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Spaceborne radar identification of desert regions as suppliers of dust into the atmosphere

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Atmosphere dust represents a mixture of minute particles of various salts and minerals. Also it contains remains of animal and vegetable organisms, spores of causative organisms and so forth. The dust is carried by winds over considerable distances and its presence in the atmosphere is among the factors which have essential influence on the global climate of the Earth. At present the Aeolian processes and their consequences are monitored from space using multispectral optical systems (TOMS, METEOSAT, MODIS etc.) only. These are not capable of reliable identification of the areas themselves that are sources of raising the dust in the atmosphere independently of the cloudiness, solar illumination and transparency of the atmosphere. This problem can be solved with the use of space radar systems of the Earth remote sensing. The paper presents the first results of the development of a radar technique of identification of desert regions in which dust from the surface is transported up into the atmosphere under the action of Aeolian processes. The work was performed using data of Earth remote sensing SAR Envisat-1 obtained over deserts of Mauritania. Specific features of display of the narrow-beam backscattering of radio waves in radar images in dependence on the surface wind speed and direction and direction of radar illumination of the surface. It is concluded that the radar means of remote sensing represent an efficient tool for detecting regions of dust raise into the atmosphere. Results of the study can be used for the development of new methods of remote monitoring of the processes in desert areas that affect the climate of vast regions of the Earth.

Keywords: radar observations, highly directional radio wave backscattering, Aeolian transport of sand and dust, sand ripples, ionization, electric field

Introduction

Atmospheric dust represents a mixture of minute particles of various salts, minerals, rocks, coal, soil, and other various mixtures and chemical compounds of mineral and organic nature. It also contains remains of vegetable and animal organisms, spores of causative microorganisms, and so forth. The dust is carried by winds over considerable distances and its presence in the atmosphere is among the factors which have essential influence on the planet climate [6]. Presence of the dust of low concentrations promotes the atmosphere heating and results in global climate warming. Although, in the case of high concentrations, the dust impedes penetration of solar radiation, so leads to the Earth's surface cooling. It is known that about 4 billion tons of the dust and sand raised into the atmosphere yearly come back with atmospheric precipitation on the continental surface and more than 1.5 billion tons are deposited on the surface of the great oceans to enter then the composition of marine sediments [4]. Taking into account the global character of the Aeolian (wind-related) processes, it is evident that their continuous monitoring is possible only with the use of space systems of earth remote sensing.

At present, the space monitoring of the Aeolian processes and their effects is performed with the use of multispectral optical systems only (TOMS, METEOSAT, MODIS etc. [6]). These optical systems along are incapable of providing reliable identification of the areas which represent the sources of raising the dust into the atmosphere and following the dynamics of the Aeolian processes. The optical systems are also known to be heavily affected by the cloudiness, solar illumination and transparency of the atmosphere. The problem can be solved instead with the use of space-borne radar systems of remote sensing of the Earth. Paper [8] presents results of detecting the appearance of the effects of anomalous highly-directional (narrow-beam) backscattering of radio waves associated with the above mentioned processes. The effects are observed at practically the same angles of local illumination of the surface $\Theta = 30^{\circ}$ in both the radar images of deserts in Mauritania obtained by the side-looking radars of the artificial satellites of Earth: "Kosmos-1500" and "Sich-1" (the operation wavelength $\lambda = 3.15\ cm$), and by the synthetic aperture radar (SAR) of Envisat-1 ($\lambda = 5.6\ cm$) satellite. An explanation has been suggested for the mechanism of occurrence of the effect due to radio wave scattering by properly oriented ionized spaces which embrace the sand ripple structures in the process of their formation in the course of Aeolian transportation of the sand-dust mixture (see Fig. 1). It has been assumed that the ionization is produced by a

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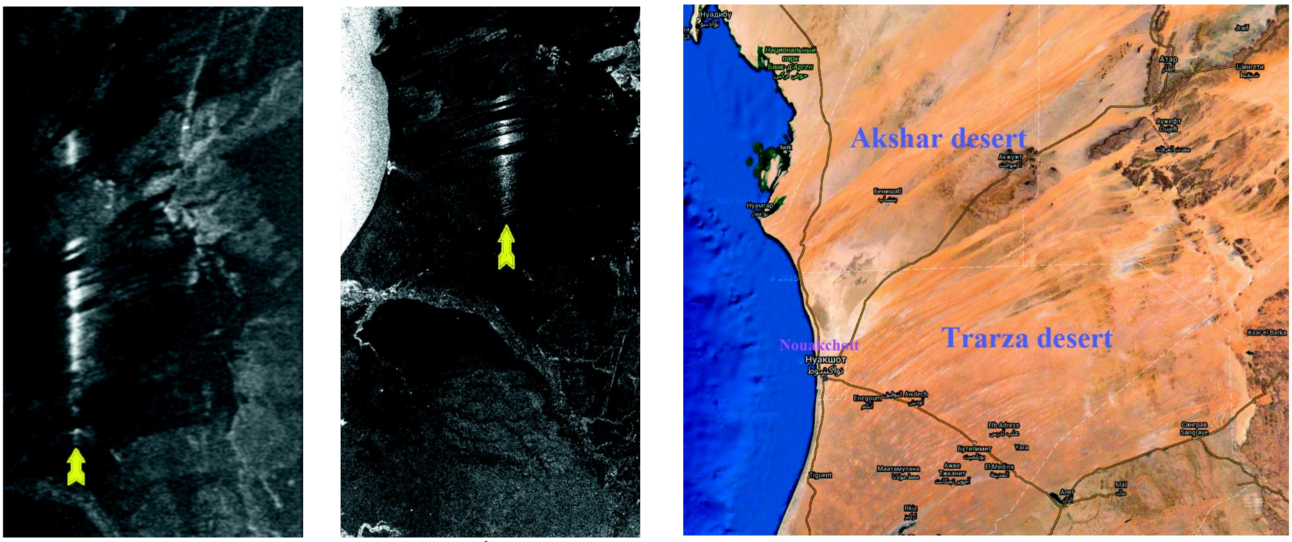


a b c

Fig. 1. Akshar and Trarza deserts (Mauritania) radar images obtained from: SLR satellite "Sich-1" on Dec. 19, 1995 (a); ASA_GM1_1P Envisat-1 on Dec. 08, 2010 (© ESA). Are allocated the effects of anomalous highly-directional backscattering of radio waves associated with the Aeolian transportation of near-surface sand/dust mixture (marked by arrows). Optic image taken from the Google Earth (c)

strong inhomogeneous electric fields (up to 250 kV/*m*) arising as a result of the Aeolian transportation.

