Monitoring Grid Coordinates Changes Model as a Base for Dynamic Digital Cadastre System

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Key words: Legal digital cadastre, Dynamic Cadastre, Crustal deformation model, prediction values, Geostatistics interpolation, Collocation, Kriging, variogram, covariance.

SUMMARY

In Legal Digital Cadastre (LDC) system the coordinates of the boundary points intend to be the main legal evidence in court. As long as the points are constant and the national grid parameters are immutable, the national grid coordinates of the boundary points remain stable relatively to the accuracy level declared by the LDC database. In countries with tectonic movements the coordinates of instability points discontinue describing its correct position after a specific period of time; this could be an obstacle for establishing LDC

As an appropriate solution, the LDC system has to have a *dynamic* nature. Any dynamic system may need a continuous maintenance process over time. In LDC system, the maintenance process aims to keep the boundary point coordinates database continually updated.

Fulfilling this maintenance successfully may be done by using such a monitoring grid coordinate's changes model – MCCM. The main functions of MCCM are to describe the changes of the boundary point's coordinates, and support its corrections in every era. Coordinates changes may be caused by crustal deformations as well as by any changes of the grid parameters definitions. Basically, Crustal deformations are the main cause of changing the cadastral boundary point's coordinates in the national grid. Geodetic monitoring of every boundary point may be needed to calculate the grid coordinates corrections. However, such process is not an economical solution at all. Thus, the MCCM uses the continuous observations of the permanent GPS control stations and periodic measurements of geodynamic control network, in order to predict the grid coordinates corrections of every boundary point in every period of time.

The use of MCCM for LDC is presented in the paper. The Kriging and Collocation prediction methods are used to evaluate the corrections of coordinates and its standard deviation errors cleverly. The paper emphasizes the advantages and the disadvantages of the two prediction methods by executing two experimentations; one of which is in Israel and the other in Japan, where both countries are exposed to tectonic movements.

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1. INTRODUCTION

During the last decades, the professional cadastre communities, all over the world, have been gathering efforts for transforming their cadastral system to legal digital cadastre - LDC.
In LDC system, the coordinates of the boundary point intend to be the main legal proof in court.

In the era of cadastral systems which are based on Torrence method (Dale, 1976), the method of reinstating the cadastral boundaries uses the authentic measurements described in the measurement field book for building the skeleton of the cadastral entities; parcels and blocks. The main two disadvantages in this process are; low accuracy of old measurements and a historical national horizontal grid, which suffered from high inhomogeneity and low relative accuracy. This problem caused low and inhomogeneous accuracy in the cadastral systems.
Thus, survey agencies have worked very hard to improve the national control grid quality, and every period of time they are putting a lot of efforts to upgrade it. Upgrading process accompanies with several changes, such as datum definition, grid origin and projection method. For example, in Israel, in 1998, Survey of Israel (SOI) upgraded the Israeli national control grid from an old grid, which based on Casini-Soldner projection to a new grid based on transverse Mercator projection. The Israel Transverse Mercator (ITM) grid has a different datum definition comparison with the old grid datum In October 2005, SOI decided that the Israeli geodetic control network will base on an array of GPS reference station. A new datum, called IGD05 – Israel Geodetic Datum 2005, was set for these permanent GPS stations (Steinberg and Even-Tzur, 2005).
Consequently, boundaries point’s coordinates change when the country upgrades its national grid. Therefore, in the era of LDC, the coordinates might be changed in every upgraded grid.

Additionally, when boundary points move physically due to crustal movements, for example, their coordinates also change. Therefore, countries with tectonic movements and crustal deformations are always exposed to changing process of their national grid coordinates. Usually, those countries establish geodynamic networks to assess the dimension of the problem.

Therefore, in the future, the LDC system might fail in describing the position of cadastral points by their origin coordinates which are being saved in the system database today.

2. DYNAMIC CADASTRE SYSTEM AS A POSSIBLE SOLUTION

Generally, licensed surveyors are used to look for authentic cadastral points in the cadastral project area which were measured and documented in the measurements field books.

Surveyor has to measure these points and link them to the current national grid for computing transformation parameters from the authentic grid coordinates values to the up-to-dated one. This process sounds useful if surveyors managed to find adequate cadastral authentic points. Unfortunately, authentic points are being destroyed with time; it is rarely to find them today. Thus, this transformation process is not essential enough for doing the job reliably.

On the one hand, such a transformation process could serve the future LDC to survive. On the other hand, using this solution make no sense for transforming the current cadastre system to LDC system, since, we loose the main advantage of the LDC which aims to support final boundary points' coordinates immediately.
Therefore, our ultimate goal is to support the "correct" coordinates in the current national grid of the real state boundaries at the same reinstating query time, without the intervention of licensed surveyors. This goal is considered superior because of many advantages, for example; it enables professional user, such as architects and zoning engineers, to obtain legal boundaries' maps which prevent legal problems in the future. Furthermore, without achieving this goal, LDC system could not support any legal cadastral queries by using the world wide internet or any digital automatic cadastral application.

To solve this issue without loosing the above ultimate goal, we can learn the principle of the desired solution from those related to the current one achieved by the described transformation method. Calculating up-to-date coordinates by transformation method, in the era of LDC means that every point's coordinates have an expiration time. In other terms, every point must have another dimension related to time.
This is the base of the solution which leads us to Dynamic Legal Digital Cadastre system.

The term Dynamic Cadastre was first mentioned by Blick and Grant (1997) as an appropriate solution of the LDC problem for dynamic nations, especially for New-Zealand. They also offer two different datum options: a semi-dynamic datum or a full-dynamic one to serve the cadastre system grid.
Full comparison between static, semi-dynamic and full-dynamic datum is detailed in a special document which was issued by the New Zealand Office of Surveyor-General, in 1998.

2.1 Preserving cadastral entity's properties

Whereas the dynamic LDC would base on semi or full dynamic system, it must include such a model that enables transforming the LDC database coordinates from one epoch (t^1) to other (t^2). This **m**odel aims to **m**onitor the grid **c**oordinates **c**hanges over the country surface - MCCM.
Furthermore, it must include several cadastral properties which are related to the human mind, zoning laws as well as conventional cadastral surveyors' regulations' rules. Some of the important properties which have been preserved since the Torrence cadastral method has been published at the end of the nineteenth century are:

- Preserving the boundary front's length measurements of the cadastral parcel. These measurements are considered accurate, since they are datum free measurements.
- Superior significance of physical evidence of boundary's point at the field in the court.

- Cadastral ordinance always aims to preserve the reliability of the measurements more than their accuracy.

