Atmospheric and oceanic phenomena in Lake Baikal visible from space on SAR and optical images

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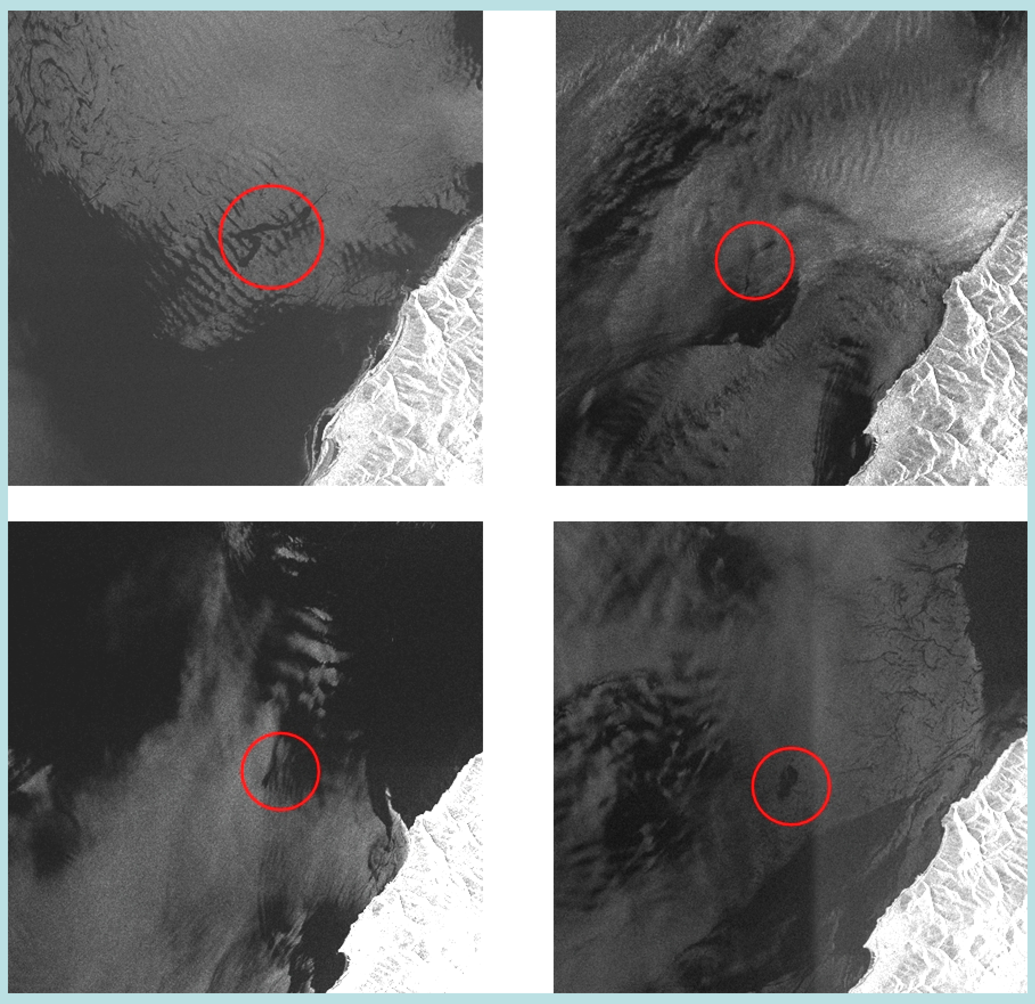

Figure 1. Evidences of seepage activity in Lake Baikal as seen on the Sentinel-1A SAR images acquired on: 18.05, 30.05, 11.06 and 30.06.2015 (slick area from 0.4 to 5 sq. km). © ESA