This paper presents the first results of application the developed technique of identification of desert regions which are responsible for the process of raising the dust from the surface to the atmosphere under the action of the Aeolian activity based on radar imaging analysis. The work was carried out with the use of the calibrated data of radar remote sensing of the Mauritanian deserts obtained by the ASAR Envisat-1 between 2004 and 2012. The study is focused on analyzing the specific features of the appearance of highly-directional backscattering of radio waves in radar images which occur with different speeds of the near-surface wind and mutual orientations of the radar illumination of the surface (azimuth SAR antenna beam pattern axis projection on the Earth's surface) and wind direction. Peculiarities of the formation of the ionized layer boundary embracing the sand ripple structures in the course of transportation of the sand-dust mixture are also analyzed and taken into account. It is assumed that the ionization is produced by a strong inhomogeneous electric fields generated due to motion of air-borne charged grits, specifically, saltons and reptons, over the sandy bed. In the conclusion, the specific features are discussed as for efficient application of radar means of remote sensing for detecting regions of raising the dust into the atmosphere.

Analysis of specific features of the effects of the anomalously highly-directional backscattering of radio waves and Aeolian transportation of the sand-dust mixture

In order to verify the proposed explanation of the mechanism of occurrence of the anomalously narrow-beam scattering of radio waves suggested in paper [8], it was estimated the efficiency of radio wave scattering by a sandy surface disturbed sand ripples. To that end, in [9] was determined the maximum possible (in the case of the oblique backscatter remote sensing) backscatter factor of such a structure in the steady state (when there is no wind-produced motion of the sand ripples) for the situation where the radio wave is normally incident upon the surface of the plane lee slope. This was taken into account that the effective depth of penetration of a radio wave with $\lambda = 5.6\ cm$ into dry sand makes dozens of centimeters, i.e. is equal to a few wavelengths. Therefore, the scattering by a sand ripple can be related to a surface-volume scattering by a great number of scatterers. The phase relationship between the respective spectral components of the radar signals scattered by adjacent humps of the ripple spaced by several λ represents a random value (so, the coherent summation of backscattered signals is impossible).

Based on the experimental data of measuring the backscatter factor σ of the desert sand in dependence on the angle of local illumination Θ [5], it was identified that the maximum possible values of σ of a sandy surface disturbed by a ripple in the steady state do not exceed −14...−17 dB. Actually, the photos of sand ripple structures (see pictures a–c in Fig. 2) indicate that the shape of the lee slope of the ripple humps differs essentially from a plane, and hence the above estimates can apparently appear to be that high.

Analysis of the experimental results

The intensity of scattering from a sand surface in the case of Aeolian transportation of the sand-dust mixture was estimated using archive radar images from the Envisat-1 satellite provided by the European Space Agency (ESA) for the fulfillment of the Project ID: C1F.30193. The images have been selected from the EOLI-SA on-

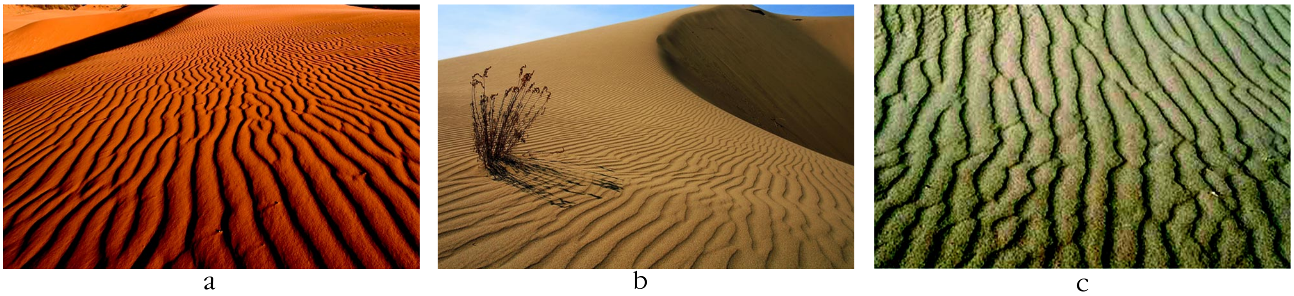


Fig. 2. Sand ripples: (a–c) photos of the structures taken from the Google Earth

line catalog with account of the data concerning the surface wind velocity and direction [2]. Then, the scattering intensities have been standardized to the scattering cross-section, with the use of standard programs provided by the ESA for the open access to process the images (NEST 4B-1.0, NEST 5.1).

