

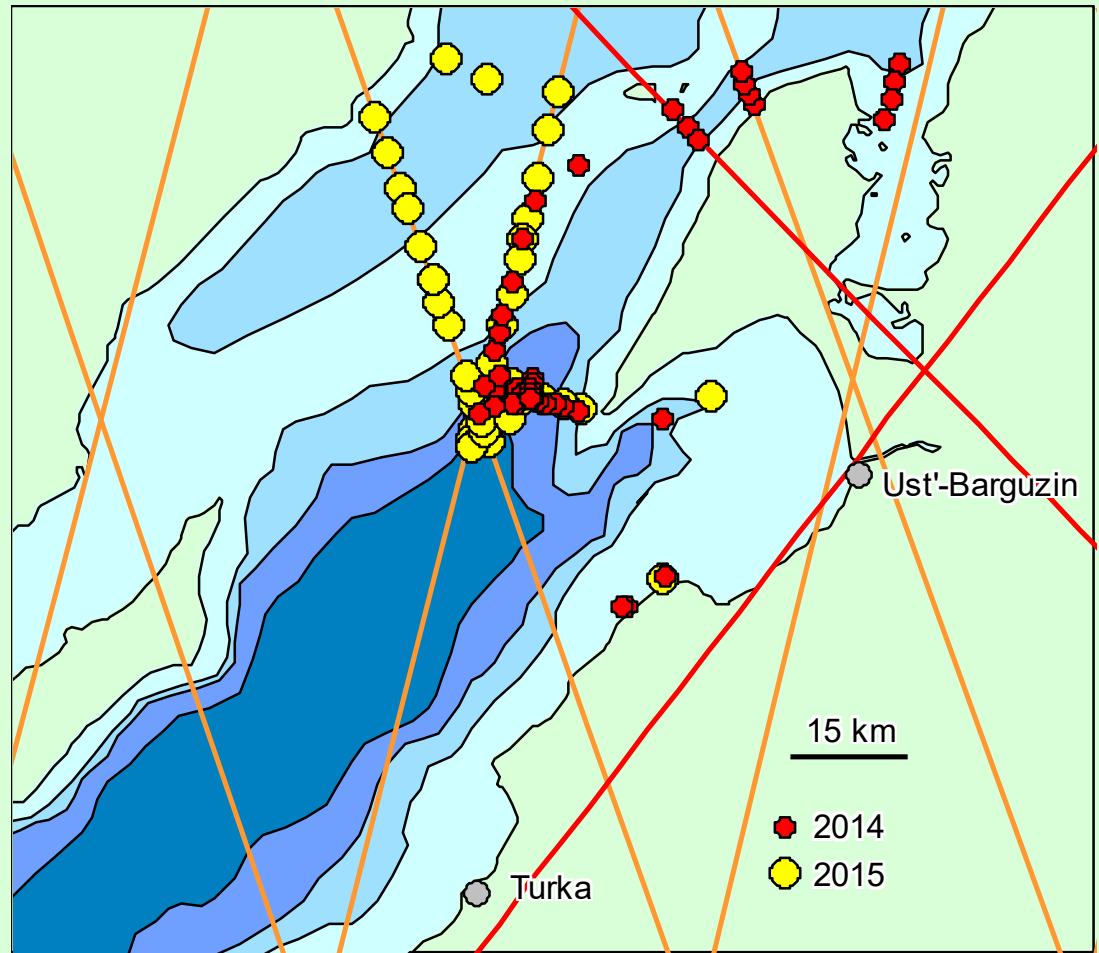
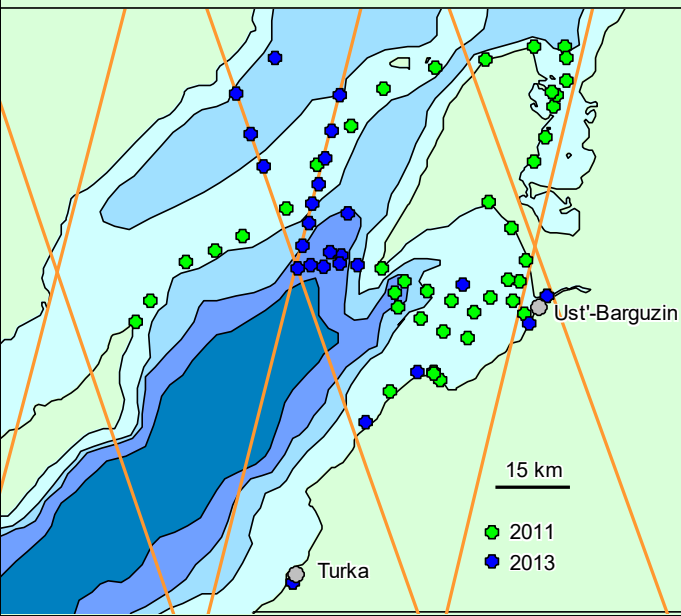
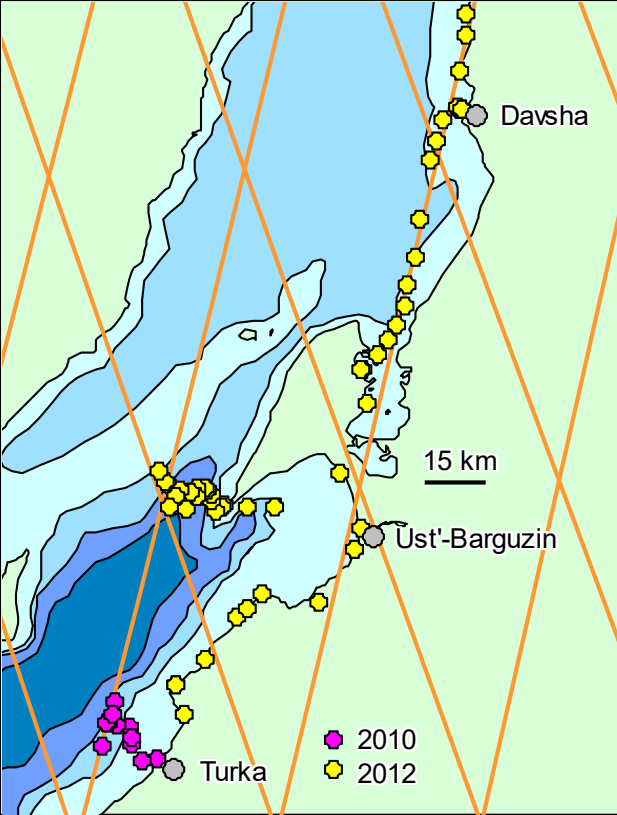


Ice cover and associated water
dynamics of Eurasian lakes
from satellite and in situ observations

*LEGOS, Université de Toulouse, France
Shirshov Institute of Oceanology, Moscow
Limnological Institute, Irkutsk
Northern Water Problems Institute, Petrozavodsk,
Institute of Water Problems, Moscow,
Great Baikal Trail (GBT) Buryatiya, Ulan-Ude*

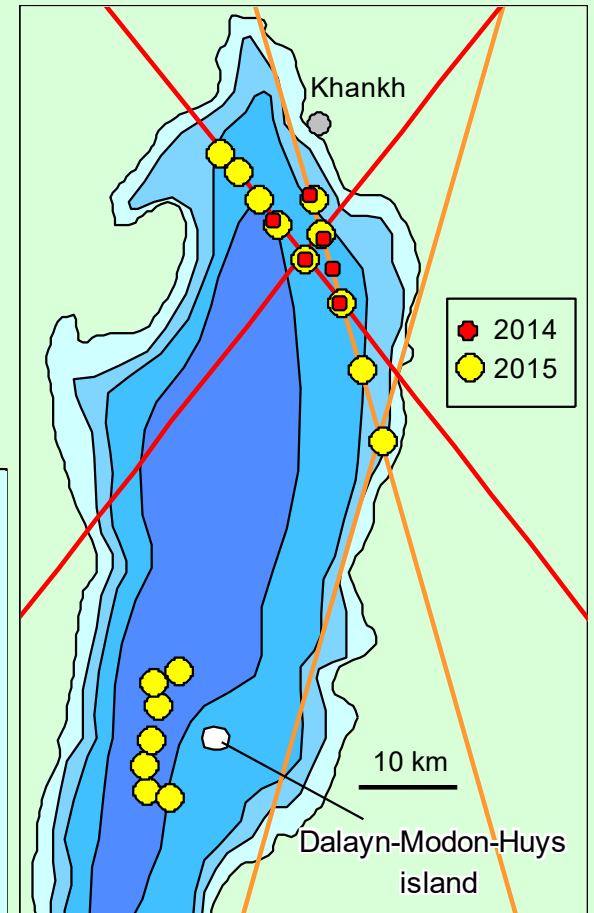
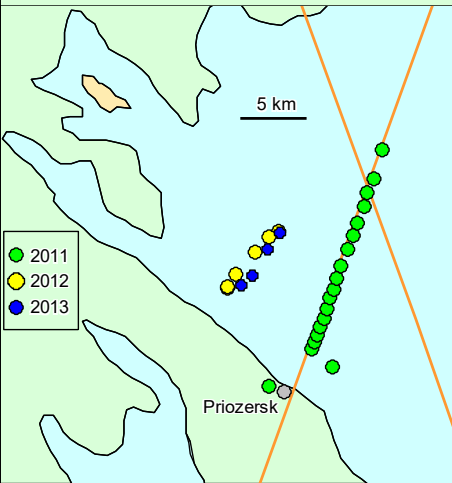
**A. Kouraev, E. Zakharova, F.Rémy, A. Kostianoy,
M. Shimaraev, N.M.J. Hall, R. Zdrovennov, A. Suknev.**

Field work - Baikal



High spatial sampling along-track
**Ground truth:
extremely important**

Field work - Ladoga, Onega and Hovsgol



Swiss-Russian project "Lake Ladoga"



