# Moving Digital Earth for Disasters Management

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## SUMMARY

*Moving Digital Earth (MDE) is the computer complex, which must couple earth and remote information to estimation of environmental flows through any area. The objective of the MDE is multi - objective regional monitoring. The primary objects of monitoring are natural processes in earth and coastal systems for early recognition and management of hazardous events: Floods, Debris Flows and others. The technology of Moving Digital Earth is the continual calculation of water/sediment flows by reforming of 2D meteorology information by simulation models. The MDE provides estimation/recognition of events initiation in any site(s) of any area, estimates tracking of hazardous accidents for urgent prediction and warning. The processes become visible and enliven by corresponding computer mapping of the area. Besides, the MDE opens a way for evaluation of scenarios for forecasting and mitigation of disasters.*

**KEYWORDS:** *Simulation, mapping, basin, coastal zone, monitoring, management, disaster, flood, debris flow*

## INTRODUCTION

The technology of the Digital Earth is based on Remote Sensing and Internet GIS for the purpose of real-time monitoring, database interoperability and dynamic simulation technology, among others (Hiromichi, 2003). Simulation models are widespread and various (Dayong and others, 2003). The next Moving Digital Earth (MDE) technology is looked as a group of 2D simulation models for Natural Systems (basin, coastal zone and others), which is a brunch of the Digital Earth. The MDE looks like a 'factory', which processes enormous flows of space information to new 'manufactured goods', i.e. to new information. The family of 2D Simulation Models produces new knowledge about processes in earth systems and especially of hazardous processes. This is in major a task for urgent perceiving, fast tracking, and prognosis of disasters spread. Other function of the MDE is to maintain a multi-objective management of natural systems by incessant monitoring. Main aims of the management are recognition, forecasting, and mitigation of disasters. The MDE is looked as acting computer doubles of natural systems with many functions and possibilities. All future installations of the MDE for any region will be available for lengthy multi-objective exploit

The MDE deals with earth nature systems in its 'computer doubles', which are as follows: river basins of any scale and any inner structure, any part of coastal zone of a sea, and a coupled system of an earth area and a nearby coastal zone. Other natural systems: glacial, marine, desert, and others should be integrated in the MDE as soon as simulation models will be worked out in similar principles. Properties for the Moving Digital Earth are discussed on the base of field observation and computing experience. All models transform natural and human external pressure/impact to flows and interactions inside the systems (Klenov, 2003a, 2003b, 2003c). The MDE is offered by parallel mapping during non-stop simulation process.

Goals for the computer simulation of an area (region) are various. The first group of applications is accompaniment and surveying of regional monitoring of the Earth. It may be assessment of erosion/accumulation processes; estimation of pollution spread, among others. The second groups of applications are the followings: self-recognition (by the MDE), tracking and forecasting of disastrous processes. The discussed is experience with several simulation models (as proposed components of the future MDE), and demands for new generation of models. Discussed are as follows: (1) plane structure on simulated area, (2) properties for the MDE, (3) installations of the MDE, (3) goals for computer monitoring, (4) problems for disasters monitoring and management.

## PLANE STRUCTURE OF SIMULATED AREA

River basin(s) and Coastal Zone are natural systems, which organize all water and related flows through an area. Operational unit of 2D Simulation Model is a multi-layer grid of square cells. A grid cell must be as small as desired to provide necessary spatial resolution. One or several operated basins (**B**) must be included in common grid (**A**) for the complete evaluation of flows in the region. The areas in **B** may be of any complexity, because all flows are self-organised for several natural systems (basin). The interested region (**C**) must be completely included in area **B**. Grid **A** is operational unit, when all flows in basins are calculated by the MDE. Grid **C** is any selected interested area (figure 1).

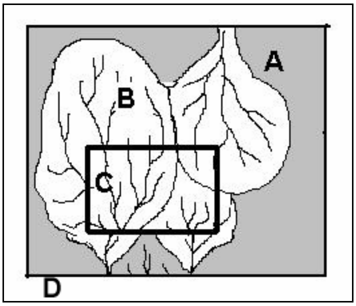


*Figure 1.* The place of simulated area **B** in a grid **A**, **C –** interested area, D- common grid

## PROPERTIES FOR THE MOVING DIGITAL EARTH

The Moving Digital Earth is an instrument for continual estimation and synchronized mapping of water, mass and energy flows through an area. It uses several 2D simulation models of governing processes on the earth, and in coastal zone of a sea. Those are River Basin Simulation Model (Klenov, 2003a), Coastal Zone Simulation Model (CZSM), Debris Flow Simulation Model (Klenov, 2003b), and simulation model of the system: River Basin - Delta (Estuary) - Coastal zone (RIDEC).