Other properties are caused by the unknown and the low accuracy measurement level, which have been carried out during several decades ago, like the incompatible between the registered area of the cadastral parcel and its area calculated from the registered cadastral measurement. This properties' category is related to several disadvantages of the current graphical cadastre system, (a system based on measurements documentations). One of the targets of the future LDC system is to overcome this undesired property.

Taking into consideration the above desired properties, the MCCM could not function as the only method for transforming the cadastral boundaries coordinates for the updated national grid in use. This is because, authentic physical monuments in the field, may still be found, even if they are rare. Despite this fact, the MCCM will be the basic component in the future dynamic LDC.

3. MONITORING GRID COORDINATES CHANGES MODEL - MCCM

The great shortage of authentic points found in the fields, which become worst with time, increases the importance of the discussed model. Thus, it must be designed to do its job cleverly and reliably.

Technically, during the transformation process, using the MCCM or not, it is compulsory to preserve the shape of the cadastral parcels. Therefore, in such country regions, where there are no significant earth deformation movements, the dynamic LDC system would never permit a situation of incompatible between parcel fronts' measurements and those which are computed by coordinates, in order to keep on the shape of the cadastral parcels.

Accordingly, the MCCM main functions would be:

- Calculating national grid coordinates in time epoch t^2, when the input is national grid coordinates in time epoch t^1.
- Calculating the accuracy of the results. This should enable the future dynamic LDC to evaluate earth deformation movement occurrence correctly, for giving up the parcel shape preserving process.

In addition, the MCCM must be at national scale for supporting every point in the country area.

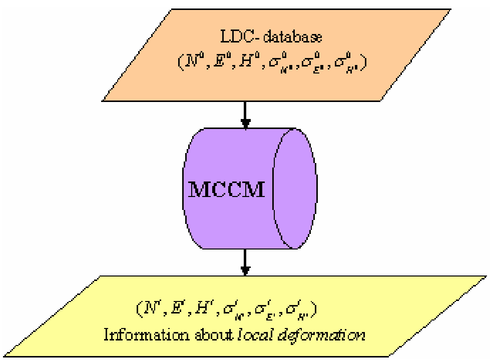


Figure 1: The MCCM main function description

3.1 Possible data sources for MCCM use

The MCCM has to make decisions according to geodetic data, which may assign specific geodetic information for calculating points coordinates' changes. Fulfilling this task needs execution of continuous deformation measurement series of representative network points', in specific time interval. Designing such network must be done taking into consideration geological aspects and physical tectonic deformation movement models, especially in dynamic countries.
The ultimate desired data base which might serve the MCCM for doing its job may be one of the coming data source or integration of them:

- Special geodynamic control network, which must be measured in specific time interval. The density of its points, their position on the country surface and the time interval of the measurements will be determined by geologic and geodetic experts. When establishing the network points, experts must consider high level of points' stability and surviving.
- Active Permanent GPS stations Network – APN, which could be the ideal input for the model, especially if the density and the position of the stations are sufficient for fulfilling the main MCCM task.
- Researches on evaluating physical deformation and earth deformations models around the country surface.

When a country decides to adopt one of the proposed data base measurements and input model, it has to decide taking into account the financial aspects beside the accuracy benefits.
The main disadvantage of such a geodynamic network is that the network's points are destroyed by time. But, on the other hand, the cost of measuring the network is cheap compared with such an APN stations array which has the same points' density of the geodynamic network. Despite this fact, countries with high earth deformation exposal might decide to enlarge the density of the APN stations for better geodynamic results. For example, the Japanese APN network named GEONET (GPS Earth Observation Network), which contains about 1000 GPS permanent stations (Takeshi et al, 2000).

Obviously, for optimizing the solution, the integration of the three data sources discussed above might be the preferable choice. The integration of dynamic physical movement models, derived from researches, inside the suggested model improves the reliability of the results, since they were proved physically.

3.2 Possible algorithms

Several researches have been carried out in order to evaluate and predict point displacements and velocities in dynamic countries resulted from crustal deformations' movements (Hager et al., 1991, Nikolaidis, 2002 Wdowinski et al, 2004). Correspondingly, automatic applications and software may be found at different websites in the internet. The most important and wide information could be found at http://www.ngs.noaa.gov/TOOLS website.

Despite these plentiful researches and applications, we could not manage to find such an algorithm or even application that may exactly suit the future dynamic LDC. This disagreement is a result of the facts that most of the deformation and displacements model researches and academic papers have concentrated:

- On the tectonic and physical motion model, whereas other factors may change the point positions cadastral grid coordinates' between epoch t^1 and t^2.
  These factors may be one, or a combination of the coming:
  1. Local deformations such as slop slides.
  2. Surveying methods and technologies improvements since the first time epoch to the desired one.
  3. Upgrading national grid definitions.
- On calculating displacements or velocities relative to a specific reference frame. While, most of the simple cadastre systems needs, depend on a national plane grid coordinates values: north and east.

Thus, most of the existed deformation models in every country will be an important part of the proposed MCCM components, but would not be the only one.

One can describe the final grid coordinates' changes $\Delta(E\text{or}N)^{Total}$, between two time epochs, of a cadastral point located in the country as:

$$\Delta(EorN)^{Total} = \Delta(EorN)^{Global} + \delta(EorN)^{Global} + \Delta(EorN)^{Local} + \delta(EorN)^{Local} + \Delta(EorN)^{Techno.} + \delta(EorN)^{Local} \qquad (1)$$

When,

$\Delta(EorN)^{Global}$ - East or North Coordinates difference as a result of global deformation model, which is a model of tectonic crustal deformation movement. Usually is based on APN.
$\Delta(EorN)^{Local}$ - Coordinates difference as a result of local deformations.
$\Delta(EorN)^{Techno.}$ - Coordinates difference as a result of surveying equipment technology and upgrading the grid definitions.
$\delta(EorN)$ - Errors and inaccuracies.

