Novaya Zemlya bora over the Eastern Barents Sea studied from space using Sentinel-1A SAR Images

Andrei Ivanov and Nadezda Terleeva

P.P. Shirshov Institute of Oceanology, Russian Academy of Sciences

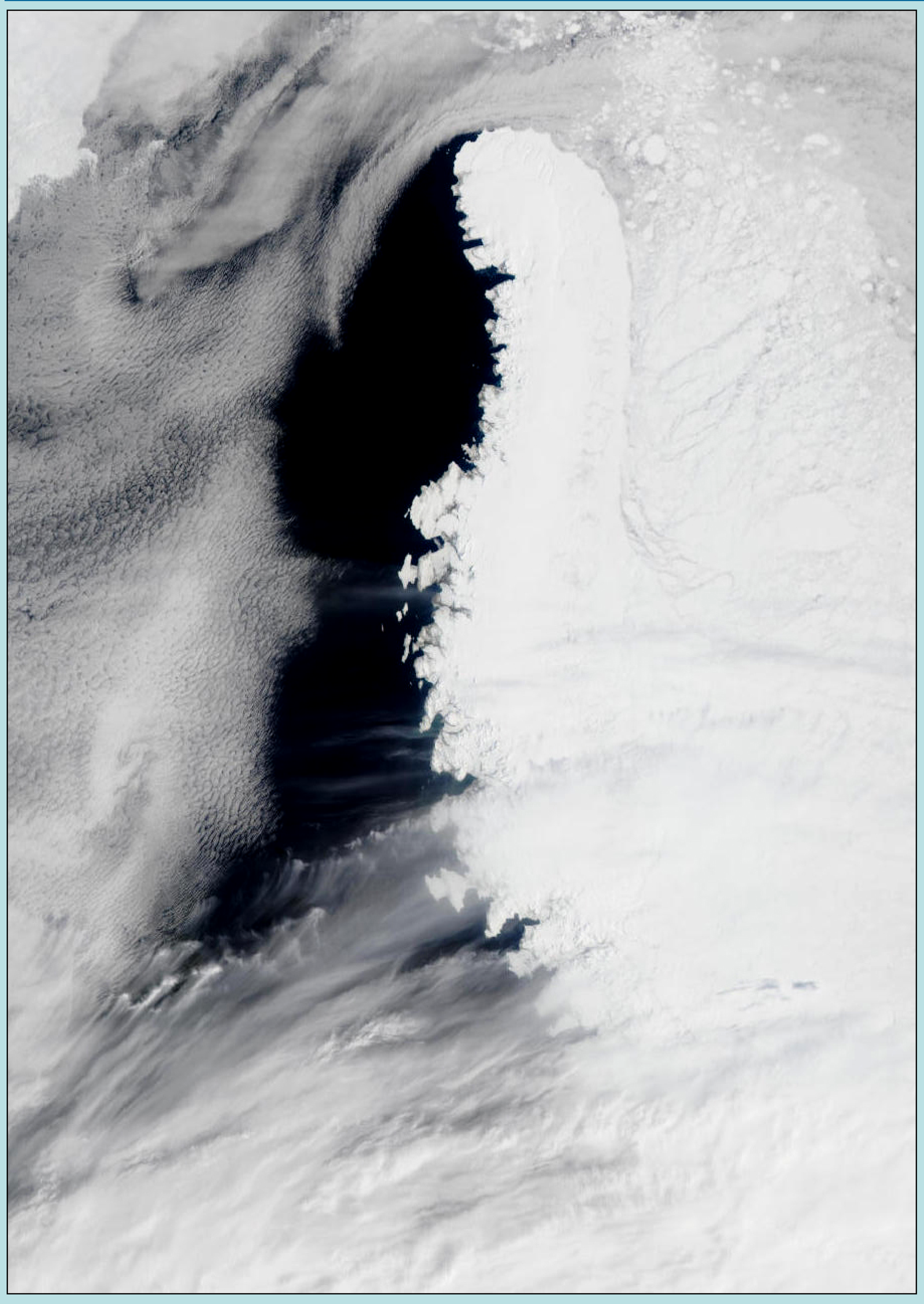

Figure 1. Cloud free area off the Novaya Zemlya archipelago during bora event imaged by Aqua/MODIS on 29.05.2015 (07:10 UTC). © NASA GSFC

