Change from ITRF92 Epoch 1988.0 to ITRF2000 Epoch 2004.0 in Mexico

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Key words: geodetic network, ITRF, IERS, plate tectonics.

SUMMARY

The National Institute of Statistics, Geography and Informatics (INEGI), with the intention to keep an updated and modern Geodetic Reference Frame, has been performing the activities required to change from ITRF 92 epoch 1988.0 to ITRF 2000 epoch 2004.0.

Among the mentioned activities are the creation and publishing of standards, network solution of station coordinates of the Active National Geodetic Network (RGNA), transformation of coordinates of the passive network and information dissemination of the change. The transformation of coordinates from ITRF 1992 epoch 1988.0 to ITRF 2000 epoch 2004.0 is mainly performed with transformation parameters defined by IERS and using a plate tectonics model.

The dissemination of information is made through national and regional training of geodetic data users, showing the algorithm, the transformation procedure and the effects of frame change on geodetic and cartographic products, additionally by the INEGI Internet site users will be kept informed.

RESUMÉN

El Instituto Nacional de Estadística, Geografía e Informática (INEGI), con la intención de mantener actualizado y a la vanguardia su Marco de Referencia Geodésico Nacional, lleva a cabo las actividades conducentes al cambio del marco ITRF 92 época 1988.0 a ITRF 2000 época 2004.0.

Entre las actividades realizadas se encuentran la definición y la publicación de la normatividad, el cálculo de coordenadas para las estaciones de la Red Geodésica Nacional Activa (RGNA), la transformación de coordenadas de la red pasiva y la difusión del cambio. La transformación de coordenadas de ITRF 1992 época 1988.0 a ITRF 2000 época 2004.0 se lleva a cabo principalmente mediante la utilización de los parámetros de transformación definidos por el IERS y la utilización de un modelo de movimiento de placas tectónicas.

La difusión se ha estado llevando a cabo con capacitaciones regionales y nacionales dirigidas a los usuarios de información geodésica que incluyen el algoritmo, el procedimiento de transformación y los efectos del cambio en productos geodésicos y cartográficos, adicionalmente se mantendrá informado al usuario mediante el portal de Internet del INEGI.

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1. INTRODUCTION

The geodetic reference frame established in México since 1993 was ITRF 92 epoch 1988.0, with the purpose to count with a high accuracy frame according to the recent GPS technology the old NAD27 datum on which the National Geodetic Network was referred was changed to ITRF.

RGNA is used to propagate the geodetic frame to points established on the Mexican territory, initially composed by fourteen GPS stations continuously operating. Sixteen years have passed since the date of the mentioned reference epoch, some network distortions arose and INEGI has decided to change its geodetic frame to ITRF 2000 epoch 2004.0, in order to maintain in optimum conditions the network where geodetic surveys usually originate.

The activities required to reach it were create, discuss and publish the standards, study and find out the procedure to obtain station coordinates of RGNA and the algorithms to change from one geodetic frame to another, and finally the user training.

The standard that establishes the change of frame was proposed, sent to other institutions, and offered through the Internet site in order to receive comments and opinions from users. Once discussed and approved by the legal department, the official publication process takes place.

The INEGI task in this issue with the purpose to change the Mexican Reference Frame are related to the FIG commission 5 Positioning and Measurement on the Working Group 5.2, Reference Frame in Practice.

On the following pages, two of the main activities to change the geodetic frame will be described, the first refers to the RGNA itself and the second, to the transformation procedure of the passive geodetic network points.

2. ITRF TRANSFORMATION

2.1 General Procedure

We could mention two general steps derived from the change of geodetic frame to obtain the coordinates of the National Geodetic Networks on ITRF 2000 epoch 2004.0. One implies data processing to obtain new coordinates for RGNA stations and the other, the transformation of point coordinates of the passive network.

a) The RGNA frame change

At present, sixteen stations conform the geodetic network as shown in the next figure.

