ALGERIAN SPACE AGENCY

CONTRIBUTION OF GNSS TO STABILTITY MONITORING OF ENGINEERING STRUCTURES: THE CASE STUDY OF BENI-HAROUN DAM IN ALGERIA

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Introduction

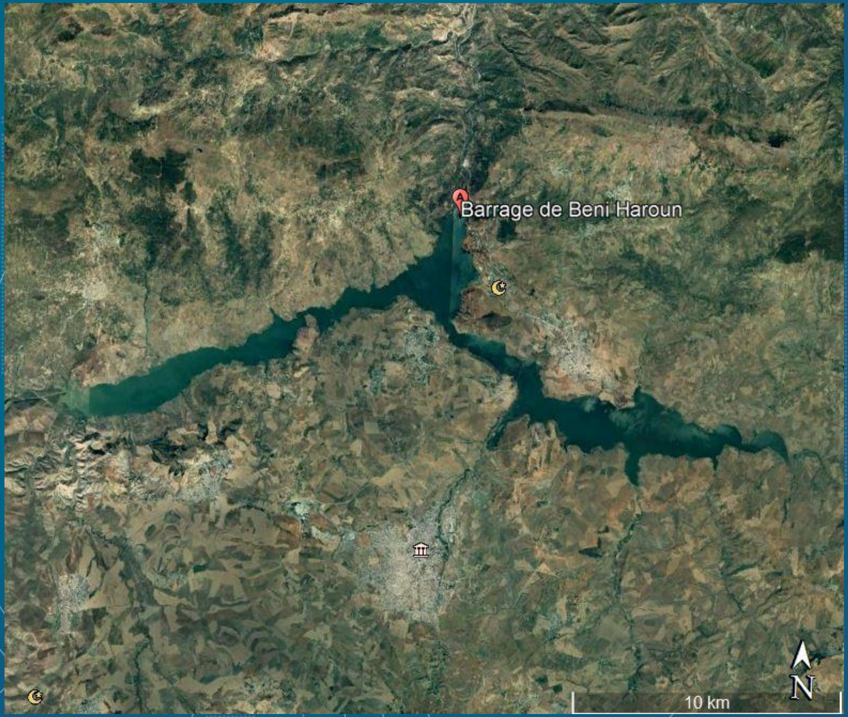
Context

- Contract of application, signed December, 2018 between the Space Techniques Centre/Algerian Space Agency (CTS/ASAL) and the National Agency of Dams and Transfer (ANBT).
- The contract relates on “Dams monitoring using space techniques”;
- Project start date : January 2019;
- Project end date : December 2020.

Objective

GPS data processing and coordinate time series analysis for the estimation of Beni-Haroun dam (Mila department/Algeria) displacement.

Presentation of the Beni-Haroun dam



- **Localisation : Noth-East of Algeria;**
- **Type : Straight-weight, made of roller-compacted concrete on a limestone bedrock foundation;**
- **Height : 118 m above the foundation**
- **Crest length : 710 m;**
- **Storage capacity : one (01) billion m^3 .**

Description of the dam's GPS monitoring system

- To reinforce the safety of the dam :
- The monitoring system consists of six (06) GMX900 single-frequency GPS stations set up in 2014 by the ANBT (National Agency of Dams and Transfers) ;
- Three stations on the dike (GC1, GC2, GC3) and one downstream (GC4) as a target network;
- Two stations on the shore on rocks as a reference network (GR1 and GR2).

GPS Data Analysis

Data Description

- GPS Data : from Fabruary 3, 2014 to July 9, 2018 (≈ 4.5 ans);
- RINEX standard format;
- Interval data logging : 1 second.

