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A Practical Deformation Monitoring Procedure and Software System for CORS Coordinate Monitoring (6838)

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Contents

INTRODUCTION

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Introduction

- GNSS/GPS is capable of detecting significant deformations...to mm-level
- However, a rigorous deformation analysis technique is still required
- Recent research works: Continuous deformation monitoring systems [SCIGN, GOCA, DDS]
- This study…

Introduction.

- This study…GPS processing strategy and deformation analysis to monitor the positional changes [3D coordinates] of local Continuous Operating Reference Station (CORS) network: ISKANDARnet, MyRTKnet.
- -Investigation of the quality of published coordinates through daily GPS solution was performed [Bernese 5.0].
- -Window-based software system for GPS deformation analysis, called Continuous Deformation Analysis System [ConDAS], developed at UTM.

Introduction.

- Deformation detection & analysis: this study combines a robust method [known as Iteratively Weighted Similarity Transformation or IWST] and final S-Transformation.

SYSTEM DEVELOPMENT APPROACH

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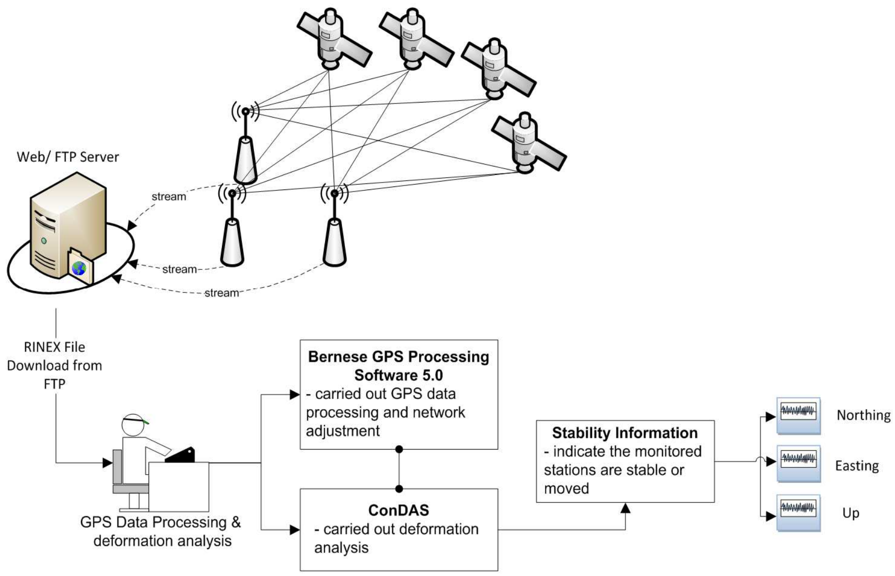
System development approach

- Overview: CORS…GPS…Bernese…ConDAS



System development approach.

The coordinate monitoring [2 parts/stages…2 steps analysis]:

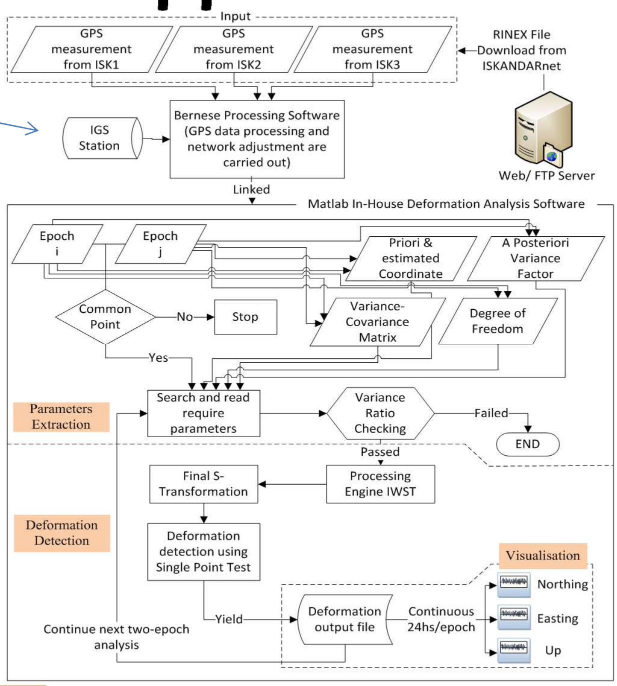
- (i) GPS data processing using Bernese [high precision GPS processing software]…Independent LSE of each epoch.
- (ii) Deformation analysis between epochs using ConDAS.

ConDAS is designed to work with Bernese.

System development approach..

