The Moving Digital Earth (MDE) for monitoring of forthcoming disasters

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ABSTRACT

Disasters in Earth Nature Systems (in river basins and in coastal zone) are generated the systems by influence under pressure and impacts of external systems. The water related disasters include the most of hazardous processes on land and sea as follows: floods, avalanches, droughts, landslides, debris-flows, erosion, abrasion, and others. The external systems are not yet able to let know about the Time, Place, and Power of future disasters all together. However, Earth systems allow doing it because of their property to delay on exterior power. The proposed and discussed is the Moving Digital Earth (MDE) technology for outstripping estimation of the Earth Nature Systems response on exterior pressure and impacts. The MDE uses only the knowledge of current System's state and methods of the Digital Systems Analysis (DSA) by high-speed computing.

Keywords

Nature systems, Digital Systems Analysis, Virtual Systems, Digital Earth, Moving Digital Earth.

INTRODUCTION

Objects of the study are dynamic Nature Systems on a land and sea (river basins and coastal zone). The Digital System Analysis (DSA) investigates their reactions on external power and internal interaction. The DSA was worked out for continual computation of governing Geomorphologic processes, which are as follows: surface water/sediment flows, infiltration, evaporation, dynamics of a river net, freezing/melting, reservoirs filling up, landslides, debris-flows, floods, soil erosion, sedimentation, underground flows, pollution transport, processes in a coastal zone, and others (Klenov, 1987, 1999a, 1999b, 2000a, 2000b, 2003, 2004, 2005). The next step was to work out the Virtual Systems (VS) as acting doubles of the Nature Systems. A join of the VS with the Digital Earth (DE) is named as the Moving Digital Earth (MDE) (Klenov, 2004).

The outer power (precipitation, temperature, wind), which is further reformed by a variety of geomorphologic conditions, is a reason of water and sediment flows through a natural system. Having such flows implies that a system is non-equilibrium, which is subjected to thresholds in water and sediment movement. Spatial structure of flows results in local unites of the flows, which often become sudden disastrous floods. Surface and underground water flows has self-regulated velocity. Due to a high activity of inner processes, nature systems are the Open Non-Equilibrium Systems (ONES). The properties of the ONES are as follows: non-stable flows, oscillations, thresholds, hazardous flows, meanders, branches, and others. The Digital System Analysis (DSA) reforms data on 2D external powers to interior flows inside a system. The executable programs use real data and become the multi-functional Virtual Double of the real area. Bordering natural systems generate own disasters (earthquakes, typhoons, et al.) and provoke disasters in Earth Nature Systems. The Earth Nature Systems separately generate slow and disastrous processes as follows: floods, landslides, debris-flows, soil erosion, sedimentation, coastal abrasion, among others. The hazardous processes turn into catastrophic ones in areas with high velocity or/and high volumes of flows in floodplains, deltas, sharp slopes, and in coastal zones.

The DSA calculates all types of flows inside catchments calculation balance inside, where river basins and river nets are bordered by watersheds. The Coastal Zone includes a part of sea (reservoirs) between a coastline and until a depth is under wind-wave influence (about 50 -100m). A deep area of a sea belongs to the Nature System, which is in competence of the Oceanology. River Basins and Coastal Zone may be of any plane configurations of elevation/depth. The DSA advantage is that it is not strongly dependent on the scale, and enables to estimate processes in any plane and mixture of the land areas and coastal zone, because of high resolution of a basic Matrix. A several empirical equations are used to calculate water/mass/energy exchange between all neighbor cells of the

Matrix. The recurrent calculation of the multi-layer Matrix repeats during non-restricted sequence of time steps. The DSA is the 'Information Machine', which continually reforms information sources to the next state of the system. The nearby other Nature Systems (Ocean, Atmosphere, and Earth Crust) are areas of other processes, and are sources of exterior energy for influence to land and coastal systems.