Pictures a and c in Fig. 3 present fragments of the radar images of an area of the Trarza desert obtained by the satellite Envisat-1 ASA_GM1_1P on January 12, 2012 and January 13, 2005. Pictures b and d of Fig. 3 depict the respective dependences of the backscatter factor σ on the angle of local illumination Θ along the fragment sections (arrows 1 to 5). The sections are drawn through the most homogeneous regions of the surface for which the effects of anomalously high-directive backscatter of radio waves were observed. Shown by the thick black

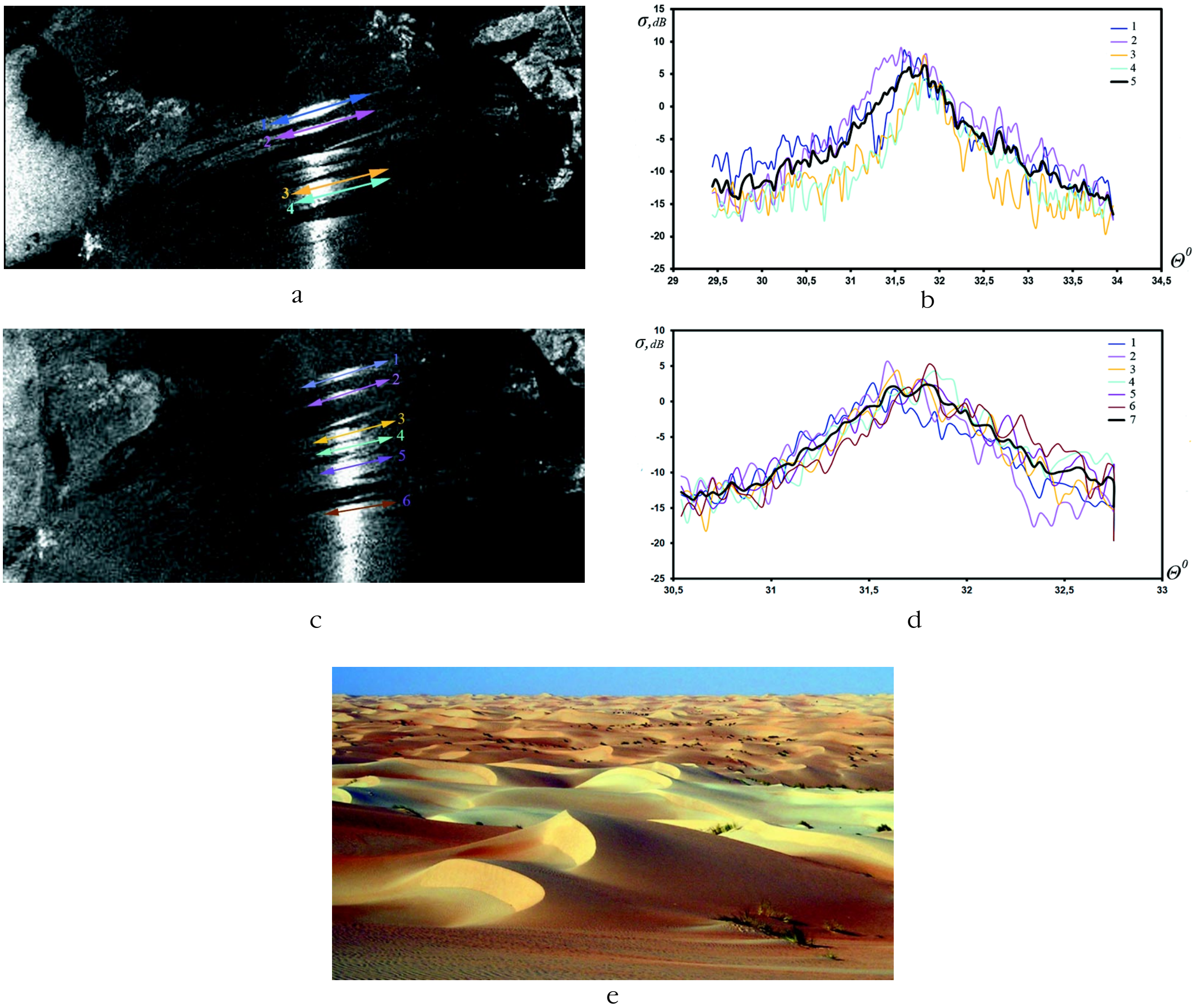


Fig. 3. Effect of occurrence of the anomalously high-directive backscattering of radio waves: (a) and (c) — fragments of the radar images of a region of the Trarza desert obtained from the satellite Envisat-1 ASA_GM1_1P on Jan. 12, 2012 and Jan. 13, 2005 (© ESA), respectively; (b) and (d) – dependences of the backscatter factor σ on the angle of local illumination Θ along sections of the respective fragments of the radar images; and (e) — sandy dunes in the region under survey (Google Earth)

lines are averaged σ (Θ)-dependences. As can be seen, the averaged observed values of σ (Θ = 31.5...32°) in Fig. 3 b and Fig. 3 d exceed 5 and 3 dB (for the same weather conditions) which values are greater by more than 17...21 dB as compared with the maximum magnitudes calculated for the static sand ripple. According to the meteorological data [2], the surface wind speed during the survey was about 5 m/s, while its direction was practically opposite to the SAR radiation direction.

Fig. 4 shows phases of developing the processes of the anomalous scattering. In the case of a light (~ 1 m/s) surface wind with unstable direction (Fig. 4 a, left-hand part of the composite radar image Envisat-1, ASA_GM1_1P, 2004-06-11) no manifestations of the effects of anomalously high-directive backscattering of radio waves were observed. However, already for the wind speed ~2 m/s and practically opposite direction of the wind with respect to the SAR illumination radiation direction (the right-hand part of the composite radar image Envisat-1 ASA_GM1_1P, 2004-11-12), the effect of anomalous scattering has proven to be significant. The lower magnitude of the maximum scattering cross-section (~ – 1 dB) at the incidence angle of sensing Θ = 31.5° in Fig. 4 b as compared with that in Fig. 3 b (~ 5 dB) can be explained by a lower speed of the near-surface wind during surface imaging.

Pictures c and d in Fig. 4 correspond to the stage of initiation of the effect of anomalous highly-directional backscattering of radio waves. The bright points in the fragment of the radar image (Fig. 4 c, Envisat-1 ASA_GM1_1P, 2010-14-12) indicate the surface areas where the effect starts to appear.

