UTILIZATION OF VECTOR RADIOTHERMAL FIELDS FOR SOLVING REMOTE SENSING AND IMAGE INTERPRETATION PROBLEMS

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ABSTRACT

Geophisical fields usually are used for practical purposes as scalar fields. As an example relief's field, radar's and optical images of the Earth surface may be regarded. From other side gravitional and magnetic fields are vector fields in the nature. In general informative capability of vector fields is higher then scalar one for the reason of some sundry components. However, to realize this advantage isn't always possible. The reasons are as undeveloped appropriate algorithms and technical difficulties. The pecularities of vector fields are investigated below on the example of radiothermal vector fields of the Earth's covers. The advantages of such approach in comparison with "scalar" methods for concrete problems are discussied.

KEY WORDS: Radiothermal, Vector, Field, Navigation, Boundary, Fire, Forest.

1. VECTOR FIELDS

Brightness temperatures on different wavelengths, polarizations, brightness contrasts relatively to bench-mark object, measurements' results and its derivatives when different conditions of observation and apparatures characterstics as well as combinations of these values may be used as components of vector radiothermal fields. As seen from previous content all these acquired values may be separated in time and, therefore, radiothermal field's vector components $\xi_i(Q)$ are functions in four-dimensional space (three spacing components and time). The following characteristics of vector fields are often used: mean value of each component $\bar{\xi}_i(Q)$, where Q = (x,y,z), matrix of the second order $B_{ik}=\overline{\xi_i(1)\,\xi_k(2)}$ (here 1 and 2 are Q_1 and Q_2) and correlation matrix $\gamma_{ik}=B_i(1,2)-\bar{\xi}_i(1)\,\bar{\xi}_k(2)$ Two-components field may also be represented as one-dimensional complex field.

$$\zeta(\vec{z})=\xi(\vec{z})+i\,\eta(\vec{z}) \tag{1}$$

and analogous to real fields complex vector fields may be introduced. However, the latter has some inconvenient mathematical pecularities.

1.1. Radiothermal vector field

The intensity of radiothermal signal on the antenna's output is determined in a following way.

$$J_a=K\left|(\dot{\vec{E}},\dot{\vec{A}})\right|^2 \tag{2}$$

where $\dot{\vec{E}}$ - complex vector for describing polarization of radiothermal signal; $\dot{\vec{A}}$ - polarization characteristics of receiving antenna; K is a constant.

From equation (2) we can see, that interaction of polarization characteristics of the signal and receiver greatly influences on the measured antenna's temperature and as a consequence on the calculated brightness temperature. Let's denote it group of parameters as $\vec{P}$.
Analysis showed, that following groups of parameters should be taken into account.
$\vec{\lambda}$ - vector of spectral signal's characteristics;
$\vec{\theta}$ - conditions of observations (antenna's and observed object mutualgeometry;
$\vec{n}$ - noise factors (atmosphere's and neighbours' objects radiaton, rains' influence, apparatus errors, influence of aircraft's frame and oth.).
So, every component of radiothermal vector is a function of indicated parameters.

$$T_{Bi}=T_{Bi}(\vec{P}_i,\vec{\lambda}_i,\vec{\theta}_i,\vec{\varepsilon}_i,\vec{n}_i) \tag{3}$$

In one's turn all arguments in (3) may be functions of $\vec{r}$ and t.

The analysis of (3) showed dependency of components. Appropriate covariation matrix is nondiagonal. The statistics theory results showed that in this case efficiency of algorithm depends on the extent of dependncy od vector components and the possibility to choose less dependent informative signs.

2. APPLICATION VECTOR RADIOTHERMAL FIELDS TO NAVIGATION PROBLEM

Let's evaluate navigation possibilities of statistical radiothermal vector field without regarding to working algorithm of concrete automatic control system. For this purpose only two parameters are considered, namely signal/noise relation F and correlation coefficient K_{zm} of real and predicted model radiothermal fields. For scalar field we have:

$$F = \frac{\sigma_z}{\sqrt{\sigma_n^2 + \sigma_{zm}}} \qquad (4)$$

where σ_z^2 - dispersion of brightness temperatures of real radiothermal field; σ_n^2 - receiver noise intensity; σ_{zm}^2 - "generalized" noise of model field.

