Earth science applications of GNSS

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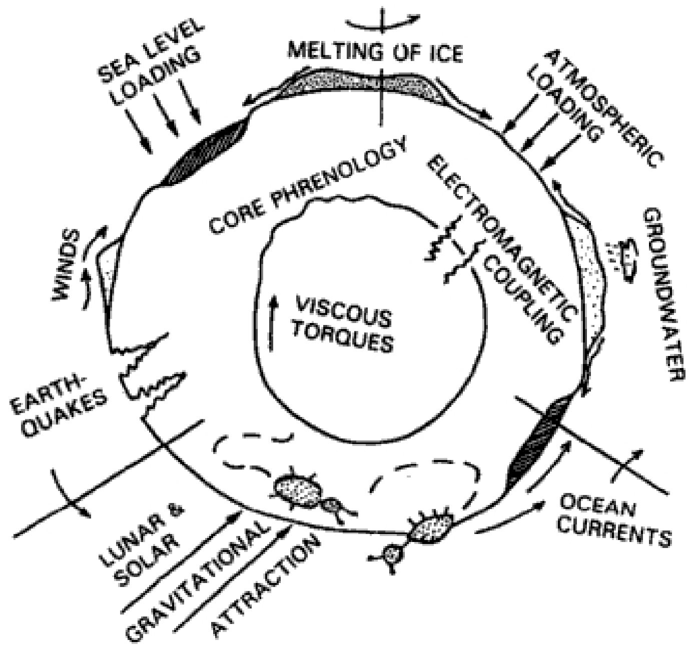
Earth sciences : Geodesy and Geophysics

Geodesy is a scientific discipline that deals with the time varying measurement and representation of the Earth, including it's gravity field, in a 3D space using terrestrial and space borne techniques (*GNSS mainly*) . Earth sciences studies :

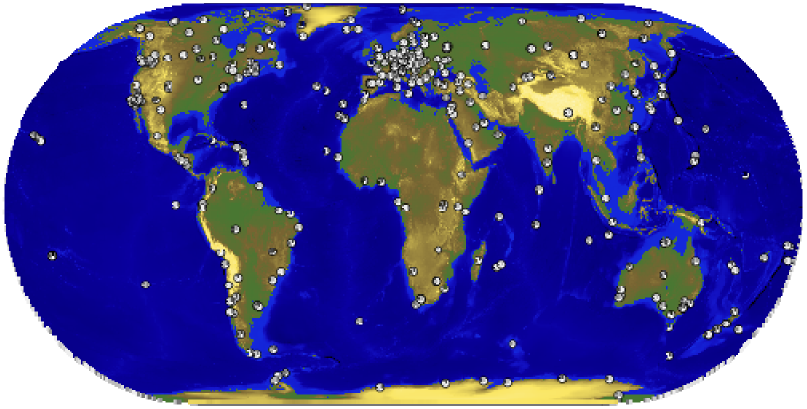
- *Tectonic plate motion and seismic deformation*
- *Landslide and geological movements*
- *Atmospheric properties (Ionosphere, Troposphere)*
- *Geodetic reference frame and network*
- *Earth rotation*
- *Tidal motion and deformation*
- *Mass transport and deformation*



Summary

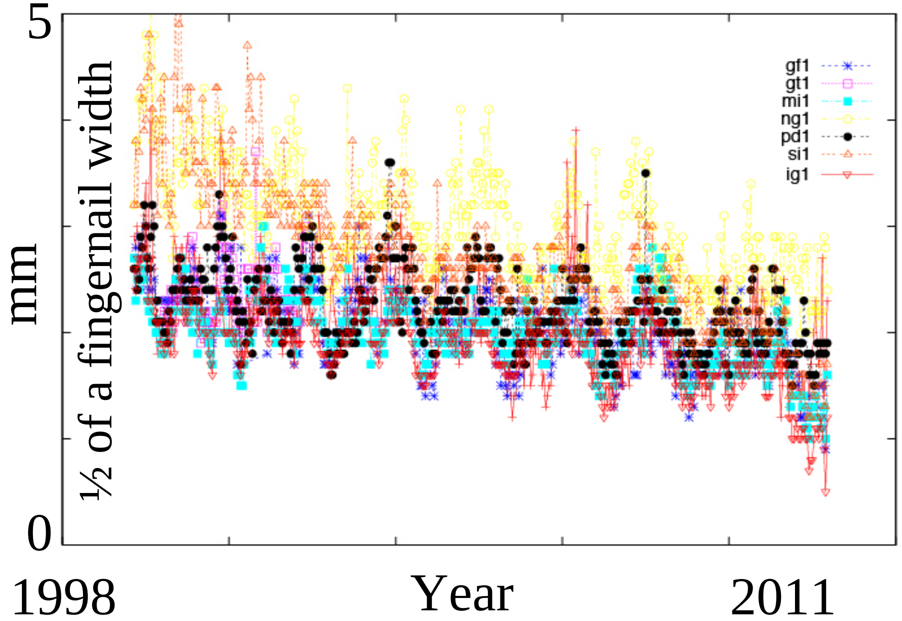
- Crustal deformation (Regional, Urban monitoring,)
- Ionosphere modelling,
- Troposphere modelling
- Actual works and perspectives (National geodetic network,…)

IGS : GPS Geodesy



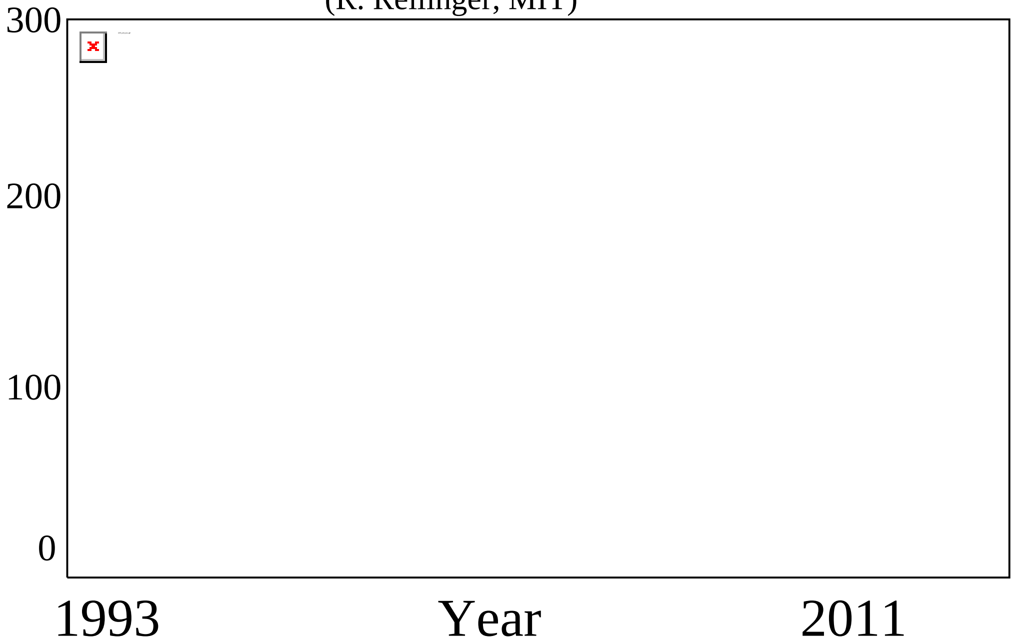
physical models and parameter estimation strategies

East site position uncertainty



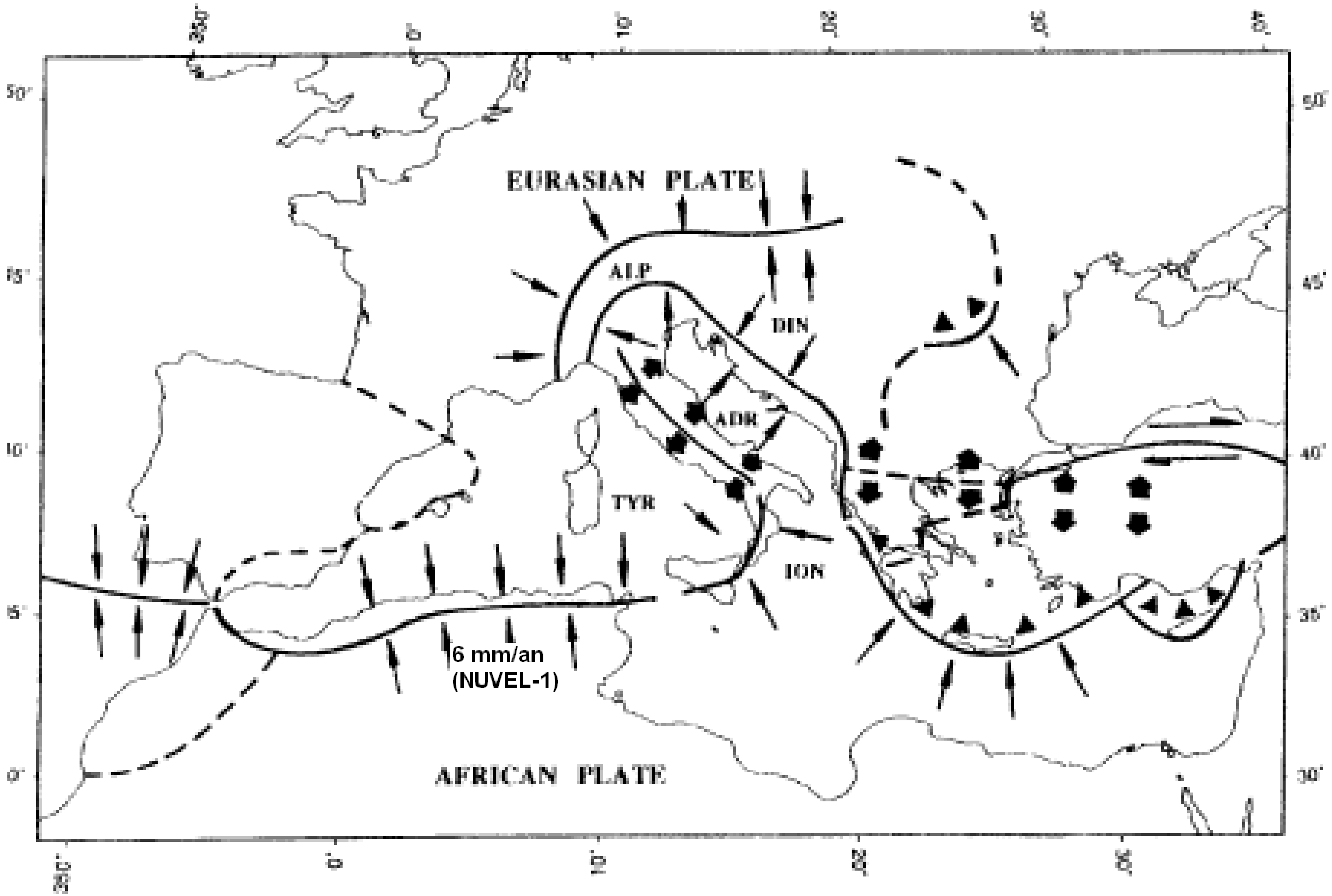
3D GPS satellite position uncertainty

(R. Reilinger, MIT)



CRUSTAL DEFORMATIONS MONITORING BY GPS IN NORTHERN ALGERIA

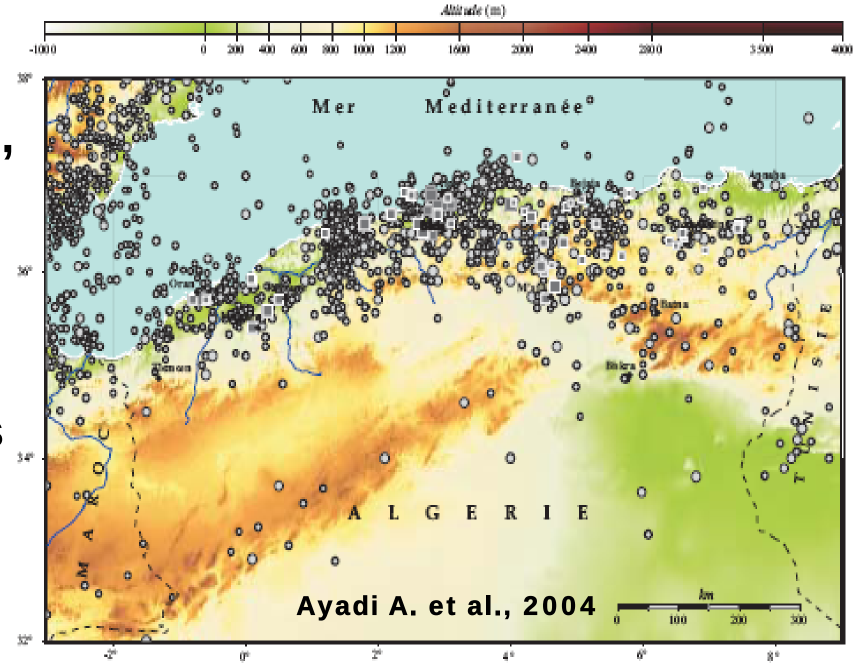
African and Eurasian Plates Boundaries



Geodynamical Context of the North of Algeria

The North of Algeria, situated at the tectonic plate boundary, particularly a complex limit of plates; it is an area with an :

- ✓ **Intense seismic activity : El Asnam (54-80), M=7.3; Tipaza, M=6.0; Aïn Témouchent, M=5.8; Boumerdès (2003), M=6.8);....**
- ✓ **Geodynamical history of several phases**
- ✓ **Fast variation of the geological structures**



Deformation

1. **A convergence motion between the African and Eurasian plates,**
2. **Response of the higher crust to the tractions by the influence of the forces.**

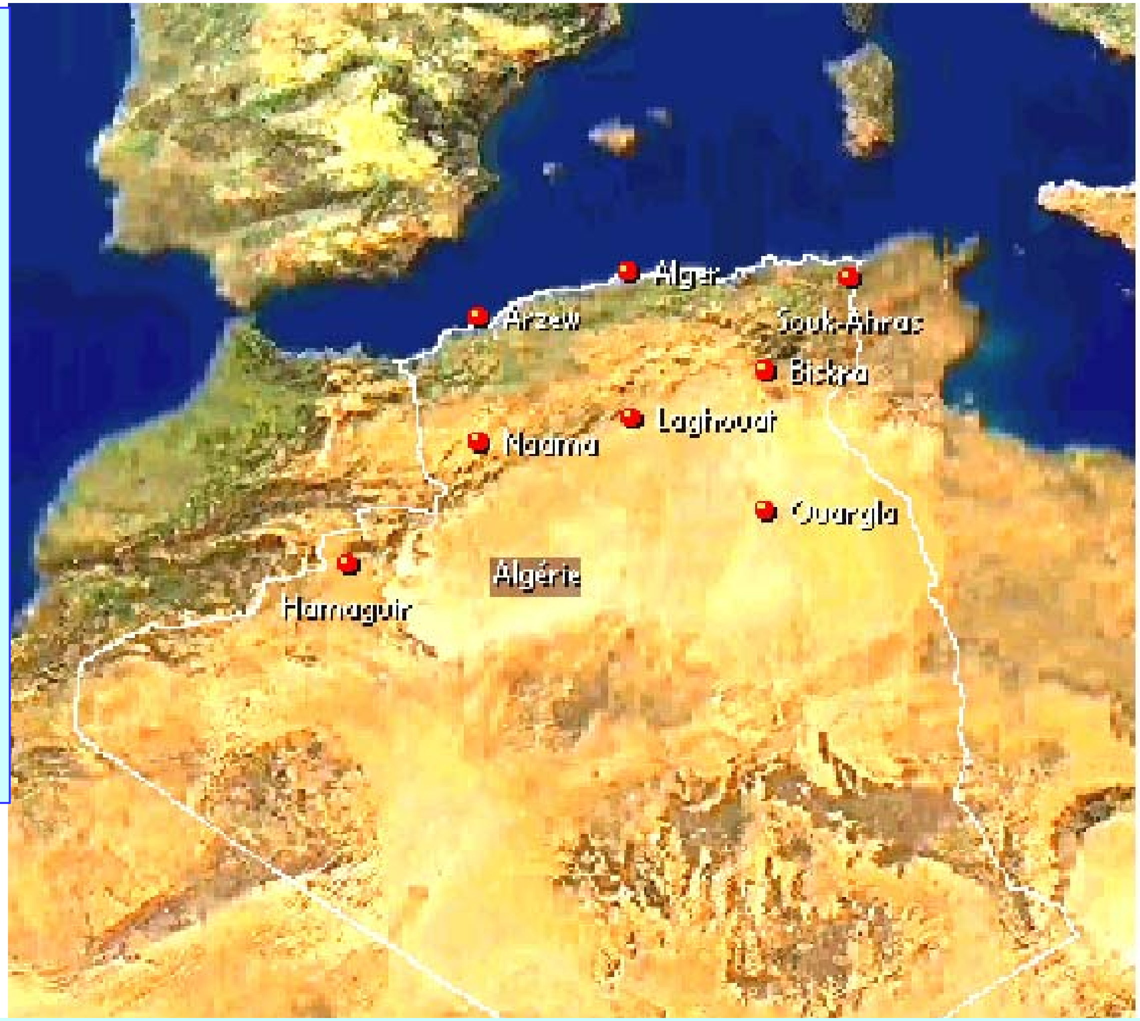
In Earth science, GPS is today a very powerful tool to quantify the tectonic movements.