Lake Baikal in the Russian Federation, the deepest and unique lake in the world, represents itself specific hydrological and weather regimes as well as different natural phenomena. Among unique those there are oil & gas seeps, local winds, and giant ice rings. These phenomena leave pronounced footprints both on the lake surface and in the ice cover. Some of them are typical for inland or semi-closed seas, whereas others are specific for large lakes. These phenomena can be imaged, mapped and studied by remote sensing, and in particular by combined use of synthetic aperture radar (SAR) and optical images. Most of them for the first time were discovered in satellite imagery. An opportunity of routinely acquired SAR images of Sentinel-1A and Landsat-8 help studying them from space allowing the extraction of a number of useful characteristics and features. The most distinct examples are presented and analyzed with purpose to emphasize the uniqueness of Lake Baikal, which is sometimes considered as a marine laboratory.

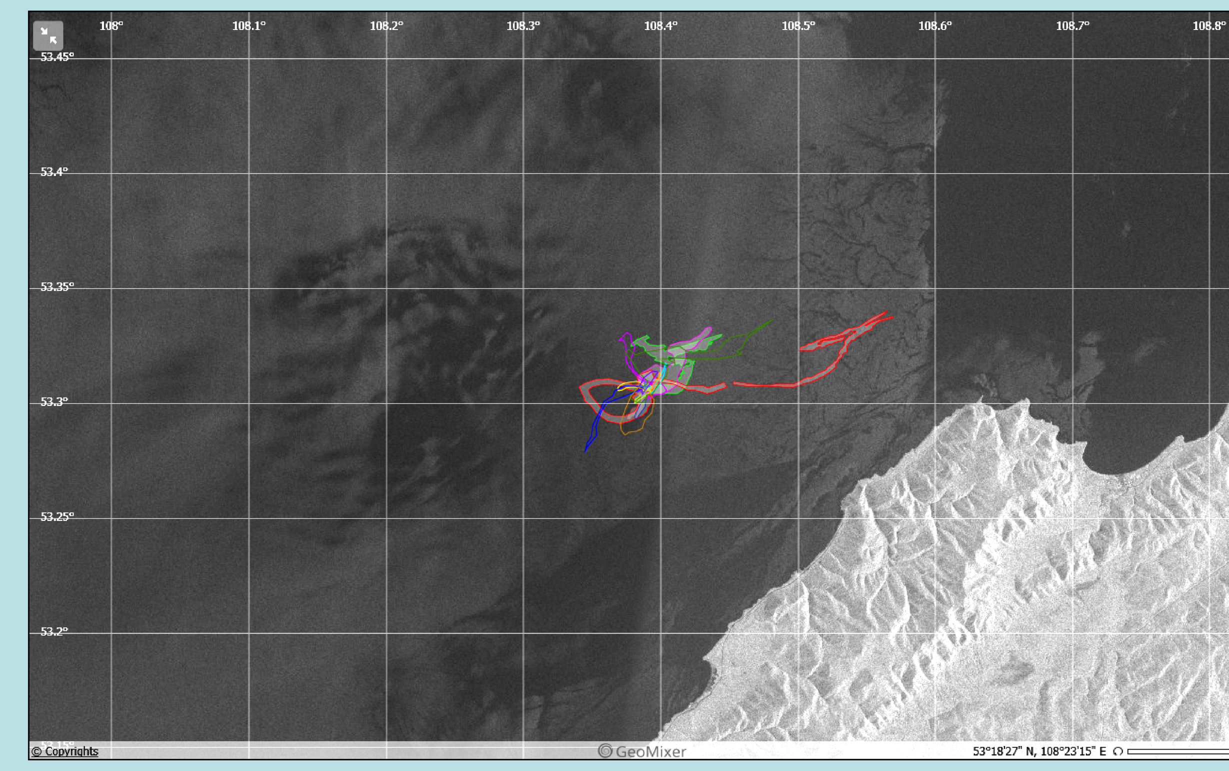

Figure 2. Summary map of all oil slicks detected over the seep located off Cape Gorevoy Utes in the Middle Baikal on the background of Sentinel-1A SAR image. © ESA, SCANEX

1. SEEPAGE OIL IN LAKE BAIKAL: Signs of oil and gas in Lake Baikal are known from the beginning of XVIII c. Oils, bitumens and gases in coastal deposits were found out for the first time by local hunters and fishermen. Today bottom oil seep in Lake Baikal is well-known near Cape Gorevoy Utes (depth ~860 m), and for the first time it was discovered on the MODIS image acquired in 2005 [1-3].