Data Processing methodology

- L1 GPS data (30 seconds) are processed in relative static mode;
- Small network (<1km) & low Height differences $\Rightarrow$ Common errors eliminated (Clocks, Orbits, Troposphere, Ionosphere)
- Daly ECEF solutions (Geocentric WGS-84)

GPS Data Analysis

Sample of baseline calculation results

Baseline	Solution type (100 %)	Horizotal RMS (m)	Vertical RMS (m)
GR1 --- gc3006	Fixe	0.0005	0.0007
GR1 --- gc3007	Fixe	0.0005	0.0007
GR1 --- gc3008	Fixe	0.0005	0.0007
GR1 --- gc3009	Fixe	0.0005	0.0007
GR1 --- gc3010	Fixe	0.0005	0.0007
GR1 --- gc3011	Fixe	0.0005	0.0007
GR1 --- gc3012	Fixe	0.0005	0.0007
GR1 --- gc3013	Fixe	0.0005	0.0007
GR1 --- gc3014	Fixe	0.0005	0.0007
GR1 --- gc3015	Fixe	0.0005	0.0006
GR1 --- gc3016	Fixe	0.0005	0.0007

Ambiguities : 100% fixed,

Baselines precision < 1mm,

Daily Positions Repeatabilities < 1mm.

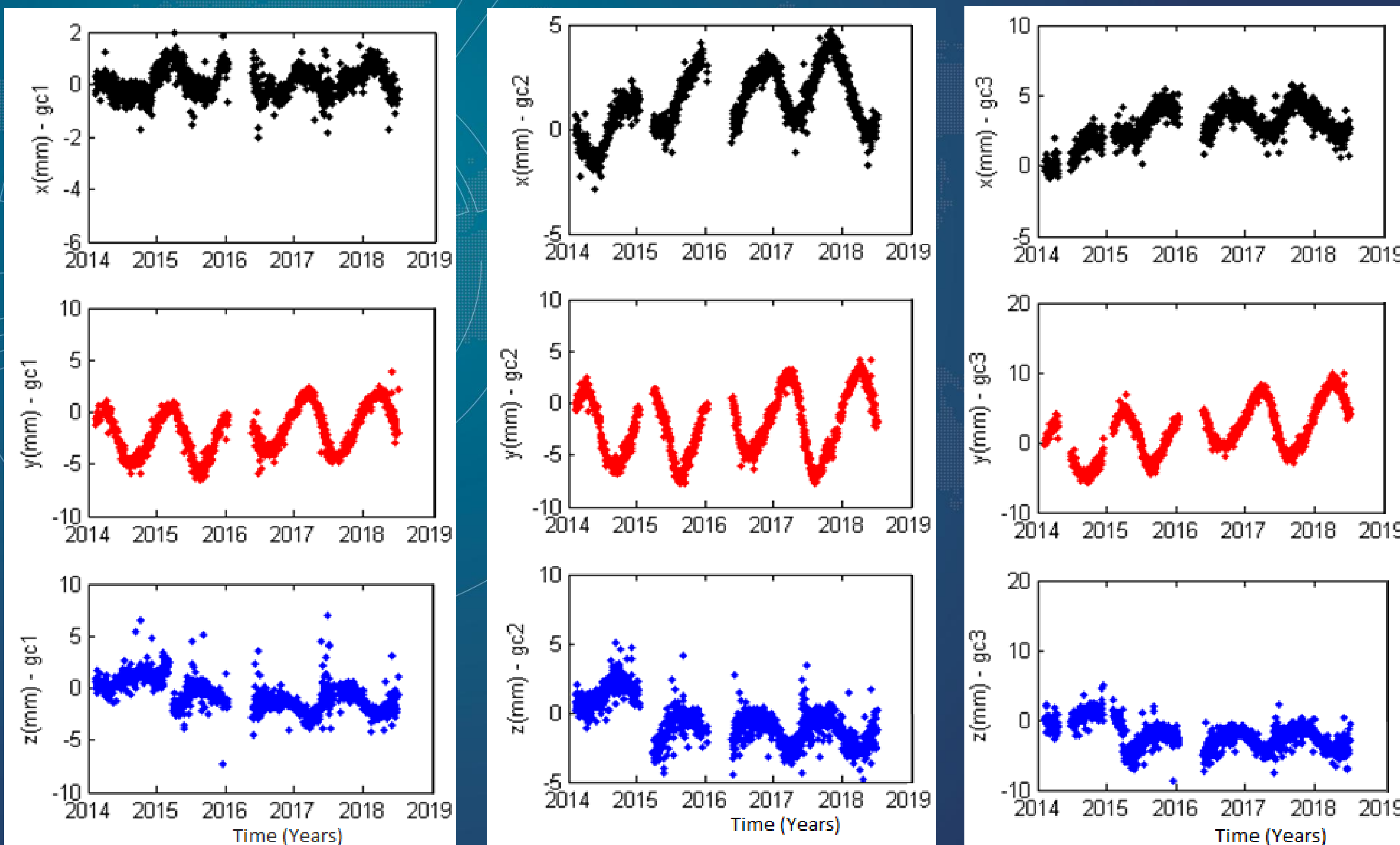
Transformation of ECEF coordinate to Dike frame

