ANNALS OF GEOPHYSICS, VOL. 47, N. 1, February 2004

Seasonal variations in natural processes and atmospheric precipitation

Alexey V. Descherevsky and Alexander Ya. Sidorin
Schmidt United Institute of Physics of the Earth, Russian Academy of Sciences, Moscow, Russia

Abstract
To study the nature of seasonal variations in time series measured at the Garm test site, a local model based on the experimental data of atmospheric precipitation penetration into the soil has been proposed. It is intended for filtration of exogenous variations in the data of various time series and a study of statistical structure of different natural processes, including earthquake preparation processes, and the mechanisms of their effect on the biosphere. Using this model, we analyze and compare variations in apparent resistivity and properties of rock moistening. It has been shown that at small current-electrode (AB) separations among all the parameters of water regime, only water saturation of the active soil layer reveals a significant correlation with apparent resistivity variations. When increasing the current-electrode separation, the seasonal variation form varies from *quasi*-sinusoidal in the upper layer up to *quasi*-triangular at the largest investigated depths (maximum separations).

Key words *natural processes – seasonal variations – precipitation*

1. Introduction

Identifying exogenous, in particular seasonal, variations in time series of geophysical data is an important task in the framework of analysis of earthquake precursors (Yamauchi, 1987; Zhao, 1987; Sidorin, 1992). Its solution is complicated by the absence of a precise modeling of the seasonal variations that affect geophysical parameters. Such a situation is typical in the time series of apparent electrical resistivity (Qian, 1985; Sidorin, 1992).

Physically, it may be expected that the strongest exogenous variations in apparent resistivity depend on different hydrometeorological factors, especially atmospheric precipitation. Atmospheric precipitation causes variations in parameters of underground hydrosphere condition, influencing many characteristics of the geophysical medium and the behaviour of some animals. These assumptions were proved experimentally (Kawada, 1966; Barsukov, 1972; Searls *et al.*, 1978; McClellan, 1980; Deng *et al.*, 1981; Sidorin, 1984, 1986; Cornea *et al.*, 1985; Shapiro *et al.*, 1985; Zhuravlev and Sidorin, 1986; Fuye *et al.*, 1988; Descherevsky and Sidorin, 1999a, 2000) and must be taken into account when searching for geophysical, geochemical, and biological precursors of earthquakes.

The investigation of data measured at the Khazor-Chashma station in the Garm test site needs to take into account the exogenous variations in apparent resistivity of rocks. This effect, of course, cannot be estimated directly by the precipitation, since the main role has been played by the water penetrating into the soil layer affecting the surface rocks.

During winter, precipitation is accumulated in snow, and its melting and penetration of moisture into the soil occurs mainly during spring. In summer, at heavy drainage of the ground water

---

Mailing address: Dr. Alexander Ya. Sidorin, Schmidt United Institute of Physics of the Earth, Russian Academy of Sciences, ul. Bolshaya Gruzinskaya 10, D-242, GSP-5, 123995 Moscow, Russia; e-mail: sidorin@ifz.ru

and a small quantity of precipitation the rainfall only slightly dampens the upper (active) layer of the soil and then evaporates and its penetration into the deeper horizons is practically absent.

Since water penetration into the soil was not measured and the problem of water penetration from the atmospheric precipitation into the soil is rather complicated, some approaches to its solution were proposed in Zhuravlev and Sidorin (1986), and in more detail in Descherevsky *et al.* (2001), in which a local model of processes of moisture penetration into the soil at the Khazor Chashma station was developed.

The model uses, as input data: 1) quantity of atmospheric precipitation for a day (mm); 2) average daily and minimum night air temperature (°C); 3) the height of snow cover (cm); iv) deficit of relative air moisture (%). The model takes into account the following processes: i) precipitation in a solid and liquid form and their accumulation in a snow cover; ii) melting and freezing of snow cover and moisture evaporation from its surface; iii) inflow of atmospheric precipitation and melted water from snow into an active soil layer; iv) balance of moisture in an active soil layer: accumulation, abundant moisture outflow due to evaporation, penetration into deep horizons and surface runoff.

The main result of the model is the determination, only by data of standard meteorological observations, of the quantity of water that practically enters into the soil. This quantity of water is important regarding the estimation of the effect of exogenous factors on variations of geophysical parameters.

