



中科院
上海天文台

Precise GNSS Data Analysis

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[**http://www.shao.ac.cn/shao_gnss_ac**](http://www.shao.ac.cn/shao_gnss_ac)





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www.shao.ac.cn

- 天体物理
- VLBI
- 光学
- 时频
- 地球动力学中心



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- VLBI
- 光学
- 时频
- 地球动力学中心
 - ❖ 卫星精密定轨、定位
 - ❖ 激光测距
 - ❖ 地球自转、参考系、行星
 - ❖ **GNSS**分析中心

课程目标

- ▶ 了解地球的基本参数及其观测、确定的方法
- ▶ 对具有多余观测的数学问题的求解方法具备基本概念；
- ▶ 了解卫星大地测量的研究内容、方法及其应用
- ▶ 初步具备计算机编程以及数据处理的能力





Content(1)

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- **Earth parameters**
- **Geodetic observing systems**



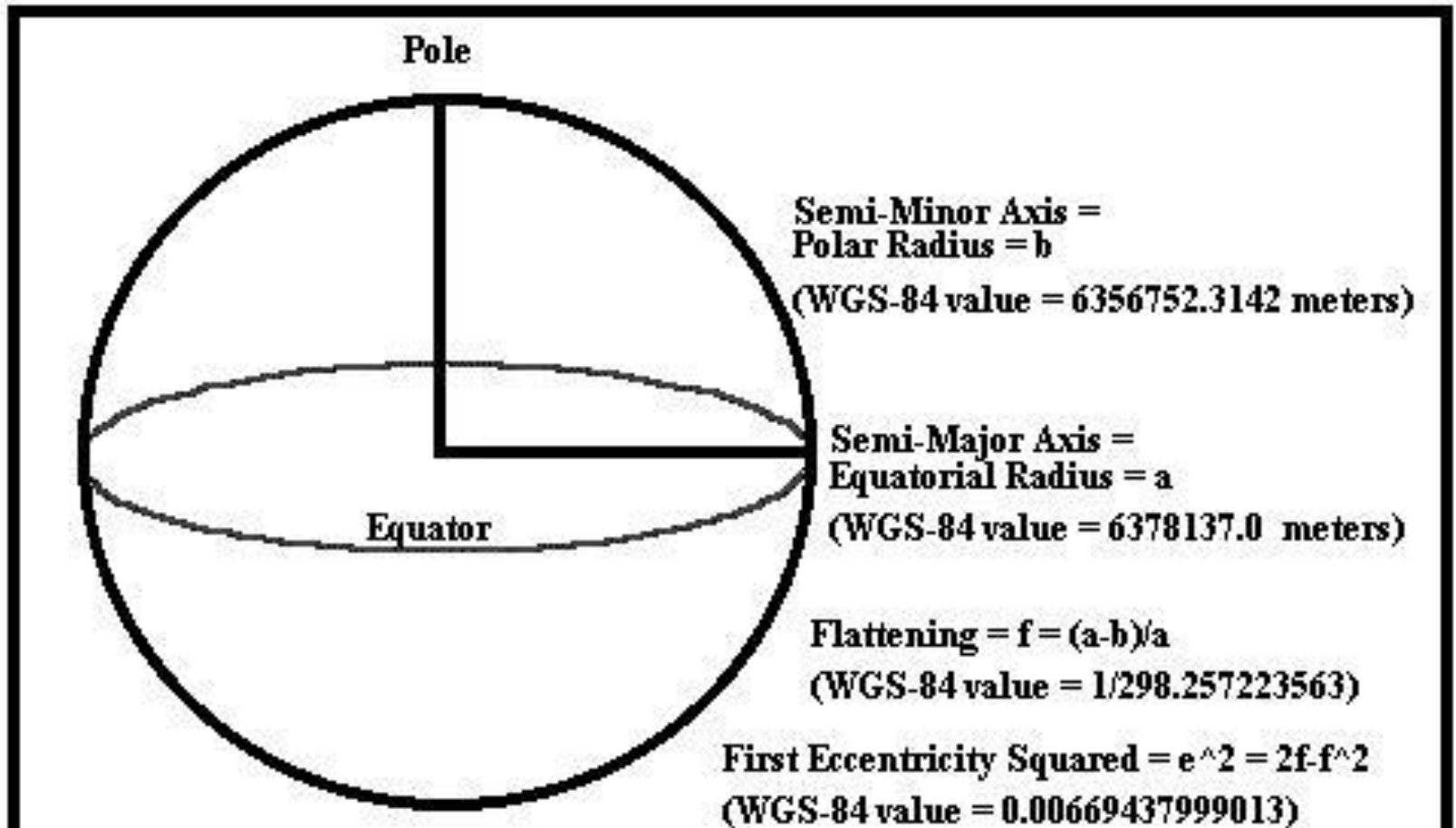
Earth-shape



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Earth-shape



Ellipsoidal Parameters

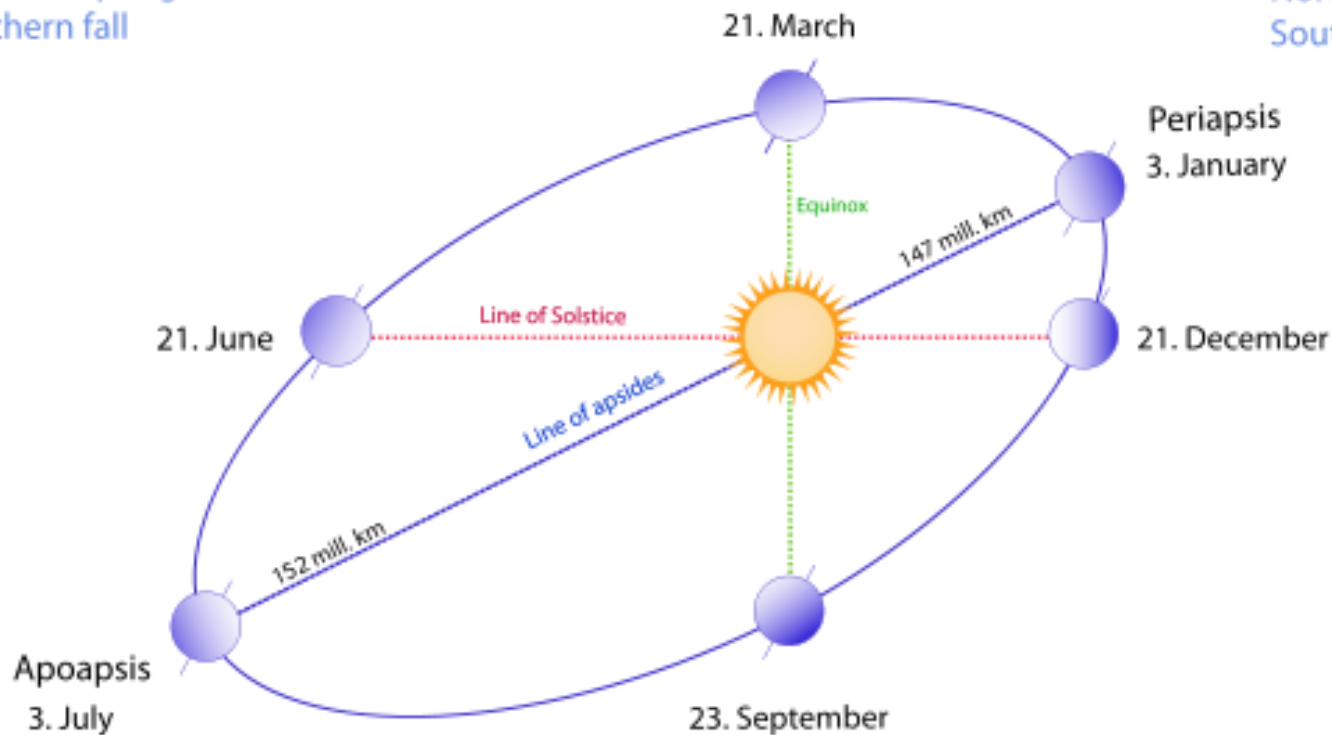




Earth rotation

Northern spring/
Southern fall

Northern winter/
Southern summer



Northern summer/
Southern winter

Northern fall/
Southern spring

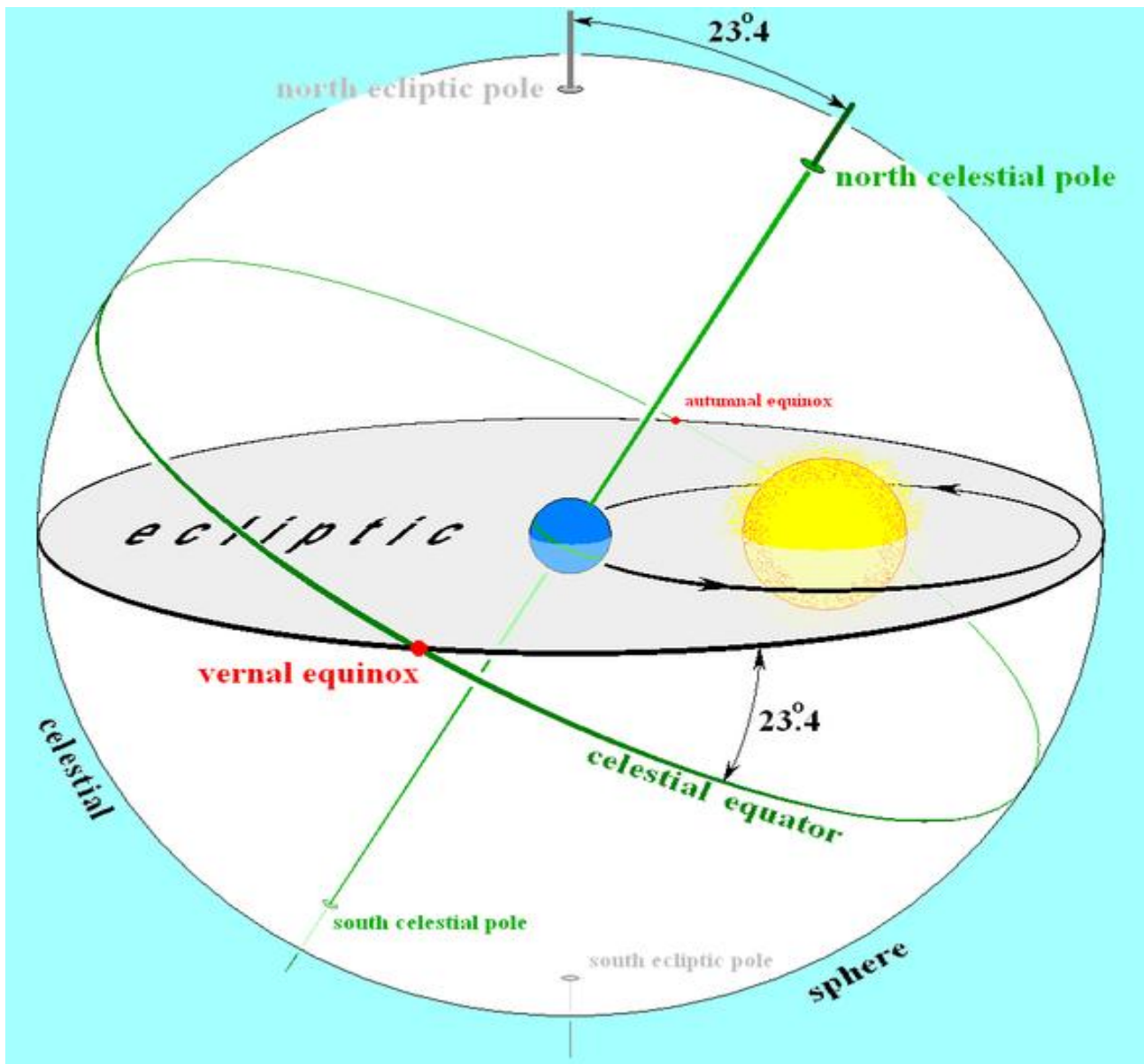
- 近日点(Perihelion)
- 远日点(Aphelion)
- 春分点、秋分点(equinox, 回归年相对于阳历365天每年延后6小时)
- 闰年(每四年闰一次)





Earth rotation

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黄赤交角：
23.4

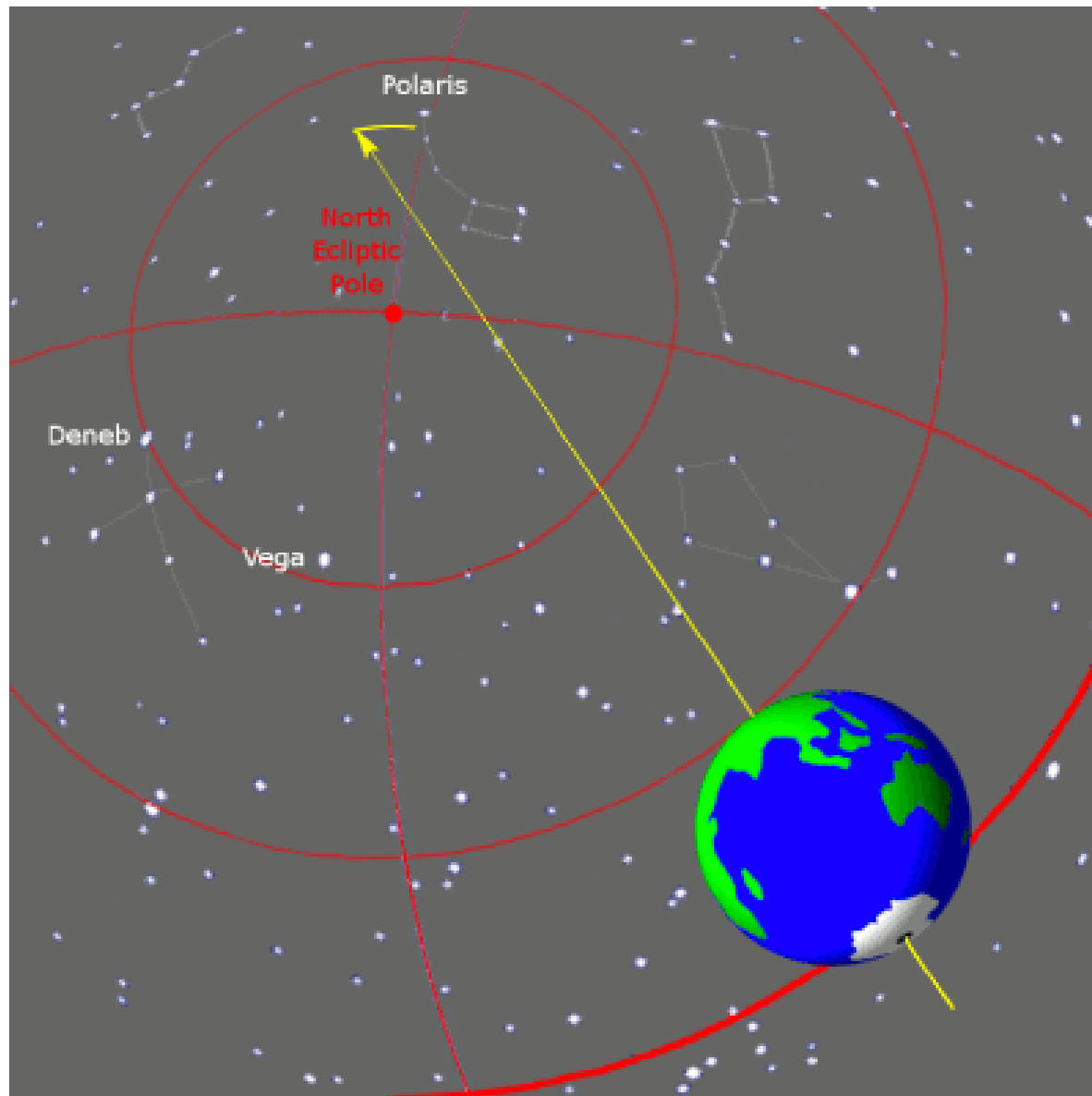
每百年变小：
0.013
degrees





Precession : 进动

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目前: **Polaris**
26000周期

日月引力

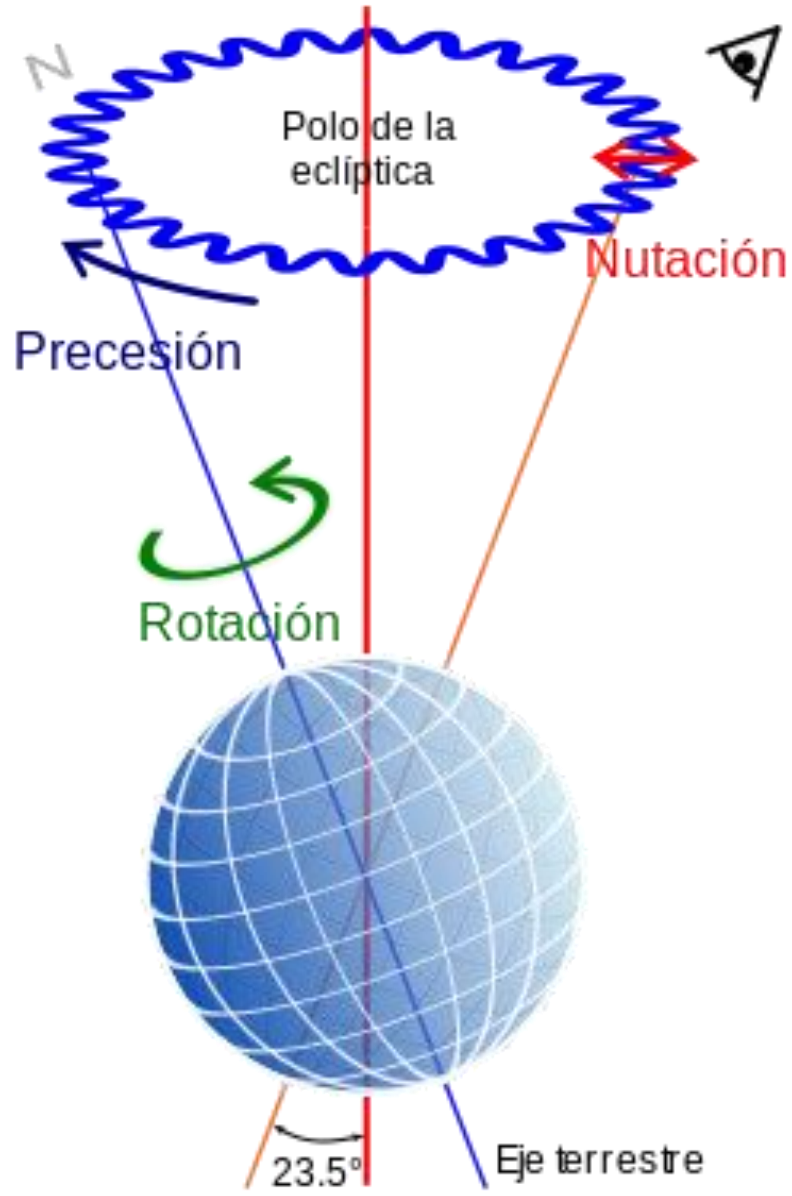
不会改变轴
本身的倾斜





Nutation : 章动

atmospheric and oceanic processes



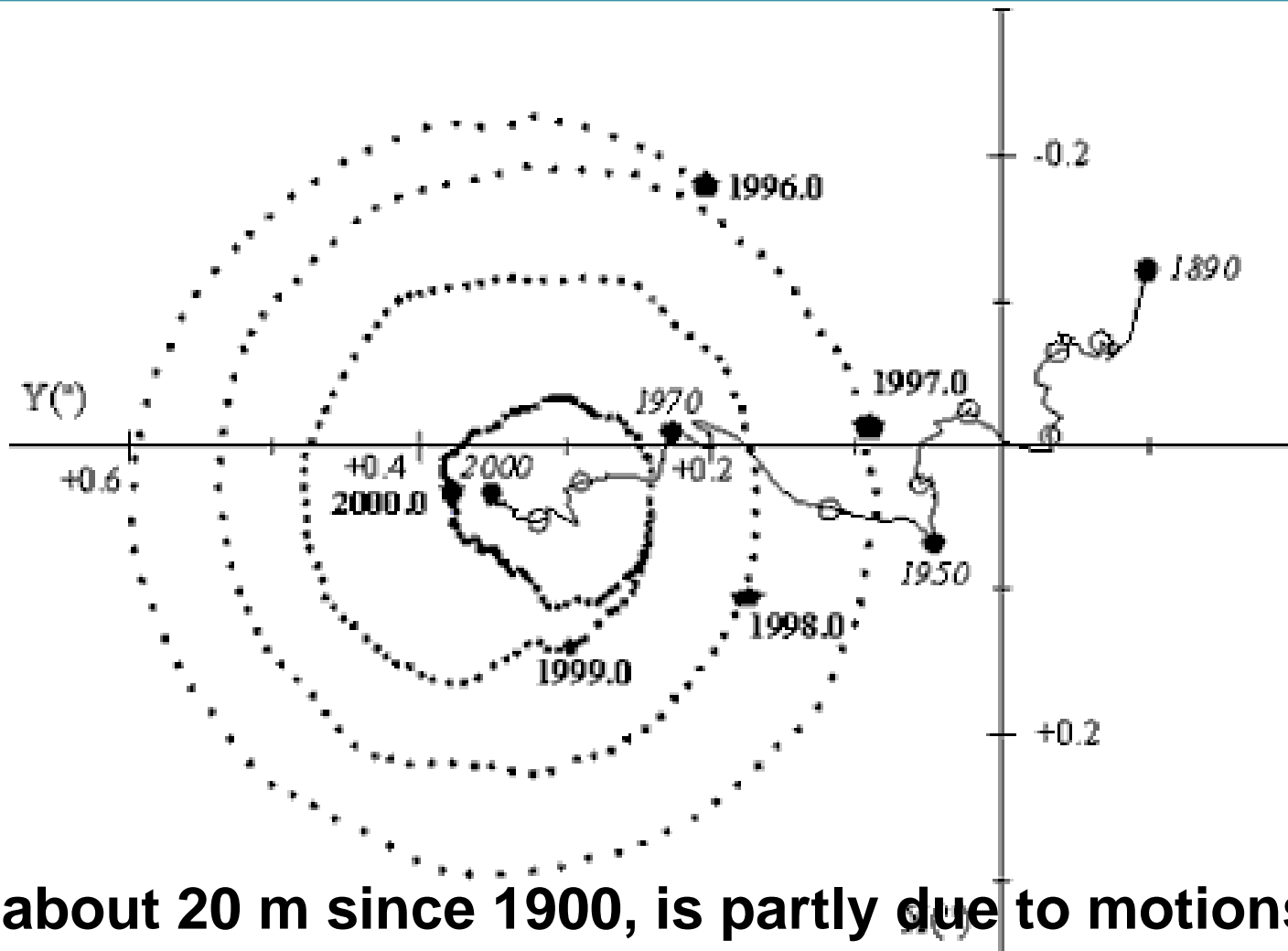
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Polar motion : 极移

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about 20 m since 1900, is partly due to motions in the Earth's core and mantle, and partly to the redistribution of water mass





北回归线的变化

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Plate : 板块

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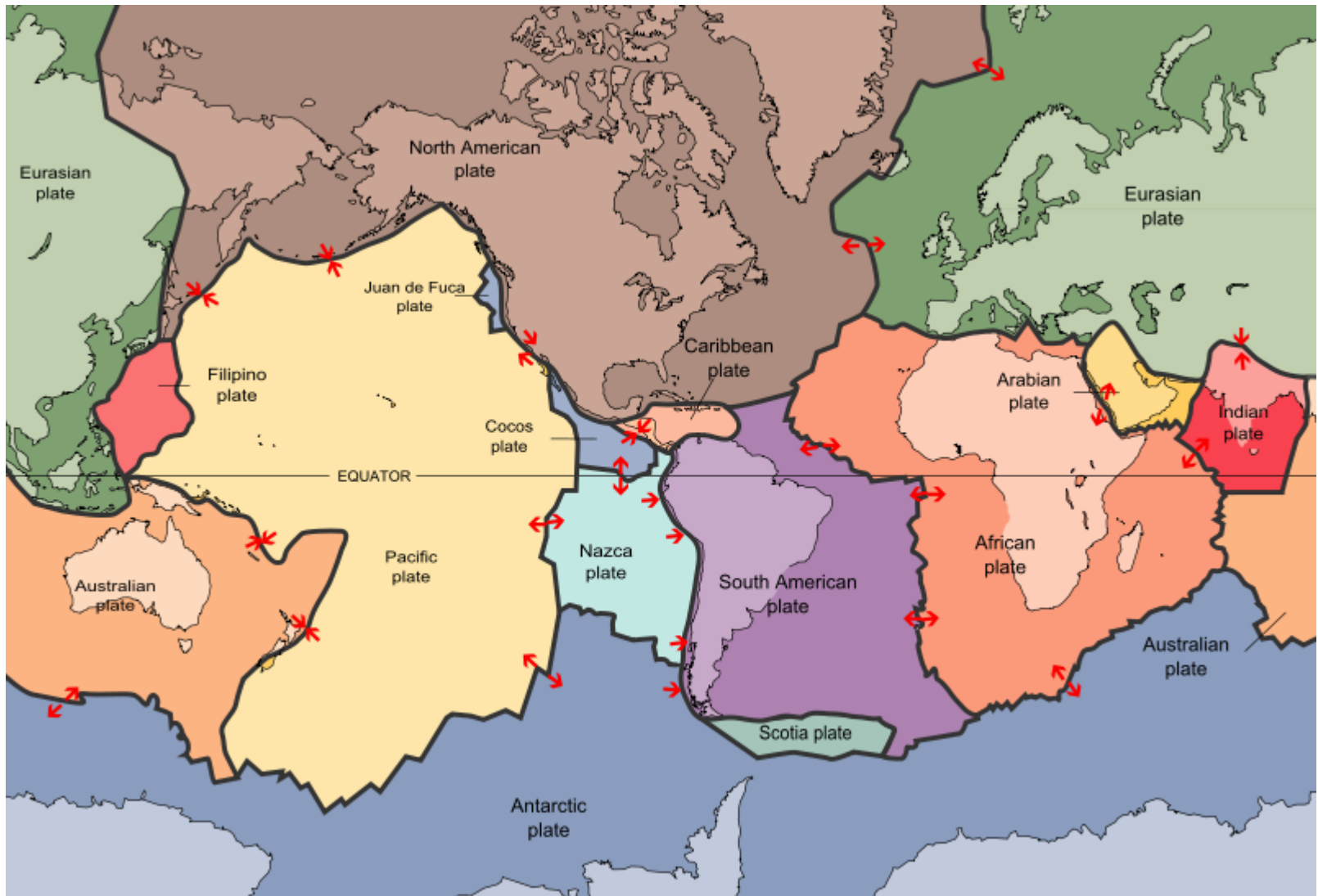