INTRODUCTION: By methods of remote sensing, the mesoscale meteorological phenomenon, known as Novaya Zemlya bora, downslope windstorm, which leaves pronounced footprints on the synthetic aperture radar (SAR) images of the sea surface, is investigated. In the winter seasons the Kara Sea is typically ice covered, while the Barents Sea has low ice concentrations. Weather data indicate that during December - February the windiest conditions occur with monthly mean wind speeds of 10-15 m/s mainly having southeasterly direction. Although a number of authors have referred to these high speed winds as a bora, there has been no systematic study of this phenomenon. Regular images from Sentinel-1A allow taking a look on this phenomenon from space, and restoring extent, strength and duration of the Novaya Zemlya bora. It is established the local bora covers either wide coastal zone of the Barents Sea to the west from Novaya Zemlya or rarely less area in the Kara Sea that can lead to catastrophic consequences in the coastal waters of the archipelago.

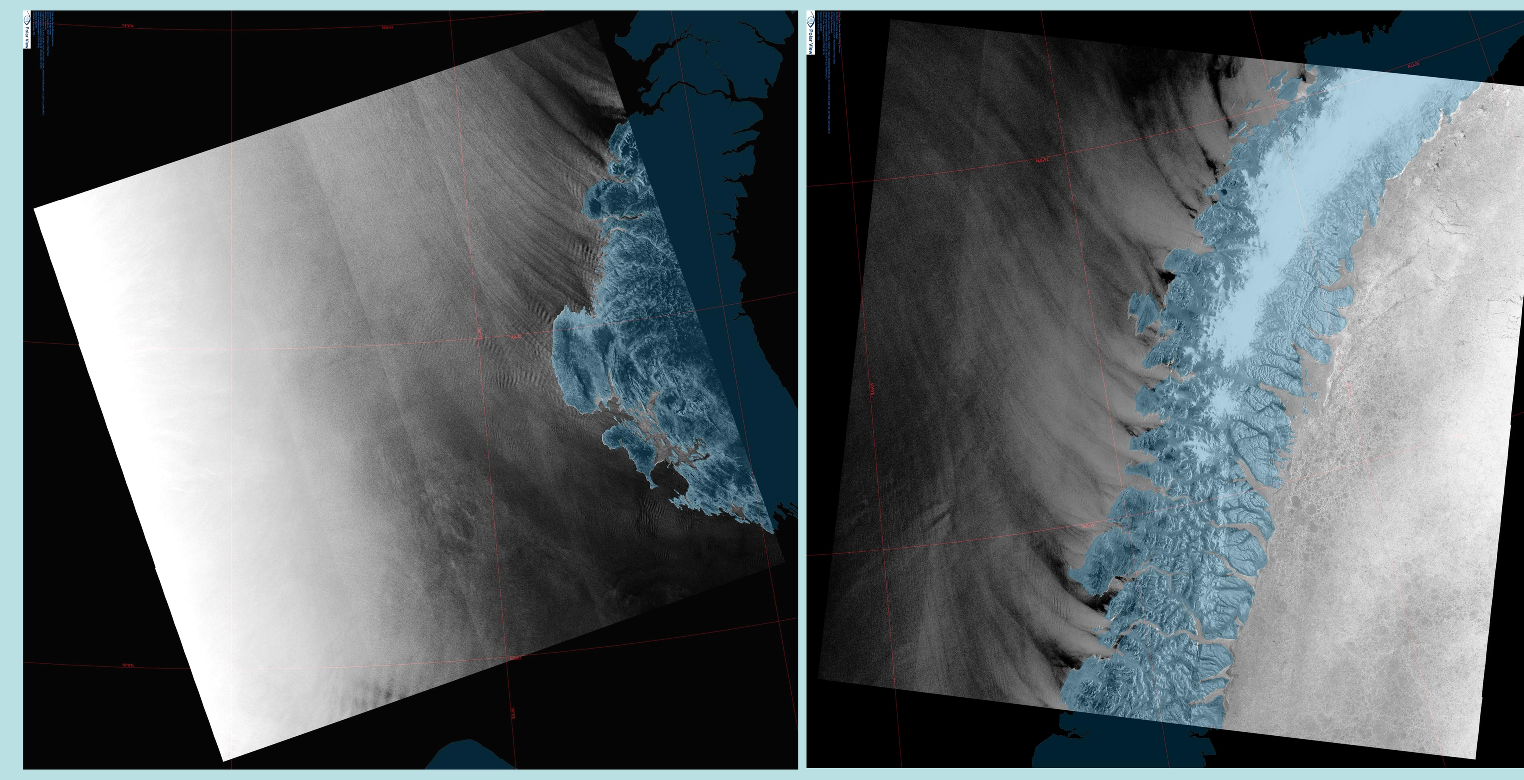

Figure 2. Bora wind-jets on the Sentinel-1A SAR images acquired on 29.05.2015 (13:57 UTC) and 30.05.2015 (03:16 UTC) . © ESA, PolarView

BORA WINDS: Bora winds are local katabatic downslope winds, when cold air is pushed over a coastal mountain range due to the presence of a high pressure gradient or by the passage of an atmospheric front over. They are encountered in mountainous coastal regions, where the mountain range is not too high (typically below 800 m) and it is close to a relatively warm sea.