If we join all the errors' components together as well as combine the different components caused by the technology improvement to the local deformation component, since it is very difficult to model this component, the summarized equation could look like:

$$\Delta(EorN)^{Total} = \Delta(EorN)^{Global} + \delta(EorN)^{Global} + \Delta(EorN)^{Local} + \delta(EorN)^{Local} \qquad (2)$$

Our ultimate goal is to describe the final desired boundary point coordinates' changes in the projection grid between two times epochs 'to' (time of measuring the points) and 'tw' (the wanted time)- $BP^{Total}(\Delta N, \Delta E, \Delta H)^{tw-to}_{\Pr ojection}$. According to equation (2), this desired quantity may be described as:

$$BP^{Total}(\Delta N,\Delta E,\Delta H)^{tw-to}_{\Pr ojection} = BP^{Local}(\Delta N,\Delta E,\Delta H)^{tw-to}_{\Pr ojection} + BP^{Global}(\Delta N,\Delta E,\Delta H)^{tw-to}_{\Pr ojection} + \delta \quad (3)$$

On the one hand, calculating the component $BP^{Global}(\Delta N,\Delta E,\Delta H)^{tw-to}_{\Pr ojection}$ would not be a problematic mission, although it is related to a well known global motion model (tectonic and crustal deformation model). On the other hand calculating the other local component is a complex mission, since the only way to calculate it depends on representative points which have to be measured in specific time intervals. As we mentioned in the previous section these representative points establishes the Geodynamic Network – GN. Thus, if we assign the GN local component of equation (3) by 'GN^{Local}', we can describe the local component of equation (3) by equation (4):

$$BP^{Local}(\Delta N,\Delta E,\Delta H)^{tw-to}_{\Pr ojection} = Function\left(sets(GN^{Local}(\Delta N,\Delta E,\Delta H)^{t_i-t_{i-1}}_{\Pr ojection}), Global\_Motion \right) \quad (4)$$

This equation clarifies the role of such a global motion model for achieving desired results, and it emphasizes that there may be several sets of measurement time epochs of the GN.
The assignment $GN^{Local}(\Delta N,\Delta E,\Delta H)^{t_i-t_{i-1}}_{\Pr ojection}$ describes the projection coordinates changes of the geodynamic network points form the 't_{i-1}' measured time epoch to the sequence time epoch 't_i'. The MCCM must be able to use methods for computing the two main components of equation (4); $GN^{Local}(\Delta N,\Delta E,\Delta H)^{t_i-t_{i-1}}_{\Pr ojection}$ and such a global motion model.

According to equation (2) it is obvious that the "local" coordinates changes $GN^{Local}(\Delta N,\Delta E,\Delta H)^{t_i-t_{i-1}}_{\Pr ojection}$ is a result of subtracting the changes of the coordinates resulted from the global motion model from the final total changes values. Equation (5) describes this expression:

$$GN^{Local}(\Delta N,\Delta E,\Delta H)^{t_{last}-t_0}_{\Pr ojection} = GN^{Total}(\Delta N,\Delta E,\Delta H)^{t_{last}-t_0}_{\Pr ojection} - GN^{Global}(\Delta N,\Delta E,\Delta H)^{t_{last}-t_0}_{\Pr ojection} \quad (5)$$

On the one hand, the final total coordinates changes $GN^{Total}(\Delta N,\Delta E,\Delta H)^{t_{last}-t_0}_{\Pr ojection}$ could trivially be calculated, directly from subtracting the geodynamic network points' coordinates in both time epochs, after linking them to the APN, using the formal transformation method described by the survey agency of the country. On the other hand, the process of producing the global component $GN^{Global}(\Delta N,\Delta E,\Delta H)^{t_{last}-t_0}_{\Pr ojection}$ is not a trivial one.

Notice that the desired coordinates are given in the national grid of the cadastral system, whereas the global motion component which is based on the APN datum usually uses geodetic coordinates: latitude, longitude and altitude (φ,λ,h) in a specific reference frame. In addition, in dynamic nations, the APN datum may be upgraded from time to time. Thus, in order to model the global coordinates' changes quantities, it is preferable that the MCCM use the international ITRF datum as a base for the global coordinates changes model which could

be derived from a specific research.
The flowchart in Figure 2 illustrates a possible algorithm for computing the global coordinates' changes quantities of the geodynamic network points. Geodynamic network point is assigned in 'GN' and it is the input of the prediction interpolation process to predict unmeasured desired points coordinates' changes.

According to the suggested flowchart, the geodynamic network points are measured every period of time t. Let us assign the geodetic coordinates points, measured in time epoch t^1 by $GN^{Measured}(\varphi,\lambda,h)^{t1}_{ITRF}$. Since they are measured, it is easy to link them to the ITRF datum.

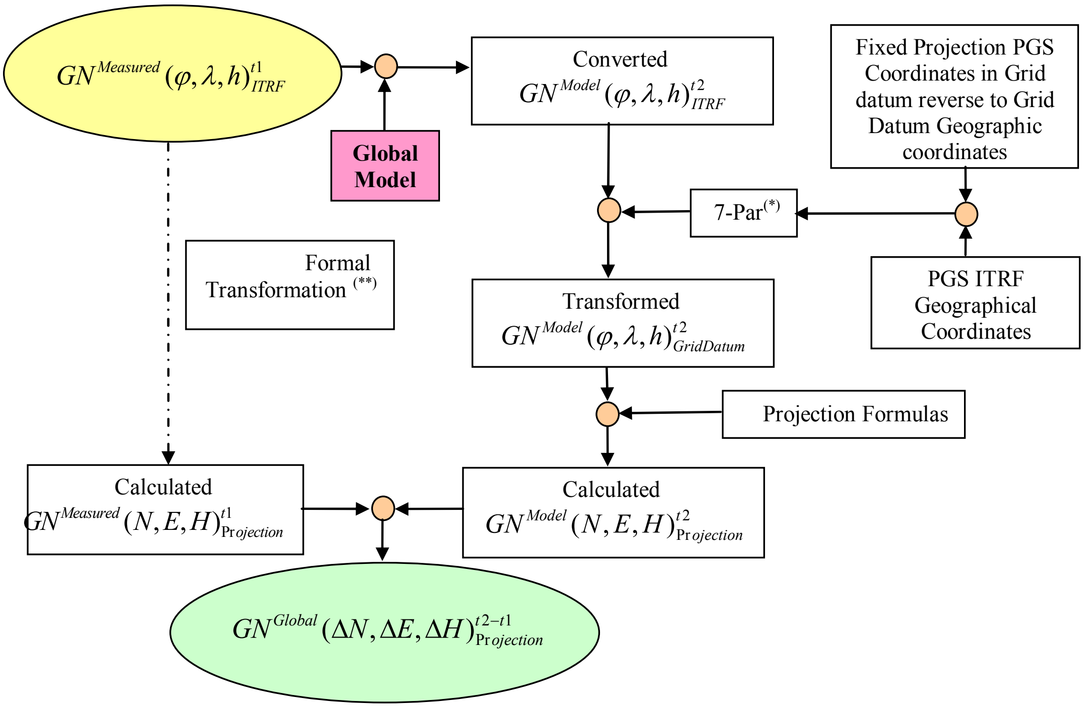


Figure 2: A flowchart describes the algorithm for computing global projection coordinates difference from time epoch t^1 to another t^2 for the geodynamic network points according to a global motion model.