Work flow:

- Bernese
- ConDAS



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GPS data processing strategy

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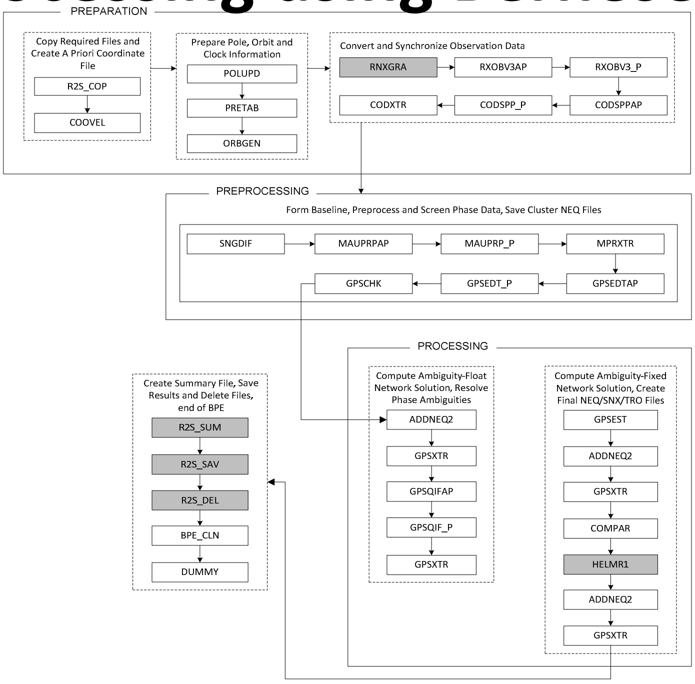
GPS data processing

- GPS baselines are thousands of kilometers in length…requires sophisticated data processing software to achieve high precision results for long baselines.
- Bernese v. 5.0 software is employed for GPS data processing [Bernese…also used in other studies]
- Bernese capability: data cleaning, cycle slip detection, ambiguity resolution and network adjustment of GPS data [Bernese allows user to control processing strategies].
- Double difference GPS data processing using Bernese…3 parts: Preparation, Pre-processing and Processing.

Double Difference GPS Data Processing using Bernese



Double difference GPS processing step, 3 parts: preparation, pre-processing and processing

Double Difference GPS Data Processing using Bernese

Table 1: Parameters and models used in GPS data processing

Parameters	Strategy
Input data	Daily
Network design	DEFINED
Elevation cut-off angle	5°
Sampling rate	30 seconds
Orbits/ EOP	IGS final orbits (SP3) and Earth Orientation Parameters (EOP)
Ocean-loading model	FES2004
Ambiguities solution	Fixed, resolved using QIF strategy
Differencing level	Double

Double Difference GPS Data Processing using Bernese

- Deformation analysis…input/deformation files for ConDAS.
- 5 parameters (priori coords, estimated coords, degree of freedom, a posteriori variance factor and variance-covariance matrices) are required to carry out the deformation analysis.
- Some processing scripts in Bernese are slightly changed to well fit the requirement of deformation analysis...to generate 3 deformation files [for every 24h epoch]: priori coordinates, estimated coordinates, covariance matrix

Deformation analysis

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Deformation analysis

- The developed deformation analysis strategy combines robust method and Similarity Transformation (S-transformation).
- Robust method: Iteratively Weighted Similarity Transformation (IWST), for stability analysis of reference stations.
- Procedure for Deformation analysis between epochs... 2 stages: i) Stability analysis of reference stations using IWST and single point test; and ii) Final S-transformation of all stations with respect to stable reference stations & deformation analysis of all stations using single point test.
- The single point test: reject any point [i.e. unstable] with its displacement extends beyond the confidence region.

IWST/robust

- IWST: stability analysis of control/reference stations.
- Displacement vectors & cov matrix: $d = X_2 - X_1$ $Q_d = Q_{x_1} + Q_{x_2}$
  - -Start W=I, apply S-transformations

    $S = I - G(G^T W_j G)^{-1} G^T W_j$; $d_j = Sd_i$
    - -Weight matrix W changed: $W^{(k+1)}(i,i) = diag[1/d^{(k)}]$
    - -Iterative procedure continues until: $|d^{(k+1)} - d^{(k)}| < \delta$
  - Transform: $Q_{xj} = SQ_{xi}S^T$
  - Check stability using single point test: $T_i = \frac{d_i^T Q_{d_i}^{-1} d_i}{m.\hat{\sigma}_o^2} \sim F(m, df_p, \alpha)$