The Barents Sea is bordered to the east by a large archipelago, named Novaya Zemlya, with mountain ranges of variable height with many gaps, through which airflow from the east can penetrate and be funneled onto the sea. The archipelago also separates usually ice covered Kara Sea and partially ice-free Barents Sea. Usually the strengthening of the offshore easterly coastal winds is by atmospheric forcing due to the passages of cold atmospheric fronts or cyclones.

As shown in [1-3], the synthetic aperture radar (SAR) images acquired by the SARs onboard the European satellites give very good opportunities for studies the surface manifestations of strong winds associated with bora events.

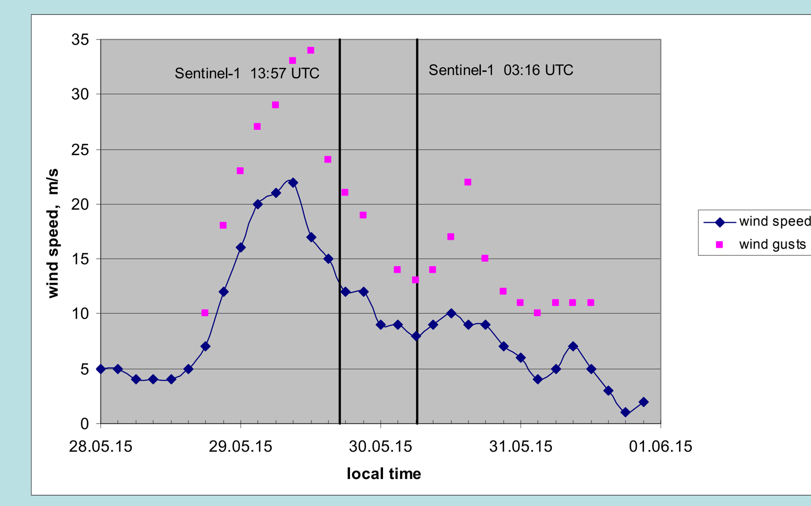

Figure 3. Wind speed measured at the weather station in Malye Karmakuly (Novaya Zemlya) from May 28 to June 1 2015; vertical lines show times of acquisitions of Sentinel-1A SAR images.

In this study practically all bora events occurred in the Eastern Barents Sea in 2015-2016 and imaged by Sentinel-1A SAR have been analyzed. Alternatively near-surface wind fields were extracted from atmospheric models; also study was supported by regular in situ measurements at the weather coastal stations. Images and results of several case studies are shown on figs. 1-7.

Findings from this study can be summarized as follows:

1. The phenomenon imaged by SAR is definitely bora, because it creates specific surface manifestations, which are very similar to those generated by boras in the Adriatic and Black Seas [1-6]. The in situ measurements and modeling also confirmed this finding.

2. At the west coast of the Barents Sea strong easterly winds are encountered throughout the year. Mostly they are generated by bora-like winds and often have speeds above 20-30 m/s.

