TECHNIQUE FOR REMOTE SOUNDING OF ANTHROPOGENIC POLLUTION IN OPTICAL AND RADIOWAVE RANGES

V.L. Mironov, A.V. Evtyushkin, S.A. Komarov, N.M. Oskorbin, and A.N. Romanov

Altai State University, Barnaul
Received June 22, 1993

Some results of experimental studies aimed at developing the techniques for remote sounding of anthropogenic pollution based on integrated spaceborne and airborne measurements in optical and radiowave ranges as well as on the data of ground–based and field observations and laboratory–based data are presented. In this studies snow cover and ground waters are used as indicators of anthropogenic pollution.

The researches aimed at developing the remote techniques for studying the processes of transport and accumulation of pollutants caused by human activities in the territory of the region are carried out at the Altai State University. By now the problems related to the mechanisms of air and subsurface water transport have been examined in detail and successively. It has been pointed out that the integrated use of the spaceborne, airborne, and field observations in optical and radiowave ranges as well as of ground – based and laboratory data are promising. Much attention was given to the detection of abnormally high content of base metals in soil and to the processes of their spread.

1. ANALYSIS OF THE POLLUTION OF A TERRITORY FROM THE STATE OF THE SNOW COVER

A great deal of the anthropogenic pollution from industrial centres is transported by airflow from the localized sources. These are stacks of the thermal power stations pipes of central, heating, and industrial enterprises. The snow cover is a good indicator of such pollutions in winter.[1] The methods of monitoring of the snow cover pollution in vast territories have been developed with the appearance of the apparatus for remote sounding of the Earth from space.[2] The state of a comparatively large territory in the South of Western Siberia and feasibility of solution to the above problem were studied based on the materials of spaceborne survey carried out during the past few years, that were borrowed from the archives of the Western Siberia Regional Center for Preliminary Data Processing (WSRCPDP) in Novosibirsk. For analysis we selected 4 pictures taken by the MSU–S apparatus, 22 pictures taken by the MSU–SK apparatus, and 8 pictures taken by the MSU–É apparatus used onboard the satellites of Kosmos and Okean series (satellites orbited at an altitude of 620 km, and the period of survey of the territory was 5–7 days).

The parameters of these apparatuses are the following. The MSU–S multispectral has moderate resolution and ensures the surface survey in the spectral ranges 0.5–0.7 and 0.8–1.1 μm. The viewing swath is 1380 km, the spatial resolution is 345 m. The MSU–SK scanner exhibits moderate resolution, conic scanning, and five spectral channels: 0.5–0.6, 0.6–0.72, 0.72–0.8, 0.81–1, and 10.36–11.75 μm. The viewing swath is 600 km. The MSU–E multispectral scanner has high resolution and ensures the survey in three spectral ranges: 0.5–0.9, 0.61–0.69, and 0.81–0.9 μm, 45–m spatial resolution and the survey band 45–m viewing swath.

The pictures taken by the first two apparatuses cover the whole territory in the south of Western Siberia for one passage and enable us to estimate and detect the sources and areas of pollution, and the pictures taken the MSU–E allow us to study the individual areas in ample detail.

Referencing of pictures was performed using the maps on scales from 1:100000 to 1:500000. The analysis showed that the fall pictures (October–November) enable us to trace clearly the dynamics of the snow cover. But we fail to detect the sources of industrial pollution in this case. In winter the pollution is manifested only in the absence of snowfalls for a long time. The local sources of pollution stand out against freshly fallen snow in the form of individual towns and settlements in the limits of a town. In March, as snowfalls cease and a thaw sets in, vast zones of pollution start to manifest themselves around the industrial centrers. So in the territory of Western Siberia and Kazakhstan they are Pavlodar–Ermak pollution zone of 120 km radius, Ekibastuz of 150 km radius, Slavograd of 30 km radius, Gornyak–Zhezkent–Zmeinogorsk—band extended in the west–east direction 100 km long and 30 km wide, and Western Kazakhstan 250×60 km band extended from the north–west to the south–east, (Pervomaiskii–Glubokoe–Ust-Kamenogorsk–Leninogorsk–Serebryansk).
The study of the archives enabled us to plan new surveys of surfaces in time. In this connection the series of the satellite surveys was ordered and executed on March of 1992. Information in the digital form was obtained from the Novosibirsk WSRCPDP. The zones of pollution of the snow cover were determined from images obtained with the help of the MSU–SK and MSU–É apparatuses used onboard the Kosmos–1939 satellite. These images, converted in digital form, were processed on a special computer network comprising the Disk SM1630–KTS series computer, IBM PC/AT–486, IBMPC/AT–286, and the IMAGE–C system. In synchronism with the space–borne survey the samples of snow were taken by a ground–based expedition, since the problem on quantitative estimate of the degree of pollution can be solved only using the data of ground–based measurements in test regions.

