ENHANCEMENT OF SPATIAL DATABASE ARCHIVE SERVICES FOR DISASTER RESPONSE

V.Savorskiy*, Yu.Tishchenko

Fryazino Department, Kotelnikov Institute of Radioengineering and Electronics, RAS,
Vvedenskogo sq., 1, Fryazino, Moscow region, 141190, Russia - (savor, tishchen)@ire.rssi.ru

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ABSTRACT:

Natural disasters force to upgrade existing spatial databases and archive services in order to support massive user requests for data and information which describe emergency region. It is often the case when necessary information is not located in one place but distributed within a set of information sites. Both these circumstances – massive requests and data distribution – interfere to provide user with requested information in timely manner. Presented work proposes an integrated approach in increasing data providing efficiency. The approach is constituted by two principal components: 1) upgrading spatial database content (what to provide), and 2) enhancement of exchange tools (how to distribute). First component - content upgrading – is implemented by enriching data model with ranks that provide designated users with estimations of suitability of data sets for description of occurred or potentially possible disasters. This component aims to spare user time while searching and choosing appropriate data. Second component – enhanced exchange tools – should give users the set of services enabling to receive data from any remote EO data centre in timely manner. Implementation of this component is analysed in wide context – from ordinary data uploading via ftp client-service application to broadcast data dissemination. Analysis is resulted in formulation of dissemination strategy.

1. INTRODUCTION

Natural disasters force to upgrade existing spatial databases and archive services in order to support massive user requests for data and information which describe emergency region. It is often the case when necessary information is not located in one place but distributed within a set of information sites. Both these circumstances – massive requests and data distribution – interfere to provide user with requested information in timely manner. Presented work proposes an integrated approach in increasing data providing efficiency.

The approach is constituted by two principal components: 1) upgrading spatial database content (what to provide), and 2) enhancement of exchange tools (how to distribute). First component - content upgrading – is implemented by enriching data model with ranks that provide designated users with estimations of suitability of data sets for description of occurred or potentially possible disasters. This component aims to spare user time while searching and choosing appropriate data. Second component – enhanced exchange tools – should give users the set of services enabling to receive data from any remote EO data centre in timely manner.

Description of principal archive structure constitutes Chapter 2 content where logical approach to construct data archive structure which is supported not only by enhanced data base attributes but as well by optimum location of data on storage media is presented. Chapter 3 contains descriptions of the estimation procedure of data ranks supporting optimization of data arrangement procedures: local and WAN optimization. The data model enabling support of enhancement functionality is presented in Chapter 4. Principal changes of presented data model with respect to convenient EO information system are presented in Chapter 5. Chapter 6 contain description of procedures of optimizing local data rearrangement, procedures of optimal data allocation over distributed mirror sites set and requirements for dissemination manager necessary for future development.

2. ARCHIVE STRUCTURE

At present spatial database archive, or spatial archive, are implemented as infrastructure incorporated data collecting, storing, and disseminating service components. One of the main purposes of spatial archive activity is to support long term storage of spatial data and products followed by permanent support of fully functional access to data from designated community [1]. Here after [1] long-term is qualified as such time interval which as a rule exceeds lifetime of hardware/software platform which was used to ingest data in archive. It means that long term requires changing media storage as well. As a consequence there is a common case when archive uses a variety of media types which differs by their performance drastically.

This – **historical** – approach in archive development interferes to use data in spatial database applications where we need to incorporate logically connected data, e.g. data for one spatially bounded object that should describe evolution of that object within given data frame. This interference in data application reveals at most in case of emergency when need to extract data from archive as fast as possible. To this end we propose to rearrange data content (at least to form special archive section for emergency purposes) in order to enhance archive functionality in emergency situations for controlled type of

* Corresponding author

disaster, i.e. to speed-up archive uploading rate. As could be seen below the proposed archive rearrangement is based on attributes including spatial and temporal characteristics of physical phenomena describing by archive data set. So, proposed approach could be regarded as **logical** approach to construct data archive structure supported not only by enhanced data base attributes but as well by optimum location of data on storage media. It should be mentioned that this rearrangement means that hardware upgrading is not a mandatory requirement. Therefore we could restrict our analysis of optimizing rearrangement by consideration of already existed storage capacities.

Let archive in total consists of N data packages $\xi_i, i=\overline{1,N}$ (elementary, or atomic, data sets) with volumes $d_i, i=\overline{1,N}$ which are allocated in K ($K<N$) archive sections $S_k, k=\overline{1,K-1}$ with volumes $D_k, k=\overline{1,K-1}$, where $\sum_{i=1}^{N} d_i < \sum_{k=1}^{K} D_i$.