ALGEONET PROJECT (ALgerian GEOdynamical NETwork)

GPS Campains : 1995 to 2004

Considered TYRGEONET Stations:

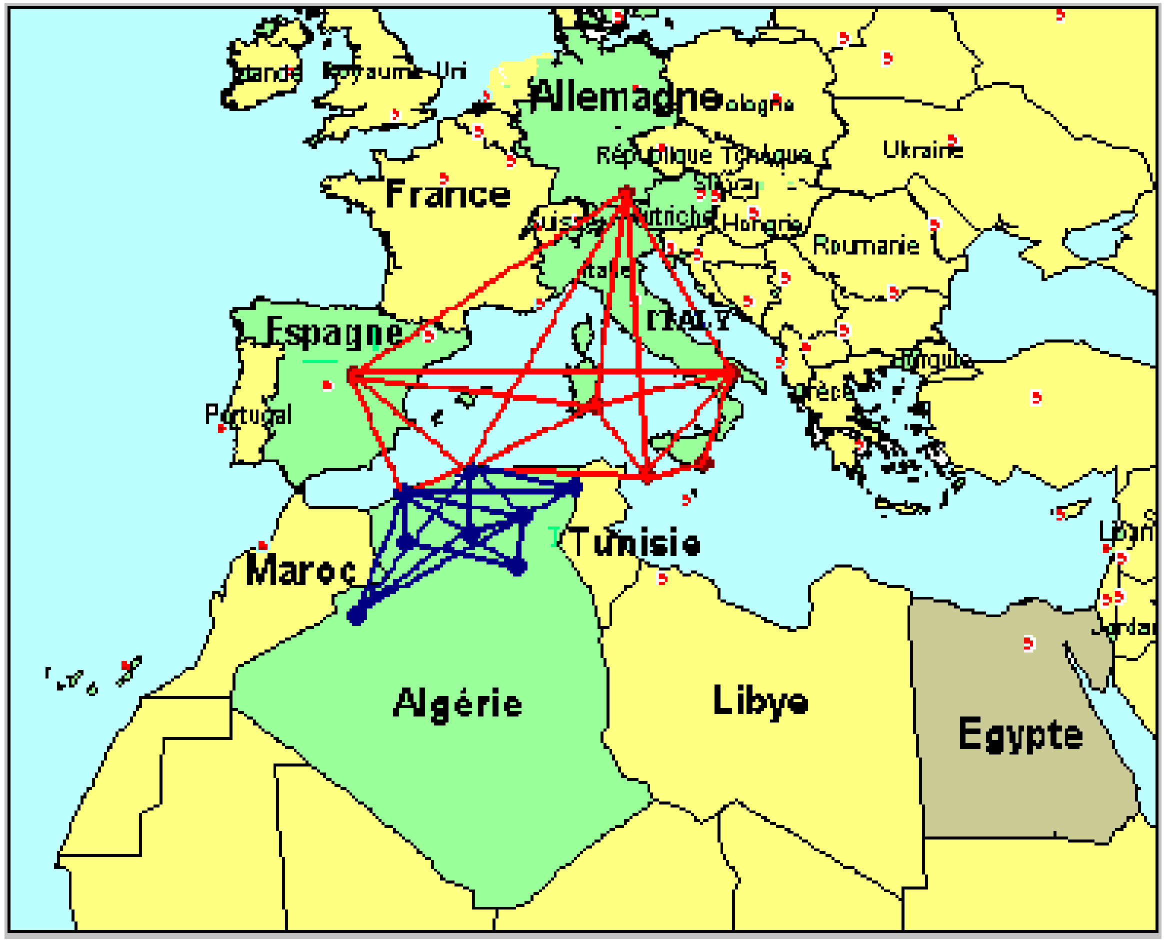
- ▲ Algiers ▲ Arzew
- ▲ Madrid
- ▲ Zimmerwald
- ▲ Noto
- ▲ Rabat
- ▲ Ceuta
- ▲ Matera
- ▲ Toulouse
- ▲ Wettzell
- ▲ Lampedusa
- ▲ Grasse
- ▲ Graz
- ▲ Cagliari



The aim of the Project :

Crustal deformation monitoring in the Mediterranean region with GPS.

INTEGRATION OF *TYRGEONET* AND *ALGEONET* NETWORKS



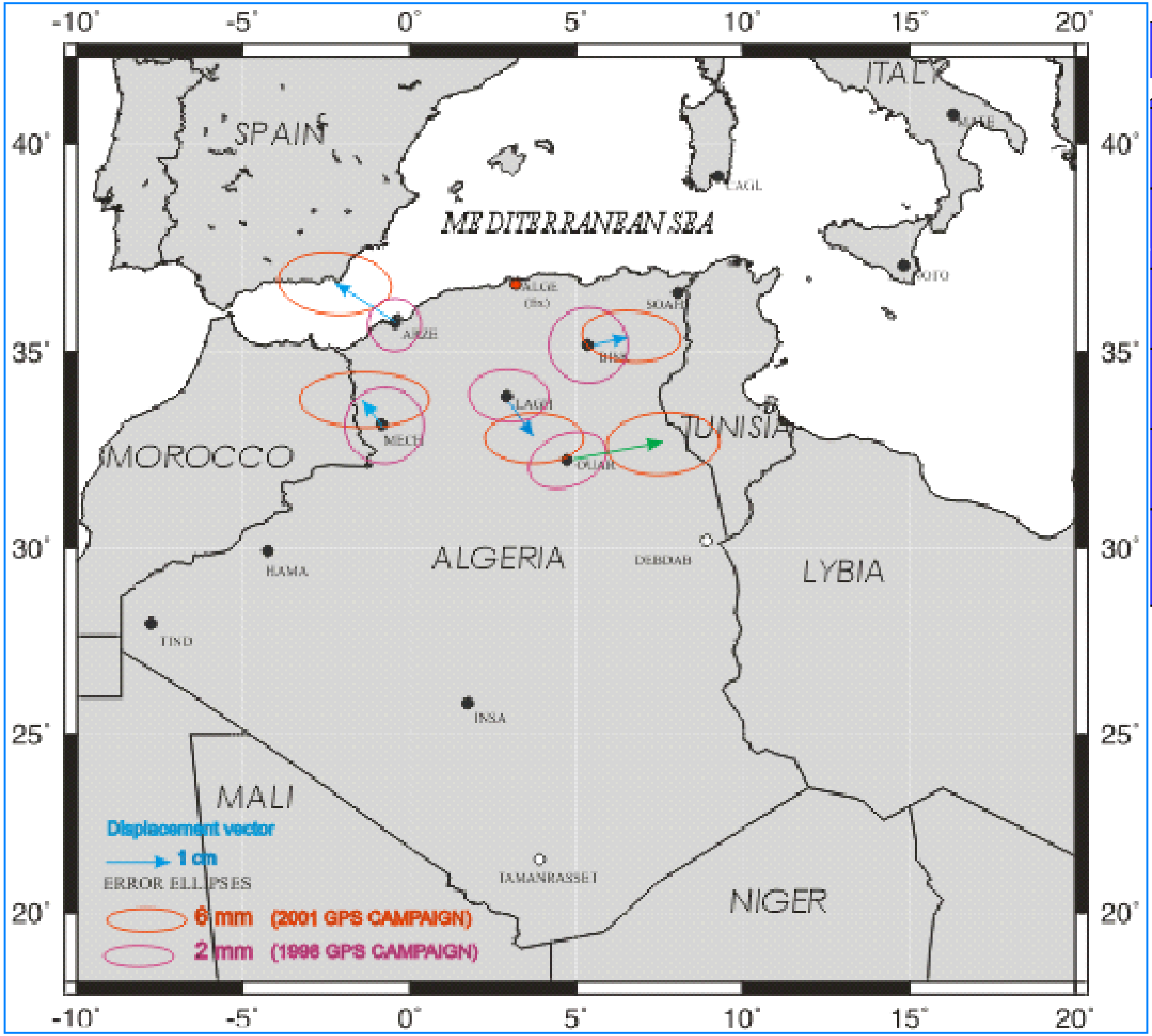
General features of the two GPS campaigns :

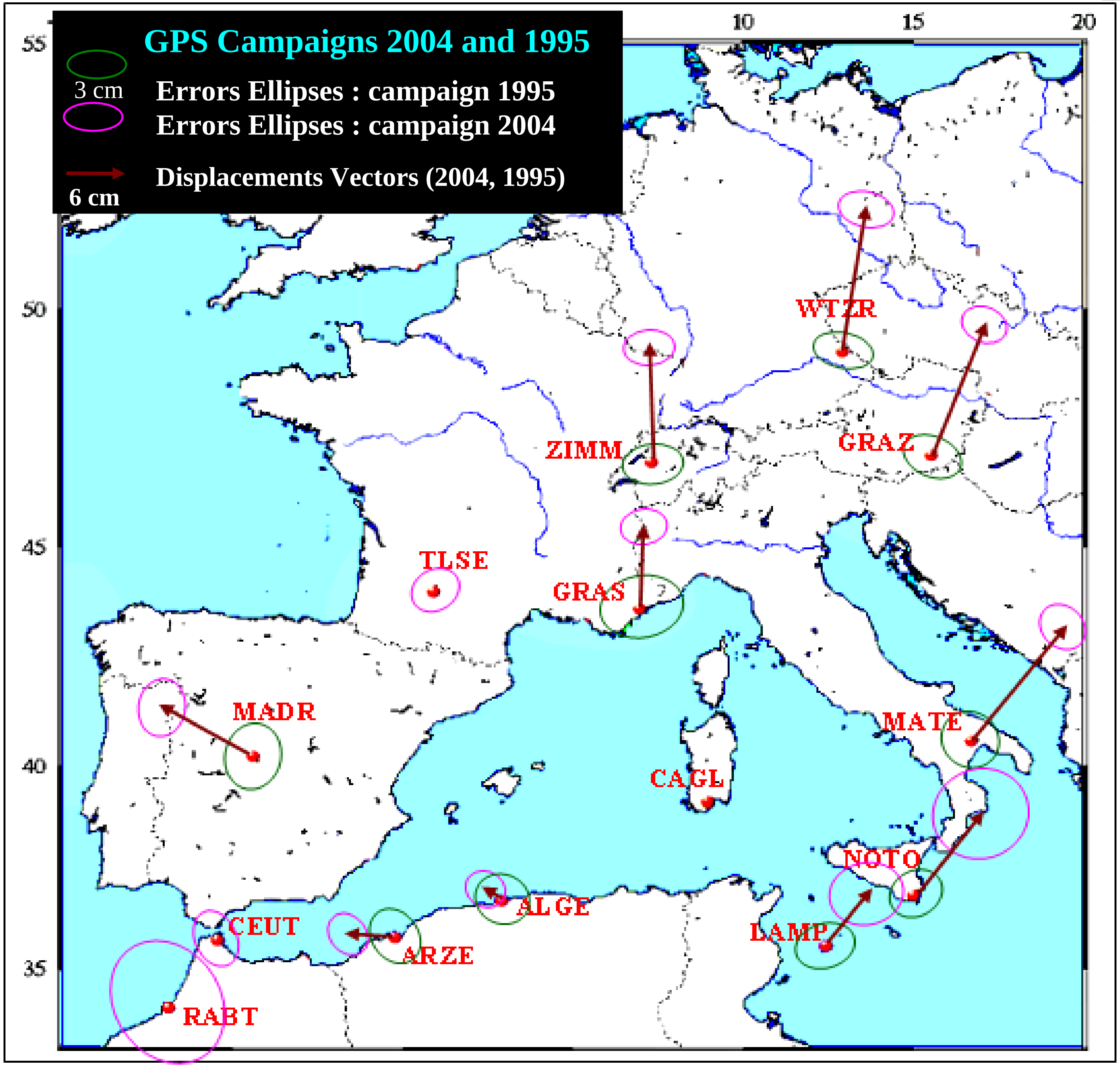
- **Occupations : 5 to 7 days**
- **Time window : 24 h,**
- **Sampling Rate : 30 s,**
- **Cut off angle : 15°,**
- **Bifrequency Receivers**

Tools and parameters of GPS data processing :

- **Software used : Bernese v4.2 and Netgps,**
- **Use of IGS precise ephemeris, satellite clock corrections ,**
- **The ionospheric dispersion taken into account estimating a model by the L_4 (geometry free) linear combination of the L_1 and L_2 observables ,**
- **Troposphere : Saastamoinen standard model was used ,**
- **Eccentricity of the phase centres reduced (orientation) ,**
- **Other effects (Tides,...) : averaged over a period of 7 days of observations .**

ALGEONET PROJECT : 2001-1998 GPS campaigns

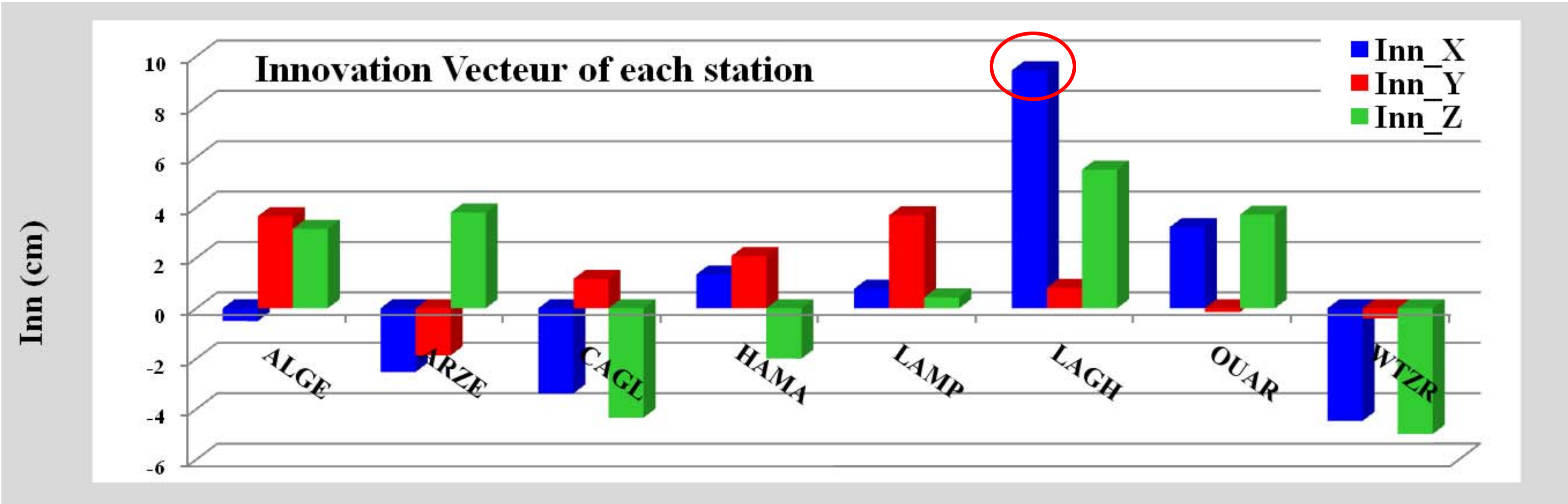




GPS Campaigns 2004 and 1995
3 cm
Errors Ellipses : campaign 1995
Errors Ellipses : campaign 2004
6 cm
Displacements Vectors (2004, 1995)
10
15
20
55
50
45
40
35
WTZR
ZIMM
GRAZ
TLSE
GRAS
MADR
MATE
CAGL
NOTO
ALGE
CEUT
LAMP
ARZE
RABT

The Kalman Filter on the North of Algeria

Innovation of the 2001 period



Results :

➢**Amplitudes of the innovation vector are in centimeter order, significant innovation on the station LAGH;**

➢**In addition, we remark that the similarity to the CAGL and ARZE stations, and a certain confidence between the measurements performed in 2001 and predicting the state vector in the same period.**

URBAN MONITORING AT ORAN CITY

The GPS network, established initially to conduct several infrastructural projects, is a adapted tool to observe and quantify the crustal deformation and probable landslides in the city, deducted from periodic measurements.

