

## REMOTE SENSING

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### Summary

Some types of modern systems and methods of remote sensing are described in this chapter. Among them such methods as radiolocation, laser location and multichannel scanning from space are described in details. **Remote Sensing** is the process of obtaining information about a remote object, without any physical contact between the sensor and the subject of analysis. Sight and vision were the first methods of remote sensing which a person used. The development of science and engineering has resulted in the creation of numerous devices and technologies for remote sensing. However the principles of operation of these systems have features similar to sensory organs of a person. It is possible to tell, that humans artificially expanded their capabilities. Such systems as the radar (Radio Detection And Ranging) and lidar (Light Detection And Ranging) are most advanced today as active methods. The multi-spectral scanning systems are used for passive methods of sounding. The term *remote sensing* most often refers to the collection of data by instruments carried aboard aircraft or satellites,

because all advantages of remote sensing are exploited in the best way in this area. Increase of resolution of systems and improvement of the data processing methods will be main directions of the development of remote sensing in near future.

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## 1. Introduction

“Remote sensing” and “Remote sounding” are particularly scientific concepts, but we encounter them since the very beginning of our lives. In short, these concepts represent methods which allowed us to determine characteristics of an object as it is situated at a distance and to determine them without direct contact. Some senses, for example: vision, hearing, smell, taste, touch, sensation of temperature, feeling of pain, determination of the position and motion of the body. But, undoubtedly, vision is most important and surprising of them. It delivers to our brain more than 90% of the information about the surroundings. And for the astronomers vision has been generally a unique means of observing the universe. Thus, our vision, hearing, and to some extent smell, are analogous to remote sensing. When we see an object we can determine our distance from it, its location, shape and color. The structure of the human eye is shown in Figure 1. At a first glance the eye very much looks like a camera. The objective of an eye consists of the cornea, iris and crystalline lens.

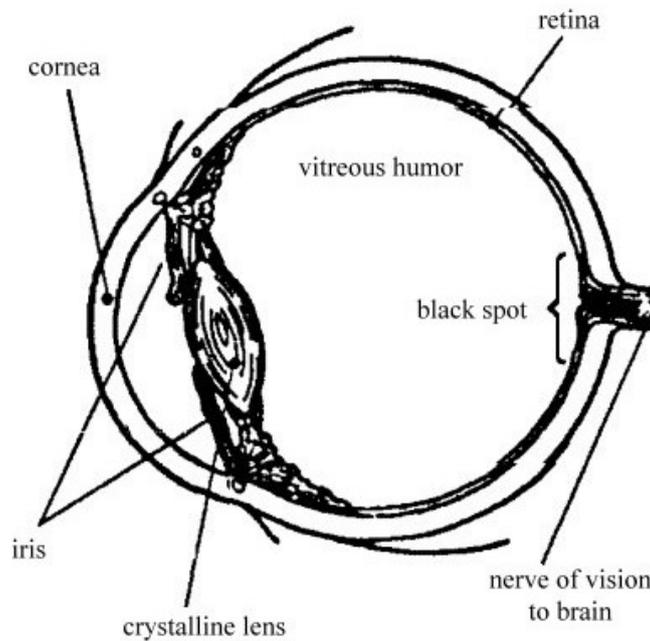


Figure 1. The scheme of a human eye.

Our eye is similar to a classical photographic device with a system of lenses and diaphragm. And it has very wide-angle objective: The field of vision of our eyes reaches almost  $180^\circ$  on a horizontal and  $140^\circ$  on a vertical. Certainly, the quality such a simple objective cannot be very high: a sharp image is received only at the center of the range of vision, and it noticeably is worsened at the circumference. The central hole in the iris is the pupil. It performs the function of the diaphragm (aperture) of a camera: it more or less closes edges of a lens in objective. The eye can change diameter of the pupil in limits from 2 mm to 8 mm. Thus, it regulates quantity of light passing through crystalline lens onto the photosensitive retina. At this point the analogy to a camera is finished, as about the retina we will not tell any more, that it is analog of a photographic film.