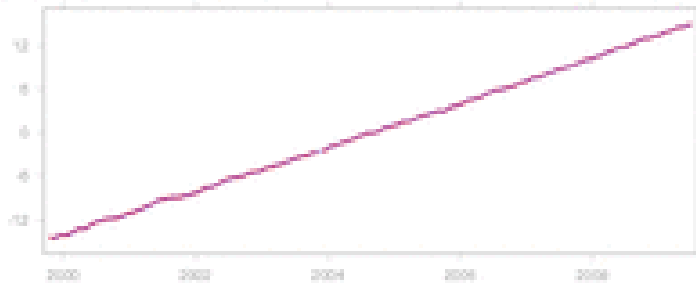


Plate : 板块

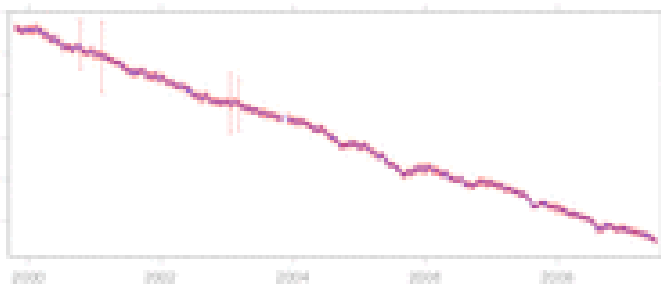
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21601M001 BJFS

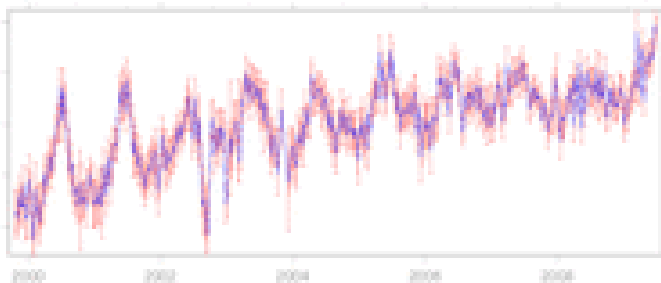
EAST cm



North cm

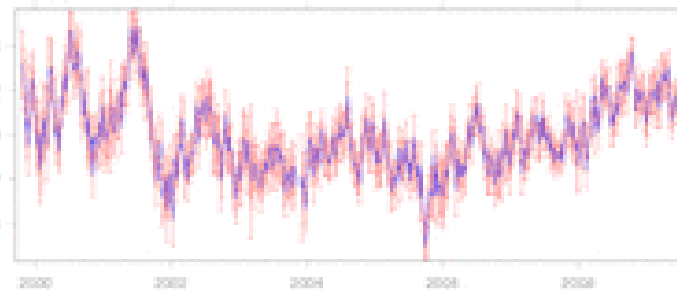


UP cm

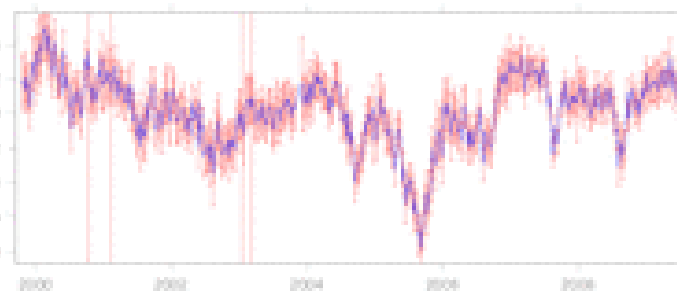


21601M001 BJFS Residuals

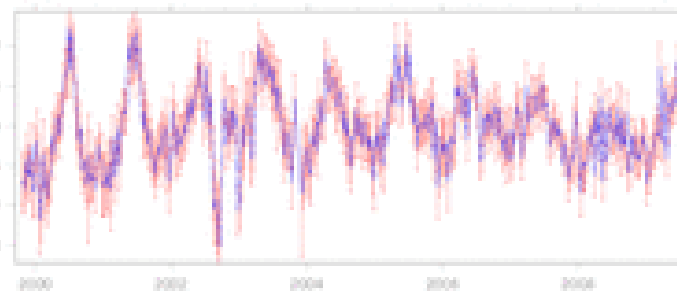
EAST mm



North mm



UP mm



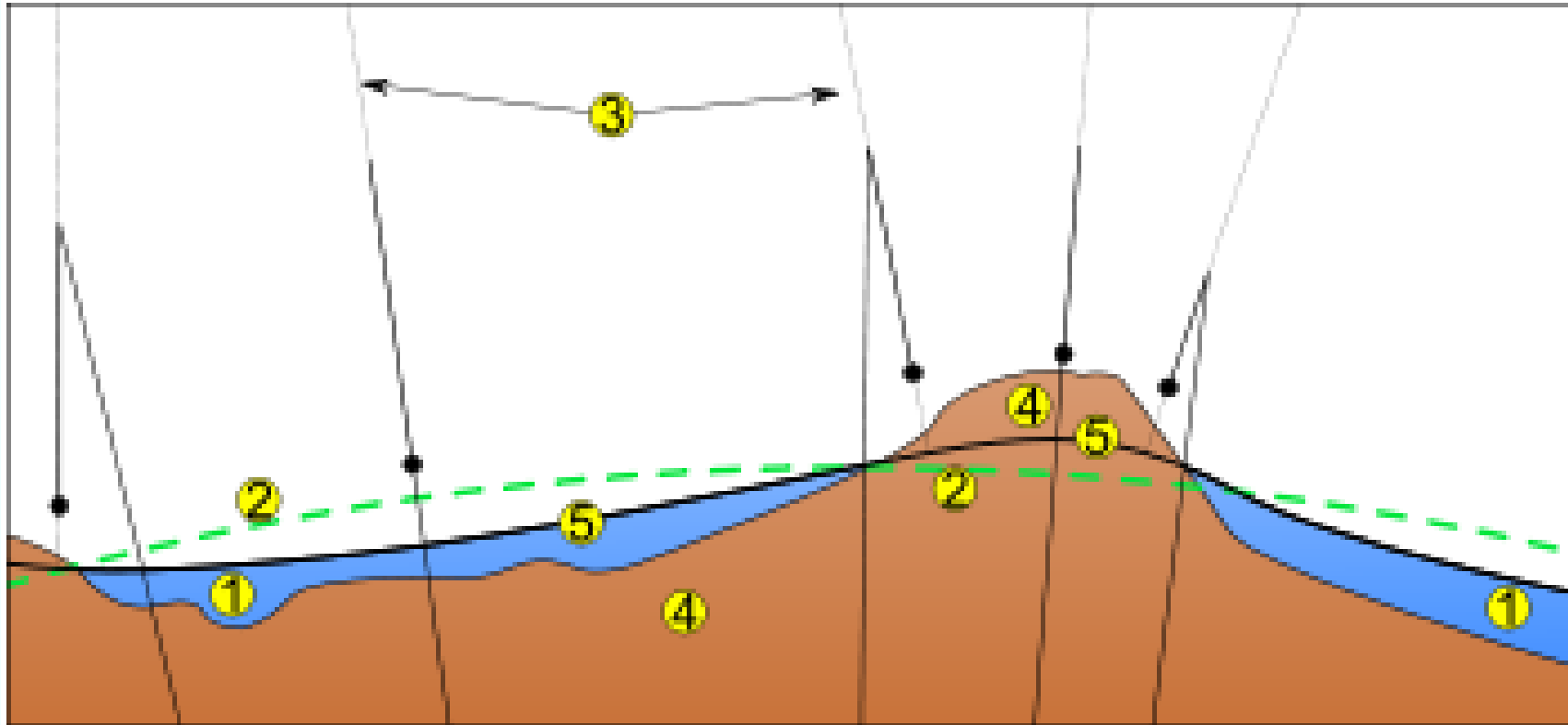
Reference Position :

X = -2148744.076 m Y = 4426641.279 m Z = 4044655.929 m



Gravity and Geoid : 水准面

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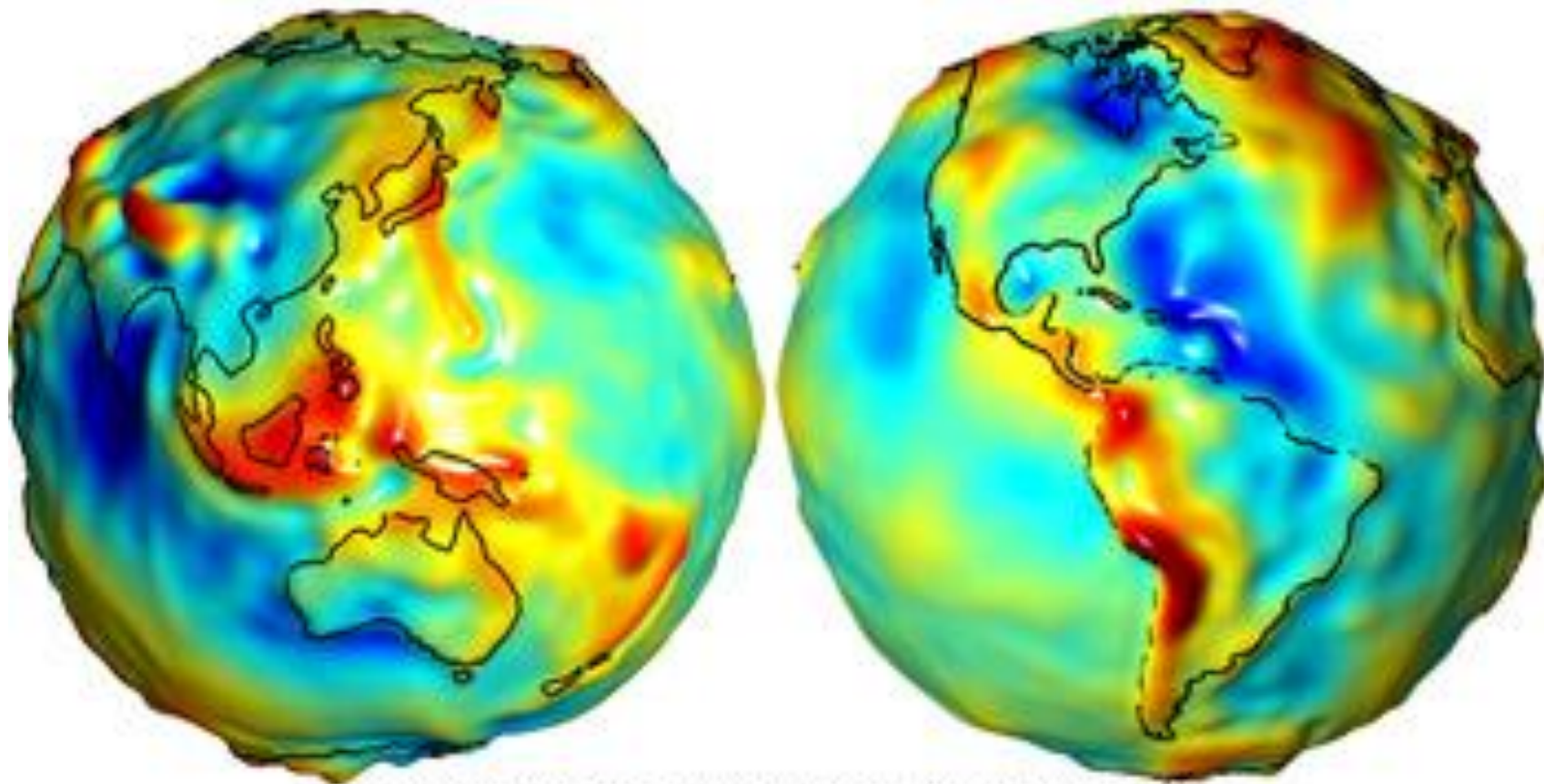
mathematical figure of the Earth



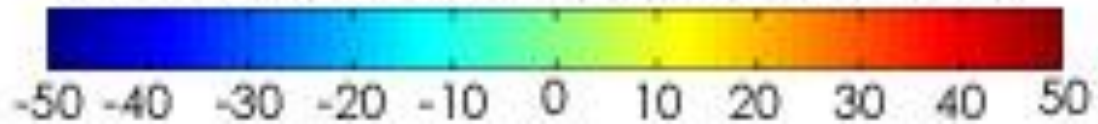


Gravity and Geoid : 水准面

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Earth's Gravity Field Anomalies (milligals)



Content(2)

➤ Geodetic observing systems



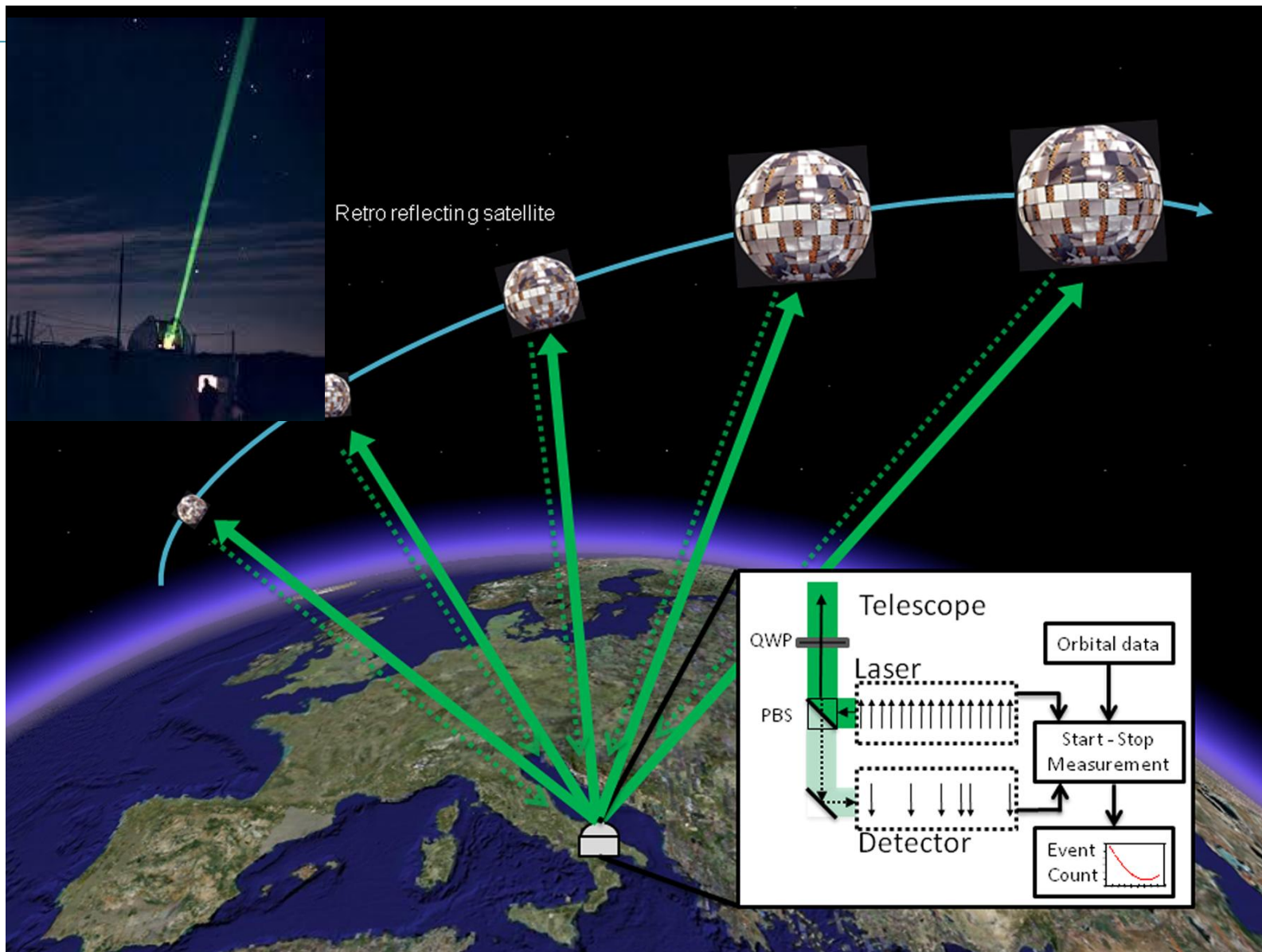
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激光测距SLR



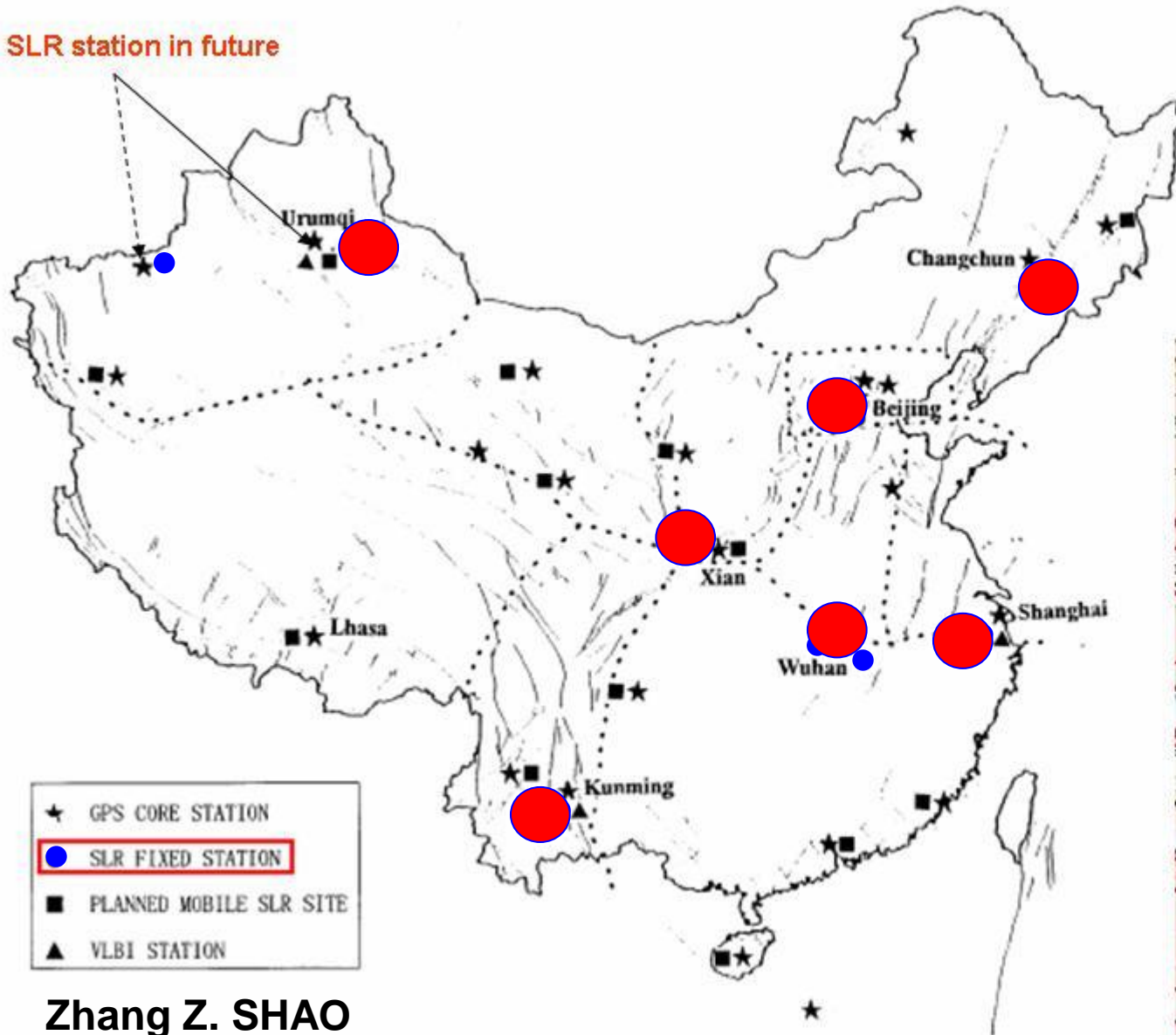
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Distribution of the Chinese SLR station

SLR station in future



San Juan SLR station in Argentina



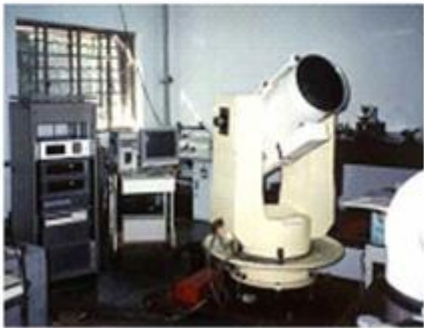
Zhang Z. SHAO



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The telescopes of the Chinese SLR stations



Site in Wuhan

| | | |
|----------|----------|-----------|
| Shanghai | Kun-ming | Changchun |
| Wuhan | | Beijing |
| TROS-1 | San Jaun | TROS-2 |



Site in Xi'an

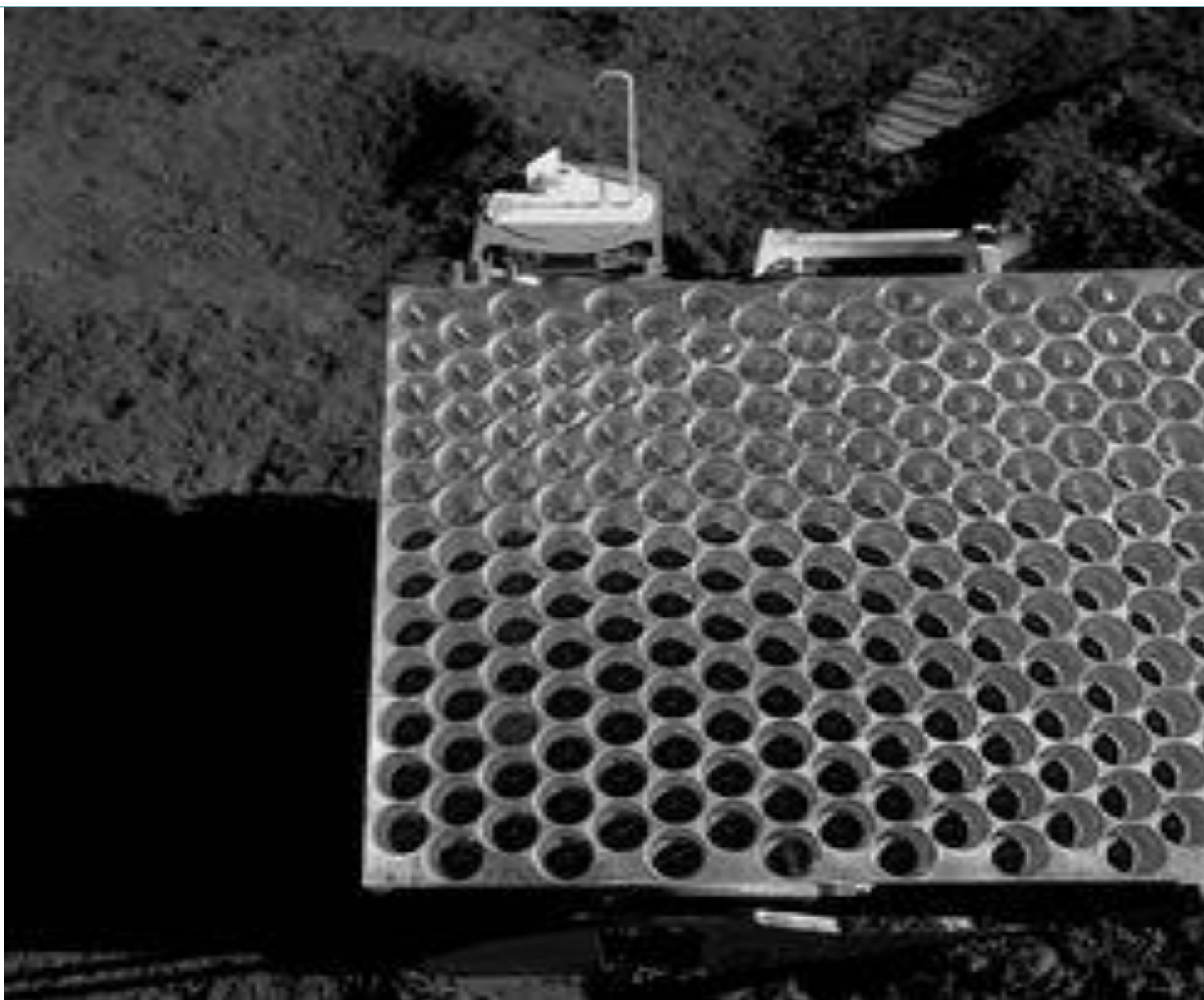
Zhang Z. SHAO





Lunar Laser Ranging

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Lunar Laser Ranging

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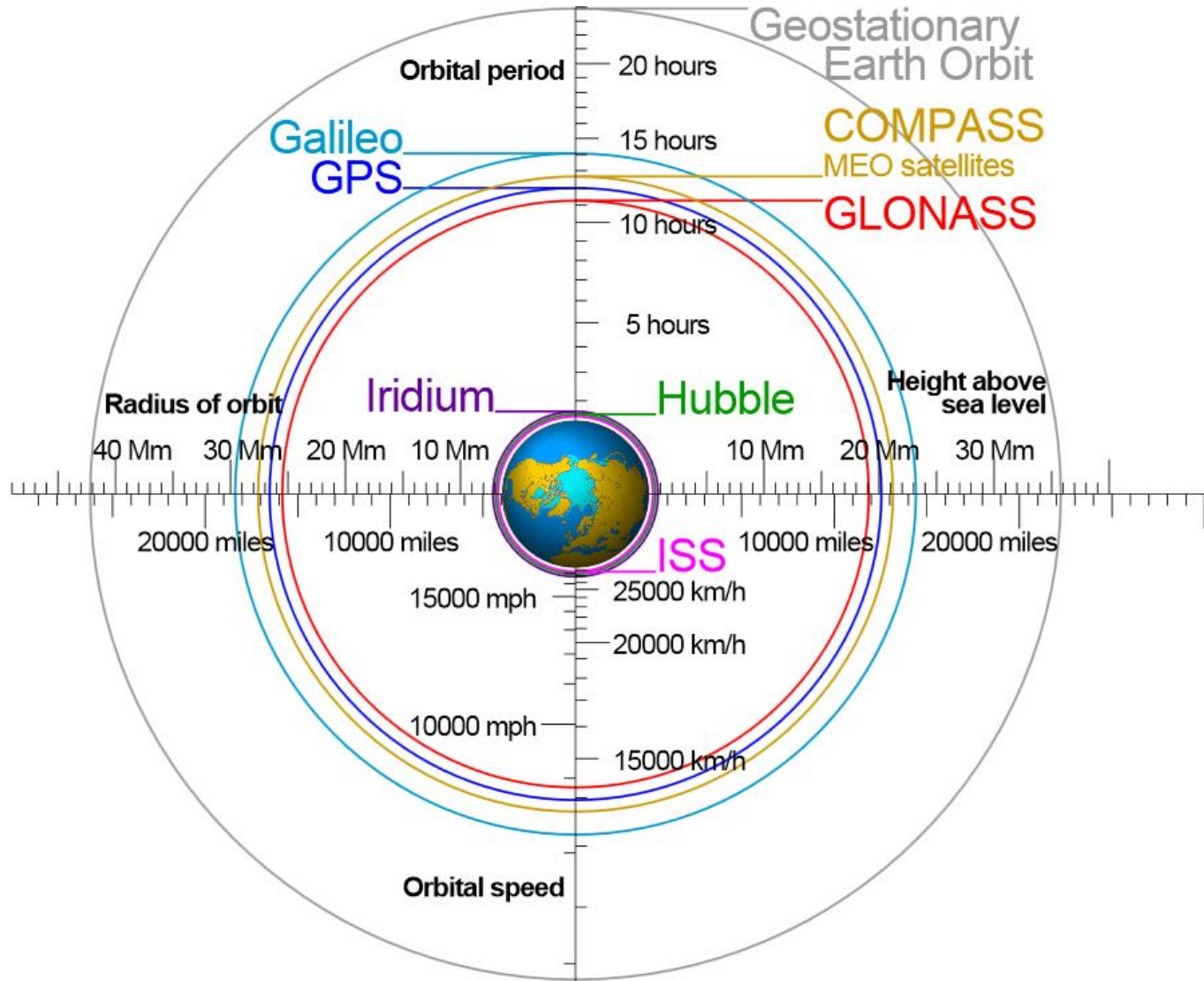
Very Long Baseline Interferometry

