Date information calibration and optimal planning of environment's remote sensing

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Abstract – The conception of informational calibration for environment's remote sensing data and corresponding imitative radiation fields models are collaborated. The procedures of criteria formation connected with informational content's satellite data of scalar radiation fields, informational calibration and optimal planning of environment's remote sensing conditions are presented. In this framework the Shennon's probabilistic metric and Fisher's informational matrix are considered. The example of regional aerospace scanner's information using for the Earth's remote sensing optimal planes are given.

Keywords: environment**,** radiation field, information content, information calibration, information metrics, optimal planning, informational matrix.

1. INTRODUCTION

Today aerospace methods of environment's investigations are the basic part of the Earth's remote sensing. Besides a specially organized instrumentation's base and measurement's equipment this methods include the organization and working following scientific and technological directions of ecological investigations:

- Imitative modeling of radiation fields and environment's parameters on the basis of corresponding direct-inverse problems solutions
- The analysis of information content, calibration and data compression concerning to the Earth's remote sensing
- The optimal planning of remote sensing ecological data gathering.

Naturally the full realization of mentioned directions is possible in the future only. However it is clear beforehand any effective solutions of modern regional and global ecological problems must be in need not only from multispectral environment's remote sensing data and imitative modeling of radiation fields but first of all depend on from complex information providing. Organization of such information providing by means of local distributed data bases, expert systems and informational nets including special mathematic, algorithmic and software supporting is significant essentially for optimal planning of the Earth's remote sensing.

2. IMITATIVE ENVIRONMENT'S RADIATION FIELDS MODELS

For construction of imitative environment's radiation fields models let us consider the “atmosphere –underlying surface” system in which a plane uniform slab of finite spectral optical thickness $\tau_{0,\lambda}$ has restricted from below by an arbitrary horizontally non-uniform and non-orthotropic reflecting bottom with spectral reflection coefficient r_λ. Spectral brightnesses coefficients of remarked above system illuminated at the top of the atmosphere by direct solar rays will be denoted by $\bar{\rho}_\lambda$ for fixed wave length λ . According to the paper [1] value $\bar{\rho}_\lambda$ can be represented approximately in the following form:

$$\begin{gathered}\bar{\rho}_\lambda(\eta,\xi,\varphi,\tau_0,x-\Delta x,y-\Delta y)=\rho_\lambda(\eta,\xi,\varphi,\tau_0)+\\ \rho_{\lambda,sur}(\eta,\xi,\varphi,\tau_0,x-\Delta x,y-\Delta y)\times\mu_\lambda(\eta,\tau_0),\end{gathered} \tag{1}$$

where $\rho_\lambda(\eta,\xi,\varphi,\tau_0)$ - the spectral brightness coefficient of a horizontally uniform atmospheric slab without reflecting bottom account

$\rho_{\lambda,sub}(\eta,\xi,\varphi,\tau_0,x-\Delta x,y-\Delta y)$ - the spectral brightness coefficient of reflecting bottom

$\theta=\arccos\eta$ - the vision angle

$\theta_0=\arccos\xi$ - the zenith Sun's distance

φ - the Sun's azimuth

$\mu_\lambda(\eta,\tau_0)$ - the transparency of the Earth's atmosphere (direct and diffuse)

Values Δx and Δy are determined by surface shifts of horizontal coordinates x and y for the direction $\theta=\arccos\eta$. Let us suppose now that solar photons which primary reflected by the real underlying surface in fixed point (x, y) are calculated exactly for arbitrary bottom reflection coefficient $r_\lambda(\eta,\xi,\varphi,x,y)$. Simultaneously solar photons which multiple reflected by the underlying surface are calculated approximately for average values of bottom albedo $\langle\bar{A}_\lambda(\xi,x,y)\rangle_{x,y}=\bar{A}_\lambda(\xi)$:

$$\bar{A}_\lambda(\xi)=\frac{1}{S_{sur}}\int\limits_{S_{sur}}\int\limits_0^1\int\limits_0^{2\pi} r_\lambda(\eta,\xi,\varphi,x,y)\eta d\eta d\varphi ds, \tag{2}$$

where ds = dxdy and S_{sur} - the environment subsatellite area for given remote sensing conditions.