The GPS network of Oran city

Main steps of the Project:

1. Reconnaissance, Monumentation,
2. GPS Measurements (using bifrequencies Receivers Ashtech ZXII-3)
3. Data Analysis and Processing,
4. Transformation of coordinates from WGS84 to Nord Sahara 1959 and linking of the ellipsoidal heights to the national reference NGA,
5. Development of Database: BDRGO.

Network caracteristics:

- Final configuration : 65 sites
- Mean Distance between the GPS sites: 1 - 6 km, with the condition of visibility on at least 3 points.
- Monumentation of the 65 stations

Ministère des Travaux Publics

Direction des Travaux Publics
de la Wilaya d'Oran

RESEAU DE POINTS GEODESIQUES DE LA VILLE D'ORAN

Echelle 1:30 000

LEGENDE

NATURE DES POINTS GEODESIQUES

- ▲ Borne
- ▲ Mirette
- ▲ Inaccessible (Mosq., Minaret, Chât. d'eau)

TOPOGRAPHIE

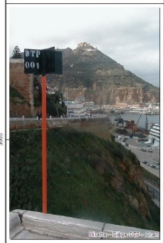
- Route nationale
- Route secondaire
- Route étroite
- Chemin de fer
- Limite de commune
- Rond point
- Echangeur

Système géodésique Nord - Sahara 1959
Projection : UTM, Fuseau :30
Quadrillage kilométrique

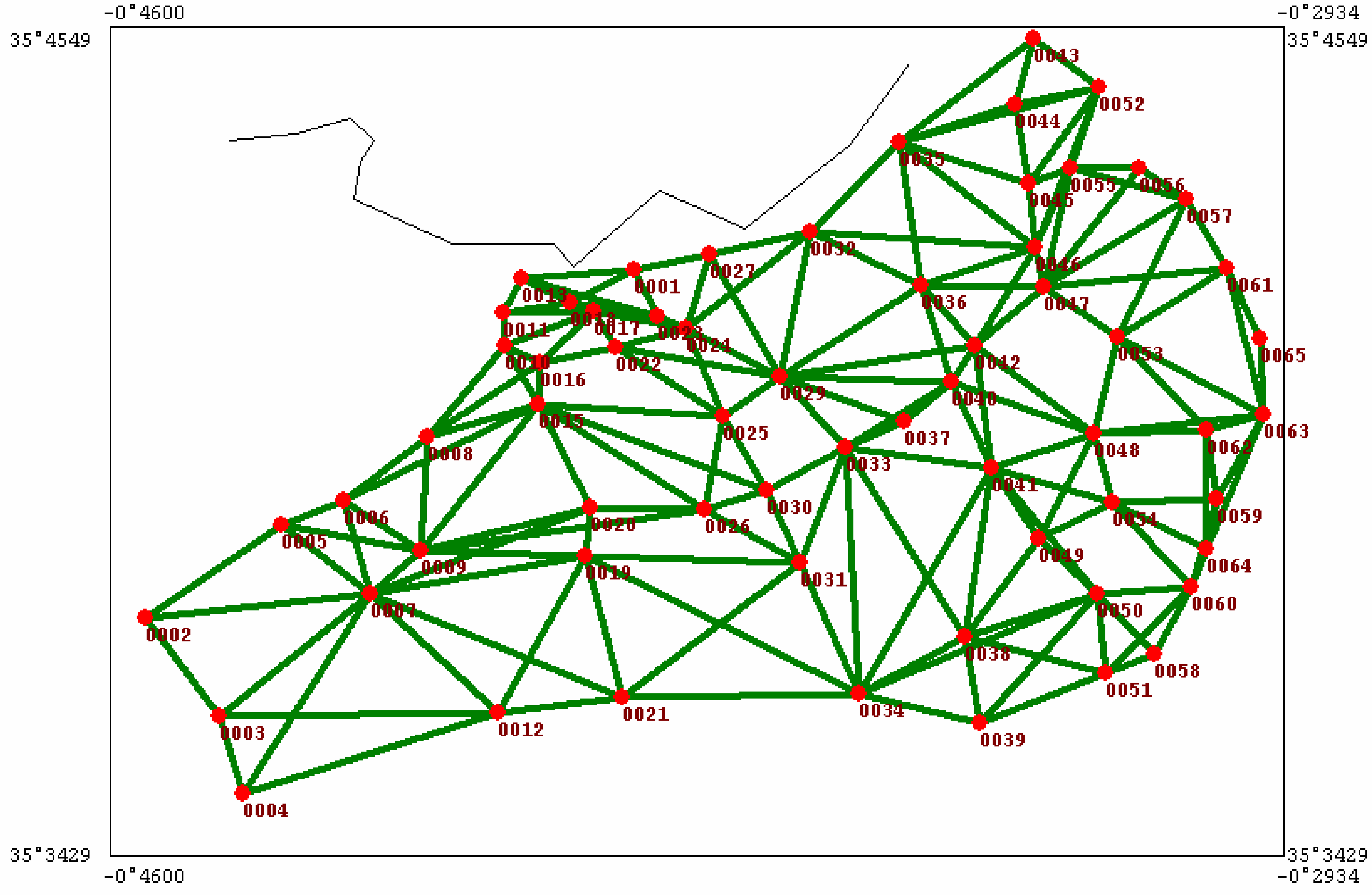
Sources : Image Spot 5 du 21-12-2004

Les données topographiques ainsi que les limites de commune ne sont portées qu'à titre indicatif pour faciliter la localisation des points géodésiques

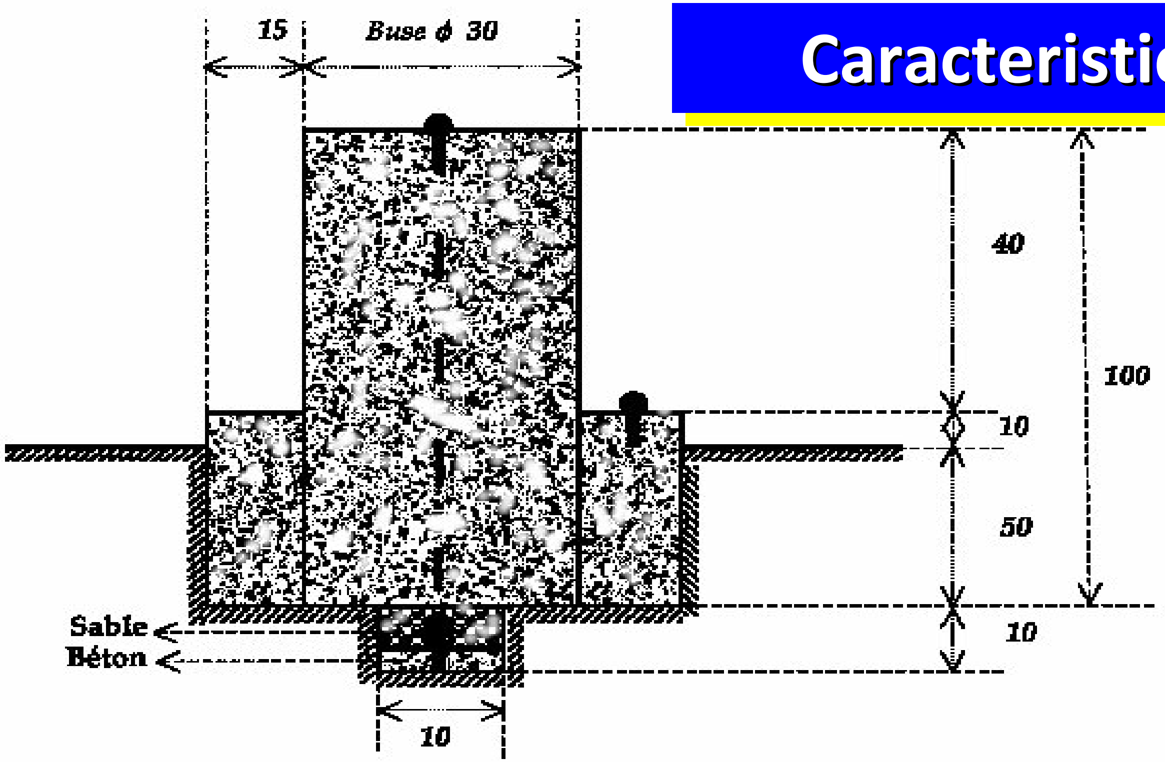
Etablie et éditée par le Centre des Techniques Spatiales, 1 Avenue de la Palestine Arzew - Juillet 2009

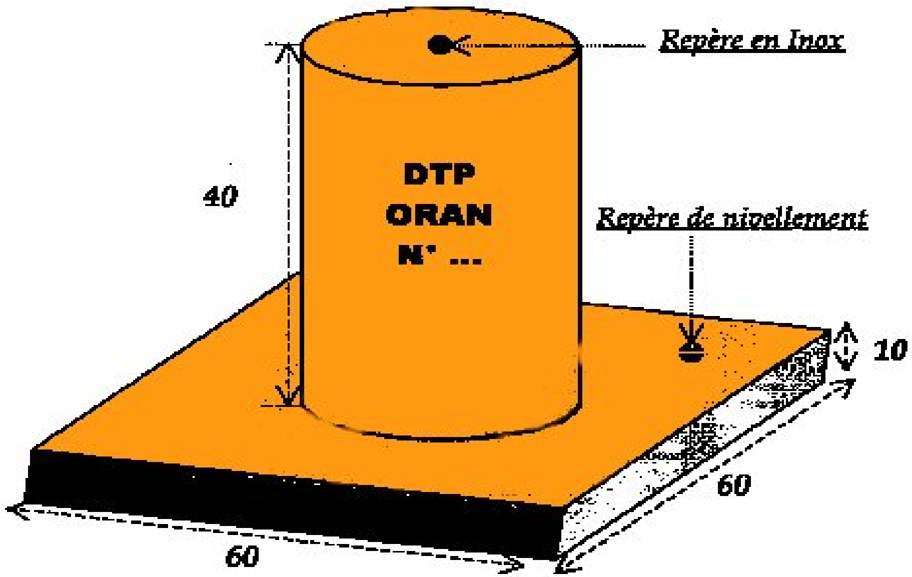


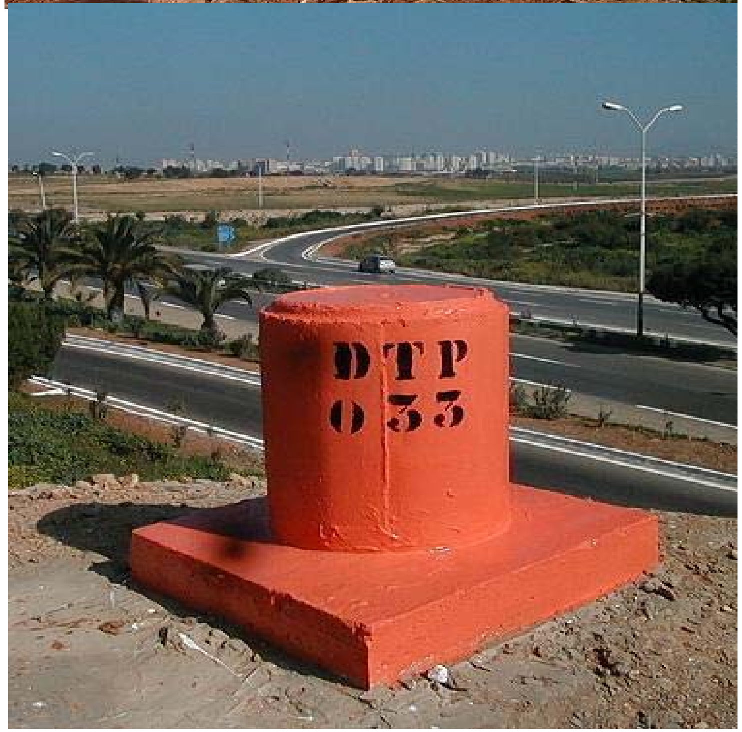
ORAN Geodetic Network: $\Delta\phi \cong$ 11' $\cong$ 20 Km $\Delta\lambda \cong$ 17' $\cong$ 25 Km