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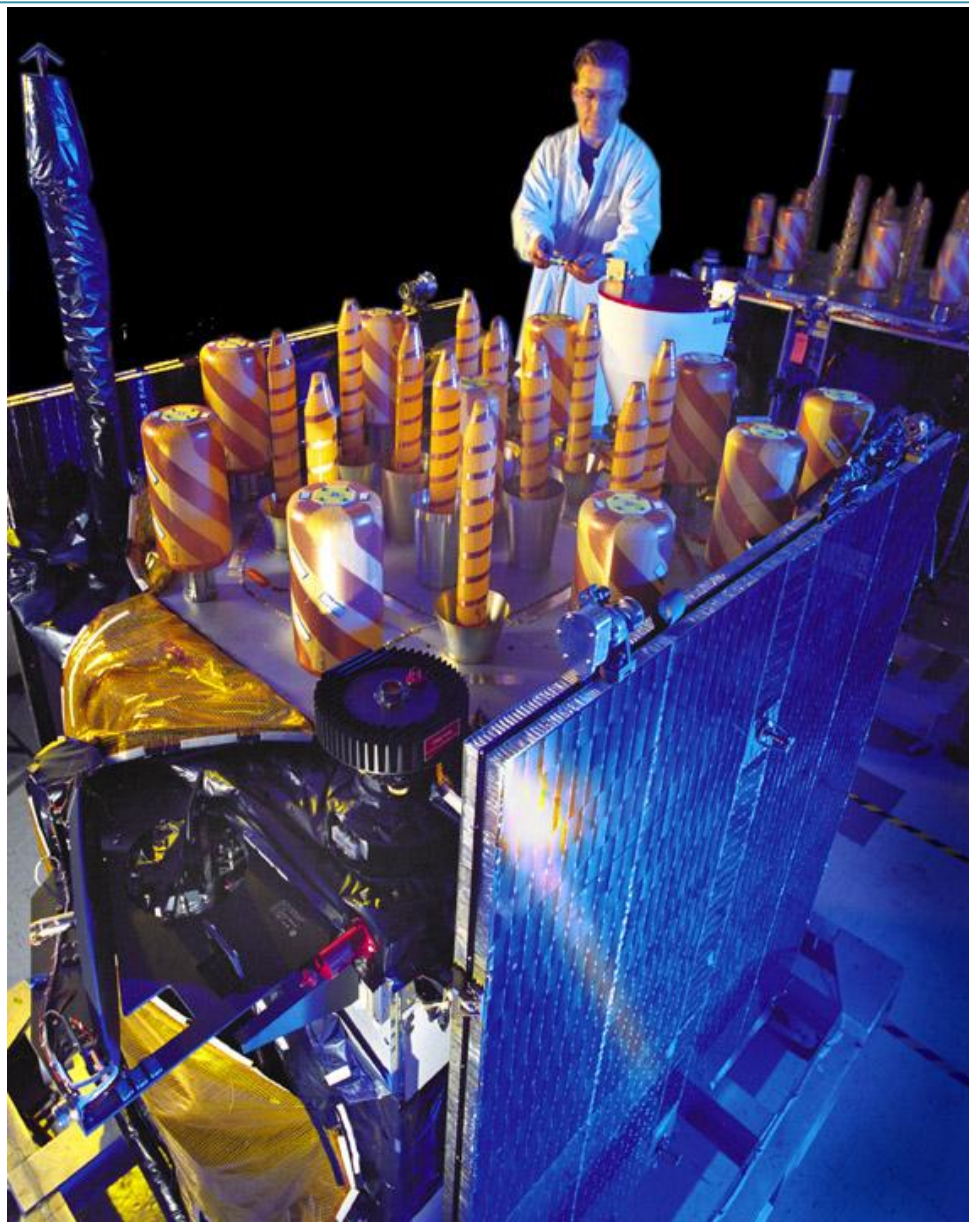
GNSS System





GNSS

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Content(3)

➤ **GPS/Galileo/GLONASS/COMPASS**



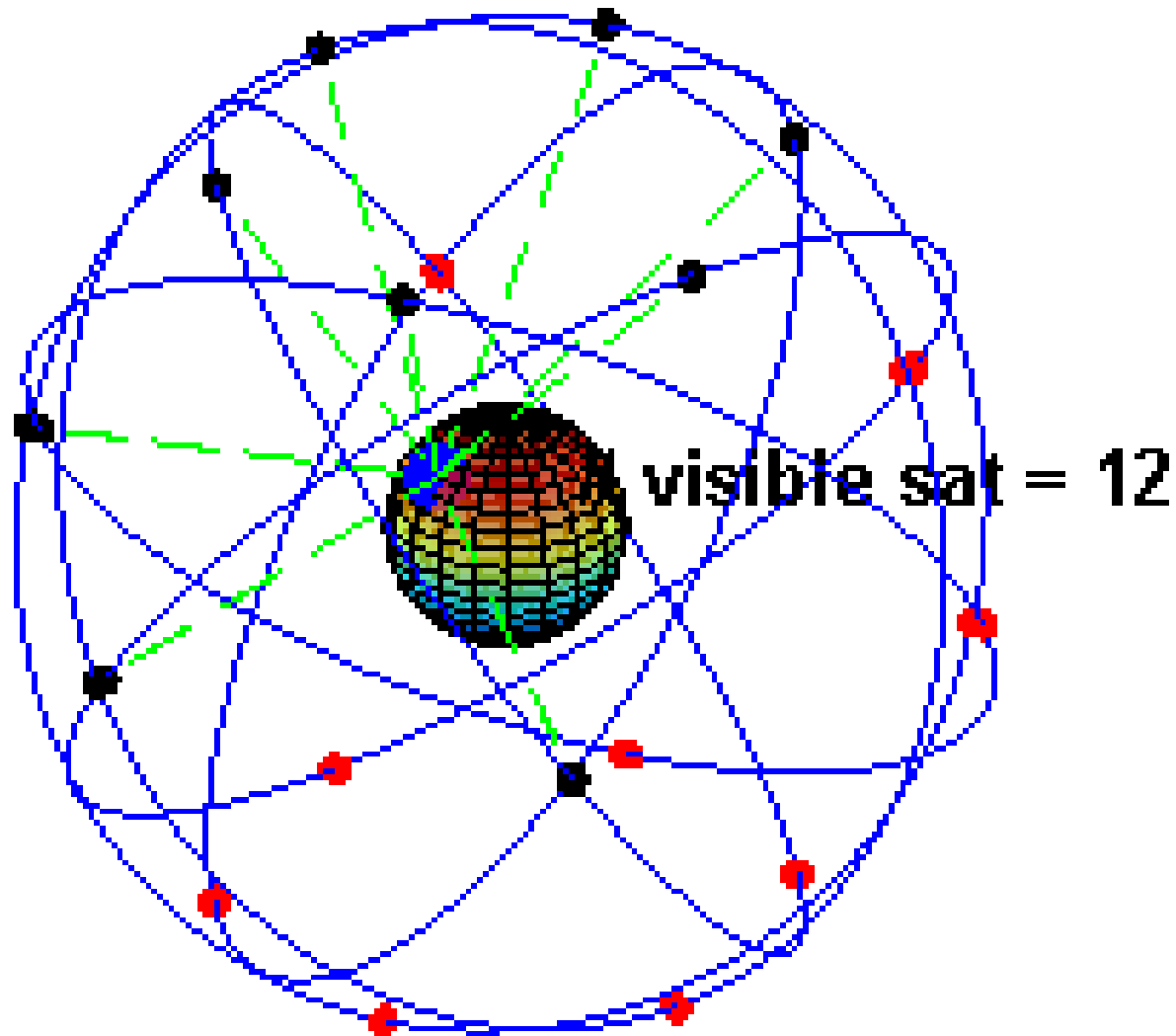
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GNSS System

Satellite orbits (<http://www.aislounae.com/>)



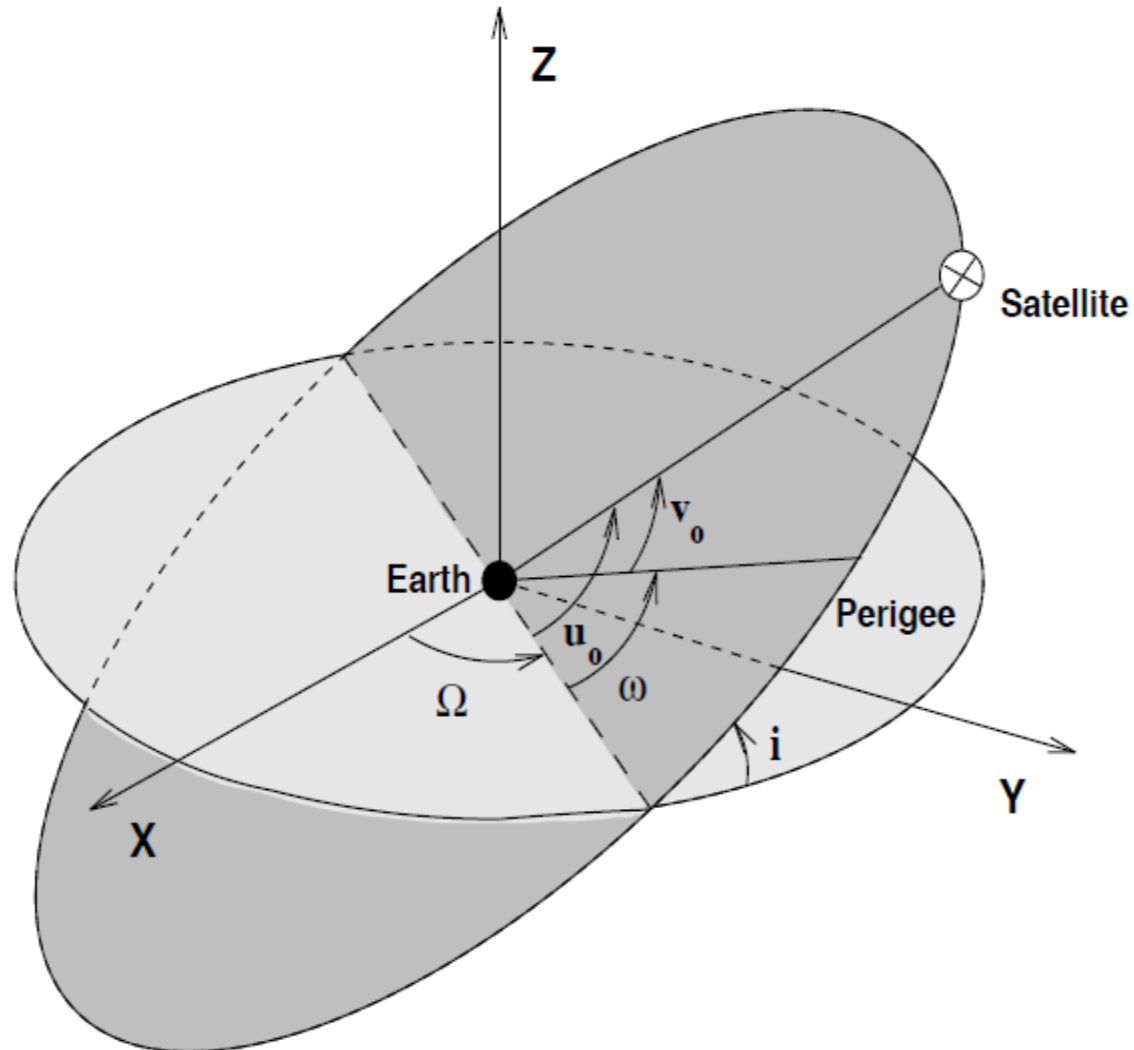
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GNSS System

Satellite orbit elements



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GNSS System-GPS

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Space Segment

BLK I

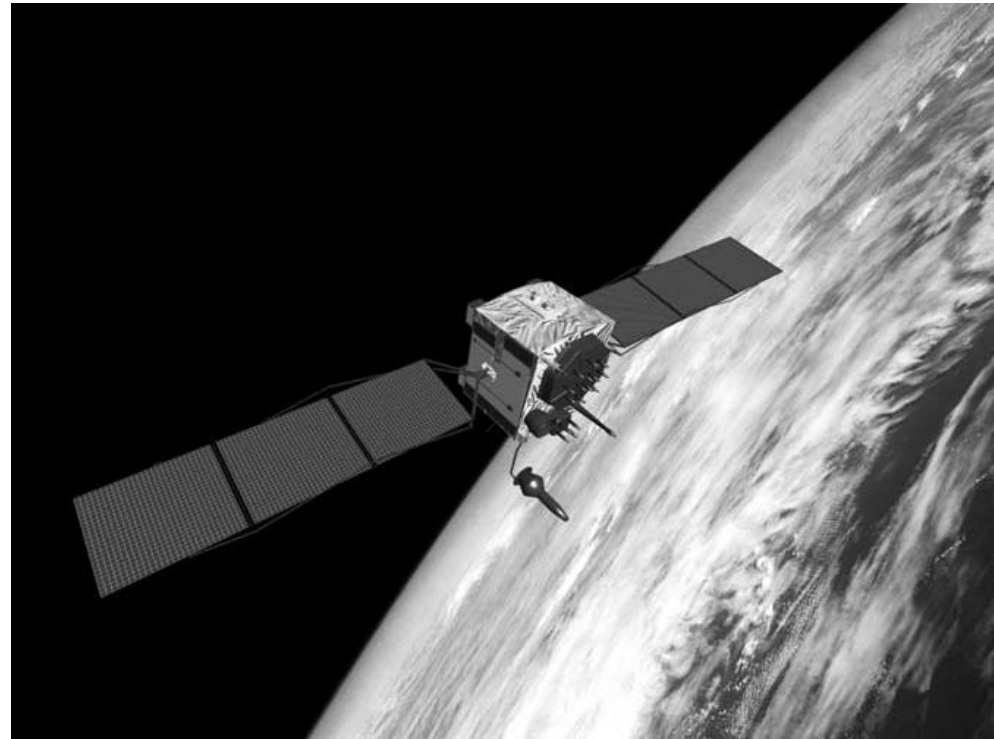
BLK II

BLK IIA

BLK IIR

BLK IIR-M

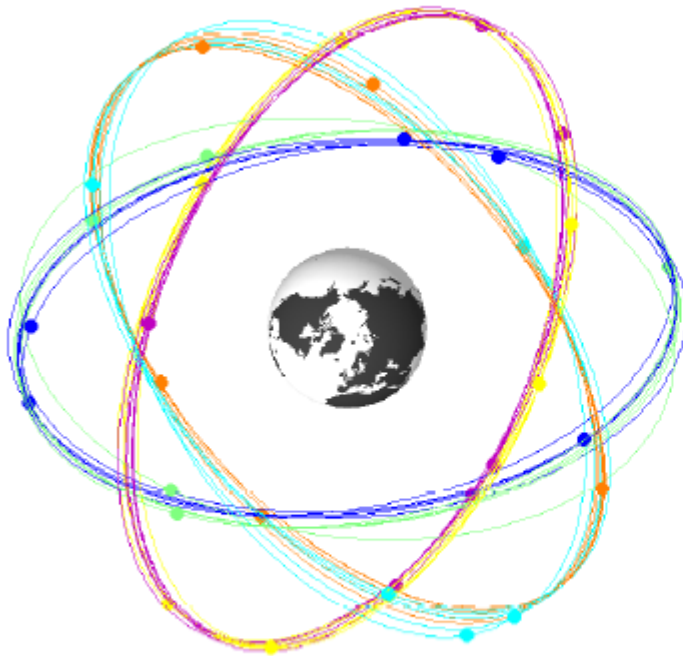
BLK IIF



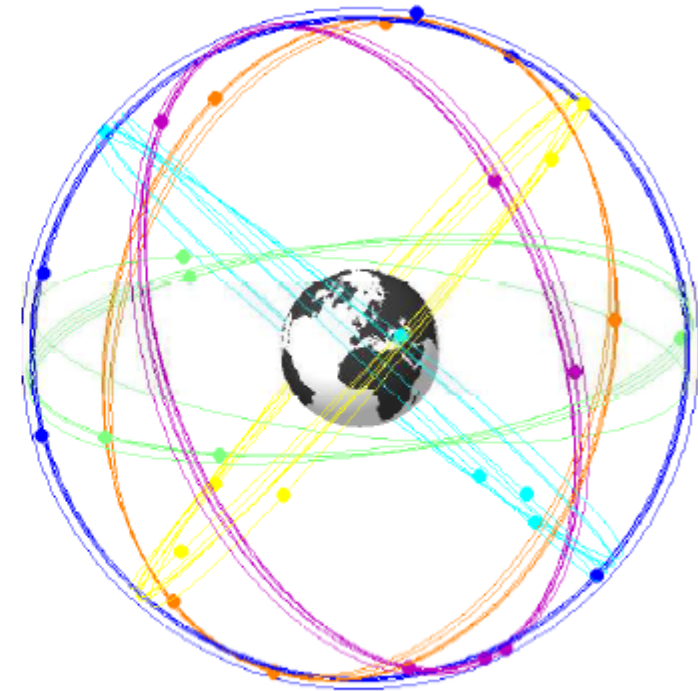


GNSS System-GPS

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(a) From a latitude of 90° .



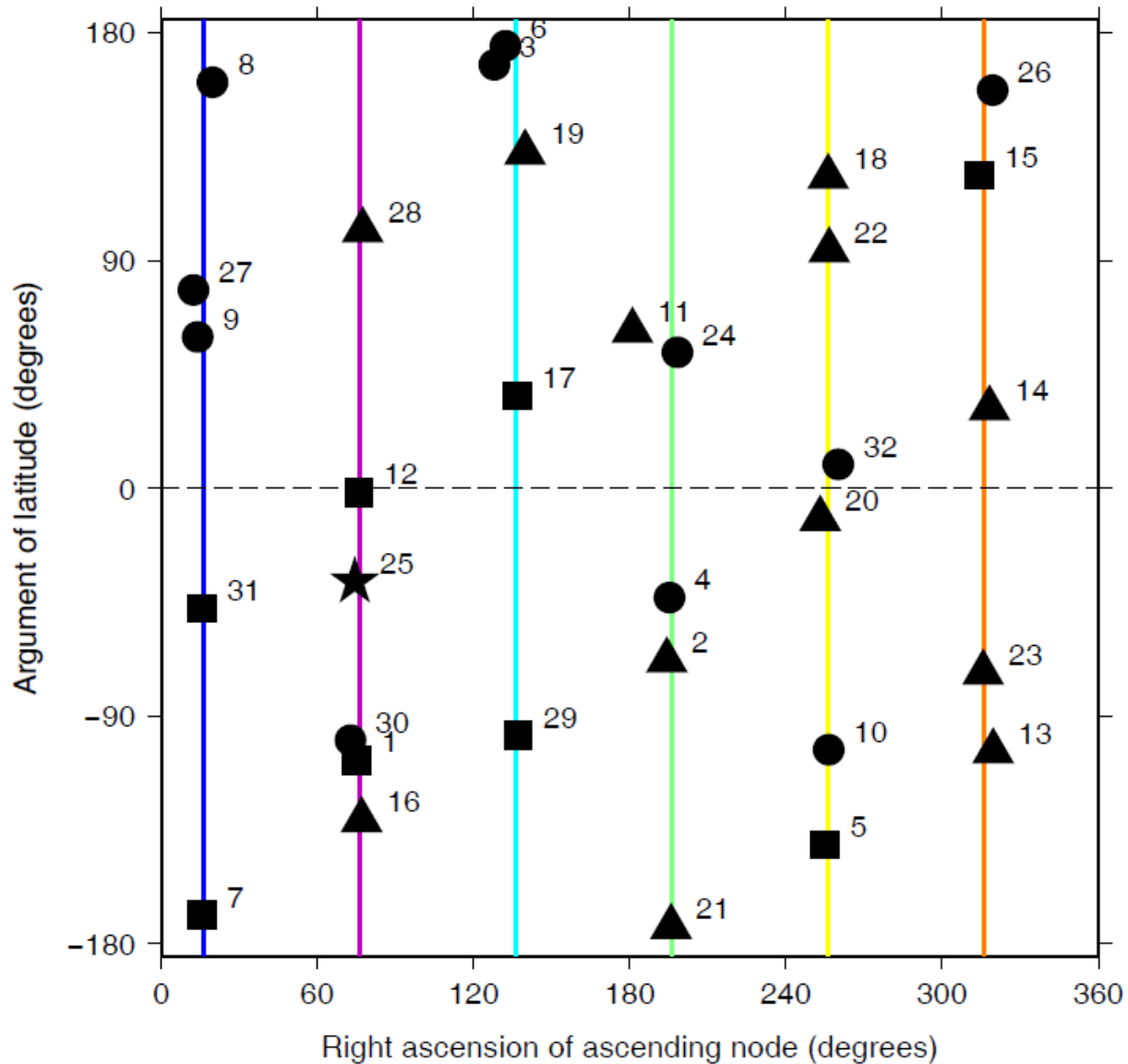
(b) From a latitude of 35° .

Expandable 24 slots





GNSS System-GPS Satellite constellation



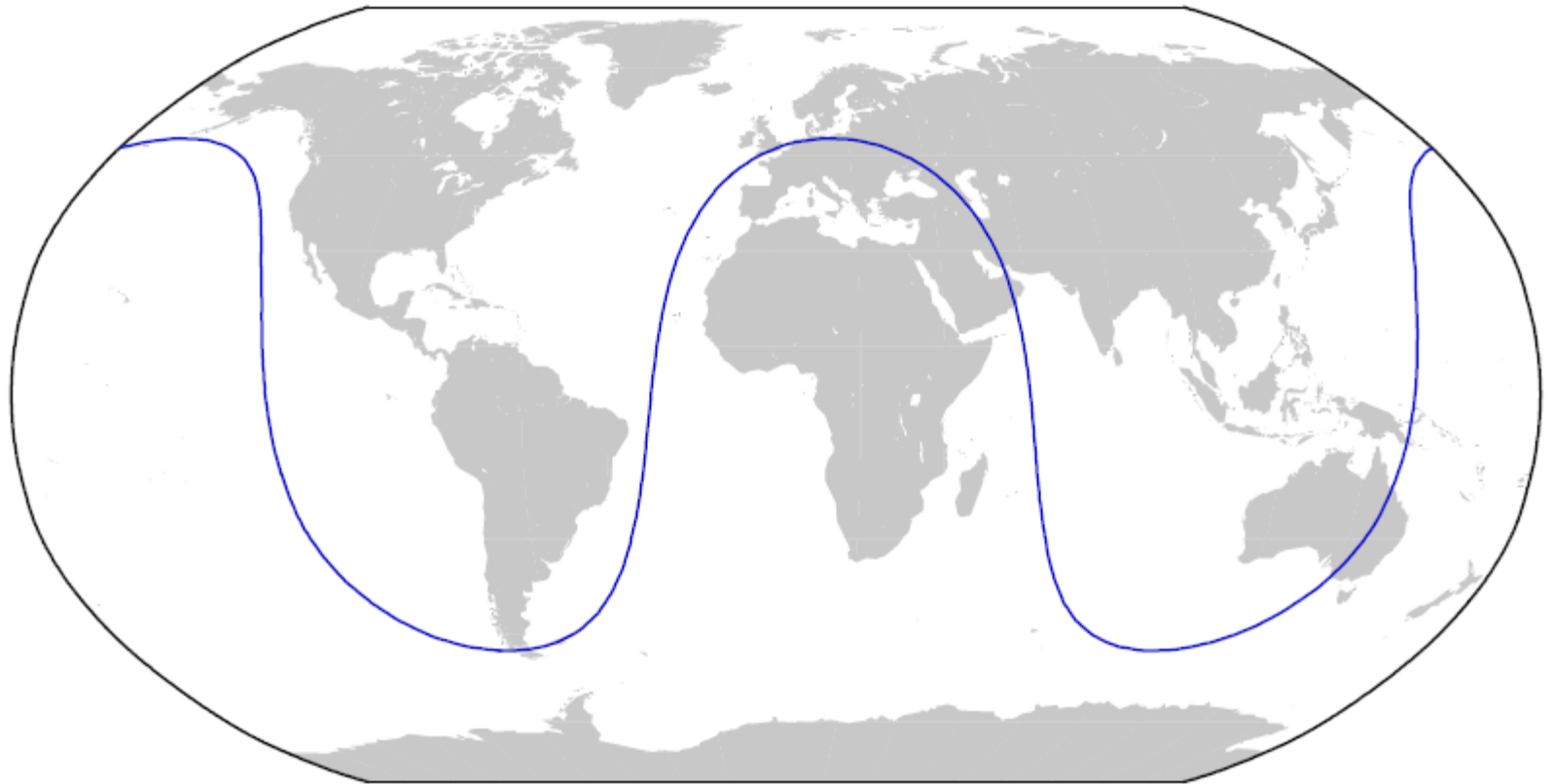
● BLOCK IIA (11) ▲ BLOCK IIR (12) ■ BLOCK IIR-M (8) ★ BLOCK IIR-1 (1)