The paper shows that these two processes (rainfall and snow precipitation and water penetrated into the soil) have a different seasonal course; therefore the processes of moisture accumulation in a snow cover and its consequent melting in spring have to be taken into account to define the problem of assessment of the effect of exogenous factors on geophysical parameters.

2. Initial data

Two sets of time series were used for this analysis:

i) the time series characterizing the process of water penetration into the soil were considered (Descherevsky *et al.*, 2001): 1) the initial series of atmospheric precipitation; 2) the series of moisture inflow into the soil; 3) the series of moisture store in the soil's active layer; 4) the series of moisture outflow from the soil's active layer.

ii) variations in apparent electrical resistivity of rocks, analyzed by the monitoring data at the Khazor-Chashma station of the Garm test site. These variations were observed at the set of four-electrode Schlumberger arrays with the following separations of the AB current and receiving MN electrodes (AB/MN): 6/2 m, 18/2 m, 30/10 m, 650/150 m, 3000/500 m (Sidorin, 1990).

Figure 1 shows the data.

3. Data analysis

Since original series contain wide fluctuations and non-stationarity of a different origin (flicker-noise structure of data), we cannot carry out correlation analysis of these data directly. Significant noise inevitably occurs at such comparison which excludes the possibility to observe the more delicate effects of relatively small amplitude which we would like to discover. Therefore, a method that is stable to random noise was used for the analysis.

The method is based on comparison between seasonal variations in apparent resistivity and hydrometeorological parameters. Long-period variations – with typical time of the years and over – have not been studied. Since these variations are present in the series of apparent resistivity, to avoid seasonal distortions and to suppress additional noise they were first filtered. The trend was estimated by a method of a sliding average, with a smoothing window 1100 days wide. To improve frequency characteristics of a smoothening filter, the Gauss weight window function was used. For the hydrometeorological parameter series the trend was not filtered.

Firstly, an Average Seasonal Function (ASF) was obtained for each series. The calculation of ASF for the apparent resistivity series is described in (Descherevsky and Sidorin, 1999b; 2003). For the hydrometeorological parameters a similar technique was used.