Making use of mentioned above suggestion the spectral brightness coefficient $\rho_{\lambda,sur}(\eta,\xi,\varphi,\tau_0,x-\Delta x,y-\Delta y)$ can be represented approximately by the following manner according to the paper [2]:

$$\begin{gathered}\rho_{\lambda,sur}(\eta,\xi,\varphi,\tau_0,x-\Delta x,y-\Delta y)=\\ \frac{r_\lambda(\eta,\xi,\varphi,x-\Delta x,y-\Delta y)\times\mu_\lambda(\xi,\tau_0)}{1-\bar{A}_\lambda(\xi)C_\lambda(\tau_0)},\end{gathered} \tag{3}$$

where value $C_\lambda(\tau_0)$ - the spectral spherical albedo of the Earth's atmosphere:

$$C_\lambda(\tau_0) = \frac{2}{\pi}\int_0^{2\pi} d\varphi \int_0^1 \eta d\eta \int_0^1 \rho_\lambda(\eta,\xi,\varphi,\tau_0)\xi d\xi \qquad (4)$$

Correlations (1) – (3) allow to form the spectral transmissing operator Π_λ which transforms measured from space brightnesses $\overline{\rho}_\lambda$ into underlying surface brightnesses according to representation given in the paper [2]:

$$\begin{aligned} &\rho_{\lambda,sur}(\eta,\xi,\varphi,\tau_0,x-\Delta x,y-\Delta y) = \\ &\Pi_\lambda \overline{\rho}_\lambda(\eta,\xi,\varphi,\tau_0,x-\Delta x,y-\Delta y) \end{aligned} \qquad (5)$$

For successive consideration of information calibration problems some radiation fields functionals for the “atmosphere – underlying surface” system to construct necessary. First of all this functionals must be independent from conditions Sun's illumination. On this basis the information calibration of the Earth's remote sensing data can be carried out. Using expressions of (1) – (5) following invariant correlations had been received in the paper [3]:

$$\begin{aligned} &\frac{\overline{\rho}_\lambda(\eta,\xi,\varphi,\tau_0,x-\Delta x,y-\Delta y) - \rho_\lambda(\eta,\xi,\varphi,\tau_0)}{\Pi_\lambda \overline{\rho}_\lambda(\eta,\xi,\varphi,\tau_0,x-\Delta x,y-\Delta y)} = \\ &\frac{\overline{\rho}_\lambda(\eta,\xi,\varphi,\tau_0,x-\Delta x,y-\Delta y) - \rho_\lambda(\eta,\xi,\varphi,\tau_0)}{\rho_{\lambda,sur}(\eta,\xi,\varphi,\tau_0,x-\Delta x,y-\Delta y)} = \\ &\mu_\lambda(\eta,\tau_0) \end{aligned} \qquad (6)$$

3. INFORMATION INVARIANTS AND CALIBRATION OF THE EARTH'S REMOTE SENSING DATA

As rule informational analysis and calibration of the Earth's remote sensing data have been based on well known entropy and information metrics notions. Last ones are founded at the Shennon's information metric which depends on from a probability distribution density p for spectral reflection coefficients of natural formations elements placed on environmental underlying surfaces. According to the Shennon's information criterion a dispersion of covariance matrix $k_{i,j}(r_\lambda^{\,i}, r_\lambda^{\,j})$ is used usually for model's parameters estimations in the processing, analysis and classification of environment's remote sensing data. It should be noted that covariance matrix sense is similar to well known light scattering matrix in the radiative transfer theory. In the time of the paper [4] the information quantity is determined by the following manner:

$$I_\lambda = \frac{1}{2}\ln\frac{\det k_{ij}\ (r_\lambda^{\,i}, r_\lambda^{\,j}),}{\prod_i \sigma^i_{r,\lambda}} \qquad (7)$$