GNSS System-GPS

Ground track for the GPS constellation
Ground track for G06 for one day

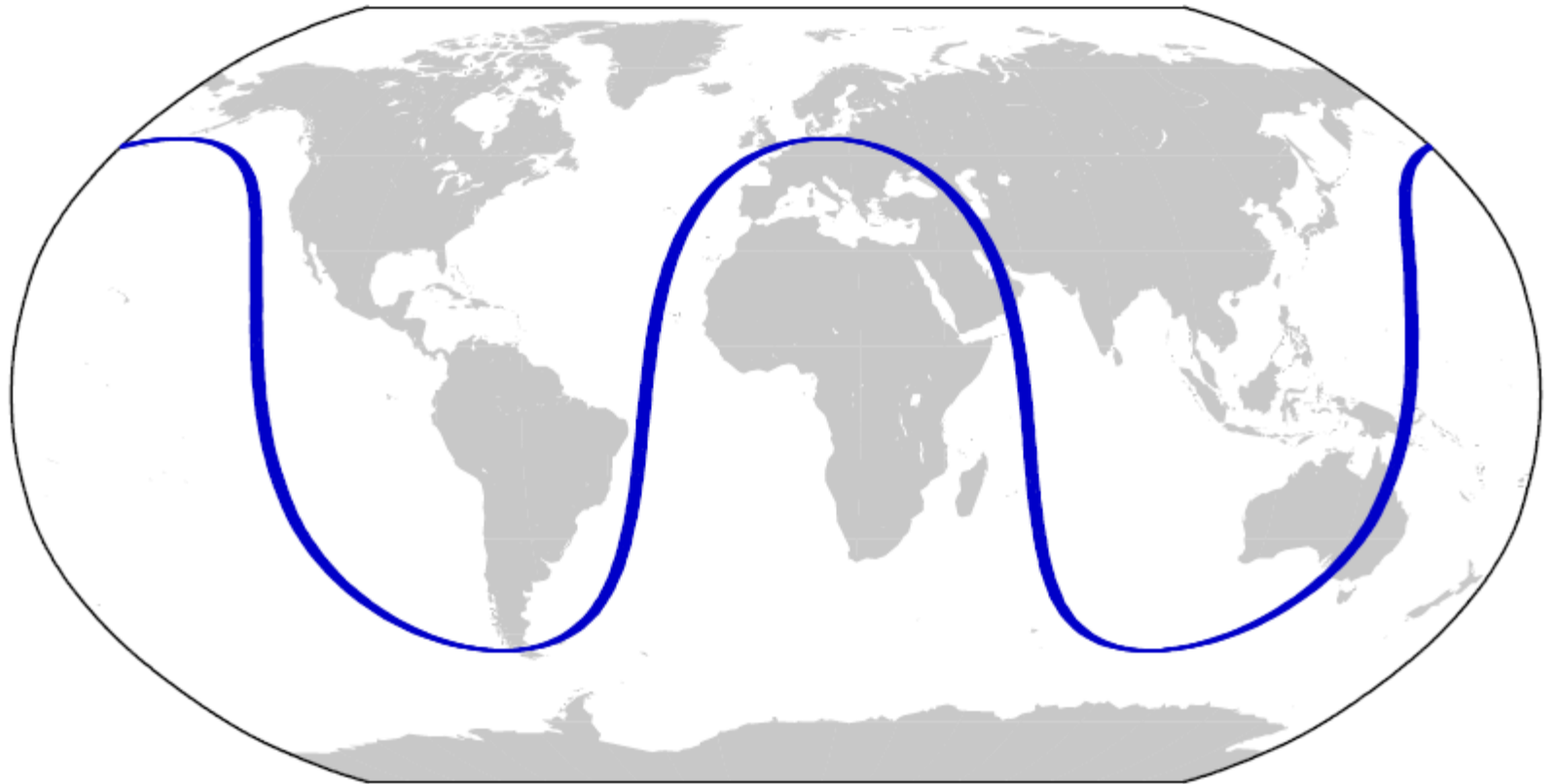


day of year 2008:060



GNSS System-GPS

Ground track for the GPS constellation
Ground track for G06 for ten days

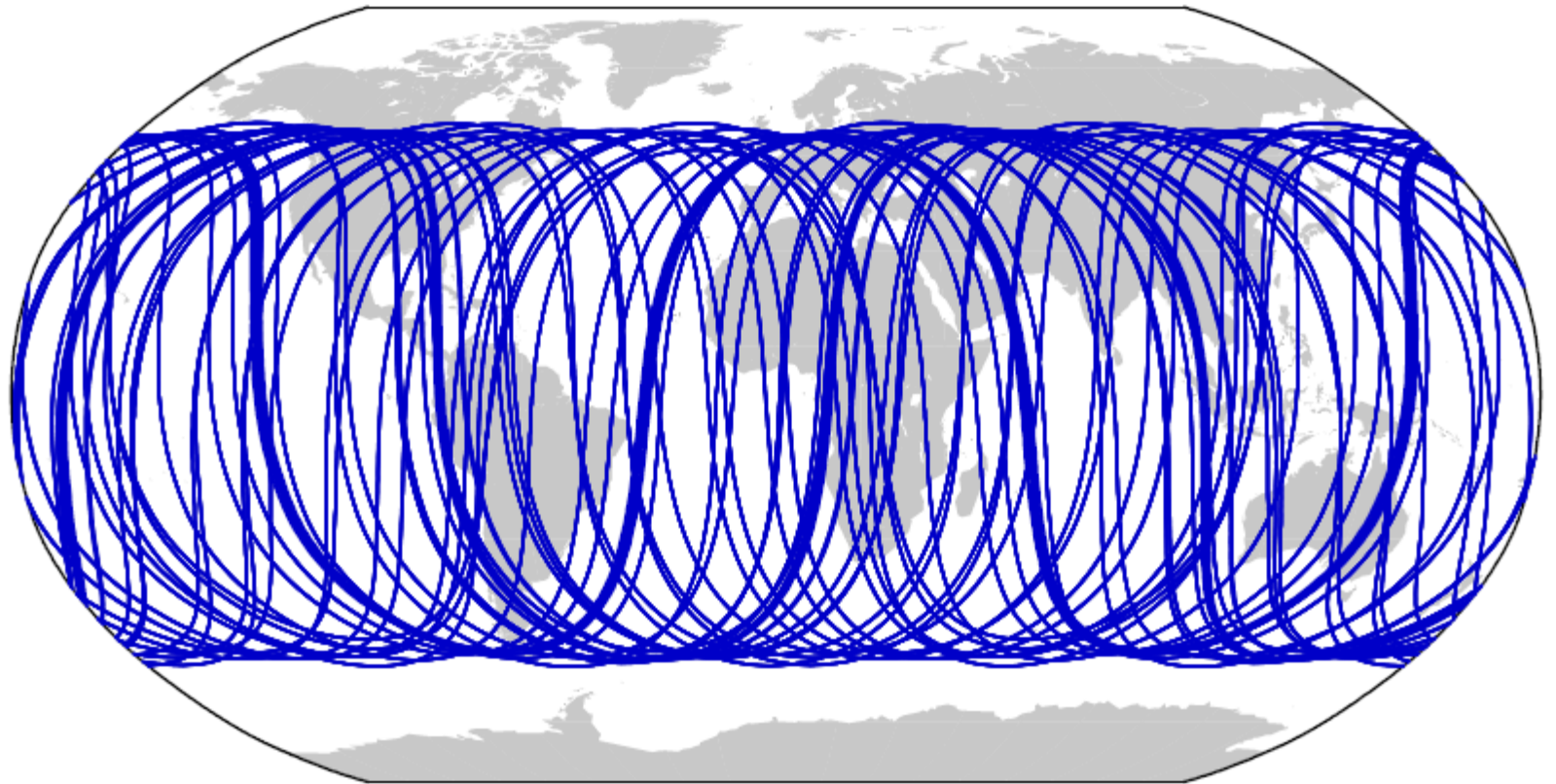


day of year 2008:060 to 069



GNSS System-GPS

Ground track for the GPS constellation
Ground track for all satellites for ten days

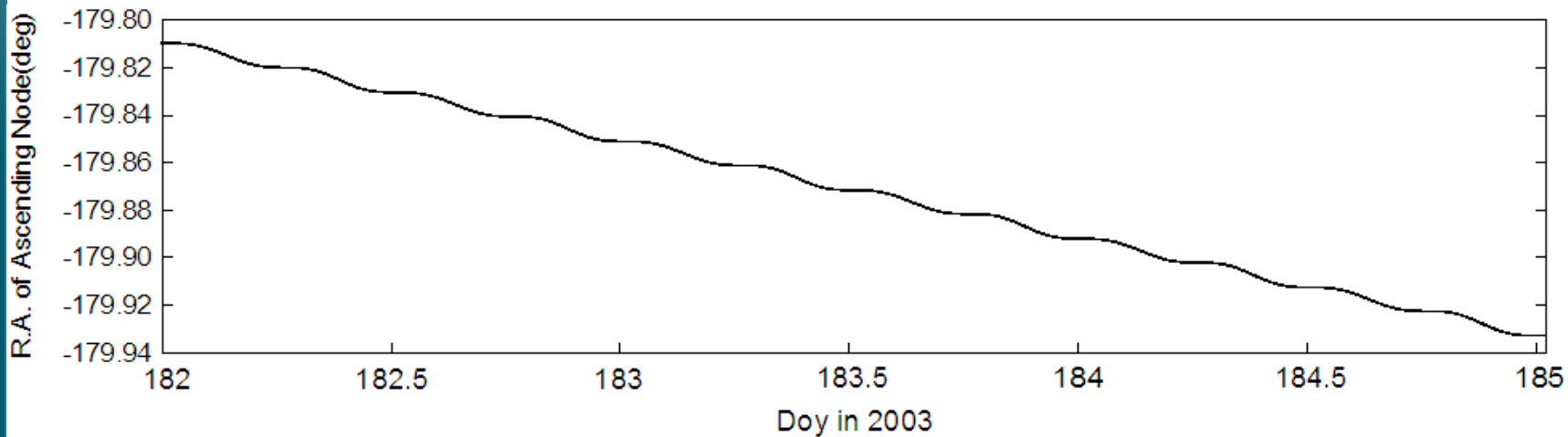
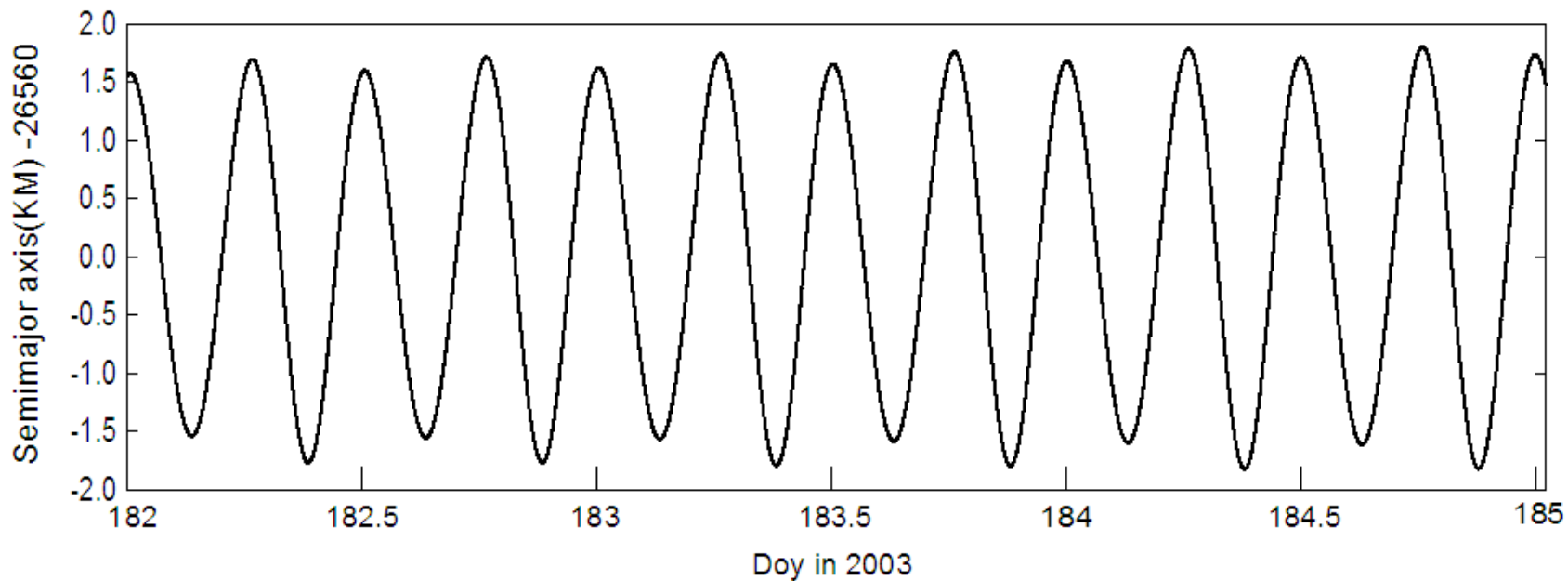


day of year 2008:060 to 069



GNSS System-GPS

中科院上海天文台



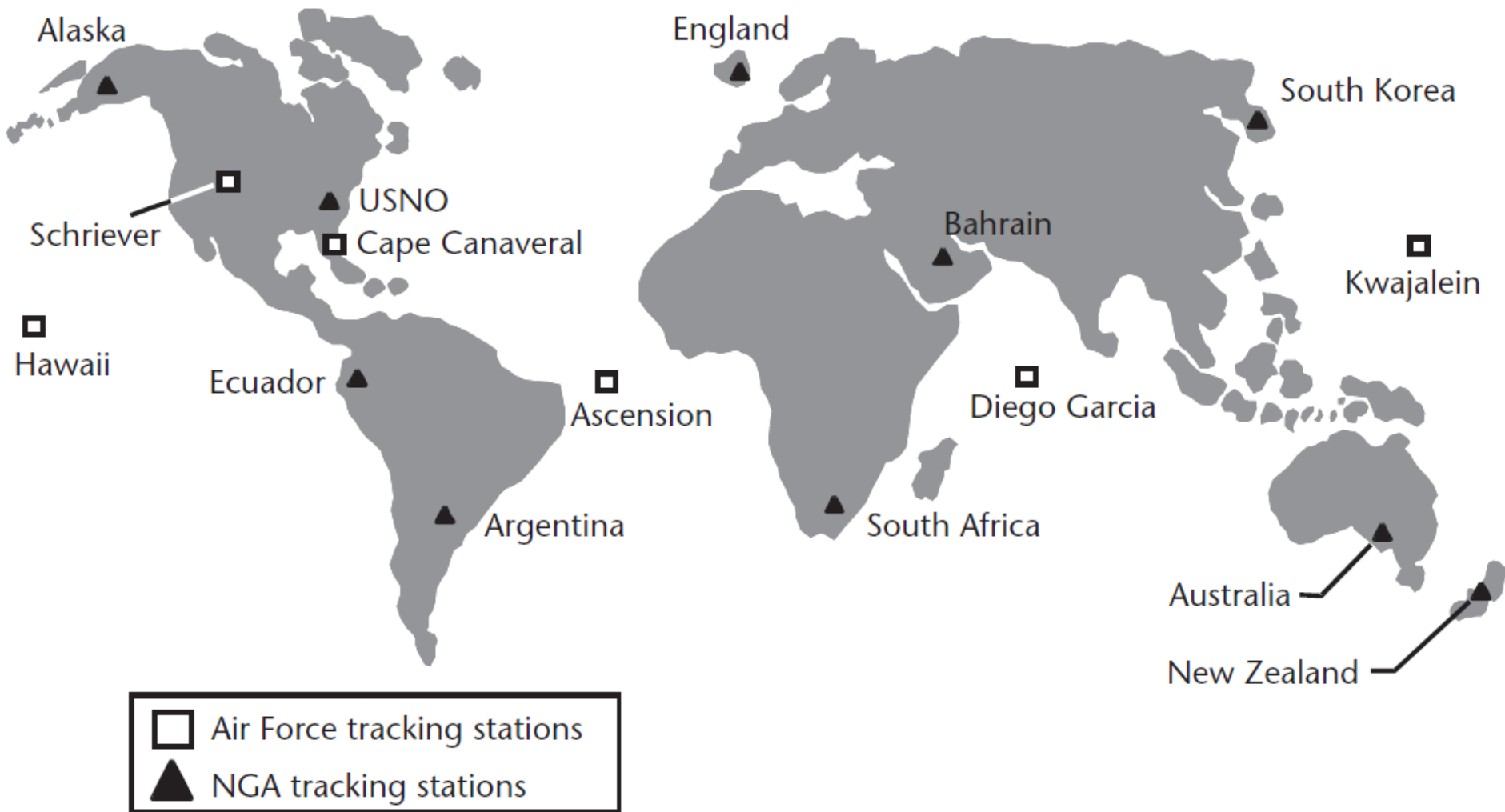


GNSS System-GPS





GNSS System-GPS

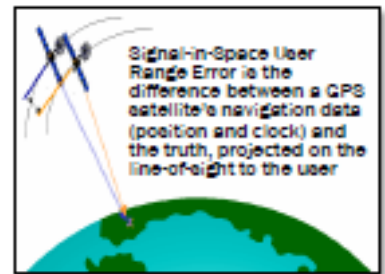
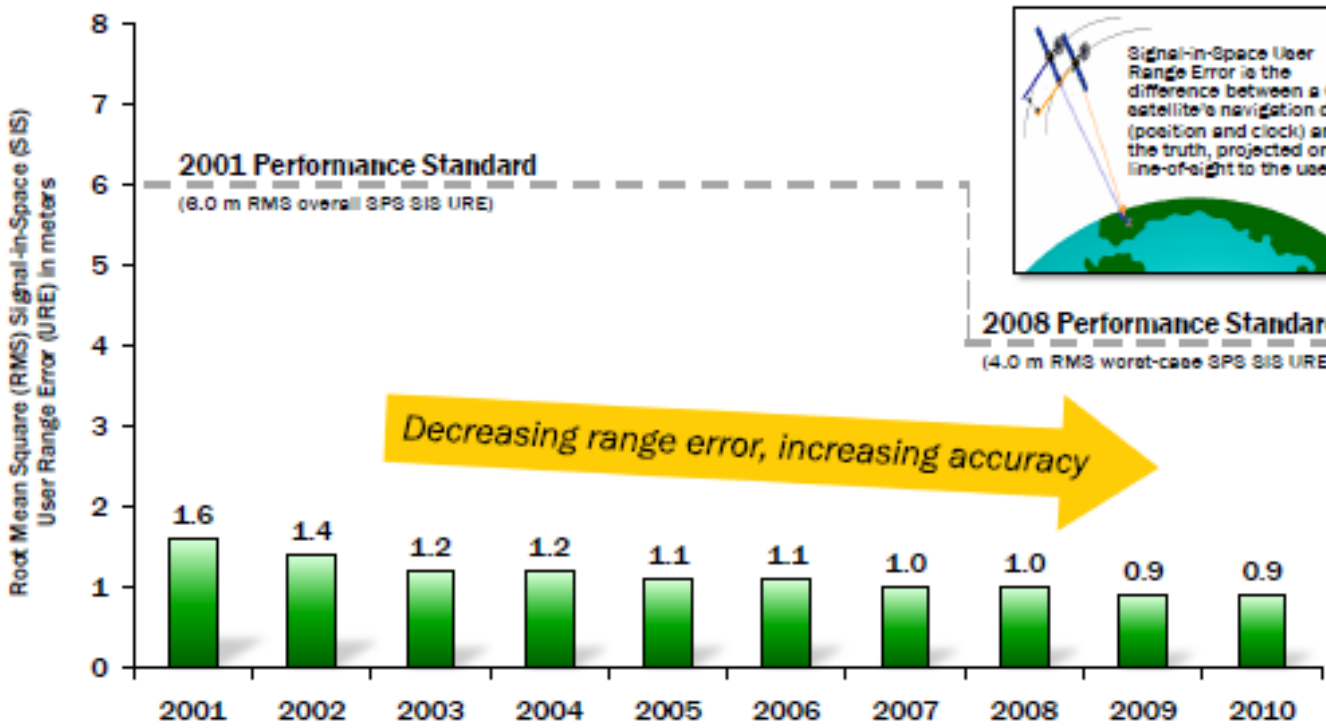




GNSS System-GPS



Standard Positioning Service (SPS) Signal-in-Space Performance



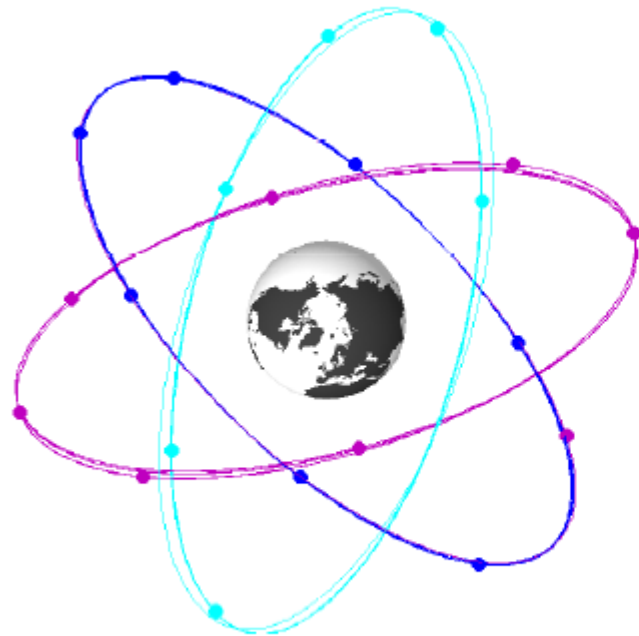
System accuracy exceeds published standard

NATIONAL COORDINATION OFFICE FOR SPACE-BASED POSITIONING, NAVIGATION & TIMING

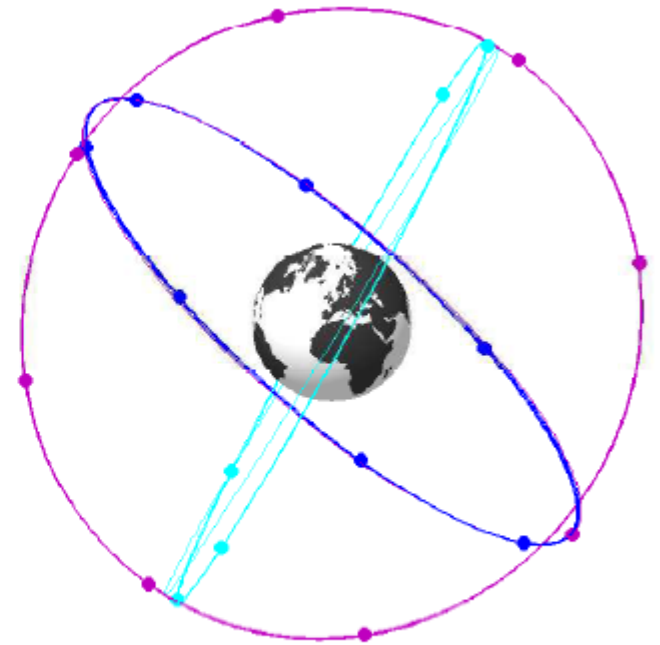


GNSS System-GLONASS

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(a) From a latitude of 90° .

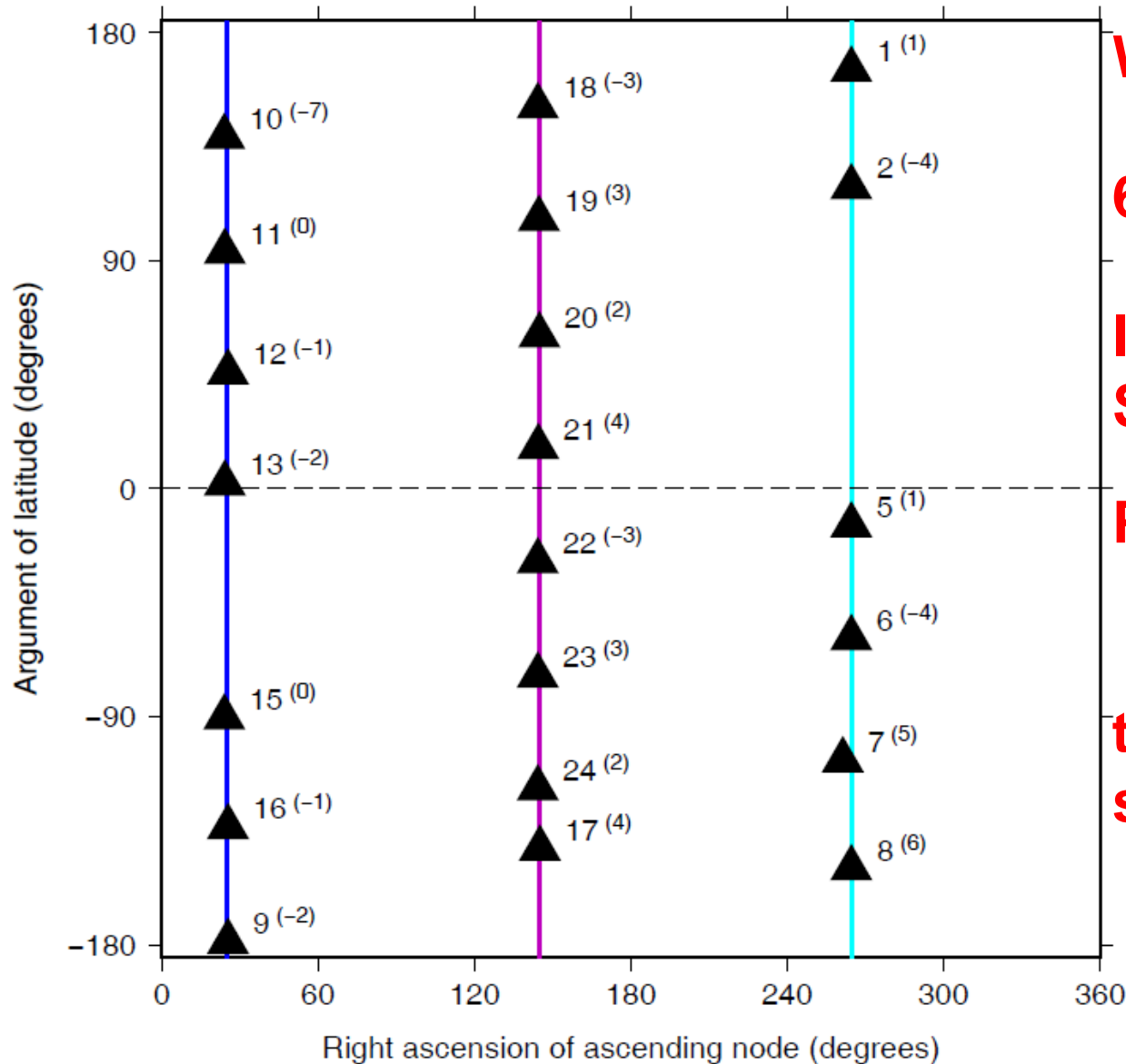


(b) From a latitude of 35° .





