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Analysis On High Rate GNSS Data Co-Seismic Response In Jiuzhaigou 7.0Ms Earthquake

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ABSTRACT: Jiuzhaigou 7.0Ms Earthquake Occured At 13:19 8th August 2017 (UTC) In Sichuan Province, China. We Processed The High Rate (1Hz) Global Navigation Satellite System(GNSS) Data Of Stations In Two-Hundred Kilometers Distance From Epicenter After One Hour With Ultra-Rapid Ephemeris By TRACK Module Of GAMIT Software And Discovered That There Are Only Two Stations Have Obvious Displacement. SCSP Station Have A Displacement About 1.5 Centimeters Forever And GSWD Station Was Not. Meanwhile, We Processed The Same Data By Rapid Ephemeris And Precise Ephemeris. To Compare, Three Result Almost Have No Difference. Last, We Gave A Group Of Different Distance Reference Stations From Epicenter In One Direction To Process And The Result Of Min And Max Distance Were Not Good, It Must Be A Probable Distance For Selecting Reference Station And It Is Related To The Data Quality Of The Reference Station.
Key Words: Track, Earthquake, GNSS, High Rate, Displacement.

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I. INTRODUCTION

As We All Known, The Earthquake Is One Of Most Serious Disasters On The Earth, There Are More Than Ten Thousand People Dead Form Earthquakes Every Year. So It Is Important To Monitor The Crustal Movement And Deformation For Earthquake Forecast. Developing Global Navigation Satellite System(GNSS) Technology Can Make An Accurate Coordinate And Displacement Change For A Fixed Observation Station. GNSS Seismology Uses Receiver As Displacement Seismometer For Earthquake Studies [1] [2]. It Is A More Appropriate Means Of Observing The Surface Deformation. Large-Scale GNSS Observation Networks (Or Stations) Are Established By Earthquake-Prone Countries Around The World For Crustal Movement Monitoring, Such As The US PBO Project, Japan's GEONET, China's CMONOC [3], Etc. Especially, High Rate GNSS Data Can Describe The Crustal Deformation Detail Clearly, More And More Researcher Get Good Research Achievement On Study High Rate Analysis On Earthquakes. However, Because Of Different Fault Location, Not The Same Geological Conditions, Every Earthquake Have A Distinctive Crustal Movement Feature And Fracture Process Of Surface. For Different Epicentral Distance Of Reference Station And Different Precision Satellite Orbit In Processing, The High Rate Data results may Be Great Difference[4] [5].

At 13:19 46 Seconds 8th August 2017 (UTC), A 7.0Ms Earthquake Occured In Sichuan Province, China. The Place Named Jiuzhaigou Where Is A Landscape And Famous Scenery. There Are Several GNSS Continuously Operating Reference Stations In 200km From Epicenter which Record The High Rate Data. This Study Will Discuss The Character Of Crustal Co-Seismic Response And Movement Use GNSS High Rate Data In This Area Affected By Earthquake.

II. TRACK PROCESSING MODULE

2.1 Theory

Track Module In GAMIT/GLOBK Is The Style Of GNSS Data Collection And Processing Suggests That One Or More Stations Is Moving, To Obtain Good Results For Positioning As A Function Of Time If The Ambiguities Can Be Fixed To Integer Values.

The Success Of Track Processing Depends On Separation Of Sites. If There Are One Or More Static Base Stations And The Moving Receivers Are Positioned Relative To These. For Separations Less Than 10 Km, The Moving Positioned Usually Easy, 10~100 Km More Difficult But Often Successful, More Than 100 Km Very Mixed Results Depending On Quality Of Data Collected [4].

As Site Separation Increases, The Differential

Ionospheric Delays Increases, Atmospheric Delay Differences Also Increase. For Short Baselines (Less Than 10 Km), Ionospheric Delay Can Be Treated As 0, Carry Phase L1 And L2 Ambiguities Resolved Separately. Positioning Can Use L1 And L2 Separately (Less Random Noise).For Longer Baselines This Is No Longer True And Track Uses The MW-WL To Resolve L1-L2.

