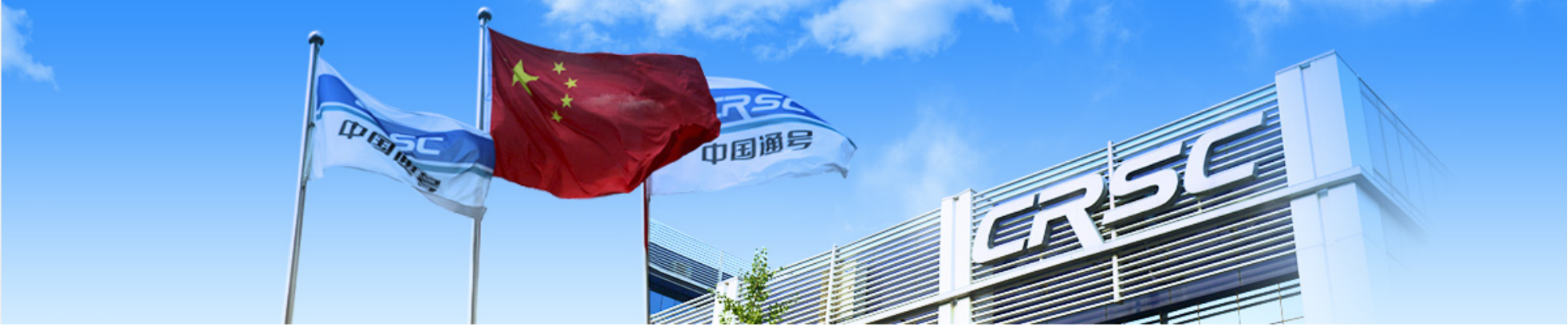


PNT Symposium Stanford University
China‘s High Speed Railway Application with GNSS

Jin Shi 2015.11

Beijing National Railway Research & Design Institute of
Signal & Communication Co., Ltd (CRSCD)

Outline

- China's High Speed Railway
- GNSS Application in Railway
- GNSS Performance Study
- GNSS Special in Railway Application
- GNSS Enhancement Tech
- Future Application
- Summary

China's High Speed Railway

- Brief History of China's High Speed Railway
  - Introduced on April 18, 2007
  - 4x4 PDL network has been finished by 2014
  - Operational speeds of up to 380 km/h (240 mph)
  - Daily ridership has grown from 237,000 in 2007 to 2.49 million in 2014
  - Cumulative ridership had reached 2.9 billion by October 2014
  - World Largest HSR Network

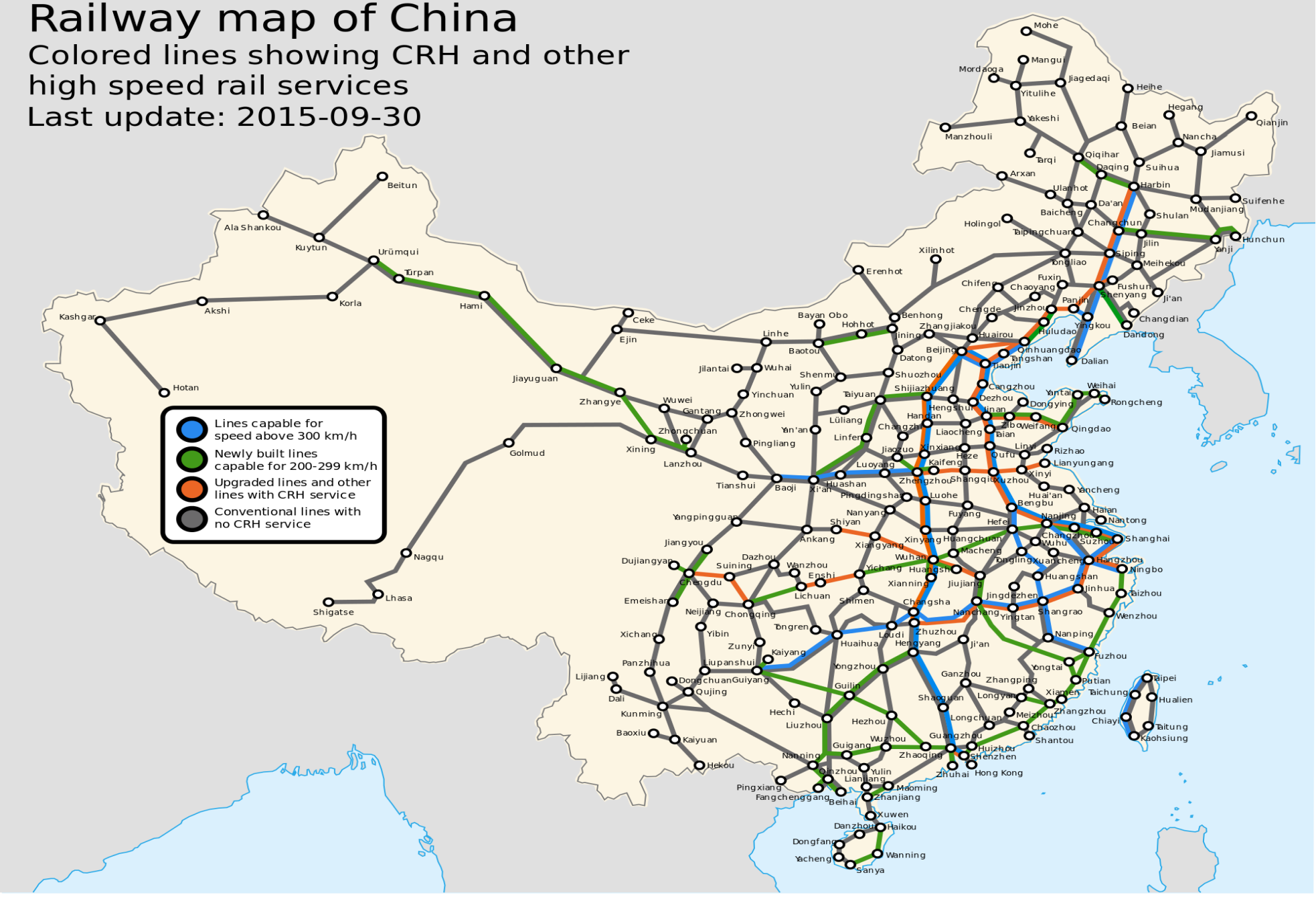
China's High Speed Railway

- Railway Map of China 2015
  - HSR line length exceeds 16,000KM (9900mi) in 2014
  - Combined with hybrid lines the length exceeds 20,380 km (12,660 mi) in 2014
  - 16,775 km (10,423 mi) is under construction
  - HSR network will double in 2020

Railway map of China

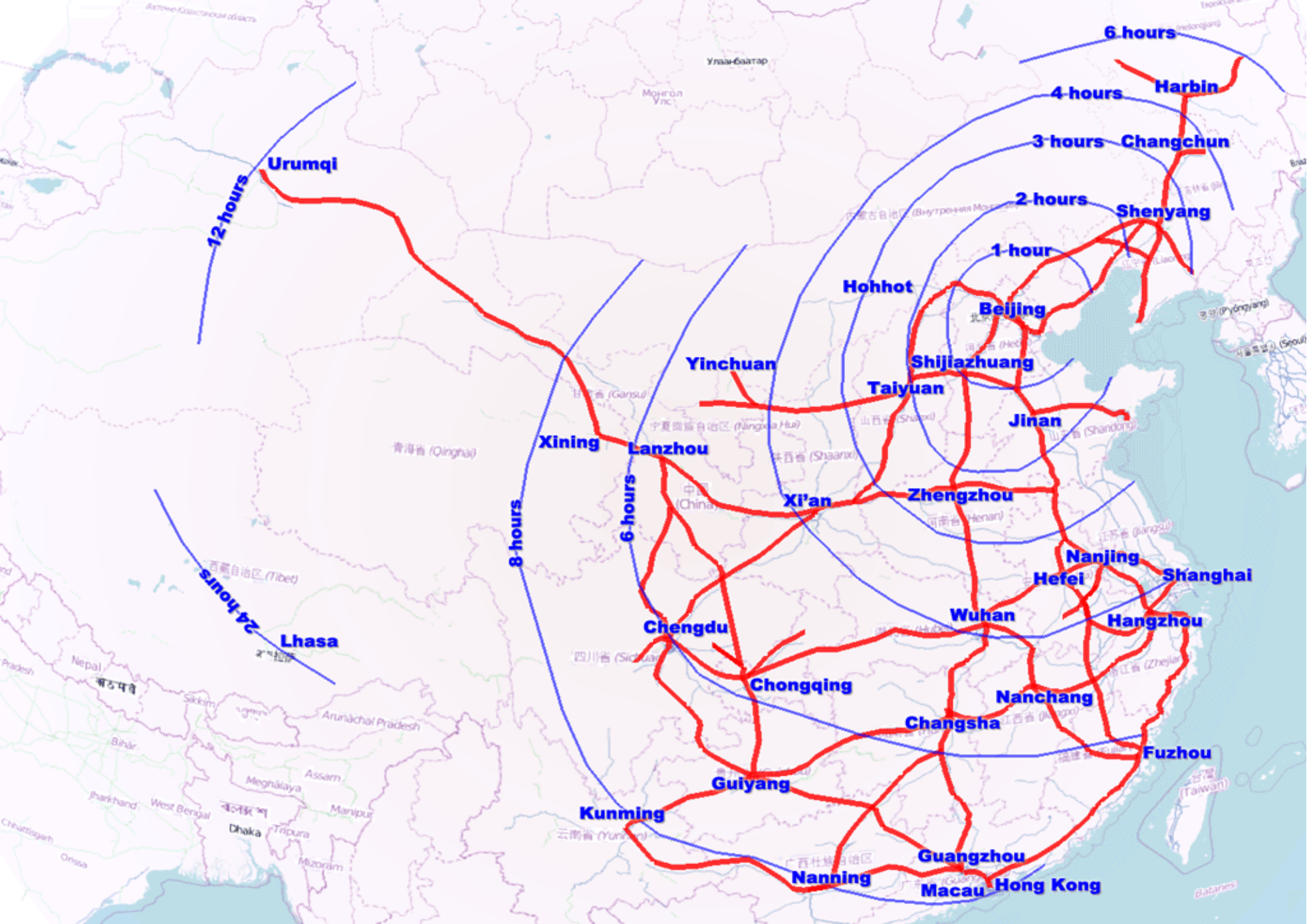
Colored lines showing CRH and other high speed rail services

Last update: 2015-09-30



China's High Speed Railway

- China's HSR Network in 2020
  - 28/32 provinces and regions are connected
  - Redefine city distance, 8 hours between core metropolis
  - Challenge to traditional railway control system
  - Revolution for transportation industry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Harbin
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Shenyang
1 hour
Urumqi
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Hohhot
Beijing
Yinchuan
Shijiazhuang
Taiyuan
Jinan
Xining
Lanzhou
8 hours
6 hours
Xi'an
Zhengzhou
Nanjing
Hefei
Shanghai
24 hours
Lhasa
Wuhan
Hangzhou
Chengdu
Chongqing
Nanchang
Changsha
Fuzhou
Guiyang
Kunming
Guangzhou
Nanning
Macau
Hong Kong

China's High Speed Railway

- The Role of CRSC in China's HSR History
  - Standard Contributor
  - System Design Solution Provider
  - Core Control System Manufacturer
  - Project Contractor and Executor
  - System Maintainer

GNSS Application in Railway

- Why China has Fantastic Construction Speed
  - Scientific planning and organization
  - Frontier design and verification technology
  - “Know How” experience during construction
  - Complete autonomy and fully customized capability
- GNSS data plays important role for Railway
  - Early stage simulation
  - Rapid and accurate construction
  - ITCS control system
  - UAV for OAM

