BORA OVER THE ADRIATIC SEA AND BLACK SEA IMAGED BY THE ADVANCED SYNTHETIC APERTURE RADAR ONBOARD ENVISAT

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ABSTRACT

Bora events over the Adriatic Sea and Black Sea are investigated by using synthetic aperture radar (SAR) images acquired by the Advanced Synthetic Aperture Radar (ASAR) onboard the Envisat satellite. These images show pronounced elongated patterns of increased sea surface roughness caused by bora winds. The comparison of the SAR images with wind fields derived from Quikscat data confirms that in all cases a strong northeasterly wind was blowing from the mountains onto the sea. It is shown that the SAR images reveal details of the spatial extent of the bora wind fields over the sea, like wind jets of 100-150 km length, which cannot be obtained by other instruments.

1. INTRODUCTION

Bora (Italian: bora, Greek: boreas – northward wind) is a strong cold wind blowing in coastal areas downhill onto the sea. Usually the cold air flows downhill over mountain ridges and funneled through corridors in the coastal mountain range. Boras are encountered in mountainous coastal regions where the mountains are not too high (typically below 1000 m) such that the adiabatic warming of the descending cold air is small. Well known coastal areas where bora winds are encountered are the Adriatic coast of Croatia, the east coast of the Black Sea near Novorossiysk (city and port in the Russian Federation), and the coasts of Lake Baikal, and the coastal waters around Greenland and the Russian island of Novaya Zemlya [1,2].

When winds associated with a bora events blow over coastal waters, they modify the small-scale sea surface roughness. Imaging radars, like the synthetic aperture radar (SAR), are very sensitive instruments to detect changes in the sea surface roughness at wavelength scales in the centimeter to decimeter range.

Meteorological data associated with bora events are routinely collected at coastal stations, but the spatial extent of the bora wind field over the sea is largely unknown. However, sea surface roughness variations caused by bora events are clearly visible on the images acquired by SAR flown on satellites. In this paper we present 7 examples of synthetic aperture radar acquired by the Advanced Synthetic Aperture Radar (ASAR) onboard the European Envisat satellite over the Adriatic Sea and over the Black Sea showing sea surface manifestations of bora events. These ASAR images are compared with sea surface wind fields retrieved from data acquired by the scatterometer onboard the American Quikscat satellite [3]. In two cases we also compare these images with cloud images acquired by the MERIS sensor onboard the Envisat satellite and the MODIS sensor onboard the American Terra satellite. If the meteorological conditions are favorable, then sea surface manifestations of bora events are sometimes mirrored in the cloud pattern. The strong lateral wind shear associated with bora events often gives rise to the generation of coastal mesoscale atmospheric eddies. Two examples from the Black Sea are presented in this paper.

2. ADRIATIC SEA BORA EVENTS

The Adriatic bora or bura is a cold and dry northeasterly wind. It blows from the eastern side of the Adriatic Sea towards the open sea and brings bright weather to the coast. It starts abruptly and blows in squalls toward the sea. It is funneled through corridors in the coastal mountain range. Fig. 1 shows a map of the Adriatic region where the boras are encountered, and Fig. 2 shows a sketch of the main corridors through which the bora winds blow onto the sea.
The winds are strongest in the Velebit Channel and in the Gulf of Trieste. In summer, the bora blows as a local wind and lasts only a few days. In winter, it may blow for 6 to 14 days and can be quite strong (wind speeds of up to 40 m/s have been measured).

In the following we present two Envisat ASAR images on which sea surface manifestations of boras over the Adriatic Sea are visible and compare them with wind fields derived from Quikscat data. Quikscat wind fields have a spatial resolution of 25 km x 25 km and are available over most parts of the ocean twice a day [3].

2.1 The 14 February 2005 bora event

Fig. 3 shows an Envisat ASAR image which was acquired on 14 February 2005 at 16:21 UTC in the Global Mode over the Adriatic Sea during a winter bora event. Since the swath width of the ASAR in the Global Mode is 400 km, one can view in this image the full spatial extent of the bora wind field over the Adriatic Sea. The wind pattern consists of several wind jets which reach to the Italian coast. These patterns correspond well with the corridors depicted in Fig. 2. The wind field derived from Quikscat data acquired the same day, but 1 hour and 33 minutes later (Fig. 4), shows that at the east coast of Croatia the bora winds were blowing from a northeasterly direction with a speed of about 15 m/s.
2.2 The 24 January 2006 bora event

Fig. 5 shows the Envisat ASAR image acquired on 24 January 2006 at 09:20 UTC in the image mode (IM) over the northern section of the Adriatic Sea during a winter bora event. The swath width of the ASAR is in this mode only 100 km.

Thus only a small section of the bora wind field is visible, in this case only the wind jets associated with the Velebit Channel and Sibenik Channel. The wind field map derived from Quikscat data, which were acquired on the same day at 03:47 UTC (Fig. 6), shows that in the area, which was imaged by ASAR, a northeasterly wind of up to 25 m/s was blowing.