Caracteristics of the Pilars







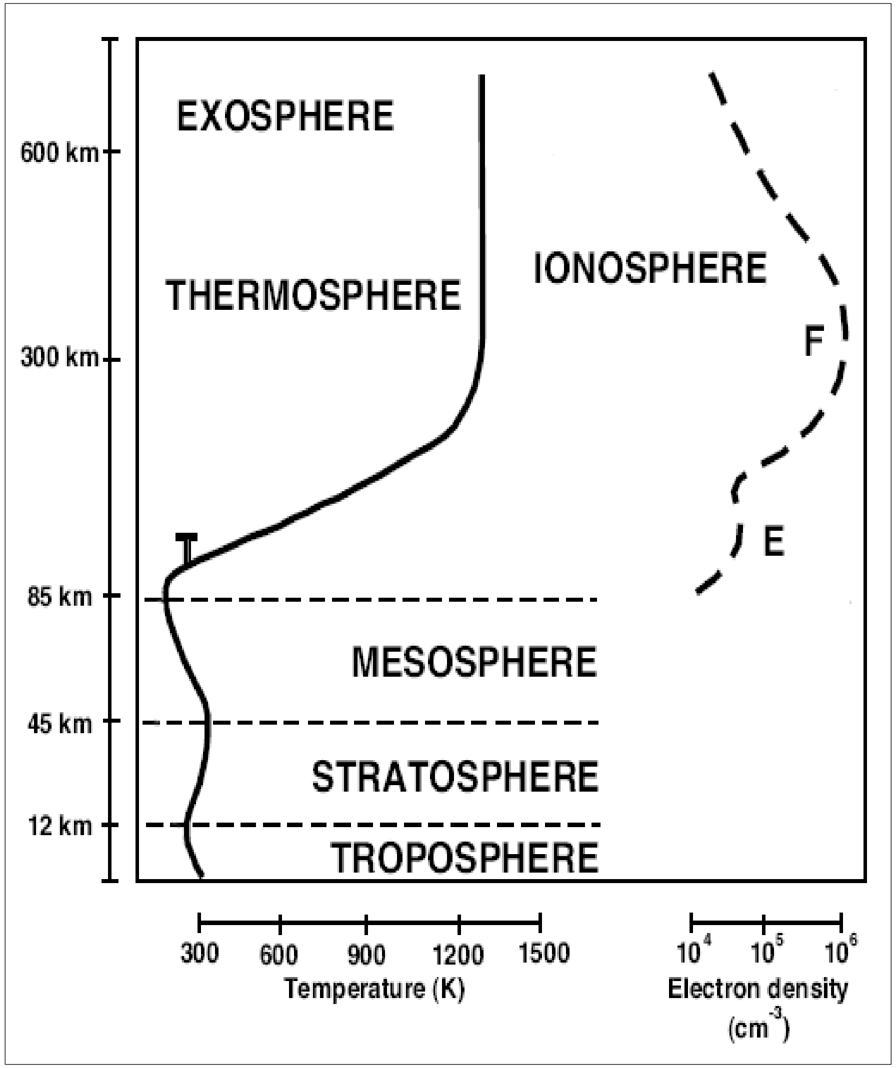
ATMOSPHERIC MODELISATION :

- **IONOSPHERIC MODELISATION (2D & 3D)**
- **TROPOSPHERIC MODELISATION (** Optimal choice)

GPS Signal in Atmosphere

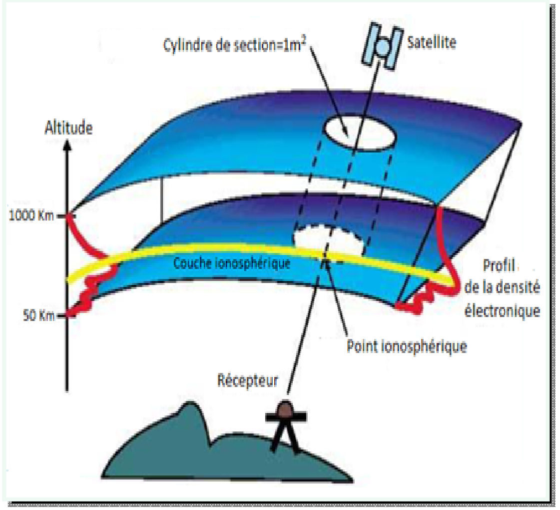
- Refractive zones of the atmosphere:
  - Ionosphere
  - Troposphere

- Impact on GPS Signals:
  - Non-linear path
  - Signal Slowdown
  - Increased travel time "satellite-receiver" : **Delay**



The Ionosphere

- The ionosphere is the high layer of the atmosphere with a high density in ions and electrons



- Divided in 3 layers:
  - D region (50 to 90Km);
  - E region (90 to 120Km);
  - F region (120 to 500Km).

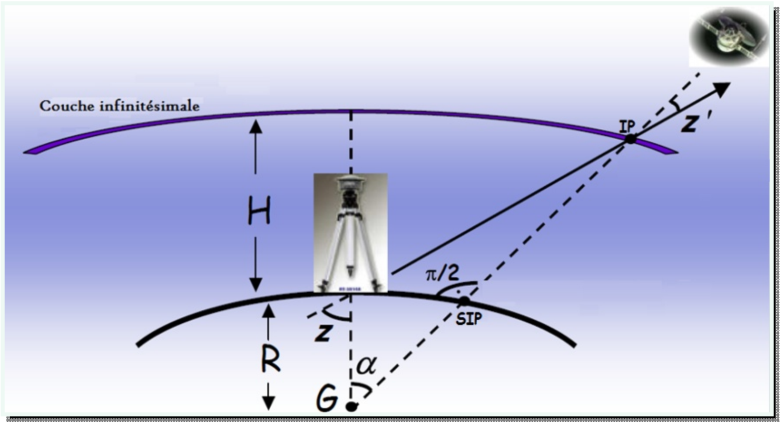
- Practically, we use the notion of (TEC, " *Total Electron Content* ") witch is defined as the number of free electrons (N electronic density) along the track (dl) between the satellite and the receiver.

$$TEC = \int_{recepteur}^{satellite} N_e \, dl$$

- the TEC Unit (TECU = 10^{16} electron/m^2).

Ionospheric Modelisation

- **The 2D ionospheric modelisation is based on the (SLM, *Single Layer Model*) principle, at 350 km altitude (maximum of the electron density)**



STEC=M(z)*VTEC

M(z)=1/cos z' : Fonction of projection between Slant TEC and vertical TEC

Ionospheric delay : $\Delta_i^{iono} = \pm(\cos z')^{-1} \dfrac{40.3}{f^2} VTEC$

Global modelisation of the delay :

$$VTEC(S,\Phi) = \sum_{i=0}^{n}\sum_{j=0}^{m} P_{ij}(\sin\Phi)\left(a_{ij}\cos jS + b_{ij}\sin jS\right)$$

Local modelisation :

$$VTEC(S,\Phi) = \sum_{i=0}^{n}\sum_{j=0}^{m} E_{ij}(S-S_0)^i(\Phi-\Phi_0)^j$$

S : Sun hour angle

Φ : Latitude du point *IP*

n : Degree maximum of the developpement in spherical harmonics

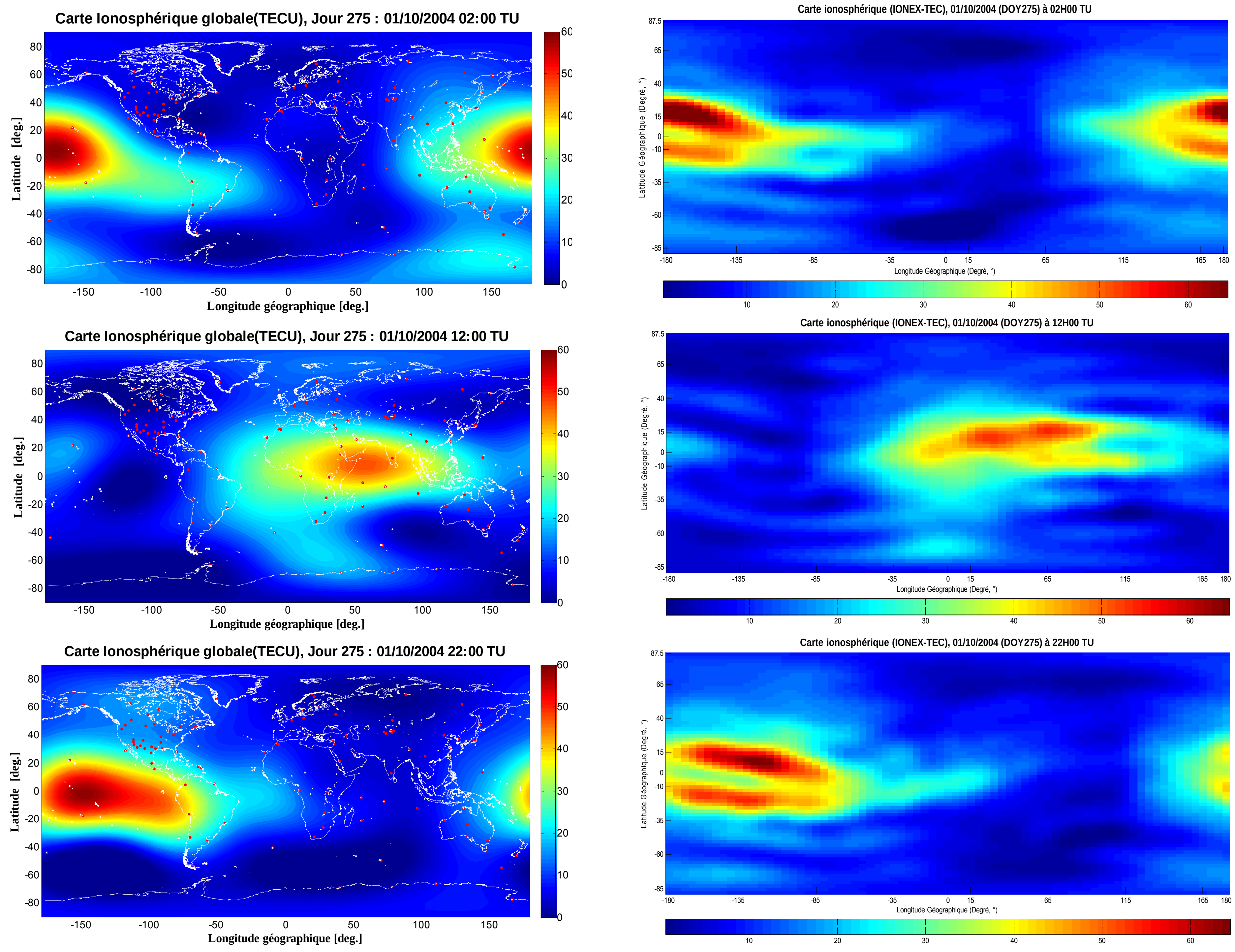
a, *b* : Coefficients (unknowns) of the TEC spherical harmonics

P_{ij} : Associated Legendre normalised functions (degree i and order j)

2D IONOSPHERIC MODELISATION

Global Ionospheric maps

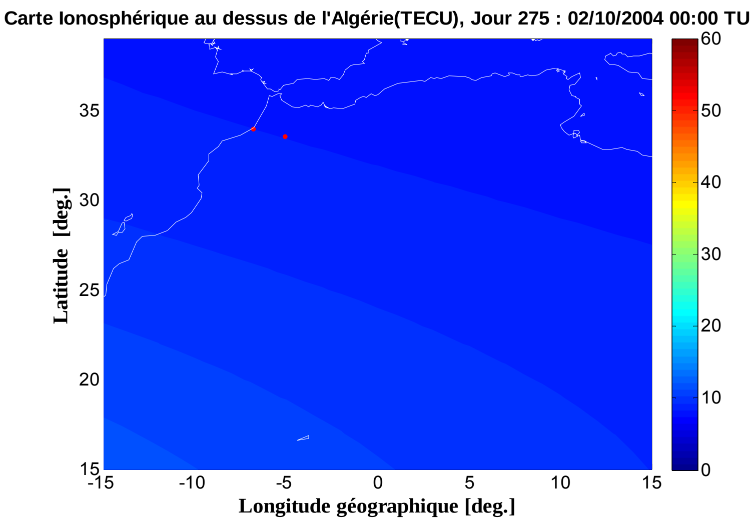
- **Comparison between the model processed with the spherical harmonics functions and the model deducted from GIMs (Global Ionospheric Maps) of the CODE, in IONEX (IONosphere Exchange) format.**


Carte Ionosphérique globale(TECU), Jour 275 : 01/10/2004 02:00 TU
Latitude [deg.]
Longitude géographique [deg.]
Carte ionosphérique (IONEX-TEC), 01/10/2004 (DOY275) à 02H00 TU
Latitude Géographique (Degré, °)
Longitude Géographique (Degré, °)
Carte Ionosphérique globale(TECU), Jour 275 : 01/10/2004 12:00 TU
Latitude [deg.]
Longitude géographique [deg.]
Carte ionosphérique (IONEX-TEC), 01/10/2004 (DOY275) à 12H00 TU
Latitude Géographique (Degré, °)
Longitude Géographique (Degré, °)
Carte Ionosphérique globale(TECU), Jour 275 : 01/10/2004 22:00 TU
Latitude [deg.]
Longitude géographique [deg.]
Carte ionosphérique (IONEX-TEC), 01/10/2004 (DOY275) à 22H00 TU
Latitude Géographique (Degré, °)
Longitude Géographique (Degré, °)

2D IONOSPHERIC MODELISATION

Local Ionospheric maps

- **Ionospheric local model (on Algeria) processed by the spherical harmonics functions, using nearest (Maroc, South Europa) IGS stations (each 6 H).**