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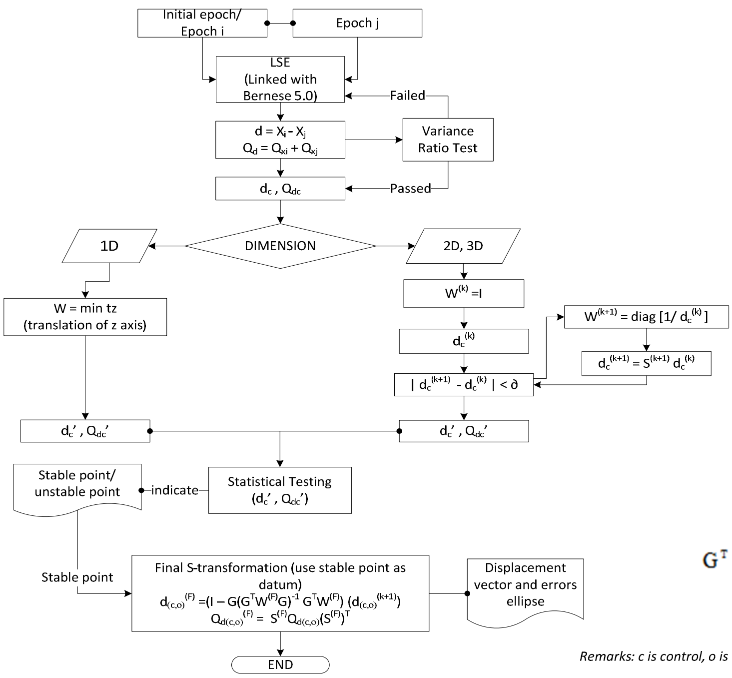
Final S-transformation

- Final S-transformation of all stations with respect to stable reference stations…
- $S=I-G(G^TW_jG)^{-1}G^TW_j$; $d_j=Sd_i$; $Q_{xj}=SQ_{xi}S^T$
- W=1 for stable reference stations, W=0 for other stations [similar to Congruency testing]
- Stability/The single point test

IWST & final S-Transformation



$$G^T = \begin{pmatrix} 1 & 0 & 0 & 1 & 0 & 0 & \dots & 1_z & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & 0 & \dots & 0 & 1_z & 0 \\ 0 & 0 & 1 & 0 & 0 & 1 & \dots & 0 & 0 & 1_z \end{pmatrix}$$

Remarks: c is control, o is object

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ConDAS

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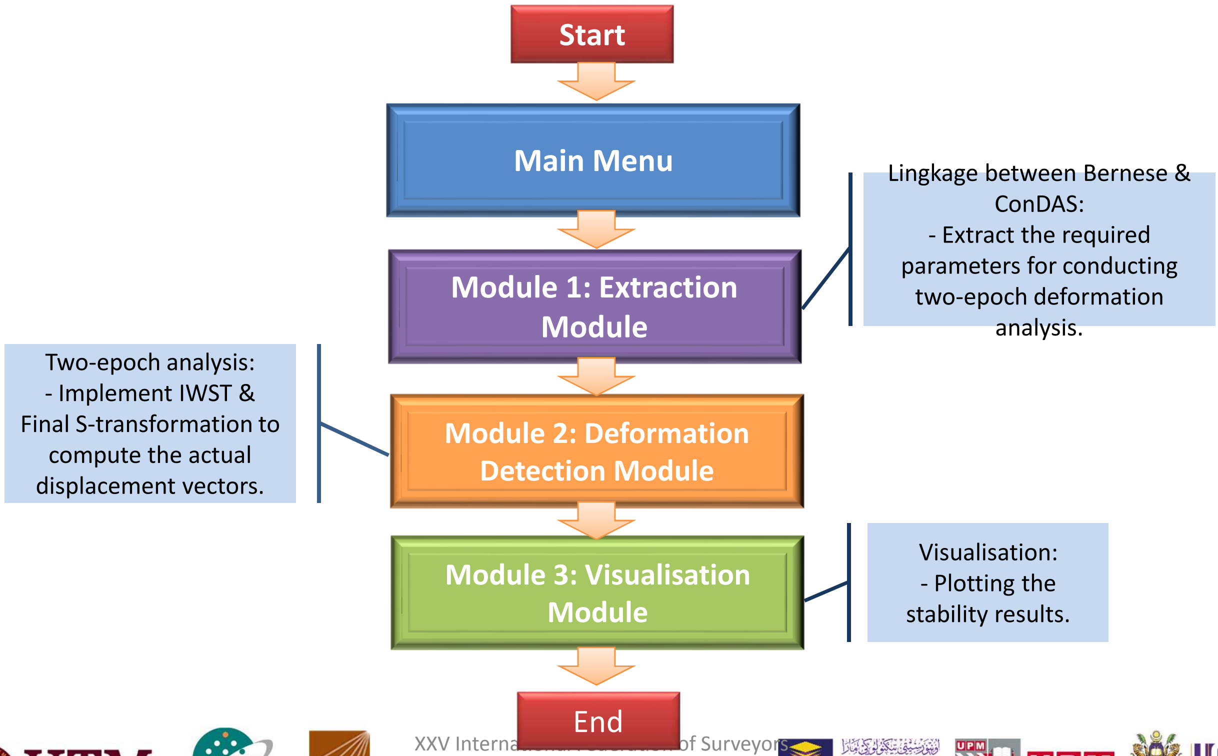
ConDAS