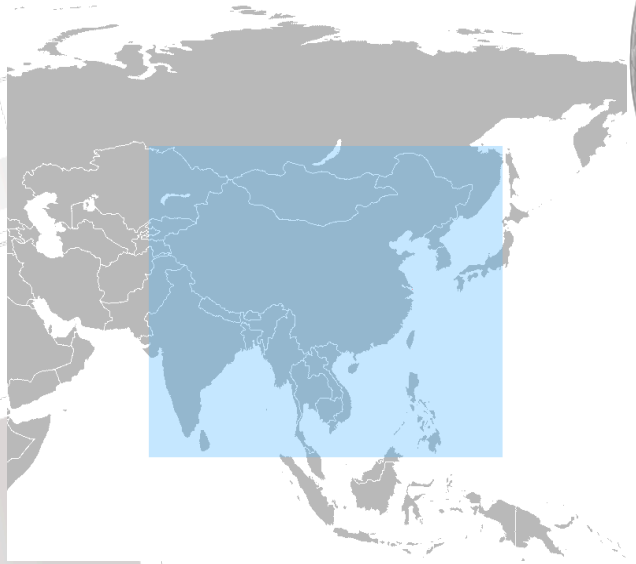
GNSS Application in Railway

- China's Contribution to GNSS
  - Brief history of Compass Navigation System
    - BeiDou-1 System—2000-2003,bidirectional System, geostationary orbit
    - BeiDou-2 System—20012-Now,bidirectional System, hybrid orbit
    - free civilian service has a 10-meter location-tracking accuracy, synchronizes clocks with an accuracy of 10 nanoseconds, measures speeds to within 0.2 m/s.
    - restricted military service has a location accuracy of 10 centimeters

CRSC

GNSS Application in Railway

- Coverage Area of Compass System
  - BeiDou-1
    - 70°E to 140°E
    - 5°N to 55°N
  - BeDou-2
    - 55°E - 180°E
    - 55°S - 55°N



GNSS Application in Railway

- Roadmap of Compass System

  B1: 1559.052~1591.788MHz

  B2: 1166.22~1217.37MHz

  B3: 1250.618~1286.423MHz

Time	Constellation	Coverage Area
2012	5GEO+5IGSO+4MEO	Asia
2020	5GEO+3IGSO+27MEO	Global

GNSS Application in Railway

- Launch Plan of BeiDou in 2016

No	Lauch Time	Load	Rocket Type	Lauch Base	Lauch Slot	Comments
1	2016年	BeiDou	CZ-3B/C	XiChang	2	#21,22?
2	2016年	TianGong-2	CZ-2F	JiuQuan	921	
3	2016年	ShenZhou-11	CZ-2F	JiuQuan	921	
4	2016年	GF-3	CZ-2D	TaiYuan	New Slot	
5	2016年	GF-5	CZ-2D	TaiYuan	New Slot	
6	2016年	GF-6	CZ-2D	TaiYuan	New Slot	
7	2016年	FengYun-3D	CZ-4B	TaiYuan	New Slot	
8	2016年	FengYun-4	CZ-3B/C			
9	2016年	HXMT				
10	2016年	CO2观测星				
11	2016年	中法海洋卫星				
12	2016年	地震电磁星				
13	2016年	SJ - 10				
14	2016年	量子通信试验星				
15	2016年	BeiDou	CZ-3B/C	XiChang	2	#23,24?
16	2016年	BeiDou	CZ-3B/C	XiChang	2	#25,26?
17	2016年	BeiDou	CZ-3B/C	XiChang	2	#27,28?
18	2016年	遥感-30				
19	2016年	遥感-31				
20	2016年	遥感-32				
21	2016年	天链1号04星	CZ-3B	XiChang	2	

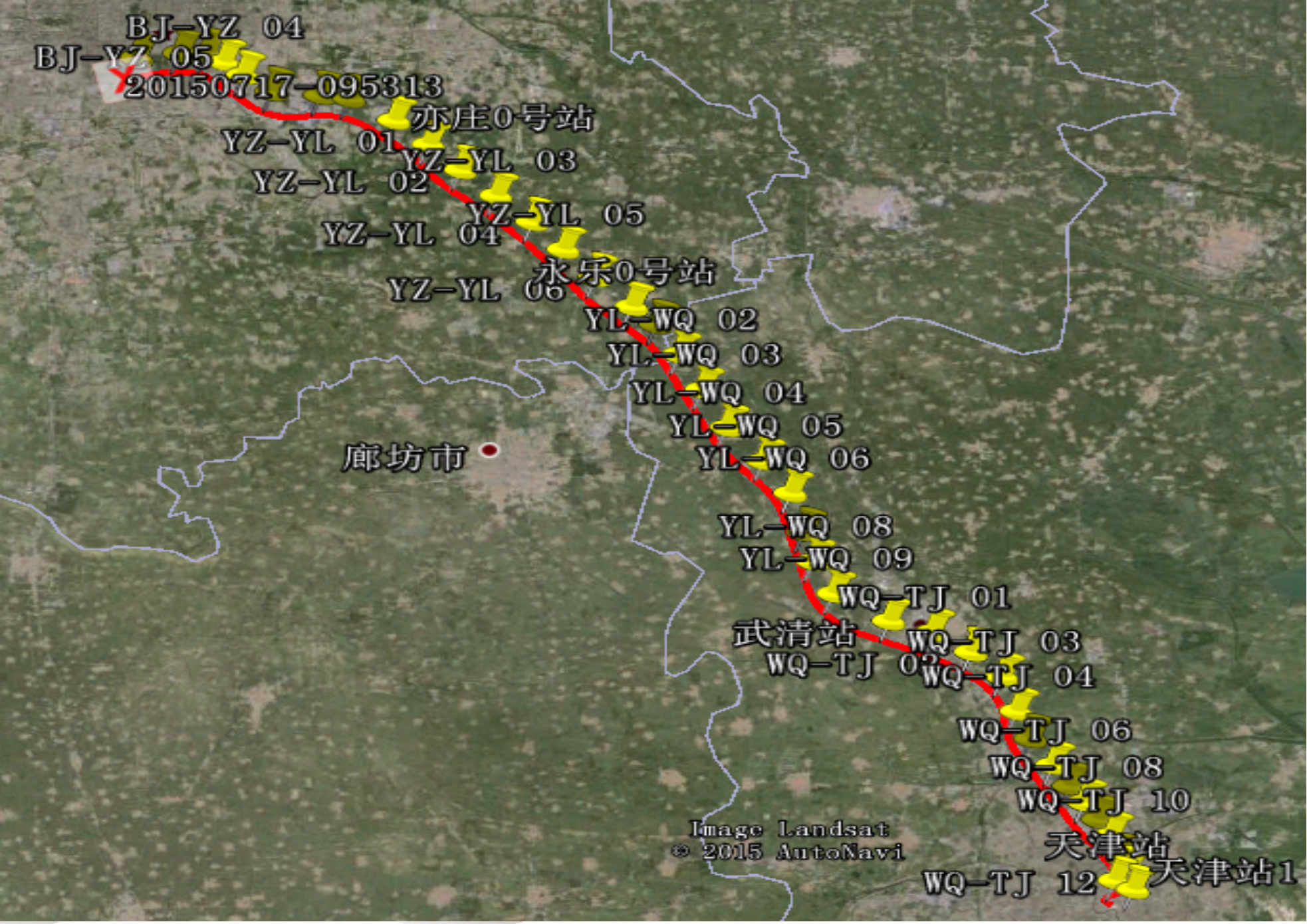
GNSS Application in Railway

- Early Design Simulation
  - Determine the location of communication base station
  - 3D Modeling and integrated with GIS system (Google Earth)
  - Typical environment confirmation
  - Geometry parameter abstraction
  - Antenna feed system 3D modeling
  - Rough performance simulation
  - Channel sounding and data acquisition
  - Fine grain performance simulation