Carte Ionosphérique au dessus de l'Algérie(TECU), Jour 275 : 02/10/2004 00:00 TU
Latitude [deg.]
Longitude géographique [deg.]
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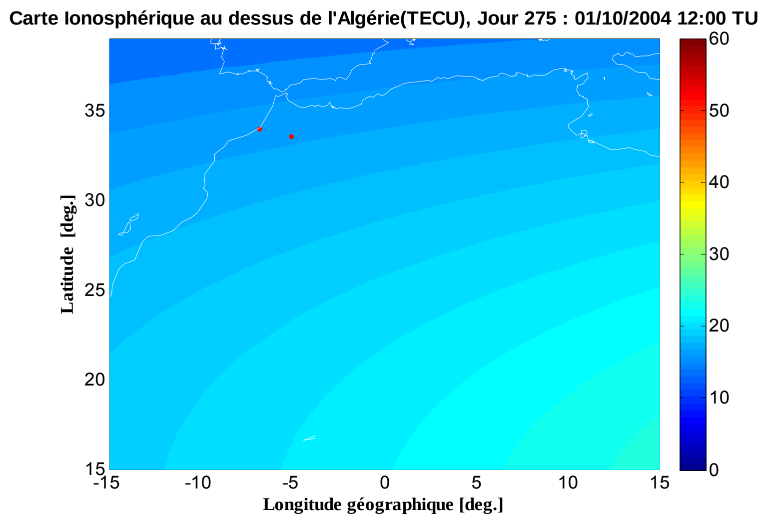
Carte Ionosphérique au dessus de l'Algérie(TECU), Jour 275 : 01/10/2004 12:00 TU
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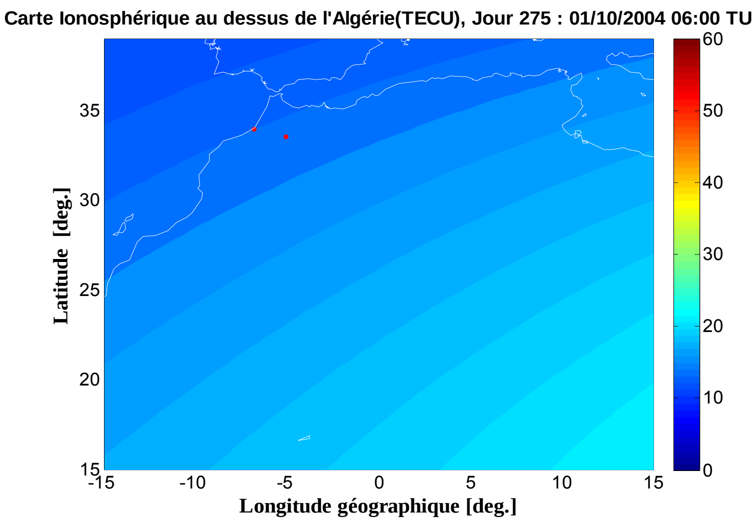
Carte Ionosphérique au dessus de l'Algérie(TECU), Jour 275 : 01/10/2004 06:00 TU
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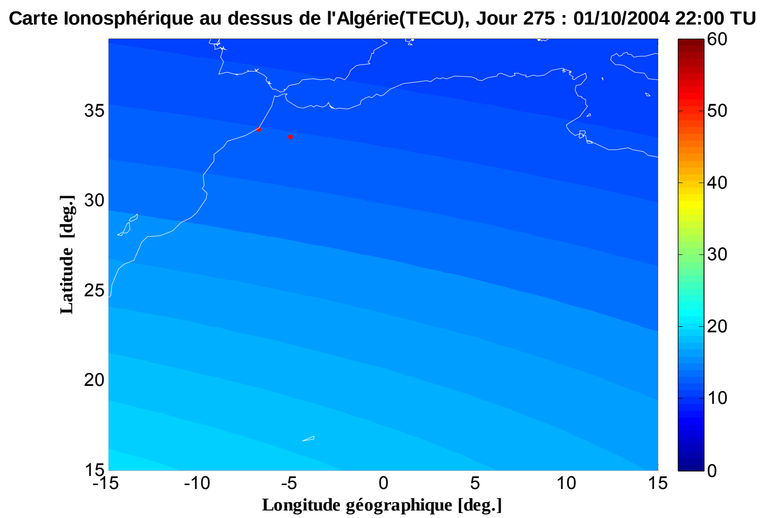
Carte Ionosphérique au dessus de l'Algérie(TECU), Jour 275 : 01/10/2004 22:00 TU
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Longitude géographique [deg.]
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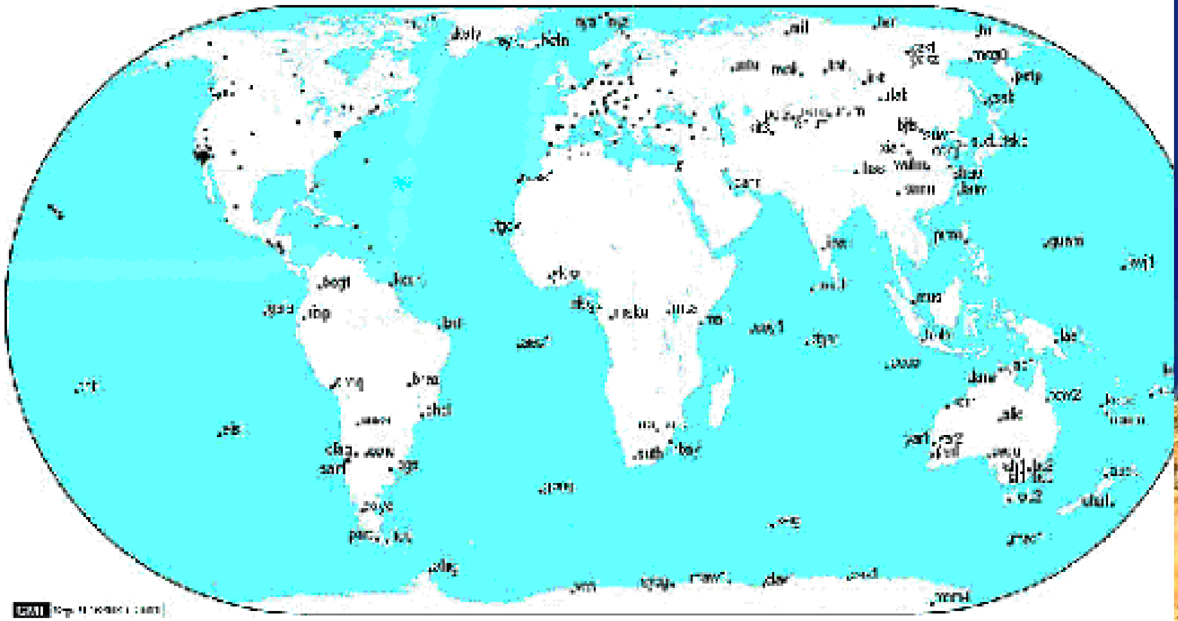
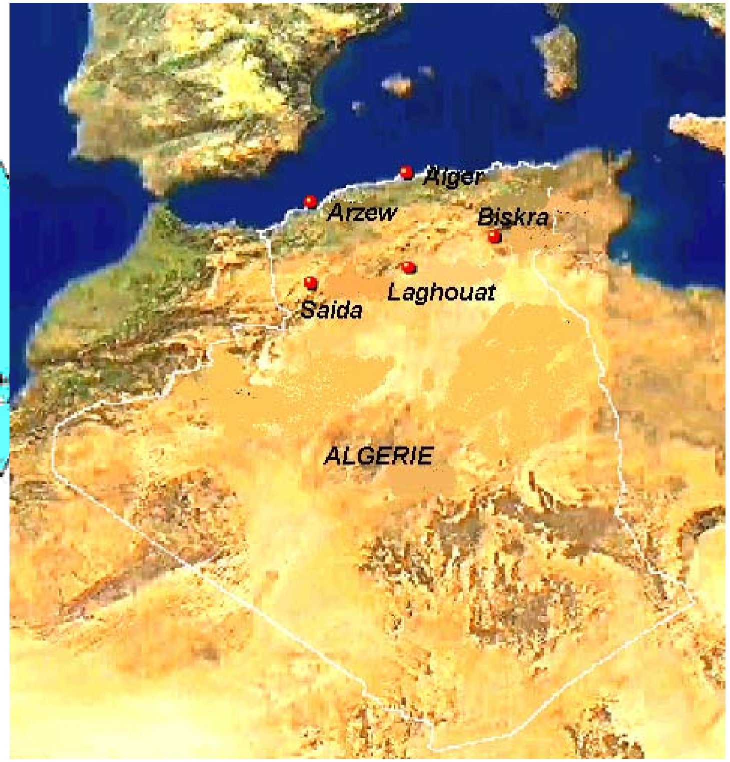
PROCESSING THE TEC FROM GPS DATA

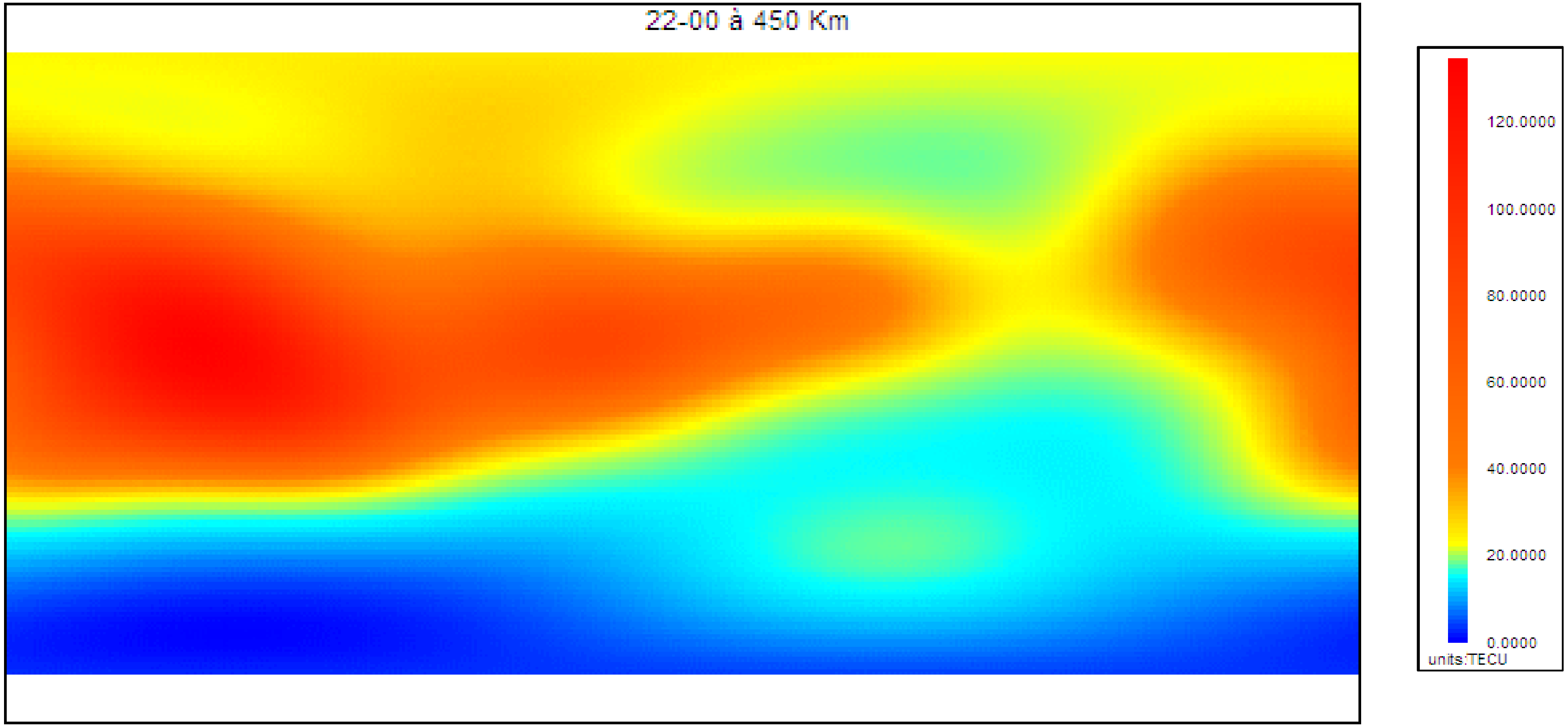
108 IGS stations IGS + 06 stations ALGEONET

24 hours observation





Ionospheric Map in 2D



Daily variation of the TEC at 450 Km height

IONOSPHERIC TOMOGRAPHY (3D)

Ionospheric Tomography = Spherical Harmonical functions (2D)

+

Orthogonal empirical functions (Altitude)

Modelisation of the horizontal and vertical ionosphere profil

$$\delta N_e(\lambda,\phi,z) = \sum_{k=1}^{K}\sum_{m=-M}^{M}\sum_{n=|m|}^{M}\left[a_{nk}^{m}\,\cos(m\lambda) + b_{nk}^{m}\,\sin(m\lambda)\right]\,P_n^m(\cos(\phi))\,\,Z_k(z)$$

Ne : Electronic density

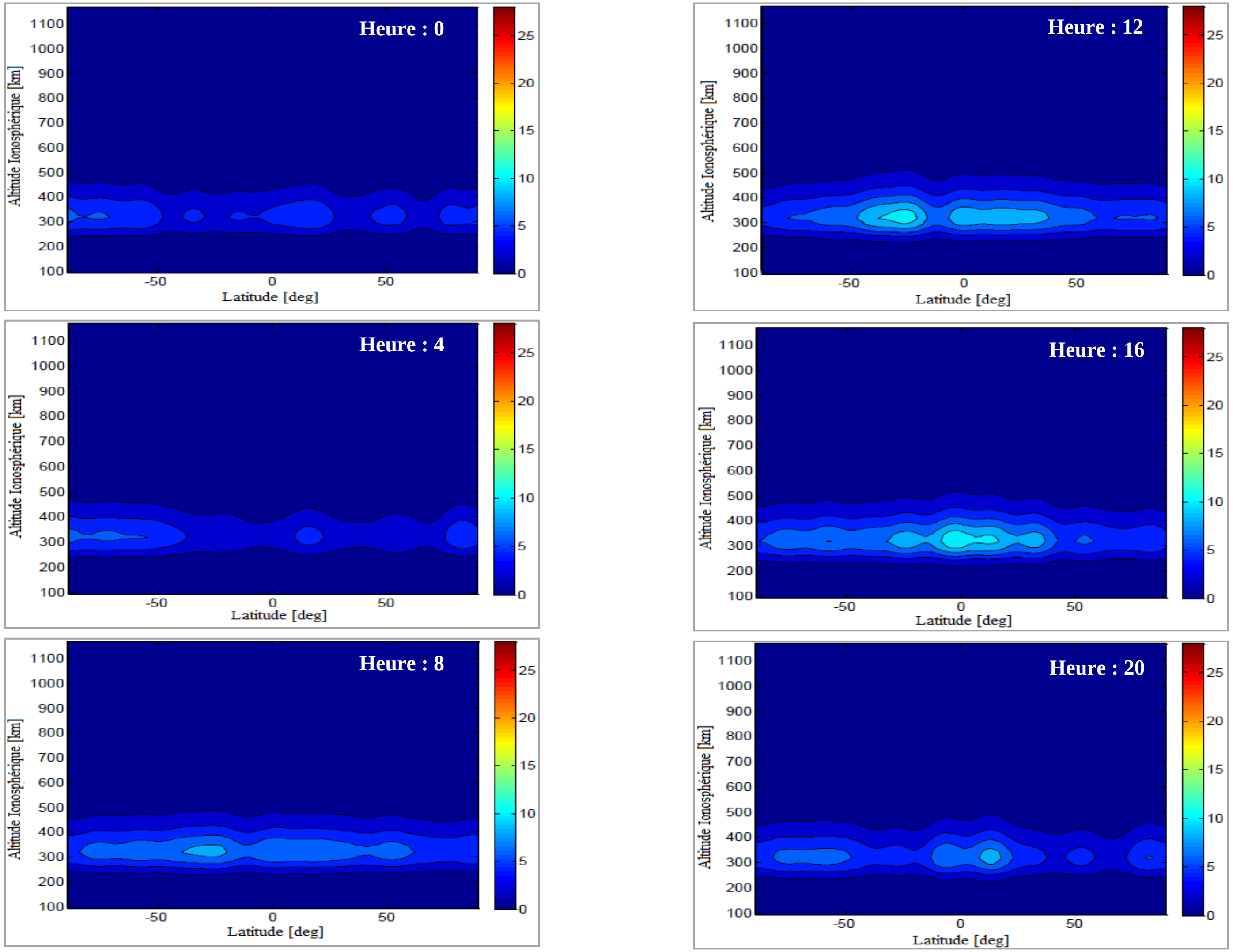
$P_n^m(\cos(\phi))$: Associated Legendre Polynôme, (degree *n* and order *m*

$Z_k(z)$: Empirical orthogonal functions (FEOs)

a, b : Coefficients of the model (to be estimated)

K, M : maximum order of the FEOs and FHSs, development respectively

Tomografical model based on the FHS and FEO (preliminary resultst)



Imges of tomography (electronic density,×$10^{11}$$e^-/m^3$), DOY275 (01.10.2004)

Tropospheric modelisation

- The troposphere is extending from the earth to 50 kilometres
- The troposphere is a non-dispersive medium for signal frequencies below 30 GHz.
- The Tropospheric error cannot be effectively reduced by dual-frequency GPS observations as used to eliminate the ionospheric error.