The retina of an eye is much closer to the sensing device of the modern video camera, consisting of a set of elementary semiconducting receivers of light – pixels. The photosensitive cells execute their role in the retina of an eye. One kind of cells is called cones, and the other - rods. There are about 7 million cone cells and 120 million rod cells in the retina of each eye. Rods work in weak light and provide evening and night sight. But they are not sensitive to colors. Therefore it seems, that “all cats gray at the night”. And cones can work only in bright light, i.e. during the day, thus they sense the color of an image. The sensing of color by the retina is explained actually by its cones of three different types located pell-mell: one sensitive to dark blue, second - to green, and the third - to red. All together they precisely transmit the information on nuances of an image. As we shall see further all receiving devices used in many systems of remote sensing are constructed on the basis of this principle.

If we hear some noise we can determine its location even in darkness with the help of hearing. The animals are especially effective in this respect. For example, bats and dolphins use echolocation for sensing their orientation in space. They emit ultrasonic impulses with frequency up to 130-200 kHz and signal duration from 0.2 to 4-5 ms, and then determine the distance from the object by the return time of the echo-signal. Humans do not have such natural equipment (behind vision), so they had to invent it themselves. Therefore visual observation and photoshooting are possible to name as the first methods of remote sensing. With the development of science and well-established electromagnetic theory, the distance methods, like acoustic one's but based on the principles of electromagnetic wave propagation, were established.

## **2. Radiolocation**

It is a historical fact that first achievements in location with the help of electromagnetic emission were attained in radio range. The German physicist Heinrich Hertz actually generated such waves electrically. Hertz observed the phenomenon of reflection of radio waves during 1886 - 1889. The capability of detection of the ships based on the phenomenon of reflection of radio waves was observed practically by Alexander Popov (Russia) in 1897. For the first time the idea of detection of the ship using radio waves, reflected from it, was precisely formulated in the patent of the German engineer Christian Hülsmeyer (1904). This patent contained the detailed definition of the device for realization of this idea. Hülsmeyer's system was only effective for a range of about 1.5 km (about 1 mile). The first long-range radar systems were not developed until the 1920s. In 1922 Italian radio pioneer Guglielmo Marconi demonstrated a low-frequency (60 MHz) radar system. In 1924 English physicist Edward Appleton and his graduate student from New Zealand, Miles Barnett, proved the existence of the ionosphere, an electrically charged upper layer of the atmosphere, by reflecting radio waves off of it. Scientists at the U.S. Naval Research Laboratory in Washington, D.C., became the first to use radar to detect aircraft in 1930.

However, the technology of that time could not meet the needs of realization of these purposes. The first activities in this area for military applications began in the 1930s, and towards the end the 1950s radiolocation was transformed into a classical training discipline included in the mandatory program of preparation of the experts in the field of radio engineering. It is surprising that with these capabilities various and numerous

radar installations and devices were created by this time. They were really capable of making it possible "to see" what in the ordinary was impossible "to see". The area of radiolocation is one of radio electronics and decision based on radar observation of various objects, i.e. their detection, measurement of coordinates and parameters of motion, and also detection of some structural or physical properties by using reflected or reradiated objects of radio waves or their own radio emission.

## 2.1. A Brief Theory of Radar

Radar (Radio Detection And Ranging), is a remote detection system used to identify and locate remote objects. The radar radiates an electromagnetic pulse, which is focused by the antenna and is sent into the atmosphere. An object, called the target, that comes across the path of this electromagnetic pulse scatters electromagnetic energy. Most radar systems use frequencies that fall in the radio range (from a few million cycles per second—or Hertz—to several hundred million Hertz) or the microwave range (from several hundred million Hertz to a several tens of billions Hertz). A part of this energy is scattered back in the direction of the radar; see Figure 2.