The two-channel digitized image of the MSU–SK (0.6–0.7 and 0.8–1.1 μm) was converted to the Gauss cartographical projection on a 1:200000 scale. The basic map was entered from a digitizer. To assess qualitatively the degrees of pollution, the gradations of the radiation intensity histogram in degrees of pollution was used. From

0235-6880/93/11 840-03 $02.00

the data of ground–based expedition obtained for test regions we derived the regression equation for the amount of solid sediment and the radiation intensity channels 2 and 4 of the MSU–SK. One of the results of data processing was the matrix printout of the schematic maps of pollution.

The routine survey in three spectral ranges was executed with the MSU–E scanner on March 5, 22, and 24 of 1992. The southern regions of Altai Krai and the adjacent Kazakhstan territories were to be inspected. Of special interest were the smoke plumes over of Gornyak in the Loktev Dictrict of Altai Krai and over Zhezkent of the Semipalatinsk Region of Kazakhstan. On the snow cover the smoke plumes for the directions of wind corresponding to the period from the last snowfall to the instant of survey moment were "left an imprints". On the matrix printouts of a monitor on a 1:140000 scale the images of pollution of the snow cover, photographed on March 24, 1992 around Gornyak and Zhezkent, were seen. The theory and experiment showed that the concentration of pollutants in the territory was very nonuniform. So the anthropogenic pollution from large enterprises was accumulated in different directions depending on the wind-rose. In addition a maximum of concentration of pollutants was observed at some distance from a local source depending on the stack height and the wind velocity. The dependence of concentration of pollutants on the depth of the snow cover was also nonuniform. The radiation intensity of a pixel recorded from a satellite was averaged not only over the specific area but also over the depth. This statement is based on the fact that soil illumination affected surveying from space when the depth of the snow cover was smaller than 30 cm. The average depth of the snow cover on the Altai plains was 30–40 cm.

In collaboration with the Scientific–Production Company "Taifun" we organized the ground–based expedition to take the snow samples along the route Ust-Kamenogorsk–Gornyak–Zmeinogorsk–Rubtsovsk. We choose the sites for sampling from the archive satellite pictures with allowance for the wind–rose. The samples of snow were subjected to an analysis on the content of base metals at the Scientific–Production Company "Taifun". The data obtained were used for the construction of isolines of concentrations of a number of chemical elements exhibiting high pairwize coefficients of correlation with solid sediment. The coordinate grid was bounded by the region of Rubtsovsk–Zmeinogorsk–Zhezkent. We interpolated these data into the whole area by the spline-approximation method with quadratic splines specified over the irregular grid. We constructed the isolines of the generalized index of pollution for the anthropogenic components (copper, zinc, arsenic, lead, and barium) and terrigenous components (manganese, yttrium, strontium, and iron). The places of barium accumulation were identified in the isolines near Gornyak and Zmeinogorsk. An ore being mined in Karamyshevo and waste of ore from the Gornyak Ore–Dressing Integrated Plant are the possible sources of barium. Thus the sources of anthropogenic pollution of the snow cover at the regional level were identified from the satellite digital scanner images. At the local level an area influenced by industrial enterprises of Gornyak and Zhezkent was determined. From the data of the snow measuring survey we constructed the maps of pollution of the underlying surface by base metals. The generalized index of pollution unables us to identify the area of pollution of the snow cover extended in the north–east direction from Zhezkent to Zmeinogorsk. This region was identified from the pictures taken by the MSU–SK in late fall as the most polluted in Altai Krai.

2. REMOTE MONITORING OF SEEPING AND FLOODING OF A TERRITORY NEAR INDUSTRIAL SETTLERS

In some cases a severe ecological situation occurs in the region of industrial settlers of the ore – dressing industry. As a result of seeping and lifting of the ground water level, harmful substances produced in technological cycle are carried out together with water not only in populated territories, but also in large cultivated territories.

To interpret the hydrological situation we propose the method combining a seasonal spaceborne scanner survey and an airborne serial superhigh–frequency radiometry of the inspected territory. Using such an approach one can monitor the moisture of surface soil as well as solve more complicated problems on remote identification of zones of seeping and on determination of the level of ground waters.[3,4,5]

The given approach was experimentally substantiated and developed at our polygon. The area of 4384 hectares selected for this purpose was the dry-farming land situated in the south-west of the Altai Krai in at the flood plain of the river Alei. The soil consisted of southern chernozem and chernozem solonetz. In this territory we investigated the composition of soil and its moisture regime in detail. A contact method (VNP–1 moisture meter) was used to measure the soil moisture in a number of control points.

We conducted the spaceborne survey of the given territory by the MSU–E scanner used onboard the Cosmos-1939 satellite. The region with enhanced surface moisture were identified by the brightness of images. This enabled us to use these pictures for optimal design of the route airborne measurements with the aim to analyze the surface moisture in detail. We also measured the radiation temperatures from onboard the AN–2 aircraft with superhigh–frequency radiometers at wavelengths of 18, 21, 27, and 50 cm along the routes passing over the nonuniform region chosen with regard to the satellite images. The values of radiation temperatures were interpreted in terms of moisture of the arable layer of soil. To do this we made the measured the complex permittivity of soil samples taken brom the test territory in laboratory conditions with the help of a bridge–type setup and plotted regression dependences.[4] We obtained good agreement of the results of measurements in control points with the ground–based measurements. Investigation and comparison of the scanner and radiometer signals received along the same route showed correlation between the moisture characteristics of the given dependences.