Smooth, mostly clear ice



Rough, hummocky (1 cm thick), snow



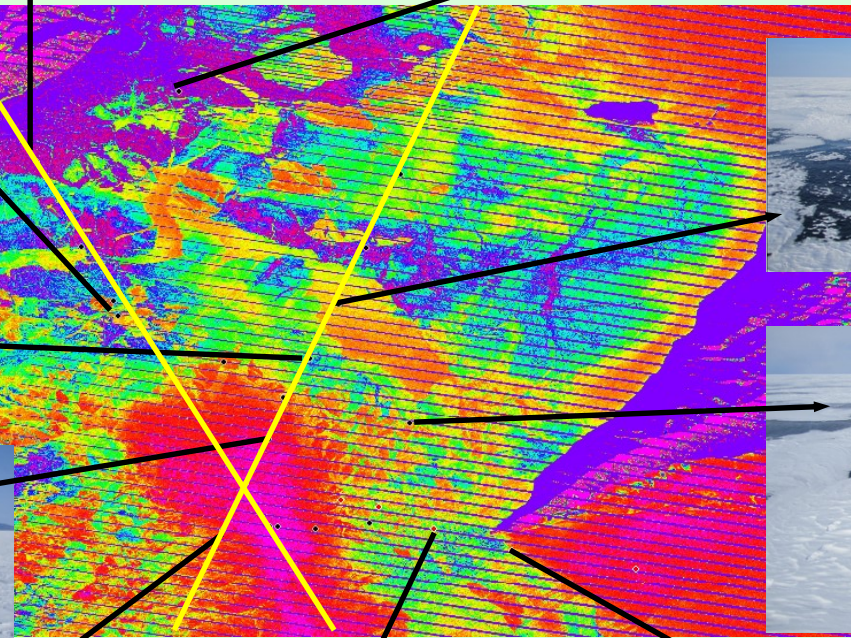
Smooth; congelated pancake ice



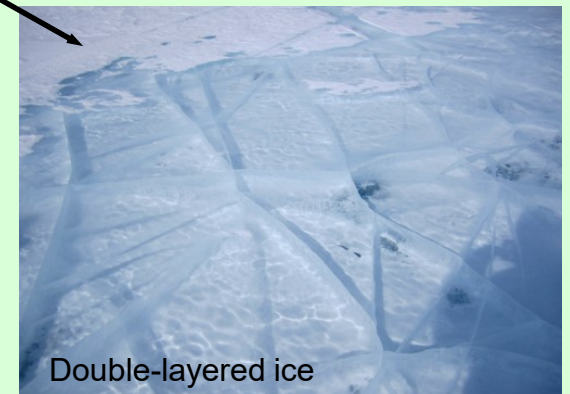
Snow-covered ice



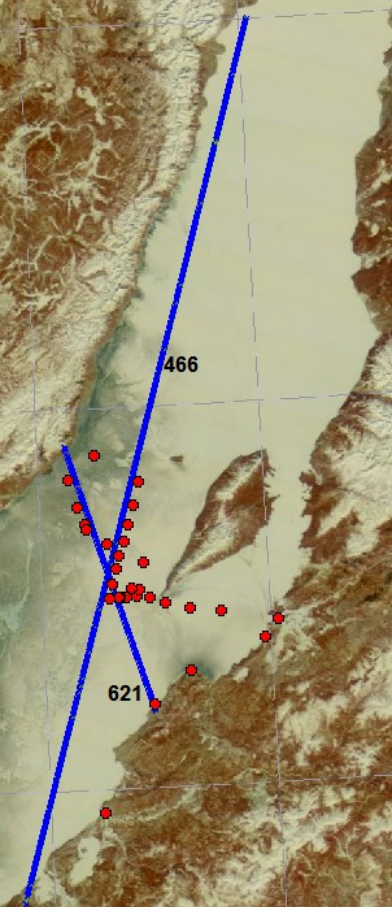
Snow, small patches of clear ice



Snow, small patches of clear ice



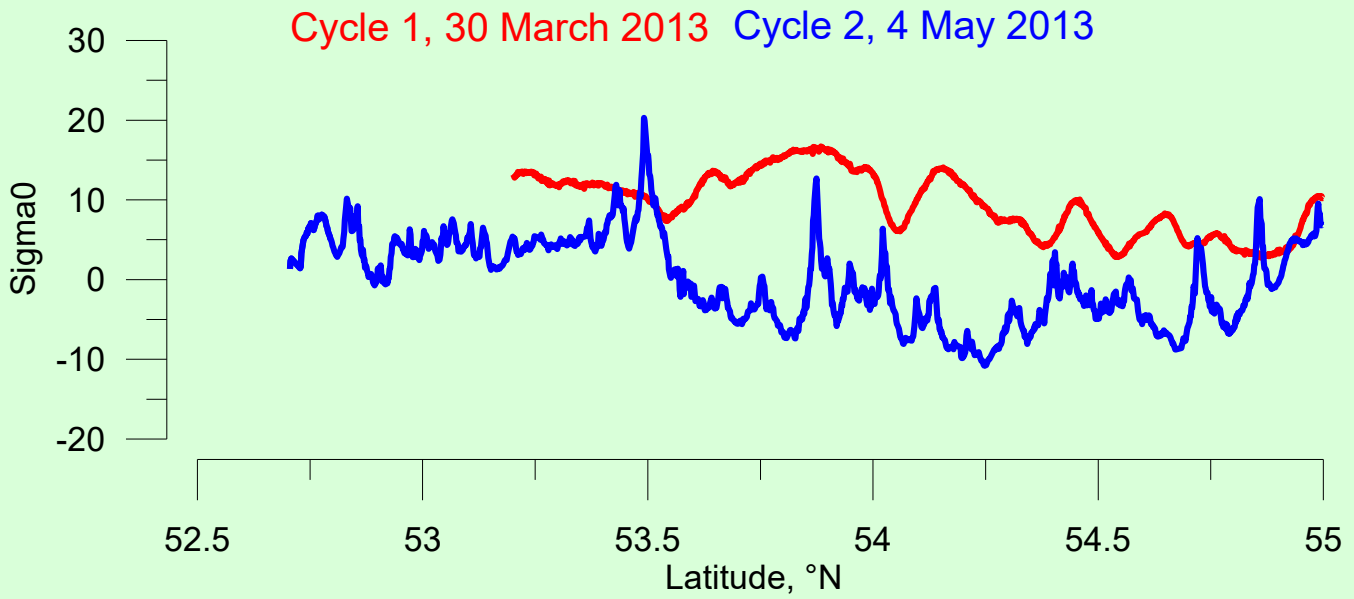
Double-layered ice



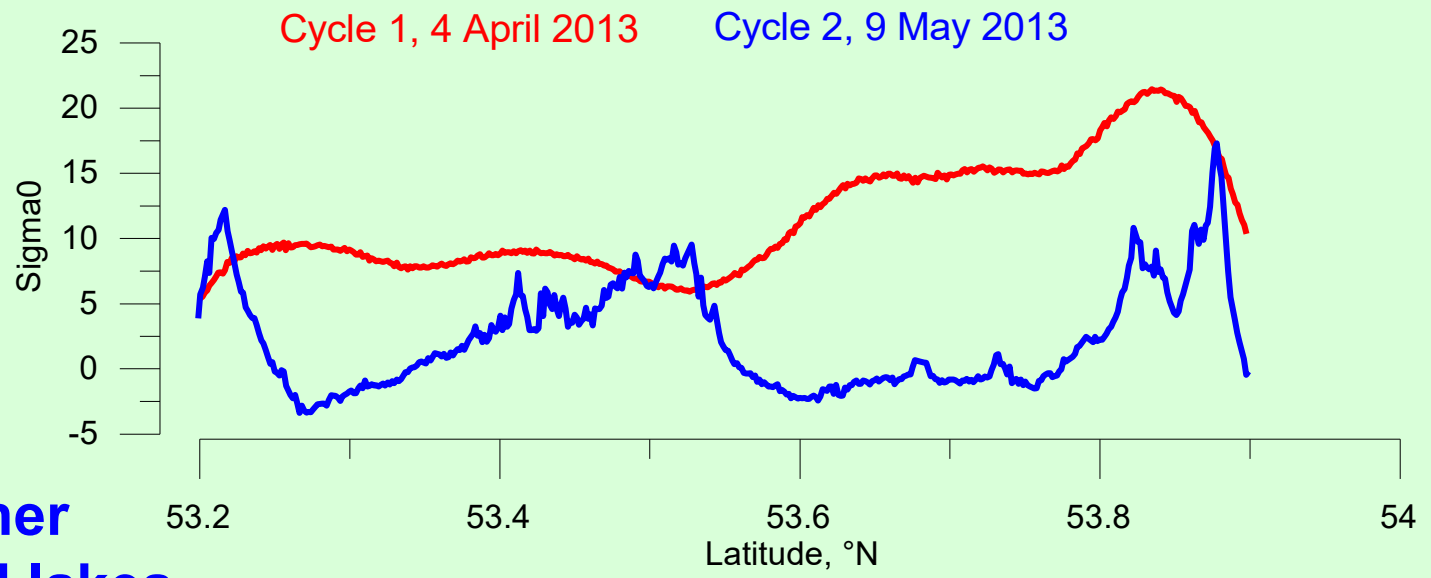
**15-20 dB
decrease,
different
patterns**

**Typical for other
altimeters and lakes**

Track 466



Track 621





**Going down to
micro scale**

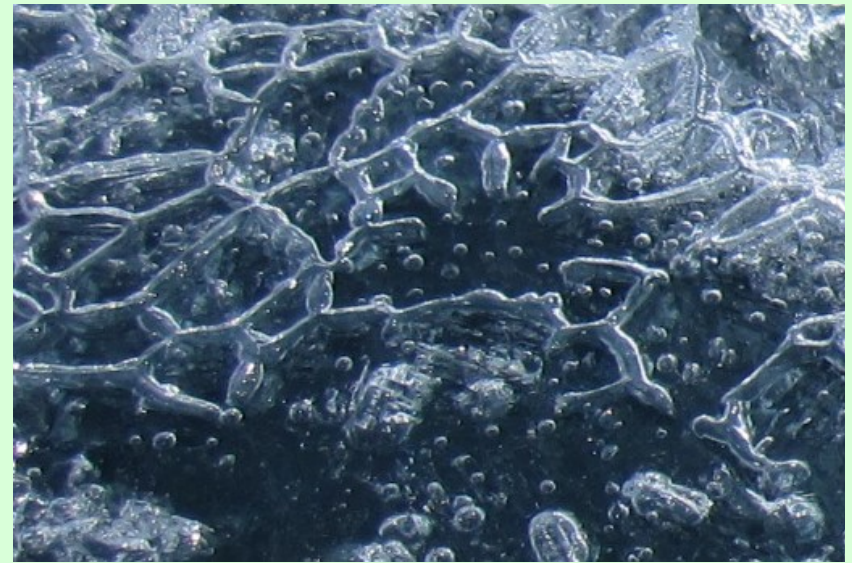
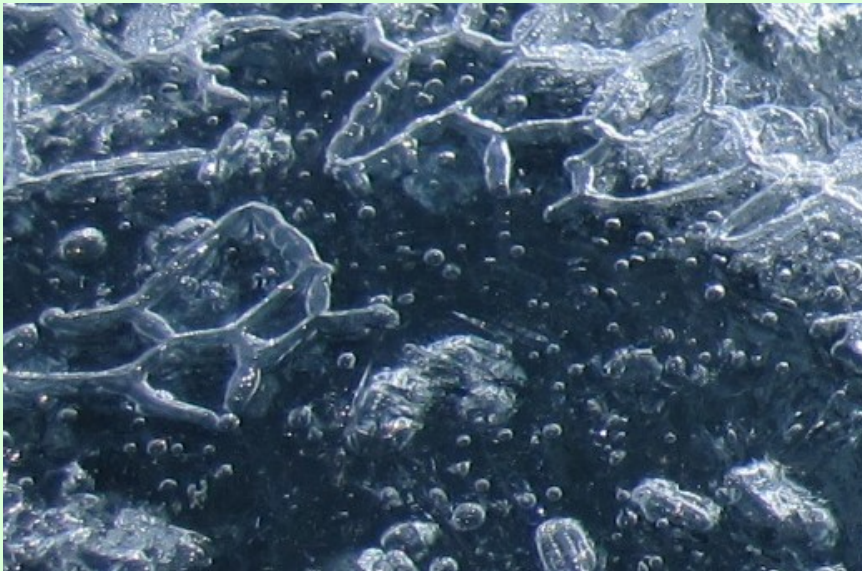
Ice structure



Air channels



Air channels formation in 9 min
Influence on albedo and waveform



Needle ice

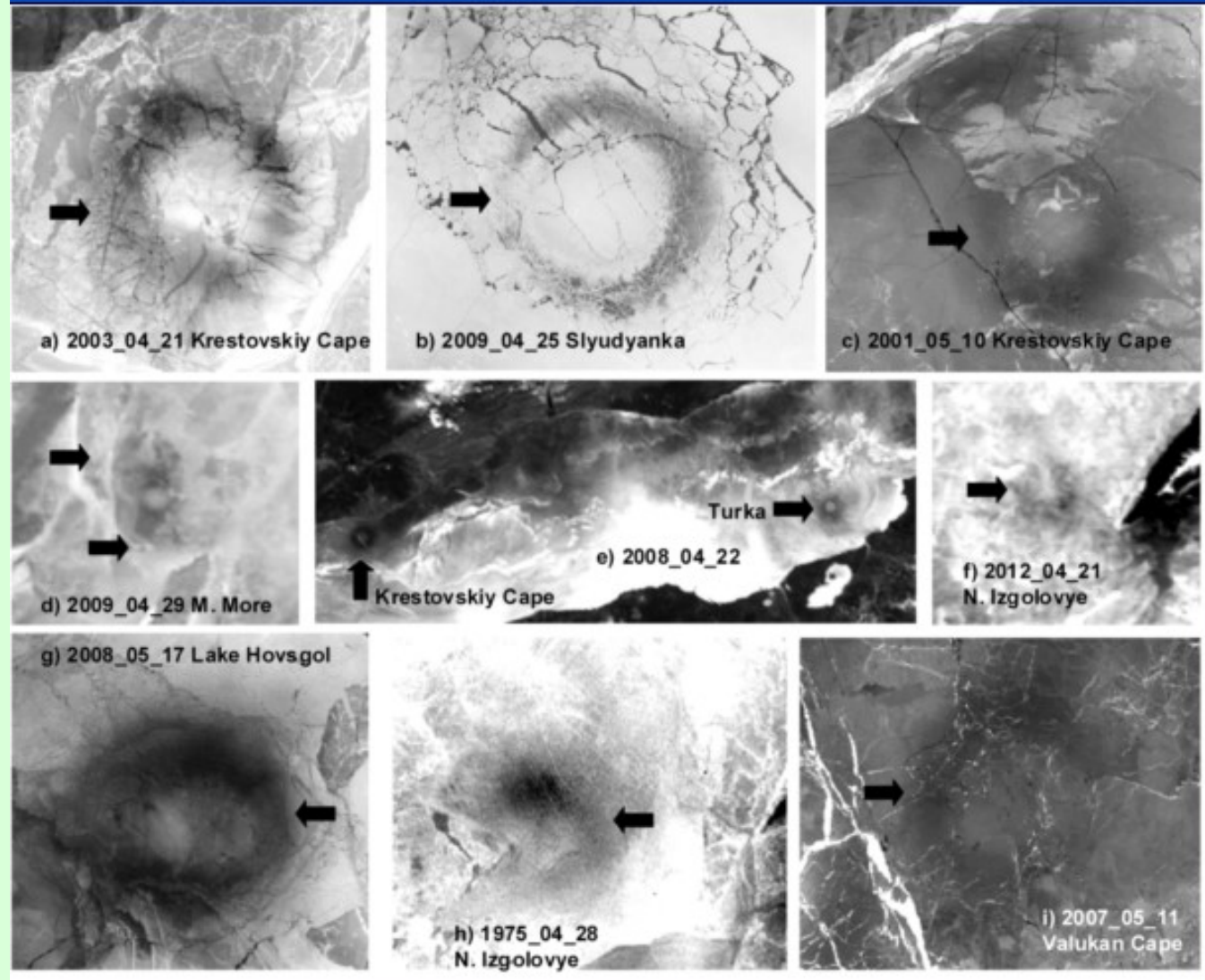


**Better understanding
of altimetric waveform
is needed**

THE LORD OF THE BAIKAL ICE RINGS

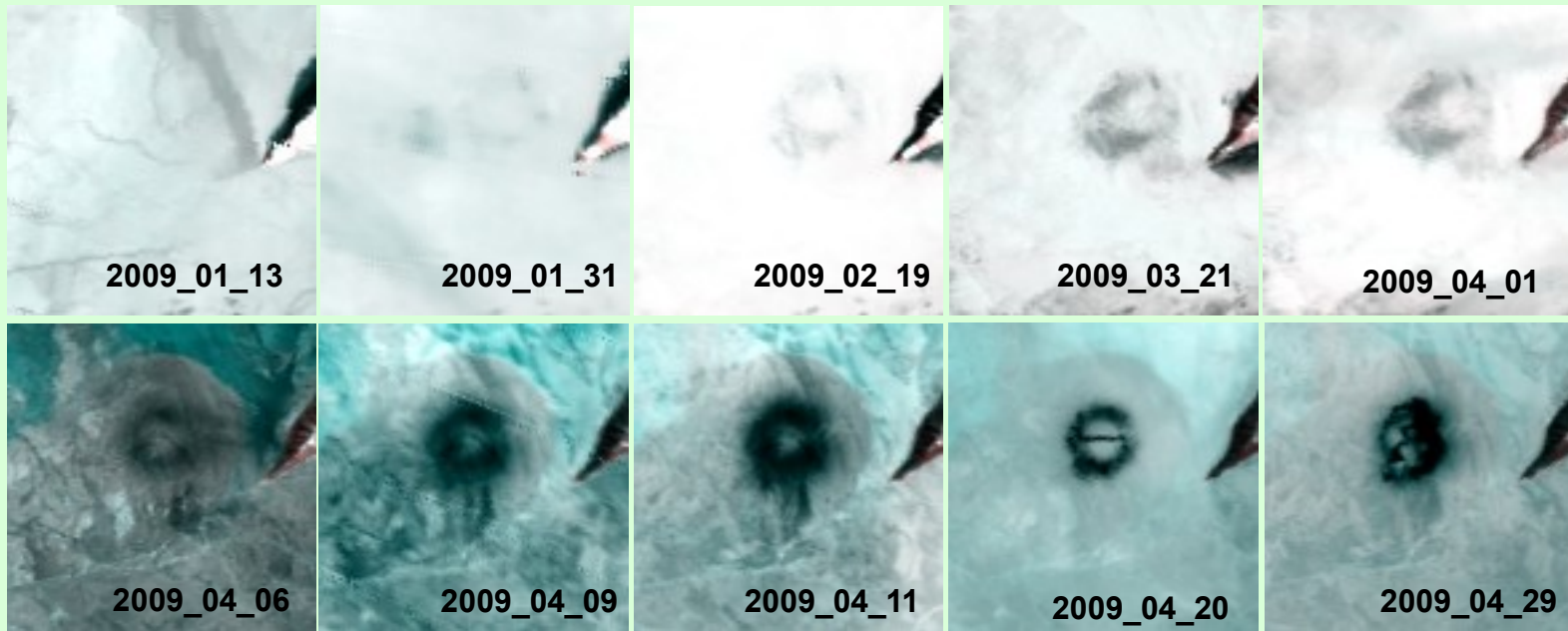
Diameter
5-7 km.
Circular shape.
Ice is thinner
in the ring

Different
years,
different
places



Rings are usually seen in April.
But they could be formed earlier

Evolution



Cape Nizhneye Izgolovye (Middle Baikal), January-April 2009

This ring has been formed between 15 Jan and 1 Feb 2009

How much time is needed to form (sustain?) a ring?