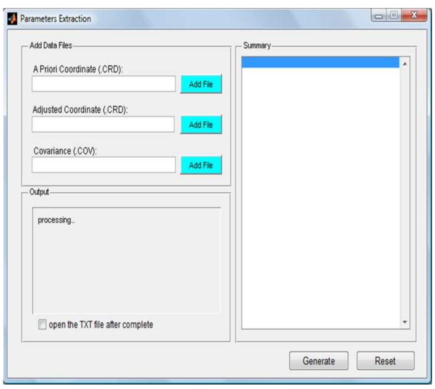
- ConDAS: In-house Deformation Analysis software
- ConDAS is designed to work with Bernese.
- The main components of ConDAS: parameter extraction (from Bernese output), deformation detection and graphical visualisation.
- All these components are integrated in one environment using MATLAB.

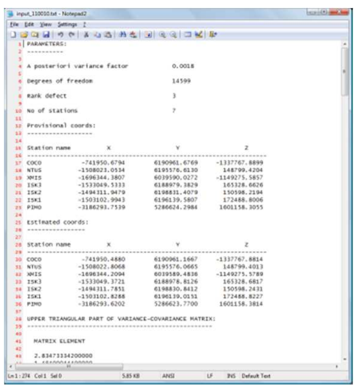
In-House Deformation
Analysis Software - **ConDAS**



Module 1: Parameters extraction

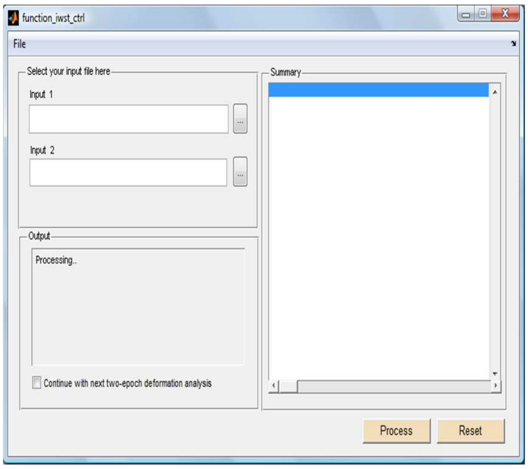
- To extract the required parameters according to the format of Bernese results files.
- 3 types of result files were used for extraction.
- GUI of parameters extraction module & deformation input file.

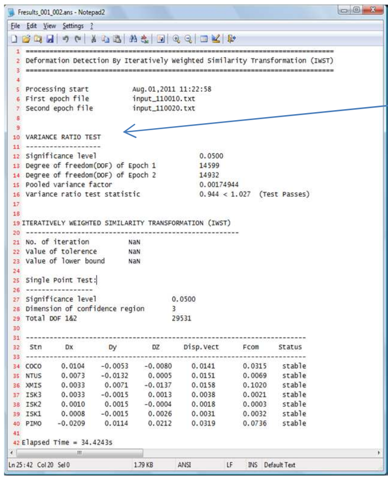




Module 2: Deformation detection

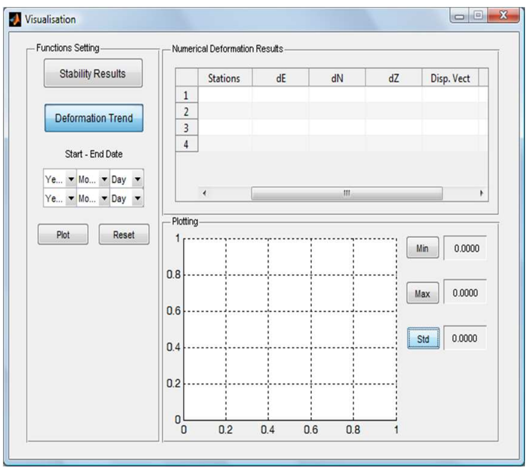
- Two-epoch deformation analysis: 2 deformation input files.
- GUI of Deformation detection module & deformation output file.





Module 3: Visualization

- 2 functions of the visualization module: i) to view the stability results of every two-epoch analysis; ii) to generate the deformation trend over a selected period.
- GUI of visualisation module.



In order to fully implement the method, ConDAS was designed to cooperate with Bernese

GPS data from ftp

Bernese

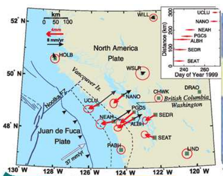
Bernese processing (24 hrs GPS data-daily solution):

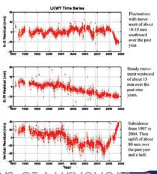
- Prepare relevant parameters and files.
- Daily solution (Sampling rate= 30s).
- Bernese processing Engine.