Then, by using a global motion model produced by APN data analysis or by integrated other research works, the MCCM can transform these coordinates to time epoch t^2, achieving $G_1^{Model}(\varphi,\lambda,h)^{t2}_{ITRF}$ coordinates. In order to transform these coordinates to the projection grid coordinates $G_1^{Model}(N,E,H)^{t2}_{Projection}$ in time t^2, the MCCM will use transformation parameters, such as Helmert 7-parameters, for transforming the ITRF coordinates in t^2 to the projection grid datum coordinates, and then calculate them by using the projection equations. The projection coordinates in epoch time t^2 is subtracted from the geodynamic network points coordinates in the projection grid - $G_1^{Measured}(N,E,H)^{t1}_{Projection}$ for achieving the desired quantity $G_1^{Global}(\Delta N,\Delta E,\Delta H)^{t2-t1}_{Projection}$. In order to calculate the $G_1^{Measured}(N,E,H)^{t1}_{Projection}$, the MCCM uses the licensed coordinates of the geodynamic points, calculated from the formal projection transformation. The formal transformation may differ from country to other, hence authors prefers to assign this process by dashed arrow in Figure (3)

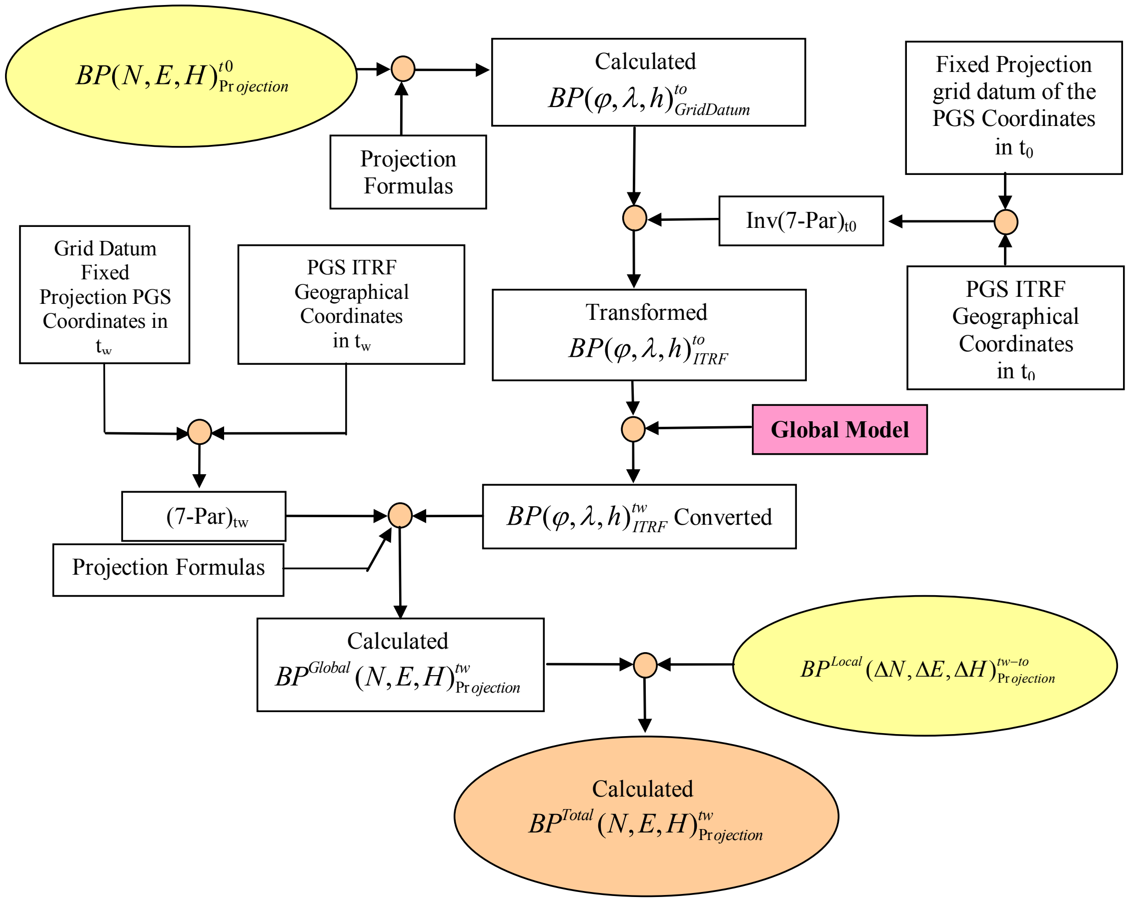


Figure 3: A flowchart describes the algorithm for computing updated national grid coordinates for cadastral boundary point

Finally, the proposed algorithm for calculating the updated national projection grid coordinates of every boundary points is given by the flowchart described in Figure 3.
Grid boundary point coordinates are given in time epoch t^0- $BP(N,E,H)^{t0}_{Projection}$. Using the grid projection equation, the MCCM can calculate the geodetic coordinates of the point in the grid datum - $BP(\varphi,\lambda,h)^{to}_{GridDatum}$. By using inverse transformation parameters in time t^0 (for example: Helmert spatial 7-parameters transformation) between the t^0 fixed projection permanent GPS stations (PGS) coordinates in grid datum and the ITRF PGS coordinates, it could calculate the ITRF geodetic coordinates of the boundary point - $BP(\varphi,\lambda,h)^{to}_{ITRF}$. Later on, by activating the global deformation model, the MCCM could calculate the ITRF geodetic coordinates at the desired time epoch t^w- $BP(\varphi,\lambda,h)^{tw}_{ITRF}$. Finally, another transformation process must be done in order to convert the ITRF coordinates of the boundary point at the desired time t^w to the up-to-date grid coordinates as a result of global model only - $BP^{Global}(N,E,H)^{tw}_{Projection}$. These coordinates must be added to the predicted changes

coordinates $BP^{Local}(\Delta N,\Delta E,\Delta H)^{tw-to}_{\Pr ojection}$, according to equation (3).

3.3 Geostatistics as a base for clever prediction of coordinates changes

For understanding the prediction process, let us imagine that we need to calculate "local" grid coordinates changes between two epochs which are located between numbers of measured GN points (see figure 4). The MCCM has to use such a clever interpolation process use measuring data to predict the component $BP^{Local}(\Delta N,\Delta E,\Delta H)^{tw-to}_{\Pr ojection}$. This could be done by using equations (3) and (4).
According to its main task, the MCCM must be able to provide quality assurance information of the result, like standard deviation errors (see figure 1).