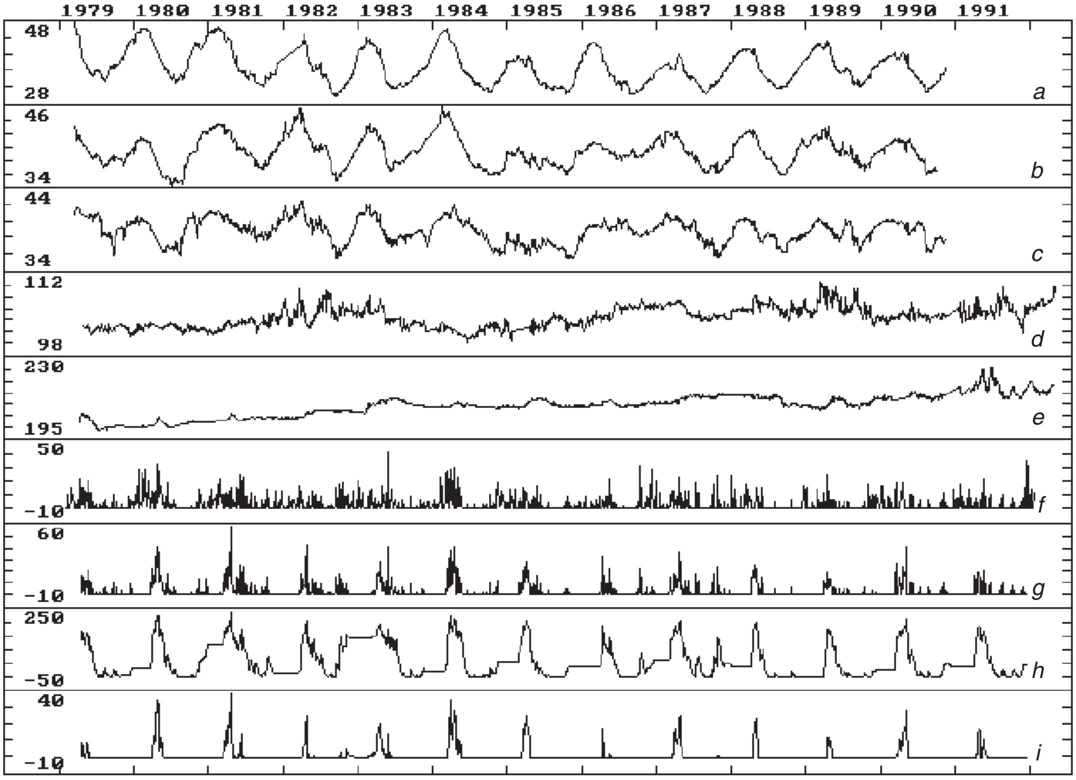

Fig. 1. Initial series: apparent resistivity at separations *a* – 6/2 m, *b* – 18/2 m, *c* – 30/10 m, *d* – 650/150 m, *e* – 3000/500 m (all of them in Ω·m), *f* – atmospheric precipitation, *g* – the moisture inflow into the soil, *h* – the moisture store in the soil's active layer, *i* – the moisture outflow from the soil's active layer (all of them in mm).

Secondly, coefficients of correlation and regression between ASF and initial realization were calculated in a sliding year window for each series. The correlation coefficient used to reveal the stability of a seasonal variation form, and the regression that of seasonal variation amplitude.

The ASFs were obtained according to the technique described in Descherevsky and Sidorin (1999b, 2003), and Descherevsky *et al.* (2001). This technique envisages the ASF estimation by a method of superposition of epochs. The ASF estimate based on the method of superimposed epochs has certain disadvantages for finite length determination. In particular, the ASF form and seasonal variation amplitude may be distorted due to various random peculiarities of the original series. To eliminate this effect, we used the method of adaptive ASF smoothing with subsequent cycle described in Descherevsky and Sidorin (1999b, 2003). Relative to the algorithm proposed in Anderson (1971), this method is simple (only one parameter, namely the smoothing window width, is variable) and provides an unambiguous physical interpretation.

The purpose of smoothing is suppression of all the unreliable peculiarities of ASF, therefore the size of a smoothing window depends on many factors: initial realization noise, intensity of a seasonal component, the series' length and others. The degree of smoothing (the smoothing window width) was determined for each realization individually by the results of special tests in such a way as to make the decrease in dispersion of ASF caused by the smoothing comparable with dispersion of the noise component of ASF (Descherevsky and Sidorin, 1999b, 2003).

Taking into account the stated considerations, the following procedure of selection of optimal ASF smoothing was used.

First of all, a non-smoothed ASF was calculated by epoch superposition by a whole term and dispersion of the residual component (after the ASF extraction) and its high frequency component was also evaluated. Besides, «partial» ASF by the first and the second part of the term were calculated and dispersion of their difference was determined. Besides the dispersion, statistics of average module of difference of the two partial ASF calculated by the first and the second part of the observation term was also used. A problem on evaluation of correlation of the partial ASF was solved at the same time. It was assumed that significant correlation between them might be considered independent confirmation of reliability of seasonal periodicity.

Further, the ASF calculated by the epoch superposition by the whole term was smoothed by a cycling sliding average; smoothing windows of different width were tested and decreasing of the ASF general dispersion and also the dispersion of its high frequency component (periods up to 14 days) was evaluated. To improve the frequency characteristics of a smoothing filter the Gauss weight window function was used.

The dispersion and standard deviation decrease caused by smoothing was compared to evaluations of the dispersion and standard deviation of a noise component of the non-smoothed ASF obtained by the methods described above.

The final optimal width of the ASF smoothing window was selected taking into account all the enlisted factors and for the series of apparent resistivity the results for the neighboring separations with relatively close amplitude of a seasonal variation were also taken into account. Although the described procedure in a way is based on subjective and qualitative evaluations, the final results by an order of a value are rather uniformly determined by calculated statistics, *i.e.* the human factor effect may bring only small distortions into these results.

As a result, the width of a smoothing window was chosen as follows: for the apparent resistivity series (AB/MN) 6/2 m, 18/2 m, 30/10 m, 650/150 m, 3000/500 m as 63, 63, 63, 123 and 63 days, respectively (Descherevsky and Sidorin, 1999b); for the series of atmospheric precipitation, 121 days; for the series of moisture inflow into the soil, 31 days; for the series of moisture store in the soil's active layer, 45 days; for the series of moisture outflow from the soil's active layer, 31 days. However, increasing the size of window by two or three times, the correlation and regression curves remain approximately the same.