ConDAS

Two-epoch deformation analysis (displacement detection):

- Extract required parameters from Bernese output.
- Execute in-house deformation analysis software.
- Compare epoch by epoch using rigorous deformation analysis





More info

- Raw GPS data in RINEX format.
- Size of 24hrs data=4-5 MB, sampling rate of 30 s.
- Main output from BPE [daily solution]: approx coords, estimated coords, covariance matrix...in 3D X, Y, Z WGS84 system; transform to local coord system when visualisation.
- How fast to get results? Bernese= few mins (daily solution), deformation analysis= few mins. Total 10 – 15mins.

TEST RESULTS

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Test Results

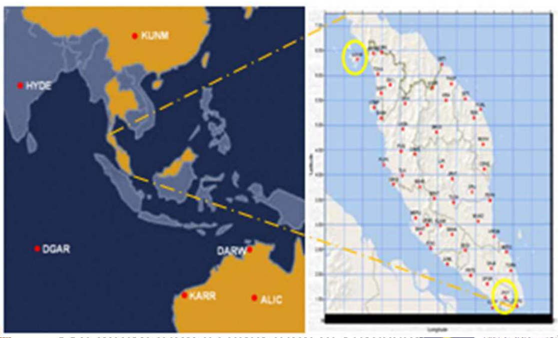
- 2 test results
- Test results 1: Malaysia Real Time Kinematic GNSS Network (MyRTKnet)...system validation, Aceh earthquake
- Test results 2: Iskandar Malaysia CORS Network (ISKANDARnet)...deformation monitoring

Test Results 1

- Validation of the entire system: using the existing GPS data set from MyRTKnet.

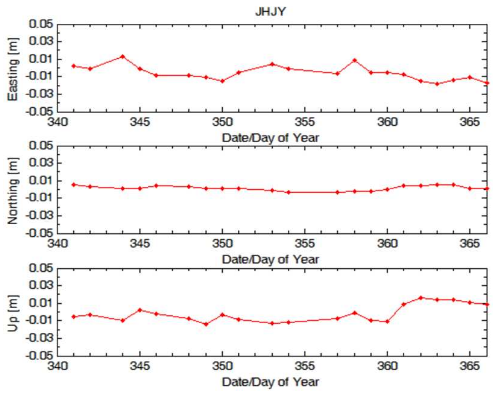
Test Results 1

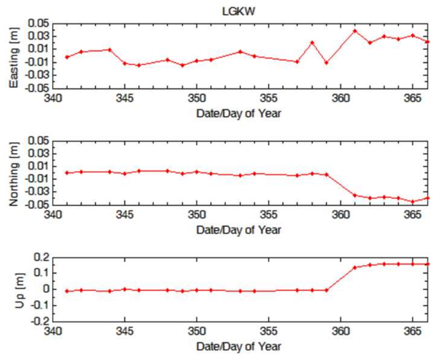
- The processed data set started from 4th until 31st Dec 2004 (i.e. before and after the Aceh earthquake incident on 26th Dec 2004).
- Control points: 6 IGS stations (ALIC, DARW, DGAR, HYDE, KARR and KUNM)
- Object points: two stations from MyRTKnet [JHJY and LGKW]



Test Results 1

- All stations were stable before the earthquake.
- JHJY station: stable
- LGKW station: moved/unstable from 26th Dec 2004 and onwards...similar with findings from Jhonny (2010).





Test Results 1

Table 2: The displacement vectors of station JHJY and LGKW

Date[D/M/Y] / Day of Year	JHJY Disp. Vector [m]	JHJY Status	LGKW Disp. Vector [m]	LGKW Status
22-12-2004/ 357	0.0108	Stable	0.0108	Stable
23-12-2004/ 358	0.0085	Stable	0.0206	Stable
24-12-2004/ 359	0.0111	Stable	0.0138	Stable
25-12-2004/ 360	0.0115	Stable	n/a	n/a
26-12-2004/ 361	0.0119	Stable	0.1439	Moved
27-12-2004/ 362	0.0221	Stable	0.1609	Moved
28-12-2004/ 363	0.0234	Stable	0.1644	Moved
29-12-2004/ 364	0.0209	Stable	0.1665	Moved
30-12-2004/ 365	0.0153	Stable	0.1657	Moved
31-12-2004/ 366	0.0191	Stable	0.1629	Moved