The observations were carried out under conditions of a near-surface wind with variable direction with respect to the SAR radiation direction which blew with a speed between 1 and 2 m/s. It should be noted that under these conditions the local maxima of backscattering (see Fig. 4 d) already reach considerable magnitudes (– 5...– 2 dB), however are observed in a broader range of the angles Θ = 28.5...31.5 as compared to the developed state (~31.5 ± 0.25). In the following sections we will get back to this effect analysis again.

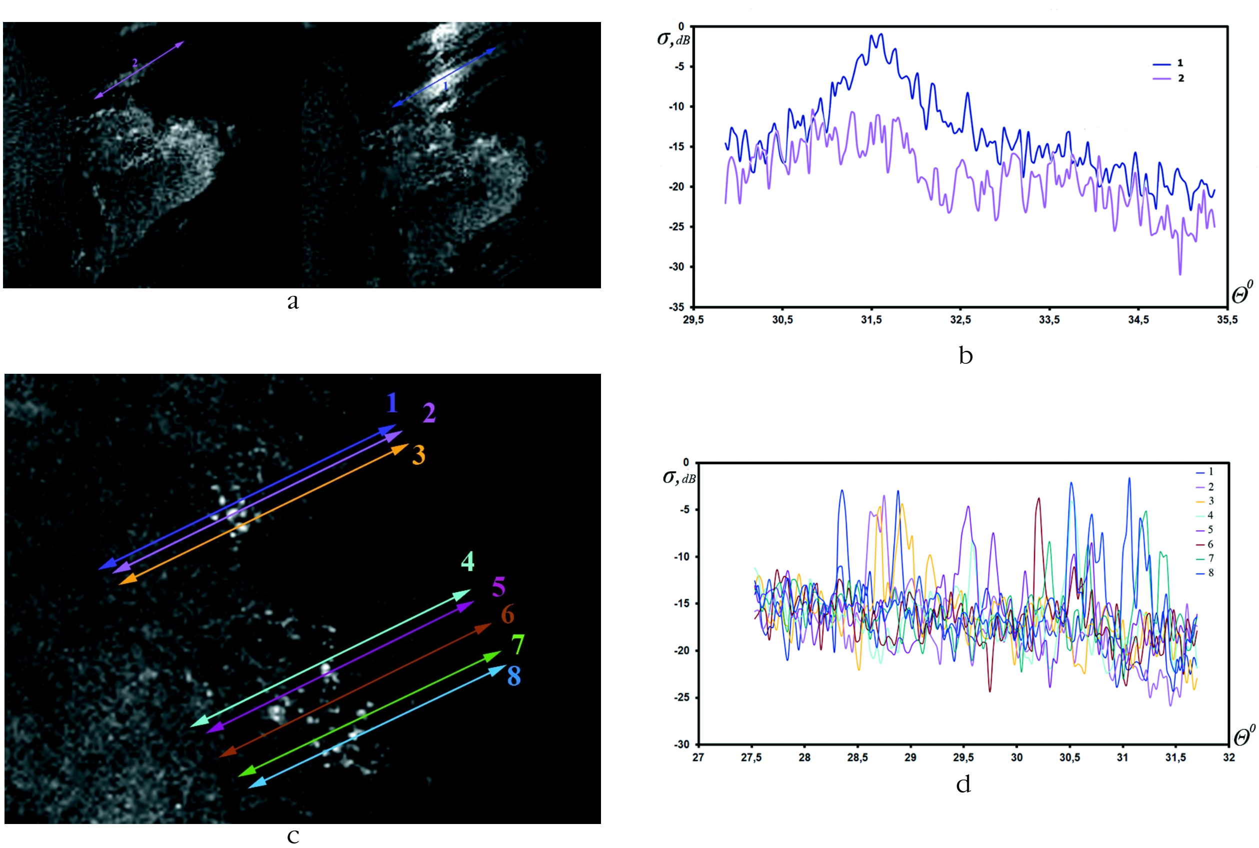
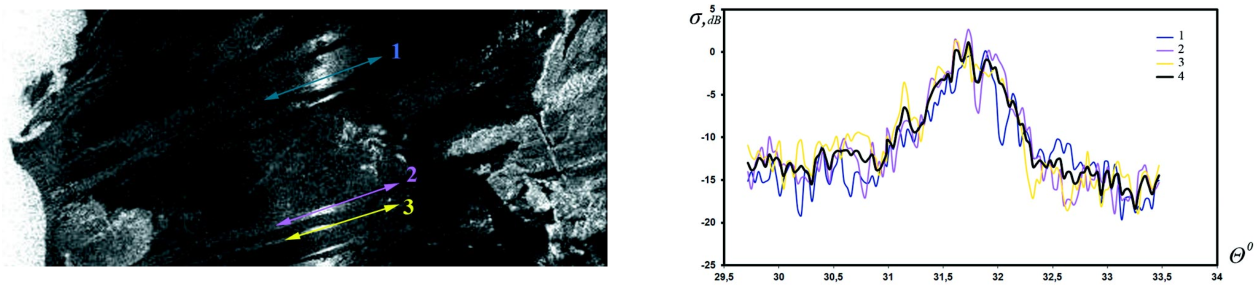


Fig. 4. Fragments of the radar images Envisat-1 ASA_GM1_1P (© ESA) obtained on Nov. 6, 2004 with the wind speeds ~ 1 m/s (left-hand part) and ~ 2 m/s (right-hand part) Envisat-1 ASA_GM1_1P (© ESA) obtained on Dec. 11, 2004, (a). Dependences of the backscatter factor σ on the angle of local illumination Θ along the depicted lines of radar image sections (b). The fragment of the radar image of a desert region obtained on Dec. 14, 2010 (c). The backscatter factor σ in dependence on the angle of local illumination Θ along the radar image sections (d)

Fig. 5 presents a fragment of the radar image (a) and respective dependences σ (Θ) (b) of crosssections (Envisat-1 ASA_GM1_1P, 2005-28-12) obtained for a region in the Tarza desert. The survey has been carried out in the situation where the near-surface wind speed was



a b

Fig. 5. The effect of anomalous narrow-beam scattering of radio waves in the situation where the opposite wind direction deflected by ~ 45° with respect to the SAR radiation direction: (a) fragment of the radar image (Envisat-1 ASA_GM1_1P, 2005-28-12, © ESA) of a region in the Trarza desert; (b) dependences of the backscatter factors σ on the angle Θ of local illumination along the sections (arrows 1 to 3) of the radar images shown in Fig. 4 a

about 5 m/s and its direction was deflected by ~ 45° (within the azimuthal plane) from the direction of radar illumination of the Earth's surface.