Rings - how and why???

Possible explanations



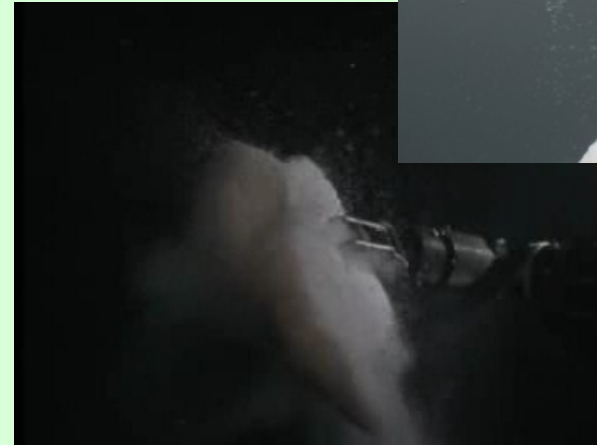
Atmospheric



Biologic



Esoteric



Methane

Next step: Ringspotting!

To understand: better measurements, parameterisation

Improve spatial resolution

Beyond visible range: thermal infrared, microwave

MODIS: after 2002

Landsat MSS, TM, ETM+:
after 1970ies

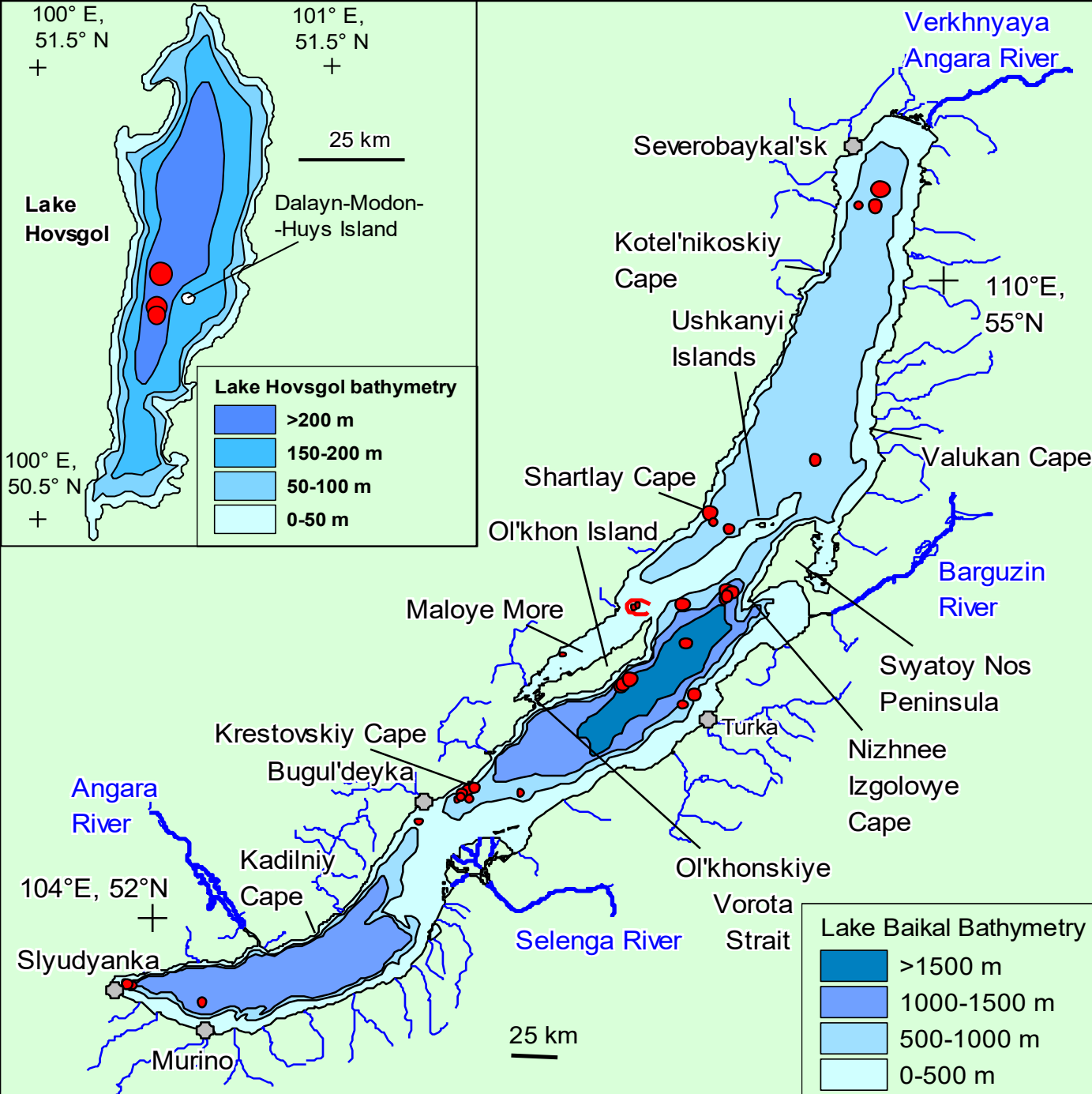
SAR (ENVISAT ASAR
and others)



Inventory

Baikal:
45 (13 known)

Hovsgol:
4 (0 known)



Inventory

Winter Name	Diameter, km	Lon E	Lat N	First seen ^a	Last seen ^a	Duration, days ^b	Depth, m	Form ^c	
1974	Shartlay C.	8.2	108.25	53.90	03/01	03/01	(1)	850	R
1974	Kotel'nikovskiy C.	2.4	109.14	55.02	03/01	03/01	(1)	850	DR
1975	N. Izgolovye C.	5.4	108.36	53.50	04/28	04/28	(1)	1550	DR
1975	Hovsgol	2.5	100.40	50.97	05/19	05/20	(2)	>200	R
1977	Krestovskiy C.	3.6	106.42	52.55	05/06	05/06	(1)	1050	DR
1985	N. Izgolovye C.	7	108.42	53.52	04/29	05/06	(1) ^d	1450	OR
1994	N. Izgolovye C.	6	108.38	53.51	04/10	04/16	(7)	1450	OR
1999	Krestovskiy C.	6.4	106.42	52.60	04/18	04/18	(1)	900	R
2000	Slyudyanka	5.6	103.83	51.68	04/27	04/27	(1)	750	R
2000	Severobaykalsk	5.4	109.37	55.35	05/15	05/15	(1)	750	R
2001	Krestovskiy C.	4.4	106.34	52.55	04/21	05/10	(20)	850	DR
2002	M. More North	7.6	107.70	53.46	04/19	04/26	(8)	400	E
2002	M. More South	3.4	107.14	53.24	04/19	04/26	(8)	60	R
2002	Olkhon East	7.6	107.58	53.09	04/26	04/26	(1)	1550	R
2003	Krestovskiy C.	5.2	106.45	52.60	04/03(4)	04/28(4)	26	950	R
2003	Off Krestovskiy C.	4.4	106.81	52.58	04/17(7)	05/08(1)	22	950	R
2003	Hovsgol	2.9	100.42	51.04	06/13	06/13	(1)	>200	R
2004	Krestovskiy C.	6	106.42	52.59	04/21(5)	05/02(3)	12	900	R
2005	Krestovskiy C.	5.6	106.45	52.61	04/15(1)	05/01(3)	17	900	R
2005	M. More North	4.6	107.68	53.46	05/01(3)	05/13(2)	13	370	R,H
2005	Olkhon East	7	108.07	53.29	05/13(5)	05/23(1)	11	1550	OR
2005	Ushkanyi Islands	6.4	108.40	53.83	05/21(4)	05/23(4)	3	650	R
2007	Murino	6	104.40	51.60	04/11(2)	04/24(2)	14	1150	R
2007	Valukan C.	5.4	109.01	54.16	05/11(5)	05/16(1)	6	770	R
2008	Hovsgol	2.2	100.40	50.95	05/17	06/02	17	>200	OR
2008	Turka	4.6	108.04	53.00	04/15(5)	04/22(11)	8	670	R
2008	Krestovskiy C.	5.4	106.39	52.59	04/10(2)	04/23(10)	14	850	R
2008	Slyudyanka	4.4	103.81	51.69	04/16(1)	04/30(3)	15	650	R
2009	N. Izgolovye C.	6.6	108.37	53.53	02/01(5)	05/03(1)	92	1350	R
2009	Slyudyanka	5.2	103.88	51.67	04/04(3)	04/27(2)	24	1050	R
2009	M. More North	3.8	107.70	53.47	04/04(3)	05/04(2)	31	370	R,H
2009	Turka	7.6	108.13	53.05	04/09(2)	04/29(4)	21	500	R,H
2010	Severobaykalsk N	7.6	109.55	55.42	01/31(9)	04/27(2)	87	750	R
2010	Severobaykalsk S	6	109.50	55.34	01/02(0)	05/07(4)	126	750	R
2010	Krestovskiy	4.6	106.35	52.57	04/21(2)	05/11(6)	21	950	R,H
2010	Bugul'deyka	4.8	106.04	52.45	04/21(2)	05/16(1)	26	450	R,H
2011	N. Izgolovye C.	8	108.38	53.53	04/15(2)	05/02(3)	18	1150	R
2011	Olkhon East	8	107.64	53.12	04/13(3)	04/26(5)	14	1350	R
2011	Krestovskiy C.	6.2	106.36	52.57	03/31(4)	04/27(4)	28	850	R
2012	N. Izgolovye C.	6	108.39	53.52	04/06(3)	04/28(1)	23	1450	R
2012	Olkhon East	7.6	107.59	53.09	04/06(11)	04/21(3)	16	1550	R
2012	Krestovskiy C.	6.8	106.37	52.58	04/06(7)	04/21(3)	16	850	R
2013	Krestovskiy C.	4.8	106.36	52.56	04/18(2)	05/04(2)	17	900	R,H
2013	Sv. Nos - Olkhon	7.6	108.04	53.47	04/29(5)	05/13(2)	15	750	R
2013	Shartlay C.	5.4	108.27	53.85	05/07(3)	05/19(2)	13	850	OR
2014	Krestovskiy C.	6	106.47	52.61	04/17(1)	04/22(4)	9	850	DR
2014	N. Izgolovye C.	7	108.38	53.50	04/01(2)	04/23(3)	23	1450	R
2015	Valukan C.	5.6	109.18	54.13	05/08(1)	05/10(3)	3	650	OR
2015	Hovsgol	6.2	100.45	51.03	05/20	05/29	(10)	>200	OR

The most complete inventory

Not a new phenomenon (1970ies)

Rings with small depths -
no gas release origins

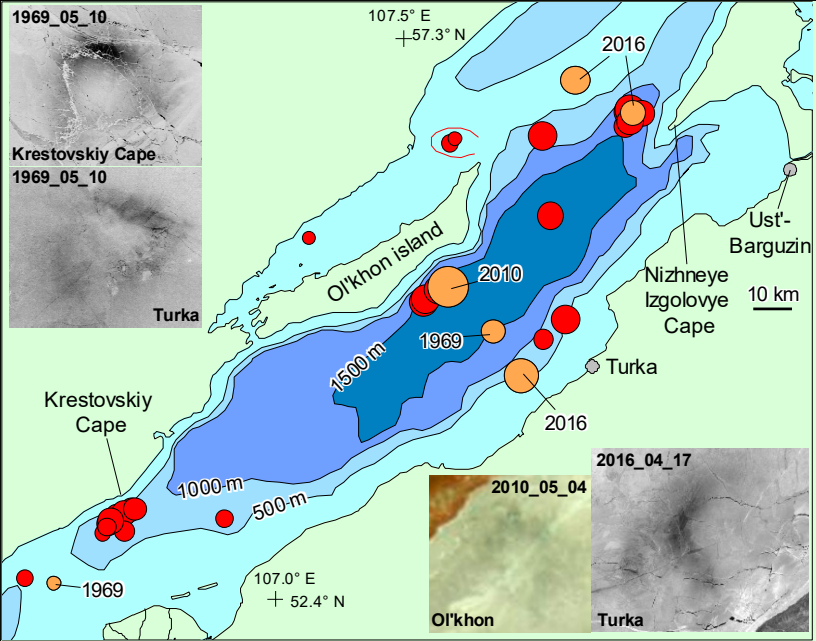
Duration 5-10 days (1-126 days)

Most frequently - April (Jan-May)