Objectives : **Optimal Choice for the Estimation of Precise GPS Stations Coordinates**

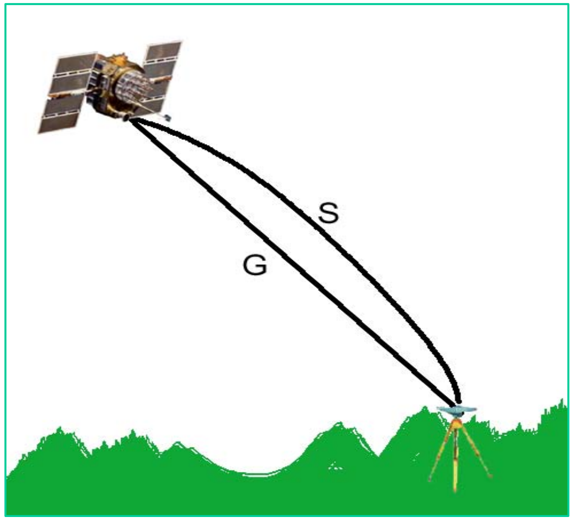
Tropospheric Delay

Physical origin and equation

$$L = \int_S n ds$$

$$\Delta L = [\int_S n ds] - G = [\int_S (n-1) ds] + (S - G)$$

$$\simeq \int_S (n-1) ds$$



Propagation Delay

Curvature of the trajectory

$$\Delta L = 10^{-6} \int_S N ds \qquad N = 10^6 (n-1)$$

Refractivity

$$N = k_1 R_d \rho + R_v [k_2' + \frac{k_3}{T}] \rho_{eau}$$

Density of total air

Density of water vapor

Tests and Results

To conduct our study, several tests were conducted :

1. Short Baseline Oran - Murdjadjo
2. Long Baseline Algiers-Tamanrasset

Baseline Oran -Murdjadjo
✓ short baseline (B = 9 km)
✓Big slope Baseline (Dh = 550 m)

The Bernese software is software processing GPS data, developed at the University of Bern:

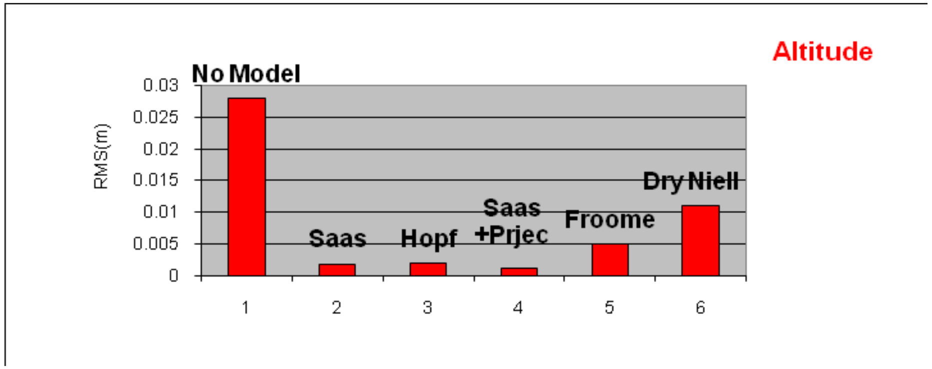
- Data processing of permanent networks.
- The determination of precise orbits.
- Parameter estimation of rotation of the earth.
- The calculation of an ionospheric model or the calibration antenna

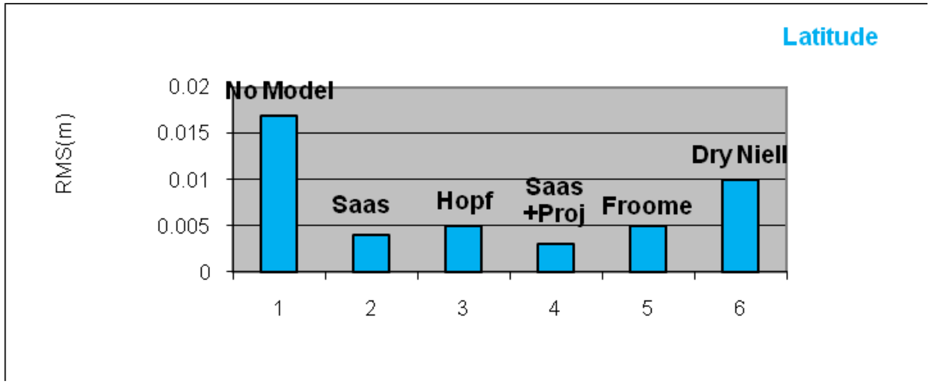
Optimal Choice for the Estimation of Precise GPS Stations Coordinates

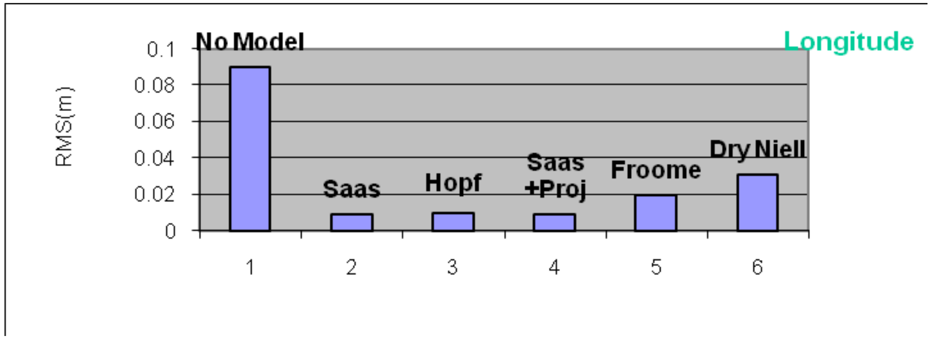
The variation of RMS based on the computational strategy used :

1. Without tropospheric model
2. Saastamoinen without projection function
3. Hopfield without projection function
4. **Saastamoinen with its projection function**
5. Essen and Froome
6. The function of Dry Niell without a priori model

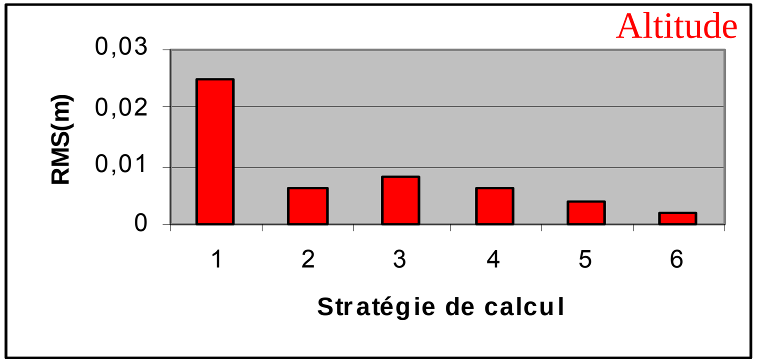
RMS over Three components of the position
1. Oran -Murdjadjo (D=9 Km, DH=550m)

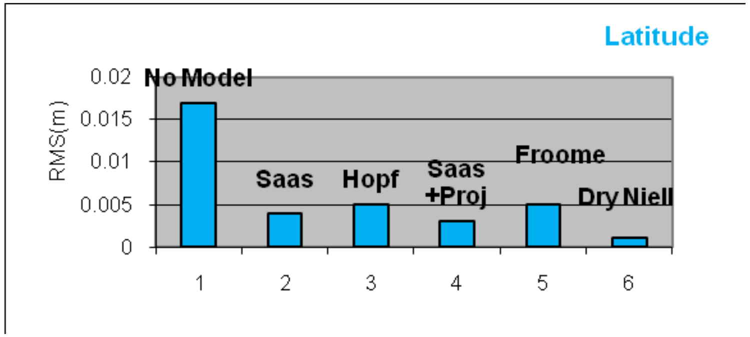


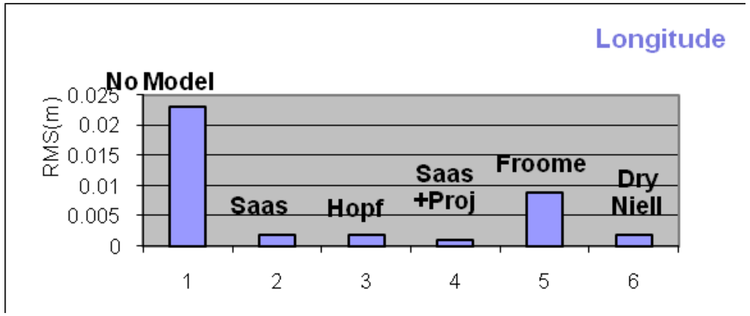




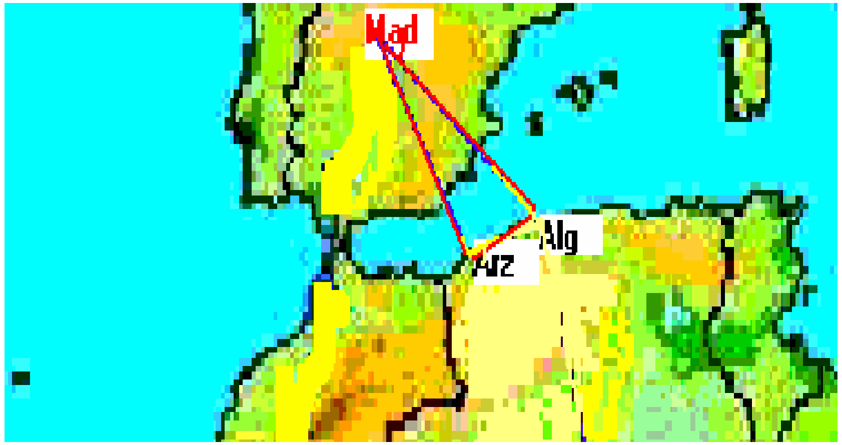
RMS over Three components of the position
2. Algiers-Tamanrasset



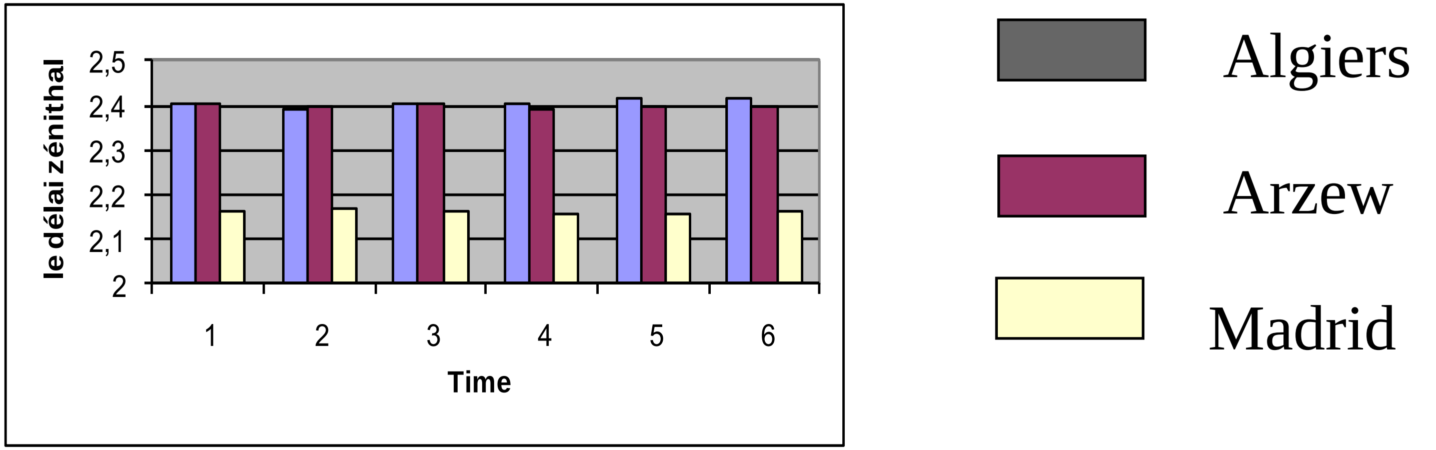




Results of a permanent network (Algiers, Arzew and Madrid)



- The Base Algiers -Arzew (400 km)
- The Base Algiers -Madrid (800 km)



Conclusions

The tropospheric delay experienced by GPS signals affects the positioning accuracy.

Case of short baselines

- The best results are obtained using the Saastamoinen model with its projection function.
- Non-use of models with or without tropospheric features projections give less accurate results

Case of long baselines

- The coastal stations (dry effect) tropospheric effect more important
- no adequate modelisation of the troposphere remove significantly the reference solution.

Perspectives

- Geodetic reference frame
- The REGAT project
- MIT- IPGS – Algerian institutions / MOU
- Other opportunities (Wegener Project,...)

Refection of the Algerian Geodetic reference network Using GNSS (GPS) Technology (INCT, CTS)

Classical (terrestrial) geodetic network

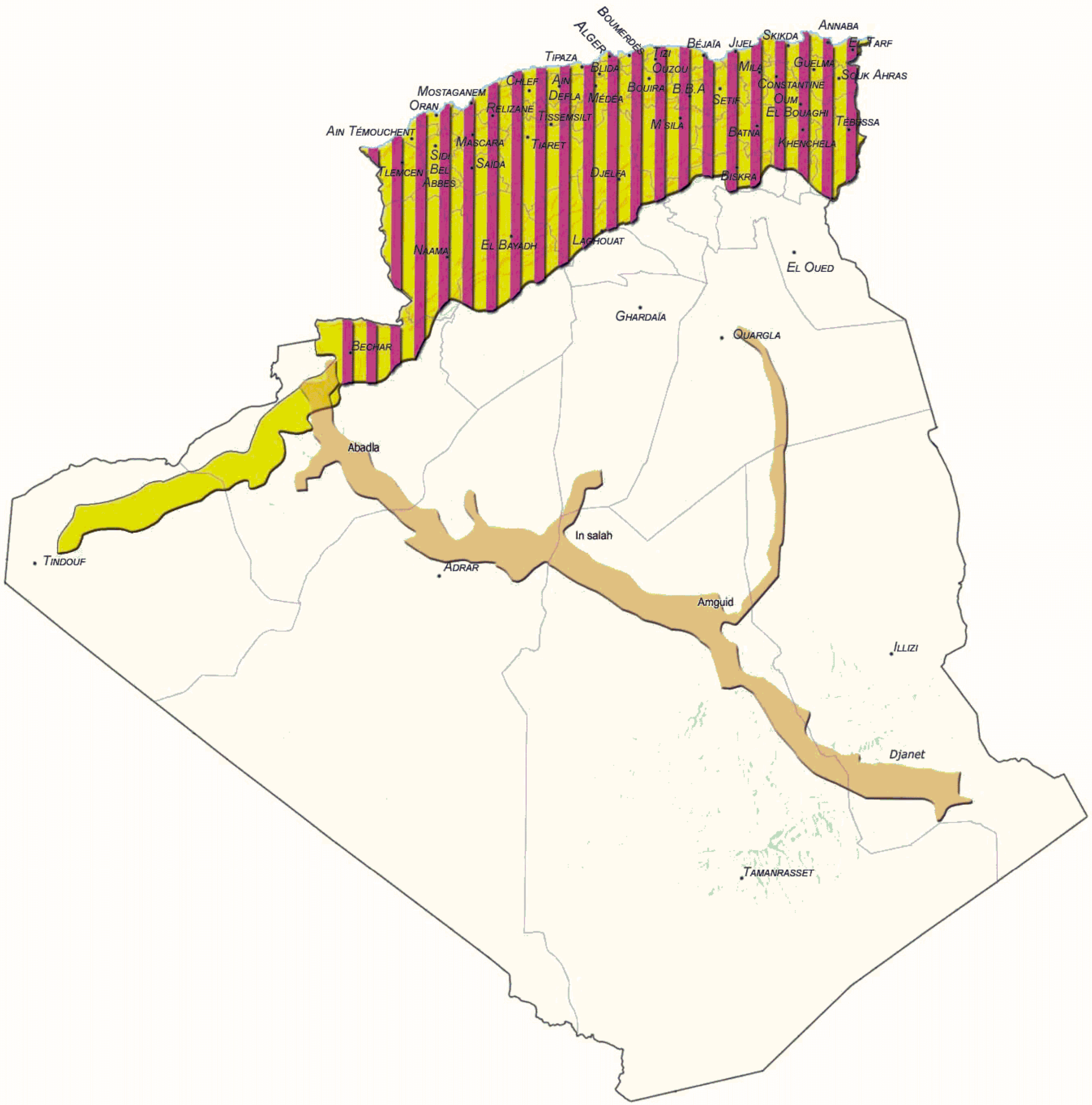
1st Order Network

- **450** points
- Distance of 30 to 45 km
- Used equipment : Theodolite T3
- Observations at night on projectors, 32 measures series
- Planimetric accuracy : ~ 10 à 15 cm.