The latter may be found for scalar field as

$$\sigma_{zm} = \frac{1}{mn}\left\{\sum_{i=1}^{n}\sum_{j=1}^{m}\left[(T_{ijz}-\overline{T}_z)-(T_{ijm}-\overline{T}_m)\right]^2\right\}^{\frac{1}{2}} \qquad (5)$$

where i, j correspond to discret readings of brightness temperature T_{ij} respectively real (r) and model (m) radiothermal fields.

Let's consider vector radiothermal field with brightness temperatures on 0.8 and 2.25 sm as components. Appropriate correlation coefficients for one trace are given in table 1. Observation angle for polarization measurements 30 degrees.

Table 1
Correlation coefficients of brightnees temperatures for two wavelengths

$T_B(0.8)$ / $T_B(2.25)$	nadir	vert. pol.(30)	hor. pol.(30)
nadir	0.76	0.42	0.6

$T_B(0.8)$ / $T_B(0.8)$	nadir	vert. pol.(30)	hor. pol.(30)
nadir	1.0	0.57	0.81

It is evident from table 1 the dependency indicated above data for different wavelengths as well as for different polarizations when wavelength 0.8 sm.

As well known methods of automatic systems' control are well adopted to independent components of state vector. The same also is preferable for analysing navigation properties of radiothermal fields for the reasons of stability and simplicity of such decision. Below we'll consider covariation matrix of brightness temperatures 0.8 and 2.25 sm channels when direction of observation is nadir.

$$K = \begin{pmatrix} t_{11} & t_{12} \\ t_{21} & t_{22} \end{pmatrix} \qquad (6)$$

where $t_{12} = t_{21} = \overline{(T_2-\overline{T}_2)(T_1-\overline{T}_1)}$; $T_1 = T_B(0.8)$, $T_2 = T_B(2.25)$.

For = 0.76 matrix of orthogonalized transformation is

$$\Phi = \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix} \qquad (7)$$

and cosequently instead field vector $\vec{T}_B = \{(T_1-\overline{T}_1),(T_2-\overline{T}_2)\}$ for solving's algorithm it is necessery to use vector $\vec{T}_B'$.

$$\vec{T}_B' = \Phi\vec{T}_B = \begin{pmatrix} T_1-\overline{T}_1+T_2-\overline{T}_2 \\ T_1-\overline{T}_1-T_2+\overline{T}_2 \end{pmatrix} \qquad (8)$$

It's covariation matrix becomes diagonal.

Sometimes in addition to (8) decorrelation transformation$(K')^{-\frac{1}{2}}\Phi$ is used, but then components' orthogonality may disturbed. It is necessery taking into account concrete algorithm in this case.

2.1. Vector fields' navigation gain

To evaluate advantages of vector radiothermal field for navigation problem solving one should adopt criteria F and K_{zm} to vector field. It may be done in a following way. For example,

$$\sigma_{zm}^c = \frac{1}{mn}\sum_{i=1}^{n}\sum_{j=1}^{m} N\left[(\vec{T}_{zij}'-\overline{\vec{T}}_z)-(\vec{T}_{mij}'-\overline{\vec{T}}_m)\right] \qquad (9)$$

where N is appropriate criterion or metric, chosen on the base a priori information about field's vector components.

Two mentioned above navigation field parameters F and are sited in table 2 separately for scalar fields (wavelenth 0.8 and 2.25 sm) and for two-components vector field provided the same brightness temperatures are used as vector's components.Two traces are analysed (numbers 1 and 2). Spherical metric in (10) was chosen. It is evident from table 2 that vector field has better navigation quality.

Table 2
Navigation parameters of radiothermal field

Wavelegth sm	K_{zm}		F	
	1	2	1	2
0.8	0.985	0.61	5.55	1.22
2.25	0.981	0.63	5.48	1.3
0.8; 2.25	0.986	0.7	5.77	1.82

3. DETERMINATION OF NATURAL OBJECTS BOUNDARIES

3.1. Scalar field case

Earlier (Maslovsky, 1990) radiothermal method of specification natural object's boundaries was suggested. As an example on Fig. 1,a the dependence of brightness