3. On the sea surface, these winds emanating from the coastal mountain gaps give rise to banded patterns resulting from wind jets and wind-shadowed areas. The pronounced wind jets generated by the boras are very clear visible on high resolution SAR images. Depending on the strength of the wind events, the jets often remains distinct in the open sea from 150 to 300 km. Typical duration is 1-5 days.

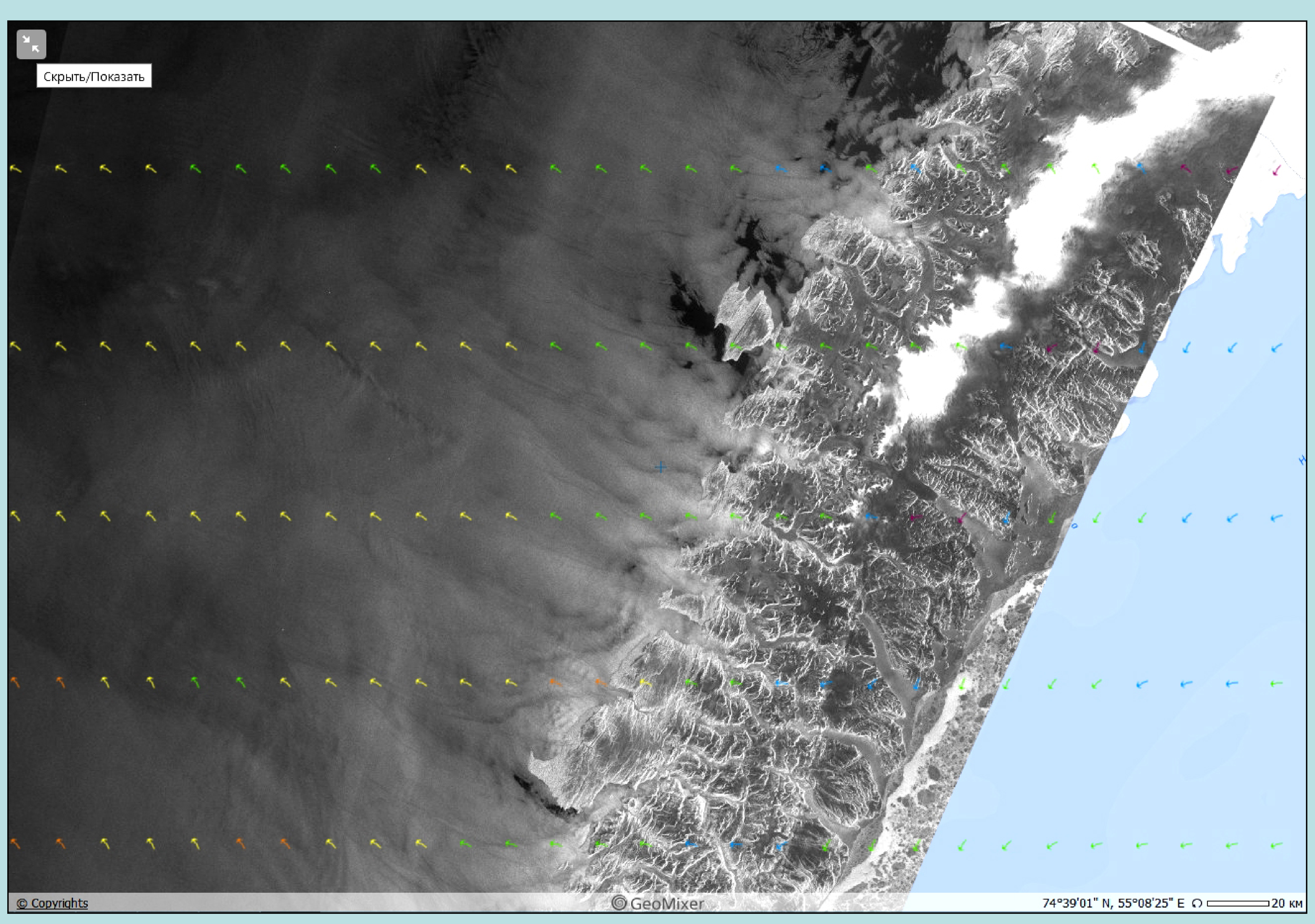

Figure 4. Wind-jets of the bora on the Sentinel-1A SAR image acquired on 9.06.2015 (03:31 UTC); color arrows show modeled wind field at 6:00 UTC © ESA, SCANEX