The determinant of covariance matrix $k_{i,j}$ has represented in the numerator of expression (7) and appropriate dispersions multiplication $\sigma^i_{r,\lambda}$ has showed in the denominator of this expression. The search of $\lambda_{i,j}$ optimal significances in which spectral reflection coefficient $r_\lambda(\eta,\xi,\varphi,x,y)$ are measured can be carried out by means of the following estimation used in the paper [4]:

$$\lambda_{i,j} = \arg\min_\lambda \ln\left\{\det\left[k_{i,j}(r_\lambda^i, r_\lambda^j)\right]\right\} \qquad (8)$$

Also the criterion of D-optimization $\Phi[D] = \ln\det[M(p,x,y)]$ for the Fisher's matrix M is used often. According to this criterion the strategy of optimal plans $P_{i,j} = P(x_i, y_j)$ for measurements of underlying surface brightnesses remotely received from satellite in each point of variables multitude (x,y) had been elaborated in paper [4]. The optimization of the Fisher's matrix M making use of next condition:

$$\begin{aligned} &\arg\max_{P(x,y)} \ln\det M[P,x,y] = \\ &\arg\min_{P(x,y)} \ln\det D[P,x,y] \end{aligned} \qquad (9)$$

constructs factually the minimizing plan of dispersion's matrix D determinant for the estimation of spectral reflection characteristics $r_\lambda = r_\lambda(x,y,G)$ in the framework of chosen model G. In successive considerations the Fisher's matrix M or inverse dispersion's matrix D are constructed usually on the basis of coefficients linear expanding concerning selected models G parameters. Also Q – optimal information content's criterion is used for optimization procedures of response function dispersions for brightnesses of optically non-uniform refection bottom. Basic surface plots distribution and registration are necessary conditions with a point of view the determination of most informative surface plots and the search of ecological stability zones likewise taking into account the optimal planning of environment's remote sensing. However information content of environment's remote sensing data must be dependent not only ecosystem's degradation type and appropriate development stage but must be fitting adequately relatively solar illumination conditions and juxtapositive at different levels of satellite information processing. Thus corresponding information measures are needed for following consideration. Naturally this information measures must be connected with measured or simulated radiation field’s data and to be nonvariable values relatively solar illumination conditions at the same time. For this purposes the conception of information calibrating functionals is supposed below on the basis of informational invariants (6):

$$\frac{\left\langle\overline{\rho}_\lambda\right\rangle_{x,y} - \rho_\lambda}{\left\langle\rho_{\lambda,sur}\right\rangle_{x,y}} = \frac{D^{1/2}\left[\overline{\rho}_\lambda\right]_{x,y}}{D^{1/2}\left[\rho_{\lambda,sur}\right]_{x,y}} = \mu_\lambda(\tau_0,\eta) \qquad (10)$$

In correlations (10) invariant values are received by calculations average magnitudes $\left\langle\overline{\rho}_\lambda\right\rangle_{x,y}$, $\left\langle\rho_{\lambda,sur}\right\rangle_{x,y}$ and corresponding dispersions $D^{1/2}\left[\overline{\rho}_\lambda\right]_{x,y}$, $D^{1/2}\left[\rho_{\lambda,sur}\right]_{x,y}$ for optically non-uniform underlying surfaces as results appropriated statistical working in the frame of spatial averaging procedure relatively horizontal coordinates x and y. Making use of expression (10) invariant correlations for the variance coefficient k_λ are founded easily:

$$k_\lambda = \frac{D^{1/2}[\rho_{\lambda,sur}]_{x,y}}{\langle \rho_{\lambda,sur} \rangle_{x,y}} = \frac{D^{1/2}[\bar{\rho}_\lambda]_{x,y}}{\langle \bar{\rho}_\lambda \rangle_{x,y} - \rho_\lambda} \qquad (11)$$