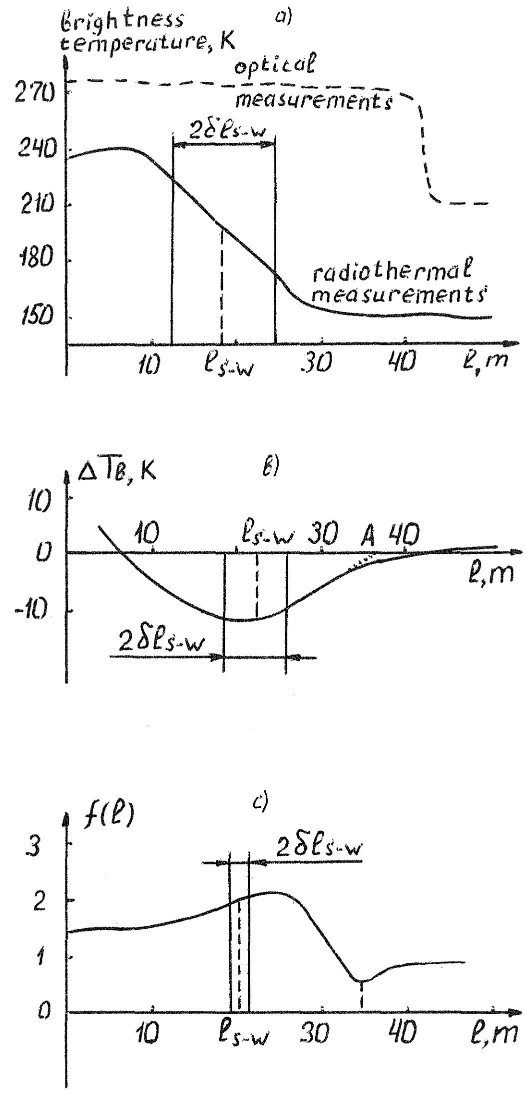

Fig. 1. Error of estimation of boundary "soil - water" location.

temperatures along trace with "soil - water" boundary is shown. The bank is rushy and for this reason boundary "soil-water" can't be identified with the aid of optical measurements. The possible error of estimation by means of radiothermal measurements is illustrated on Fig.1,a. For practical application such accuracy is unsufficuent.

The following approach is suggested to improve boundary location estimation. Discret readings of brightness temperature are $T_B(\ell_j)$. Let's consider succession of values $T_B(\ell_j) - T_B(\ell_{j-1})$ and their floating mean value (Fig. 1,b). Boundary location $\ell_{s\text{-}w}$ is determined on the base of analysis of changing floating mean value as

$$\ell_{s\text{-}w} = \ell(\Delta T_B = 0) - \frac{d}{2} \qquad (10)$$

where ΔT_B = 0 correspond to point A;
d - linear size of resolving element along envisaged trace.

General error estimation of $\ell_{s\text{-}w}$ is summarized from apparatus, antenna's errors, background radiation influence, height determination error and so on.

3.1 Vector field approach

Additional information extracted from the same data expediently to use for the following specification boundary "soil - water" location. Dispersion of three neignbouring brightness temperatures readings as the second component of radiothermal field vector is used for this purpose. This sign is sufficuently informative as water surface's brightness temperatures dispersion is essencially less then soil's one. Taking into account (10) and obstacle that components we have chosen are orthogonal we may write the the solving rule in a following way: minimum of resolving function corresponds to value $\ell_{s\text{-}w} - d/2$, where

$$f(\ell) = \left\{ (\Delta T_B(\ell))^2 + C\,\sigma_B^2(\ell) - D\left|\frac{\partial \sigma^2(\ell)}{\partial \ell}\right| \right\} \qquad (11)$$

Here C and D - constants.

Error's interval is shown on Fig. 1,c.

Additional term in (11) is introduced to emphasize minimum of solving function, as in general to the right from point A fluctuations' decreasing may continues owing to influence more "warmer" radiation of soils and vegetation covers.

Comparison of accuracy of estimation boundary location with the help of suggested approaches show the advantage of vector field method.

4.FIRE DANGER DETERMINATION

Radiothermal method of fire danger in the forest determination (Troitsky, 1991) based on the separation sampling values of brightness temperatures corresponding to forest soil's cover and crowns of trees. The essence of it is in the use stable radiation characteristics of trees' crowns as bench mark samples a priori distributed on normal law. The parameters of the latter easily may be found when data treatment. The rest of samples mainly corresponds to soil's cover radiation. In such way the latter one is related with class of fire danger in the forest (Fig. 2). Valid estimation may be reached when samples volume contains 40 - 120 of independent readings of brightness temperatures (it also means the same number of resolving elements). Obtaining of such volume isn't always acceptable and its reduction is desirable.