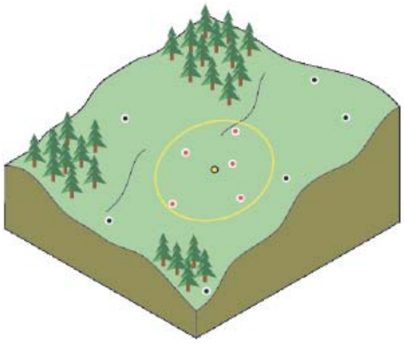


Figure 4: MCCM task description. It must be able to predict the coordinate changes of the middle point basing on surrounding points' data. This picture is taken from "Using ArcGIS Geostatistical Analyst" user book.

There are two categories of interpolation methods: Deterministic interpolation and Geostatistical interpolations (Clark, 1979). The two categories differ from each other by their way of evaluating the results accuracy.
The deterministic interpolation tries to evaluate the accuracy comparing the predicted values with measured values using soft data set statistical descriptors such as the mean and the variance (Croitoru, 2002). The main drawback of is two fold. The use of soft statistics is justified only when the values of the model are random and uncorrelated. Yet for spatial data, like displacements and velocities of the earth surface, this may not necessarily be the case. In addition, our problem values (coordinates changes values or coordinates velocities) must not be treated as scalar values without taking into account the spatial distribution of the data. As a result, it can not be expected that summary statistics will be able to account for any correlation in data, nor describe it (Ktakidis et al., 1999, Ehlschlager and Goodchild, 1994).

On the contrary, the Geostatistical interpolation method is based on spatial error analysis models. The Geostatistics science uses two primary descriptors, namely the variogram and the covariogram (Covariance), which are used to characterize a random field supposing spatial correlation between the predicted results. The variogram describes the variation of the variance between elements in the field (equation (6)), while the covariogram describes the correlation between data elements (Cressie, 1993, Clark, 1979):

$$\hat{\gamma}(h) = \frac{1}{2\left|N(h)\right|} \sum_{N(h)} \left[Z(t_i) - Z(t_j) \right]^2 \tag{6}$$

$$\hat{C}(h) = \frac{1}{\left|N(h)\right|} \sum_{N(h)} \left[\left(Z(t_i) - \bar{Z} \right) \left(Z(t_j) - \bar{Z} \right) \right]^2 \tag{7}$$

Where:

$$\bar{Z} = \frac{1}{n} \sum_{i=1}^{n} Z(t_i) \tag{8}$$

$\left|N(h)\right|$ is the number of data pairs (t_i, t_j) that are h units apart:

$$\left\{ \left(t_i, t_j \right) : \left\| t_i - t_j \right\| = h \ \ ; i = 1 \ldots n \ \ ; \ \ j = 1 \ldots n \right\}, \tag{9}$$

n is the size of the data set, and $\|..\|$ is the Euclidian distance operator. Both indices are computed by dividing all possible distance within *D* into equally spaced *lags h*, where for each lag an average value is taken. It should be noticed that these indices assume a homogenous and isotropic random scalar filed. Z(t) is the measured value in the field.

Because of the obvious requirement for supporting error estimation as a quality assurance process of the cadastral MCCM, and because of the spatial correlation between the coordinates' changes values, the Geostatistical interpolation would be adopted for fulfilling the task.

Using Geostatistics interpolation methods need a prior data analysis process in order to fit them a data error variogram and covariance models. Data could be either points' coordinates' changes from wanted epoch to another, or their velocities in every ordinate; derived by dividing the coordinates' changes by the time interval. Using the grid coordinates data sets of the GN; there are three options for predicting the "local" coordinates' changes of the points according to (see picture 5):

A. Simple linear line function that passes between the position in epoch t^0 and the last epoch that the GN is measured.
B. Simple linear line function regression considering all the measured epochs.
C. Polynomial line function or Lagrange function.

The three options above enable the MCCM to calculate the $BP^{Local}(\Delta N, \Delta E, \Delta H)^{tw-to}_{\Pr ojection}$ component based on one of the two Geostatistical interpolation methods: Collocations (Moritz, 1972) or the Kriging (Clark, 1979). The data sets input of the interpolations are set of $GN^{Local}(\Delta N, \Delta E, \Delta H)^{t_w - t_0}_{\Pr ojection}$ coordinates lists in all epochs.

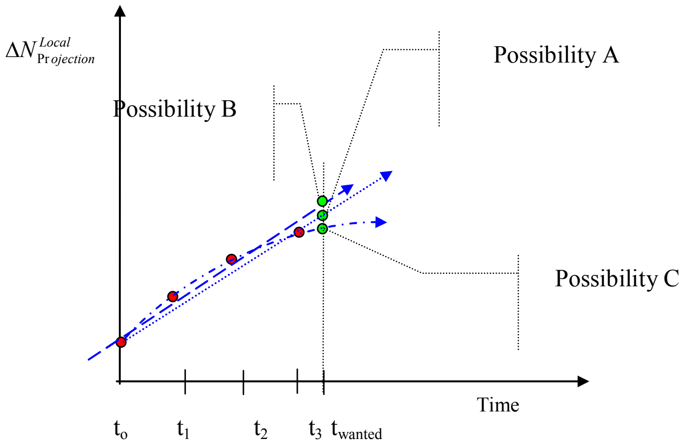


Figure 5: The three possibilities for predicted the position of the geodynamic network points at epoch 't_{wanted}' which is used for evaluating the position of unmeasured point.

4. PRELIMINARY TESTS

In order to check the applicability degree of the proposed algorithms, especially the essential degree of the integration between physical model and Geostatistical interpolation two tests have been carried out:

4.1 Checking the essentiality of physical motion model for MCCM purposes

The first test aims to check if the Geostatistical interpolation manages to describe the coordinates' changes in country with obvious crustal deformations and correspondingly trying to evaluate the essentiality of physical motion model. A good example for dynamic country is Japan. For this purpose, we try to achieve crustal displacement of the Japanese APN points. Test bold appointments and details are:

a. Data has been taken from http://mekira.gsi.go.jp/project/f2/en/index.html website.

b. There are 1200 APN points.

c. Two data sets were used: the first one includes points' displacements between 1994 and 1995, the second set between 1995 and 1996. The test values are the difference values between the two data sets.

d. NO physical motion model has been adopted when calculating the displacement.

e. The second data set is used for evaluating the necessity of a physical model.

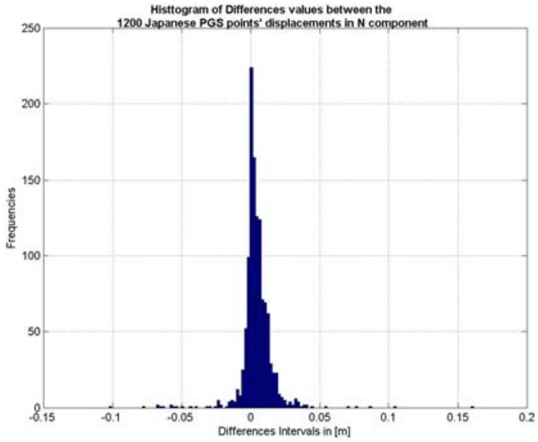
f. There is no use for such a GN, since we did not manage to achieve another data.

g. Data sets miss standard deviation errors or any quality assurance.