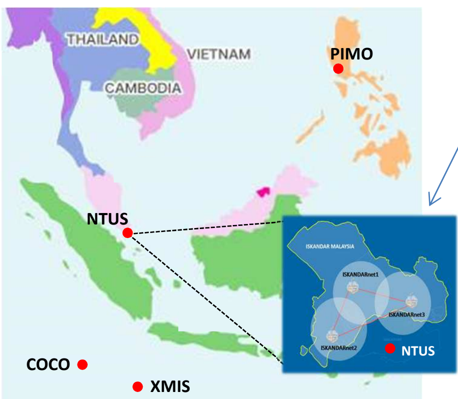
n/a = data not available

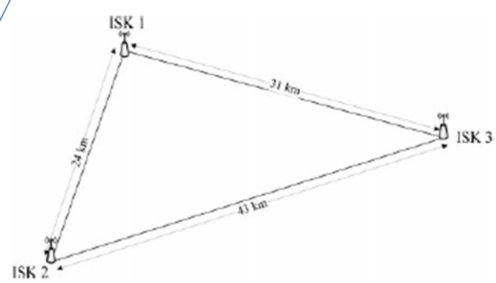
Test Results 2

- **Deformation Trend of ISKANDARnet**

Test Results

- The deformation monitoring network: 7 stations.
- Reference points…4 IGS stations (i.e. COCO, NTUS, PIMO, XMIS).
- Object points…3 stations from local ISKANDARnet (ISK1, ISK2, ISK3).





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Test Results

- 2 days…ISKANDARnet [4/1/2010-5/1/2010].
- 2 years…ISKANDARnet [4/1/2010-31/12/2011]

Test Results-2 days

- 2 days…ISKANDARnet [4/1/2010-5/1/2010].
- Reference epoch: 4st Jan 2010.
- Deformation analysis at 5% significance level.
- To show procedure.

Test Results-2 days

- Stability analysis of reference stations [via IWST]: all stable.

Station	Dx [m]	Dy [m]	Dz [m]	Disp.Vect [m]	Test statistic vs critical value	Status
COCO	-0.0017	-0.0021	0.0040	0.0048	0.0066 < 2.60547	stable
NTUS	0.0005	0.0001	0.0001	0.0005	0.0012 < 2.60547	stable
XMIS	-0.0038	0.0116	-0.0011	0.0122	0.0043 < 2.60547	stable
PIMO	0.0051	-0.0030	-0.0029	0.0066	0.0015 < 2.60547	stable

Test Results-2 days

- Stability analysis of all stations [via final S-transformation]: stable.

Station	Dx [m]	Dy [m]	Dz [m]	Disp.Vect [m]	Test statistic vs critical value	Status
COCO	-0.0007	-0.0025	0.0023	0.0034	0.0026 < 2.60521	stable
NTUS	0.0026	-0.0038	-0.0005	0.0046	0.0021 < 2.60521	stable
XMIS	-0.0002	0.0029	-0.0006	0.0030	0.0005 < 2.60521	stable
ISK3	-0.0023	0.0036	-0.0010	0.0044	0.0018 < 2.60521	stable
ISK2	-0.0016	0.0023	-0.0013	0.0031	0.0017 < 2.60521	stable
ISK1	0.0002	0.0054	-0.0008	0.0055	0.0022 < 2.60521	stable
PIMO	-0.0018	0.0033	-0.0012	0.0040	0.0016 < 2.60521	stable

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Test Results 2: 2 years

- 2 years…ISKANDARnet [4/1/2010-31/12/2011]
- Gaps in GPS data…due to on-site maintenance [2010-Mar, Jul, Aug; 2011-Apr, Mei, Jun]
- Similar analysis procedure
- Results: Fluctuations in cm level, all stations are stable

Deformation Trend of ISKANDARnet at 2010 – ISK1

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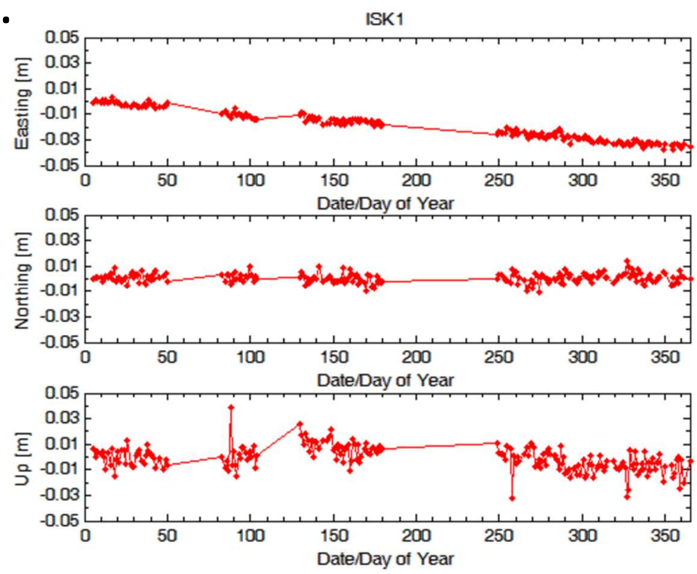

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Deformation Trend of ISKANDARnet at 2010 – ISK2