A number of expeditions of Limnology Institute of RAS and Irkutsk University worked on a detection place. In July-September of 2008 during immersions in Lake Baikal of underwater manned vehicle MIR belonging to IO RAS, a number of places on the bottom, where crude oil naturally seeping, has been investigated. By expert estimations from source opposite to Gorevoy Utes arrives about 4 ton of oil per year [3]; and it is considered that oil is completely absorbed by microorganisms, and does not pollute the lake.

Figure 3. Oil seep slicks visible though the ice on the Landsat-8 optical image of 4.05.2013. © USGS, SCANEX

Nevertheless, it was very interesting to study this phenomenon by remote sensing methods. The analysis of the oil slicks detected on ERS-2 and Envisat SAR images in 1998 and 2005, which obviously were related to this oil seep, has been done in [1]. By this study a link of oil slicks observed on the lake surface with processes of hydrocarbons migration in Lake Baikal sediments has been established. In 2015 oil slicks have been detected in the same place on Sentinel-1A SAR images. Sub-scenes of Sentinel-1A SAR images, on which oil slicks off Gorevoy Utes in the form of dark patches of various forms clearly visible, are shown on fig. 1. The size and form of these slicks strongly depend on hydrometeorological conditions, i.e., prevailing currents and wind blowing during imaging (fig. 2). In the conditions of ice cover the oil accumulating under ice can be visible in optical images of the high resolution (fig. 3).