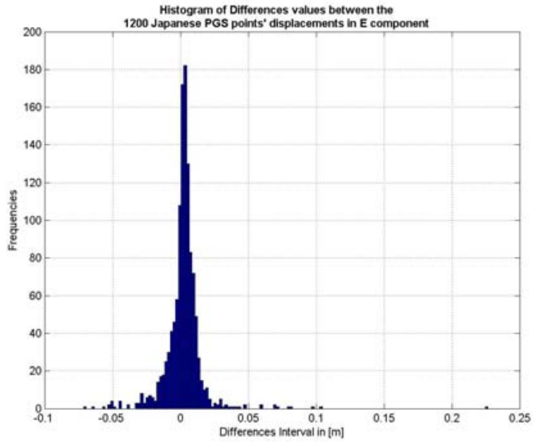
h. One reference point named IWASAKI has been chosen as a reference point to the projection.

i. Our test aims to check if the changes in the projection coordinates between the two data sets are in the same direction. If the answer is positive, no physical model is needed and the reliability of the Geostatistical interpolation might be high. Our answer estimation is negative, since Japan is a dynamic country well exposed to crustal deformations.

From figure 6 we can see that most of the differences between the values are less than 5cm, several points exceed this limit and some points have differences between 15 and 25cm. Furthermore, value of 5cm during two years is a sufficient need for an accurate physical geological motion model for Japan. Figure 6.a and 6.b illustrate the frequency of the different values between displacements occurred in two sequence years.



(a)



(b)

Figure 6: Histogram graph of the differences in the north ordinate (a) and the east ordinate (b) during two sequence years.

While Figure (7) describes the vectors of the differences in displacements between the results derived from two sequence years of measuring.

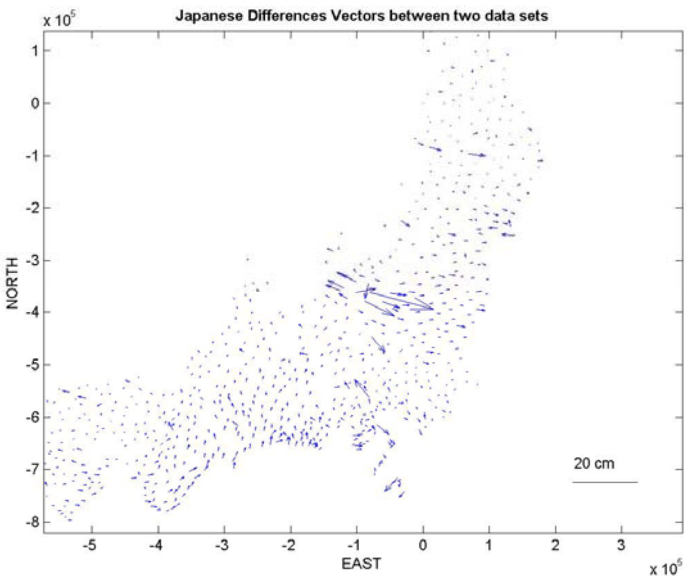


Figure 7: A quiver graph of difference vectors during two sequence years of the Japanese APN points.

4.2 Testing the applicability of the integrated data into proposed MCCM in Israeli Geodynamic network 'G1' using Geostatistics

The crustal deformation activities on Israeli surface have been investigated for 15 years, since the beginning of the GPS era. There are two high accuracy control networks in Israel. The first one is the APN GPS network includes 18 stations, which is the most accurate network with sub 1 ppm relative accuracy, suitable for monitoring crustal movements countrywide (Adler et al., 2001 and Even-Tzur et al, 2004). The second network is a geodetic-geodynamic network called G1, which was established in 1996, with the aim of understanding the deformation and recent tectonics in the country (Ostrovsky, 2001). It also designed to serve as the major geodetic control network of Israel.

Our ultimate goal is to try using these two geodetic networks to implement the proposed algorithm of the MCCM described in section (3.2). Since the G1 network was measured only twice; in 1996 and in 2002, we may not be able to evaluate the accuracy of the predicted boundary points' coordinates. Doing this evaluation may need measuring a number of G1 points during this year or before the third measurement campaign would begin.

The experimentation bold appointments are:

a. There are about 100 G1 points which were measured both in 1996 and in 2002.
b. Distances between points are around 10km.
c. In order to evaluate the two data sets including the projection coordinates changes values between the two measurements' campaigns; we used the "Geostatistical Analyst" module of the ArcGIS software by the ESRI (Johnston et al, 2001). The "Geostatistical Analyst" module includes a strong tool for best fitting process of the variogram and covariance function necessary for Geostatistical interpolation. Additionally, it enables users to produce maps of prediction values and their standard deviation errors (STDR) for the entire surface using Kriging interpolations (see for example figure 8.a and figure 8.b).
d. Data analysis concentrates on the north (N) ordinate of the point since the east (E) ordinate changes are minor as well as they are treated exactly the same as the (N).
e. Considering the results of the Kriging interpolation prediction map (Figure 8), obvious tendency through the results can be noticed.
f. Therefore, a physical motion model might be used. The proposed algorithm in section (3.2) and (3.3) is implemented by using MATLAB.
g. The physical motion model produced by Wdowinski et al. (2004) is used as the main tectonic motion model. This model is based on all the measurements data of the permanent GPS stations, existed in and around Israel. It aims to evaluate the displacements and the velocities of points around the Dead Sea Fault by using a locked fault model (Adler et al., 2001) as:

$$v(x) = v_0 \cdot \frac{1}{\pi} arctg(\frac{x}{D}) \tag{10}$$

When:

v_0 - Slip rate of the plates.
D - Depth of locked.
x - Horizontal distance from the fault.