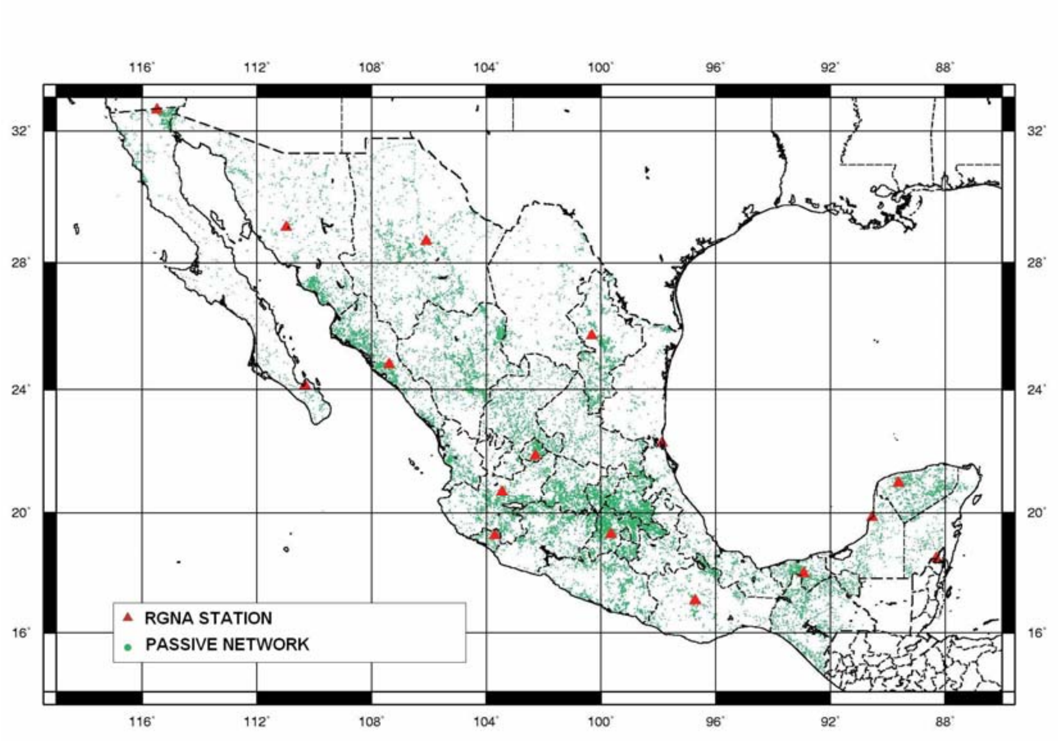
The point coordinates of the Active National Geodetic Network were referenced to ITRF 2000 epoch 2004.0 using precise geodetic software to process the RINEX data and obtain the solution on the required epoch.

The main characteristics of daily processing were:

Software	Gipsy Oasis II
Record Interval	15 seconds
Elevation mask	10 degrees
Ambiguities	Estimated as real values
Ocean Loading	Scherneck

b) Transformation of the passive network point coordinates.

The set of points in the Passive Network in the Mexican territory needed to be transformed from ITRF 92 epoch 1988.0 to ITRF 2000 epoch 2004.0. Based on Soler & Marshall, 2003 and adapting the solution to particular aspects of the Mexican case, an algorithm of transformation was studied, tested and implemented.



The elements incorporated on the algorithm are the parameters defined by the International Earth Rotation and Reference Systems Service (IERS), consisting of values of rotation, scale and translation, in combination with a plate tectonics model corresponding to the tectonic plate where the points reside.

2.2 Transformation

In order to apply the standard, the geodetic points of the Mexican Passive Network had to be transformed to ITRF 2000 epoch 2004.0, considering some elements as the IERS model, plate tectonics, Datum and Reference Frame and global plate models.

2.2.1 IERS Model

The IERS (International Earth Rotation and Reference System Service, www.iers.org) define 14 parameters for Helmert transformation between ITRF 2000 and ITRF 1992.

SOLUTION	T1	T2	T3	D	R1	R2	R3	EPOCH OF REF.	
UNITS ----->	cm	cm	cm	ppb	.001"	.001"	.001"		Technical
RATE	T1	T2	T3	D	R1	R2	R3		Note #
UNITS ----->	cm/y	cm/y	cm/y	ppb/y	.001"/y	.001"/y	.001"/y		
ITRF92	1.47	1.35	-1.39	0.75	0.00	0.00	-0.18	1988.0	15
Rate	0.00	-0.06	-0.14	0.01	0.00	0.00	0.02		

Where

T : Translation
D : Scale (Parts per billion, 10^{-9} units)
R : Rotation (arc-seconds)

The mathematical model of IERS is:

$$\begin{bmatrix} X^{ITRF92} \\ Y^{ITRF92} \\ Z^{ITRF92} \end{bmatrix} = \begin{bmatrix} X^{ITRF00} \\ Y^{ITRF00} \\ Z^{ITRF00} \end{bmatrix} + \begin{bmatrix} T1 \\ T2 \\ T3 \end{bmatrix} + \begin{bmatrix} D & -R3 & R2 \\ R3 & D & -R1 \\ -R2 & R1 & D \end{bmatrix} \begin{bmatrix} X^{ITRF00} \\ Y^{ITRF00} \\ Z^{ITRF00} \end{bmatrix}$$

Where X^{ITRF92},Y^{ITRF92},Y^{ITRF92} are the geocentric coordinates on a tridimensional Cartesian system on the reference frame ITRF 1992 epoch 1988.0 and X^{ITRF00},Y^{ITRF00},Y^{ITRF00} on ITRF 2000.