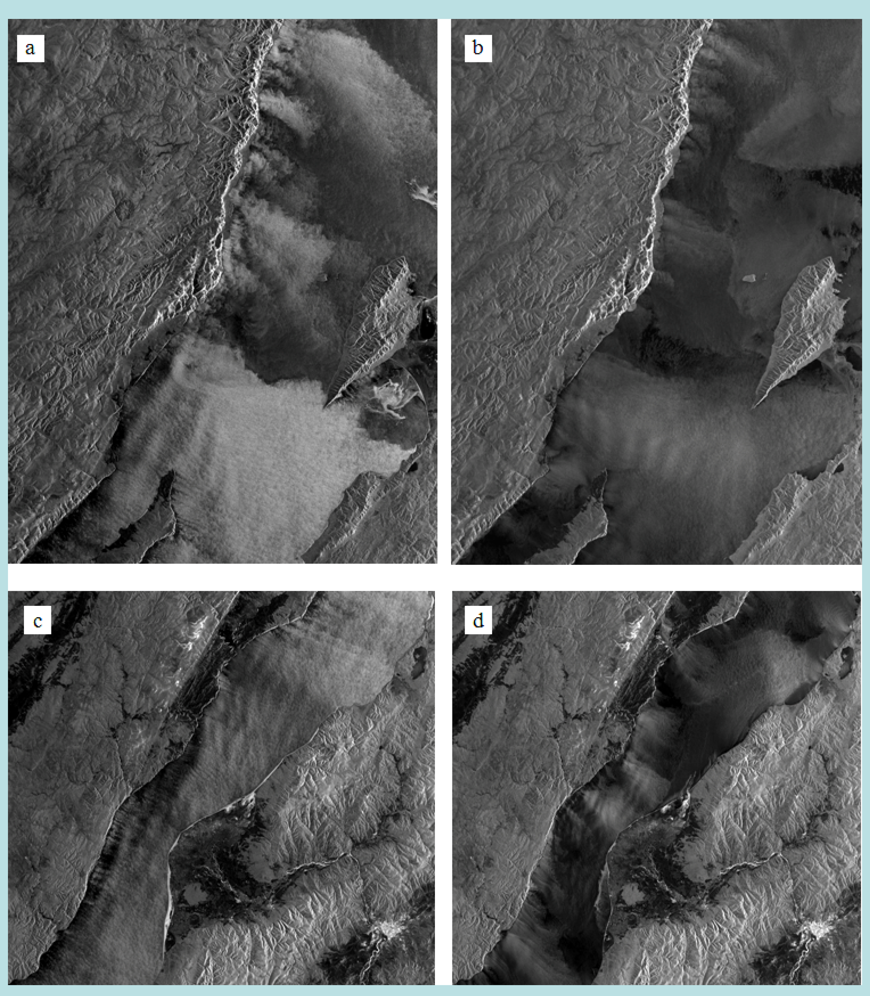

Figure 4. Bora-like local NW (mountainous) winds as seen on the Sentinel-1A SAR images acquired on: 13.12 (a, b), 14.10 (c) and 1.12.2014 (d). © ESA

2. LOCAL WINDS: Lake Baikal represents itself very complicated regime of local variable and treacherous winds. The Baikal's local winds, blowing in various directions, have more than 30 names for winds that suddenly appear and blowing both along and across the lake. These strong winds leave pronounced footprints on the lake surface, as local winds do, for example, in the coastal zones of the Adriatic Sea and the Black Sea [1].

On fig. 4 and 5 a number of examples how local winds are displayed on the SAR images of Sentinel-1A are shown. The strong wind locally enhances intensity of small-scale surface waves that leads to the increased backscatter. At known wind direction (orientation of wind strips) its speed can be easy retrieved using CMOD model [1]. On fig. 4 it is well visible that jets of cold mountainous air "jump out" onto the lake from the west/northwest, and depending on wind speed and the general synoptic situation can look as "tongues" or «cones» (fig. 4a,b,d). It also can appear as a series of numerous transversal strips, covering all lake surface (fig. 4c). Local wind Barguzin (fig. 5) "jumps" from a valley of the Barguzin River in the form of a local jet, which form depends on the general circulation; it either propagates across the lake, turns to the north (fig. 5a) or to the south (fig. 5b). Sometimes there are situations when both winds meet each other in the central part of the lake (fig. 5c,d).