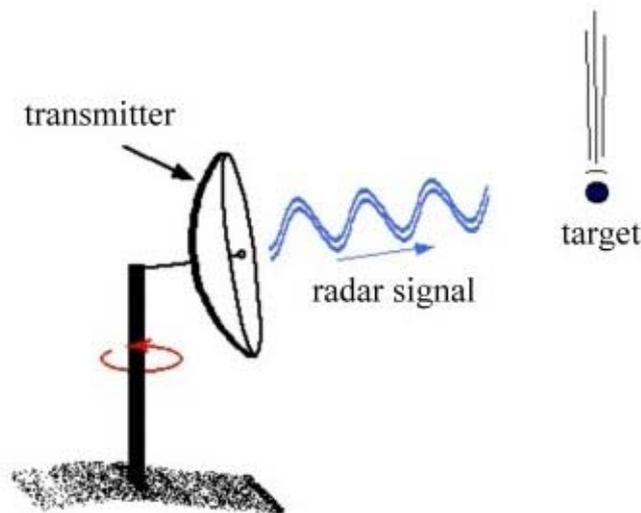


Figure 2: The electromagnetic wave is transmitted from the antenna to the target

The receiving antenna receives the backscattered radiation and transmits it to a device known as the receiver; see Figure 3. The radar produces high-frequency oscillations, which are modulated on amplitude, frequency or phase. These oscillations are transmitted to the antenna device which generates a sounding signal. A sequence of short radio pulses equally spaced in time is applied more often as a sounding signal. Most radars have transmitting and receiving antennas located in immediate proximity of each other. The radar with pulse modulation usually has one antenna and a special antenna switch for transition from transmission mode to reception mode and back. As an electromagnetic wave hits the target, electromagnetic field oscillations are generated in it as in a usual antenna. This field is a reflected electromagnetic wave, which creates in the radar an echo, a signal which has information about the target. The amplitude of the signal characterizes the dimensions and reflecting properties of the target; dead time from the beginning of radiation of the sounding signal is used for range tracking, and the frequency of oscillations bears the information on radial speed of the target due to

Doppler Effect. The polarizing parameters of a reflected wave can be used for an evaluation of properties for the purpose. Finally, the direction of arrival of the reflected wave contains information on the angular coordinates of the target.

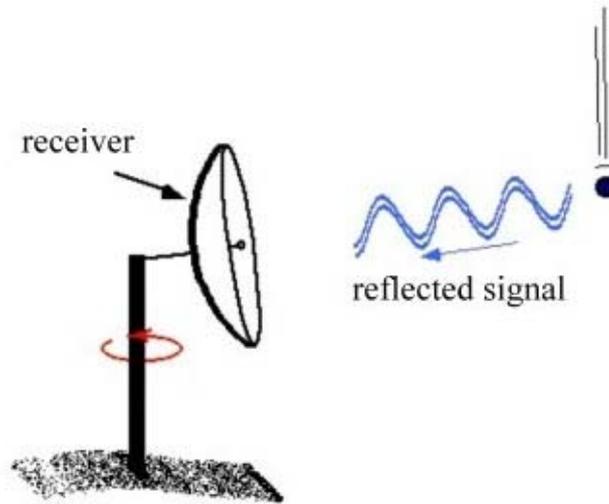


Figure 3: The scattered electromagnetic signal comes back from the target to the antenna

Resolution is an important characteristic of radar. It is determined by the width of the polar pattern formed by antenna and pulse duration. Beamwidth at half power points (in degrees) for the mirror antenna as a truncated paraboloid is

$$\Theta_{0,5} = 65 \cdot \frac{\lambda}{d_A},$$

where  $\lambda$  is wavelength,  $d_A$  is the maximum linear size of a mirror in the plane of the beam, for example, at  $\lambda = 3$  cm for producing beamwidth  $\Theta_{0,5} = 3^\circ$  the required  $d_A = 65$  cm, and for the beam to have such width at a wavelength 3 m, the size of a mirror should be 6.5 m.

The radar allows us to determine remotely not only the characteristics of the separate target, but also property of the environment. Therefore to implement remote monitoring of Earth's surface it is desirable to place radars on mobile platforms. The aircraft and space radar for viewing the earth's surface have a lot of advantages compared to visual observation and air photography. All-weather radar observation is possible owing to smaller attenuation of radio waves during propagation in the atmosphere, i.e. it is possible to make observation through haze, clouds, fog and rain. The functioning of the radar does not depend on the conditions of natural light exposure of the ground; therefore, radar observation at any time of the day is possible. The radar stations on an airplane can provide observation of a segment of the earth's surface located at a great distance. Finally, the observation of details invisible in the optical range of waves, for example of metal objects painted under a hum noise of district is possible, due to significant difference between the character of reflection from objects on the earth's surface by radio waves and light waves.