At that, the maximum value of σ showed a decrease by 3 or 4 dB as compared with the Envisat-1 ASA_GM1_1P on 2012-01-12 and 2005-01-13 (see Fig. 3) obtained for the same wind speed and practically same direction with respect to the SAR radiation direction.

As was mentioned above, we suppose that the main scatterer of radio waves in the experiments is the ionized air in the near-surface layer saturated by negatively charged grains of sand. Therefore, in order to explain the obtained experimental results of observation of anomalous radio wave scattering, let us consider the specific features of the grain motion.

Specific features of motion of the negatively charged sand grains over the surface

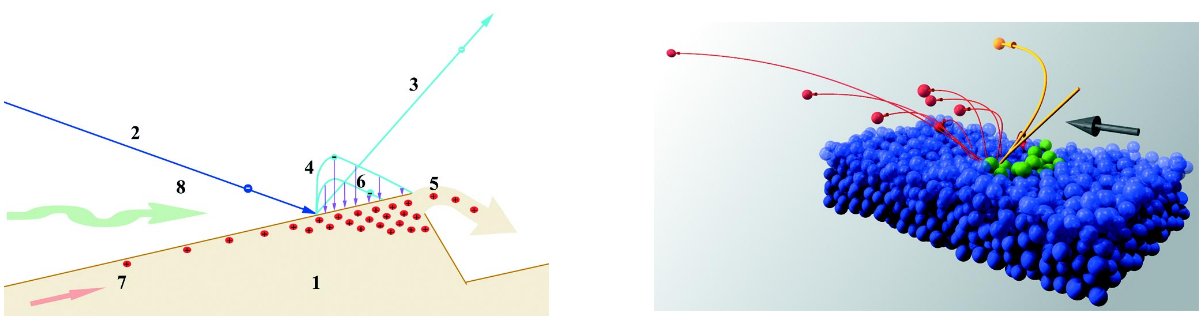
Various models are used to describe motion of the negatively charged sand grains ("saltons") over the surface with accounting of the drag, gravitational and electric forces. For example, in paper [10] the motion of such grains is described as follows:

$$ma_x = \pi D_p^2 / 8^* \rho_a C_d |V_R| (U - v_x)$$

$$ma_z = \pi D_p^2 / 8^* \rho_a [-C_d |V_R| v_z + C_1 (U^2_{top} - U^2_{bot})] - mg + qE,$$

where m, q and D_p are, respectively, the mass, charge and diameter of the grain; a_x and a_z are the grain accelerations along the x- and z-axis, respectively; V_R is the vector difference between the wind and grain speeds; U is the horizontal component of the wind speed; U_{bot} and U_{top} are the wind speeds below and above the grain; ρ_a stands for the air density; g is the gravitational constant; and E is the electric field in the place of grain location. The drag factor C_d is calculated using the Reynolds number for the respective shape of the sand grains. The raising factor C_1 is equal to 0.85 C_d. To determine the grain motion trajectory, the motion equation is integrated numerically.

It was shown in paper [12] that a result of the so-called "splash"— which occurs when a salton (flying due to wind) hits into a sand bed at a high speed– is knocking-out of another charged particle of a grain, namely, another salton. The salton rebounded from the sand bed moves at a speed practically equal to that of the impacting one (see Fig. 6). The rebounded saltons escape the sand surface at an angle 34...40° to the horizon. In addition to the rebounded saltons, one or several other grains (up to 20 depending on the speed and mass of the impacting salton [3]) also get ejected from the sand surface. These grains, known as "reptons", move at a speed approximately equal to one tenth of the impacting salton



a b

Fig. 6. A "splash" occurring due to a hit of a salton into sand ripple surface: (a) 1 — sand bad, 2 —negatively charged impacting salton, 3 — negatively charged rebounding salton, 4 — negatively charged ejected repton, 5 — positively charged sand grains, 6 — ionized space, 7 — direction of sand ripples movement, 8 — near surface wind direction; (b) 3-D representation of the results of computer simulation [1]

one. At that, the reptons escape at an angle ~70° to the horizon in different directions (in a semicircle) and do not ascend in the layer with the accelerating wind. Fig. 6, b shows a 3-D image representation [1] of the results of computer simulation of the processes which occur when a salton hits into a sand surface.

To estimate the mean velocity of sand grain flow in the near-surface layer, let us use the shear velocity which is applied for describing motion in the case of shears associated with gas flow. The shear velocity, which is also known as the friction speed [10], represents a form using which the shear stress can be rewritten in terms of the velocity units, *viz.* $u^* = (\tau / \rho)^{1/2}$ where τ is the shear stress in an arbitrary wind layer and ρ is the air density. The general rule is that the rate of shear is about 1/10 of the mean flow velocity.