The ASFs are plotted in fig. 2. Comparing the form and the phase of apparent resistivity seasonal variation at a maximum 3 km current-electrode separation (curve *e*) with moisture inflow into the soil (curve *g*), moistening of the soil's active layer (curve *h*) and the moisture outflow from the soil's active layer (curve *i*), we observe a good similarity among the curves. This indicates that the apparent resistivity increases at maximum separation between spring and summer, in concomitance with abundant inflow of melted and rain waters into a sounding volume, due to which decrease of porous solutions' mineralization and consequently, of their conductivity and increase in apparent resistivity occur.

The pattern is more complicated at minimum separations. First, the seasonal resistivity reaches the maximum earlier, at the beginning of March, and then it follows a more complicated law. Second, after reaching the seasonal minimum between summer and autumn, the resistivity does not stabilize but it smoothly increases up to February. However, in this case an observed pattern also becomes more clear, if we admit that at these separations along with soil moisture mineralization moisture variations also play an important part. Thus, at the beginning of spring simultaneously with moisture inflow, resistivity starts to decrease in accordance with the medium moistening increase. In the middle of spring, moisture inflow reaches a maximum, and resistivity decrease in this period is small, since the coming water is less mineralized and with rela-

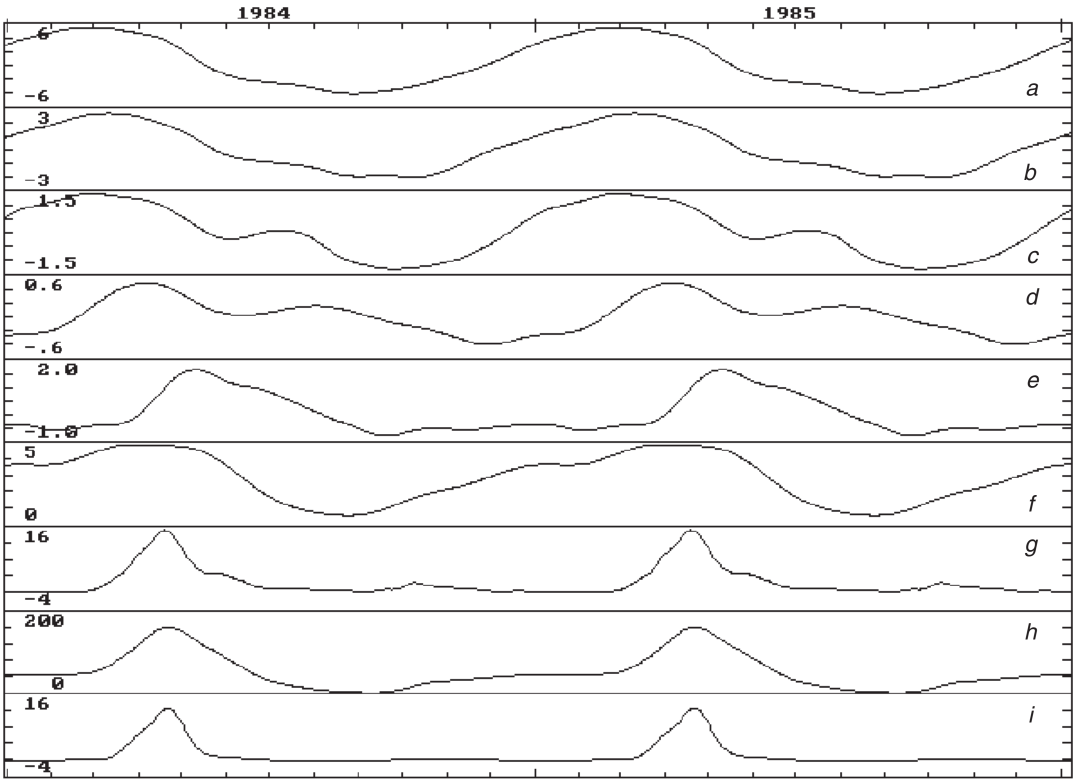

Fig. 2. Smoothed ASF: apparent resistivity at separations *a* – 6/2 m, *b* – 18/2 m, *c* – 30/10 m, *d* – 650/150 m, *e* – 3000/500 m (all of them in Ω·m), *f* – atmospheric precipitation, *g* – the moisture inflow into the soil, *h* – the moisture store in the soil's active layer, *i* – the moisture outflow from the soil's active layer (all of them in mm). Two periods of average seasonal function are given.