N. Izgolovye and Krestovskiy Capes

Inventory of ice rings
and their characteristics

Kouraev et al., Limnology and Oceanography, 2016



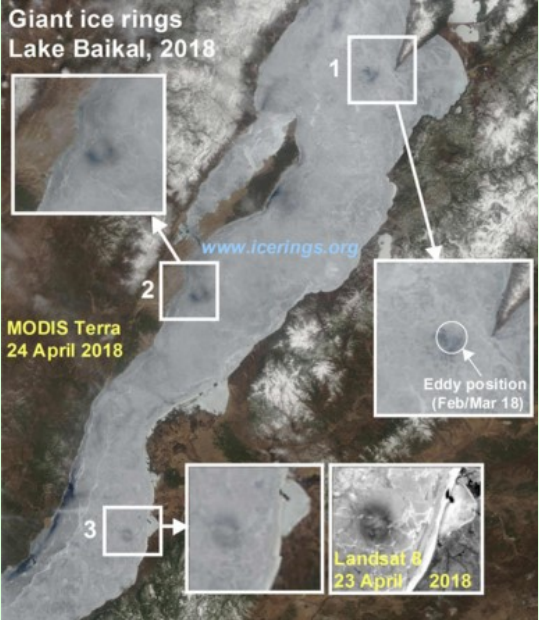
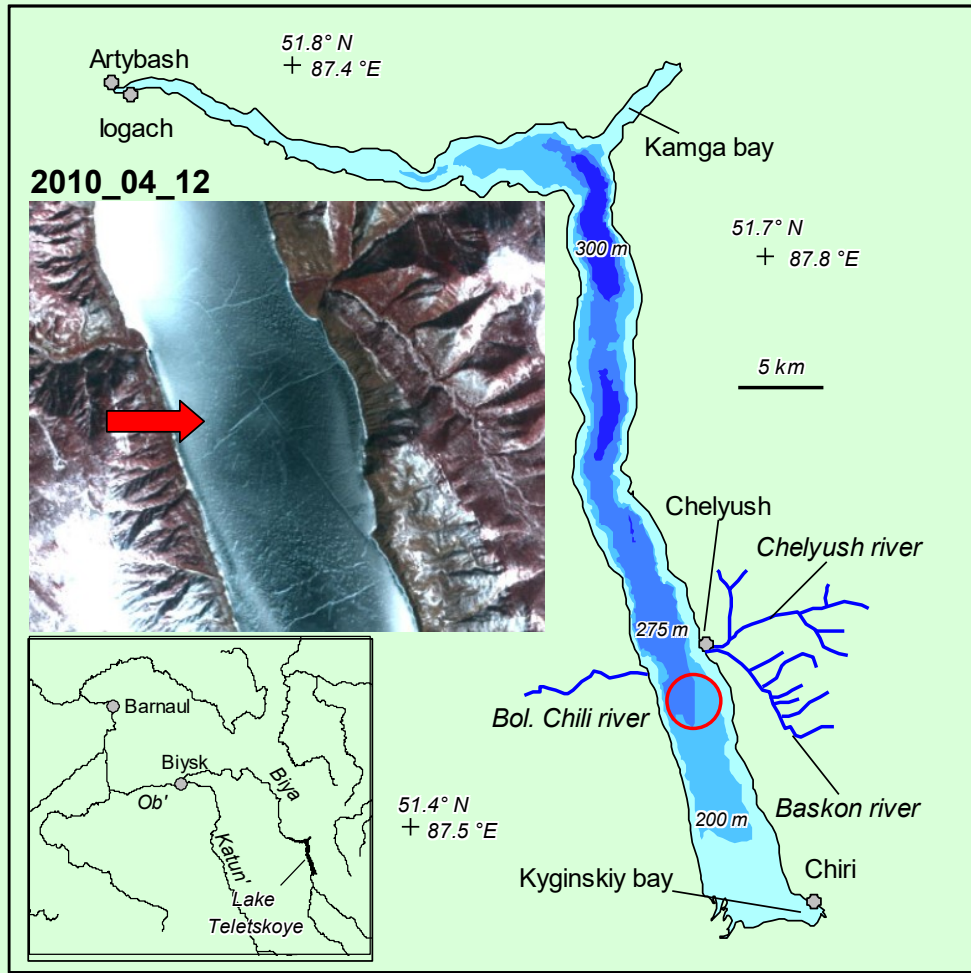
As early as 1969

51 rings for Baikal +5 in 2018-19



New rings

Baikal, Hovsgol and now...
Teletskoye lake!



From ringspotting to ring hunting: dedicated field campaigns

*"Can't rely on anyone these days,
you have to do everything yourself..."*
(Joker in "The Dark Knight", 2008)



Dedicated projects:

2011- **CNES TOSCA** "Lakelce"

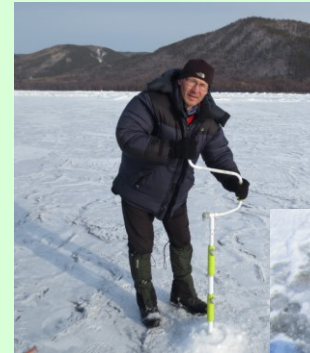
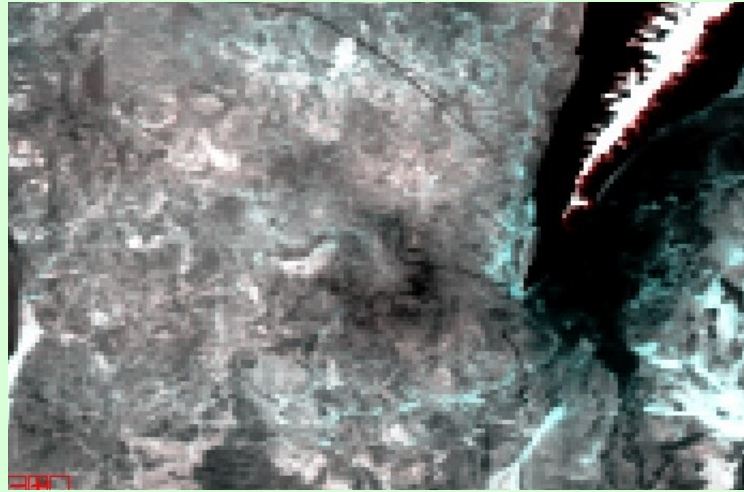
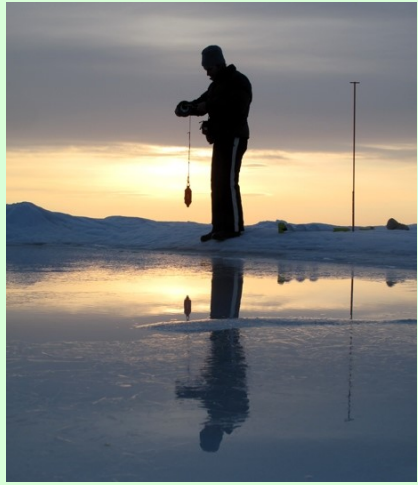
2012-15 **PICS CNRS-Russia** - "BaLaLaICA - BAikal and
LAdoga LAkes - Integrated Cooperation Activities

2012-15 **RFBR** Project "Studies of Ladoga and Baikal lakes"

2016-17 **ERA.Net RUS Plus S&T** Project "ERALECC -
EuRAsian Lakes in Extreme Climate Conditions"

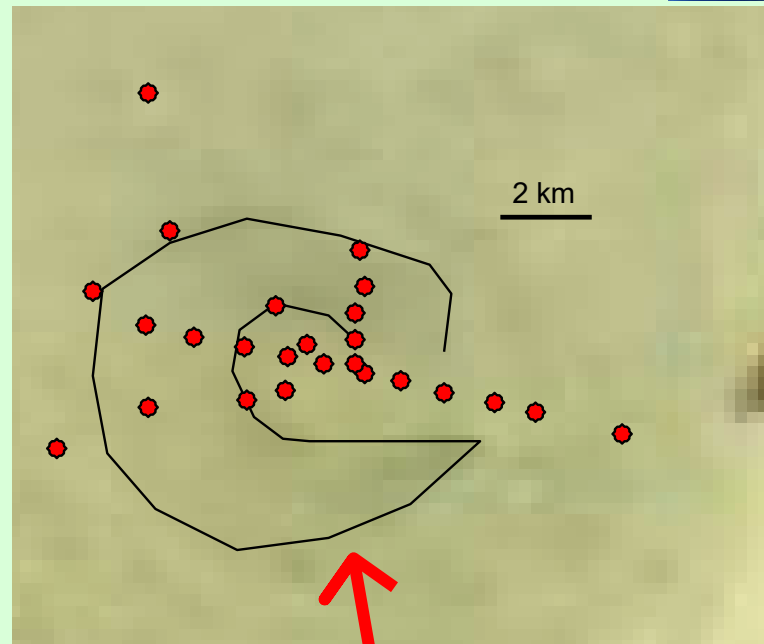
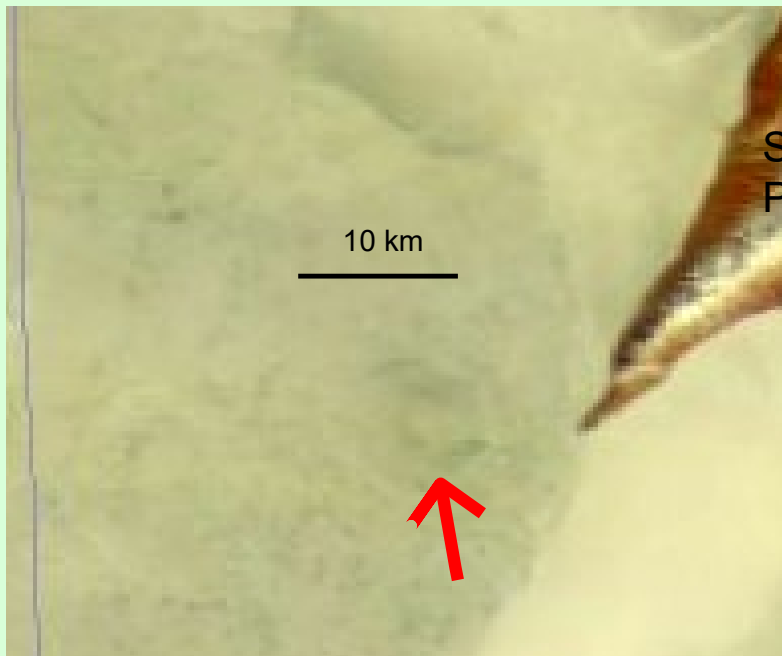
2017-19 **RFFI-RGO** "Water exchange in deep lakes on the
example of Lakes Issyk-Kul and Baikal"

Ice rings in 2012 and 2014



5-7 April 2012

MODIS 21 April 2012



Lens-like eddy

Exist before and during ice ring appearance

Anticyclonic (clockwise) currents

Increased melting at eddy boundary

Ice rings - surface manifestation of eddies

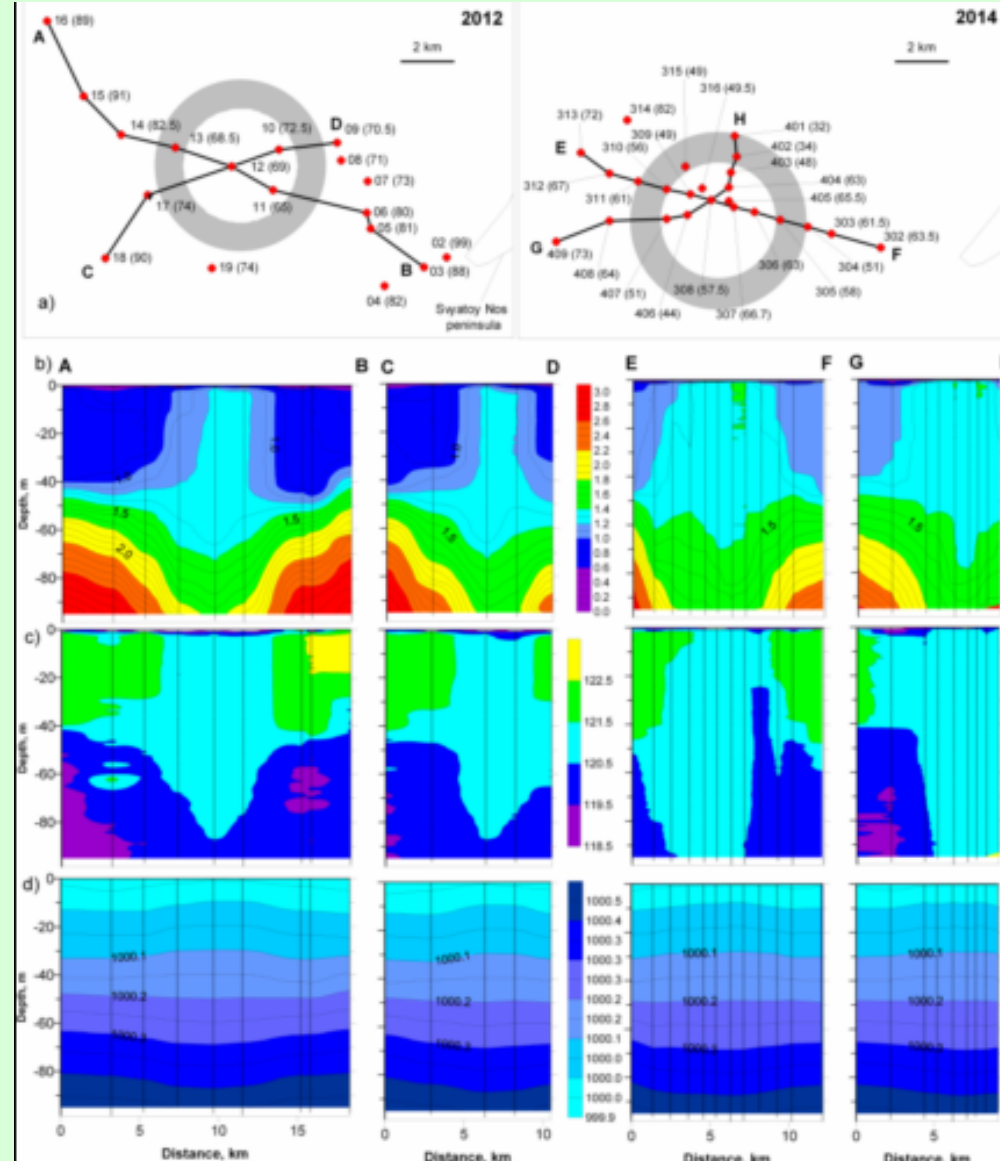
Eddy origin - combination of coastal currents, bathymetry, wind forcing, seiches, river input etc

Eddy formation - during ice cover presence or before ice formation?