Daly ECEF solutions ⇒ Local (Topocentric) frame ⇒ Dike frame (Az & Elev of gc3-gc1)

- x-axis: along the dike in the direction gc3-gc1;
- y-axis: perpendicular to the x-axis, contained in the horizontal plane and pointing downstream;
- z-axis: along the upward vertical

GPS Data Analysis

Original coordinate time series (x, y, z) of gc1, gc 2 and gc3 stations



Coordinate time series analysis

Analysis of coordinate time series => evaluate dam displacement.

Analysis methodology :

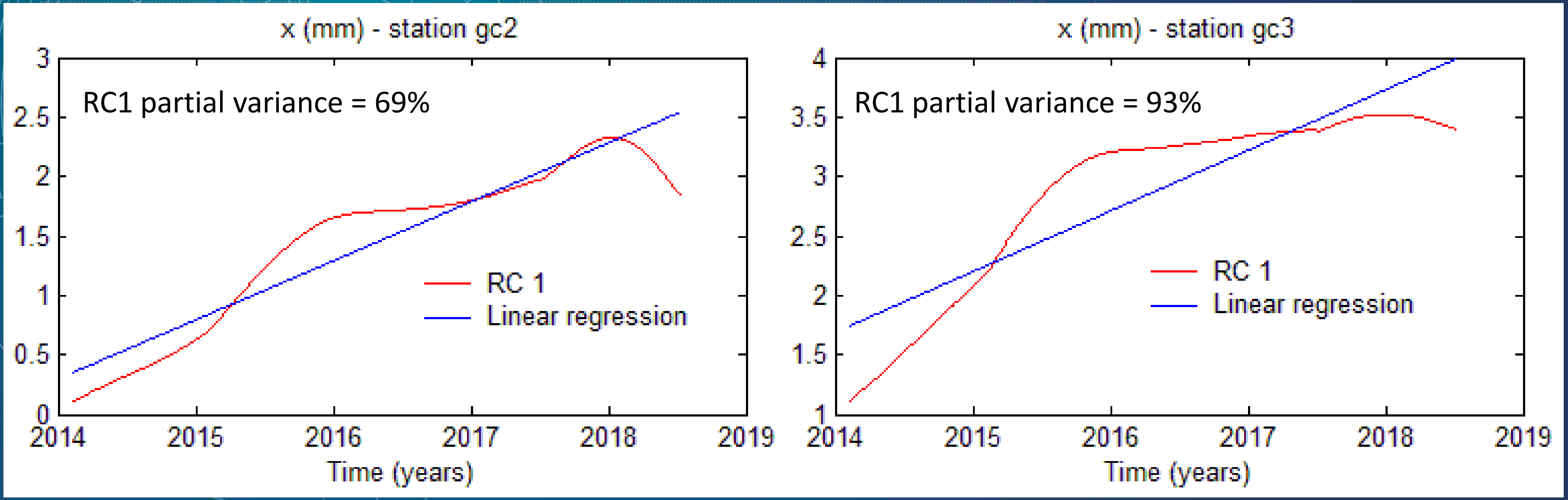
(1) the SSA method to estimate the trend and the seasonal components,

(2) the spectral analysis to characterize the noise spectrum (white or colored),

(3) the wavelet thresholding method to assess the level of noise.