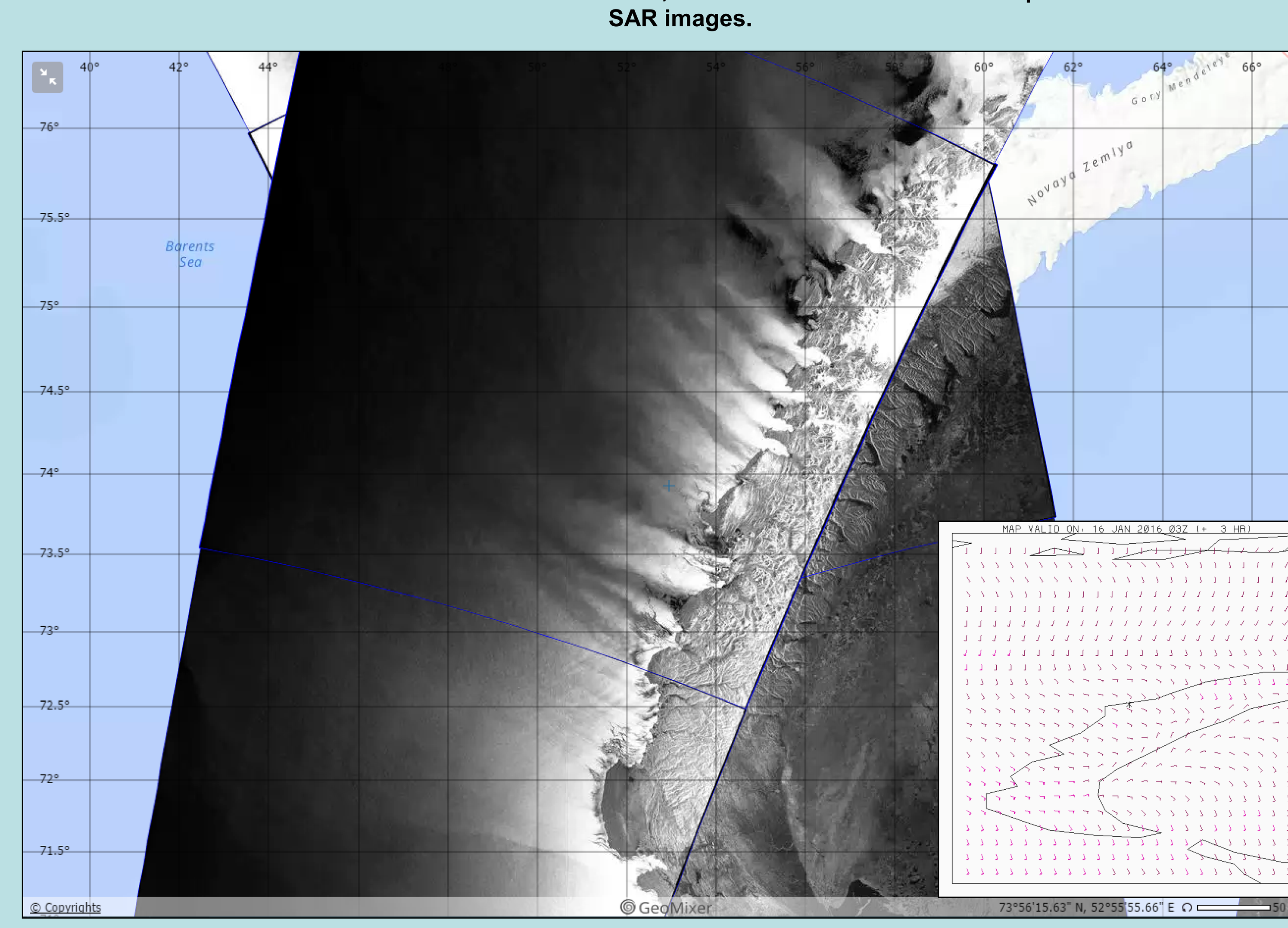

Figure 6. Wind-jets of weak bora off Novaya Zemlya imaged by Sentinel-1A on 16.01.2016 (03:39 UTC) as seen in the GeoMixer, and wind field modeled at 03:00 UTC using NOAA Air Research Laboratory tools. © ESA, SCANEX