CRSC

GNSS Application in Railway

- Early Design Simulation
  - For HSR lines
  - For Inter-City lines
  - For Metro lines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YL-WQ 03
YL-WQ 04
YL-WQ 05
YL-WQ 06
廊坊市
YL-WQ 08
YL-WQ 09
WQ-TJ 01
武清站
WQ-TJ 03
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WQ-TJ 04
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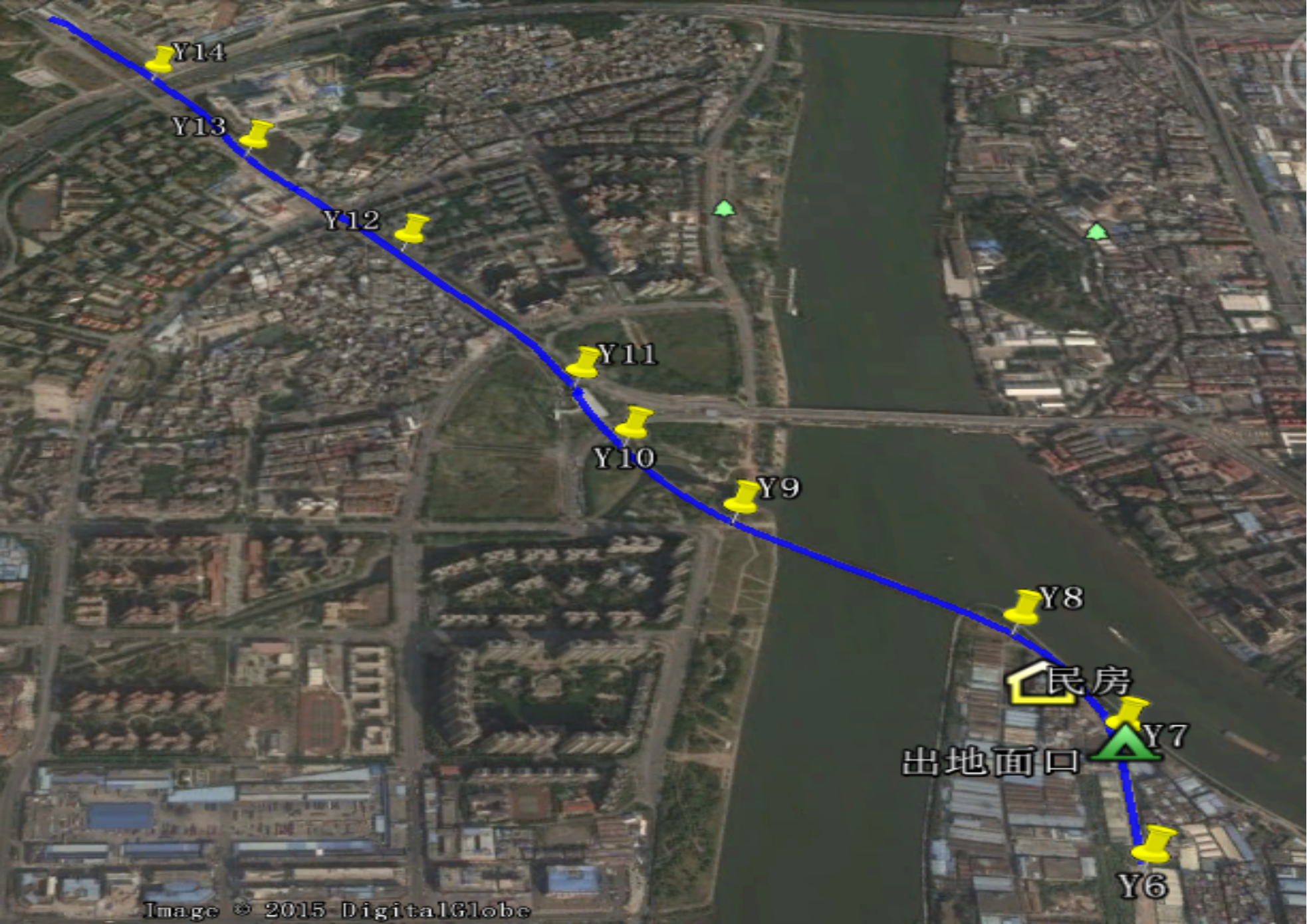
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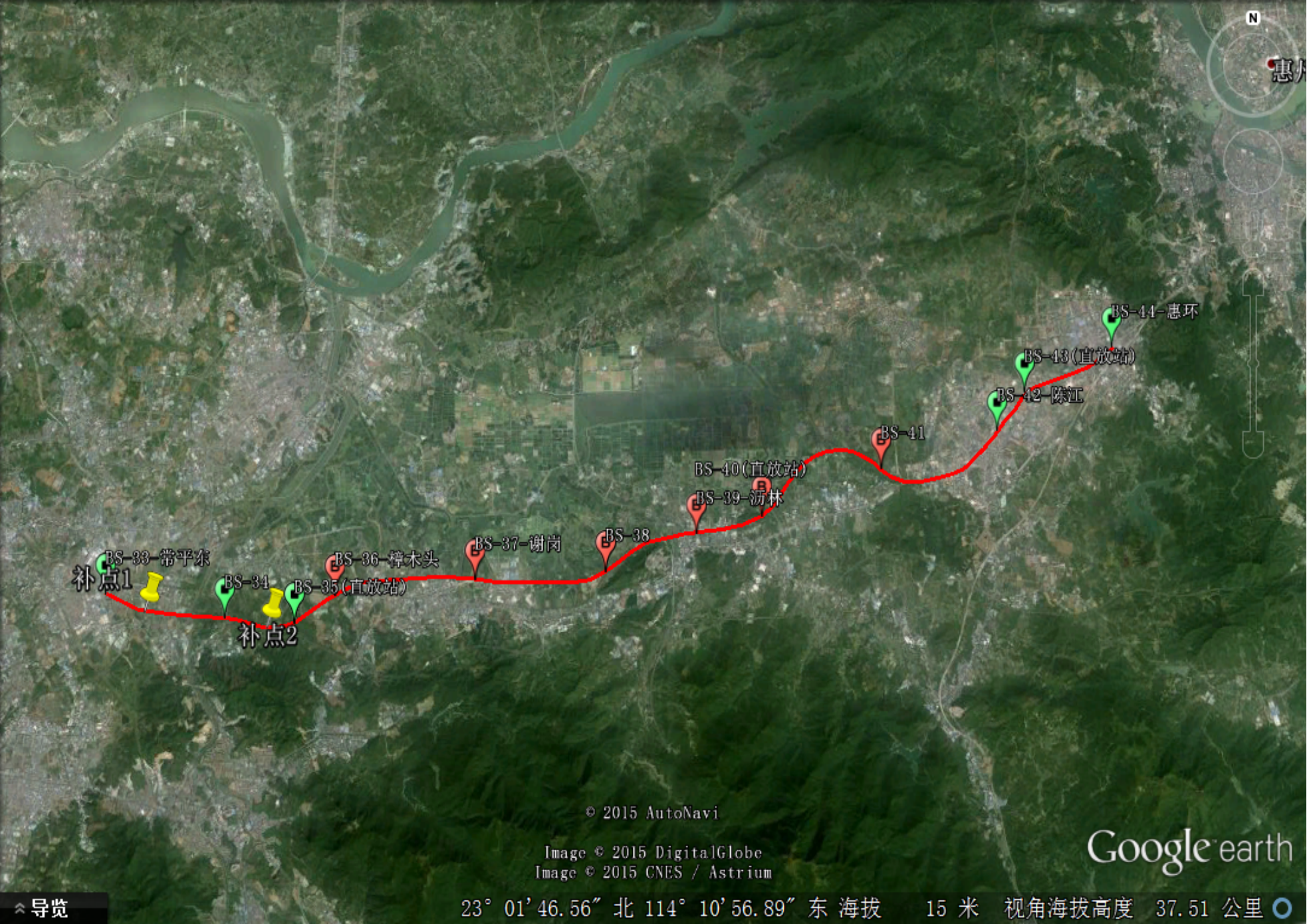
BS-33-常平东
补点1
BS-34
BS-35(直放站)
补点2
BS-36-樟木头
BS-37-谢岗
BS-38
BS-39-沥林
BS-40(直放站)
BS-41
BS-42-陈江
BS-43(直放站)
BS-44-惠环
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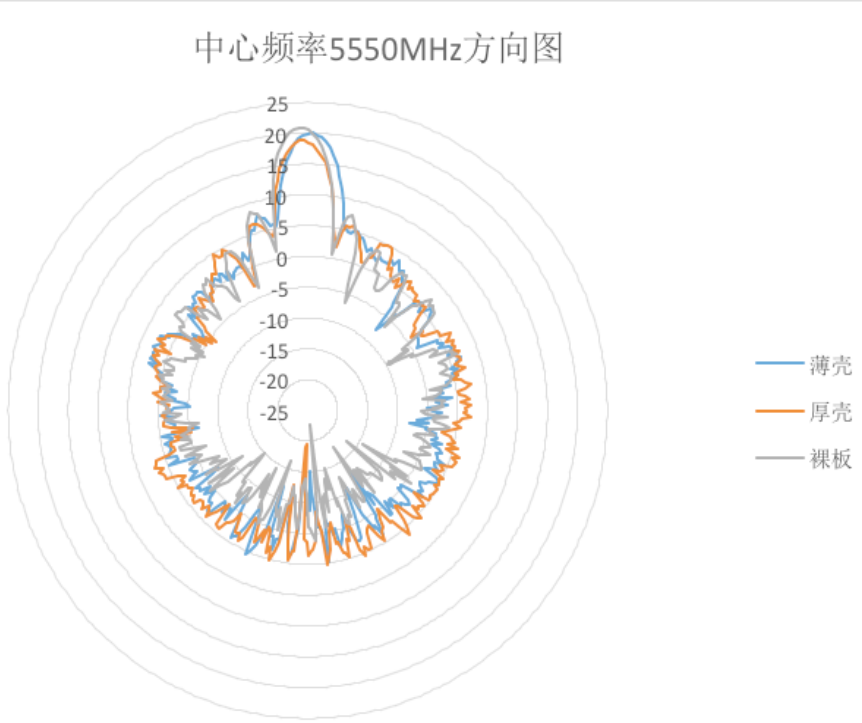
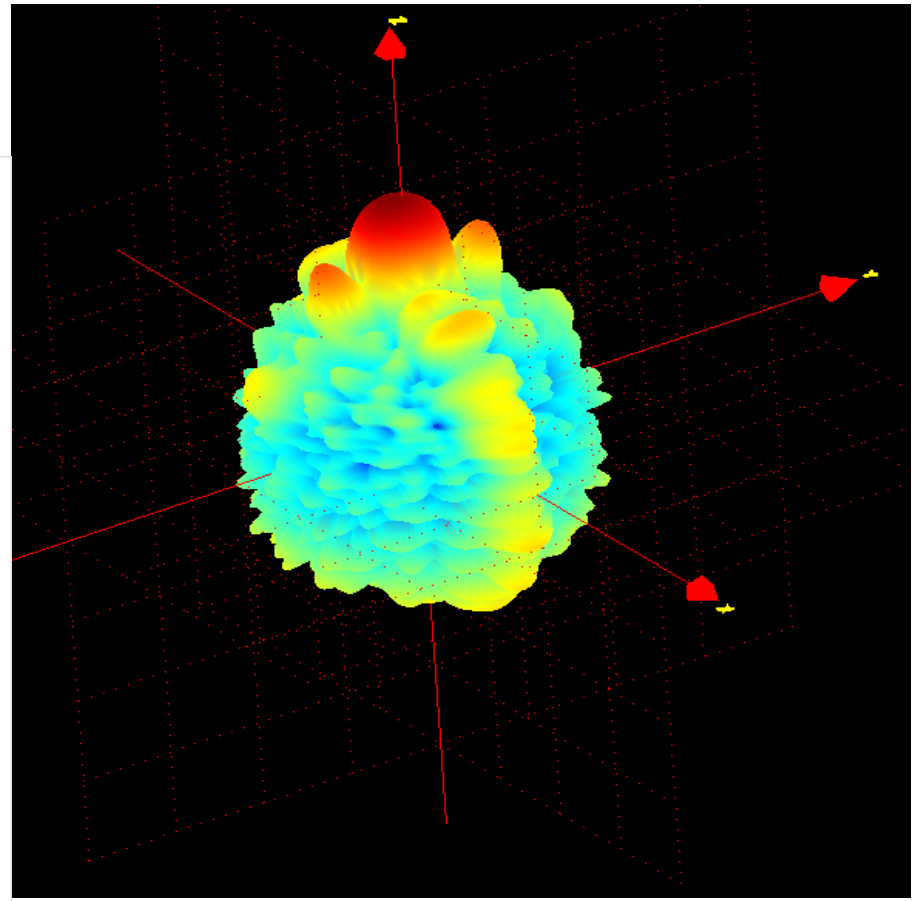
导览
23° 01'46.56" 北 114° 10'56.89" 东 海拔 15 米 视角海拔高度 37.51 公里

GNSS Application in Railway

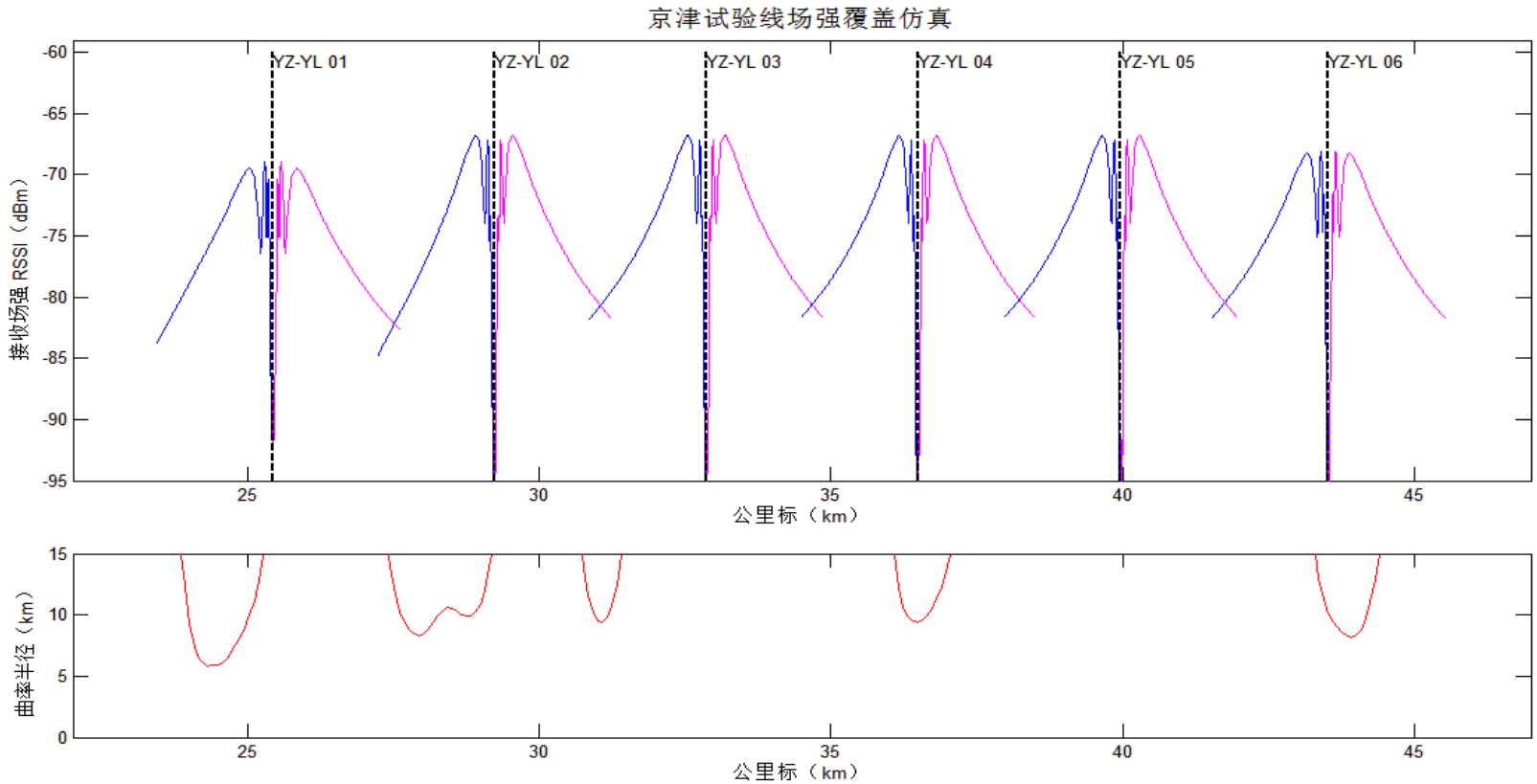
- Early Design Simulation
  - Antanna feed System Simulation