## 2.2. Types of Radar Systems

Now there are three basic radar types for viewing the earth's surface: panoramic radar, side looking radar and synthetic aperture radar. Panoramic radar views the earth's surface using circular rotations of the antenna in an azimuthal plane. Thus the image of district in a zone of the view can be observed on the indicator; it will look like a circle or sector with a maximum radius equal to distance of operation radar. The main defect of the panoramic radar is a low resolution on azimuth  $\delta$ , which is determined by beamwidth of the antenna in the horizontal plane. Beamwidth  $\Theta$  depends on the horizontal size of the antenna  $d$  and wavelength  $\lambda$  of the electromagnetic oscillations radiated by the radar: the larger size of the antenna the less is the wavelength, and thereby less beamwidth  $\Theta = \lambda/d$ . Beamwidth (linear resolution on azimuth) is increased proportionally of inclined distance. For example, the resolution will be  $\delta \approx 2.5$  km at a wavelength  $\lambda = 3$  cm and size of the antenna 150 cm the angular beamwidth  $\Theta = 1.15^\circ$  and on a distance of 120 km. Due to low resolution on the indicator of the panoramic radar the marks only from large objects are usually observed. Therefore panoramic radars are not suitable for jobs such as map-making of district, geophysical investigation etc.

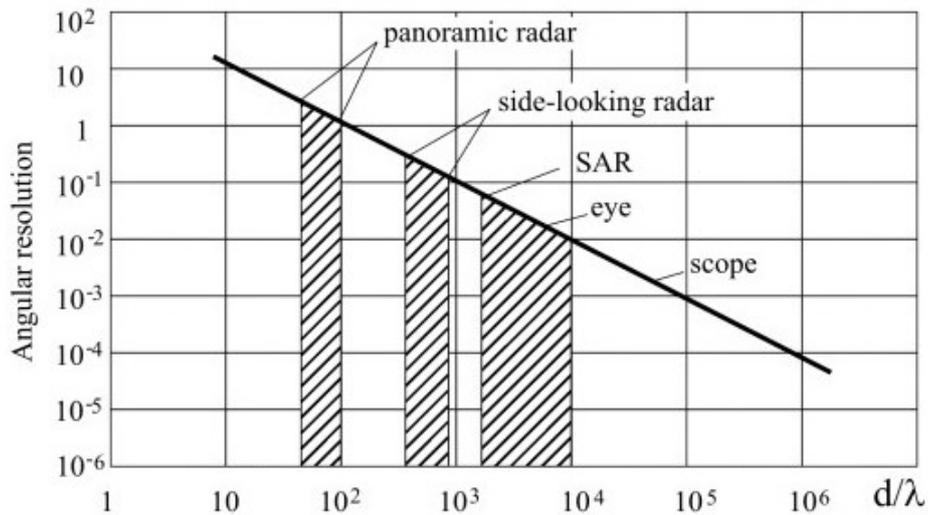


Figure 4. Resolution of various devices.

The ratio of angular resolution to the relative size  $d/\lambda$  of the antenna for the radar, optical devices, and pupil of an eye are shown on Figure 4. It is clear, in particular, that the panoramic radar has poor angular resolution compared to the human eye (approximately 100 times less). Therefore the side looking radar with synthesized aperture antenna based along fuselage of the aircraft or satellite is mainly applied for remote sensing.

In these radars a long reception-transmitting antenna is used to increase the resolution on azimuth. In contrast with panoramic radar the antenna is fixed relative to an airplane or space vehicle and placed on its side. Therefore the size of the antenna can be increased up to several meters; therefore resolution on azimuth will increase considerably. The observation of earth's regions is realized by movement of the antenna relative to the earth's surface during flight of an airplane or space vehicle on straight-

line trajectory (see Figure 5). The antenna forms one or two (at the observation of two sides) beams directed perpendicular to the path of the airplane. From here, the title is "side-looking radar". High resolution of the side-looking radar on azimuth on small distances, and also long duration accumulation of energy of reflected signals during passage over a segment of the earth's surface in a beam of the antenna allow us to receive high-quality images of district and objects nearly as good as in aerophotography.