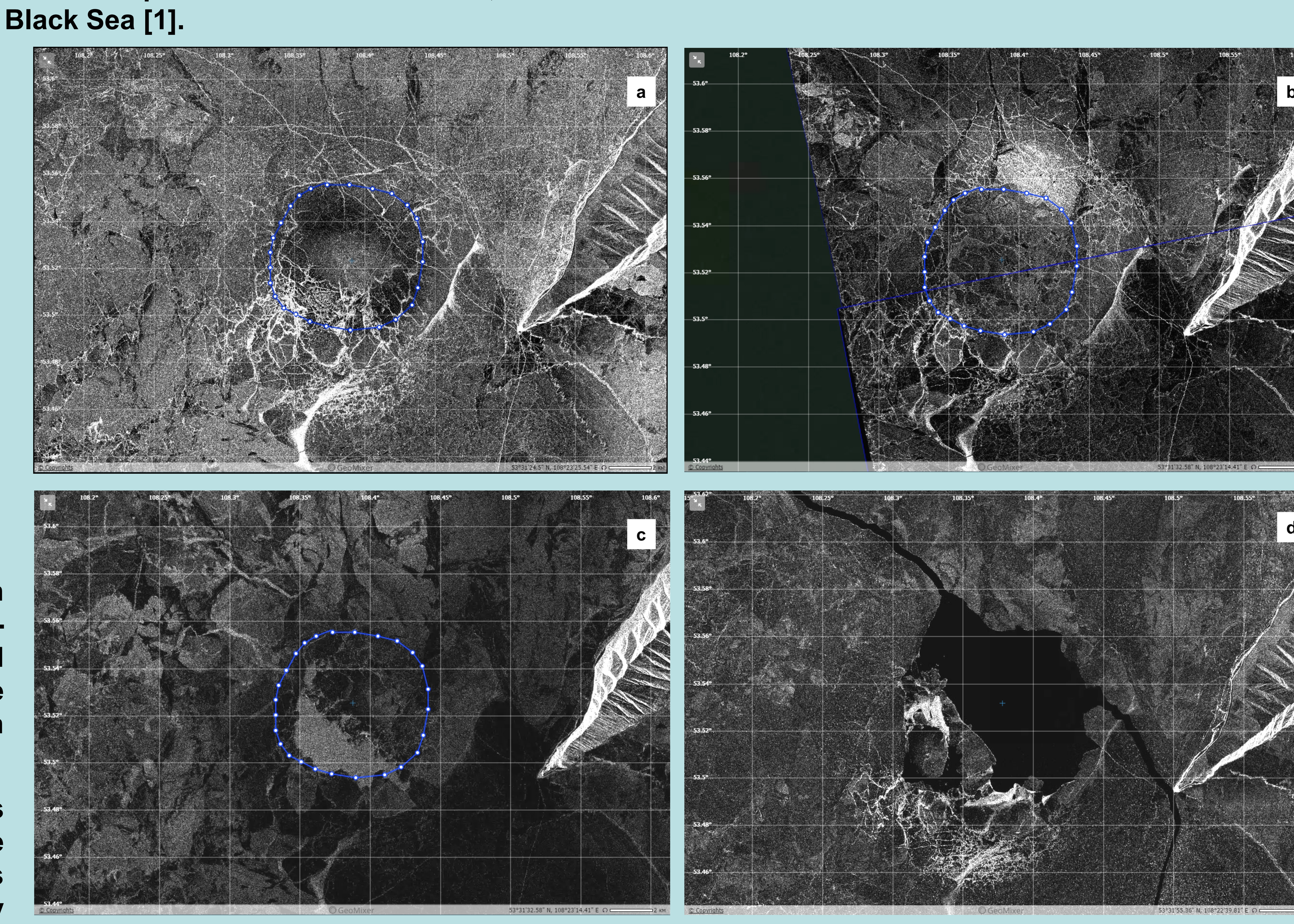

Figure 7. Dynamics of the ice ring nearby Cape Nizneye Izgolovie on a series of the Sentinel-1A SAR images acquired on: 25.03.2016 (a), 31.03.2016 (b), 5.04.2016 (c) and 13.04.2016(d); blue circle shows the ring location as seen on optical images. © ESA