GNSS Application in Railway

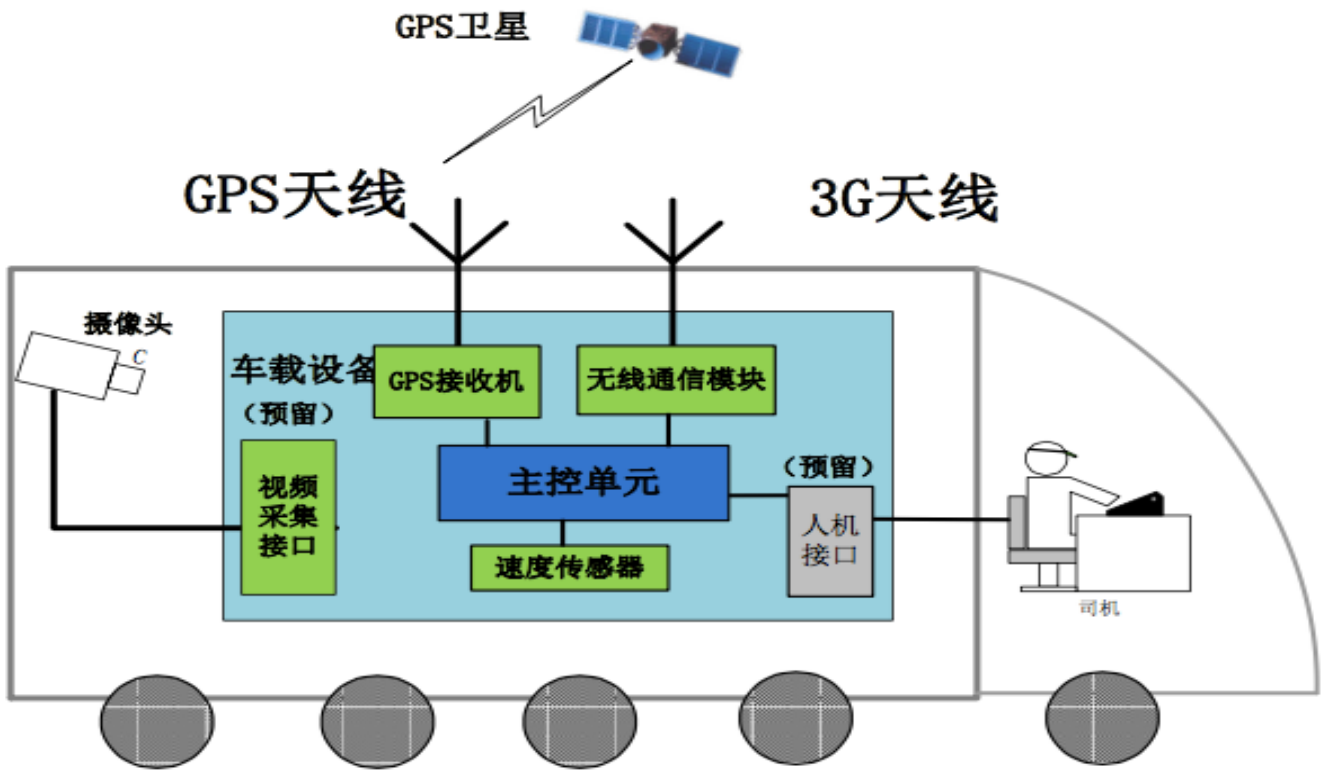
- Early Design Simulation




Siberia
Amur (Heilongjiang)
Dzungarian Basin
Turfan Depression
Tian Shan
Gobi Desert
Dahinggiangling
Songhua
Northeastern Plan
Tumen
Changbai Mountain
Yalu
Beijing
Tarim
Tarim Basin
Qiling Mountain
Xining
Yellow (Huanghe)
Kunlun Mountains
Golmud
Wei
Yellow Sea
Korean Peninsula
North China Plain
Indus
Tibetan Plateau
Nu Jiang
(Salween River)
Lancang
Jin Sha Jiang
Han Shui
Huai
Sichuan Basin
East China Sea
Brahmiputra
Lhasa
Chang Jiang (Yangzi)
Chang Jiang Downstream Plain
Himalayas Mountains
Mount Everest
Indian Subcontinent
Pearl (Zhujiang)
Mekong
Taipei
Hong Kong
Macau
Key:
opened 1984
opened 2006

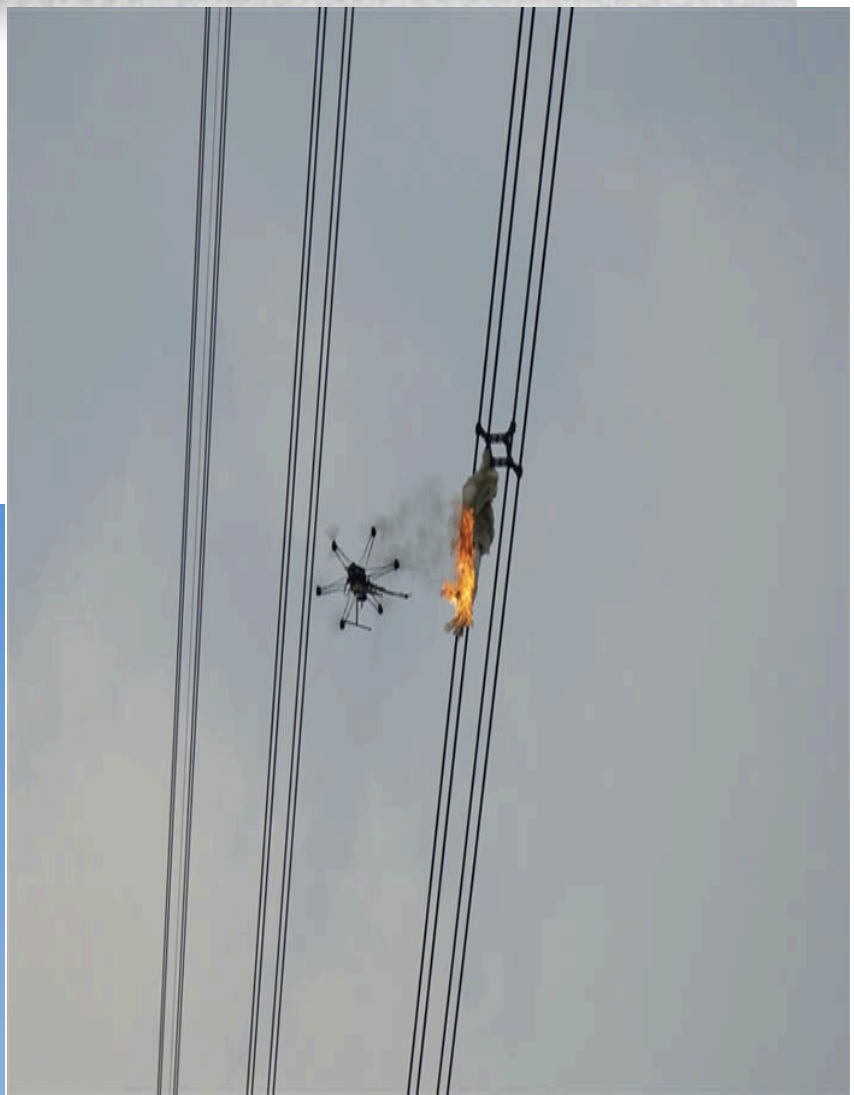
GNSS Application in Railway

- GNSS System in Qinghai-Tibet Line
  - GNSS Combined Satellite System



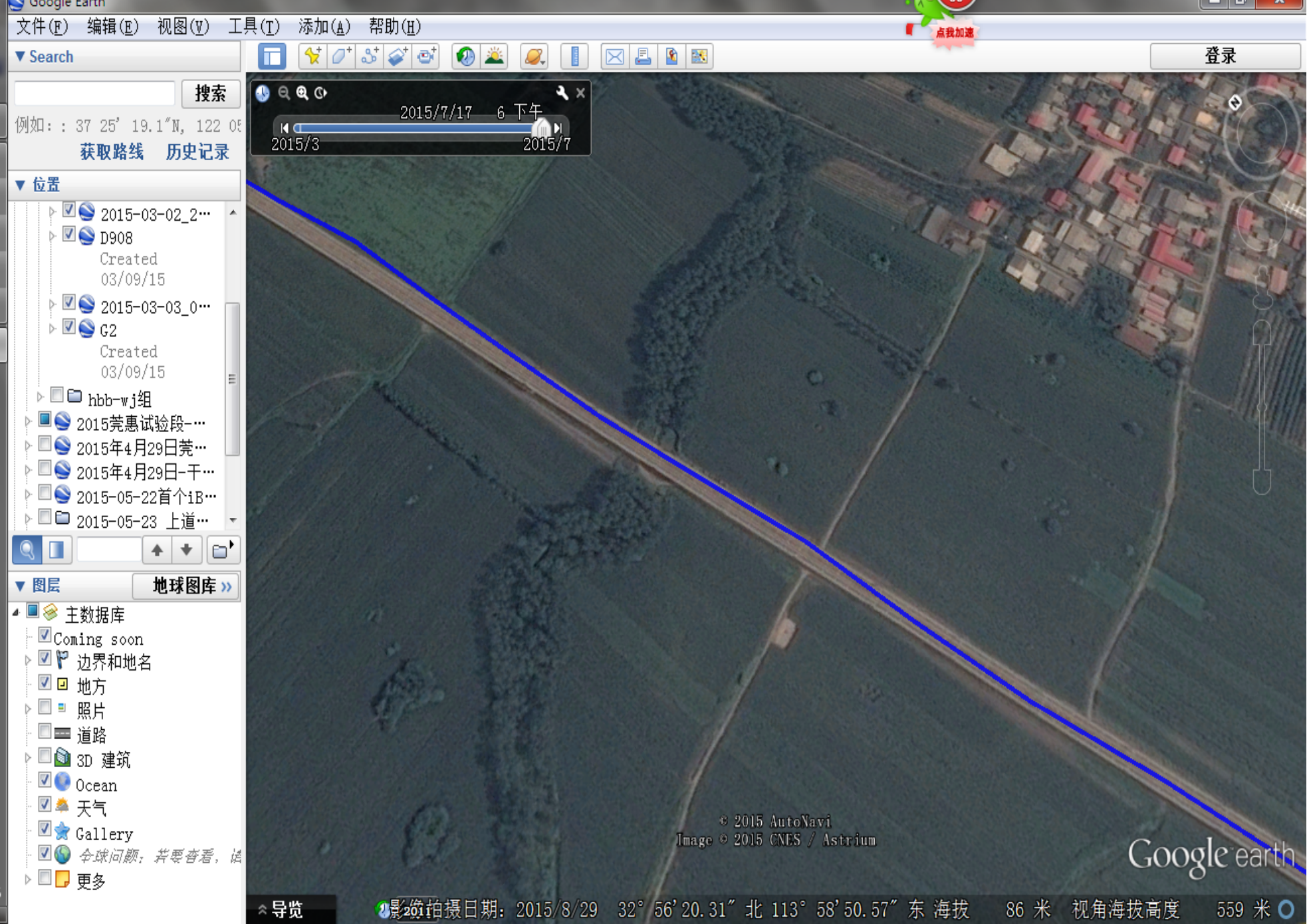
GNSS Application in Railway

- UAV for OAM
  - RF signal measure
  - Power line check
  - Line measurement before construction