tively high resistivity. At the end of spring, inflow of slightly mineralized surface waters decreases, and general saturation remains high, and due to the soil's moisture mineralization the resistivity continues to decrease rather rapidly. Furthermore, during summer mineralization and conductivity of water solutions continue to increase and saturation to decrease, the first process has a stronger effect on resistivity and it gradually decreases. Near the end of summer mineralization apparently stabilizes and apparent resistivity slowly increases with the decrease of a quantity of soil and subsoil moisture, continuing up to the beginning of spring.

A more complicated pattern of apparent resistivity seasonal variations is observed at intermediate separations (AB = 30 m, curve *c*; AB = = 650 m, curve *d*). However, the pattern of these variations fully agrees with the assumption that changes in subsoil moisture and porous solutions' mineralization cause effect to a significant degree on apparent resistivity variations at these separations as well.

Thus, the patterns of apparent resistivity seasonal variations in a wide range of separations are mainly caused by variations of parameters of porous water solutions occurring due to precipitation**.**

The correlation and regression coefficients between ASFs and original series were calculated sliding an annual window through the period of measurements. The correlation coefficient detects the stability of the seasonal variation form, and is plotted in fig. 3. We denote the series of time variations of correlation coefficients as Stab$_i$, where the index i indicates the original series, taking the values 006, 018, 030, 650 and 3000 for the apparent resistivity series and OSA, D_WATER, W_GROUND and D_W_GROUND for the precipitation series, the series of mois-

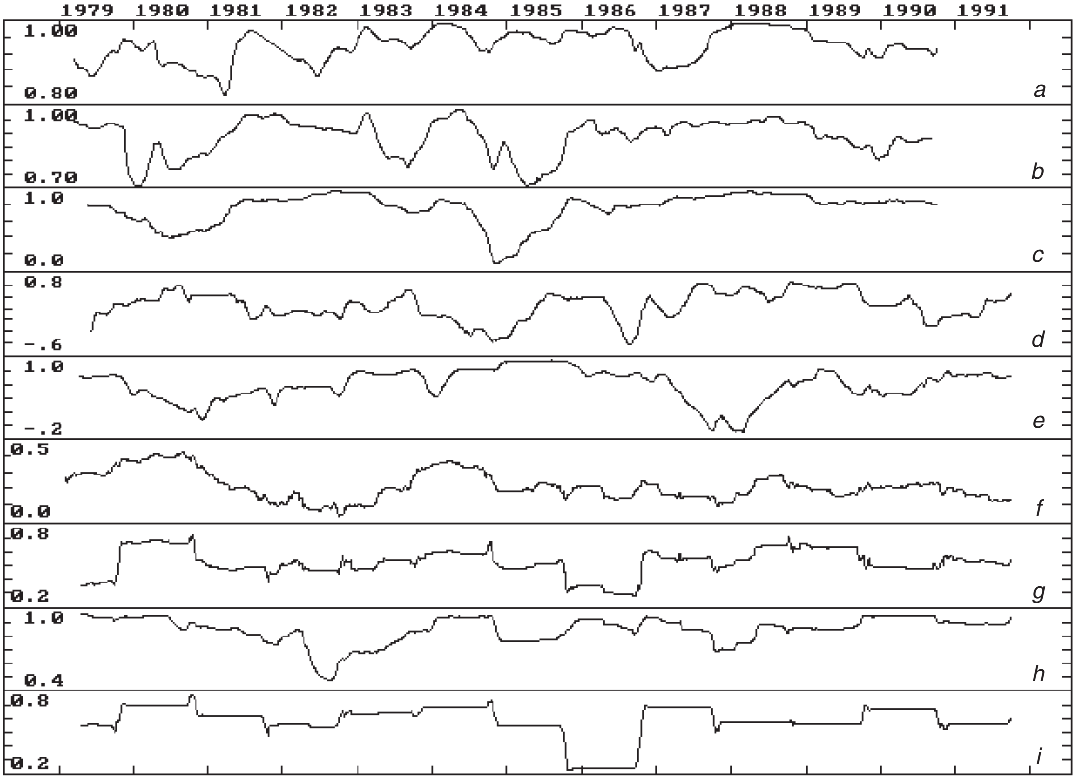

Fig. 3. The correlation coefficient estimated in a sliding annual window between the initial series and its ASF (dimensionless): the correlation coefficient for apparent resistivity series at separations *a* – 6/2 m, *b* – 18/2 m, *c* – 30/10 m, *d* – 650/150 m, *e* – 3000/500 m, *f* – atmospheric precipitation, *g* – the moisture inflow into the soil, *h* – the moisture store in the soil's active layer, *i* – the moisture outflow from the soil's active layer.