Coordinate time series analysis : Trends (SSA)

Nonlinear trends in the x-coordinate for stations gc2 and gc3



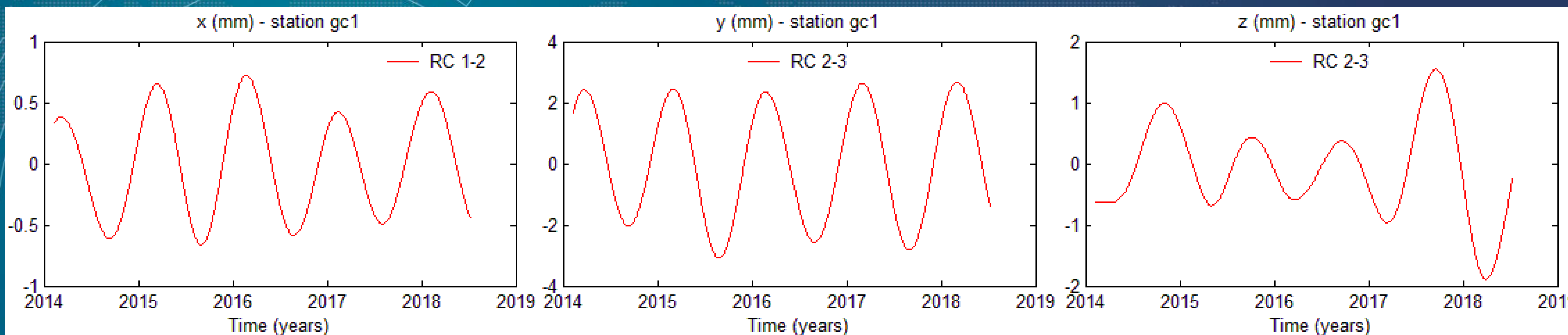
Coordinate time series analysis : Trends (SSA)

Reconstructed components (RC) associated to the trends of the coordinates (x, y, z) with their partial variances (PV), their slopes and the slopes of the initial coordinates computed from a least squares regression

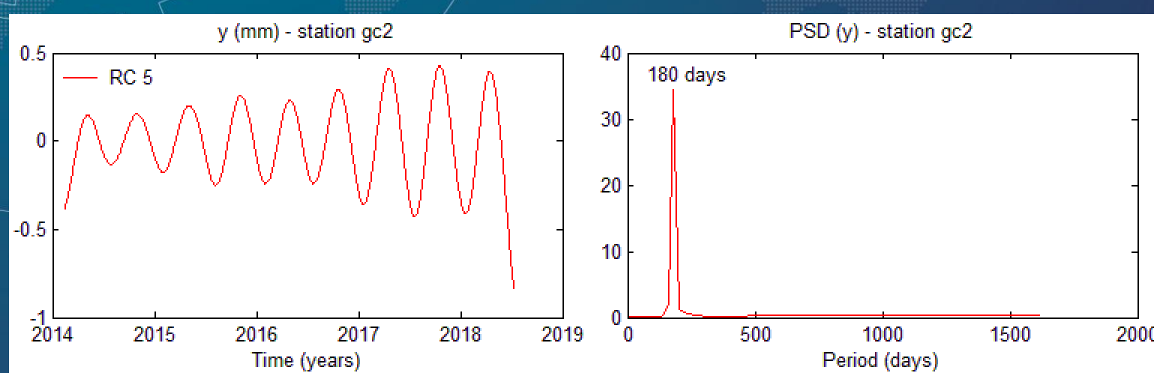
Station	Coordinate	RC	PV (%)	Slope of RC (mm/year)	Initial Slope (mm/year)
gc1	x	RC 3	12.83	0.00±0.00	0.03±0.01
	y	RC 1	44.40	0.55± 0.01	0.57±0.04
	z	RC 1	44.10	-0.38± 0.01	-0.48± 0.02
gc2	x	RC 1	69.35	0.50±0.00	0.49 ±0.02
	y	RC 1	37.42	0.43±0.02	0.48 ±0.06
	z	RC 1	33.81	-0.22 ±0.01	-0.44±0.03
gc3	x	RC 1	93.01	0.51±0.01	0.53±0.02
	y	RC 1	39.02	1.29±0.02	1.49±0.06
	z	RC 1	59.71	-0.26±0.02	-0.44 ±0.04