GNSS Performance Study

- Flat Area Case Study
  - Error bound within 10m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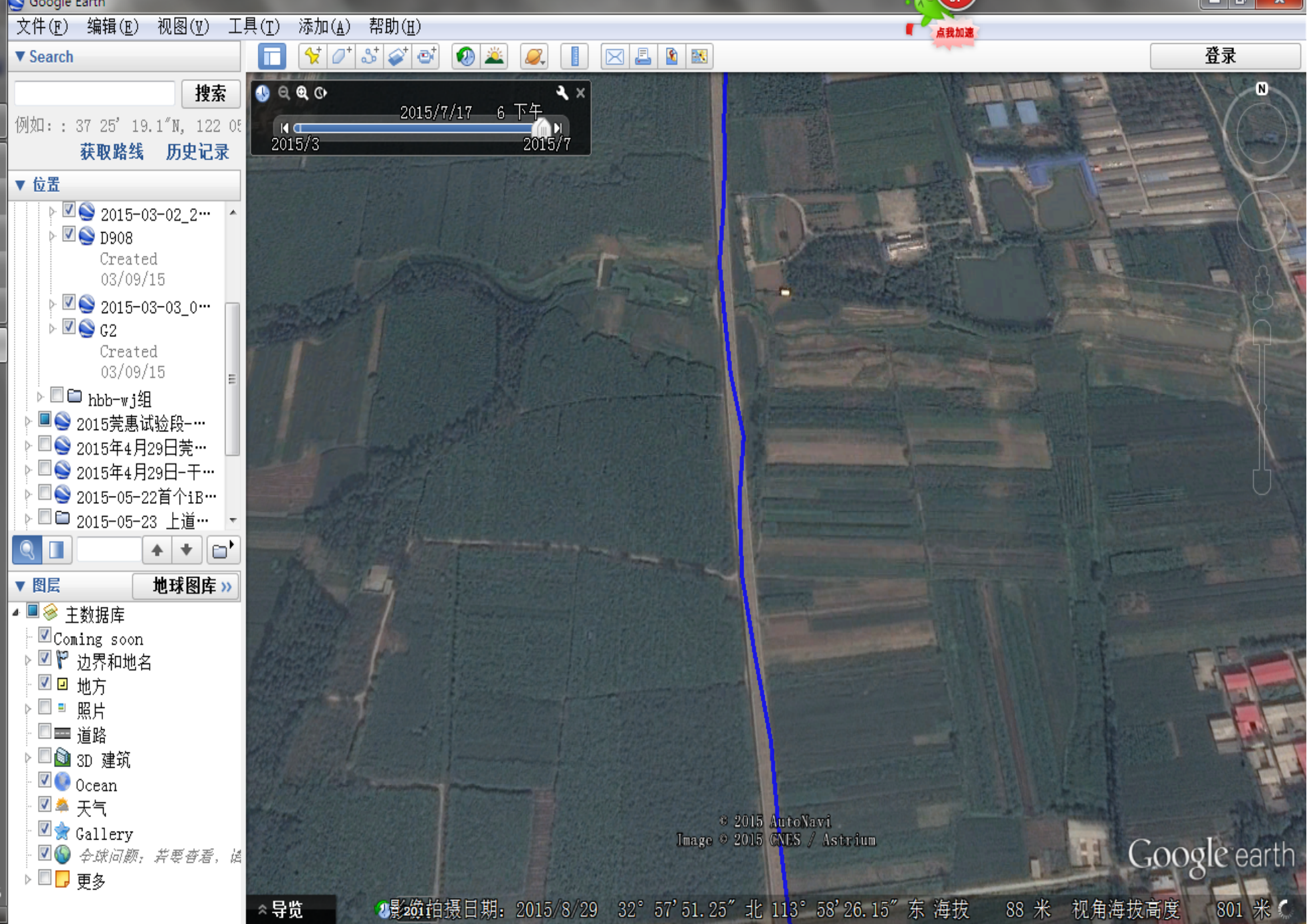
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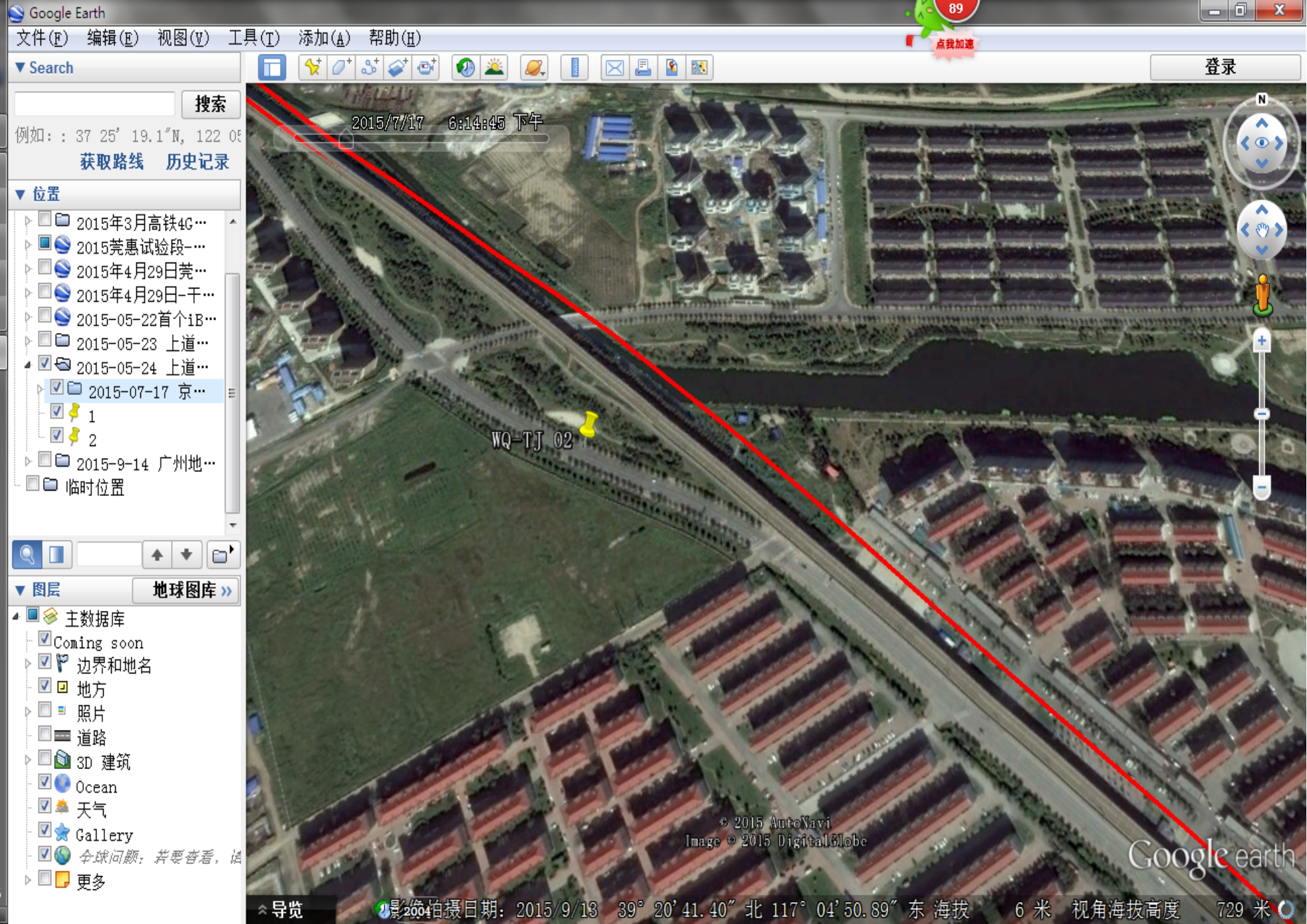
GNSS Performance Study

- City Area Case Study
  - Error can not be bound within 10m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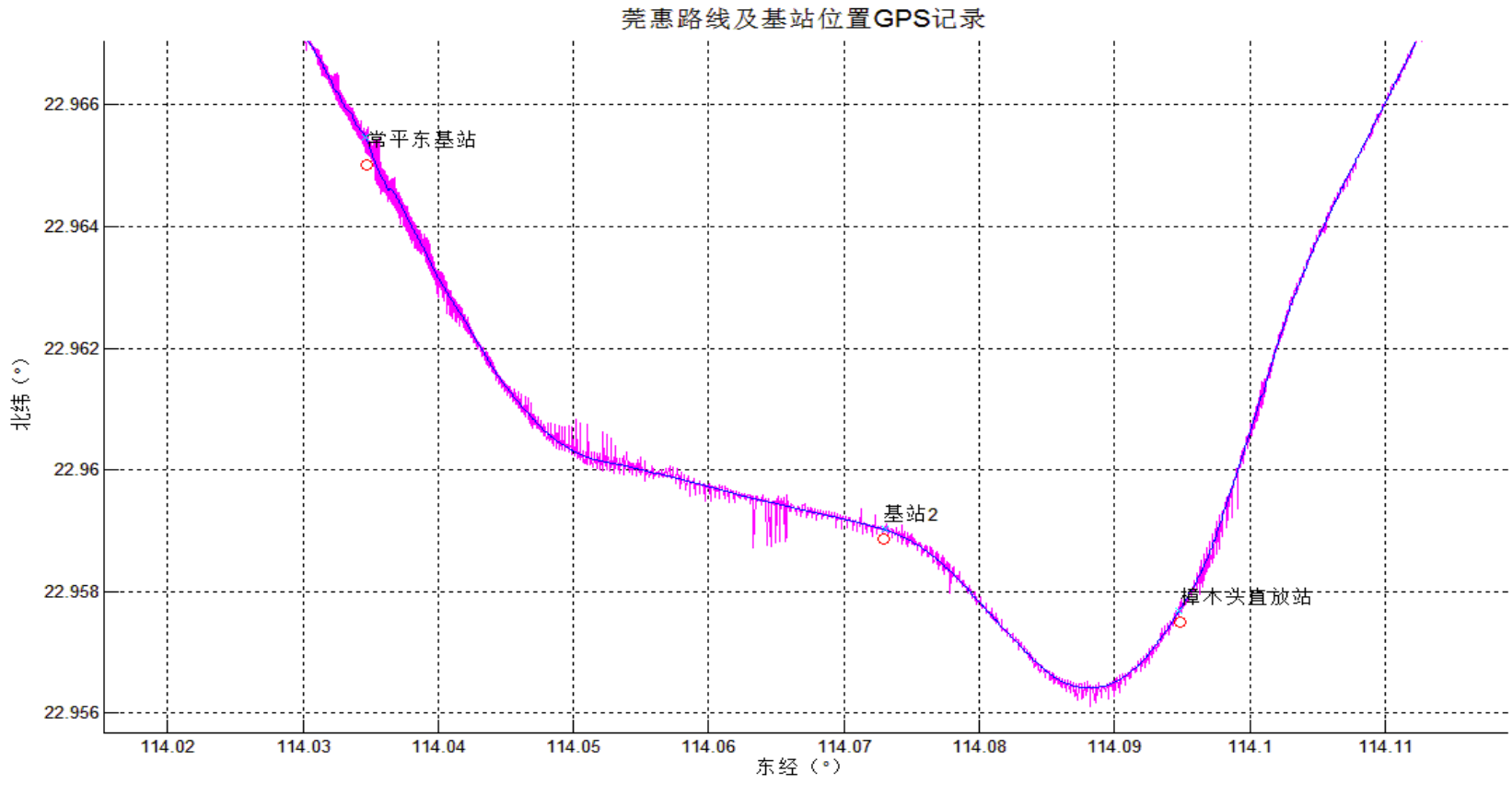
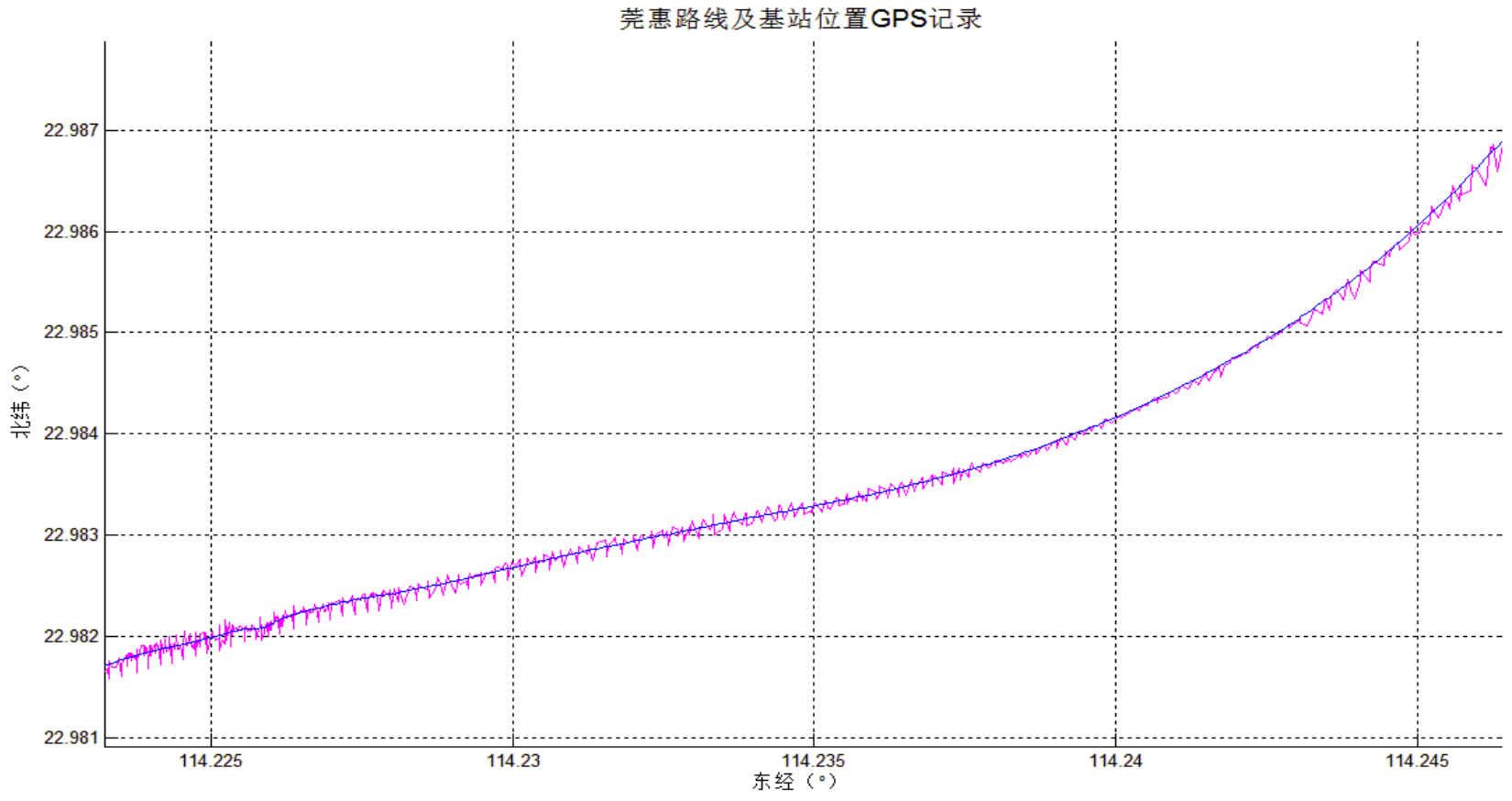
GNSS Performance Study