The DSA was used to make a 'family' of Virtual Systems (formerly being called as simulation models) which are as follows: River Basin, Coastal Zone, and join of these two most widespread systems. Requirement for entering initial data for the DSA is that the state of a system must be represented inside the multi-layer Matrix of square cells. The Matrix consists on many layers of variables and parameters. The DSA estimates all major processes in systems of any scale and any inner structure, and with a high spatial resolution. The governing exterior factors and interior processes determine an order of calculation of all moves. Each ONES has own complex of processes determining own methods of calculation – the Genetic Coding (Klenov, 1987) writes a system in form of dual multi-dimension string, and the Genetic Matrixes, estimating flows by the repeated scanning (Klenov, 1999a, 2003). For the Coastal Zone system was worked out the method of 'oblique' scanning, being in accordance with changeable direction of winds. For various tasks were worked out numerical schemes having relevant functions to governing processes. For example, oil spills diffusion over water surface under influence of any direction and power of winds and currents was calculated by special algorithms. The Genetic Coding was used for continual evaluations of toxic and oil pollution in river nets of any configuration.

The Moving Digital Earth

The join of the Virtual Systems with the Digital Earth (DE) technology is the Moving Digital Earth (MDE). The MDE must use incessant source of real time remote sensing 2D data, observed by the DE (Hiromochi Fukui, 2003), and by corresponding observations on the Earth. The primary goal of the MDE is to continually estimate processes in Earth Systems, what is equivalent to monitoring of an area on the Earth as a compound of Nature Systems. The key property of the MDE is that it transforms **only** the observed (Past) data or the current state of a nature system. Nature systems convert exterior power from neighboring nature systems to complex of flows. The external systems for the Earth systems are the Meteorology, Oceanology, and Geophysics systems with own disastrous processes.

The interface for computer mapping was elaborated primary for DOS versions and later was reforming for the expanded WINDOWS versions on the Compaq Visual Fortran. This jump multiply increases efficiency and belongings of the MDE because of a high sensitivity for large areas. On other hand, it requires that computers must as powerful as possible for the reason that requirement to computer sources increases non-linearly with enlargement of the Matrix size, resolution, and number of layers. Moreover, nonlinearly grows up deficiency of 2D distributed parameters. Input of exterior powering data (precipitation et al.) also seems as insufficient for the required resolution for small important details of a relief (valley beds, narrow ravines) will be sensed. For vast areas in a continental scale, even most powerful computers may be weak. Other problems are security, high cost, express communications, etc. The potential of the DSA now outstrips the real state of the MDE.

Both Nature and Virtual Systems delay own respond on outer power

The MDE uses **only a** Past data (what is the current state of a System or their join. The main product of the MDE is the incessant multi-purpose computer mapping. The retard of natural systems on exterior pressure is their common property because of restricted velocity of processes. If any area was observed by the DE just **before** initiation of a disaster then the MDE estimates a system state ahead, to receive a map **after** initiation of the disaster. The MDE outstrips response of the Nature System and continually shows it nearest future. It is the major foundation for estimation and recognition of disasters **before** its beginning in realty, only through rapid calculation of all flows. This physical effect must be used in practice as irreplaceable opportunity for urgent human response, for prevention of losses. It should stimulate incessant inflow and reforming of 2D multi-layer information instead of it storage.

The MDE is the technology for outstripping regional monitoring of hazardous events in any site of the area. It is supported by own system of automatic recognition of disastrous processes. The MDE includes also express delivery of information wares to people, and a lot of other functions. The obligatory order is that a time for reforming of a data to outstripping mapping must be less then the next step data arrival. Then the MDE has the irreplaceable skill for the prediction of imminent or sudden crisis. The predicted time depends on time step duration and on the time for data transfer. The conditions for persistence for more steps ahead are not yet discussed here. The criterion of the MDE efficiency is the time between the getting and reforming of Information before the next step observation. Then the 'Information Factory' will be de facto turned into the 'Information Time Machine'.

THE EXPERIENCES ON THE VIRTUAL SYSTEMS

The Digital Systems Analysis was worked out on a base of a field experience and by computing of processes with a spatial resolution provided by DOS or Windows OS, by programming on FORTRAN. Formerly, sources of major exterior factors include only a few gauges on hydrology and meteorology data. For the former Matrix operations, the precipitation records from gauges were stretched on a whole area. The local measured meteorology data were also stretched on relevant layers with corrections for a local altitude. The real-time 2D data were inaccessible. Now, in the age of the Digital Earth technology the required are vast flows of 2D remote sensing data as a source for the Information Machine.

