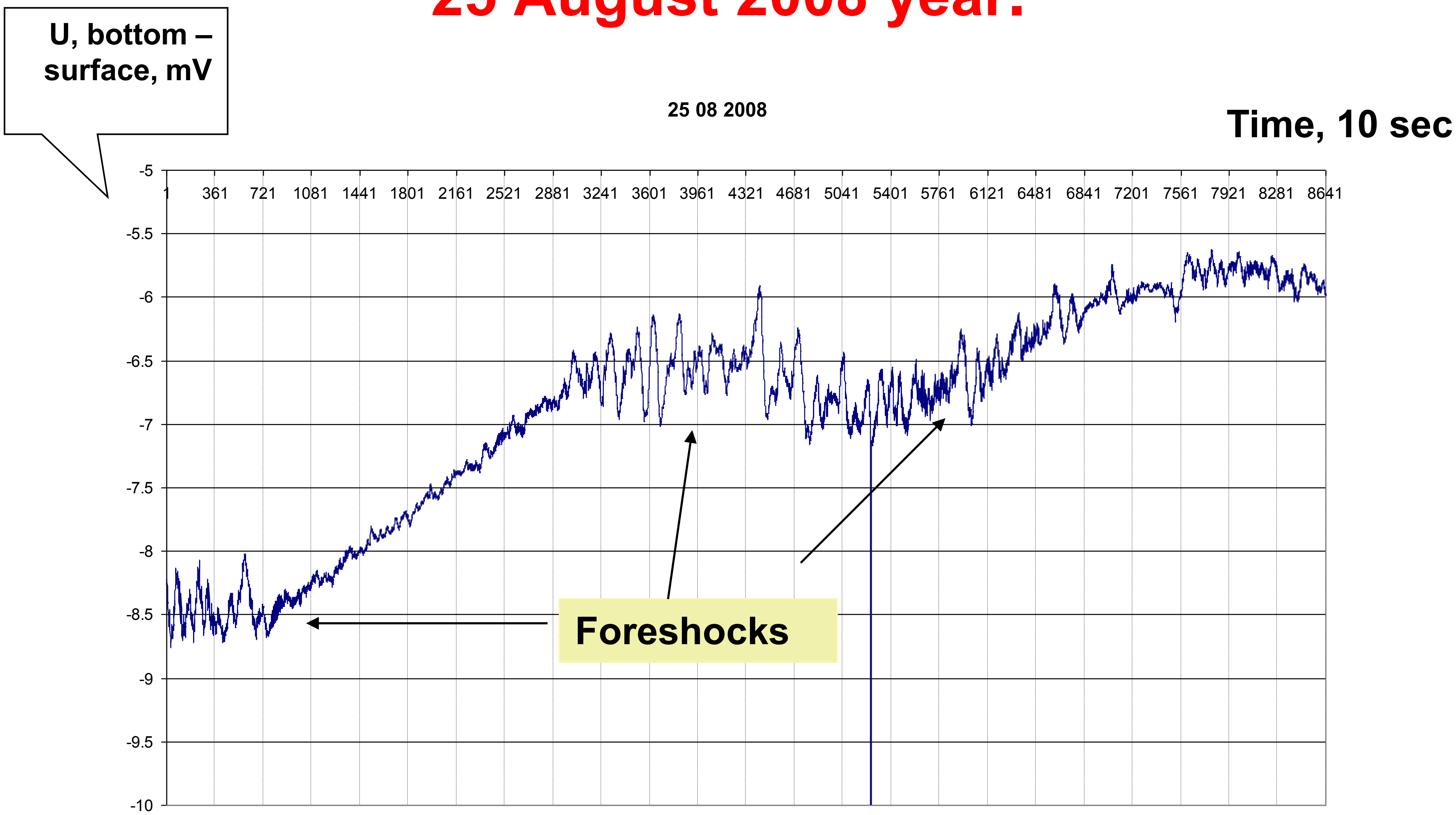


Surface – bottom electric potential difference
24 August 2008 year



Surface – bottom electric potential difference

25 August 2008 year.

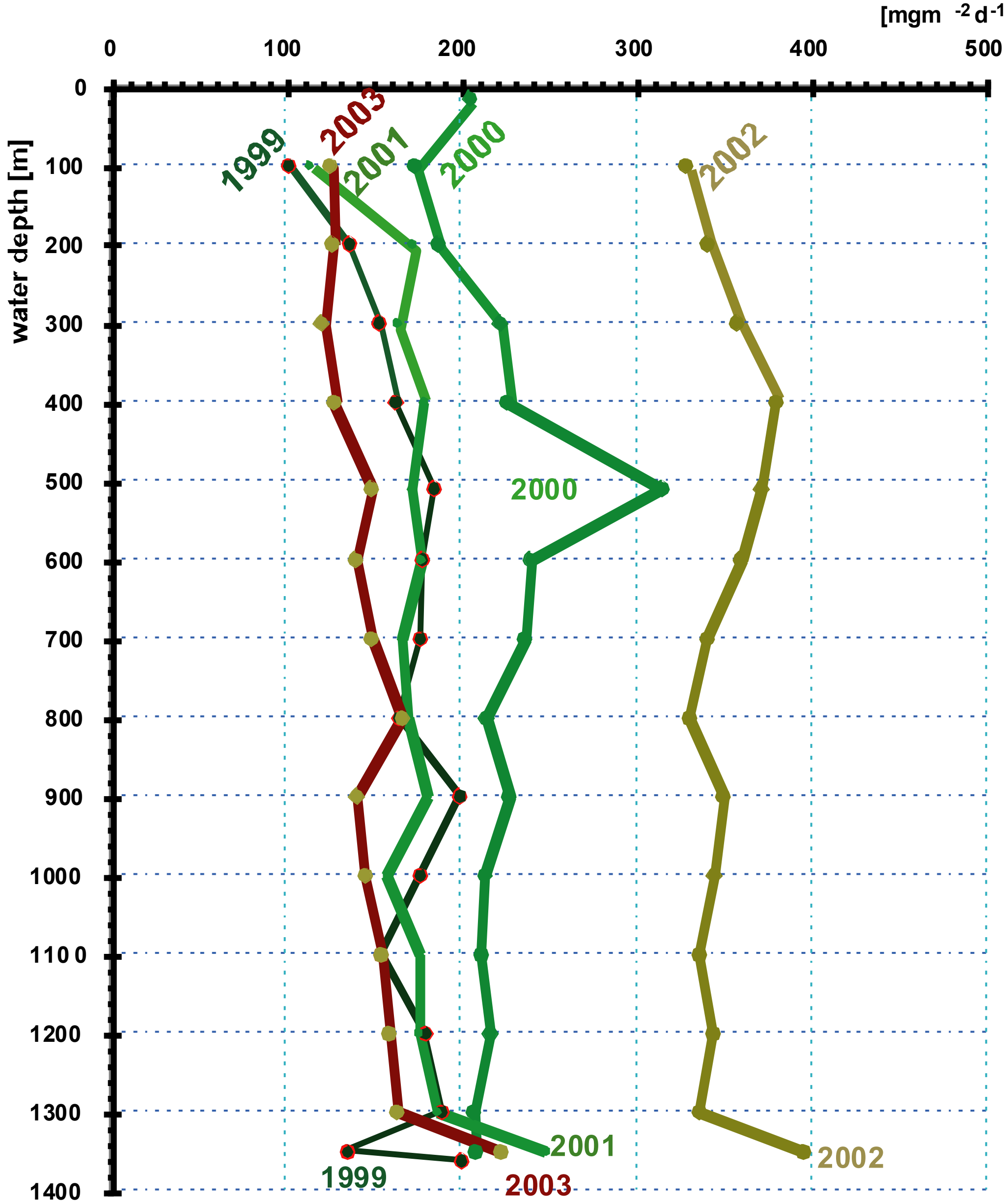


- Sedimentology study

Sediment trap after one year collection

integrating traps S-Basin