2nd Order Network

- **3291** points
- Distance of 10 to 20 Kms
- Used equipment : Theodolite T3
- Observations in day. 08 to 16 series
- Planimetric accuracy: ~ 10 to 20 cm
- Geodetic levelling by using T3 with junction to General Levelling of Algeria (Levelling network)

GEODESIE CLASSIQUE



Géodésie 1er Ordre.

Géodésie 2éme ordre.

Axe 3000.

Réseau de Géodésie Classique

1er Ordre:

450 points matérialisés distants de 30 à 45 km.

2éme Ordre:

3291 points matérialisés distants de 10 à 20 km.

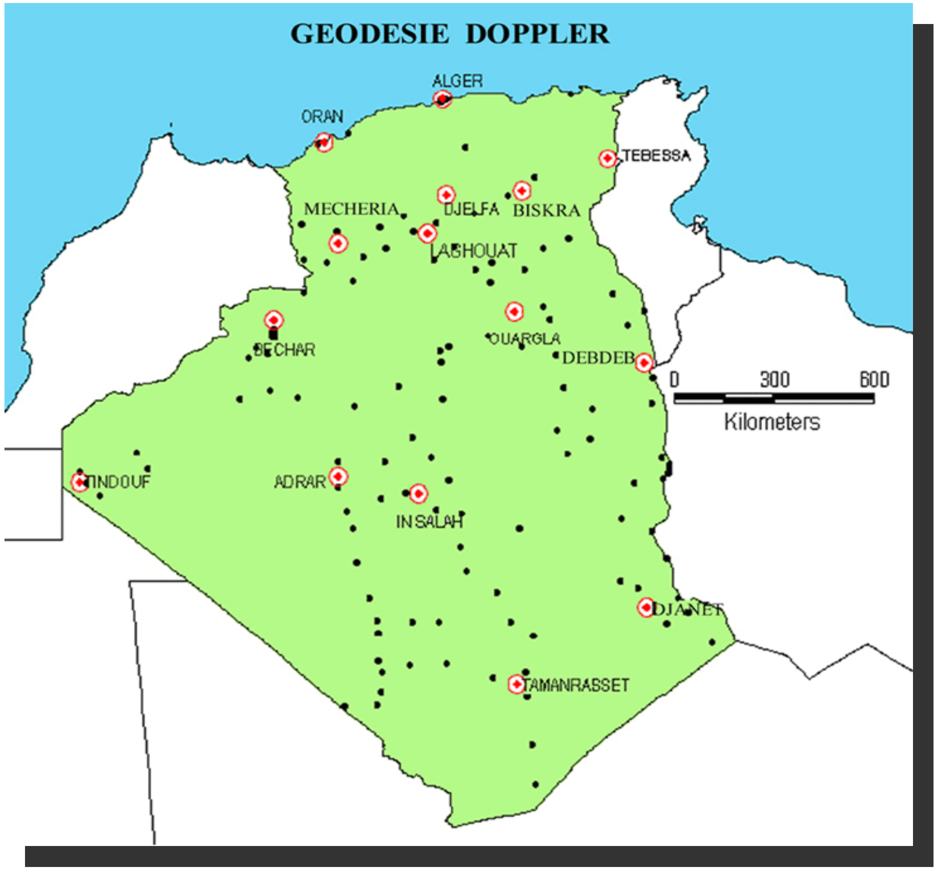
Axe 3000:

Réseau réalisé entre 1958 et 1961, il est composé de 170 points matérialisés et comprend les segments suivants:

ABADLA / ADRAR
ADRAR / AMGUID
AMGUID / OUARGLA
AMGUID / DJANET

Doppler Geodetic Network

- **122** points (1980-1990)
- Observations: 03 days
- Used equipments: JMR receivers
- GeoDop software on VAX 11/785 computer
- Accuracy : ~ meter



African Doppler Survey Project

- **18** points included in ADOS
- Accuracy : ~ 0.8 meter

GPS network

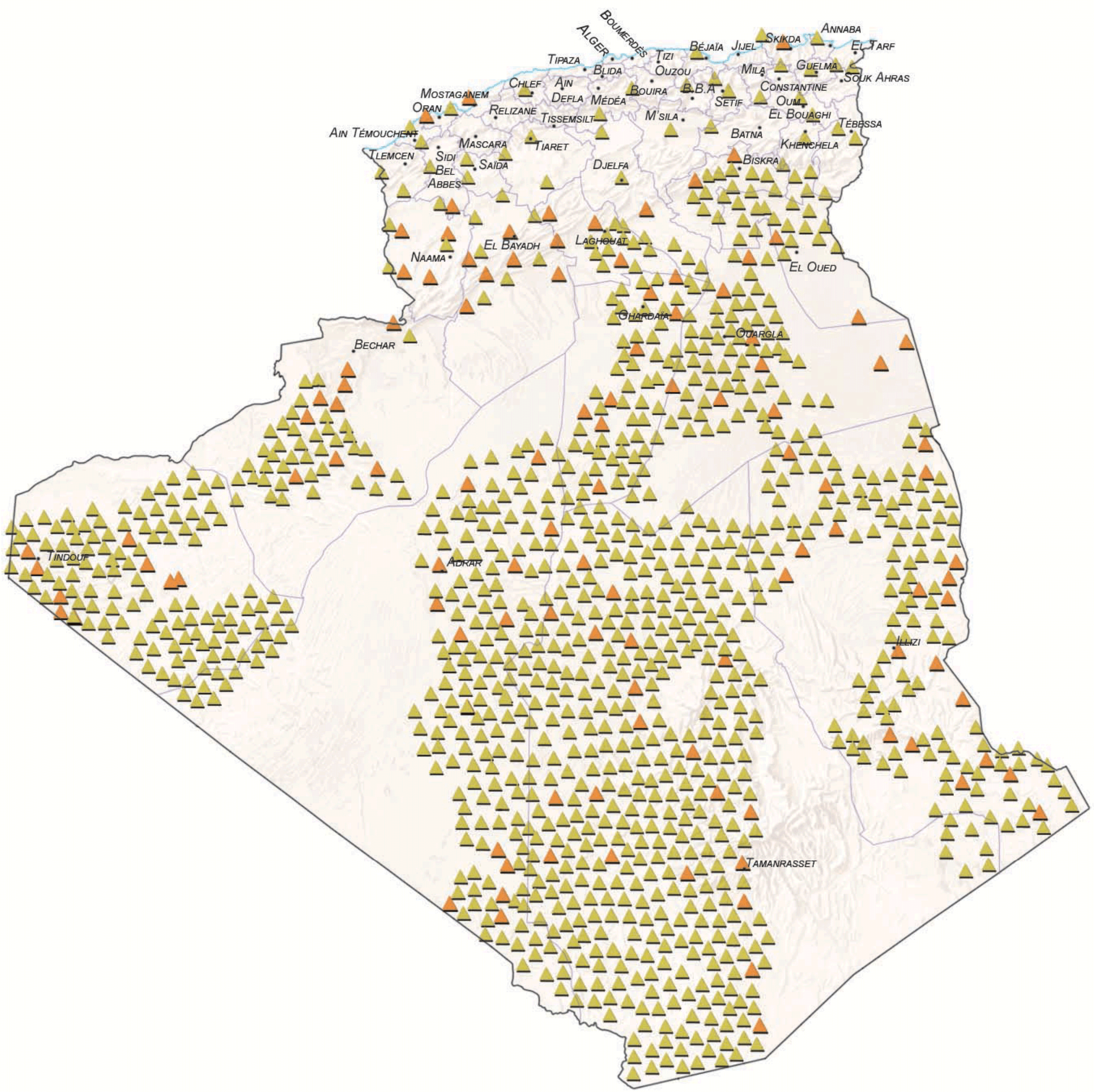
Zero order GPS network

- **15** points
- Observations : 07 days
- Software: Bernese
- IGS Precise orbits
- Planimetric accuracy : ~ 5 mm
- Altimetric accuracy : ~ 1 cm

1st order GPS network (network densification by GPS)

- Since 1997: **1290** GPS points (20 à 30 Km)
- Observations : 02 hours by session
- Software : Winprism and Ashtech solutions
- GPS broadcast orbits
- Planimetric accuracy : ~ 02 cm
- Altimetric accuracy: ~ 05 cm

GEODESIE SPATIALE



▲ Point GPS.

▲ Point doppler.

Réseau Doppler

122 points couvrant l'ensemble du térritoire national, ils sont déterminés en utilisant la technique Doppler basé sur le systeme Transit.

Réseau GPS

1290 points matérialisés et réalisés avec la technique GPS.

Permanent GPS Network

AFREF (AFrican REference Frame) Project

- 2006 - 2007: Three (03) operational Permanent GPS stations (Algiers, Oran and Constantine).
- Daily sessions in Rinex format, with a recording rate of 30 seconds

Used GPS equipment (Algiers, Oran and Constantine stations)

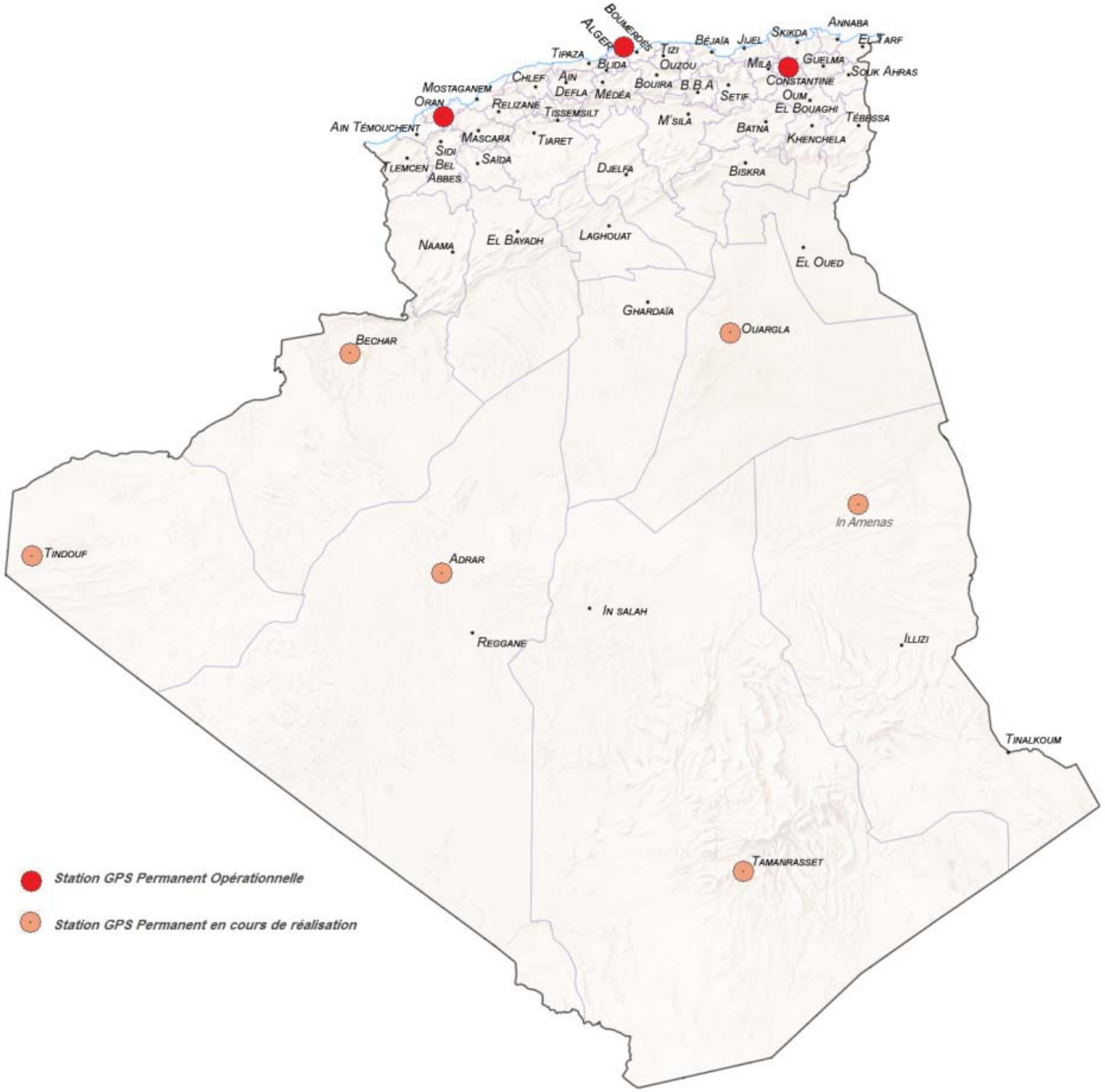
ASH701945E_M SNOW D/M Chokering

ASHTECH μZ-12

Four (04) other stations are planed (operational at the beginning of 2012): (Ouargla, Bechar, Tindouf and In Amenas).

- Receivers: GNSS multi-constellation (Leica GRX1200 GNSS)
- Chokering Antenna.

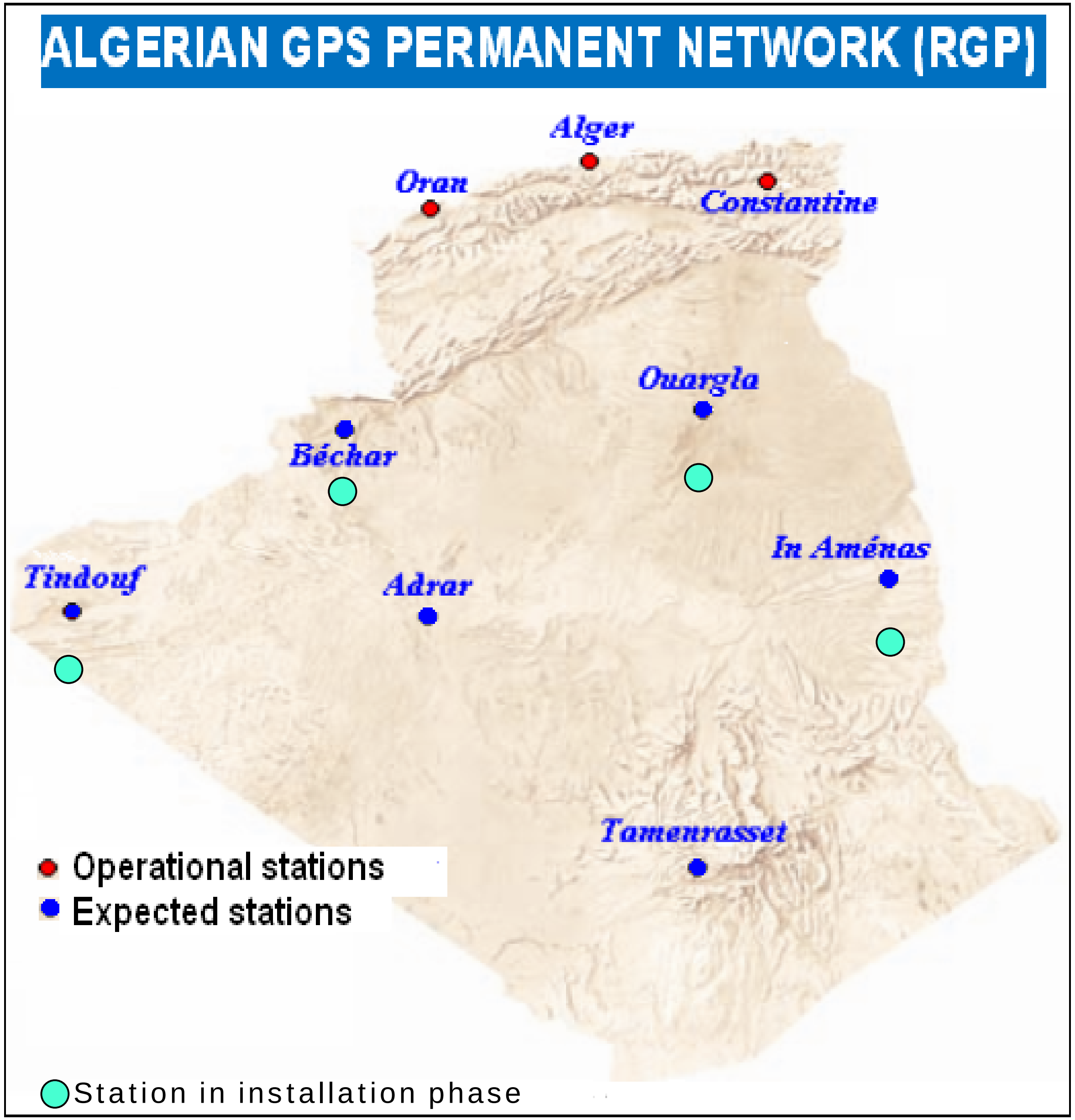
Permanent GPS Network



Configuration of the permanent GPS network project

DEFINITION OF THE

NEW GEODETIC NATIONAL 3D SYSTEM BASED ON THE GNSS TECHNIQUES



1. The Algerian Reference Network (RRA) with a sufficient density on the national territory (200 to 300 km). It is integrated in the Permanent GPS Network (RGP) .