The DSA step-by-step estimates water/mass/energy exchange between all neighbor cells of an area. The area must be set inside the Matrix to avoid missing balance of interactions with neighboring earth systems. The dimension of a Matrix lies between 100*100 cells in DOS and 1000*1000 and more cells in the Windows OS. The includes about 12-20 layers as follows: elevation, summary or current changes of elevation, sediments, pollution, water, snow, glaciers, soil resistance, infiltration, water delay, air temperature, underground water layers, aquifer thickness, and others. It provides estimation of water, mass, and energy exchange between neighbor cells under influence of parameters in other layers. Every time step a most of layers is renewed. Those are Water, Air Temperature, Elevation Changes, Soil Resistance, and others. Various tasks may require for layers of transport nets, population density, engineering, land use, among others.

The Enliven Virtual Systems

All calculation of the DSA is done inside the layers and between layers. Each layer offers continual multi-layer mapping. For the purpose of overlapping of several selected layers is useful fast raster-vector reforming of selected layers to be displayed in contours. Every time step the computer image is smoothly rewritten by scanning, what makes effect of enliven image. Being estimates during regular mapping, the enliven contours map exists only on display and may by saved as an image at any current step. Below is the view (Figure 1) of the basin for a 501st day.

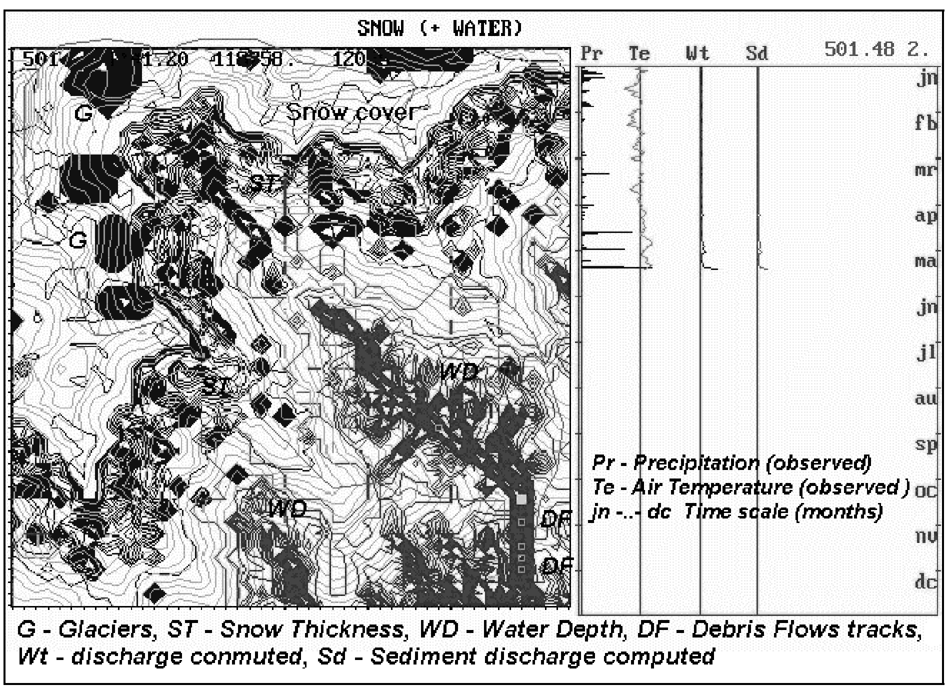

Figure 1. Continual daily step monitoring of the Cubasanty basin (Caucasus) by the DSA with a 100m resolution.