Need for dedicated studies

Anomalous water structure

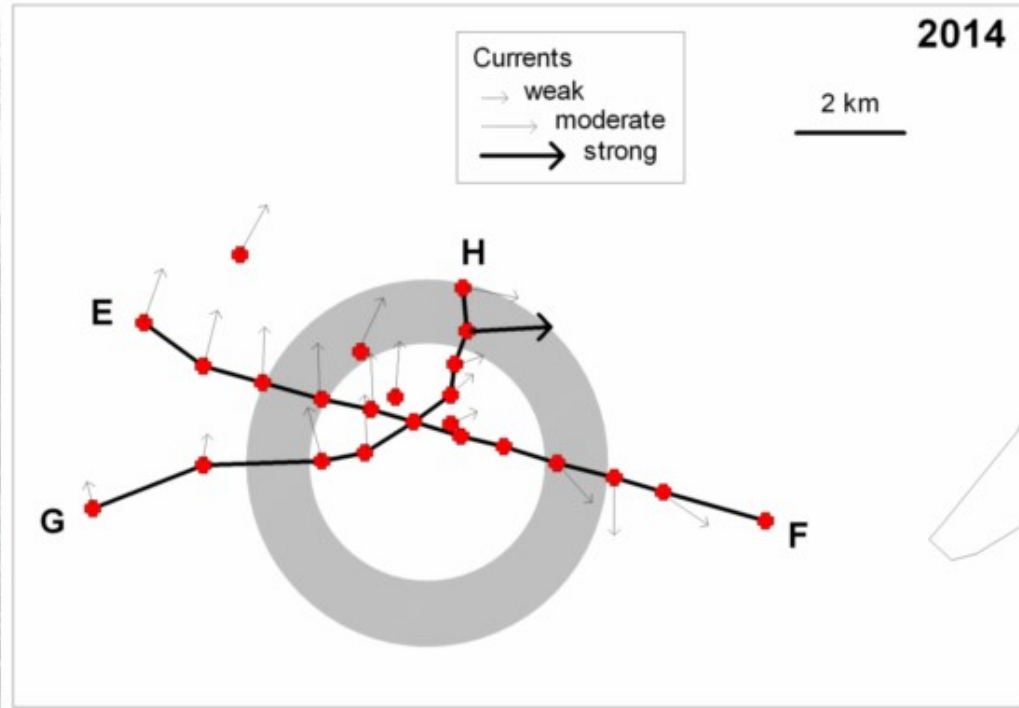
Nizhneye Izgolovye



Ice structure and currents

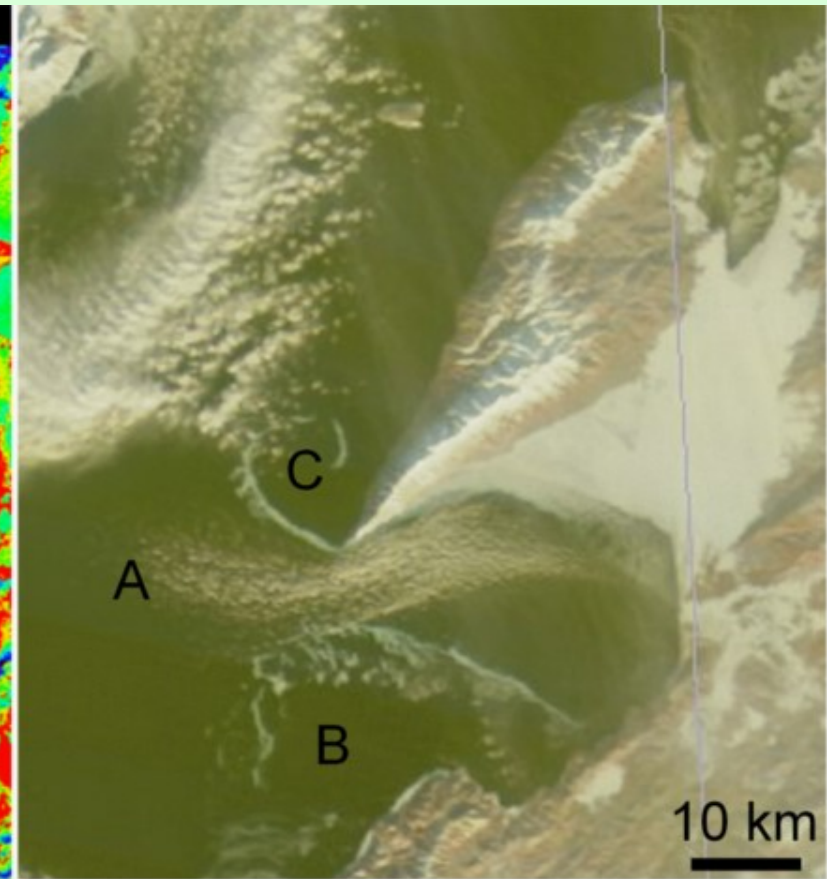
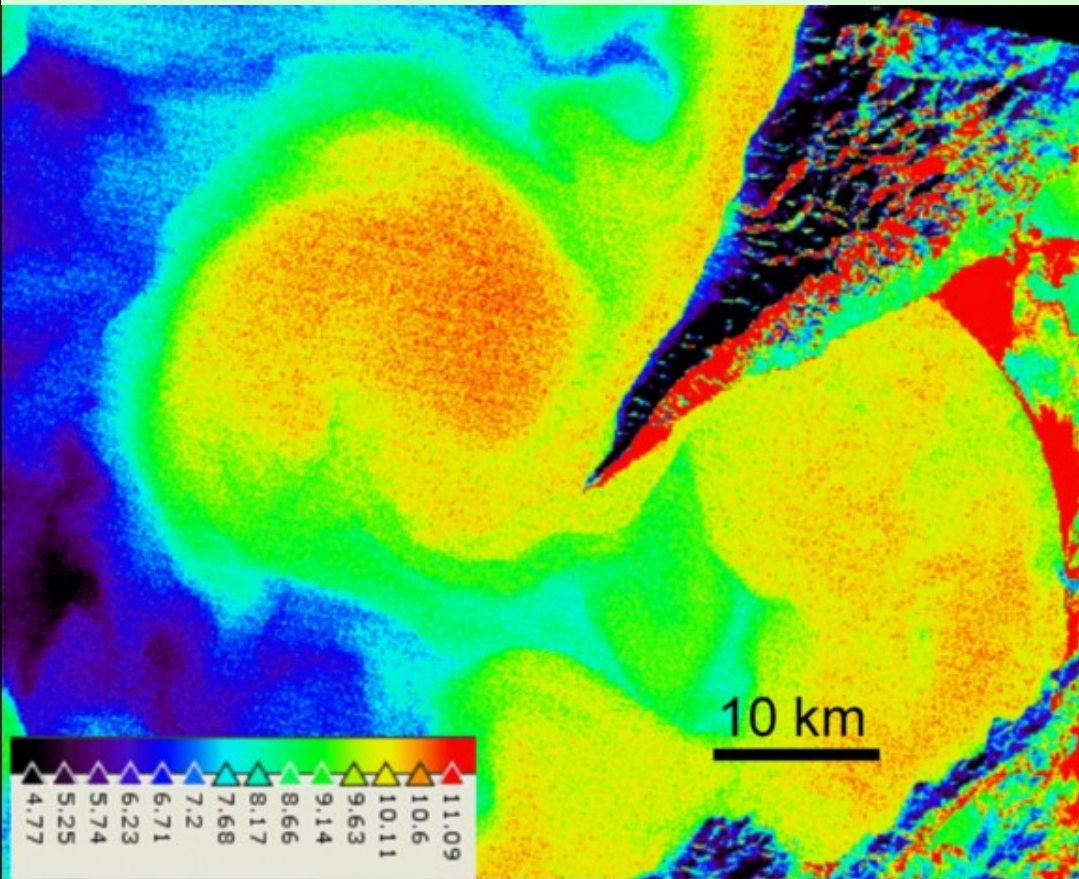


Crystals size - 10-12 cm long,
2-3 cm thick), 3 April 2014



Currents 3-4 April 2014

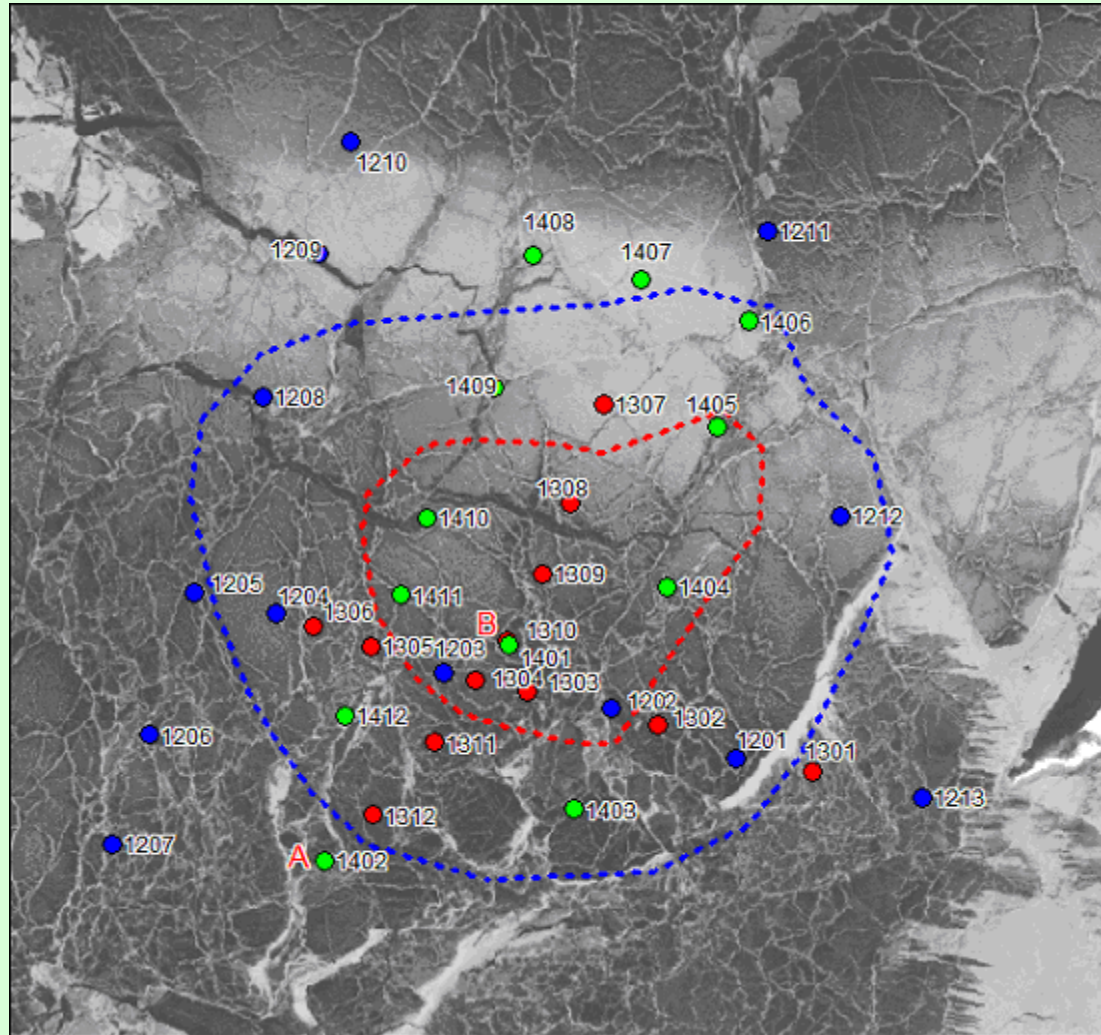
Water dynamics



**Landsat TIR 26 September 2002
-anticyclonic warm eddy.**

MODIS 31 December 2011

February 2016



14 Mar



3 Apr



7 Apr

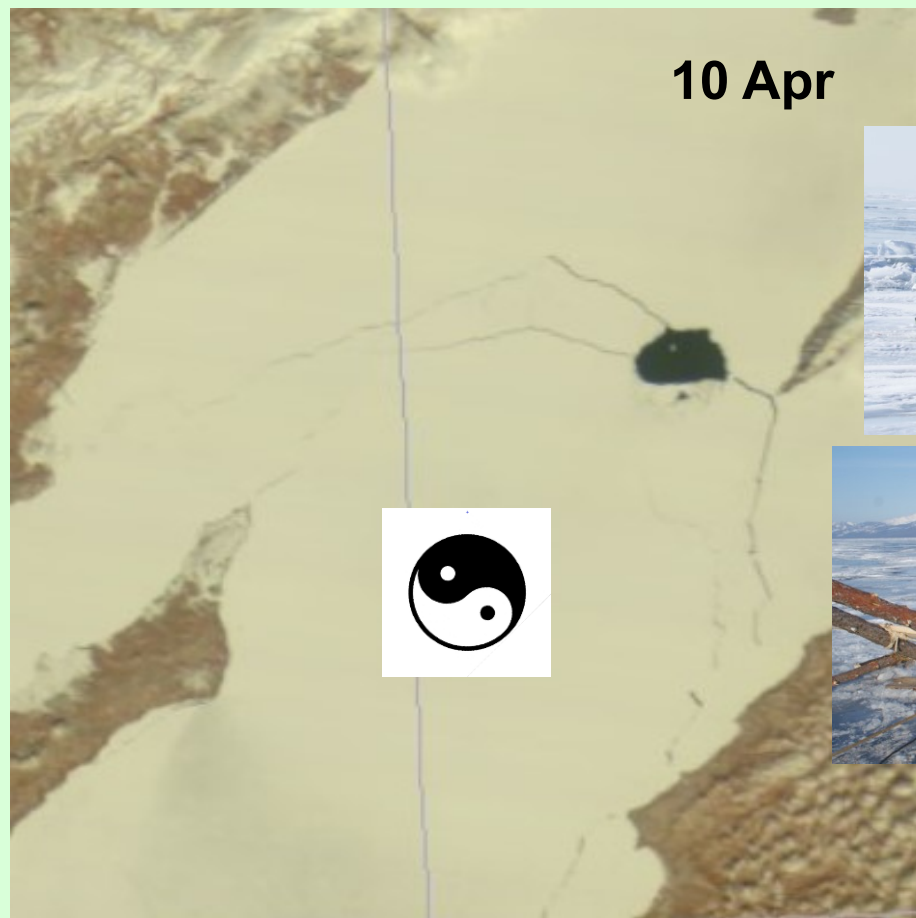


Ice ring 2016

8 Apr



10 Apr



9 Apr



*UAZ trapped in ice and
rescue activities, March 2016
(c) A. Beketov*

March 2016



Communication: administration

Ministry of emergency (EMERCOM)
Barguzinskiy National Park



Communication: normal people

Booklet on ice rings and the associated danger

www.icerings.org:

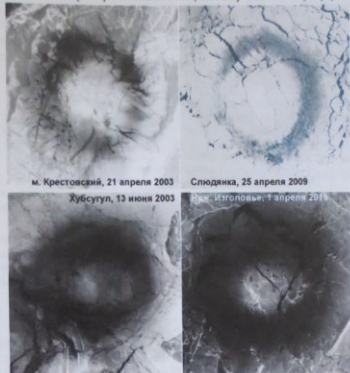
communicating

on ice rings, near real time ice conditions

THE WORLD OF THE ICE RINGS

Collecting information from fishermen, tourist operators and local people

Рис. 1. Примеры ледовых колец для озёр Байкал и Хубсугул



ЛЕДОВЫЕ КОЛЬЦА
БАЙКАЛА И ХУБСУГУЛА
В ВОПРОСАХ, ОТВЕТАХ
И КАРТИНКАХ



Рис. 2. Даже опытный водитель может попасть в переделку: УАЗ, застрявший в районе ледового кольца около м. Нижнее Изголовье, 18 марта 2016 г. © А. Бекетов.

www.icerings.org

Eddies - new monitoring strategy

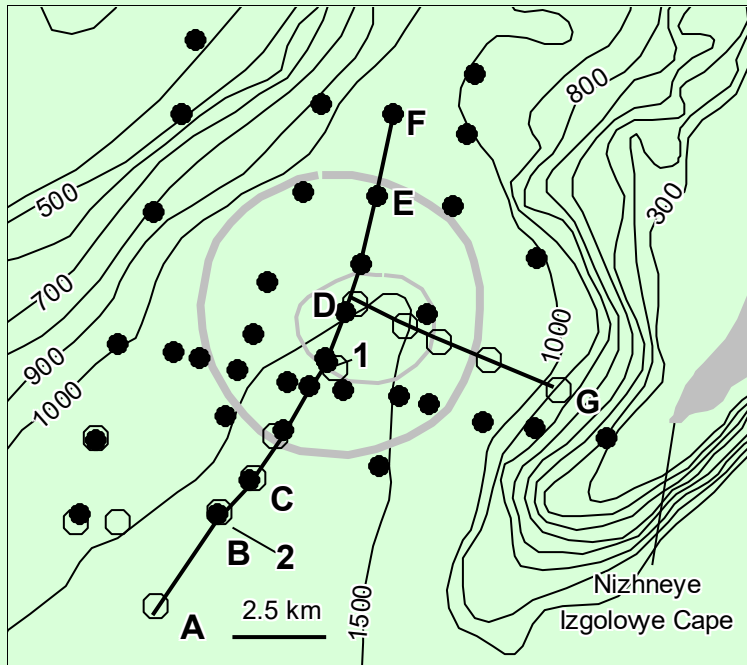
Mid-February and end of March

Current meters (tilt-meters and EM)

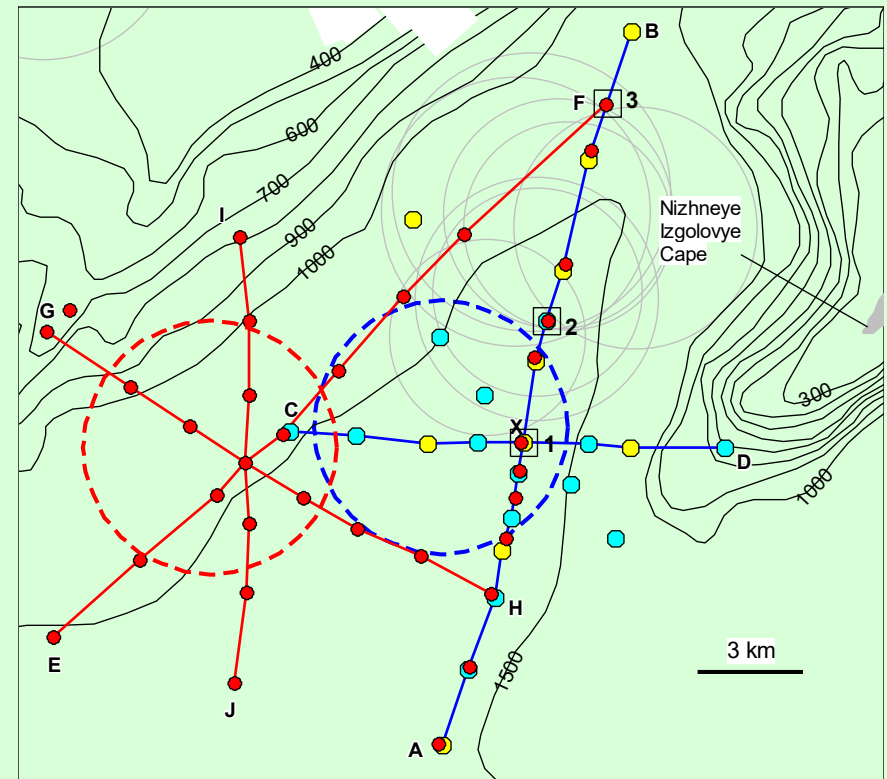
Measures down to 200 m

Ropes with thermistors and current meters (1.5 month)

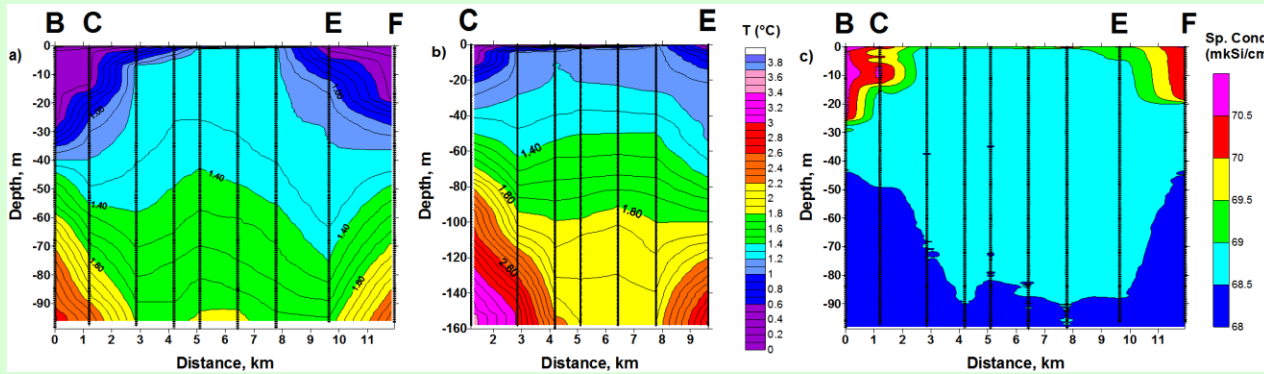
2016 - eddy in February and March



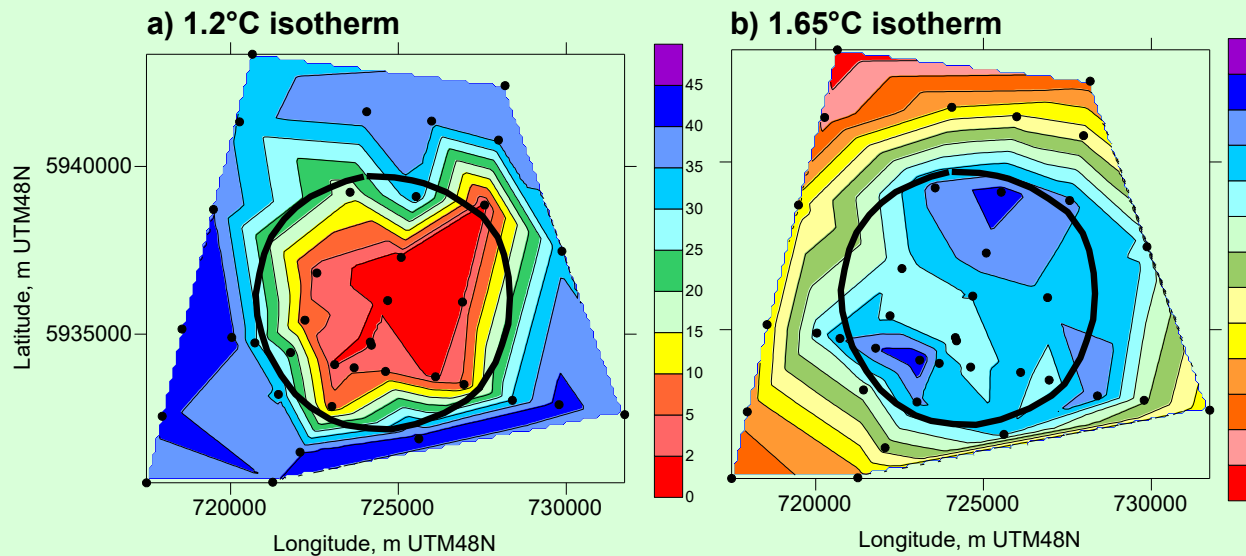
2017 - eddy in February, moved by March



February
2016

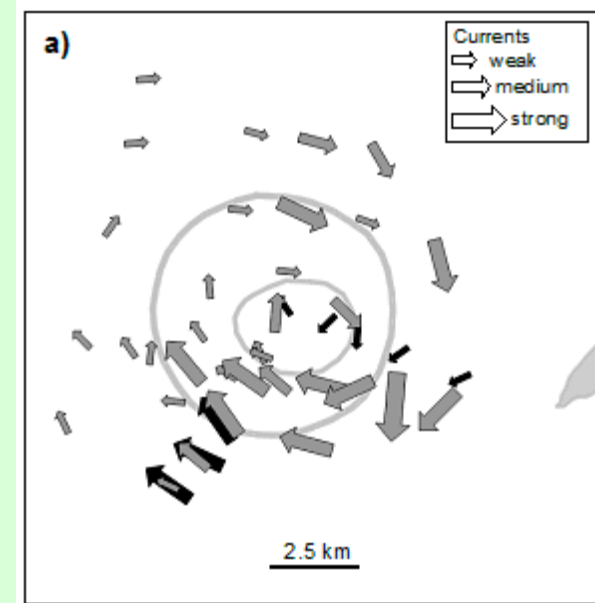


Temperature 100 and 160 m, Sp. Conductivity 100 m

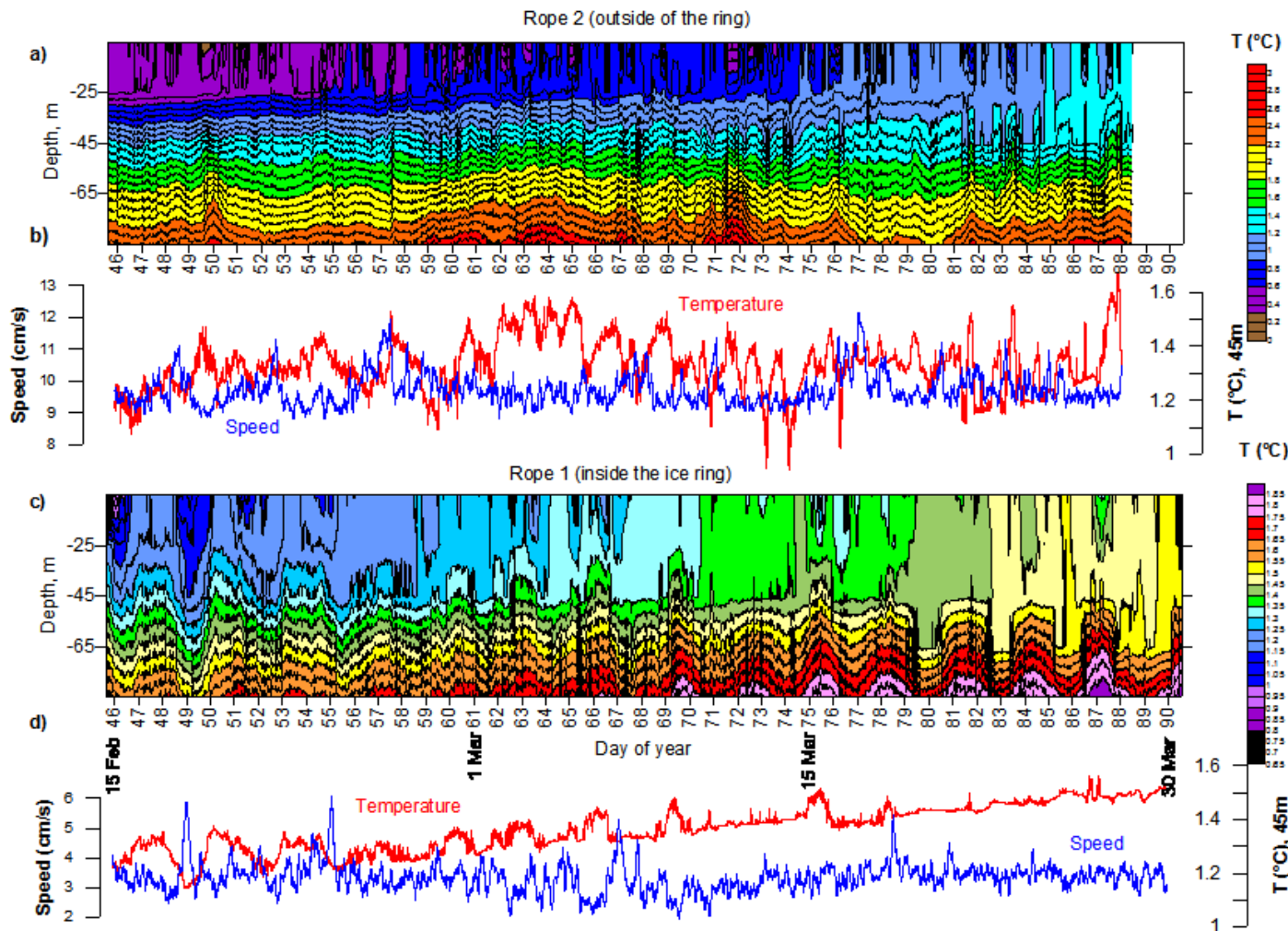


Depth of isotherms

Lower part - isotherms are affected on a larger area
Neutral layer - 10-12 km (upper part and ice ring - 6 km)