Any section should contain at least one package. In general packages allocations are described as follows:

a package ξ_i with $i=\overline{N_k, N_{k+1}}, k=\overline{1,K-1}$ are allocated in section $S_k, k=\overline{1,K-1}$, where

$N_1 = 1 < N_2 < ... < N_K = N$,

$\sum_{i=N_k}^{N_{k+1}} d_i < \alpha D_k$ for $k=\overline{1,K-2}$

and

$\sum_{i=N_k}^{N_{k+1}} d_i < D_k$ for $k=\overline{1,K-1}$

$\alpha = 0.8$ is recommended as allowed upper volume level of section for data allocation in order to have additional free space which is required for effective implementation of relocation procedures in order to spare time in ingestion of new data in emergency cases (see sec.6.1).

3. DATA PROVIDING EFFICIENCY

3.1 Local optimization

We estimate data providing efficiency in terms of local mean transfer time τ necessary for local users to receive one unit of data from archive. Here we determine local mean transfer time τ as mean time which is required to retrieve data package from archive and to transfer it to local WAN gateway. Data users form designated community which is "an identified group of potential consumers who should be able to understand a particular set of information" [1] and presumably will ask for required information in foreseen circumstances, i.e. in our case after disaster occurrence. To enhance archive functionality we need to minimize mean transfer time which for N data packages could be estimated as

$$\tau = \sum_{i=1}^{N} \tau_i P_i / \sum_{i=1}^{N} P_i = \sum_{i=1}^{N} \tau_i p_i, \quad (1)$$

where τ_i - local transfer time for given i th data package ($i=\overline{1,N}$) averaged over designed community, P_i - i th data package popularity, i.e. frequency of requests, p_i - fraction of i th data package popularity, i.e. fractional frequency of requests.

Optimum functionality of spatial data base archive service is achieved by minimizing τ via rearrangement of transfer times $\tau_i, i=\overline{1,N}$ and fraction frequencies $p_i, i=\overline{1,N}$ data packages. So, optimum mean transfer time for all designated community is estimated as

$$\tau_{opt} = \min(\sum_{i=1}^{N} \tau_i p_i), \quad (2)$$

where minimum is searched via rearrangement of $\tau_i, i=\overline{1,N}$ and $p_i, i=\overline{1,N}$ sets.

According to theorem 368 from [2] τ_{opt} is reached when data sets $\tau_i, i=\overline{1,N}$ and $p_i, i=\overline{1,N}$ are both monotonic and arranged in opposite sense. So, if data set $(p) = p_i, i=\overline{1,N}$ is arranged in non-increasing order

$$(\underline{p}) = \underline{p}_i, i=\overline{1,N}, \quad (3)$$

$$\underline{p}_1 \geq \underline{p}_2 \geq .... \geq \underline{p}_N, \quad (4)$$

then τ is reaches its minimum value when data set $\tau_i, i=\overline{1,N}$ is rearranged in non-decreasing order

$$(\bar{\tau}) = \bar{\tau}_i, i=\overline{1,N} \quad (5)$$

$$\bar{\tau}_1 \leq \bar{\tau}_2 \leq .... \leq \bar{\tau}_N. \quad (6)$$

Applying to our case we may conclude that principal enhancement of spatial archive functionality in data providing could be reached via monotonic relocating data packages over archive sections in order to fulfill conditions (4) and (6). After rearrangement

3.2 WAN optimization

Another part of data providing optimization is connected with transferring data via WAN. The scope of this work does not include optimization of data transfer topology, route optimization, so on. Instead it concerns with optimum data allocation on the set of data providing sites (mirrors) in order to increase total uploading data rate from all sites containing data copies.