The extended DSA has ability for generation of debris-flows (Klenov, 2003). The velocity of flows sharply increases from 4-5 to 100 and more km/hour. In the former 'slow' versions of the DSA, water exchange between two neighbors can vary from 0 (reservoir) to 1 (full water exchange). Debris flows may cross over 10-50 and more cells per one time step. Such rapid flows are possible even in plain rivers after accidents of dams break by reservoirs overfilling or/and by terrorism. The case study in mountainous basin used meteorology records for 20 years with a daily step. For the selected year, the time step of observation of precipitation and air temperature was 3 hours. The continuous running of the Virtual Basin was resulted in initiation of debris flows after strong rains (through response of the whole area), after strong snow melt, and in other conditions, being assessed by the DSA independently. In a whole, response of a system on exterior impacts appears through complex response of a system, what it is a talent of the DSA. The comparison of dates for computed debris-flows with independently observed events was resulted in full coincidence of the events in date.

Scenarios of artificial dams setting, filling, and overfilling were resulted in failure of dams with catastrophic floods downstream. The Virtual Systems show their wide applicability for tasks of systems management and for estimation of long time consequences of a nature and human activity. The ground of disasters is a high energetic potential of a Nature System (steep slopes, convergence of streams), and as well conditions for the high erosion potential (strong storm, rapid snow melting, weathered rocks etc.). The simple comparison of graphics of exterior factors (precipitation) with a system's response shows time delay between impact and response (Figure 1), what resulted by DOS based generation of the DSA (Klenov, 2000). The latest generation of the Virtual Systems was re-written on the Visual Fortran language, with a high sensitivity on vast matrixes.

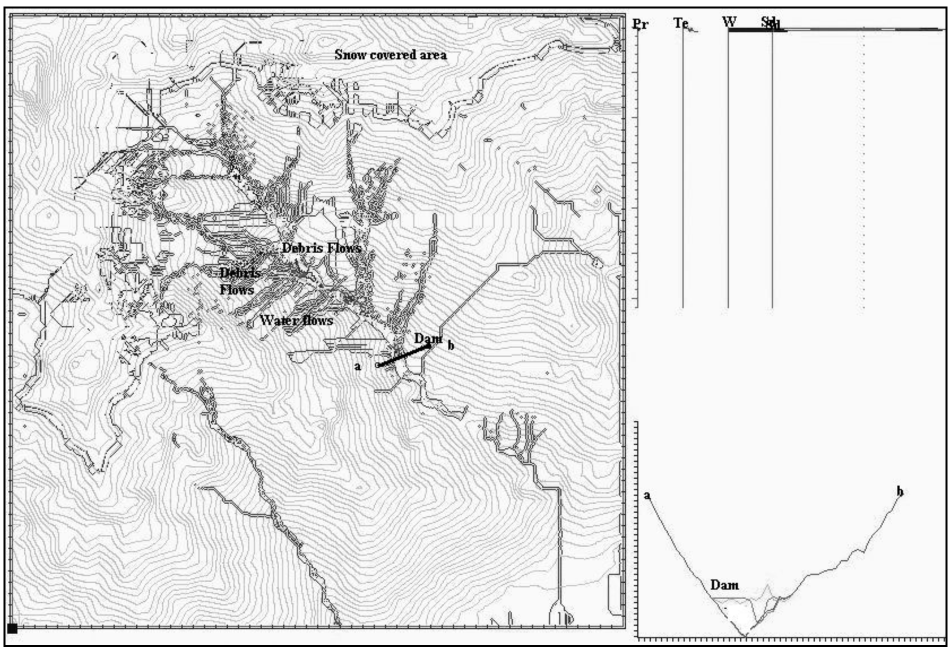

Figure 2. Scenario (with a 10m resolution) for activation of erosion and debris-flows after local storm upstream, where: Precipitation (Pr), Temperature (Te), computed Water discharge (Wt) and Sediment Discharge (Sd), 'Virtual' Dam (a-b), which being cut by debris-flows.

This is well known property of natural systems because of slow velocity of flows and a distance from rained area to any site downstream. If the DSA uses the Past data, then the Virtual System always estimates the 'next' Future. If the future is estimated **before** input of next step data, then computed map **outstrips** observation of an area. Otherwise, if the accidents reach destination sites during the current time step, then the DSA report and following warning also delay! It may happen if a time step of observation is too long, for example, for high-velocity debris-flows near the vulnerable sites. To avoid this kind of delay is necessity in smaller observation steps, or in incessant observation (Robert Laurini, oth. 2005, Timothy B. Love, 2005). Both real and virtual basins in mountains generate debris flows (Figure 2) with following non-stability of the flows, causing local erosion, sedimentation, origin and cutting of sediment jams. The tracks of debris-flows are estimated and set up with satisfactory spatial resolution. Computed debris-flows tracks are shown over a recent image and are colored in dependence of the flows velocity (Klenov, 2003).