The transformation parameters from ITRF 2000 to ITRF 92 epoch 1988.0 are:

T1 = 0.0147 meters
T2 = 0.0135 meters
T3 = -0.0139 meters
D = 0.75 ppb
R1 = 0.0 radians
R2 = 0.0 radians
R3 = -8.726646E-10 radians

As we need to reverse the process, going from ITRF 92 to ITRF 2000, we have to change the sign of the transformation parameters:

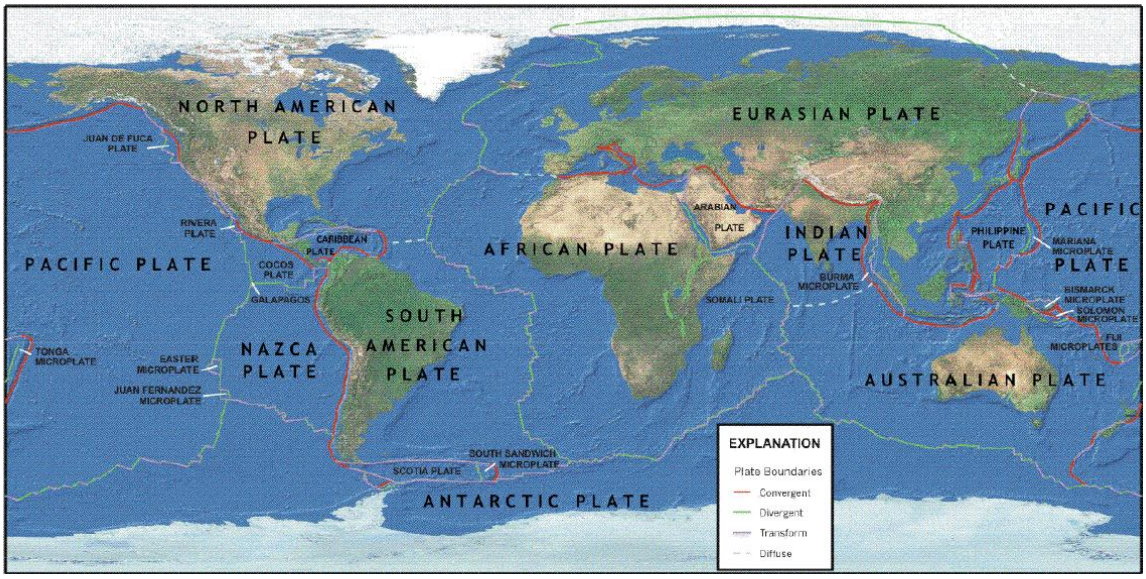
$$\begin{bmatrix} Dx^{IERS} \\ Dy^{IERS} \\ Dz^{IERS} \end{bmatrix} = \left(\begin{bmatrix} -T1 \\ -T2 \\ -T3 \end{bmatrix} + \begin{bmatrix} -D & R3 & -R2 \\ -R3 & -D & R1 \\ R2 & -R1 & -D \end{bmatrix} \begin{bmatrix} X^{ITRF92} \\ Y^{ITRF92} \\ Z^{ITRF92} \end{bmatrix} \right)$$

Dx^{IERS}, Dy^{IERS}, Dz^{IERS} are the IERS transformation effect.
To summarize, the mathematical model is:

$$\begin{bmatrix} Dx^{IERS} \\ Dy^{IERS} \\ DZ^{IERS} \end{bmatrix} = \left(\begin{bmatrix} -0.0147 \\ -0.0135 \\ 0.0139 \end{bmatrix} + \begin{bmatrix} -7.5E-10 & \text{-8.726646E-10} & 0 \\ \text{8.726646E-10} & -7.5E-10 & 0 \\ 0 & 0 & -7.5E-10 \end{bmatrix} \begin{bmatrix} X^{ITRF92} \\ Y^{ITRF92} \\ Z^{ITRF92} \end{bmatrix} \right)$$