Optimum allocation arrangement is the solution of optimization problem on uploading data rate. Total uploading rate U from of N data packages from L_i data sites could be presented in following manner

$$U = \sum_{i=1}^{N} \sum_{l=1}^{L_i} u_{il} P_i / \sum_{i=1}^{N} P_i, \quad (7)$$

where u_{il} - mean uploading rate of data package $\xi_i, i = \overline{1, N}$ from site $A_l, l = \overline{1, L_i}$. Let us

$$\vartheta_i = \sum_{l=1}^{L_i} u_{il} \ , \qquad (8)$$

then

$$U = \sum_{i=1}^{N} \vartheta_i P / \sum_{i=1}^{N} P_i = \sum_{i=1}^{N} \vartheta_i p_i \ . \qquad (9)$$

Optimum uploading rate is determined by maximum of (9):

$$U_{opt} = \max(\sum_{i=1}^{N} \vartheta_i p_i), \qquad (10)$$

As in case of transfer time optimization here we also can use the results of theorem 368 from [2]. In this case the optimum is reached where $(p) = p_i, i = \overline{1, N}$ is arranged in non-decreasing order (see (3), (4)) and $(p) = p_i, i = \overline{1, N}$ is arranged in the same, i.e. non-decreasing, order

$$(\underline{\vartheta}) = \underline{\vartheta}_i, i = \overline{1, N}, \qquad (11)$$

$$\underline{\vartheta}_1 \geq \underline{\vartheta}_2 \geq .... \geq \underline{\vartheta}_N, \qquad (12)$$

So, we proved that optimum is reached if data packages would be distributed via mirror sites in accordance with arrangement of possible total uploading rate (8). In cases where uploading rates u_{il} do not depend both on package features and on mirror site performance, i.e. when $u_{il} = u$ expression (8) could be presented in simpler form

$$\vartheta_i = uL_i \qquad (8')$$

Arrangements (3, 4) and (11, 12) are the solution of optimization problem giving the maximum possible uploading data rate from set of mirror sites.

4. PRACTICAL IMPLEMENTATION

4.1 Equivalence of $(\underline{p})$ arrangement

One of the prominent features of proposed approach is the following: one can use any monotonic increasing function $f(p)$ to use its values $f_i = f(\underline{p}_i)$ instead of $\underline{p}_i$ in order to achieve minimum of τ with the same arrangement of $(\overline{\tau}) = \overline{\tau}_i, i = \overline{1, N}$. It means that despite changes in absolute values of τ estimations the substitution of f_i instead of $\underline{p}_i$ does not change the arrangement order of $(\overline{\tau})$ which enables τ minimization, i.e. it has the same monotonic sense as while using $\underline{p}_i$ set.

For these purposes we propose to use archived data ranks R_i (see section 4.2) similar to ranks introduced in [3] for prognostic estimation of archive data set appropriateness for describing possible disaster events on site that is covered by observation data contained in data package.

4.2 Data package ranking

Approach proposed in [3] for estimation data appropriateness for disaster analysis are based on user opinions on what data package properties provide more appropriate description of region under observation. We update approach [3] in order to explicitly reveal connection between introduced ranks and popularity of data requests. Rank of appropriateness R_i of given data package $\xi_i, i = \overline{1, N}$ for describing a disaster now we propose to evaluate as follows[2]:

1) basic attributes of package ξ_i descriptor are revealed from spatial database (catalogue):
   - date of observation T_i,
   - geographic location coordinates L_i,
   - sensor type or product type (for sophisticated products generated from satellite data),
   - spatial resolution ρ_i,
2) statistical (from historical data) frequency of natural disaster events F_i, their expected intensities I_i, and their square size S_i are retrieved by their date and location values from ξ_i, for these purposes geophysical statistically generalised or historical data are used as information sources, in some special cases S_i could be determined by I_i values, but in general it should be retrieved from external sources, anyway it is supposed that $\partial S / \partial I > 0$,
3) expected rate of disaster consequences C_i is estimated as production of disaster events frequency F_i on population density π_i (retrieved from census data) and on square size of disaster S_i (or square size of its fraction represented by package ξ_i) and regional vulnerability function $V(I, T, L)$ where $\partial V(I, T, L) / \partial I > 0$:
$$C_i = F_i \pi_i S_i V(I_i, T_i, L_i), \qquad (13)$$
4) expected visible consequences C_i^{vis} of disaster event are evaluated as products of C_i and two correction coefficients: 1) visibility coefficient k_{obs} which evaluates fraction of package ξ_i that could be used for disaster consequences analysis, 2) resolution coefficient k_{res} which is estimated as a relation of resolution size k_{res}^{req} which is required for full resolution observations of disaster consequences (e.g. 2 m for earthquake 30 m for flood, so on see [4]) to actual resolution of archive scene k_{res}^{act}, so $k_{res} = k_{res}^{req} / k_{res}^{act}$:

[2] For the sake of simplicity we consider one type of disaster and omit index subscription i for attributes except on 6th step

$$C_i^{vis} = k_{obs} k_{res} C_i \,, \tag{14}$$

5) all data packaged are arranged in accordance with their C_i^{vis} values,

6) to present data package ranks in explicit manner the values of ranks of package ξ_i are estimated as follows

$$R_i = \frac{C_i^{vis} - C_{\min}^{vis}}{C_{\max}^{vis} - C_{\min}^{vis}} \tag{15}$$

Vulnerability function $V(I,T,L)$ reflects big differences between consequences of disaster occurrence in different world regions and at different dates (epochs). These differences arise from big differences in population and property protection that could be provided and permanently supported in different world regions. Disregards of differences in vulnerability can mislead in rank estimations and as a consequence we receive false data package arrangement. If we have no knowledge on $V(I,T,L)$ behaviour we should avoid discrepancy problem by restricting our analysis by archives which contain data only on region where vulnerability function is homogeneous, i.e. it does not depend on time and location parameters

$$V(I,T,L) \equiv V(I) \tag{10}$$

Relations (7-10) define grade values. Analysis of these relations proves that (p) is arranged in the same sense as (R) for given data package set $\xi_i, i = \overline{1,N}$. Indeed set of $p_i, i = \overline{1,N}$ is arranged in accordance with disaster event intensity and capability of observation system to register disaster consequences: more disaster intensity produces more human concern on disaster consequences immediately followed by search for more information on disaster zone. This growth of human concern is confirmed by results cited in review of the studies of disorders caused by disaster on exposed humans [5]. It states that method developed by [6] "has shown that higher rates of [disaster] exposure [intensity] can be a good predictor of morbidity. However, over a certain level where extreme threat and horror are ubiquitous, there appears to be a plateau effect".

According to relations (7) and (8) the $R_i, i = \overline{1,N}$ set is depended on the same factors as $p_i, i = \overline{1,N}$ one: it is arranged in the same order when they are used to describe disaster consequences. So, appropriateness in our sense measured in values of ranks $R_i, i = \overline{1,N}$ (9) is coincided in arrangements with presumable data packages popularity. If proposed rank values would contradict with popularity preferences this contradiction should be corrected using the statistics of user requests as proposed in [4].

Eventually we can state that arranged set $(\underline{R})$ could be used instead of arranged set $(\underline{p})$ - because they are arranged in the same sensed - in our procedures of $(\bar{\tau})$ arrangement aimed to minimize mean time necessary to download data package from spatial archive in disaster emergency.

4.3 Transfer time arrangement

Application of arrangement $(\underline{R})$ in optimizing procedures requires arranging package set $\xi_i, i = \overline{1,N}$ to fulfill monotonic arrangement of $R_i, i = \overline{1,N}$. In addition it requires arranging package set $\xi_i, i = \overline{1,N}$ to fulfill transfer time arrangement as well. Because we already arranged data set $\xi_i, i = \overline{1,N}$ according to $R_i, i = \overline{1,N}$ values the only way to complete such time additional arrangement is to relocate data packages on archive media. Procedures of such arrangement are described below in sec.6.1 following the description of data model necessary to implement enhanced archive functionality.

5. UPGRADED DATA MODEL

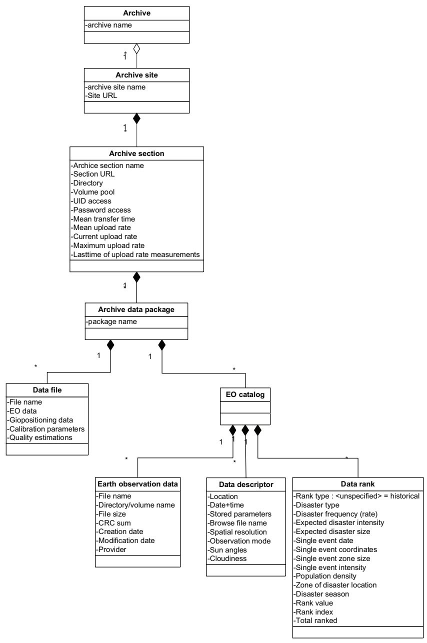

Fig.1. Upgraded data model of spatial archive optimized for disaster response

Principal changes of presented data model (see Fig.1) with respect to convenient EO information system are new data objects which are necessary for supporting new enhanced archive services:

- **Archive section** – descriptor of archive part with the permanent access properties for all contained data packages includes the following attributes:
  - **Archive section name**
  - **URL of archive**
  - Base on-line **directory** of section
  - **Volume pool name** for tape storage
  - Authorized **user name**
  - Authorized **user password**
  - Mean **time** to data **transfer** from storage to outer (WAN) gateway
  - Mean, maximum, and current **upload rate**
  - **Last time** of upload rate measurements