Several studies were implied, verified, and sometimes validated for river basins in scales from local to sub-continental (Klenov, 2000). In the case of a small tributary of the Moscow river (10 m resolution) (Klenov, 1999b), were computed and compared scenarios for watershed protection against human activated erosion. In the case of the Moscow River, with a 1 km resolution was estimated and satisfactory validated 20 years daily discharge (Klenov, 2000b), with corresponding satisfactory assessment of floods. The DSA was also implied for several gulfs in the Japan Sea, for assessment of marine farms stability against wind-wave storms. In experience on shallow Asov was assessed influence of storms on filling up submarine by sediment flows. The sub-continental Virtual System links the whole river Rhine Basin with its Delta, and the nearby Coastal Zone for scenario based evaluation of long-lasting catastrophic floods (Klenov, 1999b). For the purpose were computed changes and oscillations of a sea level, local storms in a basin, fast snow-melt, and others. Influence of tectonic deformations in the basin and setting of dams was also computed. Most of the tasks were not offered by data, but was verified by non-direct data. The scenarios are effective for study of human influences (dams building, land use policy, marine agriculture, and others) on the environment.

Response of the Virtual Basin on Earthquakes

The DSA can estimate meteorological and tectonic powers, which both simultaneously change the earth surface. The tectonics happens in any plain and mountainous basins. It has a variety of plane structure and a varied velocity. In a regions with a high seismic activity soil resistance decreases after seismic shocks. It provokes landslides and debris-flows. They may form stony dams as potential sources of disasters to be happened later, after overfilling of reservoirs. The measured data on earth surface distort are usually in deficiency what require regular measurements (Moutaz Dalati, 2005). Because of a data deficiency, the research of nature systems exploits artificial scenarios.