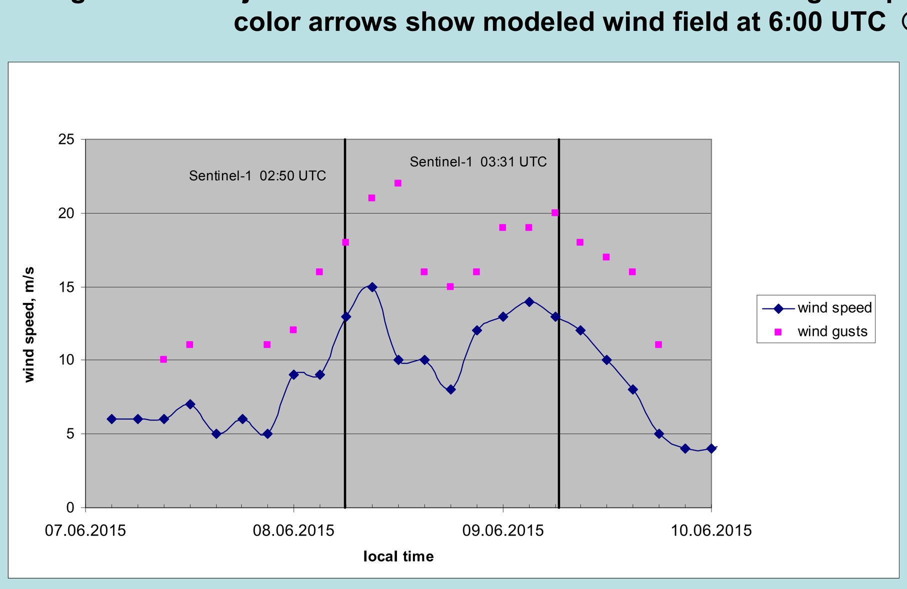

Figure 5. Wind speed measured at the weather station in Malye Karmakuly (Novaya Zemlya) in period June 7-10, 2015; vertical lines show times of acquisitions of Sentinel-1A SAR images.

4. The detailed spatial structure of these coastal winds can be captured by using spaceborne SAR images, but this is impossible by in situ measurements. Of course, the high resolution Sentinel-1A SAR images do not only yield detailed information on the structure of the wind fields, but also quantitative information about the near-surface wind fields [3-5].

5. On SAR images not only wind jets (figs. 2, 4, 6, 7) can be delineated, but also atmospheric gravity waves (AGW) and wakes (fig. 4), whose pulsations can be considered as wind gusts. If assume that the pulsations are caused by AGWs propagating opposite to the wind direction and that they are stationary, the period of the gusts can be estimated by measuring their wavelengths on the SAR image (typically several km) and by assuming the wind speed is equal to the phase speed. Typical periods derived from SAR images are several min.

6. It is clearly that these wind events can be modeled with high resolution models such as the Weather Research and Forecasting Model - WRF. As shown in [6], numerical modeling allows to reproduce a fine structure of the bora, its individual details, the spatial and temporal regime and characteristics.

7. Evidently SAR images can also be used to discriminate between the different wind field types by investigating spatial extent and surface manifestations of the wind jets. The wind jets generated by frontal type boras often extend up to 250-300 km from the coast, while the ones generated by pure katabatic boras only extend to few tens km.

8. Main mechanism provoking bora's generation is a polar cyclogenesis, which leads to development and strengthening of cyclonic circulation in the atmosphere over the Barents Sea. This is aggravated by high baric and temperature gradients between the Kara and Barents Seas.