- Point Jitter



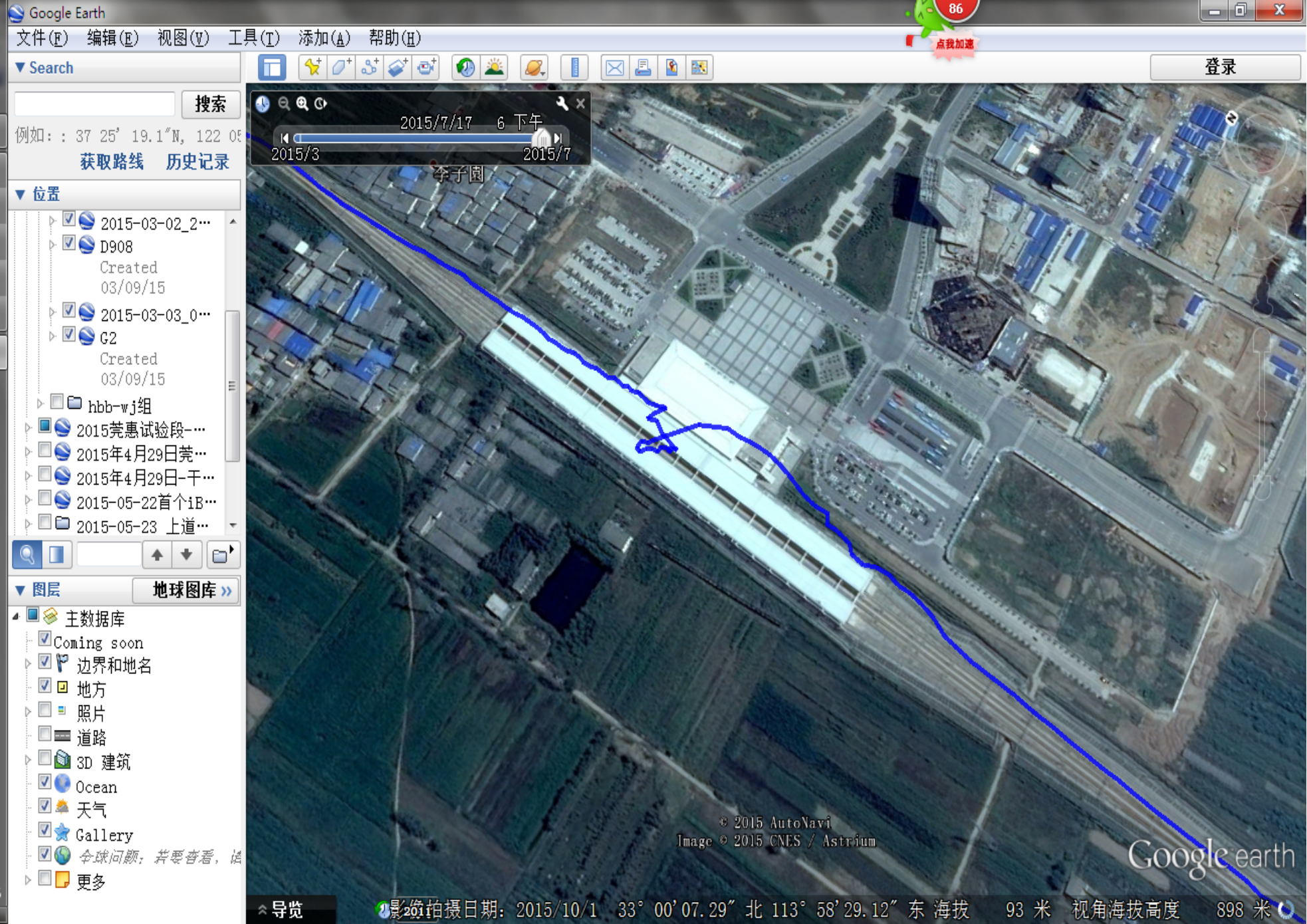
GNSS Performance Study

- Point Jitter



GNSS Performance Statistics

- Signal Shift
  - Always happen near the station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蓝坪
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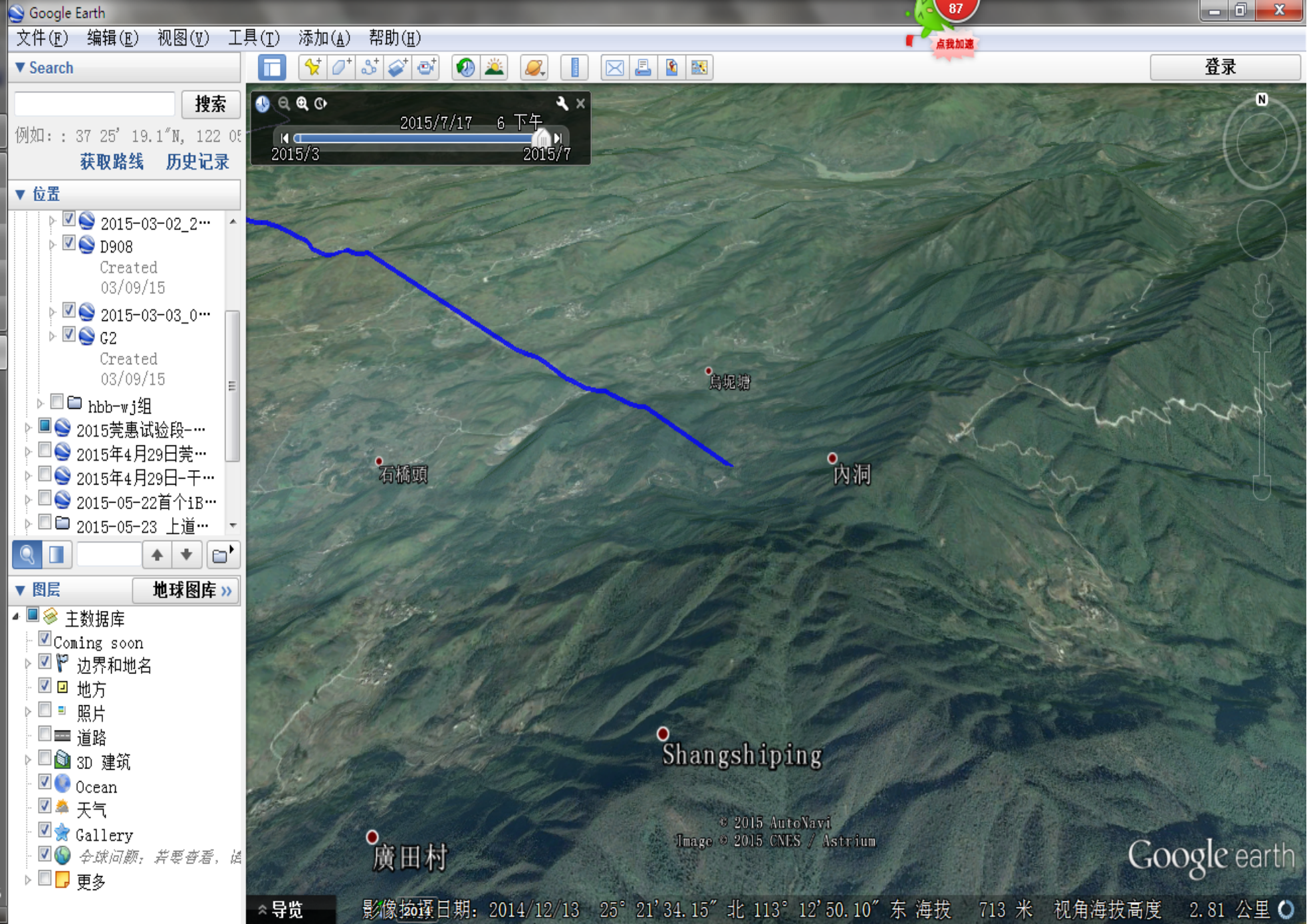
影像拍摄日期: 2014/12/13 25° 24' 37.34" 北 113° 08' 14.60" 东 海拔 255 米 视角海拔高度 1.55 公里

GNSS Performance Statistics

- Signal Lost
  - Always happen in the long tunnel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Search
搜索
例如：: 37 25' 19.1"N, 122 0
获取路线 历史记录
位置
2015-03-02_2…
D908
Created
03/09/15
2015-03-03_0…
G2
Created
03/09/15
hbb-wj组
2015莞惠试验段-…
2015年4月29日莞…
2015年4月29日-干…
2015-05-22首个iB…
2015-05-23 上道…
图层
地球图库 »
主数据库
Coming soon
边界和地名
地方
照片
道路
3D 建筑
Ocean
天气
Gallery
更多
2015/7/17 6 下午
2015/3
2015/7
乌妃塘
石桥头
内洞
Shangshiping
廣田村
© 2015 AutoNavi
Image © 2015 CNES / Astrium
Google earth
导览
影像拍摄日期：2014/12/13 25° 21' 34.15" 北 113° 12' 50.10" 东 海拔 713 米 视角海拔高度 2.81 公里

GNSS Special in Railway Application

- High speed, High reliability, High Accuracy
  - Speed > 380KM/H
  - MTBF > 10^9 hours
  - Accuracy < 2m
  - Small antenna size
  - Response Time < 1s
- Fit for mass construction
  - Easy to deploy
  - Easy to maintain (depopulated zone)
  - Environment friendly

GNSS Special in Railway Application

- 2 Dimension, Different requirement
  - Along the running direction, 5s tolerance, 500m for HSR
  - Perpendicular to the running direction, < 2 meter
  - Fast locating time < 1s
- Real track is 1.5D not real 3D
  - No need to calculate 3D cordination
  - Time shift is enough for calculation
  - Track coordinate can be exactly known in advance
- Special enhancement tech can be used
  - Get fast converge rate
  - More accurate result