Table I. Correlation between seasonal course stability coefficients of apparent resistivity and hydrometeorological parameters.

Parameter	Stab$_{\mathrm{OSA}}$	Stab$_{\mathrm{D\_WATER}}$	Stab$_{\mathrm{W\_GROUND}}$	Stab$_{\mathrm{D\_W\_GROUND}}$
Stab$_{006}$	−0.10	0.02	−0.09	−0.32
Stab$_{018}$	−0.30	−0.18	−0.07	−0.16
Stab$_{030}$	−0.45	−0.12	−0.18	−0.10
Stab$_{650}$	0.03	0.34	−0.00	0.08
Stab$_{3000}$	−0.05	−0.23	0.08	−0.31

ture inflow into the soil, the series of moisture store in the soil's active layer and the series of moisture outflow from the soil's active layer, respectively.

It should be noted that according to construction, successive values of the series Stab are heavily correlated, therefore a number of independent data values for each from these se-

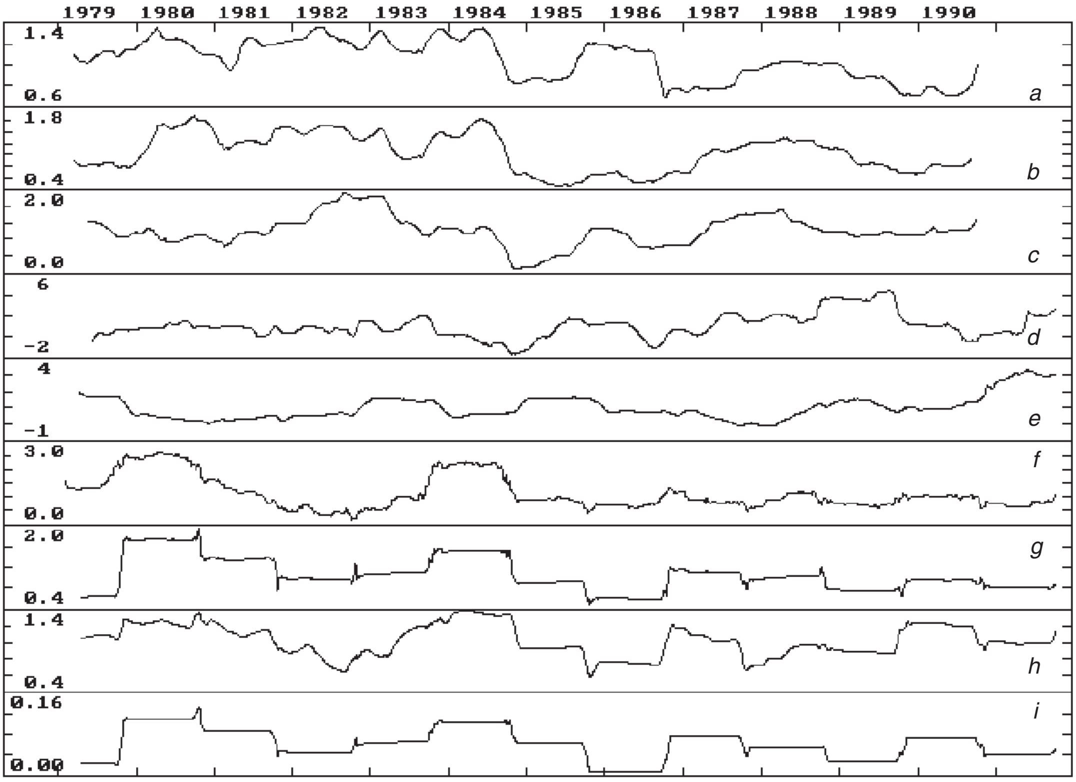

Fig. 4. The regression coefficient of ASF estimated in a sliding annual window for the initial series (dimensionless): the regression coefficient for the apparent resistivity series at separations *a* – 6/2 m, *b* – 18/2 m, *c* – 30/10 m, *d* – 650/150 m, *e* – 3000/500 m, *f* – atmospheric precipitation, *g* – the moisture inflow into the soil, *h* – the moisture store in the soil's active layer, *i* – the moisture outflow from the soil's active layer.