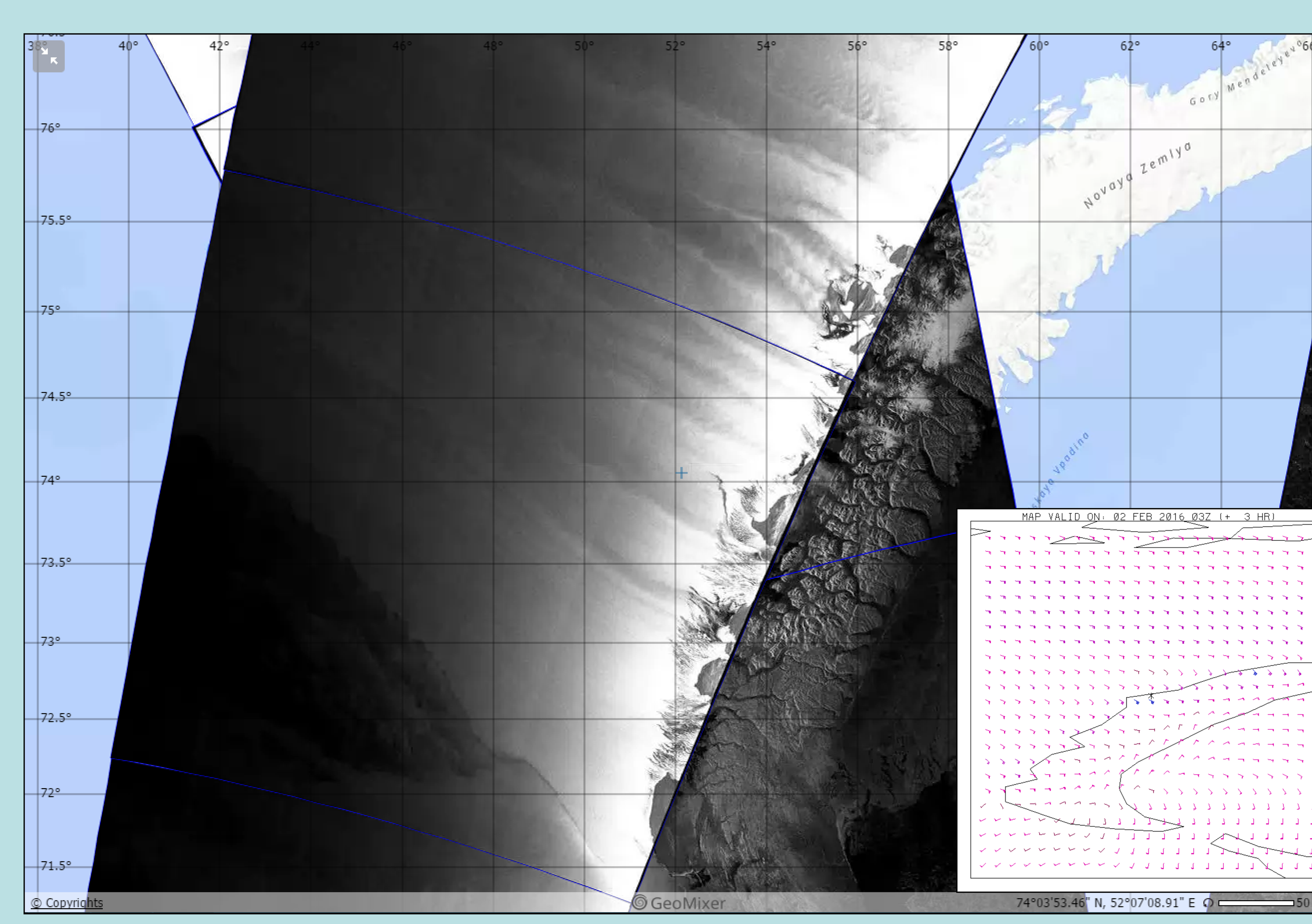

Figure 7. Wind-jets of strong bora off Novaya Zemlya imaged by Sentinel-1A on 2.02.2016 (03:38 UTC) as seen in the GeoMixer, and wind field modeled at 03:00 UTC using NOAA Air Research Laboratory tools. © ESA, SCANEX