Currents



**T °C
evolution**

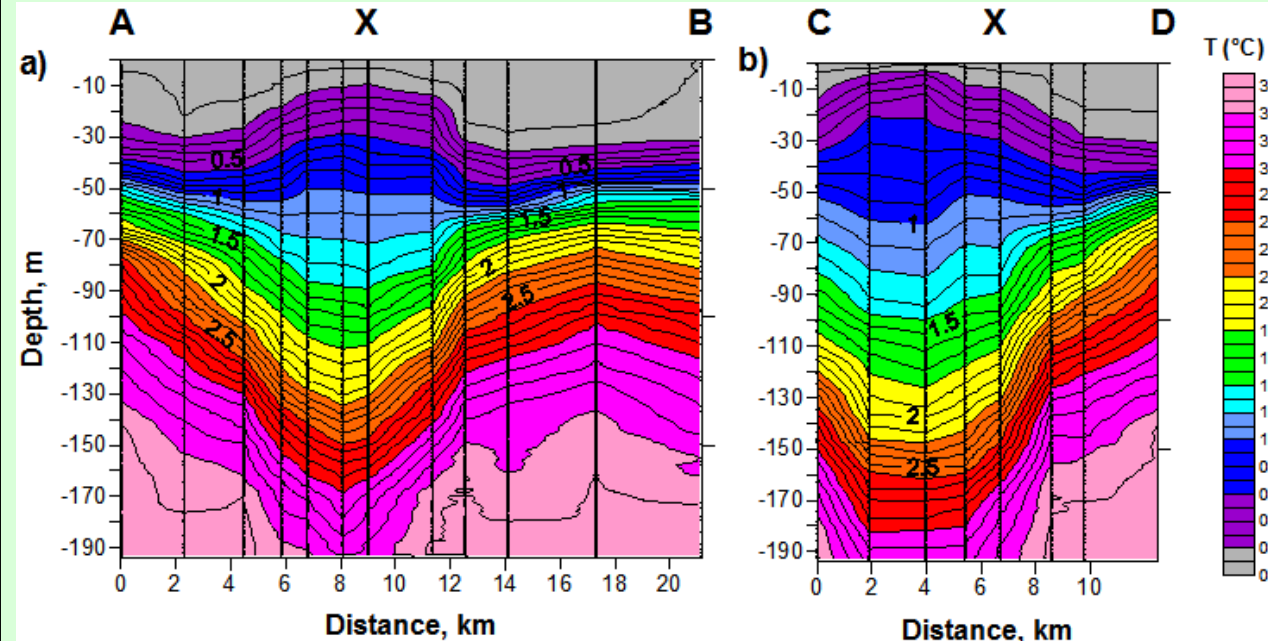
Eddy: different evolution in upper and lower part
3 days period - 1 km from eddy center - 3.39 cm/s
(confirmed by current meter - 3.35 cm/s on average)
Rotation of not perfectly symmetrical eddy

2017

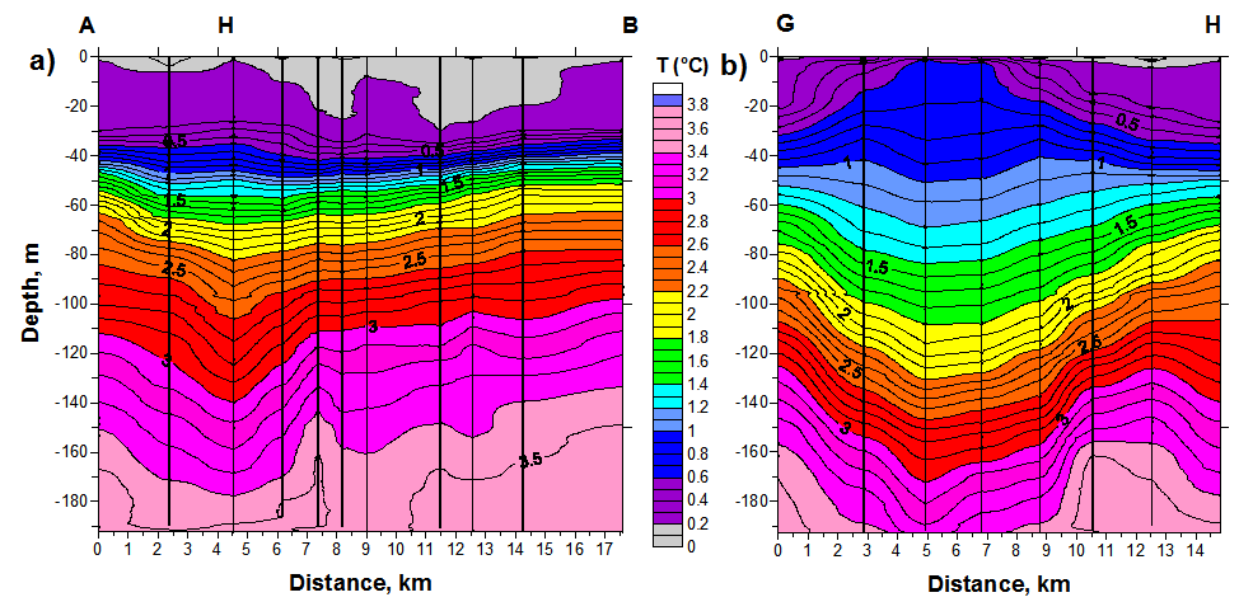
Eddy found in February
Affecting depths 200 m
and more

"Disappeared" and
found 6 km west

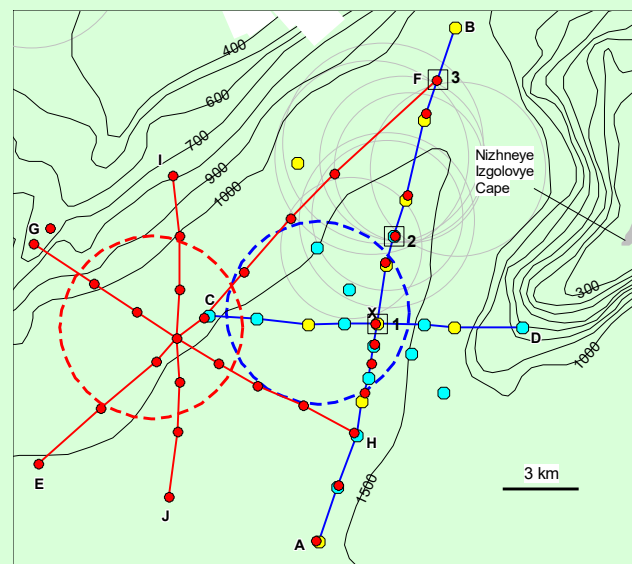
No ice ring in 2017



February



March

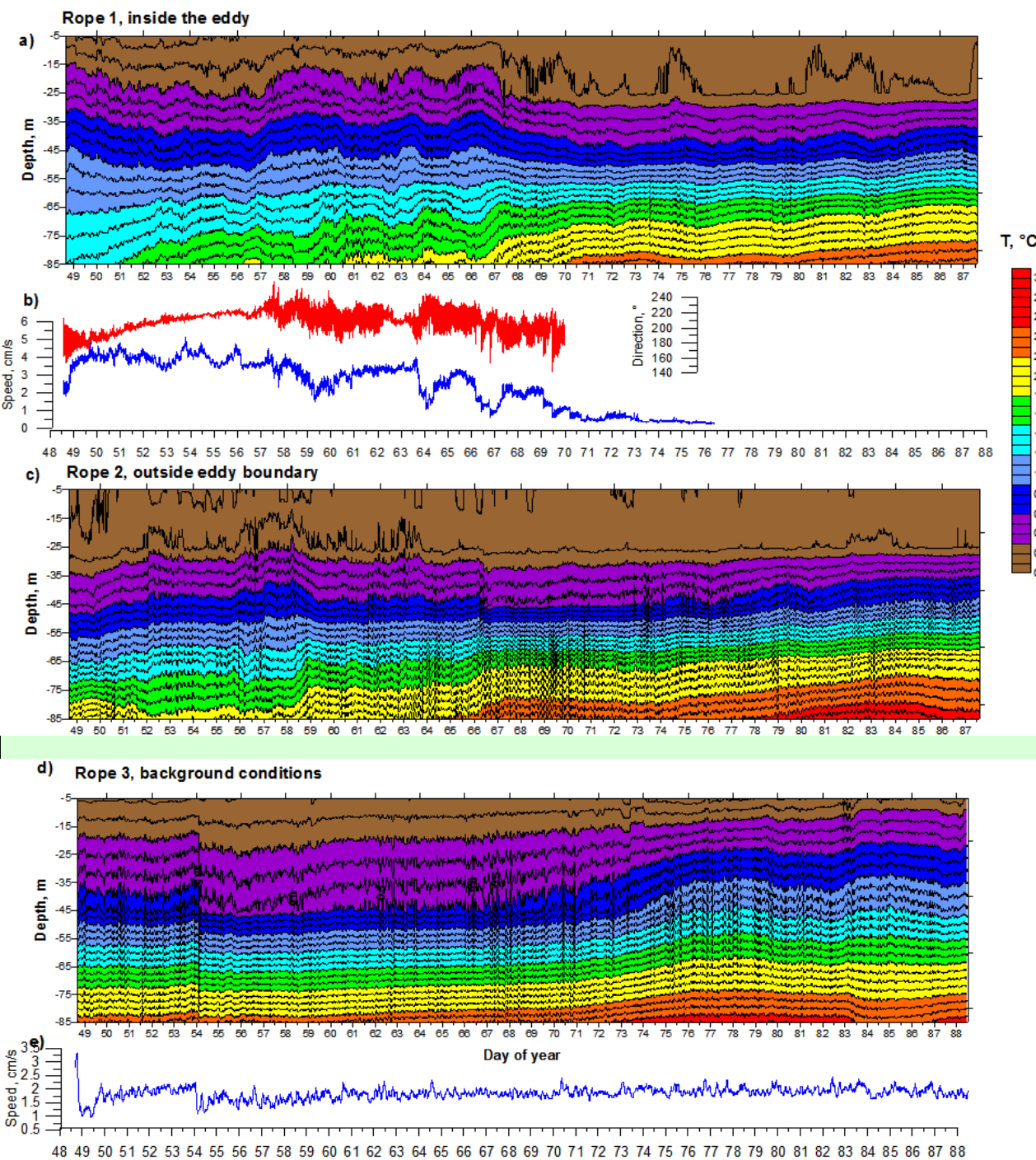


Ropes 2017

Eddy - back and forth movements, changes in speed

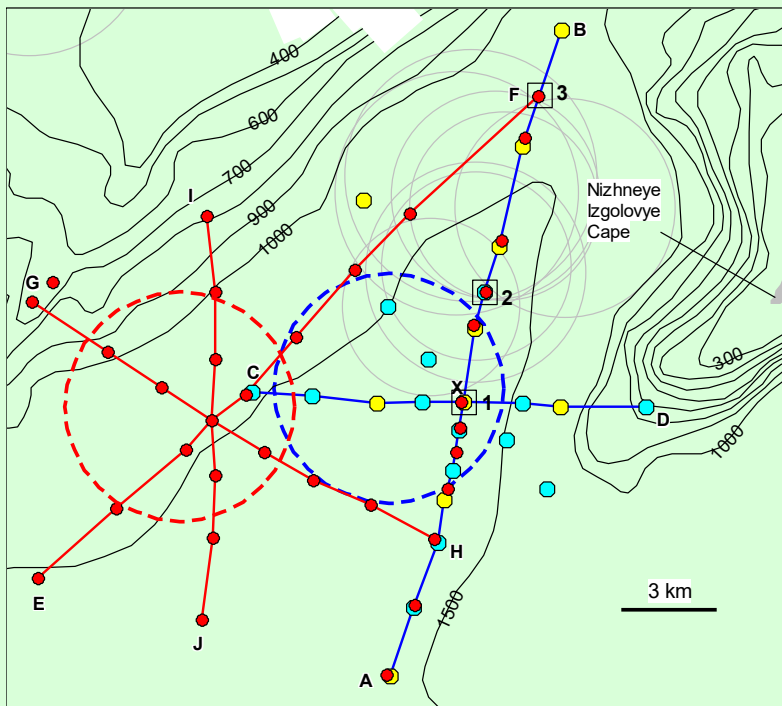
Less affected but still evident

Gradual evolution, ice rafting (4 m)



Travelling eddy

Depth between 0.3 and 1.2 °C - proxy
of distance to eddy center.
Triangulation.