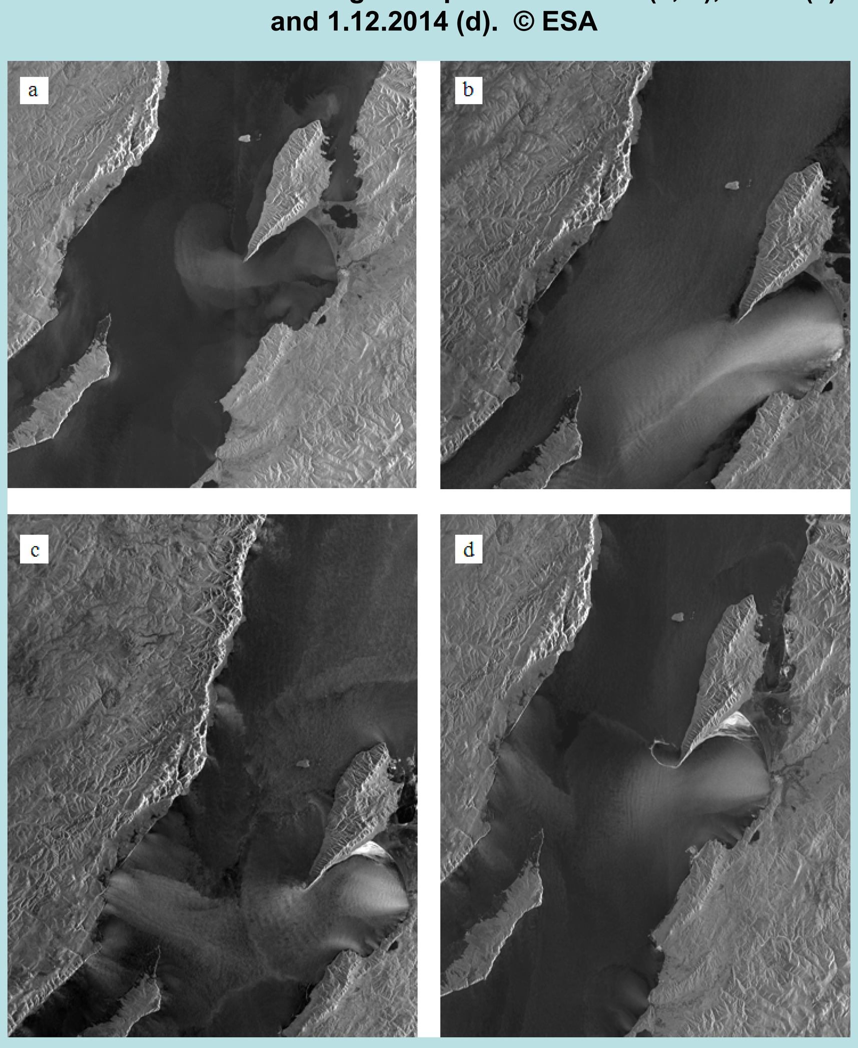

Figure 5. Barguzin local wind as seen on the Sentinel-1A SAR images acquired on: 21.10 (a), 26.10 (b), 1.12 (c) and 8.12.2014 (d) . © ESA

3. ICE RINGS: According to the collected satellite imagery, the giant ice rings on Lake Baikal are not formed every year; after the definite detection in 1999, well-developed ice rings were detected in 2003, 2005, 2007, 2008, 2009, 2013 and 2014. The typical diameter of the rings is 5-7 km that depends on the environment conditions. Fig. 6,7 show typical examples of detected ring in optical images in 2016.

This year ring appeared in Lake Baikal in middle Mach (fig. 6); its main features are early appearance, asymmetry and fast development. And for the first time the ice ring was imaged with SAR (fig. 7). It is worth to mention that SAR images show a net of cracks definitely associated with the ring. Most spectacular they are visible on color polarimetric image composed from Sentinl-1A polSAR images acquired on VV and VH (fig. 8). It ended its life as a ring on April 7.