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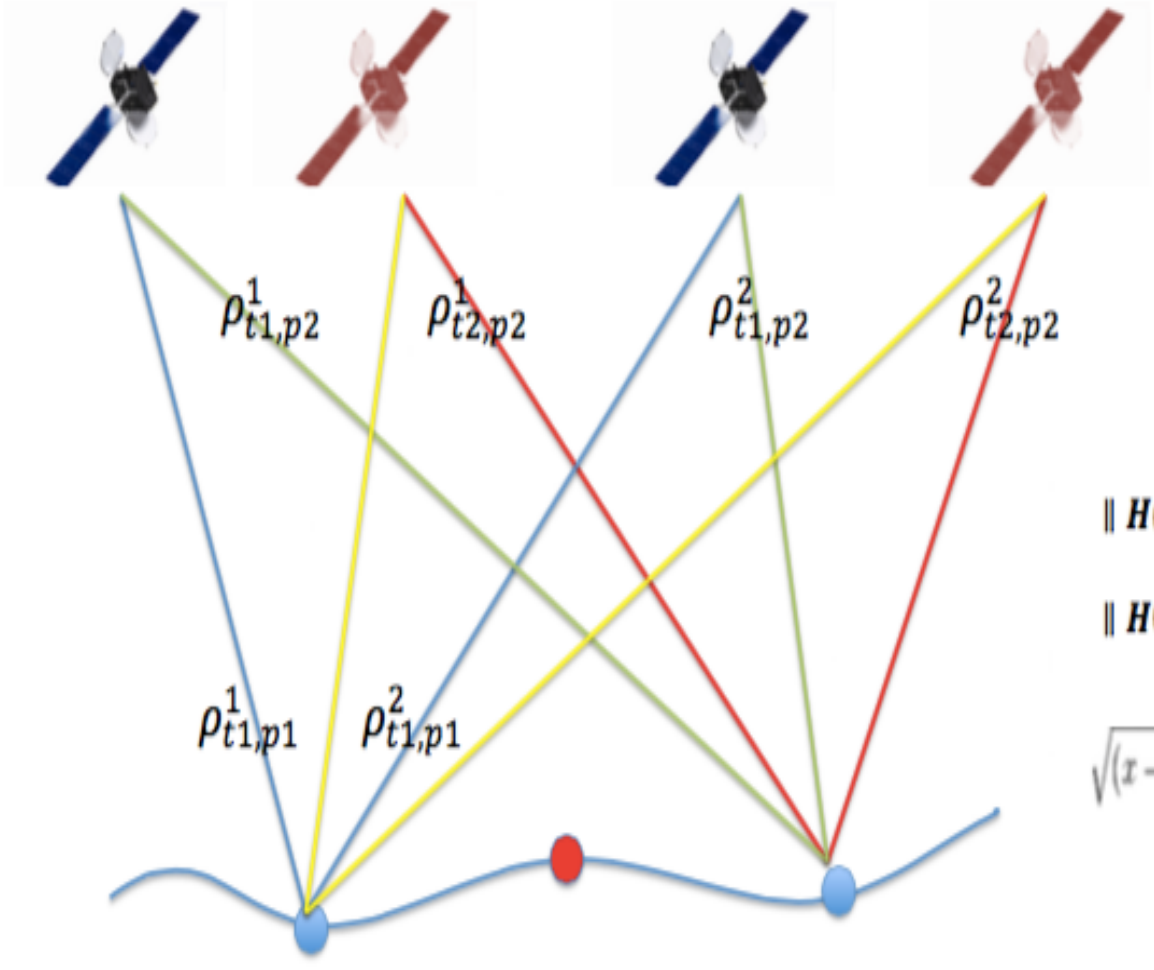
GNSS Enhancement Tech

- Dimension Reduction Enhancement Tech
  - Using the accurate geometry coordinate of the track
  - Using the satellite NAV telegram to get the satellite orbit
  - Pre-calculate the distance of every reference point at reference time point
  - All the pre-calculated data can be download to the GNSS receiver before the train is started.

GNSS Enhancement Tech

- Dimension Reduction Enhancement Tech
  - Traditional GNSS equation solves 4 unknowns
  - 4 satellites are needed to form 4 independent equations
  - Introduction of time table function *H(t)* to reduce unknowns



$$\| \boldsymbol{H}(t1+\Delta t) - \boldsymbol{PS1}(t) \| = \rho^1_{t1,px} + bc(T^{s1}_{t1} - T^{train}_{t1})$$

$$\| \boldsymbol{H}(t1+\Delta t) - \boldsymbol{PS2}(t) \| = \rho^2_{t1,px} + bc(T^{s1}_{t1} - T^{train}_{t1})$$

$$\sqrt{(x-x_i)^2+(y-y_i)^2+(z-z_i)^2}+bc=p_i,\ i=1,2,\ldots,n$$

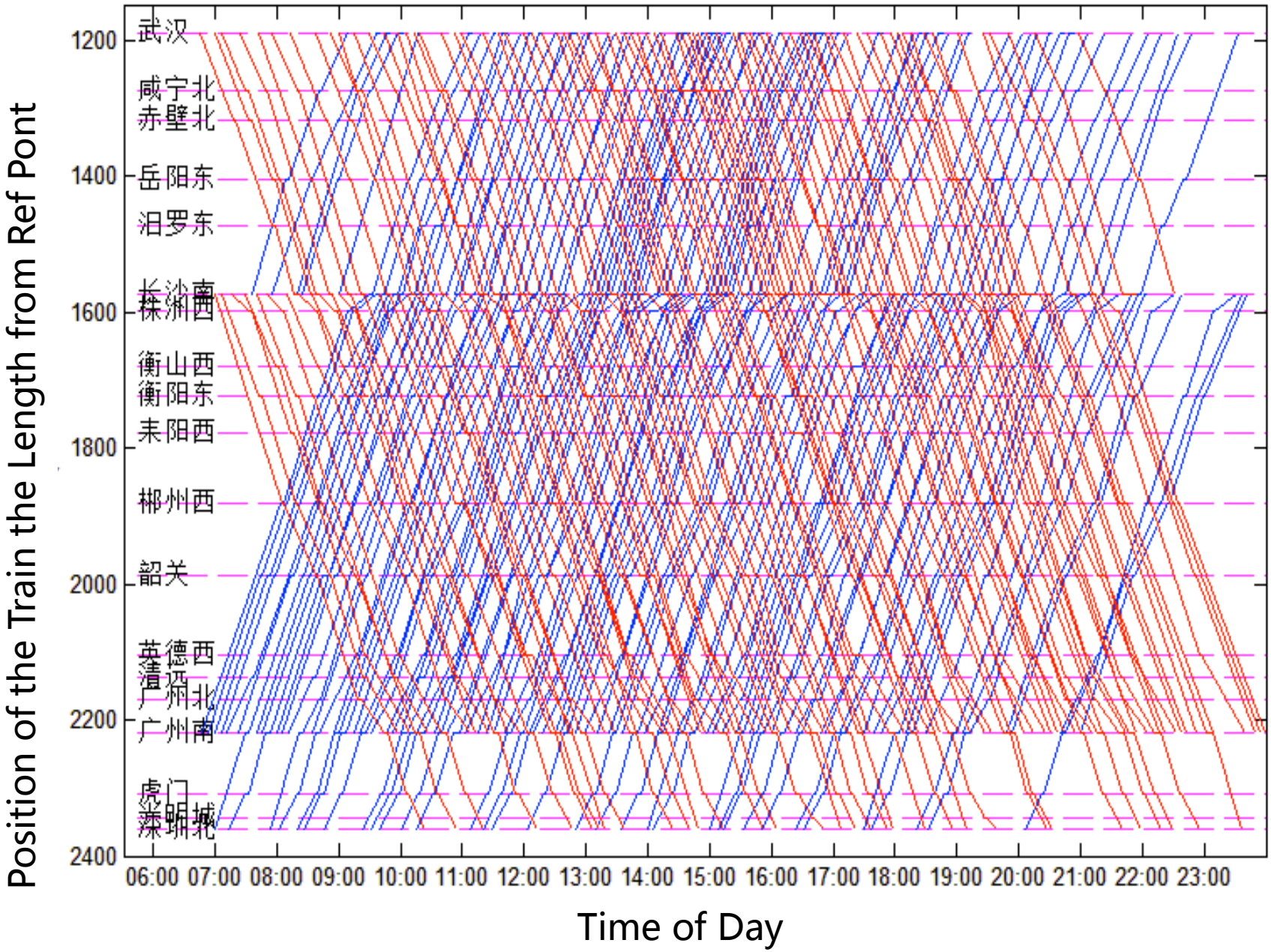
$\rho^1_{t1,p1}$ $\rho^2_{t1,p1}$ accurate value are exactly known

$\rho^1_{t2,p2}$ $\rho^2_{t2,p2}$ accurate value are exactly known

$\rho^1_{t1,p2}$ $\rho^2_{t1,p2}$

Can be calculated because satellite and point position are known

Time Table of WuHan-ShenZhen HSR Line 70% Throughput 2015.3.28

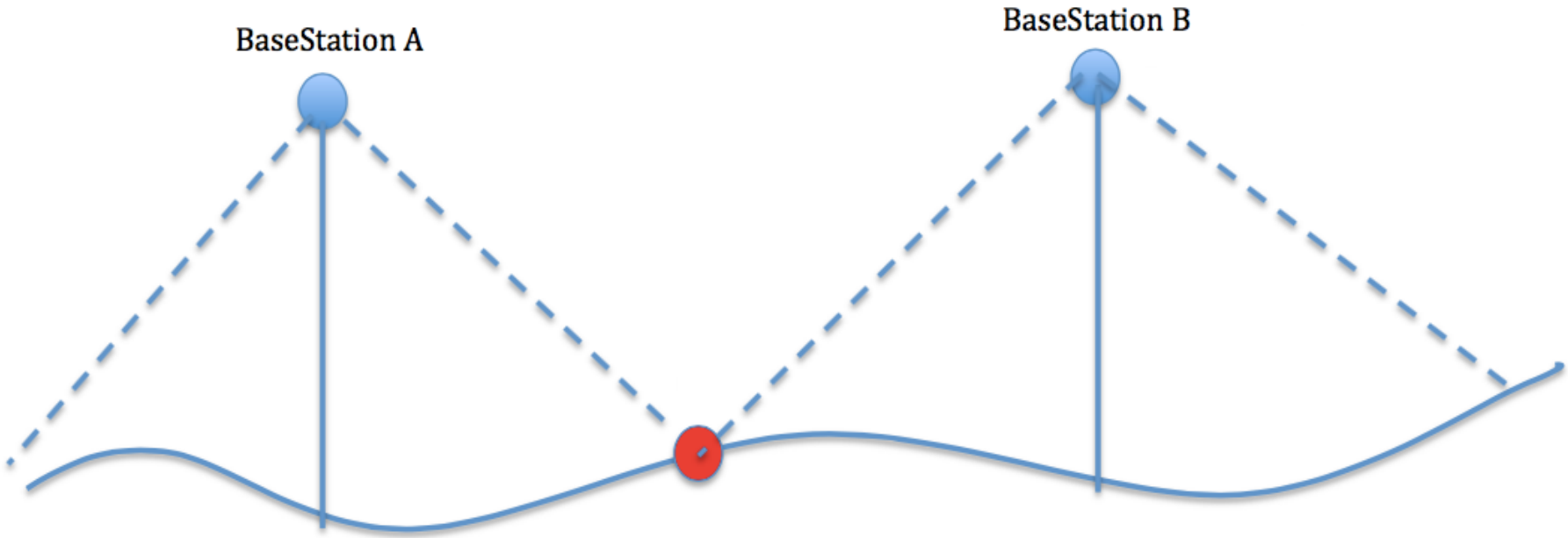


GNSS Enhancement Tech

- Direction Enhancement Tech
  - Using GSM-R communication network
  - Using LTE 4G network location reference signal
  - Using base station ID to get running direction
  - Avoid head on collision in low position accuracy
  - Using Time table function to add reference point via the balise or RF ID
  - Increase the accuracy on intersection plane