The properties of the MDE are as follows:

- 2D simulation models deal with multi-dimensional grid (of square cells) of variables and parameters by reforming of external meteorological ‘information flows’ and by control of several parameters to flows of water, mass, energy, pollution, etc. The models operate as integrated complex under active/passive interactions between many layers: elevation, water, snow, sediment, pollution, several layers of soil properties, and several layers of underground flows.
- The SM operates in non-stop repeating of calculation cycles over a grid. Regular input of external data is obligatory as a ‘food’ for the models. Under de-facto insufficient information, models can operate with artificial data and with any tentative scenarios.

- The current state of operated are (several grids of data, variables, and parameters) are used for evaluation of the next and following steps with corresponding computer mapping of selected area (figure 1) and for selected layers. In the context of the above-mentioned tasks estimated are 'water' layers (water depth, discharge, snow depth) and layer of erosion/sedimentation pattern. The raster MDE uses fast procedure of raster-vector reforming of any selected layer to display a computer maps in contours. Full re-mapping at each step is done smoothly, by grid scanning through rewriting of each cell. Other grids are recalculated and stored in a grid form.
- The obligatory is preliminary reforming of all 2D information layers to digital grids of square cells with corresponding resolution. Relevant vector maps from other sources (GIS, databases, servers) must be also reformed to the grids (geology, soil and others).
- The assets and peculiarity of each model depends on governing processes in a system under investigation. The RBSM external drivers are both precipitation and air temperature, which activate 'water flows' (through simulated area) and related processes. The DFSM estimates slow and high velocity move of water and of loaded matter, and recognise thresholds conditions. The CZSM driver is wind-wave energy of any power/direction, and currents, which both activate processes of bottom and shore abrasion and sedimentation under any plane configuration of the coastline and structure of bathymetry. Various versions of the RIDEC units the RBSM and the CZSM and calculates water-sediment flows inside subsystems and even through coastline. In spite the obvious complexity of each system, the models were worked out to be as simple and reliable as possible due taking into account of governing external drivers for leading processes, by geomorphology experience. The self-selection and even overlapping of governing land or sea processes is a skill of the RIDEC.
- The RBSM was applied for areas of scales from local to sub-continental (the Rhine basin). The RBSM was satisfactory validated for case studies, which were provided by meteorological records for assessment of flows, and by available long time hydrology records for the purpose of calibration and validation. In other case, the DFSM was validated partially. The RIDEC and the CZSM were satisfactory verified and applied even by deficiency of data.
- Each installation of above models makes the acting computer double of any area, for a lot of multi-purpose tasks for computer assisted monitoring and management of an area.

## INSTALLATION OF THE MDE

Installation and start of any model from the MDE has several steps. The first step is input of topography grid for the area **A** (figure 1). The grid dimension in new generation of the MDE may exceed 1000*1000 cells (until virtual memory permits). Cell size is established by task demands, and it may be even one pixel. A cell scale depends on size of computed area, and may be between 10 – 100 (1000) meters for local, regional and sub-continental scale accordingly. The second is quantification and input of distributed parameters: soil resistance to erosion, infiltration coefficients, sediments thickness, surface of underground basins, parameters of water flows through catchments, among others. For the CZSM necessary is bathymetry of a coastal zone or reservoirs. If a dam (channel) exists, required is to input location, height, strength, etc.

The installed model is initially 'dry'. To receive the initial state for MDE run, all dry bodies must be 'filled' by water (river net and reservoirs). Water enables to 'flow' inside a model, enables to 'fill up' reservoirs and even to destroy weak strength dams by overflow. During the self-adaptation, river net and coastal zone are gradually self-organized according to topography, to similarity to real prototypes, to minimize influence of digitalisation. During the 'prehistory', a roughness of topography along streams may is grinded. The resulted state of a system installation is saved initial files in view to forever multiple exploit. Because of any system responses not only for current influence, but remembers own history, it is necessary let the model to work with former records. For example, for modelling of debris flows must be taken into account spatial distribution and thickness of all snow cover in a basin and other information about the past. Therefore, for successful work of the MDE are necessary continual inflows of meteorology drivers (precipitation and temperature) through former seasons of current year and may be in duration of many years. It is because a nature system usually has a long time response, for example, by surface/underground water exchange.