Obviously that values k_λ in (11) don't depend on from total atmospheric transparency $\mu_\lambda(\xi, \tau_0)$ due to (6) and from $\rho_{\lambda,sur}$ in view of (10). In this case to the utmost possible estimation of information content for analyzed satellite picture fragments can be carried out by means of the following expression:

$$I_\lambda = 1/2 \log_2 \left[1 + (k_\lambda)^{-1}\right] \qquad (12)$$

Now it should be noted that for the accomplishing of real informational analysis and corresponding calculations some fitting parameterization of r_λ are useful often. For example supposing spectral (λ) and angular (η, ξ, φ) reflected radiation field behaviors are independent the corresponding reflection coefficient $r_\lambda(\eta, \xi, \varphi, x, y)$ can be represented by the following fitting correlation:

$$r_\lambda(\eta, \xi, \varphi, x, y) = R(\lambda) r\ (\eta, \xi, \varphi, x, y) \qquad (13)$$

In the case wenn optical nonuniformities of underlying surface will be a function of horizontal coordinate x only mentioned above parameterization can be represented by the following manner:

$$\begin{aligned} &r_\lambda(\eta, \xi, \varphi, x) = R(\lambda) r(\eta, \xi, \varphi, x) \times \\ &\exp[-\beta(\lambda)\alpha(x - \Delta x)] \end{aligned} \qquad (14)$$

Taking into account (14) average values and covariance estimations for log-normal distribution of spectral reflecting coefficients $r_\lambda(\eta, \xi, \varphi, x, y)$ are equal

$$\langle r_\lambda \rangle = r(\lambda) \exp\left[-\beta(\lambda)\langle \alpha \rangle + 1/2 \beta^2(\lambda)\sigma_\alpha^2\right], \qquad (15)$$

$$\begin{aligned} &\mathrm{cov}_r(\lambda, \lambda') = \langle r(\lambda) \rangle \langle r_r(\lambda') \rangle \times \\ &\exp\{[\beta(\lambda)\beta(\lambda')]\sigma_\alpha^2 - 1\}, \end{aligned} \qquad (16)$$

In expressions (15)-(16) structural deterministic functions $r(\lambda)$ and $\beta(\lambda)$ depend on completely from wave length λ only. Optical nonuniformities of reflecting bottom are represented by stochastic function $\alpha(x)$ for sounded terrain inclinations corresponding to average magnitude estimations $\langle \alpha \rangle$, correlation function $K_{\alpha\alpha}(\Delta x)$ and dispersion σ_α^2 [4]. If should be remarked specially that correlation functions $K_{\alpha\alpha}\{\Delta x, x(t)\} = \langle \alpha[x(t)]\ , \alpha[x(t) + \Delta x]\ \rangle$ are in fact spectral autocorrelation functions for optical surface nonuniformities of radiation field measured across alignment of sounded terraine. Calculations of corresponding information content have been based on the inverse Fisher's matrix determinant $\det[M] \to \det[M^{-1}]$ which is used usually. Simultaneously in advance chosen informational metrics are used for constructed response functions in the framework of imitative planning for given N spectral multitudes channels λ_i and appropriate selected informational functionals $I_{\lambda_i} = -1/2 \ln\left[\det M^{-1}\right]$. Further known information calibration metrics can be specified by means of mentioned above informational functionals $I_{\lambda i}$. Taking into account the parameterization (15) needed variations coefficient k_λ are determined for spatial spectral variability of reflecting coefficients r_λ by the following manner:

$$k_\lambda = \frac{D^{\frac{1}{2}}[r\ (\lambda)]}{\langle r\ (\lambda) \rangle} = \exp\left[\beta^2(\lambda)\sigma_\alpha^2 - 1\right]^{\frac{1}{2}} \qquad (17)$$