Coordinate time series analysis: Periodic components(SSA)

Annual signals in the coordinates (x, y, z) of station gc1



Semi-annual signal in the y-coordinate of station gc2 and its PSD



Coordinate time series analysis: Periodic components(SSA)

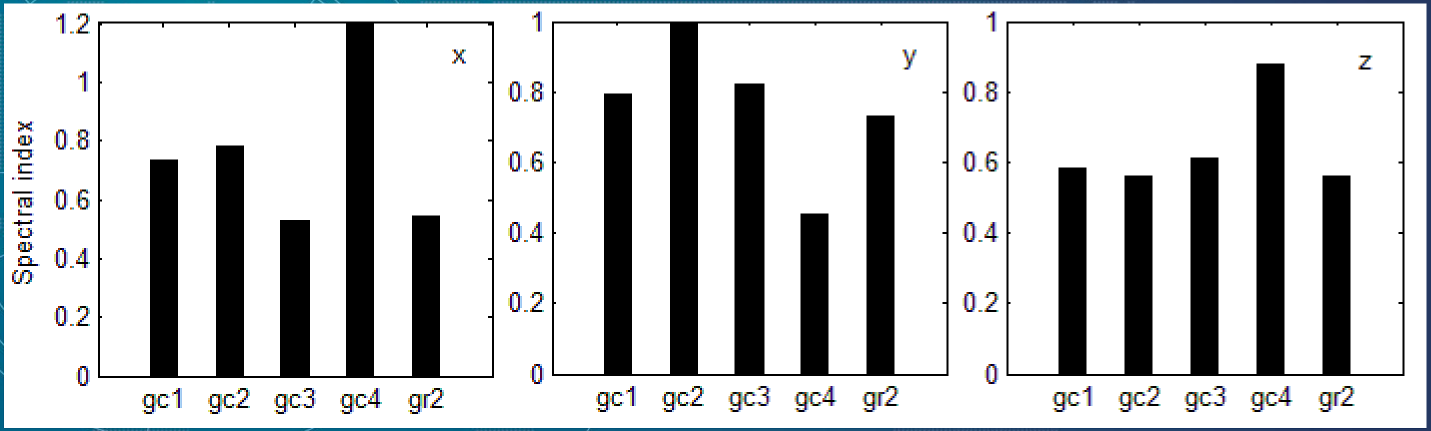
Reconstructed components, partial variances and average amplitudes (Amp) of seasonal signals in the coordinates (x, y, z) for the studied stations

Stat	Coord	Annual signal RC	Annual signal PV %	Annual signal Amp (mm)	Semi-annual signal RC	Semi-annual signal PV %	Semi-annual signal Amp (mm)
gc1	x	RC 1-2	60.71	0.55	RC 5	2.17	0.09
	y	RC 2-3	52.41	2.53	RC 5	0.46	0.16
	z	RC 2-3	28.47	0.99	RC 5	2.43	0.17
gc2	x	RC 2-3	27.59	1.39	RC 5	0.22	0.09
	y	RC 1-3	96.75	2.09	RC 5	0.74	0.28
	z	RC 2-3	43.25	1.12	RC 5	1.15	0.13
gc3	x	RC 2-3	4.88	0.85	RC 5	0.14	0.12
	y	RC 2-3	57.59	3.44	RC 5	0.69	0.28
	z	RC 2-3	25.52	1.79	RC 5	1.15	0.24

- The annual signal amplitudes for (x, y, z) 0.5 – 3.44 mm.
- The semi-annual (<0.5 mm).