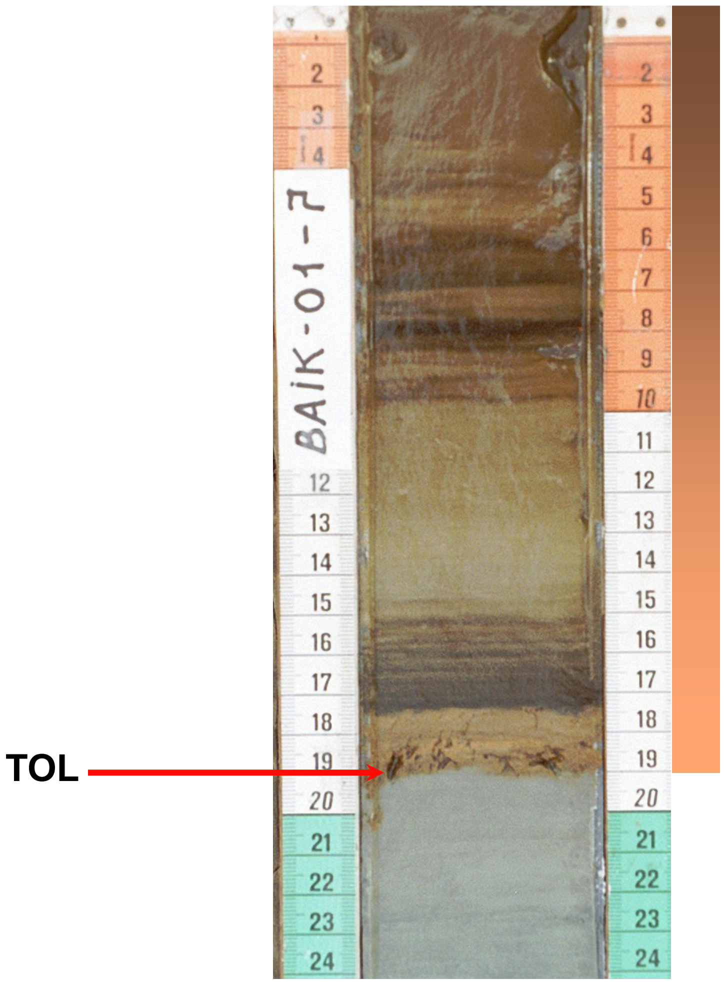
1999-2004



TOL in sediment cores

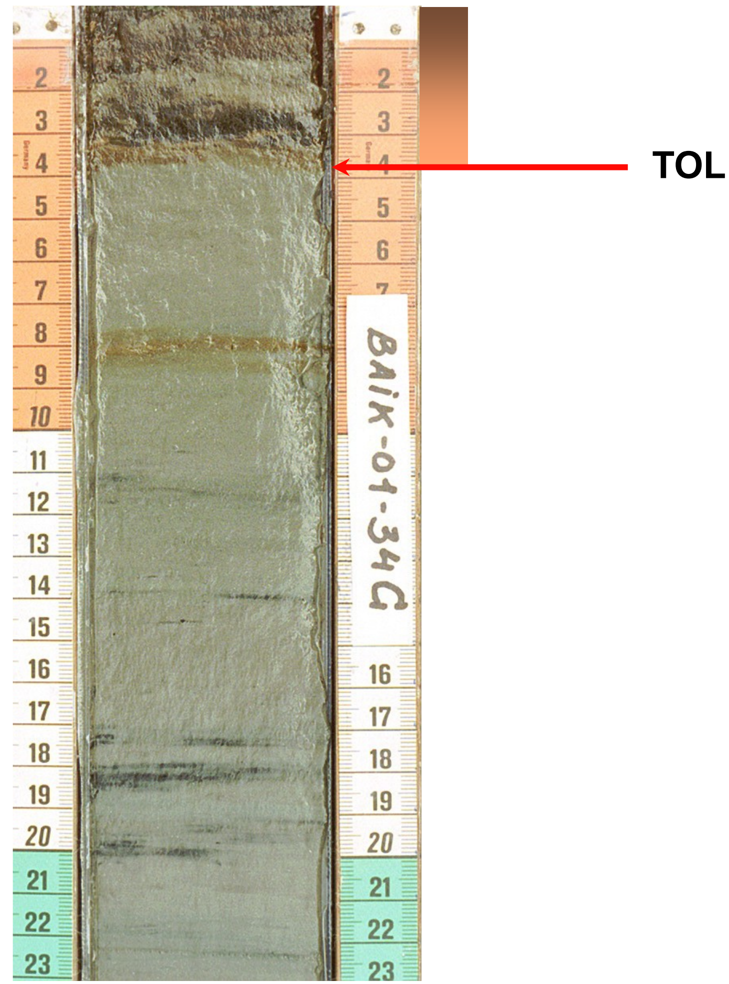
N-basin

01-7/910m



S-basin

01-34C/1340m



Summary

- **Lake Baikal is a unique reservoir of natural fresh water and is home for hundreds of endemic species**

- **Lake Baikal is a natural laboratory to study different phenomena like: paleoenvironmental records, modern climate variations, speciation (evolutionary development of biological species)**

- **In the framework of the Baikal neutrino experiment a lot unique instruments, methods and technologies were designed which are suitable for interdisciplinary study of the Lake.**