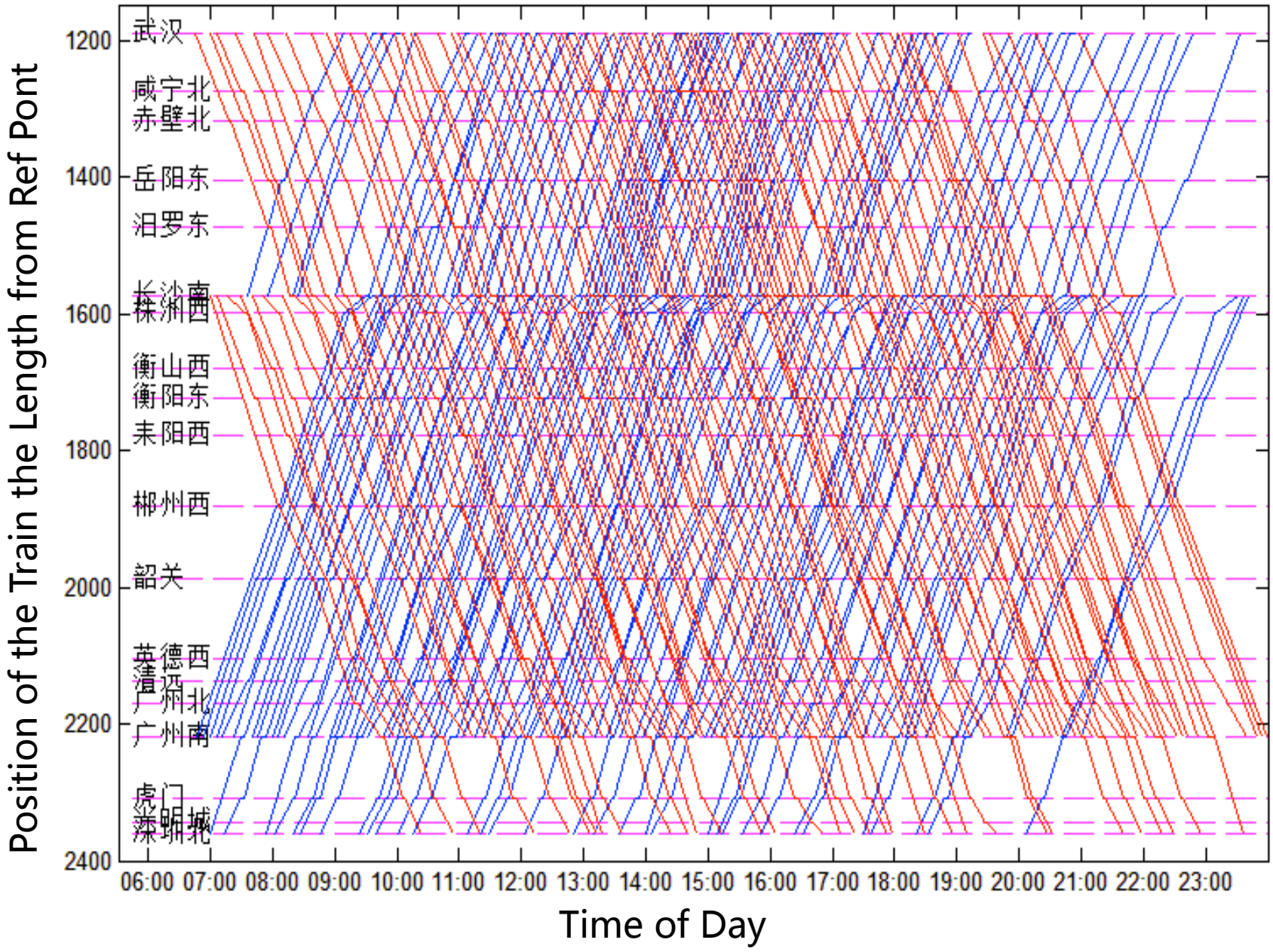
GNSS Enhancement Tech

- Direction Enhancement Tech



GNSS Enhancement Tech

- Time domain Enhancement Tech
  - Once the time is sync with satellite then the initial position can be get through time table ***H(t)*** function immediately
  - Using time domain continuity to correct position error
  - Improve error correction process especially in station
  - Big data analysis process (Human Control/ATO Control)

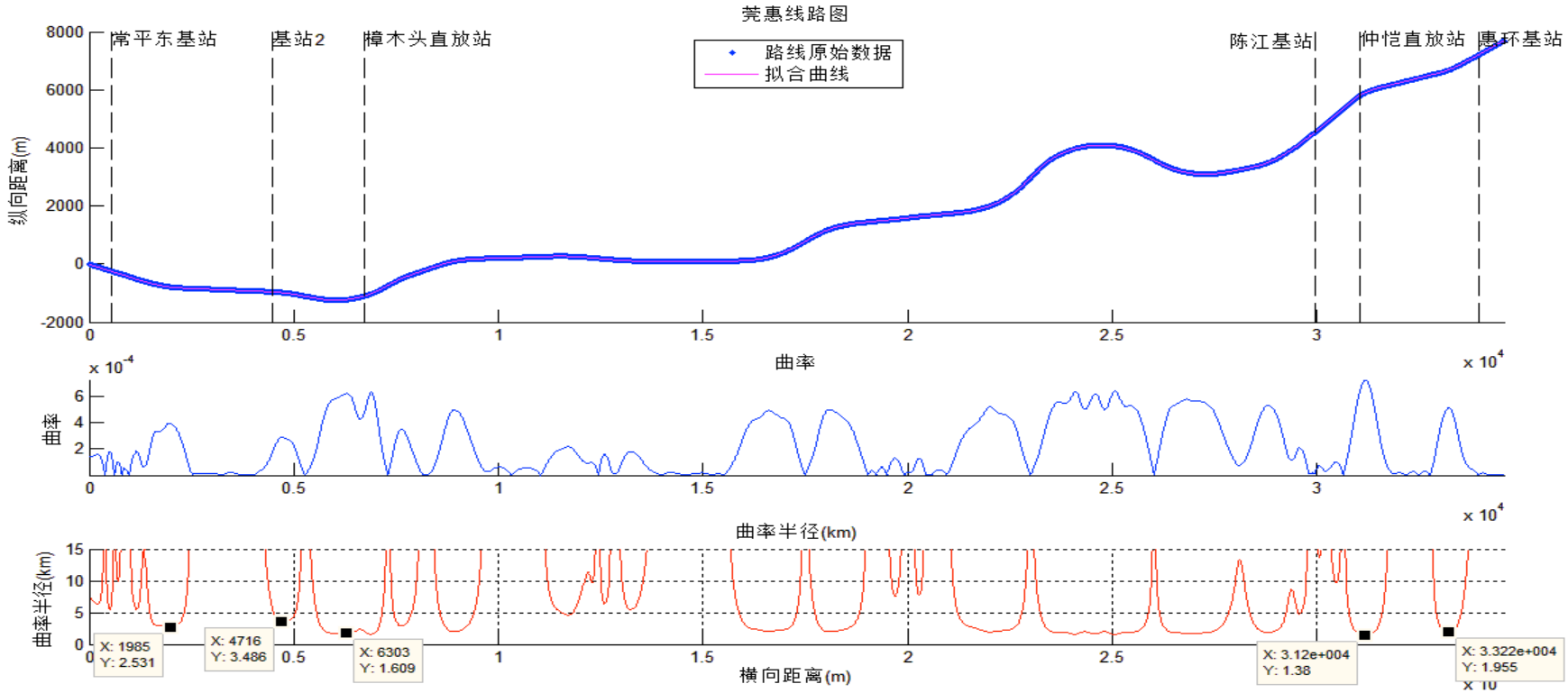

Time Table of WuHan-ShenZhen HSR Line 70% Throughput 2015.3.28
Position of the Train the Length from Ref Pont
Time of Day
武汉
咸宁北
赤壁北
岳阳东
汨罗东
长沙南
株洲西
衡山西
衡阳东
耒阳西
郴州西
韶关
英德西
清远
广州北
广州南
虎门
东莞
深圳北
1200
1400
1600
1800
2000
2200
2400
06:00 07:00 08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00 21:00 22:00 23:00

GNSS Enhancement Tech

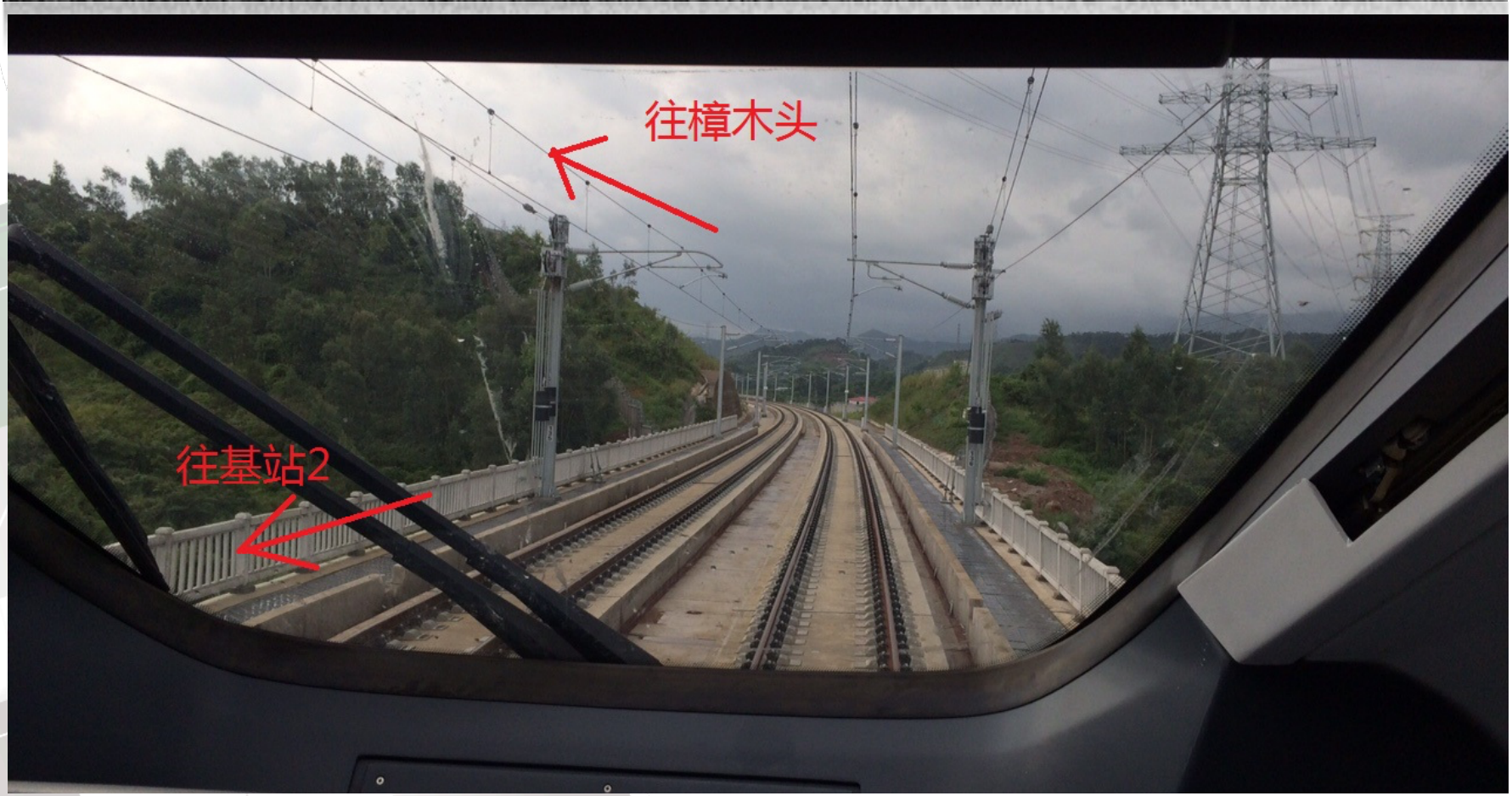
- Geometry domain Enhancement Tech
  - Railway using special geometry curves, such as

    y = x^3/6RL
  - Using curvature and altitude to do 2D MSL match process to accelerate the convergence of GNSS search process
  - Using geometry continuity to correct coordinate
  - Greatly reduce the probability of jitter

GNSS Enhancement Tech



GNSS Enhancement Tech



GNSS Enhancement Tech

- Result
  - For simple geography situation, accuracy and response time can be improved a lot
  - For complicated geography situation, the reliability of GNSS system even using enhancement tech still needs improvement although is rare(Murphy's Law)
  - More reliable and stable methodology is still on its way

Future Application

- Low Cost Railway System
- HSR Control System Enhancement
- Collision Warning System
- Smart OAM System

Summary

- GNSS is important to railway construction
- GNSS combined with enhance tech can get fantastic improvement for railway application
- The cost of accurate GNSS system can be under control
- Future usage of GNSS in unmanned railway vehicle(URV) is very promising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Thank you
Q&A

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