Program track Uses The Melbourne-Wubena Wide Lane To Resolve L1-L2 And Then A Combination Of Techniques To Determine L1 And L2 Cycles Separately. For Short Baselines Uses A Search Technique (No Longer Recommended) And Floating Point Estimation With L1 And L2 Separately. For Long Baselines Uses Floating Point Estimate With LC, MW-WL And Ionospheric Delay Constraints. The Important Method Of Track Program Is Kalman Filter Smoothing Can Be Used. (Non-Resolved Ambiguity Parameters Are Constant, And Atmospheric Delays Are Consistent With Process Noise).

L1-L2 And Melbourne-Wubena Wide Lane. The Difference Between L1 And L2 Phase With The L2 Phase Scaled To The L1 Wavelength Is Often Called Simply The Wide lane And Used To Detect Cycle Slips. However It Is Effected Fluctuations In The Ionospheric Delay Which In Delay Is Inversely Proportional To Frequency Squared. The Lower Frequency L2 Has A Larger Contribution Than The Higher Frequency L1.The MW-WL Removes Both The Effects On The Ionospheric Delay And Changes In Range By Using The Range Measurements To Estimate The Difference In Phase Between L1 And L2.

MW-WL Characteristics.In One-Way Form As Shown The MW-WL Does Not Need To Be An Integer Or Constant. Slope In One-Way Is Common, But Notice That Both Satellites Show The Same Slope. If Same Satellite-Pair Difference From Another Station (Especially When Same Brand Receiver And Antenna) Are Subtracted From These Results Then Would Be An Integer (Even At This One Station, Difference Is Close To Integer). The MW-WL Tells You The Difference Between The L1 And L2 Cycles. To Get The Individual Cycles At L1 And L2 We Need Another Technique. There Is A Formula That Gives L1+L2 Cycles But It Has 10 Times The Noise Of The Range Data (∑F/△F) And Generally Is Not Used. This Later Technique Is Called Narrow-Lane Ambiguity Resolution. In LC_AUTCLN Mode In GAMIT, L1-L2 Resolved In Autcln, And NL Ambiguities Resolved In Solve From Estimated Values Of L1 [4].

Equation For The MW-WL.

$$MW - ML = \emptyset_1 - \emptyset_2 - \frac{(f_1 - f_2)}{(f_1 + f_2)}\left[\frac{R_1 f_1 + R_2 f_2}{c}\right]$$

The Term Rf/c Are The Range In Cycles (Notice The Sum Due To Change Of Sign Ionospheric Delay).The △F/∑F Term For GPS Is About0.124 Which Means Range Noise Is Reduced By A About A Factor Of Ten. The ML-WL Should Be Integer (Within Noise) When Data From Different Sites And Satellites (Double Differences) Are Used. However, Receiver/Satellite Dependent Biases Need To Be Accounted For (And Kept Up To Date) (Http://Www-Gpsg.Mit.Edu/~Simon/Gtgk/Docs.Htm).

2.2 Procedure

Track Module processing Procedure Usually Is The Standard Use And Results From Long Baseline Kinematic Processing. Table 1 Shows The Input Files And Result Files List And Introduction.

Tab 1. Data Processing Procedure Of Track Module

Input files name	**Description**
track.cmd	Track command file (annotated with comments specific to data set, User generated)
Rinex files	1-second sampled rinex file for the hour around epicenter
Orbit files	orbit file from the MIT IGS analysis center. (IGS sp3 file could also be used).
Command	track -f track.cmd -d *doy_hh* -w *12501*>! TRAK_*doy_hh*.out
Output files name	
TRAK_*doy_hh*.out	Screen output from track. Captured output file with unix redirect.
TRAK*doy_hh*.sum	Summary file that contains the main quality results from track including the parameters from the run, bias parameters and the resolved status and phase residual statistics.
TRAK*doy_hh*.NEU.crbt.LC	Position estimates as a function of time in the NEU systems.
TRAK*doy_hh*.crbt.PRN*04*LC	Phase residuals as function of time for site CRBT and PRN 04 (these are not generated unless the res_root command is included in the command file. These files are generated for all sites except the reference site. (Only the crbt files are included here).
TRAK*doy_hh*.crbt.PRN*29*LC	Phase residuals PRN 29.