Fig. 7 presents calculated and measured dependences of the mean hop distance l of sand grains (diagram a: the circles and squares correspond to the data of papers [14] and [7], respectively) and mean height zm of the grain transportation layer (diagram b: the circles and squares correspond to the data given in papers [5] and [14], respectively) in the flow of Aeolian transportation on the shear velocity [7]. The experimental results of measuring the mean hop distance and height of the sand grain flow due to Aeolian transportation convincingly show that the process of Aeolian transportation developed. A further increase of the wind speed results in increasing the flight speed and hop distance of the saltons (and hence — in increasing the sand ripple length; see the dash line in Fig. 7 a). At the same time, the effect is not accompanied by lengthening the mean hop distance of the sand grains because of essential increase of the relative contribution of the ejected slow reptons. Specifically, the flight height of the reptons is considerably lower than that of the saltons, and the exit angle (and, accordingly, the flight trajectory with respect to the horizon) depends but very slightly on the incidence angle of the saltons upon the sand bed (within the range 8...15° with respect to the horizon [1]). With increasing the wind speed, one can observe a limitation of the mean height of the sand grain flow due to strengthening the electric field influence (see Fig. 7 b). At that, the mean slope of the flight trajectory of the charged sand grains can be estimated from the data presented in Fig. 7 to be equal to ~ 30°.

Analysis of the data makes it possible to explain the specific features of the effects of anomalously narrow-beam backscattering of radio waves.

In the case where the near-surface wind speed is less than 2 *m*/s, at the stage of origination of the anomalous narrow-beam scattering, the saltons are characterized by a low flight speed and hence, "splashes" are accompanied by ejecting of a minimum number of reptons. Here, the mean slope of the flight trajectory of the charged sand grains that determines the slope of the ionized space boundary which borders the sand ripple [8] and is responsible for the "strong" radar scattering, is determined by both the saltons and reptons. This effect is clearly seen in Figs. 4, c and d where the local maxima of the backscattering appear in a wider range of the Θ angles (28.5 to 31.5°).

The contribution of the reptons increases considerably with the wind speed, and the slope of the ionized range boundary is mainly determined by their flight trajectories. Since the exit angle with respect to the horizon (and hence, the repton flight trajectory) depends but very slightly on the angle of salton incidence upon the sand bed [1], the processes of the sand transportation over slanting skew surfaces of sand dunes covering the desert do not lead to broadening the angular sector of the backscatter intensity. The characteristic angular width of the $\sigma(\Theta)$ dependence for the anomalously narrow-band backscattering does not exceed 0.5 to 1° at a 3 dB level.

The experimentally proven the fact that the knocked-out reptons escape in different directions in a semicircle [9] explains the rather weak dependency of the intensity of anomalously narrow-beam backscat-

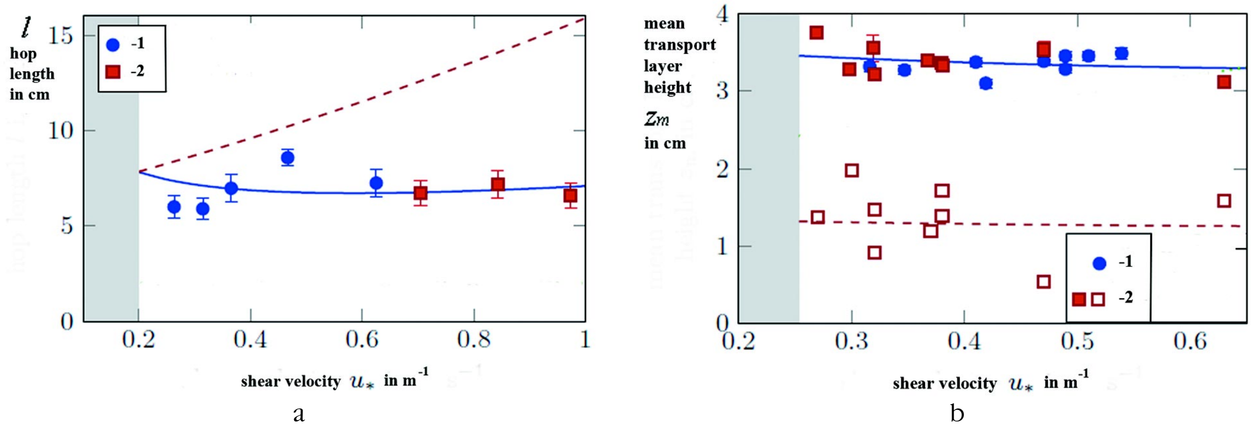


Fig. 7. Calculated and measured dependences of the mean hop distance of sand grains (a) and mean height (b) of the grain layer in the flow of Aeolian transportation on the shear velocity [13]