The same area was also imaged in the visible band by the Medium Resolution Imaging Spectrometer (MERIS) onboard the Envisat satellite at the same time.
3. BLACK SEA BORA EVENTS

Bora winds are often encountered at the east coast of the Black Sea around Novorossiysk, between Anapa and Gelendjik. Because the strongest wind occurs in Novorossiysk area these boras are often called in the literature Novorossiysk boras [1,2]. They occur in 74% of all cases in the cold season (from September to March) and in 26% of all cases in the warm season (April to August). Here bora events are defined as events during which the wind speed exceeds 15 m/s. In 78% of all cases their duration is 1-3 days, seldom 4 to 9 days, and quite seldom up to 10 days and more (1%). Their average duration is 2.4 days [1].

In winter, they are generated when a high pressure area resides over the North Caucasus and a low pressure area over the eastern Black Sea. The resulting strong northeasterly wind pushes cold air from the North Caucasus against the Varada Ridge (600 m) and forces it through the Markhotskii Pass (435 m) from where it flows down the mountain slopes towards the sea. In summer, the boras are generated when a cold front passes the coast from northwest which also forces cold air to flow down the mountain slopes.

At Novorossiysk, the wind speed often reaches values of up to 30-40 m/s during bora events. The highest value measured at the Markhotskii Pass was 50 m/s. On the average, bora winds are encountered on 30 to 40 days per year, but most often they are encountered in November and December. Sometimes bora events in the Novorossiysk area are catastrophic events causing sinking of ships and damage on houses. The last strong bora occurred in December 2001, when the area around Novorossiysk was declared a zone of natural disaster.

In the following section we present five Envisat ASAR images, on which sea surface manifestations of bora events over the Black Sea are visible.

3.1 The 29 April–3 May 2006 bora event

Fig. 8 shows a pair of Envisat ASAR images, which were acquired on 29 April 2006 at 19:13 UTC at HH/VV polarizations and on 2 May 2006 at 19:19 UTC also at HH/VV polarizations during a summer bora event at the east coast of the Black Sea which lased from 29 April 2006 to 3 May 2006. They show between the Russian towns of Novorossiysk and Tuapse pronounced stripes in the NE-SW direction, which are sea surface imprints of inhomogeneities in the wind field. The wave-like features in the upper section of the images are sea surface manifestations of atmospheric gravity waves generated by the interaction of the wind with the coastal topography. The wind field map derived from Quikscat data (not reproduced here) shows in the northern section of the east coast of the Black Sea only wind speeds around 10 m/s, which would not qualify this event to be a bora event. However, the meteorological measurements carried out at the weather station in Novorossiysk show on 2 May wind speeds of up to 20 m/s. The meteorological records show further that from 30 April at 00 UTC to 3 May at 03 UTC the wind speed was always above 15 m/s.

Weather station in Tuapse reported the wind speed in this period always below 7 m/s. This shows that the bora was confined to the region northeast of Tuapse.
September 2006 a wind speed of 11 m/s and on 16 September a wind speed 13 m/s.

3.3 The 21 December 2006 bora event

Fig. 8 shows an Envisat ASAR image which was acquired in the Wide Swath Mode (WSM) on 21 December 2006 at 7:36 UTC during a winter bora event. The sea surface wind field derived from Quikscat data acquired on 21 December at 4:06 UTC (Fig. 12) shows that at the northeast coast of the Black Sea the wind was blowing from northeast with a speed between 10 and 15 m/s. Wind stripes are visible over the northeastern section of the Black Sea as well as sea surface manifestations of atmospheric boundary rolls and convective cells over the Asov Sea (upper right hand section of the image).

9:13 UTC at VV HH polarizations during a summer bora event at the east coast of the Black Sea which lasted from 11 to 17 September 2006.

They show again pronounced stripes in the NE-SW direction, which are sea surface imprints of inhomogeneities in the wind field. Also wave-like features, which are surface manifestations of atmospheric gravity waves, are visible. The ground measurements at the weather station in Novorossiysk show at the times of the ASAR data acquisitions on 13 September 2006 a wind speed of 11 m/s and on 16 September a wind speed 13 m/s.
These features are mirrored in the cloud pattern visible on the MODIS image acquired on 21 December 2006 at 8:40 UTC (Fig. 13).

The WSM ASAR image depicted in Fig. 11 shows very clearly how a Black Sea (or Novorossiysk) bora can give rise to the formation of an atmospheric cyclonic eddy. The wind blowing over the coastal mountain range is (partially) blocked by the higher mountains further to the SE (near Tuapse). Thus a lateral wind shear is generated which gives rise to the formation of a mesoscale cyclonic eddy located west of Tuapse.

4. CONCLUSIONS

Boras are local coastal phenomena associated with strong winds blowing over a coastal mountain range onto the sea. Areas where boras occur in Europe are the east coast of the Adriatic Sea (Adriatic bora) and the east coast of the Black Sea (Novorossiysk bora). They have a great impact on coastal weather and can cause severe damage in these regions. We have presented in this paper seven synthetic aperture radar images acquired by the Advanced Synthetic Aperture Radar onboard the over the Adriatic coast and the east coast of the Black Sea and have compared them with sea surface wind fields measured by the scatterometer onboard the Quikscat satellite. The SAR images reveal much greater details of the wind field over the sea than Quikscat data and other data do. We therefore recommend taking advantage of the information contained in spaceborne SAR images when carrying out studies on bora events and when validating numerical models simulating such events.

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4. REFERENCES