III. DEFORMATION OF EARTHQUAKE

3.1 Data Set

After The Jiuzhaigou Earthquake, We Collected observation High Rate data (1Hz) Of 24 GNSS Stations Within 300km Far From The Epicenter (Fig.1) And Download The Utral-Rapid Satellite Orbit Files From IGS. However, This Earthquake Took Place In A Scenic Spot, There Is No Closed Station In Ephemeris, Only SCSP Station Is 65km To Ephemeris. The Earthquake Occur At 13:19 46 Seconds 8th August 2017 (UTC), So We Selected Time Period 13:15:00-13:00, A Total Of 900 Observation Epoch. We Calculated all Sites To The Epicenter Distance Listed On The Figure, Analyzed The Observation Data Quality By TEQC Software, Using He Track

Module (Version 1.29) Of The Latest Version Of The GAMIT Software To Process The High Frequency Data.

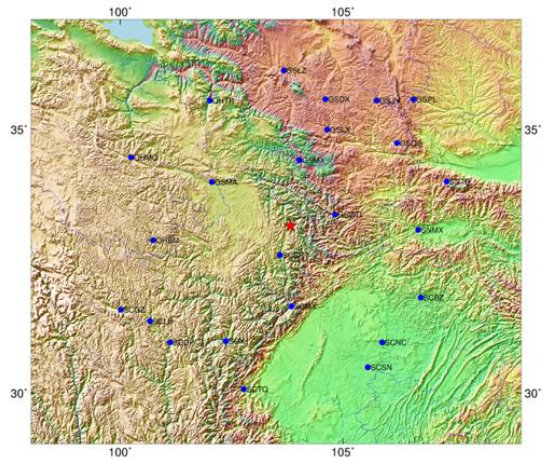


Fig.1 Distribution Of GNSS Stations Epicentral Distance Less Than 300km From CMONOC Project (The Blue Dots Respect Stations And The Red Star Respects Location Of Jiuzhaigou Earthquake Epicentral)

3.2 Deformation By GNSS Observation

After The Jiuzhaigou Earthquake, We Processed The High Rapid (1-Sec Sampling) GNSS Data Of Stations Nearby Epicenter With Ultra-Rapid Ephemeris By Track Module In An Hours. We Selected Two Stations Named SCSP And GSWD As The Roving Station, SCSP Station Is About 65km Away From Epicenter And GSWD Is About 100km Away From Epicenter. In Order To Reduce The Co-Seismic Displacement Influence, The Distance From Epicenter Of Reference Station May Longer Than 200km At Least. So We Choose SNMX Station As The Fixation, It Is About 225km Away From Epicenter, About 250km Away From SCSP, About 160km Away From GSWD. When We Start Processing, IGS Web Have No The Products Of The High Accuracy Ephemeris, Only The Ultra-Ephemeris To Download. The Solution Shows The Characters Of Co-Seismic Deformation(Fig.2).The Earthquake Make An Obvious Co-Seismic Displacement For SCSP Station And Generate About 15cm Permanent Displacement In North-South Direction And About 5cm Instantaneousdisplacement In West-East Direction. There Is A 1cm Instantaneousdisplacement In North-South Direction For GSWD Station.

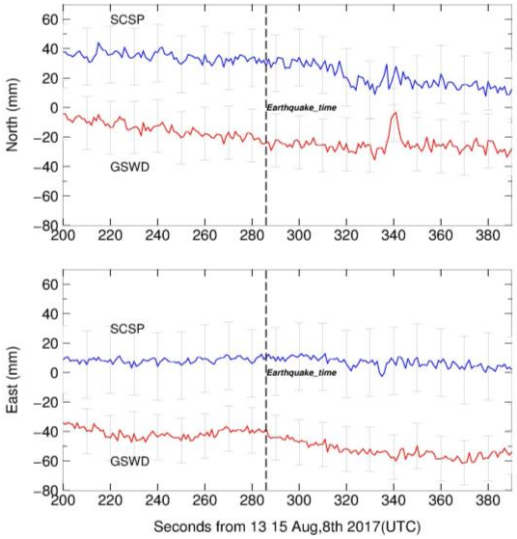


Fig 2. Co-Seismic Displacement For SCSP And GSWD Stations By 1Hz Data.