Table II. Correlation between the series showing the amplitude of apparent resistivity seasonal course and hydrometeorological parameters.

Parameter	$\mathrm{Regr}_{\mathrm{OSA}}$	$\mathrm{Regr}_{\mathrm{D\_WATER}}$	$\mathrm{Regr}_{\mathrm{W\_GROUND}}$	$\mathrm{Regr}_{\mathrm{D\_W\_GROUND}}$
Regr_{006}	0.35	0.37	0.00	0.16
Regr_{018}	0.30	0.60	0.22	0.47
Regr_{030}	−0.28	−0.03	−0.30	−0.11
Regr_{650}	−0.24	−0.22	−0.27	−0.29
Regr_{3000}	−0.23	−0.44	−0.10	−0.36

ries is much less than a general number of the series' terms. From below it may be estimated by a number of years during which observations were continued, from above – by double number of the years. Thus, to estimate a correlation coefficient between the series Stab$_i$, then 95% level of significance will be somewhere between 0.20 and 0.30. Table I shows the correlation between the Stab$_i$ series.

An analysis of table I shows that 14 values out of 20 are less than 0.2 and may be related to insignificant ones at a 95% level. A formal 95% level of significance is increased by approximately a quarter of values in the table. It is noticeably more of expected ones by the statistics of the 5% values. However it is not easy to find logic in the obtained results. Apparently, there is a relation between disturbances of a seasonal variation form for the comparable parameters, however it is not definitive, variations may be in phase ones and also in antiphase ones. As a whole, the Stab$_i$ series is not the most optimal instrument to carry on this analysis.

Figure 4 shows the regression coefficient series, denoted by Regr$_i$, which informs on the seasonal variation of amplitude.

It is worth mentioning that the largest discordance between ASF smoothed and the original series occurs usually in case of a shift of seasonal variation phase occurring due to shift of spring heavy showers' maximum in time. We observe a sharp decrease of correlation coefficient concomitantly with the increase in regression coefficient dispersion. If changes of seasonal variation occur mainly in amplitude then the correlation coefficient continues to be high and the regression coefficient increases.

Figure 4 shows a good similarity among all of seasonal course amplitude curves of apparent resistivity and the Regr$_i$ series characterizing parameters of water regime. Table II shows the correlation coefficients of series Regr$_i$ between each other.

Comparing the previous case, absolute values of correlation coefficients have noticeably increased. Now, 8 values out of 20 are not less than 0.3 and may be definitely related to significant ones at a 95% level, 5 – to insignificant ones (< 0.2), and the remaining 7 occupy intermediate position.

For the series of apparent resistivity at minimum separations, we observe a very good relation between seasonal variation amplitude and precipitation parameters, especially with the quantity of precipitation, penetrated into the soil. At medium and large separations the relation unexpectedly becomes anti-correlation. It may be deduced that during the years with the increased quantity of precipitation the amplitude of apparent resistivity seasonal variation at large separations decreases, or disturbance of a seasonal variation form occurs, since the regression coefficient decreases.

4. Conclusions

Apparent resistivity variations were analysed and comparied with time series of different parameters of rock moistening, calculated using a local model of atmospheric precipitation inflow into the soil developed by the authors. The model showed that at small current-electrode separations from all the parameters of water regime, only water saturation of the soil's active layer reveals a significant correlation with apparent resistivity variations. With increase in current-electrode separation, the relation is considerably complicated, but, it is fully in accordance with the fact that not only processes of soil moistening but variations of soil moisture mineralization affect apparent resistivity variations.

Acknowledgements

This research was supported by the Russian Foundation for Basic Research, grant No. 01-05-65503.

REFERENCES

Anderson, T.W. (1971): *The Statistical Analysis of Time Series* (Wiley, New York), pp. 704.

Barsukov, O.M. (1972): Variations of electric resistivity of mountain rocks connected with tectonic changes, *Tectonophysics*, **14** (3/4), 273-277.