- **Data rank** – catalog data object containing ranks of data package appropriateness for awaited disaster description includes the following attributes:
    - **Rank type – historical (default)** based on historical statistics, or actual based on **single** event characteristics,
    - **Disaster type,**
    - **Disaster frequency** (rate) with expected, or mean, intensity(only for historical rank type),
    - **Expected disaster intensity** (only for historical rank type),
    - **Expected disaster square size**(only for historical rank type),
    - **Single event date** (only for single event rank type),
    - **Single event location (coordinates)** (only for single event rank type),
    - **Single event square size** (only for single event rank type),
    - **Single event intensity** (only for single event rank type),
    - **Population density** in disaster zone,
    - **Region** of disaster location (worldwide zoning),
    - Disaster **season** (for seasonal disasters),
    - **Rank value,**
    - **Rank position** (starting from the largest),
    - **Total number** of ranked data.

6. ENHANCED EXCHANGE TOOLS

6.1 Implementation of optimum location data on storage media

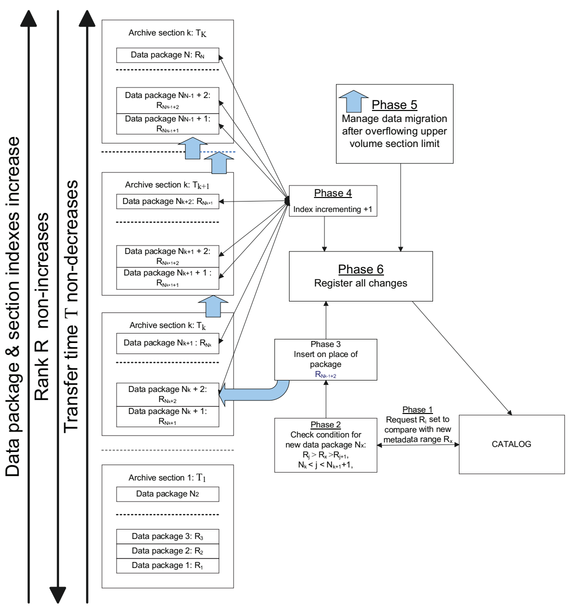

Fig.2. Functional schema of optimum data allocation

As been proved in sec.3 the optimum arrangement of data in archive allows minimizing upload time. The correct arrangement is reached via relocation the data with high data package ranks, which in disaster circumstances are proved to be equivalent to data request popularity (see details in sec.4.2), on storage media with lowest transfer time (with respect to outlet gateway). That is why we include the description of allocation procedure in this section.

Assuming the rank R_x of data package ξ_x is already known (see details in sec.4.2) the allocation procedures should include the following principal phases:

Phase 1: request Catalog to retrieve existing set of $R_i, i = \overline{1, N}$,

Phase 2: retrieve index j to fulfill the following conditions (see above sec.2)

$$R_j \geq R_x \geq R_{j+1}, j = \overline{N_k, N_{k+1}}, k = \overline{1, K-1}$$

Phase 3: new (incremented +1) indexes are recorded in Catalog for all packages with index $i > j$,

Phase 4 data package ξ_x replaces data package ξ_{j+1}, i.e. in archive section S_k,

Phase 5: if section S_k is overloaded (upper watermark is exceeded), data packages start to reload to section S_{k+1} until lower watermark would be reached, recommended values for upper and lower watermarks are 0.8 and 0.7, respectively; these procedure is repeated for section S_{k+1} if it would be overloaded after migration and so on until there would not overloading,

Phase 6: all data packages (including new one) finally update registration records in Catalog.