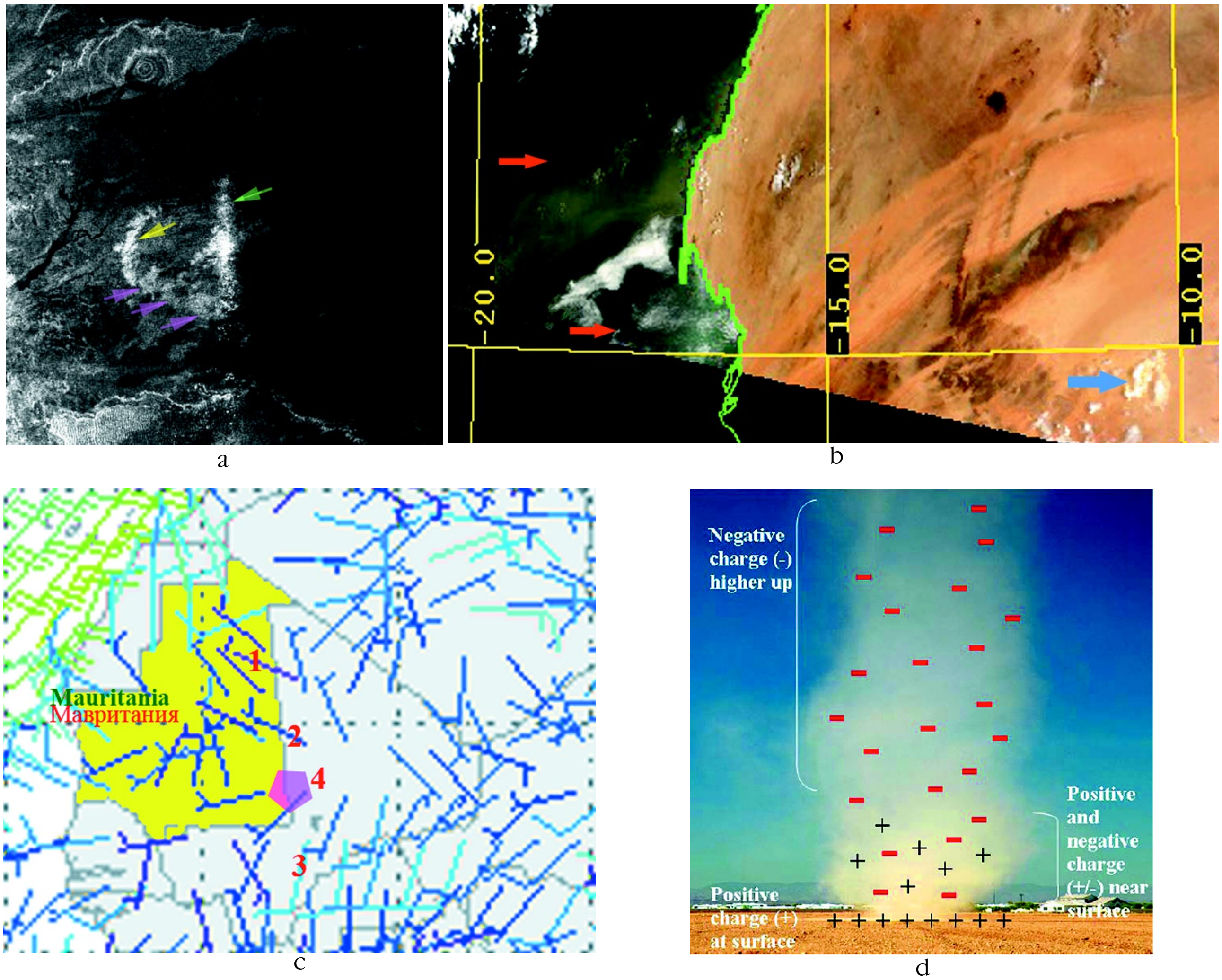


Fig. 8. Radar image (fragment of the radar image Envisat-1 ASA_GM1_1P (© ESA) obtained on June 27, 2005) of the mesoscale eddies (a). Optical image of Mauritania region (satellite MODIS [11]) (b). Meteorological data map (c) [2]: 1 — wind velocity vector near surface, 2 — wind velocity vector at a height of 10 meters, 3 — wind velocity vector at a height of 15 meters, 4 — approximate position of the center of the vortex. Schematic representation of the lifting of the charged grains of sand in the atmospheric vortex (d) [10]

tering on the wind direction relative to the direction (in the azimuthal plane) of radar illumination of the surface. In the case of downwind illumination, the effect has not been observed [8].

Aeolian transportation of sand and dust-laden air upon the surface under appropriate conditions of atmospheric stratification (e. g., updrafts produced in the vortex formation) is capable of raising dust up to high altitudes [6] and spreading it over vast distances by means of strong wind currents in the upper atmosphere layers. For instance, Fig. 8 a shows the radar image (fragment of the Envisat-1 ASA_GM1_1P (© ESA) radar image obtained on June 27, 2005) of mesoscale eddies. At the same time, Fig. 8 b — optical image (satellite MODIS [11]) — shows that raised by the eddies dust masses are transported over the ocean surface (marked with red arrows). Fig. 8 a illustrates the fact that the vortex atmospheric processes are observed not only as near-surface transport processes of sand-dust mixtures (marked with a green arrow), but also as the rise of masses of intensive charged sand particles into the atmosphere (indicated by yellow and purple arrow). The presence of a dangerous for health concentrations of dust in the air that day was also confirmed by measurements in Nouakchott [15]. Atmospheric vortex existence in this area was confirmed by meteorological data Fig. 8 c [2] and by specific cloud formation (in the form of the Greek letter “λ”) marked by the blue arrow in Fig. 8 b.

Conclusion

The paper presents the first results of the development of a radar-based technique for identification of desert regions in which the dust from the surface is transported up into the atmosphere as a result of Aeolian processes. The work has been performed using ESA archive data of radar remote sensing images of deserts of Mauritania obtained by the SAR Envisat-1 between 2004 and 2012. In particular, an analysis has been provided for the specific artifacts observed on the radar images due to manifestation of the anomalous effects of narrow-beam backscattering of radio waves which occur in the course of the Aeolian transportation of the sand-dust mixture.

The specific details of manifestation in the radar images of the narrow-beam backscattering effects on Aeolian processes were analyzed in respect to the near-surface wind speed and relationship between directions of the wind and the directions of radar illumination of the Earth's surface. The peculiarities of the formation of the ionized layer boundary, which borders sandy ripple structures, in the course of the Aeolian transportation of the sand-dust mixture have been considered. It is considered the model assuming the ionization is produced by a strong inhomogeneous electric field which is generated due to Aeolian transportation of charged sand grains, specifically saltons and reptons, over the sand bed. Within the model, the obtained estimates have made it possible to propose the physical explanation of the measured angular dependences between the cross-sections of the investigated radar images of the desert regions with Aeolian transportation processes and combinations of wind and radar illumination directions, as well as determine the optimum conditions for observations of the effects of the anomalously narrow-beam backscattering of radio waves. It has been demonstrated that the radar-based technique of earth remote sensing is capable of detecting these effects starting from very low speeds of the near-surface wind (~2 *m*/s) within a sufficiently broad range of the directions of surface illumination (not less than 90° with respect to the wind direction) within the azimuthal plane. In order to ensure the high efficiency of radar systems for identification of desert regions where dust from the surface is transported up into the atmosphere, it is necessary to ensure the radar systems are capable of operating in the mode of sequential observation of desert regions in the illuminating beam incidence angle range of about Θ=30°.