Coordinate time series analysis: Noise type (SA)

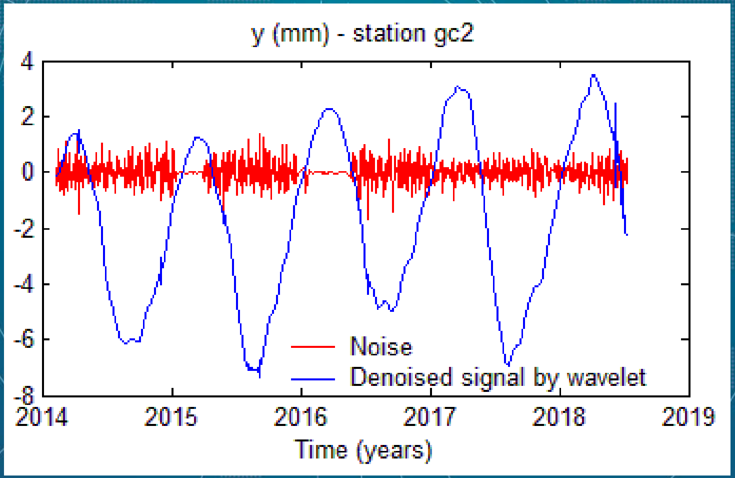
Spectral index estimates for the analyzed station coordinates (x, y, z)



- Spectral indices close to 1 => The dominant noise in the analyzed coordinate time series is flicker noise .
- Generally attributed to instrument problems, systematic modeling errors, or local movements of the geodesic monument related for example to climatic variations, etc.

Coordinate time series analysis : Noise level (Wvlt)

Noise and denoised signal of the y-coordinate of station gc2



Standard deviations (STD) of the noise in the analyzed station coordinates (x, y, z)

Station	Standard deviations (mm)		
	x	y	z
gc1	0.22	0.32	0.49
gc2	0.26	0.35	0.56
gc3	0.37	0.39	0.75
gc4	0.62	0.34	0.98
gr2	0.52	0.44	1.21

- The noise amplitude (<1 mm).
- The noise level is higher in the z-coordinate compared to x, y coordinates.

Conclusions

- In this study, we processed the GPS data from the permanent stations of the Béni Haroun dam and generated the daily coordinate time series, which are analyzed in order to evaluate the displacements of the dam's dike;
- Daily RINEX data of six (06) permanent single-frequency GPS stations (gc1, gc2, gc3, gc4, gr1 and gr2), collected between February 2014 and July 2018, are processed and expressed in a local coordinate system linked to the Beni-Haroun dike;
- Sub-millimeter precision on position components;
- Repeatability of daily position : Sub-millimetric;
- The results of the time series analysis show that the main signal present in the analyzed time series is a trend associated with annual seasonality. The trend and the annual signal represent more than 95% of the total signal in the three coordinates (x, y, z) for all studied stations;

Conclusions

- The trend, describing a possible plastic deformation of the dike, may be related to the response of the dam to water load;
- The annual and semi-annual signals, describing the periodic oscillations of the dike, are mainly due to: (1) the reservoir level fluctuations resulting from the seasonal pluviometry; and (2) the thermal effects caused by the differences between air and water temperature over the year;
- Due to the low values of linear displacement (<1 mm/year) and noise level (<1 mm), the Beni-Haroun Dam can be qualified as stable.

Perspectives

- Our approach may be used to study the deformation of engineering structures (dams, bridges,…etc), and monitoring of ground displacements due to landslides and earthquakes.
- Positions are determined in relative mode with respect to reference stations located in the vicinity of the dike target network. To be able to detect displacements in the case of global movement of the site => install at least one (01) GNSS multi-frequency station => guarantee highly accurate linkup with respect to an away reference stations.

Thank you for your attention