6.2 Implementation of optimum data location on mirror sites

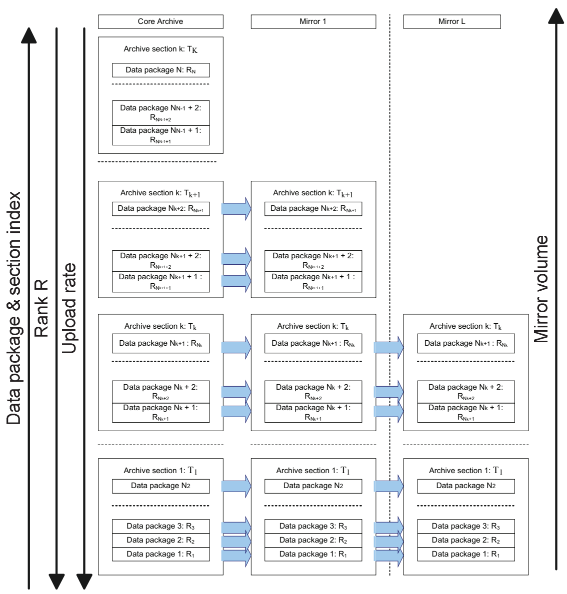

Fig.3. Functional schema of optimum data allocation

Optimum data location over the set of mirror sites is governed by data ranks as well. Basic principle of this distribution is to upload the data with highest ranks over as much as possible mirror sites in order to fulfill condition (8') supposing upload rates of all sites to be close to each other.

Assuming the rank R_x of data package ξ_x is already known (see details in sec.4.2) the allocation procedures over mirror sites includes the following principal phases:

Phase 1: request Catalog to retrieve existing set of $R_i, i = \overline{1, N}$,

Phase 2: retrieve index j to fulfill the following conditions (see above sec.2)

$$R_j \geq R_x \geq R_{j+1}, j = \overline{N_k, N_{k+1}}, k = \overline{1, K-1}$$

Phase 3: new (incremented +1) indexes are recorded in Catalog for all packages with index $i > j$ for all sites $A_l, l = \overline{1, L_i}$ (sections on different sites are discriminated from sections on the same site by URL attributes),

Phase 4 data package ξ_x replaces data package ξ_{j+1} on all sites $A_l, l = \overline{1, L_i}$ where ξ_{j+1} was previously allocated,

Phase 5: if site $A_l, l = \overline{1, L_i}$ is overloaded (upper watermark is exceeded), data packages with least ranks are excluded,

Phase 6: all data packages (including new one) finally update registration records in Catalog.

In case of emergency data packages are distributed over mirror set in broadcasting mode. Otherwise it is preceded as client-server ftp transfers.

6.3 Required distribution functionality

Upgrade of data arrangement over distributed system is just a first step of real enhancement of system performance. To complete enhancement the dissemination system should be upgraded as well. Although the dissemination enhancement is the subject of future works we need here to formulate the principal requirement which should be fulfilled by such dissemination system.

To achieve performance enhancement of the whole distributed archive system the dissemination subsystem should be upgraded as well. The upgrade includes addition of **Dissemination manager** enabling:
1) to control uploading rates from all mirror sites,
2) to balance upload loading of mirror sites in order to achieve maximum total upload rate,
3) to collect the statistics of system uploading in order to enhance system performance (primary in maximization of total upload rate) in recurrence mode,
4) to distribute data in p2p mode, i.e. directly forward data from mirror sites to designated users under control of **Dissemination manager**.

7. CONCLUSIONS

1. The data arrangement strategy of system performance enhancement aiming in maximizing upload rate is formulated and theoretically grounded.
2. The estimation procedure of data ranks supporting optimization of data arrangement procedures is designed.
3. Data model enabling support of enhancement functionality is developed.
4. Procedures of optimizing local data rearrangement are revealed.
5. Procedures of optimal data allocation over distributed mirror sites set are designed.
6. Requirements for dissemination manager necessary for future development are formulated.

8. REFERENCES

1. Reference Model for an Open Archival Information System (OAIS), January 2002.
2. Hardy G.H., Littlewood J.E., Pólya G. Inequalities. Cambridge University Press, 1952, 324pp.
3. Savorskiy, V., Tishchenko, Yu. Upgrade of Space Data Information System to Use in Natural Disaster Emergency. ISRSE 33 Proceedings, Stresa, Italy, 2009, TS-41-2 (ref.350), 4pp.
4. Savorskiy, V.P., Tishchenko, Yu.G. Event-Driven Information System Designed for Emergency Applications. Proceedings of 21 Congress of ISPRS. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, vol.37, part B8-1, pp. 241-247.
5. McFarlane A.C. Psychiatric Morbidity Following Disasters: Epidemiology, Risk and Protective Factors. In: Disasters and Mental Health, Disasters and Mental Health. Edited by Juan Jose Lopez-Ibor, George Christodoulou, Mario Maj, Norman Sartorius and Ahmed Okasha, 2005, John Wiley & Sons Ltd.
6. Bravo M., Rubio-Stipec M., Canino G., Woodbury M., Ribera J. (1990) The psychological sequelae of disaster stress prospectively and retrospectively evaluated. Am. J. Commun. Psychol, 18: 661–680.

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