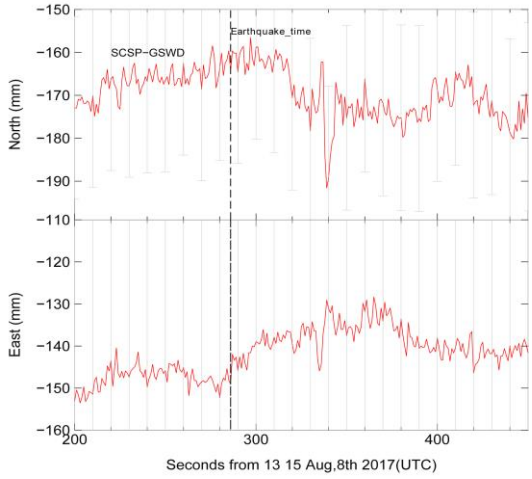
IV. DIFFERENT FIXED STATION MAKE DIFFERENT RESULT

As We All Know, The Distance Between Roving Station And Reference Station Can Directly Influence The Result Of Track Resolution. If The Distance Is Too Short, Co-Seismic Displacement Will Make A Superposition On Moving Station. Else If The Baseline Between Moving And Reference Station Is Too Long, Ionosphere Delay Can't Be Reduced Well In Processing And The MW-WL Must be Used To Resolve L1-L2 For Making Fixed Ambiguities. According To Haitao Yin's Conclusion, We Always Should Select The Reference Stations Which Have High Data Quality, The Multi-Path Effect Is Less Than 0.2m, The Spacing Is Greater Than Distance Of The Seismic Wave Propagation Rate Multiply With Continuous Time, The High Precision Results Can Be Obtained[6] [7]. Different Magnitudes, Different Geological Structures, Different Fracture Modes Can Lead To Different Results. So For This Earthquake, How To Select Reference Station To give An Accurate Result Have To Discuss [8].

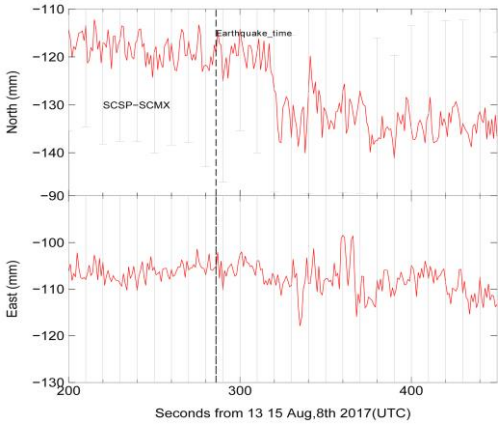
We Did An Experiment, Six Sites With Different Epicenter distances Were Selected As Reference Stations Near The Earthquake Zone, They Are GSWD SCMX GSMX GSLX GSDX NXYC Stations, The Epicenter distances are 100km, 150km, 142km, 210km, 270km And 620km Respectively (Tab.2). SCSP Station Is Close To The Epicentral (About 65km) Selected As The Roving Station.

The Following Figure 3 Show That Although The Epicenter Distance Of The Six Reference Stations Is Different, The Results Is The Earthquake Has Caused The Same Seismic Shift For SCSP Station. Especially,

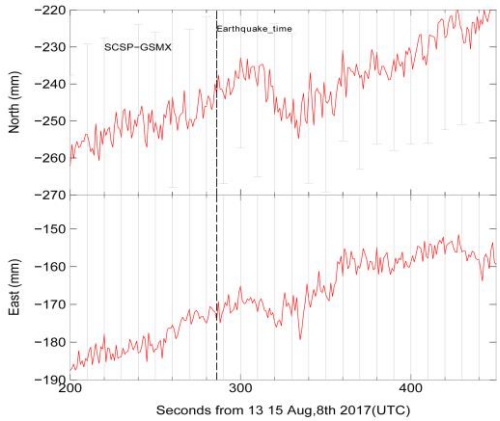
For Results Reference Station GSMX, The Time Series Appear The Two Groups Of Waveform, This Is Due To The Propagation Of Seismic Wave In The Earth's Crust With A Certain Speed, The Roving And Reference Station Spacing Is Beyond The Scope Of Seismic Effects And Not Occur Co-Seismic Situation, So The Two Groups Of Waveform Respectively Reflect That The Seismic Waves Caused Surface Displacement Of SCSP And GSMX Sites at Different Time.