The expression (17) manifests it self spatial-contrast properties of a underlying surface radiation field which are susceptible to structural angular and spatial parameters of reflecting bottom nonuniformities. Let us consider in conclusion the transformation of reflecting bottom radiation fields at height H. In this case expression (12) is converted into the following correlation:

$$I_\lambda = 1/2 \log_2 \frac{\det\left[\exp \beta^2 W_\alpha(x, y, x - \Delta x, y - \Delta y) - 1\right]}{\underset{ij}{\Pi}\, \sigma_{i,j}^{1/2}}, \qquad (18)$$

The correlation (18) had been received by the account of the covariation spectral reflecting coefficient $r_\lambda(\eta, \xi, \varphi, x, y)$:

$$\begin{aligned} &\mathrm{cov}\ _r\left[r_\lambda(x), r_\lambda(x')\right] = \\ &\langle r_\lambda(x) \rangle \langle r_\lambda(x') \rangle \times \\ &\exp\ \left[\beta^2 W_\alpha(x, x - \Delta x) - 1\right] \end{aligned} \qquad (19)$$

and the calculation of second moments of stochastic functions W_α determined for spectral reflection coefficient r_λ in the assuming of stationary, ergodic and gaussian (normal) characters of probabilities density distributions. Parameters Δx and Δy variations are responsible for the atmospheric and surface spectral spatial-frequency filtration which smooths of aerospace images in depend on from aerospace survey height H. Parameters β и α as geometric and spectral factors correspondingly are remained independent against conditions of environment's remote sensing. Thefore calibration functionals (10) in the case of information content height reduction are remained not variable also. Simultaneously corresponding informational matrix M for the determination of satellite survey optimal heights are formed by means of basis vectors of linear decomposition for value $r_\lambda(\eta, \xi, \varphi, x - \Delta x)$ relatively mentioned above structural parameters β и α.

4. OPTIMAL PLANNING EXAMPLE OF THE ENVIRONMENT'S REMOTE SENSING

In the paper [5] advanced interactive softwares had been elaborated for the processing of environment's aerospace information. Besides thematic interpretation and analysis this softwares offer to construct scanning optimal plans and allow to determine most informative plots of the environment's surface. As example in the papers [4]-[5] practical applications of real multispectral scanner's information are considered. Selected Landsat-TM images are used for the determination of aerospace survey optimal conditions. In this contest appointed degradation zones concerning to Caspian Sea coast had been studied detailly likewise. Chosen analyzed images are broken up into even number elements. For this selected segments the informational analysis is carried out at different levels of sounded ecosystem's degradation. Zones of stability, optimal plots coordinates and directions of degradations distribution are determined by means of interaction regimes calculations for each selected segment's pair of satellite images. Similar operations are repeated at each successive step of optimizing procedure with the help of preceding informational analysis. Therefore the information content analysis of the Earth's surface aerospace images is main criterion of optimal strategy concerning the determination of ecosystem degradation zones on the basis of appropriate environment's remote sensing data. As results remarked above practical tasks can be solved at each successive scanning stage of environment's satellite surrey.

5. CONCLUSION

Suggested above the conception of information functionals permits to carry out practically satellite data calibration and chosen imitative models estimation of the Earth's remote sensing data. It is clear above considered procedures and algorithms are important component of appropriate information content analysis and following remote sensing optimal planning [6]. However it should be noted that for more in-depth and complete study of information content connected with remote sensing direct-inverse problems the appropriate calibration modeling should be carried out jointly [7]. Besides the consideration of photometric and informational radiation field invariants must to include the mirror symmetry principle and corresponding investigation of radiation field invariant's properties under any linear transformations (shifts and rotations) [8]. Also the problem of spectral spatial-frequency atmospheric filtration for multispectral remote sensing data should be analyzed of course more comprehensively [9]. No doubt the approach proposed above have to be integrated by advanced geoinformatic systems for ecological data processing, interpretation, control and corresponding forecast of environment's critical zones. At last it essentially to emphasize the information content of analyzed environment's remote sensing data should be more comprehensive for such multispectral remote sensing information which includes the account of polarizations effects concerning to atmospheric light scattering and underlying surface light reflection.

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