Cornea, I., C. Radu and V. Winter (1985): Correlations between precipitations and the strong earthquakes in Romania, *Rev. Roum. Phys.*, **29** (4), 395-404.

Deng, Q., J. Pu, L.N. Jones and P. Molnar (1981): A preliminary analisis of reported changes in ground water and anomalous animal behavior before the 4 February 1975 Haicheng Earthquake, *Earthquake Prediction* edited by D. Simpson and P. Richards, (Am. Geophys. Union, Washington), 543-565.

Descherevsky, A.V. and A.Ya. Sidorin (1999a): Experimental research of apparent resistivity seasonal variations applicable to problems of seismology, *Seismic Instruments*, **32**, 62-75.

Descherevsky, A.V. and A.Ya. Sidorin (1999b): *Some Problems of Estimation Technique of Average Seasonal Functions for Geophysical Data* (UIPE RAS, Moscow), pp. 40.

Descherevsky, A.V. and A.Ya. Sidorin (2000): Correlation of seasonal variations of geoelecrical parameters with hydrometeorological elements' regime, *Electrical Correlation of Geospheric Envelopes* (UIPE RAS, Moscow), 87-99.

Descherevsky, A.V. and A.Ya. Sidorin (2003): Anomalous dependence of the seasonal variation amplitude of apparent electric resistivity on the spacing, *Doklady Earth Sciences*, **388** (1), 110-113.

Descherevsky, A.V., V.M. Mukhin and A.Ya. Sidorin (2001): *A Local Model of Seasonal Variations of Atmospheric Precipitation Inflow into the Soil at the Garm Test Site* (UIPE RAS, Moscow), pp. 36.

Fuye, Q., Z. Yulin and X. Tongchun (1988): An analysis of the seasonal variation of disturbance in georesistivity, *Acta Seismologica Sinica*, **1** (3), 69-83.

Kawada, K. (1966): Electric resistivity measurement along and across a ground fissure in the Matsushiro area, *Bull. Earthquake Res. Inst. Univ. Tokyo*, **44**, 1759-1769.

McClellan, P.H. (1980): Preearthquake animal behavior: a closer look for alternative causes, *Geophys. Res. Lett.*, **7** (5), 333-336.

Qian, J. (1985): Regional study of the anomalous change in apparent resistivity before the Tangshan earthquake ($M = = 7.8$, 1976) in China, *Pure Appl. Geophys.*, **122**, 901-920.

Searls, C., K.A. Poehls, D.D. Jakson and E.M. Wescott (1978): Changes in crustal resistivity near Palmdale, California, *Geophys. Res. Lett.*, **5** (11), 928-930.

Shapiro, M.H., A. Rice, M.H. Mendenhall, J.D. Melvin and T.A. Tombrellot. (1985): Recognition of environmentally caused variations in radon time series, *Pure Appl. Geophys.*, **122** (1), 309-326.

Sidorin, A.Ya. (1984): Electrical resistivity variations of the Earth's crust upper layer, *Rep. USSR Acad. Sci.*, **278** (2), 330-334.

Sidorin, A.Ya. (1986): The results of precise observations of apparent resistivity variations at the Garm test site, *Rep. USSR Acad. Sci.*, **290** (1), 81-84.

Sidorin, A.Ya. (Editor) (1990): *The Garm Geophysical Test Site* (IPE USSR Academy of Science, Moscow-Garm), pp. 240.

Sidorin, A.Ya. (1992): *Earthquake Precursors* (Nauka, Moscow), pp. 192.

Sidorin, A.Ya., V.I. Zhuravlev and M.G. Ostashevsky (1983): Multidisciplinary electrometrical research of geodynamical processes, *Experimental Seismology* (Nauka, Moscow), 149-162.

Yamauchi, T. (1987): Anomalous strain response to rainfall in relation to earthquake occurrence in the Tokai area, Japan, *J. Phys. Earth*, **35** (1), 19-36.

Zhao, H. (1987): Complex space-temporal model of endogen and exogen parameters and it's use for earthquake forecast, *J. Seismol. Res.*, **10** (1), 71-82.

Zhuravlev, V.I. and A.Ya. Sidorin (1986): A method and results of account of meteorological factors' effect on regime electrometric observations' data, *Rep. USSR Acad. Sci.*, **290** (1), 63-66.