After that the values of radiation temperatures obtained by means of radiometric measurements were interpreted in terms of the average moisture of the arable layer of soil. Further they were interpolated into the whole area by the net–point method[6] and registered with the base map and satellite scanner image. By means of computer processing we constructed the schematic map of the moisture characteristics of these areas. We obtained good agreement with the ground–based measurements. Using the developed approach we worked at photographic mapping of hydrological situation and at determination of the level of ground waters near settlers of the Gornyak Ore–Dressing Integrated Plant. To do this we at first prepared the base map on a 1:50000 scale using a digitizer. The scanner multispectral spaceborne survey allowed us to acquire route information in digital form, which was suitable for subsequent processing on a computer. We converted the data obtained in the third channal of the MSU–É, (0.81–0.90 μm) to the base map projection based on measurements at six control points. The water stream and aqueous soil near the settler were defined by the threshold function in the form of a truncated step. The seasonal scanner surveys (spring–summer–fall) enabled us to trace the dynamics of open water and aqueous regions of soils. In summer the regions of maximum moisturening were identified as the regions with high brightness of vegetation.

The regions with high level of ground waters (LGW) were mapped in flight around the territory on the AN-2 aircraft equipped with superhigh–frequency radiometers. The tack lengths were determined by the possible dimensions of the flooded zone and changed from 4 to 6 km. The distance between tacks was determined by the antenna directional pattern and flight height (100 m) and was 100–200 m. The flight measurements were made for an aircraft speed of 180 km/h.

We determined the values of the LGW for 19 tacks of an aircraft by the technique for estimation of the moisture of the seeding fringe and of the test ground–based measurements. Further these values were interpolated by the net–point method into the whole area and were registered with the base map and the satellite scanner image. The schematic maps of the regions with the LGW being less than 1 m and of the flooded regions with enhanced moisture of the surface layer of soil were constructed.

The total area of the territory with the LGW being less than 1 m estimated from the data of aerial spaceborne mapping was more than 150 hectares.

The data of aerial spaceborne survey in optical and superhigh–frequency ranges yield the information about the distribution of regions with enhanced moisture of the surface layer of soil and regions with high level of ground waters over the territory as well as to determine the numeral values of soil moisture and of the LGW of vast areas.

CONCLUSION

The method of design of the ground–based and airborne observations based on archived and routine synchronous satellite images allowed us to extrapolate the levels of pollution into vast territories which were not inspected by the ground–based expedition. In this case the total expense of obtaining the results was substantially lower and an opportunity appeared to perform seasonal monitoring of the territories. The results of investigation can be formulated as follows:

– regions of anthropogenic pollution of the snow cover were contoured on regional (in the south of Western Siberia) and local (the area of the triangle Gornyak–Zmeinogorsk–Rubtsovsk) levels;

– soil moisture was mapped on the basis of simultaneous sounding in optical and radiowave ranges;

– thematic mapping of reference territories of sowing areas with additional indication of the level of ground waters and type of salinization as well as seeping and flooding zones was carried out in the region of industrial settler of the Gornyak Ore–Dressing Integration Plant; it was shown that pollution of the territory by base metals, whose dose exceeds their maximum permissible concentration (MPC) many times, was due to the spread of chemical elements with seeped water.

The work done demonstrates efficiency of integrated application of the remote methods of sounding in optical and microwave ranges with the aim of monitoring and analysis of ecological situation in the comparatively large territories as part of regional monitoring. Combination of these observations with polygon and laboratory test investigations, results of chemical analysis, and computer data processing provides thematic mapping of the inspected territories.

REFERENCES

1. V.G. Prokacheva, N.P. Chmutova, V.P. Abakumenko, and V.F. Usachev, *Zones of the Snow Cover Pollution near the Towns of the USSR* (Gidrometeoizdat, Leningrad, 1988), 125 pp.

2. V.F. Usachev, D. Olonshek, V.G. Prokacheva, T Gyunter, *The Spectral Reflectance of the Snow Cover.* (Gidrometeoizdat, Leningrad, 1988), 92 pp.

3. A.M. Shutko, *The Superhigh–Frequency Radiometry of the Water Surface and Soil* (Moscow, Nauka, 1986), 188 pp.

4. Positive Conclusion on the Inventor's Application No. 4911186/09/00221315. S.A. Komarov, V.L. Mironov, A.N. Romanov, and N.V. Rychkova.

5. E.A. Reutov and A.M. Shutko, Issled. Zemli iz Kosmosa, No. 2, 99–106 (1991).

6. A.G. Vorotinzev, *Mapping for Use in the National Economy* (Novosibirsk, 1988).