Below for the simplicity we'll consider only pair of different resolving elements

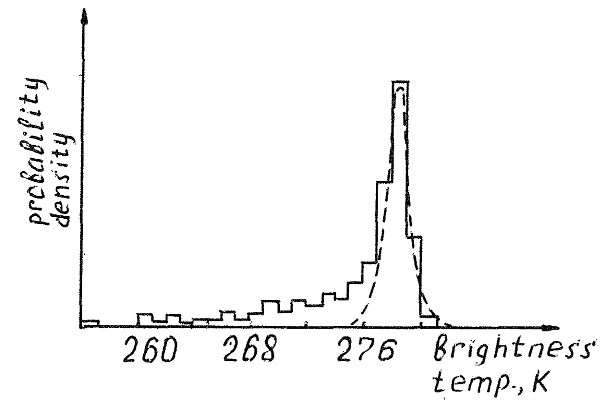

Fig. 2. Distribution of forest's brightness temperatures.

with corresponding brightness temperatures T_{B1} and T_{B2} . Tracing, scaning and multi-beams antennas measurements for this purpose suitable.

Probability soil's cover brightness temperature presence is P_s . One consider difference ($T_{B1} - T_{B2}$). Probability of brightness temperature corresponding to soil's cover in this expression is equal to $2P_s(1-P_s)$. The volume of corresponding samples increased in times (for P_s = 0.04 - 0.15 it's 1.7-1.9).

So, parameter ($T_{B1} - T_{B2}$) is informative for the problem of estimation fire danger in the forest. We'll use it as the second component (the first is T_B itself) of two dimensional radiothermal vector field. It isn't difficult to find, that $\Delta T_B = \overline{(T_{B1} - T_{B2})} = 0$, $\sigma^2(\Delta T_B) \approx 2\sigma^2(T_{B1})$ (we suggest that $\sigma^2(T_{B1}) = \sigma^2(T_{B2})$). As brightness temperature's samples corresponding to trees' crown normally distributed , then in accordance with statistics theory normally distributed appropriate portion of samples. Exclude from the general sampling this part of samples we'll find the samples' portion corresponding to soil's cover (the rest of others samples is very small for ordinary forests and is neglected). Algorithm of fire danger class K_f determination is

$$K_f = \begin{cases} [K] = \left[\dfrac{A}{1-\bar{\varkappa}} + \dfrac{B}{\sigma_{\bar{\varkappa}}}\right] & \text{when } K < 5.5 \\ 5 & \text{when } K \geq 5.5 \end{cases} \tag{12}$$

where $\bar{\varkappa}$ is normalized radiation capacity (corresponds to ; $\sigma_{\bar{\varkappa}}$ is square root of its dispersion; A and B - constants.

When vector radiothermal field is used algorithm formaly isthe same as (12), but $\bar{\varkappa}$ should be changed on $\bar{\varkappa}' = (\bar{\varkappa}_1 + \bar{\varkappa}_2)/2$ and $\sigma_{\bar{\varkappa}}$ on $\sigma'_{\bar{\varkappa}} = [\sigma(\Delta\varkappa_{12})/\sqrt{2} + \sigma_{\bar{\varkappa}}]/2$. Here normalized value $\bar{\varkappa}_{1,2}$ corresponds to $T_{B1,2}$. When tracing measurements are used $\bar{\varkappa}' = \varkappa$.

To remain the same accuracy as scalar radiothermal field approach allows one can reduce sampling volume approximately in 1.9 times (when P_s = 0.04 - 0.15).

It is necessery to say that, at first, suggested approach may be easily generalized for three and more different resolving elements. On the second the analogous approach may also be used for forest's fires mapping.

5. CONCLUSION

The results of investigation showed, that new approaches for images and data treatment allows to extract additional information without complicating appropriate arrangement. In particular an example of radiothermal images treatment shows, how vector interpretation improves accuracy of concrete problems solvings. We think this brench of data treatment has great potential.

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