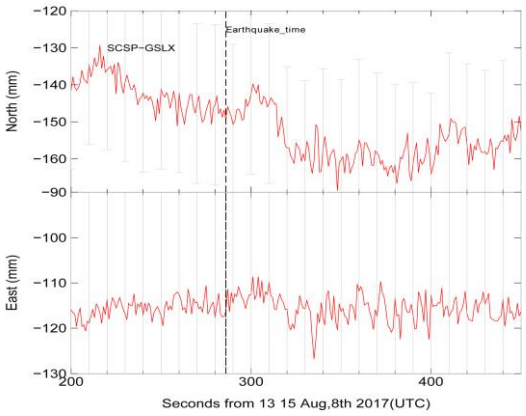
（A）



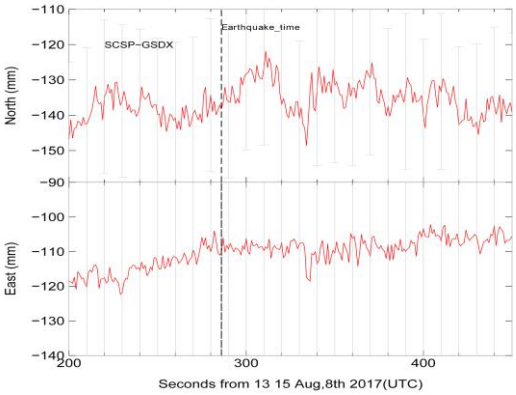
(B)



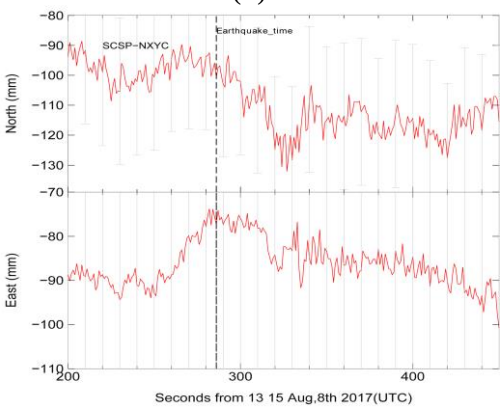
(C)



(D)



(E)



(F)

Fig3. SCSP Station Displacement Results By Different Distance Reference Stations GSWD, SCMX, GSMX, GSLX, GSDX, NXYC. (Notice: In Order To Make Figures Clearer, All The Results Time Only Show 250 Seconds, From Figure A To F The Distance Is Ranged From Near To Far)

The Following Table Shows The Reference Stations With Different Data Quality Affects The Positioning Accuracy Of The Roving Station, Which Has Little Relation With The Station Spacing From Epicentral And Roving Station. As The Reference Station, The Multi-Path Effect Of SCMX, GSDX And NXYC Stations are Small Relatively, Not More Than 0.25m.Therefore, The Positioning Results Of SCSP

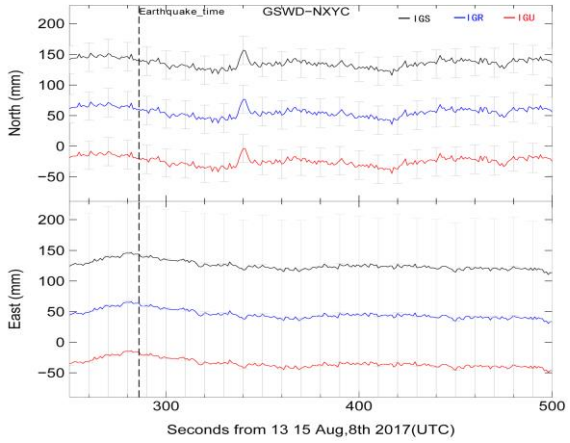
Station Are Higher.