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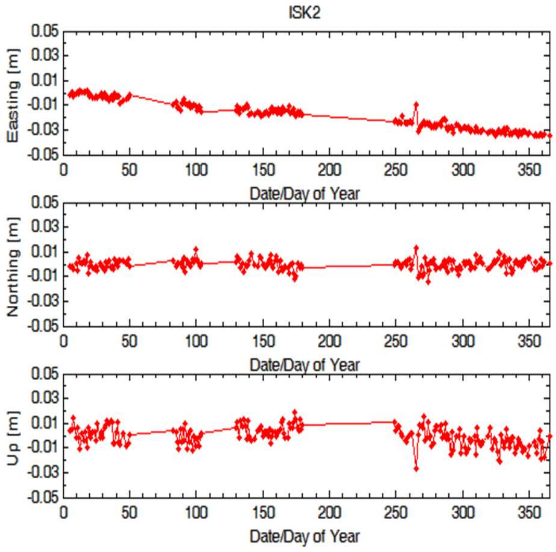

Deformation Trend of ISKANDARnet at 2010 – ISK3

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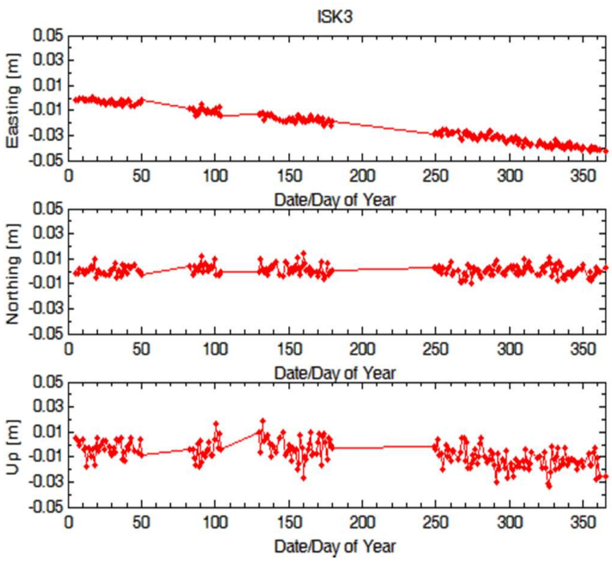
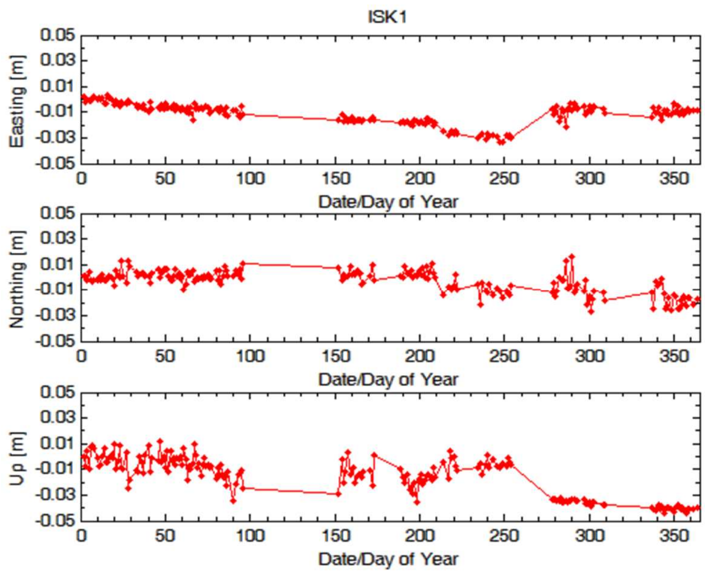


Deformation Trend of ISKANDARnet: 2010

Table 5: Statistical analysis of ISK1, ISK2 and ISK3 for year 2010

		Delta Easting [m]	Delta Northing [m]	Delta Up [m]
	Min	-0.0376	-0.0112	-0.0325
ISK1	Max	0.0036	0.0135	0.0392
	Std	0.0114	0.0037	0.0094
	Min	-0.0352	-0.0145	-0.0268
ISK2	Max	0.0017	0.0134	0.0183
	Std	0.0110	0.0041	0.0078
	Min	-0.0427	-0.0100	-0.0333
ISK3	Max	0.0006	0.0138	0.0190
	Std	0.0132	0.0040	0.0092