GNSS System-GLONASS



Walker Delta

64.8°: 24/3/1

Inner-plane Spacing: 45°

Plane Spacing: 120°

true anomaly shift: 15°

Michael Meindl, 2011

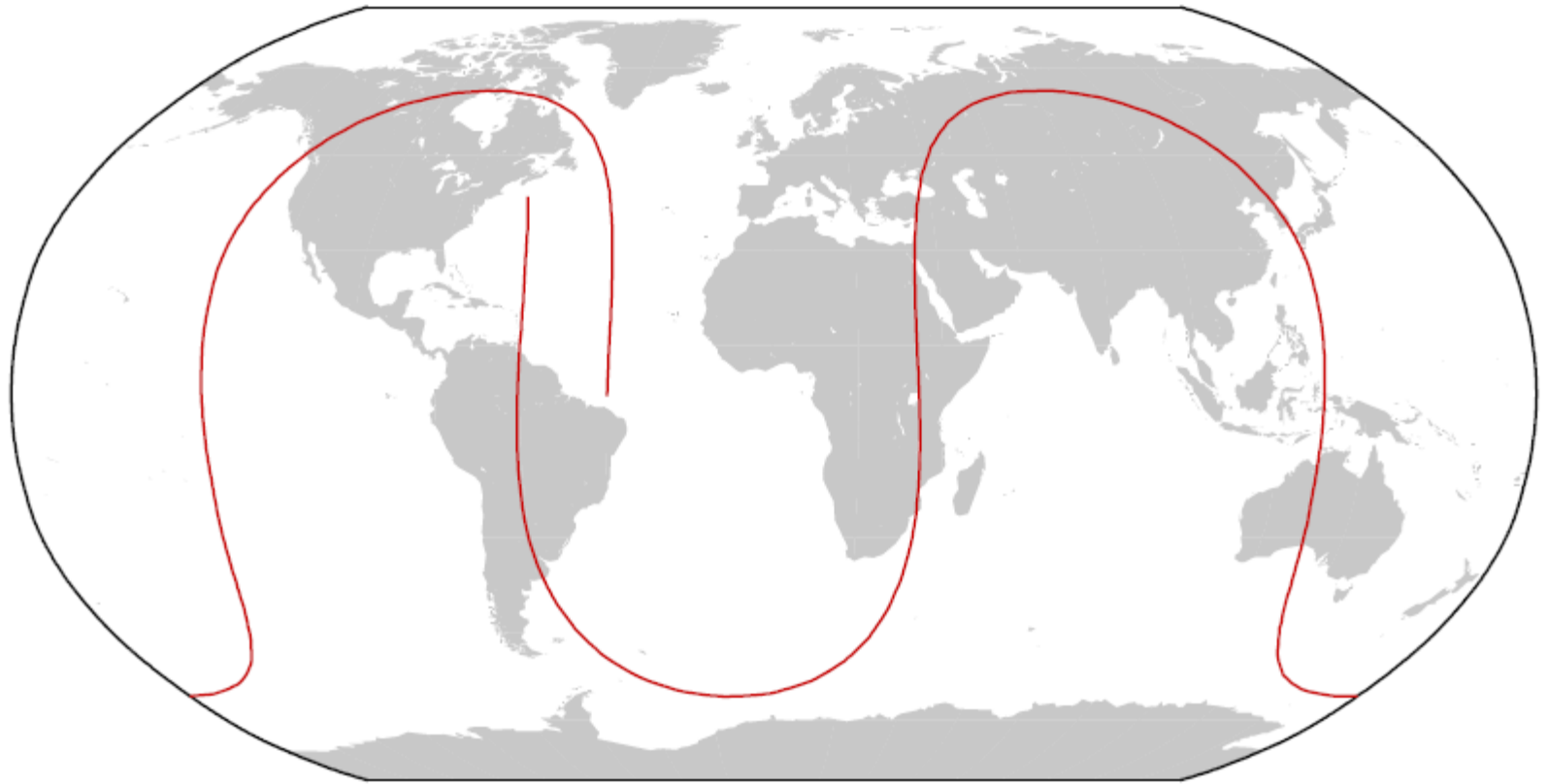




GNSS System-GLONASS

Ground track for the GLONASS constellation

Ground track for R04 for one day



Day of year 2008:060

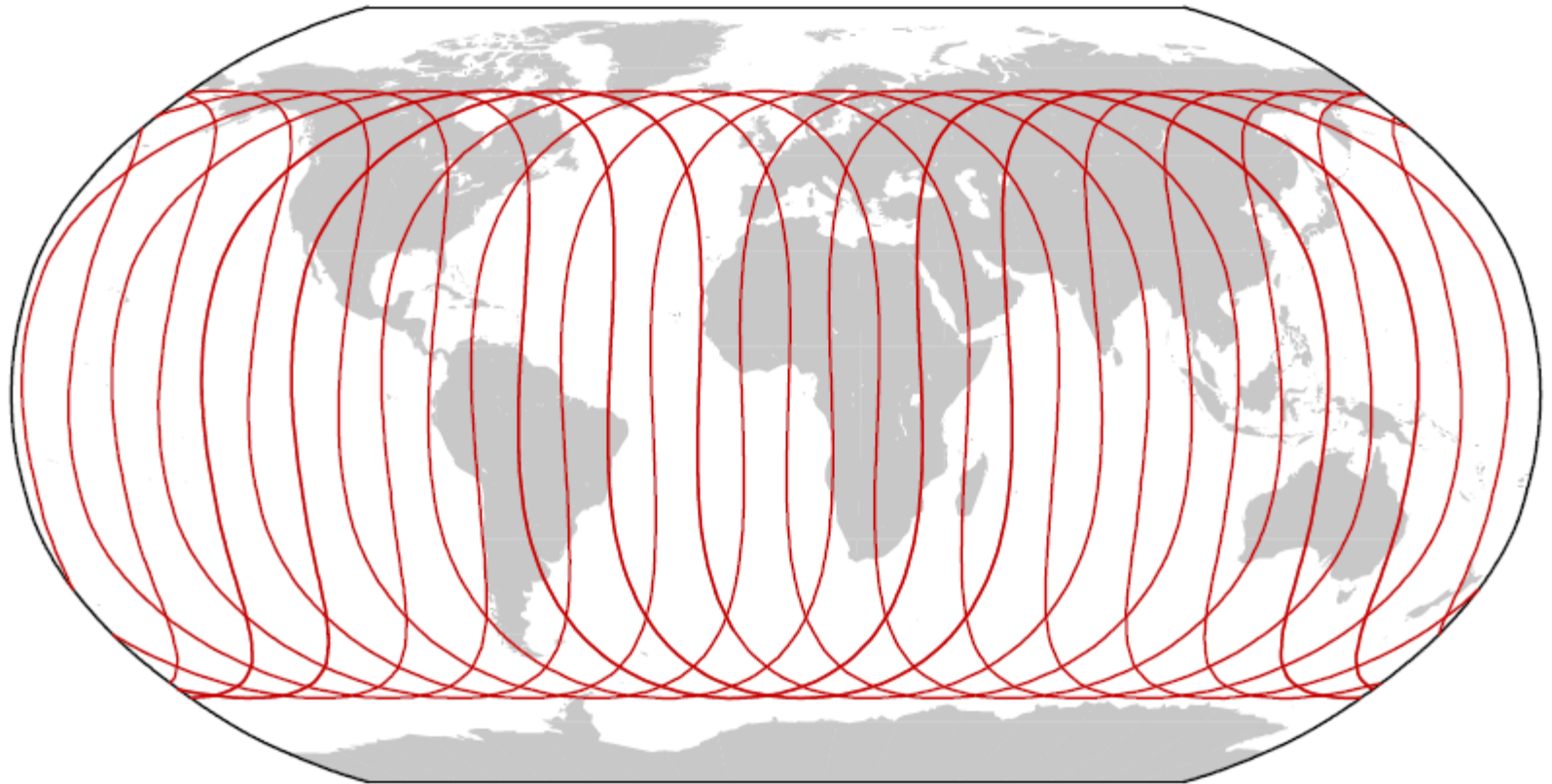
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GNSS System-GLONASS

Ground track for the GLONASS constellation
Ground track for R04 for ten days



中科院上海天文台

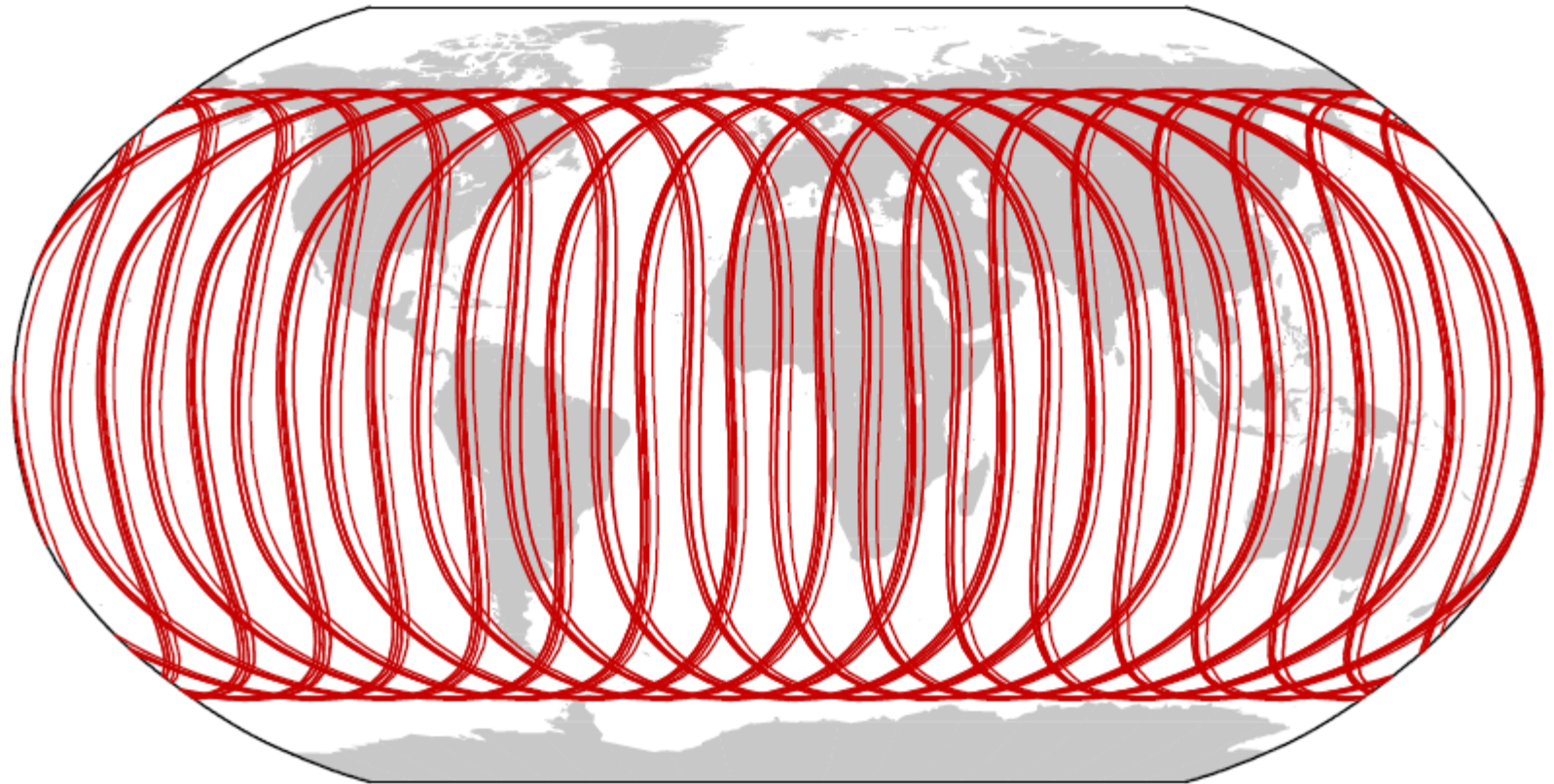
Day of year 2008:060 to 069





GNSS System-GLONASS

Ground track for the GLONASS constellation
Ground track for R01 to R08 for ten days



中科院上海天文台

Day of year 2008:060 to 069





GNSS System-GLONASS

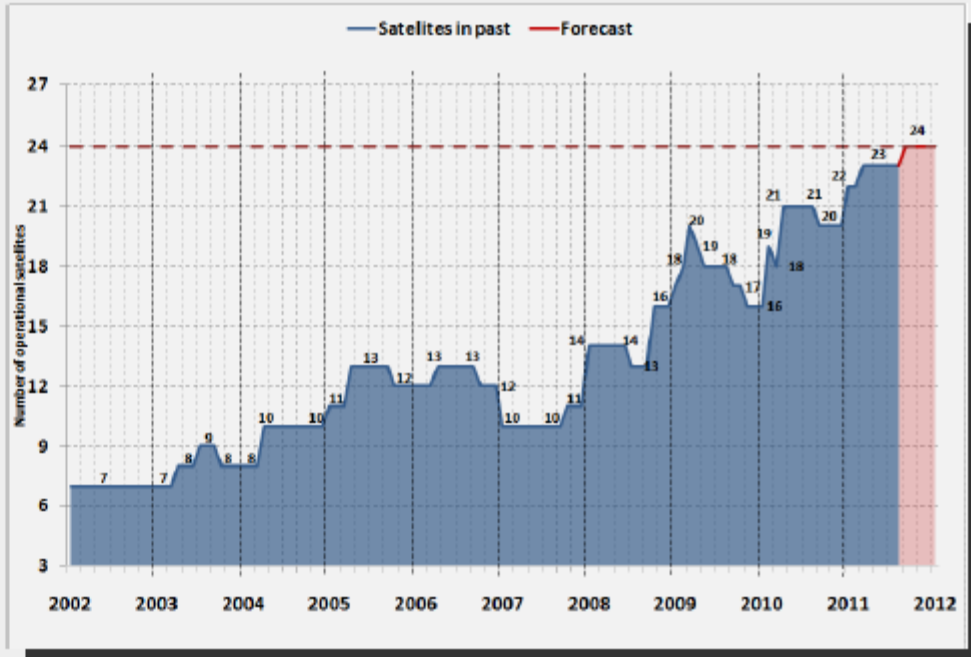
Constellation Status (03.09.2011)



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| | |
|----------------|-------|
| Total in orbit | 27 SV |
| Operational | 23 SV |
| In maintenance | 3 SV |
| Flight Test | 1 SV |

Number of operational satellites





GNSS System-GLONASS

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GLONASS Control Segment

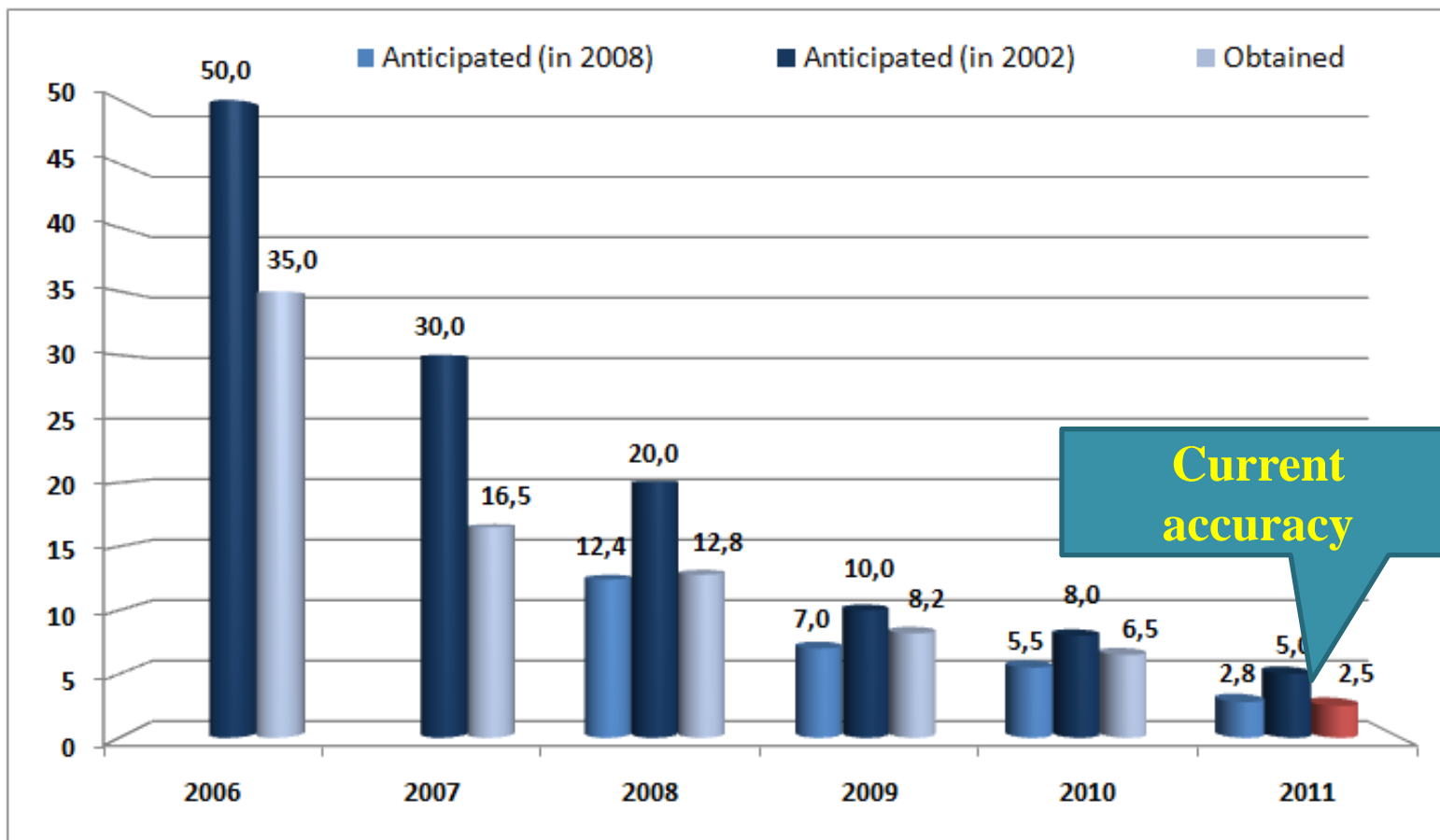


Sergey Revnivykh, 2011



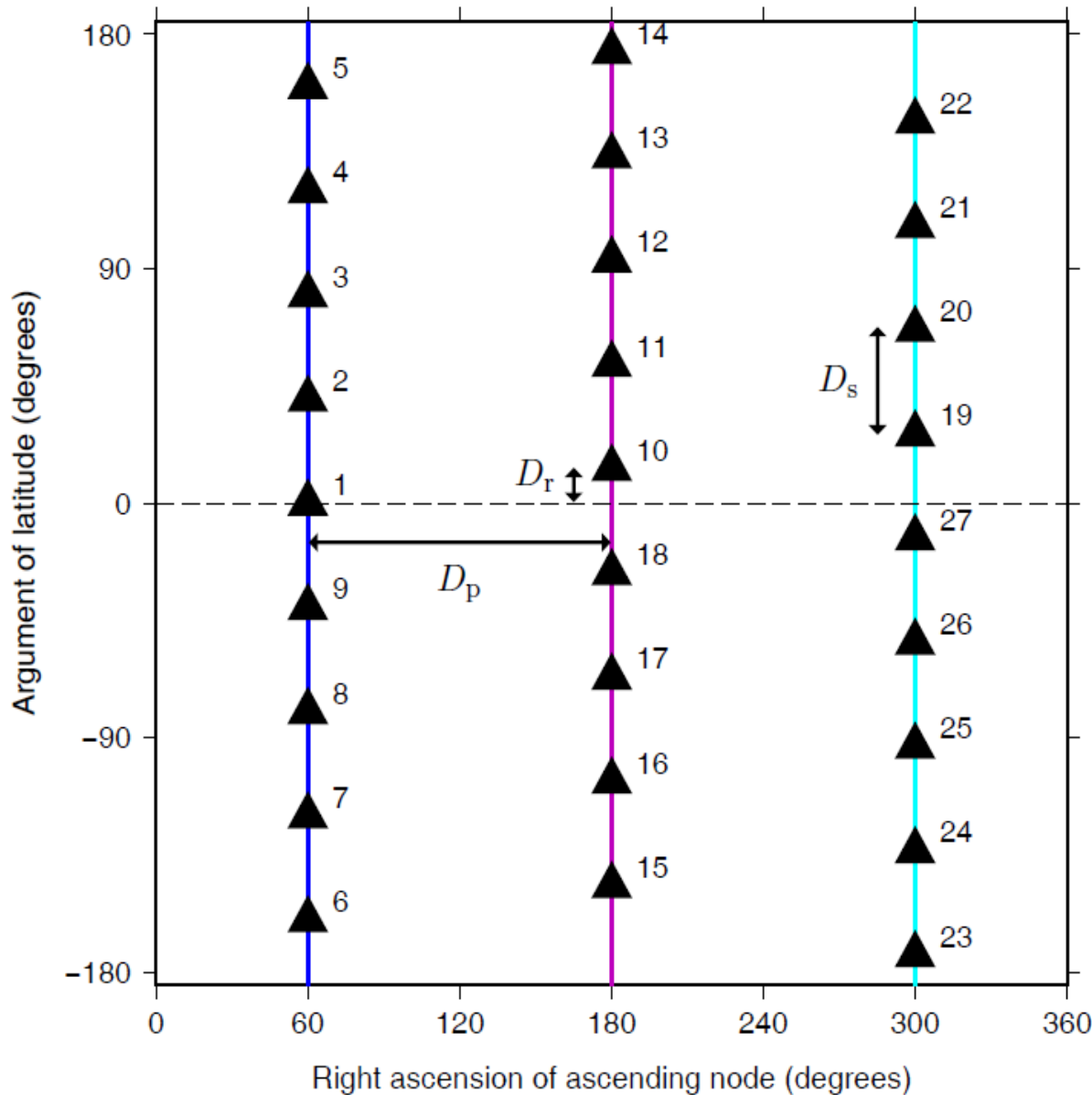
GNSS System-GLONASS

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GNSS System-GALILEO



Walker Delta

56°: 27/3/1

Inner-plane Spacing: 40°

Plane Spacing: 120°

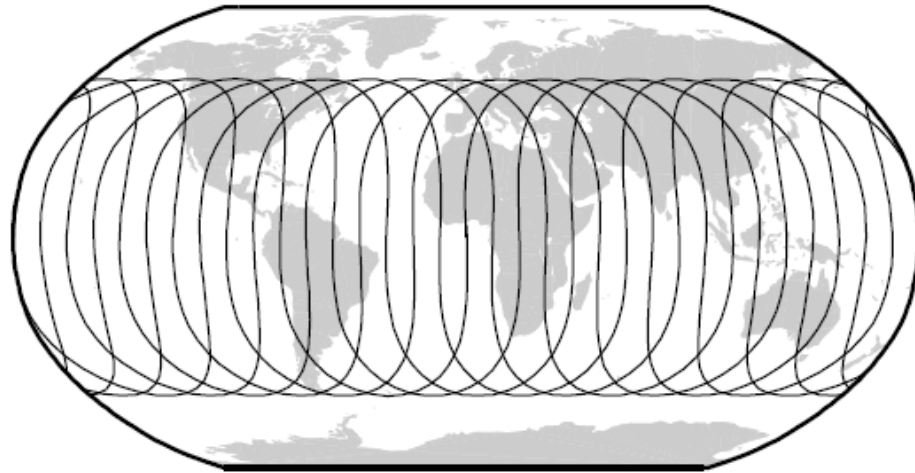
true anomaly shift: 13.3°



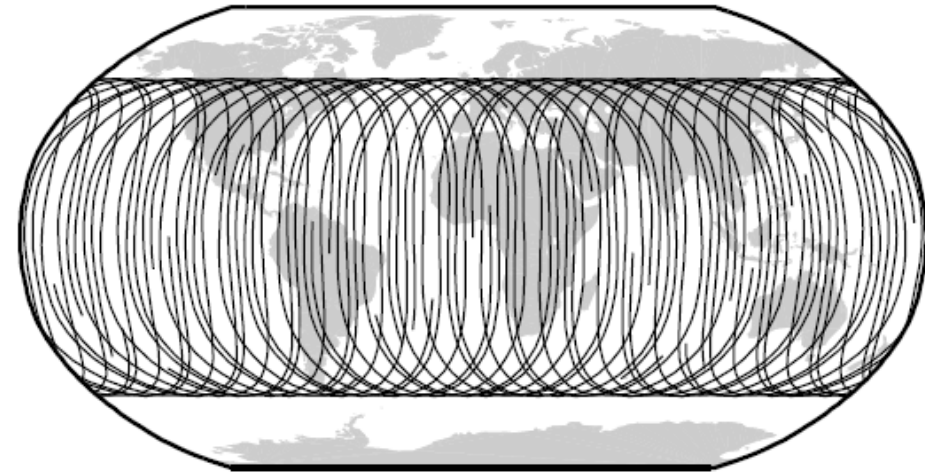


GNSS System-GALILEO

中



(a) One Galileo satellite, ten days.



(b) All Galileo satellites, one day.