Tab.2 Positioning Accuracy Of Different Distance Reference Stations With Different Data Quality (Roving Station: SCSP)

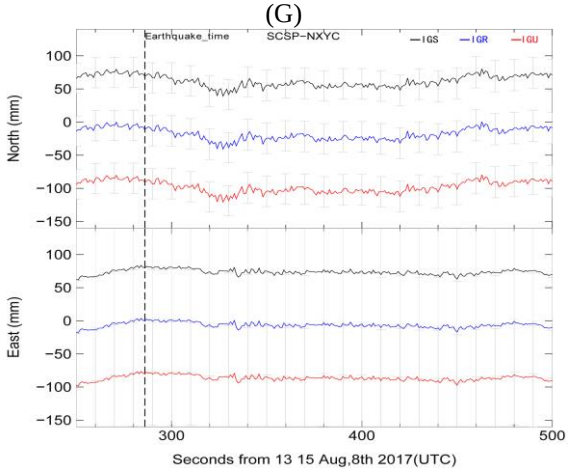
Reference Station name	Epicentral distance (km)	Distance to moving station(km)	Accuracy of NS (mm)	Accuracy of EW (mm)	Multipath-L1(m)	Multipath-L2(m)
GSWD	100	150	27.8	23.5	0.34	0.32
SCMX	150	100	9.6	11.8	0.22	0.20
GSMX	142	200	23.7	25.2	0.28	0.30
GSLX	210	280	22.4	22.9	0.30	0.27
GSDX	270	340	10.9	12.5	0.24	0.23
NXYC	620	690	11.1	13.0	0.24	0.25

V. COMPARE WITH DIFFERENT ACCURACYEPHEMERIS

In Front Of All Of Our Data Processing Result Is The Foundation Of IGS Ultra Rapid Ephemeris, Because Ultra-Rapid Ephemeris Product Cycle Is Short, The Day Will Be Able To Download, However, We Know That The IGS Also Released Ephemeris And Precise Ephemeris, The Two Ephemeris Products Than The Ultra-Rapid Ephemeris Orbit Determination Precision Is High, So We Might As Well To Compare The Following The Three Ephemeris Calculating Results.



(G)



(H)

Fig. 4 Comparision Results Of The Solution Of The Different Precision Ephemeris Of IGS, IGR And IGU. (The Black Line Is The Result With IGS Ephemeris, The Blue Line With IGR Ephemeris And The Red Line With IGU Ephemeris)

Figure 4 Shows The Results Of The Solution Of The Different Precision Ephemeris Of IGS, IGR And IGU respectively, Using The NXYC As Reference Station, GSWD (G) And SCSP (H) As The Roving Stations. It Is Show That There Is No Significant Difference In The Displacement Of The Roving Stations With Different Accuracy Ephemeris In The High Sampling Rate Data Processing.

CONCLUSION

It Is True That The Crustal Deformation Of The Epicenter Area Is Caused By Jiuzhaigou Earthquake, The Results Of Time Seriers Mean Peak To Peak Displacement Of Closest Station To Epicenter, And Made An Obvious Co-Seismic Displacement For SCSP Station And Generate About 15cm Permanent Displacement In North-South Direction And About 5cm Instantaneousdisplacement In West-East Direction. Arrival Time Difference Of Earthquake Wave Between Closest And Farthest Sites Used In This Study Is Around 50 Seconds.

Lots Of Results Show That During The Propagation Of Seismic Waves, The Energy Decreases With The Increase Of Epicentral Distance. In The Range Of Seismic Waves, The Correlation Between The Seismic Displacement Of Roving Station And The Epicenter Distance Of The Reference Station Is Not Very Obvious, However, The Data Quality Of The Reference Station Is Closely Related With Position Accuracy Of Roving Station .

After The Earthquake, Using Track Model To Process The High Rate GNSS Data, The High-Precision Ephemeris Product Cannot Be Downloaded In Time, The Result Of The IGU Ephemeris solution Is Enough To Meet The Earthquake Emergency And Analysis Needs.

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