## GOALS FOR COMPUTER MONITORING

(1) The main goal is monitoring of disasters in view to recognition of the accidents by the MDE. The core benefit of the MDE is recognition (through estimation) of floods and debris flows in any number and locations inside a protected area, in a one or/and some nearby river basins. (2) The next is fast assessment of accidents moving downstream. The fast computer tracking grants urgent forecasting and initialises warning/alarm systems. (3) The third is monitoring of disasters in correlation with forecasting of meteorology prognosis ahead from the Present to the Future. (4) The forth goal is mitigation of accidents by urgent activation of beforehand-organized actions. (5) The fifth goal is monitoring of main interacting processes in an area as follows: spatial-temporal dynamics of water resources, management of non-equilibrium systems, and a system management in innumerable tasks of engineering, and land use. (6) The sixth is long time mitigation policy. The MDE affords support for mitigation and decision support by multiple estimations of a lot of scenarios of accidents in view to evaluate the most rapid response in real case. The major problem for efficient (with any criteria of validity) long time forecasting of disasters is that sustainable management in principle cannot be reliably applied to a Non-Equilibrium Opened System (ONES), to what most natural systems belong. Response of an ONES on natural/human pressure is in principle non-predicable due initiation of unpredictable thresholds and disastrous processes, and due unpredictable response of the systems on human activity (to what belongs also mitigation).

## DISASTERS MONITORING AND MANAGEMENT

The MDE repeats full scanning of an area at every time step for identification of sites with initiation of hazardous processes. Oscillations of air temperature and precipitations lead to non-synchronized spatial oscillations of water discharge and water velocity, and to local concentration of dangerous flows. It is not a problem for the MDE to estimate the flows in affects of above mentioned factors, and with assessment of snow fall/melt, evaporation, precipitation infiltration and other processes. Local or regional concentrations of water/sediment flows under meteorology, hydrology and geomorphology conditions initiate local or regional accidents and disasters. The MDE however enables to detect initiation of disaster with varied plumage by ability to fast calculation of processes.

It is the necessity to improve ability of models for self-recognition of dangerous events without missing or false by training. It may be done by use of long time meteorology records and by comparison of computed (meteorology data) and independently observed (hydrology data) discharge and dangerous events (debris flows and floods). The period of training should be in duration for several years with a time step as small as desired. Blanks in the records distort results of computing. One part of records must be used for calibration of parameters, and other part – for continual computing by regular (monthly or annual) statistical assessment of the validity. The validated model becomes reliable for the monitoring, and for fast forecasting of disasters moving through an area. Monitoring should include permanent checking of validity and for optimisation of parameters by corresponding statistics.

The temporal step of indivisible monitoring/mapping is essential especially for local scale of an area, because of debris-flow and floods spread a valley swiftly. The step of data input must be less, then time of destination of disaster to critical sites (population and building). In the acting MDE must be foreseen forewarning system. This system for automatically perceives location of events upstream and evaluates destination time to protected sites. The task became complicated if hazardous event appears nearby vital sites to be warned.

Recognition and tracking of flood depends on a basin scale. For the large basins, destination time may be varied from several days to several weeks, and it may be easily tracked. However, it is necessary to take in account loss of the water in a basin under air temperature rise, what decrease a danger. Rise of air temperature causes increasing of evaporation in a basin and self-mitigation of a moving flood. On the contrary, cool weather and additional precipitation nonlinearly increases a danger to cause long time disastrous flood. Therefore, it is necessary continual correction of outstripping forecasting. In smaller areas, local storms cause strong suddenly local floods and debris flows (Klenov, 2003b), which may be estimated and recognised early in any site, under condition of valid distributed meteorology data.

Continual mapping follows the monitoring as irreplaceable part of a management. The mapping assists remote 'visualization' of a real region. The remote 'visualisation' of an area includes 'remote self-recognition' of disastrous flows. The MDE enables to compute alternative scenarios of future weather changes for the purpose to determine the corridor of decisions, or, by other words, to assess risk of disaster. Particularly, continual computing of snow cover during a winter provides forecasting of snowmelt floods.