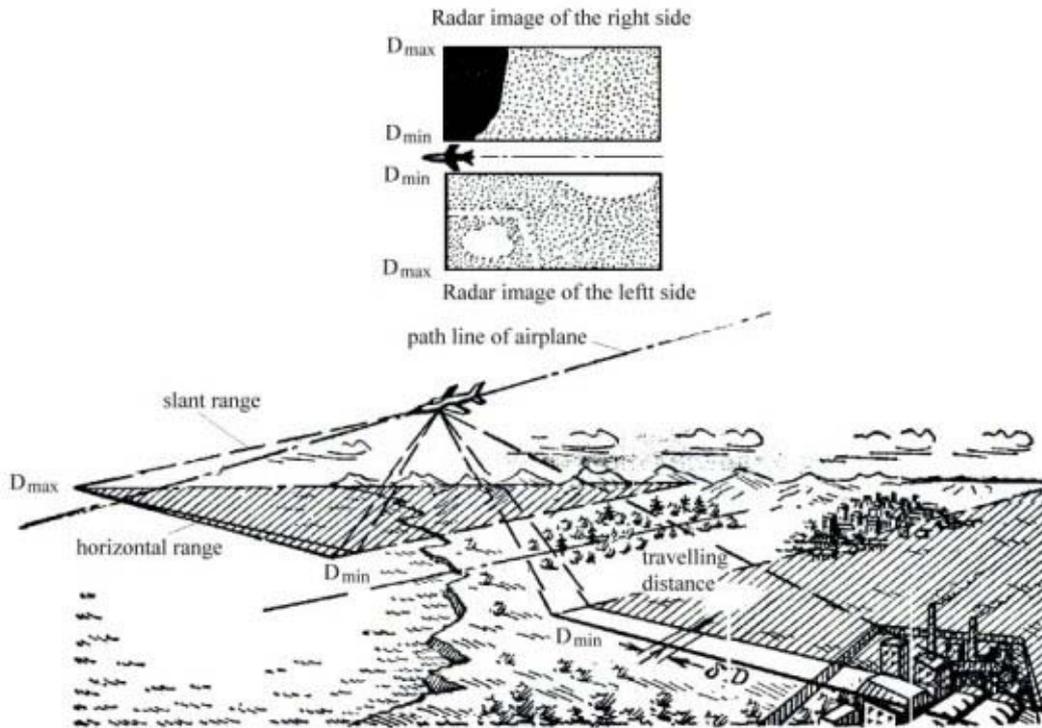


Figure 5. Side-looking airborne radar.

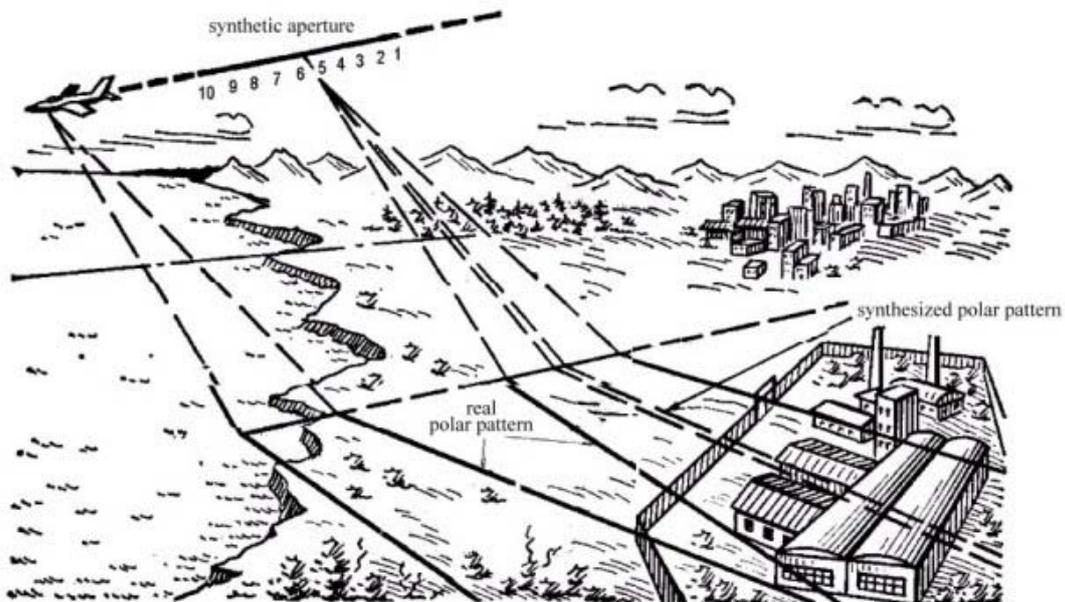


Figure 6. The scheme of formation of the synthetic aperture radar (SAR).