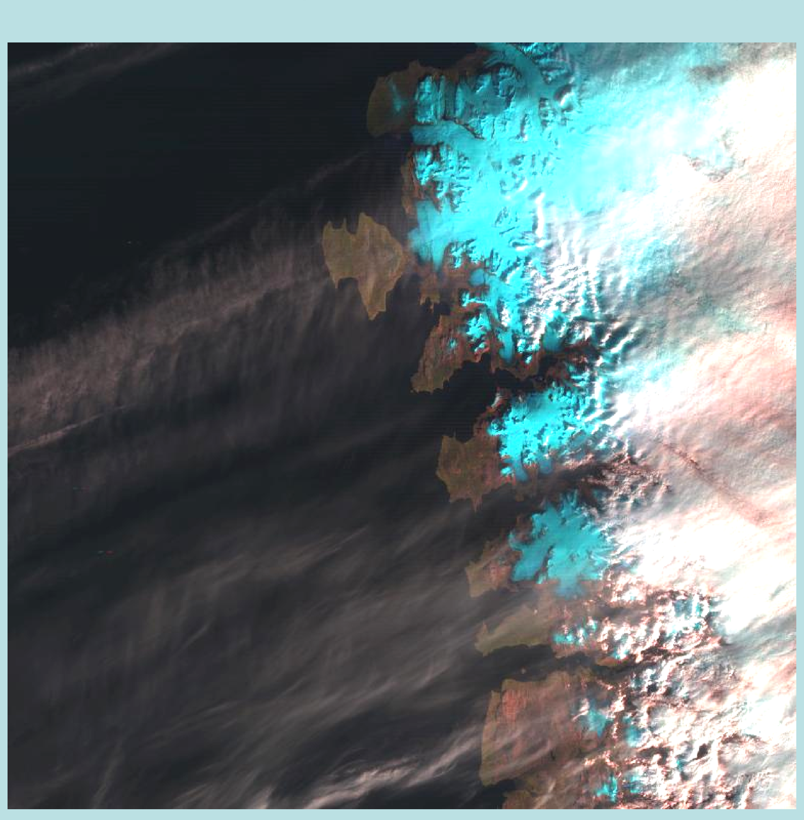

Figure 8. Bora wind-jets visible due to low cloudiness and snowdrift on the optical Landsat-5 image acquired on 14.09.1989. © USGS

CONCLUSION: The Sentinel-1A images acquired over the Barents Sea has been analyzed with purpose to study the local wind called the Novaya Zemlya bora. This approach gave very promised results, and it can be easily applied to monitoring severe local winds such as boras, foehns and other katabatic winds worldwide. Finally, it is shown that routinely use of spaceborne SAR, such as on board Sentinel-1A, for detection, monitoring and studies polar local winds has no an alternative.

Useful references:

1. Ivanov, A.Yu., Alpers W., Sumyatov A. Bora in the Adriatic Sea and Black Sea imaged by the Envisat synthetic aperture radar / Proc. Envisat Symposium-2007, 23-27 April 2007, Montreux, Switzerland (ESA SP-636) .
2. Alpers W., Ivanov A., Horstmann J. Observations of bora events over the Adriatic Sea and Black Sea by spaceborne synthetic aperture radar // Mon. Wea. Rev., 2009. 137. pp. 1150–1161.
3. Alpers W., Ivanov A.Yu., Dagestad K.-F. Observation of local wind fields and cyclonic atmospheric eddies over the Eastern Black Sea using Envisat synthetic aperture radar images // Issl. Zemli iz Kosmosa, 2010. № 5. pp. 46–58.
4. Alpers W., Ivanov A.Yu., Dagestad K.-F. Encounter of foehn wind with an atmospheric eddy over the Black Sea as observed by the synthetic aperture radar onboard the Envisat satellite // Mon. Wea. Rev., 2011. 139(12). pp. 3992–4000.
5. Alpers W., Mouche A., Horstmann J., Ivanov A.Yu., Barabanov V.S. Application of a new algorithm using Doppler information to retrieve complex wind fields over the Black Sea from Envisat SAR images // Int. J. Remote Sens., 2015. 36(3). pp. 863–881.
6. Gavrikov A.V., Ivanov A.Yu. Anomalously strong bora over the Black Sea: observations from space and numerical modeling // Izvestiya, Atmospheric and Oceanic Physics, 2015. 51(5). P. 546-556.

ACKNOWLEDGEMENTS. The authors would like to say many thanks to ESA for the SAR images of Sentinel-1A provided free of charges!