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КОСМІЧНА РАДІОЛОКАЦІЙНА ІДЕНТИФІКАЦІЯ ПУСТЕЛЬНИХ ОБЛАСТЕЙ ДЖЕРЕЛ НАСИЧЕННЯ ПИЛОМ АТМОСФЕРИ

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Атмосферний пил представляє собою суміш найменших часток різноманітних солів та мінералів. Він містить також рештки рослинних та тваринних організмів, спори хвороботворних мікробів і т. п. Вітрами він переноситься на значні відстані і його присутність в атмосфері є одним із факторів що суттєво впливає на клімат планети. В поточний час для космічного моніторингу еолових процесів та їх наслідків використовуються тільки багатозональні оптичні системи (TOMS, METEOSAT, MODIS та т. п.), які не дозволяють надійно і незалежно від хмарності, освітлення та прозорості атмосфери ідентифікувати самі райони джерела підняття пилу до атмосфери та слідкувати за динамікою еолових процесів. Таке завдання дозволяють вирішувати космічні радіолокаційні системи ДЗЗ.
В статті представлені перші результати відпрацювання радіолокаційного методу ідентифікації пустельних областей, в яких відбувається еоловий процес підйому пилу з поверхні в атмосферу. Для відпрацювання методу використані калібровані дані радіолокаційного дистанційного зондування (ДЗ) пустель Мавританії ASAR Envisat-1, що надані ESA в рамках виконання проекту ID: C1F.30193. Для ідентифікації джерел підйому пилу використані прояви аномально вузькоспрямованого зворотного розсіювання радіохвиль, що виникали при локальних кутах опромінення поверхні $\Theta \sim 30^{o}$. Проаналізовано особливості проявлення на радіолокаційних зображеннях аномально вузькоспрямованого зворотного розсіювання радіохвиль при різних швидкостях при поверхневого вітру та різних співвідношеннях напрямку вітру та радіолокаційного опромінення поверхні. Показано, що характеристики розсіювання добре узгоджуються з особливостями формування границі іонізованого шару, який облямовує структури піщаних бриж в процесі їх формування при еоловому переносі піщано-пилової суміші. При цьому іонізація викликається потужним неоднорідним електричним полем, що виникає за рахунок переміщення по повітрю над піщаною підкладкою негативно заряджених піщинок — сальтонів та рептонів. Відмічено, що радіолокаційне ДЗ дозволяє виявляти райони підняття пилу в атмосферу навіть на етапі зародження процесу незалежно від освітлення, стану хмарного покриву та запилованості атмосфери.

Ключові слова: космічне радіолокаційне спостереження, атмосферний пил, вузькоспрямоване розсіювання радіохвиль, еоловий перенос піску та пилу, виявлення районів підняття пилу в атмосферу, піщані брижі, іонізація, електричне поле

КОСМИЧЕСКАЯ РАДИОЛОКАЦИОННАЯ ИДЕНТИФИКАЦИЯ ПУСТЫННЫХ ОБЛАСТЕЙ ИСТОЧНИКОВ НАСЫЩЕНИЯ ПЫЛЬЮ АТМОСФЕРЫ

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Атмосферная пыль представляет собой смесь мельчайших частичек различных солей и минералов. Она содержит также остатки растительных и животных организмов, споры болезнетворных микробов и т. п. Ветрами она переносится на значительные расстояния и ее присутствие в атмосфере является одним из факторов, существенно влияющим на климат планеты.
В настоящее время для космического мониторинга эоловых процессов и их последствий используются только многозональные оптические системы (TOMS, METEOSAT, MODIS и т. п.), которые не позволяют надежно и независимо от облачности, освещенности и прозрачности атмосферы идентифицировать сами районы источники поднятия пыли в атмосферу и следить за динамикой эоловых процессов. Такую задачу позволяют решить космические радиолокационные системы ДЗЗ.
В статье представлены первые результаты отработки радиолокационного метода идентификации пустынных областей, в которых происходит эоловый процесс подъема пыли с поверхности в атмосферу. Для отработки метода использованы калиброванные данные радиолокационного дистанционного зондирования (ДЗ) пустынь Мавритании ASAR Envisat-1, предоставленные ESA в рамках выполнения проекта ID: C1F.30193. Для идентификации источников подъема пыли использованы проявления аномально узконаправленного обратного рассеяния радиоволн, возникавшие при локальных углах облучения поверхности $\Theta \sim 30^{o}$. Проанализированы особенности проявления узконаправленного обратного аномального рассеяния радиоволн на радиолокационных изображениях при различных скоростях приповерхностного ветра и разных соотношениях направлений ветра и радиолокационного облучения поверхности. Показано, что характеристики рассеяния хорошо согласуются с особенностями формирования границы ионизированного слоя, окаймляющего структуры песчаной ряби в процессе ее формирования при эоловом переносе песчано-пылевой смеси. При этом ионизация вызывается сильным неоднородным электрическим полем, возникающим за счет перемещения по воздуху над песчаной подложкой отрицательно заряженных песчинок — сальтонов и рептонов. Отмечено, что радиолокационное ДЗ позволяет выявлять районы поднятия пыли в атмосферу даже на этапе зарождения процесса независимо от освещенности, состояния облачного покрова и запыленности атмосферы.

Ключевые слова: космическое радиолокационное наблюдение, атмосферная пыль, узконаправленное обратное рассеяние радиоволн, эоловый перенос песка и пыли, выявление районов поднятия пыли в атмосферу, песчаная рябь, ионизация, электрическое поле.