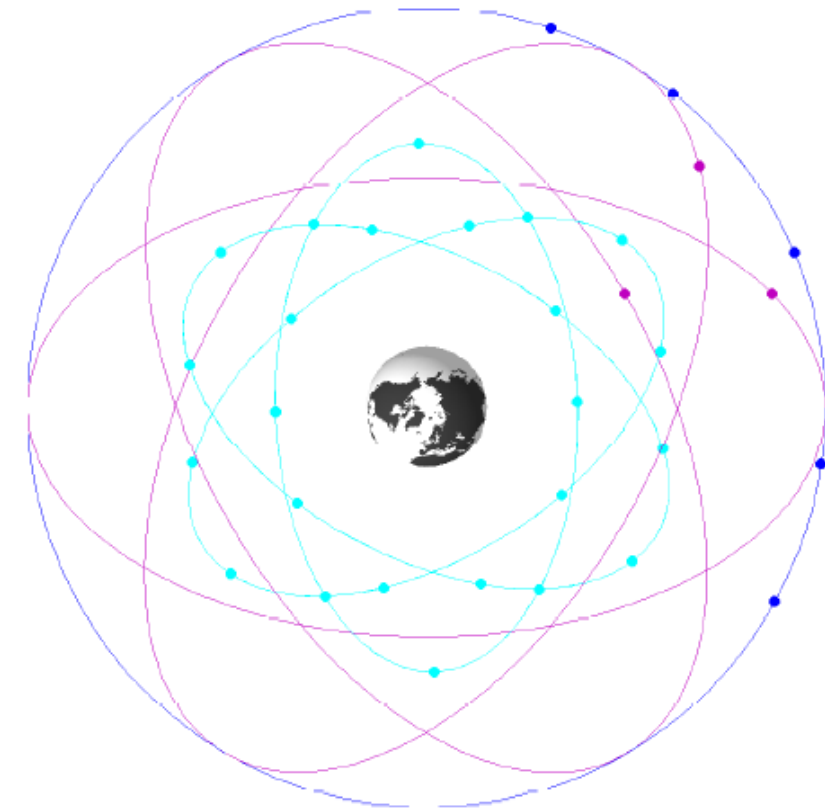
台



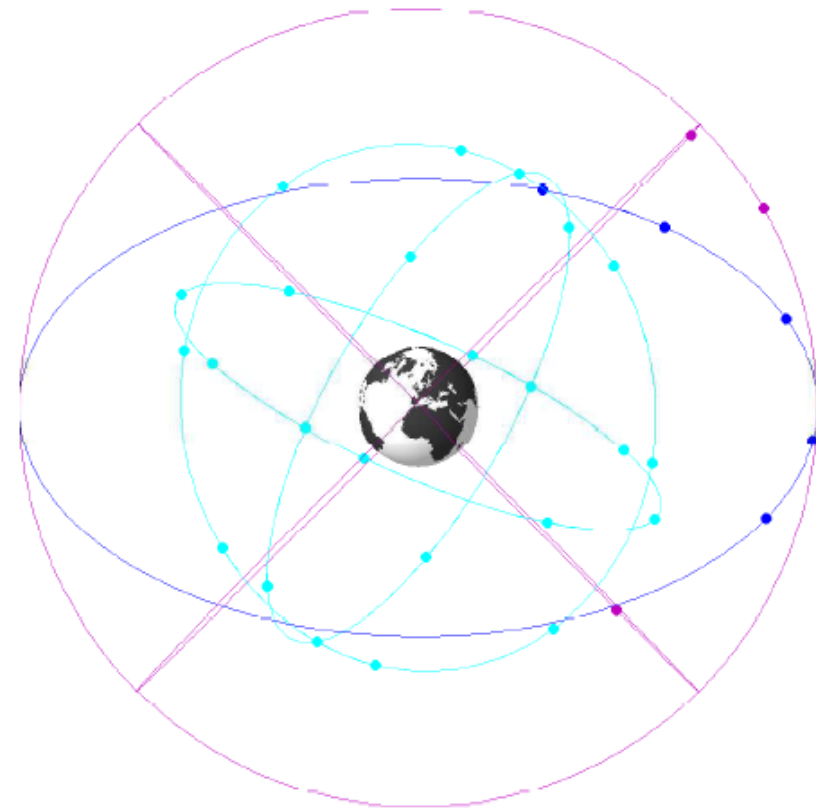
14 hours 05 minutes, 17 rev/ 10days



GNSS System-COMPASS



(a) From a latitude of 90° .



(b) From a latitude of 35° .





GNSS System-COMPASS

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➤ Constellation:
GEO/IGSO/MEO
5+5+4

| 卫星 | 发射日期 | 运载火箭 | 轨道 |
|-----------------|------------|-------|------|
| 第 1 颗北斗导航试验卫星 | 2000.10.31 | CZ-3A | GEO |
| 第 2 颗北斗导航试验卫星 | 2000.12.21 | CZ-3A | GEO |
| 第 3 颗北斗导航试验卫星 | 2003.5.25 | CZ-3A | GEO |
| 第 4 颗北斗导航试验卫星 | 2007.2.3 | CZ-3A | GEO |
| 第 1 颗北斗导航卫星 | 2007.4.14 | CZ-3A | MEO |
| 第 2 颗北斗导航卫星 | 2009.4.15 | CZ-3C | GEO |
| 第 3 颗北斗导航卫星 | 2010.1.17 | CZ-3C | GEO |
| 第 4 颗北斗导航卫星 | 2010.6.2 | CZ-3C | GEO |
| 第 5 颗北斗导航卫星 | 2010.8.1 | CZ-3A | IGSO |
| 第 6 颗北斗导航卫星 | 2010.11.1 | CZ-3C | GEO |
| 第 7 颗北斗导航卫星 | 2010.12.18 | CZ-3A | IGSO |
| 第 8 颗北斗导航卫星 | 2011.4.10 | CZ-3A | IGSO |
| 第 9 颗北斗导航卫星 | 2011.7.27 | CZ-3A | IGSO |
| 第 10 颗北斗导航卫星 | 2011.12.2 | CZ-3A | IGSO |
| 第 11 颗北斗导航卫星 | 2012.2.25 | CZ-3C | GEO |
| 第 12、13 颗北斗导航卫星 | 2012.4.30 | CZ-3B | MEO |

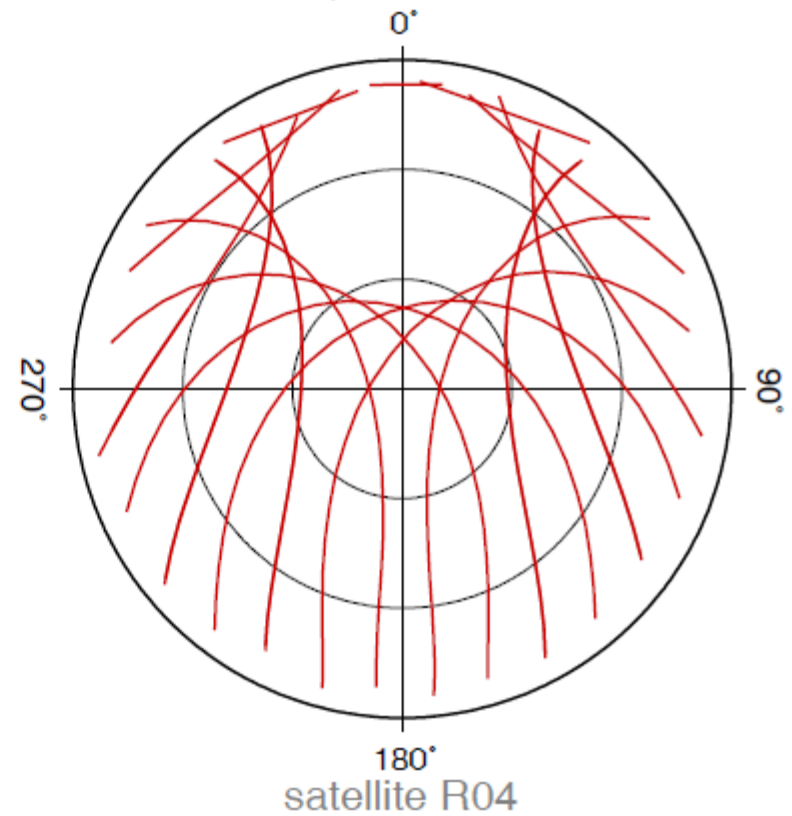
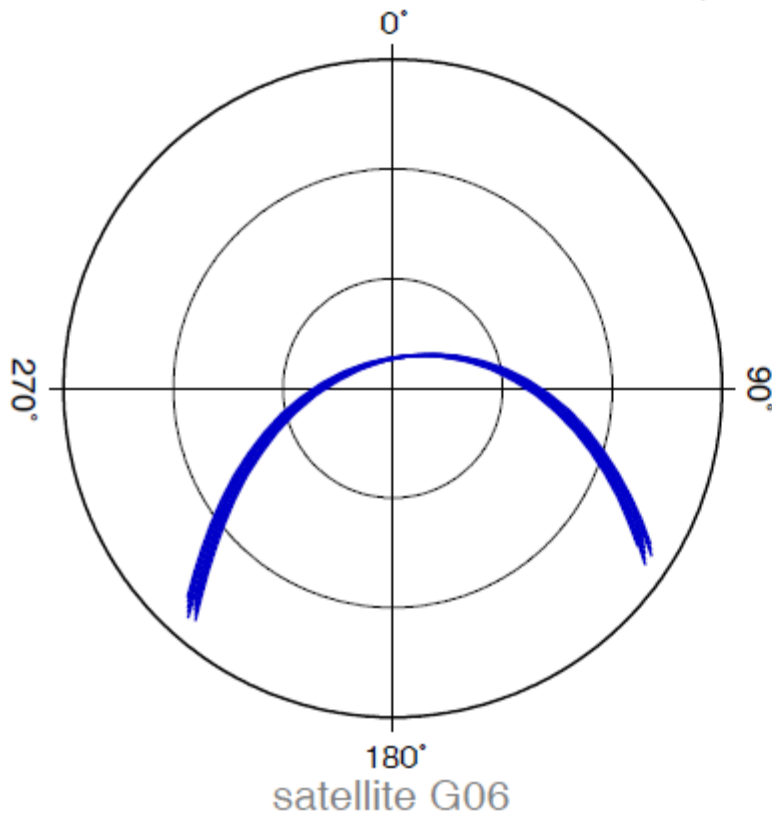




Satellite trajectory

Elevation–Azimuth–Diagram

Zimmerwald (Lat: $46^{\circ} 52'$; Lon: $7^{\circ} 28'$)



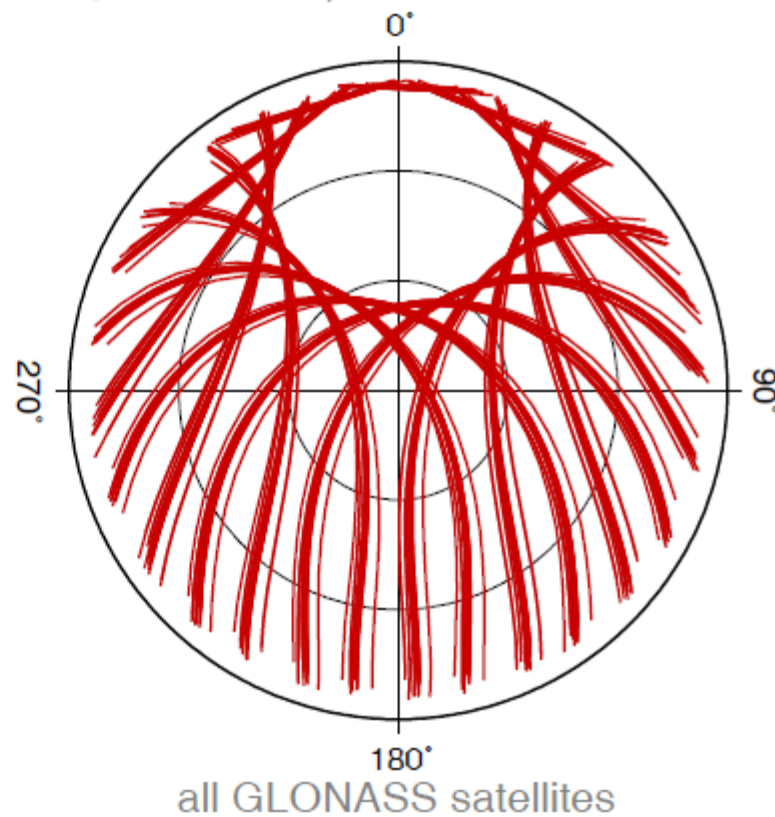
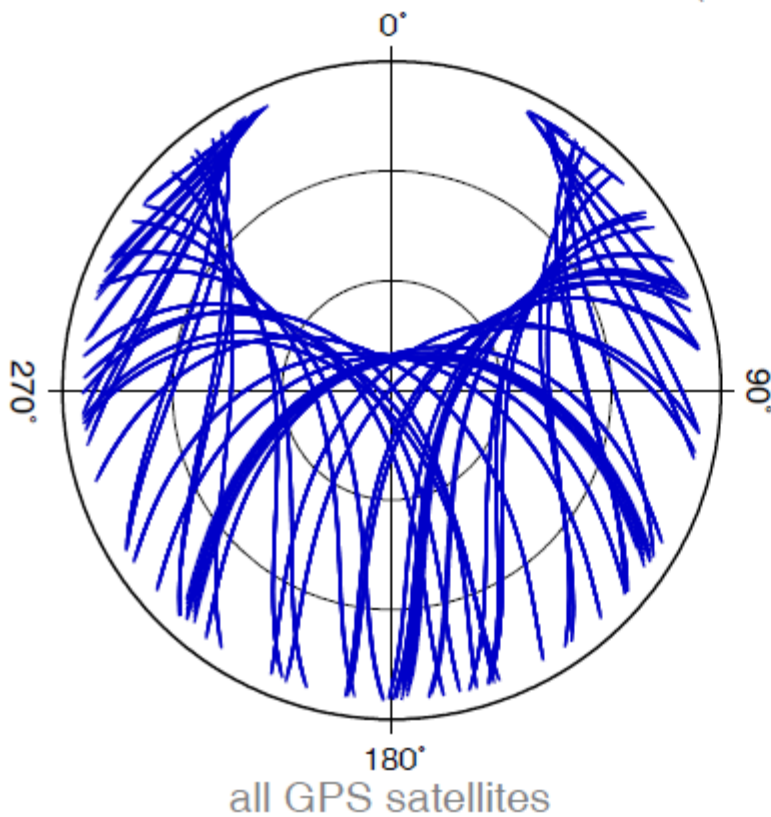
day of year 2008:060 to 069



Satellite trajectory

Elevation–Azimuth–Diagram

Zimmerwald (Lat: $46^{\circ} 52'$; Lon: $7^{\circ} 28'$)



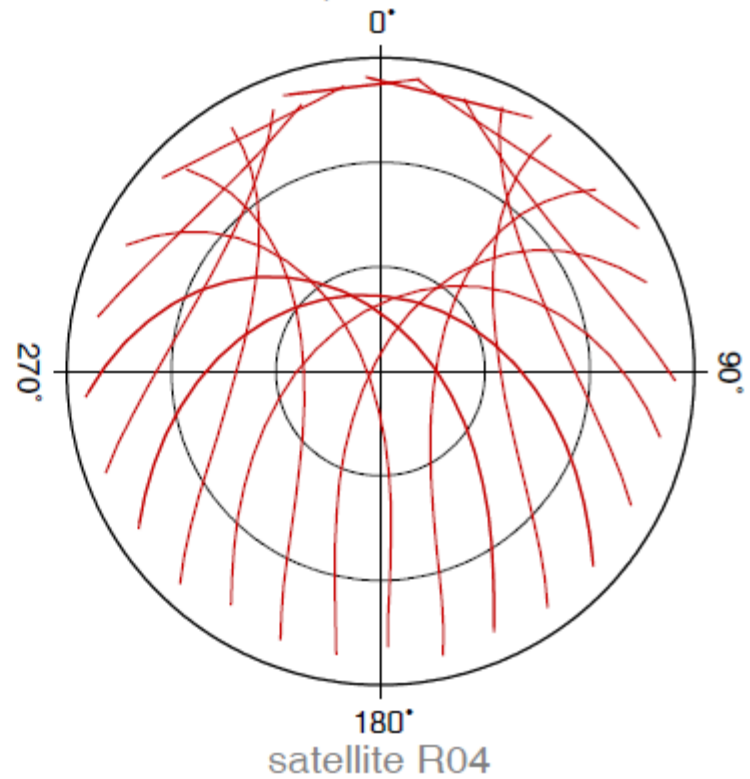
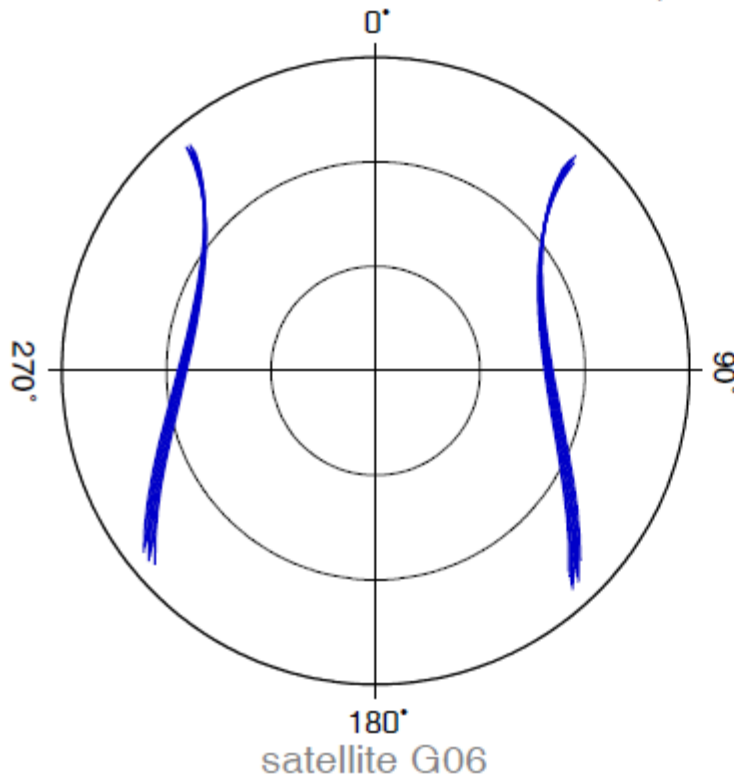
day of year 2008:060 to 069



Satellite trajectory

Elevation–Azimuth–Diagram

Ulaanbataar (Lat: $47^{\circ} 40'$; Lon: $107^{\circ} 3'$)



day of year 2008:060 to 069





Content(4)

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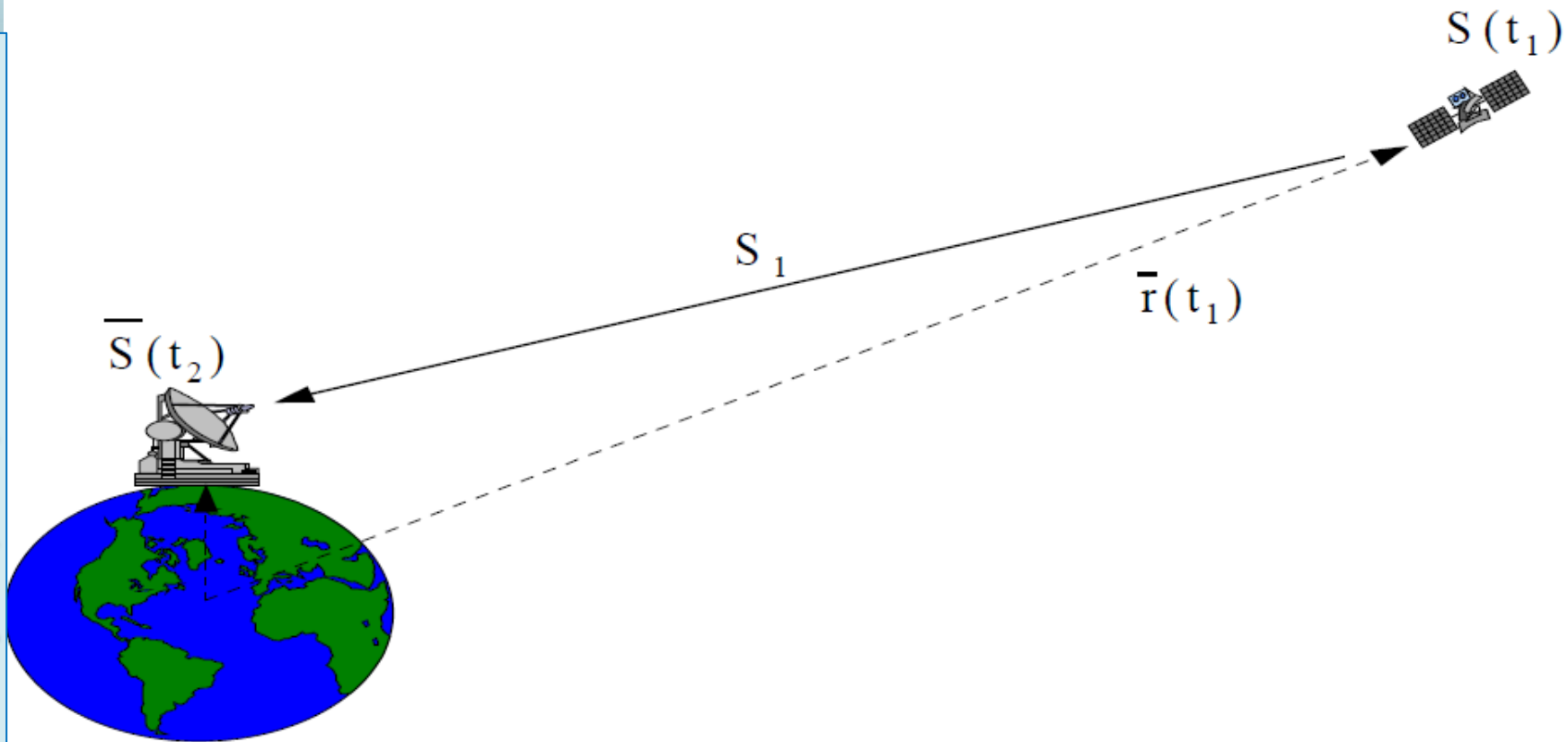
- **GNSS researches**
- **GNSS applications**





GNSS Observation

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$$P_m^j = \rho^j + c\delta - c\delta^j + f(\alpha) \cdot ZTD + \frac{1}{f_m^2} \cdot I^j + \Delta P_m^j$$

$$\rho^j = f(x_{sta}, x_{sat})$$





GNSS research summary

- **Satellite:** Orbits, clocks, satellite attitude, phase center.....
- **Travelling space:** Troposphere, ionosphere, occultation.....
- **Ground station:** position & velocity, clocks, reflection, and related applications.....





GNSS research summary

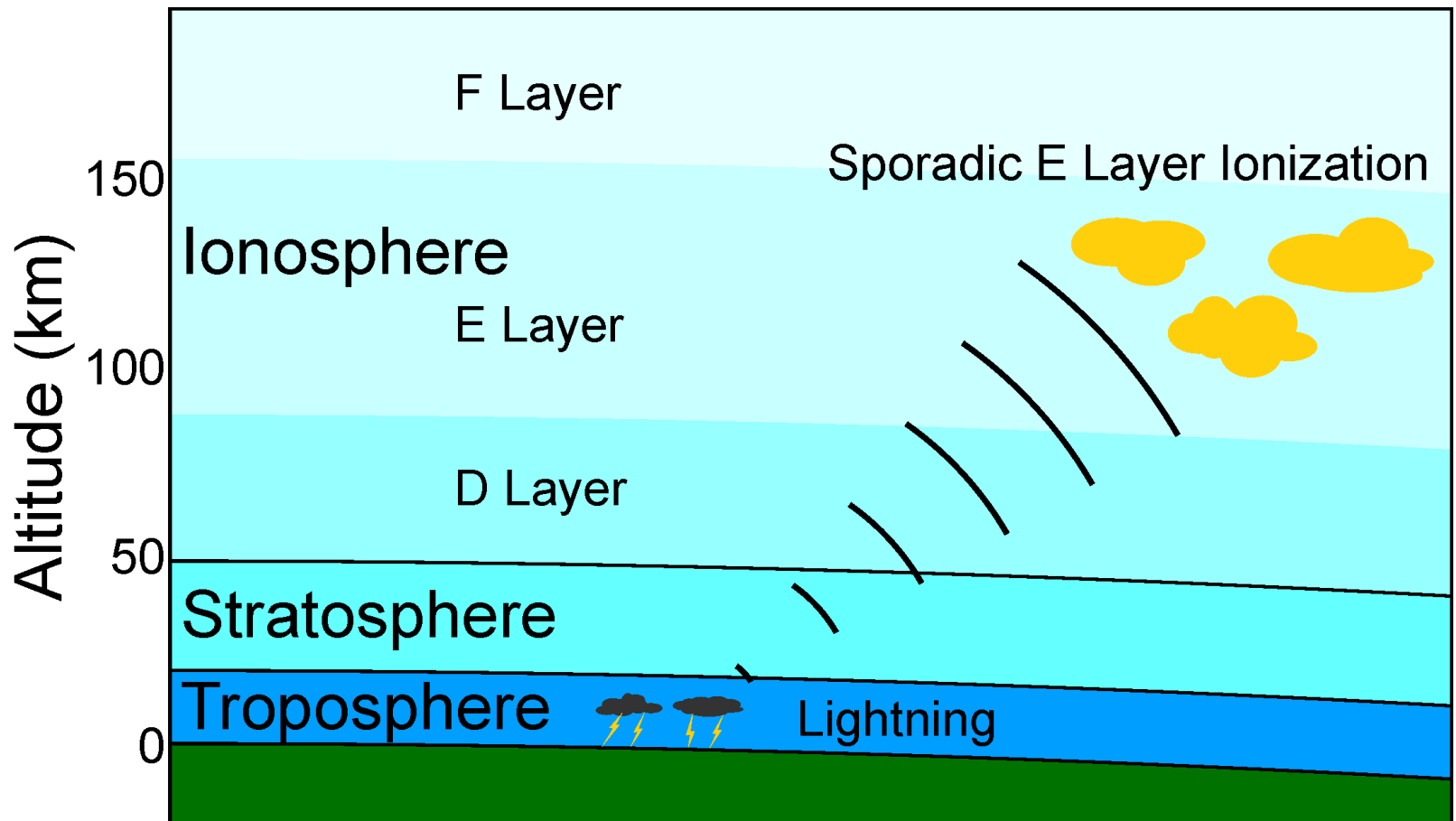
➤ **Satellite:** Orbits, clocks, satellite attitude, phase center.....





GNSS research summary

➤ **Travelling space:** Troposphere, ionosphere, occultation.....





GNSS research summary

➤ **Travelling space:** Troposphere, ionosphere, occultation.....



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GNSS research summary

➤ **Ground station:** position & velocity, clocks, reflection, and related applications.....