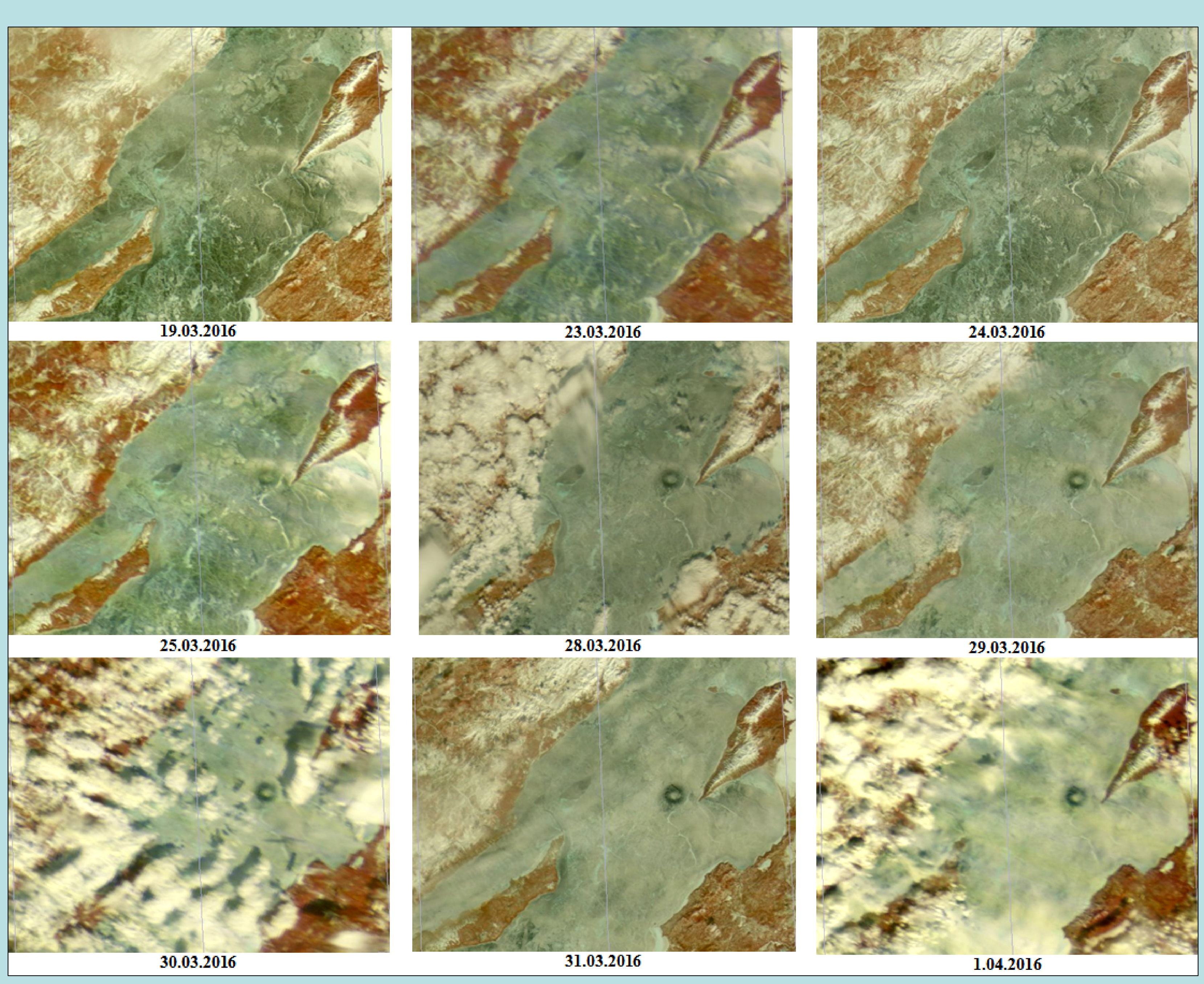

Figure 6. Sequence of MODIS images showing development of ice ring nearby Cape Nizneye Izgolovie (Middle Baikal) in March 2016. © NASA, SCANEX, Irkutsk EOStation