According to Wdowinski et al. (2004), the azimuth of the Dead Sea fault is about 13^o degree. Using equations (11), the MCCM can calculate the velocities in north and east components:

$$v_n = \cos(Az)\left(v_0 \cdot \frac{1}{\pi} arctg(\frac{x}{D}) \right)$$
$$v_e = \sin(Az)\left(v_0 \cdot \frac{1}{\pi} arctg(\frac{x}{D}) \right) \qquad (11)$$

The possible parameters values derived from the research of Wdowinski et al. (2004) are:

v_0 - 3.3 ± 0.4 [mm/yr]
D - 12 ± 3 [km].
Az - 13^o degree

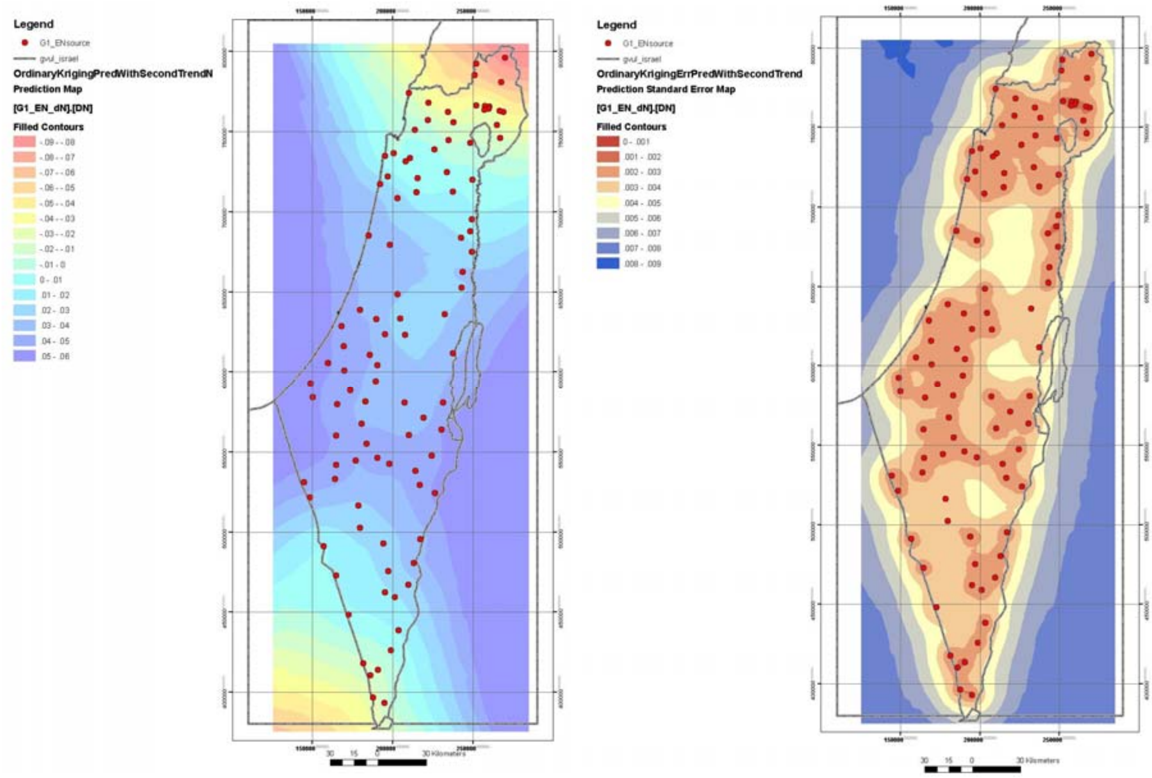
Where, the physical motion model in (11) has executed on the northern part of Israel. The velocities components of the Sinai sub-plate are: v_e=18.23 [mm/yr]; v_n= 22.66 [mm/yr] (the average of all the Israeli 11 PGS velocities). These constant components has been subtract from all the points in order to calculate their motion relative to the SRF (SENAI reference frame).

h. The collocation of Moritz, 1972, with second polynomial interpolation function has been used. We used the ArcGIS ver. 9 "Geostatistical Analysis" modules to fit the variogram and covariance functions which are used to build correlation matrix for the collocation process (see Figure 8). The Gaussian function has been adopted according to equations (12):

$$\gamma_{Semi-\text{var}iogram}(Gaussian) = C_0\left(1 - \exp\left(-3\left(\frac{h}{\theta_r}\right)^2\right)\right) + Nuggets$$
$$C_{Co\text{var}iance}(Gaussian) = C_0 \exp\left(-3\left(\frac{h}{\theta_r}\right)^2\right) + Nuggets \qquad (12)$$

Where h is the distance between points, Co is the partial sill of the semi-variogram, and θ_r is the major influence range.

For better fitting process of a variogram or semi-variogram function using Geostatistical Analysis module in ArcGIS, a map of STDR values of all the data might be use (see figure 8.a and 8.b). Minimizing the STDR map values leads to best fit of the variogram or covariance functions. Several optimization sets for equation (12) have been executed, where the two sets of parameters' values which lead to minimum STDR map values are given in Table 1.



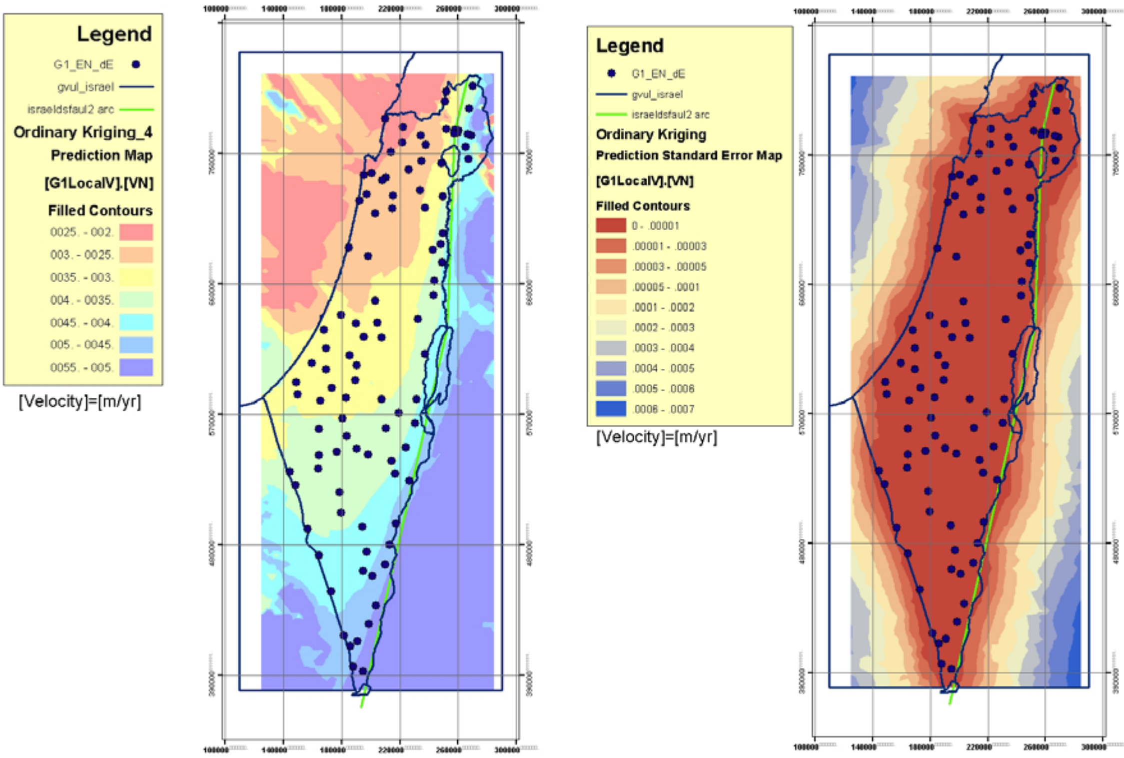
(a) (b)

Figure 8: Contour plots of the ordinary Kriging (Johnston et al, 2001) in Israel surface, describe the total changes $G_1^{Total}(\Delta N)_{\Pr ojection}^{t_{1996}-t_{2002}}$ in ordinate N (a) and their STDR values (b).