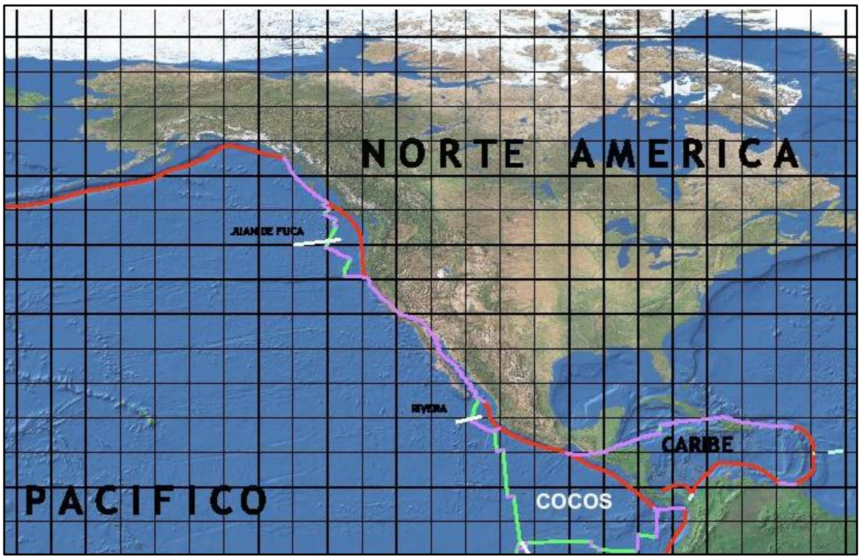
2.2.2 Plate Tectonics

The theory according to Kious & Tilling (2001), "Alfred Lothar Wegener (1880-1930) the originator of the theory of continental drift", established that the earth is subdivided by some tectonic plates, which are in motion, have different movement rates and behavior and differ from the boundaries of the continents.



Major tectonic plates of the earth (Kious & Tilling, 2001, USGS)

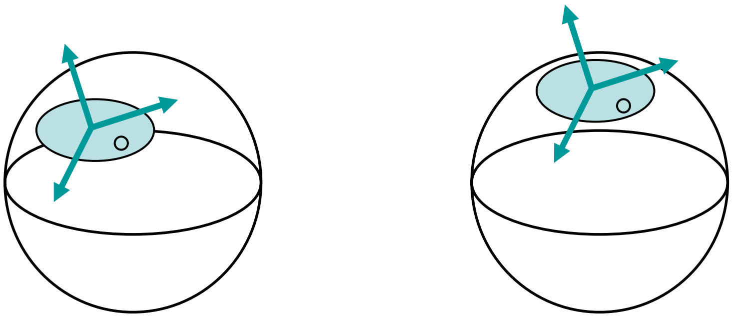
The Mexican territory is placed on two major tectonic plates, which show different movement rates, Pacific Plate (~4 to 5 cm/year) almost covering the states of Baja California and Baja California Sur, and North American Plate (~1 to 2 cm/year) that cover the rest of the Mexican States.



The particular situation of the Mexican Territory placed on two tectonic plates will need attention, first to perform the change of frame and second on future geodetic activities directed to determine the coordinates of points on the official geodetic reference frame.

2.2.3 Datum and Reference Frame

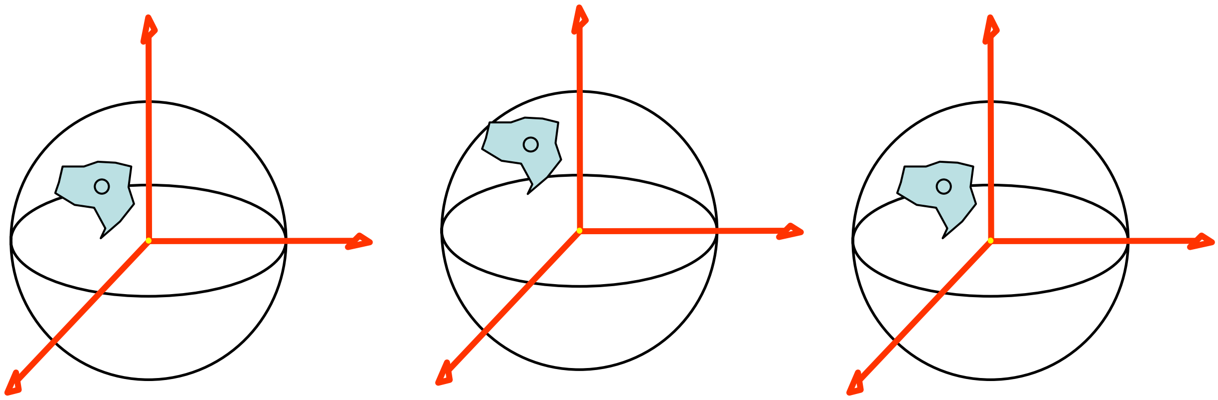
From Soler & Marshall (2003), the classical concept of Datum establishes that the coordinate frame is fixed and doesn't change in time, then, the coordinate frame is joined to the plate and move with it, in such a way the point coordinates remain the same when the plate moves.