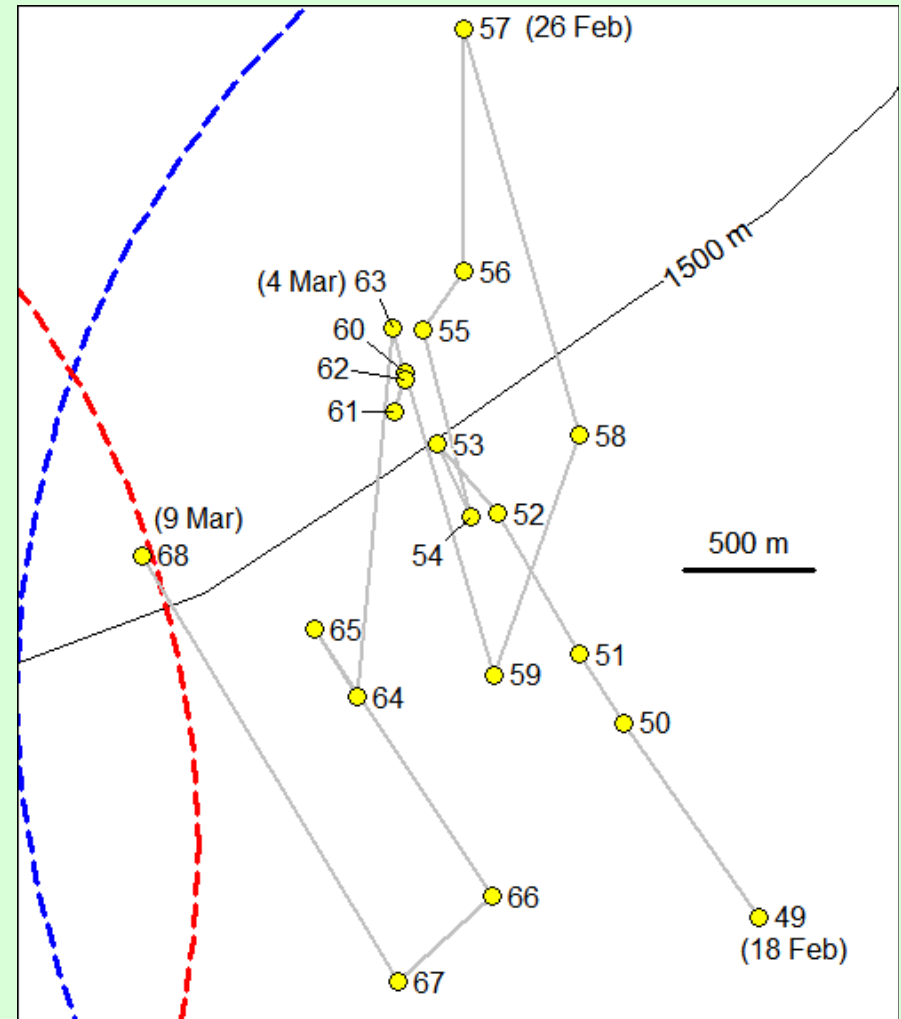


Back and forth movement

Periods of quasi-stable
position and rapid movement

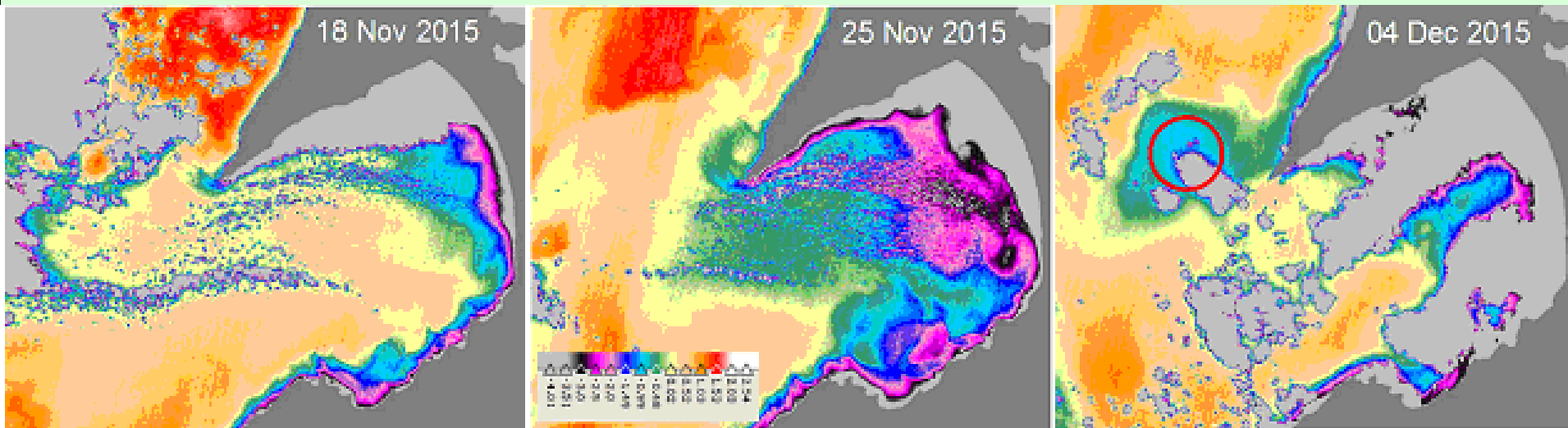
Up to 1400-1600 m/day (1.6-1.8
cm/s - comparable to
background speed)

Tangible proof of eddy
movement



Eddy formation?

Nov-Dec 2015: constant 2.5-3 m/s wind from ESE (58%) or SE (11%)



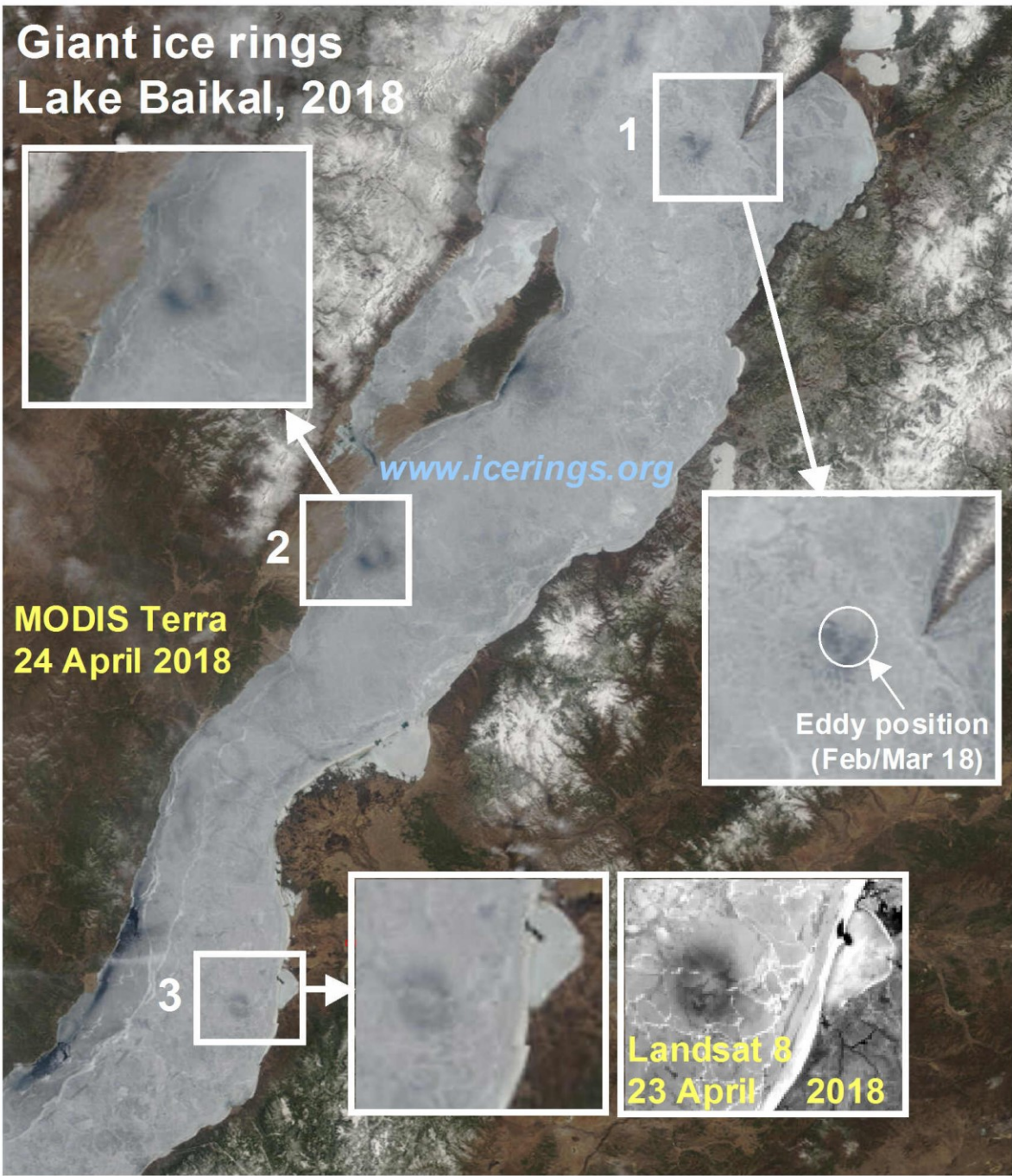
Landsat thermal imagery (light grey - clouds)

Outflow of cold (light) water from the Barguzin bay

Surface eddy with cold water - exactly where we found eddy and ice ring was formed on March 2016.

Further studies of exchange between Barguzin bay and open part of the lake are needed (ropes, surveys)

**Giant ice rings
Lake Baikal, 2018**



**April 2018:
three giant
ice rings**

**One ring is
exactly in the
eddy region -
as predicted!**

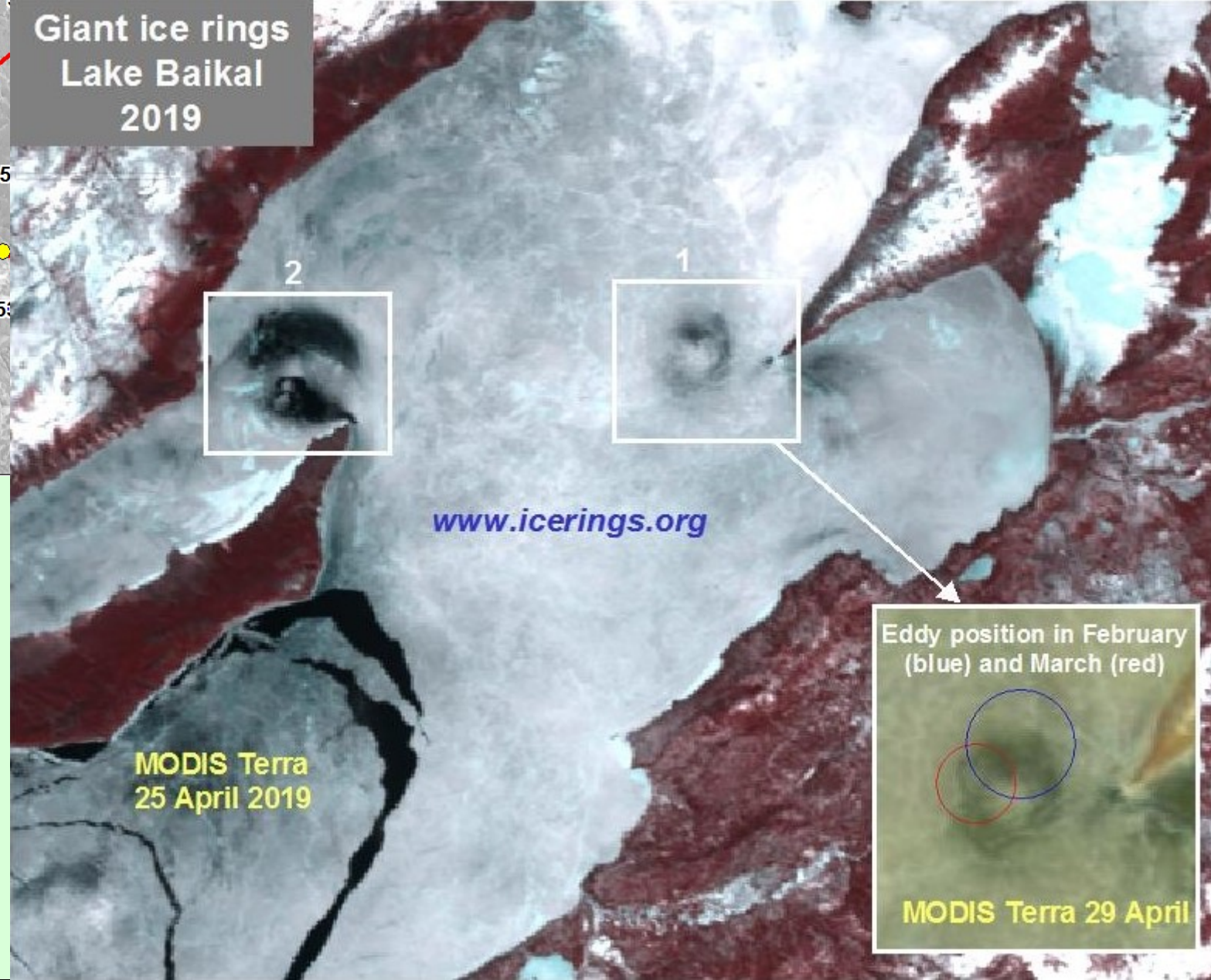
**Two rings are in
places never
observed before**

2019

мыс Нижнее Изголовье
Cape Nizhneye Izgolovye

53.5222°N 108.227°E
**Giant ice rings
Lake Baikal
2019**

53.5234°N 108.298°E
53.5055°N 108.285°E
53.484°N 108.3°E
Direct to Khoboy
Направление на Хобой



MODIS Terra
25 April 2019



Unique long-term results of eddies observation

New data on eddy shape, rotation, displacement

Ice cover - perfect opportunity to study lens-like eddies (stationary or moving) as compared to seas or ocean



Better understanding of eddies generation

Wind-driven generation of the eddy

Formation in autumn, between vertical overturning and ice formation

Baikal, Hovsgol, Teletskoye - what lake(s) will be next?