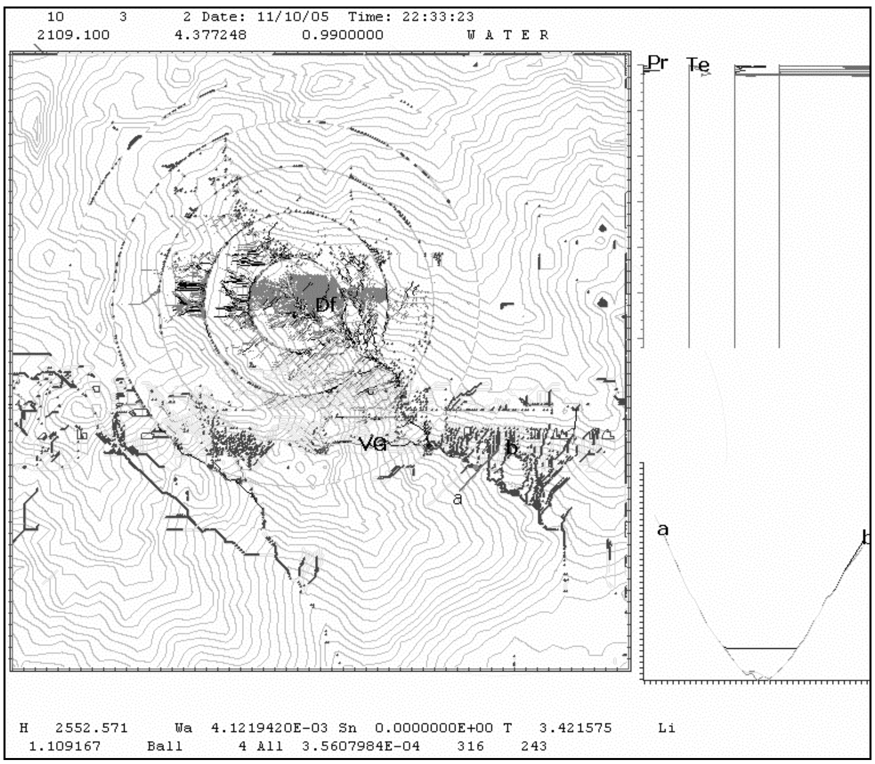

Figure 3. Scenario of debris-flows activation in the epicenter of earthquake with earth surface distorts and soil resistance reduces, where: on the bottom – current data for the Virtual Gauge (VG): H-Elevation, Wa -Water depth, T-Air Temperature, Li –Soil resistance, Ball - power of earthquake, All – Sediment thickness. Other signs are the same as on Figure 2.

For the purpose was prepared high resolution Matrix with a size about 600*600 cells (Figure 3), with 10m per pixel resolution. This is enough sensitive to see small details of valley bed (flood plain, terraces, streams, steeps, et al.). The basin is the same as used in the DOS version (Klenov, 2003), but is not yet provided by distributed parameters. The new task of the case study is to search response of the system on active faults, and on earthquake shocks. The artificial case study uses field experience in the same and other regions. The conditions of the numerical experiment are as follows:

- Zone of faults is crossing the area with some parallel faults and blocks, where faults correspond with earth crust differential movements.

- Earthquake with small deepness of hypocenter forms several zones with balls from 2 to 6. Seismic shocks cause destruct rocks integrity and make easy response of surface flows to adaptation for faults by erosion pattern.
- Earthquake shock decreases for short time slope sediments immovability.
- Earthquake and rapid tectonic deformations provoke debris-flows and activation of erosion along faults.

The linear faulting zone forms a row of sub-parallel cracks. The bordering epicenter is identified by many arks of streams around it, tentatively computed as circle blocks upraise. Commonly, every structure of fresh faults and earthquakes is detected by particular structure of flows, because faults were cleared up by erosion. The aim for the Future is to recognize a site, area, and time (simultaneously) of **future** earthquake by timely recognition of earth surface deformations (even without faults). The decision requires also for data on concentration of small earthquakes, data on radon outlet trends, and other predictors. Unfortunately, the data are now in deficiency or/and inaccessibility. The real task for the DSA is the monitoring of earth crust deformations by specific pattern of erosion processes on the phone of others erosion processes. The above discussed Virtual Systems are not yet complete MDE because of they are not supplied by real-time flows of necessary data.

The Meteorology and Geophysics powers are both determine evolution and dynamics of Earth nature systems. Their influences are counteractive. Their part in the nature systems is usually indivisible. Now, it seems, they may be divisible by the DSA and Virtual Systems, by history scenarios.

CONCLUSIONS

The three components of the MDE technology are as follows:

- The Digital System's Analysis and following Virtual Systems for a ground and coastal areas.
- The continued supply of Virtual Systems by remote and land observed data on meteorology and tectonics.
- The MDE running by rapid reforming of the information 'flow' by regional Virtual Systems for repeated estimation and multi-layer mapping of major processes, for recognition of impending disasters. 19

The summary (active and hidden) energy of a system is determined by the system's current state. Moving to the Future, an influence of the Future influences has a nonlinear or stochastic trend to increase. The data on the future exterior pressure are not offered by meteorology and seismology with a satisfactory resolution. Therefore, the long time forecasting depends on supposed influences. It is really used by established scenarios, based on statistics. But statistics for former rare events is always insufficient.

The former Meteorology and Geophysics events being before human's regular observation, can't be restored with necessary regularity because of Information Loss (IL) does not let to directly restore the far Past by any natural records (sediments, terraces et al.). The also IL distorts natural records by making false trends (Klenov, 1983). Otherwise, the ONES never forget own Past, which is condensed not in natural records, but in the System as a whole, and moreover in the structure of a relief. Automatic extraction for the Past needs to DSA running 'Ahead to the Past', what needs a giant computer sources, with an expectation but without assurance of success (Klenov, 1987). Otherwise, the short time view in the Future is reliable for the MDE. The MDE is the Project giving a chance to 'see' the nearest Future of any area. The conditions for the Project implementation were discussed above.

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