2. The Algerian Basis Network (RBA) with a density of 100 km, linked to RRA network. It will be based on the classical triangulation network .

3. The Algerian Detail Network (RDA) with a high densité (25 to 40 km).

In a MoU between INCT and IGN (France), the GPS data of the 3 permanent stations were diffused to permit the connection to the ITRF

- Reference System: NORD SAHARA,
- 2D Network
- Ellipsoid: CLARKE 1880 A ,
- Coordinates System :
  - ✓ Longitudes, latitudes in gon,
  - ✓ Lambert VLU 1960, UTM
- Precision : ?

Actual system:

- Reference System :
  - ✓ 3D Network
  - ✓ Linked to the International Terrestrial Reference System(ITRS)
- Ellipsoid: IAG GRS80,
- Origin Meridian : Greenwich,
- Coordinates System :
  - ✓ Longitudes, latitudes in degrees (° ' ")
  - ✓ Heights ellipsoidal in meters
  - ✓ UTM,
- Precision : centimetre.

Futur system:

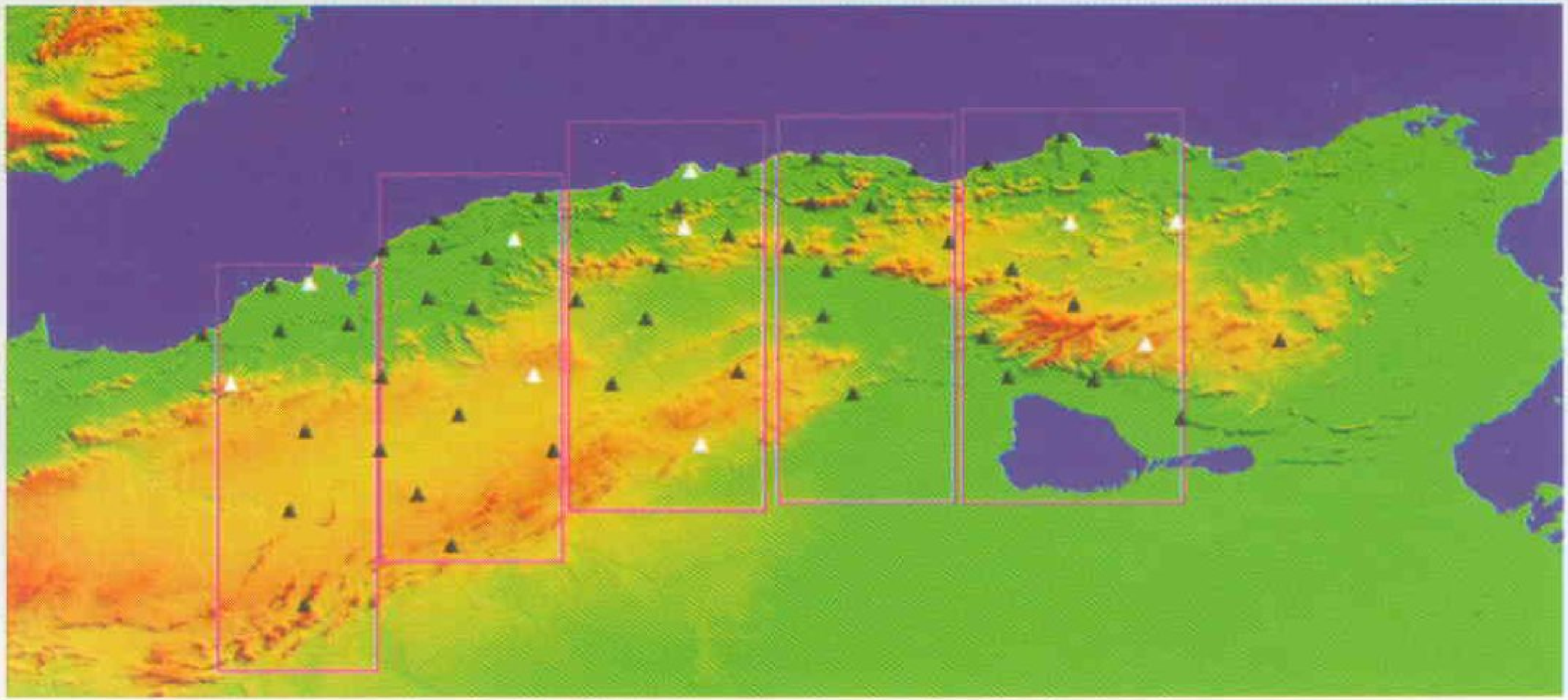
The new GNSS system will permit to well performing:

- Methodology of measurements
- Data processing for precise GPS networks,
- Methods of GPS geodetic network adjustment,
- Determination of transformation parameters between geodetic systems (Nord Sahara, ITRF,…).

Perspective: ASAL project (CRAAG, CTS, INCT, CGS, CDTA, Universities,..) for updating the map of seismic risk using space techniques.

▶ 70 expected permanent stations

PERMANENT GPS NETWORK



CARTE DU RESEAU GPS PERMANENT : PROJET REGAT

- Triangles blancs : stations installées durant la première phase
- Triangles noirs :   stations concernant la deuxième phase

Phase 1 : **12 stations installed** **–** ***Phase 2 :*** **16 stations (beginning of 2012)**

In La lettre du CRAAG – July 2011

Geodynamics of West Algeria and Alboran Sea By GPS

(*Memorandum of Understanding between*
MIT(USA) and Oran University (signed on November, 15 2011)

With the collaboration of :

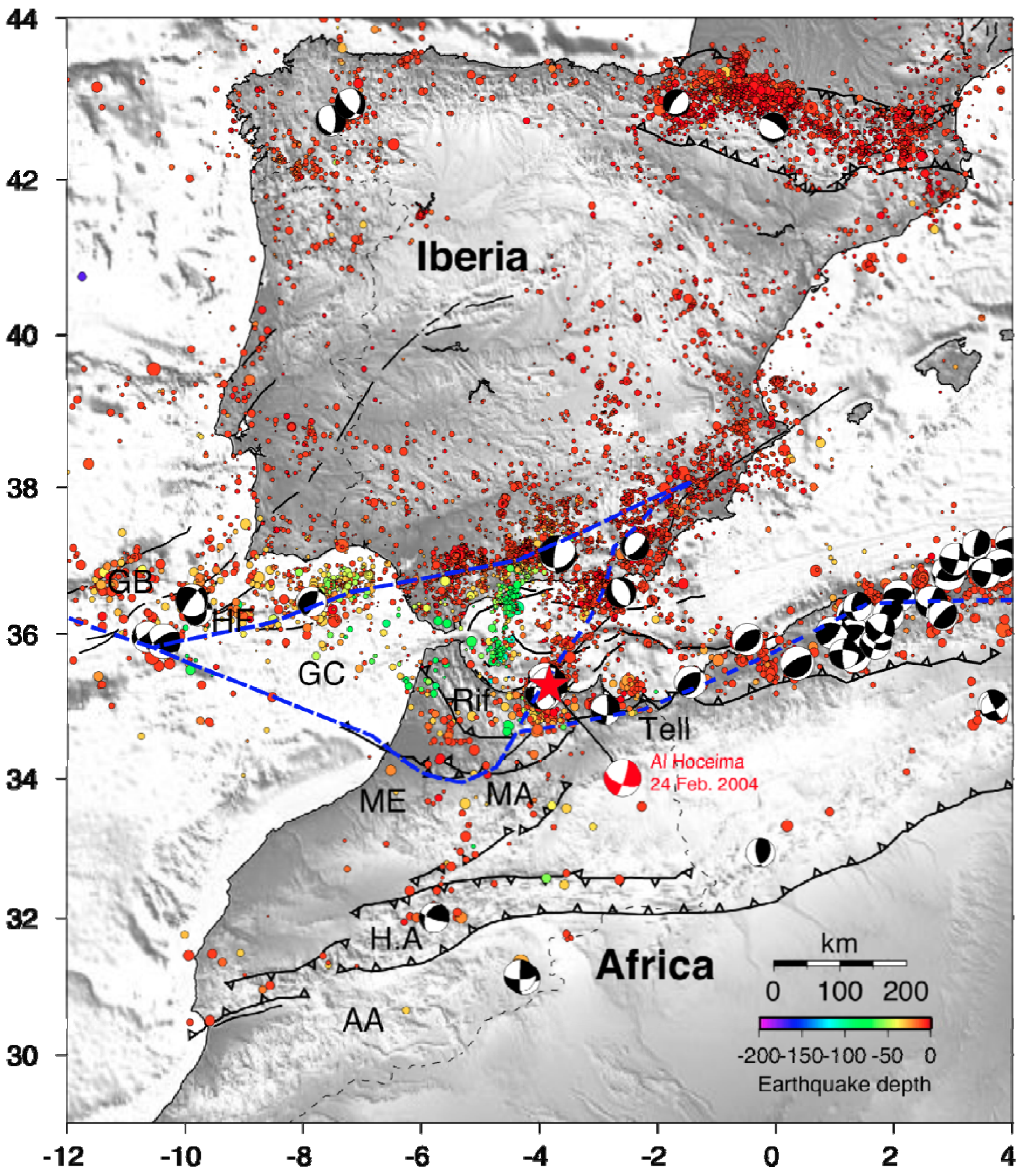
- *Algerian Space Agency (CTS / ASAL)*
- *National Cartographic Institute (INCT / Algiers)*
- *Research Centre of Geophysics (CRAAG / Algiers)*

And

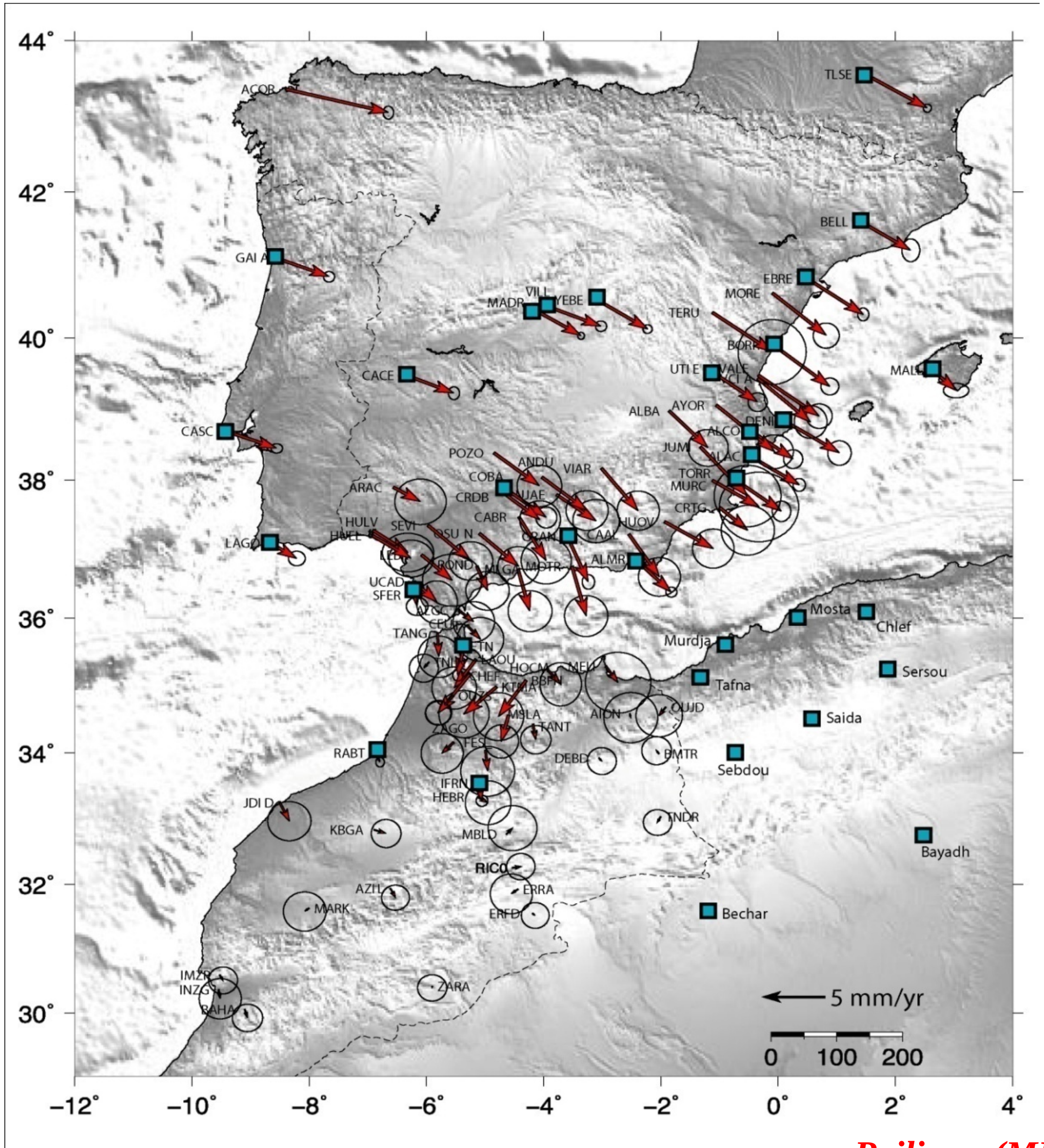
- *IPG Strasbourg (France)*

Western Mediterranean Tectonics/seismicity

Koulali et al. (2011)



PROPOSED WEST ALGERIAN GPS PERMANENT NETWORK



Reilinger(MIT), Meghraoui (IPGS), 2011

CONCLUSION

In earth sciences (Geodesy, Geophysics, Geodynamics,..) GNSS Data is an important tool, mainly to :

- Manage disaster or natural hazards (ex : reduction of the Seismic risk)
- Define precise reference frames (regional and worldwide)
-

The UN institutions (ICG/OOSA, COPUOS, Regional centres, ..), are the adequate framework to assure the dissemination of the information.

May 2001 : NAFREF resolution : (p 40- p49)
http://www.scribd.com/doc/48249990/bsg08