However, side-looking radars do not provide an effective solution to all problems of radar observation of earth's surface over large distances, despite increase of the angular resolution comparable with the panoramic radar. Therefore synthetic aperture radars (SAR) are used in general for remote sensing of Earth from space. The principle of operation of SAR differs from that of the usual radar and allows us to achieve a high angular resolution on azimuth in use on space vehicle with antenna of small size. It is based on the formation of a narrow polar pattern on azimuth by an artificially created antenna array (see Figure 6).

The trajectory of a space vehicle may be considered as a straight-line over a short interval of time (seconds). It is known, that the antenna pattern is formed as an outcome of coherent (with allowance for phases) addition of radio waves received by separate elements of the antenna. For example, if the antenna system consists from  $N$  identical antennas with size  $d$  located side by side and signals, received by each antenna, are coherently summarized, the antenna array has the same narrow polar pattern, as much as an antenna of size  $10N$ . Therefore, an increase of angular resolution is possible by coherent summation of signals of the antenna located in space on a direct line that are created by the antenna array. The principle of operation of the SAR is based on the use of straight-line motion of the space vehicle with the antenna for series formation by the antenna array on flight trajectory. The receiving aperture stores a series of signals sequentially received by the radar antenna at each point on a trajectory (for example,  $1 - N$ ), then coherently sums them and achieves the narrow directional polar pattern of the artificially generated antenna array. The size of the synthesized aperture of the antenna is equal to the length of a segment of trajectory, on which the remainder and coherent summation of signals was made. Using this method, the resolution on azimuth can be increased 100 times in comparison with the panoramic radar. The sanction on inclined distance in all types of radars is provided at the expense of pulse operational mode. The main drawback of the SAR is the difficult system of processing of signals.

The following list shows areas of application of radars:

*Agriculture and forestry.* Research on density of vegetative cover, distribution of forest tract, meadows and fields, determination of kind of soils, their temperature and humidity, management of irrigative systems, detection of fires;

*Geophysics and geography.* Determination of the structure of land tenure, distribution of condition of the transport and communication, development of systems of processing of natural resources, topography and geomorphology;

*Oceanography.* Determination of the sea and ocean surface profile, mapping of a coastline, observation of the biological phenomena, realization of ice patrol. The image of a water surface obtained by the SAR is shown on Figure 7;

*Meteorology.* Meteorological maintenance, the example of detection of a tornado in background of a thundercloud is shown in Figure 8;

*Military business, civil aviation.* Management of air traffic, maintenance of near and distant radionavigation, radar maintenance of landing of aircrafts and space vehicles.

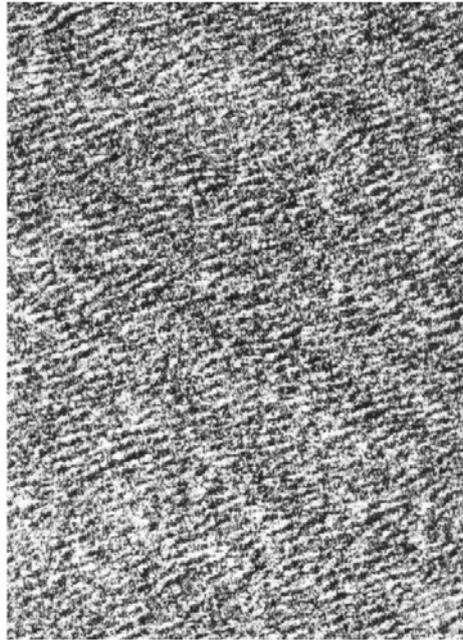


Figure 7. SAR image of the ocean.