Table 1: Parameters values of the Gaussian function of the variogram and the covariance that could be used by the collocation.

#	Function	C_0 [m/sec]^2	θ_r [m]	Nuggets [m/sec]^2
1	$\gamma_{Semi-variogram}$	3.4216E(-7)	62886	0
	$C_{Covariance}$	3.5374E(-7)	120570	0
2	$\gamma_{Semi-variogram}$	1.117E(-7)	408150	1.4699E(-7)
	$C_{Covariance}$	3.4145E(-7)	123250	1.6758E(-7)

Figure (9) shows the neglected STDR values of the Kriging interpolation using the Gaussian functions (equation (12)) for fitting the variogram and the covariance models.



(a) (b)

Figure 9: Contour plots of the ordinary Geostatistical Kriging (Johnston et al, 2001) in Israel surface, describe the prediction of local Velocities values in the North ordinate (a) and their STDR (b) after the year 2002 basing on 1996 data set.

Base on set #1 of the Gaussian parameters (table 1), the collocation interpolation method has been executed on the $G_1^{Local}(\Delta N)^{t_{1996}-t_{2002}}_{\Pr ojection}$ projection coordinates' changes data sets according to equation (5).

Results are shown on the two graphs described by Figure (9). The left graph (9.a) indicates the local velocity of the coordinates changes v_n at the northern part of Israel, and the right graph (9.b) indicates the STDR values derived from the collocation Least Square (Moritz, 1972).

The integration results of the geophysical motion model and the collocation according to the two graphs shown in figure (10) indicate the success of the proposed algorithm as well as the high quality of the geophysical lock fault model derived from Wdowinski et al. (2004). This conclusion comes as a result of the outcomes shown in figure (10); there are no significant probability that indicates an obvious local noise (local movements) according to equation (3) and (4).

Despite using the same Gaussian function parameters for the covariance model with both the Kriging and the collocation of Moritz, differences between STDR maps have been achieved.

This is a result of the fact that collocation method considers the physical tectonic parameters model STDR, while the Kriging interpolation does not. Therefore, the collocation STDR prediction results are more reliable than those derived from the Kriging. On the other hand, the local velocities values seem to be the same in both interpolation methods.

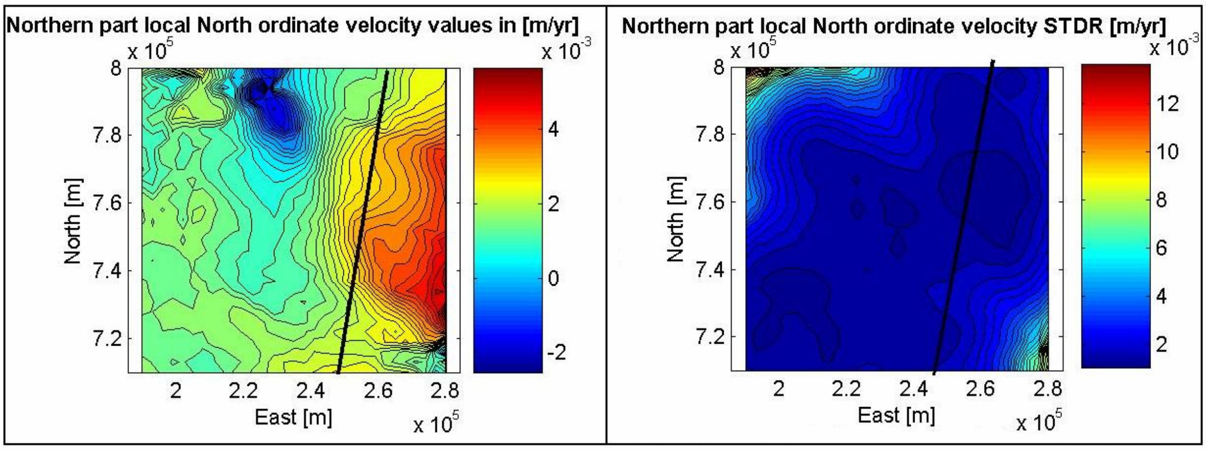


Figure 10: The left graph indicates the local velocity of the coordinates changes v_n at the northern part of Israel, and the right graph indicates the STDR values derived from the collocation Least Square (Moritz, 1972). The black bold line in both graphs indicates the DSF.

5. CONCLUSION AND FUTURE WORKS

A monitoring grid coordinates changes model (MCCM) is needed in the era of the future LDC system, especially in dynamic countries. The proposed algorithm of the MCCM could play the main role there.
The importance of using a high quality geophysical tectonic model for evaluating the dynamics in the national projection grids has been shown, using two experimentations, in Israel and Japan.
The Geostatistical interpolation methods are the basis of a prediction process which uses APN array stations or geodynamic network points data measurements sets(or both), for evaluating projection grid coordinates' changes of any point on the country surface.
In countries with insignificant earth deformation movement, the use of the Kriging method without basing on physical deformation movement model might be suitable and accurate enough for cadastral purposes. But, in countries like Japan, New Zealand, California in the USA, and even Israel which does not appear a dynamic country, a suitable geophysical movement deformation model should be adjusted for Dynamic LDC future MCCM component uses.
Continuous APN data usually support deformation movement models researches. Therefore, they may play the most important role for computing the coordinate differences, especially in countries that contain tectonic faults which may cause global deformations. But, if the country surface suffers from local deformations such as slop slides, and the density of the APN points is not sufficient for recognizing these kinds of deformations, the geodynamic network would play an important role too.

Since there is no more than two observations campaign of the Israeli G1 geodynamic network, the final evaluation of the proposed algorithm is not completed yet.
Finally, STDR prediction map could be used for designing the positions of the GN points. New GN points may be added in order to "close gaps" in the STDR in order to achieve minimum and homogeneous STDR velocities prediction values.

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BIOGRAPHICAL NOTES

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