Coordinate Frame   Plate Movement

As the figure shows, derived from a plate movement, the coordinate frame moves with the plate it and the point coordinates will not change.

On modern geodetic frames, the inverse process is implemented, the coordinate frame is fixed while the plate is rotated to the original position of the reference epoch.



a. Frame defined   b. Plate movement   c. Frame rotated

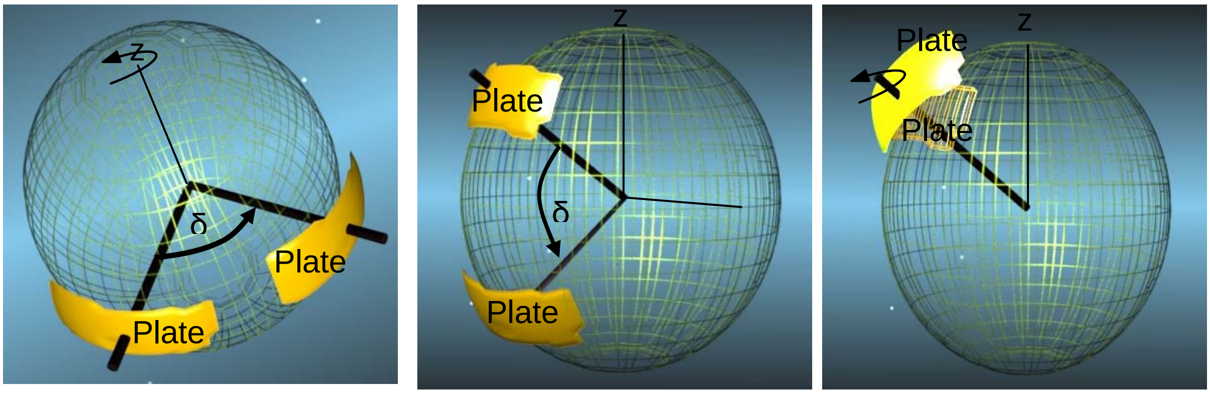
All points are returned to their position on the reference frame ITRF00 which by definition remains fixed.

2.2.4 <u>Global Plate Models</u>

The movement of point coordinates related to plate tectonics can be obtained through the use of some of the global Models of plate movement:

- ITRF 2000 (SOPAC).
- NNR-NUVEL 1A.
- APKIM.

The total rotation of a plate can be explained as the result of elemental rotations.



Longitude **Ecuatorial** **Vertical**

Elemental Rotations

The total rotation and other elements associated to these models, on the form of rotation vector on geographic or Cartesian representation, are:

Plate Abbr.	Rotation Vector (geographic) PHI [degrees]	LAM [degrees]	OMEGA [degrees/Ma]	Rotation Vector (cartesian) omega(x) [rad/Ma]	omega(y) [rad/Ma]	omega(z) [rad/Ma]	Plate Name
NNR-NUVEL 1A	(DeMets et al. 1994)						
NOAM	-2.438	-85.895	0.2069	0.000258	-0.003599	-0.000153	N. American
PCFC	-63.045	107.325	0.6408	-0.001510	0.004840	-0.009970	Pacific
APKIM	(http://dgfi2.dgfi.badw-muenchen.de/)						
NOAM	-2.4	280.8	0.1977	0.0370	-0.1940	-0.0083	N. American
PCFC	-65.2	107.1	0.6584	-0.0812	0.2640	-0.5977	Pacific
ITRF 2000 (SOPAC)	(http://sopac.ucsd.edu/cgi-bin/poleRotationValues.cgi)						
NOAM	-4.222	-84.880	0.1980	0.000308	-0.003433	-0.000254	N. American
PCFC	-63.791	110.244	0.6720	-0.001792	0.004860	-0.010523	Pacific

Table. Global Plate Model velocities.