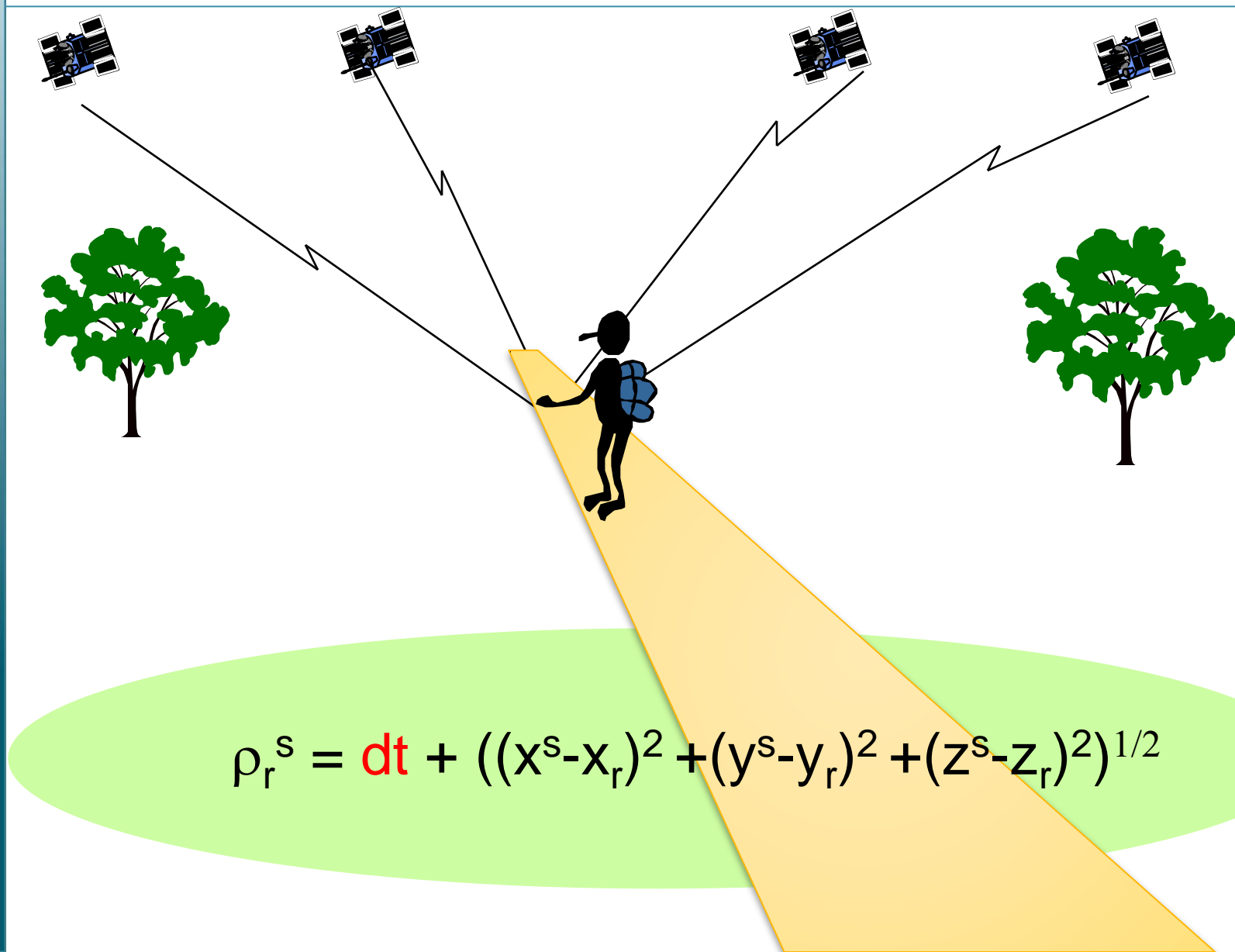
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GNSS positioning techniques

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$$\rho_r^s = dt + ((x^s - x_r)^2 + (y^s - y_r)^2 + (z^s - z_r)^2)^{1/2}$$





GNSS positioning techniques

LEO orbit determination

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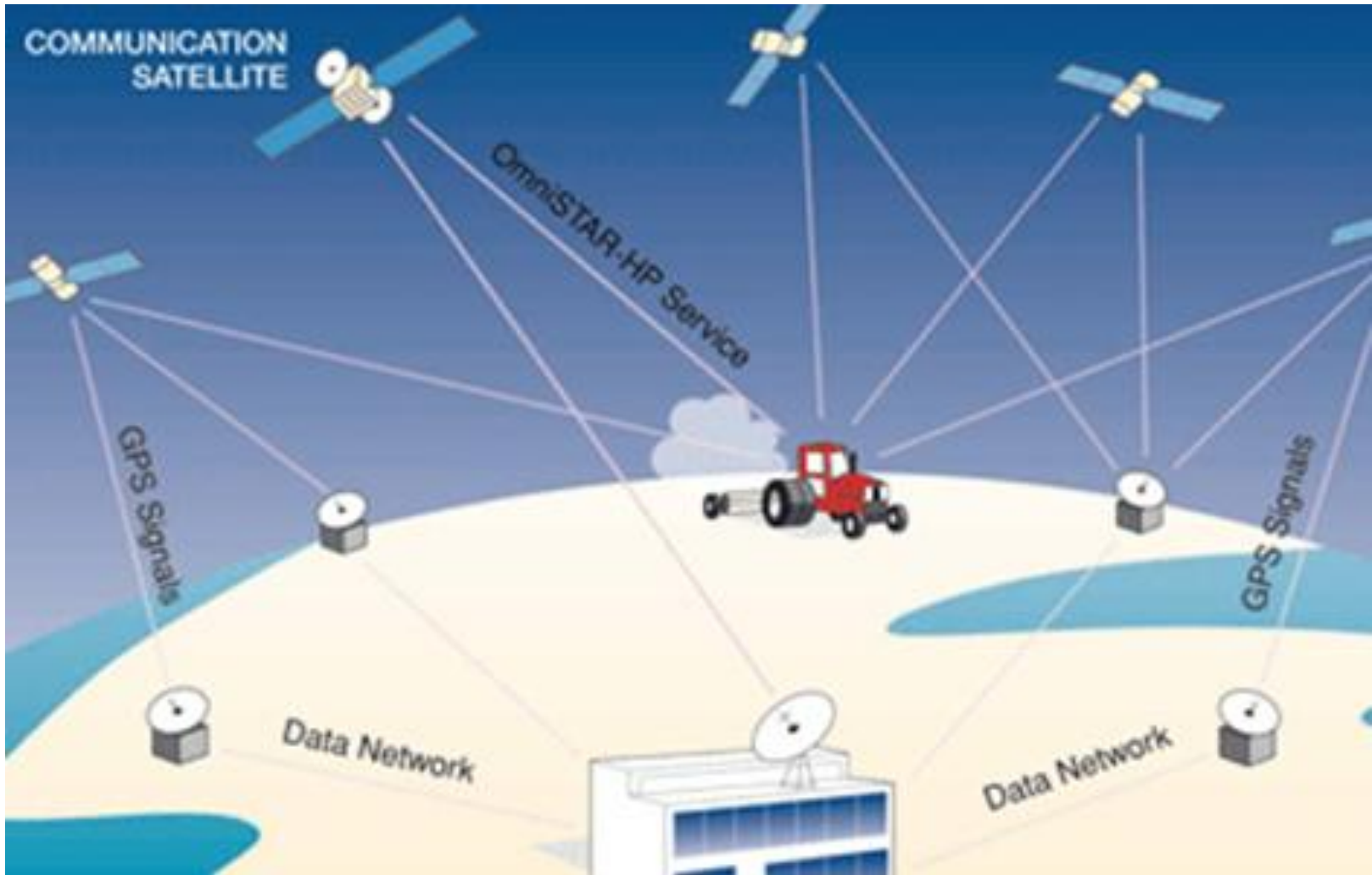




GNSS positioning techniques

RTK, VRS, WASS, Augumentation System

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<http://www.omnistar.com/SubscriptionServices/OmniSTARHP.aspx>



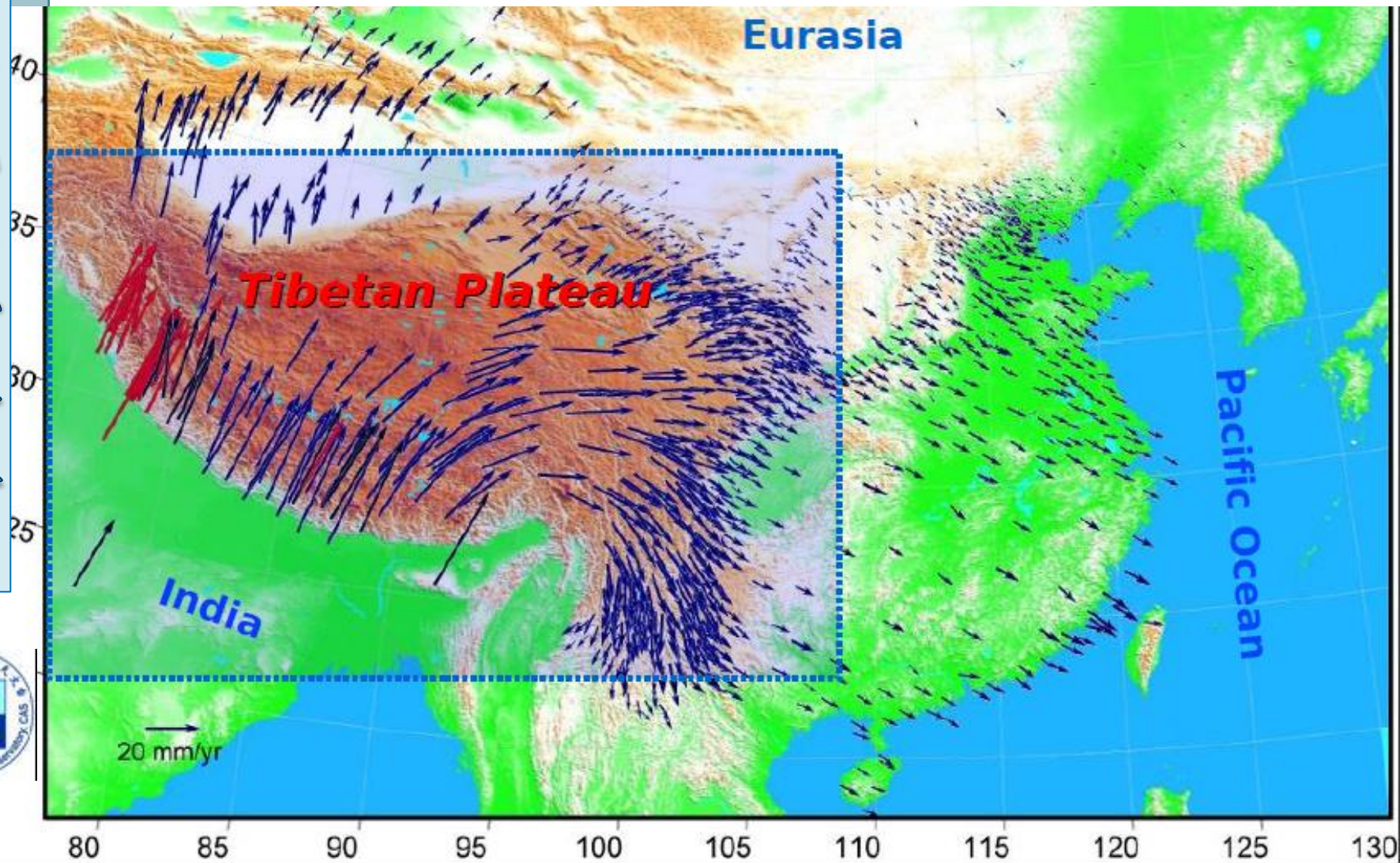


Other GNSS Application Area

Plate tectonics

Gan et al. 2008

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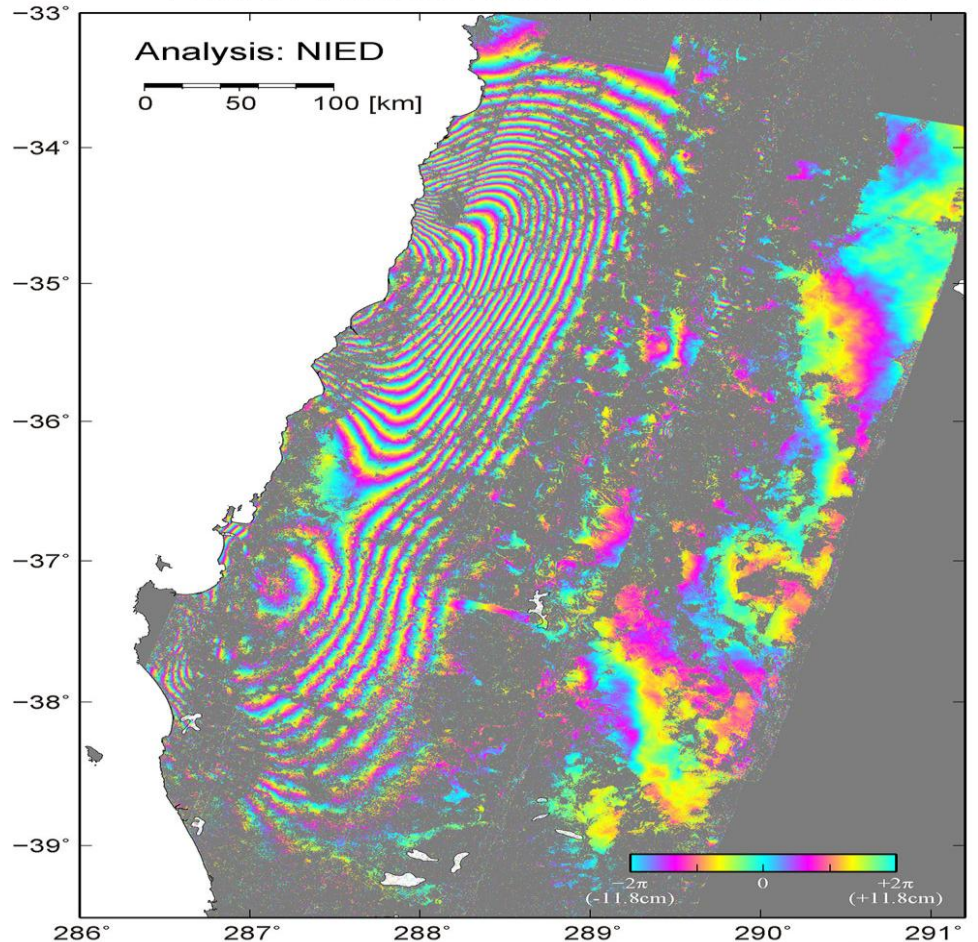


Other GNSS Application Area

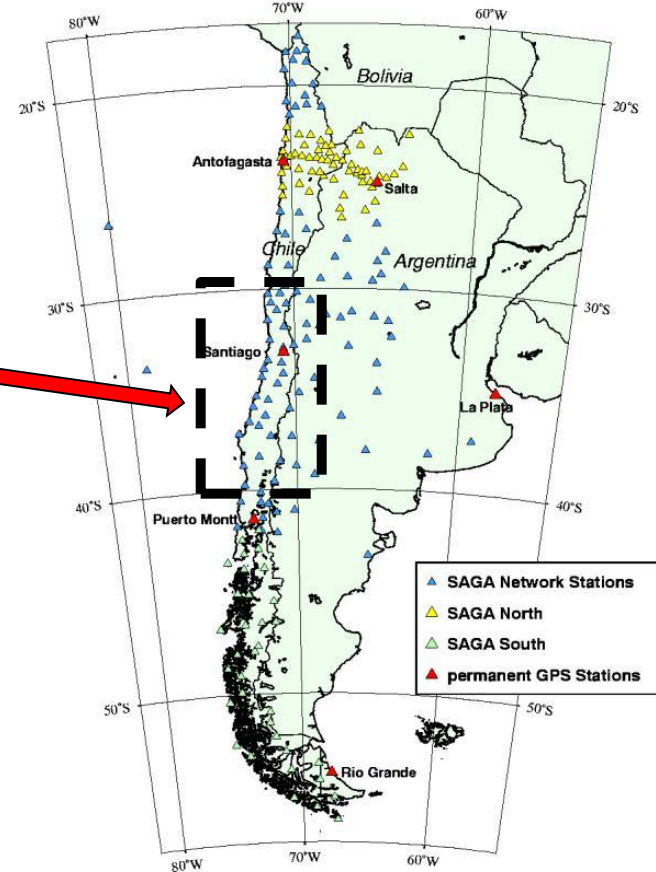
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Earthquake monitoring

PALSAR ScanSAR-ScanSAR interferometry
Path:422, Master: 2008/4/10, Slave:2010/3/1



GPS Network SAGA
South American Geodynamic Activities



286° 287° 288° 289° 290° 291°
PALSAR level 1.0 data are shared among PIXEL (PALSAR Interferometry Consortium to Study our Evolving Land surface), and provided from JAXA under a cooperative research contract with ERI, Univ, Tokyo. The ownership of PALSAR data belongs to METI (Ministry of Economy, Trade and Industry) and JAXA.

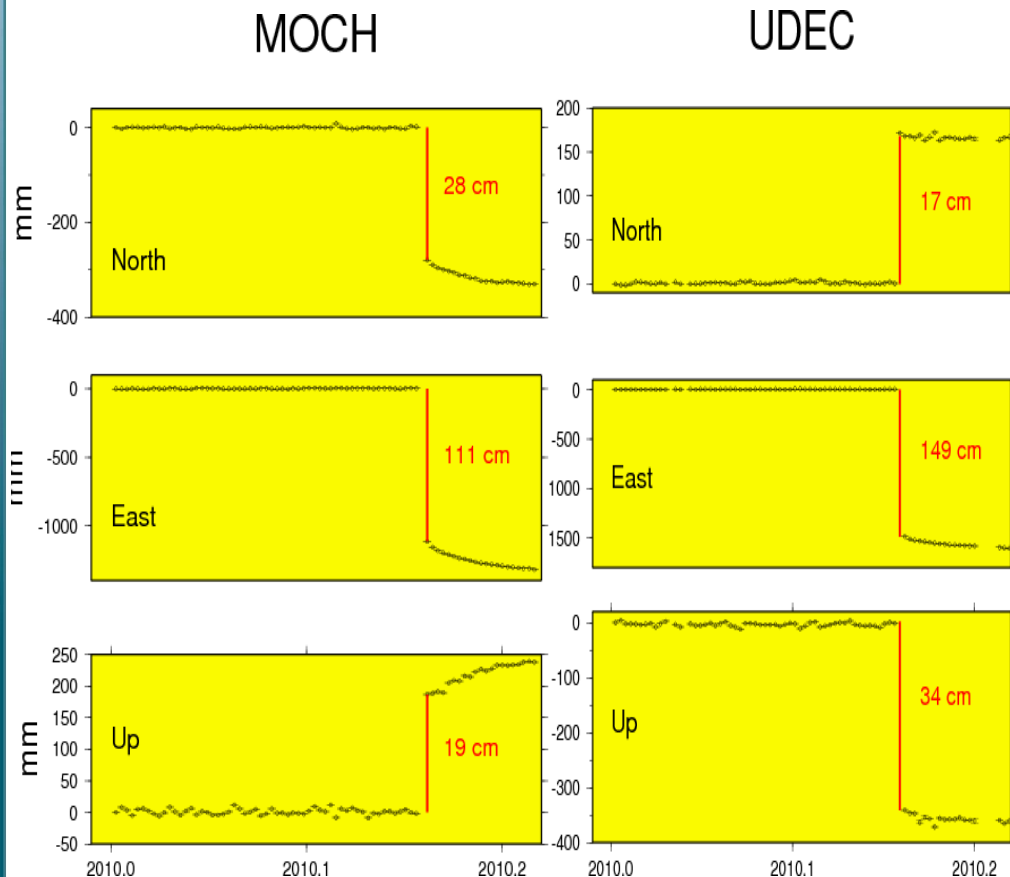




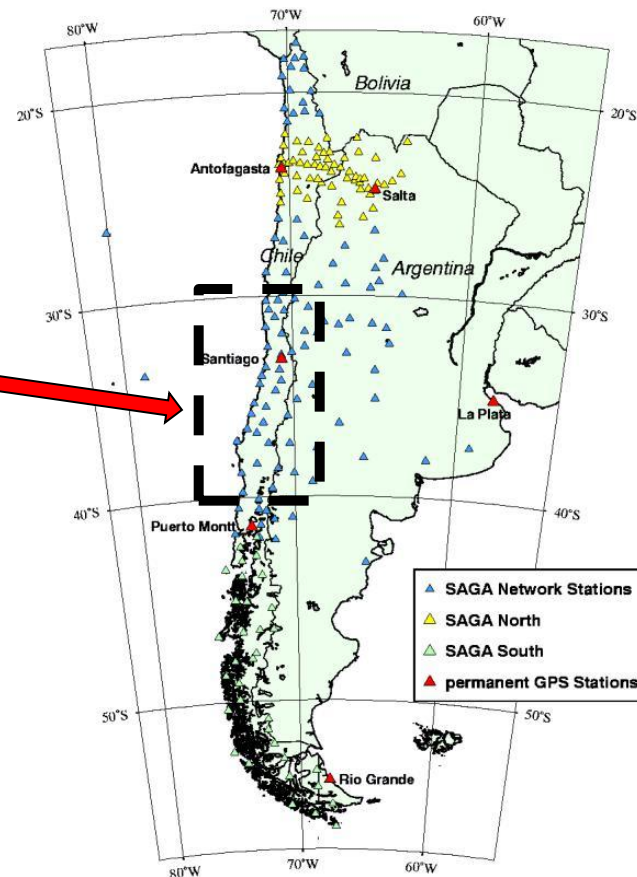
Other GNSS Application Area

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Earthquake monitoring



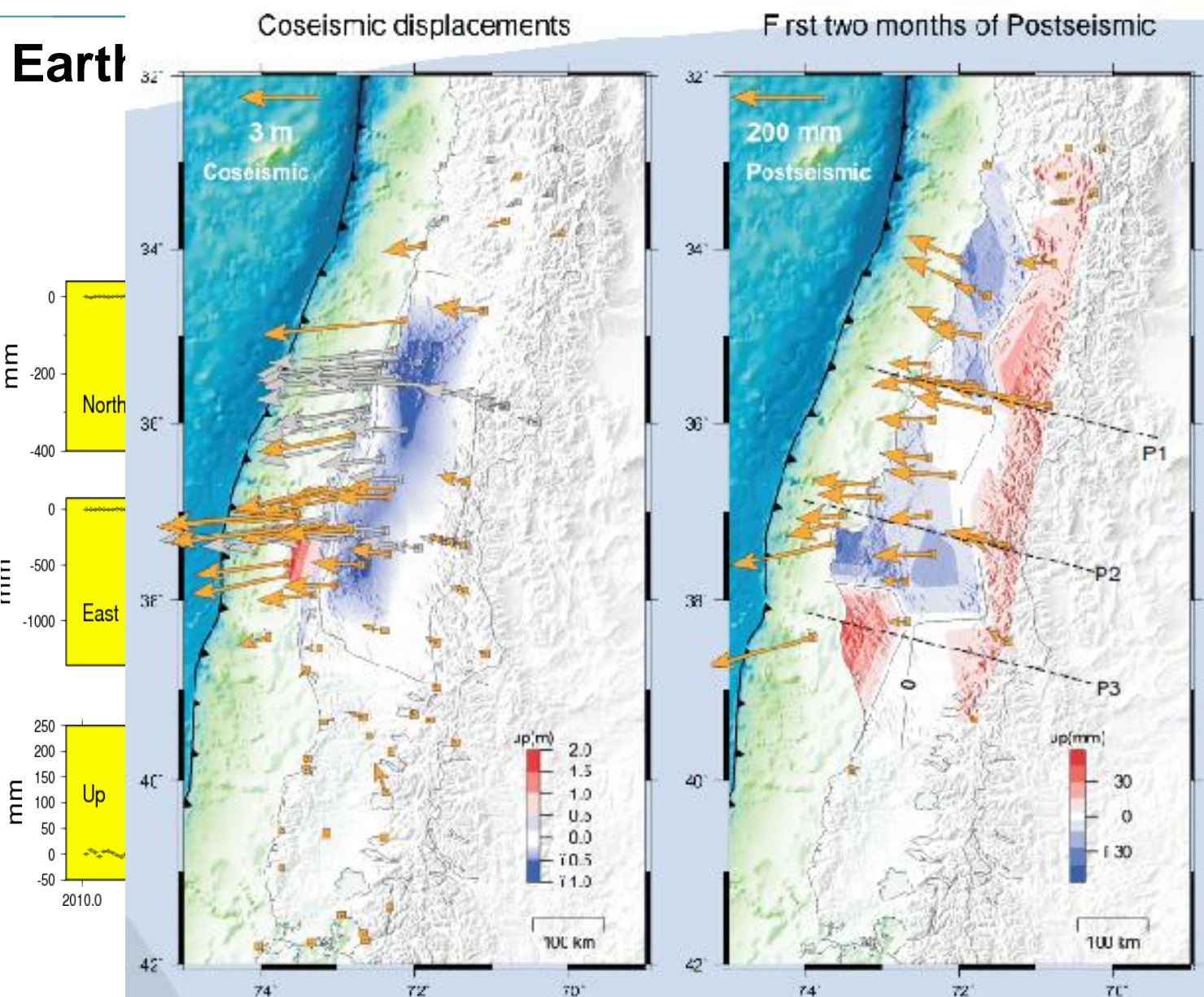
GPS Network SAGA
South American Geodynamic Activities