Deformation Trend of ISKANDARnet at 2011 – ISK1

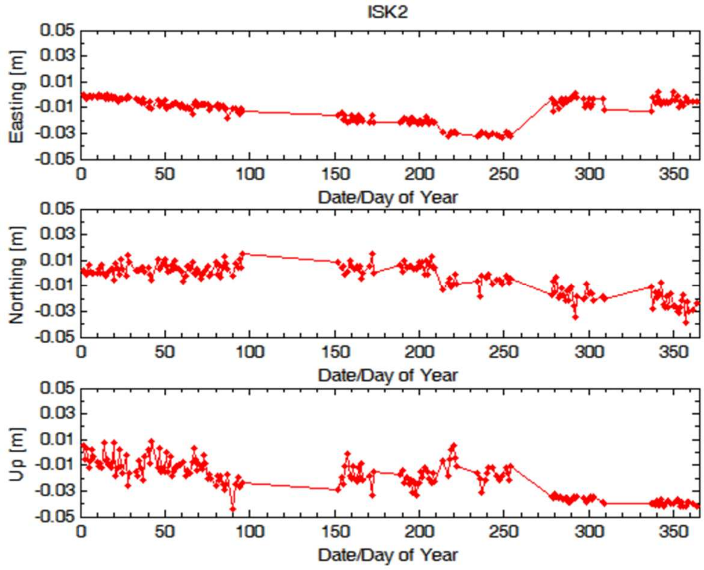


Min: -0.0336m
Max: 0.0029m
Std: 0.0080m

Min: -0.0265m
Max: 0.0166m
Std: 0.0086m

Min: -0.0441m
Max: 0.0122m
Std: 0.0153m

Deformation Trend of ISKANDARnet at 2011 – ISK2

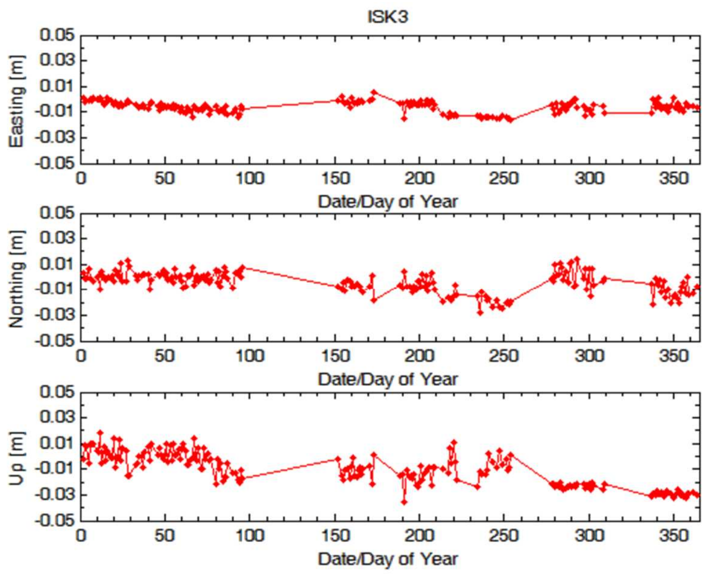


Min: -0.0330m
Max: 0.0026m
Std: 0.0092m

Min: -0.0391m
Max: 0.0152m
Std: 0.0114m

Min: -0.0441m
Max: 0.0085m
Std: 0.0131m

Deformation Trend of ISKANDARnet at 2011 – ISK3



Min: -0.0158m
Max: 0.0058m
Std: 0.0043m

Min: -
0.0279m
Max:
0.0137m
Std:
0.0082m

Min: -0.0350m
Max: 0.0185m
Std: 0.0125m

Deformation Trend of ISKANDARnet: 2011

Table 6: Statistical analysis of ISK1, ISK2 and ISK3 for year 2011

		Delta Easting [m]	Delta Northing [m]	Delta Up [m]
	Min	-0.0336	-0.0265	-0.0441
ISK1	Max	0.0029	0.0166	0.0122
	Std	0.0080	0.0086	0.01525
	Min	-0.0330	-0.0391	-0.0441
ISK2	Max	0.0026	0.0152	0.0085
	Std	0.0092	0.0114	0.0131
	Min	-0.0158	-0.0279	-0.0350
ISK3	Max	0.0058	0.0137	0.0185
	Std	0.0043	0.0082	0.0125

CONCLUSIONS

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Conclusions

- This study: coordinate monitoring of local GPS CORS network using Bernese & ConDAS.
- Bernese GPS software: special processing strategies; 3 types of output files from Bernese were extracted for deformation detection/analysis.
- ConDAS: a windows-based software system for GPS deformation detection via IWST and final S-transformation methods.

Conclusions

- ConDAS has been proven to have potential for providing high-quality stability information of CORS network.
- The test results show the suitability of the approach/software system for practical applications such as local CORS coordinate monitoring.
- Future works: to improve the flexibility of this software system in data searching, loading and code embedding.

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- Research facility/ISKANDARnet: GNSS & Geodynamics Research Group, FGRE, UTM.

Thank you for your attention!

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Double Difference GPS Data Processing using Bernese

- The preparation part: computing a priori coordinate file, preparing the orbit and earth orientation files in Bernese formats, converting RINEX files to Bernese format, synchronising the receiver clocks to GPS time and producing an easy to read overview of available data.
- The pre-processing part: creation of single difference files, editing of the cycle slips and removal of suspect observation.
- The processing part: to resolve the ambiguity. After computing a solution with real valued ambiguities the Quasi Ionosphere Free (QIF) strategy is used to resolve ambiguities to their integer numbers. Subsequently, compute and provide the fixed ambiguity solution using double differencing strategy.
- A summary results file is saved and dispensable output files are removed at the final stage of processing.