Where the cartesian rotation vector is obtained from

$$\varpi_x = \Omega * \cos(phi) * \cos(lam)$$
$$\varpi_y = \Omega * \cos(phi) * sen(lam)$$
$$\varpi_z = \Omega * sen(phi)$$

The transformation of points on plate borders between Pacific and North American plate will be less precise giving the situation of instability in the limit of two plates where most earthquakes are produced.

2.2.5 Plate mathematical model

The plate mathematical model is defined as :

$$\begin{bmatrix} Dx^{Plate} \\ Dy^{Plate} \\ Dz^{Plate} \end{bmatrix} = (from\ epoch - to\ epoch) * [\Omega] * \begin{bmatrix} X^{ITRF92} \\ Y^{ITRF92} \\ Z^{ITRF92} \end{bmatrix}$$

Dx^{Plate}, Dy^{Plate}, Dz^{Plate} are the effect of the plate tectonics movement.
The fields *from epoch* and *to epoch* for the Mexican case are 1988.0 and 2004.0 respectively.

$[\Omega]$ is the angular rotation matrix, defined as:

$$[\Omega] = \begin{bmatrix} 0 & -\omega_Z & \omega_Y \\ \omega_Z & 0 & -\omega_X \\ -\omega_Y & \omega_X & 0 \end{bmatrix}$$

In the case of the North American Plate and ITRF 2000 model, we have

$$|\Omega| = \begin{matrix} 0.0 & 0.000254 & -0.003433 \\ -0.000254 & 0.0 & -0.000308 \\ 0.003433 & 0.000308 & 0.0 \end{matrix}$$

-

Because the annual representation is needed, dividing by one million, radians/year is obtained.

$$|\Omega| = \begin{matrix} 0.0 & 2.54E\text{-}10 & -3.433E\text{-}9 \\ -2.54E\text{-}10 & 0.0 & -3.08E\text{-}10 \\ 3.433E\text{-}9 & 3.08E\text{-}10 & 0.0 \end{matrix}$$

2.2.6 Final Model

To change from ITRF 1992 epoch 1988.0 to ITRF 2000 epoch 2004.0 we apply:

a) The IERS model
b) The Plate model

Additionally, the tectonic plate to which the point coordinates are referenced must be identified.

The final model is

$$X^{ITRF00} = X^{ITRF92} + Dx^{IERS} + Dx^{Plate}$$
$$Y^{ITRF00} = Y^{ITRF92} + Dy^{IERS} + Dy^{Plate}$$
$$Z^{ITRF00} = Z^{ITRF92} + Dz^{IERS} + Dz^{Plate}$$

3. DISSEMINATION AND TRAINING

Personnel of INEGI has been training on the procedure to change ITRF 1992 epoch 1988.0 to ITRF 2000 epoch 2004.0, the importance resides in the fact that they are the link between users of geographic data and INEGI regional or local geographic product providers.

The frame transformation algorithm has been implemented on a programming language that will be available through the INEGI Internet site for users to obtain the new coordinates of the passive network or regional geodetic networks. To assure the quality of the output coordinates, tests of the program, input data and results have been made.

Some specific considerations of the change of frame have been analyzed, as the particular situation in our country where the point coordinates could be on one of two different tectonic plates, with a different movement rate and some aspects must be taken into account in the frame transformation and data processing.

The need of an updated procedure and a set of rules to process GPS data was identified, the objective is to obtain coordinates of points with the precision specified on the national standards and referenced to the correct geodetic frame defined for the Mexican territory.

Those changes will be described in operative documents that support the activities related to GPS data survey and process, similarly at INEGI Internet site recommendations to the user about this issue will be on line.

3.1 Map Effect

The map effect of the change from ITRF 92 epoch 1988.0 to ITRF 2000 epoch 2004.0 is a regular question from users of cartographic products, as well as questions like, ¿how the cartographic product is affected? ¿how large is the change from a coordinate on ITRF 92 to ITRF 2000?

Trying to answer those questions the following table was created.

MAP EFFECT		
	Change of map (milimeters)	
Scale	**Pacific**	**North American**
1:1,000,000	0.0000	0.0000
1:500,000	0.0000	0.0000
1:100,000	0.0000	0.0000
1:50,000	0.0008	0.0003
1:20,000	0.0400	0.0150
1:1,000	0.8000	0.3000

The table shows the map effect on different scale giving the change of the geodetic reference frame, for example, for the 1:50,000 topographic map published by INEGI, the effect on points in the Pacific plate is 0.0008 mm. and 0.0003 mm. for those on the North American plate.

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