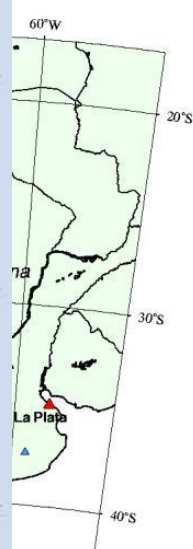


Other GNSS Application Area

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GA c Activities



AGA Network Stations

AGA North

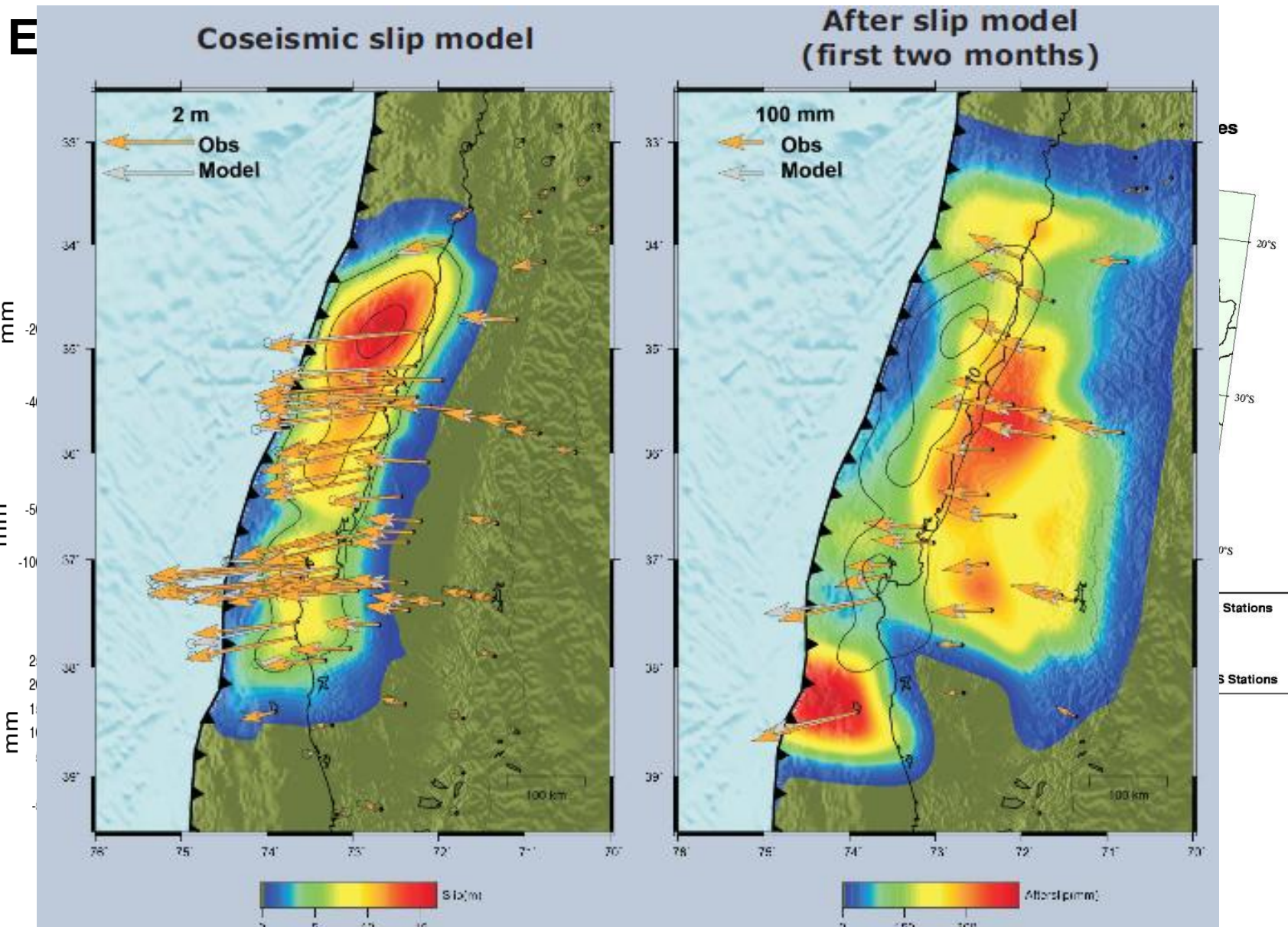
AGA South

ermanent GPS Stations



Other GNSS Application Area

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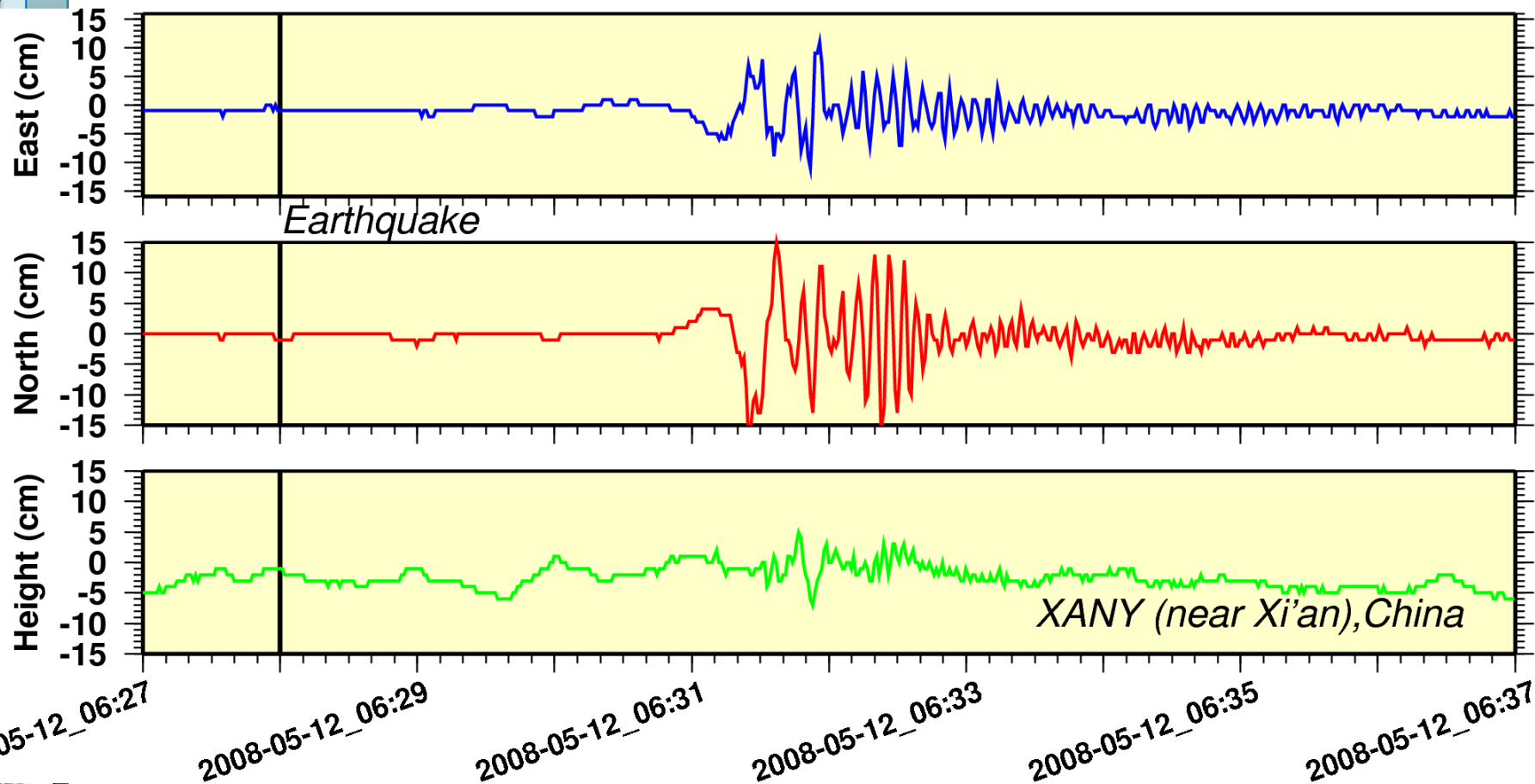




Other GNSS Application Area

中

Coseismic monitoring

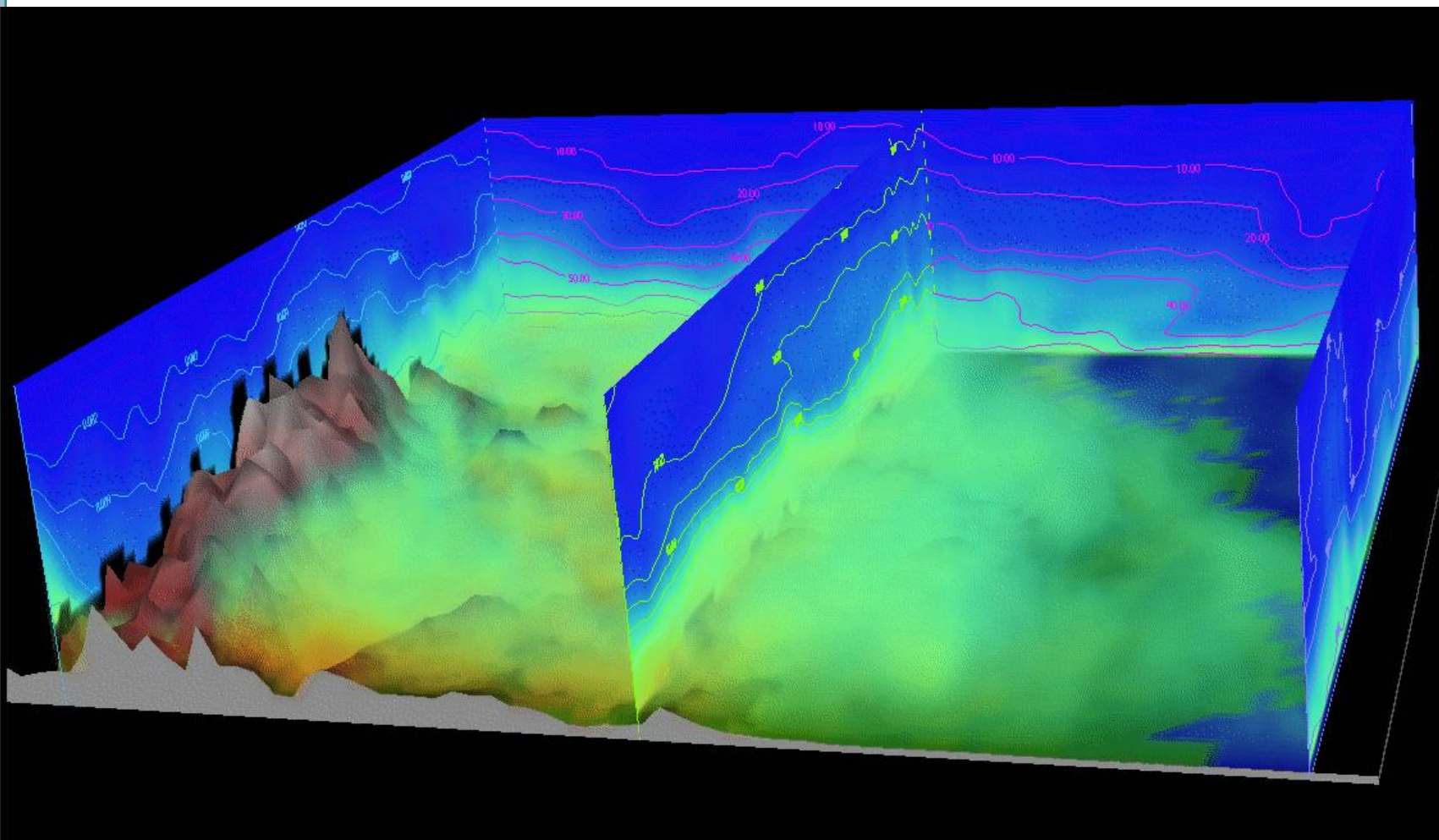




Other GNSS Application Area

GNSS Meteorology

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Other GNSS Application Area

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Soil Moisture

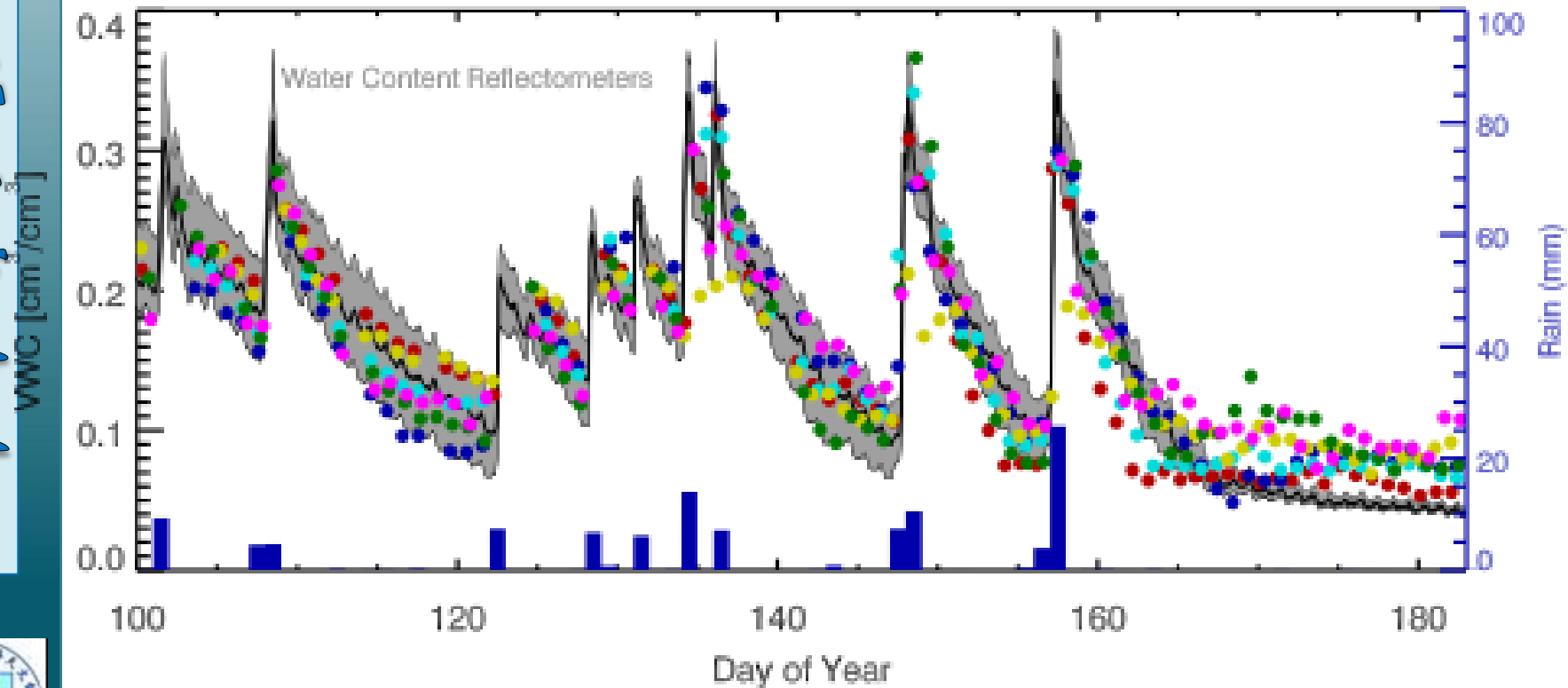




Other GNSS Application Area

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Soil Moisture

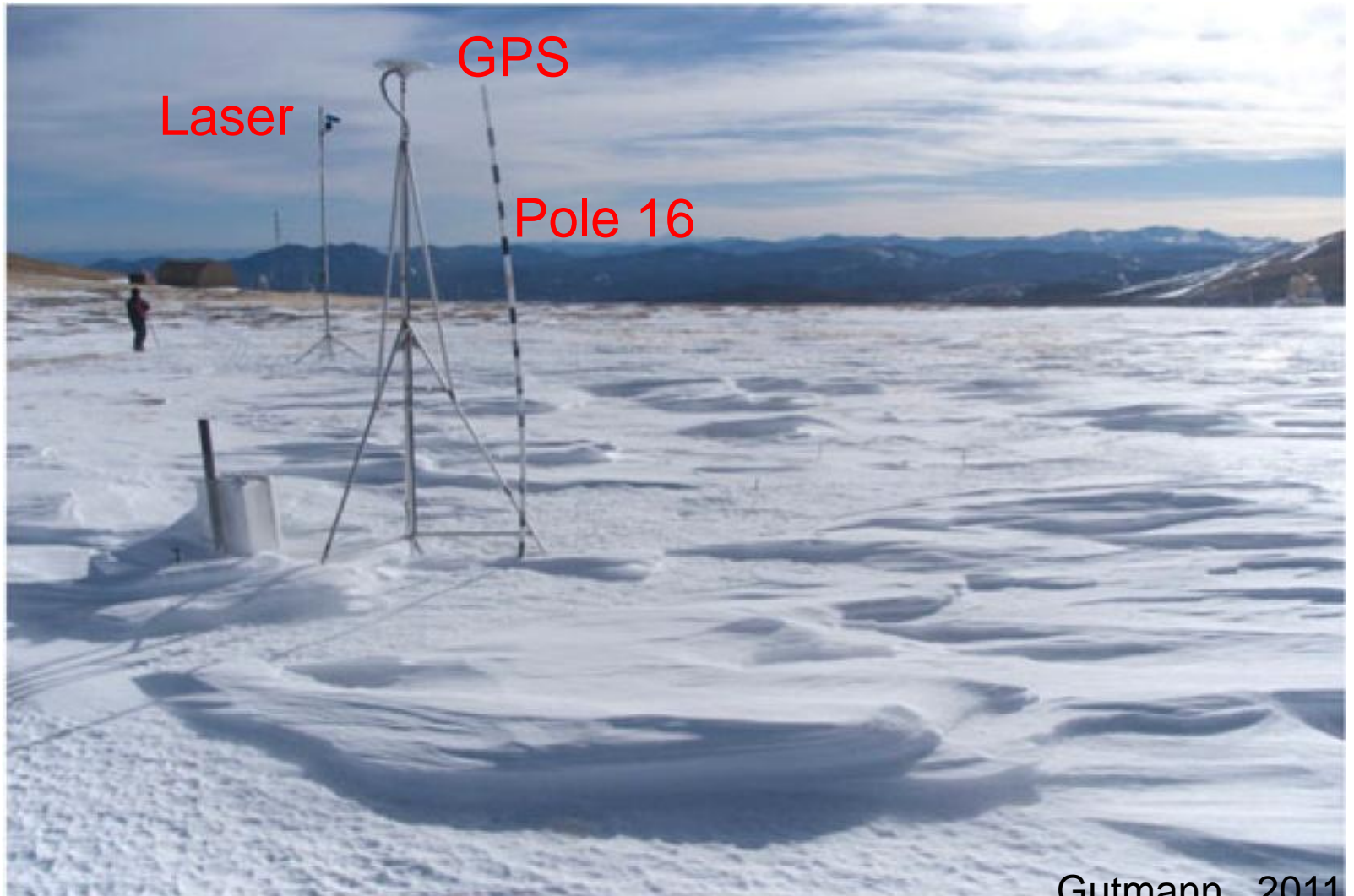




Other GNSS Application Area

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SNOW



Gutmann., 2011

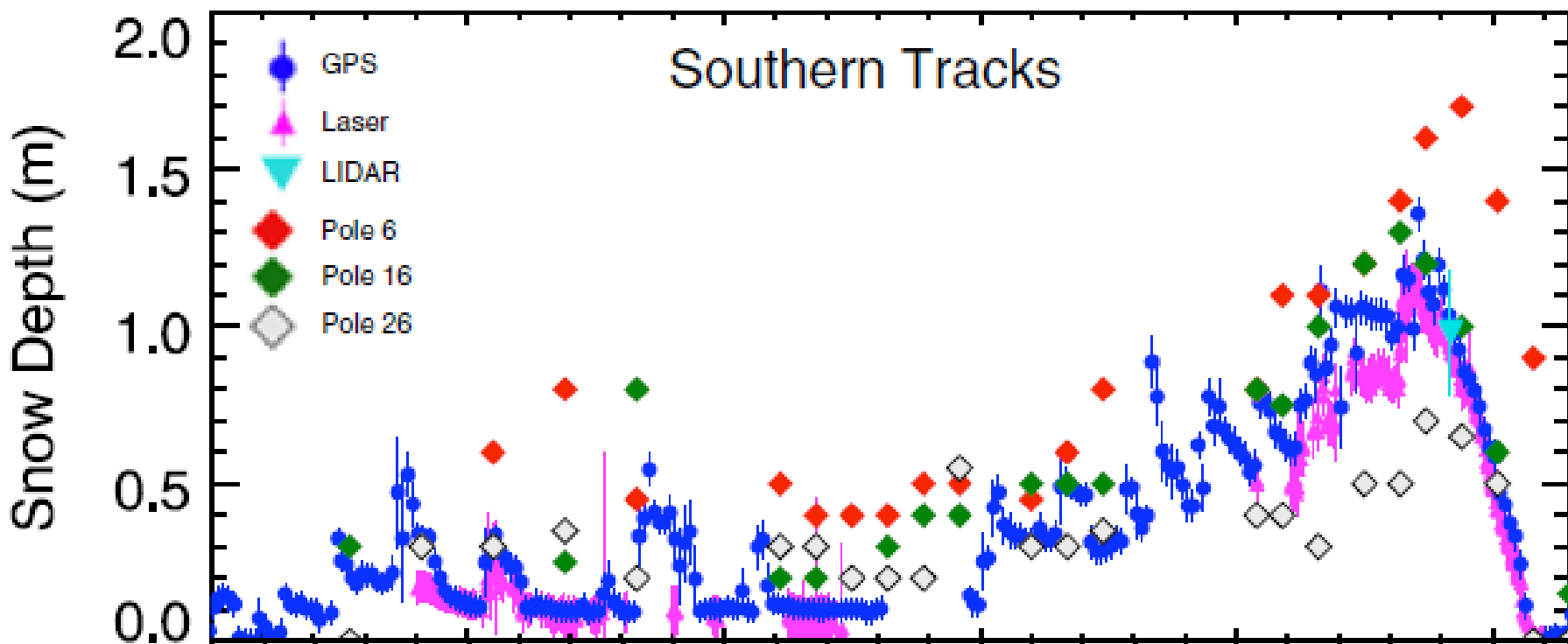




Other GNSS Application Area

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SNOW



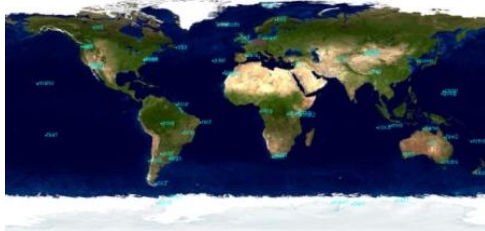


GNSS DATA ANALYSIS

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GNSS Data Center

- 1.Global GNSS network
- 2.CMONOC network
- 3.IGS general
- 4.IERS bulletin
-



GNSS Analysis Center

- 1. GNSS Preprocessing
- 2.GNSS Estimator
- 3.Ambiguity fixing
- 4.Orbit integration
-

GNSS Product Service

- 1.GNSS Orbits, Clocks
- 2.Atmosphere
- 3.ERPs
- 4.Reference Frame
-





GNSS DATA

Active **hourly** sites [map](#)

Reference Frame stations ("IGS08") [map](#)

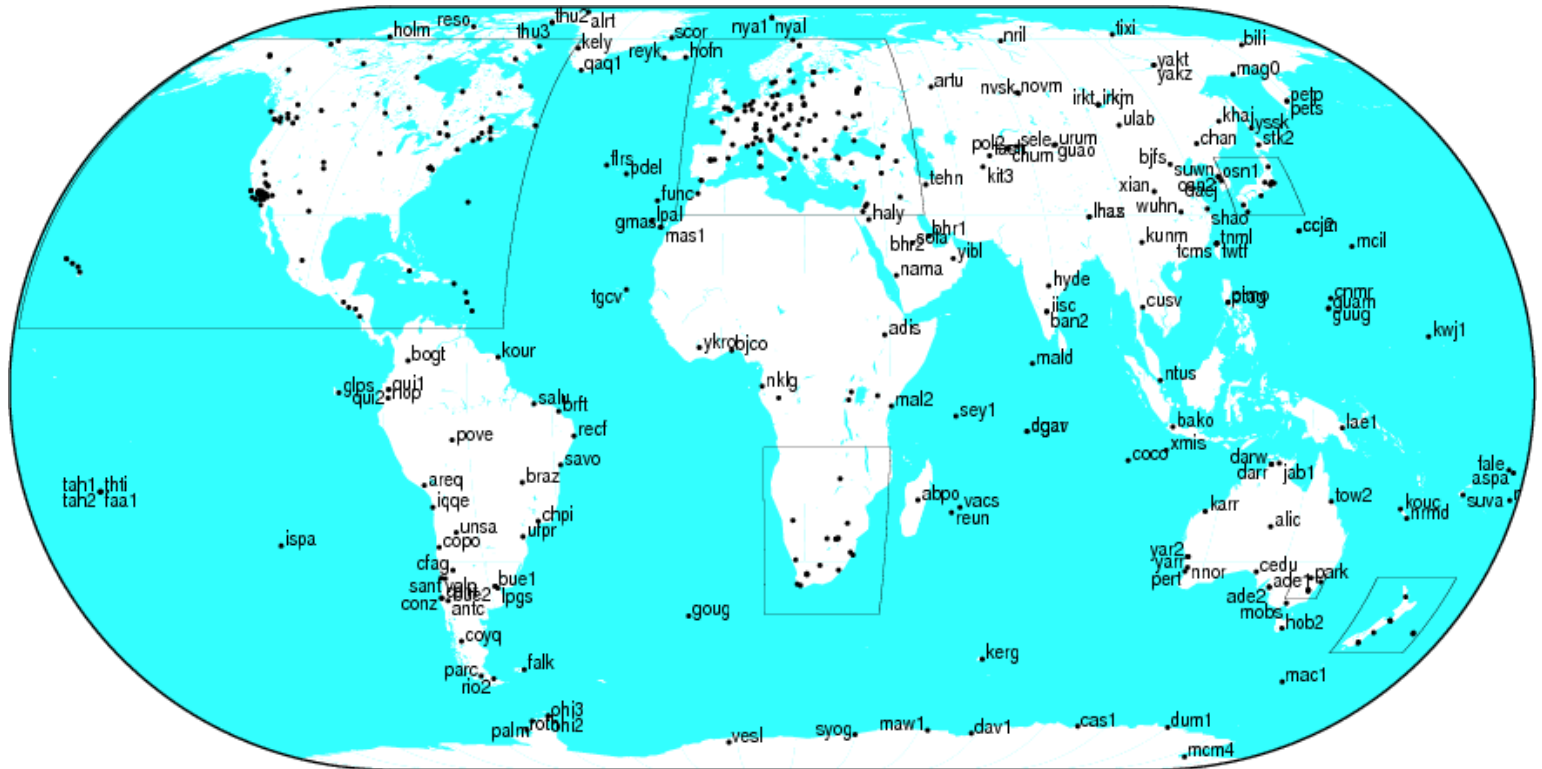
Reference Frame stations ("IGS08") [map](#) - core network

GPS/GLONASS stations [map](#)

Active **high rate** **LEO** sites [map](#)

All maps on [one page](#)

Real-Time Network [map](#), [IGS-IP NTRIP Broadcaster](#)



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CMONOC Network

附件3：中国大陆构造环境监测网络基准站设计点位图



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Crustal Movement Observation Network of China (CMONOC): 260
 Permanent + ~2000 Campaign GNSS stations
 Average baseline: 200~300 km





GNSS Products

➤ **IGS: Free and volunteer....., but service should follow NASA's policy**

Home page and ftp are denied for Chinese IP since 2011 Doy 327 (Nov. 23)

| | GPS orbit (cm) | GPS clock (ns) | Pole (mas) | Lod (μ s) | Coordinates(mm)/ velocities(mm/year) |
|-------------|-------------------|-------------------|---------------|-------------------|---|
| IGS | 2.5 | 0.02 | 0.03 | 10 | Horizontal: 3.0/2.0 |
| IGR | 2.5 | 0.03 | 0.04 | 10 | |
| IGUA | 3.0 | 0.05 | 0.05 | 10 | Height: 6.0/3.0 |
| IGUB | 5.0 | 1.5 | 0.20 | 50 | |





Working Group

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- Data Center Working Group
- GNSS Working group
- Bias and Calibration Working Group
- Antenna Working Group
- Real-Time Working Group
- Clock Product Working Group
- Space Vehicle Orbit Dynamics Working Group
- Troposphere Working Group
- Ionosphere Working Group
- Tide Gauge Working Group
- Analysis Center Coordinator and Reference Frame Working Group





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谢谢