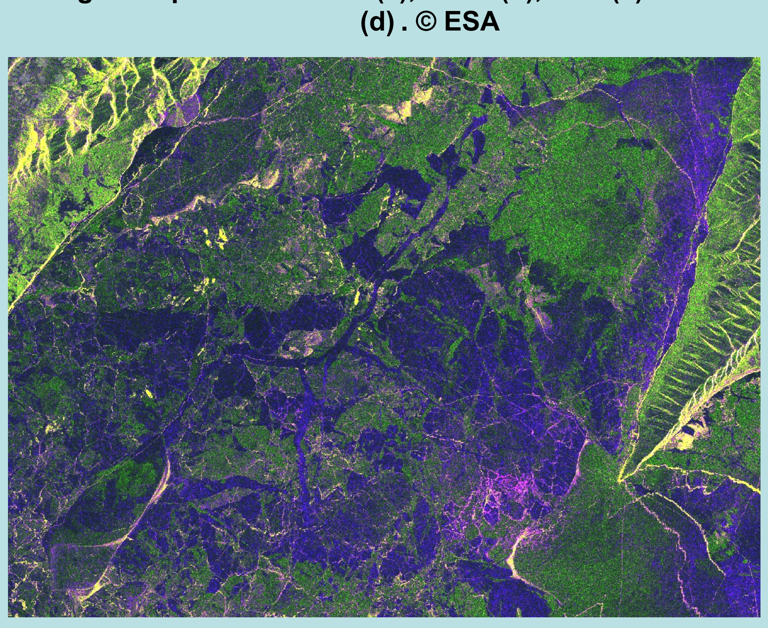

Figure 8. Color polarimetric image composed from Sentinel-1A SAR data (VV+VH) acquired on 13 March 2016 (23:05 UTC) showing a crack pattern around the ice ring (in violet). © ESA

The visibility of the ice rings in visible range is quite different than that on the SAR images, due to the physical mechanisms involved. In the visible bands (reflected sunlight) an ice ring consists of a white ice center, where the ice is thicker, and a ring proper (dark circular band), where the ice is thinner (fig. 6). Whereas in SAR imagery ring can be seen in a field of ice surface roughness only (fig. 7, 8).

The mechanisms of the ring formation are not well understood yet. But 'methane' mechanism [1] most likely is thing of the past. Per Kouraev et al. [2,3] and Granin et al [4] the ice rings are surface manifestations of warm anticyclonic eddies generated beneath the ice cover due to local circulation. Bearing in mind coastlines and local bottom topography, analysis of collected SAR and optical images also allowed us went to the same conclusion. Main evidence is a generation of eddies in the same place in ice-free conditions that from time to time is visible on optical, IR and SAR images (fig. 9). Moreover, peripheral cracks exclusively visible on SAR images may indicate about local subsidence in the ice cover over the eddy (fig. 7, 8).

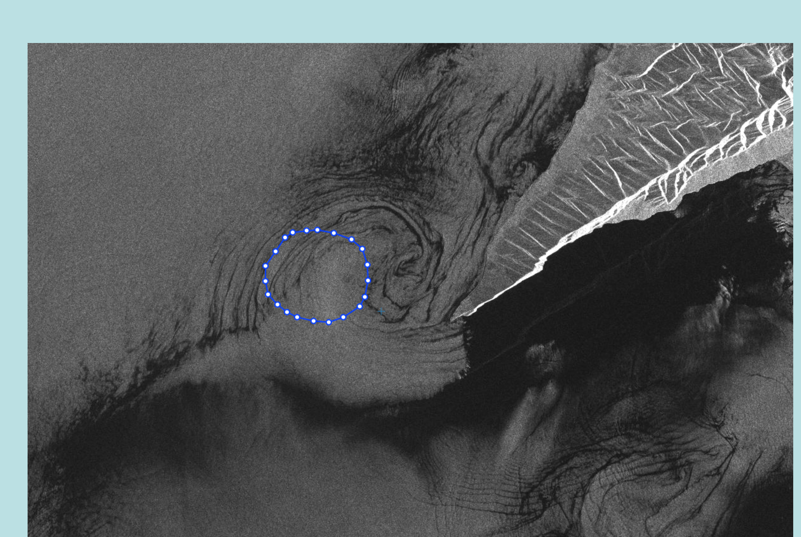

Figure 9. Overlapping of anticyclonic eddy visible on the Envisat SAR image (4.08.2005) and an contour of ice ring detected in 2014. © ESA

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CONCLUSION: The recent Sentinel-1A and optical images acquired over Lake Baikal have been analyzed with purpose to study different marine and atmospheric phenomena. This approach allowed revealing much more details of the phenomena under investigation than other data do. In conclusion, the use of multi-sensor SAR and optical images is the best way to study and monitor different phenomena occurred in large lakes.

Useful references:

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