Calculation of water/mass flows through an area requires for corresponding 'information flows'. A regular space data on distributed meteorology is basic for the MDE for both monitoring and management. The technical problem is to unit necessary data to single multi-dimensional and multi-layer flow to be compatible with a model in coordinate system, resolution and formats of data. The former 2D meteorology/hydrology records for a validation must be kept in servers. Only powerful computers afford fast reforming of information, which cover an area with a high resolution. The organization of the continual monitoring includes the followings:

1. Input and testing of elevation grid of the area. The resolution of the grid determines resolution of all other layers. The correlated size and resolution of grid must offer evaluation of flows with a satisfactory resolution in view the computing system to be efficient.

2. The several layers of soil properties and conditions of water flows and data on meteorology are to be digitally presented with necessary resolution.

3. In the case of data deficiency, the MDE should be studied on artificial examples. On the case, the initial state is non-eroded slope with a single top, and nearby piedmont (figure 2) located inside a grid with one cell resolution. The area was affected by disastrous local storm. Down slope flows resulted in (unexpected) continual process of debris flow on the piedmont. Different colours on moving map designate streams velocity. The debris flow zone looks in move like a 'fire' area. The intensive debris - flows process was recognized not in the site of initial heavy impact, but at a remote bottom of slope. Expected is that external impact will cause composite and unexpected effects.

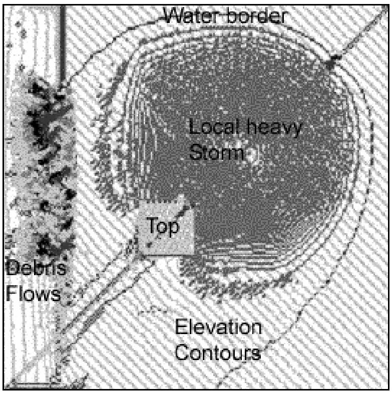


*Figure 2.* Artificial simulation of a slope response on heavy storm.

Moreover, monitoring and management is also applicable for disastrous flows of contamination through an area both in river basins and in coastal zone. It is also foreseen calculation of surface and underground water flows, both fresh and contaminated. Water resources in an area are continuously calculated and classified by quality and by quantity. Response of water habitat is foreseen by estimation of concentration of venomous substances in process biotic loss/restoration. The mitigation disasters include, for example, self-regulation of reservoir stairs for any tentative locations of dams, and consequences of dam failure.

## CONCLUSIONS

The simulation modelling is at the bottom a regular calculation of water/matter/energy flows through an area, and is a calculation of all interactions between governing components of the complex natural system. Expanded and united RBSM seems to be reliable tool for regional computer monitoring. The continual working of the computer double (with a minor step as small as necessary) is necessary because it permits to follow spatial-temporal dynamics of earth systems. The MDE is effective in recognition for hazardous flows in basins of any structure and under any spatial pattern of precipitation.

The MDE cannot be widely applied until information flows will be completed continually. Last years become possible to use multi-layer satellite data (Annoni and others, 2003, Stevens and others, 2003). Strong information flows into and through the MDE enable to exclude information not only directly observed by remote sensing but also evaluated as follows: pollution flows in water bodies, underground flows, and water discharge distribution over an area, bottom processes in coastal zone, and others. For the success, the information formats must re reformed to coincide with the MDE ones, and must be synchronized. Under these necessary conditions it is possible enhancing of self-perceiving and tracking of disasters.

The MDE maintains regular estimation for statistic criteria of the MDE accuracy. The initial data for simulation is information flow of precipitation and air temperature. The data for a checking are independently observed water/sediment flows. The permanent checking follows permanent forecasting of hazardous flows. If the 'real time' self-perceiving of growing disasters is reliable, but forecasting of disasters spread through an area contains uncertainties. Prediction an area response on external impact and on management faces not predicable response due properties of unstable system. A response of a system in management action depends on site and scale of the action. A way for management of disasters in opened un-equilibrium systems may be by estimation of multiple scenarios of system's response. The resulted should be a corridor of responses, which is widening in the future. The final task is statistical assessment of most probable response.

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