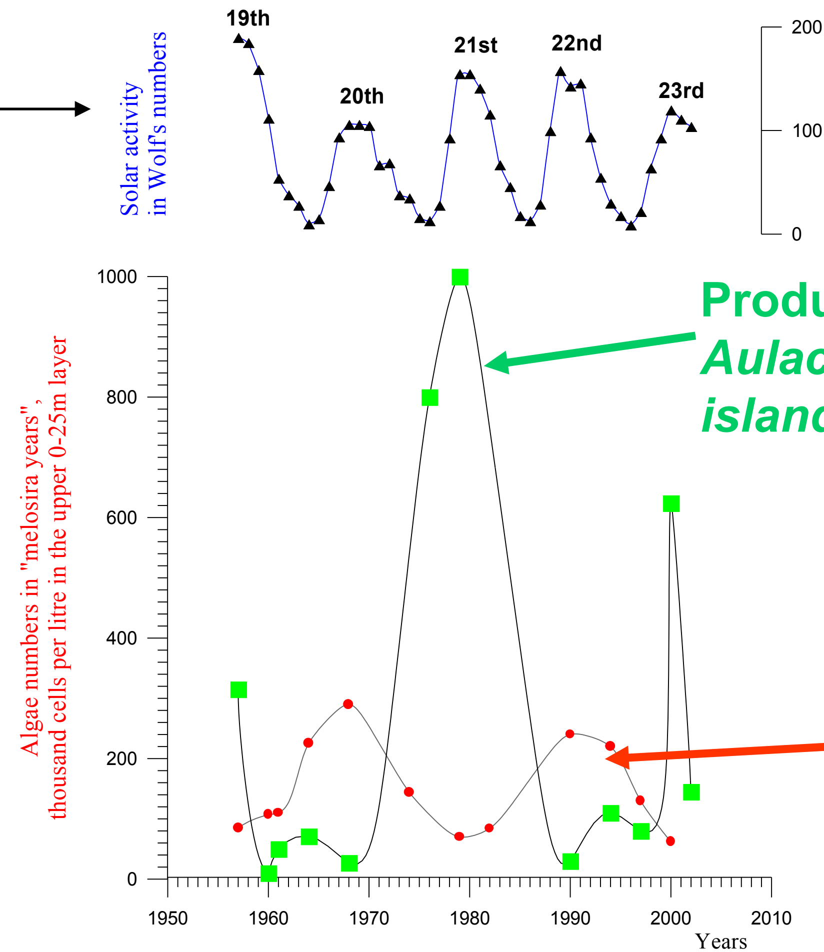
- **We are open to new collaborators in different fields.**

- **With the km3-telescope Baikal is a good place for a multi-disciplinary environmental laboratory**

Thank you!


Welcome to Lake Baikal

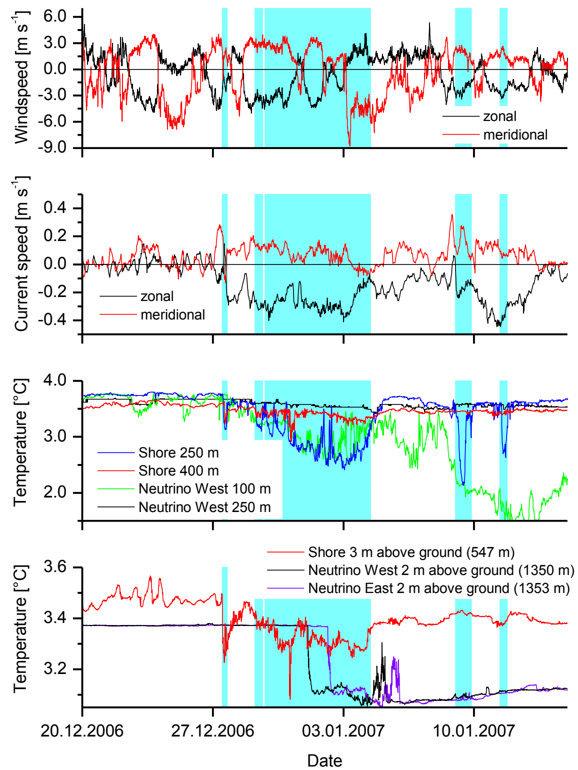
Solar activity



Productivity of *Aulacoseira islandica*

Productivity of *Aulacoseira baicalensis*

Zonal (along-shore, positive eastwards) and meridional (vertical to shore, positive northwards) components of wind speed near Listvyanka and of currents at 16 m depth at the “Shore” mooring, as well as temperatures observed at different depths at the three moorings.



- The shaded areas mark the downwelling events when the “Shore” temperature dropped more than 0.2 ° C below the NTW temperature at 250 m depth.