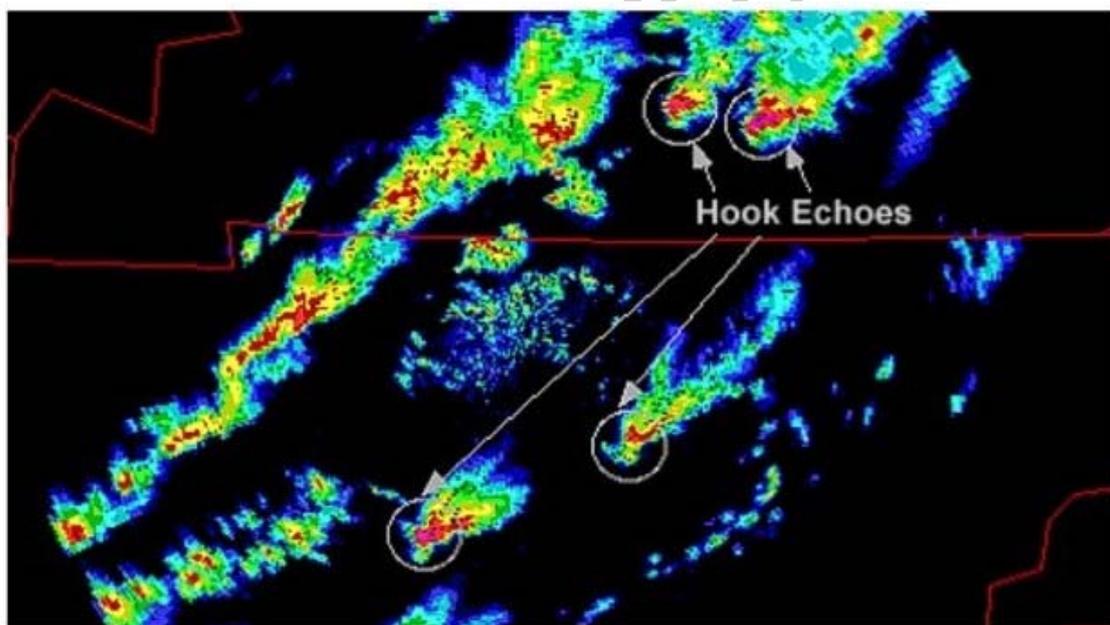


Figure 8. Area of a strong thunderstorm, which took place in Tennessee and Kentucky of May 18 1995. It is well visible by some radio echo from Tornado. Tornadoes are located in the center of an obtained radio echo on the southwest party of thunderstorms more often. The radio echo is best observed in the field of increased reflective ability.

Thus radiolocation has many applications, but does not meet all needs of remote sensing. For example, the range of electromagnetic waves used in radiolocation does not provide sufficient spatial resolution. New capabilities in remote sensing have appeared from the moment of the invention of a directional light source –the Laser.

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### Biographical Sketch

**Kirill Alexandrovich Boyarchuk**, was born on 23 December 1959, St.-Petersburg, Russia.

Field of specialization: Remote sensing, Radiophysics, Quantum electronics, Hydrophysics, Earth Atmosphere, Geophysics, Solar Terrestrial Physics, Radioactive Pollution, Ecology.

Education and Degrees:

St.-Petersburg State University, Physical department (1977-1983), Master degree, Physics.

General Physics Institute of Russian Academy of Sciences (1983-1986), postgraduate student, PhD degree, Radiophysics. (Thesis: "Processing of sea images by the optoelectronic methods")

Wave Research Center of the General Physics Institute, 1998, Doctor of Physical and Mathematical Sciences degree, Radiophysics.( Thesis: "Remote sensing of the artificial ionization traces in the atmosphere")

Professional Experience:

1999-2004 - deputy director of the Institute of Terrestrial Magnetism, Ionosphere and Radiowave Propagation Russian Academy of Science, Troitsk, Moscow Region.

1998-1999 - head of atmospheric electricity Laboratory of the Institute of Terrestrial Magnetism, Ionosphere and Radiowave Propagation Russian Academy of Science, Troitsk, Moscow Region.

1983-1998 - Postgraduate student, associate researcher, senior researcher and leading research fellow at the Wave Phenomena Department of the General Physics Institute of Russian Academy of Science, Moscow

1980-1983 - Research fellow at the Quantum Optoelectronic Laboratory at the Physical-Technical Institute of Russian Academy of Science, St.-Petersburg

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